HARNESSING IOT FOR ENERGY BENEFITS

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1 EXECUTIVE SUMMARY

The proliferation of Internet-connected products – the so called Internet of Things (IoT) – presents a significant opportunity to leverage connectivity and other functions to achieve energy benefits. These benefits include both energy savings and demand flexibility. Connectivity and other functionality, however, comes at a price: the increased power required to provide that functionality. Many organizations, including EDNA and governments around the world, have studied the energy use of connected products in order to implement policy that encourages energy efficiency of networked standby and other connected operating states. A key next step, therefore, is to identify IoT products that can use their functionality to provide energy benefits through energy efficiency and demand flexibility strategies.

In this project, we examine the landscape of residential IoT products and the functions within those products that can be leveraged to yield energy benefits. These functions include monitoring via on-board sensors and internal or external data feeds, and controls that can reside within or external to the product. We examine the extent to which products possess these functions today, the energy benefits products can achieve with those functions, and the appropriateness of adding additional functions to achieve additional energy benefits.

Our investigation shows that IoT products present many opportunities to achieve energy savings and demand flexibility, and some products present greater opportunity than others. Connectivity allows virtually any product to receive a signal that indicates that the consumer does not need its services. User expectations and the nature of the load, however, will determine the degree to which the product can reduce its energy use when its main function is not needed. Similarly, some products are highly flexible in terms of when they operate during the day, whereas others are expected to be available when the consumer wants or needs their services. IoT products that present the largest energy benefit potential include heating, ventilation, and air conditioning (HVAC) equipment and water heaters, which are large loads that tend to be highly flexible in when they consume energy over the course of the day. Connectivity in products such as ceiling fans and window coverings can enhance energy benefits yielded by other systems like HVAC and lighting by reducing the required load of those systems. Appliances other than water heaters present moderate benefit potential, which is often dependent on user behavior. Connectivity in lighting and electronic products is expected to deliver relatively small levels of energy benefit.

Policy makers and energy efficiency advocates should focus their efforts on encouraging the adoption of connectivity and other functions that can lead to energy savings or demand flexibility in high potential end uses, rather than simply encouraging connectivity for connectivity's sake. Furthermore, policy should ensure that the functions added to a product to achieve energy benefits are designed and optimized for energy efficiency and do not drive up the energy consumption of these products. Although connectivity may enable some products to save energy by reducing power draw by receiving "away" or other signals, this opportunity does not render efforts to improve product energy efficiency moot. Rather, a coordinated and systematic effort is warranted, encouraging connectivity where it provides benefits, and requiring connectivity to be efficient whenever implemented.

2 INTRODUCTION AND MOTIVATION

The number of connected products and the types of connected products have been growing and will continue to grow steadily (ACEEE 2017, EDNA 2016). About 10 billion connected products were in use in 2015, and market research firms expect continued growth to 100 billion connected products by 2030 (ACEEE 2017). A large proportion of the growth is due to the increasing availability of IoT. Consumers are adopting IoT for a variety of benefits: the convenience of operating a product remotely, improved security and comfort, entertainment, and environmental and health monitoring (Wilson et al. 2017).

A significant promise of IoT products is the ability to use connectivity, sensors, and other functions to reduce energy use in connected products and to shift energy consumption of flexible end uses to favorable times of day. Connected products offer the opportunity to use information both collected by the device itself and relayed over the network to alter their operation. These products can save energy by using information to determine which services must be provided and strategically use low power states for components or functions that are not needed at any given time. This strategic use of power has recently been termed "intelligent efficiency."

Connectivity also enables information exchange for demand flexibility, which utilizes one or more load-shaping strategies to better match demand to electricity supply. IoT products have the potential to provide demand flexibility since their connectivity can allow them to receive signals or information to alter their energy use, specifically by:

- Shedding load: reducing electricity use during a peak or emergency event, or
- Shifting load: shifting energy consumption from peaks or other periods of day when electricity is expensive or scarce to those when electricity is inexpensive and plentiful, such as during solar or wind generation peaks (U.S. DOE 2019, EDNA 2020).[1]

Signals to shed or shift load may come from the utility through load management programs like demand response or grid-interactive efficient buildings (GEBs). The decision to shed or shift load may occur locally as well, in response to real-time electricity prices, emissions, or on-site energy generation via product- or building-level energy management systems.

Connectivity and other functions, however, come at a price: added functionality requires additional power. Many organizations, including EDNA and governments around the world, have studied the energy use of connected products (e.g., IEA 2014, EDNA 2018a, EDNA 2019) in order to implement policy that encourages energy efficiency of networked standby and other connected operating states. EDNA has also examined the energy efficiency of some IoT products (EDNA 2016). However, the savings potential of some IoT devices can be substantial; one recent study commissioned by EDNA indicates that connected home technologies could reduce energy use in homes by 20% - 30% (EDNA 2018b). A key next step, therefore, is to identify IoT products that can use functions associated with connectivity and IoT services to provide energy benefits, specifically improved energy efficiency and the ability to shift flexible loads to advantageous times of day. Governments can then encourage IoT

[1] Note that demand flexibility can also entail load modulation, or real-time, autonomous matching of electricity demand to supply. For the purposes of this discussion, we focus on load shedding and shifting as flexibility strategies that many consumer products are capable of today.

adoption or added functionality in already connected products in situations where energy benefits can be realized, rather than simply encouraging IoT adoption in general (EDNA 2018b).

This project examines the energy savings potential of IoT. To do so, we first define the current landscape of IoT products and organize it into functional categories. Next, we identify functions within IoT products that enable energy benefit. We then examine a list of typical IoT products to estimate the extent to which they possess energy benefit-related functions, the potential benefit of those and any additional functions, and the market share of connected models. This information is presented in the accompanying spreadsheet. We identify and discuss IoT products with the highest potential to provide benefit. Finally, we outline policy approaches that could encourage the adoption of IoT products and functions that can yield energy benefit. Each of these activities is discussed in the sections below.

3 LANDSCAPE OF IOT DEVICES

Connected products have broad applications across all sectors, but for the purposes of this study, we limit our scope to IoT products that are typically used in the residential sector. They include traditional products that were not network connected in the past, such as coffee makers, appliances, alarm clocks, home audio equipment, and thermostats. They also include newer-to-market "smart home" products, such as home security systems, environmental monitoring systems, smart speakers, and other voice activated products. Products that have traditionally relied on network connectivity to deliver their main function, such as computers and printers, and products that deliver connectivity as their main function, like network equipment, are excluded from this scope.

