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CALIFORNIA ENERGY COMMISSION

California Energy Commission

CONSULTANT REPORT

Expanding Flexible Demand through Public Broadcast of Greenhouse Gas Emissions and Electricity Prices

Costs and Benefits of Potential Appliance Standards

Prepared for: California Energy Commission

Prepared by: Herter Energy Research Solutions

Herter Energy

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California Energy Commission

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Finally, considering the broad implications of this report's findings and recommendations, we value and appreciate in advance the contributions from policymakers, stakeholders, and the public that will help confirm or challenge the accuracy of our preliminary results.

PREFACE

The Flexible Demand Appliance Standards are a consequence of Senate Bill 49 (Skinner, 2019), which authorizes the California Energy Commission to reduce electric power sector greenhouse gas emissions through standards that "enable appliance operations to be scheduled, shifted, or curtailed" with consumer consent. The new appliance standards will support grid reliability by improving the alignment of electric demand with clean energy production.

In collaboration with the California Public Utilities Commission and load serving entities, the Energy Commission is developing a cohesive statewide approach to mass-market demand flexibility through the Flexible Demand Appliance Standards. Given the significant scope and potential wide-ranging effects of this initiative, the Commission is conducting a comprehensive analysis of various load management technology options to assess their feasibility and cost effectiveness. This white paper is one of a series completed under contract 400-22-002 intended to support this effort.

ABSTRACT

As part of its initiative to expand demand flexibility, the California Energy Commission is exploring options for delivering price and greenhouse gas emissions forecasts to appliances from California's Market Influenced Demand Automation Server, commonly known as MIDAS. The purpose of the envisioned MIDAS signaling system is to enable the coordination of appliance operations with grid conditions, lowering greenhouse gas emissions and utility bills for all electricity customers, including those in settings without access to broadband internet.

This paper evaluates broadcast radio, cellular radio, and smart meters for use in transmitting MIDAS signals to California appliances. After excluding smart meters due to the absence of universal availability, we determine that broadcast and cellular radio technologies have the technical capacity to reliably deliver MIDAS data messages statewide.

A subsequent cost-benefit analysis compares the feasible technology options across eight scenarios. Results point to a solution involving three key features: grid-friendly default schedules; plug-and-play response to broadcast MIDAS data signals; and an expansion port that enables third-party program participation. In combination, these components have the potential to cost-effectively provide 8 times the flexible demand resource of the business-as-usual scenario, delivering more than 6 gigawatts of flexible capacity to California by 2035.

Keywords: Flexible demand, appliance standards, MIDAS Plug-and-Play, CalFUSE, price response, demand response, load flexibility, distributed energy resources, greenhouse gas emissions, real-time pricing

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EXECUTIVE SUMMARY

As part of its initiative to expand demand flexibility, the California Energy Commission is exploring options for delivering price and greenhouse gas emissions forecasts to appliances from California's Market Influenced Demand Automation Server, commonly known as MIDAS. The purpose of the envisioned MIDAS signaling system is to enable the coordination of appliance operations with grid conditions, lowering greenhouse gas emissions and utility bills for all electricity customers, including those in settings without access to broadband internet.

This paper evaluates broadcast radio, cellular radio, and smart meters for use in transmitting MIDAS signals to California appliances. Smart meters are excluded from consideration due to a lack of statewide consistency: not all utilities use smart meters, and where they do exist, the protocols are not universally compatible. Detailed technical assessments of the remaining options suggest that broadcast and cellular radio technologies are both capable of feasibly delivering MIDAS signals to appliances across the entire state.

A subsequent analysis of eight different scenarios yields the following key findings:

1. Standards for default appliance settings that automatically respond to MIDAS signals upon installation – termed 'MIDAS Plug-and-Play' in this paper – could enhance the impact of the Flexible Demand Appliance Standards by 700%, as shown in Figure 1.
2. Delivering MIDAS signals via statewide public broadcast is predicted to cost about one-tenth as much as using cellular or Wi-Fi internet technologies, with estimated capacity costs under $10 per kilowatt. (See Figure 2.)

Figure 1. Potential Flexible Demand Appliance Resources, 2026-2035

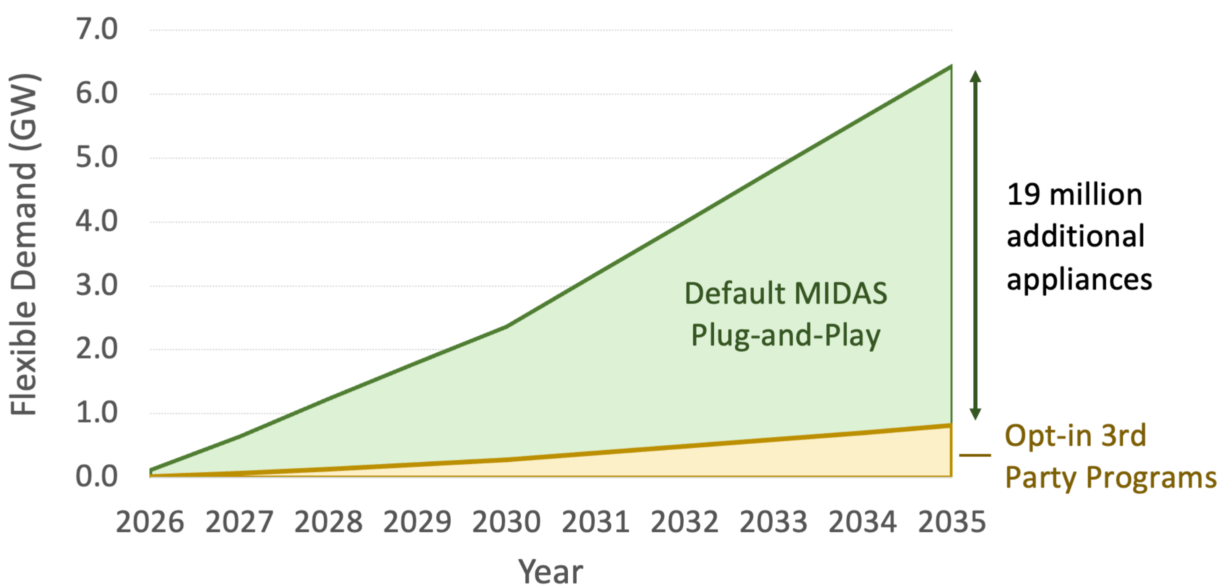
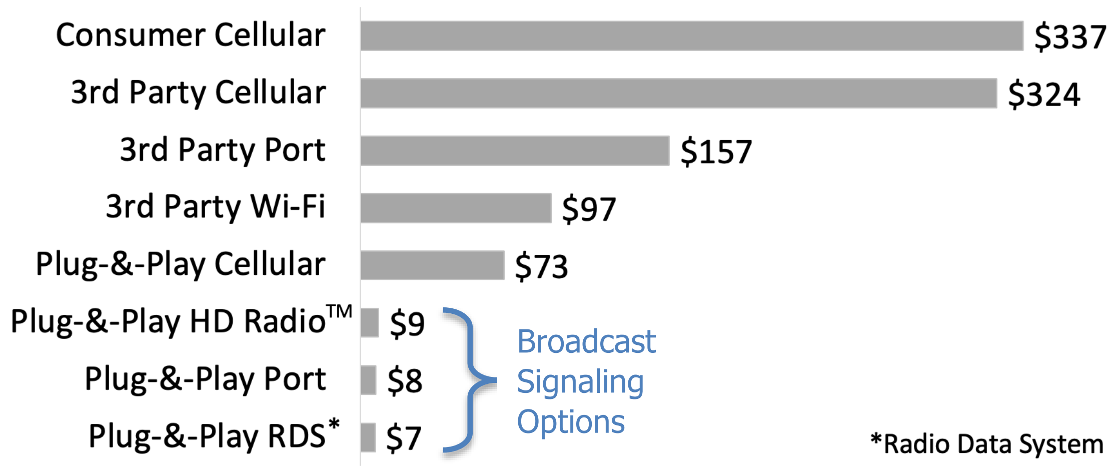


Figure 2. Average Capacity Costs for Hypothetical FDAS Scenarios ($/kW)



We conclude that implementing default MIDAS Plug-and-Play flexibility through a statewide public broadcast has the potential to deliver eight times the flexible capacity benefits at one-tenth the cost of conventional Wi-Fi solutions. Additionally, the 'third-party direct operation' prioritized by Public Resources Code §25402(f) can be cost-effectively achieved using standard communication expansion ports, which support program diversity and evolution. Together, these features have the potential to maximize costs and minimize benefits at zero cost to the State of California.

Our recommended next steps include several key initiatives: updating MIDAS, developing appliance response algorithms, demonstrating the system in action, and modeling grid effects. These steps are achievable within one to two years, paving the way for implementation by 2026.

A significant limitation of this study is the absence of a detailed analysis of consumer privacy and cybersecurity risks. These critical issues, among others, will be addressed in subsequent research in the coming months. Consequently, the findings and recommendations of this paper should be considered preliminary and subject to further validation.

CHAPTER 1: Introduction and Background

California has long been at the forefront of innovative energy policies and initiatives aimed at enhancing sustainability and grid reliability. The state's ongoing quest to expand flexible demand resources can be traced back to its complex energy challenges, which include managing high energy demands during heatwaves, integrating fluctuating renewable energy sources such as solar and wind, and achieving ambitious environmental targets aimed at reducing greenhouse gas emissions.

The vulnerability of California's energy infrastructure was highlighted during the early 2000s, when the state faced severe energy crises characterized by widespread blackouts and grid instability. These crises underscored the critical need for a more resilient and adaptable energy system. Subsequently, California invested heavily in renewable energy, which, while beneficial for reducing carbon emissions, introduced variability in power generation, leading to periods of both power surpluses and deficits.

To manage these challenges, California has increasingly recognized the value of flexible demand resources. Flexible demand involves adjusting consumer and business energy usage patterns to better align with the availability of renewable energy and overall grid needs. Communications and controls for thermostats, battery storage systems, and other "smart" appliances enable the shifting of energy use away from peak demand periods towards high supply periods, thus better aligning demand with renewable energy availability.

The push for expanded flexible demand resources is also driven by California's progressive environmental goals. The state aims to reduce greenhouse gas emissions to 40% below 1990 levels by 2030 and achieve carbon neutrality by 2045. Decarbonization involves not only the electrification or reduction of carbon-emitting end uses, but also the continued expansion of clean electricity supplies and, as addressed in this paper, a system that optimizes the use of this clean energy through strategies that maximize demand flexibility.

To promote the alignment of electricity demand with carbon-free supply, the California Energy Commission (CEC) is advancing a concept originally developed in the early 2000s by the Demand Response Committee, directed at that time by Commissioner Arthur Rosenfeld, who envisioned a statewide system capable of delivering "time-varying signals reflecting economic, reliability, or environmental conditions" to facilitate what is today recognized as demand flexibility. With the recent rollout of the Market Influenced Demand Automation Server (MIDAS), the CEC now has the capability to transmit signals that represent electricity prices, greenhouse gas emissions, or other time-dependent grid indicators directly to compatible appliances. These "MIDAS-ready" appliances could potentially be standardized under the Flexible Demand Appliance Standards. However, the specific signaling infrastructure needed to transmit data from MIDAS to these appliances has not yet been defined.

The aim of this paper is to evaluate the feasibility and costs of various communication technologies considered for the standard MIDAS signaling infrastructure. To address equity concerns, the CEC is most interested in solutions that operate independently of local internet networks, which are not universally accessible, and are notoriously unreliable.

Policy Context

The CEC has been dedicated to supporting the implementation of a statewide flexible demand system since the California energy crisis in 2001. The CEC's earliest efforts focused on four primary elements necessary to support such a system:[1]

1) Interval (Advanced) Meters
2) Time-Varying and Dynamic Prices
3) Common Information Model
4) Common Signaling Infrastructure

Over the span of several years, the CEC's Demand Response Committee, led by Commissioner Arthur Rosenfeld, successfully lobbied for the installation of interval meters and time-varying rates – items (1) and (2) above. Items (3) and (4), however, proved more challenging. The committee determined that a common signaling infrastructure must be specified in standards so that manufacturers could incorporate communications receivers able to access the flexibility signals. A standard information model including the message format must also be specified so that appliance manufacturers could program their products to receive and respond to the flexibility signals as required.

In 2008, the Title 24 Building Energy Efficiency Standards team attempted to cost justify a common statewide signaling infrastructure through proposed standards for mandatory emergency air-conditioning response.[2] The technical feasibility and cost effectiveness of the proposed system were validated by several studies; however, the effort ultimately failed due to widespread concerns about government overreach. In the wake of the political blowback, the CEC was forced to reevaluate the prudence of mandatory demand response. The lack of an immediate alternative paired with decreasing marginal electricity prices set the stage for a shelving of the four-step flexibility plan in favor of incentive-based demand response programs that persist to the present time. Today, there are still no signals "reflecting economic, reliability, or environmental conditions," and California electricity consumers have no opportunity to automate bill savings. (See box this page.)

> **California Vision Statement**
>
> All California electricity consumers will have the opportunity and capability to adjust their usage in response to time-varying signals reflecting economic, reliability or environmental conditions."
>
> – CEC, CPUC, CA ISO in "California Demand Response: A Vision for the Future" (2008)

In October 2022, the CEC adopted amendments to the Load Management Standards for the first time in four decades. The new regulations establish the MIDAS – short for Market Informed Demand Automation Server – a data warehouse and API for electricity rates, greenhouse gas emissions, grid alerts, and other time-varying grid signals.[3] The standards also

[1] CEC internal memo, "Using the Load Management Standards to Create a Successful Demand Response Infrastructure." 2008.

[2] CEC Proposed Title 24 Thermostat Standards, 2008.

[3] https://www.energy.ca.gov/proceedings/energy-commission-proceedings/inactive-proceedings/market-informed-demand-automation

require the largest utilities and community choice aggregators to upload their time-dependent rates to the MIDAS database and keep them current.

Around the same time, the CPUC published a complementary proposal for statewide load flexibility.[4] The proposal recommends the development of a universal, statewide data stream of 5-minute electricity prices to replace the current assortment of rates, supply-side programs, and distribution-level demand response initiatives.

For large numbers of customers (both residential and commercial) to adopt flexible demand management solutions at the scale necessary to support the future electricity grid, **automation technologies** for controlling various end-uses and DERs **must be inexpensive and ubiquitous**. For this to be true, there must exist a robust and stable policy pathway that is **standardized**, easy to implement, and allows the industry to develop low-cost, **flexible demand management** capabilities and integrate them into smart end-use devices and DERs **by default** for use by **all customer classes**."

– CPUC Energy Division 2021

One outcome of the staff proposal was CPUC Rulemaking 22-07-005, the Order Instituting Rulemaking to Advance Demand Flexibility Through Electric Rates,[5] which spawned a series of working group meetings. During these meetings, the CPUC, investor-owned utilities (IOUs), and Community Choice Aggregators (CCAs) unanimously agreed that the CEC's MIDAS platform would be the foundation for statewide flexibility signals going forward.[6]

MIDAS

The MIDAS database stores time-dependent rates from California load serving entities (IOUs and CCAs) along with time-dependent grid data such as greenhouse gas emissions and California Flex Alerts called by the California Independent System Operator (ISO). These data are publicly accessible via an open source API[7] to help consumers shift connected appliance loads in ways that save money, reduce statewide grid emissions, and improve grid reliability. Today, anyone with internet access and API programming competence can retrieve this information from MIDAS through the internet.

