Many Small Consumers, One Growing Problem: Achieving Energy Savings for Electronic Equipment Operating in Low Power Modes

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ABSTRACT

An increasing amount of electricity is used by equipment that is neither fully “on” nor fully “off.” We call these equipment states low power modes, or “lopomos.” “Standby” and “sleep” are the most familiar lopomos, but some new products already have many modes. Lopomos are becoming common in household appliances, safety equipment, and miscellaneous products.

Ross and Meier (2000) reports that several international studies have found standby power to be as much as 10% of residential energy consumption. Lopomo energy consumption is likely to continue growing rapidly as products with lopomos that use significant amounts of energy penetrate the market. Other sectors such as commercial buildings and industry also have lopomo energy use, perhaps totaling more in aggregate than that of households, but no comprehensive measurements have been made.

In this paper, we propose a research agenda for study of lopomo energy consumption. This agenda has been developed with input from over 200 interested parties. Overall, there is consensus that lopomo energy consumption is an important area for research. Many see this as a critical time for addressing lopomo issues. As equipment designs move from the binary “on/off” paradigm to one that encompasses multiple power modes, there is a unique opportunity to address the issue of low power mode energy consumption while technology development paths are still flexible.

Introduction

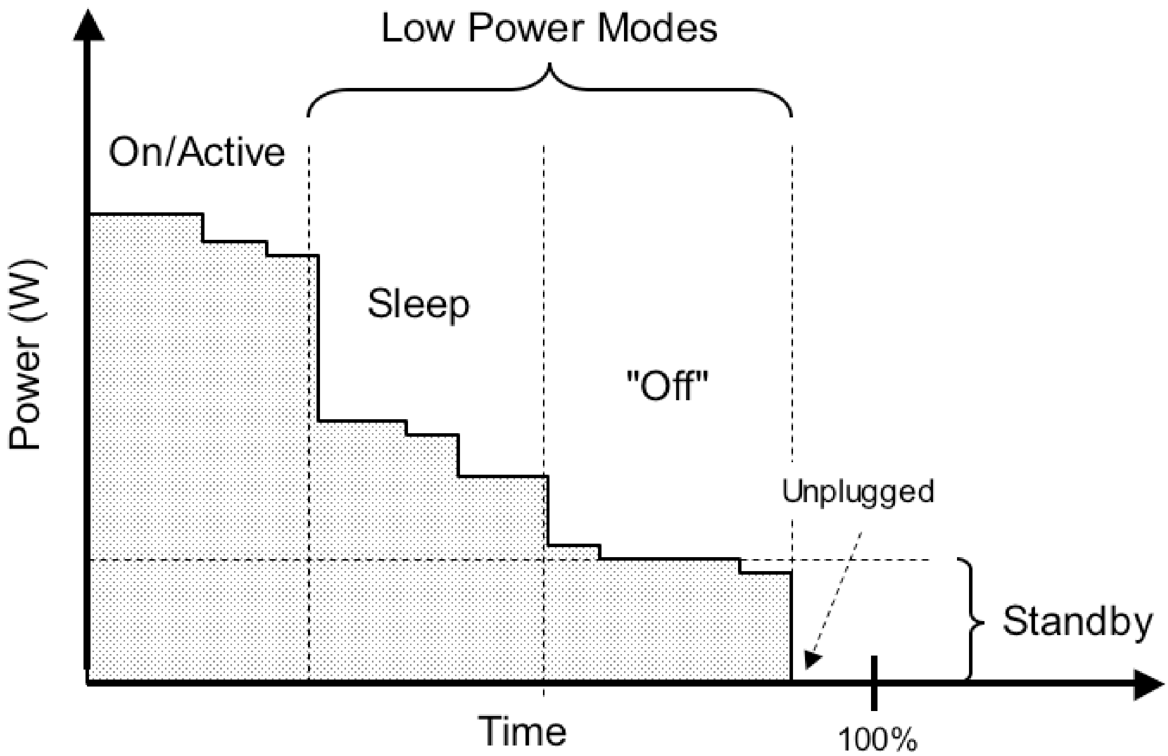
Energy consumption by equipment neither fully “on” nor fully “off” is a significant issue, and it is likely increasing (Lebot et al., 2000). This category of electricity use will soon have a large impact on energy demand. Millions of devices already have this characteristic, and billions more will have it in the future. The California Energy Commission’s Public Interest Energy Research (PIER) Program established a project to develop an agenda for an R&D initiative on reducing this emerging use of electricity. The results of that effort are summarized in this paper.

