Emerging Products

Emerging Products Review: IDSM Program Opportunities in Connected Plug Load Devices

Assessing the potential for Plug Load measures and programs featuring connectivity

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EXECUTIVE SUMMARY

PROJECT OVERVIEW

In recent years, a wide range of "smart" connected residential plug load devices have become market ready, as have secondary connected systems that control plug loads. The features of these individual devices and control systems range from reporting information to users and allowing basic schedule settings to complex monitoring and energy management control options. Although the connectivity of these devices is often focused on convenience or security for the customer, many of them have the potential for increasing energy efficiency and for demand-response or other load-shifting functionality. The purpose of this project is to review the current state of knowledge on the potential of these new plug load devices and systems for success in utility sponsored residential IDSM programs.

A comprehensive list of standard household plug loads including major appliances, small appliances, consumer electronics and miscellaneous electric loads is presented, with the aim of filtering these devices according to relevant criteria. These criteria include connectivity features that could potentially enable energy efficiency and demand response functions, potential unit energy savings, and positive market trend. Program design evaluations are also presented with the goal of demonstrating the opportunities and challenges of different program types including downstream and midstream delivery channels, as well as discussing relevant program parameters for specific device categories.

PROJECT SCOPING AND INTENDED AUDIENCE

This report evaluates market-ready connected plug load devices for opportunities in plug load programs. Unlike previous approaches that focus only on the programmatic or technology side, the approach used in this study evaluates the intersectionality between technical capability and program focused performance. This document is targeted to a program designer, implementer, or auditor and can be used to provide context in measure evaluation for residential connected plug load devices consistent with many "smart home" technologies.

FINDINGS

Of the 90 plug load devices evaluated using the flowchart selection criteria, the majority 72% were rejected as being out of scope. One of the main reasons was lack of sufficient testing results supporting estimates of any energy efficiency or demand response effects. As of the publication of this report, few smart home technologies have been vetted through field trial testing in California to the point of accepted DEER or CPUC accepted *Ex Ante* annual energy savings values. Extensive field trials were conducted on the Tier 2 Advanced power strip in connected and non-connected variants, with an accepted work paper for the non-connected variant and an abandoned work paper for the connected variant. Accepted work papers exist for smart-connected refrigerators yet the content of this work largely harmonizes with the ENERGY STAR Connected criteria and The National Appliance Energy Conservation Act (NAECA) energy consumption standards for multiple configurations of device and using DEER basis factors to determine IOU size category adjusted allowances.

Accordingly, few devices relevant to the current discussion are available immediately for participation in California IOU based programs reliant on the workpaper process.

Other plug load devices were rejected as out of scope due to limited connectivity, or to the lack of mechanism through which the connectivity could result in energy efficiency or demand response functionality.

The selection criteria resulted in three connected devices of major scope: smart connected refrigerators, clothes washers, and pool pumps. It also produced two control systems of major scope: Smart plugs (here considered paired with portable window air conditioners and under-sink hot water dispensers) and Tier 2 APS devices (here paired with audiovisual entertainment systems). Deep dives were conducted on these devices or systems. Several other devices and control systems were identified as being of minor scope; program considerations are summarized more generally for these. Of these devices, only the smart-connected refrigerator has accepted California workpapers in place.

Utility opportunities for connected smart home technologies in the plug load space were largely developed with demand response as a major IDSM consideration, especially for smart connected major appliance categories such as clothes washers and refrigerators. Such devices have limited operational space for human or connected-automation mediated improvement for efficiency. Such devices have limited potential with current features to benefit from cost-effective utility midstream incentive programs with respect to energy efficiency due to the impact of connectivity enabled features.

Of the three individual connected devices examined at length, only s pool/fountain pumps show potential for cost effective savings, as evidenced by a high Total Resource Cost (TRC) value in some utility measure circumstances. However, the connectivity-related features of the pool pumps contributed a very small portion of the energy savings, with the majority of the efficiency attributable to mechanical improvements (specifically, variable speed drive technology). The two connected control systems showed promise. The TRC values for Tier 2 APS devices controlling audiovisual entertainment devices achieve a value higher than 1 in the second year, but not far above 1 and only under certain circumstances. However, as with pool pumps, energy savings for connected Tier 2 advanced power strips are largely attributable to non-connected features. The connectivity provides other benefits, such as with installation free-ridership estimation and program auditing as well as AB793 compliance, but does not significantly contribute to energy savings for Tier 2 APS devices. Smart plugs were calculated to produce a high TRC by improving energy efficiency for window air-conditioning units, and show promise for demand-response options as well. However, the TRC values for smart plugs controlling under-sink hot water dispensers failed to reach 1. The main difference between the two devices controlled by the smart plugs is the amount of energy they normally use, and thus the extent of the possible energy savings through control. The technology alone provides substantial savings potential in some applications. However, these savings are tempered by ultimate device practical controllability as well as the "intelligence" of a control system to detect events and infer points of energy waste to reduce power during these periods without impacting user experience. Minor scoped devices are also discussed.

For many of these device types, a substantial amount of energy can be saved through improved mechanical function compared to baseline products, showing potential in many categories for continued efficiency improvement. This is largely out of discussion scope when focusing on the enabling impacts of connectivity. One challenge with pursuing additional energy savings through connectivity is that a major potential mode of improvement relies on notification-based behavioral changes: that is, the connectivity features facilitate communication to the user, and the user makes decisions that save energy. However, user behavior changes are rarely directly tested in the types of studies necessary to justify utility programs.

Smart home energy management systems may increase device-level energy savings potential with improved coordination and control of integrated devices, but there is currently insufficient data to analyze this possibility. Considering the limited efficiency improvement potential due to connectivity in the aforementioned large appliances, such systems will likely provide little improvement when devices are integrated into such systems.

Continued technical development for truly integrated smart home solutions will be required for growth of energy efficient plug load applications. A substantial number of new and developing applications may have energy savings potential and demonstrated easy installation and adaptability Clear demonstration of applications will proceed to California utility field trial testing and work paper generation. This leaves a substantial time between when new practical, demonstrable solutions are available and when they can be justified for inclusion in utility programs.

UTILITY RECOMMENDATIONS

TARGETS FOR ENERGY EFFICIENCY PROGRAMS

Most smart-connected solutions rely on human-in-the-loop energy management as a primary means of energy use reduction. This behavioral mode of operation has been shown to be successful but can be limited in total savings potential and duration of action. Additional savings can be generated using automated control systems depending on the capability of the detection or sensing system, the intelligence of the processing system to properly intuit periods of savings, and the capability of the device to act upon these periods with substantial net savings to justify the action. Smart-connected major appliances have limited bounds for energy usage reduction. Circuit control systems can provide substantial control capability, but it may be challenging to maintain reliable interface control across many products. Continued improvement in this category to better integrate with device operation for multiple classes of devices will reduce this barrier to entry for providing control.

DEMAND RESPONSE PROGRAM CONSIDERATIONS

Demand response solutions inherently rely on connectivity and are a conceptual fit for smart connected devices. Many classes of plug loads, especially consumer electronics, are traditionally difficult to integrate with demand response control. Reduction of device functionality can substantially reduce the quality of user experience, requiring clear communication of action and opt-out capabilities. Demand response solutions are better suited to major appliances for which changing the timing of usage is less disruptive to the users' schedule than for office or entertainment devices. Multiple strategies can be used, such as delaying operation or expediting processing cycles to reasonable halt points. This report considers demand response as a minor discussion aspect.

ENERGY TIME OF USE PROGRAM CONSIDERATIONS

Communication to users or automatic timing for actions requires coordination and connectivity to manage notifications and alerts. Many classes of smart connected devices can communicate to users to help reduce usage during high cost periods. Direct, automatic, coordinated action is more challenging to implement and requires processes that can be ramped up and down depending on time of day without direct user impact. A major example is water heating and climate control, but other more sophisticated approaches include reducing fountain and pool pump flows, extending drying processes for clothes, or automatically adjusting plug load luminaries to a default dimmer setting that can be overridden by the user if required. These approaches are largely not implemented into wide consumer solutions at the present time. Continued thought leadership by utilities to technology innovators can help guide the development of more feature-rich and integrated solutions that help manage energy usage based on time of use or planning of use for distributed generated energy consistent with advanced operations of smart home energy management systems.

Best Practice Considerations for Program Implementation

IDSM programs work best when they can appeal to wide audiences that cross-cut demographic market segments and focus on a product that is simple to explain to users. Users should be able to operate the device without expert knowledge, and the device should be easily integrated into existing home infrastructure. Incentives or rebates should be clearly communicated and have the potential to drive significant energy savings for the utility. For midstream retail programs specifically, the product should be able to produce robust earnings, and the incentive structure should be mindful of seasonal sales patterns and tailored to the needs and wants of targeted customers.

Retail Platform Products programs are best matched to drive market transformation. Products with current low market penetration with a positive trajectory for increased market share should be prioritized. Market transformation is dependent on scalability of the product and depends on the utility's ability to communicate with retail sales partners regarding relevant market trends, product demand, and popularity.

Demand response capability is considered in the context of connected major appliances. CalPlug's assessment has found only small energy savings from DR capabilities for major appliances such as refrigerators and washing machines, due mainly to the limited nature of DR events.

The most important factor for TRC calculation is the unit energy net savings. High unit energy savings is a challenge for residential plug loads, because most devices do not consume substantial baseline energy at the individual level.

Other challenges to positive TRC results are measure lifetime and unit installed base. A potential mitigation strategy to improve TRC outcomes may be to offer the product at the midstream level, which would somewhat lower the expense of the program, and may substantially improve the measure lifetime and unit installed rate.

Current codes and standards for ENERGY STAR connectivity criteria do not offer concrete requirements specifically aimed at EE goals and are focused mainly on complying with DR directives.

Testing and Evaluation Programs, Codes and Standards updates

Residential plug loads and consumer electronics, both with and without smart connectivity, have benefited from common efficiency standards and well-designed evaluation programs. Examples of this include reduction of standby power due to efforts such as the set-top box voluntary agreement sponsored by CTA and the DOE external low voltage power supply efficiency standards. Other voluntary agreements such as the broadband code of conduct show the potential to reduce energy use in telecommunications links and has applicability to a number of IoT device technologies. Approaches such as micro sleeping and low power standbys could reduce link energy use, a critical concern with an increasing number of IoT devices present but have not yet been implemented industry-wide. Continued efforts in implicitly improving best practices for implementation through EPA/ENERGY STAR efforts helps improve general market product performance. Overall, utility efforts supporting ENERGY STAR and voluntary agreements in addition to careful guidance of policy have a proven track record of positive action. It was a set of California IOUs that provided strong thought leadership to ENERGY STAR regarding a 5% allowance for energy efficiency to implement DR in smart connected appliances. Continued effort in guiding solution development will likely continue to show benefits in the future.

ABBREVIATIONS AND ACRONYMS

AI	Artificial intelligence
AC	Air conditioning
ADR	Automated demand response
APS	Advanced power strip
AV	Audiovisual
CAGR	Compound annual growth rate
CalPlug	California Plug Load Research Center
CPUC	California Public Utilities Commission
DEER	Database of Energy Efficiency Resources
DOE	Department of Energy
DR	Demand response
EE	Energy efficiency
EUL	Estimated useful lifetime
HVAC	Heating, ventilation, and air conditioning
IDSM	Integrated Demand Side Management
IoT	Internet of Things
IOU	Investor-owned utility
kW	Kilowatt
kWh	Kilowatt-hour
MELs	Miscellaneous electric loads
MT	Market transformation
NTGR	Net-to-gross ratio
PG&E	Pacific Gas and Electric Company
PM	Power management
PNNL	Pacific Northwest National Laboratory
RPP	Retail Product Platform

SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SHEMS	Smart Home Energy Management System
TOU	Time of use
TRC	Total resource cost
TV	Television
UEC	Unit energy consumption
W	Watt
Wh	Watt-hour

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INTRODUCTION

In recent years, a wide range of "smart" connected residential plug load devices have become market ready, as have secondary connected systems that control plug loads. The features of these individual devices and control systems range from reporting information to users and allowing basic schedule settings to complex monitoring and energy management control options. Although the connectivity of these devices is often focused on convenience or security for the customer, many of them have the potential for increasing energy efficiency and for demand-response or other load-shifting functionality. The purpose of this project is to review the current state of knowledge on the potential of these new plug load devices and systems for success in utility sponsored residential IDSM programs.

Smart and connected solutions for Integrated Demand Side Management (IDSM) have been proven effective for commercial lighting and for both commercial and residential heating and cooling. As lighting and HVAC becomes more energy efficient, plug load devices represent a larger portion of energy demand. Plug loads are an important, yet underrepresented target for IDSM programs. As plug loads are a major source of residential energy consumption, it is a crucial next step toward zero net energy (ZNE) goals to thoroughly investigate and identify device categories and program designs that could be successfully integrated into practical and executable IDSM schemes. Targeting residential plug loads not only builds upon the success of previous IDSM programs in terms of net energy and emissions reduction, but further enables better energy management capability for both utilities and customers.

The scope of this report particularly focuses on internet connectivity features of emerging technology as a highly anticipated method of advancing energy efficiency, and as a secondary priority, improving demand response options. To this end, connectivity functionality is considered in the context of individual devices as well as integrated Internet of Things (IoT) systems to methodically illuminate key features and communications capabilities that are most promising for energy savings. Analysis of potential program structures best suited to plug loads further provides a comprehensive view of successful IDSM implementation strategies. Additional ancillary considerations are also presented, including mitigating factors to saving energy through smart devices and the qualitative and behavioral aspects of energy efficiency practices. While smart home technologies show promise for saving energy, limited performance data and field research limits solid estimates for program measure savings
(King, 2018).

HISTORY OF IDSM PROGRAMS IN CALIFORNIA

Beginning with the work of Art Rosenfeld in the 1970s to create greater energy efficiency standards, major appliances have long been identified as an important source of potential energy savings. Due to early implementation of building codes designed to reduce energy consumption as well as requirements for new appliances to use less power, California is widely seen as the leader in energy efficiency practices in the U.S. Indeed, despite an increased output and demand for plug load devices and the associated infrastructure upgrades, California has managed to maintain flat per capita energy usage since the mid-1970s (Rosenfeld & Poskanzer, 2009).

While plug loads constitute a significant portion of residential energy use (U.S. Energy Information Administration, 2015b), they have not been the primary target of incentivization in most previous programs. Historically, efforts to reduce energy consumption instead have been channeled towards energy efficient heating, ventilation, and air conditioning (HVAC), lighting installation, water heating, and some major appliances (Nordman & Sanchez, 2006). These "traditional end-uses" are relatively large and thus easy to recognize and incentivize; they are also highly suitable for demand response and time-of-use initiatives. These programs, with a strong focus on lighting and HVAC, have been the major focus of utilities and very effective in California and elsewhere (Baatz, Gilleo, & Barigye, 2016). The overwhelming success of HVAC and lighting incentives has, however, created a new challenge. Most of the achievable energy savings for these categories have already been accomplished to date, meaning that programs aimed at HVAC and lighting have reached a point of diminishing returns for California utilities. As these systems have become more efficient, the relative importance of plug loads is rising. In addition, the absolute number of plug load devices continues to rise (Nordman & Sanchez, 2006). To continue an upwards trajectory in energy savings and to encourage further market penetration for energy efficient products, it is prudent for utilities to shift their focus to the incentivization of plug load devices (Charles et al., 2018). Within the greater plug load category, federal standards for electronics and major appliances and programs with mid-steam and user rebates/buyback programs have been applied to some extent but have not been employed to the extent of programs focusing on HVAC and lighting. Considering the promise of residential plug loads, also regarding the balancing of supply and demand in the electrical grid, it is useful to develop a roadmap for approaching IDSM programs for plug load devices.

Classification and Characteristics of Plug Loads

Before proceeding further with a discussion of the specific opportunities and challenges of IDSM programs for plug load devices, it is useful to first provide a definition of a "plug load" device. Simply stated, a plug load is any device that can be plugged into an outlet, including major appliances and plug-in lamps, yet plug loads fit within the broader schema of miscellaneous electric loads (MELs), which also include devices and features that are hard-wired into buildings, such as security systems (Klopfer, Rapier, Luo, Pixley, & Li, 2017). For the purpose of this report, plug load devices and MELs will be referred to collectively as plug loads in order to provide a common discussion category.

Plug loads are a growing category and are increasing as a total household load. The success of other major residential load categories such as heating and cooling (referred collectively as HVAC) has produced promising results that may be applied to the plug load category. This wide classification of devices commonly includes consumer electronics, built-in devices, major and small appliances, and moving applications such as recirculation pumps, fountain/pool pumps and point-of-use hot water heating. The distributed nature of both the devices across categories and within each category (e.g. the wide variety of consumer electronics) presents unique challenges to develop energy management strategies. New devices and categories have increased, and the total number of consumer electronic residential devices continues to increase.

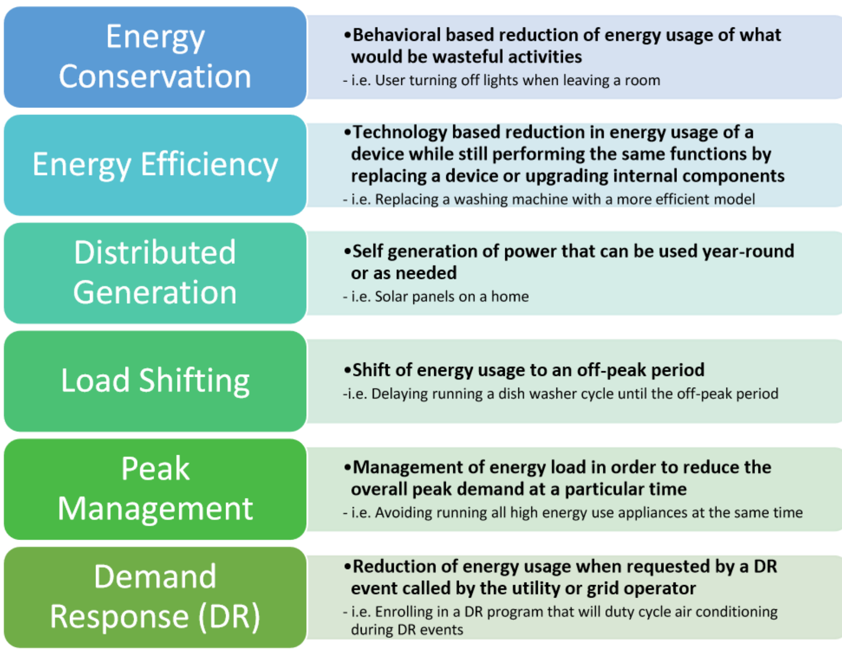
Many consumer electronic devices are highly reliant on quality user interaction which can limit the effectiveness of some common strategies for energy management and many demand response (DR) approaches. Similarly, other categories such as major appliances have limits on the depth of management possible. This is most clearly illustrated with the examples of refrigerators and clothes washers where deep, behavior focused energy management is largely unavailable as a strategy option. Additionally, targeting such devices for DR also creates concerns for usability (e.g. delays with wet clothes or melting ice) and can interfere with efficiency efforts by increasing total load during a full DR cycle. With respect to efficiency, a few technologies across multiple categories have provided large benefits, including components such as variable speed drive motors and compressors, sensor feedback loops, efficient voltage conversion/power supply, low power or quick restore sleep, and improved insulation design. While these largely physical technologies and approaches help improve efficiency across devices, other strategies relying on user behavior are also being investigated and developed. Such ways to manage energy consumption by reducing wasteful usage for a given device or set of devices. Such approaches can either be automated, like sleep or standby settings, or provide feedback to the user to encourage more energy-efficient behaviors. Connectivity (in the general sense) provides capability to allow improved interaction between devices and users to boost efficiency and to enable demand response actions. This capability also allows other features to be present on devices to increase functionality; however, these features may increase overall energy use. Understanding the modes of action for connectivity provides a framework for discussing not only the physical interfacing but the action of use to improve capability for efficiency, DR, and load shifting for IDSM applications. Time of use (TOU) pricing is discussed as a background consideration encouraging load shifting to off-peak periods.

OPPORTUNITIES AND CHALLENGES FOR PLUG LOAD IDSM DIRECTIVES

In order to identify workable strategies for implementing plug load IDSM programs, it is helpful to first address the opportunities and difficulties of addressing these devices with energy efficiency (EE), demand response (DR), and time of use (TOU) directives, and to enumerate potential impacts on devices and users. The specific actions of three major components of IDSM are generally investigated regarding plug loads (see also Figure 1):

1. Energy efficiency/conservation
2. Demand response management and control
3. Peak hour load shifting/ peak management

Many forms of building installed equipment and consumer electronic devices such as computers and entertainment devices are difficult to control through EE and DR applications. For example, some builder-installed devices perform real time operation (i.e. doorbells, smoke alarms, etc.) and are not appropriate targets to reduce operation without decreasing operational utility. Distributed or centrally managed batteries are also challenging to target. For energy efficiency efforts, reduction in usability is a common concern for effective consumer electronic device energy management. In some cases, this is due to wasteful user actions either directly (leaving a device on when not in use), or indirectly (placing hot food in a refrigerator). The first case is passive wasteful use where the device is operating as normal but is being used in a wasteful means. The second case is a specific action on the part of the user knowingly or unknowingly that contributes to device inefficiency. Within the framework of this discussion EE and energy conservation will be considered together in discussion. Similarly, load shifting, and peak management are closely aligned considerations. Both are focused on not total energy use but when energy is used. As a unit of electrical energy has varying consumer cost, carbon impact, and utility cost (often a factor of system capacity, generation and transmission to the location of use), the time where energy is used should be considered. Both load shifting and peak management can be considered on the device side together as an aspect of energy value awareness which can consider time of use (TOU) billing and other factors to shift consumption away from high value periods (often during daily consumption peaks) and toward lower value periods and if at all possible performing this action with negligible to minimal impact on overall efficiency. As energy usage follows a daily and seasonal cyclic trend, simple prediction and rudimentary management can be possible given location and time of day information without explicit constant action signals. DR is an action triggered by utility cue to reduce active load. The action of this feature is based on an explicit timed signal which requires connectivity to operate either supplied by the utility smart meter network or via a conventional internet connection.



Source: Wylie (2015, slide 16)

FIGURE 1: MODES OF INTEGRATED DEMAND SIDE MANAGEMENT

Plug load devices are particularly sensitive to efficiency and conservation aspects and must be specifically considered regarding the potential impact of on-demand utility moderation. The typical inelasticity of user-device utility is a major concern for many devices, and actions affecting device functionality, responsiveness, or basic feature access can have a strong, undesirable effect on user experience. As many residential plug loads are devices where sustained, high quality user interaction is essential for user satisfaction, power management must be careful not to interfere with the intended operation of these devices. Also, many devices have complex features that operate beyond the awareness of a typical user. Users may therefore fail to correctly identify an intentionally triggered signal and may believe a malfunction or malicious event has occurred. Active device usage may contain periods of time where the device is active, but the user(s) are gaining no added utility. An example of this would be a television left on with no one viewing.

There are several mitigation strategies to help users realize energy savings potentials and to maximize energy savings. One approach relies on using a connection to provide alerts to the user that a condition is occurring, enabling the user to save energy directly through active response, or notify remaining wasteful operation. An alternative approach relying on a more complicated control scheme coordinates the individual device with other devices and systems to provide improved controllability.

Device control through internal action by identification and action on user inactivity is a major behavioral based approach, but one that is less focused on human-in-the-loop action. The alternative to this approach at the most basic level is a means to tell users how devices are being used and ideally present identification of waste and usage patterns to the user so they can adjust general usage patterns or take broader action (maintenance, repairs, reconfigurations, etc.) to improve efficiency. Typically, this is done using a feedback approach indicating energy usage or specific actions via an interface or smart home (in a connected approach). For a home energy management system this information may appear as part of a dashboard setup. Traditionally, energy feedback has been given about a household's total energy consumption in a given unit of time, ranging from monthly, weekly, daily, to even smaller units of time since the introduction of smart meters. The means of feedback can span from paper statements, to utility online portals, and in-home devices. On average, giving users feedback on their overall energy consumption (non-device-specific) has been shown as effective in reducing household energy use (Delmas, Fischlein, & Asensio, 2013; Fischer, 2008; Karlin, Zinger, & Ford, 2015). However, the effectiveness varies between feedback methods and studies, ranging from 1% to 20% of energy savings (Fischer, 2017; Karlin et al., 2015). Users seem to benefit most from feedback that is frequent, especially (near) real-time (Delmas et al., 2013), and specific (Fischer, 2008). Up until now, device-specific feedback has been more rare and dependent on algorithms to disaggregate from the total energy consumption (Gago-Masague, Pixley, & Fallman, 2017). In the wake of smart devices, a more detailed, device-specific feedback on energy use and performance will be possible which may be valuable to both the user and the utility (King, 2018). One of the critical aspects of the feedback approach is to identify the user(s) who are key stakeholders and will act and continue to act on the feedback provided (Goldbach & Gölz, 2015).

Efficiency more generally can be addressed by specific design improvements (mentioned previously) in the technology, leading to increased operational optimization. The alternative approach is to target energy waste due to direct user interaction with the device. Treating the device as a machine in various states of operation and considering the actions (or lack of action) that contribute to waste is an approach to identify, model, and prepare solutions for reducing energy waste. Clearly identifying wasteful usage and triggering actions to provide management are common strategies for energy conservation. In this manner, logical states of operation for a device are not directly considered for energy use, but rather the strategy is focused on shifting to the lowest energy intensive state to produce the required work. If no active use is required, the device should be shifted into an off-standby state. In an overarching sense, efficiency is increased due to optimization for a lower total energy usage. However, at the level of individual periods of use, only wasteful periods are eliminated, a hallmark of a conservation-primary approach. These strategies are presented in Figure 2, which provides actions for energy consumption reduction due to wasteful usage or standby waste.

In addition to devices with internal energy management capabilities, interventional devices can be used to provide additional energy management control, such as advanced strips or controlled outlets.

Energy mitigation by plug loads and miscellaneous residential devices can be accomplished in ten specific target points (see mitigation flowchart in Figure 2). Of these points, three general categories of classification are considered: standby load (#1 to #5), wasteful usage (#6 and #7), and inappropriate usage (# 8 and#9). In addition to these three major categories, a null solution is presented for reducing energy used in various states of operation by instead using a more energy-efficient device (#0).

For the majority of devices with connectivity capability, specific control is used to provide extended management of device operation to reduce energy usage. This involves reducing standby and operational loads or reducing wasteful usage. Standby loads are mitigated by use of improved power supply design and judicious component choice and careful management of function active when the device is in a sleep state. For some devices standby modes have some level of connectivity and communication to allow periodic triggered wakeup.

Management can be affected by control of state transitions or by judicious management of state energy consumption. An example is shown in Figure 3 for the operation of a conventional pod coffee maker. State energy consumption is closely linked to repeatable device operation. Improved design is potentially possible to reduce energy usage within a state, but this is intimately tied to device design, architecture and operation. Internal management to reduce energy use when in more active forms of active states and reduce overall energy based on utility is possible but is likely a highly integrated aspect of the device design. In some devices, internal management is the major approach to improved energy efficiency. For example, devices such as building-installed equipment can benefit by improving overall power conversion efficiency and lowering operational usage through improving energy management in various active states of operation.

For many devices, targeting transitions to different states (such as standby or sleep) is an effective means for energy management, especially when a large difference exists between the power consumption of different operational states. Wasteful usage can be prevented by driving a transition to a low-power state when possible. Automatic transitions may be triggered by onboard power management (PM), user hot-keys, or via external management. A combination of behavior and technology is often in play when considering effectiveness. When approaches rely strongly on user intervention, user reactions are key to saving energy. Toward the other end of the spectrum are energy management settings, where a user's actions may not be required for an energy mechanism to have effect, but users may adjust settings that either enable non-default operating PM, or may disable or degrade the operation of PM features. A common example of this case is a desktop computer where disabling PM settings for a temporary need may turn into a prolonged term of PM ineffectiveness if the settings are not fully reverted. For settings-based concerns, the "stickiness" of PM settings should be considered in user interface and device functional design. Even further on the spectrum are devices with onboard PM that cannot be disabled. This may include devices with built in auto-off settings. In this case, typical user behavioral actions may have little impact on the energy management operation but could still have substantial impact on device overall energy usage.

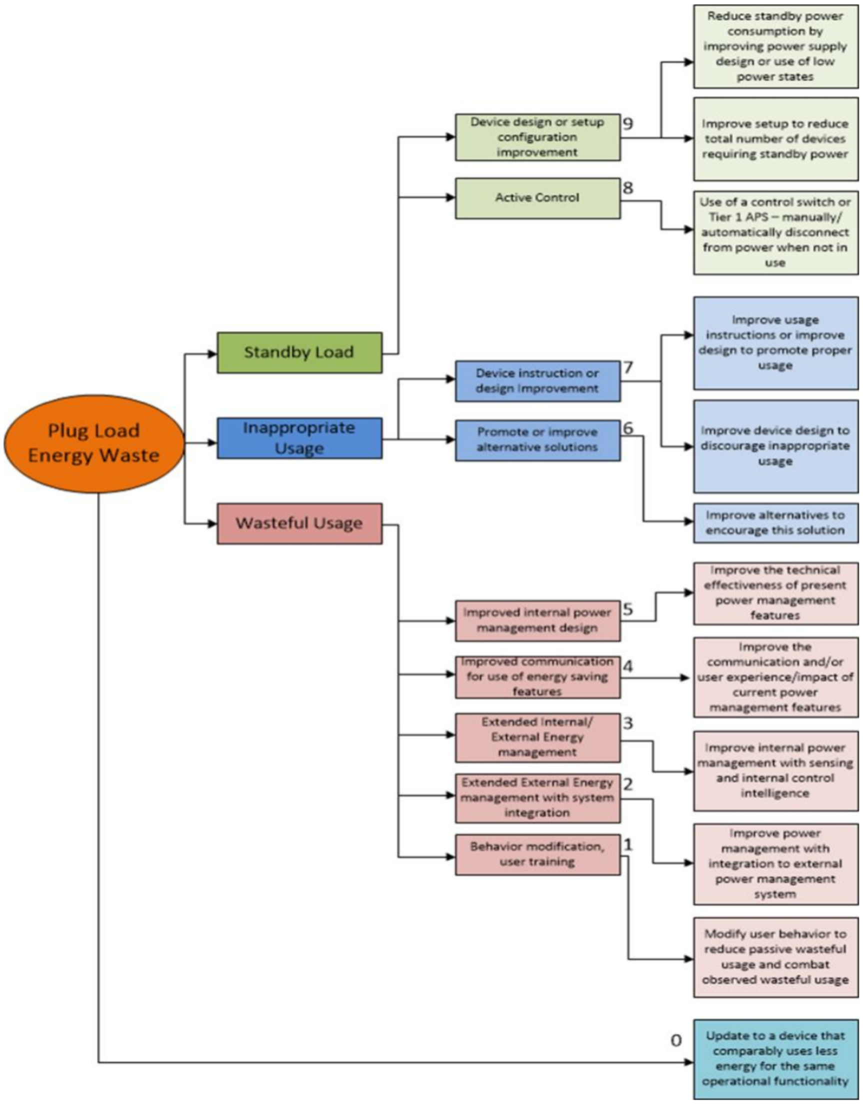


FIGURE 2: MODES OF WASTE FOR PLUG LOAD DEVICES AND USER INTERVENTION APPROACHES

For the majority of devices with connectivity capability, specific control is used to provide extended management of device operation to reduce energy usage. This involves reducing standby and operational loads or reducing wasteful usage. Standby loads are mitigated by use of improved power supply design and judicious component choice and careful management of function active when the device is in a sleep state. For some devices standby modes have some level of connectivity and communication to allow periodic triggered wakeup.

Management can be affected by control of state transitions or by judicious management of state energy consumption. An example is shown in Figure 3 for the operation of a conventional pod coffee maker. State energy consumption is closely linked to repeatable device operation. Improved design is potentially possible to reduce energy usage within a state, but this is intimately tied to device design, architecture and operation. Internal management to reduce energy use when in more active forms of active states and reduce overall energy based on utility is possible but is likely a highly integrated aspect of the device design. In some devices, internal management is the major approach to improved energy efficiency. For example, devices such as building-installed equipment can benefit by improving overall power conversion efficiency and lowering operational usage through improving energy management in various active states of operation.

For many devices, targeting transitions to different states (such as standby or sleep) is an effective means for energy management, especially when a large difference exists between the power consumption of different operational states. Wasteful usage can be prevented by driving a transition to a low-power state when possible. Automatic transitions may be triggered by onboard power management (PM), user hot-keys, or via external management. A combination of behavior and technology is often in play when considering effectiveness. When approaches rely strongly on user intervention, user reactions are key to saving energy. Toward the other end of the spectrum are energy management settings, where a user's actions may not be required for an energy mechanism to have effect, but users may adjust settings that either enable non-default operating PM, or may disable or degrade the operation of PM features. A common example of this case is a desktop computer where disabling PM settings for a temporary need may turn into a prolonged term of PM ineffectiveness if the settings are not fully reverted. For settings-based concerns, the "stickiness" of PM settings should be considered in user interface and device functional design. Even further on the spectrum are devices with onboard PM that cannot be disabled. This may include devices with built in auto-off settings. In this case, typical user behavioral actions may have little impact on the energy management operation but could still have substantial impact on device overall energy usage.

Compared to whole home user-based energy management, it is reasonable to expect that individual devices may have varied overall performance. Some devices have little user-based action that can occur (e.g. a refrigerator). Others have individual cycles that may generate waste by "over-processing", e.g. washers using extended wash cycles or unnecessarily warm water. Others have expected standard operating procedures that should not be varied (e.g. an oven, with a preheat and pre-determined bake cycle), yet reduction of waste (e.g., preheating long before oven is needed) or improved general usage to save energy may be possible even for these devices (although a tough sell in some cases). The goal in this approach is to match required processing with available processing and avoid waste, although difficult shifts in user behavior may require long term action or repeated interventions.

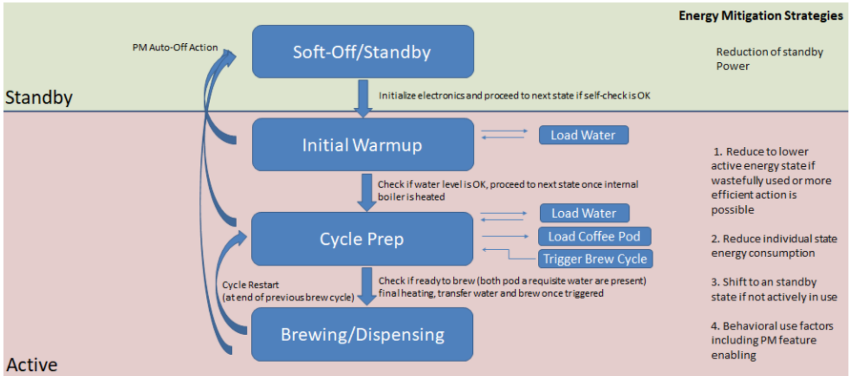


FIGURE 3: EXAMPLE OPERATIONAL STATE DIAGRAM FOR A POD-STYLE COFFEE MAKER

Although the discussion thus far identifies commonalities across subsets of plug load devices, a large and varied population exists, each with their own energy management requirements and feasible energy management strategies. One of the main reasons that plug loads have been neglected in IDSM programs compared to HVAC and lighting is that they are very difficult to target effectively due to the inherent variety of feature capabilities. Even within single device categories, there is a long tail of distribution between the simplest products with basic features and the most sophisticated products on the vanguard of current technology. Moreover, while these devices may be high energy consumers collectively, most use relatively little energy at the individual level.

It is also worth noting the impact that DR may have on energy efficiency: that is, that reduced energy use during the DR period may result in higher total energy use. One example is a DR action to stop a washing machine. Once the DR event has cleared, water re-heating and repeating parts of the cycle may be required to produce the same level of effective production (washing machine cleaning action). Similarly, DR action on items such as refrigerators, where compressor loading may not be controllable, could result in the same action occurring in a more inefficient way as more action is required in less time to "clean up" after the DR event. Refrigerators themselves are a noteworthy DR case as the specific mechanism of DR control is limited to minor adjustments of set points and compressor limiting and the disabling of accessories. Treating cost signals as action points, peak energy use periods may be planned for where minor excess utility may be curtailed and resumed at lower price points. These strategies can include delays in accessory usage (e.g. delayed ice production cycle if the ice bin is near full), delays in defrost cycles during high price periods in addition to pre-cooling and preemptive action prior to high price periods. This strategy straddles conventional DR and EE approaches and incorporates elements of voluntary load shedding at a granular device level.

Plug Load Market Background

In order to consider IDSM programs and incentive delivery channels, it is worthwhile to present an overview of the plug load market, including sales trends, manufacturing considerations, and the characteristics of the retail environment for home electronic goods.

Overview of Plug Load Market

Plug loads constitute a broad category of devices, including builder-installed hardware such as security systems, major appliances, and a variety of small home plug-in devices. Most of the products considered for residential plug load IDSM programs can be categorized as general home electronics, which have common industry production standards and include both major and small appliances. Home electronics are a highly competitive, generally low margin industry, where manufacturers and retailers must frequently reduce prices to maintain or grow market share. Price undercutting leads to low profit margins, which in turn creates a perverse incentive to produce goods more cheaply and with shorter lifetimes. This "planned obsolescence" is now ubiquitous across all major electronics manufacturers and has the aggregate effect of producing high turnover rates for most household plug loads.

Home automation and device connectivity is a growing trend in residential devices. Integration of features and the ability to observe and control remotely provide benefits to consumers such as enhanced comfort, convenience, accessibility, security, and energy savings. Early connected residential devices were focused on convenience and security as primary development goals (Balta-Ozkan, Amerighi, & Boteler, 2014; Bhati, Hansen, & Chan, 2017; Scott, 2007). Although these devices had connectivity, connectivity as a feature does not necessarily imply intelligence or ability to manage energy. Often the savings of energy is framed in the greater discussion of convenience and security as commonly a secondary selling point in market devices (Balta-Ozkan, Davidson, Bicket, & Whitmarsh, 2013). As technology develops and matures, stability in the market is providing consolidation leading to a growing uptake of smart device and appliance technologies (Markets and Markets, 2019; Mordor Intelligence, 2019) driven by remote monitoring and energy management. The majority of such devices are plug loads, particularly consumer electronic devices.

The proliferation of new devices and constant generation of further iterations of existing devices is accompanied by an increase in connectivity features. According to a study by Leichtman Research Group, as of December 2018, 83% of American households had internet service, and of these, 98% received broadband connectivity (Leichtman Research Group, 2018). Similarly, as of February 2019, 81% of U.S. adults owned smart phones (Pew Research Center, 2019b). A growing trend in broadband usage is the shift towards performing most or all internet-based activities on smart devices. While 24% of adults in 2013 reported using a cellphone as the primary method of accessing the internet, by 2019, that figure had jumped to 47% (Pew Research Center, 2019a). With the advent of new apps to easily manage a wide array of day-to-day activities, from online banking and bill payment to job applications, it is likely that internet usage via mobile devices will only continue to increase in the foreseeable future. As a background consideration, it is also worthwhile to keep in mind the continued efforts toward 5G and the associated proliferation of device usage that would surely accompany this transition.

Furthermore, it is important to note that the adoption of smart mobile device use for internet access produces cascading effects that can transform the entire electronics market. Connectivity features function optimally when they are situated within an ecosystem of many smart connected devices that communicate with each other over a cloud-based network, also called the Internet of Things (IoT). IoT has driven the development of products designed to share and manage the flow of information with other devices in a designated residential or commercial ecosystem. For example, smart speakers such as Amazon Echo and Google Home have been successful both in terms of technical function and in their ability to demonstrate to users the benefits of using smart device ecosystems for convenience and enjoyment (Kowalczuk, 2018). According to the Voicebot Smart Speaker Consumer Adoption Report of January 2019, smart speaker use stood at 26.2% of the U.S. adult population, representing a growth of 40% from 2018 (Kinsella, 2019).

Smart speakers and other inter-device communication and energy management systems make it more practical and feasible for manufacturers to add connectivity features to MELs that may not have been previously suitable for internet connection, such as refrigerators or other large appliances. This creates a positive feedback loop for producing smart devices, setting the stage for true market transformation. Additionally, the increasing cooperation between manufacturers to enable interchangeable communications with competitor products is a growing practice helping to solidify a permanent market transformation strategy.

Despite the overwhelming trend towards IoT and smart devices, there are important barriers and caveats to consider regarding connectivity features in the context of an incentive program. For example, relatively high intensity energy demand of specialized hardware and features for connected MELs may result in net negative energy savings, especially for smaller devices. The nonlinearity of energy consumption dictates that smaller devices are inherently less efficient than larger ones due to higher initial startup demand relative to size. Thus, any overhead associated with connectivity features may make certain small devices ineffectual for energy savings.

In addition to potentially increasing energy use through hardware specifications, the energy demand of cloud computation infrastructure also poses a potential threat to net savings. The simple charging of mobile devices adds only a small amount of energy consumption to residential homes. However, the information processing for mobile internet usage requires substantial off-site data centers that produce non-negligible amounts of carbon emissions. Transmission and data storage infrastructure also have a carbon footprint and must be added to the overall energy cost of cloud computing. To calculate true energy savings, internet activities enabled via mobile devices should be thought of not only in terms of physical energy demand, but also in terms of overall carbon impact. For example, solely reading e-mails on mobile devices is estimated to consume about 135kg of carbon per year for an average business user (Klopfer, Rapier, et al., 2017). Furthermore, the energy demand of cloud based IoT systems increases not at the household level, but at the level of individual devices. A recent study conducted by Cisco estimated that there are currently about eight connected devices per person in the US, with this statistic projected to increase to 13.6 devices per person by 2022 (Cisco, 2018). Considering this trend, it is important to keep in mind that energy savings of connected devices produced at the residential household level may be cancelled out and even surpassed by the externalities of the cloud computation process.

Within residences, connectivity has enabled new devices as well as becoming embedded within previously existing conventional consumer electronic devices. Connectivity itself may require an overhead of energy usage to provide functionality. Depending on the configuration and operation this may vary and should be considered for total operational impact Per a 2011 study, it is estimated that the operation of a smart phone consumes about 2 kWh/year (Fehske, Fettweis, Malmodin, & Biczok, 2011). Of this yearly operational demand, about 70% of energy is thought to be consumed by wireless interfaces such as Wi-Fi and Bluetooth (Carroll & Heiser, 2010; Pering, Agarwal, Gupta, & Want, 2006), translating into 1.4 kWh/year. This is on a per device basis, and based on a 2016 Pew Research Center study, it is estimated that the average American household has a median of 2 smartphones and 1 tablet (Figure 4). Considering these estimates, the background energy overhead needed to support connectivity features of smart appliances or emerging technology products in aggregate has the potential to reduce or outweigh net energy savings produced at the individual household level.

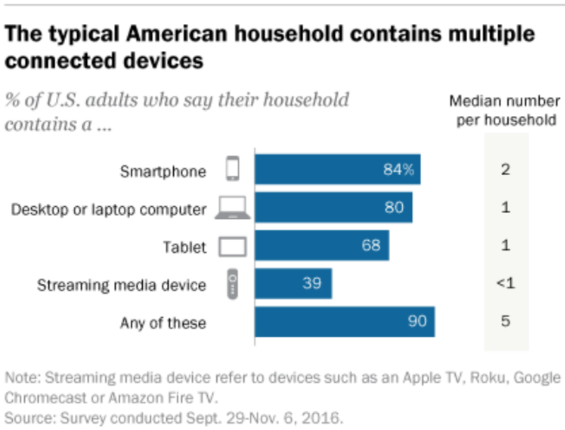


FIGURE 4: DEVICES IN AN AVERAGE AMERICAN HOUSEHOLD

Source: Pew Research Center (2017)

DEVICE MEASURES

IDSM measures include program aspects that are evaluated through total resource cost (TRC) analysis. These measures may include unit energy savings, unit install base, participant incentive and measure cost (base cost of device materials plus installation labor cost). Traditional plug load IDSM measures have been challenging due to the relatively low energy use per device (but high potential collective energy use), and distributed approach required. Previous programs targeting plug loads including large appliances and emerging technology have tended to be incentivized at the downstream level with direct install or product-specific rebates.

As market-ready connectivity features for major appliances are relatively new, they have not been thoroughly evaluated for additional savings in IDSM programs. Even if connectivity features of a specific device do add demonstrable energy savings, this may not directly translate into a successful incentive program. Particularly for small MELs with low projected savings potential, incentivization may fail to drive sales conversion. While devices sold in sufficient quantity through incentive programs may be profitable for program administrators and midstream retail partners, it is less clear that individual consumers would save enough on their home energy bills to outweigh or break even with the cost of a connected EE device. This creates a collective action problem where an eventual reduction in energy consumption is impeded by conflicting short-term interests between program administrators and the needs of residential customers. A potential solution to this problem is to promote the convenience and safety features of connectivity to the consumer as "value added." Previous research has shown that many users are not particularly motivated by the cost-saving aspect of energy savings, but they respond well to messaging that highlights how saving energy may result in better environmental and health outcomes (Asensio & Delmas, 2015). Similarly, focusing on the non-energy benefits of smart and connected devices, such as how smart devices increase safety and privacy and the convenience of remote device and home monitoring (King, 2018) may help with technology adoption.

Additionally, rather than applying the traditional downstream approach of incentivization via direct install (DI) or customer-focused product rebates, adopting a midstream or upstream approach can help to generate further energy savings and market share, especially for household electronic devices. Downstream rebate and DI programs may have been well suited for previous HVAC and lighting incentives, because these systems have high initial costs and require expertise in installation. Large "white goods," such as refrigerators, dishwashers, and clothes washing machines, have also been historically incentivized at the downstream level for similar reasons.

