Demand Response Technology Enhancements Using Dynamic Prices

For SCE Emerging Markets and Technology

3002025580

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Technical Update, October 2022

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ABSTRACT

This research investigated the current electric tariffs, enabling technologies, communication platforms, and the innovation priorities that will be needed in the near future for widespread customer adoption of dynamic pricing to effectively reduce grid congestion via automated demand response (ADR), particularly for Southern California Edison (SCE). Topics covered are an examination of the components of the SCE tariffs, overview of ADR technology (including data models, communication architectures, and standards), and potential barriers to adoption of new technical enhancements (including cost trends, persistence, reliability, storage, Internet of Things trends, and Information Technology opportunities). Key results include a recommendation for an overall communication architecture; Price-Based Grid Coordination (PBGC) that enables diverse communication paths and multiple locations translating prices to functional controls; the new concept of a "local price" of electricity to facilitate maximum use of prices as the central mechanism for managing power distribution; and a standard data model for representing price information.

Keywords

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PRIMARY AUDIENCE: This report was prepared specifically for Southern California Edison's Emerging Markets and Technology (EM&T) Program.

SECONDARY AUDIENCE: All utility and non-utility demand response practitioners interested in evaluating widespread implementation of dynamic pricing as a means of effectively reducing grid congestion and enabling demand flexibility via automated demand response (ADR).

KEY RESEARCH QUESTION

How might dynamic pricing effectively reduce grid congestion via automated demand response? What enhancements and innovation ideation to current customer technologies are needed to bring widespread implementation of dynamic pricing, particularly in Southern California Edison (SCE)?

RESEARCH OVERVIEW

This research was performed via the following tasks:

1. Assessment of relevant data elements in current and potential future SCE tariffs.
2. Evaluation of current ADR technology.
3. Review data models and communication architectures used for dynamic pricing and identify any gaps and recommended technical priorities.
4. Examination of technologies and communication standards that support streamlining Automated DR Systems.
5. Evaluation of cost trends, persistence, reliability, storage, Internet of Things (IoT) trends, and information technology (IT) opportunities.

All results were delivered in the form of written reports.

KEY FINDINGS

- An overall communication architecture, Price-Based Grid Coordination (PBGC), is defined in Section 3 of the report. It enables diverse communication paths and multiple locations translating prices to functional controls, and it offers significant opportunities for flexibility while maximizing interoperability.
- There are numerous ways for devices to receive price signals and respond, including in intelligence and control algorithms in the cloud, in the flexible loads themselves, and in central customer-site control devices.
- The new concept of a "local price" of electricity facilitates maximum use of prices as the central mechanism for managing power distribution.
- Streaming prices to loads directly or via Automation Service Providers (ASPs) on a continuous basis to facilitate nimble demand flexibility for grid operators is highly practical.
- A standard data model for representing price information underpins the communication.
- There are several technology standards well-suited for price communication, but they can be improved and supplemented to make using them simpler and easier.

WHY THIS MATTERS

There is a growing need to enable substantial customer retail demand flexibility to achieve California's ambitious goals for operating a wholesale market and electric grid with significant levels of renewable energy. An objective of this report is to explore how to develop more flexibility via dynamic pricing from existing and future customer electrical loads. Loads in buildings, such as appliances, processes, and operating systems increasingly contain sophisticated algorithms to manage their internal operation for optimum service delivery. Dynamic electricity prices can be readily integrated into such algorithms to reduce electricity bills for facility owners.

HOW TO APPLY RESULTS

The findings of this report can be used to prepare a roadmap for utilities to follow to encourage innovation in dynamic pricing-based ADR and to identify barriers to bridging the gaps discussed. The recommendations from this effort can be used to help SCE, the Emerging Markets and Technology program, and others in similar roles to identify innovative emerging technologies, software, and market solutions that may help advance DR initiatives for utilities and their customers.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- A series of studies performed by Lawrence Berkeley National Laboratory's (LBNL), known as the California Demand Response Potential Studies, have forecasted the DR and demand flexibility market and technological potential in California. These studies suggest that California might be able to double the load impacts provided by customer end-use loads and innovative technologies in the next ten years.
- The California Energy Commission (CEC) has supported development of the Market Informed Demand Automation Server (MIDAS) system (although initially targeting only "automation service providers" for their data distribution).
- The CPUC has proposed the UNIDE (Unified, universal, Dynamic Economic signal) rate. Now called CalFUSE, this price would reflect actual local distribution system costs and locational marginal wholesale pricing and would be fully consistent with the communication architecture presented in this report.

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PROGRAM: Customer Technologies Program, P170

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INTRODUCTION

Background

Demand response (DR) programs are important resources for keeping the electricity grid resilient and efficient; assist in optimizing utility investment in generation, transmission, and distribution systems; and providing societal economic and environmental benefits. Southern California Edison (SCE) for years has conducted research to provide enabling technologies to help customers successfully participate in current DR programs and future dynamic pricing tariff options. Moving forward, SCE is committed to ensuring that customers have access to the most cost-effective enabling technologies that are eligible for program incentives and can also assist customers in managing their energy costs.

SCE, through the Emerging Markets and Technology (EM&T) program, provides a pathway for innovative emerging technologies to facilitate and enhance customer participation in SCE's DR programs and dynamic pricing initiatives. The EM&T program develops and delivers technology-driven DR assessments, laboratory and field projects, and market studies that can facilitate customer enrollment and participation in cost-effective DR and promote behavioral change for time varying rates. The EM&T program is currently authorized by the California Public Utilities Commission (CPUC) as a forward-looking emerging technology program for the years of 2018 through 2022. Future authorization of the program through 2027 is currently under review and pending at the CPUC.

The EM&T program conducts multiple activities throughout its program cycle and identifies the value and purposes of the portfolio investments and the program's role in accelerating demand response (DR) innovation, along with recommendations about how the EM&T program can continue to build on its accomplishments.[1]

The focus of the EM&T program includes:[2]

- Intake and Curation: Identifying projects for inclusion in EM&T's portfolio and selecting which ones to fund based on a well-informed understanding of the broader industry context.
- Market Assessments: Creating a better understanding of the emerging innovation and consumer markets for DR-enabling technologies.
- Technology Assessments: Creating and reviewing the results of lab and field tests of DR enabling technologies with stakeholders
- Technology Transfer: Advancing DR-enabling technologies to the next step in the adoption process, including raising awareness, building capabilities, and informing initial stages of product development for DR offerings.

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[1] Southern California Edison's Demand Response Emerging Markets & Technology Program: Investment Overview 2017–2019. February 2020.

[2] https://www.dret-ca.com/about-sce/:

- Strategic Advocacy: Actively supporting key market actors to integrate DR-enabling emerging technologies into their decisions, including promoting DR emerging technologies to state and federal agencies and advancing the widespread adoption of industry standards.

Past activities from the EM&T program have generated successful results in the following areas of focus:

- Enhancing the availability of OpenADR for cost-effective DR-enabling, end-use technologies for SCE customers participating in DR programs,
- Supporting and developing DR in the California Energy Commission (CEC) T-24 Codes and Standards (C&S) for new construction,
- Encouraging innovative DR emerging technologies, as well as customer acceptance and engagement, for consumer products such as smart communicating thermostats and heat pump water heaters through upstream market enablement, and
- The development and advocacy of secure and open protocol communication standards to enable customer end use flexibility for residential, commercial, industrial, and agricultural end uses, and behind the meter storage and electric vehicle transportation systems.

Research Focus

To support the development and implementation of new models of demand response programs and the deployment of new rates and tariffs in the SCE service area, the EM&T program enlisted Lawrence Berkeley National Laboratory (LBNL) to investigate the enabling technology opportunities in that area. This included an examination of the secure communications that enable DR, potential enabling technology barriers to Dynamic Pricing and the preparation of a technology roadmap for SCE to follow in order to encourage innovation in this area. Such is the purpose of this report; to identify enhancements of current technology to bring widespread implementation of Dynamic Pricing through enabling technologies to provide price elasticity effectively as an automated demand response objective.

A series of studies performed by Lawrence Berkeley National Laboratory's (LBNL) Demand Response Research Center (DRRC), known as the California Demand Response Potential Studies, have forecasted the DR market and technological potential in California (Alstone et al, 2017 and Gerke et al, 2020). These studies suggest that California might be able to double the DR provided by customer end-use loads and innovative technologies in the next ten years. The Alstone study also indicated that customer incentive programs for DR enabling technologies would enhance and improve customer participation as the cost for these technologies became more cost-effective.

To ensure customer eligibility and participation, most of the future DR resources need to be automated through secure open communications protocols such as Automated Demand Response (ADR) to allow them to be dispatchable and flexible. The Alstone study provided the following recommendation:

> *California has made great strides in developing and promoting common standards for DR automation, and these are critical for enabling low-cost pathways to DR enabling the evolution of the internet-of-things approaches that use onboard, or built-in device connectivity to support DR and we show could be key to technology-oriented DR market*

transformation. Onboard devices can support Open Automated Demand Response (OpenADR 1.0 and 2.0), and Smart Energy Profile (SEP 1.0 and 2.0).

Further work is needed to ensure that there is adequate outreach and education to ensure that the use of these standards is coordinated among IOUs, aggregators, the ISOs, vendors, controls companies, and customers. Additional outreach should be done to inform customers regarding the enhanced value to them for making sure any investment on their part adheres to the most relevant standard.

To ensure California's DR potential effectiveness over the next 10 years, DR programs will need to be based on new combinations of DSM technologies and the integration of preferred resources such as distributed generation, storage, changes in codes and standards, and implementation of dynamic pricing structures. It is expected that a combination of dynamic prices and appropriate communication technologies will enhance the electric grid resiliency through autonomous application of ADR.

This report is focused on addressing the gaps in dynamic pricing-based ADR and identify barriers to bridge these gaps.

Objective

The objective of this report is to study the value and assess the gaps in dynamic pricing-based ADR. This objective is achieved by addressing the following tasks:

1. Assess Current and Potential Future SCE Tariffs for Data Elements and Evaluate Recent ADR Technology (Section 2)
2. Review Data Models and Communication Architectures and Identify Technical Priorities (Section 3)
3. Examine Technologies and Communication Standards to Support Streamlining Automated DR Systems (Section 4)
4. Evaluate Cost Trends, Persistence, Reliability, Storage, Internet of Thing Trends, and Information Technology Opportunities (Section 5)

With findings from this study effort, EPRI will identify the innovative emerging technologies, software, and market solutions to help SCE's EM&T program to advance its DR initiatives for SCE and its customers.

Why California Needs More Load Flexibility

California has ambitious goals for operating an electric grid with prominent levels of renewable energy (State of California, 2019). To achieve those goals, there is a growing need to meet the increase in non-dispatchable renewable supply resources with new demand side programs and processes to enable substantial load flexibility[3]. An objective of this report is to explore how to develop more flexibility from existing and future customer electrical loads. End-user electrical

[3] The CEC defines load flexibility as “Flexible demand appliance standards will promote technologies to schedule, shift, and curtail appliance operations to support grid reliability, benefit consumers, and reduce greenhouse gas emissions associated with electricity generation” (CEC, 2021b).

load flexibility applications, while not an objective of this report, is the foundation on which dynamic pricing will depend on to succeed.

Loads That Provide Load Flexibility

As the need for continuous load flexibility has become increasingly apparent to support electrical grid reliability and resilience, research has begun to focus on which end uses in what facility types are most suited to deliver that flexibility. A series of reports prepared by LBNL ("DR Potentials" reports) for the California Public Utilities Commission on the potential amount of demand response flexibility that can be obtained is a key source of estimates to support that evaluation[4]. While shedding electrical loads during times of exceptional grid stress is a necessary part of grid management, shifting the timing of these loads will be the primary way the demand side will contribute to future grid needs, particularly for integrating increasing amounts of variable renewable generation.

The DR Potential Phase 3 Report disaggregates the shift potential by facility type and end use, which can inform priorities for automating price response in loads. This report addresses what needs to change to automate this DR flexibility, and specifically which pathway(s) are appropriate for each case. As customers move onto more dynamic tariffs, they can implement this automation. In many cases this will require new products or services being offered by product manufacturers or automation vendors and will require the ready availability of the necessary grid signals (particularly prices).

The high-level DR Potential Phase 3 results show that most of the least expensive DR is available from industrial process loads, agricultural pumping, and commercial HVAC. One reason for this is that these are mostly individual large loads, so the integration costs are lower per unit of shift. For buildings, aside from commercial heating, ventilation, and air-conditioning (HVAC), major end uses that could deliver shift DR are electric vehicle (EV) charging, water heating, pool pumps, and commercial refrigeration.

From these results from the DR Potentials Phase 3 report and given the nature of control systems deployed and available today, the most immediate path to load flexibility is the use of cloud-based service provider systems. This is also practical, as the number of entities that need to receive the price signals is much smaller than with the other routes, and there are fewer technology standards questions in play.

The California Energy Commission (CEC) has supported development of the Market Informed Demand Automation Server (MIDAS) system, initially targeting only "automation service providers" for their data distribution. The second priority (pursued in parallel) should be individual devices that can take in prices directly. Vendors of building automation software will likely recognize the value of incorporating this functionality and add it to their offerings early on. This covers the set of three "pathways" summarized in Section 3 and described fully in Appendix A - Automation Pathways and Flexibility.

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[4] The first (Phase 1) was published in 2016, with the most recent (Phase 4) scheduled for release in 2022. The Phase 3 report (Gerke et al., 2020) has the most current and applicable results for this discussion.

A report on market availability of devices with the potential for, or actual capabilities for DR (Navigant, 2019), found them in thermostats, room air conditioners, dishwashers, clothes washers, clothes dryers, mini-splits, water heaters, and pool pumps. This list closely matches the products that the ENERGY STAR Connected program covers. Another survey of devices with DR capabilities (Nubbe, 2020) found major concerns for interoperability, cybersecurity, and privacy; the cost of connectivity is low and declining; and lack of actionable prices is a major barrier. This discussion is covered in Appendix D – Quantification of Demand Response Potential.

For industrial energy use, DR potential has been cited in food processing, metals production, chemicals, cement, pulp and paper, textiles, glass, and oil refining (Shonreh et al., 2016).

The cost of adding communication is cited as being $30–$40 per unit (CEC, 2021b). However, this may significantly overestimate the actual cost. A Wi-Fi light-emitting diode (LED) light bulb can be purchased for less than $8, and that bulb includes all the necessary communications in addition to the cost of the bulb itself. Moreover, an increasing number of appliances and other devices are already being shipped with communication capabilities installed by the manufacturer for other reasons. Thus, adding price responsive software can be affordable and should require no new hardware. In general, we are only likely to see the emergence of products and systems that can take in dynamic prices when those prices are deployed by utilities and available to a substantial number of customers.

The Criticality of Automation

Early DR designed for system reliability, with direct load control, was automated, often with proprietary signaling over radio or powerline carrier communications. Manual DR was also available for less critical scenarios, and can be practical for large loads (e.g., an industrial facility or large commercial building) or if it occurs only occasionally (e.g., with IOU staged Flex Alerts)[5]. Beyond that there is a low ceiling for the amount of DR that can be obtained and its frequency of utilization due to the presumed loss of system load utility and customer reluctance to participate. Even with today's limited support for DR automation, research has shown that substantially more flexibility results when automation is present (Faruqui and Bourbonnais, 2020). As most use of time-varying rates to date have been time-of-use rates, with their predictable pattern, automation has not required ongoing communication. However, as grid needs and therefore prices become more dynamic, the opportunities for automated control are rising.

In response to this, the California Energy Commission (CEC) has initiated several activities to spur the consumer market adoption of automation. These include the Load Management Standards process (CEC, 2021a), and the Flexible Demand Appliance Standards process (CEC, 2021b). In addition, the California Public Utilities Commission (CPUC) recently held a staff workshop emphasizing highly dynamic pricing (CPUC, 2021a), and initiated the IEPR rulemaking process that could support progress in this area (CPUC, 2021b).

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[5] OhmConnect is successful with manual DR, with OhmHours, though they also provide an automation service called AutoOhm to get greater participation.

The CEC Load Management Standards process (CEC, 2021a) seeks to require California utilities and other retailers to offer dynamic rates that are different every day, and provide automation capabilities so that customers, customer devices, and third-party automation service providers can respond well to such prices.

The CEC Flexible Demand Appliance Standards process (CEC, 2021b) aims to utilize California's energy regulatory apparatus to drive flexibility into the market, building on its past focus solely on efficiency. Alignment among the mechanisms used for price distribution, the nature of those prices, and the capabilities of appliances and other customer devices to use these prices is essential for a good result.

The CPUC staff workshop (CPUC, 2021a) included discussion of the UNIDE (Unified, universal, Dynamic Economic signal) rate. UNIDE is an adaptation of the pricing used in the CEC/EPIC RATES project (Cazalet et al., 2020); that project tested aspects of the TeMix system for customer/grid coordination. UNIDE is a real-time price signal in that it incorporates the wholesale electricity price, but it has at least two important and valuable features beyond that. It incorporates the relevant CAISO Locational Marginal Price (LMP), to address the fact that at any given time, electricity is not equally valuable across utility service areas. Secondly, it accounts for the substantial distribution costs in electricity distribution in a way that charges more during times when the distribution system has a higher capacity usage, to better reflect the time value of electricity and encourage reducing peak distribution system usage times, to defer or avoid investments in that system. The result is that UNIDE has a much greater "dynamic range" (the difference between the highest and lowest prices in each 24-hour period) than a tariff whose variability is only driven by the core wholesale CAISO price.

An underlying principle of UNIDE is that by offering a price to customers which much better reflects actual system costs, it can accomplish the same result in addressing system needs as other more complicated (and usually supply-side) mechanisms. As UNIDE should help reduce overall system costs, this can be reflected in overall lower bills.

The UNIDE price is fully consistent with the communication architecture presented in this report. While price formation is not a focus of this report, the UNIDE signal should certainly be part of any tests or price formation research.

Emergency Proclamation Catalyst

A flurry of activity erupted late 2021 around the implementation of UNIDE signal and continues deep into 2022:

- On November 20, 2020, the CPUC passed a ruling (R.20-11-003) to ensure reliable service during extreme weather events.
- On March 25, 2021, the CPUC published Decision (D.21-03-056) to authorize supply and demand side approaches to meet Rule 20-11-003. This was Phase 1 of the decision.
- Governor Newsom on July 30, 2021, signed an Emergency Proclamation instructing California energy entities ensure reliability during extreme heat events.
- This event was closely followed by Administrative Law Judge Stevens initiating Phase 2 of the of Decision 21-03-056.

- On September 1, 2021, TeMix proposed to the CPUC to demonstrate RATES™, using the UNIDE Roadmap.
- On December 6, 2021, the CPUC instructed several IOUs to demonstrate UNIDE using RATES™.
- On June 22, 2022, The CPUC Energy Division published a White Paper and Staff Proposal: Advanced Strategies for Demand Flexibility and Customer DER Compensation (CPUC June 22, 2022). The CalFUSE framework (California Unified Signal for Energy) was introduced and replaced the UNIDE program name.
  - Three pillars of the CalFUSE Framework (Price Presentation, Rate Reform, and Customer Options for Energy Optimization) would integrate Six Elements of CalFUSE (Standardized price access, Real-time energy prices, Real-time capacity prices, Bi-directional prices, Subscription Option, and Transactive Option)
- On July 21, 2022, the CPUC conducted a workshop: CalFUSE Whitepaper and Staff Proposal (CPUC July 21, 2022). Within this presentation, it was demonstrated how transactive rates would reduce grid demand and provide Customers financial benefits.

It is clear that Governor Newsom's Emergency Proclamation has initiated a regulatory process that has re-defined the importance and urgency of deploying Demand Response Technology Enhancements using Dynamic Prices. UNIDE has been replaced by CalFUSE to streamline and support the urgency of the Emergency Proclamation.

Overall Structure of Automated ADR

Accomplishing electricity load flexibility with dynamic prices has three parts:

- The retailer **sets** the price to best meet its revenue and operational needs.
- The price **is transmitted** from the retailer to the customer load or distributed energy resource (DER) as a controlling device.
- The customer load or DER (or controlling device) **uses** the price with other information to decide how to operate. Typically, cost savings to the customer will dictate how the device will respond to the transmitted price.

Each of these topics is complex on its own. Sections 3 and 4 of this report cover the middle part: price communication. Section 5 covers research gaps which are mostly related to how flexible electrical loads and DER use prices.

Airplane ticket pricing offers a relevant example of dynamic pricing. Fares were significantly regulated for many decades, with relatively fixed prices. A 1978 federal act moved to a much less regulated system, with variable prices. Airlines monitor historical relationships between prices and ticket sales for each itinerary and use that to set future prices. They monitor ongoing conditions (seat sales) and adjust those prices as needed, until the time of operation. Prices are used to balance supply and demand, and consider capacity constraints, the weather, and the calendar. While not a perfect analogy, utilities (if allowed by regulators and with the appropriate billing systems infrastructure) could offer a similar pricing strategy. Each day, demand could be significantly shaped (once fully in place) by dynamic prices, using previous days with similar characteristics as a guide, and minor changes could be made during the day to keep the system well balanced. Wholesale market prices can be an important input to price setting algorithms, but other factors can also be important. Locational issues such as capacity constraints are one example.

Loads in buildings, with the emergence of energy management systems, have increasingly sophisticated algorithms to manage internal operation for optimum service delivery. Among these factors is saving money with energy efficient operation. Dynamic electricity prices can be readily integrated into such algorithms, to reduce electricity bills for facility owners. While devices will occasionally shed some load during times of very high prices (and so greatly contribute to emergency response), the vast majority of changes in operation will be to shift load forward or backward in time in response to day-ahead or real time pricing forecasts. And most of this approach will leverage thermal storage in devices and facilities (Gerke et al., 2020).

Transmitting prices is mostly a technology issue. Setting and using prices have significant technology content, but they are also inextricably tied to policy and market issues. A price-based system can create clear divisions between setting prices and how they are transmitted, as well as between using prices and how they are transmitted. These divisions enable the three parts to evolve independently, so long as the interfaces between them are well defined. An essential role of the sections below is to describe those interfaces, along with the technologies needed to move the data from an interface at the utility end to one at (or close to) each flexible load and DER.

Report Organization

The report is organized as follows.

- Section 1 *INTRODUCTION* provides background to why the study was commissioned, introduces the objectives of the report, reviews the need for much greater load flexibility, the criticality of automation, and the overall structure of price communication.
- Section 2 *ASSESSMENT OF CURRENT AND POTENTIAL TARIFFS TO ENHANCE ADR CAPABILITY* reports on a comprehensive review of Southern California Edison (SCE) tariffs, including "tariff features" found that are potentially relevant to dynamic price communication. These are categorized into four categories for how they intersect the communication. Several existing tariff features are problematic for using dynamic prices for coordinating flexible loads. The selection of features for future tariffs influences requirements for price communication technologies.
- Section 3 *DATA MODELS AND COMMUNICATION ARCHITECTURES* describes the overall proposed and recommended structure of communicating time-varying price information from an electricity retailer to flexible loads and other customer devices. This includes details of its core operation, an introduction to three "automation pathways", the key roles of customer central entity devices and local prices, and the concept of "streaming" prices. It further reviews the proposed standard data model for price communication, implications for tariff design and protocols, and the transition from today's devices and capabilities to a future with much more demand flexibility.
- Section 4 *TECHNOLOGIES AND COMMUNICATION STANDARDS TO SUPPORT AUTOMATED DR* addresses technologies and communication standards to support automated demand response. This includes activities that occur before ongoing operation, gaps in the major relevant communication protocols, and how to fill those gaps.