Even within the residential sector, many products that use electricity are gaining network connectivity as a key feature that drives consumer purchasing decisions. Our review of residential products indicates that most electricity-using products offer some, ranging from many to limited, connected models. To organize the landscape of IoT products for further examination, we divide the ecosystem into seven major groups based on Nordman and Cheung (2013)'s universal device classification system (Table 1):

Space conditioning: This category includes heating, ventilation, and air conditioning (HVAC) equipment, as well as humidification and HVAC-control products. Space conditioning products comprise about 52% of a home's total load (IEA 2019) and can provide demand flexibility through shedding load during peaks and shifting load to off-peak or other favorable hours of the day. Consequently, this product category represents some of the best opportunities to realize energy benefits through IoT products.

Appliances: This category includes large appliances such as clothes washers and dryers, refrigerators, freezers and water heaters. Appliances represent about 39% of total residential energy consumption (IEA 2019). Depending on the type of product, they present varying degrees of opportunity for energy savings, demand flexibility, or both. Water heaters in particular offer significant energy savings and especially demand flexibility.

Table 1. The broad landscape of residential IoT products, segmented into seven categories for examining energy benefits

Category	Devices

Space conditioning	Heating, cooling, ventilation, humidification, HVAC controls
Lighting	Lighting and lighting controls
Appliances	Large appliances: refrigerators, ovens, ranges, dishwashers, clothes washers, clothes dryers, water heaters
Electronics	Multimedia (e.g. televisions, game consoles, audio equipment, smart speakers), information and communication devices (e.g. smart phones and tablets)
Miscellaneous	Small appliances (microwave, toaster, coffee maker, etc.), outdoor appliances (e.g. irrigation controllers, mowers and trimmers), personal health products (e.g. blood pressure monitors and CPAP machines), pool pumps
Infrastructure	Garage door openers, window coverings, security cameras and systems, breakers, well pumps, meters, environmental sensors (e.g., smoke and CO alarms)
Transportation	EVSE and passenger vehicles

Lighting includes both hardwired and plug-in lighting products and lighting controls such as switches. The adoption of LED technology is significantly improving efficiency of lighting products as a whole, and connected products have potential to further save energy by using occupancy or other information to turn off lights when not in use. Some demand flexibility potential may exist in the form of shedding load by dimming lights.

The **Electronics** category contains products that are generally discretionary and purchased for entertainment, information, and convenience. It includes televisions, game consoles, audio equipment, smart speakers, and other multimedia or entertainment products; phones, tablets, alarm clocks and additional information or communications-related equipment. Although the number and types of electronic IoT products continues to expand, the energy benefit potential of this category is lower than that of other categories, and is almost exclusively in the form of energy savings rather than demand flexibility, as discussed below.

The **Miscellaneous** category includes a range of devices including small appliances, outdoor appliances such as irrigation controllers and power tools, and personal health devices. Connectivity in most small appliances such as microwaves, toasters and coffee makers can improve convenience but present little energy benefits. Personal health products include equipment intended for fitness, such as treadmills and exercise bikes, health monitoring, such as blood pressure monitors, and chronic care, for example continuous positive airway pressure (CPAP) machines. These products generally have long lifetimes, and low penetration of connectivity with the exception of wearables and some fitness equipment. Although connectivity may allow conveniences such as communicating with doctors or downloading fitness programs, we see low energy savings or load shifting potential in most of these products

Infrastructure products are integrated into the building. It includes security equipment, smoke alarms, faucets, garage door openers, and window coverings. Many of these products are installed by builders in new buildings, and replaced during renovations or retrofits. They generally have long lifetimes, and when they do fail, are likely to be replaced with a similar product, perhaps with updated features. All of these products have existed as non-connected versions for considerable time, and connectivity is generally added as an extra feature to existing designs. Because of their long lifetimes, current market adoption of connected versions of these products is low, and is expected to grow slowly.

Transportation-related products, primarily electric vehicle supply equipment (EVSE) and passenger vehicles, are energy-intense loads with long lifetimes. Connectivity is being adopted relatively quickly in these products, as the need and opportunity to manage charging load increases with electric vehicle (EV) adoption.

IoT products possess various functions that can enable energy savings or demand flexibility. These functions are identified and discussed in the next section.

4 ENERGY SAVINGS AND LOAD SHIFTING FUNCTIONS OF IOT PRODUCTS

IoT products have long promised to bring increased convenience and functionality to consumer goods. Simply being connected, however, does not necessarily allow a product to provide energy benefits. Additional functions can help the product leverage its network connection to gather information on which it can internally decide to act, or allow itself to be controlled from an external product or source to save energy or alter its load. Note that the resulting energy savings is distinct from energy savings associated with improved technology, such as that of LED light bulbs compared to their compact fluorescent and incandescent predecessors. We explicitly examine only the savings potential related to connectivity and increased product intelligence in this project. In this section, we examine the functions that enable energy savings and demand flexibility and organize them into a simplifying framework.

To alter its energy usage, a product uses a combination of monitoring and control functions, as illustrated in Figure 2. The product controls its energy use in response to different signals and information, such as an operating schedule, power management software, or a DR event signal. These signals are produced within the product in some cases, and may be received by the product over a network in others. To increase the information on which a product is basing control decisions, it may use monitoring functions like sensors or external data sources. Monitoring functions include, for example, occupancy sensors that enable a lamp to turn itself off when nobody is in the room or weather forecasts accessed via a network connection that allow an irrigation controller to optimize watering schedules.

At a high level, to provide either energy savings or demand flexibility, a product must be able to change its operation when it receives a signal to do so. The decision-making capability within a product such as that which allows a light bulb that can flash a football team's colors when they score a goal is often referred to as "smart." For the purposes of this discussion we adopt that definition, focusing in particular on smart functions that allow the product to reduce or shift its energy use. Note that "smart" is also used to denote network connectedness, particularly in consumer-directed marketing and literature. In this project we use the term "connected" to indicate that the product is capable of exchanging information on a network or directly with another product, and reserve "smart" to indicate the product's ability to change its behavior based on information or data. Connected products are not necessarily smart, and smart products are not necessarily connected, but as we show below, the combination of the two can present significant energy benefit opportunities in some IoT products.

