Demand Response Enabling Technologies Roadmap

FINAL

Prepared for:

Southern California Edison

Submitted by:

Navigant
One Market Street | Spear Tower
Suite 1200 | San Francisco, CA 94105
415.399.2109
navigant.com

With contribution from:
Lawrence Berkeley National Laboratory: Brian Gerke, Mary Ann Piette, and Jennifer Potter

November 13, 2017

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Southern California Edison engaged Navigant, with technical guidance from the Lawrence Berkeley National Lab (LBNL), to develop a Demand Response (DR) enabling technology roadmap (Roadmap) that focuses on facilitating customer engagement for participation as fast and flexible DR services. The roadmap development drew on the findings from the 2016 California Demand Response Potential Study (referred to as the “Potential Study”) conducted by the Lawrence Berkeley National Lab, and identified the need for enabling technologies for “shift” and “shimmy” service types, as represented in the Potential Study. Shift represents DR that encourages the scheduled movement of energy consumption from one period to another based on retail price or market rates, and shift has been recommended as a s strategy that could help smooth daily net load ramps associated with solar. The shimmy service type is a form of fast responsive DR that operates on a seconds-to-minutes (“regulation”) and minutes-to-hours (“load following”) timescale that has high value for managing short-term fluctuations in the net load.

LBNL provided DR potential supply curves for SCE’s service territory that help identify the greatest contributors to DR potential across different sectors and end-uses and their levelized costs. In order to develop the Roadmap, Navigant conducted an assessment of recently completed, ongoing and planned future activities on demonstrations of advanced DR technologies and a comprehensive literature review of the available information on these technologies. The technology assessment not only covered conventional electrical end-uses such as HVAC, lighting and pumps, but also included innovative development and applications of electric vehicles and Behind The Meter (BTM) storage as DR resources. Navigant also reviewed the ongoing research currently being conducted under the California Energy Commission (CEC) such as transactive energy projects which have potential to transform the energy landscape if successfully demonstrated. Along with the input from the advanced technology assessment, the Roadmap development also involved discussions with different market actors to identify the drivers and challenges that could influence the deployment of the technologies and how possibly some of these could be overcome and packaged as a value-added offering to the customers to enhance adoption.

Figure ES-1 below illustrates a suggested Roadmap pertaining to residential and SMB customers primarily, along with cross-cutting areas (including electric vehicles and BTM batteries). Figure ES-2 shows suggested Roadmap for large C&I and agricultural customers. Note that there are a number of ongoing technology development and demonstration activities, discussed in this document, which indicate the potential for future technologies with enhanced DR capabilities for various customer sectors. Most of these demonstrations are expected to be complete within the next three years approximately, and therefore findings from these efforts at that time could provide specific guidance on prioritization and selection of technologies for realizing fast and flexible DR services.

Figure ES-1: Suggested Technology Roadmap for Residential and SMB customers and Crosscutting Areas

Year: 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 and beyond

Residential, Small/Medium C&I

Air Conditioning Load Control

Shift

Continue current programs with smart thermostat based control of HVAC

- Continue current AC control programs using smart thermostats: these offer load shifting opportunities through pre-cooling strategies.
- Default TOU rate offer to residential customers, coupled with increasing penetration of smart thermostats will help realize significantly larger shift potential through smart thermostat control of HVAC loads.

Shift & Shimmy

Track ongoing advanced HVAC development & demonstration projects

- Track ongoing advanced technology development and demonstration of high efficiency, climate appropriate HVAC systems with intelligent controls and enhanced DR capabilities (e.g. variable capacity compressor, variable speed fans, zonal control, dual-fuel heating, and thermal storage options).

Provide incentives for deployment of advanced HVAC technologies as joint EE-DR offer

- Consider incentivizing advanced HVAC technologies that offer significant energy efficiency, DR and climate benefits through joint EE-DR offerings to accelerate market uptake.
- Utilize successfully tested advanced HVAC technologies with enhanced DR capabilities to provide shift and shimmy; package this as an IDSM offer since co-benefits are substantial.

Transactive Energy Offers

Shift & Shimmy

Track ongoing transactive energy projects

- Track ongoing transactive energy demonstration projects that transmit transactive signals to a variety of enduse loads at customer premises and optimize based on energy costs, comfort settings and other user preferences.

Utilize findings from successfully demonstrated projects for load control through transactive signals

- Consider transactive energy offers on a wider scale based on the successful demonstration of ongoing projects by leveraging on IoT and proliferation of smart devices. The success of transactive energy projects and customer acceptance of such offers can potentially substantially transform the energy landscape.

Crosscutting

Electric Vehicles

Shift & Shimmy

Track findings from several ongoing projects for assessment of PEV contribution

- Draw on successfully completed pilots that have demonstrated results from managed EV charging and consider similar pilot/program offers;
- Track ongoing advanced charge management demonstration efforts for charge optimization based on transactive signals and real-time vehicle information.
- Follow use case results from Open Vehicle Grid Integration Platform (OVGIP) to identify opportunities for grid integration using open communication interfaces from different OEMs' PEVs.
- Follow ongoing Vehicle to Grid (V2G) and Vehicle to Building (V2B) demonstrations.

Design and deploy DR offers around demonstrated advanced control strategies

- Consider pilot/program activities with advanced charge management based on successfully demonstrated results from such activities;
- Leverage on OVGIP for drive market deployment of EVs as a reliable grid resource on a large scale by utilizing PEVs from different OEMs for providing grid services based on open communication interfaces.
- Consider V2G and V2B pilots based on current demonstration project results and then full rollouts based on pilot findings.
- Package this as an integrated DER offer.

Continue with EV-TOU rate offers that help engage customers and offer savings opportunities. However, transactive energy signals, if successfully and demonstrated, could supersede TOU rate offers.

Behind the Meter (BTM) Batteries

Shift & Shimmy

Establish value proposition of storage

- Track ongoing microgrid demonstration projects and solar-storage integrated projects to help establish value proposition from storage.
- Follow findings from transactive energy projects for opportunities to control batteries using transactive signals, which could potentially substantially increase storage participation.

Roll into DER offers for realization of benefits

- Default residential TOU offers will help accelerate customer adoption of storage, along with possible removal of market barriers primarily related to interconnection requirements.
- Leverage on possible accelerated market adoption of storage driven by TOU rates, relaxation of market barriers/rules and continued technology cost reductions with performance improvements for realization of the substantial shift and shimmy potential from storage (assessed to be cost-effective and a significant DR contributor for the residential sector in the potential study).
- Package this as an integrated DER offer.

Figure ES-2: Suggested Technology Roadmap for Large C&I Customers

Year: 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 and beyond

Large C&I customers	*Commercial HVAC*	*Shift*	**Continue current Auto-DR enabled HVAC control through current program offers** - Continue with well-established manual and Auto-DR enabled curtailment of HVAC loads in commercial buildings. - These systems primarily provide load shed. - Load shifting opportunities exist through pre-cooling, utilizing the thermal mass of buildings.		
		Shift & Shimmy	**Consider fast DR pilot results with existing systems and track ongoing demos with advanced HVAC systems** - Draw on findings from successful fast DR field pilots and consider deployment of commercially available systems for providing fast response (shimmy). - Track ongoing technology demonstration to specifically assess DR capabilities from commercial variable capacity HVAC systems, which could lead to future opportunities for realizing shimmy potential. - Follow findings on DR capabilities from demonstration of climate appropriate HVAC systems (VRF and IEC integration) that incorporate system optimization algorithms for DR.	**Push market uptake of advanced HVAC technologies with demonstrated DR capabilities** - Consider incentivizing advanced HVAC technologies that offer significant energy efficiency, DR and climate benefits through joint EE-DR offerings. - Variable capacity HVAC systems receive energy efficiency rebates and additional incentives for DR could accelerate market uptake.	Utilize successfully tested advanced HVAC technologies with enhanced DR capabilities to provide shift and shimmy through IDSM offerings.
	Lighting Controls	*Shimmy*	**Incentivize Auto-DR enabled advanced lighting controls (zonal and luminaire) and convey value proposition to customers** - Auto-DR enabled advanced lighting controls (zonal and luminaire) have significant shimmy potential. - Incentivize commercially available LED luminaires with networked wireless controls to accelerate market adoption (these have substantial EE benefits along with advanced DR capabilities); package this as an IDSM offering. Also zonal controls are able to provide shimmy. - Engage in customer education/outreach activities to encourage participation in DR (customers may have advanced controls installed but are often unsure of DR participation due to uncertain value proposition from DR). - Track findings from projects that are currently seeking to assess value proposition for cost-effective DR-enabled lighting retrofits in commercial buildings with quantification of non-energy benefits; utilize these in customer education/outreach efforts to accelerate market adoption through IDSM offers.	- Utilize expanded market opportunities through greater penetration of LEDs with advanced controls for realizing shimmy potential. - Continue to encourage customer adoption/market uptake by communicating value proposition of DR-enabled lighting retrofits to customers (energy and non-energy benefits).	
	Refrigerated Warehouses	*Shift & Shimmy*	**Continue Auto-DR incentives and track ongoing demonstrations for fast and flexible response capability** - Continue with refrigerated warehouse participation in current DR programs; excellent DR candidates; keep providing ADR incentives to encourage participation in DR. - Track ongoing demonstrations of fast and flexible DR capability for large industrial refrigeration sites with a Flexible Energy Management System (FEMS) that interface with SCADA controls.	**Deploy advanced technologies for fast and flexible DR** - Utilize findings from demonstration projects to realize market opportunities for fast and flexible DR services. - Continue incentivizing ADR enablement for providing fast and flexible services; these provide substantial energy savings, so package this as a joint EE-DR offer.	
	Agricultural Pumping	*Shift & Shimmy*	Auto-DR enabled Variable Frequency Pumps (VFPs) provide shimmy.		
	Wastewater Pumping and Treatment	*Shift & Shimmy*	- Wastewater treatment and pumping DR participation exists through current program offers. - Track findings from advanced microgrid demonstration projects with wastewater treatment plants for fast and flexible DR capabilities.	Utilize demonstration results to enroll additional sites for expanded program offering to provide fast and flexible DR services.	
	Industrial Processes	*Shift*	- Incentivize adoption of Variable Frequency Drives for DR Participation. - Engage with industries that are good DR candidates (flexible production schedules with batch processes) to identify every day shift possibilities.		

The Roadmap provides prospective guidance to SCE on developing innovative research in its Emerging Markets and Technology program during the next five years to possibly realize the benefits that these advanced technologies could provide for SCE's DR programs. SCE and Navigant next plan to solicit input from multiple stakeholders to ensure the Roadmap is in alignment with their strategic objectives, and to receive suggestions on tactical next steps towards implementing future SCE DR research activities in coordination with the Roadmap.

1. INTRODUCTION

Southern California Edison (SCE) engaged Navigant to develop *"a roadmap for demand response (DR) enabling technologies and customer outreach efforts that will effectively migrate existing and new automated DR capabilities to meet the new performance requirements identified in Lawrence Berkley National Laboratory's (LBNL's) Phase 2 DR Potential Study[1](Study)".*

As part of this effort, the project focused on the following two tasks:

Task 1: Assessment of innovative DR-enabling technologies

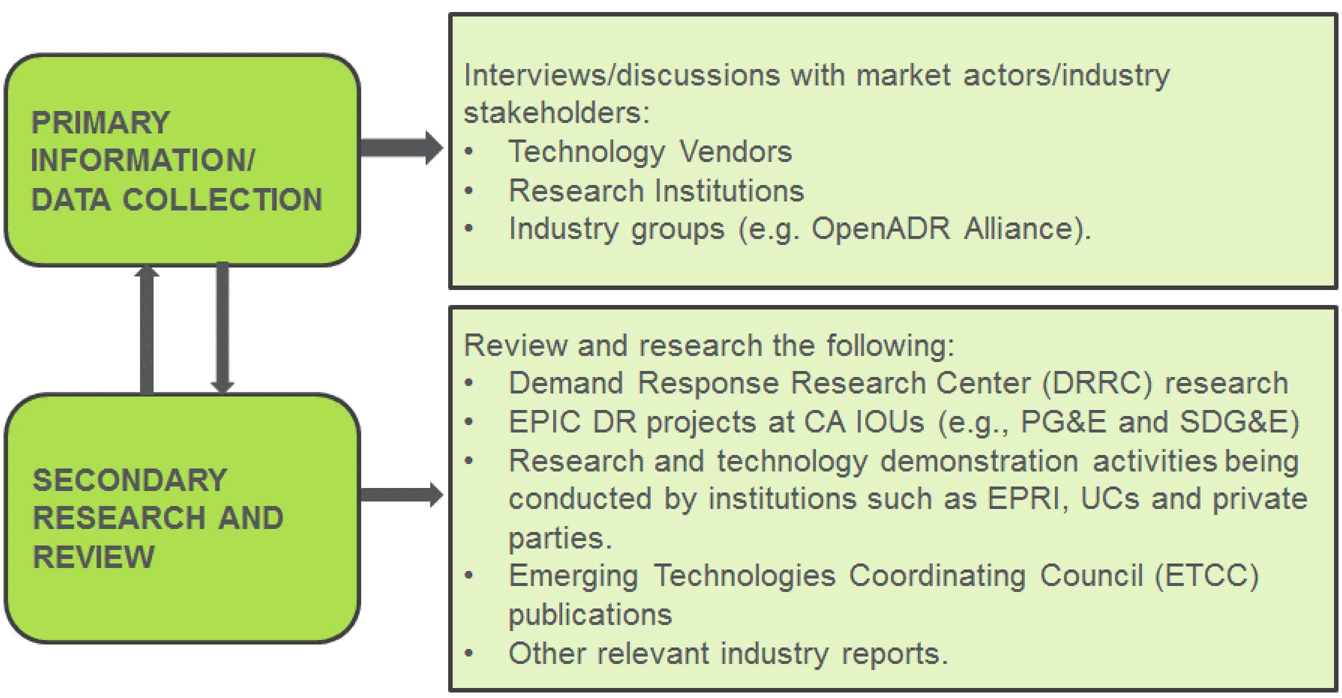
This task involved assessment of existing and emerging technologies that can provide fast and flexible DR, especially under "shift" and "shimmy" services across a wide spectrum of end-uses; consideration of technologies that can deliver load increase, in addition to traditional "shed" DR; and assessment of the current and future capabilities of technologies to adhere to Open Automated Demand Response (OpenADR) standards.

Task 2: Market barriers and opportunities influencing deployment of DR-enabling technologies

This task involved assessment of the key barriers towards realizing advanced DR services potential through deployment of these technologies, drivers/opportunities influencing market deployment, and possibilities for packaging these technologies into value-added services to customers.

Navigant deployed a two-pronged approach for information/data collection for this study, involving both primary research/data collection and review of information from secondary resources. *Figure 1* below lists the information/data collection sources under each of these two paths.

Figure 1 Information and Data Collection Sources



The report is organized into the following chapters:

[1] 2015 California Demand Response Potential Study; Charting California's Demand Response Future; Final Report on Phase II Study Results; November 14, 2016.

Chapter 2 presents DR potential results for SCE's service territory (provided by LBNL as outputs from the DR-Path model) under different scenarios considered in the potential study. The section presenting 2020 and 2025 supply curves for SCE's service territory and the results discussions is authored by Lawrence Berkeley National Lab.

Chapter 3 describes and discusses the status and future development paths of emerging DR-enabling technologies with capabilities to provide fast and flexible DR services under shift and shimmy.

Chapter 4 discusses the barriers and opportunities that influence market deployment of DR-enabling technologies.

Chapter 5 presents a proposed DR technology roadmap (Roadmap) for SCE with a summary of the technology assessment findings.

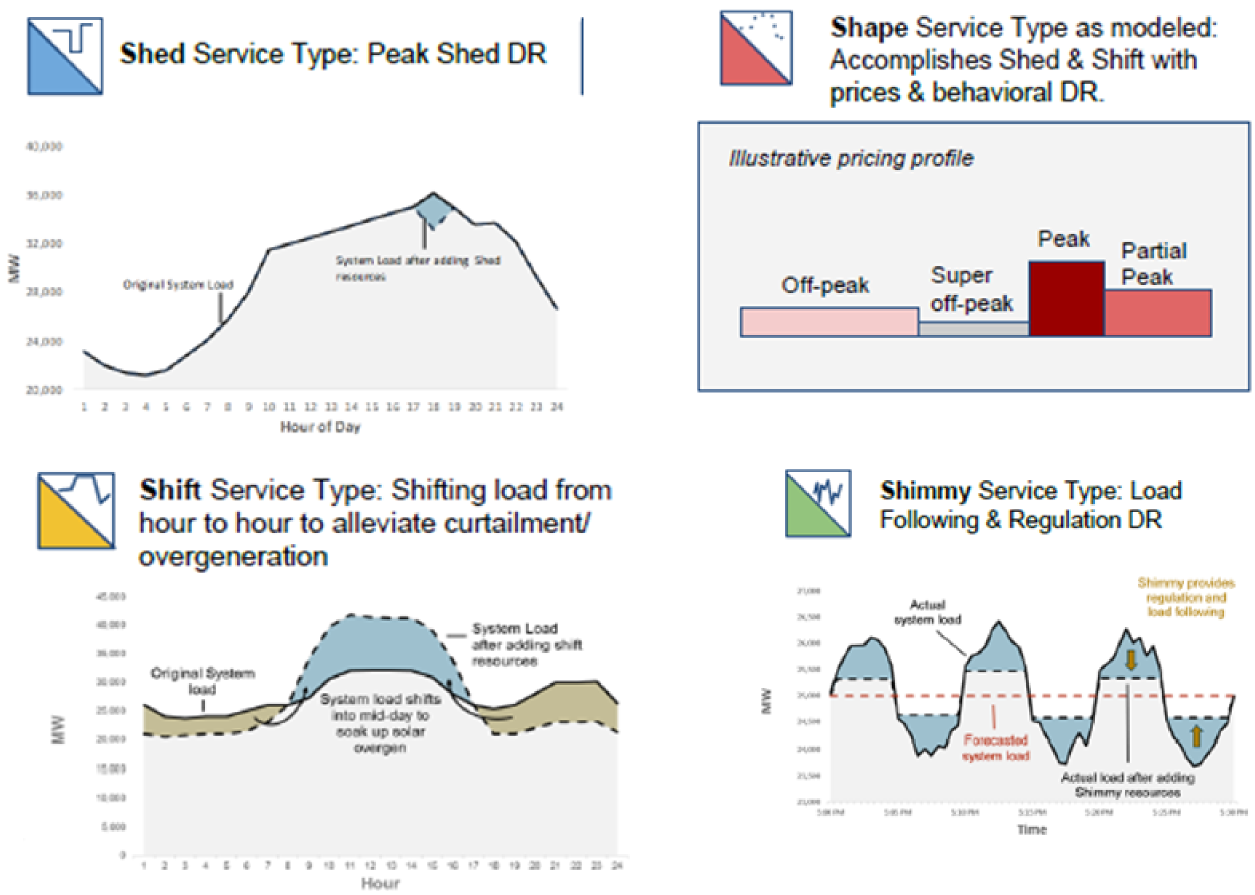
2. DEMAND RESPONSE POTENTIAL RESULTS

This chapter introduces the different types of DR services represented in the California DR potential study[2](referred to as "The Potential Study") and presents potential results for SCE's service territory from LBNL's DR-Path model.

2.1 DR Service Types in the Potential Study

The Potential Study represents four different types of DR services – shape, shift, shed and shimmy (illustrated in Figure 2 below). The focus of our discussion is on enabling technologies that can provide fast and flexible DR under the "shift" and "shimmy" service types represented in the potential study.

Figure 2: Demand Response Service Types[3]



Source: 2015 California Demand Response Potential Study, Phase II Report; Final Study Results.

The potential study defines the "shift" and "shimmy" services as follows:

- **Shift** represents DR that encourages the movement of energy consumption from times of high demand to times of day when there is surplus of renewable generation. Shift could smooth net load ramps associated with daily patterns of solar energy generation.[4]

---

[2] 2015 California Demand Response Potential Study, Phase II Report; Final Study Results; November 14, 2016.

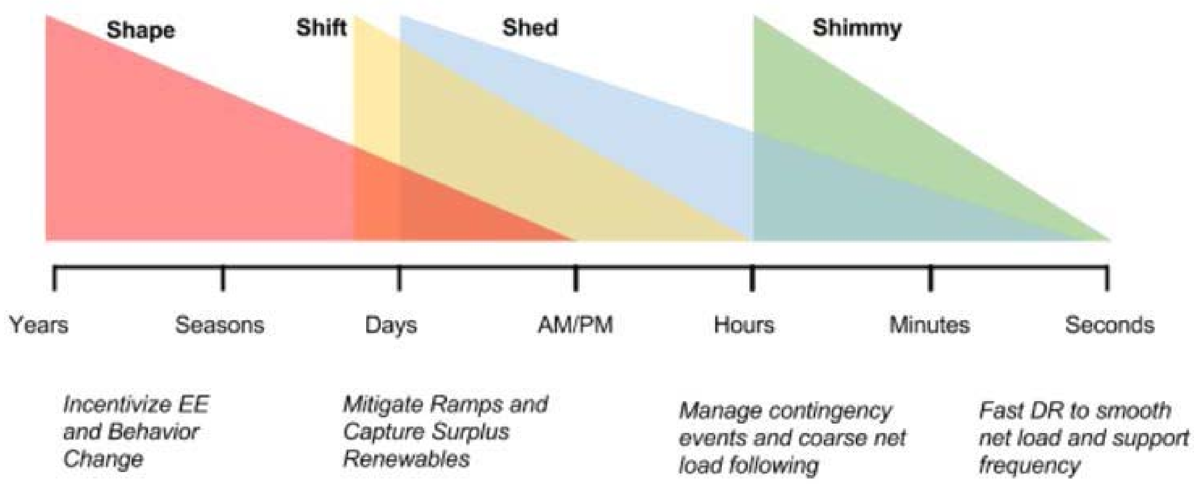
[3] *Ibid.*

[4] 2015 California Demand Response Potential Study, Phase II Report; Final Study Results; November 14, 2016.

- The **Shimmy** service type is fast DR that operates on a seconds-to-minutes (“regulation”) and minutes-to-hours (“load following”) timescale that has high value for managing short-term fluctuations in the net load.[5]

In terms of frequency of dispatch and/or response, these different service types can be represented on a timescale as follows (Figure *3* below):

Figure 3: Representation of DR Service types over Timescale for Grid Service Dispatch Frequency/Response



Source: 2015 California Demand Response Potential Study, Phase II Report; Final Study Results.

2.2 DR Potential Results for SCE

This section presents potential study output results from LBNL’s DR-Path model for SCE’s service territory. The plots below show forecasted demand-response (DR) supply curves based on the methodology used in the CPUC Phase 2 DR Potential Study[6]. Forecasts are shown for 2020 and 2025 and for four different categories of DR: shed, shift, shimmy-regulation (second timescales), and shimmy-load-following (minute timescales).

The potential results are represented in the form of DR supply curves, which show the cumulative DR quantity available (x-axis) for a range of levelized DR cost values (y-axis). Levelized cost (y-axis) refers to annualized cost per unit of DR capacity, including technology costs, financing, marketing and administration. The DR quantity shown is the total across SCE’s service territory by sector and end-use, and includes all available technologies considered in the DR Potential Study. The units are either power (Shed, Shimmy) or energy (Shift) over the entire year, aggregated from hourly values.

These supply curves show the average DR resource that could be procured and ultimately available on typical days when DR is needed in the relevant category at a particular levelized cost of procurement. For example, the shed supply curves show that the typical GWh that could be shed on a day when curtailment of renewable generation would otherwise be necessary. The supply curves have been disaggregated by sector and by end-use within each sector.

The curves shown use the following assumptions and scenarios from among those considered in the CPUC Phase 2 DR Potential Study:

[5] *Ibid.*

6 The potential results for SCE and the discussions around the results presented in this chapter were contributed by Brian Gerke, Mary Ann Piette, and Jennifer Potter from the Lawrence Berkeley National Lab.

- **Cost framework**: Net Rev. + Site + Dist. Co-benefits – an "all-in" cost-benefit accounting, including gross costs, ISO revenue streams, site-level co-benefits, and avoided costs for maintaining the distribution system. Note that this is a hypothetical portfolio that is not achievable as it is now, given that the distribution system benefits don't have an available revenue stream.
- **Technology scenario:** Business as usual (BAU) – assumes that technology performance and costs improve following conservative current trends.
- **Weather scenario:** 1 in 2: a typical weather year, expected to occur about 50% of the time.
- **Future energy efficiency (EE) scenario:** MidAAEE – a mid-range forecast of additional available EE adoption.
- **Electricity rate mix:** Rate Mix 2 – includes a representative default TOU rate with an optional CPP add-on adopted by 15% of customers. 10% of customers opt-out to a flat rate.
- **DR systems performance and costs:** The availability, cost, and performance of DR systems and batteries are based on a database of assumptions LBNL developed as part of the Potential Study. Additional end-use applications would add to the available resource. These assumptions are documented in the DR potential study Final Report.