- Section 5 *TECHNOLOGY TRENDS AND EMERGING TECHNOLOGY: GAPS AND RESEARCH NEEDS* outlines research needs to lead to full development of a price-based system. Major categories of needs are communications, flexible load control, new technology directions, and incentives and market engagement. It considers which comes first: prices or devices, how today's devices will become price-responsive, and how Internet of Things (IoT) technology and interoperability issues intersect price response.
- Section 6 *SUMMARY OF RESULTS AND RECOMMENDATIONS* provides a summary of results and recommendations.

In addition, a set of appendices provide further detail on many of these topics.

2

ASSESSMENT OF CURRENT AND POTENTIAL TARIFFS TO ENHANCE ADR CAPABILITY

This analysis provides a comprehensive review of Southern California Edison (SCE) tariffs, as available online[6]. It presents a catalogue of sixteen "tariff features" found that are potentially relevant to dynamic price communication. These are categorized into four categories for how they intersect the communication for automated DR: those that present no issues or difficulties, those that can be addressed with a simple adaptation of price communication, those that are extremely difficult to address, and some that are not relevant at all.

The purpose of this section is to guide future tariff design to result in prices that can be easily communicated to customers and devices they own to optimize their behavior for customer and grid benefit.

Further details are provided in Appendix C – Tariff Details. Information on data models is found in Section 3. Review of demand response communication standards can be found in Section 4, and in Appendix D – Technology Standard Details.

Utility tariff descriptions are complex documents, but most of the content does not affect decisions made by flexible loads. A change in the price between two times of day can encourage a shift in the pattern of energy use, but the presence of a monthly fixed charge will not. Thus, tariffs were examined with this project's specific purpose and context in mind.

The review covered all SCE tariffs, which are categorized as residential, commercial / industrial, agriculture and pumping, street lighting and traffic, and other. There are a total of over one hundred tariff documents, though some are potential add-ons to others, and many are families of variations for differences such as customer service capacity, price structure, demand charges, and simple discounts.

Key results are summarized below.

Tariff Features Found

In this report, a tariff "feature" is a provision or set of provisions that is an example of a general pattern, even as the details of the feature may be different from tariff to tariff. The features noted in our survey are listed in Table 2-1.

Each feature has implications for communication of time-varying prices to customers and flexible electrical loads so they can be optimized for customer benefit. Some features create no issue at all, others require a modest adjustment to the system, and a few create large problems as described in Appendix C.

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[6] Southern California Edison. Regulatory Information - SCE Tariff Books. https://www.sce.com/regulatory/tariff-books

Table 2-1
Features found in SCE Tariffs

Tariff Feature	Description
TOU: Time-of- Use	Tariffs that differ by time of day (in periods that are hours long), day of week (weekday vs. weekend/holiday), and season.
CPP: Critical Peak Price	Tariffs that are much higher than normal, occasionally, at a known time of day, announced shortly in advance of them occurring.
RTP: Real Time Price	Tariffs that are (potentially) different each day and announced no more than a day in advance[7] .
Differential Buy/ Sell Prices	Tariffs for which the value of electricity at a particular time depends on the direction of power flow at the meter.
Tiers	A "tier" is a set of thresholds of monthly consumption of energy, either for the entire month or select time periods by period of the day and/or day type. With a tiered tariff, the marginal cost of electricity is different in the different tiers.
Direct Load Control	Required installation of equipment that allows the utility to directly control operation of specific flexible loads (e.g., air conditioning equipment or water heaters).
Voltage/Phase	Tariffs that change costs based on the voltage of the power delivered, or the number of phases (one vs. three). This can affect fixed and/or variable costs.
Discounts	Some customers on a tariff are eligible for discounts from the base tariff depending on the type of customer, and sometimes also by location.
Demand Charges	A demand charge is calculated from the highest average power over a small period of time (e.g., 15 minutes) in a billing period. These are sometimes disaggregated by time of day.
Combined Tariffs	DR programs are described as tariffs. Some DR programs can be layered on top of other tariffs. How they combine can be complex, and some combinations are disallowed.
Sub-Tariffs	Some tariffs include a variety of options (e.g., TOU-D includes ten), each with its own prices and other provisions.
Bill Limiter	When a customer switches to some rates, there are provisions that the bill under the newer tariff cannot be more than a certain amount above what it would have been had the customer still been on the previous rate.
Eligibility	Tariffs that have requirements for enrolling in them beyond the general customer class (e.g., residential, commercial, agricultural, street lighting). Example criteria include income, medical condition, and facility type.
Rotating Outage Participation	Requirements to reduce demand to a low amount when a rotating outage is called, with penalties applied for customers who fail to meet this requirement.
Fixed Charges	Fixed monthly (or daily) charges for being a customer, having a meter, or some other factor. Some customers can choose to not have a smart meter installed, for an additional cost.
Reactive Power	Fees for measured reactive power, charged separately from real power, e.g., based on the 15-minute period with the worst reactive power in the billing period. For some large customers.

[7] Usually this refers to tariffs that are derived in part from wholesale market values. In the Southern California Edison (SCE) case, at least some "RTP" tariffs are based on tables of prices that are a combination of temperature bins, time of day, and day type.

Summary of Electrical Tariff Features and Relation to Price Communication

The intersection of time-varying rates with these tariff features are complex but can be put into the general groups (categories) listed in Table 2-2.

Table 2-2
Tariff features as they intersect price communication for automated DR

Easily Adapted	Simple Adaptation	Difficult to Address	Not relevant
TOU, CPP RTP Sub-Tariffs Eligibility	Differential Buy/Sell Prices Voltage/Phase Discounts	Tiers Demand Charges Combined Tariffs Bill Limiter	Direct Load Control Rotating Outage Participation Reactive Power Fixed Charges

Electric utility tariffs in California can be an overwhelming mixture of complex restrictions, details, and implications. Many factors have led to this, over many decades, but it seems plausible that many goals embodied in the details could be accomplished equally or better through other mechanisms than utility tariffs. In addition, some features that give a discount to certain types of customers could be converted from changes in the rates to changes in fixed fees. The latter would be much better for simpler price communication. Perhaps the evolution to more dynamic electricity prices will be taken as an opportunity to simplify utility tariffs.

These features also have other attributes of note as shown in Table 2-3.

Table 2-3
Additional tariff features as relevant to price communication for automated DR

Characteristic	Description	Examples
Core	Features that are directly time-varying prices.	TOU, CPP[8], RTP
Emerging	Features that exist today, that are not common, but have merit for future use.	Differential Buy/Sell Prices, Locational Prices
Legacy	Features that can be scaled back in use as dynamic pricing is phased in.	Event-based DR
Marginally relevant	Features that intersect dynamic pricing, but in a small enough way to make it likely not worth including them in price communication.	Discounts *(if modest),* Voltage/Phase
Irrelevant	Features that do not affect how price-responsive loads behave, so no data for them needs to be communicated.	Fixed Charges, Rotating Outage Part.
Problematic	Features that conflict with price-based grid coordination; serious consideration should be given to whether the benefit of retaining them for future rates is worth the complications that they create for customers — and ultimately for the grid in getting the full benefit of the flexible load contribution to grid operations.	Tiers, Demand Charges

[8] There are no current SCE tariffs that use variable peak pricing (VPP), but this would also qualify.

Problematic features can remain in tariffs offered that do not leverage dynamic prices, as those tariffs will not be encoded in the price distribution system.

In summary, the selection of which features to include in dynamic tariffs is critically important for how easy it is to communicate time-varying prices, and for flexible loads and DER to use them to best serve customer and utility needs.

Dynamic prices can replace tiers and demand charges to effectively implement the responsive price elasticity and subsequent demand reductions needed to support a resilient grid while at the same time deliver cost savings for customers. Simplification of electrical tariffs by dynamic pricing would be fair to all grid connected customers. However, response to dynamic prices will require devices to be smart, flexible, and respond to price signals either day-ahead or in real time, depending on the responsiveness and hysteresis of the end use. Note that early adoption of flexible load control with dynamic pricing will benefit these pioneers, plus all grid connected customers will also benefit by lowering aggregate load demand during grid congestion.

3
DATA MODELS AND COMMUNICATION ARCHITECTURES

This section describes the overall proposed and recommended structure of communicating time-varying price information from an electricity retailer to flexible loads and other customer devices. This includes details of its core operation:

- an introduction to three “automation pathways”,
- the key roles of customer central entity devices and local prices, and the concept of “streaming” prices.

This section further reviews a proposed standard data model for price communication, implications for tariff design and protocols, and the transition from today’s devices and capabilities to a future with much more demand flexibility.

The CEC (CEC, 2020) notes that “Flexible demand technologies provide the capability to shift timing of when appliances consume electricity to better match energy demand and supply, as well as enable excess renewable electricity production to be used rather than curtailed.” In this report, most references to “flexible loads” also implicitly include other devices at the customer site such as battery storage, vehicle discharging, and (rarely) dispatchable generation.

The CEC also indicates that TOU and CPP are inadequate for providing the flexibility the grid needs, and that flexibility needs will only grow over the coming years. The recommended approach is to support prices which change at least hourly and are set no longer than the day before, and so require ongoing communication.

Price-Based Grid Coordination

Lawrence Berkeley National Laboratory (Berkeley Lab) developed a communication architecture description for using time-varying prices as a control mechanism for informing the behavior of customer flexible loads; this is called Price-Based Grid Coordination (PBGC).[9]

PBGC is broadly compatible with proposals from the CEC (MIDAS) and the California Public Utilities Commission (CPUC). Further details are in Appendix D – Technology Standard Details and Appendix E – Communication Architecture Details.

PBGC is founded on digital communication. While digital communication of electricity prices is not itself new (EPRI, 2006), it is not widely used, as most customers have rates that vary not at all, only occasionally, and/or in a highly predictable manner (e.g., TOU rates). PBGC has several new features:

[9] Note that there is both the generic model of using prices as the primary mechanism for grid coordination and its particular rendition as described here. In this document, PBGC covers both.

- Articulation of the relevant devices, including where there can be a translation from a grid signal (price and greenhouse gas [GHG]) to device functional control.
- Identification of what occurs within a customer site, to understand the implications when grid power, internet communications, or both are temporarily lost.
- Addition of the concept of a "local price" of electricity, useful for a coordination of devices within a customer site and to provide other benefits.

Figure 3-1 illustrates the PBGC approach. Local area communication is that which takes place between two devices within a customer site; wide area communication is between a device in the customer site, and one elsewhere, e.g., elsewhere on the Internet. This model keeps the interface between the building and the grid quite simple, which is a sound system architecture principle (Nordman, 2019b).

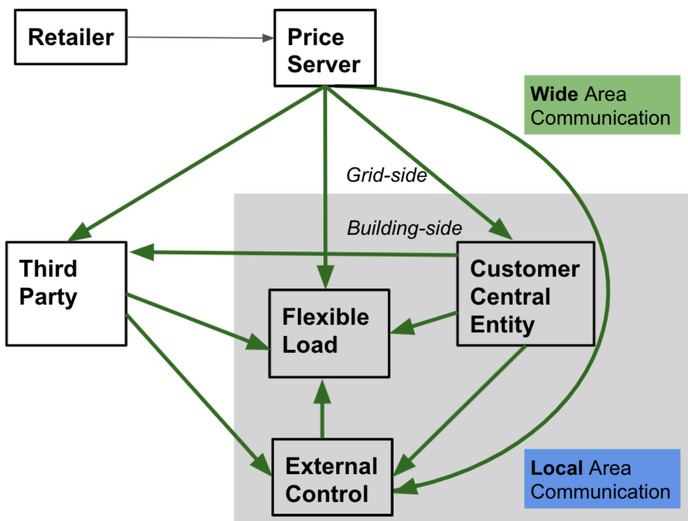

Figure 3-1
Price- based grid coordination communication architecture

The core of PBGC is that the basic control signal is one-way, sending prices from the grid to customers. There are return paths to the utility in the form of individual meter readings to compute financial impacts of customer actions and, for grid management purposes, metering of feeders and substations. By requiring only, the broadcasting of information, the overall system can be relatively simple — particularly when compared to what is required for systems with two-way communications and negotiations.

The model enables multiple locations to translate prices to provide functional control of devices.

Many mechanisms have been proposed for coordination between the grid and a much smaller number have been deployed at some scale. Among those not deployed at scale include those with complex bidding and auction schemes involving customers, and peer-to-peer energy exchanges through the grid; these require that customers add complex technology to their facilities, which is not generally available. Mechanisms that have been used at scale, and comments on their scalability and benefits, include:

- Direct Load Control. Has significant limitations on the types of devices that can be utilized, the amount of flexibility that can be obtained, and the nature of it (only delaying load, not advancing it in time). Also has problems in properly rewarding customers for their participation.
- Aggregator-based Flexibility. Practical limitations on the number and type of devices that can be engaged.
- Time of Use Pricing. Can engage all flexible loads at a customer site and can provide a significant, but static shift in loads.
- Critical Peak / Variable Peak Pricing and Event-based Demand Response. Can address all flexible loads and the most serious peak times, but customer costs need to be paid for participation on only a few days per year, and only indicates high-cost times, not low-cost times.
- Real-time Pricing. Has only been used by a small number of customers and infrastructure needed for automation (price communication availability, and most critically, customer devices) has been lacking.

Each of the above approaches other than real-time pricing has significant limits or disadvantages and so does not adequately meet customer and grid needs[10]. Thus, the PBGC model is recommended as one step for dynamic pricing communications for a variety of reasons:

- Founded on pricing, which is always present across the globe, and is increasingly being used by California utilities to encourage load shifting.
- Simple and requires only one-way communication to the customer and interval meters already widespread in California.
- Facilitates easy use by product manufacturers and others for optimizing device behavior.
- Could become a universal mechanism for grid coordination.
- Applicable to all flexible loads and DER at customer sites.
- Preserves customer privacy and autonomy.
- Provides for interoperability and innovation at the same time.
- Allows for diversity in how prices are determined and how flexible loads use them.
- Enables multiple locations to translate prices to functional controls.

In summary, PBGC is highly practical and has a clear deployment path.

Core Operation

PBGC is a simple system to address the needs of both the grid and customers for managing energy. Key PBGC concepts are presented in Table 3-1.

A critical difference between the alternative pathways is the location of the "intelligence" that translates the prices into functional control commands. These are summarized as three

[10] Other proposals in use today are Direct Load Control and Event-based Demand Response, Time of Use Prices, and Critical Peak / Variable Peak pricing. All of these have significant limitations on the devices they can cover, or the granularity of response that can be provided.

"automation pathways," as shown in Figure 3-2 as overlays to the basic diagram. The intelligence may be found[11] in the cloud, locally (in the load itself), or in the supervisory device (in the CCE).

Table 3-1
Key concepts and entities in Price-Based Grid Coordination

Entity / Concept	Description	Comment
Price	A current price and non-binding forecast of future prices.	This is the core data being communicated[12].
Retailer	The organization that sets the price that the customer pays[13]. The price broadcast is the marginal impact on the bill of the customer consuming more or fewer kilowatt-hours (kWh).	Factors that are not affected by load shifting, such as fixed costs, are not communicated. The purpose of the broadcast is coordination with flexible loads, not formal tariff publishing, bill calculation, or settlement.
Price Server	Computer that receives a price signal from the retailer and relays it via multiple communication protocols to customers and third-party organizations.	A retailer may operate its own price server. The price server makes no decisions.
Flexible Load	Loads that can directly use prices in making operational decisions.	As such products come onto the market, this is a simple path to utilize.
External Control	A hardware device that facilitates price-based control and serves a single flexible load.	External controls (e.g., a CTA-2045 module) may pass prices to a load, may make functional control decisions, or may pass control decisions made elsewhere.
Customer central entity (CCE)	A CCE can relay the price to individual loads or can make control decisions and forward them to the load.	In some cases, an external control device is needed between the CCE and the load.
Third Party	A cloud-based system[14] that passes functional controls (or prices) to a flexible load.	This is commonly a device manufacturer but does not have to be. Some use an external control device.

More information on automation pathways and how they map onto the potential for DR in the short- and long-term can be found in Appendix A – Automation Pathways and Flexibility.

[11] For the pathway purpose, an external control is not considered separately from the load itself.

[12] Additional data may also be transmitted, including greenhouse gas emission factors and grid event messages.

[13] How the retailer determines prices is outside the scope of PBGC. Retailers should set prices that best meet their needs.

[14] Note that these third parties are not necessarily traditional utility "aggregators." An aggregator has a financial or contractual relationship with the utility grid, which a third party may or may not have.

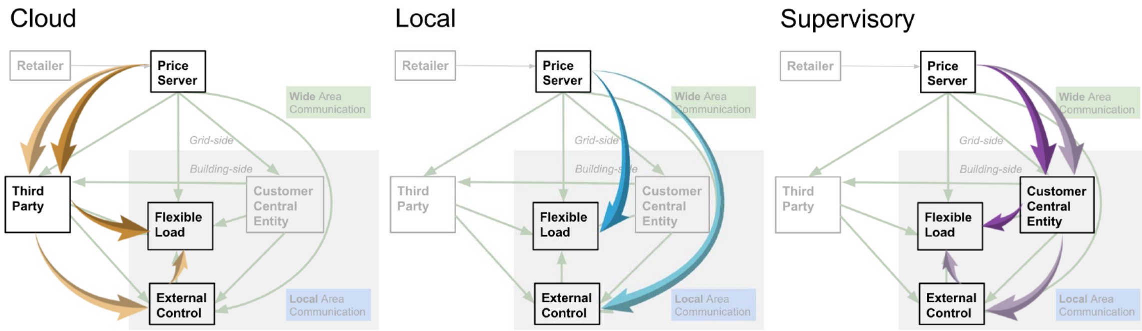

Figure 3-2
(a, b, and c) DR Automation Pathways

Customer Central Entity Devices

We use the anonymous-sounding term customer central entity, as this refers to functionality that can be hosted by a variety of different devices. This could be a building or energy management system for a large customer, or for a small one a network device like a Wi-Fi router. It should be a function of some existing device, and not a new device that serves only this function.

While such a customer "gateway" device is not required, there are many advantages to having one. These include the following:

- Receiving the grid price over multiple paths. A CCE could receive the price over broadband internet, FM radio, and cellular radio. This can provide redundancy when one fails, or detection of a compromised signal.
- Generating a local price, e.g., for microgrid operation.
- Centralizing the setting of the retailer and tariff name (including location) so these need to be updated in only one place.

Allowing individual loads to implement a communication technology for local communication is likely less energy intensive and less costly than a wide area communication technology.

Local Prices

One innovation of PBGC is the idea of a *local price.* This is a price communicated to a flexible load from another device in the facility that may diverge from the retail price of electricity at the meter. Any device in a customer site can create a local price, but the primary location is a CCE device. A local price has several important uses, including the following:

- **Differential buy/sell prices.** An electricity price that changes depending on the direction of power flow at the meter is rare in SCE territory, but common in other places, such as Hawaii. This may become a useful utility tool in future to encourage self-consumption of excess photovoltaic (PV) generation. The local price is selected from one of the two prices — or could be a price in between, which maintains the customer site at no power flow across the meter.
- **Microgrid operation.** When the utility grid is unavailable and the customer is operating as a microgrid, there is a more acute need to balance supply and demand. Pricing can be used to

inform the behavior of flexible loads as usual, but since there is no grid price, a customer central entity needs to create one.

- **Incorporating environmental factors.** Many customers may want to use a GHG signal as published by a price server (the CEC MIDAS system does this today). This can be readily accomplished by multiplying the marginal GHG value (in kilograms of carbon dioxide equivalent [kg CO_{2e}]/kWh) by a customer-selected burden (in \$/CO_{2e}) to get an adder (in \$/kWh) to the retail electricity price.

There are other applications of a local price, such as for direct current power domains, or to account for customer site-wide (or more local) power capacity constraints. Using a local price adds capability but does not add complexity; communication protocols that carry the prices do not have to know whether they are local, though the CTA-2045 standard includes a flag for this.

Price Streaming

Demand response to date has been predominantly accomplished either through event-based mechanisms (either through an aggregator or critical peak or variable peak [CPP/VPP] pricing) or as a load modifying resource through time-variant seasonal TOU rates. None of these strategies represent electricity prices that can respond to grid needs in a finely tuned manner such as varying daily based on the grid conditions for that day.

Prices that change as grid conditions do, and so are different every day, could respond to these grid needs. In this report, we use the term *highly dynamic prices* to refer to rates that are different every day and set no longer than a day in advance. Given how the grid operates, we can expect that such rates will be able to change at least hourly, and not more frequently than every five minutes. When locational concerns are considered, and locational rates offered, prices can be an even better tool for utilities. The locational aspect can be accomplished solely with more fine-grained tariff offerings[15], so it does not affect technologies within a customer site.

Such prices may be determined the day before or may be set in real time — that is, just a few minutes before each billing interval. The latter requires sending out prices on a continuous basis, analogous to how audio or video content is sent out on the internet, so we describe it as "streaming." While streaming prices is particularly important for highly dynamic prices, the prices for any type of tariff can be streamed.

Proposed Standard Data Model

To accomplish this communication, it would be helpful to have a standard way to describe such rates to knit together the domains of the electricity retailer, the communication protocols, and the loads and systems that use the prices. Ideally, such a data model for streaming prices would be defined independent of any mechanism for encoding or transmitting them, with separate descriptions created of how to map the generic model to specific mechanisms.

Some tariff information is static, or changes only infrequently, and therefore needs to be communicated only infrequently. The rest of the data are dynamic and may be communicated

[15] That is, if there are ten regions within a utility service area that have different distribution system contexts, then each could have a variation of the underlying tariff, identified by the region name.

once a day, every five minutes, or at some intermediate interval. Table 3-2 and Table 3-3 summarize the data model used for PBGC.

Table 3-2
PBGC Data Model – Static Elements

Data Element	Description
Static Data	
RetailerLong	Text string of retailer full name, e.g., "Pacific Gas and Electric."
RetailerShort	Text string of retailer's abbreviation, e.g., "PGE."
RateNameLong	Text string of tariff name, e.g., "Residential Time of Use-A." Unique to each retailer.
RateNameShort	Text string of tariff name, e.g., "TOUA." Unique to each retailer.
Country	Alpha-2 code per ISO 3166-1.
State	Coding per ISO 3166-2.
Currency	Per ISO 4217.[16]
DateAnnounced	ISO 8601 extended format,[17] "YYYY-MM-DD," e.g., "2020-05-26." The "publishing date" is particularly helpful if there is an update to the tariff after the initial announcement. Only a date is provided, no time.
DateEffective	ISO 8601 extended format, as date/time.[18] The first date that the tariff is planned to be available. No end date is specified.
URL	Web page with a description of the tariff in machine and human readable form. It should contain the current/correct tariff if there are multiple versions.
BindingPrices	True/false. True if prices are fixed once transmitted.
LocalPrice	True/false. True if the price has been adapted from a grid price by a customer entity or created entirely locally (within the customer site). If left out, the default is false.