Today, the CEC's MIDAS holds about 19,000 time-dependent rates from the largest load serving entities in the state. Each rate is assigned a unique Rate Identification Number (RIN) that identifies its country and region of use, utility, load serving entity, rate identification code, and location identification code, as shown in Figure 3.

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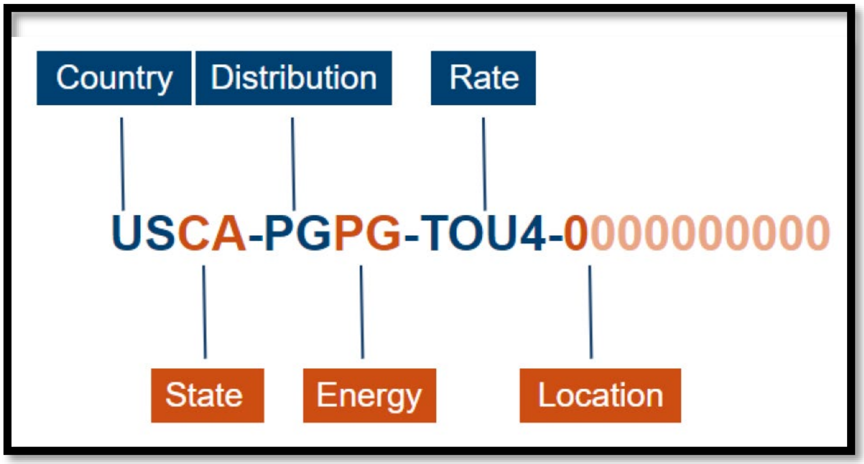
[4] CPUC Energy Division. Advanced Strategies for Demand Flexibility Management and Customer DER Compensation. June 22, 2022.

[5] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-costs/demand-response-dr/demand-flexibility-rulemaking

[6] CPUC Demand Flexibility OIR Track B Systems and Processes: Working Group 2, Joint IOU Proposal Summary July 28, 2023.

[7] Application Program Interface; https://gitlab.com/CEC-MIDAS/midas-documentation

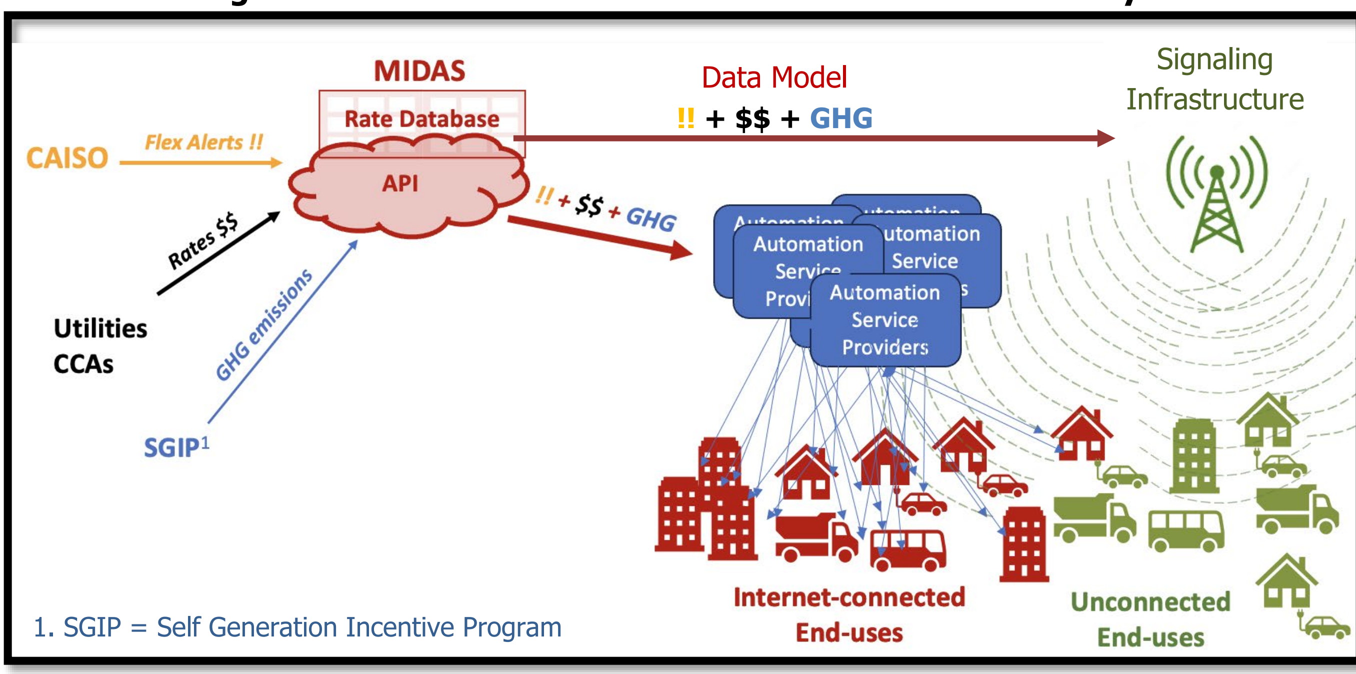
Figure 3. Format of Rate Identification Numbers as stored in the MIDAS



Source: California Energy Commission

The CEC has proposed an end-stage scenario for mass-market load flexibility as illustrated in Figure 4. Stakeholders are now looking to California agencies to define the signaling infrastructure and data messaging formats needed to make this vision a reality.

Figure 4. California Vision for Mass-Market Load Flexibility



Because the MIDAS platform was designed to send but not receive data, MIDAS response does not require that appliances have two-way connectivity. Instead, flexible appliances can receive and process the MIDAS information and act accordingly as programmed by the manufacturer or the consumer. Examples of other systems that use a unidirectional architecture include GPS receivers, radio-controlled clocks, emergency alert receivers, digital signage displays, and e-book readers. One might even consider the text sent to millions of Californians on September

6, 2022, an effective demonstration of a one-way voluntary flexibility signal.[8] A more in-depth consideration of the potential limitations and benefits of unidirectional and bidirectional signaling infrastructures will be completed under Subtask 2.5 of this contract.

Statement of Work

As of 2022, about 20 percent of low-income households and 30 percent of rural households were without broadband internet access. [9] Recognizing that not all California residents and businesses have internet access and that some appliances may not be within range of local Wi-Fi networks, the CEC is exploring alternative methods to disseminate MIDAS signals. The purpose of this white paper is to investigate these alternative transmission pathways – i.e., those "not reliant on an internet gateway device and local Wi-Fi"[10] – for the purpose of delivering MIDAS data to appliances. Specifically, this investigation considers the feasibility of broadcast radio, cellular radio, and smart meters.

For each technology that passes our initial feasibility assessment, we provide the following in relation to the delivery of MIDAS real-time pricing and greenhouse gas signals:

1. Feasibility Analysis
    - Assessments of technical performance
    - Comparison of relevant features
2. Cost Analysis: Projected costs in years 1 through 10 of FDAS implementation for:
    - Manufacturers
    - Consumers
    - Load serving entities
    - The State of California

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[8] LA Times. September 7, 2022. "A text asked millions of Californians to save energy. They paid heed, averting blackouts." https://www.latimes.com/california/story/2022-09-07/a-text-asked-millions-of-californians-to-save-energy-they-listened-averting-blackouts

[9] Public Policy Institute of California at https://www.ppic.org/publication/californias-digital-divide/

[10] CEC Contract 400-22-002

CHAPTER 2: Feasibility of Alternative Signaling Infrastructures for Flexible Demand Appliance Standards

This report considers three communication technologies identified by the CEC for distribution of MIDAS signals: broadcast radio through amplitude modulation (AM), broadcast radio through frequency modulation (FM), cellular radio technologies, and advanced metering infrastructure (AMI). Where several different communication modes and protocols exist within each of these broad technology categories, we assess in detail only those that appear most suited for carrying FDAS signals.

Initial Feasibility Review

For our initial feasibility assessment, we consider each technology with respect to six foundational principles developed by the CEC's Demand Response Committee under Commissioner Art Rosenfeld.[11]

1. Demand Flexibility[12] capability should be ubiquitous – available to every customer in the state.
2. A customer should not be required to sign up for, or participate in, a third-party[13] program to receive flexibility signals or take flexibility actions.
3. Flexibility standards[14] should not preclude existing or future utility-specific DR programs.
4. Flexibility standards should leverage market forces to make demand flexibility low-cost and customer responsive.
5. Where possible, flexibility standards should be agnostic to the underlying technology used to accomplish these goals.
6. When necessary to establish a statewide standard for technology, this should be a "default" rather than "exclusive" solution that does not eliminate or preclude any existing or prospective technology.

In addition, we provide evidence of feasibility with examples of real-world implementation.

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[11] CEC internal memo, "Using the Load Management Standards to Create a Successful Demand Response Infrastructure." 2008.

[12] The original document used the term Demand Response, which at the time covered all forms of flexibility including load shifting and price response. Since then, the meaning of DR has evolved to imply utility or third-party control of consumer loads. To relay the original intention of the text, we have replaced the narrower term "Demand Response" with the intended broader term "Demand Flexibility".

[13] The term "utility-sponsored" has been replaced by "third-party" to align with the terminology used in this paper.

[14] "The Load Management Standards" has been replaced by "Flexibility Standards" to include the FDAS, which did not exist when the original design principles were created.

Broadcast FM Radio: Feasible

FM broadcasts send analog and digital information as modulated radio frequencies that are incorporated into the standard audio broadcast. Each FM radio station in California and the U.S. is allocated ±200 kilohertz (kHz) on one of the 100 available frequencies starting at 88.1 MHz and ending at 107.9 megahertz (MHz). Of the allocated ±200 kHz, about ±50 kHz carries analog audio. Another ±50 kHz carries digital information including Radio Data System (RDS), which can deliver text messages to radio receivers within range of the transmitter.

As of 2024, there are 846 FM stations in California.[15] Of these, an estimated 60 stations are needed to reach at least 95% of the California population but 100 stations are recommended to ensure reliable coverage.[16]

Two forms of digital FM communications are potentially useful for MIDAS signaling: Radio Data System (RDS), an open standard that has been in use for 40 years, and HD Radio Technology™, which is licensed by Xperi Incorporated, a company that also licenses the technology for DTS, IMAX Enhanced, and TiVo.

California based field pilots have shown FM RDS to be an effective conduit between demand automation servers and flexible devices. A 2009 study commissioned by the CEC demonstrated the use of RDS for adjusting the temperature settings of RDS-equipped thermostats, enabling air-conditioning flexibility in near real time.[17] The studies demonstrated the transmission of price and event signals to FM-enabled thermostats, which then analyzed the signal and automatically adjusted temperature settings in near real time.

More recent studies show the successful use of RDS to shift water heating loads out of peak periods. In 2018, Bonneville Power Administration published a detailed report that ultimately led to standards requiring communication expansion ports for water heaters in Oregon and Washington. The BPA study showed that the RDS signals were able to reach water heaters deep in buildings that other communications systems could not.[18]

Following on this research, Pacific Northwest National Laboratory (PNNL) completed a study showing significant demand flexibility of RDS-enabled water heaters in Florida (Figure 5).

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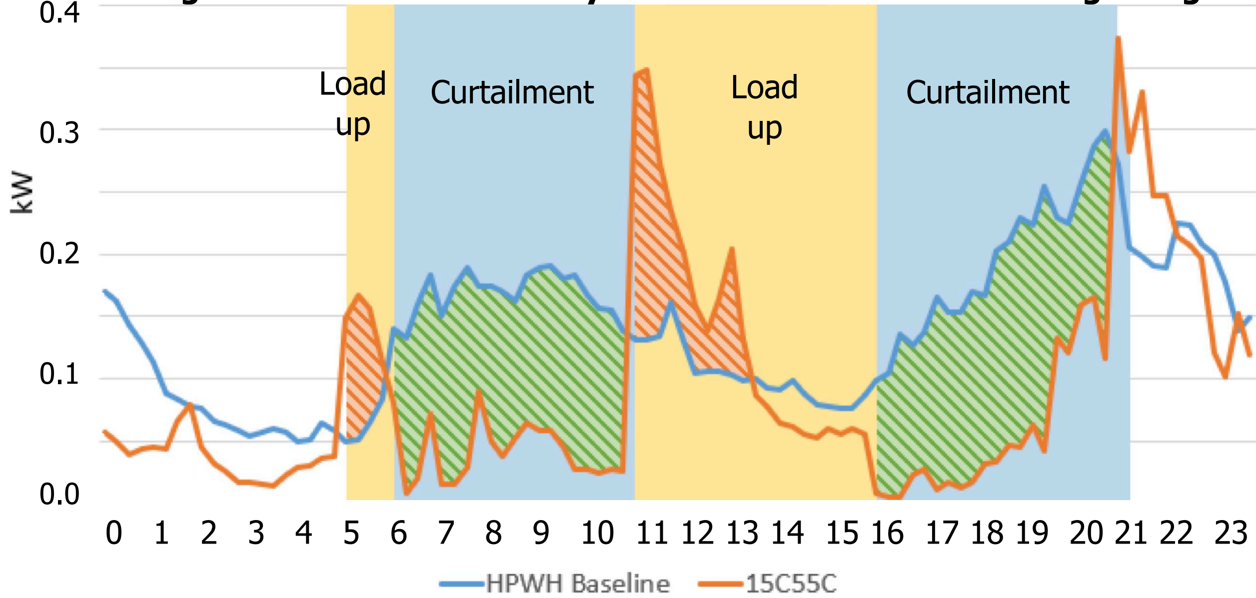
[15] https://radio-locator.com

[16] eRadio and Xperi. Radio Broadcast Response to RFI. 2023.

[17] Herter et al., 2008. https://www.osti.gov/servlets/purl/1164901

[18] Bonneville Power Authority. 2018. CTA-2045 Water Heater Demonstration Report Including a Business Case for CTA-2045 Market Transformation. *BPA Technology Innovation Project 336.*

Figure 5. Demand Flexibility in Water Heaters with RDS Signaling



Source: PNNL 2023[19]

Demonstrations of HD Radio Technology for flexible demand signaling are also available. Xperi currently has a proof-of-concept MIDAS integration running live over the air on New Jersey HD-Radio station 99.1 FM (WAWZ) and has provided a demonstration video that accompanies this report.[20] The same technology was also used for a 2023 demonstration in Texas, which proved the feasibility of reducing electric vehicle charging levels using HD Radio signals to electric vehicle level 1 charging cord adapters.

Based on these real-world examples and our assessment that FM radio does not violate the principles stated above, we believe that HD Radio Technology and FM RDS are both feasible options for MIDAS signaling and will be considered further in this paper.

Broadcast AM Radio: Feasible as an Add-on

AM broadcasts send digital information as modulated radio amplitudes that are incorporated into the standard audio broadcast. Each AM radio station in the U.S. is allocated 10 kHz on one of 116 frequencies starting at 540 kHz and ending in 1700 kHz. These lower frequency AM broadcasts can be transmitted over longer distances than FM broadcasts, can more easily penetrate buildings, and are critical for providing information to rural areas. At the same time, the amplitude modulation method is more prone to noise interference than is frequency modulation, thus compromising signal quality and reliability.

Recently, the FCC has approved AM stations to broadcast all-digital signals using HD Radio transmissions.[21] However, AM radio's potential for data transmission is constrained in the U.S. due to the limited number of digital AM HD Radio stations.