The original focus of the project was “standby power”; however, it soon became clear that a broader perspective was needed, both for research and policy. As a result, this project addresses all “low power modes.”

Terminology—The Low Power Mode (Lopomo)

In the electromechanical era, appliances usually had two operating modes: “on” (or “active”) and “off” —with “off” meaning zero power consumption. With the advent of electronics, devices could be “off” and yet still draw power. This third mode is often called “standby,” but has many other names depending on the device (or even the manufacturer of the device.) An increasing number of devices have multiple modes—such as “sleep” and “deep sleep”—between standby and active. Future devices are likely to have many different operational modes between “unplugged” and “active,” each with a different level of electricity use and functionality. Figure 1 provides an illustration of these various operational modes and power levels.

Figure 1. A Graphical Depiction of Device Power Modes



It is important to distinguish between *operational* modes—such as on, sleep, and off—and *power* levels, such as the definitions of standby recently adopted by the Department of Energy (DOE) and the International Electrotechnical Commission (IEC).[1] The DOE and IEC definitions of standby refer simply to the device’s lowest power level while connected to the mains, irrespective of functionality.

This project focuses on all of the modes between unplugged and active, which we call the “low power modes.” To simplify writing and avoid awkward word constructions, we call these low power modes “lopomos.”[2]

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[1] A product may consume its standby power level in any of the three basic operating modes: on, sleep, or off. For example, a telephone answering machine is fully on at its standby level; some printers lack a power button so are asleep in their minimum power mode; and many devices consume standby power when off. Thus, "standby" is a power level, not a operational mode. While it is sometimes more convenient to talk about a product's "standby mode", that really refers to the mode at which the device consumes its standby level, since there is no mode consistent across all devices that is *the* standby mode.

[2] One lopomo, two lopomos.

Project Summary

This project began with a literature review. We collected and analyzed measurements of lopomo energy consumption, programs and policies addressing lopomo energy use, and research and development activities regarding lopomo devices. We then convened a workshop on August 26, 2002 in Berkeley, California to discuss the results of the literature review and make recommendations for research. Finally, we conducted a survey of interested parties to verify their support for research in this area and to record their opinions of the research priorities for funding agencies. This paper summarizes the results of those activities.

Review of Literature Related to Low Power Modes

We reviewed four categories of published information related to lopomo energy consumption: established test procedures for measuring lopomo use, field measurements of lopomo consumption, government programs that address lopomo consumption, and research strategies for reducing lopomo consumption.

Energy Test Procedures

Consistent definitions and test procedures are essential for reliable and comparable measurements. Unfortunately, responsibility for definitions and test procedures of lopomos are spread among many international groups, with no overall organization or coordination. Many actually conflict with each other, either in definition or procedures. The ENERGY STAR program has established *ad hoc* product-specific definitions for most of the products that it covers, but even these tests are inconsistent in both large and small aspects.

