# Capturing Plug Load Energy Savings with a Wide Net: Horizontal Policy Lessons Learned and Future Opportunities

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**ABSTRACT**

Energy Information Administration's 2011 Annual Energy Outlook projects plug loads to grow 60% from 2010 to 2030, dwarfing traditional categories like lighting and HVAC. Although certain plug loads, such as TVs, set-top boxes and office equipment, represent large portions of the energy usage and growth, the majority of plug load energy is consumed by a diverse group of miscellaneous plug load products that are challenging to address with device-specific standards. Horizontal mandatory standards for a common plug load component, the external power supply, have already saved at least 30 billion kWh worldwide. Forthcoming California and U.S. battery charger standards are expected to save an even larger percentage of total plug load energy use. Yet, these initiatives fall short of addressing all possible horizontal plug load energy savings.

Requirements that improve power factor and promote effective power scaling are opportunities to catch further savings. Currently, many plug load devices have poor power factor, inefficiently drawing current from the wall plug outlet, and ultimately increasing energy losses in building wiring. Plug loads can also dramatically reduce energy use by intelligently scaling power to match the level of service provided to consumers. Worldwide savings from improving power factor would be approximately 16 billion kWh per year, the equivalent of taking six 500 MW coal-fired power plants offline—considered six "Rosenfelds" of savings.[1] Savings from power scaling could be even larger; in U.S. residences alone, we estimate roughly 70 TWh per year—or 20 Rosenfelds—are possible. This paper first examines lessons learned from prior horizontal plug load efforts, including external power supplies and battery charger systems. We then identify and analyze future horizontal standards opportunities in power factor and power scaling, providing technical rationale, savings opportunities and policy approaches.

## Introduction

While the growth of energy consumption associated with traditional end uses like lighting has slowed due to programs and policies implemented during the past few decades, the number of devices that plug into our wall outlets and their associated energy use continues to rise. While mandatory and voluntary policy and program efforts focus on the most energy-intensive plug loads such as computers, televisions, and set-top boxes, a notable portion (45%) of the energy used by plug loads comes from all the other miscellaneous devices in the home (Foster Porter, Moorefield, & May-Ostendorp 2006). While the individual energy impacts of devices such as

[1] One "Rosenfeld" is equivalent to taking a 500 megawatt coal plant offline as a result of improvements in energy efficiency and is named in honor of Arthur H. Rosenfeld, founder of the Center for building Science at Lawrence Berleley National Laboratory and retired California Energy Commissioner.

cell phones, mp3 players, coffee makers, rechargeable tooth brushes, and rechargeable power tools may be small, they account for a substantial portion of the overall plug load opportunity.

Policymakers have already begun to address the energy use of these smaller plug loads with horizontal standards that focus on one common element found in many products. Many plug load products

- continue to draw power when turned off or otherwise in a **standby** mode.
- require a **external power supply** to convert wall voltage ac to low voltage dc.
- utilize a **battery charger system** to operate when disconnected from the wall outlet or provide emergency back-up power when the grid is down.

These three common characteristics have enabled policymakers to address miscellaneous energy use by setting mandatory energy efficiency requirements focused on each feature, saving as much as 90% of total device energy use in some cases (Porter et al. 2010). Because each product uses a small absolute amount of energy, these types of devices are not well-suited to voluntary measures championed by many electric utilities across the country. The cost of processing rebates and running the program with a high number of units to track generally exceeds the value of the total energy savings achieved. Therefore, mandatory policy is the best choice for addressing the energy use of these small plug load devices.

The three primary horizontal policies addressing plug load energy are outlined in Table 1 below. For standby, regulations focus on driving down the power of products when they are in their lowest energy-using mode (usually a form of off). External power supplies and battery chargers are common hardware components found in many plug load products. These two power systems can be isolated, tested, and regulated to improve their efficiency.