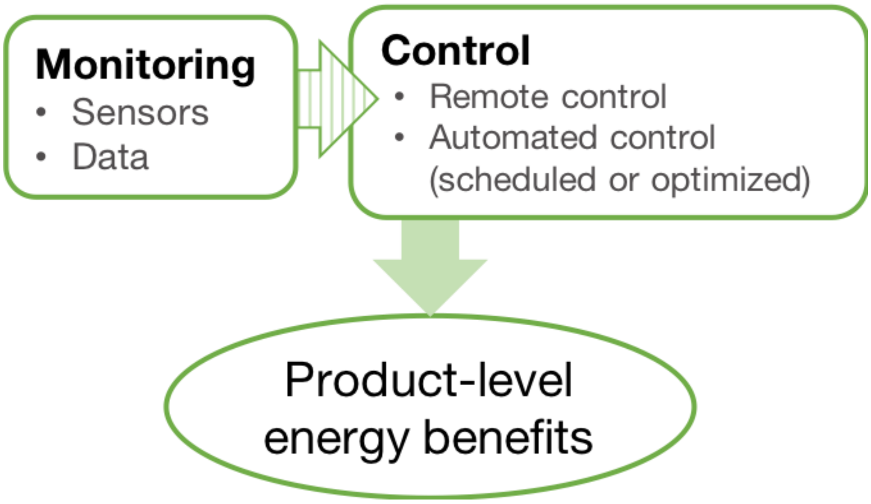

Figure 1: Functions that IoT products can use to achieve energy benefits.

In some cases, an end product achieves energy benefits based on the monitoring and controlling functions of another IoT product or a software platform. In this study, we examine energy benefits from the perspective of the end device and refer to products or platforms that provide a mechanism for achieving benefits in an end device as an “enabling tool”. An enabling tool may be another IoT product, such as a smartphone with an app to allow the user to power down a connected light remotely, a software or utility platform that determines how a product should operate and sends operational state signals to the product, or other cloud-based signals. End product functions and enabling tools are not mutually exclusive, and may be used in combination to achieve energy benefit (Porter and Hepplemann 2014). Based on our examination of IoT products, we developed a list of functions, categorized as monitoring or control types, that enable energy benefits (Table 2). These are discussed in the sections below.

4.1 Monitoring functions

Monitoring functions allow insight into the product’s operating state and environment, and includes strategies both internal and external to the product (Porter and Hepplemann 2014). Sensors within the product can monitor its current conditions and adjust its operation or send information to the user or other products as needed. Some monitoring functions that can lead to energy benefits do not require connectivity to provide benefit, but connectivity could greatly enhance the realized benefits in some situations, including:

- Occupancy sensors: monitor the presence or absence of users to help the product decide whether or not it needs to provide a service, or if it has the opportunity to power down.
- Environmental sensors: a range of sensor types that monitor ambient light, temperature, humidity, and other environmental variables to help the product determine necessary operating state. Ambient light sensors can be used to dim display screens when ambient lighting dims. Temperature sensors can be used to detect when a room is too warm to be heated.

Table 2: Functions that can enable energy beneficial strategies in IoT products.

Function	Energy beneficial strategies	Connectivity required?

Monitoring functions		
Occupancy sensing	Turns product off when not occupied	No
	Sends away signal to other products, systems, enabling tool	Yes
Environmental sensing	Adjusts operation according to temperature, ambient light, or other environmental conditions	No when the sensors are within the product
Energy use/fault detection	Provides energy use feedback to user	No if implemented on the product
	Provides energy use reporting to other devices or entities, such as an energy management system or software platform, to identify load up or load shed potential	Yes
	Self-diagnose suboptimal operation and send alerts to users when maintenance or repairs needed	No
External data	Uses weather forecasts, electricity pricing, emissions, or on-site generation data to optimize operation to save energy, cost, or emissions	Yes
Control functions		
Remote control	User modifies operation manually through an app on an enabling tool	Yes
Voice control	User modifies operation using voice commands.	No*
Scheduled control	User sets operation schedules on the product or via an app.	No
Software platform	Cloud-based software that allows users to automate information sharing and control between connected products and services (for example, IFTTT).	Yes
Optimized control	Utilizes internal and external information to modify product's state to appropriate levels.	Yes
* Note that most products today rely on cloud services to process voice commands; however, due to privacy and security concerns, some manufacturers are starting to include that functionality within the product.		

Other monitoring functions require or are significantly enhanced by connectivity:

- Energy use and fault detection: the product monitors its energy use and relays that information to a user, another product, or a cloud service. Energy use feedback delivered to the user can help them take action to reduce energy use. Energy use reporting to other devices or entities, such as an energy management system or software platform, can allow them to identify end uses that can add or shed load for load shifting purposes. Product self-diagnostics functionality can identify and report suboptimal operation to users, either through an indicator on the product itself or a network. Energy use monitoring capability is required in several ENERGY STAR specifications. Energy use monitoring or fault detection may be used to identify inefficient operation, and alert the user that, for example, the product requires maintenance to improve its operation. Or, energy use feedback can be relayed to the user with tips for saving energy like using energy savings settings. These monitoring functions generally require connectivity to relay information to the user or an external system, which then takes action to control the product.
- External data access: connected products can gather data from other products or network sources. This information is used to make decisions about product operation. An HVAC system that has access to weather forecasts, for example, can preheat or precool a home before demand peaks.

4.2 Control functions

Control functions can be manual, requiring a user to take action to change the operation of the product, or automated using rule-based strategies or learned behavior patterns (Porter and Hepplemann 2014, Karlin et al 2015).

Manual remote control capabilities allow the user to receive and process information, then act to control the operation of connected devices using an enabling tool such as an app on a smartphone, tablet or computer. These operations may be dimming or turning off a light, unlocking a door when a visitor arrives, or setting a water heater to vacation mode to reduce water heating when not needed. Voice control is another form of manual remote control; the user speaks commands to a product which contains voice recognition software and a link to the cloud to carry out commands.

Automated control can be **scheduled** or **optimized**. To carry out scheduled control, the user creates schedules directly, or provides preferences and priorities that the product then develops schedules around (Karlin et al., 2015). The product operates on the schedule, without additional inputs on ambient, occupancy, or resource conditions. Scheduled control does not require connectivity, but scheduling may be made more user-friendly if a network connection allows the user to set schedules from an app on an enabling product like a smart phone or computer.

Optimized control leverages usage, historical, or current data with algorithms to decide how best to modulate product operation to meet user patterns and preferences while reducing or shifting energy use (Heppelmann and Porter, 2014). Examples include learning algorithms, which use historic behavior patterns, user preferences, and occupancy information to develop operation schedules, such as some thermostats. Geofencing uses information on the user’s location outside the home from a smartphone or other enabling tool to determine if the user is away from home and accordingly control products to power down or shift their operation. Software platforms like IFTTT (if this, then that) automate control of one or many products based on a trigger from the user or another product. If the user is detected to be leaving home for the day based on geofencing, the software platform can signal products in the home to power down or shift into an “away” mode operation schedule. Most optimized control strategies require network connectivity; theoretically, learning algorithms could be used by unconnected devices, although we know of no cases where an unconnected product contains this function.

