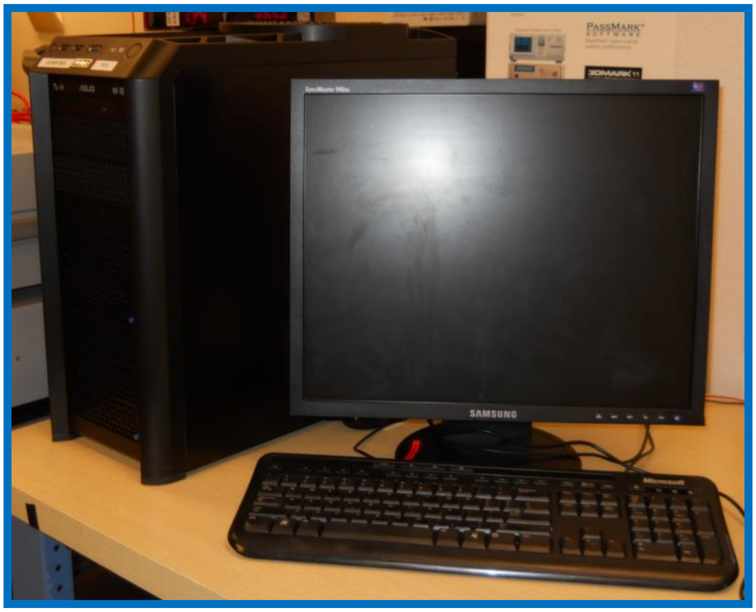
Cost-Effective Computer Efficiency

ET Project Number: ET12PGE5251



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LEGAL NOTICE

ABBREVIATIONS AND ACRONYMS

CPU	Central Processing Unit
GPU	Graphics Processing Unit
HDD	Hard Disk Drive
kWh	Kilowatt hour
FBB	Frame Buffer Bandwidth
GB	Gigabyte
GHz	Gigahertz
OEM	Original Equipment Manufacturer
PSU	Power Supply Unit
RPM	Rotations Per Minute
SSD	Solid State Drive
TEC	Typical Electricity Consumption

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1. EXECUTIVE SUMMARY

Computers consume nearly 10 terawatt-hours of electricity in California each year.[1] These and other plug-loads will become an ever larger portion of electricity consumption in the state as California aggressively pursues lighting, heating, ventilation and air conditioning, and building envelope efficiency improvements. Although this is a daunting problem, the rate of technological change in the computer industry is rapid. New and innovative efficient technologies will continue to provide opportunities to reduce computer electricity consumption without sacrificing performance.

PROJECT GOAL

This study investigated, identified, and demonstrated cost-effective efficiency opportunities in desktop and notebook computers. These opportunities may ultimately inform the development of meaningful mandatory appliance efficiency standards in California.

PROJECT DESCRIPTION

Market research, accredited lab testing, and computer engineering teardown analysis were leveraged in this work to demonstrate cost-effective efficiency opportunities in computers. Baseline desktop computer systems that represent the computers most commonly available for purchase on the market as of December, 2012 were selected by analyzing thousands of market data points. These systems were purchased from major original equipment manufacturers and tested in Ecova's accredited lab. More efficient computer components such as hard disk drives, central processing units, power supply units, and discrete graphics processing units, were identified and then tested in the baseline systems to evaluate their individual impact on overall computer system electricity consumption.

Retail prices associated with both the baseline desktop computer components and the more efficient components were developed using thousands of market data points. These prices were compared and ultimately used to determine the cost of energy efficiency at retail in 2015, when the California Energy Commission is expected to implement Title 20 efficiency standards for computers.

[1] See: Proposal Information Template for: Computers, Submitted to the California Energy Commission by Energy Solutions and Natural Resources Defense Council for the California Investor Owned Utilities, September 2011.

Notebook (commonly known as laptop) computer efficiency opportunities were also investigated. The engineering tear down analysis of notebooks identified key design differences between traditional notebooks and ultra-portable, long battery life "Ultrabook" computers.

PROJECT FINDINGS/RESULTS

Annual desktop computer electricity consumption can be reduced by nearly 30% cost-effectively (the value of lifetime energy savings offset any incremental cost of the more efficient components) based on the results of the testing and analysis conducted for this study. The findings also indicate that the Version 6.0 Draft 2 proposed ENERGY STAR specification for desktop computers is too generous and may also be too generous even if implemented in a mandatory standard context.

Figure 1 below presents findings for the four desktop computer systems that were tested and made more efficient in this project. The systems labeled DT1-1 and DT1-2 are considered medium-performance machines using ENERGY STAR's Version 6.0 Draft 2 categorization scheme. The systems labeled DT3-1 and DT3-2 are considered high-performance under the same scheme, although DT3-2 is considerably higher performance than DT3-1. The orange column is the Version 6.0 Draft 2 proposed ENERGY STAR allowance for a given system. The blue bar is the baseline electricity consumption of the system that represents the most commonly available computer in a given category today. The green bar is that same system built using more efficient yet cost-effective components that did not significantly change the performance of the system. These improvements generated a net savings of as much as $26 compared to the baseline over the life of the system.

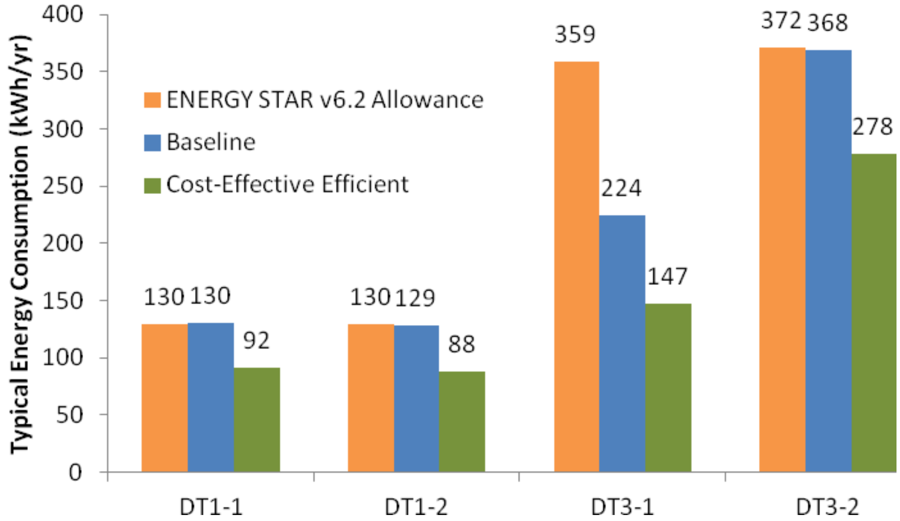

FIGURE 1: DESKTOP COMPUTER TYPICAL ANNUAL ELECTRICITY CONSUMPTION

Notebook computer efficiency opportunities also exist, but further research is needed to attribute specific savings and costs to specific design choices. This initial research suggests that the use of solid state storage drives, compact system design, and highly integrated components present compelling opportunities for efficiency. There was nearly a 60% difference in non-display annual electricity consumption between notebooks in the same performance class that used these approaches compared to those that did not.