**Table 1. Summary of Current Horizontal Energy Efficiency Policy**

| Policy | Jurisdictions with Policy | Test Procedure | Modes of Use Addressed | Timeframe of Policies | Energy Savings Achieved |
|---|---|---|---|---|---|
| **Standby power** | IEA 1-Watt: Multiple countries, international | IEC 62301 ed2.0 (IEC 2011) | Low power | 1990s to present | Multiple devices use < 1 W |
| **External power supply** | Australia, Canada, China, Europe and United States | Various international documents | Low power (no load) and active | 2004 to present | 30 billion kWh globally |
| **Battery Charger** | California, United States (pending) | DOE test procedure (DOE 2011) | Low power and active | 2012 to present | Standard becomes effective 2013 |

These horizontal policies garner substantial energy savings from plug load products that would be difficult—if not impossible—to address individually. However, there are also a number of challenges unique to horizontal plug load policies, which we discuss in turn below.

Because many different types of plug load products fall within the scope of one measure, creating a test procedure with repeatable setup conditions and technician instructions to address all possible products requires substantial effort and significant stakeholder feedback. For example, the creation of the test procedure for battery chargers required many stakeholder workshops over approximately seven years to be able to test the efficiency of any rechargeable battery charger system, regardless of battery chemistry or design. Product scope included: mp3 players, laptops, power tools, uninterruptible power supplies, golf carts, and industrial forklifts, among more than 40 other products.

Many plug load products are consumer electronics. In this product category, manufacturers constantly innovate new end-uses (e.g. cell phones to smart phones) as well as introduce entirely new products (e.g. tablets, such as iPads). New technological approaches, such as increased network connectivity, are regularly introduced. This can have impacts on the test procedure used with the regulation as well as the regulation itself.

Given the broad scope of many of these horizontal initiatives, a large number of disparate stakeholders must provide feedback during the policy creation process. This increases the complexity and time associated with the creation of test procedures and standards.

Because plug loads often have multiple common features, they may fall within the scope of more than one horizontal policy. In the most complex case, some devices, such as laptops, are subject to standby power, external power supply, and battery charger regulations in various jurisdictions around the globe. Many battery charger systems also utilize external power supplies, and so are subject to both California and United States regulations. Policymakers must be aware of the landscape of existing horizontal regulation and sensitive to possible measures that increase regulatory complexity.

In addition to these measures, opportunities exist to further curb energy use of these small plug load devices and drive down energy use. Power factor (PF) and power scaling are two promising opportunities that can not only address small plug loads, but can also be incorporated into individual measures focused on higher energy use plug loads.

## Power Factor

### What is Power Factor?

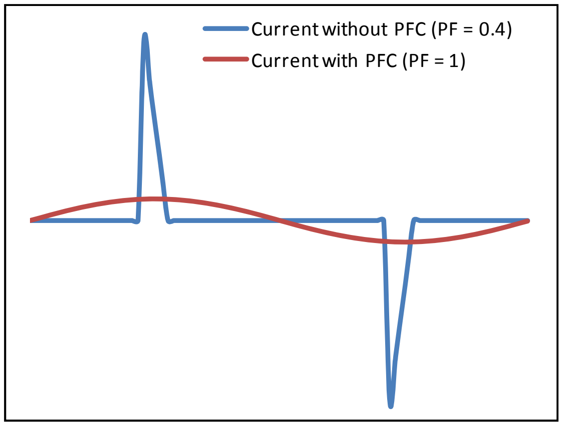
Many plug load devices today utilize switch mode power supplies (SMPSs). Although SMPSs are more efficient than linear power supplies at converting ac to dc, they also draw current from the wall in spikes. Power losses in building wiring are proportional to the square of the current; for instance if the current is doubled, the power loss is quadrupled. Therefore, drawing the current in short spikes instead of broad, smooth waves results in greater building wiring losses. An example of a device that has poor PF (0.4) is shown Figure 1.

