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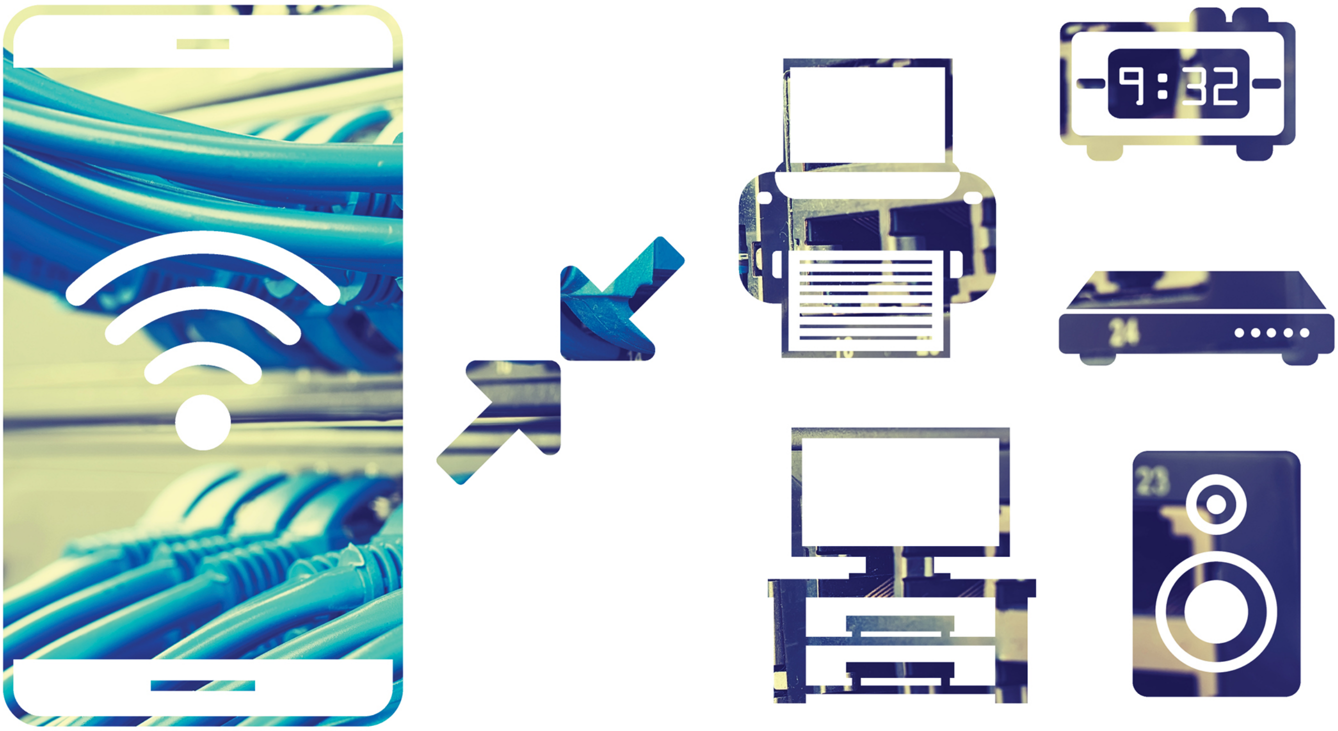

Bridging the Network Standby Gap between Mobile And Mains-Powered Products

JULY 2019

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International Energy Agency

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Electronic Devices & Networks Annex
EDNA

The EDNA Annex (Electronic Devices and Networks Annex) of the 4E TCP is focussed on a horizontal subset of energy using equipment and systems - those which are able to be connected via a communications network. The objective of EDNA is to provide technical analysis and policy guidance to members and other governments aimed at improving the energy efficiency of connected devices and the systems in which they operate.

EDNA is focussed on the energy consumption of network connected devices, on the increased energy consumption that results from devices becoming network connected, and on system energy efficiency: the optimal operation of systems of devices to save energy (aka intelligent efficiency) including providing other energy benefits such as demand response.

Further information on EDNA is available from: **www.edna.iea-4e.org**

This report was commissioned by the EDNA Annex of the 4E TCP. It was authored by Xergy Consulting and Energy Solutions. The views, conclusions and recommendations are solely those of the authors and do not state or reflect those of EDNA, the 4E TCP or its member countries.

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BRIDGING THE NETWORK STANDBY GAP BETWEEN MOBILE AND MAINS-POWERED PRODUCTS

Prepared by:

Peter May-Ostendorp, PhD
Xergy Consulting, Durango, CO USA

Eric Rubin
Energy Solutions, Oakland, CA USA

Prepared for:
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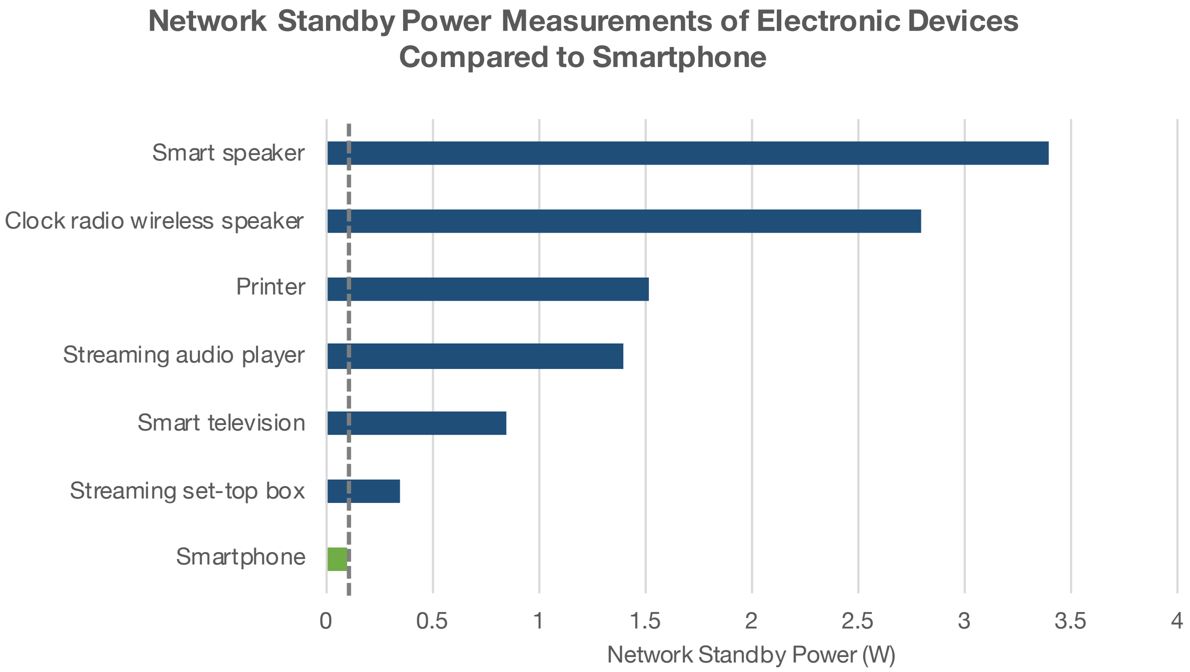
We stress that the views expressed in this study remain solely those of the authors.