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[19] https://www.energy.gov/sites/default/files/2023-07/bto-peer-2023-141192-hpwh-geb-pnnl-butzbaugh.pdf

[20] Xperio 2024. See attachment: HD-Radio_MIDAS-Polling-and-Broadcasting-2mins.mp4

[21] https://www.fcc.gov/media/radio/digital-radio

These inherent limitations and the emergence of superior digital broadcasting methods have driven the phasing out of AM broadcasting in the U.S., diminishing its viability for flexibility standards. However, AM radio does adhere to most of the stated principles and could be a cost-effective addition to an FM solution. For this analysis, then, we will neither exclude it nor consider it as the main (or sole) communication option for FDAS signaling.

Cellular Radio: Feasible

New versions of cellular communication standards are released every few years by the third Generation Partnership Project (3GPP).[22] Each is interoperable with the previous version but offers new capabilities, features, and improvements. The current backhaul cellular infrastructure in California is a subtype of the fourth generation (4G) cellular standard called LTE for "long term evolution" because it was designed to be interoperable with future releases for many years to come. The current 4G version is expected to be in operation for another five to ten years during the gradual migration to 5G (fifth generation cellular standard).

Within LTE and 5G, there are a variety of different releases, ownership, device types, and data types that result in different coverage, building penetration properties, latencies, and cost. In this white paper we focus on those that we find to be most likely to be suitable for MIDAS signal transmission.

There are a few studies showing the successful use of cellular communications for flexibility signaling.[23] Of particular interest is a recent CEC-commissioned study that demonstrates heat pump water heater response to MIDAS price signals, with results indicating 15 percent savings time-of-use price response and double the savings (29 percent) for real-time price response. [24]

Cellular communications technologies are currently being pilot tested at multiple large utilities in California. The results of these studies are pending; however, initial findings imply that cellular is a feasible technology for this purpose. In addition, cellular technology does not violate the stated principles, and so will be considered further for FDAS.

Advanced Metering Infrastructure: Not Feasible

One of the proposed communication pathways involves using utility networks to send signals through advanced metering infrastructure (AMI) to smart meters, which in turn communicate with consumer devices enabled with AMI-compatible transceivers and software. This technology option is considered infeasible for multiple reasons, including:

- Many California electricity customers live in the service territories of utilities that have yet to install AMI and so do not have access to a communicating smart meter. This fails Principle 1, availability to all users.
- The use of smart meters excludes equipment that is too far from a meter to receive a signal, for example, agricultural pumps. This also fails Principle 1.

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[22] Generation Partnership Project 2024. https://www.3gpp.org/

[23] SkyCentrics 2024. https://www.skycentrics.com/studies

[24] Grant 2023. https://calflexhub.lbl.gov/flex_library_item/price-and-load-responsive-cta-2045-controls-for-hpwhs/

- Consumers must sign up for AMI signal reception through their utility. This fails Principle 2, not requiring customers to sign up for a service.
- Relying on smart meters for flexibility signals puts utilities in the role of flexibility market gatekeeper, as only they can offer flexibility programs through their meters. This fails Principle 4, leveraging markets to reduce customer cost.

Finally, even if AMI were universally available in California, data protocols differ among utilities, so a single appliance standard could not address the entire state.

In conclusion, we find that AMI is not suitable for FDAS signal broadcasting, and so is excluded from further consideration in this analysis.

Ability to Support MIDAS Signaling

Continuing the list of requirements from the six principles in the previous section, our detailed feasibility analysis requires that the signaling infrastructure be technically capable of delivering MIDAS signals according to the following criteria:

7. Signals can reliably reach appliances that are inside building structures as well as those not in proximity to any building structure.
8. The technology can transmit at least twenty-four MIDAS data points each hour for at least eleven signals, where a "signal" references the data contents of a single MIDAS RIN representing, for example, price or greenhouse gas emissions.
9. System implementation can be completed within two years using existing infrastructure and service providers.

Radio Broadcast Data System Technology

The Radio Broadcast Data System (RBDS) is a voluntary open standard that has been in use for 40 years. The standard was originally developed by the RBDS Subcommittee of the National Radio Systems Committee jointly sponsored by the Consumer Technology Association and the National Association of Broadcasters in accordance with the American National Standards Institute patent policy. Use of the specification does not require approval from the Federal Communications Commission.[25] Because RBDS is essentially the same as the RDS International Standard (IEC 62106), it is frequently referred to as simply RDS.

RDS2, a recent update to the RDS specification, has expanded data capacity and will be backwards compatible to RDS.[26] At this time, however, RDS2 is too new to be used widely. The use of AM for RDS transmission is also possible but we could find no evidence of this technology combination being used in practice.

The RDS standard specifies a method for using standard audio broadcasts to transmit text strings up to 64 characters long. [27] The specification describes the physical layer, data-link layer, and message format, which are essential for manufacturers to develop interoperable products. The original purpose of RDS was to "enable improved functionality for FM receivers

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[25] 47 CFR Section 73.293

[26] https://www.rds.org.uk/2010/pdf/Position%20paper%2023_01%20RDS2%20-%20Frequently%20Asked%20Questions.pdf; Q20

[27] "NRSC-4-A, United States RBDS Standard Specification of the Radio Broadcast Data System (RBDS)"

and make them more user-friendly by using features such as Program Identification, Program Service name display and where applicable, automatic tuning for portable and car radios." [29]

Information sent via RDS is frequency modulated on a subcarrier at ±57 kHz relative to the base frequency, which for FM is between 87.5 and 108.0 MHz. This subcarrier data is then demodulated at the receiver. Almost all car radios in Europe and the USA use RDS. Globally, more than one billion RDS chipsets are sold per year.[28]

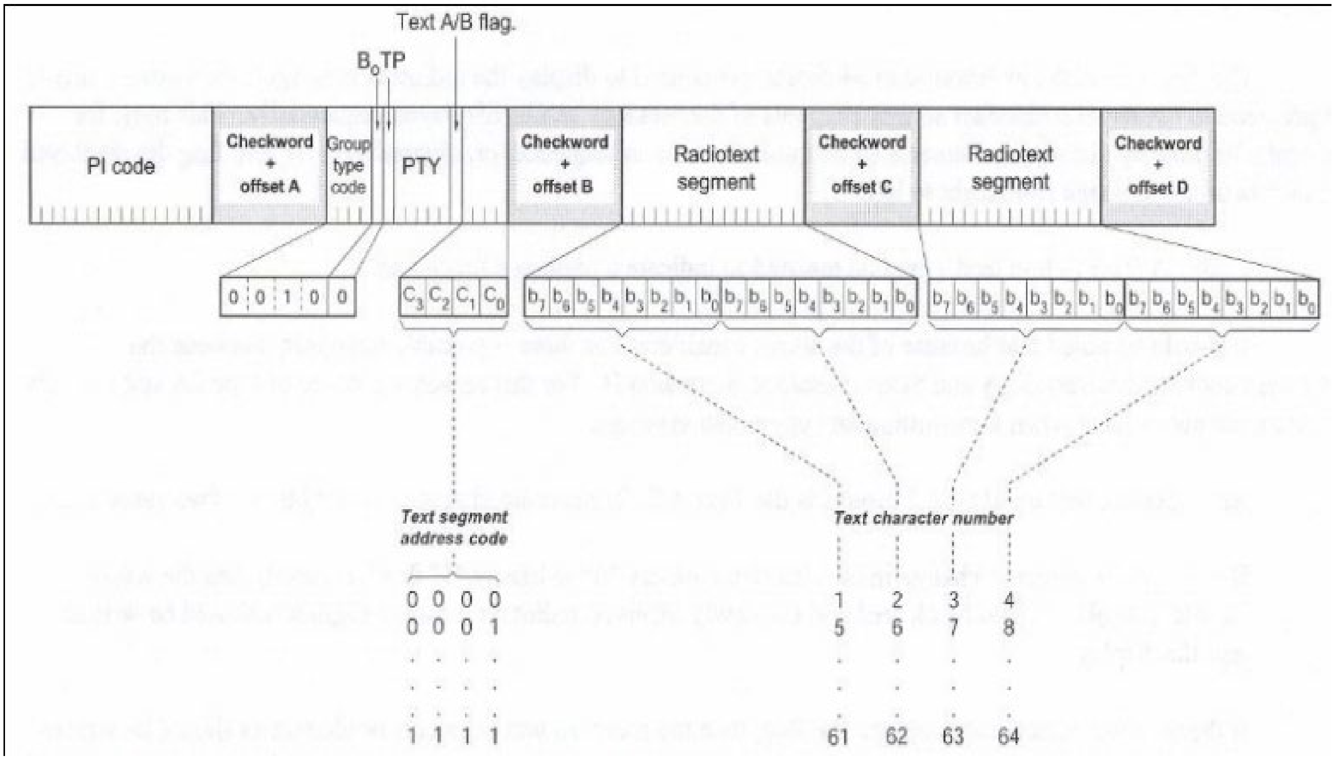
In California, there are about 900 FM stations capable of transmitting RDS signals. Figure 6 shows the perimeter of each predicted coverage area in blue. The overlapping lines provide visual evidence that nearly every location in the state has access to more than one RDS signal.

Figure 6. Reach of RDS Signals in California

Source: eRadio

[28] https://www.rds.org.uk/2010/About-The-Forum.htm

Figure 7. RDS Data Frame Structure



Source: NRSC-4-B[29]

FM-RDS uses the message data-frame structure shown in Figure 7. Each message can deliver 64 usable characters (within a 208-character message) at 1.2 kbps. We considered the possibility that this low data rate might be insufficient for sending MIDAS data. A minimum of one RIN data stream would be needed for the simplest of programs, but eleven would be more useful: one for the average statewide GHG emissions data stream plus one for each of the ten California default load aggregation points (DLAPs) defined by the SGIP.

To determine the number of RIN data streams that could be sent over RDS, we first needed to determine the size of a MIDAS broadcast message.[30] In the absence of an existing standard, we chose a minimum subset of variables from the current MIDAS database and developed the efficient data model specification shown in Table 13. We then calculated the number of these messages that RDS could broadcast every hour.

Our results, summarized in Table 1, indicate that RDS can send at least 847 messages per hour, where the broadcast contains a forecast of 48 hours. A shorter horizon forecast of just 12 hours increases the maximum number of RINs to 1,937. Although these numbers do not account for congestion from competing uses of RDS, such as station name and song titles, these numbers provide evidence that the broadcast of DLAP-specific FDAS data to the entire state of California is likely to be feasible using RDS. Beyond the 11 default RINs required in

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[29] Consumer Technology Association, National Association of Broadcasters. *United States RBDS Standard.* NRSC-4-B: National Radio Systems Committee, 2011

[30] The full MIDAS data set contains much more information than is needed for appliance flexibility.

this analysis, sufficient bandwidth remains for hundreds of additional RINs that could be used for electricity rates or system alerts.

Table 1. Estimated RDS Capacity for MIDAS Messaging

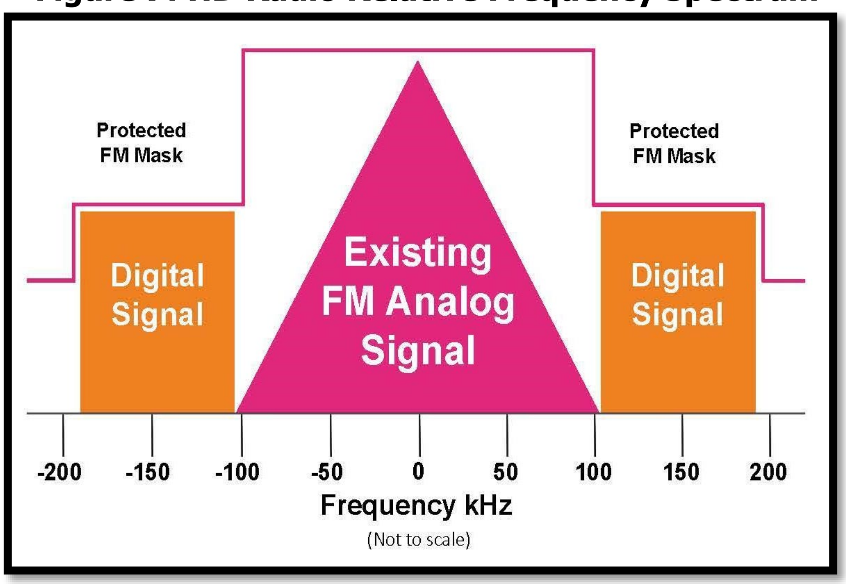
Message Content	**Effective MIDAS RINs Delivered per Hour**
12-hour forecast of hourly values	1,937
24-hour forecast of hourly values	1,356
48-hour forecast of hourly values	847

Interviews with FM station executives about the sustainability of FM for energy management resulted in differing views on the prospects of FM radio. While one suggested that FM is a dying breed, others noted that FM radio stations are still profitable as the primary entertainment in automobiles and so are likely to be around indefinitely.[31] Add in the factor of increasing RDS application revenue and the outlook for FM longevity seems very good. These prospects would improve further were California to implement contracts for public grid signal broadcasts.

HD Radio Technology

About ±100 kHz of the ±200 kHz allocated to FM radio stations is used for analog audio and its related subcarriers. The remaining ±100 kHz is allocated to digital FM radio, branded as HD Radio Technology. The 207 California stations equipped with HD Radio broadcasting equipment are expected to be sufficient for statewide MIDAS signaling.

Figure 7: HD Radio Relative Frequency Spectrum



Source: Xperi

[31] David Layer, Vice President, Advanced Engineering, National Association of Broadcasters & Terrance Carr, Regional Engineering Lead, New England / VP of Engineering; iHeartMedia

FM HD Radio transmissions are theoretically capable of delivering 348 kbps using a frame that allows for information packets to be up to 12,000 bits long.[32] According to Xperi, each HD Radio station has between 1 and 10 kbps bandwidth available for MIDAS data – a range that can transmit a nearly unlimited number of RINs.

HD Radio Technology also sends digital information through AM broadcasters. Although AM HD Radio stations are less common than FM HD Radio stations, the long-distance propagation of AM signals make it worth considering as an add-on to FM HD Radio transmissions.

HD Radio Technology's future appears less certain than FM Radio, both because the existing pool of HD Radio stations is smaller and because license fees disincentivize stations from upgrading their hardware to be compatible with HD Radio Technology.[33] However, as discussed above for RDS, prospects would improve were California to implement contracts for HD Radio public grid signal broadcasts.

Cellular Communications Technology

A cellular network is a radio network distributed over land through cellular base stations consisting of wireless transceiver communications equipment and antennas. Cellular base stations work collectively to provide radio coverage over large geographical areas. They are designed to support voice, text, and data services as mobile devices travel between them. Thus, cellular data services allow users to interact directly with the internet using mobile devices such as cell phones, tablets, and laptop computers.

Public cellular networks are part of the public internet and are operated by Mobile Network Operators, through which most people obtain their mobile phone service. Although San Diego Gas & Electric and Southern California Edison are in the process of implementing "private" cellular networks, in part to enable end-use flexibility program offerings to their customers, these networks cannot support data services for FDAS, because they are not statewide.

Cellular networks utilize a wide range of frequency bands. The lower frequencies enable a greater geographical coverage and better penetration of buildings at the cost of lower data rates. The higher frequencies enable higher data rates at the cost of shorter range and weaker building penetration.