PF is often considered in the transmission and distribution of electricity (from the power plant to the home) and in industrial and commercial buildings. Electric utilities typically encourage higher PF through their commercial and industrial rate structures—mostly to maximize the power carrying capacity of transmission and distribution lines and to improve system reliability.[2] However, horizontal PF savings opportunities for residential and small

[2] Utilities are also concerned about current harmonics, which are caused by SMPS that are not PF corrected. When multiple SMPS devices are present in a three phase wiring system, such as those used in most commercial buildings, they can sum together and exceed the current rating of the neutral line, causing it to overheat.

commercial devices have not yet been addressed by policymakers. Improving PF can save energy for building owners by reducing losses in building wiring. This is in contrast to most appliance energy efficiency efforts, which focus on reducing energy use of the device itself.

**Figure 1. Example of device with poor PF (0.4)**




Source: Denkenberger, Walters & May-Ostendorp (2011)

**Power Factor Correction Techniques**

An electronic device whose requests for current more closely match the smooth sine wave voltage provided in building wiring is "power factor corrected." The closer the match of the two waves, the nearer PF is to 1.[3]

There are two main ways to correct PF: "passive" and "active" correction. Passive PF correction (PFC) involves the use of additional analog control components (such as inductors and capacitors) and can achieve PF as high as 0.8; however, the cost and power required for these circuits generally prohibits their use for plug loads. The use of "active" digital controllers in PFC is the current state of the art, having higher efficiency and lower cost than passive PF. Manufacturers now offer effective, low-power, inexpensive integrated circuits capable of achieving PF of up to 0.99, although 0.9 is a typical figure. The latest products consume little additional power, incurring a 1.0 to 1.5% penalty on the power supply's overall ac-dc conversion efficiency. Cost is fairly independent of the power of the device, so digital active PF is more cost-effective for larger devices such as desktop computers.

Figure 2 illustrates an example of a high efficiency PF corrected power supply. The unit, which uses active PFC, maintains a 0.9 PF for most loading conditions, particularly when tested with North American voltage input (115 V). Good PF at partial load is important to achieve high operational PF in electronics products, because most electronics only place a partial load on their power supply the majority of the time.

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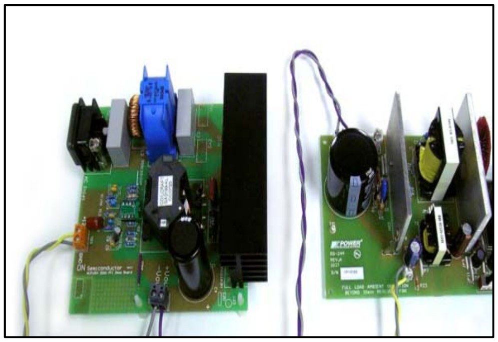
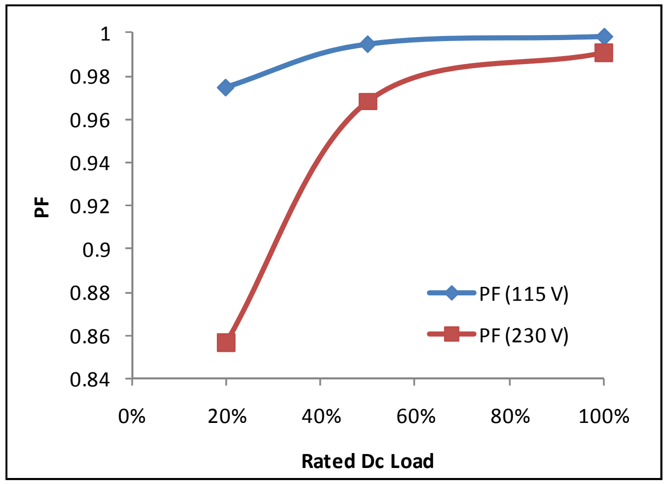
[3] Most electronic devices have a power factor less than 1. Power factor is always greater than zero.