Implications for Tariff Design and Protocols

Section 2 identified a variety of features of current SCE tariffs and discussed their compatibility with using price as a mechanism for engaging load flexibility. This comes into sharper focus when the question is whether the feature can be represented in this data model. Streaming prices can be used to communicate any price structure, from a completely flat tariff to one that changes

[16] SIX. Data Standards. https://www.currency-iso.org/en/home/tables/table-a1.html, accessed May 26, 2020.

[17] Wikipedia. ISO 8601. Calendar dates. https://en.wikipedia.org/wiki/ISO_8601#Calendar_dates.

[18] Wikipedia. ISO 8601. Calendar dates. https://en.wikipedia.org/wiki/ISO_8601#Calendar_dates.

with every interval. Other features, such as demand charges, or tiered rates, cannot be conveyed with this mechanism.[19]

Table 3-3
PBGC Data Model – Dynamic Elements

Data Element	Description
Dynamic Data	
CurrentTime	ISO 8601 extended format, “hh” or “hh:mm” or “hh:mm:ss.” Standard Time (not daylight-saving time), including the time zone of the area covered by the rate.
OffsetToFirstPrice	ISO 8601 extended format, “hh” or “hh:mm” or “hh:mm:ss.” Duration of time between CurrentTime and the FirstPrice.
IntervalCount	Number of intervals in the forecast, including the first price.
For Each Interval	
Timestamp	ISO 8601 extended format, “hh” or “hh:mm” or “hh:mm:ss,” not time of day, but relative time from the FirstPrice time. Allowed to go over 24 (but not over 99) to extend to more than 24 hours (note that this is likely not consistent with ISO 8601). Each timestamp must be greater than the preceding timestamp.
Price	The numeric value of currency in text with the appropriate number of digits. Price for purchasing electricity.
ExportPrice	The numeric value of currency in text with the appropriate number of digits. Price for customers exporting electricity back to the grid. May be the same as Price and assumed to be if “ExportPrice” is not present.

Appendix E – Communication Architecture Details provides additional information on data model elements and their usage. Appendix A – Automation Pathways and Flexibility presents the three major automation pathways and how they facilitate load flexibility.

The Transition and Legacy Devices

Today there are extremely few customer end-use loads available in the market that can respond effectively to a highly dynamic price. Hopefully, they will become available for sale soon (via the CEC load management rulemaking initiative), but there will be a long transition time in which legacy devices need either external hardware control or external software that interacts with legacy device control mechanisms to enable them to become flexible. There are a variety of types of devices, and a variety of solutions, as reviewed below; however, not all solutions apply to all types of devices.

[19] PG&E has a project to test sending individually-created prices to customers on tiered rates, which is informed by actual consumption during the month to date to estimate the tier that the customer will ultimately be on for that month, to send the correct marginal price.

Devices with No Communication

The most common electrical appliance today is one that has no native digital communication capabilities (e.g., most household appliances). In these cases, the only option is to add a mechanism to power/de-power the device to turn it on and off. This may be appropriate for devices such as pumps and resistance water heaters that generally have no ongoing need for power.

The actual switching can be done with a controlled outlet[20] or controlled circuit breaker;[21] outlets are available for less than $10. These will get control signals from a CCE or a third party. An alternative is a dedicated device that knows what type of device it is controlling. An example device[22] monitors the electricity draw of a water heater it controls so it can estimate heat added to the water tank, even as it does not monitor heat withdrawn through hot water.

Devices with Communication but No Price Response

These devices come in a variety of types, and some fall into more than one category. Some devices can receive a firmware update[23] from the manufacturer via Wi-Fi or other means, in which case the manufacturer could add capability for price response to devices currently in the field. Many devices may have limited memory capacity, so it is critical that the protocols for sending prices are simple to implement, as is leveraging existing protocols that the device already implements, to only add use of the price feature. This requires the cooperation of the device manufacturer and may require the device owner to initiate the update.

Other devices can take in functional control commands, such as to change a light level or a thermostat setpoint, or to turn on or off. An external entity can take on the control logic for the device, at least partly. For example, a cooling setpoint for space conditioning could be driven by the relative price, to be driven down at low price times to precool, be at a “normal” setpoint for “normal” prices, and then rise as the price rises. Many capabilities exist today that utilize the local Wi-Fi system for remote control, with the most common example for “smart” thermostats.

A few devices will have a CTA-2045 port but have either no module or a module that does not support price response. The existing module could obtain functional control commands from a CCE or a third party or could be replaced by a new module that directly supports price response.

Devices with Cloud Connectivity but No Price Response

These devices are controllable through a cloud service, so that upgrading that service to take in prices is all that is needed. Nothing in the customer site, including the device itself, needs to be changed. While the cloud service acts as a third party service provider, the communication path

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[20] An example of a controlled outlet (Wi-Fi) is: https://wyze.com/wyze-plug.html.

[21] An example controlled circuit breaker (Wi-Fi) is https://www.standardelectricsupply.com/Square-D-Schneider-Electric-M9F23206-Circuit-Breaker.

[22] An example dedicated water heater controller (Wi-Fi) with cloud-based computation is: https://www.shiftedenergy.com/technology/tempo-controller/.

[23] An example clothes washer currently for sale, the LG WM9000HVA, in its owner’s manual references a “Program Update” function to “Check to see if a newer version of the software is available.” https://www.lg.com/us/support/manuals-documents.

often runs through the consumer’s local area network over technologies such as via Wi-Fi and Ethernet (though some use cellular communication).

The transition will be long, but the sooner it begins, the sooner it will be substantially complete. It is also important to not let transition issues impair the long-term solution.

4
TECHNOLOGIES AND COMMUNICATION STANDARDS TO SUPPORT AUTOMATED DR

This section addresses technologies and communication standards to support automated demand response. This includes activities that occur before ongoing operation, gaps in the major relevant communication protocols, and how to fill those gaps.

The communication of prices is at the center of coordination of the utility grid with flexible loads. This section reviews overall capabilities of the core standards involved, as well as generic needs for their modification. The two core relevant protocols are OpenADR 2.0b and IEEE 2030.5, as these are used for wide area communication and can be used within a customer site. CTA-2045[24] (CTA, 2021) is a complementary technology for facilitating connectivity to individual loads.

The CEC has created the MIDAS system for disseminating prices. Details on the protocols and needed updates can be found in Appendix D – Technology Standard Details. This section reviews the high-level capabilities and needs — information that is relevant to a wide audience. There are many details that only are relevant for those modifying technology standards or directly involved in using them; these are in Appendix D – Technology Standard Details.

Notably, the CPUC's UNIDE proposal (see Section 1) can be carried by any of the technologies discussed in this section, though addressing gaps in them (see Appendix D – Technology Standard Details) will improve this.

Pre-operation Needs

Any device that takes in dynamic prices needs to know the identity of the server that is the source of the information. This applies to two distinct contexts: local and wide area. *Local* means within the customer site; that is, with the site's local area network (LAN) that provides internet connectivity. An increasing number of customers will have a local price server that relays the information from a wide area source to local devices (this would be a core function of a CCE). If such servers have a standard name in the LAN, and a standard way to be "discovered," then connecting the load to the server can be automatic. How this occurs will be specific to each protocol. An advantage of this approach is that the load does not need to know the identity of the electricity retailer or the specific tariff that the customer is on, which simplifies the process of configuring loads to use a dynamic rate.

Some loads will connect directly to an electricity retailer's price server. These need to know the identity of the retailer and the name of the tariff. They also need the location on the internet for their price server. Appendix D – Technology Standard Details includes a description of one way this could be done in a globally standard way. Alternatively, the identity of the server could be

[24] Recently the EcoPort brand name has been established as a more consumer-friendly name for the CTA-2045 standard.

entered, much like a URL in a web browser, and encode the name of the retailer and tariff. This mechanism could be common to all protocols that use internet communication.

Core elements of protocol functionality beyond initial configuration include:

- Tariff metadata. Communicating a set of basic information about a tariff.
- Dynamic prices. Communicating a series of up to dozens of time/price pairs for current and future prices.
- Cybersecurity and privacy. Implementing sufficient safeguards to prevent the data being changed while being communicated. This work does not increase any risks for cybersecurity or privacy. It does decrease them to some degree by not requiring the return of substantive data from the customer to the retailer.

Protocol Gaps and How To Fill Them

The three major protocols available today for utility communication signaling—OpenADR 2.0b, IEEE 2030.5, and CTA-2045—all can be used well today. That said, each of them has their own roles purposes and specific messaging protocols to achieve their functions. There are opportunities to enable them to fully support the PBGC model, as well as to streamline their use for manufacturers, customers, and others.

Appendix D – Technology Standard Details has full detail on the gaps, but both OpenADR and IEEE 2030.5 lack some of the static tariff metadata; adding these should be straightforward. Both standards could also use modernization, including to make them less verbose and data intensive.

CTA-2045 would be improved by identification of a standard (but optional) external interface; the standard today only defines the internal interface between the module and the flexible load. One option is for that to be a new, simplified version of OpenADR. All three standards have mechanisms for passing generic text messages for use by humans; these could add some standard messages with specific meaning for anomalous grid conditions (e.g., a grid emergency), and this way they could also be used automatically by flexible loads.

There is a need for continuing research on communication methods for ADR. Since the price data are only a broadcast (and for FM radio are literally a broadcast), there may be ways to simplify or optimize their distribution, particularly as the number of devices involved is scaled up, and the locationality of tariffs[25]. Related to this is whether data are ‘pushed’ from the price server, or ‘pulled’ by the receiving device.

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[25] With many devices in the same building and same locations receiving the same price, mechanisms could be developed to use local broadcast mechanisms within Local Area Networks and within the cellular radio system, to avoid many unicast messages from the price server. This could greatly reduce the amount of data sent across the Internet and cellular networks. The IGMP protocol was designed for this purpose, but is not likely suitable. New mechanisms would need to be designed, standardized, and accepted and deployed by network infrastructure providers.

Most work to date has been on technologies optimized for wide area networks, but we can expect to see dramatic growth in the proportion of price communication that is strictly local to a customer site; thus, more attention should be paid to that local communication to improve and optimize its functionality.

LBNL is actively engaged in the update process for all three standards.

The CEC has created the MIDAS system for distributing data about TOU prices and real-time prices. It serves an important interim role in near-term automation of TOU prices in California, and its example could inform modernization of OpenADR and IEEE 2030. Since MIDAS is not a standard, it is not suitable for widespread use unless it is converted into one.

Appendix D – Technology Standard Details covers details of how customers will use the technology and needed changes to existing technology standards.

5

TECHNOLOGY TRENDS AND EMERGING TECHNOLOGY: GAPS AND RESEARCH NEEDS

This section outlines research needs and technology gaps that need to be addressed to lead to the development of automated customer price-response systems. Major categories of needs include communications, flexible load control, new flexible end-use technology, incentives, and market engagement. This section describes how today's customer technologies can become price-responsive, and how Internet of Things (IoT) technology and interoperability issues intersect with price response.

Our collective path to a future with large amounts of load shifting occurring through dynamic pricing has a variety of barriers preventing market adoption. These include research gaps, covering technology, technology standards, policy, and products offered by manufacturers and other companies.

An important source of insight on the research and deployment needs for enabling more flexible loads is the U.S. Department of Energy's (DOE's) *A National Roadmap for Grid-Interactive Efficient Buildings* (DOE, 2021). The roadmap provides a comprehensive analysis of what is needed for flexible loads to deliver substantial benefits to the grid, to customers, and others. Two key parts of this Roadmap cover (1) the identification and prioritization of barriers to grid-interactive efficient building (GEB) deployment and (2) recommend options for overcoming barriers. The roadmap limits its focus to residential and commercial buildings, though its conceptual framing applies to other domains. It uses *demand flexibility* as the central metaphor, as an evolution of the prior DR terminology. It addresses flexibility attained through dynamic prices and direct signals. GEBs incorporate both efficiency and flexibility in their scope. In many cases, the same control systems will be addressing both, so the broader view is merited.

Figure 5-1 shows the roadmap's depiction of technology needs. All the technologies in Figure 5-1 will enable more demand-flexible buildings, thus the term *DF Enabled Technologies.* Demand flexibility will be improved with both new physical end-use systems, plus DF-enabled local and supervisory controls.

There are gaps in current technologies at the local control level for all major end uses: miscellaneous equipment loads (MELs), lighting, HVAC, and water heating. With the introduction of supervisory control Smart Home Energy Management Systems (SHEMS) and Building Automation Systems (BAS), loads can be optimized across multiple buildings (e.g., multi-building control) or improve the control capabilities of existing supervisory control systems (e.g., predictive control). Details of these gaps are described below.

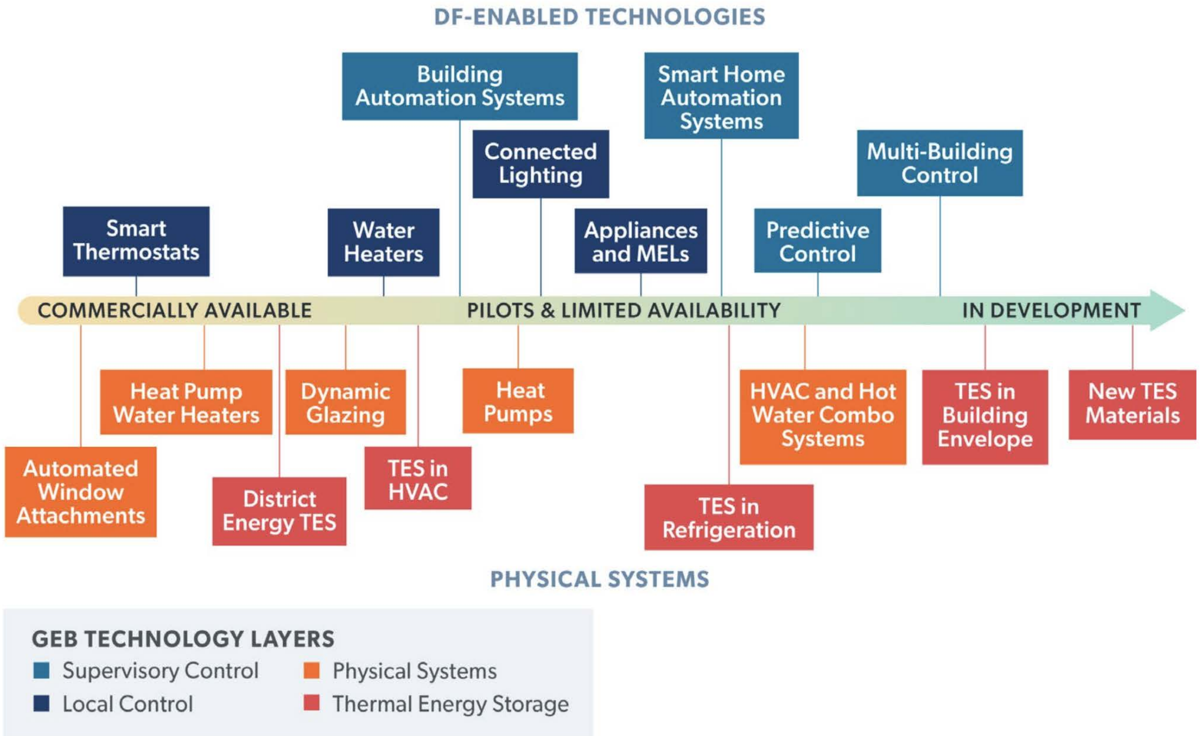

Figure 5-1
Key technologies and needs to deploy GEBs (Source: DOE, 2021)

Figure 5-1 distinguishes on the vertical axis between physical capabilities needed for new (or expanded) load shifting (below the line) and products and control systems that coordinate device operation. On the horizontal axis, technologies are arranged by their market availability. As can be seen, a core technology that merits further research in development is thermal energy storage (TES) for a wide variety of applications. TES systems hold the potential to be less costly to manufacture and integrate than battery storage and are highly efficient (battery charge/discharge cycles have inherent losses). The figure shows that TES can be developed and implemented for district or campus systems and integrated with HVAC at the building level. TES is also being developed to integrate with refrigerated and frozen food for grocery stores and cold storage warehouses. Several R&D efforts are exploring how to integrate energy storage in building walls and ceilings. Finally, there is extensive work around new materials for TES to improve the ability to store and release both hot and cold storage.

Heat pumps have been identified as a central technology to facilitate new efficiency and to meet environmental goals, and so long as new technology is being deployed into facilities, it makes sense to ensure they are flexible as well. It is no accident that nearly all the items in Figure 5-1 relate to thermal systems in buildings.

The GEB roadmap also notes that "Interoperability between DER [distributed energy resources] communications, control protocols, and building systems is lacking."

Another assessment of research needs reports on a workshop on Fundamental Needs for Dynamic and Interactive Thermal Storage Solutions for Building (Kaur et al., 2019). This addressed issues with thermal, building, and materials sciences, to understand how thermal energy storage (TES) can be better deployed and utilized. Core areas of focus were new materials for storing thermal energy, materials for controlling thermal energy flows, tools for understanding and modeling the materials and systems, and ways to use computational models to accelerate progress in this area.

The recommended future research initiatives can be summarized as:

- Identifying TES in buildings as a discrete area of study, with common definitions, methods, and pathways for increasing efficiency and utilization.
- Developing new phase change materials (PCMs) and insulation materials to increase their efficiency, cost-effectiveness, and controllability.
- "Develop[ing] algorithms (e.g., machine learning) to better manage thermal storage assets and understand economic impacts of new storage technologies"
- Validating simulation models and machine learning with physical systems.

The GEB roadmap and the TES workshop report provide a solid foundation for research needs. The rest of this section builds and expands on the content in the roadmap.

Load Flexibility Gap Analysis and Research Needs

The following discussion outlines key gaps, as well as research needs to improve the ability to provide load flexibility based on the ability to receive and respond to dynamic prices. They are grouped into three major categories: Communications, Flexible Load Control, technologies Beyond Today's Flexible Loads, and Incentives and Market Engagement. They are introduced by the context that helps frame each topic, followed by a listing of gaps, and conclude with a series of research areas that could fill those gaps.

Some key questions to answer include:

Quantification of load flexibility

- How much electric load change can be delivered by devices and systems controlled by smart algorithms automatically responding to time-varying, electricity prices under different weather and load conditions?
- How does the load response vary over time, and is it predictable and persistent?
- How does the type of digital signal such as a price or GHG signal impact load reduction by various customer segments or devices?

Load-specific research

- What end-use technologies and integrated systems advance the capability of facilities to provide flexible loads?
- How can price-responsive devices and systems minimize key impacts to end-use service delivery such as comfort and productivity?

Comprehensive price response

- How can automated price responsive facility loads be best integrated with other distributed energy resources (DERs) such as photovoltaic cells (PVs) and storage?

- How can we make energy justice a priority, and ensure that price responsive and load-flexible in-building technologies are available to low- and moderate-income households, and that they are cost effective and beneficial?

In interviews with leading industry professionals[26], we found wide support for key principles underlying PBGC, and the proposal itself. Key principles are:

- The mechanism for grid coordination should be “consistent” across utilities and across time.
- The mechanism should be simple.
- Flexible loads should not require external information to optimize its operation[27].

Further, these professionals identified additional details needed for successful device integration.

- A sufficient forecast of future prices, at least 24 hours, possibly 30 or 72 for some loads.
- A large enough difference between high and low prices during each day to lead to sufficient savings to justify the effort to introduce load flexibility.

Communications

For loads to behave flexibly in coordination with the various signals from the utility grid, a variety of data need to be exchanged among utilities, customers, flexible loads, and third-party cloud services. These data include tariffs, prices, other grid signals, and functional control signals. Several communication standards in use today are the major carriers of these data, and for grid signals, particularly OpenADR, IEEE 2030.5, and CTA-2045.[28] Widespread interoperability requires a consistent overall communication architecture recognized by manufacturers and policymakers.[29] As price-responsive devices become available, users will need to connect these to a source of price data, which requires knowledge of the appropriate electricity retailer name and tariff name. Devices may acquire the price data from an external source (e.g., the internet or FM radio) or from another device in the same customer site.

While today’s price communication protocols can carry dynamic prices, a variety of improvements and innovations could reduce costs, increase interoperability, and streamline system operation. In addition, configuring devices and systems to receive this information is not standardized and requires manual interactions to determine the source of the price data. These may be error prone and dissuade people from using the features. Automation of these processes is not available. In addition, user interfaces are often confusing and inconsistent.

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[26] Among interviews that we conducted were with David Meyers (Polaris Energy Services), Brian Branecky (A.O. Smith), Clay Nesler (Nesler Group), Frank Loge (UC Davis), Becky Bryant, Kaustabh Phalak, Matt Bye, and Scott Munns (Trane), Kay Aikin (Dynamic Grid), and Tanya Barham and Jennifer Worrall (Community Energy Labs, CEL). The CEL interview was in November 2021; all others were in October 2021.

[27] An example of such information is past and future whole-building electricity use and the load of all other devices, as is needed to optimize when demand charges are part of the tariff.

[28] We also have seen the recent introduction of the CEC MIDAS system for distributing prices and related data.

[29] Markets for appliances and other devices in buildings are national and increasingly international, so this common system architecture also needs to span these geographies, as other communication technologies (e.g., internet technology) already do.

Finally, we lack standard, widely available mechanisms for tracking the energy consumption of loads to inform analysis that they are shifting correctly. Key topics where there are gaps in current technology and a need for further research include the following:

- **Communication Protocols.** Research is needed to update existing standards to fill the gaps in the data communicated, and to harmonize as feasible across the important protocols. It also is important to add several new capabilities to the protocols. This work will require collaboration with the relevant standards committees to update the documents accordingly, as feasible. In some cases, this presents new directions, such as broadcast versus two-way communication, which the current standards do not anticipate. Evaluation of alternatives brings in issues such as backward compatibility, cybersecurity, and privacy, and impacts on company business prospects.
- **User Experience/Support**. Studying likely and actual user pain points and automation opportunities could lead to developing standards and guidelines for user interface construction for a simpler and more consistent experience across products. Systems could be developed to automatically detect potential problems or opportunities and alert the user with actionable information. This should be paired with the activity below on scaled deployment of flexible loads to glean user experience insight from those tests.
- **Technology Infrastructure**. Technology standards development could automate installing flexible loads, configuring their operation to match user goals, and monitoring their performance. Research is needed to determine how best to do this, then work with standards organizations to embody the resulting methods. Priority areas are automating price server discovery in LANs and wide area networks (WANs) and detecting and fixing anomalous conditions (see Appendix D – Technology Standard Details). For enhanced reliability, an additional feature could be automatic failover when a device ceases to communicate. The solutions will be a mixture of leveraging existing technologies and standards and developing new ones. Technologies that automatically report on device energy use (Nordman et al., 2019a) can be useful for customers and others to track flexibility performance and make visible load shift savings.

Through all these efforts, any needs of underserved communities (e.g., those without internet access, non-English speakers, the elderly, and the disabled) should be considered.

Flexible Load Control

Flexible loads have the following capabilities:

- communications ability to receive prices directly and utilize them,
- communications ability to receive functional control commands,
- controls to actuate a device or systems, shifting, scheduling, or reducing electric loads.

For the last category, many networked devices are available that switch power to an attached load using either ordinary plugs or hardwired connections. These can be controlled from another device in the customer site or in the cloud.