The lower frequency 450 MHz band, formerly used for 2G and 3G, has superior building penetration and so would be useful in supporting digital equity.[34] However, unlike in Europe where the 450 MHz band is still allocated for cellular networks, these lower frequency services are being retired in the U.S. and so are not considered a feasible option for FDAS.[35]

Most cellular networks in use today are 4G-LTE, however, these networks are transitioning to the higher frequencies and data rates supported by 5G technology. Although the high frequencies of 5G technologies necessarily translate to shorter range and poorer building

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[32] Network Working Group. PPP in HDLC-like Framing. RFC1662: Internet Engineering Task Force, 1994

[33] David Layer, Vice President, Advanced Engineering, National Association of Broadcasters & Terrance Carr, Regional Engineering Lead, New England / VP of Engineering; iHeartMedia

[34] https://altair.sony-semicon.com/blog/450-mhz-unsung-hero-of-cellular-iot

[35] https://blog.antenova.com/what-is-lte-450

penetration, 5G also supports somewhat lower frequency data services including device-to-device communications, often referred to as cellular Internet of Things (IoT).

Of the IoT technologies, LTE-M and narrowband IoT (NB-IoT) are particularly suited to FDAS because of their superior building penetration, low power consumption, and low impact on normal cellular traffic. Because they are both included in the 5G technology umbrella, they are expected to be available until 2040 and beyond.[36]

Whereas the fastest 5G networks have a maximum downlink rate of around 1,000 megabits per second (Mbps)[37] cellular IoT technologies have maximum downlink rates of between 0.026 and 1.0 Mbps, depending on the precise protocol used (Table 2). Because these downlink data rates exceed the data rate of RDS, which was previously shown to meet the requirements for FDAS signaling, an in-depth analysis of cellular messaging capacity is not required.

Table 2. Features of Cellular IoT Network Protocols

	LTE-M			**NB-IoT**	
	LTE CAT M0	LTE CAT M1	LTE CAT M2	LTE CAT NB1	LTE CAT NB2
Downlink	1 Mbps	1 Mbps	4 Mbps	26 kbps	127 kbps
Uplink	1 Mbps	1 Mbps	7 Mbps	16-66 kbps	159 kbps

Source: RFWEL Engineering[38]

Unlike radio broadcast, cellular networks have the potential for network congestion. This happens in situations that prompt unusually high volumes of traffic, such as might occur during a widespread emergency or crowded sporting event. In these scenarios, cellular data packets can stall at points on the network where nodes become overwhelmed.

While cellular communications are primarily a one-to-one exchange, recent enhancements for LTE-M[39] and NB-IoT[40] include the use of multicast, which allows the same message to be sent to multiple devices and locations. Cellular multicasting could be an important feature to support wide distribution of FDAS signals.

Removable subscriber identity module (SIM) cards have provided the mechanism for managing billing for individual customers for many years. There is some evidence that a standardized multi-service provider SIM card could potentially be used for MIDAS Plug-and-Play participation. Some newer products are now using embedded SIMs (eSIMs), which are permanently attached to the printed circuit boards, or integrated SIMs (iSIMs), which are part

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[36] https://www.nordicsemi.com/Products/Wireless/Low-power-cellular-IoT/what-is-cellular-iot

[37] 3rd Generation Partnership Project. Technical Specification Group Radio Access Network Requirements for further advancements for Evolved Universal Terrestrial Radio Access (Release 17). TR 36.913: 3GPP, 2022

[38] https://www.rfwel.com/us/index.php/cellular-iot-frequency-bands

[39] https://www.gsma.com/iot/wp-content/uploads/2019/08/201906-GSMA-LTE-M-Deployment-Guide-v3.pdf

[40] https://haltian.com/resource/nb-iot-3gpp-release-14-what-are-the-new-features/

of the cellular chipsets.[41] These technologies have the potential to decrease manufacturing costs, so their use is anticipated to increase. Future papers will further investigate these potential opportunities.

Feasibility Results

The results of our initial feasibility assessment and technical feasibility assessment are summarized in Table 3 and Table 4, respectively. Circles that are solid indicate full adherence, half-filled indicate some adherence, and empty indicate little to no adherence to the foundational principles.

Table 3. Foundational Principles Criteria Comparison

Criteria	AM/FM	AMI	Cellular
1. Available to every customer in the state.	●	○	◐
2. No need to sign up for a program to receive signals	●	○	◐
3. Does not preclude utility-specific DR programs	●	●	●
4. Leverages market forces	◐	○	●
5. Technology agnostic	◐	○	◐
6. Statewide standards are default, not exclusive	●	●	●
Pass Principles Assessment	Yes	No	Yes

Table 4. Technical Feasibility Criteria Comparison

Criteria	Radio Data System	HD Radio	Cellular Radio
7. Can reliably reach inside and outside buildings	●	●	●
8. Can transmit at least twenty-four MIDAS data points each hour for at least eleven signals	●	●	●
9. Can be completed within two years	●	●	●
Pass Technical Assessment	Yes	Yes	Yes

In the following chapters, we complete a detailed cost analysis of these three potential MIDAS signaling infrastructures.

[41] https://www.emnify.com/iot-glossary/sim-vs-esim-vs-isim

Comparison of Technical Features

Table 5 summarizes and compares a range of characteristics for the potential MIDAS signaling infrastructures included in this analysis.

Table 5. Technical Features of RDS, HD Radio, and Cellular Radio

	Radio Data System	HD Radio™	Cellular Radio
Platform	FM Radio Stations with Radio Data System technology	AM and FM Radio Stations with HD Radio Technology	Cellular 4G-LTE with NB-IoT or LTE-M capability
Ownership	Private broadcasters	Private broadcasters	Cellular companies (AT&T, Verizon, T-Mobile)
Standard Application	Text-based data for station and music	Digital music broadcast	Internet connectivity
Connection Density	Unlimited	Unlimited	Max ~100k points/ cell
Messaging Speed	1.2 kbps	96-128 kbps	26 kbps
Radio Frequency Band	88-108 MHz	88-108 MHz	400-2000 MHz
Building Penetration	Good	Good	Good
Propagation Range	Urban: 30-40 miles Rural: 100 miles	Urban: 30-40 miles Rural: 100 miles	Urban: 1-4 miles Rural: 10-30 miles
Signal Reliability	Good	Good	Good
Interference improved by:	Repeaters, error correction	Repeaters, error correction	Added towers, frequency division duplexing
Plug-and-Play Capability	Yes	Yes	TBD*
Hardware Availability	Excellent	Good	Excellent
California Coverage	>95%	>95%	80% AT&T, 70% Verizon, 60% T-Mobile
Contract Implementation	~1 year	~1 year	< 1 year
Maturity	125 years	22 years	45 years
Disaster Proof	Excellent	Excellent	Poor
Empirical Evidence	SMUD, LBNL, PNNL	TX, NJ	LBNL
Info to Cloud	No	No	Yes
Bidirectional Comms	No	No	Yes
Congestion Issues	No	No	Yes
Gateway Requirement	No	No	TBD*
Privacy Concerns	No	No	Yes
Cybersecurity Concerns	TBD*	TBD*	Yes

* To be considered in future research under this contract

CHAPTER 3:
Costs and Benefits of Alternative Signaling Infrastructures

The preceding chapters of this paper detail our analysis and conclusion that California's FDAS signaling requirements can be effectively met using RDS, HD Radio Technology, and cellular radio technologies. In this chapter, we present a cost-benefit analysis of eight potential statewide flexibility system scenarios. These scenarios are based on various combinations of the potential signaling infrastructure technologies and their achievable flexibility strategies, which are discussed further below.

Potential Flexibility Strategies

Evaluating the costs and benefits of a statewide flexible demand system requires initial assumptions about the types of programs and anticipated load responses. We start by considering existing third-party load management programs, as prioritized in Public Resources Code (PRC) Section 25403(f). We also include standard grid-friendly default appliance schedules as mandated by the flexible demand pool controls standards.[42] Lastly, we introduce a novel strategy facilitated by the California MIDAS – a plug-and-play flexibility option we refer to as MIDAS Plug-and-Play.

3rd Party Control. Short for "third-party load management program" as defined in PRC 25402(f), these programs require two-way communications, which enable visibility and control of appliances by the service provider. Depending on the provider and the contract with their customer, the appliance control strategies can range from simple intermittent load shed to dynamic optimization and transactive energy programs. FDAS can enable participation in third-party programs by establishing the standards for bidirectional internet connectivity.

- **Load Shed.** These programs call for quick demand reduction during system emergencies. Example programs in California include the Demand Response Auction Mechanism, the Base Interruptible Program, Capacity Bidding Program, and the Emergency Load Reduction Program.
- **Dynamic Optimization.** In lieu of large and infrequent demand reductions, dynamic optimization programs rely on constant modification of loads in smaller increments, following the ebb and flow of grid needs. An important goal of dynamic optimization is to attain grid benefits without disrupting or inconveniencing the consumer in any way.
- **Transactive Energy.** California is investigating the potential for transactive energy systems, which enable dynamic optimization using electricity prices as the flexibility incentive. Transactive energy devices are equipped to autonomically negotiate and contract for specific electricity amounts at offered prices. A key system benefit of transactive energy is that it helps to mitigate the risk of load synchronization.

[42] PROPOSED REVISIONS TO THE FLEXIBLE DEMAND APPLIANCE STANDARDS FOR POOL CONTROLS. California Energy Commission Docket No. 23-FDAS-01.

MIDAS Plug-and-Play. This term refers to the ability for an appliance, at installation, to automatically receive and respond to MIDAS signals. For true plug-and-play flexibility, the signal data content cannot require consumer input. This excludes price as the default signal because a consumer will need to enter their RIN for their appliance to be price responsive. Thus, MIDAS plug-and-play capability requires that the default FDAS signal be either universal or location-specific (i.e., not consumer-specific).

Consumers must always have choices to temporarily or permanently opt out of flexible appliance operations.

FDAS Default Schedule. The FDAS can specify default operational schedules that align with California's typical greenhouse gas emissions patterns and pricing structures. These schedules would be the fallback option for consumers who choose not to respond to MIDAS or third-party signals. Although communications are not required for static schedules programmed into the appliance during the manufacturing process, the public availability of MIDAS signals would enable regular over-the-air updates of default schedules, alleviating concerns related to evolving grid needs. In either case, consideration must be given to randomizing the start and end times of any setback periods to prevent load synchronization.

A final option for appliance operation is a consumer-chosen schedule. Historical evidence suggests that consumers must always be able to bypass flexibility options, whether temporarily via a short-term override or permanently by setting their own schedules.

Potential FDAS Scenarios

The following scenarios are defined for the detailed cost analysis. These scenarios are based on combinations of signaling infrastructures and feasible flexibility strategies.

1. **Plug-&-Play RDS.** Appliance manufacturers are required to embed FDAS-compliant RDS technology to enable MIDAS Plug-and-Play response. Load serving entities or the State contract with RDS-equipped radio stations for public broadcast of MIDAS data. At installation, appliances automatically modify operations in response to the default FDAS signal for their location. Consumers may opt-out of this response at the appliance. Third-party programs are not enabled.
2. **Plug-&-Play HD Radio.** Appliance manufacturers are required to embed FDAS-compliant HD Radio technology to enable MIDAS Plug-and-Play response. Load serving entities or the State contract with HD Radio stations for public broadcast of MIDAS data. At installation, appliances automatically modify operations in response to the default FDAS signal for their location. Consumers may opt-out of this response at the appliance. Third-party programs are not enabled.
3. **Plug-&-Play Port.** Appliance manufacturers are required to embed FDAS-compliant RDS technology to enable MIDAS Plug-and-Play response and an FDAS-compliant expansion port to enable third-party program communications. Load serving entities or the State contract with RDS-equipped radio stations for public broadcast of MIDAS data.[43] At installation, appliances automatically modify operations in response to the default FDAS signal for their location. Consumers may opt-out of this response at the appliance. Third-party programs are enabled through the integrated expansion port. A

[43] HD Radio stations could also be used in this scenario, with a minor increase in pricing. To avoid creating yet another scenario we used RDS here as the less expensive of the two options.

consumer who chooses to participate in a third-party program can install a communication module obtained from the chosen automation service provider.

4. **Plug-&-Play Cellular.** Appliance manufacturers are required to embed FDAS-compliant cellular technology to enable MIDAS Plug-and-Play response.[44] Load serving entities or the State negotiate contracts with cellular providers on behalf of all participants for point-to-point delivery of MIDAS data to SIM modules embedded in FDAS-compliant appliances. At installation, appliances automatically modify operations in response to the default FDAS signal for their location. Consumers may opt-out of this response at the appliance. Third-party programs are not enabled.
5. **3rd Party Wi-Fi.** Appliance manufacturers are required to embed FDAS-compliant Wi-Fi technology to enable third-party programs. A consumer who chooses to participate in a third-party program allows the chosen automation service provider to connect to their FDAS appliance through their existing broadband internet network with Wi-Fi. Note that consumers' internet service fees are not included in the cost analysis for this scenario.
6. **3rd Party Port.** Appliance manufacturers are required to embed an FDAS-compliant communication expansion port to enable third-party programs. A consumer who chooses to participate in a third-party program can install a communication module obtained from the chosen automation service provider.
7. **3rd Party Cellular.** Appliance manufacturers are required to embed FDAS-compliant cellular technology to enable third-party programs. Load serving entities or the State negotiate contracts with cellular providers on behalf of all participants for point-to-point delivery of MIDAS data to SIM modules embedded in FDAS-compliant appliances. A consumer who chooses to participate in a third-party program can contact a third-party automation service provider to activate the SIM module to take advantage of flexibility programs.
8. **Consumer Cellular.** Appliance manufacturers are required to embed FDAS-compliant cellular technology to enable third-party programs. Customers contract with cellular providers for point-to-point delivery of MIDAS data to SIM modules embedded in their appliances. Customers may also choose to contract with a third-party automation service provider.

For each of these scenarios, we estimate separately the costs to manufacturers, consumers, load serving entities, also referred to as utilities, and the State of California.

Input Values

The primary data inputs used to complete the cost-benefit analysis are provided in this section. The full analysis makes use of an Excel workbook that holds all data, input assumptions, and calculations supporting our cost analysis.[45]

Table 6 lists the input variables and values used for our analysis. The fields in **bold** indicate values to which the results are most sensitive, implying that accuracy is particularly important in these cases. Despite being the *most* sensitive of the input values, it is important to note that

[44] The feasibility of this scenario is uncertain and will be further investigated if we find it cost-effective.

[45] 2024-CEC-Flexible-Demand-Cost-Calculator.xlsx

moderate changes to these values do not affect the main conclusions of this study. Readers are encouraged to access the analysis workbook to conduct their own sensitivity analyses.