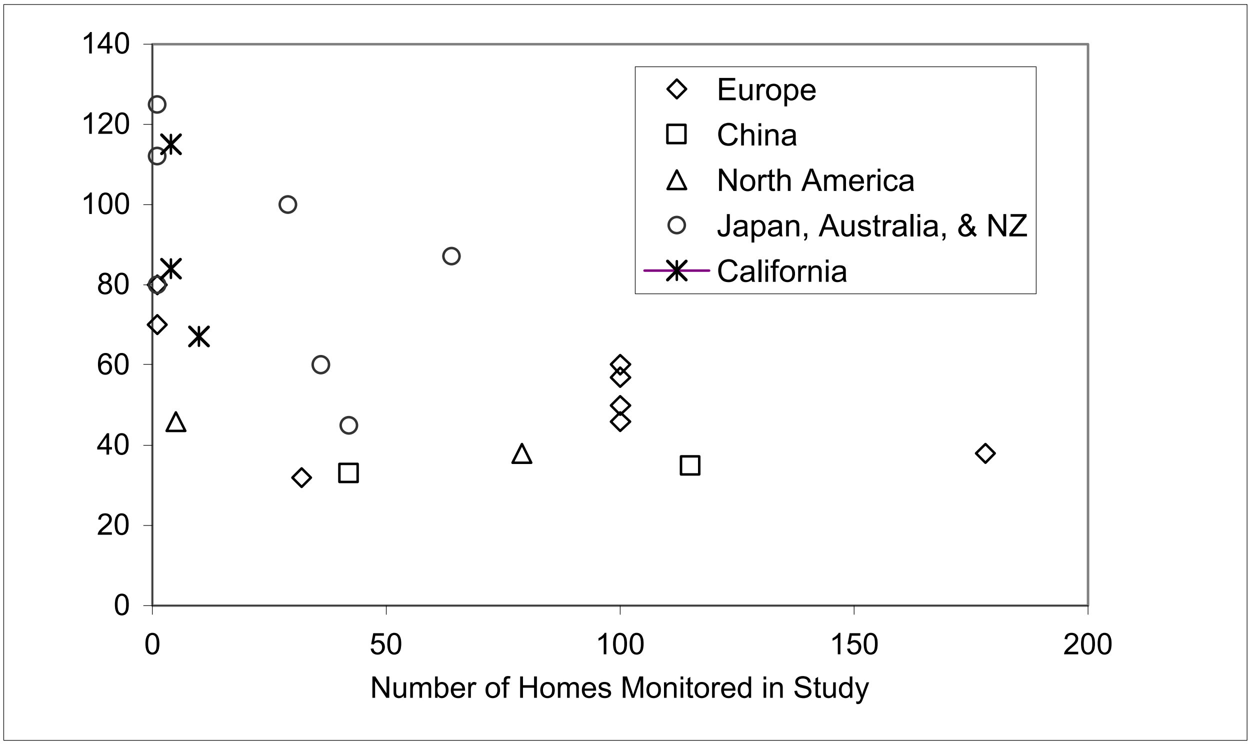
A technical committee of the IEC (TC 59 WG 9)[3] issued a draft definition and test procedure for standby power in July 2002, with publication expected in late 2004. The committee's responsibility is white goods, but the test procedure was designed to apply to virtually all electric devices that can be plugged in. No similar, generally applicable test procedure exists for the other low power modes.

Field Measurements

Virtually all relevant lopomo measurements to date have been conducted to determine standby power use in homes. Over one thousand homes around the world have been measured, including some in Europe, Japan, Australia, and China. Only one formal study in the United States has been conducted. (Ross and Meier, 2000) As a result, we have a poor understanding of both the California and U.S. standby situation. Less information is available for other low power modes. Worldwide, residential standby power measurements range from about 30 to 125 W per home, as shown in Figure 2. The power levels recorded in different countries appear to vary partly because of the range of equipment included in the category of "standby" and partly due to the type and number of devices present in these houses.

[3] The committee draft for voting is available in PDF form from: http://www.energyrating.gov.au/library/pubs/iec-standbycdv2003.pdf

Figure 2. Field Measurements of Residential Standby Power Use in Different Countries



Data are even scarcer for the commercial sector. For one class of devices—office equipment—we have rough estimates of energy use (Kawamoto et al., 2001), but for the rest we know almost nothing. No commercial buildings have been monitored, so we have essentially no idea how large lopomo energy consumption is, let alone a comprehensive list of devices with lopomos and their stock.

