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ABSTRACT

California is facing three major challenges in electrical grid operation: renewable overgeneration, steep evening ramping, and growing peak demand. The state has identified dynamic retail price response as a key strategy evidenced by CPUC's Dynamic Rates proceeding and CEC's Load Management Standards. Furthermore, the CEC launched a $16M "California Load Flexibility Research and Deployment Hub (CalFlexHub)" administered by Berkeley Lab to accelerate price-response flexible load technologies in buildings and EV charging.

There are more than 16 laboratory and field demonstration projects in CalFlexHub, each demonstrating innovative automated price-response technologies. CalFlexHub tests various pathways through which hourly price signals and triggered control commands are communicated to load-flexible devices such as smart thermostats, heat pumps, water heaters, and EVs. We identified seven unique communication and control pathways, which involve combinations of third-party cloud, device OEM's cloud, building central gateway, and local controller in between the price server and the load-flexible devices.

It is important for utilities and policy makers to understand the long-term implications of each pathway in designing future programs and creating related policies and mandates for market transformation. We propose an evaluation framework including the following aspects:

- **Functionality:** connectivity and uptime, resilience, and optimization;
- **Customer experience:** simplicity in setup, troubleshooting support, continuity, customer choice, first cost, and ongoing cost;
- **Business model and scalability:** advance interoperability, holistic solution, bridge unique gap, customer base, and value streams and pricing structures.

In this paper, we identify emerging business models associated with each communication pathway and discuss their positive features and challenges from the above aspects.

Introduction

Dynamic Retail Electricity Pricing for Load Flexibility in California

The California grid has been managing three major challenges in facing the growth of renewable energy and new loads: (1) renewable overgeneration during certain times of the year (e.g., some spring days); (2) steep ramping of generation required during evening time; and (3) the increasing system peak demand. These challenges call for: (1) shifting load from evening to renewable abundant times (i.e., in the middle of the day) in order to avoid renewable curtailment and mitigate steep evening ramping; (2) shedding load during summer peak load periods; and (3) managing electrification loads from electric vehicles (EV), heat pumps and more. The state has identified **the use of highly dynamic retail prices to motivate flexible loads as a key strategy** in response to the above challenges. The underlying premise is that highly dynamic retail prices (i.e., varying hourly or more frequently) will reflect both grid support needed from flexible loads and greenhouse gas (GHG) marginal emission trends in real time, both of which may be locational.

This new dynamic retail rate strategy is supported by a broad policy framework. In December 2021, the California Energy Commission (CEC) released the Load Management Standard (LMS) Rulemaking (CEC, n.d.-a). A backbone component of the LMS is the Market Informed Demand Automation Server (MIDAS) (CEC, n.d.-b), which is a central repository of retail electricity rates of all customer classes for public access with the intent to enable Automation Service Providers (ASPs)[1] to access dynamic rates on customers' behalf. The three electric investor-owned utilities (IOUs) have been required to upload customer rates to MIDAS in 2023 followed by other utilities. Flexible Demand Appliance (FDAS) (CEC, 2021) efforts were authorized by Senate Bill 49 for the CEC to adopt standards for appliances to facilitate the deployment of flexible demand technologies. In May 2023, as required by Senate Bill 846, the CEC established a 7GW statewide load shift goal to reduce net peak electrical demand, of which 3GW load shift is expected to come from "load-modifying" resources (CEC, 2023). Based on the referenced Commission Report, load shift from dynamic pricing will need to scale from the 30MW 2022-level up to 2,000MW needed by 2030.

In addition, the California Public Utilities Commission (CPUC) has opened the Demand Flexibility Rulemaking (R.22-07-005) in July 2022 and published an Energy Division whitepaper and Staff Proposal (CPUC, 2022) where the California Flexible Unified Signal for Energy (CalFUSE) vision is presented. The three CA IOUs have been authorized by the CPUC to conduct Dynamic Rate pilots (a.k.a. "CalFUSE" pilots) during 2022-2024 to support the vision (CPUC, 2021a; CPUC, 2021b). In January 2024, the CPUC adopted a new decision to expand Pacific Gas and Electric's (PG&E) and Southern California Edison's (SCE) Dynamic Rate pilots to run from 2024 to 2027 (CPUC, 2024a; CPUC, 2024b).

CalFlexHub Overview

In addition to the above policies, California has also invested in research, development, demonstration and deployment (RDD&D) to support the above vision on dynamic pricing and load flexibility. In 2020, the CEC issued a $16M competitive solicitation GFO-19-309 for the California Load Flexibility and Deployment Hub (CalFlexHub) through Electric Program Investment Charge (EPIC). The awarded CalFlexHub project is led by Lawrence Berkeley National Laboratory (LBNL) with many partners; its goal is to accelerate RDD&D of automated price-responsive flexible load technologies in buildings and EV charging.