For the middle category, there are dedicated external controls and building automation systems that control multiple loads. There are device-specific controllers available today, such as those for water heaters,[30] air conditioners,[31] and pool pumps.[32] An ordinary thermostat is of course a device-specific controller for a furnace or air conditioner.

An important tool for adding price responsiveness to devices is a CTA-2045 port. By implementing the CTA-2045 module with the capabilities to respond to dynamic pricing effectively, price-responsiveness can be added with the intelligence located in the module, or in a cloud system tied to the module. Adding or changing a module is quick and easy.

An increasing number of devices include adding network connections for reasons other than energy. While networked controls (switching power to a load or sending functional control commands) are available, these lack the ability (with a single known exception) to take in highly dynamic prices to their optimization algorithms. Thus, almost no devices today can be controlled by such prices without the load being replaced, a newly developed control added, or software in some device being upgraded.

Almost no consumer products are available today that can respond effectively to highly dynamic prices, and most lack the ability to respond to TOU or CPP rates. Standard and open algorithms for controlling flexible loads are not commonly available. However, this scenario is changing with some manufacturers (heat pump water heaters) as new appliance standards are developed in various jurisdictions.

Consumers, manufacturers, and policymakers lack information about how much energy example devices might be able to shift, and sophisticated controls that take in highly dynamic prices are not available. EV charging control methods for individual customers are only modestly grid responsive. There is a need to develop control algorithms that can respond to dynamic prices. Examples of promising technologies include the following:

- **Integrated Low-Cost Cooling.** Smart ceiling fans integrated with thermostat platforms, networked house exhaust fans, and sensors, to create open-source algorithms to optimize fan cooling with ventilation and energy savings with reduced and shiftable HVAC to consider precooling. This technology is most relevant to residential and small commercial buildings.
- **Heat Pump Controls.** Coordinated control of both space and water heaters to allow appliances to respond to price signals. This control might consider the mass of the facility, the storage inherent in a water heater, and other important innovations. This technology is most relevant to residential and commercial buildings.
- **Integrated Thermal Energy Storage with HVAC and HPWH.** Methods to control thermal energy storage with heat pumps (HPs). There are numerous types of TES that should be considered, such as ice, chilled water, and various other PCMS. This should include both large and small HPs, such as wall-mount HP equipment. This technology is relevant to all facilities.

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[30] Aquanta, https://aquanta.io/, which uses a Wi-Fi connection and cloud-based optimization, executed locally (so that control can continue locally based on the last operating regime sent before internet connectivity was lost).

[31] AirPatrol products can control air conditioners through the Infrared port originally intended for remote control signals. https://airpatrol.com/products/airpatrol-wifi-smart-and-universal-air-conditioner-controller

[32] Pentair is a major manufacturer of pool control devices, e.g., https://www.pentair.com/en-us/products/residential/pool-spa-equipment/pool-automation/intelliconnect.html

- **Food Store (and Cold Chain) Refrigeration Systems.** Create and test prototype controls for supermarket and grocery store systems, to incorporate price response and potentially multiple types of TES. This to take advantage of the upcoming mass replacement of these to move to less hazardous refrigerants[33]. This technology is relevant to convenience stores, grocery stores, refrigerated warehouses, and the entire cold chain.
- **Price-aware Industrial Control Systems**. Industrial process control systems have become increasingly sophisticated in recent decades, often employing a layered model spanning from individual process control technology to business planning (Körner et al., 2019). These systems could be adapted to add electricity price as an additional variable to optimize over. Flexibility can be obtained in modulating process output, or in buffering inputs as with thermal or other storage.
- **Model Predictive Control and Machine Learning.** MPC is an emerging field of control that uses a real-time model for setpoint optimization (Prakash et al., 2020). White box models use first principle physical models to control systems, Black box models are data driven. New techniques that combine the two known as gray box models show great promise in providing novel control strategies to increase load flexibility in large facilities and campuses. Research is needed to lower the cost to develop and implement these systems to save utility costs, improve load flexibility, and reduce GHG emissions. These techniques can incorporate numerous flexible loads and DERs: electric batteries, thermal storage, loads, and other systems. Research is also needed to allow these technologies to be cost effectively used in small, medium, and large commercial buildings. This technology is also relevant to multi-building campus heating and cooling systems.
- **Electric Vehicle Charging.** Assess how existing EV/grid coordination methods perform and integrate with price-responsive facilities and test a variety of price-responsive charging algorithms for how they benefit consumers and the grid. Most EV charging stations are located with buildings, but this is a growing electric end-use load.
- **Scaled deployment of flexible loads.** Numerous distributed energy resource management system (DERMS) providers and smart device vendors have technology with the potential capability to receive and respond to dynamic prices and GHG signals. However, there is a need to demonstrate commercially available equipment receiving and responding to price signals through a variety of control architectures, including cloud-based aggregation, on-site energy management gateways, and native device-integrated controls. The control systems need to have the capability to optimize equipment operation to minimize bills with time-varying prices that change daily. The demonstration should consider large numbers of devices — ranging from the tens to thousands of units — to verify load flexibility performance across climates, facility types, and occupant behavior. Examples of equipment that may be ready for large scale tests include pool pumps, EVs, air conditioning, electric batteries, and heat pump water heaters. This technology is relevant to all facility types.
- **Reference load algorithms.** Create open-source algorithms for converting price streams to device functional control for a variety of devices. These would serve as a floor of functionality that manufacturers could innovate on but ensure that such algorithms could be

[33] The California Air Resources Board is requiring switching to low global warming potential (GWP) refrigerants over the next 10 years. This will lead to the replacement of several thousand supermarket systems. https://ww2.arb.ca.gov/our-work/programs/hfc-reduction-measures/rulemaking

easily available for anyone. These algorithms could be for any flexible load or DER, but HVAC is naturally a priority. The algorithms that would take in prices and other data (sensors, internal status) and determine device operation[34].

Technology Gaps; Industry Response

When asked about what the gaps in technology are to enable dynamic price response in large commercial buildings one expert (Clay Nesler, Nesler Group, formerly at JCI) in large facility controls shared the following insights:

> "The hardware side is pretty straightforward for commercial and institutional buildings - it's basically a server that communicates with the utility or CSP (curtailment service provider) and the building automation system. In some cases, an existing server can be used or an edge device, but this is not a significant cost in the overall scheme of things.
>
> The software is generally sold as a service. For a large campus application, the optimization software either runs in a local server or is hosted in the cloud. The service fee is priced based on the expected cost savings, not the cost of development or deployment. By far the greatest cost of implementation is engineering the solution, especially for MPC and similar approaches. Even relatively simple strategies - like adjusting space temperature set points based on real-time prices - require specialized engineering analysis and the incorporation of modified control sequences and "jacketing" software for safe operation. This is the most critical "cost" that needs to be addressed.
>
> Thus, efforts to standard[ize] control sequences and tools to simplify retrofitting control software will improve the cost effectiveness of enabling automated price response."
>
> The vast majority of buildings - even complex, institutional buildings - don't have any optimization software. They just have basic BAS functionality such as time scheduling and maybe simple reset schedules. They generally don't implement optimal start/stop, demand limiting, load rolling, demand-controlled ventilation, static pressure resets or other advanced strategies. They also don't use weather forecasts or future pricing information unless they are implementing demand response. The most popular energy tools are Energy information Systems with FDD and products like SkySpark use the Haystack tagging standard (when possible) to simplify integration with the BAS.
>
> The engineering effort isn't just doing the data integration, it is also knowing what actions to take from a systems perspective which is non-trivial.

The basic concepts described by Clay Nesler are relevant to controlling other electric loads such as building loads such as space cooling or water heating. That is, a stream of prices is used to try to control electric use to optimize the system for greater use during low price times and minimize or curtail during high price times. This concept is true for industrial, agriculture, and water pumping. For industrial loads, the concept is to manage processes to accelerate production during low price times and minimize production during high price times. This might mean

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[34] An example algorithm (Nordman et al., 2014) for a refrigerator or freezer takes in prices driven by PV where they curve down during the day and are consistently high at night. The algorithm changes the setpoint based on the prices, and the normal compressor behavior based on setpoint and internal temperature takes over from there.

deferring a process such as canning, bottling, production of industrial gasses, or other types of production.

Similarly with agriculture pumping, price responsive systems will maximize pumping and watering of crops during low price times and minimize pumping during high price times. These systems often measure the soil moisture to determine how much water is needed for irrigation.

Finally municipal pumping, wastewater processing, and water conveyance are large loads in California that have been shown to be flexible (Aghajanzadeh, 2015). The requirements of these water systems can be optimized for control that again maximizes the use of low-price electricity, while minimizing the use of high-price electricity. Promising methods include shifting pumping away from the hottest months, shifting pumping to earlier in the day (particularly on days with demand response events), and even using excess PV generation to recharge groundwater in wet years (Aghajanzadeh, 2020). A previous study by LBNL showed that wastewater facilities that have implemented energy efficiency measures and that have centralized control systems are well suited to shed or shift electrical loads in response to financial incentives, utility bill savings, and/or opportunities to enhance reliability of service. Municipal wastewater treatment energy demand in California is large, and energy-intensive equipment offers significant potential for automated demand response. Large load reductions were achieved by targeting effluent pumps and centrifuges. One of the limiting factors to implementing flexible load and demand response is the reaction of effluent turbidity to reduced aeration at an earlier stage of the process. Another limiting factor is the cogeneration capabilities of municipal facilities, including existing power purchase agreements and utility receptiveness to purchasing electricity from cogeneration facilities.

Beyond Today's Flexible Loads

Another challenging gap emerging is the changes to the utility grid infrastructure and the local electrical systems in customer sites needed with the design for electrification and space and water heating. Electrification of loads today often requires expensive upgrades to power infrastructure in customer sites. Research is needed on inexpensive methods to manage power distribution for increased use of electrical heating systems. Special needs of underserved populations, and of non-buildings customers (principally industry and agriculture), have not been addressed, nor have mechanisms been created to integrate multi-day storage into customer sites or with district heating and cooling systems. Below is a summary of innovative technologies that will facilitate greater capability for load flexibility.

- **New load shift capabilities.** Assess how new hardware could increase the quantity of shift from flexible loads and reduce its cost. Examples that research should explore include:
  - **Phase change materials.** Conduct research on new PCM materials, including the physics of the materials themselves, how to integrate them into products, and control systems to take best advantage of the new storage. Consider the many applications including refrigeration, freezing, water heating, space heating and cooling, and building envelopes.
  - **Integrating battery storage with loads.**[35] Explore which end uses are most suitable to this approach, the storage capacity to include, and efficiency and flexibility performance.

[35] Loads do not export power, so this is not a complete substitute for central storage systems.

- **Power distribution infrastructure.** Assess opportunities for new approaches to power distribution, such as:
    - **New electrical solutions.** Evaluate how integrating circuit breakers, the utility meter, and digital communication can manage loads and capacity constraints.
    - **Microgrids.** Consider how microgrids can also lead to new system architectures enabled by communications, capacity management, extensive use of storage, and differential buy/sell pricing at the meter. Also explore how the same technology can serve both flexibility and reliability, and so can be co-funded to reduce the net cost for each goal.
    - **DC distribution.** Assess targeted integration of direct current (DC) power, particularly integrating local generation, local storage, and loads. Consider how this can increase efficiency, support resiliency, reduce costs, and contribute to load flexibility.
- **Needs of underserved communities.** Develop low-cost flexible devices, retrofit solutions, and other technologies that better extend the benefits of flexible loads to all.
- **Industry and agriculture.** Develop and demonstrate solutions for common industrial and agricultural loads.
- **Extensions in space and time.** Assess how multi-day storage and seasonal energy storage could be integrated into existing control and physical systems, for flexibility at longer time scales. Develop integration with district heating and cooling (non-electric energy distribution) to broaden the scope of flexibility.

Incentives and Market Engagement

Demand response today from the IOUs is primarily event-based and coordinated through aggregators rather than individual customers, as it is integrated into the CAISO market. These entities provide communication and optimization services and in turn receive compensation above what is passed onto customers that they enroll in their programs. Many aggregators do not see a clear path to monetizing the service they perform when the customer is rewarded directly by the utility for shifting load, as with time-varying pricing. Research is needed on how energy codes and standards could best advance load flexibility through voluntary and/or mandatory mechanisms, including guiding manufacturers to specific technology standards and ways to use them. ENERGY STAR should be a key partner.

Another challenging area is related to how to incentivize technology providers with new business models. There is a need to consider how DR aggregators, smart thermostat companies, and similar technology developers could be incentivized to provide price optimization services for utility customers. Current aggregators project from capacity payments and wholesale market engagement. Providing this technology for retail price response will require new methods to incentivize technology developers for this form of market engagement. Research can consider and evaluate these new mechanisms.

A final issue for incentives is the size of the price difference between the high-price and low-price times for shifted energy. The greater the difference, the more interest it will spur in both vendors and customers. For example, the current difference between the on-peak and off-peak prices for the Winter season for the PG&E E-TOU-D rates is just $0.01/kWh (the summer difference is a more compelling $0.10/kWh)[36]. Research should interview device manufacturers to ask about daily price differences they find compelling, and assess the price differences implicit in today's event-based demand response.

Which Comes First? Prices or Devices?

Today we have a small but growing use of highly dynamic prices available in small pilots for research across the country, with an even smaller number of products or services that support control using those prices. A critical question is what the trajectory of each will be between now and then. One domain or the other could greatly lead, or they could expand in tandem.

For **customers**, there may be a few people who will be interested in frequently following highly dynamic prices and manually adjusting the behavior of their flexible loads. Customers that operate energy intensive facilities and industrial processes have automation and have expressed interest in taking advantage of dynamic price swings to reduce their costs. However, it seems likely that the vast majority will not have such interest, as they will need automation to minimize those interactions. Flexible loads need to be optimizing their behavior continuously, even when no one is present or is asleep. Even for those who are enthusiastic, automation will respond better and more reliably than they ever could. Customers will want assurance they are saving money with the dynamic rate, and so will want easy access to a comparison, to see what they would pay with a fixed rate. The most plausible loads to manually control are EV charging and space conditioning thermostat settings.

Aggregators shift load for utilities in cases where the underlying rates don't adequately reflect the needs of the grid, and payments for the shift are shared between the aggregator and the customer. The most common aggregator loads today are space conditioning thermostats, water heaters, and batteries. A **Third Party** in this analysis does not necessarily have a financial (or any) relationship with the grid; a third party could be paid by the customer for the service they provide to the customer, or the ongoing optimization might be part of the overall product purchase[37]. Some emerging third parties are based around hardware such as a smart circuit breaker panel or batteries but have capabilities to control loads.

With highly dynamic tariffs, there will need to be serious exploration for how aggregators can be appropriately compensated for their role in optimizing the behavior of flexible loads and DER.

Navigating the interests of all these stakeholders will be challenging, but we should make sure to not lose attention to paramount goals, including reducing overall utility grid costs (capital and operational), reducing costs to customers, increasing system reliability, maintaining building services, increasing the capacity of the grid to add more renewables, and addressing environmental goals.

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[36] PG&E, Residential Rate Plan Pricing, https://www.pge.com/pge_global/common/pdfs/rate-plans/how-rates-work/Residential-Rates-Plan-Pricing.pdf

[37] Vendors of computers and phones often provide software update services through the life of the product as part of the initial product purchase. Price optimization could similarly be a basic product function whether the computation is internal to the device and/or cloud based.

How Will Today's Devices Become Price-responsive?

The simplest flexibility occurs when the load itself takes in the price and alters its operational patterns itself. Many devices have internal control algorithms already: water heaters, dishwashers, clothes washers/dryers, refrigerators. They can delay operation, advance operation (in the case of refrigerators and water heaters), and schedule actions (such as a defrost cycle). Such devices already have control intelligence – it only needs to be enhanced by adding consideration of time-varying prices. Modifying such algorithms is not trivial, but what the manufacturers need to do is clear. With advances in electronics and algorithms, we will see increasing sophistication, such as a water heater remembering past patterns of water draw to maximize flexibility while minimizing the chance of a run-out.

The sophistication of device algorithms will vary considerably. For example, some lighting systems might begin to dim at a high price and dim proportionally more as the price rises; this requires no consideration of future prices. At the other end, complex HVAC systems might employ sophisticated machine learning and model-predictive control to minimize energy costs while considering comfort, environmental conditions and occupancy, weather, device efficiency and system performance, and current and future electricity prices. Similarly, industrial process control needs to consider the value of the manufactured goods and any change to production that might occur to be price responsive. Often industrial controls are not centralized and many manufacturing plants have multiple types of energy using systems that can be difficult to integrate. But, if these systems can be integrated, electric loads may be coordinated to minimize coincident peak demands and shift load away from high price times.

Other loads have cloud connectivity but not price response. In this case, the control algorithms in the cloud can be updated to add price response. An example of this is Ecobee, which has had cloud-based thermostat operation for many years. In 2019 and 2020, they conducted experiments to operate the controls optimized to TOU rates, and demonstrated beneficial shift capabilities (Demand Side Analytics, 2020).

Supervisory control can also add price response. This is similar to the cloud case in that software is readily updated by the vendor and downloaded to the local control system. A major HVAC vendor confirmed that price response could be readily added to their products. The biggest barrier they have found for demand response in general is a lack of consistency, with the coordination mechanism changing from utility to utility, and sometimes changing over time for the same utility. The inconsistency and complexity make it difficult to optimize for their customers properly and most effectively.

Internet of Things (IoT) and interoperability

In information technology, and internet technology in particular, we have high degrees of interoperability, driven by the existence of single or few standards for basic purposes. For basic characters we use ASCII, for complex ones, Unicode. We use one mechanism for addressing email, one for web pages. The list goes on. Even when there are multiple solutions (e.g., formats for images on computers) there should be simple and widely available mechanisms to translate between them.

For non-IT devices in buildings, the lack of interoperability has been a persistent problem since they began to communicate at all. We have had silos of interoperability determined by manufacturer proprietary technology, facility type, country, and more. Many attempts have been made to address this problem over the decades, but two recent ones appear to have more possibility of success.

One, organized by ASHRAE 223P, is centered on large commercial HVAC systems, and it brings in content from the Haystack and Brick projects[38]. It is centrally focused on data interoperability — making information from devices available to external ones for analysis. This is distinct from ongoing operational interoperability, though ASHRAE 223P could be extended to this as well.

A second effort is the Matter project of the Connectivity Standards Alliance. This is most notable for being centrally organized by Amazon, Apple, and Google, though many other companies are also involved. The big three each have their own proprietary mechanisms they have been working to leverage for market share and profit, but they may have seen that having a core of interoperability will be essential for dramatically growing the market as a whole. Matter has started with residential use cases but has a larger vision. In the industrial context, the Open Management Alliance defines standards for interoperability. Research can support all these efforts to increase the chances of their success and influence their content to be more favorable to energy efficiency and flexibility.

None of these have electricity prices in their constructs.[39] This could be seen as a gap and problem, and it is, but in the long run it may be good in that it helps keep the technology space of power distribution distinct from that of functional control. That said, even if distributing prices for control purposes is done with separate mechanisms, prices should be recorded and reported to support analyses of why devices behave as they do.

[38] These projects are creating standards for structuring and describing device metadata and operational status, so that data from diverse devices and manufacturers can be brought into a consistent form.

[39] Matter references the Zigbee Cluster Libraries, which do include communicating prices, but electricity price has not been brought into Matter's current set of activities.

6

SUMMARY OF RESULTS AND RECOMMENDATIONS

This report outlines a comprehensive vision for how to achieve dramatically increased electric load flexibility from customer loads. It addresses how to enable customers' equipment and systems to be able to receive and respond to dynamic price signals. There are three core elements to success:

- The energy retailer **sets** the price.
- The price **is transmitted** from the retailer to each flexible load or DER.
- The load **uses** the price with other information to decide how to respond and operate.

This report emphasizes the second and third topics in this list.

Key findings are as follows:

- An overall communication architecture, Price-Based Grid Coordination (Section 3), enables diverse communication paths, and multiple locations of translating prices to functional control, and offers significant opportunities for flexibility while maximizing interoperability.
- There are numerous ways for devices to receive price signals and respond. These include intelligence and control algorithms in the cloud, in flexible loads themselves, and in central customer site control devices. All of these are now emerging.
- The new concept of a 'local price' of electricity facilitates maximum use of prices as the central mechanism for managing power distribution.
- Streaming prices to loads on a continuous basis to facilitate nimble use by sophisticated devices to benefit grid operators is highly practical.
- A standard way to represent price information (a data model) underpins the communication.
- There are several open and secure technology standards available today well-suited for price communication, but they can be improved and supplemented to make using them simpler and easier.

Research and action by utilities can support implementation of each of these findings.

Recommendations

The path forward on developing load flexibility with dynamic pricing can be significantly enhanced through targeted research as summarized in the recommendations below.

Short-term

Items that need attention in the next year or two include:

- Updating and harmonizing the key communication protocols (see Appendix D).
- Creating universal price server discovery mechanisms for local and wide area networks.
- Identifying paths to make load flexibility available to all customers, including affordable methods for moderate-income households.

- Crafting comprehensive strategies for space conditioning and water heating to enable a rapid increase in the fraction of customers having at least one substantial device that is price responsive.
- Prioritizing research on pumping and other process loads in industry, agriculture, and municipal services that are easily shiftable as with water storage.

Mid-term

Research goals for the two-to-five-year range include:

- *Developing mechanisms to broadcast prices over the Internet generally, and as adapted to specific physical layer technologies (e.g., broadband access, 5G radio, satellite, etc.).*
- Exploring ways to standardize and deploy device energy reporting to facilitate easy access to data on device energy use in response to price for utility customer and public policy needs.
- Developing solutions for managing power capacity within customer sites and at the meter to reduce the costs for electrification of previously non-electric loads, including EV charging.
- Using recent experience with the actual performance of price-responsive devices to inform updating quantification of load flexibility potentials.

Long-term

Long-term research priorities include:

- Extending work on topics from the short- and mid-term that are particularly promising.
- Exploring the envelope of how much load flexibility can be obtained without notably impacting end-use load service delivery.
- Developing new and less costly thermal energy storage and related phase change materials for a wide range of applications.
- Extending price-response to other carriers of energy (e.g., district heating and cooling) and to multi-day and seasonal energy storage.

Recommendations for SCE

SCE can move forward the above items through various routes:

- Conducting the research internally, with SCE staff.
- Collaborating with other utilities and CEC to conduct research.
- Collaborating with other research entities in California and the nation, and funding others to do such research.
- Conducting collaborative research with end-use equipment manufacturers, so that they can build control systems in end-use equipment to respond to dynamic prices.
- Advocating that these research themes be a priority for organizations such as the California Energy Commission and the U.S. Department of Energy. Working collaboratively with such state, federal and other national organizations to conduct pilot projects in this area of research.

SCE has recently initiated a test of "real-time rates" through the current "SCE Dynamic Rate Pilot"[40]. This pilot will offer dynamic rates to customers and calculate their bill with both the current and dynamic rates. Customers will pay the traditional bill, but if they would pay less under the dynamic rate, then they would be refunded the difference. This builds on the earlier "RATES" CEC/EPIC project (Cazalet et al., 2020) which tested controlling devices based on a dynamic rate calculated by the TeMix platform. That rate combines the current wholesale price with a variable distribution system adder that is related to distribution system utilization rates. The pilot is open to "residential, commercial, and industrial customers" and is to begin no later than May 1, 2022.