PROJECT RECOMMENDATIONS

The results of this study demonstrate a significant opportunity to improve computer efficiency cost effectively. If we expand to all computers in California the finding that computers can be designed to consume 30% less electricity than those typically available on the market today while simultaneously delivering net cost savings, savings of 3 terawatt hours per year may be possible.

The magnitude of this opportunity makes a compelling case for developing efficiency programs that provide incentives for more efficient computers and for pursuing mandatory efficiency standards for computers in California.

Further research is needed to definitively expand these findings beyond the medium and high-performance computer categories investigated in this study. Additional research is also needed to develop specific savings and cost effectiveness estimates for notebook computer efficiency opportunities.

2. INTRODUCTION AND BACKGROUND

Computers consume nearly 10 terawatt hours of electricity in California each year.[2] These and other plug-loads will become an increasingly larger portion of electricity consumption as California aggressively pursues lighting, heating, ventilation and air conditioning, and building envelope efficiency improvements. As such, the California Energy Commission (CEC) is considering setting mandatory efficiency standards for computers in California and the United States Environmental Protection Agency (EPA) currently provides voluntary computer efficiency standards through the ENERGY STAR program.

Both desktop computers and notebook (commonly known as laptop) computers exhibit a wide range of electricity consumption. While some of this variation is due to differences in computer performance, there is also a wide range of energy consumption in systems with a similar level of performance and form factor. This suggests that there is a significant opportunity to make computers more efficient. To support the development of meaningful and cost-effective standard levels, Pacific Gas and Electric (PG&E) commissioned Ecova to research cost-effective methods of making desktop and notebook computers more efficient. The work presented here details the results of this research and articulates the size of the efficiency opportunity for computers – it is large.

3. METHODOLOGY

The intent of the methodology was to identify a limited number of cost-effective pathways for making desktop and notebook computers more efficient, not to determine the most cost-effective efficient computer or to develop a maximum efficiency system. There are likely numerous approaches to increasing computer efficiency – this was not an exhaustive component and system-level efficiency analysis.

The methodology for identifying both desktop and notebook computer efficiency opportunities is described below. Some of the notebook computer methodology is similar to the desktop computer methodology. In these instances the notebook methodology references the desktop methodology.

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[2] See: Proposal Information Template for: Computers, Submitted to the California Energy Commission by Energy Solutions and Natural Resources Defense Council for the California Investor Owned Utilities, September 2011.

3.1 Desktop Computer Methodology

3.1.1 Market Analysis and Baseline Desktop Selection

To estimate the energy savings associated with efficiency improvements in a computer, a system to which more efficient systems are compared must be identified. These baseline systems were selected to reflect the most common attributes (such as size and type of hard drive, processor type and speed, amount of memory, type of graphics processor, etc.) found in computers available on the market today.

To identify the most common attributes of computers available today, Ecova used a retail web-crawler approach. The web-crawler collected computer system data (including computer attributes and price) from hundreds of web retailers via retail web aggregation services such as shopper.com and Google Shopping. The resulting data set contained approximately 2,700 desktop computer and 3,200 notebook computer systems. These data were then formatted and categorized by ENERGY STAR 5.0 category using attributes such as number of central processing unit (CPU) cores, channels and amount of memory, and graphics processing unit (GPU) performance. Table 1 describes these categories.

Table 1: ENERGY STAR 5.0 Desktop Computer Categories

Category	CPU Cores	Memory and Graphics
A	Anything that is not category B, C or D	
B	2 Cores	≥2 GB memory
C	>2 Cores	≥2 GB memory *or* discrete GPU
D	≥4 Cores	≥4 GB memory or discrete GPU with frame buffer width >128 bits

After categorizing the data, common components for computers in each ENERGY STAR 5.0 performance category were identified. Note that the current ENERGY STAR 5.0 categories map reasonably well to proposed ENERGY STAR Version 6.0 Draft 2 desktop categories. Given an impending ENERGY STAR update, we chose to re-cast our market research results using proposed ENERGY STAR Version 6.0 Draft 2 desktop categories. Table 2 below describes the proposed ENERGY STAR Version 6.0 Draft 2 categories.

TABLE 2: ENERGY STAR VERSION 6.0 DRAFT 2 DESKTOP COMPUTER CATEGORIES

CATEGORY	CPU CORES	CHANNELS OF MEMORY	BASE MEMORY[3] AND GRAPHICS
DT 0	≤2 Cores	1	1 GB memory
DT 1	≤2 Cores	2	2 GB memory
DT 2	≥3 Cores	≥2	2 GB memory
DT 3	≥3 Cores	≥2	4 GB memory and a discrete GPU with a FBB of ≥128 GB/s and a frame buffer width of >128 bits

Rather than cast a broad net across a wide range of computer performance levels, further analysis and subsequent testing focused on high-performance DT3 desktop computers and medium-performance DT1 desktop computers. Testing DT3 desktops ensured that high-performance systems were evaluated in the project. Selecting DT1 systems ensured that more typical medium performance systems were evaluated. Very low-performance DT0 systems in typical desktop form-factors are difficult to procure through retail channels. DT2 systems were not tested due to time and budget constraints. However, DT2 systems share characteristics with DT1 computers (in channels of memory) and with DT3 computers (in number of processor cores) - efficiency opportunities associated with DT1 and DT3 computers are likely indicative of opportunities in DT2 computers.