At the core of CalFlexHub program design (Piette et al., 2022) is a set of residential and commercial building technology projects, which demonstrate customer flexible-load technologies integrated with a dynamic pricing server such as MIDAS or a price server for

[1] Refer to businesses that offer an automation platform which integrates with distributed energy resources and allow control and optimization of these resources for energy management and/or aggregation for grid service purposes. Virtual power plant (VPP) utility program providers are such an example.

research testing hosted by project partner Olivine. These projects were developed from the CalFlexHub public-private partnership and have grown in number since CalFlexHub's launch. In addition to the technology demonstration projects, CalFlexHub also conducts a set of research activities around 1) stakeholder needs, 2) communications architectures and interoperability, 3) technology usability and cost-effectiveness, 4) customer-level and grid-level load impact evaluation, 5) equity in dynamic pricing, and 6) technology and knowledge transfer including business models and adoption barriers in commercialization. CalFlexHub activities are highly synergistic with SCE and PG&E's Dynamic Rate pilots.

Objectives

In general, there are three methods to coordinating DERs to support the grid in an automated fashion: (1) grid entity directly controls individual DERs (e.g., smart inverters); (2) grid entity dispatches a group of DERs through an aggregator; and (3) grid entity uses dynamic signals such as price, GHG, and events (e.g., emergency) to influence DERs' energy behavior either directly or through a third-party.

Currently, research on technology development and demonstration on method (3) is rare because a market for automated price response does not exist in the U.S. Only a handful of U.S. utilities offers hourly dynamic rates such as Real Time Pricing, which mainly target large and sophisticated commercial and industrial customers. California is currently the only state investing in price-response technologies; hence, it is important to document its progress. Through interactions with stakeholders in CalFlexHub, there is consensus that formulating sustainable and scalable business models will be critical to achieving California's goal with dynamic pricing. This paper presents research that supports identifying business models with long-term benefits to customers and innovation by addressing the following three objectives:

(1) Describe the price-response communication and control architectures found in current CalFlexHub demonstration projects;
(2) Identify emerging business models for price-responsive load flexibility services and investigate their advantages and challenges;
(3) Propose a set of evaluation aspects from a market transformation view for utilities' and policy makers' consideration.

CalFlexHub Technology Project Portfolio

CalFlexHub was originally designed to support 12 technology development and demonstration projects (Piette et al., 2022). This portfolio[2] has expanded since project launch. Currently, there are more than 16 projects that have tested with CalFlexHub price signals. Ten projects consisted of field testing at more than 30 sites and eight projects conducted lab testing. These projects cover the following sectors: single-family, multi-family, small commercial, large commercial, and campus.

Figure 1 illustrates the range of residential and commercial flexible load technologies in the current portfolio by sector.

[2] https://calflexhub.lbl.gov/calflexhub-portfolio/

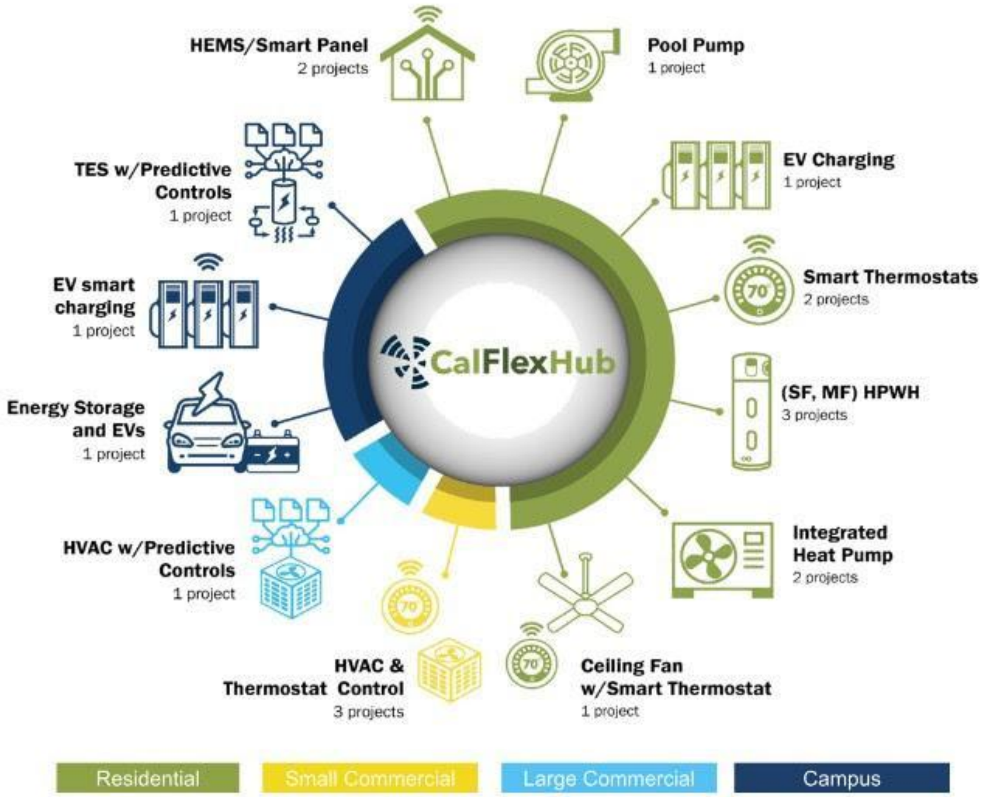

Figure 1: Price-responsive Technologies Currently Included in CalFlexHub Demonstration Portfolio