2.2.1 Shed Service Type DR Resources

In

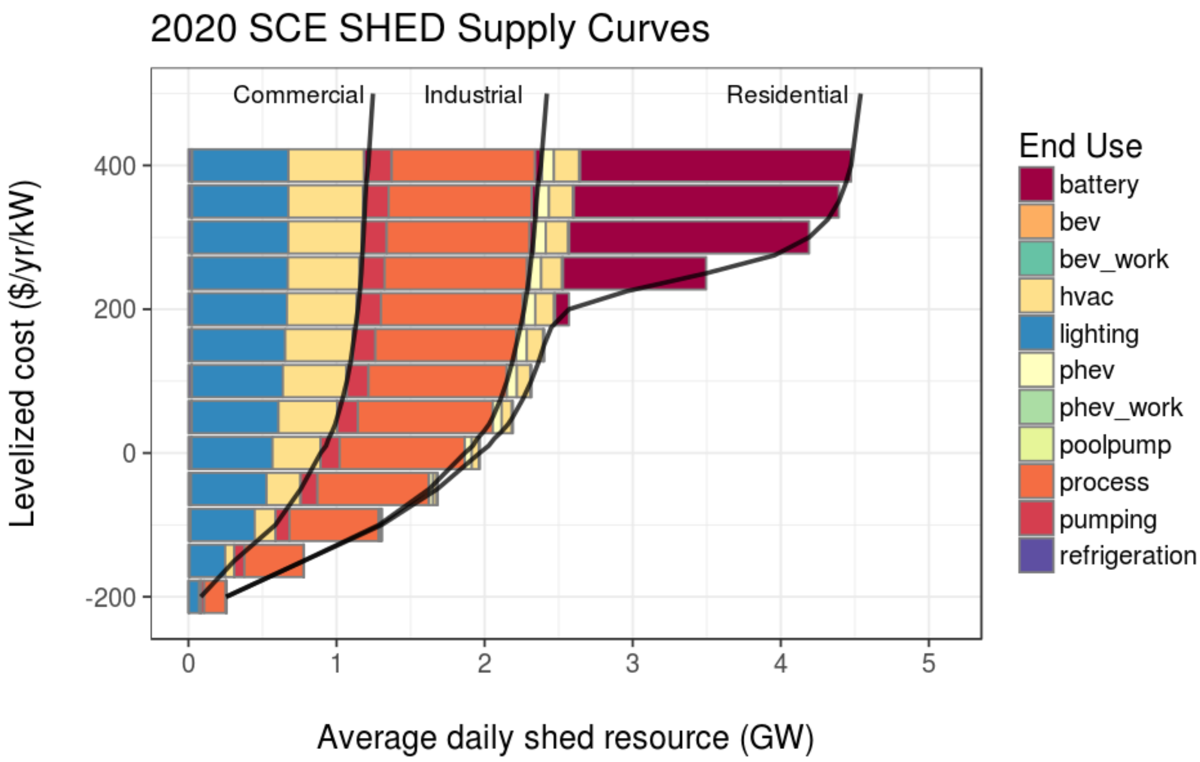
Figure 4 (year 2020) and *Figure 5* (year 2025) below, we show how the end-use technology contributions to provide Shed resources vary across levalized costs from $200 to 400 /kW-year. Each sector's contribution is grouped, with boundaries between the sectors shown using black lines. The levelized cost estimates are net of expected market revenue and site-level co-benefits from automation. The variety of resources included in the model reflects the emphasis that DR Shed has gotten over the past decades, with a range of application technology that has gone from pilot phase to deployment. For areas where the value of Shed is very high (local capacity areas, and distribution system constrained circuits) there are opportunities that are market ready across several customer classes.

For example, in Figure 4, for the supply curve forecast for 2020, at a levelized cost of approximately $-200/yr/kW, the commercial and industrial sectors account for about an average daily shed resource value of about a quarter of a GW (200 to 250MW). This indicates that if the levelized costs of the technologies are above the overall total measure costs including technology, financing, marketing and administration. However, at a neutral cost-benefit ratio ($/yr/kW = 0), the average daily shed resource value increases to significantly more for those sectors, at 2000MW (2 GW) for the two sectors, with lighting, HVAC, and process loads dominating the resource mix.

At a levelized cost of $200/yr/kW, with higher cost DR measures, slightly more resource value is technically available, but the increased costs provide less incremental value in the commercial and industrial sectors. Above this value, more average daily shed resource opens up in the residential sector. This reflects both the potential DR resource opportunity in this area (for energy storage) but the higher cost hurdles currently prevent this resource from reaching its market potential.

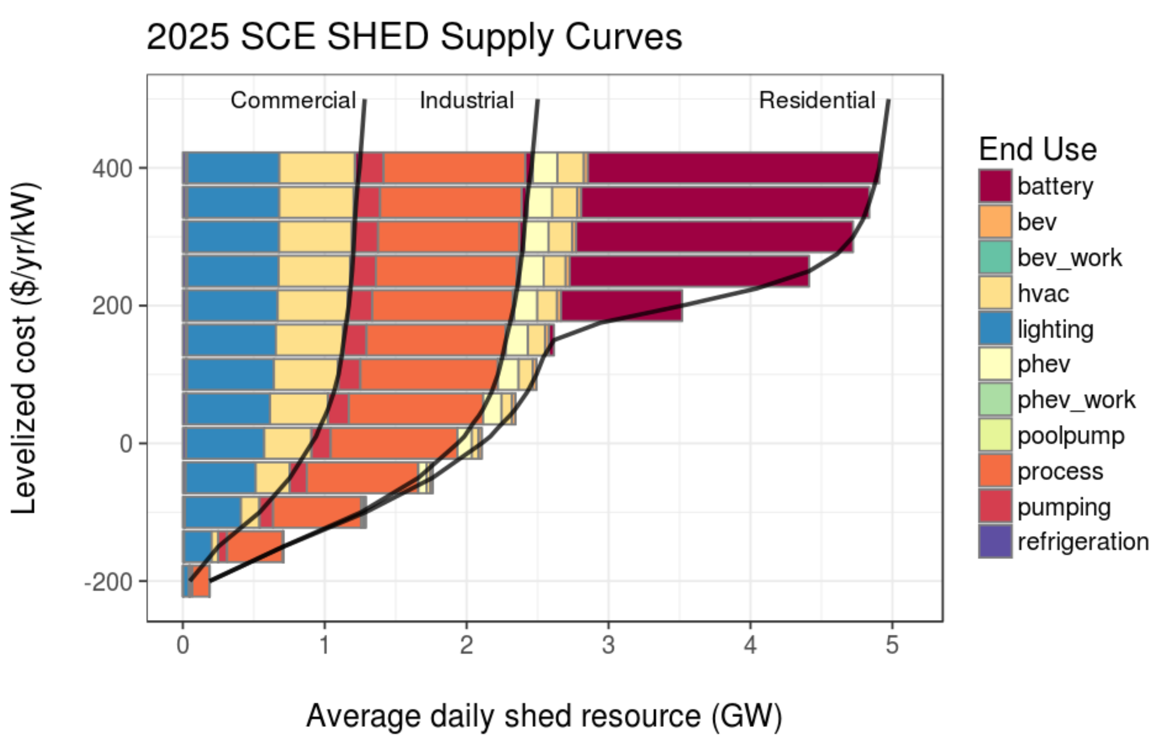
For the supply curve for 2025 in Figure 5, it reflects slightly increased DR potential in the residential sector due to end use cost reductions (such as for storage). Similar to how solar generation has reduced its costs over the last five to ten years, it is reasonable to forecast reductions in costs for residential storage systems that could also provide DR resources in 2025. This observation is also exemplified in the supply curves for shift in Figures 6 and 7. The potential is also enabled by DR service benefits that can subsidize the near and longer-term costs of the various technologies, based on the value of the services provided and the compensation payments that could be remitted to customers that could reduce the capital costs of the DR technologies.

Figure 4: Shed (GW) DR supply curve in 2025, with contributions from end-use technology categories demarcated in stacked bar graphs



Source: LBNL provided DR Potential Supply Curves for SCE.

Figure 5: Shed (GW) DR supply curve in 2025, with contributions from end-use technology categories demarcated in stacked bar graphs



Source: LBNL provided DR Potential Supply Curves for SCE.

Based on our results, targeting Commercial HVAC is in general more cost effective than Residential AC, on an average costs basis. Industrial Process loads have the potential to be a significant resource for SCE, and it is possible to target a set of very cost-competitive opportunities within the customer base. Residential batteries do not fall within a cost-competitive range, when compared to alternative end-use options in the Commercial class, however, Residential HVAC and Plug-in Electric Vehicles could provide 500 MW of cost competitive Shed, combined.

2.2.2 Shift Service Type Resources

The Shift service type resource is by far the largest opportunity we identified for DR to provide system-level value (up to ~$700 million/year) within the 2025 DR Potential Study. This value is derived from dispatchable daily energy shifts enabled with advanced control technology; economically effective DR amounts to up to ~10 percent of daily energy shifted in 2025. Shift Service Type Resources that shift load into high-curtailment hours can offer significant capital investment and operational cost savings by reducing renewable over generation, and prevent the need to overbuild renewables capacity to meet clean energy goals.

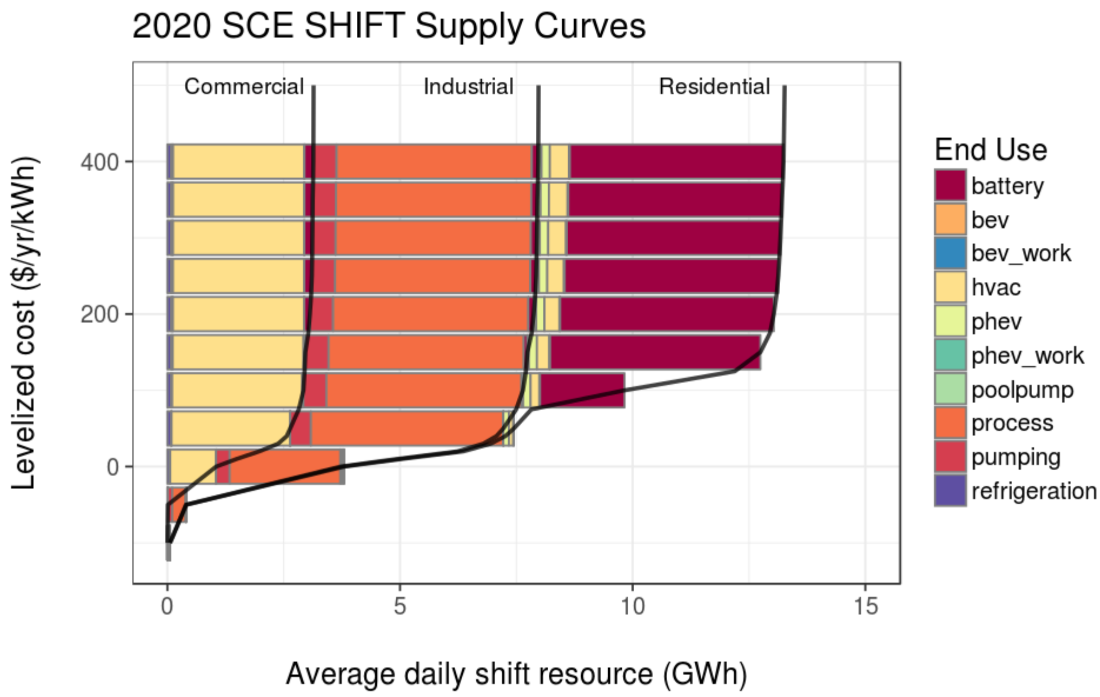
There remain significant market and regulatory barriers to capturing this value, as no market mechanism currently exists for compensating services like Shift DR. These services are technology-driven and responsive to hourly and daily changes in the needs of the system. When considering potential revenue streams from the supply-side market, Shift could *potentially* earn revenues from energy, capacity, and flexible capacity markets, but those markets are not currently organized to compensate a service like Shift DR. Shift resources would be dispatched on most days in the energy market, as their value is driven by California’s daily solar generation.

While behind-the-meter storage does not feature prominently in our estimates at $50/kWh-year[7], *Figure 6* and *Figure 7* show that costs of $100/kWh and up the contributions of behind-the-meter storage could be substantial. The contributions of each sector are grouped, with boundaries between the sectors shown using black lines. The x-axis depicts mean available GWh/day and the y-axis represents the levelized costs in $/kWh-yr. for the resource. The levelized cost estimates are net of expected market revenue and site-level co-benefits from automation. Industrial Process loads and Commercial HVAC units, all fully automated, are the main contributors to Shift DR Resources in SCE territory for both 2020 and 2025.

If there are much steeper declines in the cost of storage (and/or additional value streams accessible to storage) then energy storage technology could be a significant contributor to the Shift resource. The results also suggest that electric vehicle charging could be an important resource with more aggressive cost and/or business model advances.

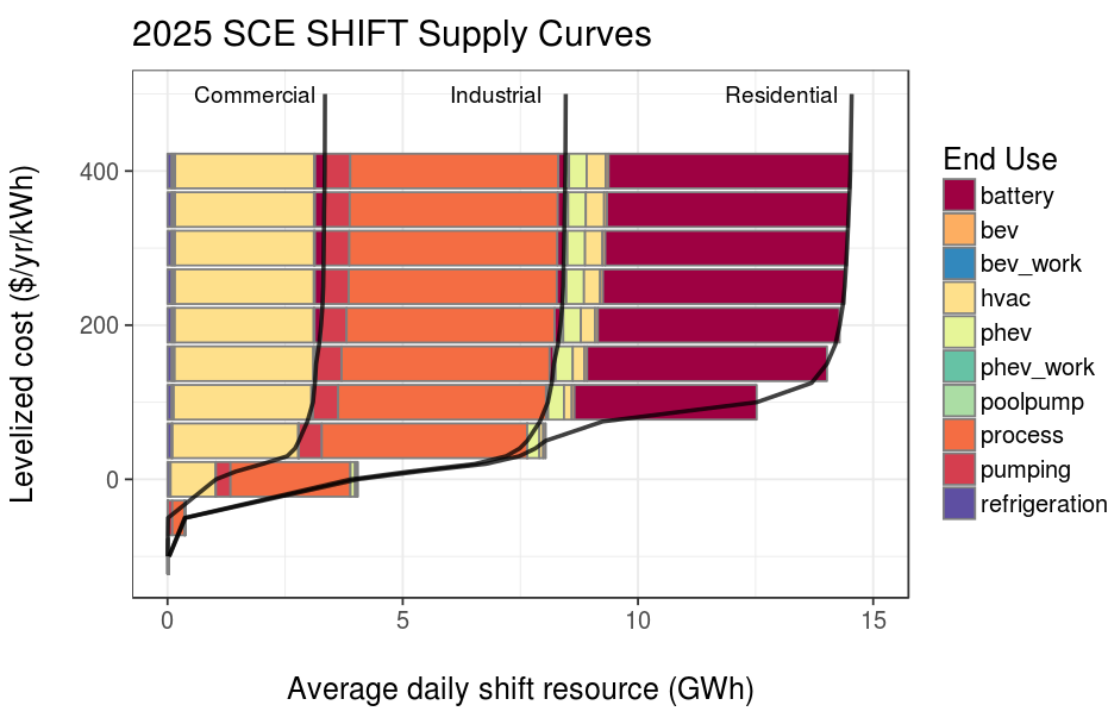
[7] We determined that $50/kWh/yr. was the cost competitive price per kWh in the 2025 DR Potential Study based on the work conducted with E3.

Figure 6: Shift (GWh) DR supply curve in 2020, with contributions from end-use technology categories demarcated in stacked bar graphs



Source: LBNL provided DR Potential Supply Curves for SCE.

Figure 7: Shift (GWh) DR supply curve in 2025, with contributions from end-use technology categories demarcated in stacked bar graphs



Source: LBNL provided DR Potential Supply Curves for SCE.

2.2.3 Shimmy Service Type Supply Curves

Fast DR that operates on seconds-to-minutes (“regulation”) and minutes-to-hours (“load following”) timescales are collectively referred to in our study as *Shimmy* resources. Rapidly responsive loads can provide Net Load Following and Regulation services to system operators and reduce the need for traditional generation resources. These resources derive value by managing short-term fluctuations in net load. The Shimmy DR Service type is separated into two key products: load following and regulation. Load-following DR resources are those capable of responding within five minutes of being dispatched, and enable load to participate in both the real-time energy and spinning reserves markets. Regulation DR Resources must be capable of responding within four seconds, and enable load to participate in regulation markets.

The technology options for Shimmy are limited compared to Shed and Shift DR due to the requirements for fast-response capabilities and the need for installing advanced telemetry and control that can make some applications cost prohibitive. Figure *8* and Figure *9* below show that for the fastest response resources (Shimmy – Regulation) the main contributions based on our model assumptions come from lighting and commercial HVAC control. In the residential sector, behind-the-meter storage is a significant contributor to shimmy-regulation potential.[8]

Figure *8* and Figure *9*, **Error! Reference source not found.**the contributions of each sector are grouped, with boundaries between the sectors shown using black lines. The levelized cost estimates are net of expected market revenue and site-level co-benefits from automation. Load following is somewhat slower (5 minutes) and in addition to HVAC and lighting we expect contributions from industrial processes and pumping could be important opportunity areas in the future. (Figure *10* and Figure *11*).

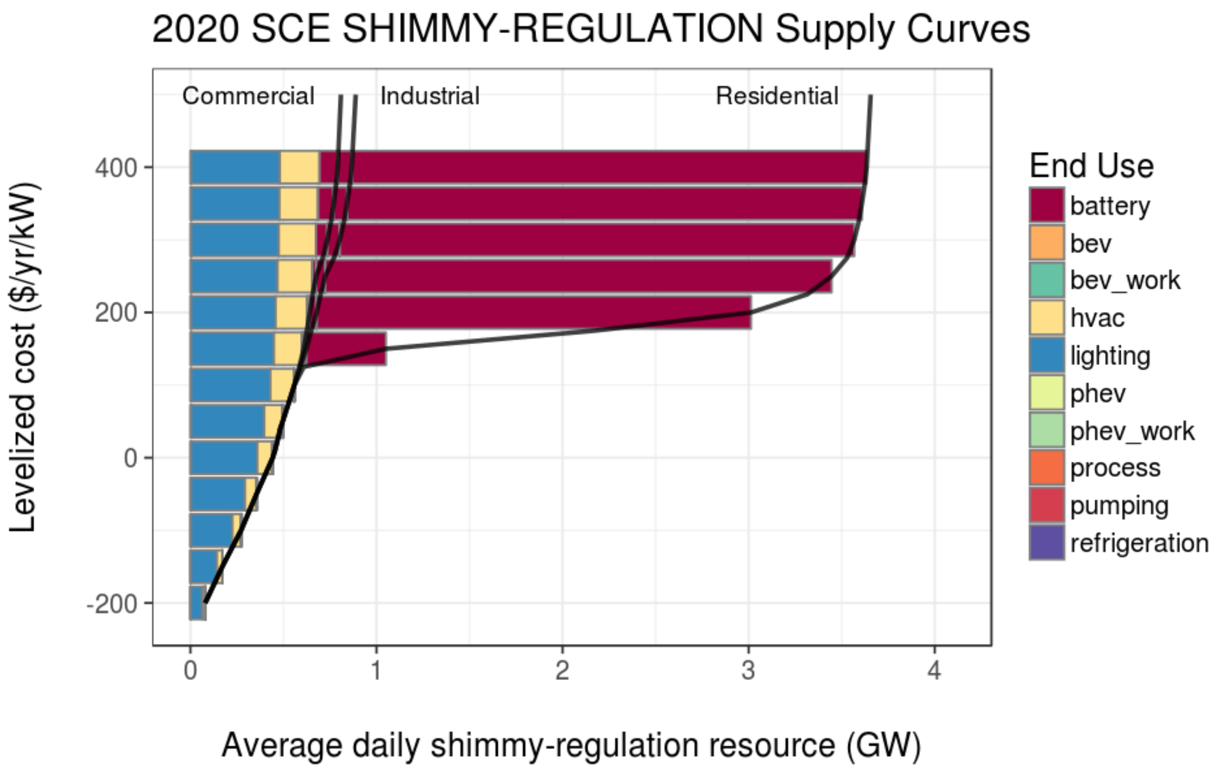
The relatively higher costs, when compared to the other DR Service types, for Shimmy resources are driven by the automated controls, the telemetry requirements for granular energy measurement, and the real-time, or near real-time communication platform requirements, (i.e. RIGs or SEGs).

In Figure 8, Figure 9, Figure 10 and Figure 11, the contributions of each sector are grouped, with boundaries between the sectors shown using black lines. The levelized cost estimates are net of expected market revenue and site-level co-benefits from automation.

Fixed behind the meter battery storage is potentially a valuable DR technology. When combined with a battery, any load can provide flexible services that meet the requirements of the Shed, Shift, and Shimmy service types. Residential and Commercial batteries have potential to provide significant services to the distribution and transmission grid along with highly-valued site-level reliability and bill savings benefits. Unlocking that potential will require simplified procedures for interconnection and processes for presenting these resources to the wholesale markets as a resource.

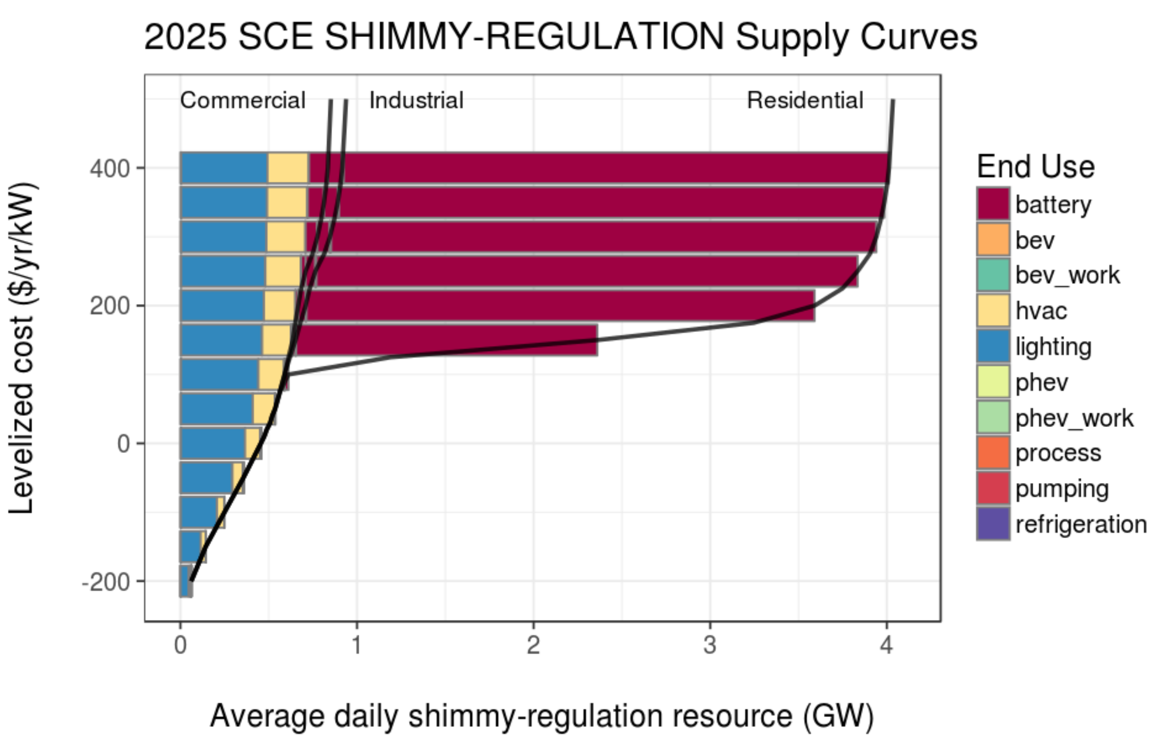
[8] Note that the "fleet" of batteries modeled for residential had a much bigger ceiling than the commercial and industrial batteries.

Figure 8: Shimmy (Regulation) DR supply curve in 2020, with contributions from end-use technology categories demarcated in stacked bar graphs



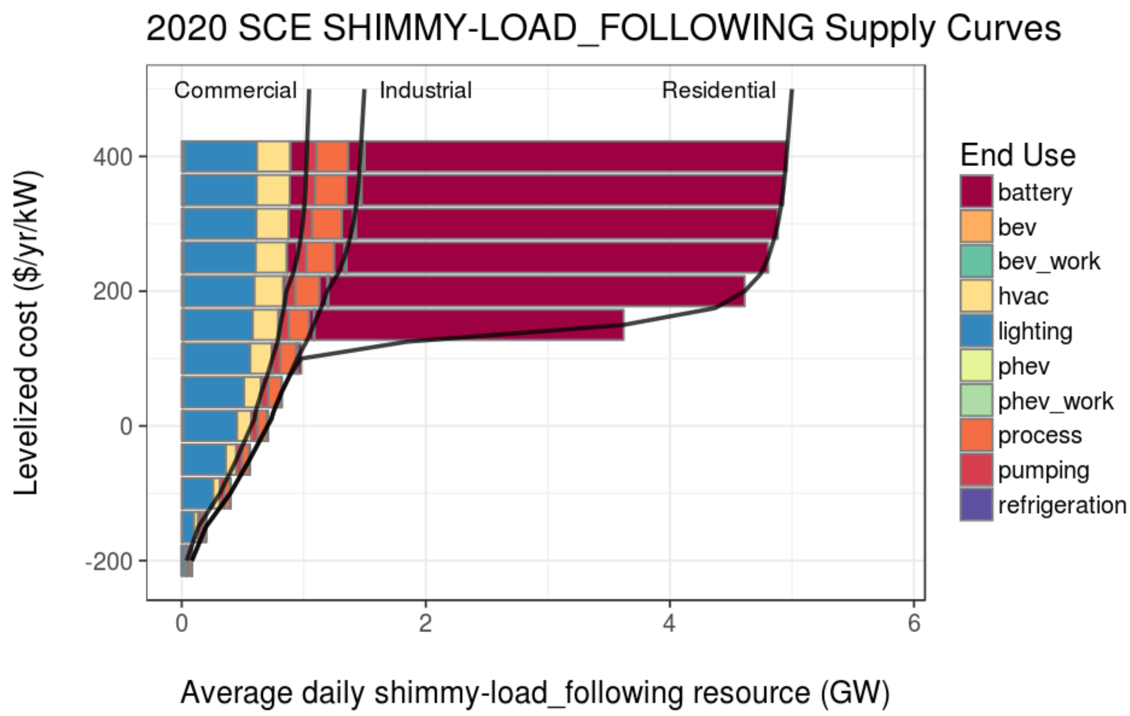
Source: LBNL provided DR Potential Supply Curves for SCE.