**Figure 2. Switch Mode Power Supply with Power Factor Correction**






Source: Lighthiser, May-Ostendorp & Walters (2011)

## The Savings Factor

Energy savings achievable through widespread PFC are difficult to estimate because there are uncertainties in

- number and types of devices plugged into each circuit in a home or commercial building, including the PF of those devices
- coincidence of use of the devices
- building wiring length and configuration and wire thickness

Regardless, order-of-magnitude estimates show that requiring active PF for large energy-using residential electronics, such as TVs, desktop computers, set-top boxes, and computer monitors is likely to be cost-effective. The global energy savings potential would be roughly 16 TWh per year (six Rosenfelds), or the equivalent of taking six typical coal-fired power plants out of operation (adapted from Foster Porter, Moorefield & May-Ostendorp (2006).[4] As technology matures and the cost and inefficiencies associated with PFC fall, the technology will become cost effective for smaller devices. This could double the overall savings. The California Energy Commission Public Interest Energy Research (PIER) Program is in the process of studying this energy savings opportunity further, which will give further definition to the savings opportunity associated with PF.

[4] Global energy draw by plug loads in 2006 was ~600,000 GWh per year. With 7% growth per year, this would be 900,000 GWh per year in 2012. We assume that PF correction applies to 45% of this load (the large products) and achieves 4% average net reduction in losses (~5% savings in building wiring, but ~1% loss in the PF correction circuitry – see Denkenberger, Walters & May-Ostendorp (2011) for calculation details).

## Power Scaling

### What is Power Scaling?

Power scaling is the ability of a product to dynamically and proportionally vary power draw with changes in workload requirements from the user. Some devices power scale by simply "flipping the switch", or turning off certain energy-intensive functions or processes when not in use. More sophisticated versions of power scaling are analogous to a lighting dimmer switch, dynamically modulating the amount power drawn in accordance with the level of service required. In this section, we will discuss examples of the different forms of power scaling in two types of plug loads—data processing equipment and displays.

With the growing number and energy use of plug loads, it may not be surprising that efforts to apply power scaling principles to electronic equipment can result in tremendous energy savings. However, electronic plug loads have not exhibited the same degree of power scaling as other household appliances or motorized equipment. For many of these products, power draw is a function of circuit design, the power supply, and the capacity or speed of the processor(s). For a given processor speed, the power draw is more or less constant for some devices, irrespective of the amount of data being processed. So being able to take the "foot off the accelerator" during periods of low demand is an important energy-saving opportunity. For plug loads, effective power scaling requires careful design and coordination of hardware and software, which are challenging, but not insurmountable.

### Power Scaling In Data Processing Equipment: Low Power Modes

The simplest form of power scaling is akin to turning out the lights when you are not in the room. Under ideal power scaling design, electronic equipment that is not being used for its intended function transitions to a lower power state. For example, in a laptop, this happens at the component level (e.g. hard drive stops spinning when not in use) and the system level (e.g. power management software).