- **Residential**: smart thermostats, heat pump water heaters (HPWH), integrated heat pump systems (IHP), pool pumps, EV charging, home energy management systems (HEMS), smart panels, and smart ceiling fans integrated with smart thermostats.
- **Small/medium commercial**: energy management systems (EMS) integrated with smart thermostats and other end uses.
- **Large commercial**: predictive controls integrated with energy management systems for HVAC optimization.
- **Campus**: predictive controls integrated with EMS controlling large thermal energy storage, chillers, solar photovoltaic, predictive controls for EV charging stations and stationary batteries, and HVAC load and batteries integrated with microgrid control.

Price Communication and Control Architectures

CalFlexHub has developed seasonal 24-hour profiles of prototype hourly varying price and GHG signal profiles. **Figure 2** shows examples of 24-hr electricity price ($/kWh) signals in spring and summer used in lab and field testing. These signals have been hosted on both the MIDAS server[3] as well as the CalFlexHub research price server with demonstration project partners having the option of using either server or both for retrieving signals.

[3] See MIDAS Documentation at https://gitlab.com/CEC-MIDAS/midas-documentation

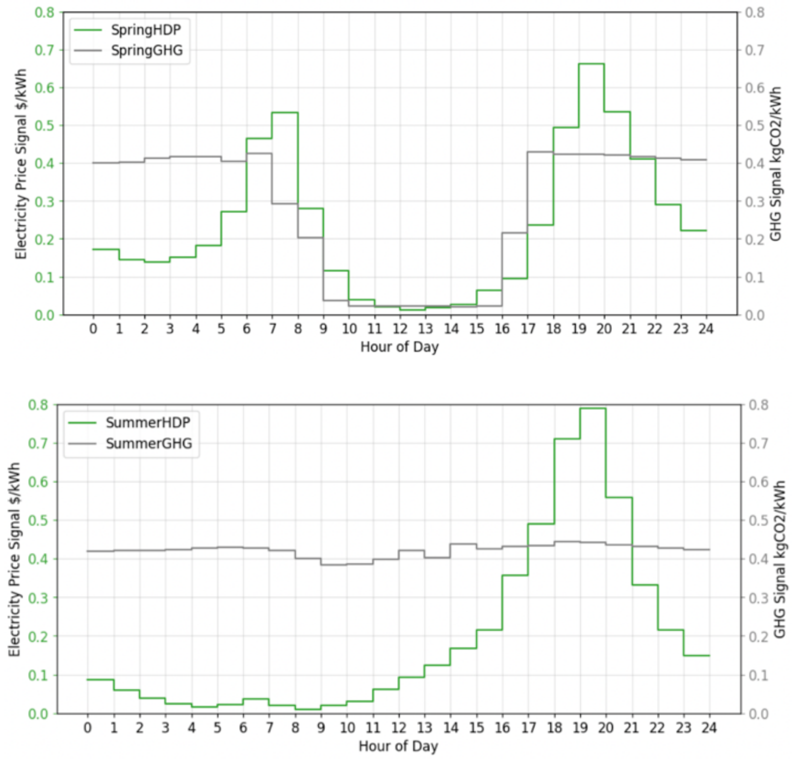

Figure 2: Prototype Spring (Left) and Summer (Right) 24-Hour Price/GHG Signals Used in CalFlexHub Testing

From CalFlexHub projects, we test and evaluate various pathways through which hourly price signals and its triggered control commands are communicated to **load-flexible devices**, also referred to as distributed energy resources (DERs), such as smart thermostats, heat pumps, water heaters, pool pumps, and EVs. A generic version of the possible pathways in price-based grid coordination has been previously published (Nordman et al., 2022). The technology demonstration projects in CalFlexHub each demonstrate innovative approaches to receiving the prototype dynamic price signals and automatically converting it into control commands which alter the load shapes of DERs. Given the nascent nature of price-responsive flexible load technologies, there are a number of variations of the steps and the hardware / software solutions involved in the price communication and control pathways. We have identified seven unique pathways as shown in **Figure 3**, which involve different combinations of third-party cloud, flexible-load device original equipment manufacturer's (OEM) cloud, building central gateway, and local controller in between the price server and the load-flexible devices. We refer to these unique pathways and structures including the technologies and involved parties as "**price communication and control architectures**" or "**architectures**" for short.