EXECUTIVE SUMMARY

Network connectivity now permeates many of the products used in homes and businesses and continues to proliferate at a rapid pace. Internet-connected devices are expected to number 30 billion by 2020 (Columbus 2016) and increase global electricity consumption by over 45 TWh by the middle of the next decade (EDNA 2016). Minimizing the energy consumed while network devices are idle is critical to limit the energy impacts of this wave of new network-connected end uses.

Mobile products have mastered the art of being idle, even while maintaining network connections, so advocates of energy efficiency naturally look to high-tech mobile devices for solutions that can be adapted to mains-powered products as well. A comparison of smartphone network standby consumption with that of networked, mains-powered products shows that a considerable gap exists between many of today's connected devices and their battery-powered cousins (see figure below). Some of this difference can be attributed to different functionality (e.g. not all products have voice recognition capabilities), but some is due to the design and optimization of the network standby function[1] itself.



Mobile products like smartphones consume orders of magnitude less power than many mains-powered products while providing network standby functionality. (Source data: EDNA 2017 and Wang et al. 2016)

What can be gleaned from the world of mobile design and directly put to use in mains-powered products, specifically for network standby conditions? To what extent are these strategies already employed in mains-powered products? What barriers do designers face when trying to implement

[1] Network standby is a function that allows a product to maintain a network connection and await a network "trigger" or message to be woken as needed

these solutions? Our research addresses these questions through consultation with industry experts and design resources.

We find that there are few turnkey technology solutions that can be directly imported into mains-powered designs.[2] What still separates the two, however, is the overall design approach utilized in the mobile space. An integrated, energy-optimal design approach, in which disparate engineering teams collaborate iteratively toward energy optimization goals (including low network standby energy use), is currently the best and only known way for manufacturers to produce devices with extremely low energy use. Our report provides details on how such a design process functions at a high level and the types of organizational changes that may be required to manage toward energy-optimal design goals.

Our research also uncovers several barriers and concerns common among manufacturers of mains-powered products when seeking to more aggressively optimize for network standby energy consumption:

- **Cost**: The integrated, energy-optimal design process is significantly more labor-intensive than traditional design approaches. The process of integrated design, quite simply, takes more human effort, and industry experts have not yet devised a way to fully automate it.
- **Complexity and verification**: Adding low power states to an individual component adds to the burden of the verification process, in which parts are tested to ensure that they perform according to specifications. More power states essentially equate to more features of the part that must be verified for proper function, an effect that compounds at the system level.
- **Latency tradeoffs**: Requiring a product or its components to enter lower power states can introduce latency or delays when a user wishes to resume using the device.

Two technological paths may provide a more solid foundation for energy-optimal network standby design in mains-powered products, while helping to address barriers:

- **Efficient network protocols**: Low-power, lower-bandwidth network protocols designed for Internet of Things products, such as Bluetooth Low Energy, Zigbee, or Z-Wave, offer the potential for deeper power management. Wi-Fi Wake Up Radio (WUR) technology is currently being developed that could enable milliwatt level network standby power consumption in higher bandwidth Wi-Fi products as well.
- **Design tools**: New design tools may also aid manufacturers in the transition toward energy-optimal design. Two complementary IEEE projects, P2415 and P2416, are developing frameworks to standardize reporting and modeling of power and power states in electronic products. This could reduce both the costs and complexities of energy-optimal design.

Policymakers can work to support and advise these efforts to facilitate a transition to more mobile-like design and mitigate network standby power.

[2] Part of the reason for this is that many of the same hardware components (embedded computing architectures, for example) can *already* be found in mobile and mains-powered products.

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1. INTRODUCTION

The number of Internet-connected devices continues to grow and is estimated to reach 30 billion by 2020, up from 15 billion in 2015 (Columbus 2016). Commensurate with this growth will be a continued rise in network standby power. This is especially true for emerging, mains-powered "smart" products, including smart lighting, home automation, smart appliances, smart street lighting, and smart roads. By the year 2025, it is estimated that these applications alone will increase global electricity consumption by over 45 TWh (EDNA 2016).

Minimizing the energy consumed while network devices are idle is critical to limit the energy impacts of this wave of new network-connected end uses. Mobile products have mastered the art of being idle, even while maintaining network connections. Today's smartphone designs can draw less than 50 milliwatts from their batteries — the equivalent of less than 0.1 Wac if the product were connected to AC mains[3] — while in a network standby state (Wang et al. 2016), and yet they remain able to receive calls, push notifications, and process other incoming network traffic with little perceived latency on the part of the user. Many smartphones can even respond to voice commands in these low power states. Similarly, wireless sensor technologies draw so little power that they can often be energized by ambient vibrations or other forms of energy harvesting (EnOcean 2015, 2016).

Proponents of energy efficiency look to high-tech mobile products as paragons of network standby efficiency, and rightly so. Mobile products, after all, bear strong resemblance in their overall architecture to many of the mains-powered products emerging on the market today. Logically, there should be components and subsystems from the mobile world that directly transfer to mains-powered product designs, conferring immediate efficiency benefits.

But what can be gleaned from the world of mobile design and directly put to use in mains-powered products, specifically for network standby conditions? To what extent are these strategies already employed in mains-powered products? What barriers do designers face when trying to implement these solutions? Our research addresses these questions through consultation with industry experts and design resources. We examine the conditions driving efficient design in the mobile sector and the subtle ways in which they differ in mains-powered product segments. The report then details the design processes that have allowed high-tech companies to create highly energy-optimized devices in the mobile world and discusses practical considerations for implementing such a process in mains-powered products. Finally, we identify developments in network protocols and design tools that may provide new opportunities for energy savings under network standby conditions and highlight implications for policymakers.