With the available information, we cannot even determine if standby or total lopomo energy use is increasing or decreasing. ENERGY STAR programs may be reducing standby in common consumer electronics, but the rapid appearance of new digital appliances and the dramatic increase in the number of appliances with standby (including the proliferation of small external power supplies for many small consumer items) may be offsetting those gains. Some of the key growth areas for residential standby include set top boxes, white goods, and home networks. Another problem is "hard-wired" standby caused by smoke detectors, security systems, ground fault circuit interrupters, and space conditioning control systems. A unique problem is digital converter boxes for TVs. As countries move from analog to digital broadcasting, TVs that receive broadcast signals will require a converter to provide an analog signal to the "old style" TV. This could lead to a mushrooming of digital converter box sales. Anecdotal evidence therefore suggests that residential lopomo energy use will probably rise significantly in the coming years. We assume that commercial sector lopomo consumption will also rise.

Energy Efficiency Programs

Voluntary and mandatory programs dealing with low power modes exist in North America, Europe, Japan, Australia, China, and several other countries. Most of the voluntary programs, such as ENERGY STAR, target the standby mode for consumer electronics and the sleep mode for office equipment. In contrast, the mandatory efficiency programs, such as efficiency standards for white goods in the U.S., Europe, Australia and Japan, generally target active modes and ignore the lopomos; however, here is increasing interest in the energy associated with lopomos and some countries are now starting to set various types of targets for these modes as part of their energy programs (e.g. Japan, Australia, Korea, Europe).

ENERGY STAR operates the world's largest program for consumer electronics and office equipment. ENERGY STAR specifications are arguably the *de facto* world standard for these products.

Research Strategies

There is only limited technical research focused solely on improving the efficiency of lopomos. The wide diversity of products partly explains the lack of specific research on the topic. Nevertheless, research that will impact lopomos is underway. Technologies borrowed from other situations (e.g., battery-powered devices, where power consumption is critical) can often be constructively applied to lopomos. Some corporate research directed to other goals has also led to low-power solutions. For example, the need to reduce heat output and weight of power supplies has resulted in greatly improved efficiencies for some products. Manufacturers have successfully cut irritating fan noise by switching off the fan altogether while in a lopomo. This could only be accomplished by reducing component heat generation while the device is in standby or sleep modes.

There are three principal research strategies to reducing lopomo energy consumption:

1. Improve the efficiency of the components
2. Improve equipment design to help device components better match functional needs
3. Improve (or modify) technologies outside the device or change user behavior

An example of *component improvement* is increasing the efficiency of power supplies in their no-load and part-load performance. Other examples include de-energizing components when not needed and designing ultra-low power circuits.

Design improvements help the device better match operational components with functional needs. These improvements enable the device to shift operating time from active to sleep and from sleep to off. These changes may actually increase energy use while in the low power modes (by shifting operating time from active) but result in lower overall energy use.

External changes can also reduce energy use in low power modes. Important examples are the communications protocols between service providers (such as cable TV providers) and set top boxes, or between a server in a home network and the appliances on the network. Protocols need to be designed to enable devices to enter the lowest possible operational state. This requires coordination between the service providers and the box manufacturers. Other external changes include construction of a low-power DC supply network in buildings (to eliminate the need for separate power supplies) and improved user interfaces that make low power modes easier for consumers to identify and use. Research is also needed on consumer behavior, as well as effective interfaces between consumers and these products.

Recommendations for Research

The following recommendations are based on the input gathered in the August 26, 2002 Workshop, through discussions with other knowledgeable persons in the field who were unable to attend the workshop, and the results of the survey of interested parties.

Both workshop participants and survey respondents strongly endorsed the need for research into the general topic of low power modes. Many from the private sector perceived the impact of this problem on their own businesses and felt that early action was advisable. The participants were also comfortable with government funding of the research, both at the state and federal level. Several survey respondents emphasized that funding agents should collaborate, both nationally and internationally, to establish uniformity in lopomo energy analysis and voluntary or mandatory standards.