Table 6. Flexible Demand Cost Calculator Input Values

Variable	Value	Source
Staff salary	$175,036	CEC 2024
Annual salary increase (%)	5%	
First-time FDAS owner	30%	[author estimate]
Number of LMS utilities	20	CEC
Plug-and-Play participation rate	**80%**	USDOE 2015: 90% (+uncertainty)
Opt-in participation rate	10%	USDOE 2015: 20% w/ free technology
Start year	2026	CEC
2025 cellular coverage (AT&T)	80%	CoverageMap.com
Cellular coverage annual growth	2%	[author estimate]
Cellular service, annual per appliance	**$12.00**	SkyCentrics
Cellular account setup	$40	[author estimate]
Radio datacast setup per station	$10,000	Xperi/eRadio
Radio annual service per station	$120,000	Xperi/eRadio
Radio stations for >95% coverage	100	Xperi/eRadio
Cellular module	**$14.56**	AliExpress
SIM module	$1.00	Horizon Tech
RDS module	**$1.50**	AliExpress
HD Radio module	**$3.23**	icsoso
ANSI/CTA-2045-B standard port	$1.10	SkyCentrics[46]
Wi-Fi module	$2.95	Digikey
Non-Recurring Engineering Costs	10%	PEKO
ANSI/CTA-2045-B standard module	$30.00	Eustis 2024 (500k to 1M units)
External cellular antenna	$5.75	50% of low-volume retail cost
External radio antenna (3 ft)	$0.30	50% of low-volume retail cost
% appliances w/ external cell antenna	100%	SkyCentrics
Utility connection troubleshoot	$80.00	[author estimate]
Customer connection troubleshoot	$20.00	[author estimate]

Following are brief descriptions of select input values that merit explanation.

Additional Staff

All scenarios assume that any initial tasks to be completed by the State, such as contract negotiations and MIDAS updates, can be done within the current scope of existing CEC staff. In fact, under plug-and-play scenarios at least, the need for staff may be significantly reduced over time as flexibility program resources are streamlined.

All scenarios assume the need for additional employees at load serving entities to manage marketing, education, and outreach. We assume a total cost of $175,036 per full-time employee in 2026 and increase this amount by 5% annually to account for inflation. We use a

[46] Consistent with page 8 of Dayem 2018. https://www.cooperative.com/programs-services/bts/Documents/Reports/Standardized-Communications-for-Demand-Response-Report-June-2018.pdf

conservative estimate 4 additional staff to support opt-in programs and one additional staff to support Plug-and-Play scenarios.

First-time FDAS Owner

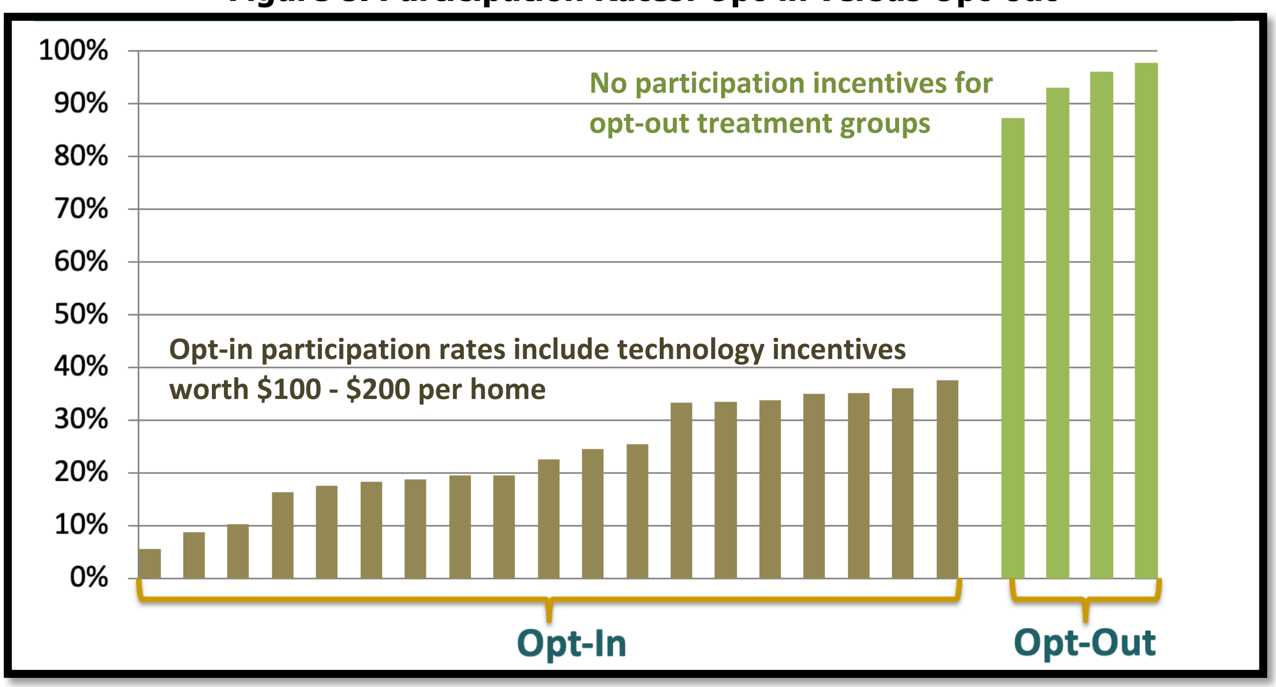
This represents, for each year after the Start Year (here we use 2026), the fraction of FDAS appliance buyers who are first-time FDAS appliance owners, where an "FDAS owner" is a consumer with at least one FDAS appliance. This implies that 70 percent of FDAS purchases each year are made by consumers that already own at least one FDAS appliance. This variable does not affect the cost analysis and is included solely to enable estimation of the number of buildings with FDAS appliances.

Participation Rates

As noted in the 2018 Bonneville Power Administration study on water heater flexibility, the primary determinant of economic outcomes is customer enrollment. Therefore, participation rates are crucial variables in this cost-benefit analysis.

We define participation as the percentage of FDAS-compliant appliances that respond to at least one flexibility signal from MIDAS or third-party sources. Our estimates are based on participation rates from treatment groups in the U.S. Department of Energy (DOE) Smart Grid Consumer Behavior Studies completed in the mid-2010s, as shown in Figure 8.

Figure 8. Participation Rates: Opt-in versus Opt-out



Source: US DOE 2015. [47]

These studies indicate average participation rates of approximately 20 percent for voluntary (opt-in) treatments with incentives over $100, and more than 90 percent for default (opt-out) treatments without incentives. For consistency across scenarios, we estimate a 10 percent opt-

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[47] US DOE 2015 "Interim Report on Customer Acceptance, Retention, and Response to Time-Based Rates from the Consumer Behavior Studies"
https://www.smartgrid.gov/archive/recovery_act/overview/consumer_behavior_studies.html

in participation rate for voluntary programs without incentives, aligning with real-world observations. Additionally, we conservatively reduce the expected opt-out participation rate for default settings from 90 percent to 80 percent to account for potential uncertainties.

Embedded Communication Modules

Chips supporting radio and cellular reception are readily available. At large volumes, the costs of communication chips and modules drop significantly, reducing the percentage cost burden of the modules. Lower pricing and wider availability lessen the burden for manufacturers and support an immediate rollout.

- FM RDS chips are readily available from local authorized suppliers. Also available from multiple manufacturers is a range of printed circuit board assembly RDS radio modules that allow for simplified interconnection of the sensitive radio chips to existing circuitry, thereby reducing non-recurring engineering costs. Open source RDS modules are also available.[48] Suppliers (local and foreign) are offering RDS modules as low as $1.50 each with 100,000 available (Spring 2024).
- Locally supplied AM and FM HD Radio chips typically include FM RDS. HD Radio chips are up to three times the cost of FM RDS chips and are physically larger, potentially resulting in higher costs for module manufacturing. Because this technology is newer, there is a lack of modules using these chips, but this situation is expected to change with time and increased demand.
- Cellular IoT chips supporting NB-IoT and/or LTE-M in a range of frequencies are readily available. Also available from multiple manufacturers is a range of printed circuit board assembly cellular radio modules that use these chips**.** This allows for simplified interconnection of the sensitive radio chips to existing circuitry thereby reducing non-recurring engineering costs. Local and foreign suppliers are offering modules with limited features and frequency support for around $4.25 to $7.00, and with more advanced features for around $14.50.

Communications Service Fees

We assume that communication service contracts are funded by utilities through amendments to the Load Management Standards.

- FM broadcasting services are available for $10,000 per station per month, covering intermediary services, radio broadcast station services, and over-the-air firmware updates. [49]
- Cellular LTE IoT service is expected to be as low as $1 per month ($12 per year) per appliance at volumes of more than 1 million appliances. This includes over-the-air firmware updates.
- Except for the Consumer Cellular scenario, consumers do not pay for the communications needed to receive the MIDAS signal.

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[48] Open source at: https://github.com/sparkfun/Si4703_FM_Tuner_Evaluation_Board/tree/V_H1.3_L1.2.0

[49] Source: Xperi and eRadio response to Request for Information.

Account Setup

We assume that Plug-and-Play scenarios do not have network or account setup costs, while cellular accounts require SIM card initialization.

Station Setup

We assume that cellular scenarios do not have station setup costs,

- FM service providers provided an estimate of 10,000 dollars per station for wide area network setup costs including hardware and licensing.
- For all cellular programs that are not plug-and-play, we assume a per appliance cost for a service technician or the consumer to set up the SIM module with the carrier, utility, and customer information.

Hardware Module and Engineering Costs

Values for modules are taken from commercial websites as listed in Table 6.

The industry standard value for first year non-recurring engineering costs is 10 percent or less of the communication module cost.

Additional Communications Hardware

Costs of ANSI/CTA-2045 universal communication modules and external antennas are included in the cost analysis. The 3rd Party Port scenario incurs additional cost to the utility or load serving entity for each universal communication module installed.

Depending on location, some appliances may need an antenna to access the wireless signal. We assume the following.

- All FDAS appliances will ship with the appropriate antenna.
- 25% of FDAS appliances will need an antenna.
- A short vertical length of wire is needed to enhance FM reception.
- High-volume costs for antennas are half the low-volume costs.

Appliance Markup

Consumers are expected to bear the increased appliance costs incurred by manufacturers plus any rounding value needed to obtain a price in increments of at least one dollar.

Maintenance and Troubleshooting

We assume that some number of appliances lose their connection and are reconnected each year at a cost per appliance.

Energy Use

The energy needs of wireless receivers are negligible at a fraction of a watt, with expected energy costs of less a dollar per year per appliance. This cost is not included in our analysis.

Calculations

Table 7 provides an overview of the input assumptions and intermediate calculations for the four Plug-and-Play scenarios analyzed. Similarly, Table 8 outlines the assumptions and calculations for the three Third-Party scenarios and one Consumer scenario. To review the full set of calculations or investigate the impacts of changing input variables, please see the attached Excel workbook: 2024-Flexible-Demand-Cost Calculator.xlsx.

Table 7. Plug-and-Play Scenarios: Features, Inputs, and Calculations

Variable	Plug-&-Play RDS	Plug-&-Play HD Radio	Plug-&-Play Port	Plug-&-Play Cellular
Communication Technology	RDS	HD Radio	RDS+Cell	Cell
Form factor	Embed*	Embed*	Embed+Port	Embed*
Out-of-Box comms	yes	yes	yes	yes
Plug-and-Play	yes	yes	yes	yes
Year 1 Network Coverage	74%	74%	74%	80%
Participation Rate	80%	80%	80%	80%
Appliance Reception Rate	90%	90%	90%	90%
Final Participation Rate	72%	72%	72%	72%
Max Station Installs /year	30	30	30	NA
Scaling Factor	2.8	2.8	2.8	1.02
Appliances Lost /year	2%	2%	2%	2%
Appliances Reconnected /year	0%	0%	0%	0%
STATE				
Additional Staff	0	0	0	0
LOAD SERVING ENTITIES				
Network Setup	$10,000	$10,000	$10,000	$0
Station Setup	*$10,000*	*$10,000*	*$10,000*	*$0*
SIM/Account Setup	*$0*	*$0*	*$0*	*$0*
Additional Comm Hardware	$0	$0	*$0*	$0
Annual Service Fee per Station	$120,000	$120,000	*$120,000*	$0
Annual Service Fee per Appliance	$0	$0	*$0*	$12
Operations & Maintenance	$0	$0	*$0*	$0
One-time per-appliance Incentive	$0	$0	*$0*	$0
Additional Utility Staff	1	1	1	1
MANUFACTURERS				
Hardware & Manufacturing	$1.50	$3.23	*$2.60*	$14.56
Additional Comm Hardware	$0.30	$0.30	$0.30	$6.75
CONSUMERS				
Per-appliance System Setup	$0	$0	$0	$0
Annual Service Fee	$0	$0	$0	$0
Operations & Maintenance	$0	$0	$0	$0

* Embedded options could potentially be very small (e.g. SD or SIM cards) to allow removability for upgrades or consumer privacy and safety.

Table 8. Third-Party Control Scenarios: Features, Inputs, and Calculations

Variable	3rd Party Cellular	3rd Party Port	3rd Party Wi-Fi	Consumer Cellular
Communication Technology	Cell	Cell	Wi-Fi	Cell
Form factor	Embed*	Port	LAN	Embed*
Out-of-Box comms	yes	no	yes	yes
Plug-and-Play	no	no	no	no
Year 1 Network Coverage	80%	80%	88%	80%
Sign-up Rate	10%	10%	10%	10%
Appliance Reception Rate	90%	90%	90%	90%
Final Participation Rate	9%	9%	9%	9%
Max Station Installs /year	NA	NA	NA	NA
Scaling Factor	1.02	1.02	1.02	1.02
Appliances Lost /year	2%	2%	10%	2%
Appliances Reconnected /year	30%	30%	30%	30%
STATE				
Additional Staff	0	0	0	0
LOAD SERVING ENTITIES				
Network Setup	$40	$40	$0	$0
Station Setup	*$0*	*$0*	*$0*	*$0*
SIM/Account Setup	*$40*	*$40*	*$0*	*$0*
Additional Comm Hardware	$0	$37	$0	$0
Annual Service Fee per Station	$0	$0	$0	$0
Annual Service Fee per Appliance	$12	$12	$0	$0
Operations & Maintenance	$24	$24	$24	$0
One-time per-appliance Incentive	$0	$0	$0	$0
Additional Utility Staff	4	4	4	4
MANUFACTURERS				
Hardware & Manufacturing	$14.56	$1.10	$2.95	$14.56
Additional Comm Hardware	$6.75	$0.00	$0.00	$6.75
CONSUMERS				
Per-appliance System Setup	$0	$0	$20	$20
Annual Service Fee	$0	$0	$0	$20
Operations & Maintenance	$0	$0	$1	$0

* Embedded options could potentially be very small (e.g. SD or SIM cards) to allow removability for upgrades or consumer privacy and safety.

Results

This section provides the results of the cost-benefit analysis detailed in the previous sections. First, we outline the estimated costs to appliance manufacturers, consumers, load-serving entities, and the State of California in years 1 and 10 following FDAS implementation. Next, we summarize the flexible demand resource potential across the eight previously described FDAS scenarios. We conclude by detailing the incremental cost per appliance and the average cost per kilowatt (kW) of the potential demand flexibility resource.

In all results tables, the 3rd Party Wi-Fi scenario is presented in bold font indicating that this is considered the business-as-usual case.

Costs

Table 9 shows our estimated costs for the defined scenarios in the first year following FDAS implementation. In all scenarios, the costs to the State of California are zero. This outcome assumes that MIDAS updates and signaling infrastructure contract negotiations can be completed with existing staff resources. Costs to manufacturers in all scenarios are negative, resulting from the assumption that all compliance costs are passed through to consumers, plus price increases resulting from rounding the retail appliance prices up to the nearest dollar. Our full cost analysis, attached to this report, shows that these costs to the State and manufacturers are consistent across all ten years following implementation.