[3] We conservatively assume that power supplies in mains-powered products can deliver 50 mW of DC power at efficiencies above 50 percent. This accounts for losses at several stages, including AC-DC (70% efficiency) and DC-DC (80% efficiency). Therefore, AC power draw of less than 100 mW or 0.1 W should be possible.

2. THE NETWORK STANDBY GAP

2.1. MOBILE: A FERTILE SPACE FOR LOW POWER DESIGN

Whether designing product packaging, semiconductors, or skyscrapers, all designs are driven by customer needs and requirements. In the realm of mobile products, one requirement consistently ranks at the top of the list: battery life. This is true for all portable electronic products, including laptops, e-readers, and tablets, but is most evident in smartphones. Even a decade after the smartphone's introduction, consumers still desire longer battery life more than any other phone feature. [4] Because of physical limitations on simply increasing battery size, manufacturers are pressed to optimize every microwatt of power. This is especially true in network standby conditions, where devices may spend most of their time. Thus, battery life and, by association, efficiency have become foundational design considerations for mobile products, because efficiency directly translates into competitive advantage and the bottom line.

Consumers' strong preference for longer battery life has spurred smartphone manufacturers to invest heavily in efficiency, but this is not the only factor spurring low power designs. Leading smartphone manufacturers like Apple and Samsung maintain large price margins on their flagship products, allowing for significant reinvestment in the highly labor-intensive process of continuously optimizing designs. The pace of innovation for these products is also extremely rapid, with annual product refresh cycles and significant architectural changes on a bi-annual basis. Smartphones are now reaching their 8th generation of product in a little over a decade, whereas video game consoles have taken over four times as long to reach 8th-generation product (Douglas 2012). Finally, manufacturers of some of the most power-optimized smartphones benefit from a vertically integrated structure. When a manufacturer controls everything from the fabrication of key processor components, the design of other key hardware like displays and batteries, and the software that runs on the device, they have significantly greater opportunities to optimize each layer of the system for maximum efficiency.

2.2. THE GAP FOR MAINS-POWERED PRODUCTS

Customer needs and market incentives drive significantly different priorities for manufacturers of mains-powered products. But even without portability and battery life concerns, mains-powered products do still have some natural power constraints. In electronics, processors, memory, and even power supplies can generate a significant amount of heat when under heavy loads, and product designers must bear this in mind especially when designing for small enclosures — such as in smaller consumer electronics — and for products that will enter power-constrained environments — such as servers that will populate racks in data centers with limited power density. The trend toward small form factor designs in all manner of consumer electronics would seem to indicate an increased sensitivity toward efficiency in design.

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[4] https://today.yougov.com/topics/technology/articles-reports/2018/02/20/smartphone-users-still-want-longer-battery-life

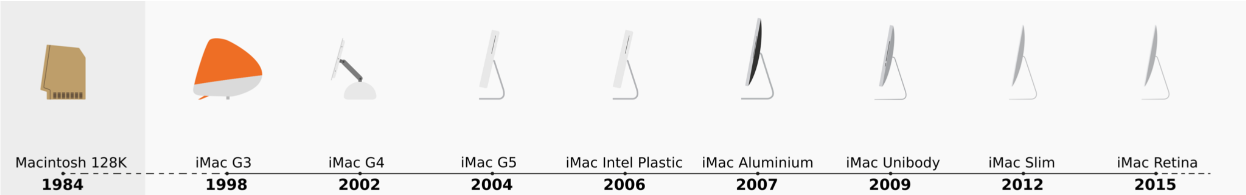

Figure 1: Shrinkage of Apple iMac form factor over time (Source: adapted from Giulia Piccoli Trapletti, DensityDesign Research Lab, 2016)

While it is true that consumer preferences for smaller form factor electronics has placed additional design pressure on manufacturers to limit *active power draw*, this will not necessarily translate into further power optimization in *low power and idle modes*, network standby in particular. When designing a product and its enclosure, engineers are constrained by the worst-case heat generation that will occur within the product. Component power consumption under peak performance in *active* modes typically drives this condition. Peak performance can occur when a computer is mining bitcoins, when a streaming set-top box is downloading and displaying a TV show, or when a video game console is rendering complex three dimensional visuals to a virtual reality headset. Consumer preference for small form factors will drive more efficient hardware choices for these conditions, but does not necessarily translate into efficient operation in network standby or other idle states.

This is where the contrast between the market and design drivers for mobile and mains-powered products become most pronounced. In the absence of mandatory efficiency regulations or targets, mains-powered products today are designed in a manner that is de facto “active power-optimal”: designers limit the power consumed and heat generated by the product in active modes of operation. On the other hand, mobile products must not only be power-optimal but “energy-optimal” as well to address battery life considerations. An energy-optimal product can draw higher power in brief bursts corresponding to increased service demands from the user, but must rapidly scale this power back most of the time to minimize total energy consumption. (This is often conceptually referred to as “power proportionality” or “power scaling”). Energy-optimal devices must optimize the power they draw in every instant and maximize the amount of time that they spend in low power states.

As a result of these differing incentives to optimize overall energy in network-connected low power modes, mobile products still lead mains-powered products significantly in their network standby power. Below, we illustrate the network standby power for a smartphone with its Wi-Fi radio enabled compared to a variety of Wi-Fi connected, mains-powered devices, ranging from Internet streaming set-top boxes like Roku to larger electronics like video game consoles and televisions. Today’s smartphones are capable of maintaining links to cellular and Wi-Fi networks and remain available for network traffic while drawing less than 50 milliwatts of power from their batteries (Wang et al. 2016) or less than 0.1 W of power[5] if connected to AC mains. Some mains-powered devices do provide additional secondary functionality in idle conditions, such as voice activation (as in the case of the smart speaker) or information displays (as in the case of the clock radio), and these have not been accounted for in this visual; however, smartphone network standby power draw is still over 70 percent lower than the next best product (a streaming set-top box). Compared to many other mains-

[5] We conservatively assume that power supplies in mains-powered products can deliver 50 mW of DC power at efficiencies above 50 percent. This accounts for losses at several stages, including AC-DC (70% efficiency) and DC-DC (80% efficiency). Therefore, AC power draw of less than 100 mW or 0.1 W should be possible.

powered electronics, smartphones highlight an order-of-magnitude gap in network standby power draw and illustrate a greater degree energy-optimized design.