Figure 9: Shimmy (Regulation) DR supply curve in 2025, with contributions from end-use technology categories demarcated in stacked bar graphs



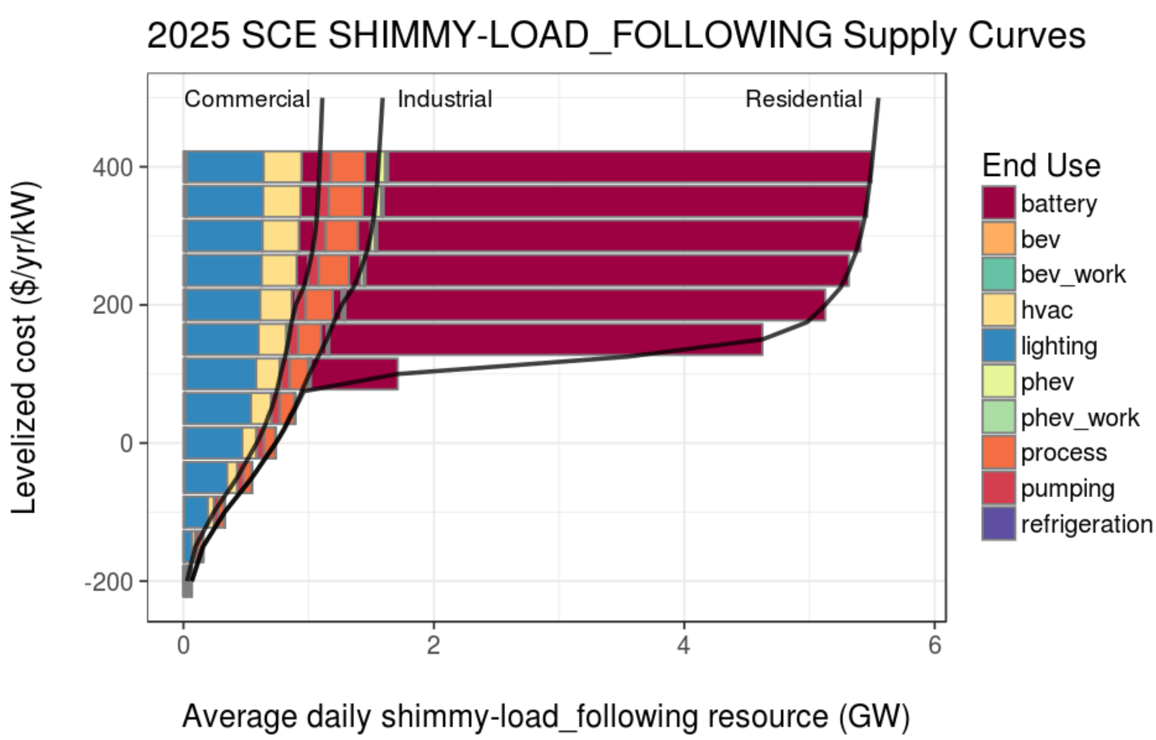
Source: LBNL provided DR Potential Supply Curves for SCE.

Figure 10: Shimmy (Load Following) DR supply curve in 2020, with contributions from end-use technology categories demarcated in stacked bar graphs



Source: LBNL provided DR Potential Supply Curves for SCE.

Figure 11: Shimmy (Load Following) DR supply curve in 2025, with contributions from end-use technology categories demarcated in stacked bar graphs



Source: LBNL provided DR Potential Supply Curves for SCE.

3. DEMAND RESPONSE ENABLING TECHNOLOGIES

This chapter discusses the status of DR-enabling technologies and the ongoing development and demonstration efforts in emerging DR-enabling technologies that could significantly enhance the capabilities of these technologies to provide fast and flexible DR services. The information on emerging technologies is primarily drawn from Navigant's review of the innovative DR enabling technologies demonstration activities currently being undertaken under the Electric Program Investment Charge (EPIC) grant[9] and other secondary sources of information. In addition, Navigant conducted a series of interviews with DR market actors/industry stakeholders to obtain additional information in this area and obtain their perspectives on the key market drivers for these technologies.

Table 1 below summarizes the different end-use technologies by sector and end-use included in the potential assessment and indicates which service types these technologies can provide (some technologies are able to provide both service types whereas others are able to provide only one type of service). It also indicates which end-uses are significant contributors to potential for SCE based off the results presented in the previous section.

[9] Results from the innovative DR technology projects under EPIC were not available at the time of this study. Navigant tried to glean as much information as possible on these projects through review of available documents and discussions with involved parties.

Table 1: Specific End-Uses and Technologies Capable of Providing Shift and Shimmy Services[10]

Capable End-uses and Technologies Identified in the Potential Study			Service Type	
Sector	**End-use**	**Enabling Technology**	**Shift**	**Shimmy**
Residential	Air Conditioning	Two-way communicating thermostat	●	
	Behind-the-Meter Batteries	Auto-DR	●	●
	Battery Electric Vehicles (BEVs) and Plug-In Hybrid Electric Vehicles (PHEVs)	Level 1 and Level 2 charging interruption	●	●
Commercial	HVAC	Manual and Auto-DR.	●	
	HVAC (with Energy Management System (EMS) and VFDs)		●	●
	Lighting	Zonal and Luminaire		●
	Refrigeration (refrigerated warehouses)	Auto-DR	●	●
	Behind-the-Meter Batteries	Auto-DR	●	●
	BEVs and PHEVs	Level 1 and Level 2 charging interruption	●	●
Industrial	Data Centers	Manual and Auto-DR	●	
	Wastewater treatment and pumping		●	●
	Processes and Large Facilities		●	
	Behind-the-Meter Batteries	Auto-DR	●	●
Agricultural	Pumping	Manual, DLC, Auto-DR.	●	
	Pumping (Variable Frequency Pumps)		●	●

Source: Synthesized from the information presented in the California (CA) DR Potential Study.

[10] In addition to the end-uses and enabling technologies listed in, electric water heaters represent an additional end-use with thermal storage capability that could be useful for “shift” and “shimmy” services (the latter with Grid Interactive Water Heaters for providing regulation). However, the potential study did not present DR potential from electric water heater given low saturation

3.1 Residential Sector Enabling Technologies

For the residential sector, potential study results indicate that behind-the-meter batteries provide highest contribution for both shift and shimmy service types. Also, Level 1 and Level 2 charging interruptions of electric vehicles can provide both types of services. In addition, residential HVAC control through two-way communicating thermostats is a shift contributor.

There are ongoing innovative technology development and demonstration efforts in controls and communications of residential end-use technologies, especially in the transactive energy field, that could significantly enhance their capabilities to provide advanced grid services. Some of the ongoing technology development and demonstration activities that can be significant potential contributors toward fast and flexible DR services (shift and shimmy) are discussed below.

3.1.1 Residential HVAC

Current controls for HVAC could potentially provide service with a five-minute signal, but would need to be aggregated to produce reliable DR service, because the optimal compressor runtime ranges from 7-10 minutes, and anything less than that could cause discomfort to the customer.[11] In order to aggregate the impacts from HVAC units that provide fast DR service, there is a need to collect compressor runtime information in real time.[12]

Advanced Residential HVAC Technologies

Advanced residential HVAC systems are likely to be equipped with enhanced DR capabilities that could provide fast and flexible grid services. Current efforts are underway to demonstrate innovative space-conditioning system that integrate several advanced features and are optimized for California climate[13]: These advanced features include:

- Variable-capacity compressor
- Variable-speed fans
- State-of-the-art inverter technology
- Integrated ventilation to optimize “free cooling” fresh air
- Dual-fuel technology to decrease energy costs and allow for consumer choice
- Zonal control
- Advanced fault detection and diagnosis (FDD)
- Alternative refrigerants for improved operations and reduced global warming impacts

The Electric Power Research Institute (EPRI) will integrate these features and test the technology performance in multiple phases in independent laboratories and eventually at three field locations under real-world operating environments to compare its performance to traditional systems. The intelligent controls will control fresh-air ventilation, zonal dampers, compressor speed, fan speed, fuel selection, and FDD, in addition to processing DR messages.

---

[11] DR Potential Study Phase II Report, LBNL, 2016.

[12] *Ibid.*

[13] CEC, *The Development and Testing of the Next Generation Residential Space Conditioning System for California (*EPC-14-021), June 30th, 2015.

This technology offers promise for enhancing the DR capabilities of residential HVAC. It incorporates a number of advanced features that offer substantial co-benefits along with DR, that could help drive customer acceptance if successfully tested.

Inverter technology enables compressors and fans to run at capacities and speeds that match the load of a residence, and zonal control prevents the conditioning of unoccupied spaces. The dual-fuel heat pump system could offer additional shift capabilities. The technology demonstration plans to evaluate thermal storage as a supplemental source of cooling, storing energy when it is the least expensive and releasing it during peak hours, thereby providing "shift" services. The project will include reviewing the feasibility of using thermal energy storage into the next-generation space-conditioning system and what type of thermal energy storage is the most appropriate one to be tested.

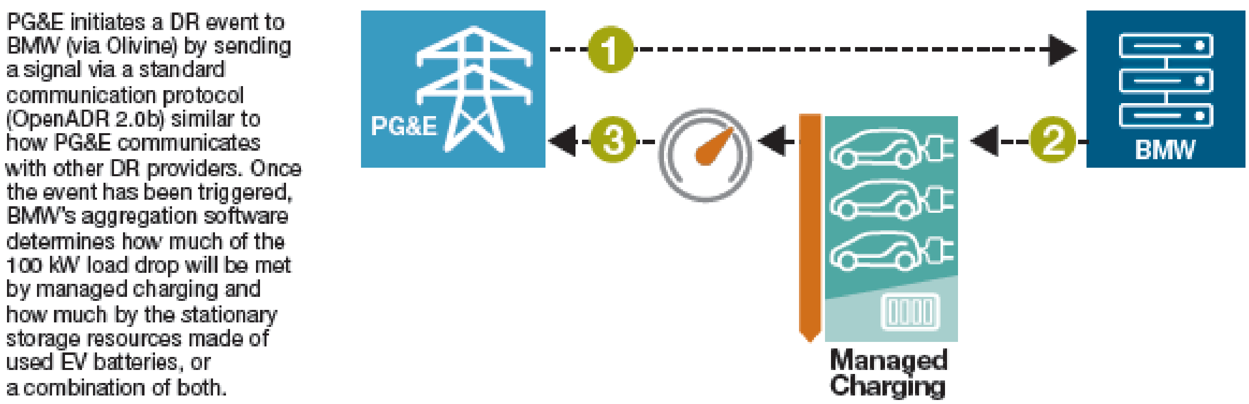
3.1.2 Electric Vehicles[14]

Electric vehicles have significant contribution toward both shift and shimmy potential. Several EV-related pilots and projects have either been undertaken or are currently underway to demonstrate the DR capabilities of EVs. These are briefly described below.

Smart Charging of Electric Vehicles

A BMW-PG&E smart charge project (ChargeForward Pilot) successfully demonstrated PEVs ability to provide viable grid services using Day Ahead and Real Time Energy (see Figure *12* below for the system architecture for the pilot)[15].

Figure 12: BMW i ChargeForward System Architecture



Source: BMW I ChargeForward: PGE&E's Electric Vehicle Smart Charging Pilot

For each DR event, BMW provided PG&E with 100 kW of grid resources from:

1. Delaying charging of 100 BMW i3 vehicles
2. Drawing from 2nd life stationary battery system built from reused EV batteries (MINI E vehicles) for one hour durations

[14] Note that even though electric vehicles and key areas of development for consideration as a DR resource are discussed under residential, these apply to the other sectors too.

[15] BMW, *BMW I ChargeForward: PGE&E's Electric Vehicle Smart Charging Pilot*

Over the BMW18 month pilot period (July 2015-December 2016), 209 dispatched DR events resulted in 19,500 kWh of energy savings. 20% of which came from delayed charging and the other 80% came from the stationary batteries, although the split was very dependent on what time of day a DR event was called (Table 2). The increase in vehicle contribution resulted from PEV and TOU rate plans incentivizing charging during this period.

Table 2: Percent of DR Load met by Time of Day from Charge Delayed vs Battery Load Supply

Time of Day DR event was called	% of Load from Delayed Charging of i3 vehicles	% of Load from stationary 2nd batteries
Average	20%	80%
11 PM – 2 AM	50%	50%

Source: Navigant Table summarizing PG&E ChargeForward Pilot Phase 1 Final Report

In 90% of the DR events (189 of 209 events), BMW successfully reached the full 100 kW grid load reduction requested by PG&E. Throughout the pilot, PG&E called an average of three to four events per week. Each customer had the ability to opt out of each event at any time. However, the overall rate was low throughout the pilot. Most events had no opt-outs suggesting that customers were not negatively impacted by the program (the most opt outs for one event was three of the one hundred i3 owners.)

Based off customer research, 98% of participants indicated that they were satisfied with the program and 93% stated that they are likely to participate in a similar program in the future if offered. Based on the success of the BMW I ChargeForward pilot, BMW received a grant from the California Energy Commission (CEC) to continue with a second phase of the pilot. The next phase will be a 24-month program for over 250 BMW's i3, i8 and performance EV and plug-in hybrid EV owners.[16] The goal is to expand and test new smart charging functionality, including optimizing customer charging across multiple charging events, shifting charging across grid locations, and adjusting charging based on the grid's RE penetration levels.

PEV Advanced Charge Management using Energy Market Prices

The grid benefits of optimized residential Plug-in Electric Vehicle (PEV) charging management from utilizing real-time vehicle information, predictive travel behavior, grid location data, and energy market price data can significantly help to meet the increasing dynamic needs of the grid due to renewables and the inclusion of granular/distribution/energy price signals. Current Total Charge Management pilot efforts by BMW are exploring the ability of flexible vehicle charging to yield a charging load that will match daily and weekly charging events and minimize energy costs.[17] The project will demonstrate not only the temporal benefits of controlled charging, but also the possible locational benefits that can be derived from being able to influence the location of charging.

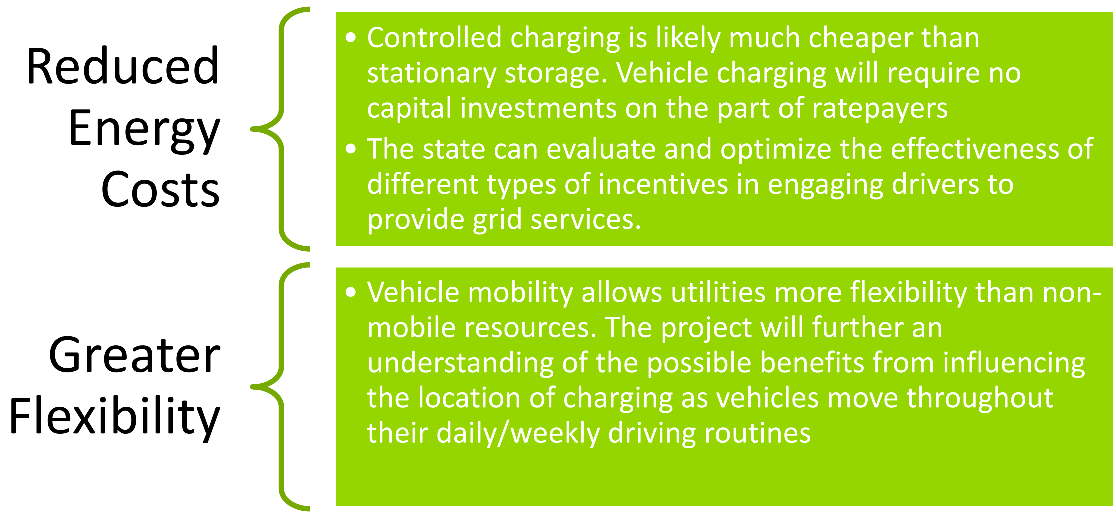
Figure 13 below summarizes the benefits from advanced charge management of PEVs.

---

[16] PG&E External Communications, *PG&E and MBW Partner on Next Phase of Pilot Studying Advanced Electric Vehicle Charing*, November 14th, 2016.

[17] CEC, *Total Charge Management – Advanced Charge Management for Renewable Integration (*EPC-15-084), May 7th, 2016.

Figure 13: PEV Advanced Charge Management Benefits



Source: Navigant Summary of CEC EPC-15-084 Grant Request Form

Through this project, BMW will demonstrate vehicle resources as a demand response, as a real grid resource or a simulated resource. Through the alignment of vehicle charging with renewable generation at the sub-Load Aggregation Point (subLAP) level, BMW will evaluate the following: (1) the level of customer engagement, (2) the technical communication functionality, (3) utility benefits. Optimized vehicle charging will help grid stability issues through the following services:

- *Load Increase and Load Following*: Opportunities to align vehicle charging with renewable integration from starting/stopping charging at home and away
- Acting as a wholesale reserve resource for CAISO
- Increased consumer participation through Transactive energy signaling:
    - *Locational Marginal Price (LMP):* develop an Extensible Markup Language (XML) based LMP node for the physical location identified by latitude and longitude pair
- *Real-time LMP identification and forecasting:* The software should be able to identify the LMP node of vehicle in real time and forecast locations using vehicles in the field.

Next Generation Grid Communication for Residential PEVs using Smart Chargers

Currently, there are no adequate communication interfaces among utilities, charging stations and residential customers with PEVs. The development of a vehicle to grid connectivity methodology will help realize the DR potential through vehicle to grid chargers. Current efforts by ChargePoint Inc. will assess residential smart chargers' real-time potential to respond to utility signals for grid stability when aggregated over a distribution circuit. ChargePoint's EPIC project goals include:

- Develop OpenADR 2.0b communication interfaces between PEV customers and utilities.
- Utilize cloud-to-cloud communication and leverage advanced techniques for retrieving vehicle information via ISO/IEC 15118 standard.

    - Integrate ISO/IEC 15118 interface stack into an existing ChargePoint Home Level2 smart charger.

- Investigate using control methods in the absence of vehicle charging information using statistical estimation, rate of charge output from charging stations or driver opt-in based on maximum charge.
- Educate and recruit 30 pilot SDG&E customers to install ChargePoint chargers.[18]

The technical demonstration consists of adding software components to ChargePoint's Network Operating System (NOS) to gain visibility into real-time charging loads and provide real-time data inputs for charge optimization, enhancing home Level 2 chargers with communication interfaces, integration of communication interfaces into prototype vehicles for proof-of-concept for vehicle to charger communication, and analysis of the data and charging behaviors.

The project's technological advancement will provide visibility into residential PEV charging loads and influence charging schedules. It will develop a network simulation based on LBNL optimization models to validate full control potential, develop a control algorithm capable of limiting the total vehicle-charging load under a virtual aggregation point. ChargePoint will then validate the performance of the controller to capture the ability to control the aggregated load to meet utility limits while ensuring driver preferences are still respected.

Development of Universal Standard for Vehicle Grid Integration

Currently, the only internationally recognized standard for vehicle-grid integration (VGI) is the International Organization of Standardization (ISO)/International Electrotechnical Commission (IEC) 15118.[19] The development of an ISO/IEC 15118 Demand Clearing House (DCH)[20] is critical for commercializing the VGI standard. Without a DCH in place, electric system operators and Electric Vehicle Service Providers (EVSPs) are unable to communicate pricing information and power level to the standards-enabled vehicles and charging stations.

The Center for Sustainable Energy (CSE) is working to develop the world's first DCH that enables the delivery of dynamic energy prices and optimized grid capacity to PEVs in a scalable standards-based format.

[18] CEC, *Next-Generation Grid Communication for Residential PEVs- ChargePoint (EPIC-14-078)*, June 30th, 2015.

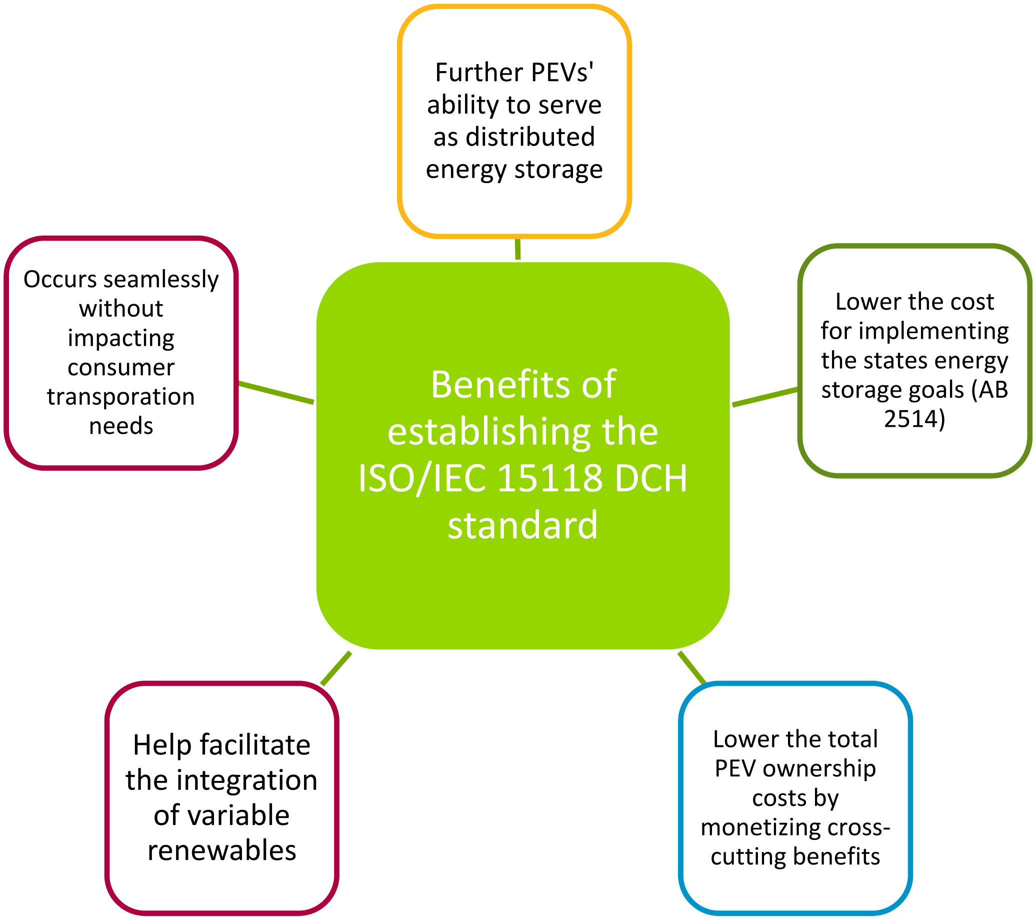
[19] ISO/IEC 15118, was developed over the last six years in an international effort involving over 140 key stakeholders.

[20] CEC, *Vehicle-Grid Integration Workshop (TN 73170).* "The Demand Clearing House or OEM Central Server should not be interpreted to side-step the notion that standardization of a physical connection method and data interactions between the EVSE and PEV can be avoided". July 11th, 2014.

Figure 14 below represents the benefits from a VGI standard.[21]

[21] CEC, *Enable Standardized Vehicle-Grid Integration through Development of Universal Standard- Center for Sustainable Energy (*EPC-14-077), June 30th, 2015.

Figure 14: Benefits from Standards for Vehicle Grid Integration



Source: Navigant Summary of CEC EPC-14-077 Grant Request Form

This interoperability foundation must provide simplicity to the customer while simultaneously allowing system operators to intelligently dispatch vehicle loads. The temporal flexibility provided by this standard will help build confidence in electric vehicles and push toward mass-market uptake. The CSE project will:

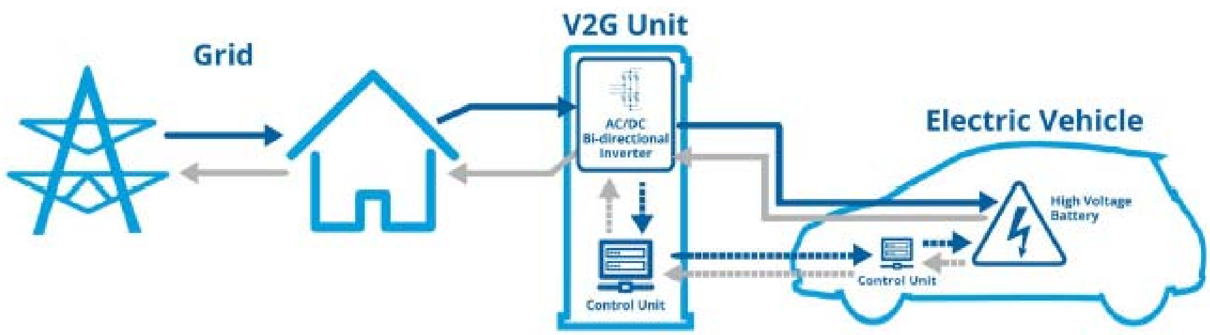
- Develop an ISO/IEC 15118 Demand Clearing House (DCH) capable of collecting wholesale energy prices from the CAISO Day-Ahead Hourly and Fifteen Minute Markets, OpenADR 2.0b signals from SDG&E and other Investor-owned Utilities (IOUs), and PEV owner charging requirements.
- Connect IOU OpenADR 2.0b and CAISO energy markets data to ISO/IEC 15118 Demand Clearing House
- Generate grid profile Tariff Tables for charging stations and connected PEVs that reflect existing and updated conditions regarding prices and available power levels over time
- Demonstrate the real-world utilization of the ISO/IEC Tariff Tables with a fleet of 26 ISO/IEC 15118 charging stations and ISO/IEC 15118-compatible vehicles at UC San Diego

- Analyze, measure, and report on the effectiveness of the enabled control system in harmonizing PEV charging with system wide and local grid conditions in real time[22]

Vehicle-to-Grid Bi-Directional System for Dispersed PEV Fleets

Historic vehicle to grid (V2G) pilots focused on aggregating a large number of PEVs downstream of one substation, while in reality V2G capable PEVs are dispersed amongst the electrical distribution grid (see **Figure 15** below for a V2G graphic). A full V2G information technology solution must be developed to provide control for aggregating numerous geographically dispersed vehicles and considering individual vehicle owner's inputs such that they have a fully charged vehicle when needed for transportation (see .

Figure 15: Vehicle-to-Grid (V2G) Graphic



Source: *http://www.cenex.co.uk/vehicle-to-grid/*

EPRI is developing a V2G demonstration technology that differs from historic projects by:

- Incorporating both ISO and DSO constraints
- Constraining power flow to local transformers
- Taking advantage of open standards for smart gird operations and V2G functionality
- Delivering real time dispatchable load capacity to the DSO and ISO[23]

The project's unique interaction between the OEM and utilities will help identify and demonstrate the operational, technical, and economic impacts of using PEVs for ancillary services[24].

---

[22] Ibid.

[23] CEC, *Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability - EPRI (*EPC-14-086), June 30th, 2015.

[24] Ancillary services (AS) support the continuous flow of energy through the grid to meet demand and correct the real-time, continual gap between predicted (and therefore dispatched) demand and actual demand. The two types of ancillary services considered in the potential study are (1) load following, where the resource follows a five-minute dispatch signal, and (2) regulation, where the resource follows a four-second dispatch signal. Shimmy DR supports the grid by reducing the need for generation units to provide this service.