Conversely, midstream programs offer incentives to retailers and distributors to stock EE equipment, while upstream programs are directed at manufacturers and suppliers (Lukasiewicz et al., 2013). Although the user may not receive direct financial reward at the mid- or upstream level, the potential for distributor-targeted programs to drive permanent market transformation is much higher than that of downstream programs, where sales of EE devices tend to dissipate when rebate or DI offers end (Lukasiewicz et al., 2013). Midstream or upstream programs may be most beneficial for smaller household plug loads (e.g., TVs, sound systems, coffee makers, etc.), as they are generally less expensive to install than HVAC and lighting, and because the replacement rate of these devices is quite high, meaning that large downstream incentives would not be recuperative or profitable for retailers or program administrators.

Device Connectivity Considerations in Measure Development

Even if connectivity features of a specific device do add demonstrable energy savings, this may not directly translate into a successful incentive program. Particularly for small MELs with low projected savings potential, incentivization may fail to drive sales conversion. While devices sold in sufficient quantity through incentive programs may be profitable for program administrators and midstream retail partners, it is less clear that individual consumers would save enough on their home energy bills to outweigh or break even with the cost of a connected EE device. This creates a collective action problem where an eventual reduction in energy consumption is impeded by conflicting short-term interests between program administrators and the needs of residential customers. A potential solution to this problem is to promote the convenience and safety features of connectivity to the consumer as "value added."

Approach

The approach taken by the CalPlug team considered multiple levels of assessment of the current state of market-ready energy efficient technology and IDSM program designs. The requested scope of this project limited its focus to connected plug load devices, with a primary emphasis on energy efficiency and a secondary emphasis on demand response functionality. The purpose of this report is to assess possible IDSM programs for plug load devices and device systems based on evaluations of trends in technology development and best practices for program design. The focus of this project is primarily on the energy efficiency aspect of IDSM as the most important mode of energy savings, but also considers demand response as a component of connected device capability. To assist in the development of new programs, the scope of this report includes new appliances and emerging technology that are market ready and that are projected to see an increase in market share. As connectivity is a key feature in many new products, elements of internet communication as well as the opportunities and challenges presented by connected devices and systems are major discussion topics. This report further reviews previous program designs for plug load incentive programs and discusses the difficulties in addressing plug load devices with traditional downstream rebate programs. An investigation of midstream incentive design is presented in order to provide program guidance and expand the range of possible incentive structures for plug load IDSM initiatives.

The first step was to conduct a thorough baseline review of technological issues and program and measure considerations: this provides a solid foundation for insightful discussions of the products and program designs best suited for plug load IDSM programs. Based on this, CalPlug developed a novel classification system for connected devices to be used as an assessment tool in selecting devices to discuss at greater length. Research on previous program and measures led to an understanding of best practices for designing programs, as well as identifying lessons learned from past IDSM efforts. Using this assessment tool, CalPlug considered a wide array of possible devices and systems to ultimately select those best suited to IDSM program implementation. This process consisted of compiling a comprehensive device list, then using the classification system's flowchart to methodically filter these devices. This process removed most devices from consideration and divided the remainder into minor and major focus categories based on connectivity criteria, claimable savings potential, and market growth potential.

For minor-focus devices, general features and considerations were considered and summarized. Selected major-focus devices were then evaluated in-depth with discussions of their features and functionality, connectivity sophistication, and considerations of IDSM program components. As part of this effort, CalPlug designed a TRC (total resource cost) calculator that that synthesizes several key factors to project potential savings ranges for each device, a crucial aspect of the final assessments of programs and measures for that device.

Based on these findings, implications for potential IDSM programs for connected plug load devices are summarized in the conclusions.

TECHNICAL CONSIDERATIONS

Assessing the modes of action for energy consumption and savings in devices provides a framework to discuss how to improve devices in design and assess their fitness for program measure consideration. In this section the authors review aspects of energy management as related to device operation to classify strategies to address improving energy efficiency and energy conservation as well as general controllability for event-based reduction requests within the context of leveraging these aspects in device category measure deign and evaluation.

POWER MANAGEMENT FUNCTIONAL TARGETING CONSIDERATIONS

The action of power management (PM) as focused on EE applications uses two general approaches that must be considered in use. The controllability and specific approach used varies across device categories. In general, two basic schemes are used for PM, either relying on feedback (e.g., motion sensor) or feed forward (e.g., automatic schedule) as the primary control. Pure feed forward control does not take into account user actions and preferences (for example, the HVAC in a building that shuts off promptly at 5:00 PM each day and stays off during the weekends) and can lead to lack of user utility when programmed schedules differ from actual usage. For this reason, some systems have limited feedback capabilities to allow users to improve performance, as a backup control approach. Scheme details are provided below.

Feedback based PM scheme:

Operational hallmark is the detection of user presence or user engagement to determine when device is not being actively used and save energy during those periods. Management in enacted in a way to reduce impact on user experience.

- Detection of user presence or likelihood of user presence
- Action after a period of no user presence (avoid triggering with intermittent but still active interaction on the part of users)
- Provide preliminary action or direct tell-tale warning of action
- Act to reduce consumption (transition to low-power mode, cut power, etc.)
- Prime device for easy user reactivation.
- Alert user to specific or chronic action to allow human-in-the-loop tuning of energy management action.

Example: Connected-type Tier 2 advanced power strip

Feed-Forward based PM scheme:

Operational hallmark is the use of prescribed rules, often based on actions and time to reduce energy usage when users likely will not be present or usage is typically wasteful. Some implementations take user feedback to override operational rules to reduce impact on user experience, if possible.

- Allow the configuration for specific actions and rules to trigger device action including time, schedule, activity or power consumption pattern.
- Enact capability in a cloud or edge-based device that allows adjustment of settings and parameters as required.
- Device acts based on programmed action as a connected device or via semi-autonomous control based on configuration
- User may have an override capacity to restore functionality for an extended or period of time (or prior to an action)
- Functionality is restored automatically once period ends or pattern returns operation.

Example: Smart socket in commercial building application, occupancy sensor-light control.

Many user-centric systems use an aspect of both feed forward and feedback as well as clear communication with users. Such systems are sustainable in the sense that they are designed to remain installed and are resistant to being disabled. With increasing intelligence, a level of autonomous control becomes possible. Feed forward systems act without user actions, which fits some aspects of autonomous control. True autonomy reacts with changing situations to dynamically balance user experience with energy usage. Intelligence crossing with connectivity enables more advanced control capability (see Table 1). It should be noted that the control classes outlined in this table strongly parallel capabilities added by features described in the connectivity class categorization. Connectivity and control used together can provide informational visibility in implementation all the way up to autonomous control. A general trend toward the identification or inference of intent rather than activity (or lack of activity) is seen with increased control capabilities.

TABLE 1: DEVICE CONTROL CLASSES

Class Identification	Class Description	Example
Operational Visibility	Information display of energy usage (performance).	Smart meter home display, SHEMS.
Actionable Visibility	Information of energy usage (performance) with clear suggested or implied actions to help improve efficiency.	Advanced SHEMS, disaggregating energy monitor.
Actionable Control	Visibility combined with clear and decisive direct action suggested or autonomous action for price or DR events	Highly advanced SHEMS, Independent device DR activity.
Narrow-system integrated Control	Automatic opt-in actions based on user preferences and actions based on processed sensor data applied across specific devices and actions; typically using rule-based actions. Such implementations feature an integrated network between devices and often internet/cloud connectivity.	Smart socket, occupancy and illumination management with occupancy and astrological timing.
Wide-system integrated control	Automatic opt-in actions based on user preferences and actions based on processed sensor data applied across a wide variety of system -devices and actions, typically using intelligent management controls that may employ self-learning to improve system performance. Such implementations feature an integrated network between devices and typically internet/cloud connectivity.	Advanced IoT/Smart home setup

In general, connected devices using feedback provide energy savings through two structures:

1. Device/System Operational Feedback – Reporting of energy use or active time can be provided to users to help with manual energy management. This is typically considered as human-in-the-loop control.
2. Direct control - Use of system sensors and actuators along with advanced controls to provide sensing and control in managed schemes where automatic reduction of consumption is enacted by reducing energy usage states where possible. Reporting and visibility is a byproduct of operation.

Human-in-the-loop control provides information of varying actionability to a user to ultimately decide the action. The implementation of a solution is directly coupled to whether the human decides to act upon the given information. In general, clearer, more direct and actionable information leads to better outcomes. The sensing and the intelligence are coupled and can be either localized or distributed, resulting in system capability trends. Distributed sensing provides multiple spatially separated sensors of different type to provide contextual control input data. Conversely, one or two devices may provide limited spatial or sensory points of information. Like sensing, control intelligence can be coordinated at a single point such as an IoT hub, a distributed edge device, or a cloud system. The architecture and approach used for these different locations for sensing and control can have impacts on solution footprint energy overhead. Table 2 outlines this opposing set of considerations in four quadrants.

TABLE 2: INTELLIGENCE AND SENSING/CONTROL CLASSIFICATION OF CONNECTED DEVICES

Distributed Sensing/Control Use of on-board sensors to the controlled device to feed control algorithm	**Non- Distributed Sensing/Control** Use of distributed sensors to feed control algorithm
Distributed Control Intelligence Cloud located decision and action-based control	**Non-Distributed Control Intelligence** Cloud located decision and action-based control

Devices with greater connectivity integration have both benefits and drawbacks. On the one hand, more connectivity increases the potential for improved energy management for the device, and greater energy savings for attached or associated devices. On the other hand, more connectivity requires greater energy consumption to maintain the necessary links. The connected device field applies to devices with any of the following options:

1. onboard connectivity,
2. retrofitted connectivity
3. indirect management or monitoring

The majority of devices with these included features belong to devices generally considered within the umbrella of SHEMS devices and systems. Without clear definitions for the terms "smart", "connected, and "intelligence" within the smart home space, some terminology has blended inconsistently across different products and categories adding confusion in the market.
The level of connectivity and intelligence are also considerations that have energy impact, for device classification, and it is important to classify possible modes of energy savings. While a device may call itself connected or be connected for some manner of operation, this may not apply to energy monitoring or management operation. Even if it does apply, the level of management may not add to the capability of direct energy management. Savings may be provided by alerts to the user to take action. Breaking apart connectivity into modes of operation is required for analysis of energy management devices.

Modern internet of things-based control systems for loads typically operate by providing managed operation or providing a user visibility for operation. Examples of this connected strategy are shown in Figure 5. Within this figure, five specific enabling strategies are shown as capabilities provided by a connected solution. Each strategy is described in more detail below:

A. Extended system connection enabled logic/control – autonomous device control

1. Remote extended logic and management for energy control – This approach uses a remote based controller/service to enable extended management of a local load. Some intelligence may be local, but extended features or most energy management capabilities may be present through this external service when connectivity is active. Commands and parameters are sent back from the remote service based on usage information and local sensors as a part of the local system. Demand response (DR) and time of use (TOU) management may be provided in device control.

2. Remote operational parameter adjustment – This approach uses a remote based controller/service to enable extended management of local loads by improving local control. In this paradigm, local control is nearly autonomous, but remote interfacing can provide non-trivial tuning and adjustment of operation to improve energy management control in addition to specific remote triggered signals. DR and time of use management may be provided in device control.

2b. Remote operational and firmware updates to extend future features and capabilities for energy management.

B. Connected notification and user directed action

3. Display of current and past device usage information – Device usage and energy footprint provided to the user to allow informed device usage knowing energy usage. User management must be through conventional device usage. Input may be reported to the user as well as another system tracking device energy usage.
3. Display of current and past device usage information with user control – Device usage and energy footprint information is provided yet the user has the ability to turn off the device via a remote interface. This system may provide helpful alerts to users to notify them when wasteful usage may be occurring or provide calculated or user set conservation targets or to save money by aligning usage up with billing rates (TOU considerations).
4. Display of information to forecast and align workflow – This approach provides information about device usage that can help save energy, such as the status of a filter that can lead to increased energy usage if not changed regularly, or the contents of a refrigerator so user do not need to open and use energy to view contents. This is indirect information assisting energy productivity while enhancing user convenience.
5. Display of current device operation for energy management with ability to manually adjust parameters - Device operation can be adjusted remotely for settings of onboard PM and operational parameters. The system may provide past usage and PM settings and operational performance and provide a user the opportunity to adjust PM parameters.

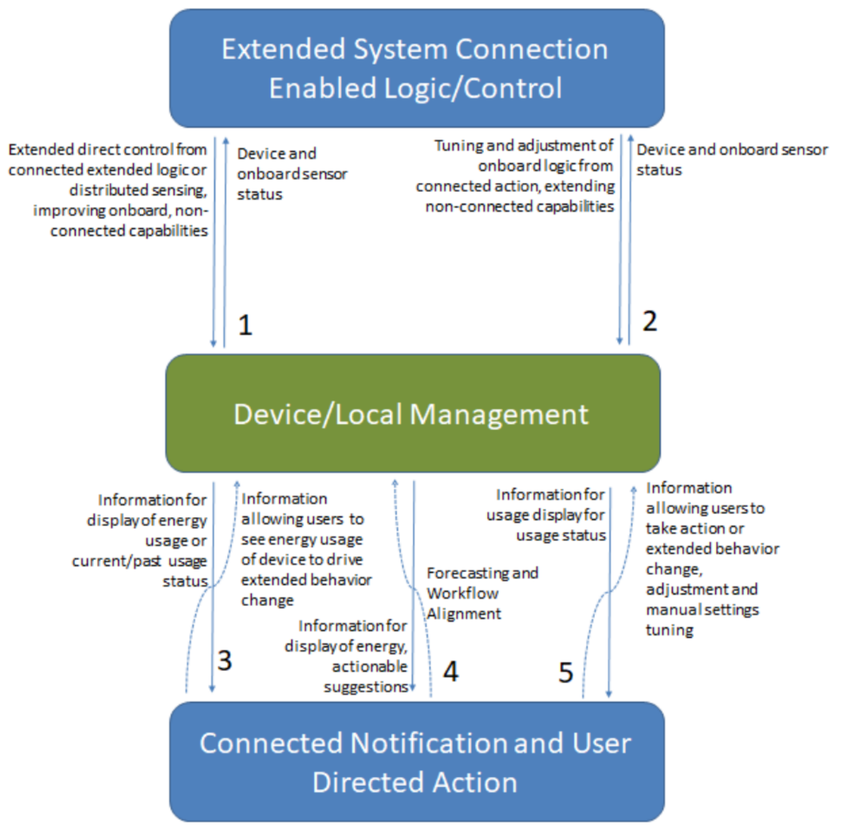


FIGURE 5: IOT-BASED ENABLING STRATEGIES FOR CONNECTED SOLUTIONS

User behavior toward devices can have an impact on energy use. This manifests in multiple ways: Users can use a device inefficiently. For example, users may leave a device on between uses rather than turn it off or put it into standby or sleep mode. This could be due to simple negligence, or to inaccurate beliefs about energy use, such as thinking that the warmup process for that device uses more energy than staying on for a while. In the previous example we did not address the impact of PM directly, although this system works with behavior to manage energy usage, the design of the system itself can have impact on functionality along the life of the device. The design of the interface and the action of the PM can have a substantial effect on the retainment rate for effective PM. If not enabled by default, PM my not be initially enabled or enabled to full reasonable functionality. If disabled, for testing or for a temporary reason, it may be difficult for users to re-enable PM.

If the user purposely disabled PM, it may be tricky for a new user of the device to re-enable it.

Some controlled devices may have interventional devices providing effective extended energy management capabilities. This device may provide direct commands to manage energy use by triggering state changes or provide power cuts to reduce both idle time and standby time. An example of such devices is a Tier 1 or Tier 2 advanced power strip (APS). The controlled device and the interventional device form a system, saving energy used by the controlled device. Other examples of this include commands provided over a high-definition multimedia interface (HDMI) link providing coordinated power-up and shutdown of audiovisual (AV) peripherals. If another device provides triggering for energy management (e.g. a TV triggering a Tier 1 APS to turn off a DVD player), this other device must be considered as part of the system as providing a sensing input for the interventional device. Interventional devices are a wide category. Traditionally these include the devices previously mentioned but may also include motion sensors and timers controlling devices in some broader definitions. Most of these devices are targeted at specific types of applications, such as AV systems and TVs. Operation of the intervention system must be focused around device operation to provide satisfactory control and savings potential.

Power Management and Connectivity Functionality

Home automation and connectivity is a growing cross-cutting trend in residential devices. Integration of features and the ability to observe and control remotely provide benefits to consumers such as enhanced comfort, convenience, accessibility, security, and energy savings. The use of connected or "smart" technology with regards to appliances as a designating term to imply energy efficiency or other IDSM characteristics such as demand response or the ability to respond to price signals. In their vanguard category for smart connected refrigerators and freezers ENERGY star provided an example guideline for connected devices (see Table 3) (ENERGY STAR, 2019a).

This guideline provides an effective means to discuss general categories and specific features, but it was not intended to provide a general discussion methodology to categorize connectivity or applications of energy management. The authors extended the work provided by ENERGY STAR to outline a guide for energy management. By providing both connected and non-connected actions of energy management, a connectivity class can be assigned for each solution provided for energy management. As connectivity in general is a loosely defined term, we are considering connectivity as communication from a device to another through a network with a gateway facing the internet consistent with the majority of IoT applications and configurations.

The categorization scheme falls short of describing some of the overreaching functional goals of communication with respect to power management (PM) at a functional level with relationship to connectivity. In this manner, devices each (in a single or across multiple categories) may have several categorical functions listed. The authors accordingly use the ENERGY STAR model for classification as a fundamental scheme and propose an extension. The details of this are presented in the following section.

TABLE 3: ENERGY STAR CONNECTED DEVICE CRITERIA

	Existing (in most specifications)	Expected to be proposed (large loads only)
Energy Consumption Reporting	Required; accuracy must be documented	
Operational Status Reporting	Defined more specifically for some product types, not all	Able to receive and respond to application layer messages typical of Open ADR or CTA-2045 that are relevant to these elements
Demand Response	Defined responses for Type I, Type II and Type III requests for some but not all product types	
Remote Management as consumer amenity	Yes, for most product types	May not be required or specified
Open Access	Uses standards in the SGIP catalog or similar; interface documentation or API required; open access may be cloud to cloud	Uses standards in SGIP catalog or similar; able to receive and respond to application layer messages w/o cloud connection (possibly with controller)
Modular DR communication	Allowed and encouraged, not required	Allowed and encouraged, not required
Connected Capability not Optional	Connected Thermostats only	Connected criteria remain optional (except Connected Thermostats)
Standby power limit	Some product types; limits vary	TBD
Consumer alerts	Many product types: alert consumers to energy wasting conditions (e.g. open refrigerator door)	Look for opportunities; not an area of concentration
Data elements reported	On-premise connectivity protocol (e.g. Wi-Fi, zwave, etc.) What additional hardware is needed to connect (e.g. Wi-Fi router, module) For a few products, DR capability summary in lieu of specific criteria	On-premise connectivity protocol (e.g. Wi- Fi, zwave, etc.) Whether a specific controller, sold separately, is needed to access connected capability What other additional hardware is needed to connect (e.g. Wi-Fi router, module) Additional data elements to be identified

Source: ENERGY STAR (2019a, page 5)

DEVICE CONNECTIVITY CLASSIFICATION SCHEME

In Table 4 CalPlug presents a 5-class characterization scheme for increasing connectivity as related to PM control. In Table 5, a modifier scheme is used which is consistent to the approach used by ENERGY STAR to specify details of specific device features. In Table 6, the application of Table 4 is presented showing subcategories for classification. Finally, in Table 7 an example classification is presented for a sample device including the shadow functionality that results due to degradation of connectivity and the resulting action on energy management. This approach does not replace ENERGY STAR's classification approach but augments it and provides a means to granularly consider features and contributory energy impact, agnostic from implementation hardware. As the class is increased, the general capacity for energy management increases. As the class increases the general maximum control tightness (often expressed as solution intelligence) generally increases, and devices may be part of a common category for multiple reasons. This approach does not consider hardware needed to implement the outlined features or communication channels such as Wi-Fi or Bluetooth. As these channels typically have communication for multiple purposes passing over them, the energy use for the communication hardware, transport overhead and backend control to enable functionality should be considered in following discussion.

Rudimentary connectivity capability is classified as zero level along with non-connected energy management solutions: that is, outside the typical connectivity space referred to as IoT and therefore directly classified but listed as unconnected in the scope of this report. Within level zero, multiple sub-classes are presented including point-to-point links, devices with operation based on connectivity, local coordinated, and place-shifting applications. These are applications of connectivity in which energy management is generally irrelevant. The use of a specific function may be predicated on the inclusion of an add-on package or may use an open standard for interfacing. These factors are attributes to the implementation of a feature rather than the feature itself and are presented as modifiers. This approach is largely consistent with what ENERGY STAR has provided in their guidelines for connected devices and parallels a similar approach used to draw out feature details.

Each device with a connected application can have the functionality described. Table 5 expresses device connectivity with appropriate modifiers to specify how the connectivity feature is implemented or affected, e.g. through open access interface, add-on features, or through manual override.

A further breakdown of CalPlug's connectivity classification system is presented in Table 6. This table forms the core of the evaluation process for determining relative levels of connectivity sophistication between devices considered in this project. The table is organized from 1a, representing basic customer feedback mechanisms to 5b, representing edge-based machine learning solutions, generally in the form of a smart home system. A classification of zero-level connectivity is also included to express how different devices default to non-connected conditions if connectivity supply is disabled.

Accordingly, the example of refrigerators (see Table 7) has a maximum connectivity categorization class of 3 with both DR and EE functionality included. For this device, all advanced energy management capability is managed by connectivity. When connectivity is lost, the shadow connectivity provides little capability for energy management action. In this manner, with a disabled connection or connectivity operation, many of the advanced energy management features provided by connectivity are lost.

TABLE 4: DEVICE CONNECTIVITY CLASSIFICATION

Connectivity Class	Class Identification	Class Description	Shadow Case
0	Non-Connected/ Null-Case	Power management applications using no connected approach	None
1	Reporting Only	Reporting of energy usage information and operational states to another device or to an operator. Solution may include manual demand response notifications.	0 – No connectivity to allow reporting, user or system not able to act on feedback
2	Real time Monitoring with control	Same as Connectivity Class 1, yet with ability to adjust onboard settings or change device operational modes via connectivity provided control or interface.	0 – No connectivity to allow reporting, user or system not able to act on feedback or make actions
3	Demand Response (automated)	Use of remote triggering for demand response actions	1 – User can see status information but is not able to adjust settings or modes
4	Network based device management of a single or set of devices	Use of remote/cloud capabilities to provide device or system operational tuning or tight control.	None – network / communication required to provide real-time DR triggering
5	Network based device management of a single or set of devices. Strong use of edge-based processing	Use of remote/cloud capabilities to provide device or system operational tuning or tight control. Major pre-post processing occurs on device for this class.	0 – Loss of connectivity may revert control feature, yet configuration may provide short term resilience at the edge device in some cases to produce continued action for an extended period.

TABLE 5: DEVICE CONNECTIVITY MODIFIER CONSIDERATIONS

Modifiers		Description
OS	Open Standards (OS) Communication	Use of Open Functional Communication Standards
ADD	Add-on connectivity interface or feature	Add on connectivity feature that can be easily implemented by the user, either by a module or port, provided at tine if sale or a reasonable period thereafter
OA	Open Access	Open access API or interfacing documentation or protocols are available for basic specified functionality
CO	Consumer Override	System provided consumer override capability to energy management or DR events

TABLE 6: DEVICE CONTROL CLASSES – LEVELS OF DEVICE CONNECTIVITY FOR ENERGY MANAGEMENT

Connectivity Class	Connectivity Functional Type	General Description	Common Example or Applied Description
0a	None	Classic energy management using onboard sensors for user interaction and/or timers to manage device's own energy state. Connectivity that may be present is not directly related to energy management operation.	Smart TV/ PC-Power management, such as sleep, idle, or auto-off features which the device uses to manage its energy own use
0b	None	Rudimentary 'smart' non-connected energy management system using pattern recognition and adaptive learning with no connected capability for energy management control or assisted learning.	CalPlug's demonstration 5W5S energy management system for set-top box energy management
0c	Point to point links	Device operates with a point-to-point link to provide commands or remote awareness of status of component operation through some type of one-way telemetry or triggering control.	Single or ganged remote controlled outlet (no network capability) with switch control or an occupancy sensor
0d	Operational – only connectivi ty	Device is inherently connected to transfer data in typical use, but connectivity is not used for intelligent energy or feature management, or link status for management of power.	A computer workstation providing internet access but not using the connectivity to directly set power management
0e	Accessory coordinated management	Devices with linked operational control to provide operational energy management of accessory devices. No external connectivity links.	Tier 1 Advanced Power Strip (APS)- Works in unison with external device such as TV, desktop computer, or AV for EE

Table 6 *continued*

Connectivity Class	Connectivity Functional Type	General Description	Common Example or Applied Description
0f	Remote Updates	Remote update of onboard software which may involve reduction in energy use or improvement in energy management capabilities	Common feature – many examples exist.
0g	Remote Usage	Point to point usage for operation or place shifting without factoring in state and status in operation. Connectivity capability just provides utility, not a means for device control focused toward energy management.	Desktop PC Remote access capability- allows access to other devices to control specific operations remotely.
0h	On Demand, Self-Control	Use of active connection by a client or server device to directly manage internal power management.	Common feature in network attached storage devices and printers to enter power save with no active use/data transfer.
0i	On demand, coordinated device control	Use of active connection by a client or server device to directly manage internal power management between a small collection of devices with connected links of devices in a coordinated automatic fashion.	Video surveillance system where cameras sense motion to trigger the recording functionality in and out of power management.
1a	Real-time monitoring	Devices with self-reported energy usage or control state. Device type does not allow direct operational logic control.	Device self-energy reporting; for example, smart plugs that report energy consumption and other factors such as number of devices connected. Other numerous industrial examples exist.

Table 6 *continued*

Connectivity Class	Connectivity Functional Type	General Description	Common Example or Applied Description
1b	Performance notification	Performance alerts and suggestions provided through interface based on sensing, connected processing, and display.	Notification of consumer-required operation with substantial energy impact in the short or long term, such as indicating a wasteful condition (refrigerator left open) or maintenance issue (i.e. changing a filter), or notification of a change in device performance that the user may correct.
1c	Operational visibility	Indication of user controllable reporting of settings with the ability to make decisions related to energy management. Remote configuration of energy management control settings.	Energy management setting reporting and control via mobile interface, a common feature in connected Tier 2 APS devices.
1d	Demand response notifications	Ability to report manual actions from a demand response alert issued by a utility demand response program	Demand response for manual (opt-in) DR control. Can be observed in some connected washers/dryers to inform users to delay/stop loads during peak energy use.
2	Real-time monitoring with control	Reporting of usage and user-provided ability to enable informed manual control.	Direct connected or cloud connected device designed to allow functional management of the device (such as triggering operations) as a part of an energy control scheme.
3	Automated demand response control	System provides options for automatic operation to delay appliance load or provide temporary appliance load reduction, typically for a short period of time from a utility triggering signal or providing a load shift.	Common DR control, numerous examples for large loads such as AC compressors or pool pumps.

Table 6 *continued*

Connectivity Class	Connectivity Functional Type	General Description	Common Example or Applied Description
4a	Cloud controlled operational tuning	Use of cloud connectivity to provide external data and/or perform deep analysis of usage patterns to continuously tune energy efficiency or TOU performance, either autonomously or with user feedback.	Elements of this strategy are implemented in many smart thermostat devices.
4b	Coordinated feedback management	Integrated management with multiple devices using edge based or cloud reconfigurable operation and management including dynamic adjustment of operation.	Coordinated home automation network where sensing, intelligent processing and management make energy decisions.
5a	Advanced coordinated feedback management	Integrated management with multiple devices using cloud-based operation and management relaying on digital twin, learning, or AI based approaches. May use phones or dongles as identifiers to track usage, may use sensor correlation to granularly adjust PM inactivity timer duration, may adjust schedules based on pattern recognition.	An advanced version of the prior category, commercially available solutions are not readily existent.
5b	Advanced coordinated feedback management (edge autonomous capable)	Similar to (5a) in operation and functionality but with edge based advanced control. Integrated management with multiple devices using edge-based control using cloud-based oversight to optimize local decision processes to reduce data transfer and improve performance.	An advanced version of the prior category, commercially available solutions are not readily existent.

TABLE 7: DEVICE CONTROL CLASSES – EXAMPLE DEVICE (REFRIGERATOR) CLASSIFICATION FOR LEVELS OF CONNECTIVITY

Feature	Functional Description	Connectivity Class Categorization	Connectivity Class Shadow Categorization
Energy and state reporting	Energy and state reporting to the user via a mobile application to provide energy usage and performance details as well as info such as number of door openings and closings and ice maker cycles per 24 hour period.	1a	0 – Loss of connectivity prevents reporting or action – capabilities lost.
Diagnostics	Diagnostic alerts to the user based on sensing coolant temperature and compressor load to indicate exterior air flow issues requiring maintenance. Alerts are sent to a user via a mobile device.	1b	0 – Loss of connectivity prevents reporting or action – capabilities lost.
Setting Control	Refrigerator/Freezer Setpoints and settings for vacation modes.	2	0 – Loss of connectivity prevents reporting or action – capabilities lost.
Automated DR Control	Device has multiple DR actions possible in response to utility signal including delay of ice maker and defrost cycles and set point adjustment. Feature is implemented with an open standard and has a consumer override capability.	3-OS,CO	N/A - Loss of connectivity prevents reporting or action – capabilities lost. DR not feasible without connection
Viewable interior	Interior of refrigerator can be viewed through a mobile app remotely providing convenience and reducing the number of times the refrigerator door is opened.	N/A – Although there may be an indirect energy benefit, there is no clear identification of the benefit as a clear and presently demonstrable energy saving mode	N/A

Reliance on connectivity is critical for DR but not always critical for EE applications. For devices which perform edge-based energy management controls for the majority of their operation and rely on the cloud for tuning and updates to schedules, a fair amount of autonomous energy management may be present even with a degraded connection, at least for a short period. Even for monitoring application, local intelligent caching of data can be used to offload data if a connection goes down for a short period of time. The advantage of this approach is reliability. By relying on non-connected aspects of operation, the device is less affected in some operation cases by short period loss of communication. Even more advanced edge-based devices that perform pre-analysis of data onboard and large amounts of processing can potentially further reduce total energy footprint and energy cost in the transport and backend cloud aspects of a solution to enable functionality.

MEASURE AND PROGRAM CONSIDERATIONS

PRIOR PLUG LOAD IDSM EFFORTS

To develop future IDSM programs, it is worthwhile to consider the incentive methods for IDSM programs that have been implemented in California and discuss appropriate set-ups for specific devices and device categories. As connectivity features of appliances and emerging technology continue to increase, it is furthermore important to consider these features for potential feasibility. Previous California IDSM residential programs have targeted high efficiency major appliances such as refrigerators, washing machines, clothes dryers, and dishwashers, as well as emerging technology products such as Tier 2 advanced power strips (APS). Pool pumps have also been addressed in incentive programs, as they are typically high energy consumers and have a large installed base in California. Different approaches to incentivizing and installing products have been taken depending on the specific features and qualities of the device.

The three main incentive structures to consider are upstream programs aimed at manufacturers and distributors, midstream programs aimed at retailers or contractors, and downstream programs providing financial incentives directly to the consumer. Table 8 reviews program types per definitions provided by California investor-owned utilities (IOUs).

For large appliances, the most common approach is replace-on-burnout programs, which incentivize customers to buy high efficiency machines when their old appliances need to be replaced. This approach is typically paired with either a downstream or midstream rebate incentive, where installation costs are assumed by either the retailer or consumer. Some programs, such as small, short-term field trials, may offer downstream direct install, whereby the utility assumes the cost of the installation at no additional cost to the customer. Downstream programs for large appliances are more typically offered in conjunction with "deemed" installation, meaning that a contractor is granted exclusive permission by the utility to implement professional installation services. The labor cost of deemed installation is usually borne by the customer rather than the utility. Conversely, midstream programs do not require any labor provisions from the utility, as it is assumed that either the retail partner or the customer will be responsible for installation.

California IOU-sponsored IDSM programs have historically offered primarily downstream incentive programs for most large appliances, such as refrigerators and washing machines (J. Wang, 2014, 2015). However, more recently programs such as the SCE ENERGY STAR Clothes Washer program that have experimented with midstream incentive structures in addition to downstream incentives to further defray costs to the utility (J. Wang, 2014). Full results of the midstream washing machine program have not yet been released. As mainstream specialty electronics retailers and big box stores typically employ their own technicians for product installation, midstream programs for white goods may be feasible. It is important to note, however, that the quality of installation services can vary across retailers. Furthermore, past programs have generally been targeted at non-connected appliances. As connected appliances grow in number and inevitably become targets of new

IDSM programs, it will be increasingly necessary to ensure proper training for both contractors and retail technicians for set-up of internet connectivity on the device, as well as to ensure that proper communication between the device and peripheral smart speakers and mobile devices is enabled.

TABLE 8: PROGRAM INCENTIVE METHODS

Incentive Method	Description
Direct Install	The program implements energy efficiency measures for qualifying customers, at no cost to the customer.
Down-Stream Incentive	The customer installs qualifying energy efficient equipment and submits an incentive (rebate) application to the utility program. Upon application approval, the utility program pays an incentive to the customer. Such an incentive may be deemed or customized.
Mid-Stream Incentive	The program gives a financial incentive to a midstream market actor, such as a retailer or contractor, to encourage the promotion of efficient measures. The incentive may or may not be passed on to the end-use customer.
Up-Stream Incentive	The program gives a financial incentive to an upstream market actor, such as a manufacturer or distributor, to encourage the manufacture, provision, or distribution of an efficient measure. The incentive may or may not be passed on to the end-use customer.
Up-Stream Buy Down	The program gives a financial incentive to an upstream market actor, such as a manufacturer or distributor, with specific requirements to pass down the incentive to the end use customer. Such an incentive buys-down the cost of an efficient measure for the end-use customer by at least the amount of the financial incentive.
Giveaway	The program provides customers with energy efficiency equipment or services for free.
Exchange/Replacement	The utility program holds events where customers can trade functional equipment for similar but more energy efficient equipment, free of charge.
On-bill Finance/Loan	The program offers financing for the cost an efficient measure as part of the utility bill. This can be an add-on option to an existing program or can serve as an organizing principle for its own program.

Source: Huang (2017, page 10)

For connected devices not included in the large appliance category, most previous programs in California have also taken a downstream approach. Notably, variable speed pool pumps, which are considered high priority devices for energy savings and demand response capability, must be installed by an expert technician due to the sophisticated features of the device and high liabilities associated with incorrect installation. Similarly, field trials for Tier

2 APS devices have so far used direct install to ensure proper usage and functionality. Although self-install manuals are included with the purchase of APS devices, there is high potential for incorrect and inefficient use of the device when installed by a user that could lead to malfunction and inefficient states of utility.

Overall, a prudent strategy for designing programs with reference to connected devices is to conduct a careful review of essential features and functionality when deciding between downstream and midstream approaches. Regarding midstream programs, highly complex or poorly understood features increase the risk of improper installation, leading to product misuse and functionality loss. Alternatively, midstream programs may be appropriately targeted at small, easy-to-use devices or even to large appliances given sufficient expertise and responsibility exercised by retail partners. Downstream incentive programs with utility-selected installation service should continue to be used for products with high associated installation risk, such as pool pumps, and products that fully depend on precise installation to produce energy savings.

Plug Load Program Design

General Design Considerations

To analyze an EE program design, it is first important to evaluate the merits of the selected devices and systems. The product should be simple to explain and operate to encourage customers to switch to the new device. The evaluator should take a realistic approach to understanding market feasibility and account for the fact that users familiar with other devices or with previous iterations of the same device will have to be persuaded to upgrade. While sufficient rebates can ease this anxiety, the product itself must be approachable for the average customer. More practically, the product should fit into existing home infrastructure with only superficial modifications, and without the need to undertake major reconfigurations. If the cost offset by the incentive program is only redistributed to infrastructure changes, the program will not be successful or cost effective for the administrator (Milostan, Levin, Muheleisen, & Guzowski, 2017).

After the product is thoroughly evaluated for cost-effectiveness, the overall structure of the incentive program should be analyzed. Much like engineering evaluation tests for structural soundness in a new building, there are certain parameters that test the feasibility of a proposed program. A field test executed by Milostan et al. (2017) identified several simple heuristics that should be applied to determine whether a midstream incentive program will be successful. Ideally, incentives should be:

- Easy to communicate and market
- Robust enough to make the savings/earnings potential appealing to product distributors
- Designed with seasonal sales patterns in mind
- Tailored to the needs and wants of the targeted market segment
- Mindful of potential incentive budget caps

Essentially, the above criteria together provide a filter to show if a program is market-ready and can be streamlined and deployed across distributors and customer bases. Proposals should include marketing strategies that are easily adaptable to different locations, and that convincingly identify the types of retailors and customers who would be interested in participating. Moreover, the incentive structure itself should be evaluated at the appropriate level of resolution to determine robustness. For example, a small decrease in profit per unit can still be appealing to retailers if it encourages higher overall sales and brings in new clientele.

Additionally, incentive programs that include limitations on the number of rebated items per customer help reduce the tendency of customers to "hoard" incentivized products when there are no limits in place. This is unlikely to be a problem with programs targeting major appliances to individual customers but can occur for lower-price goods such as light bulbs or for bulk purchases by landlords or contractors who stockpile them for later use. When customers buy more stock than they can consume in a reasonable amount of time, this can give a false impression that the program is performing at a very high level and outpacing the target goals. Establishing purchase limits helps to give utilities and retailors a more accurate view of how well the program is working and improves supply chain management by lowering the risk of shortages (de la Rue du Can, Nihar, & Amol, 2011).

As a final parameter for product selection, programs show the highest level of effectiveness when the EE device has a small market share (Letschert, McNeil, Kalavase, Fan, & Dreyfus, 2013; York, Neubauer, Nowak, & Molina, 2015). A market-ready, but relatively unknown, EE solution is a perfect candidate for an incentive program, because there is great opportunity for mutual benefit: the product gets introduced to a wider audience and the retailer can profit from increased sales volume that the incentive program may bring. However, there is an inflection point at which sufficient market penetration makes incentives unprofitable. In a report on sales projections for EE products, Letschert et al. (2013) found that products with 30-40% market share do not need subsidies or incentivization. Furthermore, incentive programs should be time-bound at a maximum of around 5 years (Letschert et al., 2013).

Resource Acquisition vs. Retail Products Platform Programs

An important aspect of developing IDSM programs is to determine the measure type that will be used for incentive delivery. There are two main types of measures for IDSM programs: resource acquisition (RA) and ENERGY STAR Retail Products Platform (RPP). RA programs focus exclusively on offering monetary incentives for energy efficient products and represent the bulk of traditional incentive programs. These are relatively short-lived programs (3-5 years) dedicated to increasing the present volume of selected EE device sales. However, as RA programs are aimed directly at the customer by the utility or third-party contractor, these programs represent short-term tactics that tend to incentivize opportunistic participation rather than sustained efforts at market transformation (MT). Indeed, program design studies have found that interest for buying EE products tends to dry up when RA programs end. Despite their general inability to transcend supply/demand configurations in the overarching market, RA programs have a distinct advantage in that they are relatively simple for deriving energy savings data. RA programs are typically paired with downstream rebates and are relatively easy to evaluate with simple savings metrics of $/kWh. Small field trials with DI initiatives or larger downstream programs with deemed installation processes are typically evaluated as RA programs. In the past, most plug load IDSM programs in California for major appliances and pool maintenance equipment have been of the RA variety and have been evaluated in terms of net-to-gross ratios (NTGR) based on well-established, standardized procedures that forecast NTGR and TRC calculations over the course of an average three-year cycle. RA programs do not depend highly on integrated growth models and are generally immune to variations in surrounding social and economic factors, making predictive values relatively easy to determine (Huang & Salazar, 2018).

In contrast, RPP programs are specifically designed to promote market transformation. While RPP has been implemented thus far in only a few cases in California, these programs have been targeted as a potential successful strategy to deepen energy savings since at least 2008, when the California Public Utilities Commission (CPUC) adopted its Long-Term Energy Efficiency Strategic Plan. Rather than focusing solely on incentivizing specific EE products in isolated markets, RPP programs are aimed at sustainable growth in market share for highly efficient appliances and consumer electronics. This includes greater adoption of new technology by the user to create demand and encourage manufacturers and suppliers to produce and distribute energy efficient devices. RPP programs are assumed to have a longer lifetime than RA programs, or around 10 years, which, for major appliances, corresponds roughly to the entire average EUL Estimated Useful Lifetime (EUL) of the product. As longer-lived products produce a lag-time effect on market share changes, it is important that market transformation programs last long enough to see through the 25-50% percentile of replace-on-burnout for EE major appliances to ensure that the trend is permanent and stable.

As the involvement of retailers is a key component of any market transformation initiative, RPP programs are inherently midstream strategies, although they involve complex interactions between upstream manufacturers and downstream users. Retailers, particularly national chains with high name recognition value, can leverage their expertise in stocking, promoting and associated marketing practices to drive customer demand for energy efficient products. For the promotion of plug load devices, which encompass a wide variation and diversity in terms of price, function, etc., the ability of single platform retailers to streamline the marketing and sales of new devices across device categories is an essential element of increasing market share and driving true market transformation. Local municipal utilities as well as IOUs do not have comparable resources to impact large-scale developments in consumer goods markets. Furthermore, as the ultimate goal of market transformation is to transform the market at the state or national level, it is important to recognize geographic boundaries and jurisdictions that utilities operate within.

Net-to-Gross Ratio Calculations

Determining NTGR for RPP programs is more challenging than evaluating RA programs, as they are more dynamic in range and scope, cover longer periods of time, and are subject to fluctuations in surrounding economic and social conditions. For example, economic recessions may be poorly predicted and may curtail customer choice to upgrade to new appliances. Likewise, public perceptions of technology may change. For example, when high efficiency front-loading washing machines were redesigned for the American market in the early 2000s, sales were initially successful, and by 2012, front-loading machines constituted nearly 50% of market share. However, due to design error, many of these machines functioned poorly, leading customers to replace their washers on early retirement with traditional top-loading agitator models and influencing others not to select front-loading machines in replacing old machines. The effect was that an increasing market trend for energy efficient washers reversed course, and the market share of front-loading machines dropped to the current level of about 25% (J. Wang, 2014). Although newer models have corrected the mistakes made in earlier generations, there has been an enduring negative public attitude toward front-loading washing machines, highlighting the importance of incentivizing products that are market ready and have been thoroughly evaluated in field and focus group tests.

Considering the difficulty in accurately predicting market transformation, modeling the progress of product uptake into the market is a challenge. One of the more commonly used methods is the Bass Diffusion Model, which was developed to understand and forecast adoption and diffusion of technology and products in the market. This method was used in PG&E's Retail Product Platform program and has also been approved for use in the California Codes and Standards Program. This model assumes two groups of consumers: 1) innovators, or early adapters (a relatively small group) and 2) imitators (mainstream adapters). According to the Bass Model, the opinions and reviews of the early adapters filter into the society-at-large to influence the behavior of the imitators, who in turn, influence each other to adopt a new technology or buy a new product. Translated into a mathematical model, this data produces an S-shaped curve distribution. The Bass Model is a useful choice for modeling projected adoption of EE appliances that have current low levels of market penetration, but that are trending upwards due to customer preference and assisted by subsidization from midstream incentive programs (Huang & Salazar, 2018; Lavoie et al., 2018).

The Bass Diffusion Model is expressed in the following equation:

EQUATION 1. BASS DIFFUSION MODEL

$$n_t = p[m - N_t] + q\left(\frac{N_t}{m}\right)[m - N_t]$$

Where
- n_t = The number of adopters at time *t*
- m = The potential number of adopters
- N_t = The cumulative number of adopters at time *t*
- p = Coefficient of innovation
- q = Coefficient of imitation

PG&E's RPP program further identified more detailed versions of the Bass Model. The Generalized Bass Diffusion Model shifts the focus to modeling the success of various marketing strategies by adding variables related to advertising and price and evaluating effects on consumer demand. The Generalized Bass Diffusion Model is characterized in the following formula:

EQUATION 2: THE GENERALIZED BASS DIFFUSION MODEL

$$(St) = m\frac{(p+q)^2}{p}(1+\beta_1)\frac{Pr'(t)}{\mathrm{Pr}\,(t)} + \beta_2\frac{A^t(t)}{A(t)}\frac{e^{-(p+q)(t+\beta_1 Ln(Pr)+\beta_{2Ln(A)})}}{1+\frac{q}{p}e^{-(p+q)(t+\beta_1 Ln(Pr)+\beta_{2Ln(A)})}}$$

Where
- S(t) = Sales at time *t*
- Pr'(t) = Rate of change in price at time *t*
- Pr(t) = Price at time *t*
- A'(t) = Rate of change in advertising at time *t*
- A(t) = Advertising at time *t*
- β_1 = Price coefficient
- β_2 = Advertising coefficient

While the Generalized Bass Diffusion Model can account for demand shift over time, it does not permit total demand increase, e.g. total demand remains as a constant. This problem was therefore addressed through an extended version of the Generalized Bass Diffusion Model (Boehner and Gold 2012). The following formula accounts for impacts on marketing variable on total market size:

EQUATION 3: EXPANDED GENERALIZED BASS DIFFUSION MODEL

$$N_t = pMP^{-e}A^fB^g + (1 + q - p)N_{t-1} - \left(\frac{q}{MP^{-e}A^fB^g}\right)N_{t-1}^2$$

where

N_t= Percentage of energy-efficient products sold at time t

p= Coefficient of innovation

q= Coefficient of imitation

M= Total potential ratio of sales of energy-efficient products to total sales

N_0= Percentage of energy-efficient products sold at time 0.