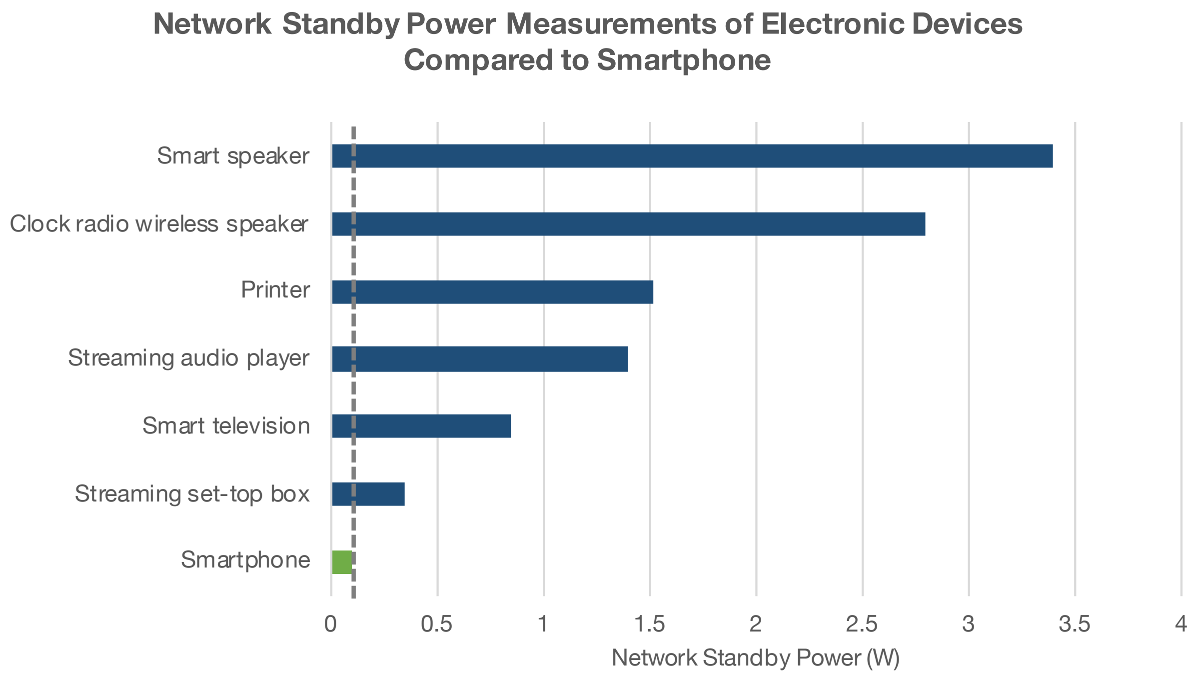

Figure 2: Mobile products like smartphones consume orders of magnitude less power than many mains-powered products while providing network standby functionality. (Source data: EDNA 2017 and Wang et al. 2016)

Even though mains-powered products lack the same market drivers, structure, and scale that have led to extremely low network standby power in smartphones, this does not necessarily mean that further optimization of network standby power in these products is not possible. To the contrary, many of the design principles that have evolved out of the mobile industry and other industries that operate in power-constrained environments (such as data centers) can be adapted to a wide range of networked consumer electronic products that receive their power from the electric grid. The following sections provide insight into the technologies and processes from the mobile world that can be leveraged to improve efficiency in all electronic products.

3. LOW ENERGY DESIGN PRINCIPLES

3.1. A SYSTEMS APPROACH

Energy efficiency policy efforts have often centered on singular technological innovations, such as the solid state lighting or high-efficiency external power supplies. The path to energy savings is turnkey: there is a dramatic leap in efficiency in a key component or subsystem, and the new technology can easily integrate with existing products. In the case of efficient power supplies, for example, a variety of consumer electronics manufacturers were able to dramatically improve overall product efficiency by substituting new external power supplies from different suppliers.

In the realm of connected devices, however, there are few turnkey solutions one can adopt from the mobile space that will generate energy savings in network standby without significant redesign. Although there are mobile processors with a greater number of power-saving states or software-based power management strategies that might ensure better efficiency during operation, they cannot simply be "dropped into" mains-powered products the way one can swap chargers on a phone. These components and strategies must be integrated into a larger and more complex electronic system. A mobile processor requires software instructions to enable its power-saving features and must interact with other electronic components (memory, for example) to ensure smooth transitions from active to idle usage conditions. Similarly, software power management needs to understand the capabilities of the hardware it controls.

A systems problem like optimizing network standby energy consumption ultimately requires systems-oriented solutions. To visualize the process used in the power optimization and design of mobile products today (Figure 3), we consider three layers[6] of abstraction at which design activities occur, progressing from narrowest to broadest scope: (1) hardware components, (2) system architecture, and (3) software.[7] Designers working at the hardware components layer consider the efficiency of individual components, such as memory and processors. In this realm, silicon designers might employ strategies to ensure that individual cores of a processor can be powered down. The system architecture layer concerns the integration of various hardware components into a functioning electronic device. Hardware designers will confirm that the various components of the system will function in a coordinated fashion and ensure that individual components will not prevent the system from reaching low power states. Finally, at the software layer, engineers and developers generate the instructions that determine the conditions under the overall device will enter low power states. For example, under what workloads will the processor be allowed to shut down certain cores or reduce its frequency or voltage? For the purposes of network standby, *all* design, at whichever layer, occurs within the context of existing network protocols, and the choice of network protocol is perhaps the largest factor in lowering network standby power levels (EDNA 2018). These protocols define the behavior of individual hardware components, such as Ethernet controllers and system-on-

[6] Those familiar with digital networks are likely accustomed to abstraction layers. Networks are often conceptualized using the Open Systems Interconnection (OSI) seven-layer model that abstracts the different layers upon which data travels and is processed in networked systems. It is important not to confuse these layers of design abstraction with the OSI model, even though the two may bear many similarities.