Four of the seven unique pathways shown in **Figure 3** can be categorized into four types shown in subsections below. Four share a commonality in that the dynamic price and GHG signal is first received by a third-party[4] ASP cloud; therefore, these four are labeled as "Type 2: Price Communication through a Third-party ASP Cloud" in a subsection below for discussion

[4] A third-party is besides the OEM of the DER technology and the utility.

purposes. Then, there are four types of architectures as labeled in the figure; the subsections below describe how each architecture works using real project examples in CalFlexHub. The type of emerging business model associated with each architecture is labeled in parenthesis in the section titles such as "OEM-1" and "ASP-2" (the descriptions of these business models are found in the next section).

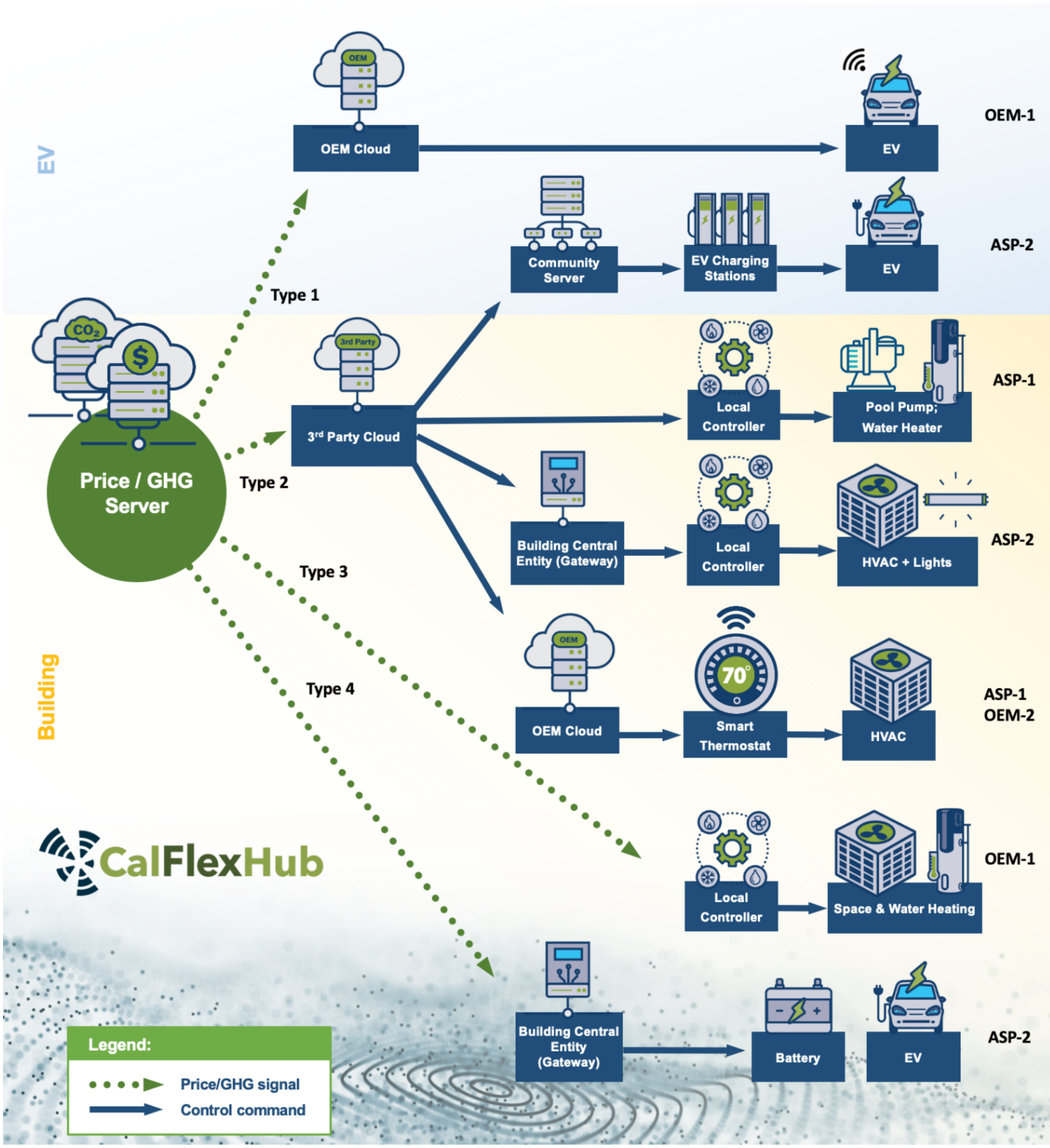

Figure 3: Representative Price/GHG Signal Communications and Controls Pathways Currently in CalFlexHub

Type 1: Price Communication through OEM's Cloud (OEM-1)

In this type of architecture, the OEM of the flexible-load device or system (also referred to as DERs in this paper) such as an EV manufacturer has developed a cloud platform to receive the price/GHG signal. The cloud platform then turns it into an EV charging command in the form of charging schedules, which is transmitted to the EV via the vehicle telematics system over a cellular network. Aside from projects in CalFlexHub, more DER OEMs are interested in aggregating their own devices to earn revenue by providing grid services to utilities.