P_0= Ratio of price for energy-efficient product to price for standard product at time 0

e= Coefficient of sensitivity (elasticity) for price term

A_0= Ratio of advertising expenditure with the program to without the program at time 0

f= Coefficient of sensitivity (elasticity) for advertising

B_0= Ratio of energy-efficient assortment with the program to without the program at time 0

g= Coefficient of sensitivity (elasticity) for assortment

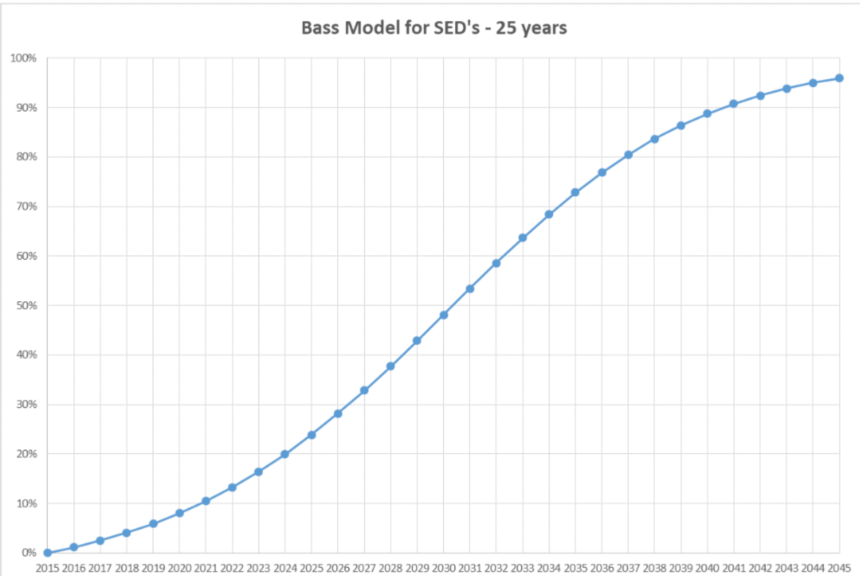
N_{t-1}= Percentage of energy-efficient products sold in the previous period

An important caveat of using the Bass Diffusion Model is the potential uncertainty in *p* and *q* coefficients. If a product is relatively new and there is not sufficient historical data available to model, it may be necessary to estimate innovation and imitation values based on past performance of analogous, but not identical, products (Huang & Salazar, 2018). This adds some risk to prediction accuracy, as customer adoption of new products is not a precise science and even very similar products may be perceived very differently by the public depending on user experience and design quality, brand prestige, marketing efforts, etc.

PG&E's study further elaborated parameters for testing RPP device market share with and without the RPP program in order to test counterfactual simulations and determine likely outcomes. These scenarios may further be expanded upon to include both participating and non-participating retailers in modeling NTGR for scenarios with or absent the RPP program, in order to generate outcomes for the entire market. Market transformation scenarios for evaluated home appliances and electronics devices including air cleaners, soundbars, freezers, electric clothes dryers, gas clothes dryers, and room air conditioners were conducted using Monte Carlo simulations to project distribution ranges for each project, and the NTGR closest to the median value of each range was chosen for ex-ante NTGR. For more detailed measure information, please consult PG&E's Retail Products Platform ex-ante work paper.

A different approach to the Bass Diffusion Model is demonstrated in a study sponsored by NEEA on super-efficient clothes dryers (heat pump dryers) in the Pacific Northwest. SEDI (Super-Efficient Dryer Initiative) tested heat pump technology and found that SEDs are 50-60% more EE than conventional dryers. Market research indicated that market penetration for SEDs is low in the U.S. (compared to Europe, where there are 25+ different models of SEDs on the market). Barriers to market share increase in the U.S. include higher cost and smaller size than traditional dryers.

As current adoption of heat pump dryers in the U.S. is virtually non-existent, it was necessary for the authors of the NEEA study to estimate the *p, q,* and *m* parameters in designing their model. *P* and *q* values were derived from a mixed methodology using analogous products and evaluating survey data from field experts (conventional dryers were ultimately chosen as the analogous product). The *m* parameter, corresponding to total population of heat pump dryer units under the Bass Model variant used in this study, was bounded by a plausible range of upmarket product penetration. As heat pump dryers are significantly more expensive than traditional models, and as the energy savings as a function of product price have not yet reached a convergence point that would make them more cost effective over EUL, the authors determined that the most likely early adapters would be households earning $100,000 or more per year (about 26.4% of U.S. households), and that super-efficient dryers most likely would compete only in this specified market segment, with no real competition from other market segments at first. Analysis of market forces was then applied to suggest that, as early adapters continued to buy heat pump dryers, the demand would increase and manufacturing costs would decrease, allowing market share to gradually gain hold in other market segments, as predicted in classic economies of scale scenarios. Figure 6 shows the predicted heat pump dryer adoption curve in NEEA (Pacific Northwest) territory from 2015-2045. The study found the inflection point to be around the year 2033, when the adoption rate should be about 63%.



Source: Lavoie et al. (2018, page 57)

FIGURE 6: PREDICTED HEAT PUMP DRYER ADOPTION FROM 2015 – 2045, PACIFIC NORTHWEST

PREVIOUS PROGRAM EVALUATIONS AND LESSONS LEARNED

Midstream IDSM programs have not been thoroughly implemented in the U.S. and there is limited historical data available regarding post-program evaluation efforts for MT initiatives. Other states outside of California have more experience with midstream incentives, but they tend to lack rigorous evaluation processes. A few exceptions exist, including NYSERDA's evaluation of the New York Products Program. In California, PG&E's Business and Consumer Electronics (BCE) program is the most comprehensive RPP program to date. NYSERDA's program offered a variety of appliance rebates through retailers, including the "Buy Green, Save Green" program offering rebates for high-efficiency models of refrigerators and clothes washers meeting Tier 2 and 3 efficiency criteria as determined by ENERGY STAR. Another concurrent program, "New York Storm Relief," offered rebates for large appliances and hot water systems for customers whose homes had been damaged by Hurricane Irene and Tropical Storm Lee. NYSERDA's programs were evaluated through telephone surveys of customers, surveys of staff at retail partner sites, and interviews of corporate retailer employees. Based on data collected, the program was moderately successful, with a final NTGR of 10%. Survey and interview results revealed an importance of "big box" retailers as essential partners in MT programs, as more than 60% of consumers surveyed reported purchasing the rebated product from one of the top five "big box" retailers. Furthermore, customer responses suggested a wide understanding and support of the ENERGY STAR program, as ENERGY STAR market shares were high for all product categories, from room air conditioning sets at 48% on the low end, to dishwashers at 74% at the high end; stated awareness of ENERGY STAR and its associated goals were similarly high, estimated at between 86%-89% of respondents. These statistics suggest that awareness of ENERGY STAR has reached a saturation point among NYSERDA constituents. PG&E's evaluation of the NYSERDA programs as presented in their report on RPP programs suggest a shift in focus to ENERGY STAR Most Efficient products in order to continue further MT and market penetration efforts for high efficiency products.

PG&E's Business and Consumer Electronics Program was implemented between 2008-2013 and aimed to deliver midstream retail incentives to promote and stock high-efficiency (generally ENERGY STAR approved) consumer electronics products such as computers, monitors, STBs, televisions, and other associated devices. The TV market was selected for formal evaluation, with the program stipulating rebate offers for models performing at least 15% more efficiently than the baseline ENERGY STAR standard model. Based on data collected from interviews of IOU program staff and retail TV buyers combined with input from a blind panel of experts, the program was determined to be successful, with an estimated 22.3% NTGR, and a market share increase of an average 11.4% for qualifying televisions. This success is tempered somewhat by concerns raised by PG&E's internal reviewers and independent analysts in response to the evaluation; discrepancies between the IOU reported gross savings (182,641,713 kWh) and the significantly lower ex-ante savings from the study findings (51,913,723 kWh) called into question the methodology used for reporting savings, and undermined the credibility of the program's success rate (Huang & Salazar, 2018).

The results of the NYPP and BCE programs highlight the importance of rigorous program design and follow-up evaluation processes in order to accurately determine RPP success. Specifically, it is critical to ensure proper evaluation of baseline performance, with methodical follow-up procedures to determine the overall health of the program and to re-assess and recalibrate baseline metrics when the program shows evidence of success in MT efforts. More generally, careful review of qualitative survey and interview data should be applied to eliminate potential biases and ensure a fair evaluation process. To achieve greater market penetration, it is important to focus on product tiers that exceed the minimum ENERGY STAR criteria to ensure proper program attribution and minimize the signal-to-noise ratio from free-rider effects.

Portfolio and Regulatory Goals

In addition to performing basic programs evaluations, it is important to consider programmatic goals in the context of wider utility portfolio and state and federal regulatory requirements. Specifically considering market transformation programs, the relatively long lifetime of such programs increase likelihood that the program will be defined as a High Impact Measure (HIM), consisting of ≥1% of the IOU total portfolio savings. While RPP programs may have only moderate success at first, the nature of market transformation as a potentially self-perpetuating phenomenon suggests that a successful program may grow non-linearly after a certain threshold is met. Per IOU standards, measures that achieve HIM status must be evaluated at a higher level of rigor than less substantial programs. It is key to successful evaluation to be mindful of potential portfolio achievements at the outset of the program, so that baseline information can be accurately collected, particularly for programs that are likely to be subject to increased scrutiny due to high portfolio savings ratios. (Huang & Salazar, 2018).

Market Transformation

Types of Incentive Programs

The key to market transformation lies in persuading large retailors to increase stock and sales of EE products. Midstream incentive programs are therefore an important way to effectively increase market shares for new EE products (Lukasiewicz et al., 2013; York et al., 2015). While direct-to-consumer rebates may be very successful for short periods of time, the market share of EE products tends to dissipate when the rebate program ends. By contrast, targeting midstream retailers and manufacturers introduces a new business model that can be followed and strengthened over the course of several years. When national retailers replace their current stock with more efficient devices, this creates a positive feedback loop that ultimately results in a sustained growth in market share for EE products (York et al., 2015).

There are two main types of midstream programs. One is the traditional buy-down program, which provides an incentive directed at the user's purchasing decision. This is accomplished through offering a rebate covering part or all the incremental cost of an EE product to influence customers to choose a highly efficient product instead of a less efficient product. The other type of midstream program is the Retail Products Platform (RPP). These programs also provide per-unit incentives for qualified EE products, but they target retailers and distributors instead of the user. The savings are still passed down to the customer, but the incentives are designed to persuade retailers to stock and sell EE products that they would not have carried without the incentive program (Dunn, Clock, Conzemius, & Dimetrosky, 2016; Lukasiewicz et al., 2013).

Within the RPP programs, there are different strategies for achieving greater retail participation using incentives. The authors of a report on behalf of the U.S. Environmental Protection Agency (EPA) and ENERGY STAR identify two main types of incentives that have the greatest potential for success: shared incentives and accelerated incentives (Lukasiewicz et al., 2013). Shared incentives require retailers to offer or "share" a portion of their EE program earnings to customers when they purchase eligible EE products. One advantage of shared incentives is that they could improve net-to-gross ratios by increasing sales volume within a retailer's given territory. Additionally, shared incentives could positively affect the program evaluation process. For example, giving half the incentive to the consumer moves half of the incentive cost to the benefit side of the TRC equation, so this would improve the overall TRC value for the proposed program. Furthermore, in the post-program evaluation period, the ability to quantify and attribute a precise amount of incentives to the user consumer would help the program evaluator to avoid making assumptions about how savings offered at the retailor level are passed down to the user. The main challenge for shared incentive programs is that they must be sufficiently large enough to offset the initial loss in revenue that retailers incur when they stock more expensive EE equipment but do not capture the entire incentive value.

Accelerated incentives are designed to move the product for the retailer more quickly by front-loading the majority of the incentive payments at the beginning of the year. Under this model, incentives-per-unit may be two to three times higher in the first six months of the year than in the last six months. While the overall annual incentive payment remains the same, the way it is distributed is more dynamic than the typical month-to-month payment structure. The advantage to this type of incentive is that it supports the natural business cycle for the retail industry. Most new products are introduced in retail stores between January and June, so retailers benefit much more from higher incentives during this period when they are seeking to avoid overstock and wish to sell as much product as possible. Toward the end of the year, the inventory tends to level off, so overstock becomes less of a concern and lower incentives can be introduced. The main challenge for this incentive type is that program participation may not remain stable throughout the year and may taper off at the end of the year, which might make it difficult for the administrator to ascertain the success of the program (Lukasiewicz et al., 2013).

Marketing Strategy

In addition to the product selection, it is important to deploy a well-developed marketing strategy to drive sales for EE programs and targeted devices. The product should be sold across multiple geographical areas and should cross-cut customer market segments to introduce the incentive program to new buyers. This could lead to changes in distributor inventory and stocking practices, which could drive long-term market transformation (Milostan et al., 2017). In a study devoted to understanding customer participation in EE programs, researchers found that retailers influencing customer choice through marketing was a successful and cost-effective way to increase program participation and market penetration. Generally, useful marketing tools include point-of-purchase materials, placement opportunities, traditional advertising, and community education materials (York et al., 2015). Additionally, for midstream programs, relevant marketing approaches include raising awareness among users and B2B users regarding benefits of EE products, such as point-of-sale marketing materials and salesforce training. Training retail staff on the details of EE products, including conveying data about energy and money savings potentials, can play an important role in convincing customers to buy a new EE product instead of an older, but more familiar, non-EE technology (Kwatra, Amann, & Sachs, 2013).

Program Participation

A recent ACEEE study aimed at discovering the drivers of participation in energy savings initiatives suggests that consumers are more concerned with price and economic savings than with energy savings vis-à-vis rebate programs for EE products (York et al., 2015). The up-front costs of EE appliances are a significant barrier to customer adoption of new devices. Rebates can help achieve initial increase in market share for these products, but to attract a meaningful contingent of participants, they must be easy to understand and redeem. Mail-in rebates are not effective, as they are time consuming, and customers often will not choose this option, particularly if the rebate is small. Point-of-sale rebates are generally the most effective, because they can operate as the deciding factor when a customer chooses an EE product over a similar non-EE product (York et al., 2015).

Advice for improving program participation also depends on the level of historic participation that programs in particular geographic regions have received. Specific recommendations for states that have already implemented strong savings targets and goals for future years (such as California) differ from states that have only recently introduced EE initiatives. For states like California, much of the "low hanging fruit" has already been exploited, so new programs will have to expand in order to prevent diminishing returns. Program administrators need to adopt programs that achieve deeper savings for participating customers and have broader aims for market penetration. This will include initiatives to bring in under-served markets, such as small family businesses, multi-family housing and rental housing. Moreover, programs focusing on midstream and upstream treatments can help to achieve greater market shares for EE products (Charles et al., 2018).

OTHER CONSIDERATIONS

For all midstream programs, it is important to consider the effects of scale when designing EE incentives. The program administrator must be able to convince retailers and manufacturers that the EE product can scale both in terms of financial return, and in terms of distribution across various geographical areas and climate zones. National retailers are an important component for market transformation, and it would not be cost effective for them to distribute products that are too limited in their targeted customer base or their ability to sell outside of particular geographical areas (York et al., 2015).

Robust programs that include incentives plus education, awareness, and relationship development with retailers and manufacturers are generally the most successful for market transformation. For example, with a robust program, PG&E increased the market share of the Energy Star v. 5 television by over 500% in one year (York et al., 2015).

Finally, for sustained market transformation, program administrators need to incorporate education and awareness into their programs, because the customer is ultimately mostly concerned with price and features on household electronics, with saving energy as only a secondary concern. A clearer understanding of how energy savings translates directly into cash savings may help to successfully market EE devices. Alternatively, customers who are already interested in becoming "green" in their daily lives will find it easier to make these changes if they are targeted through a pro-EE marketing program. Likewise, it is important to ensure that sales representatives are knowledgeable and persuasive in selling EE products, as well as encourage stocking and display practices that center rebate-eligible products. Utilities may also partner with reputable organizations that conduct online consumer product reviews in order to target customers who prefer internet shopping. For example, Connecticut Light & Power has teamed up with TopTenUSA to help customers choose EE products online (York et al., 2015).

DEVICE ASSESSMENT METHODS

To determine which new devices and connectivity features have the most energy saving potential, CalPlug designed a multi-pronged methodology to filter out unsubstantial products and further investigate products with potential merit to consider in measures for utility incentive programs. In order to provide a comprehensive screening process, the first step was to collate a list of new appliances and emerging technology. Sources consulted included reports from industry experts such as Fraunhofer USA, the National Resource Defense Council (NRDC), the National Renewable Energy Laboratory (NREL), as well as previous CalPlug investigations of emerging technology.

After compiling this list, the next step was to design a systematic method that is illustrated in a flowchart to filter the devices and determine which devices were eligible for a more substantial consideration in a category deep dive. As the parameters for this report stipulate potential claimable savings and connectivity as main points of consideration, the flowchart was developed to process out products that 1) lacked sufficient product population/unit energy consumption to warrant high claimable savings ability, or 2) lacked connectivity features altogether or featured connectivity that was determined to be irrelevant to claimable savings. As some emerging technology, such as Tier 2 advanced power strips and smart plugs are only relevant in the context of system-level control, a second flowchart separate from individual devices was developed to analyze systems according to their specific methods of device control and resulting energy savings.

Energy savings due specifically to connectivity features were determined by comparing savings potentials of similar products with and without connectivity features. Furthermore, previous research at CalPlug informed evaluation of connectivity savings associated with user interface and feedback-based behavioral modification. Demand response (DR) capability was also assessed as part of the evaluation of connectivity features.

Claimable savings, or annual energy savings (kWh/year), were considered for each device or system. These assessments were made primarily by consulting DEER values, as well as ex-ante values published in work papers provided by California IOUs based on field trial data.

After evaluating all devices through the flowchart, the successful products were selected for deep dives investigating the device category more thoroughly, including analyses of specific product features and functionality, detailed study of connectivity capabilities, and program and measure considerations. The final step for each deep dive category was to estimate potential measure cost effectiveness through a TRC calculation model. The TRC calculation procedure is discussed at greater length in a separate section and uses varying program parameters to estimate bounds of performance.

DEVICES CONSIDERED

All major categories of plug load devices were investigated to search for potential strategies to reduce energy usage. Successful efforts generally follow some adjustment or breakthrough change within a product category. This may be a change in device general operation or features. In addition to the device itself, cross cutting efforts are possible and sometimes have a lag across different categories. Changes in device product categories can be considered as a factor from the following consideration points:

1. New device, or substantial market uptake – A device is either substantially new from similar devices or a rapid change in market size has caused a change in population to consider investigation.
    a. Brand new device or substantially updated form factor
    b. Change in technology or usage – This can be the increase of a new type of a device with a new operational means.
    c. Creeping change - The change can occur in some instances where a category is silently growing.
    d. Population or underlying market shifts – Potential likely market changes due to underlying demographic changes
2. New features added with impact on energy usage – Device has new features that change energy usage characteristics.
3. Overlooked needs and features – category overlooked; this is often due to specific reasons.
4. Cross-cutting features potentially lagging in device uptake – Features in similar devices may not be applied in the following device category.

Crosscutting can be manifested in multiple ways. For example, improved power supply or motor drives may have just reached the point where this feature is cost effective to include into a particular category. Some leaders may have already incorporated this feature, yet it may not be widespread throughout the category. Innovation outside the product category can also be considered cross cutting, such as the use of connectivity for power management and control.

FLOWCHART EVALUATIONS

The scoping of devices was based on a filtering methodology considering three major sources for the initial device list including CalPlug's 2017 Plug Load Roadmap report (Delforge, Schmidt, & Schmidt, 2015; Klopfer, Rapier, et al., 2017; Urban, Roth, & Harbor, 2016). This list included the vast majority of common residential plug loads and all substantial devices in California and across the USA. While the long tail of potential devices is extensive, a threshold of approximately 1-5% current and steady household population was used as a discriminating factor for discussion consistent with other sources. Devices with a substantially growing population are considered as new potential categories and depending on (1-5 year) growth may be discussed as potential over the horizon device categories to consider in future works. Device population growth, device and population energy usage (both annual energy consumption and unit energy consumption), and current and future relevance were taken into considerations as factors. The Energy Information Administration provided projects out to 2040 for device consumption for many traditional device categories Between these multiple sources a collection of devices across consumer electronics, major appliances, and building installed load emerges. A systematic process was used to assess scoping consideration. As this report is focused on connected devices, scoping for most relevant devices are considered here. Several other devices due to lack of connectivity, market size, or projected program performance were categorized as minor scope devices. A number of these devices are classic energy management or DR targets. This category contains a potpourri of devices with relevance enough to be discussed and accordingly will receive limited discussion attention. The full list of devices is available in APPENDIX A.

The Device Flowchart in Figure 7 is used as a filtering mechanism to assess plug load devices savings potential and evaluation in major and minor scope of this report for energy efficiency, demand response and time-of-use considerations. Devices that are not considered plug loads are not considered in the scope of this report (i.e. HVAC, lighting, etc.).

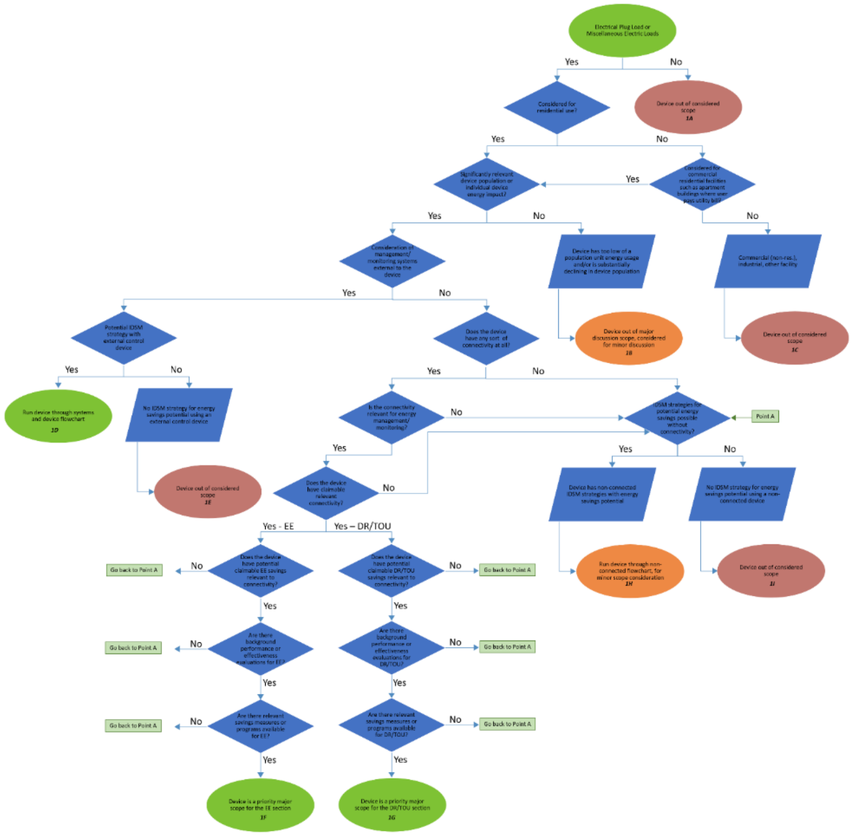


FIGURE 7: DEVICE FLOWCHART

Open larger version: https://drive.google.com/open?id=1HITbiyoOgdtopJFhUSvcPcLd8toLXdJr

The scope is confined to residential plug loads only, however, if a plug load is considered for commercial residential facilities such as apartment buildings where the user pays their utility bill, then the device is considered for the next filter. Any commercial (non-residential), industrial and other facility plug loads are out of the considered scope.

Significant relevant device population and/or individual device energy impact needs to be considered in the evaluation. Devices with too low of a population unit energy and/or a substantially declining population will not have as significant of a savings potential with their lower/declining energy usage. Devices that have too low of a population energy unit usage and/or declining population will still be considered for minor scope discussion.

While many plug loads can conduct IDSM strategies as stand-alone devices, there are many plug loads that use an external system for management/monitoring of the connected device. A couple examples of this would be a TV with a Tier 2 advanced power strip and a smart plug with a window air conditioning unit. Plug loads with an external management/monitoring system were considered together as a unit when running the devices through the flowchart, therefore any capabilities of the external system were considered along with the device capabilities during the evaluation. If the device is considered as a system with a device and has potential IDSM strategies, then the system with device is run through Figure 8, System and Device Flowchart, if there are no IDSM strategies for energy savings potential then the system with a device is considered out of the scope. If the device is being considered with no connectivity features for external management/monitoring, then it continues in flowchart Figure 9.

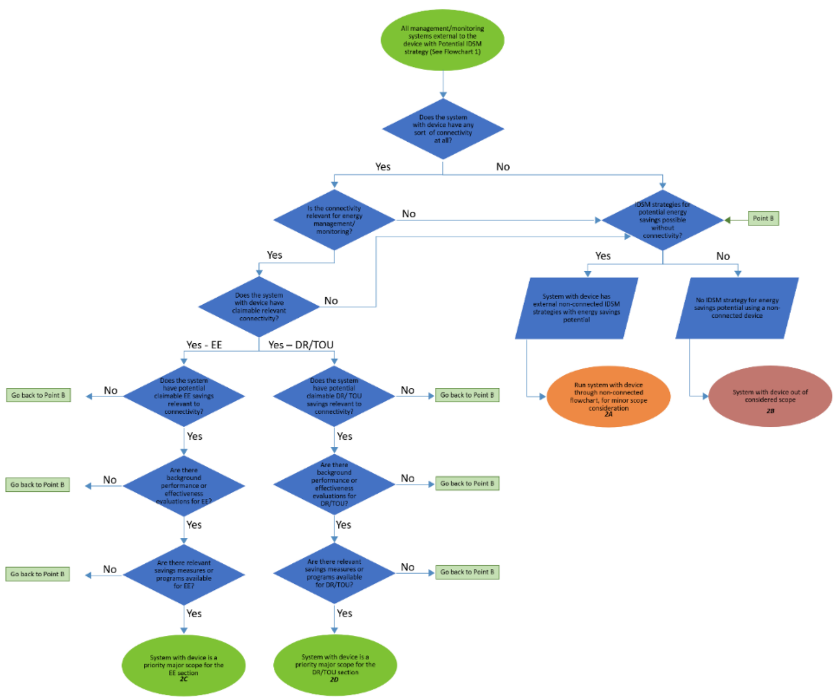


FIGURE 8: SYSTEM AND DEVICE FLOWCHART

Open larger version: https://drive.google.com/open?id=1_BLMymTcMZFigcdYi3YHF63C6gncehlw

The scope of work is particularly focused on evaluating the savings potential utilizing device connectivity, and if the connectivity is relevant for energy management/monitoring, is that connectivity claimable? However, if the device does not have said connectivity relevant to energy management operations, then the device is evaluated for minor discussion consideration on if it has IDSM strategies for potential energy savings without connectivity, if so, then the device is to be put through Figure 9, Non-Connected Device Flowchart. If the device has no IDSM savings potential, then it is considered out of scope.

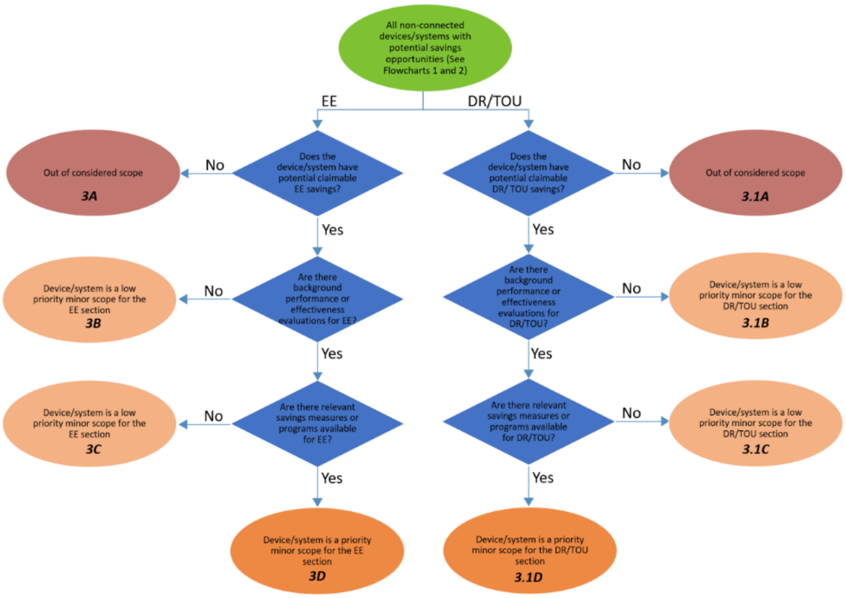


Figure 9: Non-Connected Device Flowchart

Open larger version: https://drive.google.com/open?id=1H8NuXchJVEjwSE_gMsxKQTg01hZe3mBW

Any EE and/or DR/TOU potential claimable savings (utility demonstrated and recognized) are researched and evaluated for devices that have claimable connectivity. Claimabilty in California typically relies on DEER values or *ex ante* annual savings values provided in a CPUC accepted workpaper. This criteria was not strictly stressed in evaluation but the status of Ca accepted values was noted in the final device list. Then the device is evaluated on whether there are any background performance or effectiveness evaluations for EE and/or DR/TOU. Lastly, a final consideration evaluates if devices have e any relevant savings measures or programs available for EE and/or DR/TOU in California or in other prominent locations relevant to future California programs.. If the answer is no to any of these, then the device goes back up the flowchart to Point A and is evaluated as a non-connected device.

In Figure 8, System and Device Flowchart, the same filters are applied that were applied in the Device Flowchart, but the device and system are considered together as a unit when evaluating the savings potential and whether to include it in the major or minor scope of the report. Same as in the Device Flowchart, for those that are not being considered for their connectivity, then as a unit, the device and system goes back to Point B and is evaluated as a non-connected device.

While the focus of this report is on potential savings from connected devices, non-connected devices were also considered for minor scope evaluation if they have EE and/or DR/TOU potential without connectivity as evaluated in Figure 9.

TABLE 9: FLOW CHART OUTLETS

Flow Chart 1		Flow Chart 2		Flow Chart 3	
1A	Device out of scope, not a plug load or MEL	**2A**	Run system with device through Non-Connected flowchart for minor discussion scope	**3A**	Device/system out of scope
1B	Device out of major discussion scope, considered for minor discussion	**2B**	Device out of scope, no IDSM strategy for energy savings potential using a non-connected device	**3B**	Device/system is a low priority minor scope for the non-collected plug load EE section
1C	Device out of scope, non-residential	**2C**	System with device is a priority major scope for EE	**3C**	Device/system is a low priority minor scope for the non-collected plug load EE section
1D	Run device through systems/device flow chart 2	**2D**	System with device is a priority major scope for DR/TOU	**3D**	Device/system is a priority minor scope for the non-collected plug load EE section
1E	Device out of scope, no IDSM strategy for energy savings using an external control device			**3.1A**	Device/system out of scope
1F	Device is a priority major scope for EE			**3.1B**	Device/system is a low priority minor scope for the non-collected plug load DR/TOU section
1G	Device is a priority major scope for DR/TOU			**3.1C**	Device/system is a low priority minor scope for the non-collected plug load DR/TOU section
1H	Run device through Non-connected flowchart 3			**3.1D**	Device/system is a priority minor scope for the non-collected plug load DR/TOU section
1I	Device out of scope, no IDSM strategy for energy savings potential using a non-connected device				

Connectivity Savings Assessment

When considering a connected device, two generalized approaches can be used to assess performance: estimated first-principles performance and comparison-based analysis. These similar methods use different focus points to draw conclusions for the performance of energy management capabilities.

When prior examples exist for operation both with and without the energy management features in discussion available and with reasonable model granularity, comparison can be used. Specifically, the direct savings due to the connectivity can be estimated by selecting a representative example of a non-connected version of the device and comparing it to a connected version to determine energy savings or DR action due to a specific feature. In this manner the annual savings provided by the functionality of the connectivity itself can be expressed and considered. Without considering the role of connectivity itself against a non-connected baseline, it is difficult to separate the efficacy of connectivity on energy savings from a new generation device with connectivity as compared to an older generation device without connectivity and determine which aspects led to improvements. This approach is preferred to alternative methods if sufficient field data for devices is available is also available for consideration.

In some cases, no equivalent product exists for comparison, or the granularity provided between functional equivalents is too vague to draw conclusions. The first case is particularly true for devices in which the enabling feature is essentially connected. An example of this is where connectivity enables fundamental functionality such as smart plugs. In other cases, a device may not have field trial performance data and only laboratory model action data exists to describe the action depth and frequency of the power management controls. For this approach, estimated first-principles performance assessment with functional analysis is used in determining the exact action, set of actions, or frequency of these actions used to save energy and the frequency of these actions. From this point we can build a model and draw out the effect of connected control actions to total potential savings. Within a device action we can model using an action chain approach and frequency of action how the triggering of energy saving modes can change consumption. By providing model bounds, the range for savings or action can be established and used in discussion. Comparing device action allows the impact of specific control actions to be assessed for energy impact and aggregated within the bounds of a common set of features such as energy management capabilities directly aided by connectivity. Feature assessment can be segmented as granular as required within reasonable functional bounds, and the functionality of individual features can be compared to similar mechanisms in other types of products. For example, if connectivity provides alerts to users for energy use and steps to reduce it, and in past literature this mode of action has shown 2-5% annual savings, it is reasonable to assume that if this mechanism is implemented consistently with literature, similar results can be estimated compared to a device that does not implement the same solution. The goal here is not to address the impact of connectivity itself, but to estimate the impact of the energy management features connectivity provides.

Claimable Savings

Before savings can be determined as claimable, it is first important to establish procedures for identifying whether a new device or feature saves energy in the first place. Energy savings percentage and total annual kWh savings are determined or modeled by comparing the performance of the device in discussion against a baseline average. In practice, simulated operational model projections or benchtop testing are standard methodological procedures for finding energy savings potential. Operational models identify general parameters and ranges for savings potential, while benchtop tests can confirm models, and identify areas of weakness for modeled assumptions. Realtime testing of devices also provides useful information regarding the physical operational properties and constraints of the device. Lab tests are followed by field trials of qualified devices to confirm preliminary energy savings estimates. Substantially scaled-up field trials provide the most robust data for energy savings values, however, due to time constraints and financial costs, not all new devices are subjected to rigorous field testing.

Claimable savings can be evaluated using various sources. Most of these sources come from field trials sponsored by utilities, state governments, and manufacturers. California has a well-established DEER database and *ex ante* review process that evaluates results of field trials for new or improved products and estimates potential energy savings based on the determined baseline performance of the device and environmental conditions present. For the purpose of this report, CalPlug has identified a hierarchy of source materials for finding claimable savings for the devices and systems evaluated. In this evaluation, the gold standard in California is the California Public Utility Commission (CPUC) DEER annual savings value database, which subjects field trial results to rigorous test criteria in order to provide reliable and publicly available data about energy savings potentials and estimated useful lifetimes of products. If accepted values are present a substantial reduction of work is required for an IOU to adopt this measure. This information is approved and accepted across California regulatory agencies and is therefore considered the highest priority resource. CPUC ex-ante values and accepted work papers that have not yet been approved by the DEER process are second-best sources, as they have passed the basic screening process for acceptance into the DEER database, and therefore have at least the minimum requirements for proper evaluation methodologies.

If a device or system is relatively new or does not yet have substantial market share in California, other types of sources may need to be consulted to determine potential energy savings. California municipal utility independent technical reference manual (TRM) recommendations offer the next highest quality metric, as although they have not been approved by CPUC, they have passed congruent screening processes implemented by individual utility operators. Work papers that have not been accepted due to lack of data, that have been abandoned by the sponsoring utility, or that are currently in-progress are considered next. These papers need to be evaluated with extra caution, as the CPUC evaluation process identified significant errors or problems with the potential success of program implementation.

After considering all California work papers, independently published field trial results are next in priority. Of the field trials, the highest weight is assigned to California field trials that have been sponsored by major utilities and that have a relatively large-scale test population. Similarly, CalTF (California Technical Forum) recommendations and summary reports are considered as a useful source of expert opinions on various field trial results.

When all potential resources for evaluation data and criteria for California are exhausted, it may be necessary in some cases to rely on information published by out-of-state utilities and municipalities or possibly international field trials. TRMs from other states may further provide a valuable reference point for verifying similar findings. Studies conducted in foreign countries may provide future-facing information for energy efficient devices that already have high market share elsewhere, but that show slower uptake into the American market. Finally, manufacturer sponsored field trials and operational simulation models may be considered. As there is no true oversight function for these tests, the results do not pass the same level of scrutiny that would be required by a state or federal regulatory approval process. Additionally, caution must be exercised when reviewing results of manufacturer sponsored testing because of bias potential. This list of priority consideration was used when evaluating values available from external sources when used in models. Figure 10 shows the priority hierarchy for resource consideration.

1. **CPUC DEER annual savings values**
2. **CPUC ex-ante values/dispositions/CPUC accepted work papers**
3. **California municipal utility independent TRM recommendations[1]**
4. **CA Work papers not accepted or in-progress[2]**
5. **Reported CA independent field trial results[3]**
6. **CalTF Recommendations and summary reports[4]**
7. **Relevant Out-of-state utility TRM**
8. **Out of state independent field trial reports[6]**
9. **Out of country independent field trial reports[6]**
10. **Manufacturer sponsored field trial evaluation**
11. **Operational simulation models**

[1] Avoids circular harmonization with CPUC recommendations, [2] Due to measure abandonment by supporting utility, no data or performance concerns, [3] Preferably on a large scale, if summary results are separate from work papers, [4] CalTF opinions taken and evaluated under consideration as applicable, [5] TRMs recommendations based on independent field trial results, [6] Preferably based on large field trials

FIGURE 10: PRIORITY HIERARCHY FOR RESOURCE CONSIDERATION

DEMAND RESPONSE CONSIDERATIONS

The implementation of demand response schemes for plug loads remains a challenge. In part this is because user experience is inherently linked to user satisfaction in many plug load devices. The efforts of energy efficiency and demand response blend to a degree as actions of both passive and active energy efficiency efforts can contribute to passive peak energy use reduction. Peak load calculations for usage have been considered in deemed savings programs to this point. In this manner, passive demand response can be considered by the role of efficiency on reducing peak loads. In contrast, specific demand response actions can be used to directly cause a device to shift to a lower energy state. In many cases utility can be sacrificed. For example, remote turning off air conditioning (AC)

compressors can prevent further cooling until the lockout is released. Alternatively, setting of AC thermostats to a higher value can still permit cooling but potentially not at the level requested by the user. Both examples show reduced utility to a varying degree. In some cases, utility may not be substantially be decreased or at least not for a given period under a given set of usage parameters, for example locking out an electric water heater does not prevent small amounts of water to be used near the set point for a period of time. Likewise, adjusting a low set point to a higher value, especially with enough ambient air motion (fans and ventilation) may not result in user discomfort given a short enough period.
This point can be seen when comparing HVAC to a television for both EE and DR actions using a qualitative comparison of impacts for water heating and a television to illustrate common issues with reduced utility affecting plug load usability (see Table 10)

Both the elements of gap analysis and functional performance can be used to assess demand response performance. Typically, the action of demand response is linked to device action. Depending on the specific action, the expressed value can be pressed in Watts shed during a period or total Watt-hours shifted out of a designated period during a total 24-hour evaluation period.

As users expect specific actions from systems in their home, deviation from normal actions can cause confusion. If a device acts differently than expected, a user can become confused. For many users, a feature that saves energy but does not bring added utility if not adding substantial savings (i.e. disuse costs them directly) may be disabled as a first recourse to correcting what may be perceived as "incorrect operation". For many users, the reduction in utility without warning can cause users to think the device is malfunctioning. Additionally, for custom systems, the user who set up the system may not be the only stakeholder. Clear communication and instruction are important.

The tight margin for utility or permitted usage between expected device operation and what is reasonably tolerated is a recurring theme across many plug loads. For entertainment devices, quality screen-time or usage time is a major factor in contributing to user satisfaction. For a television, the act of turning off the device if unused is a basic energy efficiency strategy. Turning off the device as a reaction to a demand event, if currently in use, can often result in user frustration. For the potential gain of typically <100 W, this may be a challenging target. For other classes of devices, utility is automatically throttled to balance performance. An example of this is personal computers. When not in use, processor and resource throttling reduces energy consumption. Acting on this directly would likely result in a degradation of computer performance and likely user frustration due to slow or sluggish actions. Similarly, the performance of a security system or video recording system cannot be justified by an event. Improving overall operation must be the primary strategy to consider.

The strategy of throttling efficiency measures by demand response cuing may be a potential approach. An option may be to decrease the activity timer during such periods as part of a program. Whereas, for example, a period of 55 minutes of inactivity before a message is provided followed by no remaining activity during a remaining 5 minutes (to produce 60 minutes from first alert to shutdown) is typically presented in an EE control strategy, in the case of a DR event, a period of 20 minutes only (15 to alert and 5 to shutdown) is permitted before an alert is provided. In this approach, a DR event did not cause the power saving action but rather temporarily tightened the settings beyond what a user may be comfortable with long term during the period of the DR event. A similar approach may turn on or temporarily make user settings more aggressive.

TABLE 10: QUALITATIVE COMPARISON FOR DEVICE USAGE AND USER IMPACT PRESENTED AS AN ILLUSTRATIVE COMPARISON

Device	Action (EE/DR)	User Consideration/User Response	Qualitative Impact[1]
Electric Water Heater	Pre-Heating in preparation for peak periods with lower overall set point. (EE)	As long as user is not inconvenienced by set points, action is largely unnoticed. Can save substantial energy during peak periods and overall.	User Impact: 0 Peak Power Usage Impact: +2 Overall Annual Energy Reduction Impact: +2
	Reducing temperature setpoint during unused periods. (EE)	User may be inconvenienced by cooler temperatures if hot water is used during abnormal periods. Can save substantial energy.	User Impact: -1 Peak Power Usage Impact: +1 Overall Annual Energy Reduction Impact: +3
	Lowering Setpoint overall (EE)	May contribute to user inconvenience for some users. May contribute to extra water use for non-recirculated systems.	User Impact: -1 Peak Power Usage Impact: +1 Overall Annual Energy Reduction Impact: +3
	Disable heating during DR event (DR)	May contribute to user inconvenience for some users with extended periods.	User Impact: -1 to 0 Peak Power Usage Impact: +3 Overall Annual Energy Reduction Impact: +1
TV	Improving device power supply efficiency and reducing standby power (EE)	May reduce heat generated by television, can potentially add to cost.	User Impact: +1 Peak Power Usage Impact: +1 Overall Annual Energy Reduction Impact: +1
	Use of automatic brightness control (ABC) or dynamic volume adjustment (EE)	May improve user's product experience. May contribute to some user confusion.	User Impact: +1 Peak Power Usage Impact: +1 Overall Annual Energy Reduction Impact: +1
	Use of input sensing and/or activity/ occupancy timers to automatically turn off device and peripherals when not in active use. (EE)	May improve user's product experience. Can contribute to user confusion. External systems may difficult to set up for some users.	User Impact: -1 to +1 Peak Power Usage Impact: +1 Overall Annual Energy Reduction Impact: +1
	Turn off TV during demand response period (DR)	Likely will contribute to user frustration without opt-in, may be mitigated with the ability to turn back on as an opt-out.	User Impact: -4 Peak Power Usage Impact: +1 Overall Annual Energy Reduction Impact: +1
	Extended dimming during demand response periods (DR)	Likely will contribute to user frustration without opt-in.	User Impact: -2 Peak Power Usage Impact: +0.5 Overall Annual Energy Reduction Impact: +0.5
	Reduction of frame rate or video processing during demand response periods (DR)	May be unnoticed or may contribute to user frustration without opt-in.	User Impact: -1 to 0 Peak Power Usage Impact: +0.5 Overall Annual Energy Reduction Impact: +0.5

[1] User Utility versus Peak savings and overall Energy Impact (-5 to +5)

Device Selection

After thoroughly assessing each device through the above described methodological procedure, most devices were filtered out of the flowchart. The main reasons that devices were not considered for further evaluation included low population and market penetration of device, low per-unit energy consumption, and lack or underdevelopment of connectivity features. Some of these devices, such as many medical devices and miscellaneous small devices were found to be lacking in sufficient positive market trend trajectories. Other devices, such as many small kitchen appliances including coffee makers, blenders, etc. have a relatively high market penetration, but do not consume enough energy on an individual unit basis to warrant inclusion in a costly IDSM program. Devices that have hybrid plug load capability, but primarily save energy through HVAC systems, most notably smart thermostats, were also determined to be out of the scope of this report, this is due to the limited energy that can be saved as a function of their own consumption (considering them as a plug load) rather than the energy that can be saved through their operation as a HVAC controller. For a complete list of devices and their exit points from the flowchart, please see Table 11.

Devices that lack well-developed connectivity features, but that are considered high efficiency devices and save energy without dedicated connectivity are considered for a minor scope discussion. These products include many large appliances, such as dishwashers, ovens, and clothes dryers. They also include smart home systems, such as home energy management systems (SHEMS), as well as integrated feedback displays, and selected small devices, such as plug-load luminaries (smart light bulbs) that are well suited to circuit-level automated controls. Although SHEMS are an interesting emerging technology category, they must be thoroughly field tested as a smart system and furthermore, must gain further traction and infrastructure integration in homes before they can truly be considered market-ready solutions. As such, we have eliminated most major appliances and SHEMS from major scope discussions, but they remain important devices to keep in mind for future IDSM considerations as technology continues to evolve and feasibility increases.

Finally, devices that successfully passed all the major criteria of the flowchart test (increasing market trend, substantial energy savings potential, and highly developed connectivity features), are each considered in deep dive discussions. Two types of devices emerged from this process: devices that have connectivity at the individual unit level, and devices that enable connected energy management solutions at the systemic level. Deep dive candidates for individual device categories include smart connected refrigerators, smart connected washing machines, and pool pumps.