If this pilot is successful, it could lead to dynamic tariffs offered by SCE and other utilities in California. While the greatest near-term shift potential appears to be from commercial and industrial customers, all customers could be offered the chance to save on their bill and contribute to utility goals, and it is important to signal the future direction of electricity rates so that product manufacturers and system control vendors can begin to embed price response into all product types.

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[40] SCE Dynamic Rate Pilot (D21-12-015), https://www.dret-ca.com/dynamic-rate-pilot/

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A

AUTOMATION PATHWAYS AND FLEXIBILITY

This Appendix describes the three major 'automation pathways' that facilitate flexible load price response: Cloud, Local, and Supervisory. These differ by the location of the intelligence that translates from prices to functional control. It also covers 'subpaths' that are distinguished by the path that the price takes on its way to the control entity, the benefits of a Customer Central Entity device, options available today, and factors that influence which pathways are chosen.

Demand response (DR) to date has been predominantly accomplished either through event-based mechanisms (either through an aggregator or critical peak or variable peak [CPP/VPP] pricing) or through time-of-use (TOU) rates. Neither of these cover electricity prices that can respond to grid needs in a fine-grained manner such as varying daily based on the grid conditions for that day.

Figure A-1 shows the overall communication architecture diagram from Section 3, annotated with three overlays—*automation pathway* —to summarize the major approaches to automation that are likely to occur.

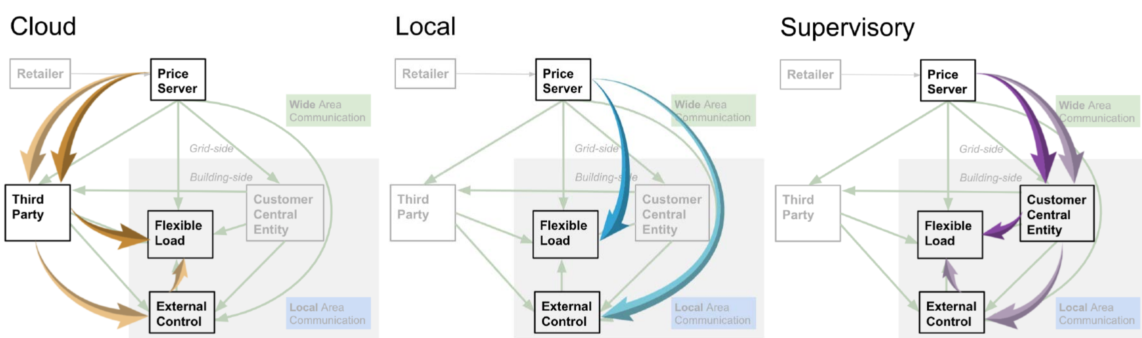

Figure A-1
(a, b, and c) DR automation pathways

Table A-1 provides additional detail on the pathways. There are three major pathways, with some alternatives for six sub-paths. There are many potential paths, but we divide them into three broad groups based on **where the intelligence resides** that translates pricing into functional control. The device's operational goals such as schedule (if any), status (e.g., temperatures), and any other relevant information are combined with the prices to drive internal operation. Examples of functional control signals are turning a device or component on or off, changing a level, and changing a thermostatic setpoint. One of the factors that creates sub-paths within these is **how the price is received by** the customer-site technologies.[41] With this in mind, we describe three primary pathways: Cloud, Supervisory, and Local as illustrated in Figure A-1.

[41] In one case, likely to be common, a third party receives the price directly from the grid and then determines the functional controls in its cloud infrastructure before sending those controls to the individual flexible load.

Table A-1
DR automation pathways

Overall Path	Sub-path	Comments
Cloud	Aggregator	Control via an entity with a financial relationship with the grid that is connected to the amount of DR delivered
	Third Party	Control via an entity that optimizes device operation on behalf of the customer and has no grid relationship for the flexibility delivered
Supervisory	Functional Control	Customer central control of device functionality, e.g., by a building / energy management system
Local	Price Distribution	Customer central price distribution with control decisions made by a device or external control
	Device Direct	Device self-control
	Via External Control	Dedicated external control device (e.g., CTA-2045 module)

For the Cloud and Supervisory pathways, it is not considered significant whether the signal passes through an external control[42] device. For the Local case, we do not distinguish between whether the intelligence is in the flexible load or the external control device.

It may seem surprising that a third party would ever get the price in a way other than directly from the grid. However, there are some reasons why this could be useful:

- When the third party receives the price directly from the grid, it needs to be informed what the customer's tariff is, and that this tariff pricing must be updated when the tariff changes. Receiving the price from some entity in the customer site (e.g., DER, external, control, or customer central entity) avoids this.
- The applicable price for the flexible load[43] to use may be a "local price" set by a device in the customer site.[44]
- During microgrid operation (when islanded from the grid, usually when grid power is unavailable), the grid price is not applicable (and perhaps not available) and so should not be used; the local price is the one that should drive flexible loads.

For the near future California is likely to see third parties overwhelmingly get their prices directly from the grid, with the other pathways growing slowly over time.

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[42] In this report, an *external control* is a hardware device that exists only to facilitate a single flexible load.

[43] Using dynamic prices to inform battery behavior is also intended, but as the great majority of devices that will use prices are flexible loads, we use just the term *flexible load* to cover the (slightly) wider full scope.

[44] Some examples of how this occurs are:

The tariff includes differential buy/sell prices at the meter, so the applicable price could be either, or something in between, and only known within the building.

The tariff could be adjusted for a DC power domain or due to customer valuation of environmental signals.

The grid goes down, but internet connectivity remains, so there is no applicable grid price.

Having prices pass through a Customer Central Entity (CCE) has many advantages, such as:

- Any special hardware or service is installed only once, rather than once for each flexible load. Examples could include an FM receiver, a cellular radio (which would have data fees attached), or a satellite receiver. In the future, utility meters might be a path for sending out prices.[45]
- If all flexible loads use a central source, then when the customer switches to a new tariff, that change needs to be made in only one place.
- A CCE could readily receive prices through multiple mechanisms for redundancy, and if there are three or more, it could detect prices that have been compromised in transit.
- Microgrid operation can be enabled by the local price being generated by the CCE or passed to it by a separate microgrid controller.
- Local prices can be calculated in only one place.
- A central device that implements functional control of multiple flexible loads can have algorithms that co-optimize among the loads.

It is important to note that these paths are not exclusive of each other, and it is likely that many or most customer sites in the future will use two or all three of the major paths for different flexible loads.

Pathway Options Today

Traditionally, demand response has been predominantly event-based, which is largely accomplished through cloud-based systems. Since TOU pricing changes infrequently, and the pattern of high-price times across seasons is generally consistent, TOU automation does not require automation with ongoing communication, so it has not spawned use of the Supervisory or Local pathways.

There are a few commercial products available that can implement automation via dynamic pricing that is different every day. One example is a CTA-2045 module from e-Radio, Inc.[46] for controlling a mini-split air conditioner. In searching for such devices, we considered flexible loads themselves, dedicated external controls, central facility systems, and cloud-based systems. This is not surprising given that few customers today are on such rates, and the number that have access to compelling dynamic rates is even lower.

One cloud-based mechanism to automate price response is the IFTTT system.[47] Elevate Energy, an Illinois nonprofit, created a collection of IFTTT applets on behalf of Commonwealth Edison, for the Illinois utility's dynamic pricing programs, which include Hourly Pricing.[48] As of September 2021, this list includes changing behavior in response to dynamic prices for thermostats (ecobee, Honeywell), a smart switch (WeMo), and a robotic lawnmower

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[45] At least one meter manufacturer is considering this possibility for future meters.

[46] e-Radio. Virtual Peaker Partners with e-Radio to Connect Water Heaters with Utilities and the Grid. https://www.e-radioinc.com/.

[47] IF This Then That. http://ifttt.com.

[48] IFTTT. ComEd. https://ifttt.com/ComEd.

(Husqvarna). Many devices facilitate IFTTT connectivity and could well implement this as well, though there is a limit to how sophisticated IFTTT can be.

A major U.S. water heater manufacturer has done development work and is ready to work on prototyping water heaters that implement time-varying rates after they become available. What time granularity and price forecast period are supportable or needed is to be determined. If the grid has more granular prices than the device can accept, then coalescing the prices to longer time periods might be needed as an interim step.

The ENERGY STAR Connected program, which recognizes devices that have communications features for energy purposes such as demand response,[49] allows for all three pathways.

Mechanisms that require a human to be in the loop on an ongoing basis are not considered to be automation. Examples of this are the ComEd IFTTT system that can automate phone or text messaging or changing the color of lights (Philips Hue) when there are dynamic price changes.

Factors Influencing Pathway Options

A variety of factors will shape how much each of these pathways is taken up in the market and used. **Utilities** should enable all pathways; there is no need to pick favorites. To understand the possibilities for automation pathways being implemented, it is worth considering the factors influencing them.

Product manufacturers may seek to monetize the optimization of their products if they can, through a relationship with a wholesale market or grid entity, which would tend to mean the Cloud pathway. Manufacturers reasonably might see themselves as best equipped to control their own products, which requires a Cloud or Local approach. Supervisory control leaves the manufacturer out of the control process entirely.

Vendors of **building automation systems** (BAS) would naturally prefer the Supervisory pathway as the only way to be involved. This could be computed on-site or in the cloud; we consider any multi-device optimization to be Supervisory, regardless of where the computation is done. The Cloud path is for flexible loads that are optimized individually as opposed to BAS systems that address multiple or dozens of devices at the same time.

Customers are likely to favor mechanisms that can save money without impairing facility services, but also consider resilience (see microgrids below), privacy, or other concerns. Customers who already have well-functioning BAS systems would likely want to have them extend their optimization rather than add parallel functionality.

When the grid becomes unavailable and a customer site islands as a **microgrid**, it may lose internet connectivity as well, and so solutions that are entirely local (either always that way or at least with a local option) are best. This only works with the Supervisory or Local pathway (and for the Local pathway, the price then needs to be received from another customer device). When islanded, the CCE will generate its own prices (a "local price") for balancing system operation.

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[49] The ENERGY STAR refrigerator spec provides an example: https://www.energystar.gov/sites/default/files/Refrigerators_and_Freezers_Program_Requirements_V5.1.pdf.

There is no cash exchange involved, as with exchanging power with the utility grid, but price can still be used as a measure of resource availability.

There is also the possibility of losing internet connectivity while the grid is still up. Having a non-internet mechanism to receive prices centrally (e.g., an FM radio) is a good method to address this. This topic leads to the general issue of signal **redundancy**. Receiving prices over multiple mechanisms provides a backup for when one fails, and if they are received with three or four methods, then it can be detected if one path is compromised and ceases to agree with the others.

One innovation could be the emergence of **price servers** that are local to a customer site. These could be analogous to a variety of network services used today, such as a domain name system (DNS) server or dynamic host configuration protocol (DHCP) server. There should be a simple and standard way to discover the identity of a local price server and simple and standard ways to receive prices from them. With this, a new device could automatically find the server and begin price-based operation immediately and without any user intervention. There could be support for multiple such servers, with a failover mechanism if one fails. This centralizes identification of the retailer and tariff so that if one or the other changes, then the change needs to be made in only one place. It also meshes nicely with receiving redundant signals. Central reception of prices also means that any other adjustments made locally can be set in only one place.[50]

Finally, there is the ever-present issue of **cybersecurity**. How that plays out for these pathways needs to be evaluated.

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[50] A caution is that we may see the emergence of multiple power domains in buildings, with different prices, but that is a topic for another day.

B
QUANTIFICATION OF DEMAND RESPONSE POTENTIAL

This appendix describes earlier work to assess how much load flexibility is potentially available at what price, estimates of the costs of automation, and factors influencing the amount of shift available.

Demand Response Quantification

As the need for, and technical potential of, demand response and continuous load flexibility has become increasingly apparent, the question has arisen of which end uses in what facility types are most suited to deliver load flexibility. Demand response potential modeling and analysis is needed for a variety of purposes, including forecasting likely impacts on grid operation, guiding decision making on investments and policies, and prioritization among possible automation mechanisms to facilitate.

One key source of such estimates is a series of reports prepared for the California Public Utilities Commission on 'Demand Response Potentials.' The first (Phase 1) was published in 2016, with the most recent (Phase 4) scheduled for 2022. The Phase 3 report[51] has the most current and applicable results for this discussion. While shedding load during times of exceptional grid stress is a needed part of our management of the electricity grid, shifting the timing of load will be the primary way that the demand side will contribute to future grid needs, particularly for integrating increasing amounts of variable renewable generation. Figure B-1 and Figure B-2 show high-level results from the Phase 3 study.

The DR potential study defined four grid services: Shift, Shape, Shed, and Shimmy. Shape is modification of customer loads based on TOU and CPP prices. Shift refers to changes in load patterns moving energy use from one time of day to another. Shed is the traditional DR for peak events. And Shimmy is fast acting load response such as seconds to minutes. The DR Potential reports takes today's TOU rates as a starting point, and so any shifting of load that results are put into the Shape category. That said, the price differentials in the current TOU rates between peak and off-peak are modest, and results in changes in load shape of about 2-3%.

For this report, one question under consideration is whether automation of load flexibility does, or should, distinguish between Shape and Shift. In part this is related to the grid coordination mechanism used. If a customer is billed at TOU rates, the TOU automation results in Shape. If the same customer is used by a third-party aggregator to Shift load for one device, then there are two distinct streams of load flexibility, one Shift and one Shape. If dynamic pricing is the sole mechanism used, then there is just one automation mechanism, and the alternative is a flat rate, so that all flexibility is Shift. This report is focused on dynamic pricing as the mechanism to

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[51] Gerke, Brian F., Giulia Gallo, Sarah J. Smith, Jingjing Liu, Peter Alstone, Shuba Raghavan, Peter Schwartz, Mary Ann Piette, Rongxin Yin, and Sofia Stensson. 2020. The California Demand Response Potential Study, Phase 3: Final Report on the Shift Resource through 2030. Prepared for the California Public Utilities Commission. July.

obtain the Shift, though clarity on how it differs from event-based demand response is helpful to have.

Key Phase 3 Results

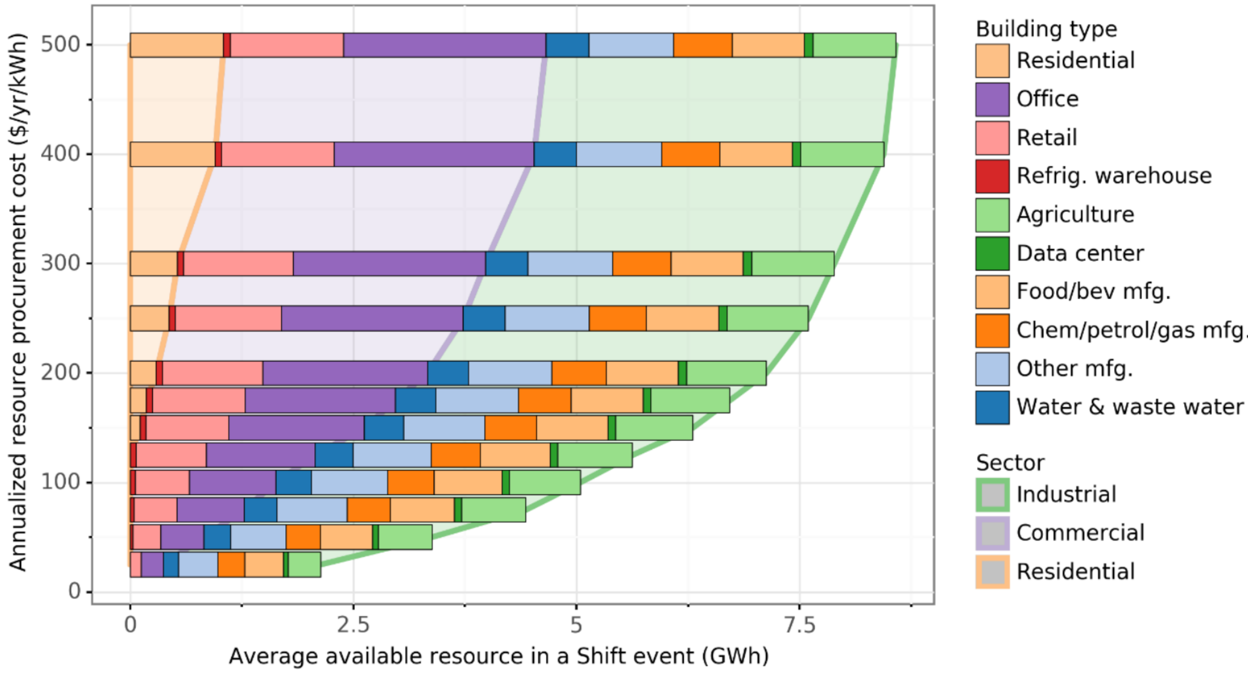

Figure B-1
Shift available in 2030, Medium scenario, by building type. (LBNL DR Potential study, Fig 3-8)

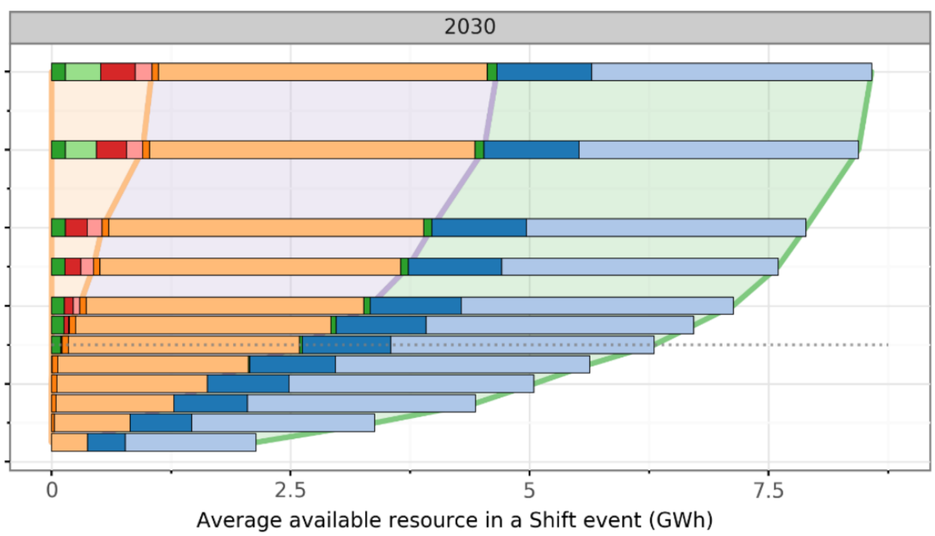

Figure B-2
Shift available in 2030, medium scenario, by end use (LBNL DR Potential study, Fig 3-3)

These results indicate where the shift can be found. The discussion below addresses what needs to change to automate this flexibility, and specifically which pathway(s) are appropriate for each case. As customers move onto more dynamic tariffs, they can implement this automation. In many cases this will require new products or services being offered by product manufacturers or automation vendors and will require the ready availability of the necessary grid signals (particularly prices).

From these high-level results, most of the least expensive DR is from industrial process loads, agricultural pumping, and commercial HVAC. These are generally individual large loads, and therefore well-suited to traditional DR communication technology (e.g., OpenADR), either through an event-based DR signal, or (preferably) a price-based one. These DR signals could be sent directly to the facility (e.g., to a building management system), or to a third party that provides optimization services[52]. In general, in such facilities there will already be a device which manages such loads, and that device can be replaced or adapted to take in dynamic prices and co-optimize bill minimization with other concerns. We can expect all three automation pathways to be utilized, though cloud-based systems are likely to be the first to do so. Some have existing control relationships with customer devices for demand response, and so only need to add the ability to receive dynamic prices and update their algorithms to consider the more fine-grained signals. LBNL is in touch with a major agricultural DR provider that is eager to add support for more dynamic prices when they become available.

For buildings, aside from commercial HVAC, major end uses that could deliver Shift DR are EV charging, residential cooling, pool pumps, and commercial refrigeration.

EV charging can be readily controlled by the vehicle (or charger) directly, or via a cloud service. Communication is increasingly common for these devices so that there may be no added hardware cost[53]. If the intelligence is in the vehicle, it would be advantageous to get the price from the EVSE, to be sure that it is the correct price. Vehicles move and so connect to different buildings. In addition, DC-charging may be from a DC power domain that has a different price from the AC domain in the same customer site. The Cloud pathway is likely to be important as is the Local pathway. The Supervisory pathway is likely to be significant only in cases in which customer site-wide coordination is needed, such as when demand charges exist, when multi-device optimization is used, or when there is already a central device that manages multiple end uses and adds support for EV charging.

Residential cooling that has network connectivity today is almost entirely optimized using cloud-based systems. The most likely communication path is to send prices to the third party, which would then send setpoint or other signals to the thermostat and then control the compressor/etc. At least one major thermostat manufacturer that LBNL has spoken with is ready to deploy support for highly dynamic prices, once they become available, and is intending to support both the Cloud and Local pathways.

Pool pumps could also be readily controlled by a cloud system, as with thermostats, or control themselves with a built-in controller, since the complexity of the needed computation to add load shifting would be low. If the algorithms require other information, such as weather, that data could be easily pulled from an Internet source.

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[52] An example provider is Polaris Energy Services, which takes in OpenADR signals.

[53] A 2019 CEC study on EV chargers found that the purchase price of Level 2 devices designed for residential use was not notably different between those that were networked and those that were not, when normalized to cost per unit of power delivery capacity. This was reported in a 2020 Load Management Standards briefing.

While some chain stores have cloud-based refrigeration management, commercial and industrial refrigeration is most likely to have local control, and so the price will flow from the grid to the control system directly, or through a customer central entity. Such systems will likely increasingly be coupled to local reliability (e.g., with PV, batteries, and microgrid capability) to preserve coldness when the grid goes down. When grid connectivity is lost, Internet connectivity might likely be lost as well, in which case a system that can operate entirely locally is preferred, given the high cost of such systems malfunctioning.

Based on this, an initial focus on the Cloud pathway is advisable, given that the infrastructure for a complete solution is closest to being in place. This is also practical as the number of entities that need to receive the price signals is much smaller than with the other paths, and there are fewer technology standards questions in play. The CEC has already recognized this with the MIDAS system, in initially targeting only "Automation Service Providers" for their data distribution. The second priority (pursued in parallel) should be the Local pathway, as it will be important to quickly be able to point to devices on the market that can take in prices directly. Vendors of building automation software will likely recognize the value of incorporating this functionality and add it to their offerings early on.

Further Considerations for Shift Potential

An appealing aspect of price-based grid coordination is that many device types in any facility type can contribute Shift, in ways, magnitude, and times at the complete discretion of the utility customer. This is unlike other mechanisms such as direct load control and aggregator-based systems that are limited in the devices and control options by the availability of programs or vendors. While the Phase 3 study covered the most important end uses, future work will significantly expand the coverage and granularity, as shown in Figure B-3. The study will also dig deeper into electrification of formerly fossil fuel driven end uses, as shifting load will reduce the impact of this on the grid and improve customer economics.