Scope of Recommendations

Many of the recommendations that we received from workshop attendees dealt with overall directions for research. Using these recommendations to create a framework of major research areas, we identified six major directions for lopomo research:

A. Understand how much energy is actually consumed in the low power modes.
B. Develop energy test procedures for low power modes and protocols to measure their contribution to whole-building electricity use.
C. Understand human behavior and preferences as they relate to low power modes.
D. Investigate feasible technologies offering energy savings opportunities and their economic costs and savings.
E. Engage in short-term research to address anticipated critical problems related to low power modes.
F. Engage in long-term research to increase the efficiency of low power modes.

Detailed research topics were also identified, including improvements to power supplies, low-power circuitry, and clearer user interfaces for the devices. Potential savings in some cases are as large as 90%.

We then distributed these research directions through our survey process and asked people how they would prioritize these directions. We also asked if there were additional research topics they would suggest.

Below we combine the results of the workshop and the survey in a discussion of each of these research areas.

How much energy is actually consumed in the low power modes? Workshop participants were struck by the absence of lopomo energy use measurements in U.S. buildings, especially compared to the data available from other countries. There was nearly unanimous agreement that better understanding of the dimensions of lopomo energy use should be a key research goal. Survey respondents confirmed this view—2/3 of the respondents ranked developing this understanding as the first or second priority for research funding. Many remarked that this understanding is a necessary precondition to developing priorities for comprehensive actions to affect lopomo energy use. Research is needed to answer such questions as:

- How large is lopomo energy use?
- How is lopomo energy use distributed across the residential, commercial, industrial, and other sectors?
- Is lopomo energy use growing?
- Are certain products or components responsible for a large part of lopomo energy use?

The answers to these questions will help funding agents select the areas deserving further research or programs. The general approach involves three steps:

1. Assemble lists of product types with lopomos.
2. Measure lopomos of products *in situ* and in the laboratory, including the fraction of time in each mode and other key information.
3. Periodically measure lopomos of new products.

In situ measurements should involve measuring the electricity use of the whole building (in addition to the contribution of each lopomo product) so that the fraction of electricity devoted to lopomos can be determined and no devices are overlooked.

The residential sector is better understood than other sectors. Most of the products with lopomos have already been identified (though new products are introduced every day). Step one is essentially compete, so work could begin immediately on the measurement phase. Less is known about the commercial sector, where a list of products with lopomos does not even exist.

Specific projects that would fall inside this general category include:

- gathering lopomo energy data in a representative sample of residential buildings by means of large-scale measurement campaigns,
- surveying and compiling lists of products with lopomo energy use in residential, commercial, and industrial buildings,
- gathering lopomo energy data in a representative sample of commercial buildings by means of large-scale measurement campaigns,
- measuring the hard-wired lopomo energy use in new, unoccupied homes (and possibly commercial buildings), and
- identifying the contributions of lopomo use to system peak.

Develop definitions and energy test procedures for low power modes and protocols to measure their contribution to whole-building electricity use. Standby power use is now fairly well defined, and an internationally recognized test procedure is nearly complete. For some ENERGY STAR products, the sleep mode is defined and test procedures exist.[4] Beyond that, however, there are few similar definitions and test procedures for lopomos.

International standards organizations (IEC, ISO, etc.) have begun to address this omission, but the pace of international standards bodies is typically slow and there has been only limited coordination. For example, two IEC committees - TC59 and TC108 - have drafted standards that use inconsistent definitions of operating states when measuring the energy consumption of the products their standards cover. Consistent definitions and test procedures are

[4] See the Energy Star Web site at: http://www.energystar.gov for specific products and test procedures.

an essential precursor to monitoring projects. The lack of common definitions and terms was often cited as an important problem that leadership research funding could help overcome.