[7] Experts such as Jan Rabaey (2009) parse these design layers more finely.

chip (SoC) processors, and place limitations on the depth of power-saving strategies that can be deployed. LTE wireless radios for mobile devices, for example, can negotiate their radio's broadcast power level based on the strength of the signal received by the tower. This functionality is only possible because it is explicitly allowed by 3GPP[8] industry standards.

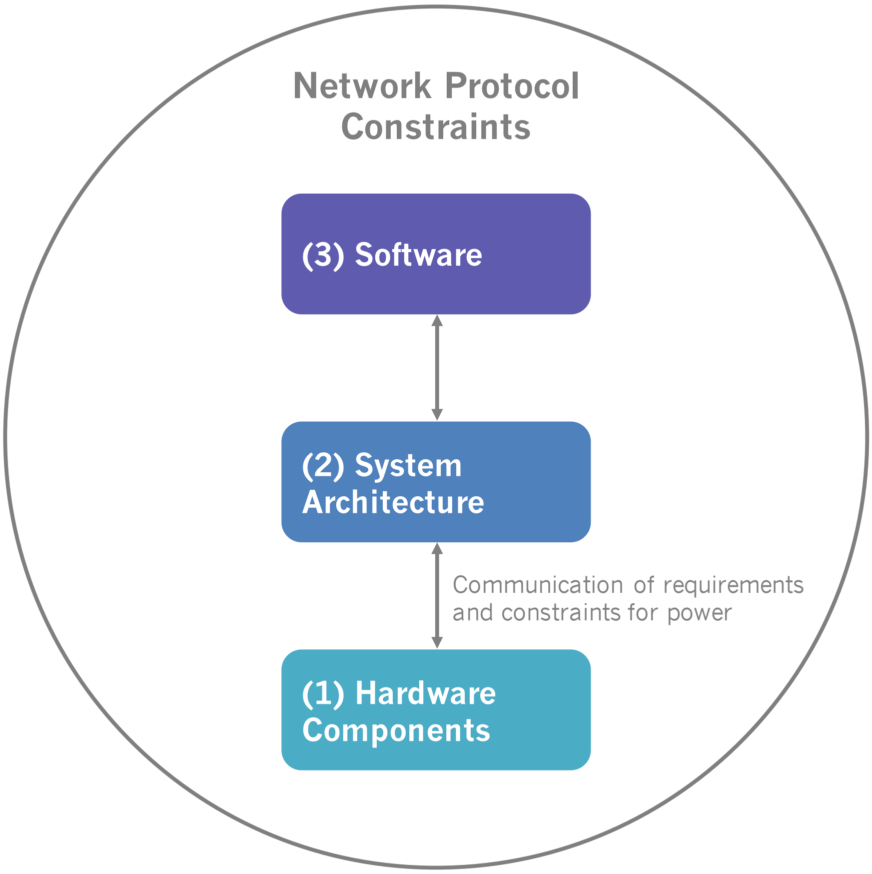

Figure 3: The layers of energy optimal design for network standby. In an integrated design process, information regarding the capabilities and constraints for power states and power management are transferred between the design layers and their respective teams. Activities at all layers are ultimately constrained by the network protocols that the product supports, along with other user requirements and market drivers not depicted.

As Figure 3 illustrates, the teams working at various design layers for an energy-optimized mobile device will communicate various requirements and constraints associated with their sphere of influence. This process occurs *continuously* throughout the design process, and design proceeds *simultaneously* and *iteratively*. No one layer dominates in terms of its contribution to meeting product energy goals. For example, should hardware designers specify a processor at the hardware layer that does not support robust low power states, it would limit the ability of software engineers to implement low power operational modes for the whole product. Conversely, poor design choices on managing "idle" software tasks might prevent systems at the architecture and hardware level from entering low power states, because they assume they still have work to perform for the user. Thus,

[8] The 3rd Generation Partnership Project (3GPP) is a collaboration between a variety of telecommunications industry associations that develops and standardizes technologies and protocols used for wireless wide area networks (WANs).

achieving energy savings in practice requires a flow of information between these layers and collaboration between the various teams executing them.

3.2. A CHANGE IN DESIGN PARADIGM

To simultaneously address the various design layers needed to produce energy-optimal products, mobile companies have evolved an integrated, low-energy design process. Major design teams and stakeholders for a product regularly communicate and collaborate around low-energy design goals. Information about the efficiency, power consumption, and ultimately battery life of the system are shared regularly from the onset of the design process. Power or energy in certain operational states may even be enshrined as a key performance indicators (KPI) that are tracked and managed so that energy targets can be achieved.

This is an iterative and time-consuming process, but it results in low power designs. Figure 4 illustrates one organization's tracking of power metrics over the course of the design. The team aimed to reduce power consumption 25 percent from the previous design. To accomplish this, engineers regularly executed models to estimate the overall power dissipation of the design. Over the course of 15 weeks, the team iterated on the design (and occasionally increasing power draw) until the power reduction goal was achieved.

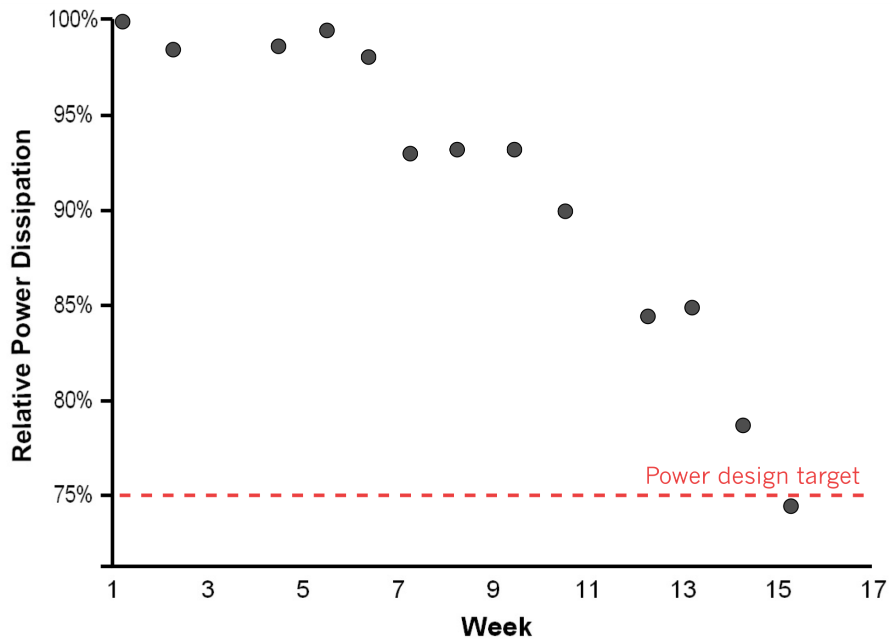

Figure 4: Design process with management toward a relative power design target. The target is only reached after 13 iterations in the 15th week of the project. Adapted from Rabaey (2009).