A 2019 report[54] assessed costs and benefits of residential demand response. Many of the methods considered were switching off power to devices with networked plug or hard-wired switches[55], with some other devices being enabled with ordinary thermostatic control. Some devices, as described below, include support for event-based DR, and a few for TOU rates. Most of the devices covered are listed in Figure B-3. Those not listed are Dehumidifier and Battery Storage, and some are explicitly disaggregated into subtypes (air conditioning and water heating). The cost analysis is driven by the assumption that the devices are part of an ongoing utility program that must be managed, which adds substantial costs. Costs for simply acquiring a price-responsive device or external control are not separately reported.

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[54] Navigant. 2019. Cost-Effectiveness of Electric Demand Response for Residential End-Uses: Final Report. Prepared for National Grid. April. Report 194701.

[55] While some devices can be readily depowered for this purpose, such as a refrigerator, resistance water heater, or pump, others with more defined cycles, such as clothes washers, may not behave as intended if interrupted this way.

Residential Sector		Commercial Sector		Industrial/Ag sector	
Building Types	End Uses	Building Types	End Uses	Building Types	End Uses
• Unknown • Single-family • Multi-family • Master meter	• Cooling • Heating • Ventilation • Indoor Lighting • Outdoor lighting • Cooking • Dishwasher • Clothes Washer • Clothes Dryer • Refrigerator • Freezer • Pool pump • Spa heater • Spa pump • Television • Office equipment • PCs • Water heating • Misc. • EV level 1 • EV level 2 • Rooftop PV	• Office • Retail-food • Retail-other • Dining • Lodging • Medical • Education • Assembly • Datacenter • Warehouse • Refrigerated warehouse	• Cooling • Heating • Ventilation • Indoor lighting • Outdoor lighting • Office equipment • Refrigeration • Water heating • Datacenter IT • Misc. • EV charging • Rooftop PV	• Ag-crop • Ag-animal • Ag-indoor • Ag-other • Chem/petrol • Food/bev • Mfg-equipment • Mfg-goods • Mfg-materials • Military • Water	• Boiler • Process heat • Process cooling • Machine drive • Electrochem. Process • Other process • Non-process • Pumping • Rooftop PV

Entries in **red** are newly being developed from AMI data in phase 4 (some were previously modeled separately)

Figure B-3
Customer types and end use planned for Phase 4 DR Potential Study (Source: LBNL)

The Navigant report lists information on devices for sale at the time the report was prepared (apparently 2018) that can take in a demand response signal of some kind. While this is not price response itself, it indicates that communication and actuation paths are in place, so that only change in the software algorithms is needed, not any new hardware. The most widely used such example is smart thermostats. Any smart thermostat can communicate and so has the hardware ability to receive a price signal (whether locally or in the cloud) and so only needs additional software to do so. Room Air Conditioners can be controlled by de-powering, or a dedicated external controller (e.g., that can adjust the setpoint). The report notes that four manufacturers had models available that can take in DR signals. For refrigerators, the report notes that several dozen refrigerator models were on the market (this as of 2019) that had DR capability for shifting defrost time, pausing ice making, or adjusting the freezer temperature. An increasing fraction of dishwashers, clothes washers, and dryers sold include communications ability (most commonly Wi-Fi) and some of these include support for event-based DR commands or time controls that enable DR. For dehumidifiers, the Navigant reports no models available, but today there are several, including from major manufacturers such as Honeywell. For mini-split systems (primarily for cooling but sometimes heating), several manufacturers include connectivity internally, while others provide optional dedicated hardware for this, including through use of the infrared sensor. These can receive some DR signals, but not prices directly. Water heaters are the most well-developed device for DR. The Navigant report only mentions availability of DR control from Rheem, but since then other manufacturers have introduced products and private conversations indicate that more will soon. In addition, some companies include CTA-2045 ports that can control the setpoint so that DR, including price response, can be easily added later. Pool pumps can be controlled with a switched plug or outlet, a dedicated controller (the Navigant reports on three manufacturers of this), or a CTA-2045 port. Any customer central battery system will have connectivity to know when to charge or discharge. For EV charging, either the EVSE or the vehicle can limit charging times (and the vehicle, the rate). Some manufacturers offer time-based scheduling, and some provide response to event-based DR or to utility TOU signals. EVSEs commonly have Wi-Fi and cellular connections, vehicles usually cellular.

Another indicator of what devices today have some demand response capability is participation in the Energy Star Connected program. At present, for Demand Response, it covers thermostats, refrigerators and freezers, clothes washers, clothes dryers, dishwashers, room air conditioners, EVSE, pool pumps, water heaters, central air conditioners and heat pumps, ice makers, and Smart Home Energy Management Systems. Note that the existence of the program for these devices does not mean that qualifying products have been submitted to the program for each device type.

A source of cost information is a recent Request for Information from the California Energy Commission on "Flexible Demand Appliance Standards"[56]. This document reports on estimates of additional costs for select features that support load flexibility. Consumer costs for time-based controls such as a delay timer, or clock-based schedule are estimated at adding $3 per device. Adding a network connection to a device is $30. Capabilities costing $40 include adding support for OpenADR (unclear if this is in addition to or instead of general connectivity), existence of a CTA-2045 port[57], or FM signal reception capability.

Another survey of devices with DR capabilities[58] found major concerns for interoperability, cybersecurity, and privacy; the cost of connectivity is low and declining; and lack of actionable prices is a major barrier.

The most notable aspect of the DR Potential Phase 3 results is the small contribution of the residential sector, compared to commercial and industrial sectors; in aggregate demand they are of similar magnitude. In 2019, California consumed about 250 TWh of electricity[59], or about 680 GWh/day. Taking 8 GWh of shift twice a day is 16 GWH/day, or 2.4% of shifted energy consumption. Put another way, 97.6% is seen as not shiftable. For the residential sector, the apparent non-shiftable value is much higher. With its wider frame of view for devices and facility types, we may see an increase in the estimate of potential Shift from flexible loads when the Phase 4 results become available in 2022.

The Phase 3 report notes the challenges in estimating potential load flexibility given that so many variables are changing at the same time, including the design and operation of the devices themselves. Estimates are easiest to create when changes are incremental, but the report notes that "the market for Shift-related technologies in California is primed for repeated disruption in

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[56] California Energy Commission [CEC], Request for Information: Flexible Demand Appliance Standards, Docket 20-FDAS-01, September 1, 2021.

[57] CTA-2045 uses legacy connectors and are produced at low volumes, driving up costs compared to a standard data / network connection.

[58] Nubbe, Valerie, Kyung Lee, Alejandro Valdez, Ed Barbour, and Jared Langevin, Grid-Interactive Efficient Building Technology Cost, Performance, and Lifetime Characteristics, prepared by Guidehouse Inc. for Lawrence Berkeley National Laboratory, December 2020.

[59] https://www.eia.gov/electricity/state/California/

the coming years, which may result in dramatic and qualitative changes in price, performance, and adoption."

The amount of shift capacity available depends on numerous factors such as:

- The nature of the coordination mechanism between the grid and the customer (e.g., event-based, price-based, aggregator controlled, negotiated, etc.).
- The customer conditions at that day and time, such as:
  - Weather,
  - Occupancy / activity, and
  - Prior shifting earlier the same day or sometimes also prior days.
- The specific financial inducements the customer has available, for timing (e.g., open-ended in timing and quantity vs. constrained) and size (how much the customer might save for a particular grid action)[60].
- The capability of the facility and equipment to do the shift.
- Any increases in energy use required by the shift.
- How much a customer/flexible load might benefit from doing shifting, as this affects investment decisions on controls, or on new hardware such as extended thermal storage.
- How much of what a customer might install and so be "free" from the perspective of grid coordination. Such other purposes include general device functionality (e.g., accessing device features from a mobile phone) and what is installed for microgrid (islanded) operation.

For shifting load, the amount of potential resource that exists depends on how much can be spent for the resource. Given this, the Phase 3 analysis reports the potential as a supply curve, showing the cumulative resource available at several cost points. Some flexible loads cost less than batteries, but for all there is some limit to what is reasonably attainable. For batteries, as they are new devices, and are not tied to a building service, there is a much higher ceiling on potential deployment than with loads. As batteries can be used for both reliability and for shifting load, one can pay for them for one purpose and use them for 'free' for the other or assign a portion of the cost to each. Due to the many complexities of battery analysis, and differences from loads, the Phase 3 report focuses primarily on flexible loads.

The study includes how much shift might be induced solely from TOU rates, the use of thermal energy storage, how the shift resource is distributed by geography and facility type, seasonal variation, and increased availability with electrification of current non-electric end uses. As an example of the latter, while California is dominated by natural gas water heating, the state's electrification goals (State of California, 2019) will drive a shift to more use of electricity, particularly with heat pump-based systems.

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[60] A simple example of this is the price differential between a high-price and low-price period.

Among the eight categories of recommendations from the report, one is on the role of tariff design, and begins (section 4.3.3):

> Dynamic prices that are in sync with the cost of serving loads could dramatically simplify Shift, allowing customers to simply pay for what they use and avoiding the need to set an assumed baseline load in order to compensate customers.

The report further notes the many advantages of a price-centric system. A second recommendation is on Communication and control, and notes that "Defining clear communication and load control standards can help to reduce the cost to integrate new technology and accelerate deployment." The current work for EPRI/SCE addresses both of those points. In addition, the Phase 4 study has an element focusing on dynamic pricing, rather than just on event-based mechanisms.

There are many possibilities for how costs of Demand Response might occur and be allocated. For example, some appliances already have Internet connectivity and so adding price responsiveness could be done with only additional software, either in the cloud or on the device. Others have no communications at all, so would need additional hardware built into the device, which usually precludes a retrofit. Once a device is purchased and installed, there may be costs associated with enabling the price-responsiveness functionality, including identifying the retailer, tariff, and source of the data, or even utility grid costs to encourage customers to purchase the capable product and do the enabling. The existence of such ongoing costs is new and may be challenging for low-cost devices. Or, we may evolve to have communications infrastructure so that enabling is on by default, and the device automatically discovers the source of pricing information over the local network so that there are no costs.

There are costs associated with a device having the ability to be flexible at all, and then the incremental cost of obtaining flexibility on a particular day. Both are also linked to the overall tariff structure. Hardware costs for implementing demand response are likely similar for both price-based and event-based DR[61]. The payment required for event participation may be similar to the price differential between high- and low-price times from a real-time rate, but this cost must be borne by all customers in raising the prices slightly across the board. For price-based DR, there is no payment separate from the price difference between the two price periods, and so no extra cost to pass on. In both cases, the fact that the shift is occurring should reduce overall costs for procuring electricity and so slightly reduce average rates.

One core technology for load flexibility is CTA-2045. As the CEC RFI notes (and conversations with manufacturers confirms), modules generally cost in the $40 range; this price can be expected to decline if manufacturing volumes rise above their current low levels. There has been some exploration of demand response in data centers, both academic studies and actual industry implementation[62].

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[61] An exception could be DR programs that require submetering to verify event participation and magnitude. Price-based DR requires only the regular utility meter.

[62] Google Sustainability. 2019. The Internet is 24x7—carbon-free energy should be too, September. https://sustainability.google/progress/projects/24x7/

C
TARIFF DETAILS

This appendix presents further information on the tariff survey. The survey was primarily conducted in the summer of 2020, with a limited update in the fall of 2021.

Tariffs offered by Southern California Edison[63] are categorized into the following groups:

- Residential. Fifteen tariffs, including options for Time of Use rates, event-based demand response, and adaptations for facility types, and customer type discounts.
- Commercial and Industrial[64]. Twenty-eight tariffs, including options for Time of Use rates, hourly temperature-driven rates[65], demand charges, and interruptible service, with discounts for economic development applications.
- Agricultural and Pumping. Nine tariffs, including options for Time of Use rates, hourly temperature-driven rates, demand charges, and interruptible service.
- Street/Area Lighting and Traffic Control. Seven tariffs differentiated by application, and whether the service is metered or not.
- Other. Sixty-seven tariffs. Many are options for other tariffs, or for highly specific customer types, demand response aggregators, community choice aggregation, net generation customers, electric vehicle charging development, pilot programs, community solar, direct access, miscellaneous fees, emergency load reduction, virtual net metering, net metering, on-bill financing, and more.

The original analysis was based on the first two categories only, but a review of the remainder found no relevant tariff features. From their names, many are combinations of features found in other tariffs, and inspection shows that this is the case.

The following are the rates in place at the time of the assessments.

Residential

Schedule D: Domestic Service
Schedule D-CARE: California Alternate Rates for Energy, Domestic Service
Schedule D-FERA: Family Electric Rate Assistance
Schedule D-SDP: Domestic Summer Discount Plan
Schedule DE: Domestic Service to Utility Employees
Schedule DM: Multifamily Accommodation - Residential Hotel - Qualifying RV Park

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[63] https://library.sce.com/?10000_group.propertyvalues.property=jcr%3Acontent%2Fmetadata%2Fcq%3Atags&10000_group.propertyvalues.operation=equals&10000_group.propertyvalues.0_values=sce-document-library%3Aregulatory%2Fsce-tariff-books%2Felectric%2Fschedules%2Fother-rates

[64] Formally these are described as "General Service and Industrial".

[65] These are called "Real Time Pricing" in that the prices are determined the day before, but they are taken from a table based on the prior day temperature, and in no way derived from recent wholesale prices or grid conditions.

Schedule DMS-1: Domestic Service, Multifamily Accommodation, Sub metered
Schedule DMS-2: Domestic Service, Mobile home Park Multifamily Accommodation, Sub metered
Schedule DMS-3: Domestic Service, Qualifying RV Park Accommodation, Sub metered
Schedule ESC-OO: Edison SmartConnect Opt-Out
Schedule MB-E: Medical Baseline - Exemption
Schedule SEP: Smart Energy Program
Schedule TOU-D: Time of Use Domestic
Schedule TOU-D-T: Time of Use Tiered Domestic
Schedule TOU-EV-1: Domestic Time-of-Use, Electric Vehicle Charging

Commercial and Industrial

Schedule EDR-A: Economic Development Rate-Attraction
Schedule EDR-A: Economic Development Rate-Expansion
Schedule EDR-R: Economic Development Rate-Retention
Schedule EDR-A: Economic Development Rate-Attraction, Standard and Enhanced
Schedule EDR-E: Economic Development Rate-Expansion, Standard and Enhanced
Schedule EDR-R: Economic Development Rate-Retention, Standard and Enhanced
Schedule GS-APS-E: General Service Automatic Powershift-Enhanced
Schedule GS-1: General Service Non-Demand
Schedule GS-2: General Service - Demand
Schedule TOU-8: Time-of-Use - General Service - Large
Schedule TOU-GS-1-RTP: General Service - Small, Real Time Pricing
Schedule TOU-GS-1: Time-of-Use General Service
Schedule TOU-GS-2: Time-of-Use, General Service, Demand Metered
Schedule TOU-GS-2-RTP: General Service - Medium, Real Time Pricing
Schedule TOU-BIP: Time-Of-Use - General Service Base Interruptible Program
Schedule TOU-EV-3: General Service Time-of-Use, Electric Vehicle Charging
Schedule TOU-EV-4: General Service Time-of-Use, Electric Vehicle Charging, Demand Metered
Schedule TOU-EV-6: General Service Time-of-Use Electric Vehicle Charging, Large Demand Metered
Schedule TOU-EV-7: General Service Time-of-Use, Electric Vehicle Charging
Schedule TOU-EV-8: General Service Time-of-Use, Electric Vehicle Charging, Demand Metered
Schedule TOU-EV-9: General Service Time-of-Use, Electric Vehicle Charging, Large Demand Metered
Schedule TOU-GS-3: Time-Of-Use, General Service-Demand Metered
Schedule TOU-GS-3-RTP: General Service - Real Time Pricing
Schedule TOU-GS-3-SOP: Time-of-Use, General Service, Super Off-Peak, Demand Metered
Schedule TOU-8-RBU: Time-of-Use - General Service - Large - Reliability Back-up Service
Schedule TOU-8-RTP: General Service - Large, Real Time Pricing
Schedule TOU-8-RTP-S: Time-of-Use - General Service - Large, Real Time Pricing, Standby
Schedule TOU-8-S: Time-of-Use - General Service - Large – Standby

Agriculture and Pumping

Schedule AP-I: Agricultural and Pumping - Interruptible
Schedule PA-1: Power - Agricultural and Pumping, Connected Load Basis
Schedule PA-2: Power - Agricultural and Pumping, Demand Metered
Schedule TOU-PA-2: Time-of-Use, Agricultural and Pumping, Small to Medium
Schedule TOU-PA-2-RTP: Agricultural and Pumping - Small and Medium, Time of Use, Real Time Pricing
Schedule TOU-PA-2-SOP: Time-of-Use, Agricultural and Pumping, Small to Medium, Super Off-Peak
Schedule TOU-PA-3: Time-of-Use, Agricultural and Pumping, Large
Schedule TOU-PA-3-RTP: Agricultural and Pumping - Large, Time of Use, Real Time Pricing
Schedule TOU-PA-3-SOP: Time-of-Use, Agricultural and Pumping, Large, Super Off-Peak

Street Lighting and Traffic

Schedule AL-2: Outdoor Area Lighting Service, Metered Service
Schedule DWL: Residential Walkway Lighting - Unmetered Service
Schedule LS-1: Lighting - Street and Highway, Company-Owned System, Unmetered Service
Schedule LS-2: Lighting - Street and Highway, Customer-Owned Installation, Unmetered Service
Schedule LS-3: Lighting - Street and Highway, Customer-Owned Installation, Metered Service
Schedule OL-1: Outdoor Area Lighting Service - Unmetered Service
Schedule TC-1: Traffic Control Service, Metered Service

Other

Schedule BG-NEM: Biogas Net Energy Metering
Schedule BioMAT: Bioenergy Market Adjusting Tariff
Schedule BSC-IMO: Bundled Service Customer, Interval Meter Ownership
Schedule BTMM
Schedule CBP: Capacity Bidding Program 0000001170 Schedule CBP: Capacity Bidding Program
Schedule CCA-CRS: Community Choice Aggregation Cost Responsibility Surcharge
Schedule CCA-INFO: Community Choice Aggregation-Information Fees
Schedule CCA-SF: Community Choice Aggregation Service Fees
Schedule CC-DSF: Customer Choice - Discretionary Service Fees
Schedule CGDL-CRS: Customer Generation Departing Load Cost Responsibility Surcharge
Schedule CHP: Combined Heat and Power Excess Energy Purchase
Schedule CISR-SF: Customer Information Standardized Request Service Fees
Schedule CPP: Critical Peak Pricing
Schedule CREST: California Renewable Energy Small Tariff
Schedule CRPP: Charge Ready Program Pilot
Schedule CRNet Energy Metering
Schedule BioMAT: Bioenergy Market Adjusting Tariff
Schedule BSC-IMO: Bundled Service Customer, Interval Meter Ownership
Schedule BTMM
Schedule CBP: Capacity Bidding Program

Schedule CCA-CRS: Community Choice Aggregation Cost Responsibility Surcharge
Schedule CCA-INFO: Community Choice Aggregation-Information Fees
Schedule CCA-SF: Community Choice Aggregation Service Fees
Schedule CC-DSF: Customer Choice - Discretionary Service Fees
Schedule CGDL-CRS: Customer Generation Departing Load Cost Responsibility
Schedule CHP: Combined Heat and Power Excess Energy Purchase
Schedule CISR-SF: CustoTP: Charge Ready Transport Program
Schedule CS-Green Tariff: Community Solar-Green Tariff
Schedule DAC-Green Tariff: Disadvantaged Communities-Green Tariff
Schedule DA-CRS: Direct Access Cost Responsibility Surcharge
Schedule DA-LRATC Direct Access Local Resource Adequacy Transfer Credit
Schedule DA-RCSC: Direct Access, Revenue Cycle Services Credits
Schedule DL-NBC: Departing Load Nonbypassable Charges
Schedule DR-CRPP: Demand Response - Charge Ready Program Pilot
Schedule DRP-SF: Demand Response Provider Service Fees
Schedule EITE: Emissions-Intensive and Trade-Exposed Customer Greenhouse Gas Allowance Revenue Provisions
Schedule ELRP: Emergency Load Reduction Program
Schedule ELRP-VPP: Emergency Load Reduction Program - Virtual Power Plant
Schedule ESP-DSF: Energy Service Provider - Discretionary Service Fees
Schedule ESP-NDSF: Energy Service Provider - Non Discretionary, Service Fees
Schedule FC-NEM: Fuel Cell Net Energy Metering
Schedule GMS: Generation Municipal Surcharge
Experimental Schedule GSN: ENVestSCE Equipment Service
Schedule GTSR-CR: Green Tariff Shared Renewables Community Renewables
Schedule GTSR-GR: Green Tariff Shared Renewables Green Rate
Schedule MASH-VNM: Multifamily Affordable Solar Housing Virtual Net Metering
Schedule MASH-VNM-ST: Multifamily Affordable Solar Housing Virtual Net Metering Successor Tariff
Schedule ME: Maritime Entities at the Port of Long Beach
Schedule NMDL: New Municipal Departing Load
Schedule NEM: Net Energy Metering
Schedule NEM-ST: Net Energy Metering Successor Tariff
Schedule NEM-V: Virtual Net Metering for Multi-Tenant and Multi-Meter Properties
Schedule NEM-V-ST: Virtual Net Energy Metering for Multi-Tenant and Multi-Meter Properties Successor Tariff
Schedule OBF: On-Bill Financing Program
Schedule OBF-2: On-Bill Financing Program
Schedule OBMC: Optional Binding Mandatory Curtailment
Schedule OBR: On-Bill Repayment
Schedule PARF: Pole Attachment Related Fees
Schedule PC-TBS: Procurement Charge Transitional Bundled Service
Schedule PEVSP 2: Plug-In Electric Vehicle Submetering Pilot Phase 2
Experimental Schedule PVS: Off-Grid Photovoltaic Service
Experimental Schedule PVS-2: On-Grid Photovoltaic Service
Schedule Re-MAT: Renewable Market Adjusting Tariff

Schedule RES-BCT: Schedule for Local Government Renewable Energy Self-Generation Bill Credit Transfer
Schedule RF-E: Surcharge to Fund Public Utilities Commission Reimbursement Fee
Schedule S: Standby - 500 kW and Below
Schedule SC: Service Connection Charge
Schedule SLRP: Scheduled Load Reduction Program
Schedule SOMAH-VNM: Solar On Multifamily Affordable Housing Virtual Net Metering
Schedule SPESD: Station Power for Energy Storage Devices
Schedule SPSS: Station Power Self-Supply
Schedule TMDL: Transferred Municipal Departing Load
Experimental Schedule UCLT: Utility-Controlled Load Tests
Schedule WATER: Water Agency Tariff for Eligible Renewables
Schedule WI-FI-1: Wireless Fidelity Rate
Schedule WTR: Wireless Technology Rate
Schedule V2G Pilot SCE Vehicle to Grid Experimental Pilot.

D
TECHNOLOGY STANDARD DETAILS

This appendix reviews issues that arise when users want to properly configure their devices to respond to highly dynamic prices, the characteristics of the key communication protocols used for price communication, and how the proposed standard data model maps to each protocol. It also describes current and anticipated capabilities of the CEC MIDAS service, and gaps in the protocol standards that can and should be filled. It further addresses how price servers can be discovered in local and wide area networks, how network technology can be utilized for retailer price server discovery, and other technology details.