Two medium performance DT1 computers that were likely to exhibit average energy consumption relative to other DT1 computers, by virtue of having similar attributes to DT1 systems in the market data, were procured. One DT3 system was selected to likely exhibit average energy consumption relative to other DT3 computers (again by virtue of matching DT3 market data). Another system with high energy consumption relative to other DT3 systems was also selected. The relatively high energy consumption DT3 computer is described in more detail below Table 5 below

The most common attributes of DT1 and DT3 desktop computers are shown in Table 3 and 4 below.

[3] Note that base memory is the starting point from which adders for additional memory are based. For example, a computer may have more than 2 GB of memory and still be considered DT1.

TABLE 3: MOST COMMON DT1 DESKTOP COMPUTER ATTRIBUTES IN DATA SET

COMPONENT	MOST COMMON	% OF DATA SET	COUNT
CPU	i3-2120 3.3 GHz	39%	183
CPU Manufacturer	Intel	90%	421
Processor Speed (GHz)	3.3	34%	159
Memory (GB)	4	41%	192
Storage (GB)	500	28%	130
Storage Speed (rpm)	7,200	50%	236
Power Supply (W)	240	5%	25

TABLE 4: MOST COMMON DT3 DESKTOP COMPUTER ATTRIBUTES IN DATA SET

COMPONENT	MOST COMMON	% OF DATA SET	COUNT
CPU	i7-3770 3.4 GHz	12%	79
CPU Manufacturer	Intel	72%	481
Processor Speed (GHz)	3.6	18%	122
Memory (GB)	8	26%	172
Storage (GB)	2,000	27%	177
Storage Speed (rpm)	7,200	63%	420
Graphics Card	Radeon HD 7570	20%	135
Power Supply (W)	460	2%	14

The high energy consumption DT3 computer was procured to evaluate efficiency opportunities for the select set of computers that are designed and sold for their ability to perform graphics intensive tasks such as video games. We did not conduct a formal market analysis to select this machine, choosing instead to select a desktop from a well-established gaming desktop original equipment manufacturer (OEM). Because the DT3 category does not have an upper bound on hardware of performance attributes, we selected this gaming system to represent the highest performance and capability that gaming enthusiasts could reasonably obtain on the market as of December, 2012 (one of the only ways to further enhance this system would be to add multiple graphics cards). Table 5 below describes this high-performance gaming desktop.

TABLE 5: DT3 VERY HIGH-PERFORMANCE GAMING DESKTOP ATTRIBUTES

COMPONENT	ATTRIBUTES
CPU	Hex Core i7-3930K
CPU Manufacturer	Intel
Processor Speed (GHz)	3.2
Memory (GB)	8
Storage (GB)	2,000
Storage Speed (rpm)	7,200
Graphics Card	Single AMD Radeon HD 6870
Power Supply (W)	875

3.1.2 EFFICIENT COMPONENT SELECTION

After selecting the baseline systems, we identified more efficient replacement components for the baseline desktop computer components. To maintain system performance in this exercise, we selected more efficient replacement components with similar performance characteristic compared with the baseline components. In most instances, replacement components were reasonably similar in price to the baseline components. Table 6 below summarizes the performance characteristics used in the selection of similar, more efficient components. A complete list of the replacement components tested can be found in Appendix 5.1.

TABLE 6: COMPONENT PERFORMANCE CHARACTERISTICS

COMPONENT	PERFORMANCE CHARACTERISTIC
CPU	Number of cores, speed, manufacturing vintage, 3rd party performance reviews
Storage	Capacity, spindle speed, read/write speed
GPU	Frame buffer bandwidth, ECMA performance category
Memory	Speed, total capacity
PSU	Similar power rating or does not limit ability to expand system

3.1.3 ADDITIONAL CENTRAL PROCESSING UNIT CONSIDERATIONS

Processor speed and number of cores alone are not sufficient metrics to compare CPU performance. Other factors such as thermal design power (TDP), front side bus speed, and design differences between various generations of the same chip can have a significant impact on both performance and energy consumption.[4]

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[4] See: http://arstechnica.com/gadgets/2011/04/ask-ars-whats-the-relationship-between-cpu-clockspeed-and-performance/, for additional detail.

To ensure comparable CPU performance, reported third-party CPU performance benchmarks were examined. In some cases, efficient CPU replacement options were further constrained by their compatibility with the baseline motherboard CPU socket in which it sits. For example, a socket LGA1155 motherboard is only functional with LGA1155 CPUs, which comprise just a small subset of CPUs available on the market today.

3.1.4 Additional Motherboard Considerations

Motherboards are a key computer component that tie all other components together – they provide the basic infrastructure a computer needs to function, coordinate input and output signals, and regulate voltage and power quality. However, most motherboards available through retail channels today are designed for enthusiasts who build their own computers and are frequently biased toward high-end in performance and capability. This makes it difficult to assess efficiency opportunities associated with motherboards in more conventional OEM desktops because there are few equivalent options for replacement.

Despite this difficulty, we briefly investigated the impact of motherboards on the energy consumption in one of the DT3 desktops. In this desktop we changed the motherboard while keeping and all other components constant. Four motherboards were tested in addition to the baseline OEM motherboard. The baseline OEM motherboard had fewer features (number of Peripheral Component Interconnect (PCI) slots, number of Universal Serial Bus (USB) slots, etc.) and an older Intel H61 chipset.[5] Three of the motherboards target the gaming desktop market and contained Intel Z68 chipsets and a large number of features. The final motherboard had a similarly large number of features and an Intel Z77 chipset.

3.1.5 Calculating Efficiency Potential In Desktop Computers

We installed and tested the more efficient components in the four baseline systems. Not all components were tested in every system (see Appendix 5.1 for more detail). We tested only one efficient component at a time so that the change in system electricity consumption could be attributed to a specific component efficiency improvement.

We measured short idle, long idle, sleep and off-mode power, as defined in the ENERGY STAR Version 6.0 Draft 2 specification for computers, for each

[5] The chipset is a group of integrated circuits designed to work together on a motherboard.

iteration of each system.[6] Following a review of these data, if the power profile for each of these modes exhibited unexpected behavior (e.g. wide variation in measured power values for a given mode, no discernible change when the system was put to sleep, etc.), the test was repeated.