Given the labor hours and coordination required between teams, a low-energy design process like the one described requires a change in organizational culture as well, and such a change can only start at the top. "If you want the best results, the whole organization has to be in on it," according to Director of Open Standards at Si2, Jerry Frenkil. "There has to be a power-cognizant culture where teams manage specifically for this. The executives and the middle managers need to be bought in."

4. BARRIERS

From their inception, mobile products have always been connected and had clear market drivers to minimize energy consumption while maintaining that connectivity. For many mains-powered products, network connectivity is still evolving, and many manufacturers are skeptical that mobile strategies can easily be transferred from the mobile world to other product segments for a variety of reasons enumerated below.

4.1. COST

A commonly cited barrier is cost. As with many energy-saving measures, increasing efficiency in network standby may add to the bill of materials. Power management integrated circuit (PMICs) require additional silicon real estate to manufacture, and area[9] is a primary driver in the cost of semiconductors.

But material costs are of less concern to manufacturers than investments in human capital. The mobile industry has invested heavily in the low energy design process and spent years cultivating in-house expertise. Building the business processes required for low energy design requires long-term investment, but the practice of low energy design is labor-intensive as well. “There’s a lot of hardware and software that needs to be touched in order to orchestrate low power modes,” says Vojin Zivojnovic, President and CEO at Aggios, a firm that specializes in developing software-based tools to better orchestrate real-time power management in electronic devices. “It only takes one component to prevent a device from completely powering down and it may take thousands of person-hours to fix this.” According to design experts, even the most sophisticated organizations in the mobile space have not been able to fully automate this process to date, especially at the system and software layers. (The lack of standardized design tools is, however, being addressed by several industry projects, described in Section 5.) Low energy design, quite simply, takes more human effort.

4.2. COMPLEXITY AND VERIFICATION

In addition to cost, some manufacturers we spoke with perceived that there are risks to pushing the envelope on low energy design for network standby. For example, there may be risk through added complexity. Adding low power states to an individual processor or SoC adds to the burden of the verification process, in which parts are tested to ensure that they perform according to specifications. More power states essentially equate to more features of the part that must be verified for proper function. Instead of one operational state that needs to be verified, there might be three. This compounds when trying to orchestrate low power states across an entire electronic system (an entire smartphone, for example) and ensure proper, coordinated function.

4.3. LATENCY

There is also a risk of increasing device latency. Requiring a product or its components to enter lower power states can introduce latency or delays when a user wishes to resume using the device. Innovators in low energy design have characterized the tradeoff relationship between energy and

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[9] More accurately, the density of chips that one can yield from a single wafer of silicon, which is a function of the chip’s area, drives cost.

latency, allowing designers to quantify the potential latency risk of introducing lower power states (Rabaey 2009). Generally, the tradeoff relationship resembles the curve shown in Figure 5. Designs operating with maximum energy will tend to have the least amount of latency, and vice versa. However, very large reductions in energy can often be achieved with little impact to latency, and this avenue remains open to manufacturers. Conversely, there is a point of diminishing returns as well, leading to minimal energy reductions and intolerable latency. Ultimately, the threshold for latency is dictated by the amount of delay that can be tolerated by the user or other dependent processes.

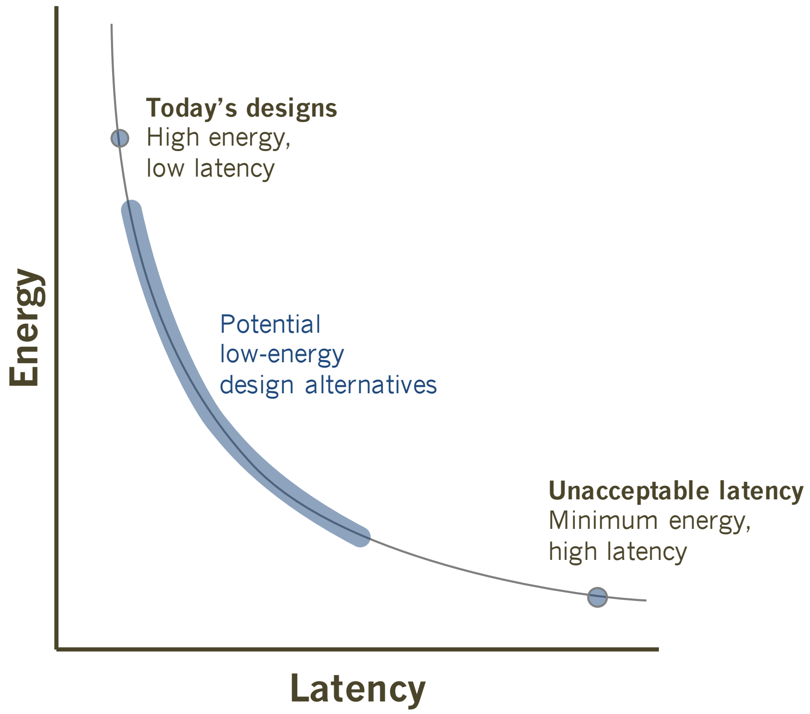

Figure 5: The energy-latency tradeoff. Significant gains in efficiency may be possible with few noticeable latency impacts or with latency that is tolerable to end users.

Despite a lack of easily adaptable, turnkey solutions for network standby efficiency and several other barriers and disincentives for manufacturers of mains-powered products to act independently on this issue, experts we interviewed were in agreement that low-energy design principles could be extended to non-mobile products. "Mobile design strategies can absolutely be applied to mains-powered products," said Jan Rabaey of UC Berkeley. "But manufacturers require an incentive to invest." The transferability of design strategies stems from large similarities in underlying systems and functionality, especially in network standby operation. Even emerging Internet of Things (IoT) devices lend themselves well to power optimization approaches, according to Vojin Zivojnovic of Aggios: "There's nothing special in these IoT devices that we haven't seen in other devices before."