Type 2: Price Communication through a Third-party ASP Cloud

This type of architecture is the most complex among the four categories and involves at least the following four variations downstream of the third-party's cloud as shown in **Figure 3**. This architecture type is also suitable for virtual power plant (VPP) programs since it allows the automation service providers to aggregate DERs.

ASP → Localized Server ("Community Server") (ASP-2). For example, the EV supply equipment (EVSE) vendor has its own cloud to receive the price/GHG signals, which are transmitted to the local servers on a campus parking lot to control the charging schedules of individual charging stations.

ASP → Local Controller (ASP-1). For example, some appliance (e.g., HPWH and pool pump) manufacturers have incorporated the ANSI/CTA-2045 standard socket and communication protocol in their products. For such appliances, installing a local controller consisting of a CTA-2045[5] port adapter and universal control module would allow an ASP to send price-based optimized control commands to the appliance.

ASP → Building Gateway (ASP-2). A gateway is a protocol-to-protocol translation function that may be served by hardware or software, or a combination of both. Some commercial building energy management system vendors offer a product line of central and local controllers in addition to its cloud platform. In this architecture, the price/GHG signal received on the ASP's cloud is sent to a central controller in the building via a gateway; the central controller will then orchestrate the local controllers to deliver desirable load flexibility. Another variation of architecture in this category is adding a gateway to the building automation system to achieve price communication and response control with large commercial HVAC systems.

ASP → OEM Cloud (ASP-1, OEM-2). ASPs can access internet of things (IoT) devices through a cloud-to-cloud integration if the device OEM offers an application programming interface (API). This is a common approach for ASPs to access smart thermostats. The ASP turns price/GHG signal into control commands such as setpoint changes, which get transmitted to OEM's cloud and subsequently to the thermostats.

[5] Besides the hardware module based approach to implementing CTA-2045, it is also possible to implement the standard only in software. For example, some HPWH OEMs now have an API that allows utility programs to send CTA-2045 commands to their products through WiFi saving the cost of a physical module.

Type 3: Price Communication through a Local Controller (OEM-1)

This is the simplest architecture type among the four categories. A local controller, which may be (although it does not have to be) an integral part of the DER physical system, receives the price/GHG signal directly, without any intermediary, and converts it into commands to control various system components. In such an architecture type, a cloud is not required although it may exist for other system functions. This architecture was employed by an integrated heat pump manufacturer as an example in CalFlexHub.

Type 4: Price Communication through a Building Central Gateway (ASP-2)

This architecture type is rarer than some of the other ones today despite its importance. A gateway is also referred to as a "building central entity" in this communication architecture where it serves as the building's single interface to the price server. It receives the price/GHG signal and converts it into control commands to modify the load shape of various devices in a home or commercial building. This type of architecture is **particularly important because it allows various flexible loads and DERs at a customer premise be coordinated to provide a desirable total load shape** in response to the price/GHG signals. In homes, this can be embedded in a smart panel or HEMS technology; in commercial buildings, the gateway can be integrated with the building automation system (BAS) or be implemented in other ways. These approaches are currently being demonstrated at pre-commercial stages.

Market Transformation Lens

California has several decades of experience with traditional DR programs, which focus on the top 50-100 hours (~1%) of the year when electricity demand is highest, typically during the summer season (Henrikson and Brief, 2008). The CA grid's need for load flexibility is transitioning from summer peak DR into continuous load flexibility which can be signaled using dynamic retail electricity price and GHG signals. This paradigm shift not only requires technology innovation but also creation of a sustainable ecosystem with effective business models that provide incentives for key stakeholders. This paper explores issues that require attention to ensure understanding of the pros and cons of emerging business models.

Some traditional DR programs are implemented by third-party aggregators, who engage in customer recruitment, technology support and program results verification, and payment processing. Some aggregators have developed a virtual DER Management System (DERMS) platform for DR dispatch purposes (i.e., the VPP model) and are expanding it for price-based optimization offerings. However, price-based optimization capability does not have to stem from a VPP platform or model. There are vendors with energy management software offerings that focus on saving an individual customer's overall energy cost and are adding price-based optimization capability. Such commercial software offering for homes or commercial building customers may or may not be attached to a physical product (e.g., gateway, controller, electric panel). We call vendors that offer price-based optimization "Automation Service Providers" or "ASP" regardless of their business focus on VPP or individual customer energy management.

In recent years, some OEMs of flexible-load DERs such as smart thermostats and EVs have started offering grid-connected energy management features to their customers as a way to enhance the customer value proposition and increase customer engagement. Some OEMs choose to build business relationships with ASPs and charge a device fee while others attempt to expand their business into providing utility services directly, or some utilize both models. In the next section, we identify a few emerging business models for OEMs and ASPs and try to understand their benefits, challenges, and price structures. Our hope is to help utilities and policy makers to understand, if these architectures and associated business models were to be scaled, what the challenges are, what long-term implications may be expected, and how one might approach evaluating those.