Similarly, UCLA is performing demonstration projects at five vehicle charging stations with bi-directional capabilities and new control algorithms to provide resilience and cost savings to EV fleet owners by enabling smart charging, V2G, and Vehicle-to-Building (V2B) services.[25] The project serves as demonstration of vehicle grid integration to ensure wider commercialization and adoption of PEVs. Artificial intelligence-based control system determines the optimized charging and/or backfill operations based on EV profiles, user preferences, grid-related events, and grid capacities.

By combining V2G charge and discharge profiles on a local and distribution wide network, the system will provide ancillary grid benefits. Bidirectional power flow will provide dynamic grid stability and reliability during both periods of over-generation and under-generation. The breakthrough will be the implementation of transformer real time monitoring to provide situational awareness of the local distribution grid state to enhance V2G effectivity and efficiency.[26] Smart charging based on energy price, user preference and grid capacities coupled with V2G services can minimize local power congestion and offer peak shaving services.

Real-time bi-directional grid communication interface for PEV dispatch

To effectively implement V2G services, the grid should be capable of effective machine-to-machine and user to machine communication. Andromeda Power is developing an advanced smart grid communication interface that allows utilities to send dispatch signals to PEVs in real-time for optimized bidirectional power flow depending on local power conditions.[27]

The communication interface operates with any standard and will provide California IOUs quick OpenADR. This project will offer a demand-side management solution to a standards agnostic V2G system, like the one being developed by EPRI.

Smart charging of PEVs with Driver Engagement

Currently, no commercially-available solutions exist for intelligently coordinating the charging of vehicles by either responding to Auto-DR signals, mitigating demand charges for ratepayers, or offering PEVs as a resource for the wholesale market. The substantial power draw to a facility from simultaneously charging PEVs can result in ratepayers facing significant demand charges as well as adding substantial loads to the grid during periods when the grid is already stressed. Current efforts by LBNL seek to develop an aggregation system for smart charging PEV vehicles to provide DR, mitigate demand charges and provide ancillary services (**Figure 16** and Table 3 below represent the smart charging control system overview in Alameda County Park)[28].

---

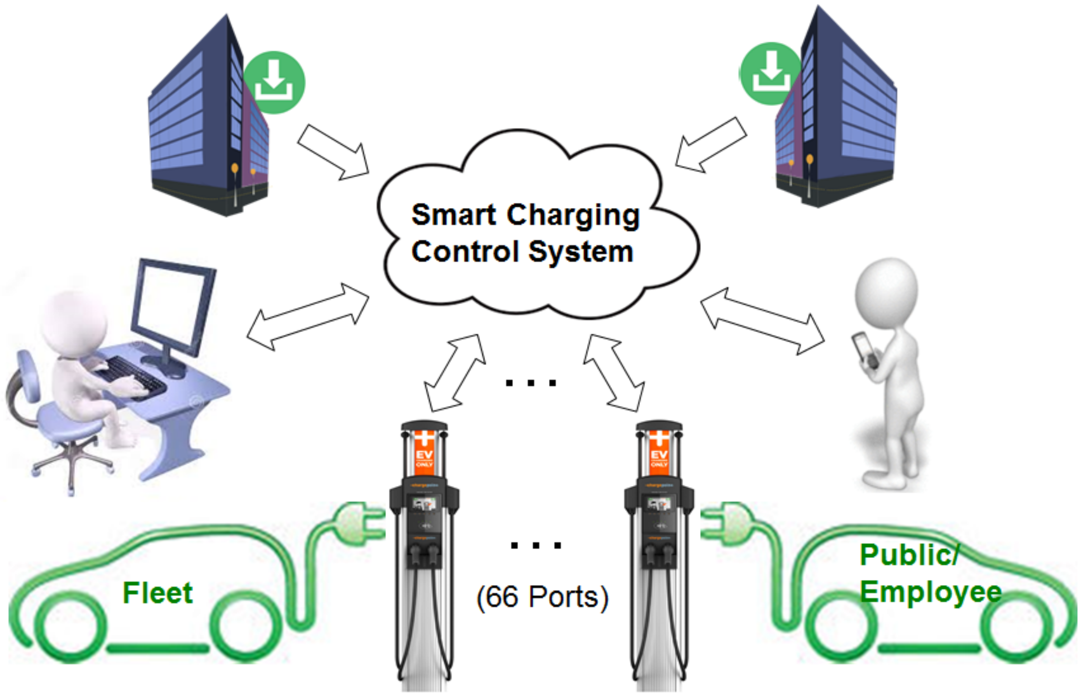
[25] CEC, *Demonstration of PEV Smart Charging and Storage Supporting Grid Operational Needs- UCLA (*EPC-14-056), June 30th, 2015.

[26] CEC, *Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability - EPRI (*EPC-14-086), June 30th, 2015.

[27] CEC, *Grid Communication Interface for Smart Electric Vehicle Services Research and Development- Andromeda Power (*EPC-15-015), February 1st, 2016.

[28] CEC, *Smart Charging of Plug-in Vehicles with Driver Engagement for Demand Management and Participation in Electricity Markets - LBNL (*EPC-14-057), June 1st, 2015.

Figure 16: Smart Charging Control System Overview



Source: LBNL Vehicle-Grid Integration Presentation; Second Annual California Multi-Agency Update on Vehicle-Grid Integration Research, December 14, 2015

Table 3: Summary of Smart Charging of PEV Project

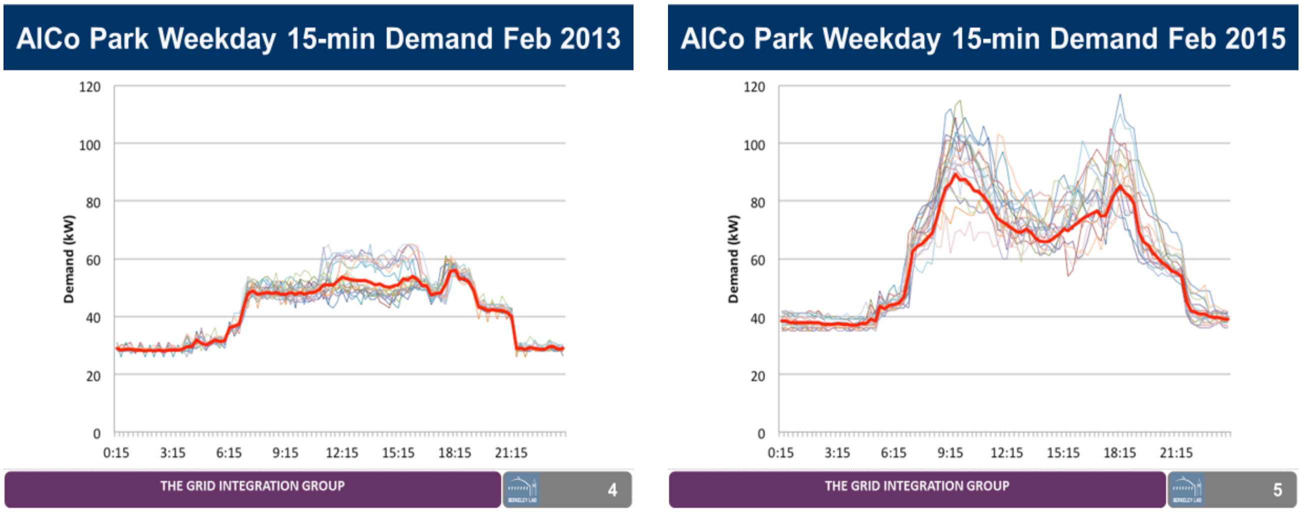
Technology	Number of Location
45 PEVs	7 locations (mostly Alco Park garage in Oakland)
66 L2 and 40 L1 charging ports	10 locations (mostly at Alco Park)

Source: Navigant Summary of CEC EPC-14-057 Grant Request Form

Alameda County (Alco) estimated that monthly demand charges increased from $100 to $1,500 at five of the locations (Figure *17* below shows the 15-minute charging profile in 2013 and 2015, which show significant increase in demand over that period).[29]

[29] LBNL, *Second Annual California Multi-Agency Update on Vehicle-Grid Integration Research*, December 14, 2015.

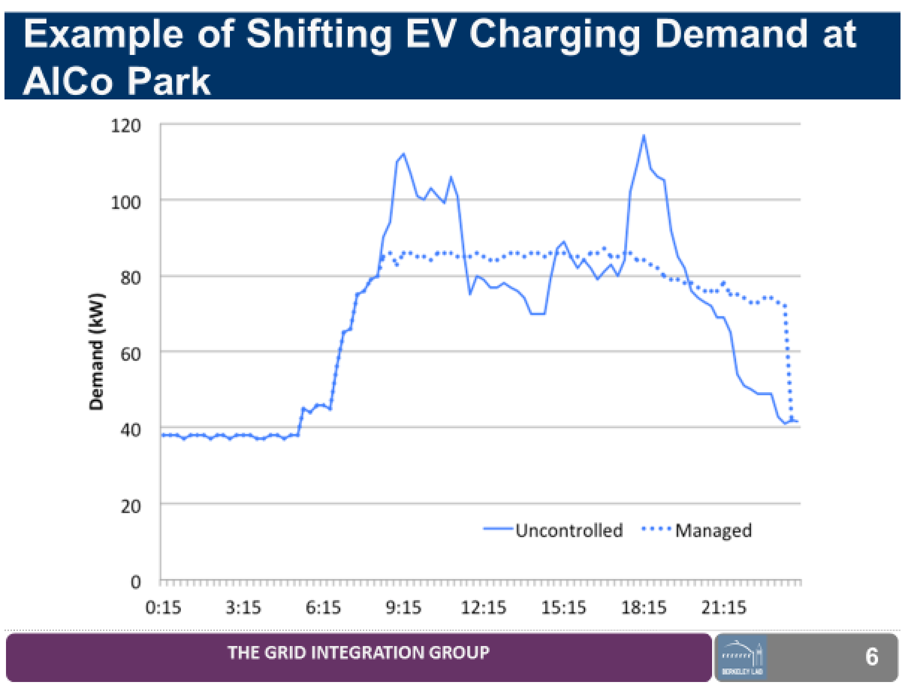
Figure 17: Weekday 15-min PEV Charging Profile at Alco Park



Source: LBNL Vehicle-Grid Integration Presentation; Second Annual California Multi-Agency Update on Vehicle-Grid Integration Research, December 14, 2015

A charging control system will be applied to the Alameda county vehicle fleet to enable participation PGE's Auto-DR programs and the CAISO wholesale markets for DR and ancillary services. Using ChargePoint's OEM API's to control charging, the project will create a flexible, modular, and scalable solution for smart county fleet and public PEVs to minimize utility fleet and electric costs as well as managing daytime peaks in energy demand (Figure *18*).

Figure 18: ***Example of Load Shifting from Smart PEV Charging***

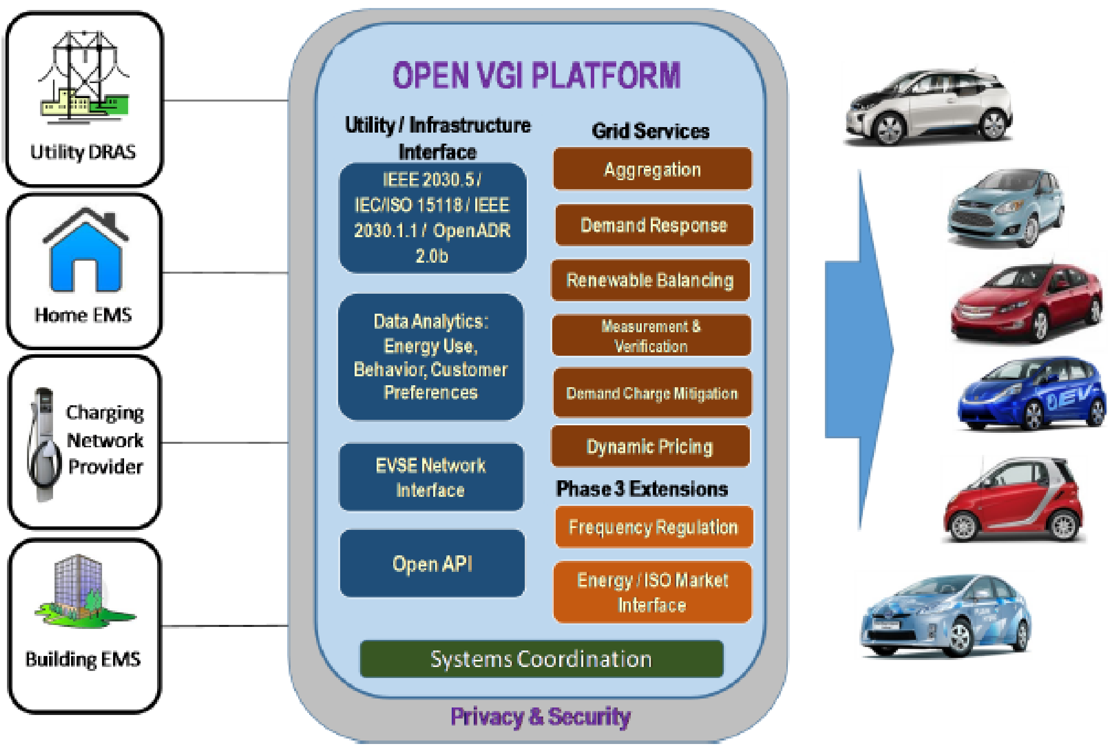


Source: LBNL Vehicle-Grid Integration Presentation; Second Annual California Multi-Agency Update on Vehicle-Grid Integration Research, December 14, 2015.

Open Vehicle Grid Integration Platform[30]

EPRI is leading the development of the Open Vehicle Grid Integration Platform (OVGIP) in collaboration with industry that will pave the way for aggregation of PEVs as a grid resource. The purpose is to develop a single unified standard based interface platform to communicate and interface with the entire base of OEM PEVs, which in turn will integrate with EVSPs, aggregators and other third-party platforms for PEV load management. It will allow the OEMs the flexibility to use diverse on-vehicle communications technologies (i.e. IEEE2030.5, ISO/IEC 15118, and Telematics) that are compatible and interoperable, through the OVGIP, with Utility standard interface protocols (OpenADR2.0b, IEEE 2030.5) and EV Service Providers' application program interfaces (ISO/IEC 15118, OCPP, and industry applied standard and proprietary APIs). **Error! Reference source not found.** below represents the OVGIP scope.

Figure 19: Open Vehicle Grid Integration Platform Scope



Source: Open Vehicle-Grid Integration Platform: General Overview; 3002008705, EPRI Technical Update, July 2016

OVGIP is currently in Phase 2 and fourth year of development. This phase involves development of prototypes, field trials of use cases, and business case analysis (Phase I involved proof-of-concept which has already been undertaken). It will test an integrated suite of automated PEV charge management control strategies including time-of-use (TOU) pricing, peak load reduction, demand charge mitigation, load balancing for intermittent solar/wind generation, Real Time Pricing (RTP), aggregated Demand Response (DR), and scheduling dispatch for ancillary services. Security and data privacy are key design elements of Phase 2. It will also test the reliability, scalability and extensibility of the platform that will be necessary to move forward to the subsequent phases which will involve market deployment of the platform.

---

[30] Open Vehicle-Grid Integration Platform: General Overview; 3002008705, EPRI Technical Update, July 2016

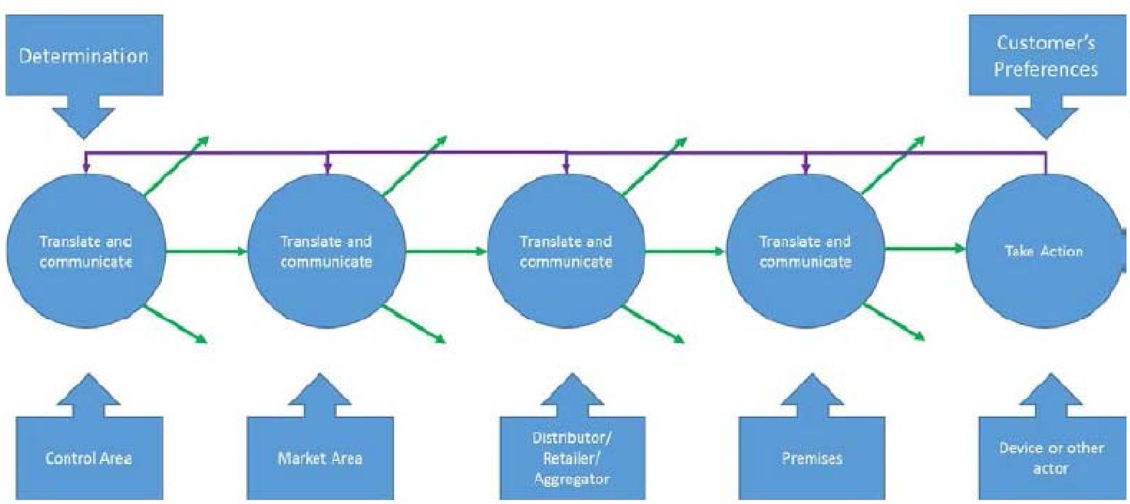
3.1.3 Transactive Energy

Transactive energy, by definition, is *"a system of economic and control mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using value as a key operational parameter"*[31]. According to the GridWise Council, in the demand response context, transactive energy is envisioned to allow an operator at the highest level in the system to send signals to the various operators and entities that run the grid, all the way to customer premises where the customer-programmed devices or the customer themselves can decide about whether to respond to the signal or not[32]. These multiple levels of control require end-to-end communications, with interoperability between systems. Also, multiple parties influence the decision criteria at the various levels. Transactive energy solutions incorporate the following design considerations:

- asynchronous information exchange
- disengaged data
- staged data filtering and pruning
- layered and loosely coupled system interactions
- customer device-based decision making (or the customer themselves directly)
- distributed control and control programming.

Figure *20* below shows a transaction train model with a chain of transactions. It illustrates the fact that the message is not getting simply translated at different stages, but additional constraints or local parameters are added to the mix during these stages. Also, the message flow does not necessarily have to follow a hierarchy, it might be peer to peer, or jump directly from the regional node to the premises.[33]

Figure 20: Transaction Train Model



Source: GridWise Transactive Energy Framework, prepared by the GridWise Architecture Council; January 2015.

---

[31] GridWise Transactive Energy Framework, prepared by the GridWise Architecture Council; January, 2015.

[32] GridWise Transactive Energy Framework, prepared by the GridWise Architecture Council; January, 2015.

[33] GridWise Transactive Energy Framework, prepared by the GridWise Architecture Council; January, 2015

Several transactive energy demonstration projects are being currently funded under EPIC (summarized in Table 4 below), the success of which could significantly enhance the DR capabilities from a variety of end-use devices. The projects indicated as wholesale focus on the role of demand response to meet the supply-side conditions, i.e., wholesale market products. The projects indicated as retail are those that focus on the role of demand response to meet the demand-side conditions, i.e. retail market products offered by the utilities. A few of these are briefly described below[34].

Table 4.* Transactive Energy Projects*[35]

Project/Signals	Market	Objective
BMW	Wholesale	EV smart charge management and optimization based on cost and carbon savings
Center for Sustainable Energy	Wholesale	Demonstrate the resource model for CAISO Proxy DR (PDR)
Ohm Connect	Wholesale	Affect load changes for a large number of residential customers at specific times/locations
Alternative Energy Systems Consulting	Wholesale	Optimize residential energy consumption based on day-ahead hourly or sub hourly pricing
California Institute of Energy and Environment	Retail	Use real or projected prices to initiate control sequences in small to large commercial building HVAC, lighting and plug loads.
Electric Power Research Institute	Retail	Demonstrate aggregation of a wide variety of load types and products on day ahead and sub hourly notifications
UCLA Luskin Center	Retail	Understand how consumer response to incentives varies by weather, day of week, and time of day
Universal Devices	Retail	Demonstrate residential and commercial automated and self-managed energy use and storage

Source: EPRI, Transactive Incentive. Signals to Manage Electricity Consumption; Presented at CEC IEPR Workshop, August 7, 2017.

Generation of Transactive Energy Signals

An essential prerequisite for transactive energy projects is the generation of the transactive signal. Under EPIC funded research, EPRI is developing Transactive Load Management (TLM) signals that accurately reflects system conditions and costs.**[36]** The price determinants will include wholesale LMPs, distribution adjustment, demand variability, supply variability, and greenhouse adder. These calculated signals serve as proxy prices reflective of current and future grid conditions. Figure *21* below shows the design framework for generating the TLM price signal. The transactive energy projects listed above in Table 4 will utilize this price signal.

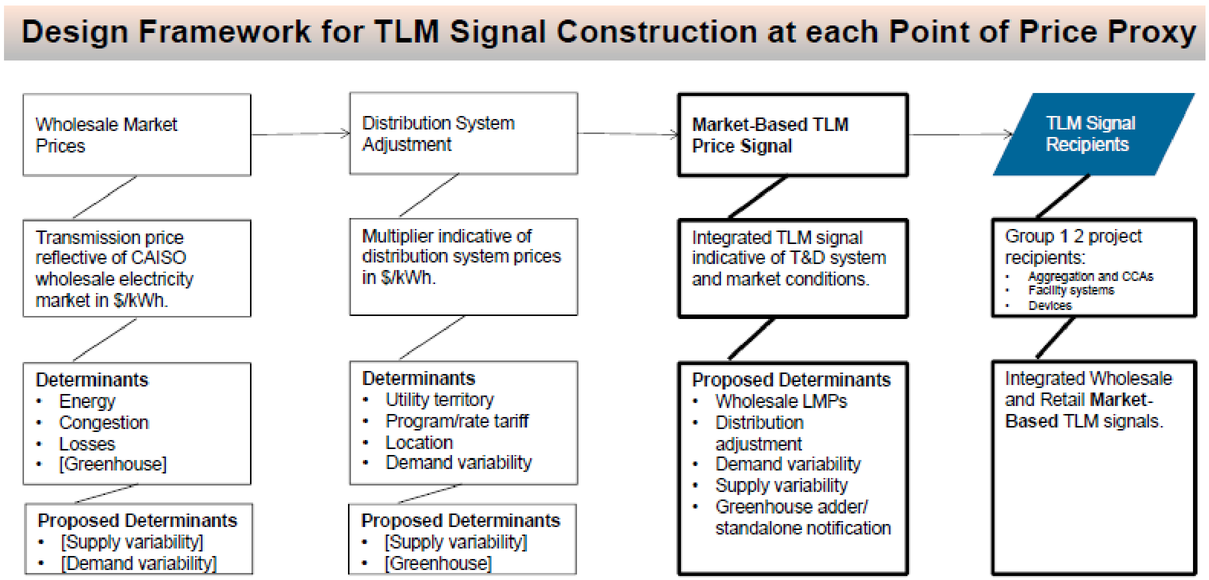
---

[34] Note that the smart charge management pilot with BMW was already discussed under electric vehicles. The transactive energy projects by CIEE and CSE are discussed under commercial sector technologies.

[35] CEC, *Transactive Incentive. Signals to Manage Electricity Consumption – EPRI* (TN 220591), August 7th, 2017.

[36] CEC, *Transactive Incentive Signals to Manage Electricity Consumption for Demand Response - EPRI (EPIC-15-045*), May 18th, 2016.

Figure 21: TLM Price Signal Design and Process



Source: CEC, Transactive Incentive. Signals to Manage Electricity Consumption – EPRI (TN 220591), August 7th, 2017.

Residential Energy Management Solutions

The potential to optimize the interaction between smart grids and smart homes has yet to be realized due to the lack of an enabling technology. To reach this potential, coordinated interoperability between a full suite of intelligent loads and DERS through intelligent synchronized controls must be developed. These controls should provide benefit to real consumers, market actors, and utilities. A current Alternative Energy Systems Consulting (AESC) research project is testing multiple communications methods through an intelligent software solution to perform aggregated control of end-use loads & devices for 100 residential homes to maximize value to the utilities, solar providers and end-users.[37] These end-uses include:

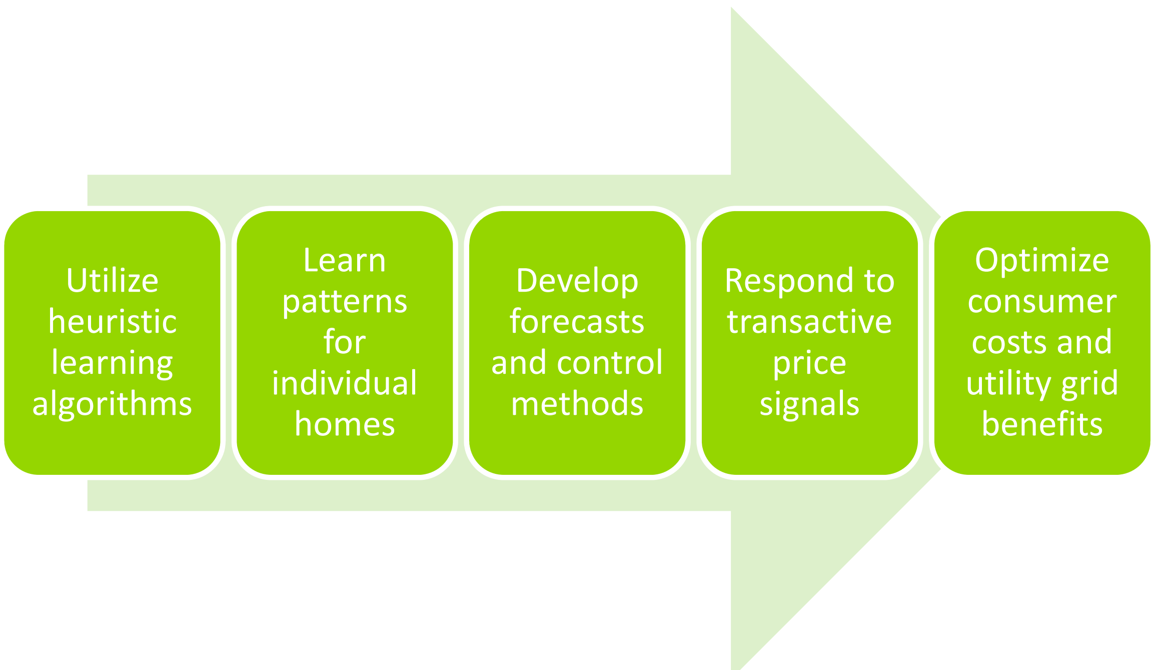
- Energy storage
- PEV chargers
- Smart thermostats
- Pool pumps
- Electric water heaters

The project involves deployment of a residential distributed energy resource management system (RDERMS) developed by Itron. It provides distributed intelligence and dynamic, transactive control of loads through bi-directional communication, closed loop load forecasts, price signals, and price response interactions with the smart grid (**Figure** *22*).