Control system deep dives include Tier 2 advanced power strips and smart plugs and circuit level controls. To model potential savings of control systems, CalPlug chose representative devices that are typically paired with either Tier 2 APS devices or smart plugs that model different levels of potential energy savings. As Tier 2 APS products are most commonly paired with TVs and other entertainment peripheral devices (such as game consoles and sound systems), CalPlug chose specifically modeled savings for TV. Of the class of consumer electronics devices, TVs consume the most energy, so they are most relevant for employing potential energy savings techniques. To model potential smart plug savings, CalPlug chose window AC devices and point-of-use hot water heaters, as these are both very commonly used products that have the potential to use substantial energy, but that are also significantly different in their energy consumption profiles to demonstrate the potential broad range of applications for smart plug use. Devices and systems considered for an extensive investigation(deep dives) are included in Table 12 in addition to devices and systems of value to mention due to potential program relevance but at a substantially lower value than the top tier devices discussed in the deep dives.

TABLE 11: DEVICE/SYSTEM FLOW CHART EXIT POINTS

Individual/Category Devices	Flow Chart Outlets	Notes
Climate Control		
Connected Thermostat	1A	Not a plug load; HVAC; Out of scope.
Central Air Conditioner	1A	Not a plug load; HVAC; Out of scope.
Furnace	1A	Not a plug load; HVAC; Out of scope.
Automatic Window Covering + Managed Control (Controller Action)	1A	Not a plug load
Air purifiers	1B	Too low of a device population & unit energy consumption
Humidifiers	1B	Too low of a device population & unit energy consumption
Dehumidifiers	1B	Too low of a device population & unit energy consumption
HVAC Zoning (Thermostat Controller Action)	1A	Not a plug load
HVAC Diagnostics (Thermostat Controller Action)	1A	Not a plug load; too low of device population
Smart ventilation (Thermostat Controller Action)	1A	Not a plug load; HVAC; Out of scope.
Smart Ceiling Fan	1B	Too low of a device population & unit energy consumption
Window AC/Portable AC	1D, 2C, and 2D	Compatible for system-based control
Nighttime Ventilation Cooling (Thermostat Controller Action)	1A	Not a plug load; HVAC; Out of scope
Ceiling Fans	1I	No IDSM strategy for energy savings potential
Air Conditioning Precooling (Thermostat Controller Action)	1A	Not a plug load; HVAC; Out of scope
Lighting		
Digital light Switch (Light Control Panel Controller Action)	1A	Lighting; Out of scope.
Lighting Control, Occupancy (Light Control Panel Controller Action)	1A	Lighting; Out of scope.
Lighting Control, Photosensor (Light Control Panel Controller Action)	1A	Lighting; Out of scope.
Lighting Control, Dimming (Light Control Panel Controller Action)	1A	Lighting; Out of scope.
Non-Connected Luminary	1A	Lighting; Out of scope.
Connected Luminary (Table/Floor lamps)	1B	Minor discussion scope
Edison Base Smart Bulbs	1B	Minor discussion scope
Water Heating		
Central Heating- Demand Recirculation Control	1D, 2C	Compatible for system-based control
Central Heating-Demand Temperature Modulation Control	1D, 2C	Compatible for system-based control
Point of Use Hot Water (Device)	1D, 2C	Compatible for system-based control

Table 11 *continued*

Individual/Category Devices	Flow Chart Outlets	Notes
Energy Management with controls		
Connected Smart Plugs (System Actuator)	1F, 1G	System Actuator Device; Considered for major scope with other relevant devices
GFCI Outlet	1B	Too low of a unit energy consumption
Advanced Power Strip, Tier 1	1I	No IDSM strategy for energy savings potential
Connected Advanced Power Strip, Tier 2 (System Actuator)	1F, 1G	System Actuator Device; Considered for major scope with other relevant devices
Integrated Home Energy Monitoring and Management System	1B	Minor scope system discussion
Home Energy Display & Feedback	1B	Minor scope systems discussion
Consumer Electronics		
TV (Device)	1D, 2C	Compatible for system-based control
PC-Desktop (Device)	1D, 2C	Compatible for system-based control
Set-top box: Streaming (Device)	1D, 2C	Compatible for system-based control
Digital television adapter/Converter box (Device)	1D, 2C	Compatible for system-based control
Entertainment Media System	1D, 2C	Compatible for system-based control
LED Projector (Device)	1D, 2C	Compatible for system-based control
VCR Player (Device)	1D, 2C	Compatible for system-based control
Blu-ray Player (Device)	1D, 2C	Compatible for system-based control
DVD Player (Device)	1D, 2C	Compatible for system-based control
Game Consoles (Device)	1D, 2C	Compatible for system-based control
Rechargeable Mobile Computing Devices	1B	Too low of a unit energy consumption
Generic Rechargeable Devices	1B	Too low of a unit energy consumption
Large and Small Home Appliances		
Connected Pool/Fountain Pump	1F, 1G	Major Scope Discussion
Connected Washer	1F, 1G	Major Scope Discussion
Connected Refrigerator/Freezer	1F, 1G	Major Scope Discussion
Dishwasher	1B	Minor Scope Discussion
Stove Range/Ovens with ventilation (system)	1I	No IDSM strategy for energy savings potential
Multi-functional cookers	1B	Too low of a unit energy consumption
Mixers	1B	Too low of a unit energy consumption
Coffee makers	1B	Too low of a unit energy consumption
Small electric kitchen appliances	1B	Too low of a unit energy consumption
Garbage Disposal	1I	No IDSM strategy for energy savings potential
Microwave	1B	Too low of a unit energy consumption

Table 11 *continued*

Individual/Category Devices	Flow Chart Outlets	Notes
Security/Accessibility/Medical Devices		
Security/ Alarms Systems	1I	No IDSM strategy for energy savings potential
Home Assistance Hubs/Tech (Google Home, Siri, Echo, Alexa, etc.)	1B	Minor discussion Scope
Medical Devices Respiratory	1B	Too low of a device population & unit energy consumption
Medical Devices mobility	1B	Too low of a device population & unit energy consumption
Medical Devices Generic	1B	Too low of a device population & unit energy consumption
Network attached data storage	1I	No IDSM strategy for energy savings potential
Network Gateway/IoT gateway	1I	No IDSM strategy for energy savings potential
Uninterruptible power source-UPS	1B	Too low of a device population & unit energy consumption
Wireless Router	1B	Too low of a device population & unit energy consumption
Ethernet Hub	1B	Too low of a device population & unit energy consumption
Modem	1B	Too low of a device population & unit energy consumption
Wireless mesh network system	1I	No IDSM strategy for energy savings potential
Small Office appliance	1B	Too low of a device population & unit energy consumption
Personal Care Devices	1B	Too low of a device population & unit energy consumption
Rechargeable personal care	1B	Too low of a device population & unit energy consumption
Small device battery chargers	1B	Too low of a device population & unit energy consumption
General manufacturing devices for home businesses	1B	Too low of a device population & unit energy consumption
Additive manufacturing	1B	Too low of a device population & unit energy consumption
Smoke Detector	1I	No IDSM strategy for energy savings potential
CO Detector	1I	No IDSM strategy for energy savings potential
Miscellaneous Electronics		
Water cooler	1B	Too low of a unit energy consumption
Water Softeners	1B	Too low of a device population & unit energy consumption
Irrigation System	1B	Too low of a device population & unit energy consumption
Garage door opener	1B	Too low of a device population & unit energy consumption
Electric Piano	1B	Too low of a device population & unit energy consumption
Fish Aquarium	1I	No IDSM strategy for energy savings potential
Waterbed Heater	1B	Too low of a device population & unit energy consumption
Home exercise equipment	1I	No IDSM strategy for energy savings potential

Table 11 *continued*

Individual/Category Devices	Flow Chart Outlets	Notes
Miscellaneous Electronics *continued*		
Solar Inverter	1B	Too low of a system population; out of scope
Indoor agriculture	1B	Too low of system population; out of scope
Invisible Pet Fence	1B	Too low of a device population & unit energy consumption
Heated towel rack	1B	Too low of a device population & unit energy consumption
Digital Touch Smart Faucet	1B	Too low of a device population & unit energy consumption
EV Charger	1I	No IDSM strategy for energy savings potential
Weather Monitor	1A	Not a plug load; Out of scope

TABLE 12: MAJOR AND MINOR DEVICE/SYSTEM DISCUSSED

		CA/CPUC Approved Effort	Effective Product Category Definition
Major scope devices	Connected Refrigerator/Freezer	Yes Work Paper *Smart/Connected Refrigerator* (Snaith, 2016)	Connected Residential Refrigerator/Freezer Version 5.0 (ENERGY STAR, 2013a)
	Connected Washer	N/A	Connected Washer Criteria Version 8.0 (ENERGY STAR, 2018)
	Connected Pool/Fountain Pump	Yes Work Paper *VSD for Pool & Spa Pumps* (eTRM, 2019)	Connected Pool Pump Criteria Version 2.0 (ENERGY STAR, 2019d)
Systems for major scope	Connected Advanced Power Strip, Tier 2 With AV Applications	Yes Work Paper *Tier 2 Advanced Smart Connected Power Strips* (RMS, 2017) (Incomplete Work Paper)	N/A
	Connected Smart Plugs with Window/Portable AC	N/A	SHEMS Criteria (Smart Plugs) Version 1.0 (ENERGY STAR, 2019c)
	Connected Smart Plugs with Hot Water Dispenser	N/A	SHEMS Criteria (Smart Plugs) Version 1.0 (ENERGY STAR, 2019c)
Devices/ Systems for minor scope	▪ Home Energy Monitor System (Management)	N/A	SHEMS Criteria Version 1.0 (ENERGY STAR, 2019c)
	- Connected Luminary (Table/Floor lamps)	N/A	N/A
	- Edison Base Smart Bulbs	N/A	N/A
	- Home Energy Display & Feedback	N/A	N/A
	Non-Connected Advanced Power Strip, Tier 2 with AV	Yes Work Paper *Tier 2 Audio Visual (AV) Advanced Power Strip* (Vu, 2015) (Approved) Field Trial *Tier 2 Advanced Power Strips in Residential and Commercial Applications*. SDG&E Technology Assessment Report (Valmiki & Corradini, 2015) Field Trial *Energy Savings of Tier 2 Advanced Power Strips in Residential AV Systems.* PG&E (Valmiki & Corradini, 2016)	CalPlug Report: *Tier 2 Advanced Power Strip Evaluation for Energy Saving Incentive* (M. Wang, Zhang, & Li, 2014)
	Connected Dryer	N/A	Connected Criteria Version 1.1 (ENERGY STAR, 2015)
	Connected Dishwasher	N/A	Connected Criteria Version 6.0 (ENERGY STAR, 2019b)

TRC CALCULATION

The Total Resource Cost Test (TRC) (California Public Utilities Commission, 2001) is one of the most commonly used tests to evaluate demand side management program effectiveness. Evaluating the benefits versus the cost of managing and deploying a resource this test can provide a quick assessment of cost effectiveness for a given set of evaluated parameters.

In general, this method can be applied to conservation, load management and programs considering fuel substitution, yet within the context of this report the discussion is primarily limited to conservation and efficiency efforts especially related to energy efficiency or energy conservation programs with some discussion application to load shifting and demand response.

The Total Resource Cost is defined as the benefits of the measure or program over the costs of the measure or program. If the result of the TRC calculation is one then the program is at breakeven, where the costs and the benefits are equal. If the TRC is less than one then the costs are greater than the benefits and therefore the program benefits have not exceeded the costs, and if the TRC is greater than one, then this program's benefits are greater than the costs and is yielding a cost-effective program.

EQUATION 4: TOTAL RESOURCE COST (TRC)

$$TRC = \frac{Benefit}{Cost}$$

Source: Navigant (2019, page 4)

When looking at the benefits and costs, several components are considered in order to evaluate the benefits and costs of the measure. The following summarizes the components considered for Benefits and Costs:

Benefits

- Energy-related costs avoided by the utility
- Capacity-related costs avoided by the utility, including generation, transmission, and distribution

Costs (dependent on program scope-economy of scale)

- Program overhead costs
- Program installation costs
- Incremental measure costs (whether paid by the customer or the utility)

In order to run these calculations with these components, the following variables were defined for the TRC calculation. For our evaluation of the measures, several of the variables were run with a range of values in order to identify what variable of a measure need to increase or decrease accordingly in order to have a cost-effective result.

TABLE 13: TRC VARIABLE DEFINITION

	Variables	Definition of Variables	Explanation
Benefits	UACt	Utility avoided supply costs in year t	The avoided supply costs should be calculated using net program savings, savings net of changes in energy use that would have happened in the absence of the program.
	TCt	Tax credits in year t	Any state or federal tax break considered a reduction in the costs test. The inclusion of tax credits or incentives depends on the region considered
Costs	PRCt	Program Administrator program costs in year t	Overhead costs are administration, marketing, research and development, evaluation, and measurement and verification
	PCN	Net Participant Costs	Participant cost = measure cost - participant incentive Can be incremental or total costs, depending on age of pre-existing equipment (i.e., replacing older equipment at the end of its EUL usually uses incremental cost for the new measure)
	UICt	Utility increased supply costs in year t	The costs in this test are the program costs paid by both the utility and the participants plus the increase in supply costs for the periods in which load is increased

Looking at the equation again with the defined variables above, the following defines how the TRC calculations were conducted for this report.

EQUATION 5: TOTAL RESOURCE COST (TRC) WITH DEFINED VARIABLES

$$TRC = \frac{Benefit}{Cost} = \frac{UAC_t + TC_t}{PRC_t + PCN + UIC_t}$$

Calculations of measure TRC are typically generated considering program logic model design and characteristics of individual measures in cost, base install size, and unit savings values. Numerous TRC calculators exist considering slightly different factors and approaches. An extended version of the California Public Utilities Commission (CPUC) derived model is presented by the Illinois TRM (Navigant, 2019) serves as a basis of our model and is expressed in the following equation:

EQUATION 6: SIMPLIFIED TRC FORMULA

$$TRC = \frac{B_{TRC}}{C_{TRC}}$$

Where

TRC = Total Resource Cost, Benefit-cost ratio

B_{TRC} = Present Value of Benefits in portfolio

C_{TRC} = Present Value of Costs in portfolio

Source: Navigant (2019, page 4)

EQUATION 7: EXTENDED TRC FORMULA

$$B_{TRC} = \sum_{t=1}^{N} \frac{UAEP_t + UATD_t + UAA_t + EB_t + RC}{(1+d)^{t-1}} + \sum_{t=1}^{N} \frac{UAC_{at} + PAC_{at}}{(1+d)^{t-1}}$$

Where:

UAEPt = Utility avoided electric and capacity production costs in year t

UATDt = Utility avoided transmission and distribution costs in year t

UAAt = Utility avoided ancillary costs in year t

EBt = Environmental Benefits in year t

UACat = Utility avoided supply costs for the alternate fuel in year t

PACat = Participant avoided costs in year t for alternate fuel devices (if applicable)

RC = NPV of replacement costs of equivalent devices

$$C_{TRC} = \sum_{t=1}^{N} \frac{PNIC_t + IMCN_t + UIC_t}{(1+d)^{t-1}} - RC$$

Where:

PNICt = Program Non-Incentive costs in year t

IMCNt = Net Incremental costs in year t

UICt = Utility increased supply costs in year t

d = Utility weighted average cost of capital, used as discount rate

Examination of this model's formula shows a set of linearly proportional benefits terms with an inverse-hyperbolic relationship to the cost terms. Of these terms, as with the CPUC model, subscripted 't' terms are dependent on values across multiple years of the program life whereas non-subscripted terms are common and not dependent on yearly scheduling.

General Variable Interdependency

Logical connection between factors leads to interdependency between the factors stated above and other preliminary factors. For example, the calculation of the benefits (cost of energy saved using a comparably new energy saving device measure), requires energy rate information and device deployment length, and deployment size. Similarly, the size of a measure within a program has a bearing on the administrative cost for the program. Typically, this includes some fixed cost plus a variable cost related to the program size, with most of the proportional cost for program manager salary and benefits as related to the measure in discussion. In this manner, program size and lifetime have dependencies in both the benefits and costs for consideration. In typical use, specific values are entered from program performance review data or forecasted. Within this equation, multiple factors have both explicit and implicit action in the model. In this project we seek to use a streamlined cost-benefit calculation in a simplified TRC model to provide a screening tool.

Model Variable Interdependency

Specific non-intuitive, non-variable definitions were included in the presented model to improve prediction and simplicity. Discussed are several key examples:

1. Labor cost calculation: A linear relationship was used to model the percent effort of a program manager's involvement into a measure. In the present model, this can be individually factored for five individuals against a known number of devices in the measure. In this manner a relationship for each individual can be made for involvement with 0 devices and increased with a relationship of % per device. This is strongly dependent on internal personnel structure and portfolio management approaches within a utility.

2. Total Devices: The total device count strongly affects both the cost and benefits aspects of the calculation, yet a positive trend exists based on most reasonable program logic considerations for a growing TRC value with additional participants.

Model Simplifications

Specific model simplifications were managed to reduce calculation burden, simplify overly complicated points relying on potentially unsubstantiated assumptions, and to help produce a more intuitive and useful screening test tool. The following are the major substantial model adjustments.

1. Present cost calculation simplifications: The model presented provides present cost calculations based on a term for the compounding of the annual effective discount

rate. In the presented model, $(1+d)^{t-1}$ =1 such that this term is unitary in presented calculations negating the compounding impact of *d*. This approach was justified by the limited impact of this term for small values of *d*, especially in short program lifetimes.

2. Programmatic scheduling of deployment and costs: To simplify calculations, programmatic factors are assumed in some calculations. Specifically, for participants in the program a programmed rate of addition is typically considered. Similarly, changes in energy cost are not possible to consider on a year to year basis due to this value being constant for program measure lifetime.

3. Reduction of considered factors: To better align with CPUC TRC calculation recommendations, the relationship only considers UAC_t and TC_t as benefits, and PRC_t, PCN, UIC_t as costs. Additional input factors related to tax and environmental benefits are ignored (set to 0).

4. Free ridership Calculation: An additional term of net to gross ratio (NTGR) is often used to express costs expended on program free riders. In the current model, this is not considered. Often in the costs term a factor for "*Measure Costs *NTGR+(Incentives)*(1-NTGR)*" is often used to address this impact. Examples of free-ridership considerations are presented in The PG&E Platform Rulebook, and a default value of 0.85 is presented as a default reference value for residential programs (Pacific Gas & Electric Company, 2018; Southern California Edison, Pacific Gas & Electric Company, Southern California Gas Company, & San Diego Gas & Electric, 2019). Depending on the location and program type, customary values are often used (Malone, Ong, & Chang, 2015; Violette & Rathbun, 2014) with ACEEE recommending 0.9 in their scorecard assessment used as a default value consistent with programs in multiple states (Gilleo et al., 2014). California DEER provides a full list of default NTGR values for estimating California programs for a wide variety of conditions (California Public Utilities Commission, 2018). The current calculation models assume a NTGR of 1.0 and do not take into consideration NTGR. This likely produces a minor overestimation of resultant TRC values. As an evaluation tool, the authors deemed NTGR to add additional complexity to the model that creates difficulty in performing device to device comparison, especially if different NGR are considered across different product categories.

The impact of these factors on the output TRC can be expressed in terms of variable sensitivity: the impact a variable has on the output calculated model TRC value with all other inputs of factors considered constant. In Figure 11 this is expressed for major input terms or calculation intermediaries (combined terms). It can be seen from this figure that the energy rate and the net annual savings for a measure are the strongest leaner factors by far in in increasing output model TRC values. Similarly, measure cost as an aggregate value of measure cost has a strong impact on TRC as an inverse-hyperbolic factor.

With basic program realistic bounded constraints, ranges of values can be tested to determine in the model which have a desired impact of a magnitude required to reach required TRC goals (typically, measure TRC>1). In this manner, multiple ranges set by program externalities or logic models can be tested to determine under which conditions TRC condition values are met.

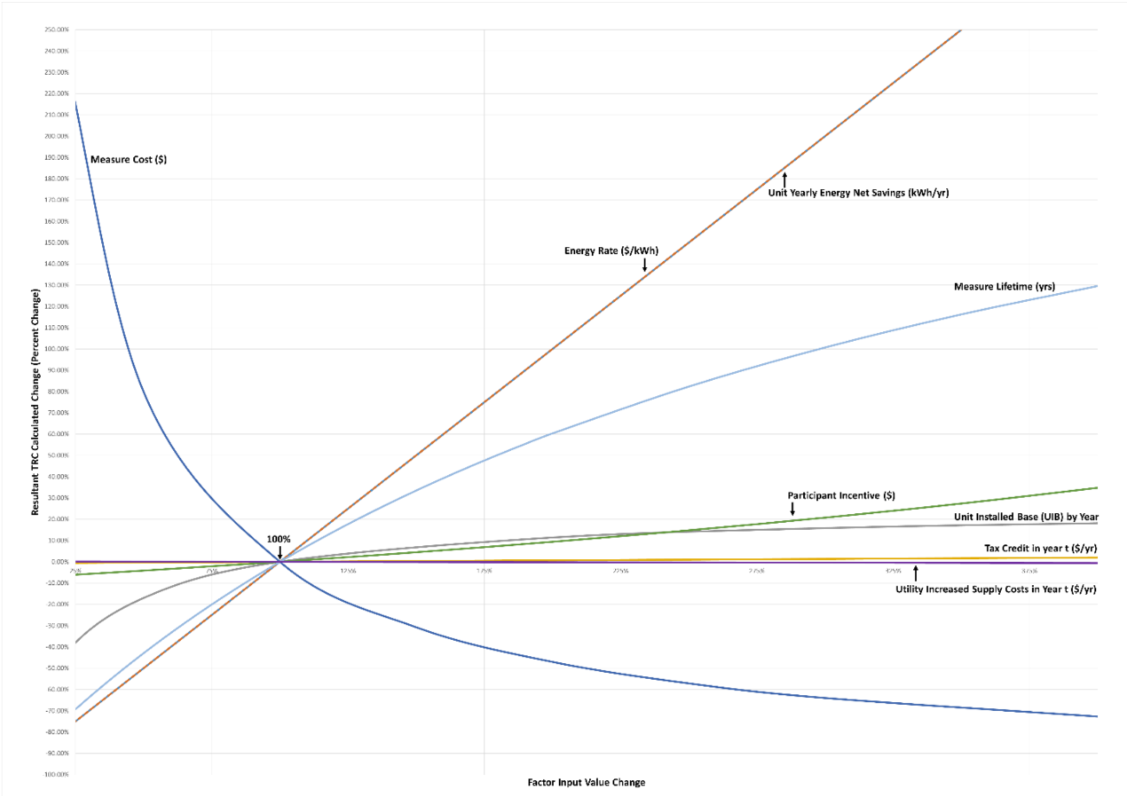


FIGURE 11: TRC SENSITIVITY TO RANGED VARIATION IN INPUT FACTORS

While TRC estimation can be used to estimate program impact, one of the drawbacks of preparing TRC calculations on a case-by-case basis, however, is that it can be difficult to derive standardized results with par-to-par comparisons across device categories in some cases due to the inherent fluctuations and inconsistencies between program requirements. For example, some measures may be highly administrative and overhead intensive, while others may rely more on the technical function of a device itself to drive savings. Such dynamic conditions put into question the ability to truly ascertain whether a TRC value reflects the true value of the proposal.

Example Measure Calculation

A generic example can be used to demonstrate the operation and consideration for use of this model. In this example a widget can be used to calculate the impact due to an added energy saving feature. Widget A serves as a baseline device with Widget B having similar functionality to Widget A yet with connectivity features. In this example we are seeking to determine the potential TRC value by replacing Widget A with Widget B through a retailer based (mid-stream) incentive program. The terms are provided in Table 14.

Note that the point of sale rebate provided by mid-stream incentive with user installation. Free ridership is controlled to be near negligible per the omission of the NTGR calculation factor. This may not be a safe assumption and may cause TRC to be overestimated in some cases where free ridership is non-negligible. This calculation approach is used consistently across the TRC calculations performed in this report.

Considering the aforementioned measure logic model parameters an analysis was conducted to calculate the resultant TRC. Multiple levels of incentive were provided, resulting in a spread of values from $20 to $120 as a function of provided incentives and unit totals presented in Table 14. In this analysis and figure, energy saving performance was considered for a performance spread of 50 kWh to 300 KWh annual savings. This wide range example provides extended parameter boundaries covering the total units, annual savings, and incentives provided and can serve to illustrate common measure logic boundaries.

The results graphed in Figure 12 below are calculated using the unit energy net savings of 300 kWh/year, measure lifetime of 10 years, measure cost of 500 dollars, and ranging in participant incentive from $150 to $250 (increasing by $10), and unit installed base ranges from 0 to 15,000 over three years (increasing by 500).

The varied expressions in Table 14 were individually adjusted to demonstrate impact on resultant TRC values similar to the approach used when evaluating variable sensitivity except for demonstrable values. Clearly the TRC of Widget B is most strongly affected by annual savings followed by the measure cost considered across the unit base install quantities from 0 to 15000 units over a three-year period of modeled growth. The values for participant incentive and lifetime are substantially less impactful on final TRC values. The results of this analysis are presented in Figure 12 through Figure 15. In in Figure 12, the modeled measure presented TRC values greater than unity for situations where annual savings provided 250 or 300 kWh within the bounds of 15000 total devices over the measure lifetime. The relatively high measure cost modeled of $250 is a major contributing factor in this example to a high required savings for achieving unitary or higher TRC values. For individual device categories discussed within this report similar parallels will be made between variance in parameters and resulting measure TRC values.

TABLE 14: SUMMARY OF TRC CALCULATOR INPUTS FOR WIDGET B

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year *t*	Unit Yearly Energy Net Savings (kWh/year)[1]	50 – 300 kWh/year
		Energy Rate ($/kWh)[2]	0.15
		Unit Installed Base (UIB) by year[3]	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
	Tax credits in year *t*	Tax Credit in year t ($/year)[4]	--
Costs	Program Administrator program costs in year *t*	Employee Costs ($)[5]	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)[6]	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)[7]	$150-350
		Participant Incentive ($)[8]	$20-140
		Unit Installed Base (UIB) by Year[9]	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000 (3 total)
		Measure Lifetime (years)[10]	8-12
	Utility increased supply costs in year *t*	Utility Increased Supply Costs in Year *t* ($/year)	--

[1] A CPUC deemed annual savings *ex ante* value of 350kWh is shown for representative savings for operation of Widget B compared to a baseline set by Widget A. Additionally, this device can also act in a demand response mode with an average of 80W shed on command for up to 10 minutes and an average of 15 watts shed over a period of a 4-hour event. This data was sourced from a recent, independent California field trial
[2] This is the average cost of avoided energy use to the customer. This value can be averaged across time of use and season if device usage model can be formed.
[3] Participation expected to be between 5,000 and 15,000 total across the total program lifetime. An even increase of 1/3 of this total is added per year. Note: This is a modeled consideration and actual rate of participant growth and churn may vary substantially.
[4] No tax credit considerations for Widget B.
[5] Based on employee salaries and benefits. See calculator for details.
[6] Based on 2013 marketing and outreach values from SCE. See calculator for details.
[7] Widget B measure cost ranges depending on the model.
[8] Widget B Participant Incentive typically $200.
[9] Participation expected to be between 5,000 and 15,000 total across the total program lifetime. An even increase of 1/3 of this total is added per year. Note: This is a modeled consideration and actual rate of participant growth and churn may vary substantially.
[10] Expected measure lifetime is 8 years. Device usable lifetime is CPUC deemed at 10 years.

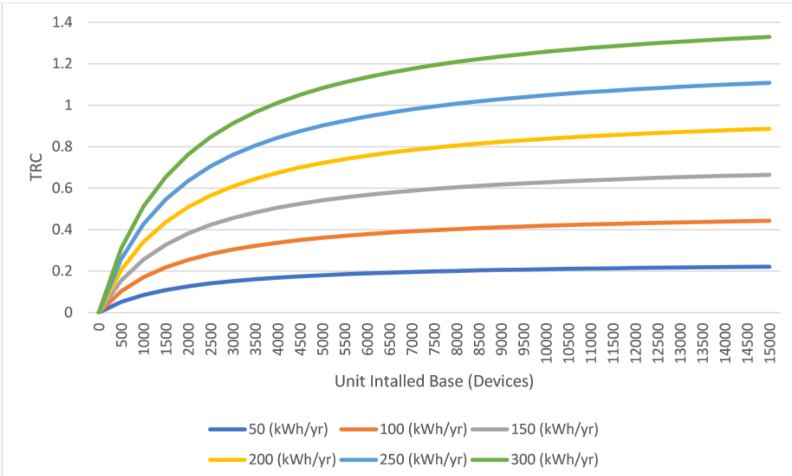


FIGURE 12: EVALUATION OF MODEL TRC VALUES FOR VARIED ANNUAL SAVINGS AND UNIT NUMBERS WITH A FIXED PARTICIPANT INCENTIVE OF $50, FIXED MEASURE COST OF $250, AND FIXED MEASURE LIFETIME OF 10 YEARS

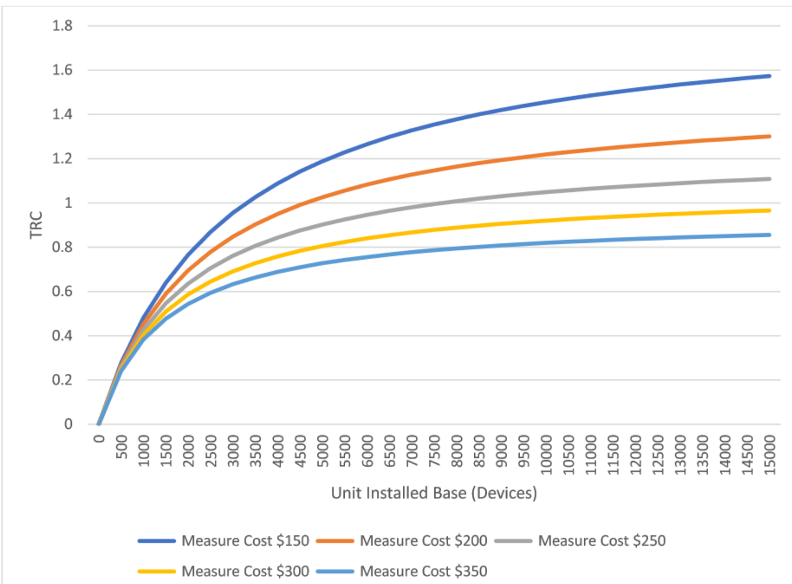


FIGURE 13: EVALUATION OF MODEL TRC VALUES FOR FIXED ANNUAL SAVINGS OF 250 KWH AND UNIT NUMBERS WITH A VARIABLE MEASURE COST, FIXED MEASURE LIFETIME OF 10 YEARS, AND FIXED INCENTIVE OF $50

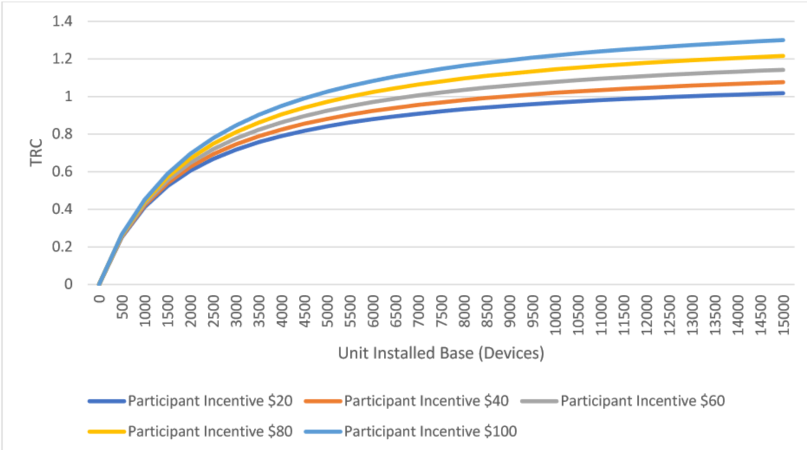


Figure 14: Evaluation of Model TRC Values for Fixed Annual Savings Of 250 KWh and Unit Numbers With A Variable Participant Incentive, Fixed Measure Lifetime of 10 Years, and Fixed Incentive of $50

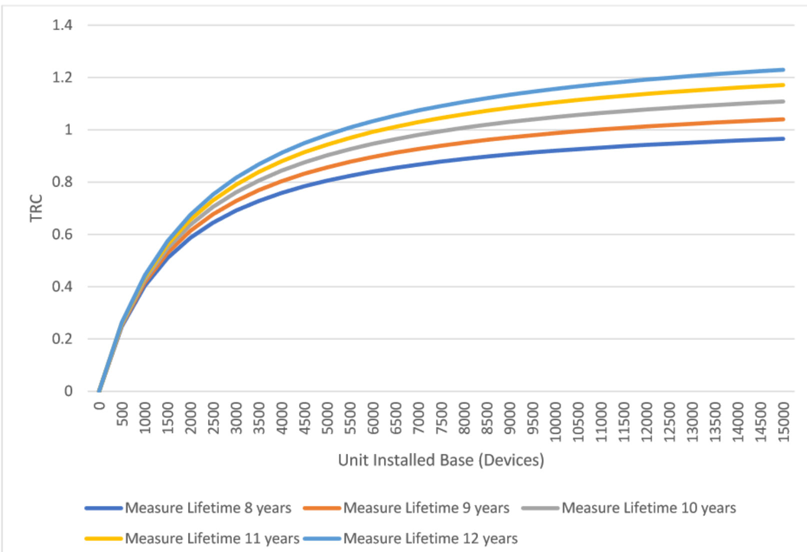


Figure 15 Evaluation of Model TRC Values for Fixed Annual Savings of 250 KWh and Unit Numbers With a Variable Measure Lifetime, Fixed Measure Cost of $250, and Fixed Incentive of $50

EVALUATION OF MINOR SCOPED CATEGORIES

In our evaluation of residential plug load devices for current potential in utility-sponsored programs, several common categories were excluded from major consideration due to multiple factors within the selection hierarchy. These factors primarily included lack of internet connectivity capability, low current market trend outlook, and low per-unit energy savings potential, among other factors consistent with the previously discussed scoping process. This tight exclusion of devices due to strict adherence to the selection criteria can leave out several device categories that are worth mentioning for broad energy savings potential and potential consideration in programs. Accordingly, the selection criteria in the flowchart sorted rejected but otherwise promising plug load devices and systems into a minor scope category. The discussion of those device categories in this section adds contextual value to programs that may not match the selection boundaries used in scoping for the discussion of this report.

For the large appliance category, dishwashers and clothes dryers are considered for minor scope discussions. Although these appliances have fewer, less sophisticated features than current market-ready connected refrigerators or washing machines, they have ENERGY STAR connectivity specifications. As trends toward further development of smart appliances continue, it is likely that smart dishwashers and dryers will continue to evolve and grow in market share. It is therefore worthwhile to briefly discuss technical features and program parameters that might suit future IDSM programs targeted at dishwashers and clothes dryers.

For the control system category, smart lighting control systems, home energy feedback displays, and broader integrated home energy management systems are considered for a minor scope discussion. These systems were largely disqualified from major scope consideration because these types of integrated smart home systems have not been thoroughly field-tested, and currently have too low of a population to be able to derive confident TRC estimates. While ENERGY STAR specifications do not currently address smart homes as integrated systems for energy savings, there is currently an ENERGY STAR program in development for SHEMS. Smart home systems constitute a growing trend, and, as internet infrastructure continues to support the proliferation of these systems, they may become more relevant to IDSM programs in the future. Thus, potential energy savings from smart home systems are evaluated here.

LARGE APPLIANCES

ELECTRIC ELEMENT AND HEAT PUMP CLOTHES DRYER

The energy usage of a washing machine and clothes dryer can be consider linked as the energy required for a process: the laundering of clothes. A washing machine that saves by leaving additional moisture in clothes will cause the dryer to use more energy to remove this water. Electric tumble dryers come in vented and condenser forms. Condenser dryers have no exhaust output and use a heat exchanger to condense water vapor, while vented dryers expel water vapor in an airstream to the outside of the home. In addition to this distinction, electric dryers also are made in heat pump and heating element varieties. Heat pump types are typically condensing and use a refrigerant loop to provide heating while using the cold side of the loop to provide exhaust air dehumidification.

Beyond the specific dryer technology used, substantial energy savings can occur from preventing over-drying. Sensing the output humidity of the drying chamber can provide a cue as to when the clothes are dry. This technology has been in use for decades and generally consists of a pair of electrodes on the back wall of the dryer drum to sense the moisture on passing fabric. Newer approaches can use sensors in the exhaust steam or sensors that tumble with clothes to provide feedback to tell the user or the machine when the clothes are dry; appropriate action is taken to stop the drying process once all required moisture has already been extracted. The efficiency of the drum motor on any dryer is a point of improvement. The use of variable speed drives compared to conventional induction motors can produce significant savings, comparable to other large motor applications.

The incorporation of smart, connected technology has limited application to improving dryer efficiency. The sensing system conventionally used permits the dryer to automatically operate via a conventional feedback system, without the need for connected processing. Tracking dry time and load size over time could potentially identify maintenance issues, enabling proactive repairs, yet this capability is not in conventional use.

Electric dryers do have the potential for DR action. Stopping the drying process or providing an alert to delay initial use provides a means to shed substantial load. Operation is typically similar to that of washing machines.

Potential program and measure features for smart clothes dryers were obtained through the statewide measure evaluation for the "Residential Clothes Dryer" program (eTRM, 2018). The IOUs determined the baseline energy usage of a non-connected dryer to be between 460-500 kWh/year. The high-efficiency measure targeted dryers using an average of 111-363 kWh/year, per ENERGY STAR guidelines. The average cost of the measure was $856-1391, and similar to dishwashers, the labor cost was borne by the customer. For a similar program targeting a smart dryer, energy savings may be comparable to a non-connected dishwasher as discussed previously, given limited EE savings mechanisms from connected features. Considering the $300 higher average cost of connected appliances, the total measure cost for a smart dryer may range from about $1,160-1,700.

DISHWASHER

Dishwashers share many commonalities with clothes washers in function and operation. Like clothes washers, the heating of water is a major point of energy use in cycle operation, yet unlike clothes washers hot water is required for sanitary cleaning operation. Using mains hot water can reduce the requirement for internal heating to cycle required temperature, yet total energy system energy (dishwasher combined with the hot water heater) is not substantially reduced when considered as a combination. Similarly drying the washed dishes is an energy intensive process. The use of appropriate air circulation and venting can shorten drying time and reduce energy usage compared to less efficient designs using static heating elements. Design to encourage efficient load placement and adequate spray coverage has a large impact on energy use by reducing chronic cycle runtime. Similar to other devices, the inclusion of variable speed drive technology also improves efficiency. Managing cycles based on demand is conventionally accomplished with a turbidity sensor. This is not new technology and is incorporated in a simple feedback loop to determine the completion point for washing. The use of connected approaches can provide minimal benefit to dishwashers with respect to energy savings.

Similar to other large washing appliance such as clothes washers, dishwashers can benefit from DR capabilities by preventing the start of cycles or pausing during operation in response to a demand response event.

Potential program and measure features for smart dishwashers were obtained through IOU work papers on the Residential High Efficiency Dishwasher program (Loo & Jimenez, 2017). These papers considered data from the 2012 CLASS survey to determine potential measure features and establish baseline efficiency of installed dishwashers. The IOU determined the baseline energy usage of a dishwasher to be 307 kWh/yr. and estimated the cost of an average dishwasher at $280.25. The high-efficiency measure targeted dishwashers using an average of 199 kWh/year, per ENERGY STAR guidelines, which on average cost $1,764.11. The labor cost was not included, as installation was paid for by the customer. For a similar program targeting a smart dishwasher, similar energy savings may be expected as for high efficiency dishwashers without connectivity, because, as previously discussed, there is limited potential for feedback-based connectivity to produce great savings with such appliances. Additionally, as discussed, most energy savings for dishwashers comes from improved mechanical function and water saving design. As discussed in a work paper on smart refrigerators, the typical cost of a smart connected appliance averages $300 more than for a non-connected appliance. This would increase the measure cost for smart dishwashers to roughly $2,000. The actual energy savings impact due to connectivity is likely limited to the 2-7% range consistent with other smart product categories due to user alerts (Mitchell et al., 2014). Cycle enhancements may potentially be leveraged by connectivity, but to date the specific impact due to this is negligible.

Control System Plug Loads

Some devices related to lighting, climate control, water heating, or charging of mobility solutions may fall between categories and may or may not be considered plug loads. In some cases, devices integrated as part of control systems with plug loads merits discussion as a general point of integrated controllability.

Smart Lighting in Controlled Systems

General Overview

Although built-in overhead lighting is often studied as a separate category, movable plug-in lamps are generally considered plug loads, and other types of lights may be considered miscellaneous electric loads, such as garage lights. Connected plug load lamps can provide a point of control. Such devices may include traditional Edison-base LED smart bulbs or built-in, non-replicable LED components. Connected control systems such as APS devices or smart plugs can be used to provide a level of controllability to non-connected lamps. Non-LED bulbs use more energy, and thus have higher increased savings potential when placed under such control. Tabletop and floor lamps are increasingly being combined with smart speakers or diffusers, although the current market share for these devices is low. These combined devices may provide additional challenge in control as all aspects may not be integrated into onboard connectivity. Additionally, control systems would manage all device aspects (i.e., turning off the light and smart speaker both) when only control of one device aspect is desired. For the general class of plug load lamps, the following controls are general applicable for both EE and DR applications:

Active Load Management

The use of connectivity can allow sensing and coordinated control of connected lamps to turn them on or off using remote user commands or timed settings, or based on sensor inputs or on linked input from other actuators. Currently, sensor control is typically limited to direct control. An example of this is a motion sensor that provides the sensing to turn on a light when activity is present. Without continued activity, the device is powered off. An example of linked control includes turning on a lamp when another device is actuated, e.g., turning on the internal garage light when the garage door is triggered. Adding connectivity often increases power consumption compared to non-connected solutions. In fact, given the low energy consumption of LEDs, in low-use lamps, any savings provided by smart connected solutions can be easily offset by the constant power required for connectivity. unless substantial savings are obtained through enabling advanced control. CalPlug modeled and reviewed this consideration previously (Klopfer, Rapier, et al., 2017). Control of active period of use by user-driven or specific automated control authorized by a user is generally tolerated. However, powering off lamps in a residential setting in response to a DR event may pose a burden on the user while providing such little load reduction that the application does not merit the effort.

Dimming and Mixing

For multicolor LED light sources, a large color gamut can be generated by mixing component light sources. For natural colored lighting, this allows the color temperature to be adjusted, providing cooler or warmer light. In this technological approach, dimming can be used to reduce total light output and thus energy demand. For single color LED light sources, the inclusion of a LED power driver circuit that allows for dimming can provide similar total light output control. Dimming light brightness to respond to environmental conditions is one means of EE control to match excess user utility to required utility in normal usage. In DR control, cues for action may include the shift of color temperature.

Category Considerations

Plug load lamps provides a potential controllable load for IoT control systems. Substantially more control than is present in the market is possible with current control hardware in use. The continued use of AI and video surveillance systems provide a new potential type of sensor to provide contextual usage through more advanced means beyond motion sensors. Thin includes person counting, tracking location of persons in the home to reduce lighting in areas they have left, and estimating whether users are unlikely to immediately return(e.g., if sensors indicate nobody is home). Privacy challenges are always a concern in such approaches. The generally low power consumption of LEDs reduces the potential wasteful load that can be turned off or shed, especially compared to traditional incandescent light sources. The strong growth of connectivity integration in lighting leaves the possibility for continued improvements in general controllability as a feature that can be used on top of connectivity added for convenience. In this manner, the connectivity is leveraged rather than added specifically to enable advanced energy controls. While reducing active waste will always have beneficial impacts, high granularity control for a few lamps requires substantial effort to provide small gains.

Home Energy Display and Feedback

General Overview

Identification of total home energy use and reporting this back to household members has shown a potential for savings. Such devices may be connected or non-connected in configuration. Non-connected devices typically use the Home Area Network (HAN) of the advanced metering infrastructure (AMI) household smart meter to report back to users the current and historical energy usage. Typically, these devices are single displays placed on counters or mounted on walls to provide at-a-glance information at this single location. Current residential solutions offerings in this category have shifted towards cloud-based solutions that use smart meter AMI data in addition to cloud processing and the use of integrated displays, such as smart phones, to present data to the user. In general, the more recent and granular the data is (with respect to when and how the energy was consumed) the more actionable and interesting is to the user. This has driven some solutions to bypass the smart meter as the source for usage data. Monitoring individual outlets via smart plugs or smart outlets or breaker level sub-meters can provide a varying degree of granularity in terms of the monitored devices. Cost and system complexity are factors in limiting the total degree of direct metering. The use of artificial intelligence to provide disaggregation has shown the ability to determine both power usage per device and real time states of operation for multiple devices on a single circuit. With high-speed measurements and harmonic monitoring along with cloud-based data processing solutions such as the Sense power monitor have shown whole house disaggregation for major loads.

In-home devices can increase the visibility of energy consumption, help users learn about their energy habits, and enhance knowledge about energy usage in general (Buchanan, Russo, & Anderson, 2014). Ehrhardt-Martinez, Donnelly, and Laitner (2010) conducted a meta-review for ACEEE, summarizing the results of 57 feedback studies. Aggregated real-time feedback (mostly given through in-home devices) was examined in 23 studies, all but one of them conducted in the U.S. or Canada. The median savings reported for this approach were 6.9%. Feedback disaggregated on the appliance level was used in five studies, of which one was from the U.S. and one was from Canada. The median savings from this approach were 14%. Similarly, Faruqui, Sergici, and Sharif (2010) reviewed 12 pilot programs in Canada and the U.S. (two of these were located in California) and concluded that on average IHDs led to a reduction in electricity use of 7% (range 3% to 13%).