4.3 The role of connectivity

As discussed above, connectivity is a requirement to enable many (but not all) energy benefit functions. In many cases, connectivity can enhance the capability of the function or improve the user interface, but is not required. In addition, connectivity opens the opportunity to apply monitoring and decision making functions in one product to the control of other products. For the most part, we focus in this study on the benefits that could be achieved in the primary product the functions act upon. In most cases, we examine benefits from the perspective of the end device, as opposed to the system level. Additional benefit may be realized in secondary products if the primary product relays its control activity via a data link (IEA 2017).

5 IoT ENERGY BENEFIT POTENTIAL IN HIGH-IMPACT OPPORTUNITIES

In the accompanying spreadsheet, we examine the range of IoT products on the market today and compile information regarding the presence of energy benefit functions, energy benefit opportunity, market share of connected products, and price. We identify products that already have, or could add, energy benefit functions, and identify situations where energy benefit functions may not yield enough benefit to justify the added power requirements of the functions. In this section we summarize that investigation by highlighting the end uses that present significant opportunity to realize energy benefits through connectivity.

5.1 Assessing energy benefits

Although IoT products have potential to leverage their connectivity and other functions to operate intelligently, each of those additional functions requires some amount of power to operate. For IoT products to yield positive energy benefit, they must yield more benefit than the additional impact. In the context of energy savings, the assessment is straightforward: the net savings of an IoT product is the savings within the product, minus the energy use of the functions that enable the savings. For example, a connected light bulb must save more energy through scheduling, dimming, remote control, occupancy sensing, or other techniques than it uses to provide the functionality associated with those techniques, for example a network connection or an occupancy sensor. The energy use related to connectivity is relatively constant and persistent, and does not depend significantly on whether functions that enable energy benefits are operating or not. In other words, the energy consumption of a Wi-Fi connection in a product exists whether or not that connection is leveraged for energy benefits. The energy benefits realized, especially energy savings, often depends on user behavior, and automated or out-of-the box solutions requiring little effort on the consumer's part can yield more savings (Ehrhardt-Martinez et al. 2010).

5.1.1 Total energy use of connectivity: upstream energy use

Most of the energy impacts reside in the product itself, and are related to the power required to operate additional components that provide functions such as network connections, sensors, voice recognition, and power management. However, connected products also incur some amount of energy use by other products that transfer and store the information moved over that connection. This upstream energy use - that of wide area network equipment that connect buildings to the Internet, and servers and other equipment in data centers - also contributes to the energy impact associated with connectivity. It is generally estimated as energy use per unit data transferred (EDNA 2019). The less traffic a product requires to maintain its network link, the less upstream energy it will incur. Most IoT products examined in this study have very low data transfer requirements in network standby, and consequently the upstream energy impacts are low compared to network standby power - on the order of 0.1% to 3% for HVAC equipment, lighting, and appliances in 2020 (Xergy analysis of TEM outputs of EDNA 2019). Upstream energy intensity is decreasing rapidly through time as data center and network equipment becomes more efficient, and as the utilization of the equipment increases due to increasing traffic (i.e., the same equipment handles more traffic). By 2030, upstream impacts are expected to be on the order of 0.01% to 1% for the same IoT products. Because upstream impacts are typically small relative to product-level impacts for increased functionality, we focus below on product-level impacts of providing smart and connected functions to examine whether or not energy savings outweighs energy cost.

In the context of load shifting benefits, the equation may be cast in terms of economic benefit to the consumer. We assume a positive benefit exists when an IoT product's load shifting can save the consumer more money than the cost of the energy used by the enabling functions within the product. Because the economic benefits vary from utility to utility and country to country, we consider this issue qualitatively in most cases as the flexibility of the load - that is, whether or not a particular end use can operate flexibly over the course of the day, or if use patterns are of an on-demand nature.

5.2 Potential energy benefits of IoT products

End uses that show potential to provide energy benefits by leveraging connectivity or other IoT functions are discussed in the sections below. We refer the reader to the accompanying spreadsheet for additional and more detailed information.

5.2.1 Space conditioning

For the purposes of this discussion, we separate HVAC into two categories:

- Central HVAC systems, which includes air conditioners, furnaces, boilers, heat pumps, and hybrid systems that distribute conditioned air via ducts or heated fluid through radiators throughout the home.
- Room heating or cooling products such as room or window air conditioners, space heaters, and ductless heat pumps.

5.2.1.1 Central HVAC systems

Central HVAC systems have multiple components, including indoor and outdoor compressors, heating elements, and heat exchangers, ducts or pipes, fans and blowers, thermostats, and intelligent circuitry to operate the system according to space conditioning needs. HVAC systems can contain virtually all of the energy benefit functions listed in Table 2, in various combinations. In particular, functions that can reside in central HVAC systems include (ACEEE 2018; European Commission 2017):

- Occupancy sensors to monitor whether or not occupants are active, asleep, or away from home.
- Environmental sensors to monitor indoor and outdoor temperature and humidity and adjust space conditioning at the home or room level.
- Status monitoring to communicate to a utility or software platform the system status and current ability to add or curtail load.
- Advanced diagnostic monitoring: Sensors placed within the system to identify malfunctioning components like compressors or blowers, leaks in ducts or piping, or constricted flow alert the user to needed maintenance or repairs. Connected units may relay this information to the user's HVAC contractor (ACEEE 2018).
- Advanced zone and vent control: Sensors within the system monitor space conditioning needs by zone or room, and the system is designed to direct space conditioning where needed, through strategies like multi-zone control, automatically adjusting vents for forced air systems, or automatically adjusting valves for radiators. Connectivity or a connected thermostat is not required for this function, but may enhance control and better optimize energy use (Urban et al. 2016)

- External data, including local weather forecasts to anticipate heating or cooling requirements and occupant calendars to anticipate home occupancy and vacancy
- Remote control via an app on an enabling tool
- Automated control through manual scheduling, automated scheduling using learning algorithms, and geofencing

Many connected HVAC systems today use a connected thermostat to provide the network connectivity and related monitoring and control functions such as automated scheduling or geofencing, manual remote control via an app or voice, and communications with the utility or other software platforms that allow the system to shift its load to beneficial operating periods (Karlin 2015). Some can use additional sensors to monitor temperature in various rooms. However, some systems have integrated connectivity into the control circuit board in the indoor unit, potentially bypassing the need to use a connected thermostat for those functions. (In all cases, the intelligence to adjust variable speed compressors, fans, and pumps always resides on the central HVAC control board.)