The power values were then used to calculate the system Typical Electricity Consumption (TEC) in kWh per year using the duty cycle and methodology also defined in the ENERGY STAR Version 6.0 Draft 2. Note that all TEC values described and presented here represent electricity consumed by the entire computer system, not an individual component.

Once TEC values for each iteration of each desktop computer were calculated, the system-level impact for a specific component change in a specific desktop was estimated using Equation 1.

$$\Delta TEC_{component} = TEC_{baseline} - TEC_{component}$$

EQUATION 1: COMPONENT SAVINGS CALCULATION

Where $\Delta TEC_{component}$ is the system level kWh savings resulting from installing a more efficient component in a particular system, $TEC_{baseline}$ is the baseline desktop computer system annual electricity consumption and $TEC_{component}$ is the more efficient desktop computer system annual electricity consumption.

3.1.6 COMPONENT PRICE METHODOLOGY

We developed the following methodology to estimate the difference in price that a consumer would see in purchasing a more efficient computer system in 2015, the tentative effective date of the Title 20 being considered by the CEC. This methodology leveraged retail price data, historic component price data, and price analysis of online component retailers.

The first step in the price methodology was to calculate the average online component prices for baseline and more efficient components. This involved gathering online retail price data at the component level using the previously mentioned web-crawler tool and direct data collection from online retailers such as newegg.com and Fry's Electronics.

6 See ENERGY STAR Computer V6.0 Draft 2 Specification at: http://energystar.gov/products/specs/sites/products/files/COMP_Draft2_v6_Specification.pdf

The next step in the methodology was to account for a Title 20 standard effective date of 2015 by discounting the component price for baseline and more efficient components. The Title 20 process is a multi-year effort and certain computer components change price over time. We used a Compound Annual Growth Rate (CAGR) approach to discount component prices to approximate their price in 2015.

We used historic data for specific components (i.e. CPUs, GPUs, and storage drives) to develop CAGRs for these specific components using Equation 2, where $P_{original}$ is the average component price for the first year for which Ecova found price data, $t_{original}$ is the first year when Ecova found price data for a component, P_{now} is the average current component price, t_{now} is the current year and *CAGR* is the compound annual growth rate.

$$CAGR = \left(\frac{P_{now}}{P_{original}}\right)^{\frac{1}{t_{now} - t_{original}}} - 1$$

EQUATION 2: CALCULATING CAGR

We then applied the CAGR to current average component prices to generate 2015 prices using Equation 3 where P_{future} is the 2015 price and t_{future} is 2015.

$$P_{future} = P_{now}(1 + CAGR)^{(t_{future} - t_{now})}$$

EQUATION 3: APPLYING CAGR TO DEVELOP FUTURE COMPONENT PRICES

In the final cost methodology step, we calculated a net cost per lifetime kWh saved value for each component using Equation 4 below where $Cost_{component}$ is the cost of the more efficient component, $Cost_{baseline}$ is the cost of the baseline component, $NPV_{savings}$ is the net present value of electricity savings over the lifetime of the computer, $TEC_{baseline}$ is the electricity consumption of the baseline system, $TEC_{component}$ is the electricity consumption of the more efficient system and *measure life* is the lifetime of the computer.

$$\$/kWh = \frac{(Cost_{component} - Cost_{baseline}) - NPV_{savings}}{(TEC_{baseline} - TEC_{component}) \times measure\ life}$$

EQUATION 4: CALCULATING COST OF SAVINGS PER KWH

Measure life, discount rates and electricity rate assumptions can be found in Appendix 5.2.

3.1.7 Maximum Efficiency and Cost Effective Efficiency System Development

Computers are a system in which components interact and react to each other, often in non-deterministic ways. Because of this, the impact of installing multiple, more efficient components in a system is not necessarily equivalent to summing the savings from each individual component that would be installed in a system. Further, savings from some components, such as PSUs, are dependent on the electricity consumption of other components. For example, a more efficient power supply saves less when used in conjunction with other, more efficient components than when used in isolation. To this end, we tested the set of cost-effective components identified for each system as a system. All system-level energy and cost savings results are based on these system-level data rather than the component-level savings and costs.

After evaluating the TEC impacts of individual components and their cost in each of the four baseline systems, we developed cost-effective efficient systems. These systems were built using the set of components that saved the most energy, while maintaining a net present value of zero or less (a negative net present value indicates a net economic savings in this case) assuming 2015 component prices. Note that some of the components used in the cost-effective systems were sometimes not cost effective on their own, but the total sum of the components selected was cost effective on a system level.

3.2 Notebook Computer Methodology

3.2.1 Notebook Selection and Energy Analysis

Notebook efficiency opportunities are inherently more difficult to investigate because notebook computer components are typically highly integrated. For example, CPUs and GPUs are often soldered directly into the motherboard; – replacing them with more efficient components would require cutting and micro-soldering hundreds of leads repeatedly. In some cases, storage drives and memory are also highly integrated.

To investigate efficiency opportunities in notebooks, we pursued a baseline system-level comparison approach rather than the component replacement approach used for desktops. Four notebook computers were selected for testing. All of these notebooks were categorized as NB2 systems using the proposed ENERGY STAR Version 6.0 Draft 2 characterization scheme with the exception of screen size (screen impacts on system energy consumption were removed using an approach described shortly). Table 7 below details the notebook characterization scheme.

TABLE 7: ENERGY STAR VERSION 6.0 DRAFT 2 NOTEBOOK CHARACTERIZATION

CATEGORY	NB 0	NB 1	NB 2	NB 3	NB 4
CPU Cores	Cores ≤ 2	Cores ≤ 2	Cores = 2	Cores ≥ 2	Cores ≥ 2
Channels of Memory	Channels < 4	Channels < 4	Channels ≥ 2	Channels ≥ 2	Channels ≥ 2
Screen Size	Screen Size ≤ 11.6" (Diagonal)	11.6 < Screen Size ≤ 13.3" (Diagonal)	-	-	-
Base Memory	1 GB	2 GB	2 GB	2 GB	4 GB
Base Graphics	Integrated Graphics	Integrated Graphics	Integrated Graphics	Integrated Graphics	dGfx = G3
Graphics Adders	dGfx ≤ G7	dGfx ≤ G7	dGfx ≤ G7	dGfx ≤ G7	G3 < dGfx ≤ G7 (greater than G3 and less than or equal to G7)

We leveraged the ENERGY STAR 5 qualified product list (QPL) and the European Commission's Eco Declaration database to select notebooks for testing and analysis. We used the energy consumption data in these databases to select notebooks with the largest possible energy consumption difference. In theory, these large differences in energy consumption reflect differences in system design associated with energy efficiency. Note that because ENERGY STAR 5 does not include screen power impacts, most of the variation in energy consumption seen in notebooks with relatively similar screen sizes can be attributed to non-display design choices.