5. TOWARD LOW ENERGY DESIGN

Fortunately, several network technology and standards development trends may ease the transition to low-energy design. Below, we summarize these developments and provide considerations for the policy community on how to move forward.

5.1. A CHANGING LANDSCAPE FOR NETWORK PROTOCOLS

Several of the stakeholders we interviewed lamented that one of the elements that designers simply cannot change when they attempt to optimize a device's network standby energy profile is the existing network protocol landscape. However, communications protocols are themselves dynamic, especially when industry consortia identify new product use cases and gaps in existing standards. The development of the Bluetooth Low Energy (BLE) standard clearly illustrates how protocols can rapidly evolve when energy is a design constraint. "If you were trying to optimize your power in a Bluetooth wireless use case, there used to be only so many things you could do to make it more efficient," says Ben Eckermann, Technical Director and Systems Architect for Digital Networking at NXP Semiconductor. "Eventually they needed Bluetooth Low Energy to get to a lower power tier." BLE specifically addresses variety of home, health, and fitness scenarios for devices that are designed to operate for years off of a coin battery cell.

Similar transitions are underway in the realm of smart home products, many of them mains-powered. In particular, lower power and bandwidth network protocols like Zigbee (part of the IEEE 802.15.4 family of low-rate wireless personal area network technologies) are gaining increased traction in the marketplace as consumers begin to adopt smart home technology. Smart home edge devices like smart LED lamps, lighting and power controls, and power outlets are increasingly turning to low power protocols like Zigbee to minimize product cost and size. Early generations of these products employed Wi-Fi technology, which was well understood and broadly available, but these designs often consumed 1 to 2 W in network standby states. Using lower power protocols like Zigbee and Z Wave, today's products can easily draw less than 0.5 W while maintaining network connections.

This pivot to lower power network protocols is also being enabled by smart speakers, which many view as the emerging control center for smart home systems. Penetration of smart speakers like Amazon Echo and Google Home continue to grow rapidly, with nearly 20 percent estimated ownership in developed countries (Martin 2018), so these products will be a key element in standardization of connected home products. Smart speakers currently require Wi-Fi connectivity for the backbone of their high-speed communication with the cloud, but manufacturers are adding Zigbee hub functionality to allow certain models to communicate with smart home products directly, without the need for a third party hub.[10] The inclusion of Zigbee hubs further cements low power and low-bandwidth protocols like Zigbee and Z Wave as the smart home network protocols of the future.

Protocols like Zigbee and Z Wave may not be able to address the needs of many existing office, IT, network, and entertainment products with higher bandwidth needs, but they may provide

[10] The Amazon Echo Plus contains a Zigbee hub and can provide basic functionality to compatible products, but for full application support, proprietary smart home hubs like Samsung SmartThings or Philips Hue may still be required. It is unclear whether Zigbee hub functionality in smart speakers could eventually obviate proprietary smart hubs like Samsung SmartThings, Wink, and Philips Hue that currently add to the growing list of small network equipment installed in smart homes.

opportunities to ensure that the growing wave of smart home technologies have the best foundation for low-energy network standby. Low-bandwidth devices such as smart thermostats, lighting controls, power controls, outlets, light bulbs, appliances, smoke detectors, and sprinkler systems could be viable candidates. Devices with higher bandwidth, lower latency functions that operate continuously, such as video streaming from smart doorbells or web cameras, would likely still require Wi-Fi or similar high-bandwidth protocols.

For manufacturers looking to maintain compatibility with Wi-Fi network infrastructure while enabling low power draw in network standby, new developments in the IEEE 802.11 standard may eventually provide a path forward. The 802.11 standard is currently exploring the concept of standardizing a hardware-based efficiency strategy for Wi-Fi called Wake-Up Radio (WUR). Wi-Fi products with WUR would contain a secondary, low power radio (a WUR could operate at less than 1 mW) that listens for a network trigger (a wake-up packet) and wakes the main Wi-Fi radio when a device's "name" is called on the network (IEEE 2018c).[11] Although WUR is being developed with battery-powered use cases in mind, it has been touted as a low latency solution and, therefore, could be suitable for mains-powered products as well. WUR is still likely a couple years away from ratification and is not a part of the recent Wi-Fi 6 (802.11ax) standard. The task group working on WUR provisions (802.11ba task group) is expected to release a second draft of standards language in fall of 2018, with potential for ratification by 2020 (IEEE 2018c).

[11] As with other network protocol-based efficiency strategies like Energy Efficient Ethernet (IEEE 802.3az), WUR needs to be supported both at the wireless access point or router as well as by the edge device.