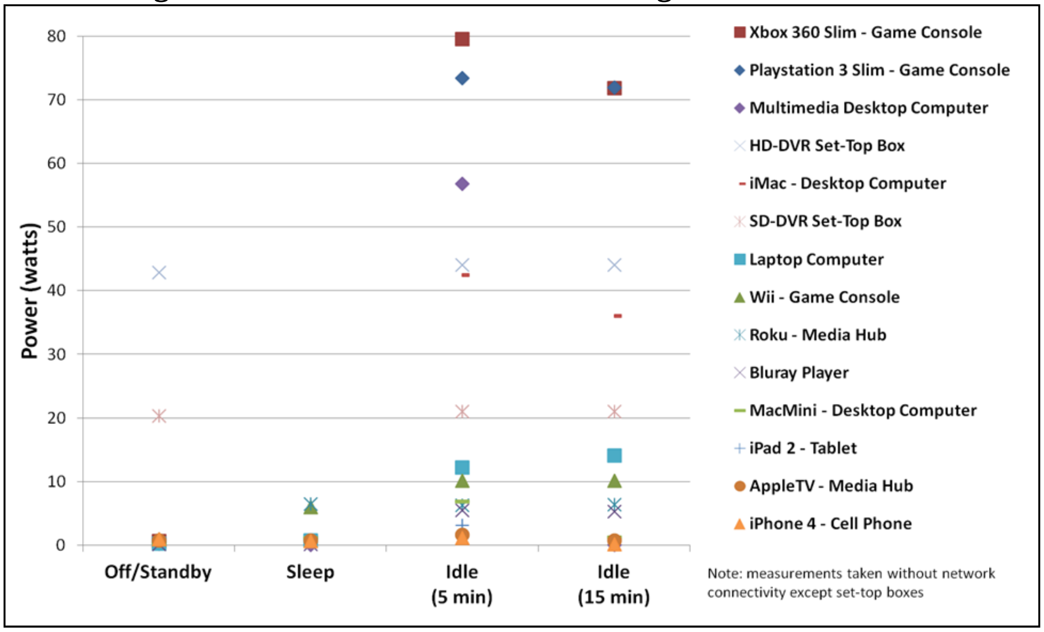
In Calwell et al. (2011), we measured the power use in non-active modes in high-end multimedia gaming desktop and laptop computers, new game console platforms, small form factor desktops, multimedia players, set-top boxes and cellular phones.[5] We found that computers and cell phones were capable of the most effective and nuanced power scaling, because they can shut off individual components like their displays or hard drives after short periods of inactivity, and eventually the entire device powers down (see iMac in Figure 3). It should be noted that although power scaling capabilities are available when the product is shipped, the default-enabled power management settings in Windows and Mac operating systems can be adjusted by users, and are often disabled by computer buyers, resellers and IT managers.

Current generation set-top boxes are an example of poor power scaling, because they draw the same amount of power whether they are active or inactive, on or off (Figure 3). Fortunately, cable television providers are beginning to address this issue, and the technology exists to power scale many set top boxes. There are plenty of examples of other data processing equipment that effectively power scale in non-active modes. In computers, for example, power

[5] These non-active modes include off/standby, sleep and idle.

scaling during non-active modes is accomplished with power management software that powers down the computer after a prescribed period of user inactivity.

**Figure 3. Measured Power Draw during Non-Active Modes**



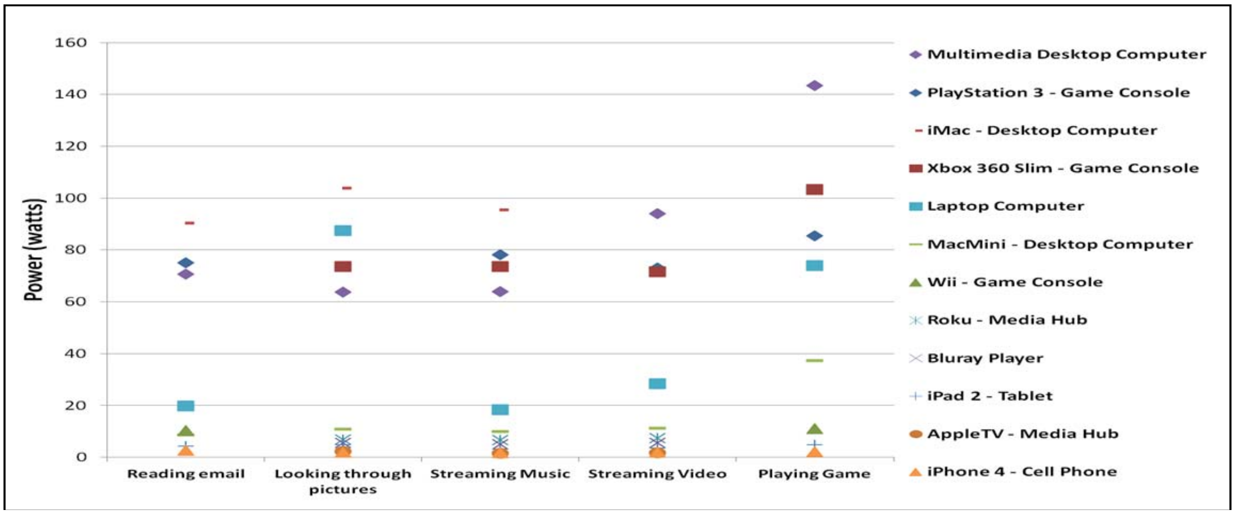

Source: Calwell et al. (2011)