Identity of the Retailer, Tariff, and Location

One possibility for managing identity is to have the customer manually enter this information into each device that needs it, be it a Customer Central entity (CCE), an individual flexible load, an external control, or a third party. These will be plain text strings of abbreviated names and so fewer than ten characters each, ideally much less. It may be that qualifying this information with the geographical region will be helpful or necessary, e.g., country and state (location in this context is the "location within the retailer's grid"). Presumably, this information would be provided on each bill, and so would be readily available to the customer.

In principle a CCE could provide this information to other devices in the customer site, but if it could do that, it presumably could just provide the ongoing price information as well. The most common situations would be:

- A customer site with no CCE, with all other entities acquiring their own price stream
- A customer site with a CCE, which then provides the prices to all flexible loads

There is a third possibility, with a hybrid. This could occur when a flexible load lacks a local communication technology (e.g., one that only receives FM radio signals) or is too distant from the CCE (e.g., a pool pump out of Wi-Fi range of the CCE).

If a customer does not manually enter the retailer, tariff, and location information, there are other possibilities. If the identity of the retailer and/or tariff is considered sensitive information,[66] then

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[66] One alternative, not used or planned for use in California, is to consider this to be public information, much as property ownership is public information. To some this may seem odd or alarming, but there is precedent. In some places, e.g., Gainesville, Florida, electricity usage information is already public information (http://gainesville-green.com/map-search), and in many places, water usage also is (this often comes up when water is in short supply). The information in question here is not usage information, but rather, the tariff the customer is on. That said, the tariff name could include potentially sensitive information such as whether the customer has a special tariff due to a medical condition or low income; separating these aspects from the marginal price charged would be helpful, e.g., with the special conditions only affecting fixed costs and so not affecting flexible load operation. A customer could use its own street address to query a regional service (e.g., statewide) that provides the retailer, tariff, and location. Or, a customer could know its retailer, as well as an account number or a street address, and use that to query the retailer manually or automatically for the tariff and location. Addressing these issues can be done in parallel to developing the infrastructure for ongoing price distribution.

a process of authentication of the customer is needed, which adds significant complexity, whether this is done manually or automatically. Having all the information readily accessible to a customer through their bill, or from an on-line platform already in existence for other purposes (e.g., for paying the bill), is certainly the most straightforward, and should be available even if other more automated mechanisms are created.

Core Protocols for Price Communication

Three protocols are most central for price communication: OpenADR 2.0b, IEEE 2030.5, and CTA-2045B. These are reviewed in detail below. Also reviewed is the recently published California Energy Commission (CEC) application programming interface for price retrieval (MIDAS). For each there is a general introduction on how the standard operates, as well as detail on how prices are communicated. Crosscutting issues and how to evolve the standards are discussed in following sections.

OpenADR 2.0b

OpenADR messaging is between a server device (a *virtual top node,* VTN) and a client device (*virtual end node,* VEN). In some cases, these are cloud-to-cloud, and so do not directly involve customers; this corresponds to the Price Server to Third Party path in Figure A-1. The cases most relevant to this discussion are from a grid entity (e.g., a utility or other retailer) to a customer site, or to the inside of a single customer site.

Pricing

A basic capability of the OpenADR standard is the SIMPLE mechanism, which maps prices onto four levels, but this is far too coarse for use in managing most flexible loads, or for the fine-grained load shaping anticipated by the CEC and California Public Utilities Commission (CPUC). The standard also defines several features for encoding more fine-grained price data, which build on its generic ability to specify "events" at specific times. Most relevant here is ELECTRICITY_PRICE, which can send an absolute price, a relative price, or an index (multiplier) to a reference price (only absolute price is further considered in this discussion).[67] OpenADR lacks most of the static data elements, but for the time being, these could be encoded in text fields with a keyword/value system (see below).

OpenADR has published a program implementation guide[68] that covers how to use the standard for a set of example demand response mechanisms, several of which include pricing. These are critical peak pricing, time of use (TOU), real-time pricing (RTP), and a final one called "Distributed Energy Resources (DER) DR Program" which is prices to all devices. The TOU and RTP options are cast as being only for electric vehicles (EVs), though they do not have EV-specific content.

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[67] OpenADR 2.0a only supports the SIMPLE mechanism, not actual prices, so is not suitable for use as-is. That said, it could be amended to add actual prices. This would not be technically difficult, but other issues in terms of how to position 2.0a vs. 2.0b and security are much less clear.

[68] OpenADR Alliance. 2016. *OpenADR 2.0 Demand Response Program Implementation Guide.* Revision Number: 1.0. Document Number: 20140701.

The RTP example in the program guide is for a set of 24-hourly rates for one day. OpenADR is known for being verbose, which is a result of sending a lot of information more than just the key data points, and using XML, which takes a lot more text than more modern alternatives such as JSON to communicate the same information. Key elements in the example are:

- Identifier of the entity sending the information (the VTN)
- Start time and total duration for the list of prices
- For each interval, the duration and price
- Specifying $/kilowatt-hour (kWh) as the measurement unit for the price
- Identifier for the entity receiving the information (the VEN)
- Noting that no response is required

Some of the data model elements map directly to OpenADR constructs, as shown in Table D-1 (though the use of marketContext is a specific mapping not in the standard).

Table D-1
Mapping between the proposed pricing data model and OpenADR elements

Price Schema Data Model	OpenADR Mapping	Comments
Static Data		
RetailerShort	eventDescriptor:marketContext	These two fields can be combined to become a single unique identifier.
RateNameShort		
Currency	eiEventSignal:CurrencyPerKWh	Currency per ISO.
Dynamic Data		
CurrentTime	eventDescriptor:createdDateTime	The time the payload was generated, which should be functionally equivalent to the current time.
OffsetToFirstPrice	activePeriod:properties:dstart	The start time of the event. The offset to first price can be derived from dtstart – CreatedDateTime.
Each Interval		
TimeStamp	interval:duration	OpenADR has an overall start time, then durations for intervals. The time stamp for the first interval is dtstart, the second interval time stamp would be dtstart+ 1st interval duration, etc.
Price	interval:signalPayload:payloadFloat	Signal interval series with a signalName of “ELECTRICITY_PRICE.”

Also, *currentValue* and *event level eiTarget* are not relevant. The *oadrResponseRequired* field should be “never,” as this is one-way communication.

For the dynamic data, there are three parallel data streams, as shown in Table D-2: the time stream, and two price streams.

Table D-2
OpenADR interval structure example

Signal	Interval 1	Interval 2	…	Interval 25	Interval 26	…
Duration (common)	5 minutes	5 minutes	…	1 hour	1 hour	…
Electricity_Price ($)	0.15	0.14		0.16	0.17	
x-Export_Price ($)	0.05	0.04		0.06	0.07	

For the remaining static fields, Jim Zuber of Quality Logic proposed a method[69] to encode these data elements into OpenADR 2.0b. Robert Anderson of Olivine implemented this in an OpenADR server. A comparison of the server output and the program guide example show close correspondence between them. The main substantive difference is the use by Jim Zuber of a comment field to encode the static data not natively encodable with OpenADR. An example is as follows[70]:

```
<ei:vtnComment>
BindingPrices:True;
LocalPrices:False;
RetailerLong:Pacific Edison;
RateNameLong:E-TOU Dynamic;
DateAnnounced:2020-01-01;
DateEffective:2020-06-01;
URL:http://www.example.org/PacEd/paced-etou-dyn
</ei:vtnComment>
```

With this convention, any number of data fields can be included so long as they use ordinary text. Note that the example above is all one data element, which is why XML constructs are only visible at the beginning and end.

For the dynamic data, IntervalCount does not have a clear corresponding field in OpenADR, but intervals are labeled with a count value (starting at 0) so the last interval in a set will be the total number of them; the count value is named *interval:uid.* For assigning prices to times, OpenADR has a start time for the full set, then the individual intervals (*interval:duration;* length of the period), so the subsequent timestamps can be calculated. Price is placed in *interval:signalPayload:payloadFloat* as part of a signal interval series with a signalName of *ELECTRICITY_PRICE.* If a separate price for sending power back to the grid exists, then that is sent as a signal interval series with a signalName of *x-Export_Price.*

The standard has a facility for servers to send out time values, so that clients have the same sense of time as the servers providing them with information.

IEEE 2030.5

IEEE 2030.5 is intended "to enable utility management of the end user energy environment," which on its own sounds like top-down control. Much of the management of inverter functions

[69] Jim's assistance for this project was invaluable.

[70] The original text is one lengthy line, with no space or return after each semicolon. These have been added for readability. This comment is within eventDescriptor.

that it includes is top-down, but as the abstract also references "time of day pricing" in its first sentence and includes "pricing communication" as one of the document keywords, more distributed coordination is clearly part of its mission and scope.

In the IEEE 2030.5 context, a grid entity sending prices is a *server* and a device receiving the prices (wherever and whatever it is) is a *client.* Messages are exchanged with the REST API construct, and results are expressed in XML, or compressed into EXI.

IEEE 2030.5 capabilities are grouped into *function sets,* so that devices need only implement function sets relevant to them. The function sets most relevant to price communication are Pricing and Messaging, though several of the more basic function sets that facilitate basic operation are also needed.

One recognition of how Pricing is different from other types of coordination is that per Table 12 of the standard, a "device certificate" is not needed for price or message communication.

Pricing

The overall structure of how pricing is implemented in 2030.5 is shaped by it supporting a wide variety of tariff structures, including TOU rates, tiered rates, and more. In addition, several functions support "events" (p. 76), including demand response and load control (DRLC). As DRLC coordination supports a lot of complexity around events (e.g., opt-in and -out, participation details, replacement, and cancelled events), some of that complexity is enabled for Pricing. While much of this does not apply to normal pricing, such as randomization, these elements are still present in the data structures for communicating pricing.

While the usual mode of operation for the standard is for a client to "pull" data from a server, it also has a generic facility to "push" data from server to client with a subscription service. This can be used for pushing out prices. Subscriptions need to be renewed every 24 hours.

The IEEE 2030.5 standard does use the term *pricing server,* which nicely aligns with the term *price server* used in Price-Based Grid Coordination (PBGC). The standard also supports pricing, which is different depending on the direction of power flow with the RateComponent feature;[71] each direction of power flow (into and out of the customer site) requires its own use of RateComponent. It states, "Pricing servers SHOULD support at least 48 TimeTariffInterval instances for at least one RateComponent instance." The 48 instances are conveniently larger than the 46 that facilitate 2 hours of 5-minute pricing and 22 hours of hourly pricing. This is hypothesized as a plausible endpoint for the evolution of highly dynamic pricing.

Individual time periods are defined by TimeTariffInterval resources (which can be collected in a TimeTariffIntervalList), with an accompanying ConsumptionTariffInterval (and ConsumptionTariffIntervalList), which has the corresponding prices.

Appendix D of the standard notes how certain tariff structures can complicate grid / customer coordination. Specifically, that "consumption- based tariffs ... depend on usage accumulated during a given billing period in order to be able to provide accurate Pricing information."

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[71] The flowDirection attribute of a RateComponent indicates the applicable direction of power flow.

CTA-2045

The CTA-2045[72] standard defines an interface between a smart grid device (SGD) and an external adapter — a modular communications interface (MCI) — for purposes of enabling demand response. In the fall of 2020, the fields in the price communication data model were added to the standard with the 2045B revision. The A version of the standard supported a current price and one following price (with a time for the following price). For the B version, the number of time/price pairs that can be sent was increased from two to many dozen. CTA-2045 only defines communication from the module to the SGD and not communication from the module to the outside world (see below).

The relevant section of the standard is titled Price Stream Communication. That section clarifies that the underlying model is continuous streaming of prices, as the data model envisions. The module may be receiving streamed prices, or could be sent TOU or CPP rates, and then convert those to a stream internally to the module. A "capability bitmap" from the SGD indicates if it can accept streamed prices. Static data are transferred with the SetStaticTariff command; dynamic data with the SetPriceStream command.

Table D-3 lists the elements of CTA-2045 as they correspond to the price communication data model. Fields are optional unless noted as mandatory. The standard has a static field for "Export Price Available" to indicate if these exist and will be communicated with the dynamic data. Text fields are padded with 0x00 values (ASCII Null). Flags can be true, false, or unknown.

The "previously negotiated SGD Maximum Payload Length" determines how many time/price pairs can be sent in a message (each pair takes 8 bytes), but a "Message Index" field allows for multiple sets of pairs. Times are encoded as UTC seconds.

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[72] Consumer Technology Association. 2020. Modular Communications Interface for Energy Management CTA-2045-B. November.

Table D-3
Price communication data model elements mapped to CTA-2045 fields

Data Model Element	CTA-2045B	Comments
Static Elements		
RetailerLong	Retailer Long [30]	
RetailerShort	Retailer Short [6]	Mandatory
RateNameLong	Rate Name Long [30]	
RateNameShort	Rate Name Short [6]	Mandatory
Country	Country Code	Mandatory; same ISO standard
State	Principal Subdivision Code	Mandatory; same ISO standard
Currency	Currency Code	Mandatory; Sent with each dynamic data set; a mandatory "Digits After Decimal Point" field adjusts integer prices
DateAnnounced	Date Announced [8]	
DateEffective	Date Effective [8]	
URL	URL [60]	URL should use "https"
BindingPrices	Binding Prices	
LocalPrice	Local Price	
Dynamic Elements		
CurrentTime		A separate mechanism, SetUTCTime, is used
OffsetToFirstPrice		Not applicable; times all absolute
IntervalCount	Number of pairs in sequence	Mandatory
TimeStamp	time	Mandatory to have at least one time
Price	price	Mandatory to have at least one price
ExportPrice		Same fields; a separate stream sent with SetExportPriceStream

Once this capability achieves wide use, we may discover needs for modifying or extending it. Otherwise, it seems sufficient for supporting price streaming from the MCI to the SGD.

CEC MIDAS Application Programming Interface

On July 27, 2021, the CEC released the first version of documentation[73] of the application programming interface (API) for the price portal the CEC is creating, called MIDAS (Market Informed Demand Automation Server). The initial version of the standard only supports TOU

[73] Shepherd, Morgan, David Cuffee, and Karen Herter. 2021. Market Informed Demand Automation Server (MIDAS) Documentation: Connecting to and Interacting with the MIDAS Database – July 27, 2021, Beta Draft. California Energy Commission.

tariffs, which are presently by far the most common ones charged to California residential and commercial utility customers. The MIDAS system supports sending data in XML or JSON.

To obtain the MIDAS data, a user client registers with the system and then can pull the data from the pricing server. It does not broadcast data. MIDAS is intended at this time for use only by “application service providers” (ASPs), but presumably later will be extended to individual customers and/or flexible loads.

MIDAS defines a 16-character “rate identification number (RIN)” to combine six individual data fields. In Table D-4, below, “RIN[x:y]” refers to the starting character and number of characters in the RIN. The data model puts location information into the tariff name; MIDAS has this as a separate field, which may be a better solution. The RIN also lists the “poles and wires” company (“distribution”) which can be different from the retailer, as with California’s Community Choice Aggregation providers. MIDAS does not support long names of the retailer and rate.

Table D-4
Static data mapped into the MIDAS RIN

Data Model Element	MIDAS RIN Component	Comments
RetailerLong		Not supported
RetailerShort	Energy	RIN[7:2]; only two characters available
RateNameLong		RateName in RateInfo Table; “LSE’s name for each rate plan, consistent with the CEC’s Interval Meter Database required by Title 20 Section 134¬4-part h.”
RateNameShort	Rate	RIN[9:4]; only four characters, but does not include location
Country	Country	RIN[1:2]; same ISO standard
State	State	RIN[3:2]; same ISO standard
	Distribution	RIN[5:2]; Distribution utility
	Location	RIN[13:10]; length allowed to be 1–10 characters

The MIDAS system tracks holidays, as they have distinct prices in TOU rates. This complexity does not arise when rates are streamed.

MIDAS does provide for additional static data about rates beyond what the data model does. In addition to the above-noted Distribution utility, these are listed in Table D-5. Note that the RateInfo Table also includes the items from the RIN, including Country, State, Energy, Distribution, RateCode, and Location.

Table D-5
Other data model elements mapped into MIDAS RateInfo Table

Data Model Element	MIDAS RateInfo Element	Comments
RetailerLong		Not supported
RateNameLong	RateName	"LSE's name for each rate plan, consistent with the CEC's Interval Meter Database required by Title 20 Section 134¬4 part h"
	RateTypeID	General form of the tariff, e.g., TOU, CPP, RTP, …
	SectorID	< CHECK >
	TimeZoneID	Name of time zone (standard time only); the data model assumes UTC time.
	API	URL of where to obtain price data
URL	RatePlanURL	MIDAS does not mention the option of including machine-readable data in the URL.
	AltRateName1	Alternative name
	AltRateName2	Another alternative name
	SignupCloseDate	"The last date a customer may sign up for the rate"
	EndUseID	Uniquely identifies rate
BindingPrices		Not supported
LocalPrice		Not supported

MIDAS also includes fields for data about how the information was uploaded to the system from the retailer.

While MIDAS does support time-varying TOU rates, it does not support streaming prices, as the data model is designed for. The introduction to the documentation notes that it will support continuous data streams, but details of how this is planned is not yet available.[74]

Protocol Gaps and Proposed Improvements

The four protocols described above do have gaps in what we would like, either to add necessary or desirable features, to harmonize them with our data model, or to extend them to facilitating more broadcast communication, or adapt to local-only communication. The topics discussed below are likely not exhaustive but cover the most critical issues.

[74] "In the future, the MIDAS will support other time-varying system data such as California Flex Alert signals and marginal greenhouse gas (GHG) emissions." A Flex Alert is episodic, and so might readily also support CPP/VPP pricing on top of TOU rates. Marginal GHG emissions are inherently a continuous stream of data as real-time prices are, so the mechanism for that might readily be easily extended to such prices, for a time when they are readily available to customers.

Missing Data Elements

OpenADR 2.0b, IEEE 2030.5, and the MIDAS API all lack some of the static data elements in the Price Streaming Data Model, but these would be easy to add to each if they were to be modified. In addition, the MIDAS API does not support differential buy/sell prices. Moreover, the MIDAS API as it exists now is designed for TOU rates and will need to be updated to support streaming.

A consistent way to encode some of the missing static data elements into OpenADR was described above, but as this is not part of the OpenADR standard, it would have to be separately adopted by many organizations to accomplish interoperability. Much better would be to amend OpenADR itself to explicitly identify support for these fields in a simple and consistent way[75]. A similar method could be defined for IEEE 2030.5, though the availability of free-form data fields for the IEEE 2030.5 standard is considerably less than with OpenADR, so encoding in the available fields may not even be possible. As with OpenADR, this route is also less desirable.

It is also possible for manufacturers to simply start using the data fields above without or before a standards modification, but that would require being actively out of compliance with the standard, which raises a new set of problems and barriers.

Auxiliary Data

While pricing can do most of what is needed for grid / flexible load coordination for energy purposes, there are gaps. Some are known today, and some may become apparent in the future. One of these gaps is to send out messages that are intended for both human and machine use. These messages could be readily communicated over the same path as price. OpenADR, IEEE 2030.5, and CTA-2045 all have facilities for sending messages, but guidance is lacking on how to use them in a standard way, including for those that have data elements (e.g., times) as part of the message. Some known useful messages are as follows.

Flex Alerts

California makes effective use of occasional announcements that the grid is stressed by high demand and that voluntary cutbacks would be helpful for the common good. In the future we would expect these times to be accompanied by high prices, which could automatically induce a lot of shifting and shedding, but there may still be times when alerts intended for people are needed or helpful.

Announced Shutoffs

California has periodic Public Safety Power Shutoffs (PSPSs) for large utilities that have power lines in places that are in danger of starting wildfires during times of high wind, low humidity, and other conditions. These are for defined areas of the distribution system, and with a forecast start time and end time. At present, the Price Streaming Data Model encodes location as part of the tariff. It may be that this is insufficient for PSPS announcements. Whether there should be a

[75] Consideration should be given to use of the EiDistributeQuote message (part of EiQuote) as an alternative mechanism.

separate location data element for both price diversity and PSPS, or just a description of location in the PSPS message, deserves further consideration.

Grid Emergency

A grid emergency would be an indication that the grid is short of energy or the ability to deliver it, is or could be unstable, or is experiencing some other problem. An associated message could be that the emergency is over. Sites capable of islanding (microgrid operation) might island before the grid fails. Customers and devices might shed loads, to help better balance supply and demand. Sensitive process loads might begin a controlled shutdown. Backup generation that takes time to become ready might start up.

Distribution Startup

Utilities occasionally need to cut power to a segment of the distribution system for rotating outages. An entire grid also can go down, but this is equivalent from the perspective of the customer; once the grid goes down, to the customer it does not matter why or if it was announced in advance (other than possibly having a forecast restart time). On re-energizing a segment of the distribution system, it may be advantageous to announce this and to provide information about how quickly customers might increase their power draw (or power exported into the distribution grid) to manage the transition back to ordinary operation. Such behaviors could be fixed in advance, but that would limit utility options and customer capabilities. Thus, these messages would convey the general state of the grid as it starts up, and how quickly customer sites should ramp up their demand. The term *black start* refers to energizing a power plant or section of a utility grid without external support. This is distinct from how retail customers experience outages.

Service Discovery

A basic issue for many IT systems is discovering where on the network to find a service, to "discover" its identity and capabilities. Grid coordination in general and pricing is no exception to this; providing time-varying price information is the service. The mechanism for this, *service discovery,* is how a device on a network determines the identity of another device that can provide a service that it is interested in, and details of how to obtain the service. In web browsing for example, this is determining the URL of the page wanted, which can be determined by a link in a prior web page, forwarded to the browser by another application, or manually entered by the user.

OpenADR 2.0b references service discovery only in the context of the Extensible Messaging and Presence Protocol (XMPP). XMPP is one way to transmit OpenADR messages, but not the only one. When XMPP is used, the XMPP Service Discovery method is to be used. However, in the example shown in section 9.3.4.9.2 of the standard, the VEN device needs to already know the domain name of the VTN, and the discovery process confirms that the VTN supports OpenADR 2.0b. That is, it does not support a way to find the VTN name in the first place.

For IEEE 2030.5, a flexible load device might obtain information from a server within the local site, or elsewhere on the internet. In general, DNS methods are used for service discovery. IEEE 2030.5 provides for two mechanisms for a flexible load device in a customer site to discover a suitable server – mDNS (with the ".local" domain) and xmDNS (with ".site"). In practice, xmDNS is not supported, and the great majority of uses of IEEE 2030.5 are for wide area communications. Automatic discovery is not used; rather, the network location of the server is either built into the receiving device as it arrives on the customer site or is entered manually. Most uses of IEEE 2030.5 are for inverter management, and are direct to the individual flexible load, rather than through a customer central device for subsequent relaying locally. OpenADR is similar in that most uses are direct-to-flexible-load (or direct to a building management system that functionally controls flexible loads), with the most common use being demand response (to shift and shed loads).

However, for a future in which intra-customer communication becomes much more common, service discovery for price distribution would be highly valuable, to make initial device setup simpler and more automatic, and to improve reliability and maintenance to allow easy failover to a new server if one fails or is replaced. OpenADR might well leverage the same discovery mechanism as IEEE 2030.5 — mDNS — for intra-customer-site use.