The definitions and test procedures determine how to test the lopomos for a single device. A protocol for measuring the lopomos of all the products inside a building must then be used to collect the data for representative samples (discussed earlier). Again, developing procedures and field-testing them is an important step.

Understand human behavior and preferences as they relate to low power modes. Small differences in operational settings (such as enabling power management features) can easily lead to significant differences in annual energy consumption as reduced power levels replace the "always on" state of many electronic products. For this reason, the human dimensions of energy consumption must be carefully included in all lopomo research. Three areas deserve special attention:

1. Can additional consumer education change the way consumers operate a device?
2. Can improved product design (e.g., "user interface") encourage users to exploit the lopomos?
3. How much do consumers value the lopomos? For example, in what cases would a hard "off" switch be tolerated? Desirable? What maximum delay times are acceptable when switching modes?

The impact of consumer education and training should not be underestimated. Media campaigns in Japan, Germany, and, to a lesser extent California during the electricity crisis, probably caused many users to more frequently enable the lopomos (or simply unplug devices).

Any program aimed at educating and mobilizing people to use products more efficiently will be more successful if the energy-related controls in these products present a logical, clear, and consistent appearance. Thus, the research necessary to develop and promote design guidelines for controls related to power management is likely to pay off handsomely. The California Energy Commission sponsored research in this area and it appears to be headed towards a successful outcome with the development of a voluntary standard for user interface elements (Nordman 2002).

A similar area of analysis mentioned by several survey respondents involves understanding the market behavior of both end-use consumers and product manufacturers. Questions included:

- Would consumers change their purchasing behavior to favor products with reduced lopomo energy consumption?
- How are efficient lopomo technologies adopted by product manufacturers and included in their products? For example, why do some manufacturers choose to implement efficient power supplies?
- Are there "non-energy benefits" inherent to efficient lopomo devices that consumers would find attractive?
- How can we change usage patterns to shift time from active to lopomos?

Investigate energy savings opportunities and economic feasibilities of technologies to reduce energy use of equipment while in low power modes. Greater understanding of the technical potential for energy savings is integral to informing the adoption of state programs that address lopomo energy consumption. Knowledge of the economic costs and benefits of various lopomo options can determine which programs will save the greatest amount of energy for the lowest total cost. The following questions should be addressed:

- Which products or components use the most lopomo energy?
- What are the technical options to reduce lopomo energy use and how much will they save?
- How much do those technologies cost?

The results of this research are often depicted as "technology-cost curves" for single devices or "supply curves of conserved energy" for an entire end-use category. Developing these curves for lopomo energy use is unusually difficult because so little data exist on energy use, stocks, and patterns of usage. Furthermore, some devices are penetrating the market very rapidly, so energy savings are sensitive to sales rates.

Some products and components are so clearly important that they deserve immediate attention. Set top boxes and digital converter boxes are good examples of products deserving immediate investigation, as they are products that both use significant amounts of lopomo power and are forecast to have rapid market growth in the next few years. Power supplies and battery charging systems are good examples of components that deserve immediate investigation.

Survey respondents generally saw this as a research topic that could occur only after a better understanding of lopomo energy consumption had been developed. Those who ranked it as a first priority usually felt that enough is already known about lopomo energy consumption to move forward to this step. This is undoubtedly true for certain products, as mentioned above; however, more research is likely needed on lopomo energy use in general before comprehensive research on this topic can occur.

Engage in short-term research to address anticipated critical problems related to low power modes. Short-term research can provide valuable support to program development. Some of the results can be used to as inputs to the technology cost curves and other policy tools. Short-term research can also demonstrate proof of a concept to justify additional research or the technical feasibility of a mandatory standard.

Television set top and digital converter boxes are obvious targets for short-term research. This research could investigate technologies to reduce power consumption through improved components and communications protocols. By demonstrating that boxes with lower power use are technically feasible (and economic), programs to address the anticipated flood of these boxes can be developed.

Hard-wired standby in new homes was already identified as an important measurement target. Another example of short-term research would be the development of prototype smoke detectors, built-in LED lighting systems, and other products that would offer the same functionality at lower power levels.