## Power Scaling During Active Modes

Electronic devices are capable of more functions than ever before. There are now numerous devices that play high definition video, music, stream movies, and surf the Internet. However, not all devices use the same amount energy while performing these tasks. For example, if you check email using your game console, the energy consequences are much different than if you check it on your cell phone. Similarly, checking email should require less power than when playing a graphics-intensive game.

To better understand the active-mode power scaling abilities of different electronic products, in Calwell et al. (2011) we measured power draw over time for a common set of “universal tasks” that could be performed on a variety of devices. Not surprisingly, devices that were designed to be mobile had the lowest absolute power draw and the greatest dynamic range. However, among the products we tested, efficiency was most often achieved through fundamental improvements to hardware, not necessarily with power scaling. Most devices were capable of a small degree (perhaps 2:1) of power scaling among tasks. The best example of active-mode power scaling was observed in a laptop, which was capable of performing all tasks, and adjusted power draw by a factor of four or more among the tasks (Figure 4). Conversely, power scaling capabilities were not observed in the newest PlayStation 3, Xbox 360 and Nintendo Wii game console platforms. Regardless of whether the game consoles were used to play a game or streaming music on Pandora, they consistently drew about 80 W.

**Figure 4. Power Draw Associated with Popular Tasks**




Source: Calwell et al. (2011)

## Example Technologies to Enable Power Scaling

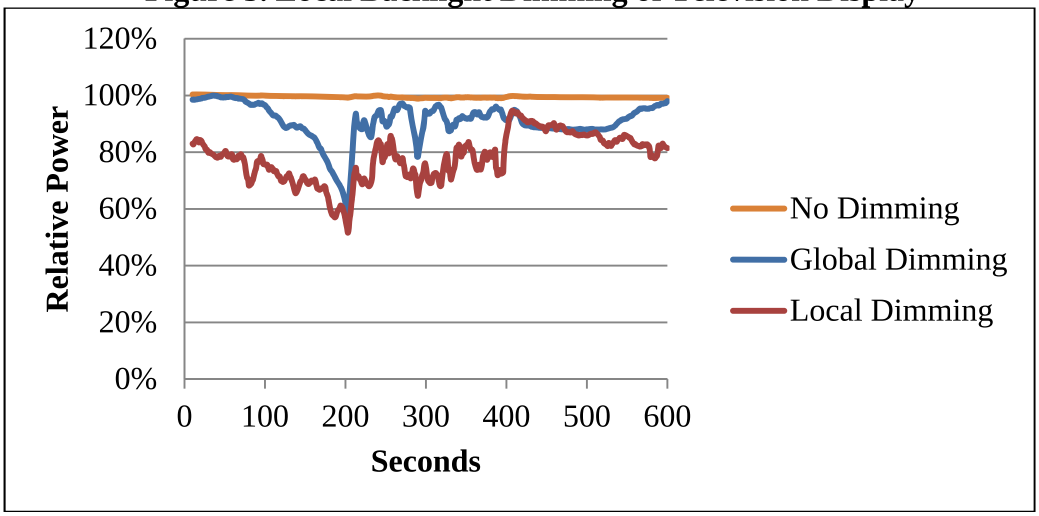
**Processing power.** One of the technologies that enables power scaling in mobile multimedia devices is the multi-core processor (Dayem, May-Ostendorp, & Lighthiser 2011). Additional cores help spread the computing loads across multiple processors, each of which is power-managed to dynamically scale frequency and voltage to computing loads. Some cores can be switched off if computational requirements are low. The net effect of multi-core processors is increased computing performance with lower power draw and much better power scalability during periods with reduced requirements.