For LAN service discovery, there is an internet technology mechanism for well-known uniform resource identifiers.[76] This mechanism may be helpful for service discovery or other aspects of price distribution.

Price Server Names

A *price server* is the device (likely utility-run) that sends out prices to customer devices. The naming of price servers is in many ways a subset of the naming of computers on the internet, including web servers. This problem was addressed 37 years ago with the creation of the domain name system (DNS), which translates names like `sce.com` to numeric IP addresses and facilitates tree structures of names with the dot separation. We can apply DNS technology to price servers. It is a principle of internet architecture that if a solution to a problem already exists, do not create a second solution[77]. This is one way to address WAN service discovery.

As an example, suppose there is a server — `eprice.ca.gov` — for any price in California, and suppose a customer has SCE as their utility and RESRT5 as the tariff. The customer could go to `eprice.ca.gov/sce/resrt5` and request the tariff for SCE and that tariff. Or they could go to `sce.eprice.ca.gov` and request the tariff[78] or just go to `resrt5.sce.eprice.ca.gov` and get the current price without needing to specify anything else.[79] This would work whether everything was hosted on the same server or if there were subsidiary servers for each utility or tariff. As domain names are global, this readily scales to other states and countries, and to other forms of energy. The DNS system has security and redundancy capabilities that would be inherited automatically for this application.

[76] Nottingham, M. Well-Known Uniform Resource Identifiers (URIs)m RFC-8615, May 2019.

[77] Carpenter, Brian, Architectural Principles of the Internet, RFC-1598, 1996.

[78] Note that we might encode the name of Pacific Gas and Electric Company as “PGE”. This is also a common abbreviation of Portland General Electric. However, since the California PGE is under the “ca.gov” domain and the Oregon PGE would be under “or.gov” then there would never be any ambiguity.

[79] The system could be further extended by adding locations within a rate, though the identity of a region with a distinct tariff could be encoded in the tariff name.

Using DNS for this purpose is an implementation detail in the scheme of the overall architecture, but it is an example of leveraging powerful technologies already in use today for non-energy purposes.

It is not an accident that the examples above use the `.gov` domain name; this is controlled for those who can create entries within it, unlike ones such as `.com` and `.org`. Commentators have pointed out that in cases such as voting information, it is possible for people to put up sites with fake information, but if all such sites were in the `.gov` domain and voters knew that, the potential would be greatly reduced. The same principle applies to electricity prices. Such a base `.gov` URL could then lead to a non-.gov domain through a redirection (this is commonly done in web browsing) so would not require that the public sector be the entity that runs the underlying service. That said, using the above conventions for encoding the retailer's name and tariff (including location) in a consistent way would help. Defining a standard name for a LAN price server would also be helpful.

Security

A hallmark of both OpenADR and IEEE 2030.5 are their security mechanisms, as compromised communication could not only harm customers in the behavior of their devices but could also harm the utility grid. Both standards are based on two-way communications. As pricing only requires one-way communication, an adaptation is required. The MIDAS API does not address security yet. Only the first version has come out, so we can expect that this will be addressed in a future modification.

There are multiple aspects to security issues. One is to ensure that data traffic is not corrupted between the sender and receiver of data. Both standards use SSL/TLS (Secure Sockets Layer / Transport Layer Security) for this purpose; IEEE 2030.5 specifically HTTP over TLS. TLS is very widely used and is the source of the "s" in "https" for many web addresses. OpenADR supports both RSA and ECC public key cryptography. IEEE 2030.5 mandates ECC.

IEEE 2030.5 also provides for limiting the types of information accessible to different devices, and which can set data elements. This does not apply to pricing since all devices in a customer site should have access to price data, except that no device in a customer site should be able to set the price data.

Security cannot always be done totally within a single mechanism;[80] for example, the standard states that "VENs must facilitate registration by providing a 'certificate fingerprint' which can be easily transmitted out-of-band to the VTN." As the number of devices using the standard grows, it will be essential to ensure that these mechanisms are user-friendly. OpenADR also supports XML signatures. IEEE 2030.5 supports a six-digit PIN for out-of-band authentication.

Another issue is for each side to be able to authenticate their identity so that the other side of the interaction is confident that they are communicating with the device they think they are, and not sharing data with other devices. One recognition of how Pricing is different from other types of

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[80] As another example, an increasing number of email and other IT systems employ two-factor authentication (or multi-factor authentication more generally).

coordination in IEEE 2030.5 is that per Table 12 of the standard, a "device certificate" is not needed for price or message communication.

Neither one of the standards natively supports one-way communication, so that adaptations to security measures will be needed for that.

OpenADR 2.0b states that "All certified OpenADR 2.0 products must be upgradable." This notion is increasingly becoming the norm, with the recognition that over time, holes in existing security mechanisms may likely be uncovered and need to be fixed, and newer more robust mechanisms will become available.

Broadcasting

A price broadcast over FM radio is inherently one-way. A technology vendor for this, e-Radio USA Inc., has authentication technology available to ensure that a bad actor cannot broadcast incorrect price data and have devices assume that it is correct. This is essentially a closed system in which the same company controls both ends of the data link, and so the security mechanism does not need to be in an open standard.

It may be desirable to create a new mechanism for price broadcast over the Internet, with an appropriate authentication mechanism. The data could be encoded in a format compatible with OpenADR or IEEE 2030.5, but as both standards are based on two-way communication, this would be a distinct protocol. Broadcasting is not well developed in Internet technology so this might require innovation in core protocols, or perhaps more likely, use mechanisms developed for streaming media Content Distribution Networks. However, it was done, a receiving device would only need to know the identity of the retailer and the name of the tariff to know which tariff to "listen" to among many that might be broadcast. Data in the MIDAS API format could be similarly broadcast if a mechanism were created.

Whereas FM radio is inherently a broadcast medium, internet communications are point-to-point.[81] To address this, without sending out data to parts of the network for which there is no recipient, a mechanism called the Internet Group Management Protocol (IGMP[82]) was created. It enables "multi-cast," where a single data stream is sent to many devices on the network with a high degree of efficiency. The generic multicast facility enables many devices to send data into the multicast stream. This is not needed for prices, and a more secure source-specific multicast (SSM) way of using IGMP ensures that only one device can send data into the stream. The cellular radio system has a similar mechanism — Multimedia Broadcast Multicast Services (MBMS) — which can avoid large numbers of unicast messages. Since data bandwidth on cellular networks can be scarcer than in our wired networks, multicast may be especially useful, or useful sooner, for this context.

More research is needed into this topic to understand possible security issues that may be involved, and to understand how the locationality of price broadcasts might affect how best to

[81] Broadcast data are used in internet technology, but only within local area networks or subdivisions within a LAN called a *subnet.* These are for network purposes not readily accomplished through other means. Price communication would not generally fall into this category.

[82] IGMP only applies to IPv4 communication. For IPv6, there is a parallel mechanism called *multicast listener discovery* (MLD).

use multicast systems. There is always the option of relying only on traditional unicast, and in the near term that is the most likely solution to be used.

Pushing vs. Pulling Data

Both OpenADR 2.0b and IEEE 2030.5 support both push and pull of data from central price servers to customer sites and flexible loads. In both cases, pulling data is much more commonly used and is the base case of operation anticipated by the standards. In IEEE 2030.5, data are pushed with a “subscription” service from some servers. One reason for the emphasis on pulling data is that LAN firewalls typically block incoming web requests from the outside and initiating the conversation from inside the LAN prevents this problem. However, this requires ongoing polling from the customer site to determine if a new message is available. Something like occasional demand response signaling (e.g., a “shed” command that arises only every few days or weeks) that is not scheduled in advance would require polling.

One solution for routine price communication (e.g., on a five-minute cadence) is for a customer to request the next price immediately after receiving the current price, but having the server wait before sending out the next price, as it likely will not be available until the five minutes have expired. This requires attention to network time-outs, as a firewall will only remember the “hole” being created by a request for a finite time period. Another solution is to manually create an exception in the firewall rules for the price communication, but this has many problems of its own, and is unlikely to be a desirable route.

This topic also raises the question of the underlying transport mechanism. HTTP is currently used by both OpenADR and IEEE 2030.5, but it may be more efficient to use XMPP or MQTT.

For now, flexible load deployments will need to use the existing pull or push mechanisms, which will require substantial scale-up of infrastructure for utilities to serve the large number of customers and devices involved. This is one of the reasons that a CCE is desirable, so that only one device per customer site needs to obtain prices from the outside rather than each of (potentially many) flexible loads doing it separately. Later, if standard broadcast mechanisms are developed, then these could be used in new flexible loads and central entity devices or retrofitted onto existing ones with software updates. Whether push or pull methods are used should be informed by the efficiency of their usage. This is related to the volume of data required for each periodic price transmission, as discussed below.

Data Efficiency

OpenADR 2.0b and IEEE 2030.5 are both highly verbose in their operation, for three reasons. They both use XML, which takes a lot more bytes of data than more recent alternatives such as JSON. They both send more data elements than are really needed for communicating prices. Finally, they both implement pricing as part of constructs that are for a much wider variety of purposes — general purpose events — and so inherit unneeded complexity from this. Mechanisms could be defined to essentially subset and streamline the data from both standards in a way that would retain complete semantic harmonization but use far fewer bytes of data. This would be particularly useful for data links that have some constraints, such as for cost of cellular data, or for future low-bandwidth in-building technologies. In addition, when many tariffs are being broadcast, the amount of data sent out overall is multiplied.

WAN vs. LAN Communication

Price communication today is generally a wide area network (WAN) issue. Prices either flow from one grid entity to another (e.g., from a retailer to an aggregator) or from a retailer to an individual flexible load or central building management system that directly controls the flexible load. Price communication entirely within a customer site is much rarer. Only IEEE 2030.5 directly contemplates wide use within a LAN, though in practice that feature is not commonly used today.

Both standards would benefit from adding capability to better support LAN-only use. In the OpenADR case, this would be for LAN service discovery. In both cases, it should be considered if any adjustments should be made to the security and authentication mechanisms.

For WAN communication, there is the question of what to call the entity that send out prices. The term *demand response automation server* (DRAS) is used today for the device that sends out any DR signal, so a price is naturally a (specific) subset of that. The term *distributed energy resource management system* (DERMS) also conceptually covers sending out prices, but DERMS systems are generally much more command-and-control in their operation than pricing inherently is and are often used for more power-related issues (as with inverter management), and so cover a much wider range of topics than pricing alone. A DERMS system is often the one that determines what control should be done, so that determining what prices to send out could be a generic DERMS function. The MIDAS API documentation uses only the term *server,* though previous CEC load management standards documents used the term *price portal.* The PBGC architecture uses the term *price server.* Ultimately, it is not so important what the entity is called, as long as there is consensus on what communication protocols to use, and how to use them, for each "coordination architecture" supported.

Possible Protocol Evolution

Changing any of the three standards in question relies on issues of *process* and *content*. For process, it requires a critical mass of interest in making a revision. There is a burden of complexity in having multiple versions of a standard out, so this is not undertaken lightly, but when the revision is fully backwards compatible, that concern is eased. Each organization has its own procedures for deciding when and how to make a revision. For content, one needs to identify the topic areas to be considered to change, ideally with a sketch of the solution, and possibly even draft standards text, so that others can fully understand the proposals and their implications.

IEEE 2030.5 is currently in the midst of being updated. The first version was dated 2013 and the second 2018, and a third version is planned to come out in 2022. In 2020, a call went out for proposals to modify the standard, and most or all were about inverter issues and metering — none on pricing. In the fall of 2021, LBNL proposed to add price metadata, and the proposal was accepted. As of March 2022, the standard is in the final stages of revising the text for the 2022 revision and includes the metadata additions.

There has been discussion of creating an adaptation of OpenADR that is optimized for price distribution and other simple messaging. It came up at the 2019 International OpenADR

Symposium (June 2019)[83] but has been discussed before and after that. The Symposium presentation noted that the new standard could be strictly a subset of 2.0a or 2.0b or could be created separately from these. Procedurally, the OpenADR Alliance can initiate a revision process at any time but would need a critical mass of interest from its stakeholders to do so.

CTA-2045B was updated to incorporate the Price Streaming Data Model elements, so needs no further updating at this time for the interface it covers, from the module to the appliance. For CTA-2045, when the 2045B version was established, the number of time/price pairs that can be sent was increased from two to many dozen. While this is helpful, there is still work to be done for the standard. The biggest issue is that CTA-2045 only defines communication from the module to the appliance (the *smart grid device,* SGD). Communication from the module to the outside world is often proprietary, though it could be OpenADR or IEEE 2030.5. The ideal outcome would be creation of a much simpler form of one or both standards, and to use that for communication to the module. As an organization, the Consumer Technology Association (CTA) generally works faster than either the OpenADR Alliance or IEEE, so it could define the simpler version and then shift the content to the other organization.

The CEC can change the MIDAS definitions any time it chooses. At some future time, it might deposit the content with a recognized standards development organization, but that seems unlikely in the near term.

Based on the discussion above, the following recommendations should be considered:

- Add the missing data elements (mostly static) to the three WAN protocols.
- Define standard ways to use the messaging functions to send out common messages so they can be interpreted by both humans and devices. For MIDAS, add a message function (this could be readily done when price streaming is added). For the data model, add definitions of the common messages. As in all these cases, what is defined is just the content of (mostly existing) text message fields; this might be readily done with a common external document/standard. OpenADR 2.0b, IEEE 2030.5, and CTA-2045 already have the capability to send such messages.
- Reconsider service discovery both at the WAN and LAN levels as described above, and add features as needed.
- Explicitly reference using DNS names for finding price servers, as described above. There would need to be a document defining this separate from the individual standards.
- Support one-way broadcast of prices, reconsidering security mechanisms in this context.
- Enable the use of JSON (or a similar efficient method) encoding of price data, at least as an option. Allow receiving devices to support only the efficient method (senders likely will need to support XML also).
- Consider adaptations of each protocol when used only within a LAN.

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[83] See "OpenADR for Everyone" presented by Bruce Nordman, LBNL; https://www.openadr.org/assets/symposium/2b.Nordman-OpenADR 2019.pdf

None of these are necessary to begin streaming out prices but addressing them would have a wide variety of benefits and should be prioritized.

How Network Automation Could Ease the User Experience

Imagine that it is a few years in the future, and a customer has just bought a new refrigerator. As a default feature (and a requirement for ENERGY STAR compliance, which she insisted on), it can adjust its temperature setpoints for the refrigerator and freezer compartments based on dynamic prices. It also can receive a grid signal of a possible grid shutoff (e.g., due to wildfire risk) with the same communication mechanism, and this causes the unit to immediately pull down the temperatures to their lowest reasonable point regardless of price.

She connects the refrigerator to the local Wi-Fi network (ideally with a pairing mechanism that does not require manually entering the network name and password). The refrigerator uses a standard mechanism to automatically search for and discover a local "price server" — local to the customer site. If it finds such a server, it subscribes to broadcasts from that server, or regularly queries it for new prices. This should ideally require no user interaction beyond the Wi-Fi pairing to set up. The device might ask the user for preferences about how responsive to price the load should be.

If there is no local price server, the device will ask for the retailer and tariff names, then search on the internet for a price server. Other than entering the retailer/tariff names, the process should be completely automatic.

The DNS is an example of device/service discovery and applies at both the local and wide area levels. Each organization has a local DNS server so if someone searches for rates.sce.com from within the SCE network, that will be resolved to an IP address and returned without ever involving the outside world. A request for this from outside SCE would be routed to the company's DNS server from a higher-level one. Without DNS we would need to manually enter IP numeric addresses which would be time-consuming and error prone. This is the type of automation that we need to create for load flexibility systems.

Another type of network service is the dynamic host configuration protocol (DHCP), which is how devices on a network (as an ordinary computer) are assigned a dynamic IP address, rather than having to hardwire a fixed one. A device on a network can discover the location of the DHCP server automatically and interact with it routinely.

Any device on a LAN could host a price server — it could be a dedicated device, any PC, a Wi-Fi router, or a building automation system. This is an example of the term *customer central entity* — to refer to the device that happens to be hosting the function of price serving, regardless of what type of device it is. In this case the CCE only serves prices, but it could also host load control algorithms for some or all devices in a facility.

DNS systems, and many network systems, have mechanisms so that if a device fails or is otherwise unreachable, then requests are automatically redirected to a backup device. Larger sites will want to have such redundancy for a price server, so we should create standard mechanisms for this.

This example raises another automation need that is not energy-specific, but particularly acute for energy applications. As many devices in customer sites get connected to local Wi-Fi networks, sooner or later there will likely be a time when the service set identifier (SSID) of the network (its name as seen by the user) changes, the password changes, or both. Making a list of every connected device and manually updating each one would be time-consuming and error prone. It could be easy to forget a device that is networked but that the user rarely interacts with directly (e.g., the water heater in the basement). Creating an automatic system that can move devices with existing connections to the new SSID or to the new password could circumvent this need. Care must be taken for this to not introduce cybersecurity or privacy risks.

E
COMMUNICATION ARCHITECTURE DETAILS

This appendix expands on the content about our communication architecture presented in the body of the main report, particularly details of the data communicated.

In parallel to the development of Price-Based Grid Coordination (PBGC), the California Energy Commission (CEC) made public a proposal[84] for the upcoming Load Management Standards (LMS) update, called MIDAS (Market Informed Demand Automation System). Comparing PBGC and MIDAS, there is broad consistency between the two approaches. The differences are generally more a matter of emphasis rather than any fundamental incompatibility. The CEC also proposes to disseminate marginal greenhouse gas (GHG) signals in parallel to retail prices. In addition, the California Public Utilities Commission (CPUC) has made staff proposals for a similar model, called UNIDE (UNIfied, universal, Dynamic Economic signal), which is also in the same vein as PBGC[85] (CPUC, 2021).

Prices that change every day in response to grid conditions could help the grid balance supply and demand and manage capacity constraints. Given how the grid operates, we can expect that such rates will be able to change at least hourly, but not more frequently than every five minutes. When locational concerns are considered, and locational rates offered, prices can be an even better tool for utilities. This can be accomplished solely with more fine-grained tariff offerings, so they do not affect in-building technologies.

Figure E-1 shows the complete PBGC architecture. It shows that some communication is in the form of functional control signals, sent by a control device (third party, external control, or Customer Central Entity (CCE) that has incorporated the price into flexible load operational objectives and made control decisions.

[84] California Energy Commission [CEC], Draft Staff Analysis of Potential Amendments, Mar 3, 2021 https://www.energy.ca.gov/publications/2021/analysis-potential-amendments-load-management-standards

[85] California Public Utilities Commission [CPUC], Advanced DER and Demand Flexibility Management Workshop, May 2021, https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-costs/demand-response-dr/demand-response-workshops/advanced-der-and-demand-flexibility-management-workshop

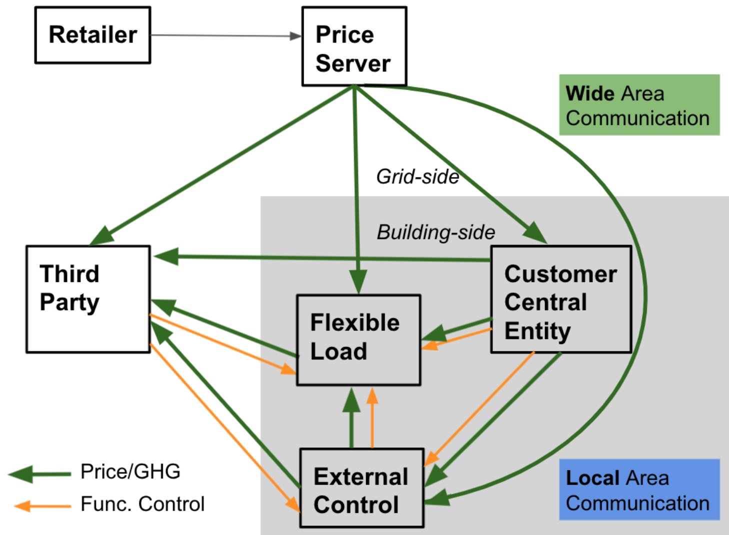

Figure E-1
Overall PBGC communication architecture – full detail

Data Model Issues

The data elements for the Price Streaming Data Model are listed in the main report. The model has a set of static data elements that rarely or never change, such as the identity of the retailer, the currency, etc. The dynamic data elements are sent on a regular basis each time a future price changes[86] or additional future prices are added to the list; these data are just times and prices. Any communication protocol should cover both. This section discusses the data elements in general terms for how they may be covered or encoded in protocols.

Many of the static data elements are not available in some protocols, so a convention outside of the protocol standard will need to be defined to do this (e.g., putting the elements into some available text field with a defined encoding[87]), or the standard will need to be amended.

Retailer/Tariff Names

As there is no existing standard for retailer and tariff names, any encoding will necessarily be an artifact of this proposal. For use internationally, a specification should be made about what characters are allowed; the easiest way to do this is to specify if the characters are limited to US-ASCII, or if UTF-8 (which allows for characters with accents and non-roman character sets) could be used. However, these characters take more bytes of data than US-ASCII characters, which raises the question of how many bytes should be defined as a minimum to be supported by a given protocol. The long names are for user convenience, so if they are unintentionally abbreviated, the loss is low. The abbreviations in contrast will be used for machine-to-machine communication, so ambiguity is not an option.

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[86] It is assumed that once a time period begins, price is not allowed to change for that period. Whether the duration of the period should be allowed to change is an open question.

[87] This sort of band-aid is far from ideal and can easily break interoperability. Putting such content in the standard itself is really the only satisfactory solution, though it takes time to make that happen.

The proposed data model uses the term *rate,* but *tariff* is more technically correct. That said, most customers are more familiar with the term "rate", as evidenced by the use of that term (rather than tariff) on many electric utility websites.

Country, State, and Currency Codes

These are already well defined by ISO standards.

Dates

A protocol may have an existing way to encode dates, in which case adopting that for new dates is likely the best option. That said, the existing encoding might be binary, with the available data field a text one, in which case adopting the ISO format would be likely preferred. It is important to identify which data elements are just dates, and which are dates and times.

URL

The syntax for a URL is already well-defined by standards. Questions that arise are:

- Should a minimum length to be supported[88] be specified?
- Should internationalized URLs be allowed (IRIs, which use the Internationalized Domain Name (IDN) standard, but are often encoded as "punycode"[89])?
- Should any conventions on the URL be recommended?
- Should recommendations be made for the human-readable part of the web page? The machine-readable portion needs a standard. It would have a few mandatory sections, with another set that is optional.

Flags

The two true/false flags should be readily encodable. There is a question of whether there should be an option for "not known."

Dynamic Data

The general encoding of pairs of times and prices is likely to be defined by the protocol standard. The key is for there to be an unambiguous translation between that and the reference data model, so no information is lost. The choice of absolute versus relative time will be made by the protocol.

Some protocols may not include the "ExportPrice" field, as that is a newer and less common feature than the regular "sell" price. This might be encodable as a separate field or sent as a separate "rate."

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[88] Many protocols have limits on the length of some or all data fields. The RatePlanURL in MIDAS can be no longer than 500 characters.

[89] See https://en.wikipedia.org/wiki/URL, accessed June 21, 2021.

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