Persistence is an issue with any measure; in-home devices and other feedback mechanism have their own challenges, in that the utility must rely on the customer to maintain interest in the feedback without additional or new stimuli. For instance, Houde, Todd, Sudarshan, Flora, and Armel (2013) tested the Google Powermeter for eight months in a sample of 1,628 households across the U.S. The researchers found average savings of 5.7% in the first four weeks, but after that the savings declined. In contrast, in their summary of a pilot study in the Sacramento Municipal Utility district, Ashby, Conley, Jimenez, and Steeves (2015) report that on average the IHD did not lead to savings during the first two months during which the displays were installed. However, customers showed average electricity savings of 2.6% during the first year after the IHD was uninstalled. Recent feedback studies of smart meter customers equipped with in-home devices found a 5%-7% reduction of electricity usage that persisted for the study periods (11 and 9 months, respectively) (Schleich, Faure, & Klobasa, 2017; Schultz, Estrada, Schmitt, Sokoloski, & Silva-Send, 2015).

Demand response strategies seem to benefit from installing IHDs in customers' homes, as the real-time display of energy usage and cost aids with learning about energy usage and facilitates decision making at on-peak times (Jessoe & Rapson, 2014). Faruqui et al. (2010) concluded in their review that in-home devices can support load shifting under TOU rates. Jessoe and Rapson (2014) found that alerts about critical peak pricing events combined with an IHD led to a 12% to 18% reduction in electricity consumption, compared to a 0% to 7% reduction for the alert-only group. Martin and Rivers (2018) pointed out that consistent savings over peak and non-peak times could also result from changing conservation behavior habits. Martin and Rivers (2018) followed almost 7,000 Canadian households with established TOU pricing and researched the effects of real-time feedback via an in-home device. They found that in-home device reduced overall electricity usage by 3% throughout the day, which points to habit formation and adjustments of thermostats. Furthermore, the treatment effect persisted and even increased over time, starting at 1% and increasing to 6% several months later. Their results suggest that households didn't use the IHD to respond to TOU prices on a daily basis but instead responded to the information about energy usage to change their habits more broadly (see also Rivers, 2018).

CATEGORY CONSIDERATIONS

Providing claimable savings is often a challenge for this product category in utility programs due to the indirect behavioral method and device non-specific mode of action. For the operation of many devices in this category only gross energy usage is displayed per period of time. The feedback must have impact on the user as an energy use or bill paying stakeholder, identifying useful information to motivate change in behavior. The user must identify the causal link between a specific action and a reduction in energy use (Abrahamse, 2019; Ehrhardt-Martinez et al., 2010). In some use cases this is obvious, but in others it may not be such. If a user knows he or she left on an appliance and sees the impact of this, then the user may proactively limit future wasteful behaviors. Yet this is more challenging if the user does not fully understand the corrective action that must be taken to reduce further energy use. Indeed, a recent study found that enhancing the standard in-home device display with personalized and actionable information yielded significantly greater savings than the standard energy consumption display (Mogles et al., 2017). The success of in-home devices are influenced by the design, ease of installation, and maintenance requirements, which may influence user engagement (Ehrhardt-Martinez et al., 2010).

INTEGRATED HOME ENERGY MONITORING AND MANAGEMENT SYSTEMS

GENERAL OVERVIEW

Smart home energy management systems (SHEMS) extend upon home energy display and feedback systems by providing controllability and direct management of residential energy usage similar to building energy management controls used for commercial applications. In the current discussion, this category includes a collection of systems that permit the management of energy use toward strategic electrification and management of distributed energy resources (Ford, Karlin, Sanguinetti, Nersesyan, & Pritoni, 2016). The individual components can act at various levels of integration and can include devices that provide control to smart thermostats, smart plugs, and controllable lighting. In addition to these devices, other systems that control generation, storage, and power flow are considered. Such devices may monitor on-site generation and control charging of on-site storage or immediate use of available generated energy in water heating or space pre-cooling strategies. These generation and usage considerations for space and water thermal management are largely outside the plug load space of consideration. Previous considerations around dedicated home energy management systems have largely been integrated into discussion of integrated smart home devices and controllers, forcing a practical redefinition of the category. Many aforementioned devices can be considered elements of SHEMS, but due to the varying nature of these systems, SHEMS warrants a dedicated discussion.

SHEMS leverage smart home infrastructure for energy management capabilities. ENERGY STAR has outlined the SHEMS specifications, detailing key system features and operations (Daken, 2019). As of January 2020, a version 1.0 specification is available. With perspective to plug loads SHEMS operating as a package of devices and services can provide the following key features

1. Control and/or integration of required devices
2. Consumer remote access via cloud interfacing
3. Grid services to manage time-varying price, optimized for TOU pricing

4. Collection of local data for processing, and review of field data
5. Provide a user interface for energy use feedback and settings control
6. Provide low power modes as required for nighttime, vacations, and safety modes
7. Act on occupancy and notice and resolve issues related to improving system operation health

In addition to these general features, for managed DR control, the following criteria must exist:

1. Implementation of DR must be on at least one device
2. DR event override is available to the user with a DR event duration of 72 hours or less

The levels of integration and management capability of the outlined system are very broad. Currently challenges still exist in tight integration of devices. Sensors and controller systems can be included as part of a SHEMS Solution. Energy usage can be reduced through sensing of occupancy and intent and directing individual devices to act as situationally appropriate within their capabilities. Careful distributive sensing can give greater awareness for preemptive action, but the challenge lies in how specific actions will take place across a wide variety of devices within the system. This requires integrating devices with onboard connected sensors as well as independent sensors (e.g., passive IR sensors, power meters, and disaggregation systems) and devices that can be used implicitly as sensors (e.g. manual activation of a device implies activity). Both edge and cloud-based computing systems enable sensing networks to form actionable intelligence, which can be applied to device actions relative to an individual user or specific user base for the managed devices. By tracking previous patterns of use, turning off devices with no anticipated use without impacting user utility may be increasingly possible. CalPlug demonstrated this in classrooms for projectors using a linear supervised machine learning approach, yet neural networks, especially those based on long short-term memory neural networks show promise in early research (Klopfer et al., 2018). Further development appears to be a continued industry challenge at the present time. Current offerings are providing linked solutions with devices without strong modeling of typical use and energy saved. This challenge is the same as that for smart plugs (covered in a later section) where savings potential is highly variable upon configuration and situational usage. Understanding the practical limits of how much energy can be reduced by modeling actions within practical operational boundaries provides some sanity checking of potential system performance. Continued industry development of solutions and substantial subject independent field tests of individual energy saving applications will be needed to draw tight parallels for savings capability, especially in EE applications.

Specific Subsystem Considerations

Within the greater topic of SHEMS, specific specialized subsystems exist to provide control for processes to reduce over utility. A smart thermostat is a common example of this. More advanced systems have great potential to reduce energy use, such as smart HVAC zoning and control, controlled kitchen and home ventilation based on linked device operation, thermal sensing, or air quality. Hot water circulation control and domestic hot water thermal management is another point to consider. The specific impact of these systems was presented by Fraunhofer USA (Urban et al., 2016). While these devices use sensors and actuators, in some applications they exist without connectivity providing extended operational capabilities, and are thus not a major focus in the discussion of connected devices. Like with other product categories, integrated solutions based on intelligently operating sensor-actuator systems can improve in performance through self-learning and optimization strategies as well as reducing the barrier to entry for consumers to adjust operational parameters such as set points and vacation modes. Clearly the performance with regard to payback period and program cost effectiveness affects how much can potentially be saved, and similar to other examples, savings modes must enable substantial reduction in energy usage to merit the effort.

MAJOR SCOPE INDIVIDUAL DEVICES

SMART CONNECTED REFRIGERATORS

BACKGROUND

Domestic refrigerators and freezers are major household appliance and are substantial contributors to household energy consumption (Radermacher & Kim, 1996). Indeed, 12% of the total residential annual primary energy budget nationally is related to the operation of domestic refrigerators (Radermacher & Kim, 1996). In 2010 per household this ranged between 660 and 827 kwh (Southern California Edison, 2012). These devices have been the targets of some of the earliest energy efficiency efforts. From initial mass production in the 1920s through the 1950's reliability improvements in device design, compressor function, and refrigerant system operation led to substantial improvements in reliability. By 1958, 94% of American households had a refrigerator (Radermacher & Kim, 1996) cementing this appliance as a major plug load category. Initial environmental concerns for refrigerators were highlighted by the discovery of CFCs (the common refrigerant of the time) causing ozone layer damage by UC Irvine researchers Rowland and Molina (Molina & Rowland, 1974). While CFCs in addition to their most common replacement, HCFCs have a large global warming potential, the consistent and long operational lifetime of these devices leads to substantial global warming potential due to the operation of the device and the energy required for operation. In fact, switching away from the CFC R-12 to the HFC R-134a, can lead to a 4-10% decrease in primary refrigerant loop efficiency. When considering lifetime GWP, both the primary energy carbon dioxide generation used for refrigeration as well as the leakage and/or release of the refrigerant gas must be considered. In sealed units such as refrigerators, leakage is typically low, yet recovery rates may vary. Improving both the GWG impact of the refrigerant used and the efficiency of operation of a specific refrigerant has an impact on overall efficiency and GWG impact due to the refrigerant leaking itself – both factors are model significant in many modeled refrigeration device operational lifetimes. Hydrocarbon refrigerants, despite their flammability are being revisited as major refrigerants due to low GWP values and improved efficiency compared to commonly used refrigerants such as R-134a, especially in small capacity units. Additionally, new generation refrigerants such as R-152a and R-1234yf may be candidates for light duty refrigeration applications and are already seeing uptake in the automotive air conditioning market. Commercially obsolete refrigerants including carbon dioxide (R-774), sulfur dioxide (R-764), and ammonia (R-717) are bring reinvestigated for low GWP values and low flammability, but each have substantial operational considerations related for safety, equipment cost, or stable operation across a wide temperature profile. While ammonia and carbon dioxide have shown recent commercial viability in plant and package operational use due to their low GWP potential and relative high efficiency (within specified performance bounds), the potential for such refrigerants to be widely used in the cost sensitive, light duty domestic refrigeration market is likely far off into the future.

In addition to improving the refrigeration cycle efficiency, reducing the cabinet heat load, reducing parasitic electrical losses, and reducing on/off cycling losses are major efficiency considerations.

FEATURES AND FUNCTIONALITY

Considering only energy efficiency as a function of IDSM, in normal operation, only substantially wasteful actions on the part of the user have major energy impact on overall efficiency. This includes leavings doors open, blocking seal closure or restricting airflow to the compressor and condenser units. During extended periods of non-door opening (for example during vacations), defrost cycles and temperatures can be adjusted to reduce energy consumption. In this manner the efficiency is largely physics-limited on the part of device operation. Intelligent control may have in addition to these general efficiency design strategy categories, device monitoring may provide the user information about operational concerns with impact on energy use such as improperly sealed doors, low airflow, and high cabinet temperatures due to blocked or inadequate ventilation. Additionally, low refrigerant charge or increasing electrical load due to compressor or motor drive failure may be detectable and can have an impact on energy usage. In most of the stated cases, the prevention of low frequency, high loss events are the major focus. Additionally, identification of malfunction conditions that lead to extended wasteful conditions. In addition to direct modes of action, indirect energy savings can be potentially provided by allowing users to know the contents of the refrigerator without needing to open the door to visually check. Such features have the potential for energy reduction, but careful evaluation of real-world performance is required to truly assess the energy impact of such features.

As with many connected devices, the implemented connectivity in many current "smart refrigerator" designs connectivity enables both convenience and energy focused features. Except for lack of maintenance and egregious energy-costly acts (such as leaving the door open for extended periods or opening them many times), manageable user behavior does not play a substantial role in waste as a mode of savings to address. Hence, most energy efficiency strategies are linked to device operation largely away from user control. The exception to this is preventing wasteful usage such as overzealous chill setpoints or engaging a vacation mode (if available) to reduce the operation of defrosting and anti-sweating mechanisms when doors will remain closed for an extended period.

ENERGY STAR® provides category guidance under the 2013 ENERGY STAR Residential Refrigerators and Freezers Product Specification (Version 5.0), within this a first set of optional "connected" criteria for this product category (Snaith, 2016; U.S. Environmental Protection Agency, 2013). Traditionally, domestic refrigerators were not considered for time of use and demand response strategies due to the tight link between health and safety and limited potential control through power-cut strategies. The inclusion of connectivity features along with increasingly sophisticated onboard electronics addresses some of these prior concerns and allows viable control strategies to be used. Despite the added controllability, aspects of this device inherently limit the range of modes to reduce or shift energy consumption. Limited modes of savings are possible for this device category and typically are focused on managing the relate to anti-sweat heaters / defrost cycle capabilities as well as ice making. For household refrigerators and freezers, the common modes of waste are presented in Table 15. The current ENERGY STAR specification testing does not evaluate capability for TOU, yet management of onboard resources to delay unnecessary operations is functionally possible. Conceptually the energy management capabilities of a smart-connected refrigerator can fall into several specific feature classes (see Table 15).

TABLE 15: LIST OF ENERGY USE SOURCE MECHANISM AND SPECIFIC TARGETING STRATEGIES FOR ENERGY EFFICIENCY, TIME OF USE, AND DEMAND RESPONSE

Energy Use Source	EE Mitigation Focus Points	TOU Management Focus Points	DR Management Focus Points
Compressor cyclic average load	Internal device improvement (reduce cabinet heat loss, more efficient cycling, refrigerant strategies, efficient electrical supply strategy- e.g. variable frequency drive)	Pre-cooling of freezer and internal temperature management to reduce total load during peak periods.	Delay compressor operation at short-term critical DR event. In some cases where variable speed drives are in use, lower functional loads for longer periods reduce total peak consumption and may be a viable future strategy to reduce instantaneous power consumption at the expense of lower efficiency and longer cycle time.
Anti-sweat / Defrost Cycle	Optimization of cycle operation based on sensing and feedback	Timing cycles where possible to operate out of peak periods without impacting user experience	Delay operation for potentially extended DR event.
Ice Making	Efficient electronic times and drive motors/solenoids. Optimizing schedule to match peak efficiency of cooling for loading given other known cooling operational parameters.	Optimization of generation of ice to take into account to delay ice generation if remaining amount will sustain through peak load period.	Delay operation for potentially extended DR event.

The major target of the ENERGY STAR category is demand response for this product category. In 2010, the Association of Home Appliance Manufacturers (AHAM) with the US Department of Energy proposed a guideline to better address how demand response (DR) can be applied to refrigerators and other household "smart appliances" (Association of Home Appliance Manufacturers, 2011; U.S. Environmental Protection Agency, 2011). A 5% energy efficiency allowance was proposed to offset connected refrigerators and freezers with smart grid functionality to help develop market share. A concern was raised by California's IOUs in an August 2011 joint statement to the U.S. Environmental Protection Agency that the 5% consumption allowance traded energy efficiency for DR functionality leading to concerns meeting legislated climate goals with an uncertain benefit to DR (BSH Home Appliances Corporation, 2011; Pacific Gas & Electric Company, San Diego Gas & Electric, Southern California Gas Company, & Southern California Edison, 2011). This allowance would also offset additional energy used by connected features to manage energy use. The specific DR benefit is debated. Pacific Northwest National Laboratory provided a cost-benefit analysis for near-future implementation of connected home appliances with 50% of customers able to receive and act upon grid signals leading to a 90% curtailment for spinning reserves and 50% delay load with an event occurring at least once a day for 261 days of the year (Sastry, Pratt, Srivastava, & Li, 2010). These values are aggressive, and they represent a proposed *pessimistic* implementation schedule. To illustrate the gap between this projection and current status, in 2013, PG&E's SmartRate residential DR program topped 100,000 participants with an average of 12% billing total energy cost saved (Marshall, 2013) This is only 2.2% of PG&E's total 4.6 million residential customer base. The average load reduction on "Smart Days" for 2012 was 14% with not more than 15 event days called for this year. (Marshall, 2013). Clearly more work is required to boost DR implementation to these projected levels and demonstrate the capacity of DR in this product category.

Two specific types of DR events are under consideration for response from this product category (See Table 16). In the first type of response, a short term response referred to as "spinning reserve" (Mitchell et al., 2014). This event is typically in response to a substantial, short term events and produces large savings over the short period of operation by substantially adjusting both cooling parameters and disabling accessory operation. The second type of response is referred to as "delayed load" events. As compared to spinning load events, delayed load events do not have effect on refrigeration and only affect operation of accessories. automated demand response operation by use of Temporary Appliance Load Reduction (TALR) signal is consistent with "spinning reserve" (ENERGY STAR, 2013b).

Sastry et al. (2010) provide calculation base lines to assess the impact of connected features on DR and energy management to estimate feature savings potential. The used energy for defrost and ice making amounts to 134 kWh/year, or about 30% of average consumption of 450 kWh/year for devices in this category (Sastry et al., 2010). Of this, 5.5kWh for refrigerators and 5.7 kWh for freezers is estimated to be peak period load, such that actual load shifting only will contribute 4% of total load due to these features shifted. These findings were backed up by Energy Star's reported test findings where 13% average power reduction occurred during events for the delayed load event (ENERGY STAR, 2012). When a spinning load event was evaluated a substantial amount of energy use was deferred by effectively halting all major energy use functions of the refrigerator Considering the period may or may not occur when the compressor would have otherwise been running, the average is over 50% energy reduction. This testing did not include the impact of user override which is an option. The impact of TOU can be considered from these factors. Assuming a peak of 4 hours from 4 to 8 PM, a <12% average power reduction can be possible during this period by careful modulation of accessory use during this period as some user override is assume. For energy savings, feedback is expected to provide 3-6% energy savings due to behavioral feedback of connected interfaces to influence user for this product category. Details for the operation of more advanced potential features such as intelligent diagnostics is largely uncharacterized.

TABLE 16: DEMAND RESPONSE TYPE AND CORRESPONDING DEVICE ACTION

Considered DR Type	Description	Reaction
Spinning Reserve events	Substantial event requiring major short-term energy reduction (up to 10 minutes)	Accessories are disabled for a period maximum of 10 minutes and setpoints are adjusted temporarily effectively restricting load to maximum of 50% of average energy consumption across a 24-hour period
Delay load events	Longer term period requiring load reduction (10 minutes to 4 hours.	Accessories such as ice makers are stopped and anti-sweat cycles and defrost cycles are shifted beyond the event period.

CONNECTED FEATURE CLASSIFICATION

Global Smart Refrigerator Market is currently growing and is valued at USD 322.41 Million in 2018 and expected to reach USD 1008.91 Million by 2025 with the compound annual growth rate (CAGR) of 17.70% over the forecast period (MarketWatch, 2019c).
The overall US refrigerator market is 9.4 billion with an annual growth rate of 0.8% CAGR (2019-2023) (Statista, 2020). Of this, a major growing configuration is the French door style with opening double doors for the refrigerator compartment and a single drawer style freezer below. This market is growing at a CAGR of roughly 5.9% worldwide over the next 5 years (MarketWatch, 2019a). Although freezer on top configuration is the most common, this category is growing and of importance as this is a major common configuration for current commercially available residential refrigerators. The majority of these devices have through-door service for ice and water dispensing. As the energy model provided by ENERGY STAR and adopted (through modification of DEER calculations) for SCE's white paper is dependent on specific device configuration, the French door style will be used as a base reference for discussion. This is represented by the following expression:

EQUATION 8: FEDERAL STANDARDS FOR ENERGY STAR EFFICIENT REFRIGERATOR (FRENCH DOOR CONFIGURATION)

$$AEC = 8.85*(AV) + 458.3 \text{ where } AV = 18 \text{ cuft}$$

Where: AEC = Annual energy consumption
AV= Volume
Cuft = Cubic ft.

Features of operation enabled by connectivity are presented in Table 17.

TABLE 17: CURRENT PRODUCT CATEGORY RELEVANT CONNECTIVITY FEATURES FOR REFRIGERATORS

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
1a- Real Time Monitoring	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Reporting of energy usage over time to the user directly via a manufacturer supplied app or corresponding ecosystem app or potentially through a home energy management system. May provide energy usage information as well as number of door actuations or other operational statistics.	Loss of alerts to user. Entire feature unavailable for energy management relevant operation.
1b- Connected Performance notifications	1	Category potential value added feature, implementation availability unknown	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Potential to provide alerts to users regarding device performance leveraging connected solution to provide advanced diagnostics and alerts to manage device performance. Note: This feature may not be present and may be partially implemented.	If onboard management is available, degradation to type 0b and interfacing via an onboard display.
1d- Manual demand response notifications	1	Category potential value added feature, implementation availability unknown. Much of this functionality is superseded by ADR (category 3) functionality with user opt out options.	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from ZigBee interfacing from the home smart meter	Demand response targeted, potential TOU targeting	Ability to provide demand response notification to the user for specific manual action. May be used to alert user about potential scheduling for TOU savings potentials.	No alerts provided to user for users. Alerts may be on the device itself, over an interfacing app.

Table 17 *continued*

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
4a- Cloud controlled operational tuning	1	Category potential value added feature, implementation availability unknown	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from ZigBee interfacing from the home smart meter	EE and TOU potentially targeted	Ability to provide precise tuning of ice making, defrost and temperature cycling for energy savings and peak period reduction. May involve user awareness of operation, but operation largely automatic	Major operation may be lost except for cached control elements. Operation may or may not be degraded to 0b connectivity class with loss of connectivity.
2- Real-time monitoring with control (supersedes 1a when reported information is available with relevant control)	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Primarily EE targeted	Ability to manually change operational modes remotely including initiation of vacation settings.	Inability to adjust operational parameters. Loss of reporting and control of features remotely.
3- Automated demand response control	3	Category key feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from zigbee interfacing from the home smart meter	Primarily DR targeted	Automated demand response control capability with potential user override potentially with the TALR signal response and action capability.	Inability to receive and act on ADR signals.

[1] Feature status: 1= Feature uncommon, in development, or deployment status unknown, 2=Common feature in device category, 3= Key category feature required for ENERGY STAR compliance for Connected Refrigerators/Freezers (v. 5).

Clearly the key features of operation are Category 3 and Category 1A. Category 2 also can be considered, yet the impact of adjustability is limited for refrigerators from the user's perspective. Considering Category 1A, from the previously mentioned PNNL study, 3 to 6% energy usage reduction is possible due to behavior feedback (Sastry et al., 2010). As this value exists within the range of savings possible from home energy management systems for feedback, this seems possible, but the number of decisions that can lead to energy savings on the part of the user is so much greater when it comes to a household of loads that can have their operation adjusted versus a device with inherently little user controllability. With a base load of 617 kWh (see Equation 8), this would correspond to a savings of 18.51 kWh to 37.02 kWh reduction in energy usage annually due to reporting feedback. A value of 450 was also presented in the PNNL model, a more generous 617 kWh that is consistent with an average size for the specified configuration is used.

Considering the DR aspect of IDSM, the range of 12% to >50% period load reduction estimate is possible with varying levels of response to DR signals. Spinning load DR capability is limited in total time duration to 10 minutes per period. While the load shedding is deep, the period is small: for a single 10-minute event at 50% reduction, this corresponds to a reduction of 5.87 Wh per period (assuming an average 1.69 kWh/day load corresponding to 617 kWh per year). For 261 events in a year this corresponds to 1.53 kWh. Calculating the delayed energy can be modeled similarly. Similarly, for a single day, a 4-hour period of 12% reduction results in 50.7 Wh daily reduction. Alternatively, calculated, the power consumption of 0.367 kWh corresponds directly to the operation of the defrost and icemaker functions. Elimination of 4 hours (the maximum value) corresponds in 61.18 Wh reduction for a single event per day. Both evaluation methodologies arrive at a similar value. For a modeled 261 events for a year, this corresponds to 15.97 kWh annually. This approach models DR savings as kWh per period versus watts of load shed at a gross level by estimating energy used over a period due to an event. The actual wattage reduction depends on the features of a specific device and the probability these features would have otherwise been active without the event. To approach this problem, Mitchell et al. (2014) presents values for two refrigerators in operation. Refrigerator B consumed ~80 W for cooling function with ice production during an extended period. In contrast, Refrigerator A used a variable speed compressor and a multi-route evaporator leading to a variable range of 55-70 W average. The authors report that Refrigerator A can reduce to 15 W from 105 W (90 W reduction) if the compressor was on when the signal was received. For delay load events, only about 10 W was possible. Refrigerator A was reported to provide power reductions of 70-80 W for spinning load critical events and was noted to respond inconsistently with a reduction of about 20W from normal operating load for delay events, albeit with inconsistent delays for action. These values are summarized in Table 18.

TABLE 18: SUMMARY OF LOAD SHEDDING POTENTIALS

Refrigerator	Delayed Load Shedding Potential (max 4 hours)	Percentage Load reduction to 2009 Baseline average (319W)	Spinning Load Shedding Potential (max 10 min)	Percentage Load reduction to 2009 Baseline average (319W)
A	20W	6.27%	55-70	17.24%-21.9%
B	10W	3.23%	~80W	25.08%

Source: Mitchell et al. (2014)

Comparing these numbers to PG&E's 2012 load reduction numbers (Marshall, 2013), it is clear that the load shed is less than 10% of the average total household load that was previously able to be shed for extended periods. For short term periods, the value is substantially higher with 17.24% to 25.08% of this load able to be reduced, yet only for a maximum of a 10-minute period.

Program and Measure Features

Potential program and measure features for refrigerators were obtained through a work paper published by SCE in 2016 titled "Smart Connected Refrigerators" (Snaith, 2016). This study conducted a comprehensive review of all ENERGY STAR qualified refrigerators available on the market. In comparing connected efficient refrigerators and non-connected products, the utility found that, due to extra available features, connected refrigerators cost $300 more than non-connected refrigerators on average. This raised the base measure rate of the product. As high efficiency refrigerators in the tested French door configuration cost in the range of $1,000-1,200, CalPlug has assigned a base cost of between $1,300 -$1,500 for a connected refrigerator. Applying the suggested $72.90 for an hour and 30 minutes of labor as provided by SCE's measure guidelines, CalPlug estimates the measure cost at between $1,373-1,573.

Although the participant incentive dollar amount was not included in the consulted work paper, CalPlug estimated a range of between $50-150 per connected refrigerator. Other states have current incentive programs aimed at ENERGY STAR refrigerators (although connectivity is not stipulated) such as the $50-75 rebates offered for various tiers of qualifying products in New Jersey (New Jersey's Clean Energy Program, 2020), and a $100 rebate offered in Mississippi (Entergy, 2020). Based on these incentives, a reasonable range estimate for smart connected refrigerators between $50-150 aligns with other state programs and provides a potential overhead for the extra expense of smart features.

As SCE's study did not implement a full IDSM program, CalPlug assigned standard IOU estimates for the unit installed base (UIB) of between 5,000-15,000. The measure lifetime was considered at between 1-14 years, which considers the full range of the product EUL. In the next section, TRC values considering these measure features are presented and evaluated.

TRC Ranges

The following values were used for the initial calculations for connected refrigerators based on the testing and research done on the device (see Table 19).

TABLE 19: SUMMARY OF TRC CALCULATOR INPUTS FOR CONNECTED REFRIGERATORS

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	18.51-37.02
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	$1,373-1,573
		Participant Incentive ($)	$50-150
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
		Measure Lifetime (years)	14
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

TABLE 20: INPUTS AND RESULTS FOR MAXIMUM TRC VALUE

Unit Yearly Energy Net Savings (kWh/year)	Unit Installed Base (UIB)	Measure Cost ($)	Participant Incentive ($)	Measure Lifetime (years)	BENEFITS	COSTS	TRC
37	15000	1373	150	14	83250	1517920	0.055

The maximum TRC value from these parameters was an extremely low, namely 0.05, which resulted from year 3 of the results at 15000 devices, measure cost of $1373, measure lifetime of 14 years and participant incentive of $150 (see Table 20). The full results from the measure cost of $1373, measure lifetime of 14 years and unit yearly energy net savings of 37 kWh/year is graphed below Figure 16. As illustrated in the graph, none of these results are close to the TRC of 1 (the breakeven point for cost and benefits of the measure). These low TRC values are due to the low unit yearly energy net savings that are associated with the smart refrigerator, in order to yield larger TRC values the unit yearly energy net savings needs to be much larger. With the results from the initial test not yielding promising TRC results, CalPlug ran the calculation on a more theoretical larger range of values to find the bounds in order for the TRC to be greater than one, given the Unit Energy Net Savings increasing to 300 kWh/year estimated from potential market trends and the incentive range was increased to $300, the following results were found.

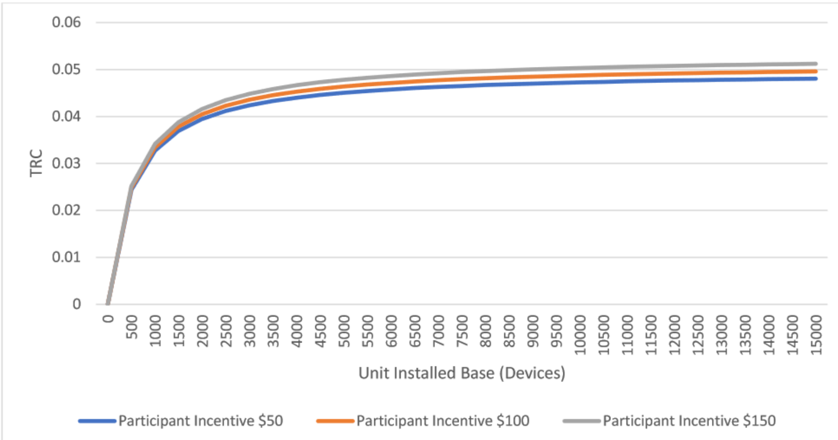


FIGURE 16: EXTENDED RANGE CONNECTED REFRIGERATOR TRC RESULTS WITH MEASURE LIFETIME OF 14 YEARS

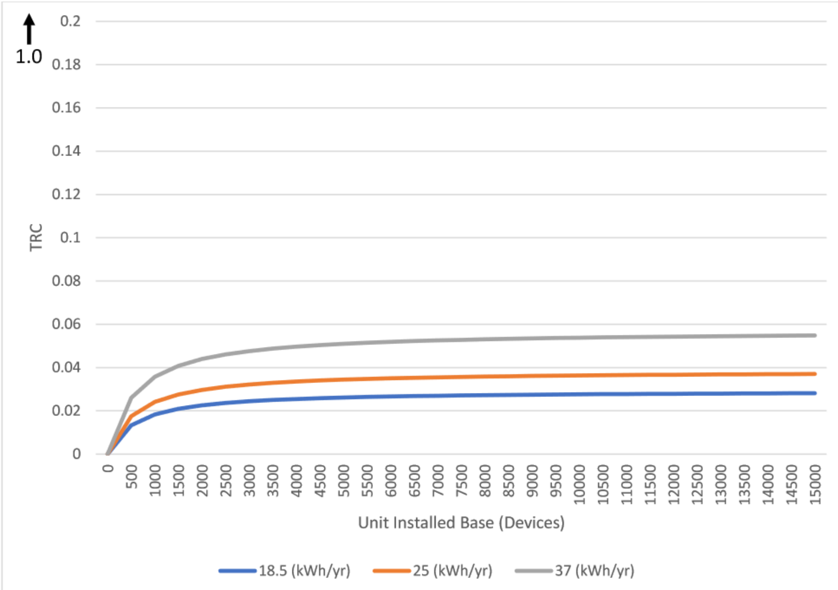


FIGURE 17: CONNECTED REFRIGERATOR TRC RESULTS FOR MEASURE LIFETIME OF 14 YEARS

Given the increase in range of the variable values written out above, 0.5 was the maximum TRC potential value which yielded from year 3 of the results at 15000 devices, measure cost of $1373, measure lifetime of 14 years and participant incentive of $300. While the TRC maximum increased a lot relative to the previous maximum, 0.5 TRC values is still not yielding a break-even potential program.

All that being said, CalPlug also looked at a smaller potential program of a maximum 5,000 unit installed base over three years, the results, as expected, are even lower than the larger program, see Table 21 and below for parameters and results.

TABLE 21: TRC EXTENDED RANGE RESULTS CONNECTED REFRIGERATORS

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	37.02
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-1000
			Year 2: 1000-2500
			Year 3: 2500-5000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	$1,373
		Participant Incentive ($)	$150
		Unit Installed Base (UIB) by Year	Year 1: 0-1000
			Year 2: 1000-2500
			Year 3: 2500-5000
		Measure Lifetime (years)	14
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

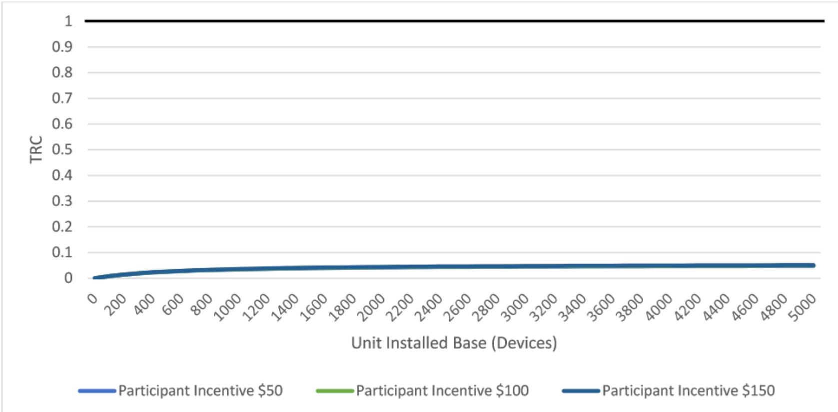


FIGURE 18: ≤ 5000 INSTALLED UNITS FOR CONNECTED REFRIGERATORS TRC RESULTS WITH MEASURE LIFETIME OF 14 YEARS

The maximum in this 5,000 unit installed base program example is, like the 15,000 unit installed base program, is extremely small at 0.05 TRC value.
All this demonstrating that low Unit Energy Net Savings for these high cost devices, such as smart connected refrigerators, with minimal incentives, are not yielding cost effective programs.

ANALYSIS OF DEVICE

Connected refrigerators were investigated extensively circa 2011 for their potential as a target for connected IDSM energy management. Program effectiveness requires sufficient market uptake of sufficiently savings devices. The energy management capability for EE that is enabled for connectivity at the present is limited to user alerts for consumption. This 3-6% savings is small considering other targets available in the home. Users have limited action they can provide in response to these alerts to reduce consumption. Other more advanced modes of energy management presented in this section are not at the potential level to provide extensive feedback for their effect on energy management. Vacation modes and other settings that may be enabled by users could provide savings during these periods, yet the effectiveness of these approaches depends on how frequently the user actually uses them (how often they are away for extended periods). The effectiveness of these features should be further characterized.

The effect of connectivity on DR is largely a function of either the immediate load shed, or the average load reduced during the active period averaged during the period or averaged over a 24-hour period. The period averaging shows the savings for short term events is substantial yet with a limited period. When considering with shed peak load values (presented in watts), similar results are seen. For short term, high level reduction an assumption is made that operation of cooling systems would have otherwise occurred during this period consistent with previous operation – this can be highly variable and situationally dependent. A true field trial averaging events out over many subjects can help to clarify the real effects. Additionally, the use of user override was not evaluated and considered to be 0%. The real impact is likely higher, but possibly not substantially higher. The changes occurring for a DR event in all cases presented are largely not apparent but to the most observant user.

Considering relatively low potential for extra energy savings through connected features, TRC estimates for smart refrigerator IDSM programs are less promising than anticipated. The addition of a relatively high measure cost further complicates saving potentials, and the estimated unit installed base and measure lifetime are insufficient to produce cost-effective results. The purpose of studying connected refrigerators as a deep dive despite poor TRC estimates is because the positive market trend of these devices and status as a major appliance and high consumer of electricity makes an in-depth analysis salient. Further development of features and functionality geared toward energy savings may make connected refrigerators more cost effective as IDSM program targets in the future.

SMART CONNECTED WASHING MACHINES

BACKGROUND

Automatic washing machines were first patented and sold in the U.S. in 1937. Since then, there has been a steady increase of technological innovations to improve the efficiency and cost effectiveness of home clothes washers. Unlike refrigerators, which need to be on the household premises to be useful, clothes washing machines are accessible outside of the home, either through shared laundry facilities in apartment buildings, or off-site at public laundromats. Thus, washing machines, as well as clothes dryers, have been historically less prevalent in individual homes compared to other major appliances. However, in recent decades, trends including cost reduction measures taken by manufacturers and an increasing desire among consumers for higher convenience standards have been largely successful in increasing the installed base rate for washing machines. The nationwide 2016 American Community Survey conducted by the U.S. Census Bureau estimated that 85% of American households have a clothes washer in-unit (U.S. Census Bureau, 2016). A further analysis conducted by the Association of Home Appliance Manufacturers (2019) estimated a total shipment of nearly 11 million units of new washing machines in the U.S. in 2019. Moreover, residential washers are currently on an upwards trend: in the past five years (since 2014), sales in the U.S. have grown at an average rate of about 4.8% per year although the 2019-2023 compound annual growth rate estimation is more modest, at 1.3% per annum growth.

Compared to other large household appliances, clothes washers are significantly less energy intensive. Washing machines in the U.S. are generally rated in the range of 400 to 1300 W, converting into 118 – 383.5 kWh/year, assuming 295 wash cycles per year, which is the average residential usage as approved by DOE and ENERGY STAR test procedures, and as adopted in the SCE work paper The PNNL cost benefit analysis on connected appliances confirms this range, suggesting an average of 0.71 kWh/cycle, or 209 kWh/year (Sastry et al., 2010). To put this usage into perspective, an average clothes dryer consumes between 750-800 kWh/year) (U.S. Energy Information Administration, 2015a). Nevertheless, optimizing clothes washer efficiency has been a challenge in the U.S., due to specific needs and expectations of the American consumer compared to counterparts in other industrialized countries. This challenge is mostly attributable to the noncompliance of American households in switching to front-loading washers.

There are two main types of clothes washers: top-loading and front-loading. Top-loading (or v-axis) machines feature a tub with a central vertical axis agitator that fills with water and rotates the detergent and clothes items before the machine drains completely and is filled up again with rinse water. The cost difference of a top load washer versus a front load washer is substantial. This is approximately between $300 and $500. The cost of a front load washer is between $600 and $1200 for an equivalent capacity and quality front loader. Considering a top load baseline energy usage of 400 kWh, compared to a front loading machine 150kWh V-axis machines use about 40 gal. of water per load (Constellation, 2017). Alternatively, front-loading washers (or h-axis) machines feature a drum that spins the load on the horizontal axis using only a small amount of water to tumble the laundry and using intermittent sprays of water to rinse. H-axis machines are more energy and water efficient than top-loading models, and use about 20-25 gal. of water per load, or slightly more than half that of v-axis machines. H-axis machines spin faster than agitator models, averaging about 1300 RPM, in comparison to only 700-900 RPM for v-axis machines, which further translates into more efficient rinsing and drying. The lack of an agitator in h-axis machines also reduces the noise pollution from the device (Golden, Subramanian, Irizarri, White, & Meier, 2010; Hustvedt, Ahn, & Emmel, 2013). An early study of clothes washing machine efficiency in the U.S. found that h-axis washers could save 38% of water usage and 58% of energy usage over comparable v-axis models (Tomlinson & Rizy, 1998). Tests performed by Reviewed.com confirm this value with an average of 50% reduction in energy use when front loaders are paired with electric hot water heaters (Wroclawski, 2018). The results from this study were partially responsible for the renewed interest and incentivization from the U.S. Department of Energy (DOE) towards driving a market share increase of front-loading machines (Golden et al., 2010).

While European and Japanese markets were early adapters of the more efficient front-loading models, Americans have historically preferred top-loading machines for several reasons. The relatively compact size of traditional h-axis washers was dismissed by American consumers as inconvenient and less suitable for washing larger loads of laundry. Additionally, while the small spaces typical of European and Japanese homes favor smaller, less noisy appliances, the comparatively large size of the average North American home does not impose the same restrictions on appliance size, and noise pollution can be more easily diffused without causing undue distraction or irritation. Finally, Americans have traditionally resisted h-axis machines due to other inconvenience factors, including bodily strain that may occur when bending over to load laundry, inability to add more clothes to the wash after the door is shut and locked into place, and fears of water spillage when opening the door (Golden et al., 2010; Hustvedt et al., 2013). With these concerns in mind, front-loading washers were re-engineered for the American market in the late 1990s by increasing the average tub size and widening doors of new models. This strategy, in addition to better public education about the energy and water savings potential of front-loading washers, has led to an increasing market share for h-axis models in the U.S. However, because some early re-engineered models were poorly designed, and due to added expense of new generation front-loading machines, market transformation has been slow, and, as of 2019, only 25% of U.S. home washing machines are of the front-loading type. Although some of the top-loading machines currently on the market are new high-efficiency models without agitators that eliminate much of the excess water and energy waste of typical v-axis designs, these represent a relatively small population of high-efficiency models as approved by the ENERGY STAR Program (about 26%) (J. Wang, 2014).

FEATURES AND FUNCTIONALITY

Most of the energy used in washing machines is for heating water. This accounts for about 90% of total energy use (Janeway, 2016). Front-loading washers in the U.S. have an internal heater that is used to maintain the temperature of water drawn from an external water heater (this is the main design difference from European h-axis models, which use internal heaters to actively heat ambient temperature water drawn from the main water supply). Given that energy usage is overwhelmingly a function of the water volume consumed in washing machines, it is not surprising that models using less water also use less energy. Despite this, there are important behavioral aspects to consider for energy consumption of residential washing machines. For instance, energy usage can be vastly decreased by selecting the cold wash option, thus eliminating energy draw that would be used to heat water.

The action of the machine energy consumption is spread between power supplies, pumps, electromechanical actuators, drive motors, and heaters. In operation, the total quantity of water that must be heated and transported holds a substantial energy signature such that reduction of total water volume leads to direct energy use reduction. The use of inverter and variable-frequency drive (VFD) technology especially in direct drive configurations allows efficient drive as well as flexibility for specialized motion, leading to potentially more effective cycle designs with less overall energy use.

As we have established that water heating is the predominate determining factor for washing machine energy usage and accounts for 90% of device energy consumption, this suggests that almost all energy savings potential comes from physical design features that reduce water usage and from the selection of cold water wash cycles. The length and the specific programs of cycles matter to best match required cleaning with energy usage as well as appropriate water level for a given load size. Some machines will use auto sensing approaches typically based on load weight to match required water compared to load size (Janeway, 2017). The tradeoff for energy usage per cycle is not always directly apparent. For example, the use of delicates cycle, where appropriate, reduces the total wash length in most machines with less total agitation action and no final spin cycle. The result is often comparably lower energy use in the machine itself but a larger burden for any following drying process. The use of the permanent-press cycle versus normal or heavy wash where appropriate can lead to reduced energy usage from the spin cycle but may overall consume more energy for total process action by requiring warm water. User education into effective machine use and judicious auto selection of defaults can help users make energy efficient choices. So far, functions are largely independent of the connectivity features of smart washing machines. While real time monitoring and user feedback features of smart washers may help consumers to make more informed choices about the cycle and temperature selections that conserve the most energy, it is unclear how much added savings could be achieved through energy usage notifications and tips. Further notification of machine performance and diagnostic functions may indirectly contribute to energy savings by encouraging customers to keep their machines in optimal operating condition, however these functions have not been thoroughly field-tested. Accordingly, a mechanism of action for connected solutions to reduce energy consumption is largely reducing over utilization beyond the typical actions of the user and the onboard automation. The adjustment space is small for this category with the perspective of the user including the following:

- Avoid overloaded or inefficient operation leading to re-washing
- Selection of appropriate load size (and accordingly) water level
- Selection of appropriate load temperature
- Selection of appropriate load cycle

Other than providing feedback to the user and potentially overriding action, there is little action that can be leveraged by provided connected intelligence for energy savings.

With perspective to demand management, cycle lockout and cycle pause or expedite actions have been demonstrated (Sparn, Jin, & Earle, 2013). An energy penalty is often paid for cycle pausing due to the need for water reheating and restarting (repeating) cycle segments. Sparn et al. (2013) reported on a user override approach that is used to expedite cycle operation using cold water only and a high rate of spin. For this cycle the energy use is actually increased against a cold water cycle baseline but leads to dryer clothes out of the washer that reduce total drying operational time (Sparn et al., 2013). Planning delays in running major appliances is a common time of use strategy, yet the capability is largely absent in the marketplace for scheduling and utility-based alerts for planning machine usage. User alerts via phone or a simple indicator or alert to bring awareness to users via the back-end utility communication is likely a first large scale implementation step.

CONNECTED FEATURES CLASSIFICATION

For energy efficiency purposes, savings for washing machines were estimated based on work papers which investigated the performance potential of ENERGY STAR clothes washers intended for residential settings (Huang, 2017; J. Wang, 2014). This study included parameters for both top-loading and front-loading models and evaluated appliances with both gas and electric configurations. The study compiled measures from the following appliance rating agencies: ESME, CEE, and ENERGY STAR. For the purpose of this report, we will assume a front-loading electric model between 3.3 and 4.2 Cu. ft, as this set of specifications most closely resembles the current smart connected washing machines on the market. These calculations assume 295 wash cycles per year, which is the average residential usage as approved by DOE and ENERGY STAR test procedures, and as adopted in the SCE work paper. The annual energy savings for high efficiency washing machines considering the selected model features are presented in the following table (Table 22):

TABLE 22: ANNUAL ENERGY SAVINGS FOR HIGH-EFFICIENCY WASHING MACHINES

AGENCY	ANNUAL ENERGY SAVINGS (kWh/YEAR)
ESME	64.9
CEE	85.55
ENERGY STAR	153.4

The total savings can be further broken down to attribute a potential savings range for connectivity features. The features most relevant for energy efficiency for washing machines are classified as 1a, 1b, and 2 in CalPlug's connectivity feature guide. These generally include real time monitoring to provide feedback to the customer via mobile app, alerting customers to schedule maintenance and repairs, and allowing users to remotely start and stop the device as well as select wash cycle settings while not at home. As previously discussed, Sastry et al. (2010) estimated a 3-6% savings potential due to consumer feedback connectivity features. When applied to the overall savings estimates listed in the table above, EE savings due to connectivity may be conservatively estimated at between 1.95-4.6 kWh/year, while a more liberal estimate would produce a range of 3.9-9.2 kWh/year.