Emerging Business Models

Business models are critical for building a growing ecosystem for dynamic pricing and a nascent topic. Currently, the emerging price-responsive technologies and their demonstration are funded by CalFlexHub and the utilities' pilots; supporting business models are just now beginning to emerge. The number of full-scale hourly dynamic retail rates is underwhelming in the U.S. today, but there are examples in energy service jurisdictions where retail electricity market is deregulated and some retailers offer dynamic pricing along with customer assistance to help manage their energy cost[6].

As mentioned earlier, the "Type 2: Price Communication through a Third-party ASP Cloud" architecture overlaps with the emerging virtual power plant business models, which have been addressed in a few research publications (Xu et al., 2021; Ropuszyńska-Surm and Węglarz, 2019; Tan et al., 2022). The first study discussed the generic advantages and disadvantages of VPP; the other two studies identified a limited number of existing VPP examples in multiple countries with the intent to inform VPP design in Poland and China, respectively. These VPP examples are oriented towards wholesale electricity market participation and focus more on distributed generation assets; they have minimal overlap with the emerging business models for optimizing dynamic retail electricity prices discussed in this paper.

Therefore, existing knowledge and experience on business models around dynamic price response is rather limited as California transition to offering dynamic rates to majority of ratepayers in the next few years. The business models discussed in this section are somewhat hypothetical for research purposes based on anecdotal evidence found in CalFlexHub and the current Dynamic Rate pilots. In this paper, we explore a few likely near-future business models based on the technologies, communication architectures, and players seen in CalFlexHub so far. These are not intended to be a comprehensive list of possible business models at this early stage but are setting the foundation on how technology and service providers can effectively address the growing market for energy management in the future.

Emerging Business Models for OEMs

OEM-1: OEM offers price response without a fee. The OEM of the load-flexible DER technology may develop and own a dynamic price response capability as an embodied feature in their product (e.g., EV, integrated heat pump) and not charge their customer any additional price for it. This model is plausible when the added feature is not costly to the OEM and the embodied

[6] Here is one example: https://octopus.energy/smart/agile/

internet-connected product has sufficient monetization value such that recouping the cost of the price response feature is not an issue. For example, an EV OEM may use this bill-saving feature as a value-added product component as opposed to charging for this single feature. Another plausible scenario for this model is when energy management and bill savings is a core purpose of the DER product such that charging an additional fee for price response is not a good product sales strategy. For example, the primary value of an integrated heat pump system with energy storage is to lower a customer's utility cost for space heating/cooling and water heating. Therefore, price response is likely going to be a standard feature of this product so as to increase the product's bill-saving performance for greater customer value and market competitiveness.

OEM-2: OEM provides API and charges a device fee. The customer device OEM may decide not to develop a dynamic price response capability on their own but rather provide 1) an easy way to connect a CTA-2045 module (e.g., some HPWH OEMs) or 2) an API to allow a third-party ASP to offer price response services to their customers and charge the ASP a device fee and/or API fee (one-time or recurring). This model is plausible when the product is a low-value commodity, and developing and owning a price response capability such as a cloud platform would significantly increase the product costs. Currently, some smart thermostat OEMs have adopted this model although some of them may shift away from this model in the future as they develop a business interest in providing energy management and grid services as dynamic pricing tariffs become more prevalent.

Emerging Business Models for ASPs

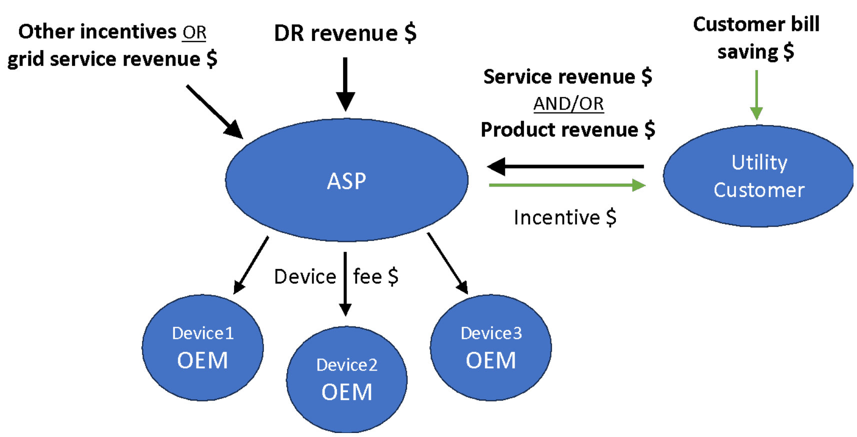

Figure 4: Potential Revenue Flow in an ASP Business Model

ASP-1: ASP offers cloud-based service. Some ASPs provide dynamic price response and load optimization services using cloud-based service without any significant hardware installation at customer site. Such service is typically funded by utility pilots or R&D projects today so neither the utility or the customer is charged for it. It is unclear how these ASPs will collect their revenue when such service is fully commercialized. **Figure 4** illustrates potential revenue flows among utility customers, ASPs, and device OEMs in potential ASP business models. Today's ASPs are typically DR aggregators for whom DR payments from utilities and/or the wholesale market are the primary revenue. If an ASP expands their service from DR aggregation to retail price optimization, it is likely that the resulting customer bill savings will reside with the customer. Whether the ASP will charge customers a service fee or the ASP will have to pay customers incentives to encourage participation are both possible scenarios. However, such monetary relationship between the ASP and customer may depend on (1) how monetizable the ASP model will be given that many OEMs charge significant device fees to a third-party who wants to integrate the devices with their platforms and (2) how much customer bill savings will be available.