Energy savings achieved by a smart, connected HVAC system depends on climate and occupant behavior, as well as the energy benefit function(s) it utilizes. Energy savings potential of systems that use automated scheduling and monitoring can yield 7- 10% reduction in cooling load, and 6-8% reduction in heating load (ACEEE 2018). Automated vents and zoning may reduce heating and cooling load by 10% (ACEEE 2018). Reported energy savings of HVAC systems using connected thermostats from utility programs in the US is 8 – 10 % for heating and cooling (BPA 2016). The power requirements of the network connection and other energy benefit functions that yield this savings is low in comparison. Average annual energy use of connected thermostats is about 15 kWh/yr (EDNA 2019) although some manufacturers claim much lower energy use (e.g., ecobee 2015, Nest 2015). Additional sensors and external data acquisition may require annual energy use of 20 kWh/yr or less (EDNA 2019). Compared to heating and cooling energy use on the order of 1,000s or 10,000s kWh/yr, and therefore savings on the order of 100s to 1,000s of kWh/yr, the additional energy use of added functions is minimal compared to the savings they can yield.

HVAC systems are flexible in their operation over the course of the day, with particular potential to shift load from daytime demand peaks. Electric utilities already leverage this flexibility to run DR programs to reduce air conditioning load on hot afternoons, for example. Consumer comfort and schedules may limit the amount of load shifted (European Commission 2017).

The stock of connected HVAC systems is growing significantly, mainly due to the growing market of connected thermostats. By 2025, 63.7% and 41.4% of North American and European homes are forecast to have a connected thermostat, respectively (Frost and Sullivan 2019). The European Commission estimated 30% of HVAC systems would be connected in 2025, and 45% in 2030 (European Commission 2017).

5.2.1.2 Room space conditioning products

Room air conditioners, ductless heat pumps, and space heaters condition and circulate indoor air in a room rather than on a whole-home scale. They present opportunities to use smart and connected functions to reduce or shift their energy use, using the following functions:

- Internal sensors to monitor temperature and humidity and adjusting operation to meet set points.
- Scheduling and manual control enabled through an app on an enabling tool

- The ability to report energy use to users or third parties
- Reporting operational status to identify maintenance issues like dirty filters

Energy savings potential will vary depending on climate and user preferences. However, we expect that savings potential is much larger than the energy use of the enabling functions. The energy use of a Wi-Fi connection and additional sensors that could enable savings is about 15 kWh/yr (EDNA 2019). Like central HVAC systems, room space conditioning products are highly flexible in their time of operation, and can participate in demand flexibility strategies such as pre-conditioning, and curtailing load during peak demand. Load control programs for connected room air conditioning units is estimated to save consumers 2-3% of annual cooling costs (ACEEE 2018).

Room air conditioning and ductless heat pump installations are increasing, as are their connected counterparts. About 200 million connected AC units are already in use (ACEEE 2018). With air conditioning and ductless heat pump installations increasing every year in response to increasing global temperatures, leveraging smart, connected versions of these products is important.

5.2.1.3 Ceiling fans

Ceiling fans can increase occupant comfort and decrease HVAC system load, particularly air conditioning, by circulating air through a room and providing a cooling effect. This allows air conditioners to be set to higher setpoints. Smart, connected ceiling fans can improve their operation in comparison to an unintelligent, unconnected fan with the following additional functions:

- Internal sensors to detect room occupancy, humidity, and temperature to adjust fan speed to optimize occupant comfort, or turn off if the room is not occupied (ACEEE 2018)
- Remote control through an app
- Integrating with thermostats or other HVAC controls to adjust fan speed to HVAC system output (ACEEE 2018).

Ceiling fans have shown much potential in reducing cooling load by allowing cooling set points to be increased by 4°F (2°C) without sacrificing comfort (ACEEE 2018). The study resulted in average cooling savings of 4–11% (GSA 2016). Our analysis of ENERGY STAR-qualified models as of May 2020 suggests that energy efficient, connected fans can use less than 4 kWh/yr to provide a network connection and sensing functions.

We classify ceiling fans as highly flexible loads, however the benefit of shifting or shedding a ceiling fan load of about 30 W (the average power of ENERGY STAR-qualified fans in high speed in the US as of May 2020) may not yield impressive demand savings. A better opportunity may be presented by using the fan’s connectivity to communicate DR or other load shifting events, and operating the fan while the air conditioning is curtailed to better maintain occupant comfort and decrease the likelihood that demand savings of the air conditioner is fully realized.

Market penetration of connected models is currently low; of more than 200 U.S. ENERGY STAR-qualified models, only three were connected as of May 2020.

5.2.2 Lighting and controls

Energy benefit functions of smart connected lighting products can include

- Occupancy sensing to turn off lights when nobody is in a room

- Ambient light sensing to dim lights when natural light is available
- Remote control
- Voice control
- Scheduling
- Integration with software platforms

Energy savings of smart, connected lighting has been studied to some degree but remains uncertain. Most of these systems use LED lamps, which are very efficient at providing light. To achieve savings, connected lamps must use less energy to provide their connectivity (via often proprietary wired and wireless protocols, or Zigbee or Bluetooth) than they save by altering their operation. In addition, some connected lighting products require a proprietary hub, which relays information to and from the lamps and the product cloud. Several studies have shown that network standby impacts in lighting can in fact increase energy use of lighting in the home. Connected LED bulbs draw 0.5 W on average (Urban et al. 2016), and can use up to 50% more energy on an annual basis than unconnected lighting, depending on the degree to which the duty cycle is altered (CSA Group 2020). CSA Group (2020) estimates that a connected lighting system would need to reduce on mode time of lamps by about 1.5 hours per day to offset network standby power requirements. Connected switches can reduce energy use of non-LED lamps by 7 to 20%, depending on lamp usage (Bonn and Rivest 2016).

Load flexibility of connected lighting is characterized as low. Some potential shifting may be possible by dimming lights, although this still needs to be quantified in the residential sector. We estimate market share to be low at present, but likely growing as many connected lighting products have become available on the market in recent years.

5.2.3 Appliances

Appliances include kitchen and laundry products such as refrigerators, freezers, ovens, ranges, dishwashers, exhaust hoods, clothes washers, and clothes dryers. They use components such as compressors, fans, motors, and heating elements to perform household cooking and cleaning tasks. Water heaters are also included in the appliances category and are discussed separately in the subsection below.

Some large appliances have functions that can save energy or provide demand flexibility, and connectivity is required to achieve or can enhance energy benefits. Energy savings potential is related to the ability of the large appliance to monitor its operation through necessary sensors, optimize operation to needed capacity, and in some cases to alert the user to take action. These sensing and monitoring functions include:

- Energy use monitoring: products can monitor energy usage and operating data and alert the user when the product’s operation is suboptimal or when energy use increases. For example, the door of a refrigerator may be open, or increased usage may indicate that maintenance is required. Necessary functions include the ability to monitor energy use and assess issues through on-board sensors and processing, and the ability to provide the user with information, likely via a network connection that relays information to a smart phone app, for example.
- Optimizing operation to be appropriate with the task performed: dishwashers and clothes washers, for example, can be equipped with sensors that detect how dirty the dishes or clothes are and use the appropriate cleaning cycle. Although connectivity is not required to achieve this function, it could relay this information to the user (European Commission 2017).