Smart connected washing machines are increasingly seen as an opportunity for demand response (DR) and time of use (TOU) events. As previously discussed regarding smart refrigerators, DR capability has been identified as a priority for new smart washing machines by the DOE and ENERGY STAR program. Under current test procedures and standards, smart washing machines must feature load shifting and load shedding capability in order to qualify as a connected device approved by ENERGY STAR and eligible for the 5% connectivity credit (ENERGY STAR, 2018). Per CalPlug's connectivity classification system, ENERGY STAR's requirements correspond to Category 3 as the key feature for smart washers, specifying automated demand response (ADR) functionality. While Category 1d also addresses DR initiatives, this category does not permit automated control of DR command and is more suitable to TOU.

TABLE 23: PRODUCT CATEGORY RELEVANT CONNECTIVITY FEATURES FOR WASHING MACHINES

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
1a- Real Time Monitoring	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features; sometimes uses Near Field Communication	Largely EE targeted	Reporting of energy usage over time to the user directly via a manufacturer supplied app or corresponding ecosystem app; notifies users immediately when washing cycle is finished (for convenience, not EE).	Loss of alerts to user. Entire feature unavailable for energy management relevant operation.
1b-Connected Performance notifications	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features; sometimes uses Near Field Communication	Largely EE targeted	Provides alerts to users for scheduled maintenance; uses sensors to identify functionality problems and alerts user to schedule repairs. Sensors detect level of soil and load size to calculate detergent and water needs.	If onboard management is available, degradation to type 0b and interfacing via an onboard display.
1d- Manual demand response notifications	1	Possible based on device features/functionality, but ADR (cat. 3) is prioritized	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from ZigBee interfacing from the home smart meter	Demand response targeted, potential TOU targeting.	Ability to provide demand response notification to the user for specific manual action. May be used to alert user about potential scheduling for TOU savings potentials.	No alerts provided to user for users. Alerts may be on the device itself, or over an interfacing app.

Table 23 *continued*

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
2- Real-time monitoring with control (supersedes 1a when reported information is available with relevant control)	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features or through mobile device connectivity outside of home (3G, 4G, LTE)	Primarily EE targeted	Ability to change operational modes/select cycles remotely via mobile app; allows user to start and stop loads while not at home	Inability to adjust operational parameters. Loss of reporting and control of features remotely.
3- Automated demand response control	3	Default settings to enable 4-hour delay load capability and temporary appliance load reduction capability of 10 minutes	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from Zigbee interfacing from the home smart meter	Primarily DR targeted	Automated demand response control capability with user override feature	Inability to receive and act on ADR signals.
4a- Cloud controlled operational tuning	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and communication via smart speaker (typically Alexa, Google Assistant, Nest, or Android); May have supplemental connectivity to Smart Energy (SE) network provided from Zigbee interfacing from the home smart meter	EE and TOU potentially targeted	When connected to energy monitoring device, many models can provide the user with information regarding energy consumption, and can instruct/program machine to automatically run during off-peak times Smart speaker connectivity enables voice command for selecting/starting/ stopping cycles.	Major operation may be lost except for cached control elements. Operation may or may not be degraded to 0b connectivity class with loss of connectivity.

[1] Feature status: 1= Feature uncommon, in development, or deployment status unknown, 2=Common feature in device category, 3= Key category feature required for ENERGY STAR compliance for Connected Washing Machine.

There are several ways that smart washing machines could potentially respond to ADR signals that are specifically identified in the ENERGY STAR evaluation criteria. These include manufacturer default settings that allow up to 4 hours in load delay capability (load shift), and the ability for temporary load reduction up to 10 minutes per event (load shed). As in the case of connected refrigerators, the PNNL report also estimated a range of 50% - 90% for DR savings for smart washing machines. The 12% savings rate that PG&E found in their field study may also be applied, establishing a possible range of 12% to >50% energy savings for the DR function of connected washing machines. Assuming the baseline of 0.71 kWh/cycle (209 kWh/year) estimated by the PNNL report, and assuming a wash time of 60 minutes/cycle, the potential savings for 10-minute shed load event at 50% reduction would produce 5.92 Wh of savings for a washing machine in use at the time of the event. Assuming 261 events per year, the annual savings would total 1.55 kWh if the machine is in-use for 100% of the events. As this is unlikely, a more realistic savings may be about 0.39 kWh/year, assuming usage during 25% of events. For a load shift event of 4 hours, a 50% reduction results in a savings of about 59 Wh per event. Again assuming 261 events per year at 100% operation, the maximum savings would correspond to 15.4 kWh per year.

PROGRAM AND MEASURE FEATURES

Potential program and measure features for smart washing machines were obtained through series of IOU work papers from 2014-2015 (Huang, 2017; J. Wang, 2014). These papers considered data from ENERGY STAR, ESME and CEE to estimate program and measure ranges. The measure costs for eligible washing machines were between $625-748 based on the weighted averages determined by California IOUs.

Although the participant incentive dollar amount was not included in the consulted work papers, CalPlug estimated a range of between $85-155 per connected washing machine. Although no current state-wide incentive program is offered, the Southern California Metropolitan Water District currently offers $85 per high efficiency washing machine purchased (SoCal WaterSmart, 2020). Based on this incentive, a reasonable range estimate for smart connected washing machines between $85-155 aligns with other California programs and provides potential overhead for the extra expense of smart features.

CalPlug assigned standard IOU estimates for the unit installed base (UIB) of between 5,000-15,000. The measure lifetime was considered up to 12 years, which considers the full range of the product EUL. In the next section, TRC values considering these measure features are presented and evaluated.

TRC RANGES

The following values were used for the initial calculations for connected washing machines based on the testing and research done on the device (see Table 24).

Table 24: Summary of TRC Calculator Inputs for Connected Washing Machines

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	153
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	$625 (Energy Star); $748 (ESME)
		Participant Incentive ($)	$85-155
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
		Measure Lifetime (years)	10-12
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

The maximum TRC value from these parameters was 0.43, which resulted from year 3 of the results at 15000 devices, measure cost of $625, measure lifetime of 12 years and participant incentive of $155. The full results from the measure lifetime of 12 years is graphed below. As illustrated in the graph, none of these results are close to the TRC of 1 (the breakeven point for cost and benefits of the measure).

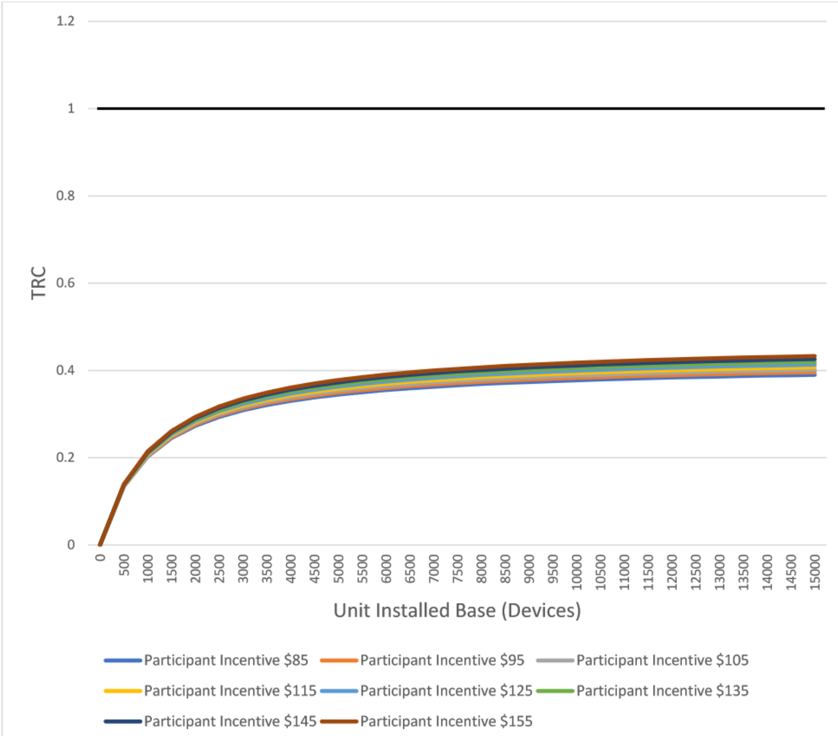


Figure 19: Connected Washing Machines TRC Results for Measure Lifetime of 12 years

With the results from the initial test not yielding promising TRC results, CalPlug ran the calculation on a more theoretical larger range of values to find the bounds in order for the TRC to be greater than one, given the Unit Energy Net Savings being 153 kWh/year. The follow ranges of the variables were calculated.

TABLE 25: SUMMARY OF EXTENDED RANGE TRC CALCULATOR INPUTS FOR CONNECTED WASHING MACHINES

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	153
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
			Year 4: 15500-20000
			Year 5: 20500-25000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	$625 (Energy Star)
		Participant Incentive ($)	$85-255
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
			Year 4: 15500-20000
			Year 5: 20500-25000
		Measure Lifetime (years)	11-15
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

While these ranges were already stretching beyond reasonable numbers to consider for a program, the results still did not yield any TRC values over 1, with the Unit Energy Net Savings at 153 kWh/year. The maximum TRC value was 0.62 in year 5 of the program with an incentive of $255 and measure lifetime of 15 years.

Seeing that that the large ranges of variables run with the Unit Energy Net Savings of 153 kWh/year were not resulting in any cost-effective results for the measure, CalPlug then tested an increase in the Unit Energy Net Savings in order to figure out what Unit Energy Net Savings would result in a cost-effective measure. By doubling (approximately) the Unit Energy Net savings to 300 kWh/year, then the results started showing the TRC values getting above one by the second and third year, but even these results are likely beyond reasonable values for the programs, i.e. there aren't likely going to be incentives that even go above $100-150 (the incentive value listed on the market was $85), but the lowest incentive seen going above 1 is $215 (also given the measure lifetime at 13).

This demonstrates that low Unit Energy Net Savings for these high-cost devices, such as washing machines, with minimal incentives, do not yield cost effective programs.

Alternatively, programs with Unit Installed Base of less than 5,000 are illustrated in Figure 20.

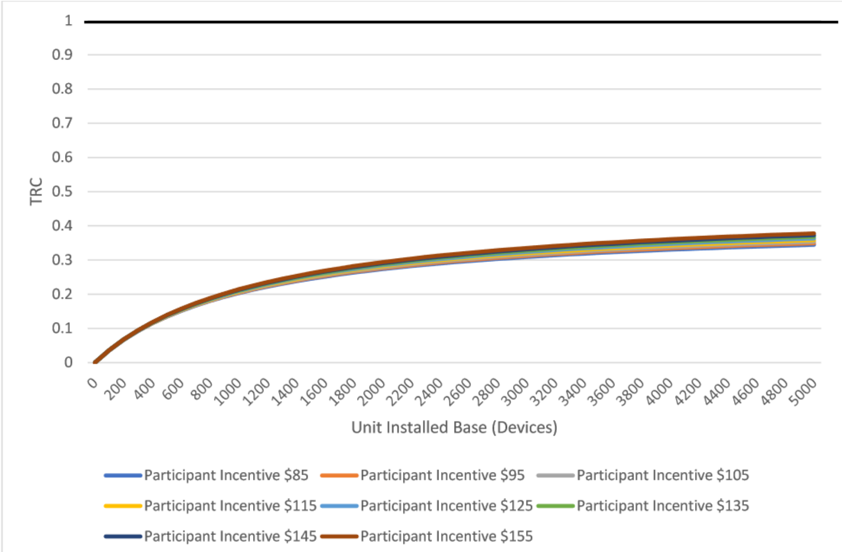


FIGURE 20: ≤ 5000 INSTALLED UNITS FOR CONNECTED WASHING MACHINE WITH MEASURE LIFETIME OF 13 YEARS

ANALYSIS OF DEVICE

The main energy savings potential for washing machines lies in the reduction of water heating and overall water consumption. High-efficiency products on the market have been shown to save more energy than non-high efficiency machines, due primarily to their design features requiring less water and energy use than traditional top-loading agitator models. Customers can save substantially on energy usage by simply using cold or warm water cycles as opposed to using hot water. These facts are generally well-known, and connectivity features are not required to encourage this behavior. A relatively small amount of savings may be attributed to connectivity features, in the range of 3-6%. These savings assume customer behaviors, such as positive response to utility or manufacturer issued advice for optimal machine operation as well as assuming substantial decision space for the customer to act upon alerts. Currently tightly connected sensor and affector control loops to reduce over processing that leverage connectivity are not available on current market products Potential linking of high efficiency heat pump water heaters with scheduled washes may be an approach that could be considered to reduce energy use in warm or hot water loads, but the effectiveness or practicality of this has not been assessed. This category does provide a good demand response target with multiple options and strategies for implementation considering both the energy usage of the device itself as well as process devices. Similarly, this category also lends itself to automated alerts that can empower users to start loads at times to reduce energy consumption. All points considered, connectivity features are typically used for convenience, rather than for direct energy savings. One of the most commonly cited benefits of smart washers advertised by manufacturers is the ability to notify users when the wash cycle is finished. While this serves as a convenient reminder and helps the customer to use time more effectively, these notifications do not reduce energy consumption. Similarly, the ability to start and stop cycles remotely does not affect overall energy usage.

While more apparent in modes of action than EE capabilities, DR capabilities of connected washing machines may have further impact on period peak reduction or period energy savings, but this is difficult to predict, and, even given the best-case scenario, the energy savings potential is likely very small at the individual level. This also assumes that periods of DR action would coincide with typical washing machine use periods. The limited nature of load shed events render energy savings difficult to accumulate based on coincidental frequency with current appliance use data available. Also, the possibility of manual override of DR signals could further curtail savings, although this is not modeled in this report. While DR savings have the potential to be non-negligible at the population level, it is not clear that these savings could be used to justify the extra expense of purchasing a smart washing machine for the individual user.

Considering relatively low potential for extra energy savings through connected features, TRC estimates for smart washing machine IDSM programs are less promising than anticipated. The addition of a relatively high measure cost further complicates saving potentials, and the estimated unit installed base and measure lifetime are insufficient to produce cost-effective results. The purpose of studying connected washing machines as a deep dive despite poor TRC estimates is that the positive market trend of connected washers and their status as a major appliance and high consumer of electricity makes an in-depth analysis salient. Further development of features and functionality geared toward energy savings may make connected washing machines more cost effective as IDSM program targets in the future.

Pool Pump

Background

Pool pumps are an essential part of pool maintenance critical to ensure basic health and safety standards. They are also one of the largest single energy consuming devices in homes (Hunt & Easley, 2012). There are over 8.5 million residential pools installed in the U.S., and of these, about 1.2 million are in California (ENERGY STAR, 2020; P.K. Data, 2016). This represents a substantial population of pool pumps. Furthermore, as an estimated 200,000 new residential pools are built in the U.S. each year, there is consistent and increasing demand for energy to maintain home swimming pools (ENERGY STAR, 2020). Thus, energy saving techniques through targeting pool pump efficiency is highly relevant for IDSM strategies in California.

Historically, pool pumps were not seen as energy saving devices, as they were initially limited to single fixed-speed pumps. Even in the early 2000s, the only market-available pumps were either single or two-speed pumps. Although two-speed pumps are more energy efficient than traditional single speed options, they nonetheless still operate on pre-programmed fixed-speed RPMs, meaning that they are not adjustable to efficiently meet dynamic energy requirements. The first serious attempt to improve pool pump efficiency in California came in 2001, when energy shortages led the CPUC to approve programs developed by the IOUs to implement a timer switch requirement and motor efficiency program to reduce energy loads generated by pool pumps. The timer switch requirement proposed a $25 payment to pool owners to move their pumping time to off-peak hours, while the motor efficiency requirement offered to pay incentives to upgrade pumps that would result in an expected energy efficiency improvement of 5-12% (Fernstrom, Zohrabian, Westberg, & Worth, 2016). More recently, the IOUs have shifted to variable speed drive (VSD) pool pumps as the main IDSM program target. Because VSD pool pumps can be programmed to respond to dynamic conditions in energy demand requirements, these devices are preferable for energy savings compared to both single speed pumps and two-speed pumps. Utilities also benefit from the expanded DR capabilities enabled by VSD pumps, as the high-intensity cycles can be explicitly programmed to run at off-peak times (eTRM, 2019).

FEATURES AND FUNCTIONALITY

In California, Title 20 requires all new pool pumps to be either two-speed or VSD pumps, thus eliminating single-speed pumps from consideration. Furthermore, market transformation efforts should focus on devices that are more sophisticated than minimum ENERGY STAR qualifications in terms of energy savings potential, suggesting that VSD pumps may be more effective targets than two-speed pumps. Thus, the current assessment will focus exclusively on VSD pool pumps.

Most VSD pumps sold to residential customers operate at between 0.5 to 3.0 hp. VSD pumps use permanent magnet motors, that create a magnetic field between the rotor and the windings where the magnets spin the rotor. This is more energy efficient than the induction mechanism in traditional permanent split-capacitator (PSC) motors used in single-speed pumps, which require additional electricity to induce a magnetic field into the rotor (eTRM, 2019; Hunt & Easley, 2012). The main advantage of permanent magnet motors is that they enable programmable functions that can adjust dynamically to specific tasks. Conventional PSC pumps can only run at a set rate of 3,450 rpm. With only one setting available, PSC pumps must be able to deliver the highest maximum required energy output under the highest demand activity in the filtration process. Performing pool sweeps, circulating water through heaters, and pumping water to fountains require relatively high energy consumption, although these activities combined account for only about 10% of the total filtration time. The other 90% of filtration involves simply circulating water through the pool, which is much less intensive in terms of energy demand. This means that PSC pumps are over-engineered for 90% of the operational time (Hunt & Easley, 2012).

In contrast, VSD pumps conserve enormous amounts of energy through dynamic adaptability, and, more specifically, through the physical processes explicated in the Pump Affinity Law. While the constant churn of single-speed pumps turns over the pool in about 6.3 hours, VSD pumps require between 12-24 hours to turn over the entire pool. This is because energy consumption, pump speed, and water flow have a direct, nonlinear relationship, where cutting the pump speed and flow rate in half corresponds to a reduction to 1/8 of the original power demand. In other words, slower flow rates lead to greater energy savings. Applying the Pump Affinity Law, while single-speed pumps flowing at the standard rate of 66 gpm (gallons per minute) would require 12.6 kWh/day, or 4,599 kWh/year (assuming 365 day use that may be typical of a southern California residence), a variable speed pump programmed to flow at 22 gpm would require 19 hours to clear the entire pool, but would only consume 2.2 kWh/day or 803 kWh/year. A difference of 3,796 kWh/year represents significant energy savings of VSD pumps over traditional single-speed pumps (Hunt & Easley, 2012). ENERGY STAR also estimates relatively high savings potential for VSD pumps over single-speed pumps, at about 2,800 kWh/year. Per ENERGY STAR evaluation of pool pumps, VSD pumps also save about 500 kWh/year compared to two-speed pumps (ENERGY STAR, 2016).

Moreover, despite slower flow rates, VSD pumps do not sacrifice filtration quality or water sanitation. Because there is less pressure on the motor, variable speed pumps are also quieter and have longer useful lifetimes than other types of pool pumps. Furthermore, using variable speed pumps reduces the chance of broken pipes and other related failures of plumbing infrastructure that can occur from excessive strain (eTRM, 2019; Hunt & Easley, 2012).

CONNECTED FEATURES CLASSIFICATION

The connected features most common across the variable speed pool pump category per CalPlug's classification systems correspond to types 1a (real time monitoring), 1b (performance notifications), 1d (manual demand response notifications that may be used for TOU scheduling), 2 (remote control), and 3 (automated demand response capability). Table 26 presents these capabilities in depth.

TABLE 26: CURRENT PRODUCT CATEGORY RELEVANT CONNECTIVITY FEATURES FOR POOL PUMPS

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
1a- Real Time Monitoring	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Reporting of energy usage over time to the user directly via a manufacturer supplied app or corresponding ecosystem app	Loss of alerts to user. Entire feature unavailable for energy management relevant operation.
1b-Connected Performance notifications	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Alerts user to current operational mode (on/off/standby), informs user of current motor speed and flow rate, and provides maintenance reminders/ alerts users if abnormal energy use occurs	If onboard management is available, degradation to type 0b and interfacing via an onboard display.
1d- Manual demand response notifications	1	Possible based on device features/functionality, but ADR (cat. 3) is prioritized	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from ZigBee interfacing from the home smart meter	Demand response targeted, potential TOU targeting.	Ability to provide demand response notification to the user for specific manual action. May be used to alert user about potential scheduling for TOU savings potentials.	No alerts provided to user for users. Alerts may be on the device itself, or over an interfacing app.

Table 26 *continued*

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
2- Real-time monitoring with control (supersedes 1a when reported information is available with relevant control)	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features or through mobile device connectivity outside of home (3G, 4G, LTE)	Primarily EE targeted	Ability to start or stop the pump remotely and to adjust the motor speed or flow rate	Inability to adjust operational parameters. Loss of reporting and control of features remotely.
3- Automated demand response control	3	Default settings to enable 4-hour response capacity for load shift over a 12-hr period, and load shed capability of 3 events at 20 minutes each over a 24-hr period. May be subject to demand increase of 10% motor speed (rpm) during times of grid oversupply	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from Zigbee interfacing from the home smart meter	Primarily DR targeted	Automated demand response control capability with user override feature	Inability to receive and act on ADR signals.

[1] Feature status: 1= Feature uncommon, in development, or deployment status unknown, 2=Common feature in device category, 3= Key category feature required for ENERGY STAR compliance for Connected Pool Pump

As previously discussed, 3-6% of total energy savings may be attributable directly to EE-focused notifications. If we assume a reasonable average savings of about 3,000 kWh/year compared to single-speed pumps based on the data provided by NREL and ENERGY STAR (ENERGY STAR, 2016; Hunt & Easley, 2012), the connectivity savings yields between 90-180 kWh/year. The users' energy-saving actions, such as responding to real-time monitoring, scheduling regular maintenance, and the ability to control the settings of the device remotely, depend on behavioral interaction and customer awareness of best strategies to manage and reduce power consumption through smart connected features.

DR savings from pool pumps are limited because they correspond to relatively short action periods. ENERGY STAR stipulates that a VSD pool pump operating at 100% rpm capacity shall be reduced to 1/3 of operating capacity during load shift events (up to 4 hours over a 12-hour period), and may shut off for up to 20 minutes during a load shed event (ENERGY STAR, 2019d). Given these parameters, a reduction of 66% of the baseline energy consumption 2.2kWh/day over a 4-hour load shift period would produce 242 Wh. Assuming 261 events per year (as previously modeled for connected refrigerators and washing machines), this would produce 63.2 kWh/year of savings. Energy savings from load shed events at 20 minutes each would correspond to between 31 Wh per event. Assuming 261 events per year (as previously modeled for connected refrigerators and washing machines), this would produce 8.1 kWh/year of energy savings.

PROGRAM AND MEASURE FEATURES

Potential program and measure features for variable speed pool pumps were obtained through the statewide measure "VSD for pools and spa pump" (eTRM, 2019).
This study estimated costs for installation of variable speed pumps based on data obtained from a similar IDSM program for pools in multifamily residences throughout southern California. Specific data regarding material costs was inferred from searching MSRP for variable speed pumps between 1 and 3 hp. As these material costs were not specifically disclosed, CalPlug conducted a similar search of MSRP price ranges online for variable speed pumps and estimated a reasonable range of $500-$1000 per device. Also included in the measure cost were the required permit cost to install a pool pump in southern California (an average of $220.94) and the utility estimated labor installation cost of $67.55. The gross measure cost was then calculated to be between $788.49-$1,288.49.

Although the participant incentive dollar amount was not included in the consulted work paper, CalPlug estimated a range of between $150-250 per variable speed pump. A midstream program offered by SCE during the 2019 calendar year offered $200 incentives for qualified VSD pool pumps at participating retail locations (Southern California Edison, 2020). A similar program offered by Sacramento Municipal Utility District (SMUD) offers $250 to customers purchasing qualified VSD pumps at participating retailers or through qualified contractor services (Sacramento Municipal Utility District, 2020). Based on these incentives, a reasonable range estimate for VSD pool pumps of $150-250 aligns with previous California programs.

CalPlug assigned standard IOU estimates for the unit installed base (UIB) of between 5,000-15,000. The measure lifetime was considered up to 11 years, which considers the full range of the product EUL. In the next section, TRC values considering these measure features are presented and evaluated.

TRC RANGES

The following values were used for the initial calculations for connected pool pumps based on the testing and research done on the device.

TABLE 27: SUMMARY OF TRC CALCULATOR INPUTS FOR CONNECTED POOL PUMPS

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	686 (CPUC); 1,750 (CPUC); 2,800 (Energy Star); 3,796 (DOE)
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	$1221-1721
		Participant Incentive ($)	$150-250
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
		Measure Lifetime (years)	9-11
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

The maximum TRC value from these parameters was 5.71, which was obtained in year 3 of the results, with Unit Energy Net Savings of 3886 kWh/year, 15000 devices, measure cost of $1221, measure lifetime of 11 years and participant incentive of $250. There was a huge range of estimated Unit Energy Net Savings found in the literature, ranging from 686 to 3,796 kWh/year, comparing the results across the Unit Energy Net Savings, a huge discrepancy was found depending on the Unit Energy Net Savings. Graphed below is a comparison of the different Unit Energy Net Savings, with huge range of results depending on the Unit Energy Net Savings. The constants used to graph the figure below were that the measure lifetime was 10 years (average) and the incentive was $200 (average), measure cost was $1221 (low end).

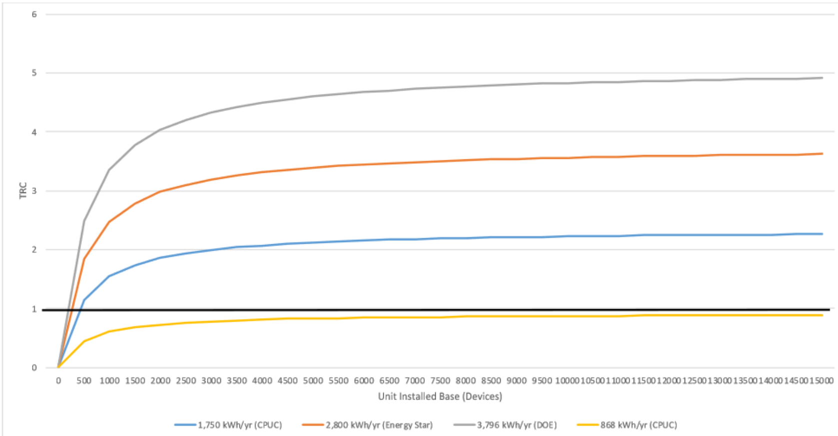


FIGURE 21: CONNECTED POOL PUMP TRC RESULTS FOR MEASURE LIFETIME OF 10 YEARS

The significance of unit energy net savings demonstrates that for high cost devices, such as pool pumps, do not yield cost effective programs when paired with low incentives. As seen for these calculations, with a range of Unit Energy Net Savings found for the device, the higher they are, the better the TRC values they yield. Unit Energy Net Savings is therefore an important determining factor in modeling IDSM program success.

ANALYSIS OF DEVICE

Variable speed pool pumps mostly save energy through more efficient pumping mechanisms compared to single-speed or two-speed pumps. The Pump Affinity Law underpins this finding and demonstrates how slower pumping speeds substantially reduces the amount of energy required to perform a full turn-over of the pool water. However, while savings due to intrinsic properties of VSD pumps may save significant amounts of energy over single-speed baseline products (2,800-3,796 kWh/year), only about 3-6% of the energy savings is attributable to the feedback-based connectivity features (about 90-180 kWh/year) that allow users to monitor energy use and program devices to operate during off-peak hours. This discrepancy highlights the fact that connectivity-based EE features for pool pumps are limited.

Although there is more opportunity for DR control for pool pumps than EE savings, realistic energy conservation through load shift is likely to be at maximum 63 kWh/year and only 8 kWh/year for load shed potential savings. While the per-event savings may be promising, DR activation periods are generally too short to transform into substantial savings in aggregate. The potential adverse effects on health and safety from excessive use of DR signals further limits the ability of pool pumps to save substantial energy savings through DR events under current grid configurations.

Despite low savings attributable directly through connectivity ability in variable speed pool pumps (either through DR communication ability or EE feedback and remote-control features), CalPlug's TRC estimates show that pool pumps are likely to produce significant energy savings if employed in an IDSM program. This finding highlights the importance of evaluating emerging technology and improved appliances based on their increased mechanistic functionality, which in many cases, largely surpasses current connectivity features as actuators of energy savings.

MAJOR SCOPE DEVICE CONTROL SYSTEMS

A SYSTEM APPROACH

An alternate approach to managing energy efficiency and demand response in plug load devices is using external control systems. This general category includes installed systems such as circuit- board controls and controlled wall outlets as well as portable devices such as smart plugs and advanced power strips.

Circuit board and plug-level level controls are one of the earliest home automation technologies and connected residential IDSM solutions. Early connected residential IDSM solutions took the form of broadcast DR control that could delay the action of controlled devices. California has been using home DR applications since the 1990s, using smart grid signals to temporarily disable air-conditioning compressors at peak load periods, a form of circuit level control (Edison International, 2016). This has been implemented using pager systems, smart meter infrastructure, and internet connectivity. Efforts to use set point adjustment with connected smart thermostats is gaining traction to accomplish similar goals by temperature set point control (NEST Labs, 2016). In other countries, such as Great Britain, the Radio Teleswitch has allowed broadcasts to control users' loads and switch recorded metering rates such that devices can take advantage of lower energy rates with a differential tariff rate structure (Fell, 2017). Both traditional applications were based on unidirectional price signals with intent to primarily reduce demand during peak periods, which is a common DR strategy.

The mode of action for total energy reduction with circuit level control was largely implemented by automatic timers, small-scale feedback control, and remote management using rudimentary forms of connectivity. Early connectivity technologies such as X10 control used remotes, long range RF control, Touch-Tone dial-in, and later TCP/IP connections to provide control of connected home loads. These connected residential devices were focused on convenience and security as primary development goals (Balta-Ozkan et al., 2014; Balta-Ozkan et al., 2013; Bhati et al., 2017; Scott, 2007). In these configurations the user had some limited ability to remotely turn off devices (power cut control) and set timers, but truly integrated control as a residential consumer solution was not yet available.

Circuit-level controls are now frequently used to manage lighting in commercial buildings, and integrated controlled outlets are gaining traction. ASHRAE 90.1 requires automated control for controlled power receptacles (American Society of Heating Refrigerating and Air-Conditioning Engineers, 2019). Similarly, California's Title 24, Section 6 (California Energy Commission, 2016) requires occupancy controls for outlets and lights to for specific applications such as stairwells (130.1(c)) for energy conservation applications, and sections 141.0(b) and 130.5(d) specify receptacle control configurations as well as retrofit compliance requirements. However, these major code requirements have been focused on commercial applications.

Freestanding connected control systems such as smart plugs and advanced power strips offer several advantages in residential applications, such as relative low cost and ease of installation. This makes them attractive to users who are unwilling or unable to make the substantial investment of time and money required by more involved systems, while still targeting a few key plug load devices in the home.

This section reviews three residential applications of control systems: smart plugs used to manage window air conditioners and point-of-use water heaters, and Tier 2 advanced power strips used to manage audiovisual entertainment devices. These devices and configurations of control systems are representative of major energy-consuming products that may be well suited for targeted control to reduce energy usage. They include a range of devices and feature characteristics, in order to give an overview of the kinds of devices that could be paired with either smart plugs or APS products.

Smart Plugs

Features and Functionality

In its basic form, a smart plug is inserted between a plug load device and the electric socket and features remote connectivity that provides added functionality. These devices are similar to other control devices in differing form factors such as smart sockets (installed in the wall) or smart breakers (installed in the circuit breaker box) in that they provide control by turning on and off mains power to an interfaced device. However, the onboard intelligence and capabilities for smart plugs or smart plug meters can vary greatly across the category. Some devices can be programmed to follow schedules or react to sensor inputs based on real-time edge control. Other devices react due to direct commands from a controlling system. A subset of devices report back power usage while others allow reporting and control or just control. Some may be equipped with onboard sensors to identify occupancy or advanced energy usage pattern detection, while others have no such capability. Some use timers and schedules programmed or cached in the device for control while others use triggering signals to provide all control. Beyond power control and measurement, some devices have interfacing capability to provide operational control to some devices that permit infrared or serial interfacing.

When consumer electronics and appliances are plugged into smart plugs, these solutions can quickly control energy use by cutting power, ideally when the attached devices are on but not being used. When appropriately applied, this solution provides simple and straight-forward means to control a large variety of equipment types. A major flaw in this approach is the limited ability of traditional smart plugs to provide satisfactory device management with only power-cut controls. As an increasing number of consumer electronics incorporate standby modes, simple power off control may not be effective in many use cases. In other cases, turning off or quick cycling a device can be harmful. There are also challenges with verifying that the device is not being used, and thus with avoiding interruptions of usage periods.

New generation devices are generally connected directly or indirectly back to a controller over a TCP/IP network. Indirect connections generally use dedicated home automation physical connections and/or protocols such as RS-485, Zigbee, Insteon, Z-Wave, Lora, etc. to connect back to a gateway that aggregates and connects the devices on the automation network to the controller or internet. Direct connections use Wi-Fi or Ethernet to directly to communicate with the controller or internet without an intermediary connection network. The ability of such systems to manage loads is directly connected to the "intelligence" of the control system that provides the actual load management. The specific control action may be a physical controller or a cloud-based service. The proliferation of smart phones with sophisticated applications in addition to voice control integration for many control devices allows a clean user experience, further allowing these devices to be integrated into more sophisticated and powerful control solutions.

IDSM control may be provided by either direct or indirect action. For demand response actions, remote signals via connectivity provide the impetus for action and provide event triggering. As power cut is the only control available for most units, the relevant aspects are the duration of the power cut and what the device does when the power is reinstated. For energy efficiency applications, various smart plug solutions can provide several modes of action. Each mode of EE control listed has a practical effectiveness that varies on specific connected device and application.

1) Human-in-the-loop—notification only: The device provides a means for notification for device state or energy usage and accordingly provides a means for the user to act by changing device usage through direct interaction with the device. This is consistent operation with connectivity class 1A.
2) Human-in-the-loop—notification and control: The device may provide a means for notification for plug state (On versus Off) and may report energy usage. Users can control outlet power state directly or via a remote interface or set timers to automatically manage outlet state with a fixed schedule. This is consistent with connectivity class 2.
3) Automatic sensing and control: The device uses sensing of power signature or other onboard sensors to manage outlet state. This may be in addition to previously mentioned features. This is consistent with connectivity class 4a.
4) Coordinated automatic sensing and control: The device uses sensing information provided by other devices to control outlet status. This is consistent with connectivity class 5a.

Smart plugs, like other types of control systems, can manage many types of plug load devices. In general, larger loads that can tolerate power cut control and will automatically resume operation when power is restored work well for this application. Some promising applications include portable or window-mount room AC units, space heaters, point-of-use hot water dispensers, pumps, pet heaters and lights, domestic hot water circulation, lighting, and timer and/or remote replacement for process control. This report covers two use cases, focusing on high energy demand plug load devices: specifically, window AC units and point-of-use hot water devices.

However, other plug load devices are not well suited to control by power cut, whether from smart plugs or any similar solution. These limitations stem from a range of sources; a few are mentioned here. Some devices use very little energy when not being used, and thus the additional cost and energy use of a control system cannot be justified. Yet many of those same devices are in standby rather than off mode for a reason—e.g., to keep a clock running—and cutting power can reduce the performance of the device. For example, programmable coffee makers generally use little power when not in brewing or warming cycles but cutting power will zero out the clock and remove any timed settings the user has programmed. Devices that require shutdown procedures, most notably computers, will experience performance problems if turned off with sudden power cuts.

While many devices can potentially operate with smart plugs, a smaller subset operate well with them and can result in energy savings and stable operation. This section presents two cases of potential controllability in a retrofit application where intelligent energy efficiency capabilities are added by the means of a smart plug. Window-mount and portable air conditioners are large energy users, and conventional, unconnected units do not sense occupancy. The result is that temperature can be maintained in an unoccupied space, resulting in wasteful operation. Similarly point-of-use hot water dispensers, such as those mounted under sinks, heat water all day in expectation of use. The energy used during the period of thermostatic heating and non-use is effectively waste. Preventing operation during extended periods of non-user interaction with the device can save energy without reducing user utility.

CONNECTED FEATURES CLASSIFICATION

Smart plugs in conventional use may operate alone or be integrated components of SHEMS systems. In most cases energy reporting (connectivity class 1a) and control of the connected load comprise the main features of operation (connectivity class 2). Demand response can be mediated by a SHEMS controller or through a smart energy Zigbee protocol via a smart meter AMI gateway. This results in a period where the connected load is unpowered; depending on the application, the power is later restored automatically or requires manual reactivation. In more advanced configurations, sensing via onboard power electronics and power analysis or via external sensors as mediated by the SHEMS control can be used to provide control inputs. Depending on the complexity of the system, this can comprise a 4a or 5a connectivity class system. See Table 28 for configuration summary details.

Table 28: Current Product Category Relevant Connectivity Features for Smart Plugs

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
1a- Real Time Monitoring	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Reporting of energy usage over time to the user directly via a manufacturer supplied app or corresponding ecosystem app	Loss of alerts to user. Entire feature unavailable for energy management relevant operation.
1b-Connected Performance notifications	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Alerts user to current operational mode (on/off/standby), suggestions provided through sensors.	If onboard management is available, degradation to type 0b and interfacing via an onboard display.
2- Real-time monitoring with control (supersedes 1a when reported information is available with relevant control)	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features or available intermittently through mobile phone tethered connection via Bluetooth	Primarily EE targeted	Ability to provide tighter control for energy management than APS algorithm can provide. Scheduling inputs can be provided for real-time control.	Inability to adjust operational parameters. Loss of reporting and control of features remotely.
3- Automated demand response control	3	Assuming 10 demand response events per year with a 4-hour duration results in an average load shedding of 1.7 kWh for window AC and .08 kWh for hot water dispensers over a 24- hour period.	Typically managed over persistent Wi-Fi connection to home router with other connectivity features and may have supplemental connectivity to Smart Energy (SE) network provided from Zigbee interfacing from the home smart meter	Primarily DR targeted	Automated demand response control capability with user override feature	Inability to receive and act on ADR signals.

[1] Feature status: 1= Feature uncommon, in development, or deployment status unknown, 2=Common feature in device category, 3= Key category feature required for ENERGY STAR compliance for Smart Plugs.

Smart Plug Control of Window Air-Conditioning Units

Background

Window mount room air-conditioning (AC) units are suited to control by power cuts if they can resume operations with identical settings after power is restored. Connected devices do exist within this category, such as Friedrich's line of Kuhl air conditioners. The current discussion focuses on non-connected devices (e.g., current stock already in homes) that are granted connected control through external systems, specifically, smart plugs. Generally, non-connected AC units tend to have simple knobs and switches rather than digital displays. Efficiency for this type of device is classified by the Combined Energy Efficiency Ratio (CEER) and governed by federal energy standards Code of Federal Regulations at 10 CFR 430.32(b) with test procedure methods specified at 10 CFR 430, Subpart B, Appendix F. ENERGY STAR requires a minimum of 10% greater efficiency than federal standards to qualify. Units rated at 6,000 BTU/hr. and 28,000 BTU/hr. range between 12.1 and 9.9 $CEER_{BASE}$, respectively, without reverse cycle capability. With 20 BTU recommended per square foot of space to be cooled. Assuming an average master bedroom size of 14 x 20 ft., resulting in 280 sq. ft., a unit of 5600 BTU is recommended. This BTU value is at the low end of advertised capacity values, suggesting that most larger units are cooling more than a single room, or are oversized. Using a unit that is oversized for a given area can lead to short-cycling and reduced system energy efficiency (Townsend & Ueno, 2008). With between 500 and 1200 watts commonly used in operation, 850 W will be the considered active load in the current discussion. For plug control, set point adjustment is not an option, and power cut control must be used.

Timing for cutting power to the room AC is important. Any occupants in the room will probably notice if there is a sudden reduction in AC, and thus experience reduced user satisfaction. The ideal application would be to cut power during medium and long periods of wasteful usage, when the AC is running but the room is not occupied. As most smart plugs are not configured to act as a thermostatic controller (with the noted exception of Think Eco's Modlet device), either fixed timers or occupancy sensing could contribute to reducing wasteful runtime. With an assumed duty cycle of 50%, for 30% of the year, a full year average of 127.5 W is assumed. If during the 30% of the year when the device is operational and considering an aggressive action of reducing 20% energy due appropriate triggering or sensing of wasted use, this would result in an average of 102 W average annual load. The difference is 1121 kWh - 893.52 kWh = 227 kWh potential savings in this configuration. Considering +/- 20% variability this results in a range between 181 and 273 kWh potential saving. Although programs have existed in New York City for smart-plug mediated control of window mounted ACs, CalPlug could locate no major efforts in California. With an area of sufficient window air-conditioners, this may be a worthwhile program to investigate. . This suggests it may be a fruitful new avenue for energy saving. However, the lack of strong data also means that the model presented is shown with wide potential value bounds.

Sensing and control due to feedback and human-in-the-loop control is likely consistent with previous results for generalized energy impact. The visceral nature of ambient temperature combined with the high potential cost, high level of user controllability, and conspicuousness of the controlled device likely has an impact on driving up the potential for energy management. Central AC smart thermostats can shed some light on this providing parallel user remote control of operation (albeit with set-point adjustment). Considering 10% savings potential due to this mechanism of control, 1121 kWh – 1009.0 kWh = 112 kWh. With a 5% potential variability, this results in a range of approximately 58 kWh and 168 kWh annually. This is an estimated 10% +/-5% savings potential by implementing smart plugs and occupancy sensing estimated. Extensive studies do not go into depth on what can be expected, so these values are provided as a first–order calculation estimate of savings potential due to implementation of smart plug technology.

Demand response control for this same device configuration is highly promising. Given the analog nature of the settings for most non-connected window AC units, the unit should automatically resume normal activity whenever the power is restored. Thus, the concern about not returning to the previous state after the demand response event should not be a problem in most use cases. Assuming ten demand response events per year (all assumed within the 30% modeled period of AC operation) with a 4-hour duration results in an average load shedding of 425 W. For a single event over a 24-hour period, this results in an average load reduction of 66 W over a 24-hour period resulting in 1.7 kWh reduction over a 24-hour period. Across a year for 10 events this is 17 kWh/year reduction due to modeled DR response. This model does not consider the re-cooling period at the end of the event requiring additional energy to restore room temperature to the setpoint. This would have a net negative impact on savings.

Program and Measure Features

As no qualified measure programs currently exist for incentivizing smart plugs, measure ranges were assumed based on standard IOU estimations for typical unit installed base rates. Incentives were determined as a reasonable percentage of material costs.

To calculate material costs, CalPlug conducted a search of MSRP price ranges online for smart plugs and estimated a reasonable range of $15-30 per device. Given the nature of the smart plug as a relatively inexpensive device easy to self-install, CalPlug modeled this program at the midstream delivery channel, thus eliminating labor costs.

CalPlug estimated an incentive range of between $5-10 per smart plug device. This represents a maximum rebate of about 30% per device.

CalPlug assigned standard IOU estimates for the unit installed base (UIB) of between 5,000-15,000. The measure lifetime was considered up to 5 years. In the next section, TRC values considering these measure features are presented and evaluated.

TRC Ranges

The values in Table 29 were used for the initial calculations for smart plugs with window AC. Note that the calculations assume that the customer already owns (or separately acquires) the non-connected window AC, as well as any other SHEMS components it may be linked to: the incentive measure is for the smart plug only. This also means that the calculations are agnostic about AC model, providing a comparable measure performance indicator for a product able to provide between 58 kWh and 168 kWh savings annually when used under smart plug control.

TABLE 29: SUMMARY OF TRC CALCULATOR INPUTS FOR SMART PLUG CONTROL WITH WINDOW AIR CONDITIONING UNITS

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	58-158
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	$15-30
		Participant Incentive ($)	$5-10
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
		Measure Lifetime (years)	3-5
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

The maximum TRC value from these parameters was 1.6 (see Table 30), which resulted from year 3 of the results at 15000 devices, measure cost of $15, measure lifetime of 5 years and participant incentive of $10.

The full results from the measure cost of $15, measure lifetime of 5 years, unit yearly energy net savings of 158 kWh/year. is graphed below. As illustrated in the graph, both the $5 and $10 incentives yield TRC values greater than 1 (the breakeven point for cost and benefits of the measure) by the end of the first year at 5000 devices.