Table 9. Estimated Year 1 Costs for FDAS Scenarios ($M)

Technology	California State	Appliance Manu-facturers	California Consumers	Load Serving Entities	Total FDAS Costs
Plug-&-Play RDS	$0.0	-$0.1	$2.0	$7.4	$9.4
Plug-&-Play Port	$0.0	-$0.8	$4.0	$7.4	$10.6
Plug-&-Play HD Radio	$0.0	-$0.1	$4.0	$7.4	$11.3
Plug-&-Play Cellular	$0.0	-$0.2	$23.0	$10.2	$33.0
3rd Party Wi-Fi	**$0.0**	**-$0.7**	**$5.8**	**$14.0**	**$19.1**
3rd Party Port	$0.0	-$0.8	$2.0	$20.4	$21.6
3rd Party Cellular	$0.0	-$0.2	$23.0	$17.7	$40.5
Consumer Cellular	$0.0	-$0.2	$25.9	$14.0	$39.6

Turning to consumer costs, first-year costs can be seen to range from $2.0 million to $25.9 million. These values are primarily influenced by the appliance markup, which is dependent on the costs of the required communication hardware. For example, the relatively high costs of cellular communication modules contribute significantly to higher consumer expenses in all three Cellular scenarios. Another dominant consumer cost is the initialization and ongoing maintenance of the appliance's connection to the signaling infrastructure. These connection costs are especially high in the 3rd Party Wi-Fi and Consumer Cellular scenarios.

Finally, the costs to load-serving entities in the first year range from $7.4 million to $20.4 million, depending on additional needs for staff, hardware, maintenance, and communication service fees. These expenses are significantly lower or absent in the Plug-and-Play scenarios.

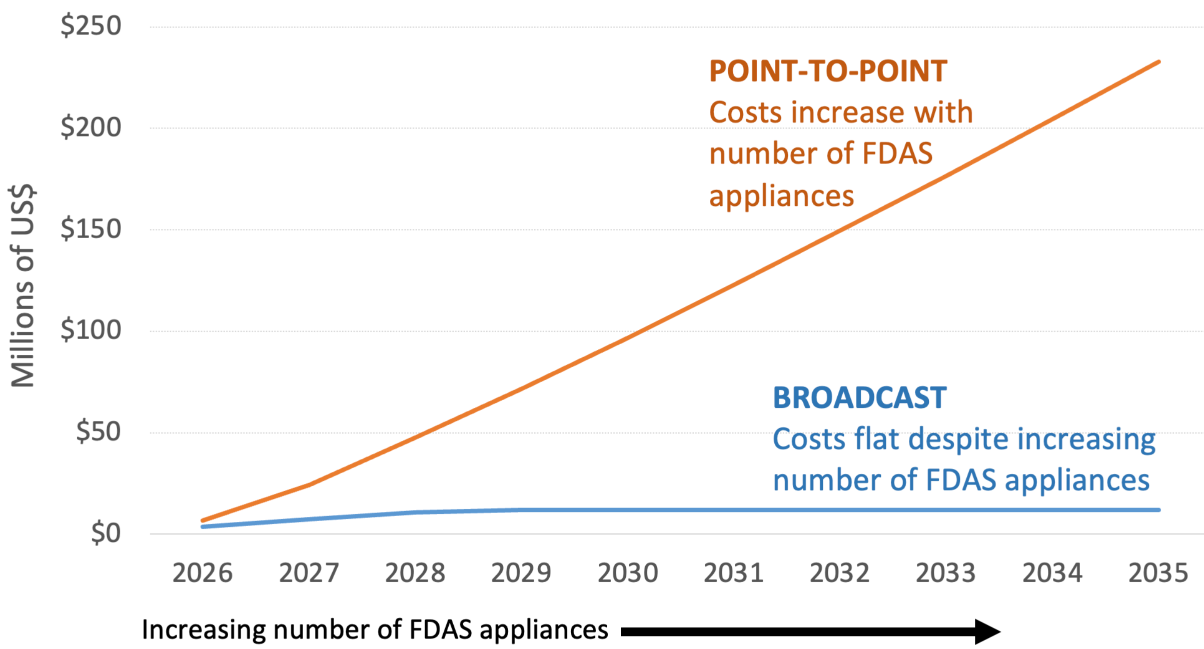
Statewide, the estimated first-year costs for the defined FDAS scenarios range from $9.4 million to $40.5 million. The three lowest-cost scenarios incorporate the MIDAS Plug-and-Play flexibility strategy.

Table 10. Estimated Year 10 Costs for FDAS Scenarios

Technology	California State	Appliance Manu-facturers	California Consumers	Load Serving Entities	Total FDAS Costs
Plug-&-Play RDS	$0.0	-$0.1	$10	$17	$27
Plug-&-Play Port	$0.0	-$0.8	$14	$16	$28
Plug-&-Play HD Radio	$0.0	-$0.1	$17	$17	$34
Plug-&-Play Cellular	$0.0	-$0.2	$97	$238	$334
3rd Party Wi-Fi	**$0.0**	**-$0.7**	**$26**	**$18**	**$44**
3rd Party Port	$0.0	-$0.7	$7	$79	$86
3rd Party Cellular	$0.0	-$0.7	$97	$67	$162
Consumer Cellular	$0.0	-$0.7	$160	$18	$178

Table 10 shows our estimated costs in the tenth year following FDAS implementation. The year 10 costs follow a similar pattern to the first year, except for notably higher expenses for load-serving entities in the Plug-&-Play Cellular scenario. These increased costs stem from the per-appliance service fees associated with cellular technology, which escalate in proportion to the number of connected appliances. In contrast, the number of appliances connected under a broadcast signaling infrastructure does not impact costs. (See Figure 9.)

Figure 9. Costs of Broadcast vs. Point-to-Point Communications



We estimate that a plug-and-play architecture would grow the population of flexible appliances in California to more than 20 million by 2035. With cellular connectivity costing $12 per year per appliance, and radio broadcasts costing less than $1 per home per year, it is clear why scenarios using broadcast radio are significantly more cost-effective. (See Figure 9.) These results are consistent with the findings of the Bonneville Power Authority, who noted, "the use of FM broadcast signals…is also the least expensive way to communicate to hundreds of thousands of households at scale." [50]

Benefits

Table 11 presents the estimated demand resource potentials for the scenarios considered in this study. These results show that the four Plug-and-Play scenarios have 7 to 8 times the potential resource of the other scenarios, all of which rely on customers signing up for programs that allow appliance remote control through Wi-Fi or cellular communications.

Table 11. Estimated Flexible Demand Resource Benefits

	Millions of Flexing Appliances		Flexible Demand Resource (MW)	
Scenario	**Year 1**	**Year 10**	**Year 1**	**Year 10**
Plug-&-Play RDS	0.6	21.6	115	6,400
Plug-&-Play Port	0.6	21.6	115	6,400
Plug-&-Play HD Radio	0.6	21.6	115	6,400
Plug-&-Play Cellular	0.6	19.4	112	5,800
3rd Party Wi-Fi	**0.1**	**2.6**	**14**	**800**
3rd Party Port	0.1	2.8	14	800
3rd Party Cellular	0.1	2.8	14	800
Consumer Cellular	0.1	2.8	14	800

Cost-Benefit Analysis

Combining the potential benefits in Table 11 with the aggregate 10-year costs (2026-2035), we estimate the average incremental costs per appliance as shown in Table 12.

Table 12. Preliminary Statewide Cost-Benefit Results

Scenario	2035 Resource (GW)	Cost to the State	Incremental Cost per Appliance	Capacity Cost ($/kW)
Plug-&-Play RDS	6.4	$0	$10	$7
Plug-&-Play Port	6.4	$0	$11	$8
Plug-&-Play HD Radio	6.4	$0	$13	$9
Plug-&-Play Cellular	5.8	$0	$100	$73
3rd Party Wi-Fi	**0.8**	$0	**$135**	**$97**
3rd Party Port	0.8	$0	$211	$157
3rd Party Cellular	0.8	$0	$436	$324
Consumer Cellular	0.8	$0	$454	$337

[50] Bonneville Power Authority. 2018. CTA-2045 Water Heater Demonstration Report Including a Business Case for CTA-2045 Market Transformation. *BPA Technology Innovation Project 336.*

Readily discernable is the fact that the three scenarios involving both MIDAS Plug-and-Play and broadcast signaling infrastructure are estimated to be about an order of magnitude more cost-effective than the business-as-usual scenario – or any other scenario for that matter. This result stems from two principal factors:

1. Consumers are more likely to accept plug-and-play options, as opposed to strategies requiring active involvement, and
2. Broadcast signaling is significantly more cost effective than point-to-point signaling where millions of appliances are involved.

CHAPTER 4: Discussion and Recommendations

The recent implementation of the MIDAS platform provides California with an unprecedented opportunity to enhance load flexibility beyond conventional demand response programs through plug-and-play participation in statewide flexibility. Our analysis indicates that by establishing standards for broadcast MIDAS Plug-and-Play connectivity, California can expand its flexible demand resources by more than 6 GW. As a result, we recommend that California continue the research needed to support standards for statewide MIDAS Plug-and-Play flexibility using a broadcast signaling infrastructure.

Some of the more interesting implications of our findings include:

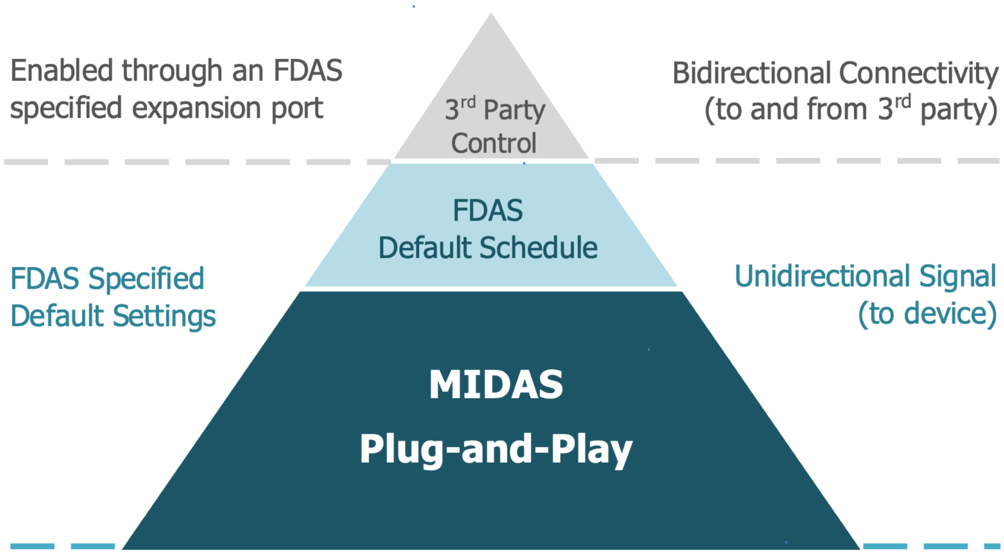
- The costs to the State or manufacturers in all scenarios are zero or negative, meaning the incremental per-appliance costs are fully borne by consumers and load serving entities. We expect that the roughly $10 incremental cost of each FDAS appliance under the broadcast Plug-and-Play scenarios would be reimbursed in short order through consumer bill savings, utility program streamlining, and system efficiencies.
- Of the eight scenarios considered in this analysis, only the Plug-&-Play Port scenario enables third-party programs as well as MIDAS Plug-and-Play flexibility. Thus, the Plug-&-Play Port solution is the most cost-effective of the solutions that include the enabling of third-party programs prioritized in PRC Section 25403(f).
- Should future efforts result in the standardization of MIDAS signaling and automated appliance response, the FDAS would not only expand demand resources in the near term, but also set the stage for consumers to benefit from real-time pricing in the future.

Further discussion and implications of these findings are explored in the following sections.

A Proposed Framework for Statewide Flexibility

Based on the findings of this paper, we propose revisiting and refining the California Loading Order to redefine Demand Response using the hierarchical framework depicted in Figure 10. In this context, MIDAS Plug-and-Play and FDAS default schedules constitute the baseload flexibility resources and third-party load control programs serve as peaking demand resources, activated only when the baseload resources are insufficient to meet grid needs.

Figure 10. Components of the Recommended Statewide Flexibility Framework



The following sections provide a series of use cases to explore how these components could be implemented in a future that incorporates MIDAS Plug-and-Play demand flexibility.

Component 1. MIDAS Plug-and-Play for Baseload Flexibility

The MIDAS system's use of unique Rate Identification Numbers makes possible the development of standards for receiving and responding to default MIDAS data streams. With a MIDAS Plug-and-Play architecture, consumers can effortlessly participate in demand flexibility options, without contacting anyone, providing personal information, or signing a contract.

Upon installation, FDAS-compliant appliances would immediately begin responding to default FDAS grid signals from the MIDAS. The default RIN might, for example, align with California's Self Generation Incentive Program (SGIP) greenhouse gas emissions forecast, which is freely and readily available.[51] The SGIP forecasts vary by location, so appliance responses could be further enhanced geospatially, using relative signal strength triangulation services of the default MIDAS signaling infrastructure.

Preliminary calculations suggest that customers on time-dependent rates who allow their appliances to respond to GHG data could see significant savings on their energy bills. Customers could save even more by entering their MIDAS rate identification number (RIN),

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[51] The Self-Generation Incentive Program (SGIP) was commissioned by the CPUC to flex batteries and water heaters in California. A similar signal developed for global use is increasingly being used by companies include MicroSoft, Google nest Labs, Toyota, BMW, Apple, Amazon Alexa, CPower, Enel X, and EVSE manufacturers. For more information, see https://watttime.org/solutions/load-shifting/

which is available on their electricity bills and online accounts.[52] This input could be done at the appliance user interface, where available, or through a Bluetooth connection between the appliance and a smartphone application.

Standard user interface features can be designed to enable customers to choose personalized response levels for greenhouse gas and price response, managed through a user-friendly interface. GHG response options could vary from 'no response' to 'full response.' Similarly, appliances with access to the customer RIN could provide input options to ascertain the extent to which the consumer prioritizes GHG or bill savings. Once the appliance is connected and the consumer has selected their preferred level of response, the appliance's runtime adjusts in accordance with manufacturer specifications.

Should a consumer opt out of responding to MIDAS signals, their appliance runs according to the FDAS-specified default schedule. Consumers can also sign up for a third-party control program, which would supersede the MIDAS functionality.

Component 2. FDAS Default Schedules for Regular Load Shifting
Like Energy Star computer power saving features, flexible appliances can be shipped with standard default schedules, leaving options for consumers to change them at or after installation. If the MIDAS signal for an appliance is unavailable or MIDAS functionality disabled, the appliance reverts to this schedule unless otherwise programmed.

At installation, appliances connected to MIDAS could automatically download an up-to-date default schedule, similar to how computing devices check for software updates upon setup. Appliances with automated cycles (pool pumps, water heaters, thermostats, batteries, and EVSEs) would follow FDAS default schedules, while appliances with manual cycles (washing machines, electric dryers, dishwashers, and again EVSEs) could use FDAS default delay-start functions.

Consumers may override FDAS default schedules by setting their own custom schedules. In addition, they could opt to enroll in a third-party load management program.

Component 3. Third-Party Programs for Fine-Tuning Grid Stability
Should California achieve a smooth-running baseload flexibility system, the need for emergency response might be diminished, but unlikely eliminated. As more and more behind-the-meter appliances flex load automatically, the optimization of their performance relative to each other at the home and distribution level can be supported by third-party programs. In addition to the conventional demand response programs that exist today, future third-party programs are anticipated to offer subscription and transactive energy services as envisioned by the CPUC's CalFUSE framework.[53]

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[52] CCR Title 20 Section 1623

[53] https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf

Next Steps for Enabling MIDAS Plug-and-Play FDAS

Given the broad scope of our findings, we recommend that the CEC proceed cautiously, with actions aimed at testing the viability of the MIDAS Plug-and-Play architecture through low-cost, low-risk technology demonstrations, data model development, MIDAS modifications, and grid modeling. These tasks can be conducted concurrently with soliciting stakeholder input to deepen the understanding of the potential impacts on systemwide costs and reliability.