- Status reporting: provides users with information about the contents of the appliance to reduce the frequency of door openings using a network connection. For example, some refrigerators track food contents and expiration dates, and some ovens[2] can monitor the internal temperature of food and send alerts when food is cooked to avoid over cooking.
- Manual remote control: Through a network connection, users may turn off an appliance, for example if the food is cooked or the clothes are dry (European Commission 2017).
- Exchange information between complementary products. Moisture sensors in washers and dryers can help determine the best cycle based on the clothes being laundered. For example, GE laundry equipment uses CleanSpeak technology to pass information from washer to dryer concerning how much moisture is left in the clothes.[3] The dryer can adjust the drying cycle accordingly.
- Connecting to other IoT products that can receive an away signal. For example, a Whirlpool washer and dryer can connect to a Nest thermostat and receive occupancy signals. If the occupants are away during the cycle, the washer and dryer switch to a longer but lower power cycle to save energy.[4]

These energy savings features are relatively new, and the amount of energy they actually save has not been studied. Vendors claim savings of 30-50% for some of these strategies (Goetzler et al. 2016), but field studies are needed to verify these claims. Network connectivity adds an estimated power draw of 2.5 W (EDNA 2019), equating to about 22 kWh/yr.

Appliances vary in their load shifting potential. Clothes washers, clothes dryers, and dishwashers offer moderate demand flexibility by shifting the start time of a cycle to off-peak hours or other favorable times of the day. Once a cycle is active, however, it does not present this shifting potential. Refrigerators and freezers can flexibly operate energy-intensive activities such as performing defrost cycles and making ice (ACEEE 2018; European Commission 2017). We characterize other appliances, however, as inflexible. Ovens and ranges are classified as inflexible as most users will not accept delay in food preparation. However, automated functionality may allow these appliances to offer some demand flexibility. For example, an automated cleaning function could make load shifting possible in ovens in the future. ACEEE (2018) estimates that load shifting can yield electricity cost saving of 5-9% for dishwashers, 4-7% for clothes washers and dryers, and 2-4% for refrigerators that can operate ice making and defrost cycles flexibly.

Market adoption of connected appliances is currently in the low single digits, and expected to grow to about 4 to 20% by 2030, depending on appliance (European Commission 2017, IHS Markit 2018).

5.2.3.1 Water heaters

Storage water heaters have long been leveraged for demand flexibility through DR programs. Before water heaters were network connected, they were controlled using load control switches and one-way communication to halt and resume operation. Network connectivity allows 2-way communication, which improves insight into the efficacy of load control programs and opt-outs (EPRI 2014).

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[2] See, for example, https://www.geappliances.com/appliance/GE-27-Smart-Built-In-Convection-Double-Wall-Oven-JKD5000SNSS

[3] https://products.geappliances.com/appliance/gea-support-search-content?contentId=18003

[4] https://homeharmonizing.com/whirlpools-nest-connected-washer-and-dryer-to-be-showcased-in-ces-2015/

Connected water heaters broaden the opportunity to realize energy savings by heating water only when it is needed. Functions they implement to realize energy benefit include:

- Energy monitoring to report maintenance issues
- Scheduling, set by the user via an app or the water heater controls
- Enabling vacation mode via remote control, software platform, or geofencing
- DR and load control participation
- Optimizing energy consumption to reduce cost and emissions or use on-site generation

The energy savings potential of connected water heaters is estimated to be 9 to 18% (ACEEE 2018). The additional power required for energy benefit functions is largely due to the network standby load of the Wi-Fi connection, which is estimated to be around 2 W (EDNA 2019), or less than 18 kWh/yr. Demand flexibility potential is also large; up to 75% of water heater operation may be available for shifting or shedding (European Commission 2017).

Market share of connected water heaters is low, and we expect slow growth due in part to its long product lifetime. Due to high savings and load shifting potential, they should be one of the first products for governments and efficiency advocates to consider pursuing activities that encourage connectivity and intelligence.

5.2.4 Miscellaneous

5.2.4.1 Small appliances

Small appliances, including coffee makers, microwave ovens, toasters, rice cookers, multi-cookers, generally use heating elements to prepare food or drink, and reside on countertops. Connected small appliances possess little energy benefit potential. Connectivity in these products can improve convenience by allowing users to monitor, start, or end food or drink preparation. However, most small appliances power down heating elements when they do not need to be heating food, and those that have a “keep warm” function can shut off heating elements after a period of time. Drip coffee makers, for example, often have a timer to turn off the warming burner sometime after brewing a pot of coffee. Therefore, we expect connected small appliances to offer little energy savings over their unconnected counterparts. In addition, we characterize the demand flexibility of small appliances as low. Users expect to be able to have fresh coffee or warm food when they want it, and are unlikely to be willing to shift their use of these products to other times of day.

5.2.4.2 Pool pumps

Pool pumps consume a large amount of electricity, averaging 3500 kWh/year in homes with pools in the U.S. and Canada (CEE 2013). Much of the energy savings potential of pool pumps is related to the pumping technology utilized - variable speed pumps can use 80% less energy than single speed pumps (CEE 2013) - and the additional savings that connectivity could tap is unclear. Assuming that a variable speed pump contains the intelligence to regulate the speed and rate of water flow, additional functions that connectivity may enable includes remote control and status monitoring that allows the pump to report energy consumption and suboptimal operation that may indicate the need to clean filters or perform maintenance (ENERGY STAR 2018). The primary energy benefit that connected pool pumps present is demand flexibility; they can draw in the range of 1 to 3 kW (CEE 2013). As an intermittent (and in some cases variable) load, connected pumps can shift or shed all or some of their load to maximize energy use during advantageous times of day.

5.2.4.3 Irrigation controllers

Smart, connected irrigation controllers use weather data and forecasts to provide appropriate amounts of irrigation and prevent overwatering using the following functions:

- Remote control
- Scheduling
- Optimized control based on real-time watering needs

Connectivity can greatly enhance the user experience by allowing remote control and scheduling via a mobile app, whereas unconnected models require the user to create schedules and prevent unnecessary watering from the controller itself. Either type of controller can use additional soil moisture or rain sensors to modify watering schedules based on need, however these sensors are generally sold separately from the product (CA IOUs 2017). Energy savings potential is likely low at the product level, but water savings can yield significant additional energy savings in the form of energy use avoided in water treatment and delivery. More study is needed to quantify the opportunity (CA IOUs 2017). Irrigation controllers present demand flexibility potential as watering schedules are likely best determined by temperature and time of day.