ASP-2: ASP offers price response as part of a physical product. Some ASPs may offer a physical product that underpins their price response and load optimization service. For example, such underpinning products can be EVSE, smart panels, HEMS, and commercial building energy management systems that require hardware installations. These physical products are the core value of the ASP's business offering and price response will be an incremental value add for the customers. The possible revenue flows in **Figure 4** are also applicable to this model although compared to the cloud-based ASP model discussed in the previous section, product purchase cost is an important additional revenue stream for the ASP.

Architecture and Business Model Evaluation – Discussions of Attributes

The emerging business models discussed for OEMs and ASPs are still in development as the market evolves toward using dynamic rates to incentivize demand flexibility. Other business models beyond those in the paper may emerge as well. In this paper, we describe some of the implications of different communication architectures and the associated potential business models from a market transformation standpoint. To achieve California's goal of 3GW load-modification-based load shift, the adoption of dynamic pricing and the supporting automation technologies must grow on the order of 50-fold in six years. This means policies, program designs, and public/private sector investments with clear strategies are likely needed to support market transformation. The price communication and control architectures discussed earlier reflect technology vendors' roles and their business models. Therefore, towards developing understanding of scalability and long-term implications and to support creating a sustainable ecosystem, we propose a framework for evaluating these architectures and associated business models from the following three aspects, with each containing multiple attributes:

- **Functionality:** connectivity and uptime, resilience, and optimization;
- **Customer experience:** simplicity in setup, troubleshooting support, continuity, customer choice, first cost, and ongoing cost;
- **Business model and scalability:** advance interoperability, holistic solution, bridge unique gap, customer base, and value streams and cost structure.

In this section, we propose a set of preliminary criteria for evaluating each attribute in the above three aspects – functionality, customer experience, and business model and scalability – to initiate a robust discussion on this nascent topic. This framework is unique in that it emphasizes customer value and ongoing experience, and it is combined with business model scalability for technology and service providers. In comparison, the Ropuszyńska-Surm and Węglarz study (2019), for example, considers six components in comparing VPP business models – strategy, resources, network, customers, value proposition, and revenue. It has some overlap with the proposed framework in this paper although it focuses more on how large distributed generator and energy storage assets can generate revenue in wholesale energy market and not focusing on customer's ongoing experience with flexible load technologies.

Utilities, policy makers and price response service providers (e.g., OEMs, ASPs) are the key audience for this paper. For example, utilities may consider these factors in designing a market transformation program in the future to promote interoperability, increase customer choice, and enable customer energy opportunities and information.

Functionality

Connectivity and Uptime. Fewer steps and points of failure in the communication pathway. Architectures that are dependent on the uptime of two or more clouds and end-use responsiveness might encounter more connectivity challenges.

Resilience to Loss of Live Price Stream. Ability to maintain a set of day-ahead or default price schedules locally for backup during short periods of connection loss.

Optimization. Local agency for energy management resides with an ASP whose business goal is optimizing multiple devices or end uses with strong analytical expertise and utility industry experience. When the energy management function resides within a single device OEM, its limited visibility to other devices on the same premise can make total load optimization challenging.

Customer Experience

Simplicity in Setup. Only simple set up is involved or embedded functionally that allows for easy self-installation. It can be challenging if the set-up requires significant customization and especially if it is not covered by a vendor.

Troubleshooting Support. Troubleshooting is dependent on a single entity who has a core business interest to own customer service success related to price response. It can be a significant challenge if troubleshooting is dependent on multiple entities where ASP has limited influence on device OEM.

Continuity. ASP business models often promote the use of devices that have open APIs. When device OEM discontinues support or the customer changes brands, ASP can work with alternative products and continue the service.

If the optimization service is underpinned to an expensive product, then stranded assets are a significant risk for customers. Open-source protocols supported by industry standards can help mitigate the risk of a single business supported proprietary cloud service discontinuing.

Customer Choice. Promote choices of device OEMs and ASP providers (if applicable) as well as other options related to user experience such as user needs settings, override ability, and optimization decision. The ASP and device OEM integration model tends to open up options for both ASP vendors and device OEMs for customers to choose from because open API is essential to such a market model. When price response optimization is embedded in a self-contained, specialized DER product, there tends to be fewer vendors for such specialized systems.

First Cost. ASP service that has low/no first cost to customers due to standardized integration approach or the price function is embedded with the ASP's overall product or service. Some ASPs may have a higher first cost due to customization requirements or other costs. If price response is embedded in an expensive product (e.g., physical system, HEMS, EVSE), then the customer has to bear a higher first cost of the product and installation in order to access the price response feature.