[37] CEC, *Residential Intelligent Energy Management Solution – Advanced Intelligence to Enable Integration of Distributed Energy Resources (EPIC-15-048*), May 20th, 2016.

As part of this project, AESC will test different tariff structures ranging from dynamic day ahead hourly prices all the way to transactive energy. RDERMS has a web-connected hub that analyzes price and weather data to communicate with end-devices and optimize consumption with the goal of lowest cost to the consumer. The system could consolidate day ahead load forecasts – from potentially millions of homes - and facilitate dynamic price signal iteration by transmitting forecasts to a demand clearing house ultimately connected to the grid operator.

Figure 22: Matching Local Grid Needs with Consumer Behavioral Patterns



Source: Navigant Summary of CEC EPC-15-075 Grant Request Form

Aggregated Demand Resources and Transactive Tariff Effectiveness

The collective potential of customer-side, smart-connected devices needs an aggregation platform that accounts for consumer preferences for these devices' individual performance. EPRI is assessing transactive tariff effectiveness to influence aggregated demand side resources and consumer behavior to provide grid services.[38] The software aggregation platform that EPRI is developing will combine DR from multiple residential and small commercial customers to enhance grid stability and reliability. The project will largely demonstrate two things:

- The ability of a wide variety of load types and aggregated products[39] to provide DR and a better customer experience
- Better understand individual preferences for residential and small business customers for load management using data from the connected devices.

[38] CEC, *Customer-centric Demand Management using Load Aggregation and Data Analytics- EPRI (EPIC-15-075)*, June 30th, 2015.

[39] Products include smart thermostats, heat pump water heaters, EVS, PV, and storage

The project will design, develop, test and validate operational strategies for load management utilizing behind the meter resources as well as build a flexible and open demand-side resource integration platform (OPEN DSRIP) to enable DR participation. Key components include responding to transactive tariffs reflecting grid conditions, adjusting the participant's energy consumption profiles, and developing OPEN DSRIP to incorporate the operational strategies and control algorithms. The Open DRSIP platform can also serve as a reference design for industry DR capabilities.

Retail Automated Transactive Energy System

Universal Devices, Inc. is developing a low-cost and standards bases Retail Automated Transactive Energy System (RATES), using a simplified tariff structure and low-cost behind-the-meter energy management system that could unleash DR potential from several residential end-use devices.[40]

The Intelligent System (ISY) hardware/software energy management platform brings in price and value signals and applies machine learning algorithms using customer's preferences and sensory data to automatically shift load usage or purchase additional energy while excess energy is credited. UDI's transactive energy design includes temporal and locational value considerations, full lifecycle mechanisms (offer, transaction, and delivery), is bi-directional (signal generation can see historical transactions to account for previous excess DER generation or previous purchasing data).

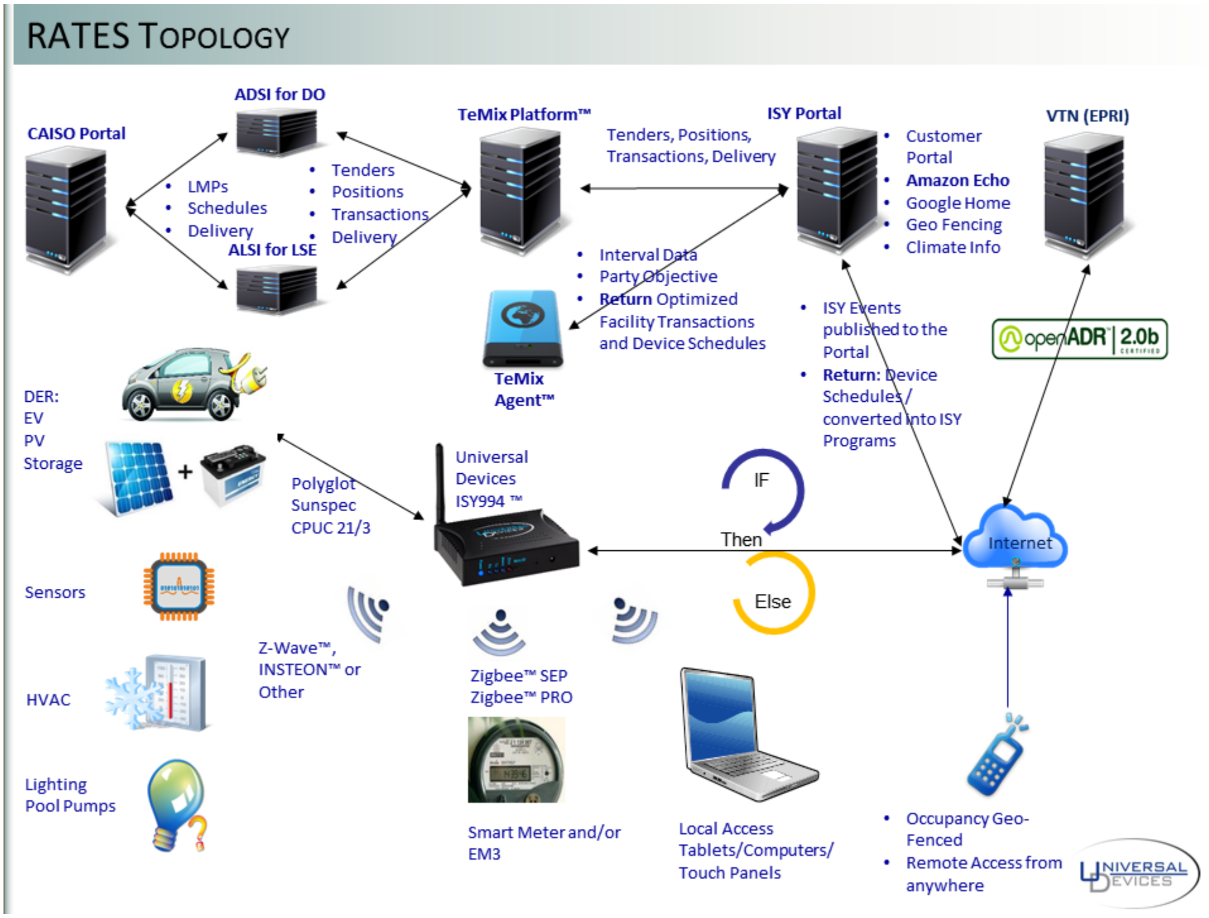
UDI's RATES allows for the sale of both real and reactive energy/power for voltage regulations, solves DER integration issues, and provides load shift/shed services. The platform operates on a five-minute update cycle and incorporates residential and small commercial loads.[41] The TeMix agent, which is the central energy management system, brings in prices from CAISO portal, distribution operators, load serving entities, smart meter data, occupancy Geofenced data and other transactive energy platforms to communicate with different end-use loads and generations sources including DERs, sensors, HVAC, lighting, pool pumps (*Figure 23*).

---

[40] CEC, *Complete and Low-Cost Retail Automated Transactive Energy System (RATES) – Universal Devices, Inc. (EPIC-15-054*), June 30th, 2016.

[41] Navigant interview with Universal Devices, Inc. August 3rd, 2017.

Figure 23. Retail Automated Transactive Energy System (RATES) Topology



Source: Retail Automated Transactive Energy System (GFO 15-311 Status Report)

3.1.4 Behind-the-Meter (BTM) Batteries

Behind-the-Meter Batteries are identified as the largest contributor to shift and shimmy potential for the residential sector in the potential study. The value proposition of BTM batteries is being currently demonstrated through microgrid projects and are not discussed in this report. The technical capability of batteries to provide both shift and shimmy is well established. Addressing market barriers tied to battery adoption (e.g., streamlining interconnection procedures and permits/approval processes) can help realize the potential from this resource.

3.1.5 Customer Engagement and Analytics

Program Design to Increase Customer Participation

Other than the technology focused efforts, pilots are underway to test customer engagement through innovative DR program offers. UCLA is conducting a pilot to test the effectiveness of innovative design strategies for residential DR programs including[42]:

- Tailored energy-analytic feedback

[42] CEC, *Identifying Effective Demand Response Program Design to Increase Residential Customer Participation – UCLA (EPIC-15-073)*, June 30th, 2016.

- Aggregated vs. single-period event information
- Non-Energy Benefits (NEB) including environmental benefits
- Social comparisons

The pilot will also vary the time in which DR information is offered to households to better understand how timing affects participation and response. UCLA will offer alternative DR program designs to 12,500 customers within all the electric IOU service territories. Customer responses will be grouped by income, household structure, climate zones and technology (plug-in vehicles and rooftop PV).

The project will undertake five randomized control studies to test the effectiveness of DR program strategies. It will assess the impact of energy analytic feedback on customer participation, the framing and timing of incentives to maximize persistence, effect of health and environmental messages on customer participation, and effect of social comparisons.

Customer Empowerment

OhmConnect is exploring prosumer (customers who both draw from and contribute to the grid) interest in a third-party demand response market to provide policymakers and regulators with information to develop the policies and limitations for a third-party demand response market.[43]

This project will distribute "smart" thermostats and power strips to existing residential homes. Between 3000-5000 electric utility customers will be eligible to receive one of the two following types of equipment: 1) a wi-fi-enabled "smart" thermostat or 2) a Wi-Fi-enabled "smart" power strip, which will enable prosumer interaction with the grid to effectively supply electricity and save money. Improved residential demand response will help improve grid reliability. Prosumer grid-edge resources increase allow for more distributed resources to be utilized for the coordination of electricity supply and demand.

3.1.6 Innovative Control with FM signals

For devices that aren't directly connected to the internet[44], other signaling techniques need to be deployed. MelRok worked on an SDG&E residential pool pump pilot in which they retrofitted pool pumps with radio based-FM receivers.[45] The advantage of such a system is that it can cost effectively and reliably reach devices that are typically not networked, such as pool pumps, smaller roof top units, window units, and in some parts of the country electric water heaters. **Table 5** below compares internet based communication with radio based communication.

[43] CEC, *Empowering Proactive Consumers to Participate in Demand Response Programs – OhmConnect (EPIC-15-083*), May 18th, 2016.

[44] MelRok's Touch Energy Iot Router communicates simultaneously with more than 100 energy devices over multiple physical interfaces ((RJ45, Wi-Fi, RS485, KYZ pulse input, ZigBee, 4G, dry contacts) and via multiple protocols (Modbus RTU, Modbus TCP, BACnet/IP, SNMP, SEP, others).

[45] SDG&E, *Residential Pool Pump Real Time Demand Response Pilot using FM Radio – Melrok* (Agreement# 5660040262 Report), February 2016.

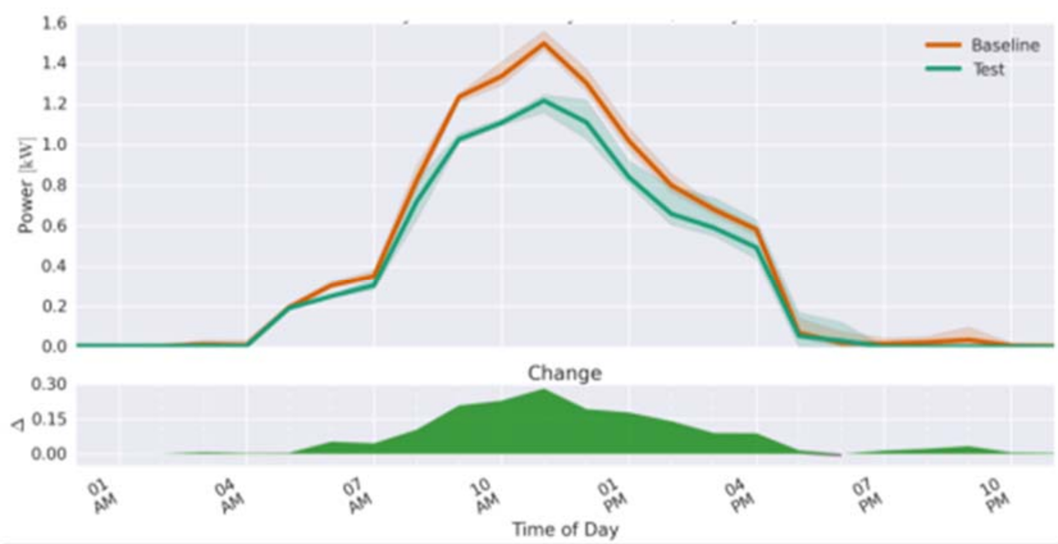
Table 5. Internet-DR Signaling vs. Radio-based Signaling

Internet DR Signaling		Radio Based Signaling	
+	-	+	-
• Can provide feedback to the utility/aggregator within a few seconds • Enables advanced controls, sensing, and feedback	• Response time can be affected if on the same IP server as occupants/other devices	• Can control 10,000s of devices within milliseconds • Drives down cost. Doesn't need much power or maintenance	• Need to be retrofitted with FM receivers • Can't provide feedback at the device level

Source: Navigant Summary of MelRok Interview

The SDG&E pool pump pilot achieved, on an average, 0.3 kW of peak demand reduction for a participant household (*Figure 24*).

Figure 24. Average Daily Demand Profile Comparison – 10 Minute Load Shed Per Hour



Source: Residential Pool Pump Real Time Demand Response Pilot using FM Radio – MelRok (Agreement# 5660040262 Report), February 2016

3.2 Commercial Sector Enabling Technologies

For the commercial sector, the potential study identified commercial HVAC (manually controlled and Auto-DR enabled) as a significant shift contributor and lighting with varying degrees of control as a significant shimmy contributor. Other commercial sector enabling technologies included in the potential study for providing shift and shimmy services are refrigerated warehouses, electric vehicles and behind-the-meter storage. A discussion on the current state of DR-capability of commercial end-use technologies and areas of future advancements follow.

3.2.1 Commercial HVAC

HVAC is the most commonly controlled load during DR events in commercial buildings. For small commercial buildings, the potential study considers switches and smart thermostats for HVAC load control. For medium sized buildings, the enabling technologies are either smart thermostats or Auto-DR, while for large-sized buildings it is Auto-DR.

For Packaged Roof Top Units (RTUs) with basic thermostat controls, common DR strategies include temperature reset and pre-cooling. More powerful or intelligent control systems include automated shut-off of units, cycling or intermittent shutoff, or turning down variable speed compressors or fans in the RTU. In lieu of variable speed, larger high efficiency RTUs often have multi-stage compressors, and one of the stages can be turned off during a DR event. For chillers, DR strategies include reset of chilled water temperatures, or cycling of fans. In variable air volume air handling systems, fan pressure or speed can be limited. Because components of a chiller system interact in a complex way, one needs to ensure that one control action does not result in a compensating control action elsewhere in the system. For example, raising chilled water temperature can cause the fans to run faster to try to maintain cooling. Increased fan power would negate the effect of chilled water temperature reset for DR. [46]

There exists extensive program implementation experience with manual and Auto-DR control of commercial HVAC load. HVAC systems with Variable Frequency Drives (VFDs) are extremely responsive and allow for full automation to maintain customer comfort levels and limit disruption to operations. Additional pilots are necessary to demonstrate the scalability, interoperability and performance of these technologies. Areas of emerging technology research and demonstration that influence DR-capability of commercial HVAC systems for fast and flexible response are discussed below.

Demand Response with Variable Capacity Commercial HVAC Systems

EPRI is involved in research and demonstration of DR with variable capacity commercial HVAC systems (see Figure *25* below for a variable capacity HVAC system)[47].

These variable capacity HVAC systems are primarily associated with energy efficiency (EE) and customer comfort. Variable refrigerant flow (VRF) systems and roof top units (RTUs) offered by most manufacturers include variable speed compressors, electronic expansion valves, and a multitude of refrigerant management features to match output of the HVAC system to load on the building. Over the last five years EPRI has gained significant knowledge and understanding of these systems through laboratory and field evaluations for EE. Variable capacity systems, with their onboard instrumentation and communications capabilities, are candidates for implementing both EE and DR at the same time. Efficiency rebates have been in place for such equipment but DR capabilities can push the technology further into the mainstream market. While the energy efficiency potential of these systems is well understood, additional tests are necessary to understand DR capability of these systems through the reduction (or increase) of power draw and their ability to communicate using open protocols like OpenADR. Additional operational data is required from field-installed systems to demonstrate advanced DR capabilities.

[46] Demand Response Cleanup (Including Changes to Space Conditioning, Lighting, Energy Management, Power Distribution, and Solar Ready Sections) – Draft Report; Measure Number: 2019-ALL-DR-D; Residential and Nonresidential Demand Responsive Controls; July 2017.

[47] Demand Response with Variable Capacity Commercial HVAC systems". EPRI Project ID: 1-108128; February 2016.

Figure 25. Commercial Variable Capacity HVAC

Source: Demand Response with Variable Capacity Commercial HVAC systems". EPRI Project ID: 1-108128; February 2016.

EPRI intends to identify and review available variable capacity HVAC systems and engage with vendors and manufacturers to understand their capabilities related to DR. Through this project, it intends to develop test and analysis plans of variable capacity HVAC systems that meet host utility DR objectives for implementation within the hosting service territory.

Commercial HVAC Systems with Integration of Variable Refrigerant Flow and Indirect Evaporative Cooling

EPRI is developing and demonstrating a Climate Appropriate commercial HVAC system that integrates Variable Refrigerant Flow (VRF) and Indirect Evaporative Cooling. VRF and Indirect Evaporative Cooling individually offer benefits and are market ready, but have not been tested in integration.[48]

The project will develop and demonstrate control systems and algorithms which can provide the integrated solution and will evaluate cost effectiveness of the integrated solution for new and retrofit buildings, including the cost of control system integration. It will incorporate predictive analytics and cloud based controls to enable better occupant comfort, energy performance and peak demand management. The integrated controls with system optimization algorithm are expected to provide enhanced DR capabilities. The system will use on-board OpenADR Virtual End Node (VEN) to obtain signals regarding grid conditions and optimize system operation (e.g. precooling of spaces based on historic occupancy patterns).

[48] "Climate Appropriate HVAC systems for commercial buildings to reduce energy use and demand"; CEC, EPC-15-004.

Fast DR Feasibility Demonstration

Successful integration of renewable resources into the grid requires the dynamic and real-time demand management of residences, buildings, campuses and microgrids. To provide regulation-shimmy services, various DR enabled technologies and strategies must be able to rapidly respond to utility signals (seconds). This includes the time for a technology to check server for a DR signal, download any instructions, toggle any end-use loads to decrease (or increase load), measure the impact, and then send feedback to the aggregator/utility. MelRok Energy IOT is currently working with SDG&E to evaluate the DR response speed through an OpenADR 2.0b cloud based system.[49] The company focuses on real time energy management by monitoring building energy management systems (EMS) from the cloud. The challenge lies in enabling open cloud technologies to economically connect to billions of previously installed energy devices at working utility customer locations.[50]

To enable the real-time connectivity necessary for fast DR, MelRok made its OneTouch Energy IoT platform backwards compatible with all legacy devices and their native protocols while also incorporating all emerging open systems and new standards. The OneTouch platform better integrates renewables and other distributed renewables at a facility, grid, or microgrid level to rapidly analyze, control, and balance energy loads to accommodate variability in supply. The Touch Pro simultaneously collects data from multiple IP-based energy meters and sensors, three voltages lines and 24 current transformer sensors at speeds of 1 Hz frequency. The Touch Pro replaces the use, cost and complexity of:

- 8 three-phase meters
- Multi-protocol communication interface
- BACnet/IP data client
- Modbus TCP data client
- SNMP data client
- BACnet/IP data server
- Modbus TCP data server
- SNMP data server
- Data acquisition system
- Data logger
- OpenADR client
- Data streaming engine

A joint LBNL and MelRok study for SDG&E demonstrated a fast DR system architecture using OpenADR 2.0b to test the response time for frequency regulation at the SDG&E Energy Innovation Center.[51] ***Figure 26*** below is a schematic of the controls and communications platform used in the project.

The project goals included:

---

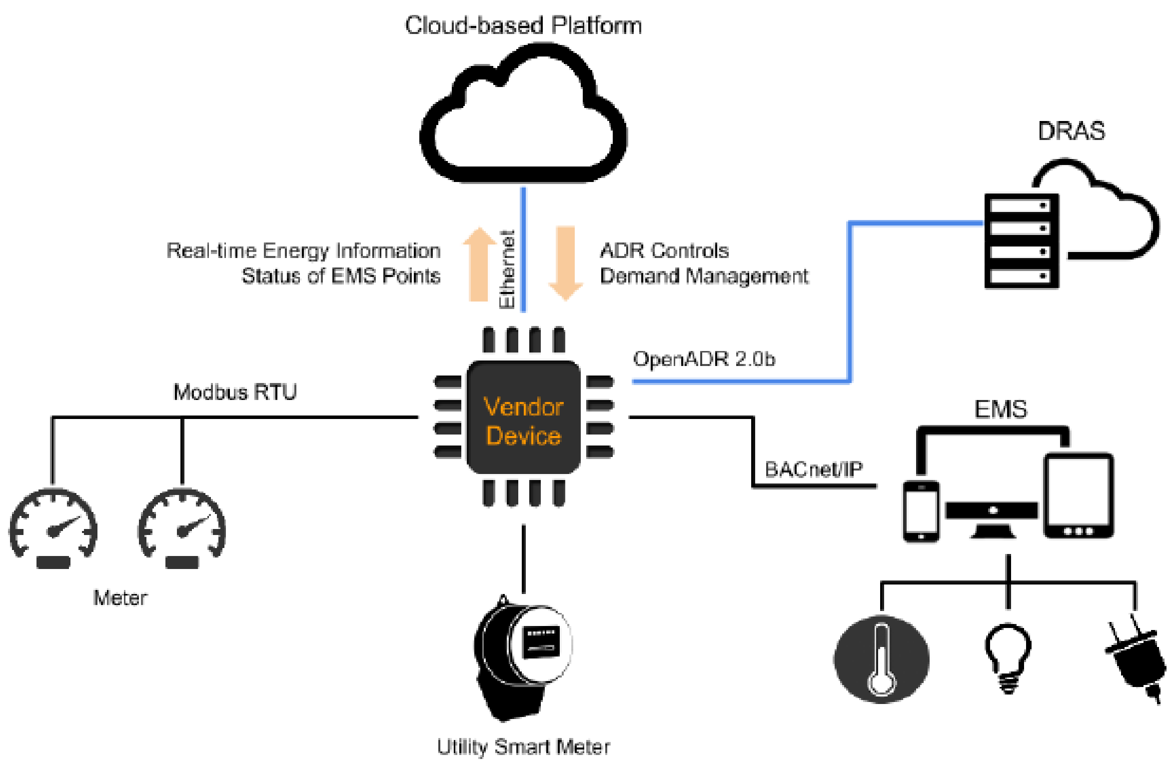
[49] Navigant interview with MelRok. July 25th, 2017.

[50] MelRok Energy IOT, *The Internet of Things for Energy*, https://MelRok.com/resources/white_papers/iot_for_energy_white_paper.pdf, March 2015.

[51] SDG&E, *Fast Demand Response Technologies and Demonstration at SDG&E Energy Innovation Center using OpenADR – LBNL & MelRok* (Project No.DR14SDGE0001). March 2016.

- Demonstrate how OpenADR can simplify the interactions between the OpenADR cloud server
- Automate building controls to provide fast DR with OpenADR signals
- Provide fast DR solutions to enable customer participation in ancillary services using OpenADR 2.0b protocols

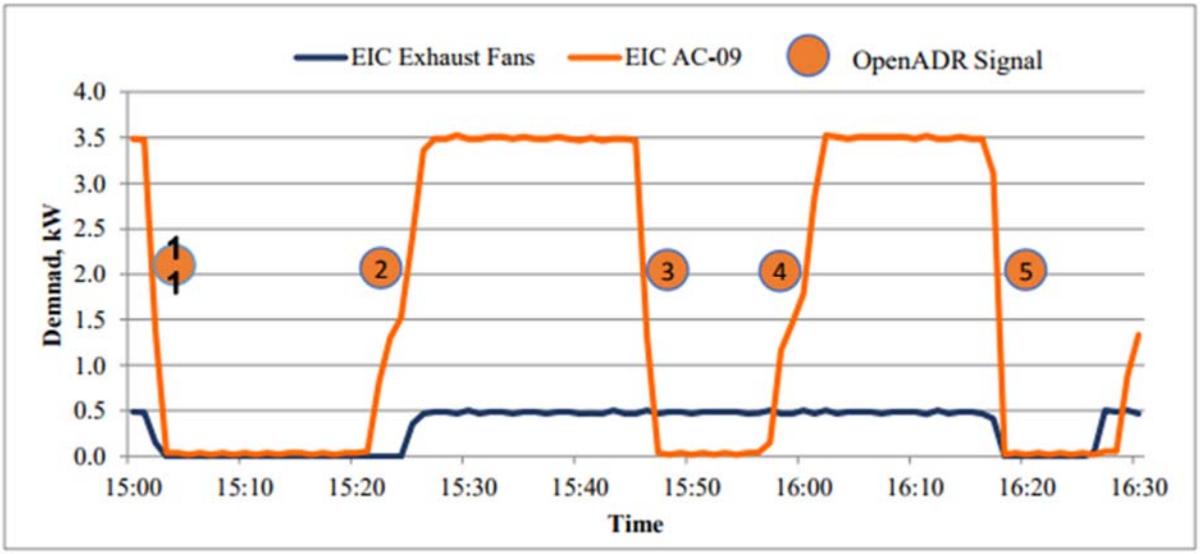
Figure 26. **Schematic of communication, control and data acquisition provided by the Vendor's platform**



Source: SDG&E, Fast Demand Response Technologies and Demonstration at SDG&E Energy Innovation Center using OpenADR – LBNL & MelRok, March 2016.

The project demonstrated the ability to use fans and AC units through OpenADR 2.0b protocol to respond to DR events and day-ahead hourly prices. The measured response time ranged from 3 to 5 seconds for the DR strategy of shutting down exhaust fans, and from 5 to 12 seconds for the DR strategy of shutting down AC (Air-Conditioning) units (*Figure 27* below).