Using this approach, we procured two notebooks with relatively low energy consumption: one with relatively average energy consumption and one with high energy consumption compared to other systems in the QPL. These notebooks were then tested using both the ENERGY STAR Version 5 test procedure that does not measure display power and the proposed ENERGY STAR Version 6.0 Draft 2 test procedure that does include display power. These data were then compared to discern display power from non-display power to allow for comparison of systems with slightly different screen sizes and NB2 characteristics.

Upon completing the testing of the systems, we performed a tear-down analysis to uncover component and design differences that are not typically revealed in retail notebook specifications. We disassembled the notebooks and catalogued storage, memory, and motherboard information.

3.3 TESTING AND INSTRUMENTATION

All testing occurred in Ecova's lab, an EPA-recognized, CEC approved, and ISO/IEC 17205 accredited laboratory.[7] Equipment used for the testing phase of this project consists of high precision laboratory-grade instruments. Ecova's measurement equipment is calibrated by an ISO/IEC 17025 accredited calibration laboratory. The equipment includes the following:

- Chroma Programmable AC Power Source 61602
- Yokogawa WT1600 Digital Power Meter
- Yokogawa WT500 Digital Power Meter
- Yokagawa WT210 Digital Power Meter

Testing complied with ENERGY STAR's instrumentation measurement accuracy requirements:

- Power measurements with a value greater than or equal to 0.5 W shall be made with an uncertainty of less than or equal to 2% at the 95% confidence level.
- Power measurements with a value less than 0.5 W shall be made with an uncertainty of less than or equal to 0.01 W at the 95% confidence level.

All power supply measurements were conducted in Ecova's lab using the Generalized Internal Power Supply Efficiency Test Protocol R6.6.[8] Units were tested at 10%, 15%, and 20% of their rated nameplate DC power output to capture power conversion efficiency close to a realistic load point. Analysis of ENERGY STAR datasets indicated that power supplies are most commonly loaded at around 15% of their rated load during idle operation.

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[7] For detailed information see http://www.energystar.gov/index.cfm?c=third_party_certification.tpc_labs and http://l-a-b.com/accredited-labs?field_scope_text_value=ecova&title=&field_state_value=All&field_country_value=All

[8] Available at: http://efficientpowersupplies.epri.com/pages/Latest_Protocol/Generalized_Internal_Power_Supply_Efficiency_Test_Protocol_R6.6.pdf.

4. RESULTS

4.1 DESKTOP COMPUTER RESULTS

4.1.1 BASELINE SYSTEMS

We procured and tested baseline desktop computer systems representing the most common attributes of the DT1 and DT3 categories defined by ENERGY STAR Version 6.0 Draft 2. DT1 represents medium-performance systems commonly found in homes and offices while DT3 represents higher-performance systems containing discrete graphics cards more likely to be used for media-intensive applications.

Two DT1 systems (DT1-1 and DT1-2) were procured from separate OEMs, one based on an Intel CPU and the other using an AMD CPU. The specifications of these baseline systems are listed in Table 8 below.

TABLE 8: BASELINE DT1 DESKTOP COMPUTER SYSTEM SPECIFICATIONS

	DT1 MOST COMMON (MARKET DATA)	DT1-1 MEDIUM PERFORMANCE BASELINE	DT1-2 MEDIUM PERFORMANCE BASELINE
CPU	Intel i3-2120 3.3GHz	AMD E2-3200 2.4GHz	Intel Core i3-2120 3.3GHz
Number of Cores	Dual Core	Dual Core	Dual Core
Memory	4 GB	2x2GB DDR3-1600MHz SDRAM	2x2GB DDR3-1333MHz SDRAM
Storage	500 GB, 7200 rpm	Seagate Barracuda SATA 7200RPM 500GB	Hitachi Deskstar 7K1000.C SATA 7200RPM 500GB
GPUs	Intel HD Graphics (integrated)	AMD Radeon HD 6370D (integrated)	Intel HD Graphics 2000 (integrated)
Power Supply PSU Size	240 W	OEM 300W	OEM 300W
Purchase Price ($)	–	$574	$360

As noted in the methodology, we used a slightly different selection process for DT3 systems. As with the DT1 systems, we selected DT3-1 to closely resemble the common build defined by our market research, but we made some component choices in order to procure a system that would allow us to evaluate the cost effectiveness of a greater number of efficiency opportunities. This modification was not made in DT1 systems, because the market data indicated that the most commonly available components were not the latest generation of components (which are also likely to be more efficient).

Because the DT3 definition encompasses desktops with a wide range of performance characteristics, we selected DT3-2 to be intentionally high-performance (and potentially energy-intensive). Despite its current categorization as a DT3 computer, DT3-2 is very different than the representative market system in its use of a hex-core processor and a large power supply. The system even weighs thirty pounds more than the other DT3 system. Both the DT3-1 and DT3-2 baseline system specifications are listed in Table 9.