5.2.4.4 Personal health

IoT personal health products generally present low opportunity for energy savings and load shifting. Chronic care equipment may always be on, and transmitting critical information to health care providers. Health monitoring and exercise equipment loads are intermittent, and should be able to power down to low levels when not being used without relying on connectivity to do so. Connectivity, therefore, does not appear to add significant energy savings opportunity. Connectivity may allow transmission of load shifting or shedding requests, but our assessment is that these loads have low flexibility. Wearables such as watches, glasses, and clothes, can act as enabling devices, leveraging their connectivity to use geofencing to alert products when the occupants are away, much like a smartphone. We rank the potential benefit of leveraging wearables as enabling devices as low, however, because we expect most that consumers most will rely on their smartphones, which are usually in their possession, for this functionality.

5.2.5 Infrastructure

5.2.5.1 Home safety and security products

Connected home safety and security products include security systems and cameras, doorbells, door locks, smoke and carbon monoxide detectors, air quality monitors, and garage door openers. These products can be outfitted with many of the functions identified for energy benefit, including:

- Occupancy sensing
- Environmental sensing
- Remote control
- Voice control
- Software platform integration

Rather than leveraging these functions to improve energy use, safety and security products generally use them to provide the expected service, often related to safety, and convenience. However, in some cases, functions in the product existing for other purposes can yield energy benefit. Many of these types of products use occupancy sensors to monitor for occupants or intruders, which can draw very little power; one study measured passive infrared sensors to use about 0.002 W in the field (Floyd et al. 1997). Some safety and security products may be able to leverage occupancy sensors to power down other components when they are not needed. For example, a video doorbell may rely on occupancy sensing to turn on and record video when someone is in the vicinity, rather than recording continuously. The service provided by security and safety products is generally not interruptible, and therefore we classify these products as having low load shifting potential. Data is limited, but we expect a relatively low market penetration of connected models, with a high growth potential in the future given the number and types of models available on the market today.

5.2.5.2 Window coverings

Rather than saving energy themselves, window coverings, like ceiling fans or thermostats, can generate energy savings in HVAC and lighting systems by reducing the heating or cooling load of the home, or by decreasing the need for artificial light. On cold days, window coverings can be opened to let warming sunlight in, and closed to reduce heat loss through the windows at night. On warm days, the converse operation may reduce cooling load by covering windows to avoid sensible heating during the day, and uncovering the windows at night to radiate the heat to cooler air. Window coverings can also allow sunlight into rooms and reduce the need for artificial light.

Smart, connected window coverings include motorized shades and blinds as well as films that adhere to or are integrated into the window glass and can be electrically manipulated to be transparent or shaded. Energy benefit functions in these products include:

- Manual remote control by the user
- Scheduled operation
- Light sensors that allow the covering to provide shade or transparency based on ambient conditions

Smart, connected window coverings do not present energy savings at the product level, but they can reduce heating and cooling load by a substantial 11–20%, and lighting load by 3% (ACEEE 2018). Depending on technology, they can draw 0.5 W to 2.3 W in network standby, or up to 20 kWh/yr (European Commission 2017, EDNA 2019). This impact is small relative to the savings potential of cooling loads. Window coverings operate sporadically and for short durations throughout the day, yielding no demand flexibility potential. They have low market share, and as they are fairly expensive, costing an estimated $350– 500 per window for motorized shades and blinds and $27 per square foot for smart film, we expect low growth in the share of connected products (ACEEE 2018).

5.2.6 Electronics

Connectivity in electronics - those products generally purchased for entertainment and information purposes - enhances convenience and usability of products. To some extent, they possess functions that could lead to energy benefit, including:

- Occupancy sensors
- Ambient light sensors
- Remote control
- Voice control
- Schedules or timers to enter low power state when not in use

Connected electronics could receive away signals from geofencing or software platforms, but we have yet to see these strategies implemented. Although most products in the home rely on wireless communications to communicate with the cloud and other products, some entertainment and information products can leverage wired data connections (HDMI and USB) to save energy. These products are usually stationary and work together to provide a service to the user, such as a TV connected to a set-top box, game console, or soundbar, or a computer connected to a display. HDMI and USB standards allow attached products to send power down and power up signals to each other. The energy savings opportunity appears limited to the situations described above; we do not expect users to be receptive to adding wired connections to products that do not otherwise need them.

We categorize demand flexibility of electronics as low. Market share of connected products is high for many products in this category, as connectivity is an essential function for products like smart speakers and game consoles.

5.2.7 Transportation

The primary energy benefit associated with transportation products is the ability to shift EV charging load to advantageous times of day. EV charging is highly flexible, and ultimately depends on when the driver needs the EV to be charged and ready for driving. In general, charging in the residential environment is controlled by EVSE, which is a discrete device external to the EV that provides current regulation and fault detection in accordance with applicable safety standards. In the future, charging may be managed and controlled using software in the vehicle itself, as was piloted by Pacific Gas and Electric and BMW in California (PG&E 2017).

Depending on the vehicle, the amount of load available for shifting or shedding may range from less than 3 kW to 10 kW or more. Demand flexibility is generally accomplished today via DR events sent by the utility to connected EVSE. In the future, the EVSE or vehicle may control charging based on other information gathered from the network, such as electricity price signals or emissions intensity, or on-site generation to optimize charging. In addition, they will be able to respond to requests for electricity, either from the grid or the home, releasing stored electricity from their batteries when the grid or home needs it in so-called vehicle-to-grid and vehicle-to building distributed energy resource management strategies.

Energy savings opportunities of connected vehicles (electric or fossil fuel powered) are related to providing feedback and information, including route information and driving tips, to the driver to encourage efficient driving, and could reduce fuel cost by 3 to 20% (Hyundai 2017). In addition, connected vehicles can be used as enabling tools to yield energy savings in the home. Like smartphones, connected vehicles may use geofencing to send away signals to products within the home, allowing them to power down until the occupant returns home (MediaPost 2020).

5.3 Central IoT products for controlling connected homes

Connectivity allows products to connect to, transfer data between, and potentially control other products in the home. But not every product needs to have the capability to decide when an energy savings or shifting opportunity exists and how to act on it. A smart, connected home ecosystem can instead be orchestrated by a single or small number of products that receive external and internal information, identifies energy savings or shifting opportunities, and then transmits simple instructions to connected products in the home to adjust their power state. In this ecosystem, that central product may possess functions like voice control or optimized control that require significant standby power, and can leverage those functions for other products in the house, which then require fewer functions to realize energy benefits - likely only a network connection (perhaps a low power one like Zigbee or Bluetooth LE if appropriate) and enough intelligence to adjust its power state in a reasonable manner. This ecosystem is similar to one in which a home energy management system is connected to and controls applicable loads in the house, but with one important difference. The central IoT product in this case is one that is already in the home. It may be a smart, connected thermostat, speaker, or phone. Some smart, connected thermostats and speakers already possess the functions to control other products in the home via voice control, geofencing, and software platforms For other products, it might not make sense to have these functions, and could instead waste energy with redundant functionality and cause interoperability issues if multiple products are trying to control the house.