Figure 27. ***SDG&E EIC Exhaust Fan and AC Unit's Power Response Times***



Source: SDG&E, Fast Demand Response Technologies and Demonstration at SDG&E Energy Innovation Center using OpenADR – LBNL & MelRok, March 2016.

Virtual BMS Enabling Small Commercial DR Participation with Price-mediated Automated Demand Response

Commercial customers require significant energy for their services and greatly contribute to peak demand energy, however few DR solutions address these commercial customers. While large commercial customers often have BMS/EMS that respond to price signals, small commercial customers do not and consequentially cannot easily participate in DR. The California Institute for Energy and Environment is developing a cost-effective energy management system that allows a wide range of hardware and service offerings.[52] The open source and open architecture DR management platform (XBOS/DR)[53] can interface with multiple hardware devices and software applications from different vendors, running parallel to the business models of many companies who want to maintain a single vendor, proprietary solution.[54] The platform's ability to create a virtual BMS provides large and small commercial customers a variety of DR capabilities.

Through the following solution offerings, this project will better enable the following DR offerings/grid benefits (summarized in Table 6).

Table 6. DR Capabilities and Benefits of the Virtual BMS

XBOS/DR Offerings and Capabilities	Benefit
Receive pricing signals, evaluate energy demand, respond to managed demand requirements	Enable automated DR resulting in optimized grid and customer benefits

[52] CEC, *Customer-controlled, Price-mediated, Automated Demand Response for Commercial Buildings- CIEE (EPIC-15-057)*, June 30th, 2016.

[53] The Demand Response management platform is based on the eXtensible Building Operating System (XBOS/DR)

[54] CEC, *Customer-controlled, Price-mediated, Automated Demand Response for Commercial Buildings- CIEE (EPIC-15-057)*, June 30th 2016.

XBOS/DR Offerings and Capabilities	Benefit
Enable different customer groups to adapt DR with individual preferences for each commercial building	Improve commercial customer DR participation through customized DR offerings
Track, evaluate and control multiple heterogenous devices	Increase DR impact potential by integrating a varied suite of technologies for varied customer types
Interoperate with various building systems (e.g. BMS or networked thermostats)	Enable building coordination of building management with the operation of other building systems
Retain the electrical usage history of connected devices	Provide the basis for understanding usage patterns for effective demand optimization and management
Maintain load diversity through price signals or advanced controls	Prevent system destabilizing from similar loads switching on and off simultaneously
Establish data and system security	Prevent disruptive intrusions or theft of confidential information
Provide additional customer value. Software should also provide other services such as management of demand charges and turning off equipment during non-business hours	Because DR is implemented at a relatively small scale in many commercial buildings, inexpensive software and additional services increase DR uptake

Source: Navigant Summary of CEC EPC-15-057 Grant Request Form

By providing pricing-based load management algorithms (system will receive transactive signal), information from based on a variety of metrics including load type, existing schedules, service prioritization, and historical demand across a diverse group of technologies and end-uses, a larger range of commercial customers are able to participate in higher value DR programs.

Integrated Load Management with Storage, Energy Efficiency and PVs

The Center for Sustainable Energy (CSE) is developing strategies to optimize DER participation in retail and wholesale tariff sutures as well as future markets structures (i.e. transactive energy).[55] Table 7 below shows the two DER optimization portfolios CSE is considering for commercial buildings:

Table 7. CSE DER Optimization Technology Packages

Portfolio #1 (Large retail and schools)	Portfolio #2 (Grocery/Supermarkets)
• Battery Energy Storage • PVs • Integrated Load Management	• Thermal energy storage • Energy Efficiency (refrigeration, lighting) • Integrated load management

Source: Navigant Summary of CEC EPC-15-074 Grant Request Form

[55] CEC, *Meeting Customer and Supply-side Market Needs with Electrical and Thermal Storage, Solar, Energy Efficiency and Integrated Load Management Systems – Center for Sustainable Energy (*EPC-15-074), May 18th, 2016.

One of the objectives of the project is to design operational strategies to respond to a simulated price signal or automated notification from a grid operator, distribution utility, demand response aggregator or other entity. The project will receive the Transactive Load Management (TLM) signals that EPRI is generating.

3.2.2 Commercial Lighting

Commercial lighting is identified as a significant shimmy contributor and is assessed to be a cost-competitive for providing both shimmy load following and shimmy regulation.

Common DR strategies for lighting in non-residential facilities are dimming, non-essential lighting shutoff, and partial shutoff, depending on the lighting technology and the facility layout. Many automated DR device manufacturers have developed products designed to either integrate with existing lighting control systems or establish new lighting control capabilities.[56]

The potential study included lighting controls at three levels- standard lighting controls (existing standard practice lighting systems that meet Title 24 requirements), zonal (zonally controlled luminaires) and luminaire controls (highly granular digital controls for individual luminaires/fixtures).[57] In the zonal control system, a centralized panel controls each channel (or circuit) in unison. The potential study considers that zonal and luminaire lighting systems are enabled with Auto-DR technologies and can provide shimmy. Workstation specific luminaires are the most advanced form of lighting control and incorporate the following characteristics: 1) they provide separate, dimming control of the cubicle's "ambient" and "task" lighting components, 2) occupancy sensors and control photosensors are integrated into the fixture's design and operation, 3) luminaires can be networked using physical cabling, microcontrollers and a PC running control software.[58]

Commonly perceived barriers towards penetration of advanced lighting controls are recent retrofit of the lighting stock in commercial buildings, high costs associated with lighting controls and disruptions to business operations. However, the situation is changing with increasing adoption of LED luminaries with networked wireless controls. LED technology is well-suited for advanced wireless controls strategies as the fixtures are easy to dim, which is essential for advanced controls strategies like institutional tuning and daylight harvesting.[59] Also, the LED light source is less susceptible to shortened lifetimes due to on/off cycling that occurs with aggressive occupancy sensor control, which can cause fluorescent lamps to fail early. Therefore, as the lighting market is increasingly filled with LED lighting options for commercial building spaces, installation of advanced wireless controls with LED fixtures is likely to be more common in the future.

Recently completed and ongoing demonstration of DR-enabled advanced lighting technologies are briefly described below.

Wireless Lighting Controls Automated Demand Response

SDG&E conducted a scaled field placement project to evaluate, monitor and validate the DR capabilities of connected lighting points to leverage OpenADR for greater participation in DR

---

56 *Demand Response Cleanup (Including Changes to Space Conditioning, Lighting, Energy Management, Power Distribution, and Solar Ready Sections) – Draft Report*; Measure Number: 2019-ALL-DR-D; Residential and Nonresidential Demand Responsive Controls; July 2017.

57 2015 California Demand Response Potential Study; Phase 2 Results, 2016.

58 2015 California Demand Response Potential Study; Phase 2 Appendices, 2016.

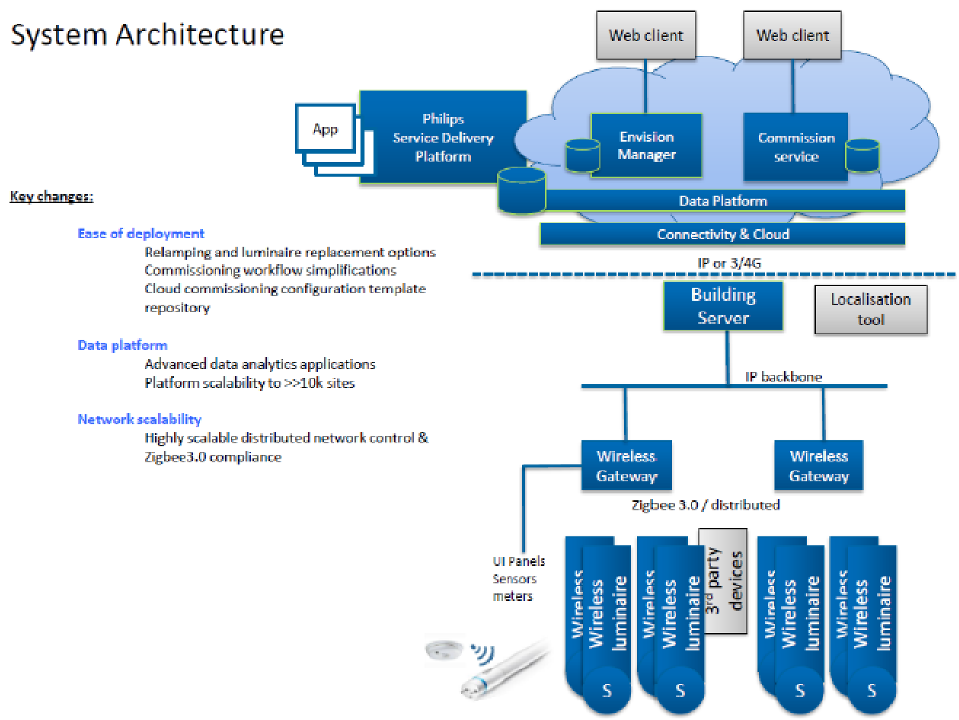
59 "Wireless Advanced Lighting Controls Retrofit Demonstration"; prepared for the General Services Administration; by the Lawrence Berkeley National Lab (LBNL), April 2015.

programs.[60] Buildings often do not have proper metering for DR participation and require an aggregator to participate. By connecting luminaries with embedded sensors and wireless controls connected to a building EMS, various markets segments and buildings without metering for DR program participation can explore potential demand savings and increased participation in Auto-DR programs. The project goals were to:

- Determine the reliability of lighting points to receive DR signals without customer intervention
- Validate demand reduction for each time-period tested
- Validate that DR strategies implemented using Auto-DR incorporate consumer preferences and reliable respond to DR events[61]

Figure 28 below shows the connected lighting points system architecture demonstrated in the project.

Figure 28 Connected Lighting Points System Architecture[62]



Source: San Diageo Gas & Electric Emerging Technologies Program, *Wireless Lighting Controls Automated Demand Response,* August 2016.

The project demonstrated demand reductions using a connected LED lighting systems with embedded sensors and wireless controls integrated into the luminaire. The luminaires connect wirelessly to wireless access controls (WACs) that are connected to the EMS. As a prototype, the version of the solution used for this project allowed for grouping of fixtures by functional area. Newer versions allow

[60] San Diageo Gas & Electric Emerging Technologies Program, *Wireless Lighting Controls Automated Demand Response (DR15SDGE0001 Report)* , August 2016.

.

[62] San Diageo Gas & Electric Emerging Technologies Program, *Wireless Lighting Controls Automated Demand Response (DR15SDGE0001 Report)* , August 2016.

for fixture by fixture control. To accommodate the normal changes in a building's space utilization, the easy to use interface allows for fast reconfiguration of the lighting points without any wiring changes or need to relocate fixtures. The solution is scalable for any job size, from small to large. Integration into EMS or building management systems (BMS) can be achieved through the network gateways. The project reported average 60% reduction in demand during DR events over the LED baseline.

Value Proposition for Cost-Effective, DR-Enabling, Non-residential Lighting System Retrofits

While the current CA Building Energy Efficiency Code (Title 24) requires DR capabilities, there has been little focus on integrating lighting DR into the broader commercialization path for DR-enabling lighting controls.[63] LBNL is undergoing a study to identify, quantify, and evaluate the costs and benefits for implementing Demand Response lighting controls as required by Title 24 across the non-residential building stock. California's current commercial DR requirements are based on the CEC's Time-Dependent Valuation (TDV) metric, which accounts for societal value proposition at large. Due to the unclear value proposition to the end-use consumers, it is likely that most code compliant projects do the minimum (or less) amount of control to meet the code requirements.[64] Even though Title 24 requires the system to be responsive to Auto-DR signals, it does not require OpenADR capabilities or even to be ready for DR deployment.[65] The LBNL project will quantify lighting DR capabilities value to help overcome adoption barriers for increased uptake of Auto-DR capable systems. The research will serve as the groundwork for re-shaping Auto-DR program designs from both a marketing and valuation perspective.

3.2.3 Refrigerated Warehouses

In addition to commercial HVAC, refrigerated warehouses offer substantial shift opportunities due to their huge thermal mass. These facilities can absorb excess solar during the day and shift the cooling cycles to reduce the temperature during the day, and then shut off electricity to refrigeration units during other times to save energy, while holding the temperature utilizing the facility's substantial thermal mass. Even for regular shed DR, refrigerated warehouses are often able to shut off their cold storage areas for 3 to 6 hours without negatively affecting products.

A substantial fraction of refrigerated warehouses has integrated control systems where each component of the refrigeration system is under the supervisory control of a central controller, thereby making them excellent candidates for Auto-DR enabled control.

Full automation technologies are readily available and can optimize energy operations for DR and EE for these facilities. Demonstration of Auto-DR for refrigerated warehouses indicate that facilities demonstrated consistent DR results. Control technologies installed for EE and load management purposes can often be adapted to use the OpenADR protocol at a reduced incremental cost. Also, improved controls associated with Auto-DR prepare facilities to be more receptive to EE and DR in general due to both increased confidence in the opportunities for controlling energy cost/use and access to real-time data.

LBNL and VaCom Technologies collaborated on drafting a "Refrigerated Warehouses Demand Response Strategy Guide", which is intended to assist refrigerated warehouse owners and operators in making strategic decisions related to implementing an electric demand management strategy at

[63] CEC, *The Value Proposition for Cost-Effective, Demand Response-Enabling, Nonresidential Lighting System Retrofits in California Buildings- LBNL (EPIC-15-051)*, June 1st, 2016.

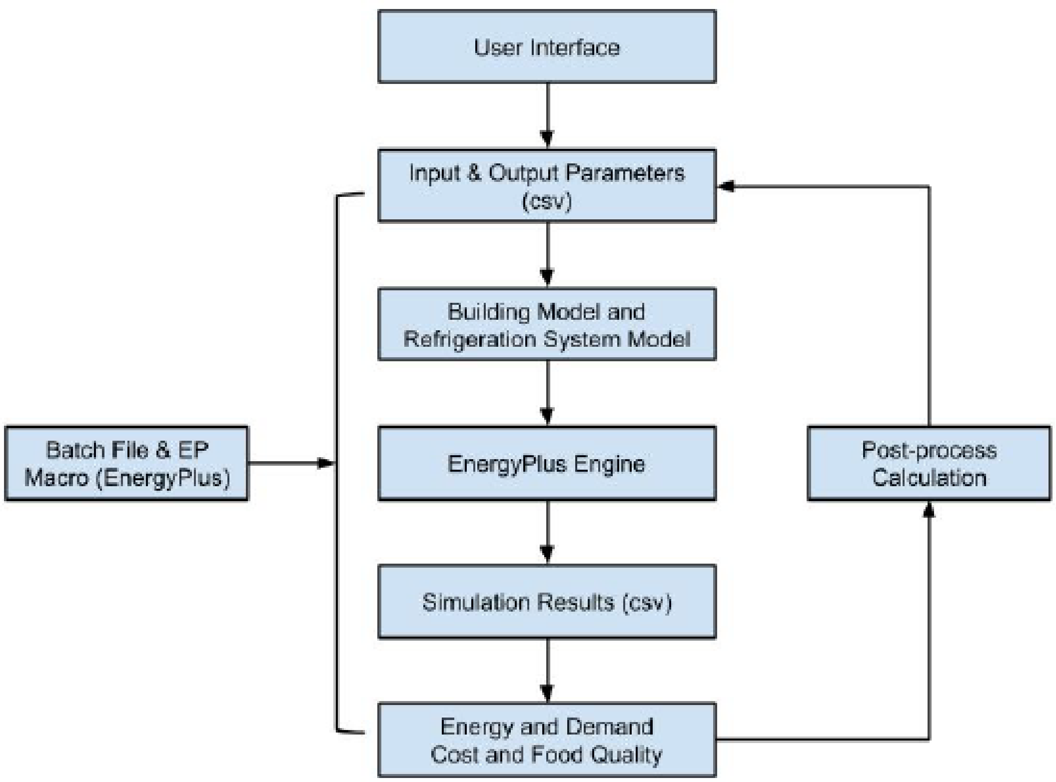
[64] *Ibid*.

[65] Navigant interview with Lutron. August 23rd, 2017.

their facility, including DR[66]. This guide expands on the complex relationship between EE and DR. The work explores which EE measures increase operating flexibility (e.g., improved DR), when coupled with smart controls; as well as which measures and methods serve a dual purpose (i.e., to the benefit of both EE and DR). The work also points out where certain measures could work at cross purposes (i.e., with competing objectives to the detriment of DR, EE, or owner's cost), and how these competing objectives can be balanced through more integrative analysis, design, and control. Finally, the guide also distinguishes between DR and permanent load-shift strategies, and weighs the benefits and challenges of both approaches.

LBNL has developed a Demand Response Quick Assessment Tool[67] for Refrigerated Warehouses (DRQAT-RW) that was tested at a large cooler facility in Southern California (see ***Figure 29*** below for a schematic of the tool). The tool can make accurate recommendations about EE and DR potential in individual refrigerated warehouses. The objective of this tool is to provide a reliable way for simulating the operations of individual refrigerated warehouse facilities.

Figure 29 **Schematic Framework of DRQAT-RW**



Source: Development and Validation of Demand Response Quick Assessment Tool for Refrigerated Warehouses in California; LBNL, August 205.

---

[66] Refrigerated Warehouse Demand Response Strategy Guide Doug Scott, Rafael Castillo, Kyle Larson and Brian Dobbs, VaCom Technologies Daniel Olsen, Lawrence Berkeley National Laboratory Energy Technologies Area November 2015.

[67] Development and Validation of Demand Response Quick Assessment Tool for Refrigerated Warehouses in California; LBNL, August 205.

EPRI is currently testing flexible demand response capability at an industrial refrigeration site.[68] The project will develop and test a flexible energy management system (FEMS) that incorporates real-time sensory to achieve fast demand reductions and flexible demand adjustments or ramping based on grid conditions. The demonstration will interface existing supervisory control and data acquisition (SCADA) controls with FEMS using OpenADR and/or real-time interfaces to evaluate capability and issues for providing fast and flexible DR with plant systems. It will develop control strategies and test plans for piloting the architected system and monitoring its performance to achieve targeted demand adjustments.

3.3 Industrial Sector Enabling Technologies

Potential study results for SCE's service territory indicate the possibilities for cost-competitive shift of industrial process loads. Potential from industrial process loads is also represented under shimmy load following potential[69]. Only behind-the-meter batteries in the industrial sector are included in the potential results under shimmy regulation. The other two types of industrial end-uses included in the potential study were wastewater treatment facilities and data centers. However, no significant cost-competitive shift or shimmy potential is identified with these end-uses for SCE.

3.3.1 Industrial Processes

Depending on the type of industry and the specific processes, it may be possible for certain industries to provide "every day" shift and shimmy services, through structural adjustments to production schedules in certain portions of their processes and stagger these over the course of one day and over multiple days may be good candidates for "every day" shift, as represented in the potential study.[70] There are likely challenges associated with translating traditional shed experience from industrial processes toward providing these fast and flexible DR services and customized strategies are necessary depending on the type of industry and their business processes.

Greatest potential for Auto-DR exists in industries with flexible production schedules and batch processes. For example, cement plants have batch processes and have flexible schedules that can be shifted. Stores of crushed limestone and raw mix at the plant are large enough to last for days if necessary, so responding to a demand response event by shutting down raw mills and quarrying should have no impact on plant operation.[71] Other good candidates for DR include industrial gases and food processing. From a controls perspective, other suitable candidates for DR include tortilla manufacturing, wineries, ice cream and frozen dessert manufacturing, and cheese manufacturing.[72]

The challenges associated with implementing Auto-DR in industries include variation in loads and processes across and within sectors, resource-dependent loading patterns that are driven by outside

[68] CEC, *Develop and Pilot Test Flexible Demand Response Control Strategies for Water Pumping Stations and Industrial Refrigeration Plants- EPRI (*EPC-16-026), May 11th, 2017.

[69] The potential study does not provide additional details regarding which specific types of industrial process loads are shift and shimmy load following compatible.

[70] Navigant's interview with industrial DR expert.

[71] 2006-2015 Research Summary of Demand Response Potential in California Industry, Agriculture and Water Sectors. Final Project Report; LBNL; August 2015.

[72] Assessing the Control Systems Capacity for Demand Response in California Industries; Lawrence Berkeley National Laboratory, January 2012.

factors such as customer orders or time-critical processing (e.g. tomato canning), the perceived lack of control inherent in the term "Auto-DR", and aversion to risk, especially unscheduled downtime.[73] Industries with variable frequency drives (VFDs) offer demand response opportunities, but high costs, lack of controls and perceived lack of flexibility in processes.[74]

3.3.2 Wastewater Treatment and Pumping

Wastewater treatment and pumping facilities have established traditional DR shed capabilities through tried and tested DR strategies at these sites. These include over-oxygenation of wastewater prior to a DR event to reduce facility demand, utilizing wastewater storage capacity to reduce facility peak demand, and shifting backwash filter pump load. DR case studies for these sites show large load reductions through control of effluent pumps and centrifuges. Use of centralized computer controls, such as Supervisory Control and Data Acquisition (SCADA) systems in wastewater treatment facilities make them good candidates for Auto-DR.

Wastewater treatment and pumping sites could potentially provide faster DR service through the deployment of variable speed pumps and drives. Loads can be shed or shifted by: lowering the throughput of aerator blowers, pumps, and other equipment; temporarily transitioning to onsite power generators; anticipatory over-oxygenation of wastewater; or storing wastewater for processing during off-peak periods. Large load reductions/shifts can be achieved by targeting effluent pumps and centrifuges.

A microgrid project for wastewater treatment is being undertaken to demonstrate the fast response capability of these sites (discussed below).

Advanced Microgrid for Wastewater Treatment Facility for Ancillary Services Provision

Trane U.S. Incorporated has deployed and is testing an integrated advanced microgrid at a wastewater treatment plant in Santa Rosa, California.[75] Trane U.S. intends to show the efficacy of a microgrid in the industrial by demonstrating that the plant can operate without compromising water quality guidelines, perform to U.S. Department of Energy (DOE) microgrid standards, and deliver reliable ancillary services to the grid.

As a relatively large energy consumer, an industrial microgrid can leverage its heavy load to provide ancillary services to the grid, if it has the capacity to do so. Often, industrial processes will have distinct critical loads, adjustable loads, and sheddable loads. Critical loads cannot be modified without affecting essential processes while adjustable and sheddable loads can be modified without unacceptably disrupting processes. This in combination with generation and energy storage allow the microgrid controller to increase or decrease load either with advance notice or dynamically in real time based on signaling and/or price cues from the system operator.

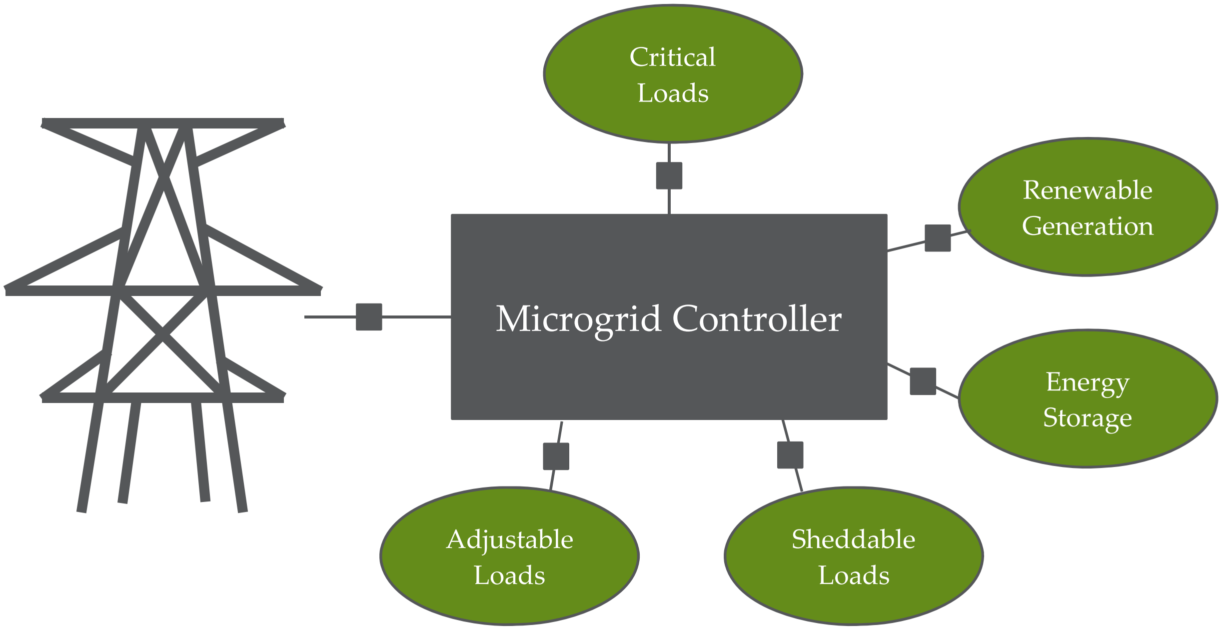
[73] Demand Response Research Centre Final Report; LBNL, November 15, 2015.

[74] Examining Synergies between Energy Management and Demand Response: A Case Study at Two California Industrial Facilities; LBNL, April 2012.

[75] CEC, *Laguna Sub Regional Wastewater Treatment Plant Advanced Microgrid- Trane U.S., Inc. (*EPC-14-059), June 8th, 2015.

Figure 30 below shows a simplified representation of these resources in an industrial microgrid.

Figure 30: Simplified Representation of Industrial Microgrid



Source: Navigant

The project goal is to install, commission, and operate a microgrid controller (MGC) to actively coordinate the activities of the plant loads, gas fired generators, photovoltaic system, and battery. All elements controlled by the MGC are mature technologies that are well understood, but operation of these individual elements as an integrated system is novel. Overall operation of the plant and of the MGC will be continuously logged at 4-second intervals throughout the test period. The demonstration will test the adaptive logic functions of the MGC to reliably convert load elections to hour by hour load shedding/power operating bands.

Flexible DR for Water Pumping and Industrial Refrigeration

EPRI is currently testing technologies to provide flexible demand response in water pumping stations and industrial refrigeration plants.[76] Both industries have inherent storage capacity and only require technology that can sufficiently and automatically respond to demand signals.