TABLE 9: BASELINE DT3 DESKTOP COMPUTER SYSTEM SPECIFICATIONS

	DT3 MOST COMMON (MARKET DATA)	DT3-1 HIGH PERFORMANCE BASELINE	D3-2 VERY HIGH-PERFORMANCE BASELINE
CPU	Intel i7-3770	Intel Core i5-2500 3.3GHz	Intel Core i7-3930K 3.2GHz
Number of Cores	Quad Core	Quad Core	Hex Core
Memory	8 GB	2x4GB DDR3-1333MHz SDRAM	4x4GB DDR3-1333MHz SDRAM
Storage	2 TB, 7200 rpm	2xHitachi Deskstar 7K1000.C 7200RPM 1TB	Seagate Barracuda SATA 7200RPM 2TB
GPU	AMD Radeon HD 7570 (G3)	AMD Radeon HD 6850 (G5)	AMD Radeon HD 6870 (G7)
PSU Size	460 W	OEM 600W	OEM 875W
Purchase Price ($)	–	$850	$2300

4.1.2 SYSTEM-LEVEL DESKTOP RESULTS

The results presented here demonstrate that desktop computers commonly available on the market today can be made significantly more efficient cost-effectively. The medium performance DT1 desktops' annual electricity consumption was cost-effectively reduced by 30% compared to their baselines, and the high-performance DT3 systems' annual electricity consumption was cost-effectively reduced by 24 to 34% compared to their baselines.

Figure 2 and Table 10 below present the individual system-level results for desktop computer systems. The figure shows TEC in kWh per year for the baseline desktop computer systems in blue, the cost-effective efficient systems in green, and the proposed ENERGY STAR Version 6.0 Draft 2 specification levels in orange. Detail regarding the components used in the cost-effective efficient builds can be found in Appendix 5.1.

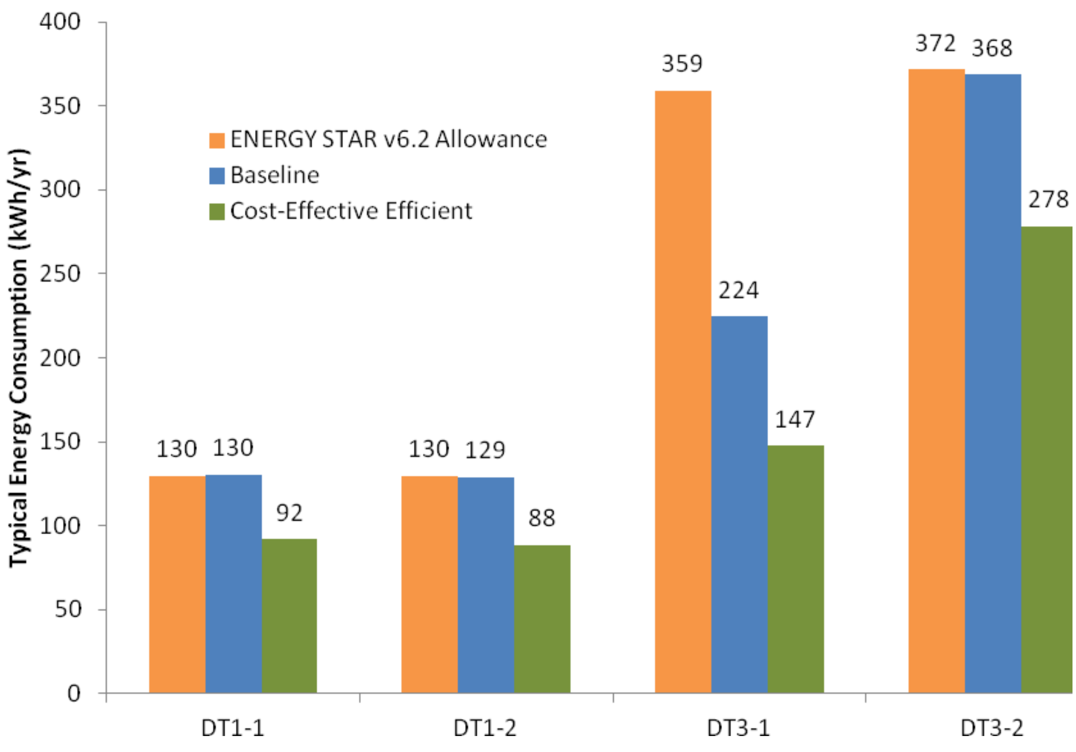

FIGURE 2: DESKTOP COMPUTER SYSTEM ENERGY CONSUMPTION COMPARISON

Note that the ENERGY STAR Version 6.0 Draft 2 TEC allowance (orange column) for a given desktop computer system includes the base TEC for its respective desktop category (i.e. DT0, DT1, DT2 or DT3) as well as various

TEC adders that account for discrete graphics cards, additional storage devices and additional memory. The DT3 systems had very large TEC allowances due to their use of high-performance discrete graphics cards.

Of the four baseline systems, three qualified for ENERGY STAR Version 6.0 Draft 2 by a margin of 1% or less. In contrast, the DT3-1 baseline system qualified by a 38% margin. The baseline desktop computer testing suggested that commonly available desktops would qualify for ENERGY STAR Version 6.0 Draft 2. This implies that in certain instances, proposed ENERGY STAR Version 6.0 Draft 2 specifications may be a reasonable TEC baseline for desktop computers commonly available in the market today. In the DT3 category, proposed ENERGY STAR Version 6.0 Draft 2 levels could overstate baseline energy use.

The cost-effective efficient builds utilized a set of computer components that generated savings while incurring no net cost over the lifetime of the product (the net present value of the electricity saved over the life of the system was greater than the incremental cost of the efficiency measures) with component prices adjusted to the year 2015.

Note that the cost effectiveness of the efficient system as a whole may be different than the cost effectiveness of the individual components due to interactions between component-level savings measures, as previously described.

The table below shows that the energy consumption of DT1-1 can be cost-effectively reduced by more than 38 kWh per year (30%) compared to the baseline. These energy savings require $3.09 in incremental component costs and yield 154 kWh of energy savings (valued at $25.86) over the lifetime of the computer. The set of more efficient components in this system generate a net savings of $22.77 (every kWh of electricity saved generates $0.15 in net benefit) over the lifetime of the computer.

Energy consumption in the DT1-2 system can be cost-effectively reduced by more than 40 kWh per year (31%) compared to the baseline, assuming 2015 component prices. These energy savings require $1.50 in incremental component costs and yield 160 kWh of energy savings (valued at $26.87) over the lifetime of the computer. The set of more efficient components in this system generate a net savings of $25.37 (every kWh of electricity saved generates $0.16 in net benefit) over the lifetime of the computer.

Energy consumption in the DT3-1 system can be reduced by more than 77 kWh per year (34%) compared to the baseline. Assuming 2015 component prices, these energy savings require $25.93 in incremental component costs and yield 307.8 kWh of energy savings (valued at $60.37) over the lifetime of the computer. The set of more efficient components in this system generate a net savings of $25.63 (every kWh of electricity saved generates $0.08 in net benefit) over the lifetime of the computer.