Ongoing Cost. Customers do not need to pay an ongoing fee and will receive all or most of the bill savings. Given the discussions on emerging business models earlier, this may align with OEM models and ASPs whose optimization service is embedded in a product; it will likely be more challenging for ASPs whose business model is built around a cloud platform and need revenue from either subscription fee or shared DR payments and customer bill savings.

Business Model and Scalability

Advancing Interoperability. Promotes transparency of performance and savings data. ASP architectures require exchanging data with many types and brands of device OEMs, which promotes interoperability. Implementing interoperability features may not be a priority need of self-contained systems.

Holistic Solution. Ability to orchestrate multiple end uses in a home or building to optimize the total load shape. There is an important need for innovative architectures and business models that provide resolution between traditional DR and price response in which case total load optimization is desirable.

Currently, the VPP model is gaining traction in utility DR programs nationwide. The majority of such programs aggregate devices by type to deliver a greater number of megawatts of DR resource to the bulk power system; it is less common to see supporting distribution system as the main goal in today's VPP program design. Aggregating similar devices, or "homogeneous VPP" tends to be less costly to implement and simpler to scale compared to approaches that address whole-building optimization; however, homogeneous VPP can lead to fragmentation of available resources in the long run. The VPP model is technology agnostic and therefore is inclusive of integrated whole-building resources, to which bringing down technology and integration costs is a significant challenge.

Bridging Unique Gaps. Although it is often technically possible for device OEMs to develop optimization capability and offer related service to their customers, there may be an investment gap for ASPs to fill because the near-term market signal and customer demand is not strong enough to attract such investment by OEMs.

Customer Base. Product or service has strong value and is affordable to a diverse and large customer base to support scalability. Some products and services may need to overcome the challenge of a narrower customer base due to applicability or affordability.

Value Streams and Cost Structure. Value streams such as sales of a product aside from customer bill savings or DR revenue is a plus. Fixed cost of software development for price response capability with low engineering cost favors profitability.

It is more challenging to ensure monetization when DR revenue and customer bill savings are the main value streams provided byASPs. High customer recruitment and variable engineering cost in addition to software development cost would increase the business risk for ASPs and they are likely to pass down some of this risk to customers through product/service pricing. Recouping these costs from subscription fee and/or an upfront customer cost will be likely.

Conclusion and Future Direction

The state of California has established a key strategy to use highly dynamic electricity prices to motivate customer load flexibility using automated technologies. The CalFlexHub program is a four-year RDD&D program funded by the CEC to foster building up a pipeline of automated price-responsive technologies for building loads and EV charging. In this paper, we have identified four types of price-response communication and control architectures found in CalFlexHub technology demonstration projects. The automated solutions in these architectures are typically provided by either the OEM of a load-flexible DER or an ASP or a combination of both. In many cases, how the OEM and ASP will monetize such pre-commercial and early-commercial offerings is still emerging. In this paper, we identify and predict emerging business models for OEMs and ASPs based on our current knowledge. These architectures and business models have different advantages and challenges, which will have long-term market implications if implemented at scale. Therefore, in this paper we proposed a set of evaluation aspects and attributes; we then discussed desirable features and potential challenges for each attribute from a market transformation perspective.

Communication architectures and business models involving third-party ASPs are potentially advantageous for advancing interoperability and offering holistic solutions to customers including optimization across multiple end uses. A greater level of interoperability tends to bring more customer choices for products and vendors and is also favorable for better continuity for customers when individual product/service discontinues. However, identifying value streams that provide sufficient incentives for all parties involved in the ASP models – the ASP, OEMs, and customers – is a significant challenge. On the cost structure side, device connection fees charged by OEMs and engineering cost for customized integration pose challenges for ASPs as well. These challenges are bigger if the ASP is offering price-response as a service instead of embedding it in a physical product such as a EVSE, smart panel, or HEMS.

OEMs of flexible-load DERs (e.g., smart thermostats, HPWHs, EVs) show growing interest in offering grid-connected energy management services and features to their customers to enhance customer value proposition. When price-response is offered by OEMs, there are generally fewer steps in the communication and control pathways which implies fewer points of failure and less dependency on multiple clouds. It also implies troubleshooting tends to involve fewer parties. Some OEMs are capable of offering price-response as an additional feature to their customers at no additional charge because their main business models are built around selling the underpinning product. Some potential limitations in these architectures and business models are: the OEM may not have motivation to advance interoperability and coordinate with other loads and DERs for whole home or building optimization; and customers may experience stranded assets when product or service discontinue.

The above preliminary discussions around the potential advantages and challenges of ASP vs. OEM oriented architectures and business models will evolve as the ecosystem grows. Our intent is to help utilities and policy makers get oriented in thinking of long-term market implications in designing market transformation programs and formulating related policies in the future. In the remaining two years of CalFlexHub work, we will continue to track how emerging architectures and business models will develop and solicit wider feedback for the evaluation considerations proposed in this paper.

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