The project will develop and test a flexible energy management system (FEMS) for municipal water pumping plants and industrial refrigeration plants that incorporates real-time sensory to achieve fast demand reductions and flexible demand adjustments or ramping based on the conditions on the local electrical distribution system. The industrial FEMS is capable of modulating pump and refrigeration equipment operation to match system demands during critical periods, within system-configured process limits and constraints. A 20% demand adjustment is achievable through adjusting variable speed drives that control plant operation commensurate with fluctuating system conditions.

As part of their pilot the Electric Power Research Institute has agreed to:

- Identify control strategies appropriate for fast and flexible demand response
- Develop an upstream fast response signaling system

[76] CEC, *Develop and Pilot Test Flexible Demand Response Control Strategies for Water Pumping Stations and Industrial Refrigeration Plants- EPRI (*EPC-16-026), May 11th, 2017.

- Pilot test developed control strategies in a pumping station and refrigeration plant to ramp up or ramp down power dependent on signaling from CAISO or the system operator at a local level
- Identify effective control strategies and monitoring equipment appropriate for achieving target levels of fast and flexible demand response
- Develop market signaling interface using OpenADR 2.0 to communicate fast and flexible DR event information. It will interface existing supervisory control and data acquisition (SCADA) controls with FEMS using OpenADR and/or real-time interfaces to evaluate capability and issues for providing fast and flexible DR with plant systems.
- Develop control strategies and test plans for piloting the architected system and monitoring its performance to achieve targeted demand adjustments.

3.3.3 Data Centers

Data centers are highly automated and are potentially good candidates for shift. There are certain energy intensive batch processes in these facilities that tolerate delays and can be shifted such that they are scheduled to be completed before a set deadline. Typical DR strategies in data centers include - server and computer room air conditioning (CRAC) unit shutdown, server idling by load shifting or queuing IT jobs, and temperature set point adjustment. This sector has the potential for energy savings and DR by way of prioritizing certain non-time-sensitive data processes (which account for the bulk of the energy usage), and by reducing the amount of “error on the side of caution” overcooling.[77]

Obstacles to DR implementation in data centers include the perceived risk to equipment with increased temperature and humidity set points, the lack of control over some servers in certain data center configurations (such as co-location), and the current lack of information on DR activities at data centers.[78] The enabling technologies need to link data center operational requirements with the supply side systems, and provide aggregation to visualize metered DR information. utility operated automation at these sites due to the highly sensitive nature of operations and reluctance of data center operations to relinquish control of batch processes or server room cooling.

3.4 Agricultural Sector Enabling Technologies

Agricultural pumping sites with Auto-DR enabled Variable Frequency Pumps (VFPs), which are capable of changing pumping speeds in response to DR dispatch signals within 5 minutes or less, can provide Shimmy services. Irrigation pumps with VFPs and automation have the best potential to participate in DR. In addition to upgrading pumps to the efficient VFDs, the agricultural customer must have controls with access to the internet so they can receive price signals or DR event triggers. The automated controller at the pump can receive the DR signal and adjust the irrigation schedule according to the DR event. This automation can permit ramping pumping up during off peak hours and down during on peak hours with no manual customer interaction. While these pumps are available today and could provide fast DR services, high costs associated with these upgrades pose challenges.[79]

[77] Demand Response Research Center Final Report; LBNL, November 2015;

[78] *Ibid.*

[79] Marks, et.al. Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study. January 2013. LBNL. https://esdr.lbl.gov/sites/all/files/LBNL-6108E_0.pdf

Mobile Cloud-Based Software for Energy and Water Management for Agricultural Pumping

An innovative technology demonstration for agricultural customers with software for monitoring and adjusting pump operations for energy and water management offer DR opportunities.

The key challenges facing the agricultural sector are:

- *Lack of Data*: Farmers currently can't manage energy consumed in the field. Most of their consumption data comes in the form of paper utility bills
- *Lack of Mobile Capabilities:* There are few mobile applications to better manage data for making informed energy consumption decisions
- *Use of analog, Unconnected Field Equipment and Hardware:* Most sensors are not connected to cellular or Wi-Fi networks. Remote data loggers or other data retrieval methods are expensive and cumbersome.

Ability to access field data and monitoring and control of pump operations could help realize DR benefits. Wexus Technologies has developed a software platform to drive agricultural EE and DSM. Their software-as-a-service platform offers a comprehensive cloud platform connected to smart meter networks, can issue alerts/notifications regarding high energy/water usage, and provides continuous, full system monitoring for identification of equipment faults and repairs[80] (see Figure 31 below for Wexus software representation).

Figure 31: Wexus Software System Representation

Source: https://wexusapp.com/

[80] CEC, *Wexus Energy and Water Management Mobile Software for the Agricultural Industry – Wexus Technologies Inc. (*EPC-14-070), June 30th, 2015.

Through customized alerts and reporting, the mobile cloud—based software platform allows farms to quickly respond to changes in energy (and water) usage, adjust and optimize equipment in the field, and reduce operational expenses. The software captures and re-formats utility meter, tariff and billing data, and sends customized reports to farmers. Wexus partnered with Polaris Energy Services to access their data loggers and cellular network control devices. The platform is OpenADR compatible and the technology is being currently deployed through PG&E's Auto-DR program.[81]

As part of the project, the Wexus solution is being deployed at three agricultural locations in PG&Es service territory. The project team estimates an annual 10% savings with savings of 2.4 million kWh and over $400,000 in energy and water savings.[82]

[81] Navigant Interview with Wexus Technologies

[82] Wexus factsheet.

4. TECHNOLOGY DEPLOYMENT DRIVERS

This chapter discusses the factors that currently influence DR deployment and are likely to affect market uptake of DR-enabling technologies in future. Realization of the potential for different types of DR services requires addressing the deployment related challenges. Navigant interviewed industry stakeholders (primarily technology vendors and DR service providers along with researchers involved in innovative technology development) to get their perspectives on the key market drivers for deploying DR-enabling technologies, discussed below. In addition, Navigant reviewed additional available information on the topic to glean insights on the market barriers and opportunities for deployment of DR-enabling technologies.

4.1 Standards and Interoperability

One of the underlying premises for realizing the potential associated with advanced fast and flexible DR services is that the various control and communications technologies for enabling DR are based on open standards and communication protocols and that the various devices out in the field are interoperable. The CA Demand Response Potential Study defines Plug-and-Play DR as follows: *The ability to acquire technology from different vendors, specify the communications interface between products and have all such products install and work together easily and quickly is known as "plug-and-play".*[83] Even though there have been significant advancements in the industry in the development of open communications and interoperability, challenges remain.

The DR Pathways presented in the Potential Study assume that enabling technologies will be able to communicate and interface together to provide end use control and response to signals from an aggregator, consumer, or utility. The study envisions that Plug-and-Play grid will continue to evolve and that communication standards will improve to make device connection and response easier and quicker than is currently the case today.

However, the study notes that even though "Plug-and-Play" will continue to evolve, and enabling technologies will be able to communicate and interface, challenges remain. Some of these relate to:

- Lack of interoperability in control technologies and communications platform.
- Difficulties in coordination across field devices, communication networks and management and control systems.
- Integration of infrastructure elements requires overcoming challenges regrading interoperability, standards, and processes.
- Data integration challenges from several disparate systems required to run a DR program.
- Engagement of multiple stakeholders with different perspectives.

There are challenges associated with specification of DR requirements in current building codes.[84]

[83] CA DR Potential Study Phase II.

[84] "Codes and Standards Enhancement (CASE) Initiative: 2019 California Building Energy Efficiency Standards; Demand Response Cleanup (Including Changes to Space Conditioning, Lighting, Energy Management, Power Distribution, and Solar Ready Sections)- Draft Report; July 2017.

The demand responsive control requirements are not well harmonized and the code language is unclear, which leads to compliance and enforcement challenges.

Initiatives are underway to harmonize and clarify the external and internal communication requirements for all demand responsive controls. These indicate that all systems need to have an OpenADR 2.0a or OpenADR 2.0b certified Virtual End Node (VEN) for external communication. If an EMCS is installed, all VENs in the building must be capable of communicating with the EMCS. For internal communication requirements, all demand responsive control systems will be required to use one of the following communication protocols: WiFi, Zigbee, BACnet or Ethernet. Control systems can use other protocols, but at a minimum they must be able to use one of these four protocols. As part of the code changes, stakeholders suggest that Title 24, Part 6 avoid using prescriptive language in how VENs can be configured within the building control systems if the VENs are able to communicate with the control system. If the building has an EMCS, the VEN must be capable of communicating with the EMCS, but the EMCS does not need to have an integral VEN. VENs can be integrated within controls or can be stand-alone devices and can be located either on-site or off-site.

With increased availability of commercial cloud-based solutions, for thermostat controls, current discussions are directed toward allowing cloud-based VENs to be OpenADR 2.0 certified instead of individual thermostats being OpenADR 2.0 certified. PG&E, in its recent DR program application indicates that the Auto-DR compliance testing for residential and SMB customers can be done at the manufacturer's internet/cloud application level rather than at the end-use device itself.[85] A drawback stemming from Open ADR certification in the cloud rather than at the individual device is the potential problem of stranded assets. Under this scenario, the signal from the utility server to the vendor's cloud-based VEN uses OpenADR, while the signal from the cloud-based VEN to the thermostat uses proprietary communication protocols. So, if a customer ends their cloud contract or a vendor goes out of business, the utility is left with stranded assets. Despite this perceived drawback, the industry is likely to move toward cloud-based VEN certification which will allow more DR thermostats to be compliant with code requirements and meet utility program eligibility requirements. Discussions with industry stakeholders suggest a strong preference toward OpenADR certification for cloud-based VENs for thermostats. Although the market is currently exploring off-site VENs, it is unlikely to apply to large customer loads (customers with greater than 500 kw average demand) to avoid the stranded asset problem.

Discussions with vendors suggest that there are difficulties in having integrated controls across different devices in the field. For example, there have been discussions around integrated controls for HVAC and lighting in commercial buildings. Interoperability between lighting and HVAC systems for integrated control of both systems by sending a single DR signal will be difficult to realize in large commercial buildings (greater than 10,000 square feet). Lighting and HVAC controls operate independently and do not communicate with each other since these are provided by different manufacturers. Industry trends indicate that is likely to remain the norm which will restrict the possibility of sending a single DR signal which is then relayed to the lighting and HVAC systems. On the home automation front, discussions with some prominent vendors suggested that the market is still in the early stages of integration. For example, thermostat vendors are working with different home product manufacturers to provide a seamless customer experience across different types of products/services. A C&I DR service provider suggested that having a common platform that has the flexibility to integrate with multiple players will be a key toward deployment of DR as part of a DER strategy.

[85] "Pacific Gas and Electric Company 2018-2022 Demand Response Programs, Pilots and Budgets"; prepared testimony.

4.2 Customer Awareness and Value Proposition

Discussions with industry stakeholders indicate a low level of awareness regarding DR programs. Unlike energy efficiency programs, stakeholders have relatively lower awareness of voluntary DR programs. Findings from recent stakeholder outreach activities indicate that only a small percentage of customers who occupy buildings that are compliant with Title 24 demand responsive control requirements are enrolled in DR programs.[86]

A key challenge indicated by stakeholders toward customer participation in DR programs is the uncertain value proposition. Customers are often uncertain about how to assess the benefits and costs associated with DR program participation. This is becoming even more complex for customers to assess with proliferation of DERs which combine energy efficiency improvements, on site generation, storage and demand response. A key challenge is the risk and uncertainty inherent in estimating future benefits associated with these investments, given that programs and tariffs change frequently. For advanced lighting controls, for example, discussions with vendors indicated that customers are often unwilling to bear the additional costs associated with DR enablement due to uncertain value proposition from DR program participation. Possibilities for penetration of advanced luminaire level controls is likely to increase with greater penetration of LEDs and more opportunities for lighting retrofits.

Third-party DR service providers indicated that they would like to see partnerships with utilities in developing customer awareness and driving customer adoption in DR.

4.3 Market/Regulatory Requirements

Market rules and regulatory requirements influence deployment of DR-enabling technologies. For example, a primary requirement for increasing deployment of BTM batteries, which is assessed to have significant contribution toward shift and shimmy potential, will be to streamline procedures and processes related to obtaining interconnection agreements and approvals for distributed storage installations. Other drivers for storage deployment will be solutions that that will require less equipment and lower field connection and installation costs for storage and new telemetry technologies that could substantially lower costs than current certified telemetry equipment. Stakeholders perceive the "net export constraint" to be a barrier towards storage participation in DR, according to which BTM batteries can participate in wholesale DR programs only is the customer has positive load. So, for BTM batteries paired with solar, participation is usually impossible due to solar export during the day.

Current telemetry requirements pose challenges toward DR participation in the ancillary services market. Current costs associated with telemetry are very high and restrict participation of smaller sized resources. PG&E tested the technical feasibility of a low-cost solution using advanced interval meters that communicate wirelessly via ZigBee with a gateway device (HAN). The HAN then pushes the data to a cloud-based system that can aggregate and provide the data to a remote intelligent gateway (RIG), which provides real-time telemetry to the CAISO.[87] These alternatives could help a large number of smaller loads to participate in the ancillary services market. Also,

[86] "Codes and Standards Enhancement (CASE) Initiative: 2019 California Building Energy Efficiency Standards; Demand Response Cleanup (Including Changes to Space Conditioning, Lighting, Energy Management, Power Distribution, and Solar Ready Sections)- Draft Report; July 2017.

[87] CAISO Telemetry Solution Over Broadband Lab Test and Proof of Concept" Robert Anderson, Olivine, and Sam Piell, PG&E, May 2017

telemetry with statistical sampling may be another option in the future for small customer participation since CAISO has approved the use of statistical sampling for settlement.

Timely access to customer data is a key driver for expanding DR services by third-party providers. A recent CPUC resolution approving the click-through authorization process to release customer data to third-party DR service providers is likely to expand the customer participation base and boost DR expansion.[88]

Discussions with vendors suggested that non-uniform data reporting requirements across utilities creates challenges. For example, vendors would like to see a standard thermostat report which specifies the fields for which data needs to be pulled. One of the problems cited by vendors was the fact that utilities often have different specifications regarding the fields along which the data needs to be reported and the interval at which the data needs to be pulled, which makes development of a standard report difficult. Vendors suggested that having standard data reporting requirements across utilities would make implementation easier and indicated that they would like to see the OpenADR alliance develop the specifications regarding the standard reporting requirements. Another suggestion was for utilities to manage firmware and software updates across different vendors in such a manner that it does not adversely affect the system integration. One of the major thermostat vendors suggested developing best practices around data extraction and integration. For example, whenever a thermostat firmware update takes place, it needs to be managed such that the system integration is not affected across different vendors' products.

[88] CPUC Energy Division Resolution E-4868, August 2017.

5. CONCLUSIONS AND PROPOSED DR TECHNOLOGY ROADMAP FOR SCE

This chapter presents a proposed Roadmap for SCE, which is based on a summary of findings from the technology assessment information presented in the previous chapters. The technology assessment summary highlights key areas of technology development and demonstration required for enhancing DR capabilities to provide fast and flexible DR services (shift and shimmy services in the potential study), and accordingly suggests a technology roadmap.

Figure 32 below shows suggested Roadmap pertaining to residential and SMB customers primarily, along with cross-cutting areas (including electric vehicles and BTM batteries). Figure 33 shows suggested Roadmap for large C&I and agricultural customers. Note that there are a number of ongoing technology development and demonstration activities, as discussed earlier in this document, which indicate promise for future technologies with enhanced DR capabilities. Most of these demonstrations are expected to be complete within the next three years approximately, and therefore findings from these efforts at that time could provide specific guidance on prioritization and selection of technologies for realizing fast and flexible DR services.

Figure 32: Suggested Technology Roadmap for Residential and SMB customers and Crosscutting Areas

Year: 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 and beyond

Sector	Area	Type	Earlier period	Later period
Residential, Small/Medium C&I	*Air Conditioning Load Control*	*Shift*	**Continue current programs with smart thermostat based control of HVAC** Continue current AC control programs using smart thermostats: these offer load shifting opportunities through pre-cooling strategies.	Default TOU rate offer to residential customers, coupled with increasing penetration of smart thermostats will help realize significantly larger shift potential through smart thermostat control of HVAC loads.
		Shift & Shimmy	**Track ongoing advanced HVAC development & demonstration projects** Track ongoing advanced technology development and demonstration of high efficiency, climate appropriate HVAC systems with intelligent controls and enhanced DR capabilities (e.g. variable capacity compressor, variable speed fans, zonal control, dual-fuel heating, and thermal storage options).	**Provide incentives for deployment of advanced HVAC technologies as joint EE-DR offer** Consider incentivizing advanced HVAC technologies that offer significant energy efficiency, DR and climate benefits through joint EE-DR offerings to accelerate market uptake. Utilize successfully tested advanced HVAC technologies with enhanced DR capabilities to provide shift and shimmy; package this as an IDSM offer since co-benefits are substantial.
	Transactive Energy Offers	*Shift & Shimmy*	**Track ongoing transactive energy projects** Track ongoing transactive energy demonstration projects that transmit transactive signals to a variety of enduse loads at customer premises and optimize based on energy costs, comfort settings and other user preferences.	**Utilize findings from successfully demonstrated projects for load control through transactive signals** Consider transactive energy offers on a wider scale based on the successful demonstration of ongoing projects by leveraging on IoT and proliferation of smart devices. The success of transactive energy projects and customer acceptance of such offers can potentially substantially transform the energy landscape.
Crosscutting	*Electric Vehicles*	*Shift & Shimmy*	**Track findings from several ongoing projects for assessment of PEV contribution** - Draw on successfully completed pilots that have demonstrated results from managed EV charging and consider similar pilot/program offers; - Track ongoing advanced charge management demonstration efforts for charge optimization based on transactive signals and real-time vehicle information. - Follow use case results from Open Vehicle Grid Integration Platform (OVGIP) to identify opportunities for grid integration using open communication interfaces from different OEMs' PEVs. - Follow ongoing Vehicle to Grid (V2G) and Vehicle to Building (V2B) demonstrations.	**Design and deploy DR offers around demonstrated advanced control strategies** - Consider pilot/program activities with advanced charge management based on successfully demonstrated results from such activities; - Leverage on OVGIP for drive market deployment of EVs as a reliable grid resource on a large scale by utilizing PEVs from different OEMs for providing grid services based on open communication interfaces. - Consider V2G and V2B pilots based on current demonstration project results and then full rollouts based on pilot findings. - Package this as an integrated DER offer.
			Continue with EV-TOU rate offers that help engage customers and offer savings opportunities. However, transactive energy signals, if successfully and demonstrated, could supersede TOU rate offers.	
	Behind the Meter (BTM) Batteries	*Shift & Shimmy*	**Establish value proposition of storage** - Track ongoing microgrid demonstration projects and solar-storage integrated projects to help establish value proposition from storage. - Follow findings from transactive energy projects for opportunities to control batteries using transactive signals, which could potentially substantially increase storage participation.	**Roll into DER offers for realization of benefits** - Default residential TOU offers will help accelerate customer adoption of storage, along with possible removal of market barriers primarily related to interconnection requirements. - Leverage on possible accelerated market adoption of storage driven by TOU rates, relaxation of market barriers/rules and continued technology cost reductions with performance improvements for realization of the substantial shift and shimmy potential from storage (assessed to be cost-effective and a significant DR contributor for the residential sector in the potential study). - Package this as an integrated DER offer.

Figure 33: Suggested Technology Roadmap for Large C&I Customers

		Year	*2017 – 2018 – 2019 – 2020 – 2021 – 2022 – 2023 – 2024 – 2025 and beyond*	
Large C&I customers	*Commercial HVAC*	*Shift*	**Continue current Auto-DR enabled HVAC control through current program offers** - Continue with well-established manual and Auto-DR enabled curtailment of HVAC loads in commercial buildings. - These systems primarily provide load shed. - Load shifting opportunities exist through pre-cooling, utilizing the thermal mass of buildings.	
		Shift & Shimmy	**Consider fast DR pilot results with existing systems and track ongoing demos with advanced HVAC systems** - Draw on findings from successful fast DR field pilots and consider deployment of commercially available systems for providing fast response (shimmy). - Track ongoing technology demonstration to specifically assess DR capabilities from commercial variable capacity HVAC systems, which could lead to future opportunities for realizing shimmy potential. - Follow findings on DR capabilities from demonstration of climate appropriate HVAC systems (VRF and IEC integration) that incorporate system optimization algorithms for DR.	**Push market uptake of advanced HVAC technologies with demonstrated DR capabilities** - Consider incentivizing advanced HVAC technologies that offer significant energy efficiency, DR and climate benefits through joint EE-DR offerings. - Variable capacity HVAC systems receive energy efficiency rebates and additional incentives for DR could accelerate market uptake. Utilize successfully tested advanced HVAC technologies with enhanced DR capabilities to provide shift and shimmy through IDSM offerings.
	Lighting Controls	*Shimmy*	**Incentivize Auto-DR enabled advanced lighting controls (zonal and luminaire) and convey value proposition to customers** - Auto-DR enabled advanced lighting controls (zonal and luminaire) have significant shimmy potential. - Incentivize commercially available LED luminaires with networked wireless controls to accelerate market adoption (these have substantial EE benefits along with advanced DR capabilities); package this as an IDSM offering. Also zonal controls are able to provide shimmy. - Engage in customer education/outreach activities to encourage participation in DR (customers may have advanced controls installed but are often unsure of DR participation due to uncertain value proposition from DR). - Track findings from projects that are currently seeking to assess value proposition for cost-effective DR-enabled lighting retrofits in commercial buildings with quantification of non-energy benefits; utilize these in customer education/outreach efforts to accelerate market adoption through IDSM offers.	- Utilize expanded market opportunities through greater penetration of LEDs with advanced controls for realizing shimmy potential. - Continue to encourage customer adoption/market uptake by communicating value proposition of DR-enabled lighting retrofits to customers (energy and non-energy benefits).
	Refrigerated Warehouses	*Shift & Shimmy*	**Continue Auto-DR incentives and track ongoing demonstrations for fast and flexible response capability** - Continue with refrigerated warehouse participation in current DR programs; excellent DR candidates; keep providing ADR incentives to encourage participation in DR. - Track ongoing demonstrations of fast and flexible DR capability for large industrial refrigeration sites with a Flexible Energy Management System (FEMS) that interface with SCADA controls.	**Deploy advanced technologies for fast and flexible DR** - Utilize findings from demonstration projects to realize market opportunities for fast and flexible DR services. - Continue incentivizing ADR enablement for providing fast and flexible services; these provide substantial energy savings, so package this as a joint EE-DR offer.
	Agricultural Pumping	*Shift & Shimmy*	Auto-DR enabled Variable Frequency Pumps (VFPs) provide shimmy.	
	Wastewater Pumping and Treatment	*Shift & Shimmy*	- Wastewater treatment and pumping DR participation exists through current program offers. - Track findings from advanced microgrid demonstration projects with wastewater treatment plants for fast and flexible DR capabilities.	Utilize demonstration results to enroll additional sites for expanded program offering to provide fast and flexible DR services.
	Industrial Processes	*Shift*	- Incentivize adoption of Variable Frequency Drives for DR Participation. - Engage with industries that are good DR candidates (flexible production schedules with batch processes) to identify every day shift possibilities.	

The tables below provide a summary of the technology assessment discussed earlier in the document, which form the basis of the information presented in the suggested Roadmaps.

Table 8 below presents a summary of residential HVAC assessment.

Table 8. Technology Discussion, DR Capabilities, and Co-Benefits of Residential HVAC Technologies

Technology	Topic	Description
Residential HVAC	**Areas of Technology Development and Demonstration**	• Switch-based or thermostat-based control of HVAC units provide shift; advancements in technology likely to offer enhanced DR capabilities for shift and shimmy. • Ongoing advancements in HVAC technology to help meet California's climate objectives; DR strategies will be integrated with advanced HVAC systems and controls. • Development of advanced systems with intelligent controls focus on integration of the following features[89]: » Use of variable-capacity compressor and variable-speed fans with state-of-the-art inverter technology. » Integrated ventilation to harness fresh air for "free cooling". » Dual-fuel technology for switching between electricity and natural gas. » Zonal control » Options and feasibility for integration of thermal storage
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Advancements in use of variable capacity compressor and variable speed systems could significantly enhance DR potential • Incorporation of pre-cooling strategies will enable greater shift contribution • Successful testing of thermal storage will offer additional shift possibilities.
	Co-benefits	• Substantial co-benefits likely to drive market adoption; • Systems will incorporate advanced fault detection and diagnostics to ensure proper installation, operation, and maintenance; • Use of alternative refrigerants for improved operation and lowering climate impacts will provide significant advantages. • More efficient operation of units will help lower costs and provide higher occupant comfort.

[89] Electric Program Investment Charge: Proposed 2018-2020 Triennial Investment Plan; CEC, April 2017

Table 9 below presents a summary for intelligent residential energy management solutions that receive transactive load management signals.

Table 9. Technology Discussion, DR Capabilities, and Co-Benefits of Residential Energy Management Solutions

Technology	Topic	Description
Residential Energy Management Solutions (Transactive Energy)	**Areas of Technology Development and Demonstration**	• Demonstration of intelligent residential energy management system for aggregated control of a variety of residential end-use loads is currently underway; utilizes transactive energy signals.
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Successful demonstration of residential EMS that integrate control strategies over a variety of load types and respond to transactive signals can significantly open possibilities of contribution from a variety of residential end-use loads.
	Co-benefits	• Substantial co-benefits through optimization of price and comfort under real-time market conditions.

Table 10 below presents a summary for plug-in electric vehicles.

Table 10. Technology Discussion, DR Capabilities, and Co-Benefits of Plug-In Electric Vehicles

Technology	Topic	Description
Plug-in Electric Vehicles	**Areas of Technology Development and Demonstration**	• Pilots have demonstrated the feasibility of using managed EV charging as a flexible grid resource (delaying of charging, drawing power from 2nd life stationary battery system). • Advanced charge management demonstration efforts underway that optimize charging based on real-time vehicle information, predictive travel behavior, grid location and energy prices (transactive signals). • Advanced grid communication for residential PEVs under development with cloud-to-cloud Open ADR 2.0b communication with vehicle charging network for optimized PEV charging. • Efforts underway to develop ISO/IEC 15118 Demand Clearing House (DCH) to translate Open ADR 2.0b protocols to ISO/IEC 15118 tariff tables that charging stations can respond to (dynamic energy prices). • Demonstrations planned on end-to-end V2G integrated system that is ISO and DSO aware for providing storage and ancillary services.
	Fast and Flexible DR Contribution (Shift and Shimmy)	• High potential contributor for shift and shimmy • Grid integrated optimized charge management with advanced techniques (transactive energy signals) could significantly enhance the potential, if demonstrated successfully. • Development of next-generation grid communication for residential PEVs will provide visibility into charging loads and ability to influence charging schedules.