Energy consumption in the DT3-2 system can be cost-effectively reduced by more than 90 kWh per year (25%) compared to the baseline assuming 2015 component prices. These energy savings require $42.51 in incremental component costs and yield 362 kWh of energy savings (valued at $60.37) over the lifetime of the computer. The set of more efficient components in this system generate a net savings $17.86 (every kWh of electricity saved generates $0.05 in net benefit) over the lifetime of the computer.

TABLE 10: DESKTOP SYSTEM-LEVEL ANNUAL ENERGY CONSUMPTION AND LIFETIME COST SAVINGS

	DT1-1	DT1-2	DT3-1	DT3-2
Baseline TEC	130 kWh	129 kWh	224 kWh	368 kWh
Efficient Build TEC	92 kWh	88 kWh	147 kWh	278 kWh
Lifetime Net Savings of Efficient Build	$22.70	$25.37	$25.63	$17.86

All of the more efficient systems described above fall within the same ENERGY STAR Version 6.0 Draft 2 performance category as their respective baseline systems. Further, the more efficient components used in each of the more efficient builds had performance parity with the baseline system components (as described in the methodology section of this report). As such, the more efficient desktop computer systems presented here did not reduce the non-energy performance compared to the baseline systems.

4.1.3 COMPONENTS USED IN EFFICIENT SYSTEMS

We achieved the cost-effective electricity savings demonstrated in the efficient systems described above by installing a set of more efficient components. We identified the components for a given system by systematically testing the energy impacts of multiple individual component swaps, as described in the Methodology section.

Figure 3 below describes the impact of individual computer component efficiency opportunities compared to baseline systems in the medium-performance DT1 category. The horizontal axis shows lifetime system-level electricity savings for a specific component compared to the baseline DT1 systems. The vertical axis shows the incremental efficient component cost compared to the equivalent baseline system component assuming 2015 prices. Components that fall below the $0 incremental cost line are cheaper than the equivalent baseline component.

The components circled with dark blue were used in the efficient DT1-1 system and the components circled in light blue were used in the efficient DT1-2 system. Complete detail regarding the components tested in the two DT1 systems can be found in Appendix 5.3. Recall that while some of these components may not be cost-effective in isolation, ultimately the efficient system was cost-effective as the price and energy impacts of specific components were balanced on a system level. In other words, certain highly cost-effective measures can help to "pay" for less cost-effective ones, resulting in an overall cost-effective system.

Note that additional evaluation of PSU efficiency opportunities and costs confirmed our cost-effective efficient system PSU selection. See Appendix 5.4 for additional detail.

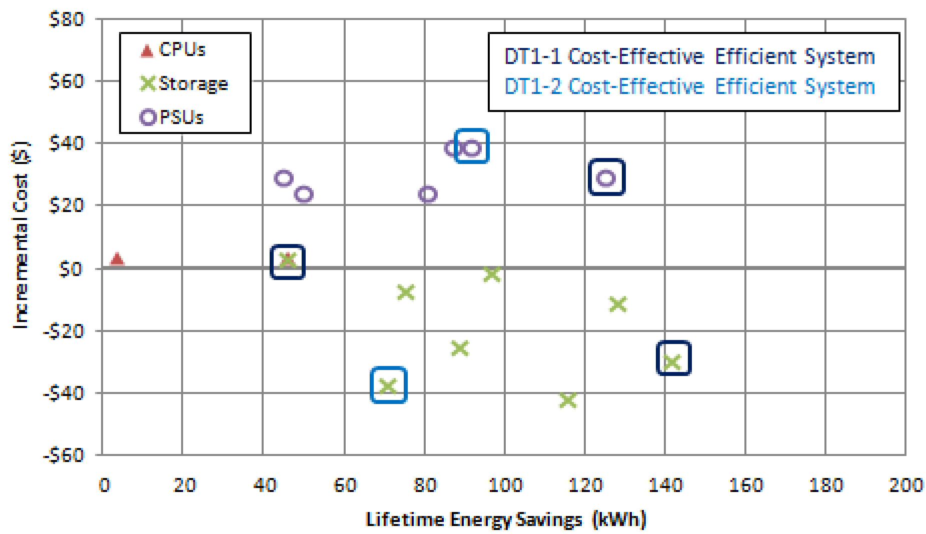

FIGURE 3: COMPONENT INCREMENTAL COST VS ENERGY SAVINGS FOR DT1 SYSTEMS USING ADJUSTED 2015 RETAIL PRICES

Figure 3, above, shows that efficiency opportunities associated with storage were the least expensive and also saved a significant amount of energy in DT1 systems tested. CPUs had the smallest impact on electricity consumption in the systems tested and PSU opportunities were larger but generally more expensive on an incremental first cost basis. The Conclusion section of this report includes further discussion regarding savings opportunities.

Figure 4 describes the impact of individual computer component efficiency opportunities compared to baseline systems in the high-performance DT3 category. Note the addition of discrete GPUs to the graph. Discrete GPUs fall outside of the definition of DT1 systems but are present in the DT3 systems that were tested. Note also that no CPU efficiency opportunities are shown in the figure. CPU efficiency opportunities were not identified in the DT3 systems tested. We used the components circled with dark blue in the efficient DT3-1 system and the components circled in light blue in the efficient DT3-2 system. Complete detail regarding the components tested in the two DT3 systems can be found in Appendix 5.3.