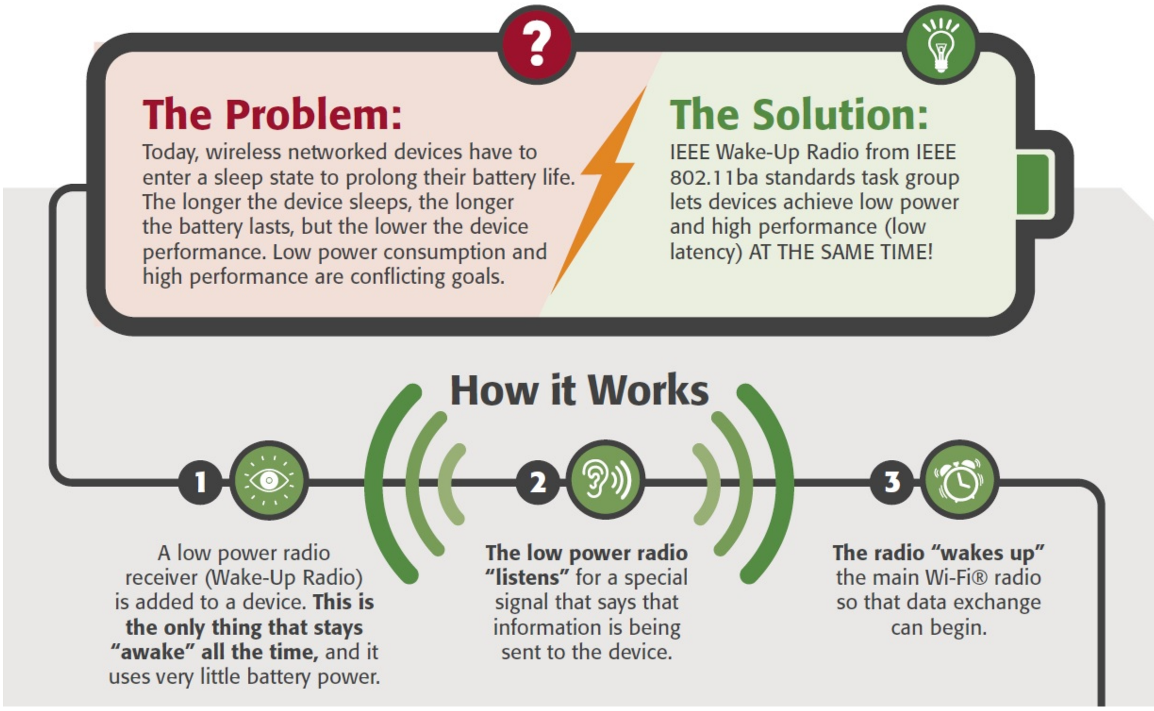

Figure 6: IEEE's WUR initiative promises to provide a solution that will allow Wi-Fi based products to perform network standby functions with low latency and extremely low power draw. (Source: IEEE 2018)

5.2. BETTER TOOLS FOR LOW ENERGY DESIGN AND OPERATION

Key stakeholders in the electronics industry have recognized the need for better tools to enable both low energy design and operation of electronic devices. Since 2015, a variety of organizations — including Intel, Broadcom, Microsoft, Qualcomm, IBM, Nvidia, ARM, Cisco, Si2, and Aggios — have embarked on two complementary IEEE projects that could help make low energy design and operation of electronic systems more commonplace.

The first project, IEEE P2416, involves standardized modeling for power states of various electronic components (IEEE 2018a). This information can be used during design to inform decisions around component selection and achievable power targets. The larger goal of the 2416 effort, as described by Si2's Jerry Frenkil, is to ensure that manufacturers have sufficient information to optimize the hardware or asset efficiency of electronics early in the design process. The efforts in 2416 most directly impact decisions made at the lower two layers of the design stack.

The second project, IEEE P2415 led by Aggios, is developing a unified framework to understand the allowable power states of an entire electronic system (IEEE 2018b). The project refers to this model of overall device power states and functionality as a "unified hardware abstraction" or UHA. With a UHA in hand for a given electronic device design, engineers can develop power management instructions that will optimize a device's energy while in use. P2415 and the UHA most directly influence decisions made at the software layer of the design stack. Recently, using tools developed as part of the P2415 project, Aggios was able to achieve an 85 percent reduction in network standby power in a video game console (reducing from about 10 W to 1.5 W) (Aggios 2018).

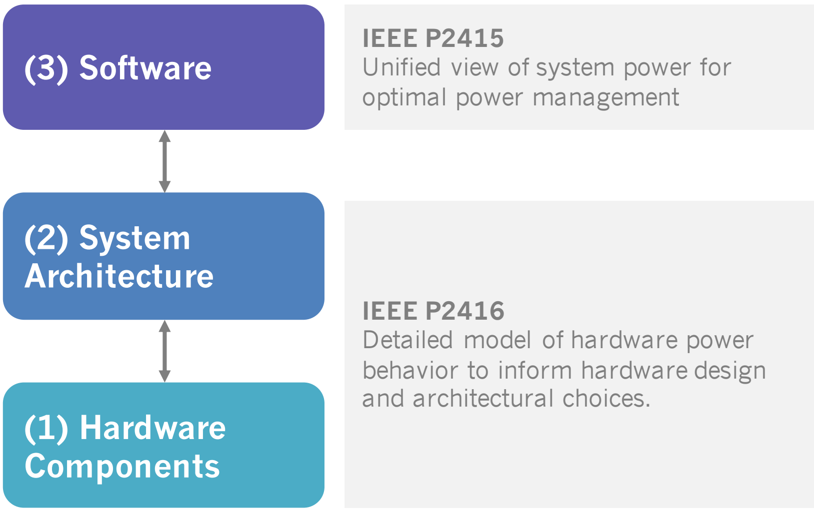

Figure 7: IEEE projects P2415 and P2416 collectively address all layers of the design stack

5.3. CONSIDERATIONS FOR POLICYMAKERS

Mobile products and other devices from power-limited applications still provide some of the best examples of what is possible for efficiency in mains-powered products, but there are few turnkey efficiency solutions that can be directly adopted from mobile designs. Rather, designers of mains-powered products can adopt the general and non-proprietary principles and processes that designers in other product segments have evolved and transfer them to the mains-powered domain, where manufacturers have fewer incentives to optimize designs for energy.

The change we speak of in this report entails a shift in organizational culture and design practice that is beyond the purview of most policy activities. Although policymakers cannot prescribe the tools and design practices employed in the industries they regulate, the policy community may undertake activities that complement and enable industry efforts.

5.3.1. Addressing Network Protocols

Two general areas of potential exist. First, policymakers can address network protocols, the foundation upon which the design process rests. The policy community naturally does not have a direct hand in the design and development of network protocols, but energy efficiency research funds and emerging technology programs can help fund participation in standards development by technical advisors, who can monitor developments and advocate for new power-saving provisions. Mandatory efficiency regulations and voluntary labels may also help to encourage the use of the most appropriate, low power network protocols in emerging smart home and mains-connected IoT applications, where designers might otherwise opt for more power-hungry and high-bandwidth network technologies by default.

5.3.2. Addressing the Design Process

New, industry-led efforts may provide more realistic and cost-effective paths to low energy design for network standby. Projects like IEEE P2415 and P2416 should, at a minimum, be monitored by the energy efficiency community, if not directly supported. However, for the projects to be successful, the design standards and tools developed by the projects must be adopted and put into practice in industry.

Energy efficiency programs, labeling organizations, and regulatory bodies could provide incentives for manufacturers who contribute to, develop, and eventually use the standards being developed by these projects. Use of low energy design standards could be fostered further through product design competitions that require their use. University teams, for example, might be asked to develop specific network-connected devices through use of the P2416 and P2415 approaches. As techniques mature, efficiency stakeholders could even collaborate with industry to promote training and certification that ensures manufacturers and their employees are well-versed in these principles. Such certifications could even eventually become a factor in obtaining special distinction as an organization under voluntary labeling programs like ENERGY STAR.

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