Finally, issues of enabling rates and user interface controls were mentioned as potential critical problems that might be able to be addressed through short-term, focused research.

Many survey respondents rated this research topic overall as a lower priority, though higher in value than long-term research (see below). On the other hand, specific technologies (or technology families) were mentioned as important components on which to focus, either because their lopomo energy consumption was perceived to be high or because the prevalence of those particular technologies was expected to increase rapidly in the near future. Examples included the digital set top boxes mentioned above and home networking systems. Many survey respondents mentioned the problem of devices connected to networks being kept awake by the network or by the need to maintain connectivity, with the possibility of large increases in consumption due to this, and large savings if the problems can be solved. The increased penetration of broadband technologies into the home may be a driver for new product growth and corresponding lopomo use.

Engage in long-term research to increase the efficiency of low power modes. Most efficiency improvements in the lopomos result in savings of only a few watts per product. But the potential savings are large because the improvements apply to so many products and because the products operate in the lopomos so many hours each year. Some savings will also occur when better designed lopomos allow a product to shift time from an active mode to the lopomos.

There are three principal research strategies to reducing the energy consumed in the lopomos:

1. Improve the efficiency of the components
2. Improve software to help equipment operation better match functional needs
3. Improve external aspects to facilitate energy savings

Several components appear ripe for additional efficiency improvements. Power supplies deserve the greatest attention because they exist in all of the products. In many cases, efficiency improvements to power supplies will save power no matter what mode the device is in - active or lopomo.

Rechargeable products represent an increasing fraction of products with lopomos. Batteries, and the circuitry to charge them, draw upon increasingly sophisticated technologies. Improving the efficiency and overall performance of battery-charger system will yield both energy savings and environmental benefits (by increasing battery longevity) Long-term research could lead to a system with performance characteristics tailored to maximize energy efficiency and minimize disposal costs. Alternatively, adding a battery to a device may allow better power management or reducing standby use to zero during some periods.

Manufacturers are striving to add increasing functionality to products while in the lopomos. More efficient circuitry could provide both increased functionality and energy efficiency. This should be another research area. The California-supported CITRIS[5] program is an example: CITRIS researchers developed circuitry with power requirements 1/100 of current levels. Stray air currents, ambient light, and local temperature differences may be able to supply enough power to operate these circuits.

Many companies, universities, and research institutions are already tangentially involved in these topics and, through collaboration, will be better positioned to market the fruits of the research profitably.

Although these research areas are undoubtedly of value, the majority of survey respondents considered long-term research to be a low priority. Some felt that the technologies necessary to reduce lopomo energy consumption already exist—therefore, there was no reason for investment in new technology development. Others felt that the need for new products did

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[5] Center for Information Technology Research in the Interest of Society, http://citris.berkeley.edu

exist, but that government actors were not the best to implement research in this area. Respondents believed that the private sector was better positioned to develop the means to increase the efficiency of lopomos.

Overall Conclusions and Recommendations

Even with the limited information available, it seems clear that the electricity consumed by devices while in lopomos already represents a significant fraction of total residential consumption. There is also evidence that lopomo energy use will rise sharply. These trends suggest that undertaking a range of programs to reduce lopomo energy use is important.

We have outlined a framework for research, plus many specific projects. The research covers a broad spectrum of activities, from field measurements to understanding consumer behavior to exploration of entirely new technologies. Some of these projects—such as development of energy test procedures—need to begin almost immediately. Other aspects—such as investigations of new technologies—can wait. But, together, this research agenda will ensure that programs to reduce the energy use of low power modes will be effective for both the short and long term.

There was clear guidance from survey respondents that the first priority for research is to understand how much energy is consumed by lopomo devices. The results of the survey also showed a fairly emphatic rejection of long-term research to improve the efficiency of lopomo devices, at least as a high priority for government funding. The relative priority of the other four topics of research were analytically indistinguishable in our survey results.

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