Multi-core processors can achieve even deeper energy savings by allowing individual cores to “nap” when their services are not required, a technique called “power gating.” Most multi-core processors contain “homogenous” cores, meaning that each core is a generic processing resource with identical capabilities. This configuration is common in desktop and laptop computers where systems are highly configurable and the processor needs to adapt to any number of applications. Heterogeneous multi-core systems, however, contain purpose-built cores that perform specialized tasks. Today these units are most often found in cell phones, where specialized cores watch for incoming calls, process video, and operate built-in cameras as required. When they are not in use, specific cores can power down. Compared to homogenous cores, purpose-built cores can operate at lower frequencies, delivering specific functionality with lower energy demand.

**Indicators and displays.** In addition to devices with computer-like functionality, power scaling techniques are also being used in displays. Turning off the display when not in use, through the use of presence sensors, heat sensors or timers can reduce total time the display spends illuminated, increasing the time spent in low power modes. For example, the Sony Bravia televisions have “Intelligent Presence Sensors” that can recognize when a face is viewing the set, and can turn off the set when no one is watching, or adjust the image based on the locations of the viewers. Considering the fact that 80% to 90% of the energy a television consumes is used to produce the image, adding presence sensors to televisions in the U.S. could save approximately 5-8 TWh/year[6].

LCD backlight dimming is another power scaling solution to reduce energy use in displays. Applicable primarily to larger displays, such as TVs or monitors, the most aggressive backlight dimming can save as much as 20% (Figure 5). Backlight dimming reduces the amount of light in darker areas of the screen, resulting in better contrast and deeper blacks. Therefore, manufacturers are motivated by more than energy savings to use backlight dimming.

**Figure 5. Local Backlight Dimming of Television Display**




### Scaling Up Energy Savings

It is conceivable that power scaling techniques could extend even further to a wide range of electronic products. Manufacturers of wall-plug powered products currently have little incentive to save energy because wall-outlet power is cheap compared to battery power and there are few policy requirements (or other drivers) in this area. Internet-connected televisions, game consoles, set-top boxes, Blu-Ray players, desktop computers and an assortment of other home products with computer-like components are ripe for efficiency improvements though power scaling. Other opportunities exist for less energy-intensive devices as well, with a focus on transitioning to lower power modes more often, and keeping the power draw in those modes very low. However, the challenges of implementing mobile processing techniques in mains-powered devices should not be underestimated.

Latency is a key challenge for many plug loads. For example, gamers have become accustomed to pausing games to hold their game state, and leaving the console powered on for hours or days until the next session. While equipping consoles with aggressive power management software has the potential to save a lot of energy, the software must also be capable of saving game state when the console shuts down, and quickly resuming when reactivated. This type of consumer-friendly power scaling would have a greater degree of success, but will require modifications by both console manufacturers and game developers, which are separate entities. Cost and other unique challenges may also exist.

[6] Savings calculated using ENERGY STAR 5.3 on mode power draw and duty cycle. We assumed that half of the total stock of U.S. sets were ENERGY STAR.

These challenges are likely worth facing given the energy savings opportunity associated with broad adoption of power scaling. U.S. residential plug load energy use is approximately 250 TWh per year (Bensch et al. 2010), and electronics use approximately 80% of their energy in active mode. A conservative estimate suggests that power scaling can cut this energy use by one third, indicating overall energy savings of approximately 70 TWh per year—or 20 Rosenfelds—are possible in the U.S. alone (adapted from Calwell et al. 2011).

## Policy Recommendations

### Power Factor

Although energy efficiency test procedures for TVs, computer power supplies and large commercial and industrial battery chargers already measure PF, other large plug load test procedures currently do not. These protocols would need to be modified to account for PF, ideally incorporating measurements at partial loading conditions (such as low power modes) as well as full loading conditions (active mode). Once measurement methods are determined, PF can be incorporated as an additional metric for comparison, and PF requirements can be created.