6 KEY BARRIERS AND MISSED OPPORTUNITIES

As we show above, possessing connectivity and other smart functionality does not necessarily lead to energy savings or load shifting ability. Many barriers to realizing energy benefit exist, but some missed opportunities exist that could be easily addressed.

A persistent barrier that connected products face is **interoperability**, which is discussed at length in EDNA (2018b). It is generally asserted in the efficiency community that to be most useful, IoT products must be able to communicate across product types and manufacturers. Open protocols enable interoperability and are promoted by programs like ENERGY STAR. Other barriers in the product design process include a lack of focus on energy efficiency in the design phase, especially in relatively new products or features and in situations where the consumer is purchasing the product for convenience or other non-energy reasons. A recent investigation of TVs connected with smart speakers to enable voice control, for example, found that TV standby power averaged about 20 W when connected to a smart speaker, compared to about 0.5 W when not connected (NRDC 2019).

Other barriers exist on the consumer side. Some consumers may not be aware of or interested in the energy benefits of IoT, or perceive value in connectivity in general if it comes with a higher **price** tag. Security of connected products continues to be a concern, and with recent stories of hacked security cameras and other connected home products in the news, manufacturers will need to improve **security** measures to prove to consumers that the products are safe. Consumers who do adopt connected products from several manufacturers may find themselves frustrated by the **number of apps** it takes to control their home, as most products tend to be controlled from the manufacturers' custom made app. In addition, we have observed products that need an app to function can become unusable when the manufacturer goes out of business or stops supporting the app.

Some of the best opportunities for realizing energy benefits through IoT products are for end uses that are often replaced in emergency situations. Consumers often replace HVAC equipment, water heaters, and other appliances when they fail, and have few objectives for the new unit other than having one that works (ENERGY STAR 2010). These products also have a long lifetime, so missed opportunities to adopt energy beneficial IoT models can have long-lasting impact. Consumers and contractors, therefore, must understand the value of a connected replacement to be able to choose it when making replacement decisions.

Finally, if energy savings and load shifting rely on a network connection, that connection must be reliable. Recent EVSE pilots, for example, have found that load control opportunities are missed when the EVSE loses its connection (Dayem and Mercier 2020).

Missed opportunities exist where functions that could enable energy benefits are present in a product but not utilized to reduce energy use. Examples include doorbells and security cameras that use occupancy or motion sensors to monitor for intruders, but could deactivate video recording if the sensor detects no occupancy.

7 CONCLUSIONS AND POLICY RECOMMENDATIONS

Our investigation has shown that many opportunities to leverage IoT products to achieve energy savings and demand flexibility exist, but some products present greater opportunity than others. Table 3 is a qualitative summary of our assessment (the details of which are included in the accompanying spreadsheet), and shows varying opportunity for IoT products to be leveraged for energy benefits. Smart, connected HVAC equipment and water heaters present both high energy savings and load shifting potential. The operation of connected ceiling fans and window coverings can be coordinated with HVAC and, in the case of window coverings, lighting load to enhance savings or load shifting potential related to HVAC and lighting end uses. Appliances other than water heaters present moderate benefit potential. Connected irrigation controllers can enable considerable embedded energy savings in reducing landscape water use. Connectivity in pool pumps and EVSE enables valuable load shifting of those large loads.

Table 3: Qualitative summary of energy benefit opportunities for product categories. Detailed information is included in the accompanying spreadsheet.

Product category	Product type	Energy benefit potential	
		Energy savings	Demand flexibility
Space conditioning	HVAC equipment	**High**	**High**
	Ceiling fans	**High** (HVAC)	**Moderate** (HVAC)
Lighting	Lighting and controls	Low	Low
Appliances	Water heaters	**High**	**High**
	Other appliances	**Moderate**	Clothes washers, clothes dryers, dishwashers: **Moderate** Refrigerators, freezers: **Moderate** Others: None*
Miscellaneous	Pool pumps	Low	**High**
	Irrigation controllers	**High**	None
	Health products	Low	Low
Infrastructure	Window coverings	**High** (HVAC); **Moderate** (Lighting)	None
	Home safety and security products	Low	None
Consumer Electronics		Low	Low
Transport	EVSE	Low	**High**

	Passenger vehicles	**Moderate**	None
* Appliances such as ovens and ranges may present some demand flexibility in the future if functions like cleaning become automated.			

Policy makers and energy efficiency advocates should focus their efforts on encouraging the adoption of connectivity and energy benefit functions in high potential end uses, rather than simply encouraging connectivity for connectivity's sake. To ensure energy benefits are realized, product functions and capabilities may need to be specified. U.S. EPA's ENERGY STAR program is developing this type of approach in its Connected Criteria,[5] which may require products to report energy consumption and operational status, and be able to be controlled remotely by energy management systems or other user-authorized entities. These optional criteria are currently applied to ceiling fans, pool pumps, appliances, room air conditioners, and central air conditioning and heat pump systems. The ENERGY STAR connected thermostat specification requires energy use and operational status reporting, remote management by energy management systems or other entities, scheduling, and feedback to users on how their settings impact energy use (ENERGY STAR 2017). By specifying energy benefit functions and their required capabilities, energy-related programs and policies will likely yield better results. Policy may also need to encourage implementation of power intensive functions on as many products as needed to control the home, but no more to avoid redundancy and interoperability issues. Smart, connected thermostats are good candidates for the hub role because almost every home has space conditioning and could benefit from a connected thermostat.

Policy should also take into account how user behavior will impact the energy benefits realized in IoT products. For example, users generally expect products like appliances to provide their services when wanted. Still, some functions within these products, like oven cleaning cycles or ice making in a freezer, are flexible in times of operation. Products with functions that are not expected on demand therefore should be configured so that those demand flexibility or energy savings can be realized right out of the box, rather than relying on the consumer to implement enabling settings.

Our research has illuminated another important energy savings opportunity. Many IoT products are gaining connectivity and other functions for reasons other than energy benefit, primarily convenience and security. This increased functionality can drive up energy consumption of these products if not well designed and optimized for energy efficiency. Although connectivity may enable some products to save energy by reducing power draw by receiving away or other signals, this opportunity does not render efforts to improve product energy efficiency moot. **Rather, a coordinated and systematic effort is warranted, encouraging connectivity where it provides tangible energy benefits, and requiring connectivity to be efficient whenever implemented.**

[5] https://www.energystar.gov/products/spec/connected_criteria_energy_star_products_pd

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