Step 1. Implement MIDAS Updates to Support FDAS

Mere access to the CEC's MIDAS via an open-source communication pathway is insufficient for ensuring demand flexibility. We recommend the development and documentation of the following MIDAS modifications to support a plug-and-play functionality:

- Create at least one new RIN to act as the default FDAS data source
- Develop additional RINs for multiple default Location IDs to enable geospatially specific FDAS signals
- Develop an efficient data message format specification for delivering MIDAS signals directly to appliances, building upon the work shown in Table 13

The following sections discuss these recommendations in further detail.

FDAS Default RIN(s)

The primary objective of the Flexible Demand Appliance Standards is to reduce greenhouse gas emissions while ensuring the reliability of the electric grid. In the short term, this involves promoting energy usage during periods when renewable resources, such as solar and wind, are plentiful. Over the long term, as fossil-fuel powered plants are phased out and grid-related greenhouse gas emissions approach zero, the focus will shift toward enhancing grid reliability.

The establishment of one or more standard default RINs will enable the smooth transition of the statewide flexibility signal content from greenhouse gas emissions indicators to reliability indicators. Under this strategy, the characters specifying the default RIN remain unchanged, while the content of the data streams is modified as necessary to meet evolving grid requirements. Initially, we recommend using California's SGIP greenhouse gas emissions data source, a standard used in state programs since 2014, which provides hourly forecasts of GHG emissions for ten California DLAPs. [54]

We also advise that the CEC conduct an annual review of the default data source's effectiveness, collaborating with the CPUC, ISO, and load serving entities to make adjustments that fine-tune the statewide baseload flexibility resource. Beyond the SGIP data, other potential data sources for this purpose could include ISO nodal pricing and Optimum Load Shaping data. [55]

FDAS Default Location IDs

The creation of default RINs for appliance standards can be easily accomplished using existing CEC resources. This strategy can address appliances by location through the creation of

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[54] https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/self-generation-incentive-program

[55] https://optimumloadshape.com/about/

multiple RINs with varying Location IDs. (See Figure 3.) Initially, we recommend establishing a single statewide default RIN plus an additional default RIN for each of the ten California DLAPs. The CEC might also consider how standards could allow for expanding the number of locations in the future, for example, by using an evolving list of location IDs that can be accessed through the MIDAS.

FDAS Data Message Format

FDAS-compliant appliances must be capable of parsing the MIDAS signal. We recommend developing a standard message format that utilizes the smallest effective subset of data fields available in the MIDAS database. This specification will equip manufacturers with the necessary details to process MIDAS data efficiently, enabling them to design appliances that respond appropriately in accordance with FDAS requirements.

Table 13 provides a MIDAS data message specification we developed to aid in our technical feasibility analysis. At just 40 bytes for 24 hourly values, the tiny size of this message format makes it ideal for efficient transmission of MIDAS data to appliances no matter the signaling infrastructure.

Table 13. Draft Data Message Format for MIDAS Signals

Parameter	Range of values	Example	Size (Bytes)
Location ID	Up to 8 characters	PGE NVENERG	8
Message Type	1 to 250; 255 extend	"1" = Rates "2" = GHG "3" = Flex Alert	1
Timestamp		1708017238	4
Units of measure (gCo2/kwh)	0 to 250; 255 extend	"0" = no units "1" = gCO2/kwh	1
Value interval (minutes)	1 to 250; 255 extend	60	1
Number of values	1 to 250; 255 extend	12	1
Each value (in array)	0 to 250; 255 extend	(price or CO2)	24

Step 2. Develop Response Algorithms and Control Logic for an Appliance

If Step 1 is successful, the MIDAS signaling infrastructure will be prepared to distribute data to appliances. The next step involves developing the software that enables appliances to receive and respond to the signal. Recommended steps to achieve this include:

a. Choose an appliance for initial testing. We recommend starting with water heaters, which have a history of successful load management applications.
b. Develop a model of key operational aspects that are consistent with ANSI/CTA-2045.
c. Develop a set of rules and response algorithms for how the appliance will respond to the MIDAS hourly forecasts.

d. Program the rules into the appliance controller and perform local tests using simulated MIDAS information. We recommend the use of an ANSI/CTA-2045-B module, which has a standard set of rules for water heater load management and are less complicated to modify than the appliance itself.
e. Produce a report outlining the rules, algorithms, and test results.

Step 3. Demonstrate the End-to-End System with Usability Testing

If Step 2 is successful, we recommend a minimal end-to-end demonstration showing the feasibility and effectiveness of MIDAS signaling, appliance reception, and load response. This would establish proof of concept for MIDAS Plug-&-Play flexibility and potentially uncover issues for further consideration. We recommend the use of a water heater with the ANSI/CTA-2045-B port occupied by the module programmed in Step 2. We further recommend the demonstration and usability testing of all three potential communications pathways for receiving MIDAS signals: Wi-Fi, FM, and cellular.

Step 4. Model the Potential Effects on the Grid

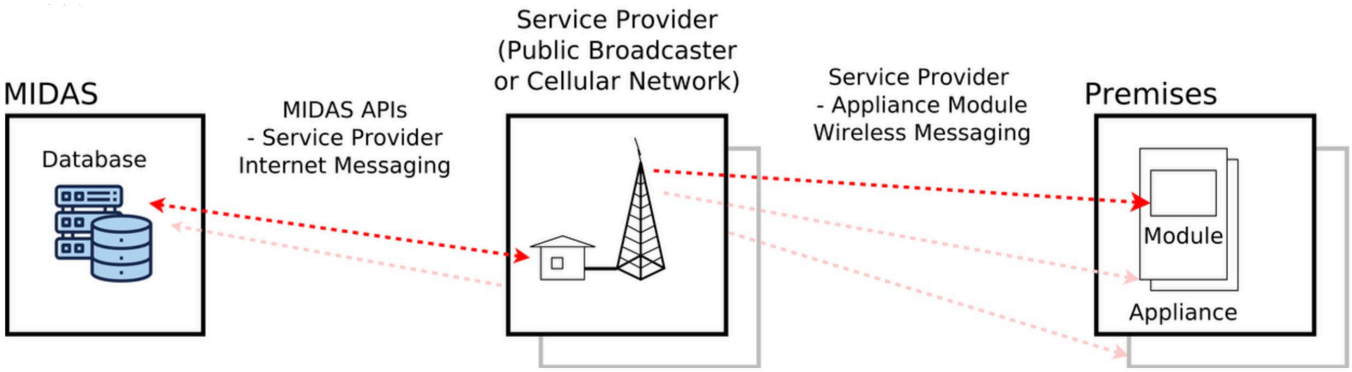
In parallel with or following Step 3, we recommend a study to integrate the predicted demand resources with ISO grid operation models to simulate potential systemwide consequences of injecting 6 gigawatts of load flexibility resource into the California grid over the next 10 years. The simulation model would represent the interaction between flexible appliance operation and grid performance by predicting flexibility related load spikes and dips and corresponding effects on grid stability. Simulated scenarios should specify demand flexibility standards, renewable energy supply fluctuations, weather-related impacts, and seasonal consumption changes.

Step 5. Specify the Elements of a Standard Signaling Infrastructure

After successfully completing Steps 1 through 4, and assuming no major concerns are raised by stakeholders or discovered during further investigations, the next step would be to establish standards for the MIDAS signaling infrastructure. These standards are crucial for achieving MIDAS plug-and-play flexibility, which our calculations indicate is essential to meet the 3 GW capacity goal for FDAS.

Figure 11 illustrates the essential roles of a communications service provider in acting as a signaling infrastructure between MIDAS and FDAS-compliant appliances. According to this framework, one or more communication service providers will access MIDAS information via the internet, convert the minimum required data subset into a standard message format, and then transmit these messages to the FDAS communication module in compliant appliances. It is important to note that while an 'appliance' could be a gateway facilitating further signal transmission to appliances, for security reasons, appliances downstream from a gateway cannot support plug-and-play functionality.

Figure 11. Elements of a Common Signaling Infrastructure for MIDAS Data Delivery



To test the feasibility of this architecture, we successfully implemented a proof-of-concept open software module that a communications service provider might use.[56] Using the existing MIDAS APIs, the module is authorized by MIDAS, retrieves MIDAS information using the appropriate RINs, and then translates the data into the efficient data message format shown in Table 13. This confirms that the processing requirements for service providers are feasible and suggests that rapid deployment in the market is easily achievable.

Other Considerations and Potential Future Research

This paper is the first in a series to be produced under CEC contract 400-22-002. The findings of this study are preliminary and based on information available at the time. We recommend that the State proceed cautiously and continue to explore this topic further. Some of the key issues that require further investigation are outlined in this section.

User Interface

To ensure user-friendly interaction and promote broader consumer engagement, the FDAS user interfaces should be somewhat standardized across appliances. A consistent and intuitive interface across various devices, regardless of manufacturer, will help mitigate confusion and cognitive overload, thus encouraging consumer participation and enhancing overall program effectiveness. Without such standardization, the diversity of user interface designs could lead to consumer frustration and lower participation rates, significantly undermining the potential benefits of the FDAS system.

Economic Impacts and Equity

Our current calculations provide evidence that the recommended MIDAS plug-and-play system will, on average, lower electricity bills. Additionally, by mandating that all appliances incorporate basic flexibility options independent of home internet access, the FDAS is expected to enhance the equitable distribution of flexibility benefits. Despite these apparent boons, we identify and discuss in this section two potential equity concerns to keep in mind as we proceed.

Default Operation. Appliances in rental properties, which often house low-income residents, may be more likely to operate on default settings. If these default settings are configured for GHG response rather than price response, low-income customers and renters may not realize the maximum possible savings. Should the savings disparity between these settings prove

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[56] Available at https://github.com/ludobgit/MIDAS.git

substantial, the choice of FDAS default settings will require careful consideration. Future research under this contract is anticipated to provide further insights into this issue.

New Occupant, Old Settings. Imagine moving into a new home ten years from now, equipped with FDAS appliances still programmed to the previous owner's schedule. As many have experienced with existing smart thermostats or doorbells, connecting and reprogramming these devices can be complex. To prevent renters and others in similar situations from missing out on benefits, the FDAS could incorporate standardized options for resetting appliances to default settings

Customer Privacy

The unidirectional broadcast recommended for MIDAS plug-and-play flexibility does not raise customer privacy concerns, as it does not collect data from customer premises. In contrast, bidirectional communications involve exchanging consumer data between appliances and a centralized system, which could introduce some or all of privacy issues outlined in Table 14.

These concerns will be explored in further detail in a future paper.

Table 14. Potential Privacy Risks of Bidirectional Signaling Architectures

Risk	Description	Mitigation Measures
Security Breaches and Personal Data Exposure	Bidirectional data transmission can expose occupancy patterns and other personal information, which could be accessed by unauthorized parties.	Implement data anonymization techniques to ensure that data cannot be traced back to individual users. Conduct regular security audits and updates to safeguard the system against vulnerabilities. Employ advanced encryption to protect data from unauthorized access.
Data Misuse and Surveillance	Without strict controls, data might be analyzed for targeted advertising, rate manipulation, or even sold to third parties without the consumer's explicit consent. Personal data could be also used for surveillance by government or private entities, tracking not just energy use but broader behavioral patterns.	Develop clear standards that define the use, storage, and sharing of data. Provide users with controls over their data, including options to opt-out of data sharing and to manage the data collected.
Third-Party Access	The involvement of third-party vendors in managing the flexibility system could lead to additional risks if these parties have personal consumer data and lesser security measures.	Develop clear standards that define the use, storage, and sharing of data. Reduce the amount of sensitive information at risk by collecting only the data needed for flexibility system functionality.

Cybersecurity

Cybersecurity risks also vary with the signaling system architecture. In general, unidirectional signaling poses fewer cybersecurity risks compared to a bidirectional architecture. Table 15 provides a preliminary assessment of common cybersecurity risks associated with unidirectional and bidirectional systems. We recommend conducting a comprehensive investigation of cybersecurity issues before implementing a MIDAS signaling infrastructure or developing standards.

Table 15. Cybersecurity Risks Depend on Signaling Architecture

Risk	Description	1-way	2-way
Manipulation of Signals	Signals to appliances could be intercepted and altered, leading to incorrect actions being taken by the appliances based on corrupted data.	possible	possible
Denial of Service Attack	A flood of fake signals could be sent to appliances, overwhelming them or the network infrastructure.	unlikely	possible
Propagation of Malware	Appliances could become vectors for the spread of malware. If one device is compromised, it could potentially distribute malware to other connected devices or back to the central system.	not possible	possible
Vulnerability to Hacking	Compromised devices could be used to access broader network systems.	not possible	possible

No matter the communication architecture, robust security measures must be implemented to mitigate these cybersecurity threats. Following are some common actions that can be taken to help prevent unauthorized access to flexibility systems.

- **Strong Authentication and Encryption**: Use strong authentication methods and encryption to prevent unauthorized access
- **Regular Software Updates and Patches**: Ensure that firmware and software on connected devices are regularly updated to protect against known vulnerabilities.
- **Network Monitoring and Anomaly Detection**: Implement advanced monitoring tools to detect unusual network activity that could indicate a cybersecurity threat.
- **Firewalls and Intrusion Detection Systems**: Use firewalls and intrusion detection systems to protect network traffic and prevent unauthorized access.
- **Security Audits and Testing**: Conduct regular security audits and penetration testing to identify and address vulnerabilities.
- **Consumer Awareness**: Educate consumers on the risks and provide guidelines on securing their home networks and connected appliances.

These issues will be explored in further detail in a future paper.

Potential Grid Effects

A mass-market system of appliances automatically responding to real-time pricing or greenhouse gas emissions can significantly benefit consumers and the grid. However, if not meticulously designed, it could also exacerbate grid instabilities due to demand synchronization, signal reliability, and cybersecurity concerns. Table 16 outlines several destabilizing factors that may arise from such a widespread and autonomous demand resource.

Table 16. Potential Risks of Rapid Expansion of Flexible Demand Resources

Risk	Description	Potential Solutions
Synchronized demand shifts	If large numbers of appliances simultaneously adjust their operation based on the same signals, this could lead to unexpected demand spikes or troughs that destabilize the grid.	Diversify the algorithms and signal criteria across different appliances and manufacturers to help prevent simultaneous mass responses and smooth out demand spikes
Data integrity threats	False data could lead to inappropriate actions by appliances	Initiate appropriate data integrity and security measures at the MIDAS.
Signal transmission reliability	A failure in the communication infrastructure could lead to inappropriate appliance responses, or no response at all, potentially causing discomfort or disrupting energy management strategies.	Implement robust fail-safes and redundancy measures in the communication infrastructure to help ensure consistency and reliability of signal transmission.
Security vulnerabilities	Malicious entities might manipulate or disrupt the signals, leading to broader grid instability.	• Enhance cybersecurity measures to protect the integrity of the signals. • Regularly update and test security measures to maintain effectiveness against evolving threats. • Always provide consumers with manual override capabilities

The effects of a statewide flexibility system on wholesale electricity markets, transmission, and distribution are beyond the scope of this contract. As discussed previously, we recommend that the State pursue the development of a simulation model to aid in designing safeguards into a future system.