The current U.S. EPA ENERGY STAR® specification for computers requires their internal power supplies to have PF of greater than 0.9. Mandatory TV standards in California require PF > 0.9 for TVs with a load greater than 100 W. These policies represent an initial step to taking full advantage of the energy savings associated with PF in large plug loads.

To tap into PF energy savings for small plug loads, the most straightforward approach is to measure PF as part of existing horizontal component requirements for external power supplies and battery charger systems. Manufacturers are already performing this test procedure on products to ensure compliance with mandatory standards expected to take effect in the market in 2013. Adding in a measurement for PF in low power modes and active mode would be minimal burden to manufacturers, and enable policymakers to have data and take advantage of additional energy savings associated with PF improvement. The U.S. Department of Energy (DOE) external power supply test procedure measures PF at partial and full loads, although the current U.S. policy does not address PF. Unfortunately, the first national policymaking body to finalize an active mode battery charger test procedure (DOE 2011), rejected stakeholder suggestion to include PF measurement in its procedure. Other jurisdictions to adopt battery charger policy can improve upon this test protocol and incorporate the measure into the test procedure and policy to garner additional energy savings.

Another possible model is to consider the existing European Union approach that regulates PF for loads greater than 75 W. Creating a PF policy has a few unique challenges:

- U.S. DOE currently uses only one energy use metric, and therefore any future attempt to incorporate PF would need to be incorporated into this metric. This does not necessarily guarantee that PF would be improved because manufacturers can trade off energy savings improvements in other modes of operation to avoid improving PF
- PF savings as a percentage of total savings expected from an energy efficiency measure tend to be relatively small (less than 10% of total device energy use) Because of the relatively small savings compared to other measures being considered in a policy, PF requirements can be dropped by policymakers in negotiating processes in favor of retaining other energy savings in the device itself

- PF is difficult to understand and visualize

Because PF correction is more economical in larger devices, we recommend that it be incorporated in individual product standards in the near-term. It is also possible in the near term to have PF correction apply to the larger devices within a horizontal standard, such as the larger battery chargers. These efforts will help drive costs down the learning curve to enable cost-effective PF correction in smaller devices in the future.

**Power Scaling**

Many plug load policies already specify power limits for standby, sleep, and idle modes for various electronic plug load products, but policymakers could also consider introducing latency and performance considerations associated with power scaling. Some questions could include:

- How many minutes can elapse between when no activity occurs with a device and when it drops into a sleep mode?
- How rapidly must a product return from sleep mode to idle mode?
- By what percentage must the power consumption drop between active or maximum performance mode and idle mode?
- To what extent can products be expected to maintain minimal network connectivity during sleep or hibernate modes?

Current power scaling technology should be considered when evaluating new energy consumption and power mode limits to further reduce energy use.

For the small plug-load devices, power scaling is most important for networked devices. Additional research is needed specifically on network power scaling. Many devices are now networked, and increasingly new devices are networked together in homes and offices (e.g. IP phones, cell phones, storage devices). A first step would be to develop a standard protocol that assesses power consumption of network routers, hubs, and switches as the amount of network traffic flowing through them varies. Thereafter, labeling programs and eventually mandatory standards could be developed to promote those design approaches that meaningfully scale power consumption to network activity. Because power scaling is very end-use specific, it could also be appropriate to address with voluntary agreements with manufacturers.

## Conclusion

Significant energy savings are possible through improving power factor and power scaling in the diverse and ubiquitous plug load product category. Energy savings of this magnitude will require horizontal standards similar in spirit to the international standards for external power supplies, and the forthcoming California and U.S. battery charger standards. Although power factor is challenging to conceptualize, it is relatively straightforward to measure, and can be added to the test procedure in device-specific standards in the near term. Power scaling is more challenging to address through policy mechanisms because it involves a number of components, and is very device-specific. However, with the number of devices now becoming network-connected, developing a standard protocol to assess power scaling abilities of network equipment is a reasonable first step. Considering the current—and growing—global energy consumption of plug loads, these opportunities must not be ignored.

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