Technology	Topic	Description
		• Open Vehicle Grid Integration Platform (OVGIP) development with standard communication interface will significantly PEV capabilities for providing grid services.
	Co-benefits	• Optimization of price and convenience based on advanced charge management techniques likely to offer significant customer benefits and customer acceptance.

Table 11 below presents a summary for commercial HVAC.

Table 11. Technology Discussion, DR Capabilities, and Co-Benefits of Commercial HVAC Technologies

Technology	Topic	Description
Commercial HVAC	**Areas of Technology Development and Demonstration**	• Currently, commercial HVAC systems are a significant shed contributor through manual and Auto-DR curtailment strategies; shift opportunities exist through precooling of buildings utilizing the thermal mass. • Fast DR capability (frequency regulation with 4 sec. response) successfully demonstrated for commercial HVAC system (piloted at one site in SDG&E's service territory). More such test cases necessary to establish technology performance. • DR capabilities with variable capacity commercial HVAC systems currently being demonstrated. • Development and demonstration efforts underway to integrate Variable Refrigerant Flow (VRF) with Indirect Evaporative Cooling in commercial HVAC through advanced controls, which will incorporate system optimization algorithms for demand response. • Development of an open source and open architecture DR management platform based on eXtensible Building Operator System (XBOS/DR) underway for small-sized commercial buildings that lack BMS/EMS. The platform is being tested to respond to transactive energy signals.
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Potential study results indicate commercial HVAC as a significant shift contributor; contribution toward shimmy is relatively low. • Advanced HVAC technologies with variable capacity systems offer enhanced DR capabilities. • Development of Climate Appropriate commercial HVAC systems (through integration of VRF and Indirect Evaporative Cooling via advanced controls) will incorporate DR strategies and provide new opportunities. • Development of the XBOS/DR platform for energy management in small commercial buildings with receipt of transactive signals could significantly enhance DR participation from this customer segment.
	Co-benefits	• Climate Appropriate HVAC systems integrate high efficiency components optimize occupant comfort and can reduce energy use and peak demand. Therefore, these systems offer substantial benefits that could drive market adoption.

Table 12 below presents a summary for commercial lighting.

Table 12. Technology Discussion, DR Capabilities, and Co-Benefits of Commercial Lighting Technologies

Technology	Topic	Description
Commercial Lighting	**Areas of Technology Development and Demonstration**	• Commercial lighting with advanced controls is market ready and is currently offered by vendors. • Increasing penetration of LED luminaires with networked wireless controls increase potential opportunities. • Demand reductions using a connected LED lighting system with embedded luminaires and wireless controls integrated into the luminaire have been successfully demonstrated (luminaires connect to wireless access controls, which are in turn connected to the EMS). • Market barriers toward adoption of advanced lighting control technologies are recent retrofit of the lighting stock in commercial stock in commercial buildings, high costs, uncertain value proposition, and perceived disruptions in operations. • Efforts are underway to assess value proposition for cost-effective, DR-enabled lighting retrofits in commercial buildings, especially quantifying non-energy benefits (NEBs). These will also estimate system level savings when advanced lighting is integrated with other building controls (dynamic envelope control, HVAC and plug loads). Findings could provide guidance for overcoming adoption barriers for increased uptake of Auto-DR capable lighting systems. • Benefits from integrated lighting and HVAC control strategies are not yet established, but are currently being researched. E.g., data feeds from lighting controls could be integrated with a building EMS to enhance overall facility DR and demand management performance (e.g., occupancy data informs HVAC zonal controls). Research is underway to estimate indirect DR benefits and limitations associated with these reductions in building load triggered by lighting control systems
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Lighting is a significant shimmy contributor. • Zonal and luminaire level lighting controls enabled with Auto-DR have substantial DR contribution.
	Co-benefits	• DR potential study attributes only a portion of advanced lighting control costs to DR due to substantial co-benefits from advanced lighting controls, thereby establishing this as cost-effective. Advanced lighting controls can provide substantial energy savings. Potential study assumed 75% reduction in advanced lighting control system costs for DR due to substantial energy savings benefits from these systems. • Estimation of NEBs can greatly increase value proposition to customers and increase market uptake of advanced lighting controls. Non-energy benefits include reduced maintenance costs of buildings and improved occupancy comfort.

Table 13 below presents a summary for refrigerated warehouses.

Table 13. Technology Discussion, DR Capabilities, and Co-Benefits of Warehouse Refrigeration Technologies

Technology	Topic	Description
Refrigerated Warehouses	**Areas of Technology Development and Demonstration**	• Refrigerated warehouses offer substantial shift opportunities and have demonstrated DR performance. Most sites have individual component level controls that are under the supervisory control of a central controller, making them good candidates for Auto-DR. • Existing control technologies can be adapted for ADR at a relatively low incremental cost. • Fast and flexible DR capability being currently demonstrated through a flexible energy management system (FEMS), which interface with SCADA controls and respond to OpenADR 2.0 based communication.
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Auto-DR enabled control of load in refrigerated warehouses could contribute toward both shift and shimmy. • Successful demonstration of fast and flexible DR capability through SCADA controls and flexible energy management system could significantly enhance shift and shimmy potential from large industrial refrigeration facilities.
	Co-benefits	• Control technologies offer energy efficiency benefits and access to real-time data. • Potential study assumed 30% reduction in DR-enabling technology costs due to co-benefits from energy savings and lowering of peak demand charges. • Industry guide and tools exist to help refrigerated warehouse and facility owners in strategic decision making regarding EE and DR savings opportunities jointly.

Table 14 below presents a summary for Behind-the-Meter (BTM) batteries.

Table 14. Technology Discussion, DR Capabilities, and Co-Benefits of Behind the Meter Batteries

Technology	Topic	Description
Behind the Meter (BTM) Batteries	**Areas of Technology Development and Demonstration**	• Lowering of battery costs and improvements in performance offer substantial DR opportunities. • Findings from transactive energy projects that are currently being undertaken will help establish storage performance for DR in response to transactive price signals. • Storage deployment faces challenges due to interconnection requirements, unclear control and communication requirements, undefined safety standards, and relatively high costs. • To establish a stronger value proposition for storage, current technology demonstration activities include storage as part of microgrid projects, which will help define how energy storage can more effectively participate as part of a larger grid system. Also, demonstrations of joint solar and storage projects are planned to help establish the benefit and value of the combination.
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Potential results indicate batteries as a significant cost-competitive shift and shimmy contributor, especially in residential.
	Co-benefits	• Batteries provide substantial co-benefits in addition to DR benefits. • The demonstration of the value from batteries as part of microgrid projects will help establish.

Table 15 below presents a summary for industrial processes.

Table 15. Technology Discussion, DR Capabilities, and Co-Benefits of Industrial Processes

Technology	Topic	Description
Industrial Processes	**Areas of Technology Development and Demonstration**	• Industries with flexible production schedules and batch processes are good candidates for Auto-DR (e.g., cement, food processing, industrial gases. • Industries with VFDs are good candidates for DR; barriers to adoption include lack of controls, perceived process inflexibility for VFD adoption and high costs. • Industries that can make structural adjustments to their production schedules in certain portions of their processes and stagger these over the course of one day and over multiple days may be good candidates for everyday shift, represented in the potential study.
	Fast and Flexible DR Contribution	• Industries with flexible schedules and batch processes and equipped with VFDs and centralized controls for Auto-DR can potentially provide significant contribution toward shift and shimmy (load following).

Technology	Topic	Description
	(Shift and Shimmy)	
	Co-benefits	• Installation of VFDs offer substantial energy savings benefits to facilities. • Also, installation of Auto-DR enabled centralized controls can provide real-time visibility into production processes.

Table 16 below presents a summary for wastewater treatment and pumping.

Table 16. Technology Discussion, DR Capabilities, and Co-Benefits of Wastewater Treatment and Pumping

Technology	Topic	Description
Wastewater Treatment and Pumping	**Areas of Technology Development and Demonstration**	• Established good candidates for Auto-DR due to centralized controls and ability to shift certain processes without hampering operations (e.g. over-oxygenation prior to DR event, shifting backwash filter pump load) and control of effluent pumps and centrifuges. • Current advanced microgrid demonstrations for wastewater treatment plants will help identify opportunities for fast and flexible DR using advanced controls. • Demonstrations underway to test fast and flexible DR capability of water pumping stations through a development of a Flexible Energy Management System (FEMS) architecture that interface with SCADA controls and use Open ADR 2.0b based communication protocols.
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Wastewater treatment and pumping sites with variable speed pumps and drives could provide shimmy • As already demonstrated through field experiences, these sites are good candidates for providing load shifts. • Successful demonstration of fast and flexible DR capabilities will provide further opportunities for tapping into the potential from this segment.
	Co-benefits	• Microgrid projects can offer substantial benefits and therefore demonstration of DR capabilities as part of these projects can greatly facilitate realization of DR potential from large wastewater treatment facilities. • Deployment of FEMS can help realize energy savings for facilities in addition to DR benefits.

Table 17 below presents a summary for wastewater treatment and pumping.

Table 17. Technology Discussion, DR Capabilities, and Co-Benefits of Agricultural Pumping

Technology	Topic	Description
Agricultural Pumping	**Areas of Technology Development and Demonstration**	• Experience exists with shifting of agricultural pumping loads. • Agricultural sites with Variable Frequency Pumps (VFPs) and controls with two-way communication that can respond to dispatch signals with 5 minutes or less can provide fast and flexible DR. • Auto-DR enabled controls for pumps with mobile cloud-based software platforms for monitoring and control of pump operations could expand DR capabilities.
	Fast and Flexible DR Contribution (Shift and Shimmy)	• Ag pumping is not identified as a significant shift or shimmy contributor in SCE's service territory. • However, increased adoption of Variable Frequency Pumps could expand ability to provide fast and flexible DR services.
	Co-benefits	• VFPs provide more efficient operations and lead to energy and cost savings. • Also, Auto-DR enabled control of pumps and software for monitoring of field operations offer substantial co-benefits through higher controllability and remote detection of faults in equipment. • Potential study assumed 75% reduction in initial DR-enabling technology costs due to co-benefits from energy savings higher controllability.

REFERENCES/BIBLIOGRAPHY

Aghajanzadeh, Arian, Aimee McKane, Craig Wray, and Peter Therkelsen. 2015. “2006-2015 Research Summary of Demand Response Potential in California Industry, Agriculture, and Water Sectors.” Lawrence Berkeley National Laboratory.

Anderson, John (OhmConnect, Inc.). 2017. “OhmConnect, Inc. Comments on August 8, 2017 IEPR Commissioner Workshop on Demand Response.” TN#: 220854. CEC.

Bienert, Rolf, Barry Haaser, and Shannon Mayette (OpenADR). 2016. “OpenADR Alliance Update. Annual Member Meeting.” May 25.

Black, Doug, Samveg Saxena, and Jason MacDonald (LBNL). 2015. “Smart Charging of Plug-in Vehicles and Driver Engagement for Demand Management and Participation in Electricity Markets.” presented at the Secon Annual California Multi-Agency Update on Vehicle-Grid Integration Research, December 14.

California Energy Commission. 2015a. “Laguna Sub Regional Wastewater Treatment Plant Advanced Microgrid (EPC-14-059).” Recipient’s Name: Trane U.S., Inc.

———. 2015b. “Smart Charging of Plug-in Vehicles and Driver Engagement for Demand Management and Participation in Electricity Markets (EPC-14-057).” Recipient’s Name: DOE-Lawrence Berkeley National Laboratory.

———. 2015c. “Next-Generation Grid Communication for Residential PEVs (EPC-14-078).” Recipient’s Name: ChargePoint, Inc.

———. 2015d. “Assessing the Ability of Smart Inverters and Smart Consumer Devices to Enable More Residential Solar Energy (EPC-14-079).” Recipient’s Name: Electric Power Research Institute, Inc.

———. 2015e. “Demonstration of PEV Smart Charging and Storage Supporting Grid Operational Needs (EPC-14-056).” Recipient’s Name: Regents of the University of California, Los Angeles.

———. 2015f. “Development and Testing of the Next Generation Residential Space Conditioning System for California (EPC-14-021).” Recipient’s Name: Electric Power Research Institute, Inc.

———. 2015g. “Distribution System Aware Vehicle to Grid Services for Improved Grid Stability and Reliability (EPC-14-086).” Recipient’s Name: Electric Power Research Institute, Inc.

———. 2015h. “Enable Standardized Vehicle-Grid Integration through Development of Universal Standard (EPC-14-077).” Recipient’s Name: Center for Sustainable Energy.

———. 2015i. “Wexus Energy and Water Management Mobile Software for the Agricultural Industry (EPC-14-070).” Recipient’s Name: Wexus Technologies, Inc.

———. 2015j. “Wexus Energy and Water Management Mobile Software for the Agricultural Industry - Fact Sheet (EPC-14-070).” Recipient’s Name: Wexus Technologies, Inc.

———. 2016a. “Grid Communication Interface for Smart Electric Vehicle Services Research and Development.” Recipient’s Name: Andromeda Power, LLC.

———. 2016b. “Customer-Centric Demand Management Using Load Aggregation and Data Analytics (EPC-15-075).” Recipient’s Name: Electric Power Research Institute, Inc.

———. 2016c. “Empowering Proactive Consumers to Participate in Demand Response Programs (EPC-15-083).” Recipient’s Name: OhmConnect, Inc.

———. 2016d. “Meeting Customer and Supply-Side Market Needs with Electrical and Thermal Storage, Solar, Energy Efficiency and Integrated Load Management Systems (EPC-15-074).” Recipient’s Name: Center for Sustainable Energy.

———. 2016e. “Transactive Incentive Signals to Manage Electricity Consumption for Demand Response (EPC-15-045).” Recipient’s Name: Electric Power Research Institute, Inc.

———. 2016f. “Residential Intelligent Energy Management Solution: Advanced Intelligence to Enable Integration of Distributed Energy Resources (EPC-15-048).” Recipient’s Name: Alternative Energy Systems Consulting, Inc.

———. 2016g. “The Value Proposition for Cost-Effective, Demand Response-Enabling, Nonresidential Lighting System Retrofits in California Buildings (EPC-15-051).” Recipient’s Name: Lawrence Berkeley National Laboratory.

———. 2016h. “Complete and Low-Cost Retail Automated Transactive Energy Systems (EPC-15-054).” Recipient’s Name: Universal Devices, Inc.

———. 2016i. "Customer-Controlled, Price-Mediated, Automated Demand Response for Commercial Buildings (EPC-15-057)." The Regents of the University of California, on behalf of the California Institute for Energy and Environment.
———. 2016j. "Identifying Effective Demand Response Program Designs to Increase Residential Customer Participation (EPC-15-073)." Recipient's Name: The Recipients of the University of California, on behalf of the Los Angeles campus.
———. 2016k. "Total Charge Management: Advanced Charge Management for Renewable Integration (EPC-15-084)." Recipient's Name: BMW of North America, LLC.
———. 2016l. "Vehicle-Grid Integration in California Using the ISO 15118 Global Interoperability Standard - Fact Sheet (EPC-14-077)." Prepared by: Center for Sustainable Energy.
California Energy Commission, and John Clint (AESC Sr. Program Manager). n.d. "Advanced Intelligence for Residential Distributed Energy Resources - Fact Sheet (EPC-15-048)."
California ISO. 2017. "California Vehicle-Grid Integration (VGI) Roadmap: Enabling Vehicle-Based Grid Services." TN#: 217997.
Cappers, Peter, Jason MacDonald, Janie Page, and Jennifer Potter. 2016. "Future Opportunities and Challenges with Using Demand Response as a Resource in Distribution System Operation and Planning Activities." LBNL-1003951. Lawrence Berkeley National Laboratory.
Cappers, Peter, Jason MacDonald, Janie Page, Jennifer Potter, and Emma Stewart. 2016. "Future Opportunities and Challenges with Using Demand Response as a Resource in Distribution System Operations and Planning Activities." Report Overview Presentation, January.
CEC Energy Efficiency Research Office. 2013. "Innovative Low-Energy Occupant-Responsive Controls for Heating, Ventilation and Air Conditioning Systems (PIR-12-026)." Recipient's Name: Regents of the University of California/California Institute for Energy and Environment.
"Characterization of Demand Response in the U.S." 2016. *Wires Energy Environ* 5 (June):288–304. https://doi.org/10.1002/wene.176.
Considine, Toby (TC9 Inc), and William Cox (Cox Software Architects LLC). n.d. "Organization for the Advancement of Structured Information Standards (OASIS)." http://www.oasis-open.org/.
CPower Energy Markets, Inc., EnerNOC, Inc., and Energy Hub, Inc. 2017. "Joint DR Parties Comments Barriers to Demand Response." TN#: 220855. CEC.
CPUC. 2017a. "EE-DD Integration Energy Division Staff Proposal." TN#: 220508. 2017 IEPR CEC Workshop on Demand Response.
———. 2017b. "Resolution E-4868: PG&E AL 4992-E, SCE AL 3541-E, and SDG&E AL 3030-E/ KJS."
De Martini, Paul, Tony Brunello, and Annie Howley. n.d. "Planning for More Distributed Energy Resources on the Grid. A Summary for Policy-Makers on the Walk-Jog-Run Model." Newport Consulting Group, More Than Smart, ICF International.
"Demand Response Research Center." 2015. Energy Research and Development Division, Lawrence Berkeley National Laboratory. www.energy.ca.gov/research/.
"Demand Response with Variable Capacity Commercial HVAC Systems." 2016. Electric Power Research Institute.
Elberg, Richelle, and John Gartner (Navigant). 2015. "Navigant Research: Communications Technologies for EV Charging Networks. RFID, Wi-Fi, ZigBee, Ethernet, Cellular, and AMI Equipment and Services: Global Market Analysis and Forecasts." Navigant Research.
"Energy Operation Version 1.0 OASIS Standard." 2014. OASIS Energy Interoperation TC. http://docs.oasis-open.org/energyinterop/ei/v1.0/os/energyinterop-v1.0-os.pdf.
EPRI. 2016. "Open Vehicle-Grid Integration Platform: General Overview." 3002008705.
"Final Report on Phase 2 Results 2015 California Demand Response Potential Study Charting California's Demand Response Future." 2016. Lawrence Berkeley National Laboratory.
Franz, Dammon (TESLA). 2017. "Tesla Comments on Barriers to DR Workshop." TN#: 220857. CEC.
Ghatikar, Girish, Aimee McKane, Sasank Goli, Peter Therkelsen, and Daniel Olsen. 2012. "Assessing Th Control Systems Capacity for Demand Response in California Industries." LBNL-5319E. Lawrence Berkeley National Laboratory.
Goli, Sasank, Daniel Olsen, Aimee McKane, and Mary Ann Piette. 2011. "2008-2010 Research Summary: Analysis of Demand Response Opportunities in California Industry." LBNL-5680E. Lawrence Berkeley National Laboratory.
Greer, Chris. 2014. "The Evolving Smart Grid: What's New in the NIST Framework and Roadmap." May 2.

GridWise Architecture Council. 2015. GridWise Transactive Energy Framework, Version 1; January 2015.
Hauenstein, Heidi, and Bijit Kundu (Energy Solutions). 2017. "Demand Response Cleanup (Including Changes to Space Conditioning, Lighting, Energy Management, Power Distribution, and Solar Ready Sections) - Draft Report." Codes and Standards Enhancement (CASE) Initiative. 2019 California Building Energy Efficiency Standards.
Hiraiwa, Hirokazu, Krystal Maxwell, and Casey Talon (Navigant). 2016. "Navigant Research: Commercial Building Automation Systems. HVAC, Lighting, Fire & Life Safety, and Security & Access Controls and Building Management Systems: Global Market Analysis and Forecast." Navigant Research.
John, Heff St. 2017. "Stem and CPower to Combine Behind-the-Meter Batteries and Demand Response." *Greentech Media*, August. https://www.greentechmedia.com/articles/read/stem-and-cpower-to-combine-behind-the-meter-batteries-and-demand-response.
Jung, Christina Sookung, and Casey Talon (Navigant). 2017. "Navigant Research: IoT for Intelligent Buildings. Hardware, Software, and Services for IoT in Commercial Buildings: Global Market Analysis and Forecasts." Navigant Research.
Kaluza, Sebastian (BMW), David Almeida (PG&E), and Paige Mullen (PG&E). 2016. "BMW I ChargeForward: PG&E's Electric Vehicle Smart Charging Pilot."
Kaneshiro, Bruce (CPUC). 2017. "CPUC Demand Response Accomplishments." TN#: 220510. 2017 IEPR CEC Workshop on Demand Response. CEC.
Khohanim, Michel (Universal Devices). 2017. "Retail Automated Transactive Systems (Rates)." California Energy Commission.
Langton, Adam (BMW Group). 2017. "Total Charge Management (TCM) EPIC Project." TN#: 220590. California Energy Commission.
Marnay, Chris. n.d. "Los Angeles Air Force Base Vehicle to Grid Pilot Project." LBNL-6154E. Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory. http://eetd.lbl.gov/EA/EMP/emp-pubs.html.
National Institute of Standards and Technology. 2012. "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0." U.S. Department of Commerce.
———. 2014. "NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0." U.S. Department of Commerce.
OpenADR Alliance. n.d. "OpenADR: Using OpenADR for DER."
Page, Janie, Chuck McParland, Mary Ann Piette, and Stephen Czarnecki. 2015. "Design of an Open Smart Energy Gateway for Smart Meter Data Management." Demand Response Research Center, Lawrence Berkeley National Laboratory.
PG&E. 2016. "PG&E and BMW Partner on Next Phase of Pilot Studying Advanced Electric Vehicle Charging." November 14, 2016.
———. 2017a. "Pacific Gas and Electric Company 2018-2022 Demand Response Programs, Pilots and Budgets Prepared Testimony."
———. 2017b. "Automated Demand Response in Title 24, Part 6: Stakeholder Outreach Assessment." PG&E's Emerging Technologies Program.
———. 2017c. "PG&E Comments Regarding August 8 Demand Response Workshop." TN#: 220852. CEC.
"Phase 2 2015 California Demand Response Potential Study Charting California's Demand Response Future." 2016. Lawrence Berkeley National Laboratory, Energy Technologies Area.
Piette, Mary Ann. (Lawrence Berkeley National Laboratory). 2016. "Demand Response Research Center." CEC-500-2016-061. California Energy Commission (Prepared by Lawrence Berkeley National Laboratory).
Piette, Mary Ann, Oren Schetrit, Sila Kiliccote, and Iris Cheung (Lawrence Berkeley National Laboratory). 2015. "Costs to Automate Demand Response - Taxonomy and Results from Field Studies and Programs." LBNL-1003924. California Energy Commission.
Potter, Jennifer, and Peter Cappers. 2017a. "Demand Response Advanced Controls Database User Manual v.1." Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory.
———. 2017b. "Demand Response Advanced Controls Framework and Assessment of Enabling Technology Costs." Lawrence Berkeley National Laboratory.

"Residential Pool Pump Real Time Demand Response Pilot Using FM Radio." 2016. Agreement# 5660040262. San Diego Gas & Electric Emerging Technologies Group and MelRok, LLC.
Rish Ghatikar (EPRI). 2017. "Transactive Incentive-Signals to Manage Electricity Consumption (TIME) System." TN#: 220591. California Energy Commission.
SGIP. 2017. "SGIP's Smart Grid Catalog of Standards."
Sparn, Bethany, and Hunsberger Randolph. 2015. "Opportunities and Challenges for Water and Wastewater Industries to Provide Exchangeable Services." NREL/TP-5500-63931. National Renewable Energy Laboratory. www.nrel.gov/publications.
Strother, Neil, and Krystal Lawrence. 2016. "Navigant Research White Paper: IoT and the Future of Networked Energy. A Platform for Enhanced Energy Cloud Applications, Services, and Business Models." Navigant Research.
Strother, Neil, and Casey Talon (Navigant). 2017. "Navigant Research: Emerging IoT Business Models." Navigant Research.
Taylor, Gabriel D. (CEC). 2017. "Proposed DR Elements of the Building Standards (2019 Title 24, Part 6)." TN#: 220547. 2019 IEPR Workshop. Efficiency Division California Energy Commission.
Tierney-Lloyd, Mona (EnerNOC). 2017. "IEPR Workshop on Barriers to DR." TN#: 220577. CEC.
Tierney-Lloyd, Mona (EnerNOC), Jennifer A. Chamberlin (CPower), Erika Diamond (EnergyHub), and Sara Myers. 2017. "Comments of Joint Demand Response Parties (CPower, EnerNOC, Inc., and EnergyHub) on Staff Proposal on Energy Efficiency and Demand Response Integration."
Universal Devices. 2017. "Retail Automated Transactive Energy System (RATES) Status Report." June 20.
Ward, Allan, Gabriel Herrera, and Sara Kim (CEC). 2017. "Application of the California Energy Commission for Approval of Electric Program Investment Charge: Proposed 2018 Through 2020 Triennial Investment Plan."
Watson, Dave (LBNL). 2011. "Automated Demand Response for Title 24 (2013)." Demand Response Research Center, Lawrence Berkeley National Laboratory.
Wei, Joy, Francis Rubinstein, Jordan Shackelford, and Alastair Robinson (LBNL). 2015. "Wireless Advanced Lighting Controls Retrofit Demonstration." General Services Administration.
"Wireless Lighting Controls Automated Demand Response." 2016. SDG&E Emerging Technologies Program.
Yin, Rongxin, Sila Kiliccote, and Mary Ann Piette. 2014. "Linking Measurements and Models in Commercial Buildings: A Case Study for Model Calibration and Demand Response Strategy Evaluation." Lawrence Berkeley National Laboratory.
Yin, Rongxin (LBNL), Douglas Black (LBNL), and Michel Kamel (MelRok). 2016. "Fast Demand Response Technologies and Demonstration at SDG&E Energy Innovation Center Using OpenADR."
Ziegenfus, Scott. 2012. "Demand Response and Light Control." *ASHRAE*, BACnet Today and the Smart Grid.