CHAPTER 5: Limitations

The following topics are outside the scope of this study (contract subtask 2.2) and so are not addressed in detail in this paper. Many, but not all of these topics will be addressed in future research under CEC contract 400-22-002.

- Consumer privacy
- Cybersecurity risks related to the signaling infrastructure between the MIDAS database and the residence
- Potential impacts of mass-market demand flexibility on grid stability
- How appliances might or should respond to hourly price and greenhouse gas signals
- Potential effects on human health of any of the communications systems mentioned in this paper
- Feasibility of television broadcast technologies such as ATSC 3.0

Additional caveats include:

- The results of this study are preliminary, based on the knowledge available at the completion of this paper, the first in a series to be delivered under CEC contract 400-22-002. The findings and recommendations provided in this paper might evolve as additional information is uncovered through our continuing investigation.
- This paper should be considered in conjunction with the deliverables of Task 2.5, which address the potential benefits of bidirectional communications.
- Further investigation into the issues listed as limitations above could have substantial implications for our findings.
- Although the authors believe the costs used for this analysis to be accurate at this time, we make no explicit claims to the ongoing accuracy of these costs in the future.
- Additional technical feasibility evaluation will be needed if the planned public broadcast needs to deliver more than 48 hours of data per RIN per hour.
- To limit the number of scenarios, we include a single hybrid option that includes oth MIDAS Plug-and-Play and 3rd Party enablement. Other promising hybrid combinations may be available. For example, manufacturers might embed both a one-way radio receiver and a Wi-Fi module. Adding these scenarios is elementary using the Flexible Demand Cost Calculator.
- We did not compare the differential costs and benefits of static versus dynamic default operational schedules, where dynamic refers to the ability for the default schedule to be updated over-the-air at installation and potentially beyond.
- Appliance flexible capacity values are based on preliminary estimates that will be updated in subsequent research.

CHAPTER 6: Conclusions

This paper investigates the feasibility, costs, and benefits of multiple communications technologies intended to expand statewide demand flexibility through appliance standards for public MIDAS price and greenhouse gas data delivery to appliances.

The preliminary results of our analysis, the first in a series under this contract, suggest that the Flexible Demand Appliance Standards have the potential to increase demand resources in California by more than 6 GW by 2035 through the implementation of standards for MIDAS plug-and-play capability, grid-friendly default schedules, and communication expansion ports that enable third-party programs. These benefits come at no cost to the State of California, while the costs paid by consumers and load serving entities are almost negligible relative to the costs of existing demand response programs.

The system components that make these standards possible are expected to increase FDAS impacts by a factor of eight relative to flexibility programs that rely on consumer home internet. Each of these components, described below, improves FDAS cost-effectiveness by either reducing costs or increasing benefits through increased participation.

1. **MIDAS Plug-and-Play Functionality Increases Benefits**

Implementing standards for MIDAS Plug-and-Play capability would provide consumers with immediate options for appliance flexibility and potential bill savings upon installation. Our analysis indicates that this functionality would multiply the expected FDAS resource capacity by eight times compared to Wi-Fi-based programs, potentially achieving over 6 GW of flexible resource capacity by 2035. Additionally, our findings suggest that achieving the FDAS 3 GW capacity goal would be unlikely without the integration of MIDAS Plug-and-Play

2. **FDAS-Defined Default Settings Increase Benefits**

History indicates that consumers are more likely to adopt default settings than actively sign up for a program. We conservatively estimate that FDAS default settings for MIDAS response and operational schedules could achieve over 70 percent participation in some form of FDAS-enabled demand flexibility. In contrast, a business-as-usual scenario requiring active signup is expected to yield less than 10 percent participation.

3. **Broadcast Signaling Infrastructure Reduces Costs**

By 2035, we project over 30 million FDAS-compliant appliances in California. Communication technologies that charge per-appliance fees see costs rise linearly with the number of appliances deployed. With current costs of $12 per appliance per year for cellular services and just $1 per home per year for statewide broadcast radio, broadcast signaling architecture emerges as the more cost-effective solution.

4. **Third Party Enablement via Expansion Port Reduces Costs**

Among scenarios that enable third-party programs, the Plug-&-Play Port scenario emerges as the most cost-effective. This hybrid scenario integrates standards for a communications expansion port with embedded radio receivers that facilitate MIDAS Plug-and-Play. In this scenario, the expansion ports enable customers to participate in third-party flexibility programs without incurring significant costs to the FDAS.

APPENDIX A: Interpretation of Authority: PRC 25402(f)

Public Resources Code §25402(f) grants the CEC the authority to develop Flexible Demand Appliance Standards as follows. Terms to be defined following the excerpt are in bold font.

> (1) Adopt, by regulation, and periodically update, standards for **appliances** to facilitate the deployment of flexible demand technologies. These regulations may include labeling provisions to promote the use of appliances with flexible demand capabilities. The flexible demand appliance standards shall be based on feasible and attainable efficiencies or feasible improvements that will **enable** appliance operations to **be scheduled, shifted, or curtailed** to reduce emissions of greenhouse gasses associated with electricity generation. The standards shall become effective no sooner than one year after the date of their adoption or updating.
>
> (2) In adopting the flexible demand appliance standards, the commission shall consider the National Institute of Standards and Technology's reliability and cybersecurity protocols, or other cybersecurity protocols that are equally or more protective, and shall adopt, at a minimum, the North American Electric Reliability Corporation's Critical Infrastructure Protection standards.
>
> (3) The flexible demand appliance standards shall be cost effective. When determining cost-effectiveness, solely for purposes of this subdivision, the commission may consider, as appropriate, the cost of flexible demand appliances compared to nonflexible demand appliances, the value of increased or decreased emissions of greenhouse gasses associated with the timing of an appliance's use, the life-cycle cost to the consumer from using a product that complies with the standard, and the life-cycle costs and benefits to consumers, including the ability to conserve energy and better align consumer and electric system demand. The commission shall consider other relevant factors, as required by Sections 11346.5 and 11357 of the Government Code, including, but not limited to, the impact on housing costs, the total statewide costs and benefits of the standard over its lifetime, the economic impact on California businesses, and alternative approaches and their associated costs.
>
> (4) The commission shall consult with the Public Utilities Commission and load-serving entities to better align the flexible demand appliance standards with demand response programs administered by the state and load-serving entities and to incentivize the deployment of flexible demand appliances.
>
> (5) The flexible demand appliance standards shall prioritize all of the following:
>
> (A) Appliances that can more conveniently have their electrical demand controlled by **load-management technology and third-party load-management programs**.
>
> (B) Appliances with load-management technology options that are **readily available**.

(C) Appliances that have a **user-friendly** interface and follow a **straightforward** setup and connection process, such as remote setup by means of an internet website or application.

(D) Appliances with **load-management technology options** that follow **simple standards** for **third-party direct operation** of the appliances.

(E) Appliances that are **interoperable** or **open source**.

(6) On or before January 1, 2021, and as necessary thereafter, the commission shall include as part of each Integrated Energy Policy Report adopted pursuant to Chapter 4 (commencing with Section 25300) a description of any actions it has taken pursuant to this subdivision and the flexible demand appliance standards' cost to consumers.

(7) For purposes of this subdivision, both of the following definitions apply:

(A) "Flexible demand" means the capability to schedule, shift, or curtail the electrical demand of a load-serving entity's customer through direct action by the customer or through action by a third party, the load-serving entity, or a grid balancing authority, with the **customer's consent**.

(B) "Load-serving entity" has the same meaning as defined in Section 380 of the Public Utilities Code.

Following are our interpretations of the terms in bold text, which are used but not defined in PRC 25402(f). Each term is followed by its associated paragraph number in parentheses.

Appliances (1). Any device that uses electricity from the grid.

"Enable" (1). To implement the hardware, software, and any other technology needed for a customer to choose the intended functionality. The intended functionality may or may not be activated at installation, depending on customer choices.

"Be scheduled, shifted, or curtailed" (1). The subject of this action could include human and non-human actors.

"Load-management technology and third-party load-management programs" (5A). This phrase refers to two concepts that may work separately or together. "Load management technology" implies a system that manages electrical loads with or without third-party interaction. Load management technology can be internal or external to the appliance, and inside or outside the premises. Examples of load management options include:

- Customer control via local technology such as an appliance interface or smartphone
- Manufacturer control via remote technology using digital telecommunications
- Third-party control via remote technology using digital telecommunications

In contrast, "third-party load-management programs" implies the involvement of a third-party, which we define as any entity that is not the customer or the device manufacturer. Thus, a third party could be an installer, an automation service provider, the customer's load serving entity, or the grid balancing authority. These concepts are key in distinguishing plug-and-play from third-party flexibility. Settings, communications, and data sources can be made default settings in the appliance and thus do not necessitate consumer interaction. In contrast, a third-party program must be explicitly chosen by the consumer, often through a contractual agreement.

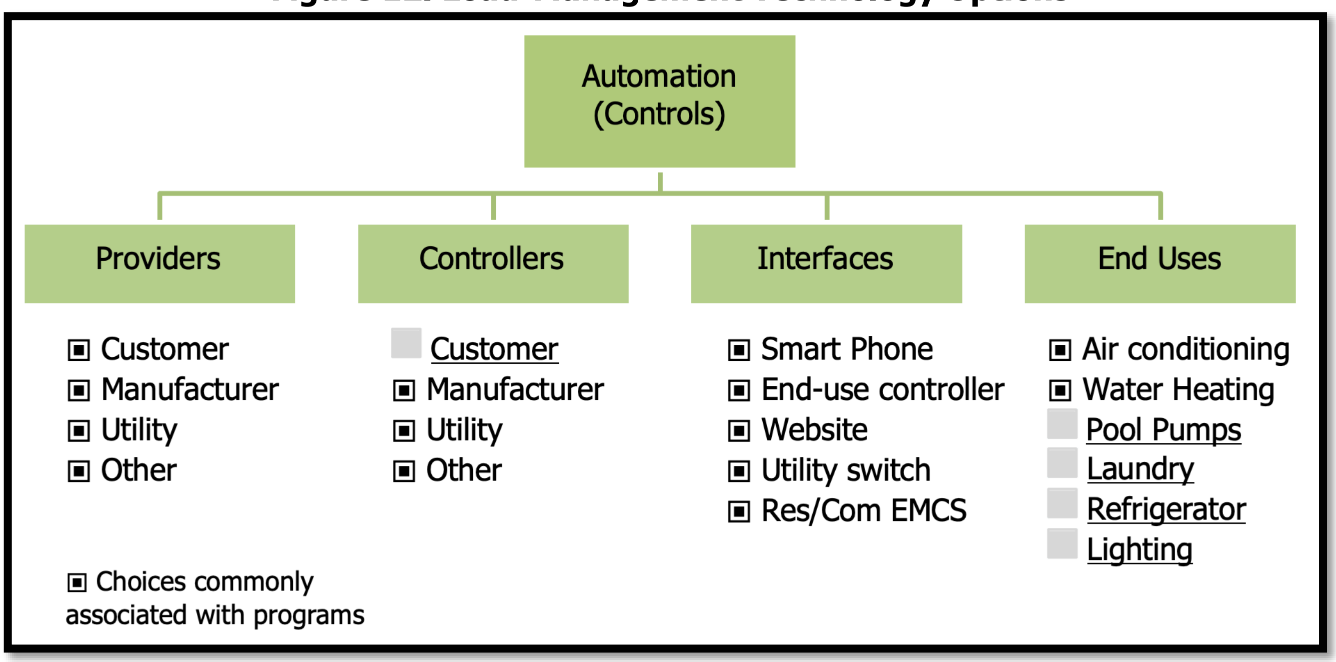
"Readily Available" Technology Options (5B). Technology that is both available in the marketplace for the manufacturer, and readily available at the appliance for the customer.

"User-Friendly" Interface (5C). A device that scores at least 50 on the System Usability Scale under testing by a representative sample of at least 100 customers.[57]

"Straightforward" Setup and Connection (5C). Similar to "user-friendly," a device whose setup and connection can be done in an allotted time, for example, no more than 15 minutes total using the appliance interface, smartphone app, or website. Setup includes technology options such as default or chosen settings, communications, and data sources; and chosen load management programs.

"Load-management Technology Options" (5D). Here we make use of a United States (U.S.) Department of Energy framework (Figure 12 with unmined opportunities underlined) as a starting point in characterizing the broad landscape of possible technologies under this umbrella. The framework includes not only the form of the automated control technology itself (e.g., thermostat or energy management system), but also relevant contextual characteristics such as the party that chose and provided the technology, the party that makes decisions about how the technology affects the consumer device services, and the controlled end uses.

Figure 12. Load-Management Technology Options



Source: Derived from US DOE 2010[58] (updated for 2024 context)

"Simple Standards" (5D). Standard that are empirically shown to be understood and implementable by manufacturers for their target purpose, which in this case is flexibility. An

[57] See http://usability.gov/

[58] U.S. Department of Energy. Smart Grid Investment Grant Technical Advisory Group Guidance Document #2, Topic: Non-Rate Treatments in Consumer Behavior Study Designs. August 6, 2010.

example of empirical testing might include a score of at least 50 on the System Usability Scale under testing by a representative sample of manufacturers.

"Third-party Direct Operation" (5D). This section of the code directs the CEC to enable options for customers to sign up for third-party load control programs, run by utilities or demand response providers. These programs pay or otherwise incentivize electricity customers to shed load during grid events (e.g. supply shortages or congestion events). These programs generally earn revenue by selling the aggregate load shed to the electric utilities and ISO during times of grid stress. In this paper, we refer to this concept as 3rd Party Control.

"Interoperable" Appliances (5E). "Interoperability refers to the basic ability of different computerized products or systems to readily connect and exchange information with one another, in either implementation or access, without restriction." (HeavyAI.com)

"Open" Source, Standard, and License (5E). "…open source code is created to be freely available, and most licenses allow for the redistribution and modification of the code by anyone, anywhere, with attribution. In many cases the license further dictates that any updates from contributors will also become free and open to the community. This allows a decentralized community of developers to collaborate on a project and jointly benefit from the resulting software."[59] Examples of open-source specifications for energy management include:

- FlexMeasures (https://flexmeasures.io)
- OpenEMS (https://openems.github.io/openems.io/openems/latest/introduction.html)

Note that "open source" is different from an open standard, which is "a standard that is freely available for adoption, implementation, and updates… often jointly managed by a foundation of stakeholders. There are typically rules about what kind of adjustments or updates users can make, to ensure that the standard maintains interoperability and quality."[60] Some well-known examples of open standards include Internet Protocol (IP), XML, SQL, PDF, HTML, and cellular 5G. Open standards for energy management include SCADA, DERMS, and ANSI/CTA-2045.

"Customer's consent." This term incorporates both opt-in and opt-out mechanisms to ensure that individuals have control over their participation in programs or services. Opt-in consent requires individuals to actively agree or "opt-in" to participation in a program, typically by providing explicit consent through checkboxes, forms, or other means. Opt-out consent allows individuals to decline or "opt-out" of default program participation. Opt-out mechanisms provide convenience for users by minimizing set-up decisions, but they must be accompanied by clear disclosure and easy-to-access options for changing the default settings.

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[59] https://www.ibm.com/blog/open-standards-vs-open-source-explanation/

[60] ibid.