TABLE 30: INPUTS AND RESULT FOR MAXIMUM TRC VALUE

Unit Yearly Energy Net Savings (kWh/year)	Unit Installed Base	Measure Cost ($)	Participant Incentive ($)	Measure Lifetime (years)	BENEFITS	COSTS	TRC
158	15000	15	10	5	355500	222563.4	1.60

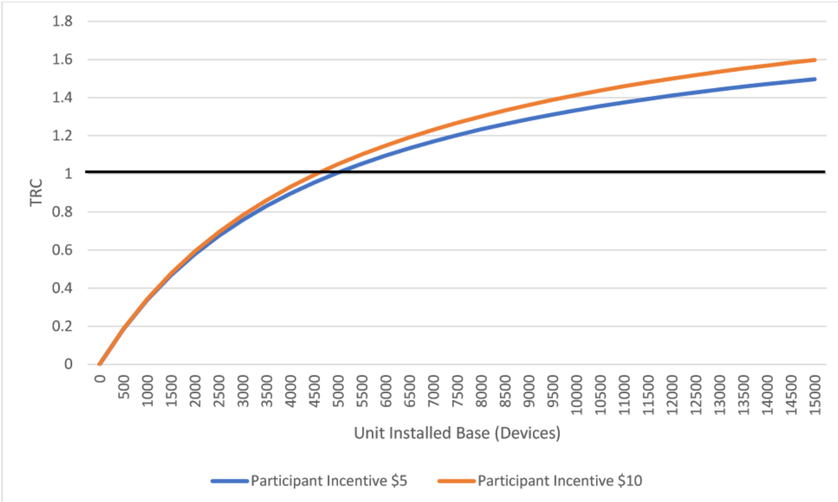


FIGURE 22: MAXIMUM SAVINGS FOR SMART PLUGS WITH WINDOW AC WITH MEASURE LIFETIME OF 5 YEARS

Table 15 is only referencing the results from the maximum unit energy net savings value (158 kWh/year) of the range calculated (58 – 158 kWh/year). Below a comparison of 58, 108 and 158 kWh/year is illustrated in order to demonstrate the difference in TRC values depending on the unit energy net savings. In order to make the comparison, the measure cost was kept constant at $15, the participant incentive was kept constant at $10 and the measure lifetime was kept constant at 5 years.

As demonstrated in Figure 23, the minimum of the unit energy net savings range, 58 kWh/year, never hits a TRC above 1 in a 15,000 device program in three years, showing that the a unit energy net saving that low will not yield a cost effective program. When looking at the median of the unit energy net savings range, 108 kWh/year, in a 15,000 device program in three years, the TRC value becomes greater than one at 11, 500 devices in year three of the program. This increase in the unit energy net savings made a significant impacted increasing the TRC values. Lastly, looking at the maximum of the unit energy net savings range, 158 kWh/year, the TRC values increase at a much faster rate than the other two unit energy net savings values run. The TRC exceeds a value above unity (TRC =1) at the end of year one at 5,000 devices. Overall looking at the range of unit energy net savings potential, the higher the value, the more cost-effective program will result.

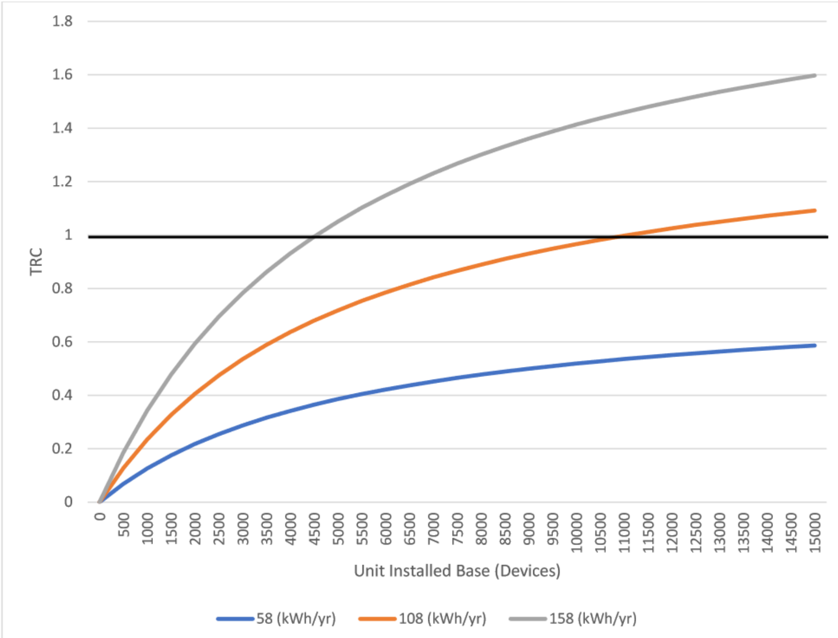


FIGURE 23: MINIMUM SAVINGS FOR SMART PLUGS WITH WINDOW AC WITH MEASURE LIFETIME OF 3 YEARS

SMART PLUG CONTROL OF HOT WATER DISPENSERS

BACKGROUND

Many residential kitchens now feature hot water dispensers located at the sink to provide instant hot water via a separate small faucet. These devices are fed from the mains water supply and plug into a standard 120 V outlet, usually located under the sink. This type of device uses substantial power during heating cycles, as maintenance of water temperatures require bursts of high power. Point-of-use hot water dispensers waste most of this energy, as they keep the water at the set temperature all day long, even though they may only be used a few times a day. These devices provide an excellent opportunity for energy savings through smart plugs. Schedule-based settings could be used to reduce energy use while residents are asleep or at work, timed so that the water heater restarts and resumes set temperature by the time users may need it. The hot water dispenser is also promising for reductions during demand-response events, as the service the device provides is convenient and variable rather than required and discrete. That is, if the hot water dispenser is unpowered during a DR event, users can still heat water on the stove or perhaps in the microwave; they are not prevented from obtaining the needed service. Also, if the hot water dispenser is unpowered, the water will not immediately become cold but will lose heat gradually over the course of the DR event; this variability means the water may remain hot enough for the user's satisfaction for some time into the DR event.

CalPlug investigated control on counter top water heaters which can serve as a baseline device for modeling(Klopfer, Xia, Pixley, Rapier, & Li, 2017a). In that investigation approximately 20 W of energy was used on average to maintain temperature once heated at a steady state. Assuming no usage, the yearly energy consumption would be 175.2 kWh/year to hold water at standby. As a loss of utility occurs with a change in water usage, this is normalized out. If we use nearby motion as an indication of user occupancy, and hence potential usage, we can make the calculation assumption that during 50% of the period of an average day, no users are present in the area of the hot water dispenser to require imminent use of hot water. The challenge in this situation is a user immediately entering the area after no previous occupancy for an extended period and requesting hot water without giving the system enough time to reheat. Using this model, we can make the assumption that 50% of the time during a 10-minute (the heat-up period) period does not have likely usage for hot water. Provided this sensing and control capacity, 87.6 kWh/year can be reduced due to action of the controller on just the energy required to maintain the internal boiler water thermostatically at the selected dispensing temperature. Considering variability bounds of +/- 10%, this results in a savings range of 78.83 kWh and 96.36 kWh. Similar to the previous example, after a drop in boiler temperature, a heat-up period is required to restore the temperature to the setpoint. The small quantity of liquid in the boiler limits this total reheat power requirement in comparison to the continual heat loss with continued thermostatic temperature maintenance at the set point.

For demand response action, a peak wattage of typically 1500W can be reduced with an average wattage likely around 20 W, based on previous calculation examples considering average cyclic load (Klopfer, Xia, et al., 2017a). For a four-hour DR period, this results in a total savings of 0.08 kWh for the event period.

Program and Measure Features

The program considerations for modeling smart plugs with point of use water heaters are identical to those discussed in the smart plug and window AC system configuration, except for the unit energy net savings. As no qualified measure programs currently exist for incentivizing smart plugs, measure ranges were assumed based on standard IOU estimations for typical unit installed base rates of 5,000-15,000. Incentives were determined as a reasonable percentage of material costs ($5-10 per smart plug), and a measure cost of $15-30.

TRC Ranges

The values in Table 31 were used for the initial calculations for Smart Plugs with Hot Water Heater based on the testing and research done on the device.

TABLE 31: SUMMARY OF TRC CALCULATOR INPUTS FOR SMART PLUGS WITH HOT WATER HEATER

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	79-96
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	Based on 2013 marketing and outreach values from SCE. See calculator for details
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	$15-30
		Participant Incentive ($)	$5-10
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
		Measure Lifetime (years)	3-5
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

TABLE 32: INPUTS AND RESULTS FOR MAXIMUM TRC VALUES

Unit Yearly Energy Net Savings (kWh/year)	Unit Installed Base	Measure Cost ($)	Participant Incentive ($)	Measure Lifetime (years)	BENEFITS ($)	COSTS ($)	TRC
96	15000	15	10	5	216000	222563.4	0.97

The maximum TRC value from these parameters was 0.97, which resulted from year 3 of the results at 15000 devices, measure cost of $15, measure lifetime of 5 years and participant incentive of $10 (see Table 32).

The full results from the measure cost of $15, measure lifetime of 5 years, unit yearly energy net savings of 96 kWh/year. is graphed below. As illustrated in the graph, neither of the $5 and $10 incentives yield TRC values greater than 1 (the breakeven point for cost and benefits of the measure) by the end of the third year at 15000 devices.

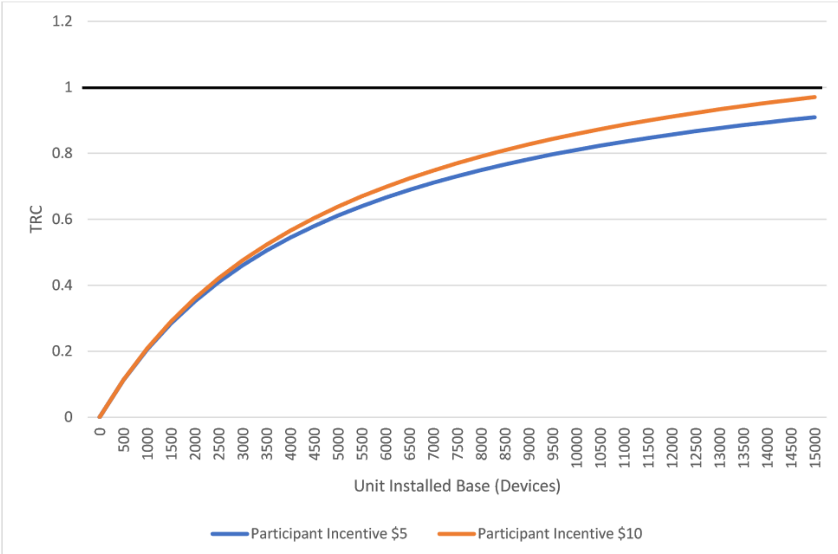


FIGURE 24: MAXIMUM SAVINGS FOR SMART PLUGS WITH HOT WATER DISPENSER WITH MEASURE LIFETIME OF 5 YEARS

Figure 24 is only referencing the results from the maximum unit energy net savings value (96 kWh/year) of the range calculated (79 – 96 kWh/year). Below a comparison of 79 and 96 kWh/year is illustrated in order to demonstrate the difference in TRC values depending on the unit energy net savings. In order to make the comparison, the measure cost was kept constant at $15, the participant incentive was kept constant at $10 and the measure lifetime was kept constant at 5 years.

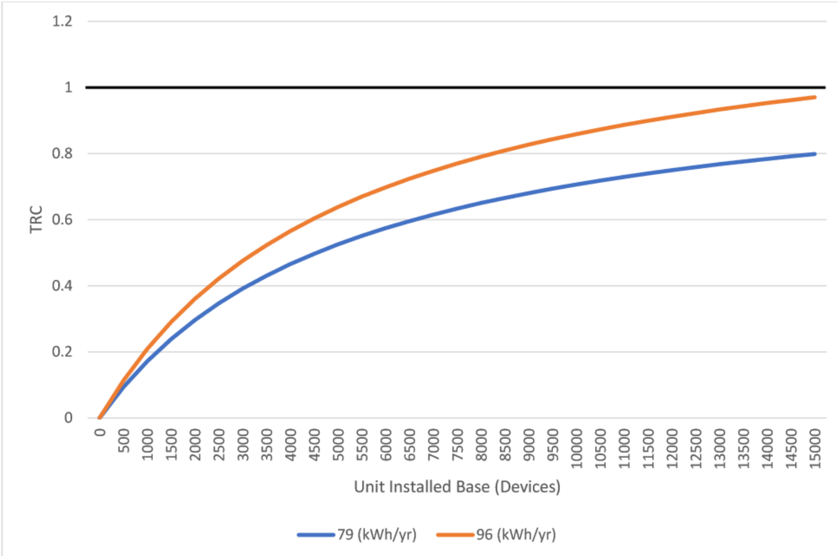


FIGURE 25: MINIMUM SAVINGS FOR SMART PLUGS WITH HOT WATER DISPENSER WITH MEASURE LIFETIME OF 3 YEARS

As demonstrated in Figure 25 above, both the minimum and maximum unit energy net savings, 79 and 96 kWh/year, never hit a TRC above 1 in a 15,000 device program in three years, showing that the a unit energy net saving that low will not yield a cost effective program. The unit energy net savings of 96 kWh/year does get very close to a TRC of 1, so a small increase in the unit energy net savings could make the program cost effective. Overall, like the smart plug with window AC, looking at the range of unit energy net savings potential, the higher the value, the more likely a cost-effective program will result.

ANALYSIS OF WINDOW AC AND HOT WATER DISPENSER APPLICATIONS

Both plug load air conditioning units and window mount AC units provide examples of loads that smart plugs can control with savings potentials possible for the given use applications. As many devices can be interfaced to a smart plug to produce savings, the results of the applications provide a generic measure guide for a smart plug to manage a connected device that can produce savings equivalent to either example when under smart plug control. It is clear based on the presented models that savings values under approximately 100 kWh/year require increasingly large numbers of devices to create a cost-effective measure with a TRC>1 with this annual savings requiring nearly 10,000 units of scale to reach a unitary TRC value.

As the range for the point-of-use water heating application is below this point, it can be seen in Figure 25 that at no modeled population does TRC reach unity. In addition to TRC, the payback period for the user must be considered. Given an incentive discount, at 100 kWh/year and the conventional energy rate, the device should pay for itself with energy bill savings within a three-year period. This is well within the device's useful life and measure life. With a lower savings potential, the payback period increases (assuming the same device cost). From the utility side, TRC might be reached with larger population sizes, but if customers do not expect sufficient value for purchasing the device, reaching these population sizes will be unlikely. With this said, the bound of 100 kWh/year is an approximate minimum value for savings required for practical usage.

As shown with other categories, the incentive value itself has a substantially lower impact on measure effectiveness comparatively. In implementation, unless the smart plug is directly WiFi enabled and connects directly to a cloud service, a functioning system to perform DR action or remote control or non-sensor-based control will require an IoT hub or similar device to permit interfacing. For sensor-based control, additional modules would be required for operation. While the current discussion focuses on a single device to enable control, deep energy management would require additional system components for high level functionality.

This challenge for SHEMS operation is noted by ENERGY STAR in the specification discussion as a challenge to proper operations. Providing solutions as modules to address specific applications is a means to address users. Smart plugs have so wide of an application, that specific applications and best practices likely would be required to provide users assistance to see the application and benefit of this technology as well as assistance in implementation. Many applications may benefit from installers for corresponding devices, for instance an automation contractor applying the solution as part of a larger smart home deployment.

There has been some interest in programs for smart plugs and similar mains control approaches incusing automatic phase balancing for residential electric hot water heaters and electric vehicle controllers. Extended investigation across a variety of applications has not been studied in the residential sense in the way it has commercially (Langner & Trenbath, 2019). Constellation Energy provides recommendations for residential use citing from 1% to 4.58% dependent on use and in conventional operation (Constellation, 2018). Yet limited interest exists currently with respect to programs incorporating this technology nationwide in a residential setting. Extended field trial investigations for smart plug technology, especially with defined applications and more advanced control schemes will be necessary to demonstrate program practicality.

Installation and operational success require clear definition of value and a clear pathway for non-intrusive operation, yet whatever applications are used, substantial savings must be actualized in order to allow this device to provide an economic measure in a utility portfolio.

Tier 2 Advanced Power Strips

Features and Functionality

Tier 2 advanced power strips (APS) represent the third wave of power strip technology. Manual power strips allowed users to cut power to a number of devices at one time. The original advanced power strips, later called Tier 1, offer one outlet for a master device (such as a television or desktop computer) and others for controlled devices (ideally peripherals that would only be used in conjunction with the master device). When the master device is turned off or transitions to a low-power mode such as sleep or standby, the Tier 1 APS cuts power to the secondary controlled devices. Substantial savings for residential Tier 1 APS systems have been shown in earlier tests; one study estimated an average annual savings of 30.1 kWh for office (IT) systems and 75.1 kWh for entertainment systems (cited from Illume, 2014). Households with gaming systems, which tend to have high energy use even while idle or in sleep mode, are estimated to save even more with their entertainment APS, up to 122 kWh/year (Illume, 2014).

Tier 2 APS devices further add to the functionality by using algorithms and sensors to gauge whether devices connected to them are being actively used. While specific features of Tier 2 APS products vary by manufacturer, all models operate via algorithms identifying non-engagement with a device, which signal to other connected devices to power down. Additionally, most models use sensors in the form of InfraRed (IR) controls to detect user feedback via remote control. Some models also incorporate passive IR motion sensors for further detection of user engagement, although this feature has been demonstrated to interfere with automatic shutdown functions, meaning it may counteract energy savings but prevents nuisance actuations (Klopfer, Xia, Pixley, Rapier, & Li, 2017b). Tier 2 APS systems may also use motion sensors, light sensors, and other inputs. Typically, when the Tier 2 APS system does not detect activity or presence during a pre-set delay period (usually 1 to 2 hours of inactivity), it produces a signal to any potential users that it will deactivate soon, such as a red light. A countdown process begins, and the device is automatically switched off if no further movement or activity is detected within that timeframe (typically ten minutes). As with any external device control system, savings results from reducing the active time the device would have been on until the user manually shut the device off. For connected peripherals, any wasteful time they would have been on can be claimed as active savings, while any off time can be claimed as standby load savings. The technical sophistication of Tier 2 products promises a significant energy savings potential over previous Tier 1 APS devices. One summary of multiple studies listed the range of savings for Tier 1 APS devices as 16-20% and the range of savings for Tier 2 APS devices as 22-50% (King, 2018). However, Tier 1 APS devices also cost about half as much as their Tier 2 counterparts, and thus may remain cost-effective for many consumers.

Wireless internet connectivity is a feature increasingly added to Tier 2 APS devices. The main manufacturers of Tier 2 APS devices offer their most recent Tier 2 APS devices in two forms: with or without connectivity capability. As such, it is important to probe the value of internet connectivity for energy savings potential. Connected and non-connected models have the same specifications for the essential hardware, including processor power, outlet capacity, and circuit monitors, as well as integrated software solutions for IR filtering and LED display.

Two major vendors offer devices with similar connectivity features including limited remote power management, relay of energy consumption information to the user, and real-time messaging from the utility provider to the consumer via mobile device. These messages typically include energy savings tips and warnings and are distributed over a cloud-based network. The devices offered by these vendors use different approaches for the physical connectivity. Persistent Wi-Fi connection provides a reliable connection if available. Alternatively, Bluetooth connectivity allows bootstrapping connectivity via a phone app. In this manner, the unit itself does not need to have a persistent connection via Wi-Fi but will utilize the phone's connection to the internet as necessary when the user is in proximity. This option provides connectivity to individuals without Wi-Fi in the home who depend on their smartphones for internet access, a common situation in low-income communities.

The connected and non-connected Tier 2 APS models are similar in common functionality as related to the mechanisms for energy savings: an example of the variations by feature between non-connected and connected Tier 2 APS products are provided in Table 33 and Table 34. These tables provide side-to-side comparison of features of connected and non-connected devices for the same manufacturer. For both manufacturers, the general functionality is the same between connected and non-connected models, except for the added energy management capacity provided by connected features.

TABLE 33: BRAND-A TIER 2 APS CONNECTED AND NON-CONNECTED

Brand-A Features	Tier 2 Non-connected	Tier 2 Connected
6 device outlets (2 always-on)	Y	Y
64k advanced microprocessor	Y	Y
IR shielding	Y	Y
Power monitoring circuit	Y	Y
Auto AV synchronization	Y	Y
Timer control	Y	Y
Dimmable LED	Y	Y
Active power-down	Y	Y
Remote power management	N	Y
Receive warnings, tips, energy savings suggestions on connected mobile device	N	Y

TABLE 34: BRAND-B TIER 2 APS CONNECTED AND NON-CONNECTED

Brand-B Features	Tier 2 Non-connected	Tier 2 Connected
7 device outlets (2 always-on)	Y	Y
Resettable circuit breaker	Y	Y
Electromechanical relays rated for 1000,000 switching cycles	Y	Y
IR filtering	Y	Y
LED status indicator	Y	Y
IR and Motion Sensing Multi-sensor (IR & IR-OS)	Y	Y
True RMS power measurement outlet for TV (master device)	Y	Y
Optional TAV-Link	Y	Y
Energy data communicated to users via mobile device app/ communication utility via cloud portal	N	Y

CONNECTED FEATURE CLASSIFICATION

According to CalPlug's classification system, connected Tier 2 APS devices are categorized as Type 1a, 1b, and 1c. Connected Tier 2 products are capable of real time monitoring and operational visibility functionality, provide performance alerts and suggestions, and can perform basic remote control of energy management features (see Table 35).

TABLE 35: CURRENT PRODUCT CATEGORY RELEVANT CONNECTIVITY FEATURES FOR TIER 2 APS

Connectivity Category and Functional Type	Feature Status[1]	Implementation Status	Connectivity Interface	IDSM Function	Specific Function Description	Impact of Connectivity Degradation or Loss
1a- Real Time Monitoring	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Reporting of energy usage over time to the user directly via a manufacturer supplied app or corresponding ecosystem app	Loss of alerts to user. Entire feature unavailable for energy management relevant operation.
1b- Connected Performance notifications	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Alerts user to current operational mode (on/off/standby), suggestions provided through sensors.	If onboard management is available, degradation to type 0b and interfacing via an onboard display.
1c- Connected operational visibility	2	Common category feature	Typically managed over persistent Wi-Fi connection to home router with other connectivity features	Largely EE targeted	Indication of user controllable reporting of settings with the ability to make decisions related to energy management. Remote configuration of energy management control settings.	Better energy management and control for devices via mobile interface.

[1] Feature status: 1= Feature uncommon, in development, or deployment status unknown, 2=Common feature in device category, 3= Key category feature required for ENERGY STAR compliance for Tier 2 APS.

The connected Tier 2 APS products allow the consumer to monitor the energy consumption levels of all devices connected to the Tier 2 APS system in real time and remotely change settings of the APS device via the mobile app. Additionally, the app enables communications to the user from designated utilities regarding energy savings tips and suggestions, as well as any current warnings and reminders about service provision or TOU initiatives.

In practice, Tier 2 APS devices designed for connectivity may not always actually benefit from connectivity. Devices may have no wireless internet access due to installation errors or other user mistakes, problems with the internet connection itself, or a range of other technical problems. Connected-style devices that lack connectivity default to a type 0a (see Table 6), and the device exhibits the same functionality as a non-connected Tier 2 APS device.

TIER 2 ADVANCED POWER STRIP CONTROL OF AUDIOVISUAL DEVICES

BACKGROUND

Tier-2 advanced power strips are a focused approach to combatting entertainment related energy usage. Entertainment-related audiovisual (AV) devices are estimated to comprise about 60% of residential plug load energy usage, with televisions identified as the main sources of plug load demand in homes (Klopfer, Xia, et al., 2017a; Peters, Frank, Van Clock, & Armstrong, 2010). A significant amount of the energy used by these devices is wasteful, occurring when a user leaves a device in active mode when not in use. Additional waste occurs in the form of standby or vampire loads for devices that could be turned off without loss of performance. On a per-device basis, standby loads consume only a small fraction of overall household energy usage. However, in aggregate, vampire loads accumulate and can account for up to 10% of residential energy consumption, contributing a substantial amount of energy waste (Lawrence Berkeley National Laboratory, 2019).

Televisions are the largest contributing category to plug load demand in residential settings, and studies have estimated that the average household in California uses approximately 685 kWh annually for AV devices (Valmiki & Corradini, 2016; M. Wang et al., 2014). A 2011 study conducted by Fraunhofer USA (Urban, Tiefenbeck, & Roth, 2011) estimated an installed base of 353 million TVs in American households, or approximately 1.13 units per person (see Figure 26). While energy efficient television sets have been developed under the ENERGY STAR program for some time, it is only through more recent technological developments, such as the Tier 2 APS system, that the consumer has been enabled to better control and manage waste and standby loads.

As technology moves forward, many of the catalysts for the continued growth of this category must be continually reassessed. The use of RF remotes based on Bluetooth (and similar) links replacing traditional infrared (IR) links adds to the challenge for new setups. Overall, the use of optical media for watching content has been slowly dropping (Klopfer, Rapier, et al., 2017), and the use of integrated home theater packages and sound bars with tight linking over HDMI, optical, or Bluetooth is increasing. Such systems can often sense lack of content and accordingly power down the device when no active content has been provided for an extended period. The increase in IP-based TV solutions in lightweight streaming boxes is continuing to replace the large set-top boxes for paid services as traditional paid service subscriptions decline in the long term (Munson, 2019). While Tier 2 APS is not intended to control these devices, content is now being sourced more from these lower power devices rather than other sources that were controlled such as optical media players, reducing overall devices that can be controlled. The inclusion of HDMI-CEC capabilities can allow attached HDMI peripherals to automatically power down to a standby state as required when not in active use as managed by the master device. If power management is enabled on the IP streaming device, inactivity can lead to a shutdown of both the streaming and master device, largely fulfilling the role of a Tier 2 APS device. Continued development of Tier-2 APS devices will likely continue to improve functionality and capability. Currently new game consoles can be configured in a means where energy savings features do not operate in an ideal way, leaving a highly energy consuming device operating at full power for an extended period. Clear coordination between an APS and game console in future generations of APS devices to provide a mediated save and shutdown may be a substantial feature to consider developing.

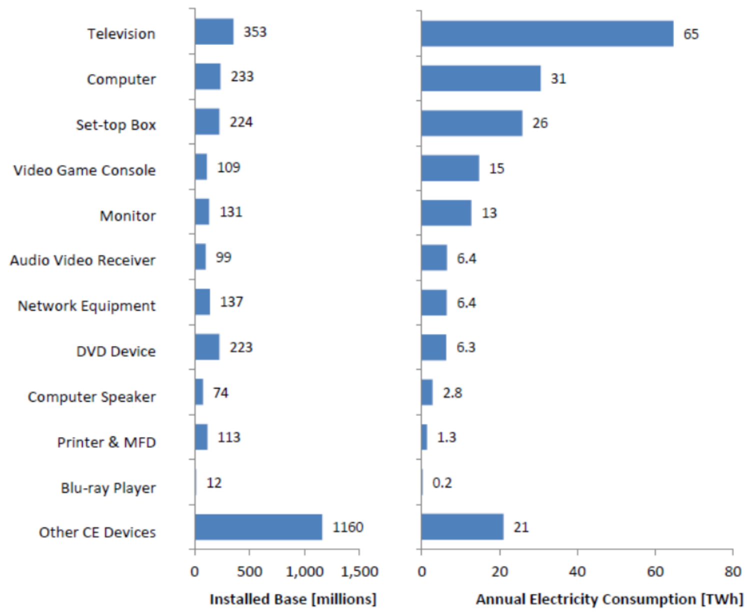


FIGURE 26: TIER 2 APS PERIPHERAL DEVICES ENERGY CONSUMPTION TRENDS

Source: Valmiki and Corradini (2015, page 11)

Energy consumption of AV devices and peripherals is projected to increase through the year 2040, per a comprehensive study conducted by the US Energy Information Administration in 2014 (see Figure 27) (Valmiki & Corradini, 2015). This study included set-top boxes, home theater systems, DVD players, and video game consoles in addition to TVs. Indeed, as TVs become more sophisticated with high resolution graphics (e.g., 4K TVs), and with increased integrated wireless internet functionality for convenient access to online streaming services, it is likely that the installed base and energy consumption rate of household TVs will continue to grow, and peripheral devices will increase in direct proportion. This growing trend will demand new solutions for managing connected devices as part of a system. Tier 2 APS products are well suited for this task, and as such, it is reasonable to expect that more households will be responsive to the adaptation of advanced power strips as the energy demands of home entertainment systems accelerate.

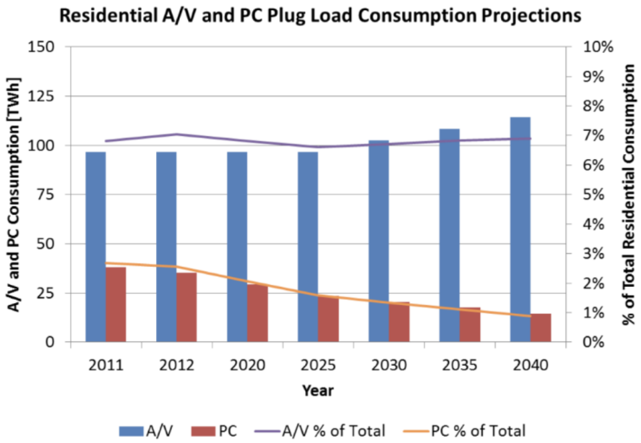


FIGURE 27: TRENDS IN RESIDENTIAL ENERGY CONSUMPTION FOR AUDIOVISUAL DEVICES AND DESKTOP WORKSTATIONS

Source: Valmiki and Corradini (2015, page 10)

Tier 2 APS devices present a potential mitigatory solution to the problem of wasteful active and standby loads for entertainment AV devices. Indeed, entertainment systems provide the ideal circumstance for saving energy using APS-style solutions, which function best with a group of interrelated devices. Entertainment systems generally include several peripheral devices that can only be used in conjunction with the TV (or in some cases, with another AV device, such as a projector or sound system), enabling more effective identification of periods when peripherals do not need to be on.

There is reason to be optimistic about the performance of Tier 2 APS systems for continued market growth and act as a driver of energy efficiency initiatives. Reducing costs would make this technology more affordable and improve the return on investment for managing energy. A series of California field trials in 2015 conducted by device manufacturers and sponsored by IOUs found an estimated 25% to 50% annual energy savings for Tier 2 APS devices, or between 250 and 350 kWh per year (Klopfer, Xia, et al., 2017a; Valmiki & Corradini, 2015). This underlines the potential savings for this broad category of control device, yet caveats exist about specific configuration performance.

PROGRAM AND MEASURE FEATURES

Residential IDSM programs including a measure for Tier 2 APS systems are most likely to be successful through downstream or midstream models. All of the previous California field trials used downstream direct-install research designs. The advantage of direct installation for Tier 2 APS is that it reduces the likelihood that the device will operate in reduced functional form due to behavioral error. Although implementers have described the installation process of the Tier 2 APS as easy (Valmiki & Corradini, 2016), field tests have thus far employed trained installers and include no examination of how well users could follow the manufacturer's instructions. Installation may prove difficult for some households, especially those with older or less technologically savvy residents. Additionally, more advanced TVs, such as HD or 4K products, may require more steps for setup and thus higher technical skill than other types of devices. Furthermore, for connected APS devices, there are additional setup steps and the challenge of verifying Wi-Fi connectivity, meaning more opportunities for user error. Examples could include an improperly configured Bluetooth connection that does not communicate as expected with mobile devices, or failure to correctly install and utilize mobile apps provided by the manufacturer. Users may even make very basic mistakes, such as plugging devices into the wrong sockets. Sufficiently frustrated users may give up trying to install the equipment or may uninstall it if it doesn't work as expected. As installation problems could reduce or even negate energy savings for the device, steps to ensure proper set-up of the APS devices is crucial element of any program.

Direct installation of the APS device can address initial installation errors; the major disadvantage is cost. Direct-install programs typically provide installation labor at no cost to the customer, in addition to the rebate or reduced price for the device itself. While the labor needed for installation may not be cost prohibitive for small field trials, it becomes much more expensive when scaled at the size of standard multi-year IDSM program assuming 5,000 - 15,000 participants. Using an estimated $40/hour installations cost (congruent with other IDSM programs), and estimating about an hour of installation per device, the program would range from $200,000-600,00 in installation costs alone. Installation costs may also be avoided or reduced if coordinated with retrofit programs or other situations in which installers are already scheduled to visit those households (Morris, 2017); however, this greatly adds to the complexity and range limitation of the program. In general, it is important to note that cost effective feasibility for direct-install programs may decrease as the scale of the program increases.

Installation expenses may be offset somewhat by reductions in device cost, if the utility can negotiate a better bulk rate when purchasing directly from a manufacturer. Previous field trials estimated obtaining Tier 2 non-connected devices for $60, and Tier 2 connected devices for $65. This is compared to MSRPs of between $69.99-$79.00 for non-connected Tier 2 APS devices, and $99.99 for connected Tier 2 APS products, revealing a savings of about $5/unit (on average) for non-connected, and $34.99/unit for connected devices.

Midstream incentive programs can also be appropriate for Tier 2 APS products, particularly as they further their transition from emerging technology to mainstream retail products. Midstream approaches have not yet been put into effect for Tier 2 APS in California. However, at least one utility-wide incentive program for Tier 2 APS devices has been put into effect by DTE Energy based in Detroit, Michigan (DTE, 2020). This program offers a rebate through the utility's website for qualified APS products to customers in the DTE territory. The program quotes the retail price of the product at $42.25 and offers a rebate of $22.25, for a final customer price of $20.

For utilities, the ability to transfer marketing and associated program costs to retail sales partners through a midstream program in exchange for incentive payments can be very cost effective, especially if the per unit incentive rate is low. Also, as new iterations of Tier 2 APS devices are regularly added to the market, it is also worthwhile to consider the effects of product obsolescence for program development. Midstream programs have fewer start-up costs for the utility, helping to avoid wasting investments on installation or high downstream rebates for products that are known to have high turnover rates. However, it should also be noted that the primary EE benefit of a Tier 2 APS program is to convince customers to switch from standard outlets or power strips or perhaps Tier 1 APS options to the more energy-efficient Tier 2 APS option. Thus, if customers stop using their incentivized Tier 2 APS device because they purchase a new and better Tier 2 APS, the actualized energy savings continue to accumulate.

Midstream programs primarily function through either retailers who sell the device, or contractors who install the target device or a related device. With few exceptions (e.g., high-end home theaters), most entertainment AV equipment is purchased and installed by customers rather than contractors, landlords, or other third parties. Thus, it would be difficult to imagine an effective midstream program aimed at contractors. This leaves targeting retailers: for instance, those selling standard power strips who could encourage customers to "buy up" to a Tier 2 APS, and those selling televisions and other entertainment devices who could encourage customers to bundle in a Tier 2 APS to upgrade their experience. An important challenge posed by retail-based programs is the potential for device misuse. As there is no supervised installation process, customers may incorrectly implement the device of its features, hindering the ability of the device to function properly. Similarly, a lack of education on the part of sales associates at retail partner sites may lead to incorrect advice to customers on the installation process or failure to provide comprehensive information regarding optimal performance of the device. A midstream program could potentially ameliorate installation problems by devising a way to remotely verify correct installation for connected APS devices; however, the logistics and privacy concerns could be substantial barriers.

The estimated useful life of a Tier 2 APS device is 5 years, per DEER estimates. Additionally, standard devices on the market provide electrical relay rated up to 100,000 switching cycles. On a first principles basis, high capacity for switching cycles supports device longevity by reducing the likelihood of mechanical failure (Bonneville Power Administration, 2013). As most IDSM programs are conducted for no longer than 5 years, on a technical basis, the Tier 2 APS device longevity should be able to meet and exceed IDSM program duration. At an estimated $65, the cost-per-device for Tier 2 APS products is also non-prohibitive and most likely profitable for a utility over the lifetime of the program.

Another relevant factor is whether programs target connected or non-connected Tier 2 APS devices. As presented earlier, connected and non-connected devices share most of their features and functional capabilities: algorithmic computation processors and IR sensors are the main drivers for energy savings for Tier 2 APS devices and are not a connection-leverage function. Still, the addition of connectivity features could add marginal savings value related to user interaction with the system. To assess the difference in EE savings between connected and non-connected Tier 2 APS, work papers published by California IOUs were consulted, as there were no official CPUC DEER values available, although CPUC approved ex ante values are available for the non-connected Tier 2 APS variant. Non-connected device potential savings data were obtained through a 2014 SDG&E field trial (Valmiki & Corradini, 2015). This work paper evaluated non-connected Tier 2 APS with AV systems in 53 residential host sites in the San Diego metropolitan area over the course of nine weeks. The study found an estimated annual energy savings projection of 234 kWh with the use of the non-connected Tier 2 APS device. The program benchmarked the device cost at $60/unit. Connected device potential savings data were obtained through a 2016 SCE field trial (RMS, 2017). The field trial installed Tier 2 APS with AV systems in 92 residential households in SCE utility territory and tested them for four weeks. Results showed an estimated annual savings rate of 240.4 kWh with the use of the connected Tier 2 APS device. The program estimated the device cost at $65/unit. The similarities in methodologies between the two field trials suggest that they may be evaluated as equivalent for the current purpose. Comparing these two studies produces an estimated added savings value of 6.4 kWh/year for connected Tier 2 APS devices.

TRC Ranges

The measure cost effectiveness for connected Tier 2 advanced power strips were assessed based on modeled program parameters and work paper derived annual savings values. These values model a connected Tier 2 APS product paired with a standard size downstream or direct install program (5,000-15,000 unit installed base) with a measure lifetime of 3 to 5 years. A range of TRC values were run through the calculator tool in order to get a better understanding of the bounds of input values yielding a TRC value greater than or equal to one. Table 36 displays the inputs and ranges used in the calculations of the relative benefits and costs.

Table 36: Summary of TRC Calculator Inputs for Connected Tier 2 APS

Benefit/ Cost	Variable	Terms of Variable	Value or Range
Benefits	Utility avoided supply costs in year t	Unit Yearly Energy Net Savings (kWh/year)	240.4
		Energy Rate ($/kWh)	0.15
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
	Tax credits in year t	Tax Credit in year t ($/year)	--
Costs	Program Administrator program costs in year t	Employee Costs ($)	Based on employee salaries and benefits. See calculator for details
		Marketing & Outreach ($)	5-15% From 2013 marketing and outreach values from SCE
		Research & Development ($)	--
		Measurement & Verification ($)	--
	Net Participant Costs= Measure cost - participant incentive	Measure Cost ($)	80
		Participant Incentive ($)	30-55
		Unit Installed Base (UIB) by Year	Year 1: 0-5000
			Year 2: 5500-10000
			Year 3: 10500-15000
		Measure Lifetime (years)	3-5
	Utility increased supply costs in year t	Utility Increased Supply Costs in Year t ($/year)	--

The calculations show that when the measure lifetime is 3 years, the TRC value remains below unity (that is, does not exceed the breakeven point of 1) until the third year of the program, given an incentive value of at least $55, the highest evaluated incentive, and with a unit installed base of 12,500 units.

When the measure lifetime is 4 years, the TRC value can exceed 1 during the second year with an incentive value of at least $55 and a unit installed base of 10,000. In the third year, participant incentives can be as low as $45 and 13,500 unit installed base to get a TRC greater than or equal to one. It can also result a TRC greater than or equal to one in the third year at a $50 participant incentive of 11,500 unit installed base.

Lastly, evaluating the measure lifetime at 5 years, the TRC value can be greater than or equal to 1 during the second year with an incentive value of at least $50 and a unit installed base of 9,500. In the third year, participant incentives can be as low as $35 and 14,000 unit installed base to get a TRC greater than or equal to one. The maximum TRC value within the bounds listed is the result of the measure cost being $55, 15,000 unit installed base and the measure lifetime is 5 year, at a value of 1.14.

One major finding of this is that it demonstrates that labor costs comprise a crucial part of the measure cost (in this case the labor cost is $20 of the $80 total measure cost) to a relatively inexpensive product, which means it will take longer for the program to pay off. This results in the TRC values not reaching unity (TRC=1) for any scenario until year 2. Additionally, it shows that the increase in measure lifetime lowers the necessary unit installed base necessary to yield a TRC greater than or equal to 1.

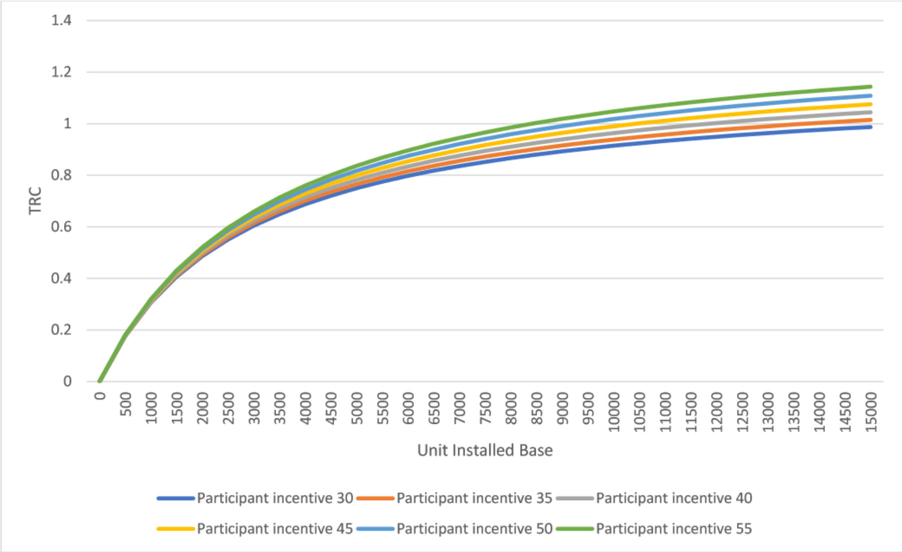


FIGURE 28: CONNECTED TIER 2 APS TRC RESULTS FOR MEASURE LIFETIME OF 5 YEARS

COMPARISON BETWEEN CONNECTED AND NON-CONNECTED TIER 2 APS

In order to compare the non-connected and connected Tier 2 APS potential program cost effectiveness, CalPlug calculated TRC values for both Tier 2 APS devices, keeping other factors constant. The inputs for the TRC calculation are the same for the connected Tier 2 APS as shown in Table 36 except that the participant incentive is held constant across calculations at $55 and the measure lifetime is held constant at 3 years. The inputs for the TRC calculation for the non-connected Tier 2 APS are the same other than the unit yearly energy net savings, which is 234 kWh/year for non-connected devices compared to 240 kWh/year for connected devices.

The following figure illustrates the results from the input values listed above. The orange line graphing the connected Tier 2 APS results and the blue line graphing the non-connected Tier 2 APS results. As shown in Figure 29, both the non-connected and connected Tier 2 APS yield TRC values greater than 1 (the breakeven point for cost and benefits of the measure) by the first year of the program. However, with a difference in unit energy net savings of only 6 kWh/year, the results do not show a substantive increase in TRC for the connected Tier 2 APS compared to the non-connected Tier 2 APS.

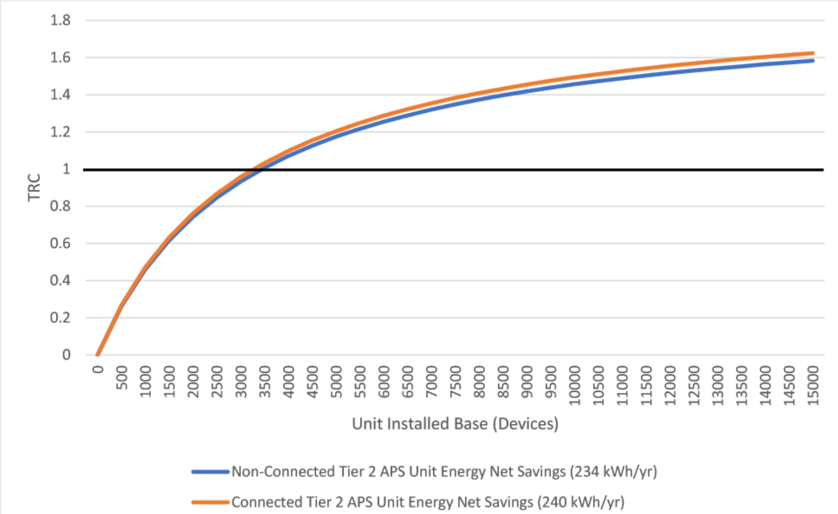


FIGURE 29 CONNECTED VERSUS NON-CONNECTED TIER 2 APS TRC RESULTS FOR MEASURE LIFETIME OF 3 YEARS

ANALYSIS OF DEVICE

The findings from the TRC calculations confirm that utility incentive programs for Tier 2 APS devices aimed toward AV equipment are promising.

Compliance with California legislation directing future IDSM programs is a crucial aspect for determining whether a device or system is viable. Both Brand-A and Brand-B Tier 2 APS products have been tested in California IOU field trials, with resulting published work papers demonstrating that both manufacturers meet state standards for EE initiatives.

It was established earlier in this section that connected and non-connected devices show relative equivalency in terms of hardware and software specifications and functionality, with the exception of wireless internet access capability. Results from two field trials indicated that non-connected Tier 2 APS devices save on average 234 kWh/year, and connected Tier 2 APS devices save on average 240.4 kWh/year (RMS, 2017; Vu, 2015), producing a marginal added savings value of 6.4 kWh/year for connected Tier 2 APS devices. Programs for implementation are seen as equivalent. However, the connectivity features require additional steps and requirements during installation; this could increase labor costs for direct-install programs and the chance of user error and misuse in the case of user-install programs. Perceived difficulty of use or installation may be an additional barrier to uptake.

On the other hand, the extra features available with the connected Tier 2 APS, despite their limited effect on energy saving, may add appeal for customers and increase the rate of uptake and the likelihood of continued use. At this point, no study results are available to quantify these issues.

As home entertainment systems represent a major draw of electricity demand in homes, and this usage is trending upwards, it is appropriate and timely to consider incentive programs aimed at managing residential devices. It is additionally important to note the ubiquity of wasteful energy consumption across different types of households. For example, the survey portion of SDG&E's field trial on Tier 2 APS revealed no significant correlation between demographic features and energy savings (Valmiki & Corradini, 2015). The main demographic data considered included number of AV devices, number of residents, cable subscription status, renting vs. owning, single-family vs. multi-family buildings, and households with or without children. This suggests that energy waste through AV systems crosscuts demographic groups and socioeconomic status.

Moreover, California field studies on Tier 2 APS in residences have shown promising retention rates of 78% for the SDG&E study (Valmiki & Corradini, 2015) and 84% for the PG&E study (Valmiki & Corradini, 2016), suggesting broad customer interest in Tier 2 APS devices.

Compared to more complex energy-management systems, Tier 2 APS systems are relatively easy to install and do not necessitate significant infrastructure upgrades for compatibility. Devices sold at commercial retail stores do not have any special requirements for professional installation. Manufacturers provide instruction manuals with their products, with the expectation that users will be able to follow a self-explanatory process to install their devices and adjust the settings to suit their needs. For connected devices, an additional Bluetooth guide is included in the instruction manual. For users who are already familiar with wireless internet setup procedures, this step may not prove burdensome. However, it is worth noting that most people working in the energy efficiency field or reading a report such as this are substantially more technologically capable than average. No research is available on how easily the average consumer can correctly install a Tier 2 APS device, but other findings show that many untrained users are, for instance, unclear about how to change their computer power management settings or what they mean (Pixley & Ross, 2014).

Previous California IOU field trials of APS Tier 2 all relied on direct installation of devices at the residential test site by vendors and engineering consulting firms, in order to implement customized metering capability. Even in the case of a larger IDSM program, it may be beneficial to continue professional installation because users may fail to install the device correctly. This might occur for devices that require the selection of a master device. Effective internet connectivity may also be impeded by a device that is not correctly set up, and if the basic functions of the device are operable, customers may remain unaware that the internet function on the device is effectively disabled. Any proposed program would benefit from addressing the potential for user errors or technical malfunctions to compromise the ability of the device to perform as intended.

Users could unintentionally reduce energy efficiency with their choices, as well. One standard, non-connected setting on many Tier 2 APS products is "Music Mode." This setting allows users to override the power down process for up to 8 hours (as opposed to the standard one hour on the default setting), while playing music or other background media. While this setting may not contribute extra energy consumption if used sporadically as intended, users who override the shutdown function on a regular basis may not receive any net benefits of energy reduction from using a Tier 2 APS device (Klopfer, Xia, et al., 2017b).

However, as manual overrides of shutdown functions require regular effort, a more likely result of noncompliance is the complete removal of the APS device. The PG&E field trial on Tier 2 APS devices found that the most common scenarios for removing the device involved customers who were accustomed to leaving the TV on all day, e.g., for pets. It is important to note that this study also identified a likely program persistence range of between 80-87%, meaning that only a minority of 13-20% would be likely to deliberately disable Tier 2 APS energy savings functionality.

Additional behavioral barriers to energy savings may occur in the case of connected Tier 2 APS systems. As outlined earlier, the added savings potential for connected versus non-connected devices is calculated to be relatively small (6.4 kWh/year, about 2.7% savings increase). In order to realize these savings, it is imperative for users to employ and interact with connected features on a regular basis. This means consistent monitoring of energy consumption via mobile app, adjusting device settings to lower energy usage if needed, as well as heeding advice issued by utilities (e.g. TOU warnings).

Tier 2 APS devices are suited to take advantage of TOU initiatives. Connected Tier 2 APS products in particular can be beneficial in enabling TOU reminders to household members through mobile apps. The ability to remotely power down devices via mobile app also assists customers in complying with TOU protocols. DR capability is not supported by Tier 2 APS. The types of devices controlled through Tier 2 APS, such as TVs and game consoles, are not amenable to intermittant power shutoffs during use, and customers would furthermore find this to be unacceptable.

CONCLUSIONS

This report reviews the current state of knowledge on the potential of new smart connected plug load devices and systems for success in utility sponsored residential IDSM programs.

A comprehensive list of standard household plug loads was used and filtered through a detailed criterion flowchart to identify the most promising connected solutions. Devices were selected for major or minor focus based on connectivity features that enable energy efficiency and demand response functions, potential unit energy savings, and positive market trends. Major focus deep dives were conducted for three devices: smart connected refrigerators, clothes washers, and pool pumps. Major focus deep dives were also conducted for two connected control systems: specifically, smart plugs controlling window air-conditioning units and in-sink hot water dispensers and Tier 2 APS devices controlling audiovisual entertainment devices. Program design evaluations are also presented with the goal of demonstrating the opportunities and challenges of different program types including downstream and midstream delivery channels, as well as discussing relevant program parameters for specific device categories. Minor scope devices and systems were also discussed.

PLUG LOAD ENERGY SAVINGS ENABLED BY CONNECTIVITY

Connected residential plug load devices are increasing filling the long-awaited role as the appliances of the future in the long envisioned smart home. Despite continued development and pressure from tech developers, chronic low uptake has continued to plague the marketplace with continual reevaluations on growth potential (Economist Staff, 2016;

MarketWatch, 2019b). The process to drive market awareness and value has not been linear, with many recent reviews and re-corrections on growth strategy.

User experience and solution value have been two key considerations in smart home technology growth. User experience is directly connected to ease of use. The now ubiquitous use of smart phones and tablets provides an easy and convenient interface to interact with smart devices. Even this added convenience may be too slow in some cases. The use of smart speakers to allow verbal commands to control home automation devices has provided a further catalyst to indirectly drive category growth. Many mainstream adopters have questioned the value of added complexity. In considering this, users must decide what applications bring true value while maintaining ease of use for all members of the household using the system. Currently health and security applications have been a substantial growth field. Energy applications also have grown with the smart connected thermostat being a major category. This device provides a clear value application by providing an easy and convenient interface for controlling home climate while providing energy savings benefits. Installation and setup is relatively easy and straight-forward and can be completed by the user or a handyman. The integrated smart thermostat solution works simply, operating without strong user intervention or tweaking. Other home management and device control systems have similar ease of use and reliance on settings rather than repeated behaviors: users may be primarily motivated by comfort, safety, or security, but in the process, substantial energy can be saved. In this manner, multiple substantial benefits for all stakeholders can be realized.

Using the smart thermostat as a model, shortcomings can be seen with other smart connected product categories, especially for many plug load devices. For large appliances, the setup of smart connected features is bounded by actual benefits that are able to be provided with contemporary devices. Consider smart refrigerators: being able to remotely see what's inside may provide some benefit to the user, but how often does a typical user want to adjust internal temperature set-points or the rate of ice production? Adding these features to smart applications does add value, but that value is largely limited by practical control. Most refrigerator users are aware that leaving the door open for extended periods wastes energy, so telling a user this is likely limited in potential behavioral change. In some cases, connectivity-enabled features could theoretically enable deep automated energy management, but the implementation is not present in current models. Accordingly, the impetus for the convenience value of selecting this feature in a device or setting up connectivity may be limited compared to other categories. Once set up, the actual energy saving capabilities require direct user identification of a condition and determination of a remedial action and follow-up continued action from this feedback. As refrigerators offer limited actions that users could do to save energy, the potential savings of feedback is limited.

Across product categories, energy efficiency savings due to connectivity are limited to notification-based behavioral interactions. As suggested by a PNNL study of connected major appliances, about 3-5% of energy savings (kWh/year) may be attributable directly to feedback-based connectivity features (Sastry et al., 2010). Furthermore, the connectivity criteria stipulated by ENERGY STAR specification guidelines for all large appliances do not offer concrete requirements specifically aimed at EE goals, which leaves manufacturers without clear guidelines or industry pressure to improve EE functionality of connected features. For example, connected refrigerators are currently limited to user alerts for EE savings through connectivity. While other potential modes of savings are possible, such as vacation mode and feedback capability that may be integrated into a smart home system, these solutions either have not yet been fully implemented by manufacturers or have not been systematically tested in field trials. This finding is corroborated by similar results from the 2016 Fraunhofer home automation scoping report (Urban et al., 2016), which also discussed the limited nature of energy savings potential obtained purely through feedback alerts and behavioral adaptation.

The potential for energy efficiency or conservation is limited for other major appliances as well. For smart connected clothes washers, similar concerns exist about the action space for user action in response to feedback, although there are more ways users can waste energy with inefficient clothes washing practices. Clear feedback indicating concerns about use (e.g. inappropriate settings for load type or exceptionally large load for setting) can help average users direct energy use feedback to reduction. Leveraging cloud-based intelligence from onboard sensors leading to improved controllability is also a potential means of savings but not one well explored.

Devices such as smart plugs and other circuit-level control solutions can provide rudimentary device control through power cut mechanisms. With an increasing number of devices with onboard control electronics, this type of power control can substantially limit the total number of applicable devices that can be effectively and safely controlled through this system. Some more advanced IoT solutions have infrared, RS-232 Serial or MODBUS interfaces to help mediate integrated device control rather than power cuts, yet these devices are not widespread in the market and are generally focused on controlling specific devices. Smart connected pool or fountain pumps are similar in terms of nuanced control. Feedback can be used to vary device flow to avoid over-producing, especially at non-required times with sufficient granularity of control. The effective use of this type of control requires a controller system that can act upon periods of waste to reduce energy use. This may be using a feedback loop such as a temperature/thermostatic system, occupancy control, or by use of a timer. Unlike the smart thermostat example, this solution is individually tailored to a specific application and control device. The implementation for control can substantially complicate setup and stability concerns by adding multiple points of system failure. While savings is possible, the actual savings is greatly dependent on application. The major potential targets are large loads with simplistic rules of operation that are poorly controlled in general use. Continued development of more advanced IoT systems with edge intelligence and/or advanced AI-enabled cloud intelligence will continue to improve the capability of these devices to work in an adaptable role to reduce user setup burden, while acting in ways that better balance energy savings with user experience. Continued hardware development to better interface with devices and to allow better onboard control can help also make such solutions more widely applicable.

Continued interest on the part of technology developers to provide solutions that use intelligence to actively reduce energy usage is ongoing. Extended investigations in using smart plugs for specific applications in a connected, smart home setting is not well characterized as far as best practices. Comprehensive evaluations of approaches will be needed with extensive independent field trials focused around this general approach to show effectiveness in commonly applicable demonstration applications.

NON-CONNECTIVITY SAVINGS

Although the primary focus of this report is on the impact of smart connected devices, a brief mention should be made of opportunities for non-connected plug loads. A relatively high percentage of energy is saved through improved mechanical function of devices, such as high-efficiency machines compared to baseline products. This finding is especially clear in CalPlug's study of variable speed pool pumps, which save about 70% of energy compared to traditional single-speed pumps. As discussed above, these savings are exclusively due to the particular nature of the Pump Affinity Law, which dictates a non-linear relationship between pump speed and energy consumption, so that a pump operating at about 1/2 of the original speed requires only about 1/8 of the original energy draw. This example highlights an important point: engineering of machinery for improved mechanical function and efficiency underpins energy savings, while connectivity features at the individual device level may contribute only small reductions in energy usage. Indeed, although pool pumps demonstrate this finding most dramatically, similar findings are discussed regarding high efficiency refrigerators, which rely on machine optimization of defrost cycles and temperature regulation for energy savings, and front-loading washing machines, which use design features to dramatically reduce the amount of water used and associated water heating activity required. This is also true of system-control devices, such as Tier 2 APS products, which were found to be very comparable in energy use between connected and non-connected versions of the same models. While connectivity is an important aspect of emerging products, it is nevertheless worthwhile to include energy savings due to improved physical function in analyzing potential device candidates for IDSM programs.

Plug Load Demand Response Capabilities in Connected Plug Loads

Demand response inherently requires connectivity, making smart home devices ideal to leverage. Although the goal of this report was mainly to address EE, the DR aspect of IDSM is part of the energy management operation of many smart home devices. The connection is so deep that the original definition of smart connected appliances by ENERGY STAR specifications for connected appliances prioritized DR capability in their connectivity criteria standards. This is even to the point of providing a 5% allowance in energy use to provide DR capabilities, compared to non-connected products within the same device category. Other independent analysts have voiced similar concerns, as noted in various letters to ENERGY STAR (BSH Home Appliances Corporation, 2011; Pacific Gas & Electric Company et al., 2011). While improved ENERGY STAR standards for EE goals may help to alleviate the problem of excess energy use through connectivity, many of these goals rest on addressing behavioral motivation and change, which is more difficult to target than the relatively simple task of programming machines to respond to automated signals. Nevertheless, CalPlug's assessment has found only small energy savings from DR capabilities due to the limited control that can be provided for many categories of devices. For major appliances, unsafe operation can exist from stopping major functions (i.e., substantially reducing or disabling cooling capacity in a refrigerator). The major mode of action for refrigerators and freezers is to limit use of accessory items such as ice makers and defrost cycles during a DR event and pause compressor cycles for a specified period in some cases. Similarly, for other appliance categories such as washers, other than lockouts, abbreviated cycles are a potential means of action that does provide some level of event total load reduction and total average power reduction across the day of a DR event. Many consumer electronics are not substantial targets for DR events, due to the chance that user experience will be largely impacted. Accordingly, the Tier 2 APS and its control of audiovisual systems has been investigated primarily as EE approach rather than being applied to DR. Screen and light diming are always considered strategies for DR with displays, yet implementation of effective residential solutions utilizing these approaches in a user unobtrusive way is still forthcoming.

Program Cost Effectiveness (TRC) Considerations

In this report CalPlug used the total resource cost (TRC) as a metric to evaluate key aspects of program design to assess the cost effectiveness of measure strategies based on devices in categories that were investigated. The authors built and demonstrated a screening tool and performed numeric analysis to assess the sensitivity of resultant TRC values to the variance of input parameters due to changes in potential program models. The most important factor for TRC calculation is the unit energy net savings. Products with truly substantial energy savings are guaranteed to be successful given reasonable ranges for other TRC inputs (for example, pool pumps). High unit energy savings are a challenge for residential plug loads, because most devices just do not consume enough baseline energy at the individual level for a reduction in energy usage to make a significant difference. For example, a small kitchen appliance such as a coffee maker or blender already uses such small amounts of energy that the fractional difference between the baseline energy draw and energy savings from power-saving features or control functions would be too small to justify an expensive, resource-limited IDSM program.

Potential exceptions may be large appliances, which draw relatively large amounts of energy on either an intermittent basis (e.g., washing machines) or sustained basis (e.g., refrigerators). However, as CalPlug found from deriving TRC ranges for smart connected washing machines and smart connected refrigerators, even large plug load appliances struggle to be effective in IDSM programs. Although CalPlug's analysis found relatively low TRC values for both refrigerators and washing machines, these device categories were important to include in deep dives because they have high market trend trajectories and they currently have the most comprehensive market-ready connectivity features among major appliances. Thus, the preliminary flowchart analysis suggested that these devices should be considered in greater depth to determine possible TRC ranges at a more granular level.

CalPlug's results showed limited energy savings potential for connected major appliances in their current state of market-ready features. There are a few reasons for this. First, connected appliances are expensive products. Indeed, a recent work paper on connected refrigerators published by SCE suggested adding an overhead connectivity cost of $300 to the measure cost per device (Snaith, 2016). This reflects the higher average cost of connected refrigerators compared to non-connected high-efficiency appliances, which are already priced in the $1000-$1200 range. Considering also the standard service and installation fee, the measure cost reflects a very expensive program for the utility to initiate.

Other challenges to positive TRC results are measure lifetime and unit installed base. The standard lifetime of an IDSM program issued by California by IOUs is 3 to 5 years. While relatively short programs may be easier to assess accurately for success, they may not endure long enough to see a program that has high start-up costs through to a breakeven or cost-effective point. This may be especially true for large appliances with high base measure costs. Similarly, shorter programs may curtail the unit installed base, as initial adaptation of the program may be slow at first. However, as discussed in the section on market transformation, diffusion of emerging technology may have a non-linear trajectory, and may accelerate rapidly despite slow initial uptake.

A potential mitigation strategy to improve TRC outcomes may be to offer the product purely at the midstream level, which would somewhat lower the expense of the program, and may substantially improve the measure lifetime and unit installed rate. Midstream programs would eliminate labor costs to the utility and pass them on to retail partners. However, as labor costs are estimated by the IOU at only about $40/hour, this would not represent a significant cost reduction, and TRC values would not likely improve substantially from labor cost reduction alone.

More significant benefits of midstream programs would affect the measure lifetime and the unit installed base, which have a direct relationship. By exposing the product to a wide variety of retail venues (especially mass-market big box stores with wide geographic dispersal), the unit installed base could gain more traction than in location- and time-limited downstream programs. Under these conditions, the unit installed base could well exceed the standard 5,000-15,000 units that are typically assumed for IOU downstream programs.

Similarly, as the unit installed base rate increases, the earnings of the program as a percentage of the total IOU portfolio may also increase, resulting as a High Impact Measure at 1% of the earnings. This could encourage the development of a program oriented toward market transformation, which could exceed the standard 3 to 5-year measure range if it continues to generate profit. As market transformation typically requires at least 10 years to yield visible results, measures that are not employed for sufficient lengths of time may not fully realize their objectives and may be more difficult to assess for success. Implementing midstream programs to target large appliance plug loads may be beneficial based on this analysis. However, as previous appliance programs offered by California IOUs have been at the downstream level, it is difficult to estimate the probability of success for midstream programs. The dynamic retail and customer demand environments make assessment even more challenging.

Measure Indirect Energy Benefit Considerations

Beyond the deemed savings or performance values mandated within programs to assess measure performance, design of programs to accomplish other points should be considered. While reporting of energy usage information may have practically bounded impact on reducing total energy use it is still a component of AB793 and required for compliance. Support of solutions that may have reduced complexity but are applicable to households that do not have the high level of connectivity required for full system integration should be considered. An example of this is a variant of the Tier-2 APS device that operates using smart phone Bluetooth connectivity rather than home Wi-Fi for cloud access. Some feature operations of connected systems can take place adequately without fully connected interfaces. The control of an LED light bulb with a timer and motion sensor uses substantially less energy when implemented without a connected variant, using IoT sensors and a smart bulb (Klopfer, Xia, et al., 2017b). In many applications, simpler can be better. Unless the connectivity is already in place, adding the energy usage required for connectivity for simplistic control strategies can negate any energy savings while adding to risk of solution instability. The displays on a device may have similar practical notification impact to a consumer: for instance, an indicator light on a device notifying the user of an issue (such as need for a filter change) may have just as much impact as an alert on the user's smart phone, meaning the connected solution did not add substantial value. It is important to remember that adding connectivity without a clear understanding of how the connectivity improves energy use can lead to inconsequential waste, and that in some cases, more energy can be saved by non-connected equivalent solutions.

Other Considerations

In addition to specific program, measure and device recommendations, there are several general background considerations that help to inform IDSM project design and implementation for connected devices.

One such consideration is acknowledging the difference between intelligence and connectivity. Smart and connected have largely been interchangeable terms in marketing literature, leading to general confusion in the market place. The inclusion of artificial intelligence has further muddied what comprises a smart system over differing intelligence levels. CalPlug sees connectivity as a means to implement deep intelligence. The classification table developed by the CalPlug team explains the varying levels of connectivity sophistication, from basic energy usage reporting functionality (category 1a) to edge-computing capability that can form the basis of a true smart home system (category 5b). Although reporting energy activity through basic internet connectivity can help users to understand their energy consumption patterns, users must manually perform any implementation of energy saving measures. In contrast, machine intelligence functions at the holistic, systemic level, so that household devices can self-regulate energy consumption based on the energy consumption patterns of other devices in the household. These regulation activities may be enhanced or mediated through home smart speaker systems. As CalPlug's analysis has demonstrated, most connected appliances currently available on the market do not yet possess this level of sophistication. However, these features are within reach of current technology and smart home systems more fully integrated with connected major appliances are an evolving trend. As smart systems have greater potential to capitalize on energy efficient features for total household energy savings and power management than individual devices, this trend is an important over-the-horizon consideration for targeting connected devices in IDSM programs.

Alternatively, it is just as important to point out the potential net energy use increases that could occur through connected devices. As discussed in the case of washing machines, manufacturers tend to develop connectivity features with user convenience in mind rather than focusing on high efficiency energy savings potential. The ability to control a device remotely is convenient and may save time for the customer, but except in the case of using these features to follow TOU directives, control itself does not translate into any energy savings. Moreover, in some cases, control capability may contribute wasted energy. For example, the option to pre-heat a connected oven while commuting to home provides convenience. However, there is a strong possibility that the customer will overestimate the time needed to heat the oven and may underestimate the time it will take before arriving home. In this scenario, a smart feature could cause the customer to use more energy than would have been used without the ability for remote control.

At the aggregate population level, it is also important to consider the overhead energy consumption of wireless internet mediated by mobile apps or smart speakers. Some household energy savings are transferred as an externality to the energy cost of IoT and cloud computing. This energy is not used by residential customers but is added to the emissions produced by backend servers in data centers, which are also part of the larger utility-operated grid system. Each mobile device may consume up to 2 W/year. in Wi-Fi connectivity processed through cloud-based servers. Considering these estimates, the background energy overhead needed to support connectivity features of smart appliances or emerging technology products in aggregate has the potential to reduce or outweigh net energy savings produced at the individual household level.

PROGRAM DESIGN

There are several aspects of program design that should be considered when developing IDSM strategies for plug load products.

First, the feasibility of the individual or system control device should be assessed. IDSM programs work best when they can appeal to wide audiences that cross-cut demographic market segments. Particularly if midstream programs are considered, it is important to keep in mind that retail partners cater to many different types of households across varying geographic and climate zones. The product should be simple to explain to end-users, and end-users should be able to operate the device without expert knowledge. Moreover, the device should be easily integrated into existing home infrastructure, and connected products should be able to interface with existing Wi-Fi, Bluetooth, and home smart speaker devices. Programs should aim at targeting products above the basic ENERGY STAR requirements to minimize free-rider effects.

Second, the incentive structure of the program should be considered. Incentives or rebates should be easy to communicate and have the potential to drive significant energy savings for the utility. For midstream retail programs specifically, the product should be able to produce robust earnings, and the incentive structure should be mindful of seasonal sales patterns and tailored to the needs and wants of targeted customers.

Downstream or midstream incentives should be designed around the needs of the device in questions. Care must be taken for specialty services, such as variable speed pool pumps, which must be installed by a certified technician for programmable features to be optimized. For these products, downstream programs with deemed installation by a utility-qualified contractor should be used to maintain quality control. Devices with complex features or poorly understood functionality may also be best suited to the downstream delivery channel. There is some evidence from the IOU field trials for Tier 2 APS that suggest that emerging technology with advanced control features may fail to deliver results because average end-users do not know how to optimize energy saving features. Technician-provided education may help to improve public understanding of these products.

Previous large appliance incentives have tended to be downstream; however, shopping trends favoring big box retailers with robust resources for distribution and installation are making midstream programs more feasible. Incentive types that are well adapted to downstream programs may need to be adjusted to midstream programs. For example, simple buydown incentives distributed directly to the end-user are not suitable for Retail Products Platform programs. Instead, shared incentives or accelerated programs are more appealing to midstream retail partners. Shared incentives enable retailers to pass down part of the incentive to the customer while retaining a designated portion for their own marketing and distribution needs. Accelerated incentives are calibrated to accommodate fluctuations in seasonal sales patterns and are front-loaded toward the beginning of the calendar year to offset the cost of retail operations that accrue early in the year and taper off toward the end.

Programs should be developed to encourage and deepen participation. Program administrators should be mindful that customers are generally more interested in cash savings than energy savings, so programs should clearly communicate how energy savings translate directly into reductions of utility bills. Additionally, rebates should be easy for the end-user to redeem, as this encourages customers to select high efficiency devices over comparable non-efficient devices. For example, midstream programs with shared incentives should allow the customer to receive the incentive at Point-of-Sale. As connectivity features grow, midstream programs should make provisions/qualifications for employee training at the retail partner sites. More generally, programs should seek to expand the customer pool by aiming incentives at hard-to-reach customers, including multi-family housing, low income residential areas, and small home-based businesses.

Finally, program evaluation processes should ensure proper measurement of baseline performance during the first year of the program in order to clearly determine the success of the program and recalibrate the baseline metrics on an ongoing basis. Performing regular review of the program helps to combat free ridership by ensuring that attribution is correctly calculated and by enabling a dynamic environment where new products can be continuously added to target high-performance devices that surpass current ENERGY STAR minimum requirements.

MARKET TRANSFORMATION

Retail Products Platform (RPP) programs have an advantage over Retail Acquisition (RA) programs for market transformation, but RA programs are easier to analyze, because they are controlled within stricter time and location bounds. RPP programs are delivered through retail channels, meaning they are subject to the whims of market supply and demand and subject to changes in the larger economic and political environment. This makes market transformation difficult to predict. Market transformation can be best analyzed using the

Bass Diffusion Model, although this relies heavily on current assumptions and decreases in accuracy for longer term predictions as uncertainty increases.

Products with currently low market transformation with a positive trajectory for market penetration should be prioritized. However, as Letschert et al. (2013) report in their study on energy efficient product sales, there is an inflection point (as low as 30-40%) where market transformation enters a positive feedback loop and incentives are no longer needed. This finding further highlights the importance of performing regular program reviews.

More generally, market transformation is dependent on scalability of the product. This reinforces the need to communicate with retail sales partners regarding relevant market trends, product demand and popularity, and the ability for the product to succeed in various markets and across market segments. Moreover, programs that include measures to develop relationships between utilities and retailers and provide education retail salesforce employees tend to have increased success at the midstream level. For connected devices, specialized training for retail staff to improve communication of features and functionality to customers is beneficial.

Over-the-Horizon Trends

The development of new smart home product categories and the expansion of up-and-coming categories such as telemedicine also adds the potential for new opportunities as well as challenges. Continued improvements in the controllability of current devices and systems also expand opportunities. For example, robotic vacuum cleaners may soon be able to outperform conventional human-operated ones with perspective to energy performance. Edge intelligence solutions will likely increase the scenarios in which the robot can outcompete the human with respect to energy. Adding connectivity to a device with edge intelligence can potentially allow this robotic product category to perform health, safety, and security functions in addition to cleaning, allowing consolidation of functionality to less hardware, inherently saving energy. Thus, the reduction of redundant functional solutions is an indirect way that connectivity can save energy in such devices. Table lamps integrated with aroma diffusers, lamps and air purifiers, as well as smart speakers integrated with network/safety hardware, have already been demonstrated. These consolidation trends are likely to increase in the near future. As product categories continue to evolve, new forms of controllability may emerge. For instance, many classes of consumer electronics are resistant to demand response events because they cannot reduce energy use while maintaining functionality. However, much of what has been learned from mobile computing can be applied backwards to plug load electronics, where critical battery events trigger device processing changes that reduce energy use without substantial user impact. Further application of this approach may improve the applicability of DR to a wider variety of consumer electronics.

Connectivity itself is a major consideration to solution implementation. As wireless providers continue to upgrade and expand their service to include faster, more reliable internet, such as 5G connectivity, implications of improved national infrastructure will affect the supply and demand of connected appliances, emerging technology, and consumer electronics. Manufacturers of smart products will see improved capability to develop connectivity communications features that rely on high-speed internet to function properly. Edge devices and link hardware can implement strategies such as micro sleep and inherently low energy use protocols to prevent excess energy use on idle links. Much work is presently being developed for smartphone applications that will likely filter back to broader IoT applications. Simultaneously, users continue to increasingly see the benefits of implementing smart home solutions for convenience and potential energy savings, leading to higher market demand for connected devices.

These trends are accompanied by potential challenges, including the need for utilities to implement more sophisticated power management and grid distribution systems to meet the rising electricity demand. Future IDSM programs may furthermore seek to integrate online retail channels into incentive programs, as increased home internet usage enables and encourages customers to purchase electronics and appliances through third-party distributors such as Amazon. These challenges and opportunities remain to be addressed in future IDSM evaluation projects.

UTILITY RECOMMENDATIONS

TARGETS FOR ENERGY EFFICIENCY PROGRAMS

Most smart connected solutions rely on human-in-the-loop energy management as a primary means of energy use reduction. This behavioral mode of operation has been shown to be successful but can be limited in total savings potential and duration of action. Additional savings can be generated using automated control systems depending on the capability of the detection or sensing system, the intelligence of the processing system to properly intuit periods of savings, and the capability of the device to act upon these periods with substantial net savings to justify the action. Smart connected major appliances have limited bounds for energy usage reduction. Circuit control systems can provide substantial control capability, but it may be challenging to maintain reliable interface control across many products. Continued improvement in this category to better integrate with device operation for multiple classes of devices will reduce this barrier to entry for providing control.

DEMAND RESPONSE PROGRAM CONSIDERATIONS

Demand response solutions inherently rely on connectivity and are a conceptual fit for smart connected devices. Many classes of plug loads, especially consumer electronics, are traditionally difficult to integrate with demand response control. Reduction of device functionality can substantially reduce the quality of user experience, requiring clear communication of action and opt-out capabilities. Demand response solutions are better suited to major appliances for which changing the timing of usage is less disruptive to the users' schedule than for office or entertainment devices. Multiple strategies can be used, such as delaying operation or expediting processing cycles to reasonable halt points. This report considers demand response as a minor discussion aspect.

ENERGY TIME OF USE PROGRAM CONSIDERATIONS

Communication to users or automatic timing for actions requires coordination and connectivity to manage notifications and alerts. Many classes of smart connected devices can communicate to users to help reduce usage during high cost periods. Direct, automatic, coordinated action is more challenging to implement and requires processes that can be ramped up and down depending on time of day without direct user impact. A major example is water heating and climate control, but other more sophisticated approaches include reducing fountain and pool pump flows, extending drying processes for clothes, or automatically adjusting plug load luminaries to a default dimmer setting that can be overridden by the user if required. These approaches are largely not implemented into wide consumer solutions at the present time. Continued thought leadership by utilities to technology innovators can help guide the development of more feature-rich and integrated solutions that help manage energy usage based on time of use or planning of use for distributed generated energy consistent with advanced operations of smart home energy management systems.

Best Practice Considerations for Program Implementation

IDSM programs work best when they can appeal to wide audiences that cross-cut demographic market segments and focus on a product that is simple to explain to users. Users should be able to operate the device without expert knowledge, and the device should be easily integrated into existing home infrastructure. Incentives or rebates should be clearly communicated and have the potential to drive significant energy savings for the utility. For midstream retail programs specifically, the product should be able to produce robust earnings, and the incentive structure should be mindful of seasonal sales patterns and tailored to the needs and wants of targeted customers.

Retail Platform Products programs are best matched to drive market transformation. Products with current low market penetration with a positive trajectory for increased market share should be prioritized. Market transformation is dependent on scalability of the product and depends on the utility's ability to communicate with retail sales partners regarding relevant market trends, product demand, and popularity.

Demand response capability is considered in the context of connected major appliances. CalPlug's assessment has found only small energy savings from DR capabilities for major appliances such as refrigerators and washing machines, due mainly to the limited nature of DR events.

The most important factor for TRC calculation is the unit energy net savings. High unit energy savings is a challenge for residential plug loads, because most devices do not consume substantial baseline energy at the individual level.

Other challenges to positive TRC results are measure lifetime and unit installed base. A potential mitigation strategy to improve TRC outcomes may be to offer the product at the midstream level, which would somewhat lower the expense of the program, and may substantially improve the measure lifetime and unit installed rate.

Current codes and standards for ENERGY STAR connectivity criteria do not offer concrete requirements specifically aimed at EE goals and are focused mainly on complying with DR directives.

Testing and Evaluation Programs, Codes and Standards updates

Residential plug loads and consumer electronics, both with and without smart connectivity, have benefited from common efficiency standards and well-designed evaluation programs. Examples of this include reduction of standby power due to efforts such as the set-top box voluntary agreement sponsored by CTA and the DOE external low voltage power supply efficiency standards. Other voluntary agreements such as the broadband code of conduct show the potential to reduce energy use in telecommunications links and has applicability to a number of IoT device technologies. Approaches such as micro sleeping and low power standbys could reduce link energy use, a critical concern with an increasing number of IoT devices present but have not yet been implemented industry-wide. Continued efforts in implicitly improving best practices for implementation through EPA/ENERGY STAR efforts helps improve general market product performance. Overall, utility efforts supporting ENERGY STAR and voluntary agreements in addition to careful guidance of policy have a proven track record of positive action. It was a set of California IOUs that provided strong thought leadership to ENERGY STAR regarding a 5% allowance for energy efficiency to implement DR in smart connected appliances. Continued effort in guiding solution development will likely continue to show benefits in the future.

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APPENDIX A

List of all residential plug loads considered in discussion for this project

Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Climate Control									
Connected Thermostat	8	No	Yes	Yes	0	0	0	1A- Not a plug load; HVAC; Out of scope.	Internet Enabled Thermostat; As a device it is out of scope, however as a system it can be considered for potential energy savings
Central Air Conditioner	8	No	No	Yes	0	0	0	1A- Not a plug load; HVAC; Out of scope.	New AC models have ENERGY STAR criteria; savings are through HVAC system; out of scope
Furnace	8	No	No	No	0	0	0	1A- Not a plug load; HVAC; Out of scope.	Out of scope; HVAC
Automatic Window Covering + Managed Control (Controller Action)	8	No	Yes	No	0	0	0	1A- Not a plug load	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)
Air purifiers	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Insufficient device population; Possible future IDSM strategy through home assistant hubs
Humidifiers	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Insufficient device population; Possible future IDSM strategy through home assistant hubs
Dehumidifiers	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Insufficient device population; Possible future IDSM strategy through home assistant hubs
HVAC Zoning (Thermostat Controller Action)	8	No	Yes	No	0	0	0	1A- Not a plug load	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)

[1] 1 = Major Scope Devices, 2 = Major Scope System (Tier 2 APS), 3 = Major Scope System Peripheral Devices (Tier 2 APS), 4 = Major Scope System (Smart Plug), 5 = Major Scope System Peripheral Devices (Smart Plug), 6 = Minor scope system peripheral devices (Tier 2 APS), 7 = Minor Scope System, 8 = Out of Scope

[2] Importance of discussion: 0 = N/A, 1 = negligible, 2 = considerable, 3 = substantial

Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Climate Control continued									
HVAC Diagnostics (Thermostat Controller Action)	8	No	Yes	No	0	0	0	1A- Not a plug load; too low of device population	Energy savings are indirect through feedback to the costumer; Out of Scope, HVAC
Smart ventilation (Thermostat Controller Action)	8	No	Yes	No	0	0	0	1A- Not a plug load; HVAC; Out of scope.	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)
Smart Ceiling Fan	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Increase HVAC-based management controls though sensors/mobile apps
Window AC/Portable AC	5	Yes	Yes	Yes	3	2	2	1D, 2C, and 2D- Compatible for system-based control	Discussed as a system with smart plugs
Nighttime Ventilation Cooling (Thermostat Controller Action)	8	No	No	No	1	0	0	1A- Not a plug load; HVAC; Out of scope	A method of scheduling natural ventilation to minimize HVAC loads
Ceiling Fans	8	Yes	No	No	0	0	0	1I- No IDSM strategy for energy savings potential	No current strategy for potential savings
Air Conditioning Precooling (Thermostat Controller Action)	8	No	No	No	1	0	0	1A- Not a plug load; HVAC; Out of scope	A technique that offsets AC temperature to reduce compressor cycling degradation
Lighting									
Digital light Switch (Light Control Panel Controller Action)	8	No	Yes	No	1	0	0	1A- Lighting; Out of scope.	Touch sensitive switch with sensors to operate lighting and HVAC; out of scope
Lighting Control, Occupancy (Light Control Panel Controller Action)	8	No	Yes	No	1	0	0	1A- Lighting; Out of scope.	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)

[1] 1 = Major Scope Devices, 2 = Major Scope System (Tier 2 APS), 3 = Major Scope System Peripheral Devices (Tier 2 APS), 4 = Major Scope System (Smart Plug), 5 = Major Scope System Peripheral Devices (Smart Plug), 6 = Minor scope system peripheral devices (Tier 2 APS), 7 = Minor Scope System, 8 = Out of Scope

[2] Importance of discussion: 0 = N/A, 1 = negligible, 2 = considerable, 3 = substantial

Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Lighting continued									
Lighting Control, Photosensor (Light Control Panel Controller Action)	8	No	Yes	No	1	0	0	1A- Lighting; Out of scope.	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)
Lighting Control, Dimming (Light Control Panel Controller Action)	8	No	Yes	No	1	0	0	1A- Lighting; Out of scope.	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)
Non-Connected Luminary	8	Yes	No	No	0	0	0	1A- Lighting; Out of scope.	No current strategy for potential savings
Connected Luminary (Table/Floor lamps)	7	Yes	Yes	No	2	0	0	1B- Minor discussion scope	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)
Edison Base Smart Bulbs	7	No	Yes	Yes	2	0	0	1B- Minor discussion scope	Possible future IDSM strategy through home assistant hubs (Google Home, Amazon Alexa, or Echo)
Water Heating									
Demand Recirculation Control	5	Yes	Yes	Yes	2	0	2	1D, 2C- Compatible for system-based control	Discussed as a system with smart plugs
Demand Temperature Modulation Control	5	Yes	Yes	Yes	2	0	2	1D, 2C- Compatible for system-based control	Discussed as a system with smart plugs
Point of Use Hot Water (Device)	5	Yes	Yes	No	2	0	2	1D, 2C- Compatible for system-based control	Discussed as a system with smart plugs

[1] 1 = Major Scope Devices, 2 = Major Scope System (Tier 2 APS), 3 = Major Scope System Peripheral Devices (Tier 2 APS), 4 = Major Scope System (Smart Plug), 5 = Major Scope System Peripheral Devices (Smart Plug), 6 = Minor scope system peripheral devices (Tier 2 APS), 7 = Minor Scope System, 8 = Out of Scope

[2] Importance of discussion: 0 = N/A, 1 = negligible, 2 = considerable, 3 = substantial

Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Energy Management w/ controls									
Connected Smart Plugs (System Actuator)	4	Yes	Yes	Yes	2	1	2	1F, 1G- System Actuator Device; Considered for major scope with other relevant devices	Smart plug paired with peripheral devices
GFCI Outlet	8	Yes	No	No	0	0	0	1B- Too low of a unit energy consumption	Required by building codes
Advanced Power Strip, Tier 1	8	Yes	No	No	0	0	0	1I- No IDSM strategy for energy savings potential	Non connected device; no IDSM managnement capability
Connected Advanced Power Strip, Tier 2 (System Actuator)	2	Yes	Yes	Yes	3	0	0	1F, 1G- System Actuator Device; Considered for major scope with other relevant devices	APS Tier 2 paired with peripheral devices
Integrated Home Energy Monitoring and Management System	7	Yes	Yes	No	2	1	2	1B- Minor scope system discussion	Consistent with advanced HEMS solutions
Home Energy Display & Feedback	7	Yes	Yes	No	2	0	0	1B- Minor scope systems discussion	Reporting feedback from Integrated Home Energy Monitoring and Management System
Consumer Electronics									
TV (Device)	3	Yes	Yes	Yes	3	0	0	1D, 2C- Compatible for system-based control	May be controlled through energy management system (e.g. Tier 2 APS); may have device-level energy savings features
PC-Desktop (Device)	3	Yes	Yes	Yes	3	0	0	1D, 2C- Compatible for system-based control	May be controlled through energy management system (e.g. Pier 2 APS); may have device-level energy savings features

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Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Consumer Electronics continued									
Set-top box: Streaming (Device)	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Examples include: streaming services and TV dongle add-ons such Chromecast, Apple TV, Amazon Fire Stick, etc.)
Digital television adapter/ Converter box (Device)	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Media device
Entertainment Media System	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Devices include: sound bars and home theater equipment
LED Projector (Device)	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Media device
VCR Player (Device)	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Declining trend in device population
Blu-ray Player (Device)	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Declining trend in device population
DVD Player (Device)	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Declining trend in device population
Game Consoles (Device)	6	Yes	Yes	No	2	0	0	1D, 2C- Compatible for system-based control	Declining trend in device population; May be controlled through energy management system (e.g. Tier 2 APS)
Rechargeable Mobile Computing Devices	8	Yes	Yes	No	0	0	0	1B- Too low of a unit energy consumption	Devices Include: Mobile phones, laptops, and tablets
Generic Rechargeable Devices	8	Yes	Yes	No	0	0	0	1B- Too low of a unit energy consumption	Devices Include: rechargeable vacuum, toys, short range mobility devices electric scooters & bikes, and power tools

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Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Large and Small Home Appliances									
Connected Pool/Fountain Pump	1	Yes	Yes	Yes	2	3	2	1F, 1G- Major Scope Discussion	Discussed in detail in the report
Connected Washer	1	Yes	Yes	Yes	3	2	2	1F, 1G- Major Scope Discussion	Discussed in detail in the report
Connected Refrigerator/Freezer	1	Yes	Yes	Yes	3	1	1	1F, 1G- Major Scope Discussion	Discussed in detail in the report
Dishwasher	7	Yes	No	Yes	2	0	0	1B- Minor Scope Discussion	Possible trends for IDSM strategies in the future
Dryer	7	Yes	No	Yes	2	0	0	1B- Minor Scope Discussion	Possible trends for IDSM strategies in the future
Stove Range/Ovens with ventilation (system)	8	Yes	No	No	0	0	0	1I- No IDSM strategy for energy savings potential	May be considered with connected thermostat, HVAC; Out of scope
Multi-functional cookers	8	Yes	Yes	No	0	0	0	1B- Too low of a unit energy consumption	Devices include: instant pot, rice cooker, air fryer, crockpot/slow cooker, toaster oven, and waffle/sandwich iron
Mixers	8	Yes	No	No	0	0	0	1B- Too low of a unit energy consumption	Devices include: juicers, blenders, coffee grinders; not on continuously consume energy for short amounts of time.
Coffee makers	8	Yes	No	No	0	0	0	1B- Too low of a unit energy consumption	Devices include: pod coffee, drip coffee, espresso machines
Small electric kitchen appliances	8	Yes	No	No	0	0	0	1B- Too low of a unit energy consumption	Small appliances include: wine opener, can opener, pasta maker, electric peeler,etc.
Garbage Disposal	8	Yes	No	No	0	0	0	1I- No IDSM strategy for energy savings potential	Kitchen device
Microwave	8	Yes	Yes	No	0	0	0	1B- Too low of a unit energy consumption	Used for small amounts of time with little standby energy consumption from clock display

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Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Security/Accessibility/ Medical Devices									
Medical Devices	8	Yes	Yes	No	0	0	0	1I- No IDSM strategy for energy savings potential	Head unit, data storage connectivity + links + Security Devices: Security Cameras, night-lights, motion sensors, digital timers, alarms, doorbells, and smart Locks
Home Assistance Hubs/Tech (Google Home, Siri, Echo, Alexa, etc.)	7	Yes	Yes	No	0	0	0	1B- Minor discussion Scope	May be considered with HEMS or device specified apps
Medical Devices Respiratory	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	CPAP Machine, ventilator, oxygen cylinder, bi-level positive airway pressure, and Nebulizer
Medical Devices mobility	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Stair Lift, lift equipment, hospital beds (Massage bed), scooter, electric wheelchair
Medical Devices Generic	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Devices include: blood pressure monitors,blood glucose monitors, electrocardiogram monitors/home telemetry unit
Network attached data storage	8	Yes	Yes	No	0	0	0	1I- No IDSM strategy for energy savings potential	Computer Data Storage
Network Gateway/IoT gateway	8	Yes	Yes	No	0	0	0	1I- No IDSM strategy for energy savings potential	Computer networking device
Uninterruptible power source (UPS)	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Backup power source

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Individual/Category devices	Scope Rating[1]	Plug Load /MEL?	Connected?	Claimable Savings?	EE[2]	DR[2]	TOU[2]	Flow chart characterization	Notes
Security/Accessibility/ Medical Devices continued									
Wireless Router	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Computer networking device
Ethernet Hub	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Computer networking device
Modem	8	Yes	Yes	No	0	0	0	1B- Too low of a device population & unit energy consumption	Computer networking device
Wireless mesh network system	8	Yes	Yes	No	0	0	0	1I- No IDSM strategy for energy savings potential	Computer networking device
Small Office appliances	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Devices include: Electric stapler, shredder, Cordless Phones, pencil sharpener, USB Hub, docking station, Alarm Clock/ Radio, Printer/Fax/Copier
Personal Care Devices	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Devices include: Aromatherapy Diffuser, dental hygiene product, massage chair, Hair dryer/straightener/curler, Irons, Electric blanket, Heated night-light toilet seat
Rechargeable personal care	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Devices include: Electric toothbrush, Electric shaver, etc.
Small device battery chargers	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Generic category for dedicated battery chargers, EPS charger

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Security/Accessibility/Medical Devices continued									
General manufacturing devices for home businesses	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Devices include: sewing machine, jewelry die press machine, etc.
Additive manufacturing	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	3D Printers
Smoke Detector	8	Yes	No	No	0	0	0	1I- No IDSM strategy for energy savings potential	Home maintenance device
CO Detector	8	Yes	No	No	0	0	0	1I- No IDSM strategy for energy savings potential	Home maintenance device
Miscellaneous Electronics									
Water cooler	8	Yes	No	No	0	0	0	1B- Too low of a unit energy consumption	Home device
Water Softeners	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Home device
Irrigation System	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Home maintenance device
Garage door opener	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Home maintenance device
Electric Piano	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Home entertainment
Fish Aquarium	8	Yes	No	No	0	0	0	1I- No IDSM strategy for energy savings potential	Home beautification
Waterbed Heater	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Home device

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Miscellaneous Electronics continued									
Home exercise equipment	8	Yes	Yes	No	0	0	0	1I- No IDSM strategy for energy savings potential	Devices include treadmill, elliptical, exercise bike, etc.
Solar Inverter	8	No	No	No	0	0	0	1B-Too low of a system population; out of scope	Battery operated
Indoor agriculture	8	Yes	Yes	No	0	0	0	1B- Too low of system population; out of scope	May be a growing trend because of recent legislation (California Proposition 64 in 2016); Currently insufficient population Energy savings would be resultant from lighting and HVAC.
Invisible Pet Fence	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Pet care
Heated towel rack	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Personal device
Digital Touch Smart Faucet	8	Yes	No	No	0	0	0	1B- Too low of a device population & unit energy consumption	Home device
EV Charger	8	Yes	Yes	No	0	0	0	1I- No IDSM strategy for energy savings potential	Growing trend, may be considered for savings in future IDSM strategies
Weather Monitor	8	No	Yes	No	0	0	0	1A- Not a plug load; out of scope	Home device

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