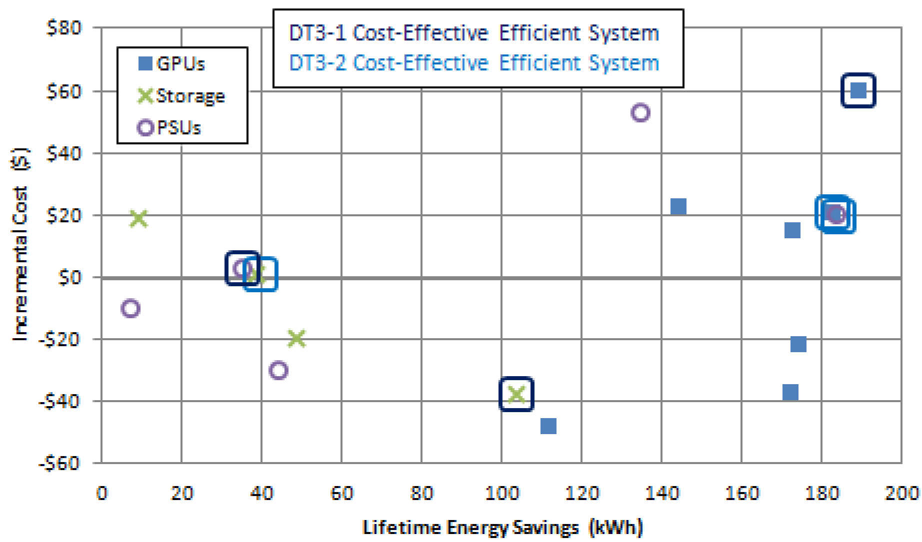

FIGURE 4: COMPONENT INCREMENTAL COST VS ENERGY SAVINGS FOR DT3 SYSTEMS USING ADJUSTED 2015 RETAIL PRICES

As the figure above shows, GPUs offered the most compelling efficiency gains in the DT3 systems tested. PSU and storage efficiency opportunities were also present but generally less dramatic. The Conclusion section of this report includes further discussion regarding savings opportunities.

4.1.4 ADDITIONAL MOTHERBOARD EFFICIENCY RESULTS

The five motherboards that we tested in DT3-1, a high performance desktop system, had a significant impact on system energy consumption. Figure 5 shows the TEC of the desktop with the various motherboards. The columns represent motherboards with different chipsets.

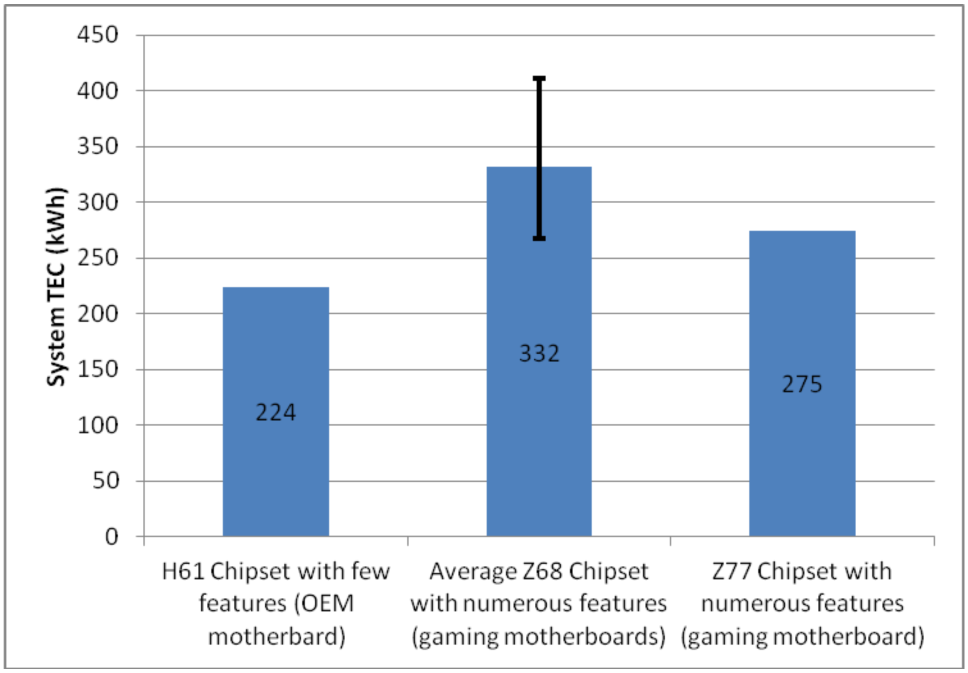

FIGURE 5: MOTHERBOARD TESTING IN DT3-1

The column titled "H61 Chipset with few features" is the system-level TEC for the baseline desktop that used the motherboard that came with the OEM system (DT3-1). This board had few features, such as PCI slots and USB ports, compared to the other motherboards that are typically purchased by individuals building their own computer system for video gaming or other graphics intensive applications. The column titled "Average Z68 Chipset with numerous features" is the average TEC value for the system associated with three motherboards that used identical Z68 chipsets. The error bars on this average capture the range of the Z68 motherboard system TEC values. These motherboards had numerous features such as multiple PCI slots and multiple USB slots. The third column, titled "Z77 chipset with numerous features", is the system TEC with another motherboard typically sold to individuals building their own desktop.

These data indicate that there is a large variation in motherboard energy consumption across chipsets. The average difference in TEC between systems using Z68 chipset motherboards and the similarly featured Z77 chipset was nearly 60 kWh. The difference was more striking when the Z68 board systems were compared to the H61 OEM motherboard system, although this comparison is tenuous, as the OEM motherboard had far fewer features.

These data also indicate a surprising degree of variation in motherboard energy consumption when the same chipset is used. The spread in TEC values for the motherboards that used the Z68 chipset and had nearly identical features was more than 140 kWh. This implies that design plays a significant role in motherboard efficiency. Anecdotal evidence from Tom's Hardware Review indicates that motherboards with the same chipset have an idle power spread of more than 10W.

The differences in motherboard design may be due to the use of inefficient field-effect transistors (FETs) and voltage regulation modules as well as narrower, more resistive printed circuit traces.[9] Anecdotal evidence also suggests that basic input/output system (BIOS) power management may play a role in motherboard energy consumption.

While these findings are compelling, the baseline motherboard consumed far less energy than the other motherboards we tested. This implies that basic OEM motherboards may be designed in a more efficient manner when compared to after-market motherboards available on the market today. To fully understand the impact that motherboard design has on computer energy consumption, a more detailed engineering tear-down analysis is needed. Consultation with motherboard design experts within the computer industry may also provide some insight into motherboard efficiency.

[9] See: EPRI and Ecos, *Challenges and Energy-Saving Opportunities in Measuring, Reporting, and Promoting High Efficiency Secondary Power Supplies,* September, 2008, http://www.energy.ca.gov/2008publications/CEC-500-2008-023/CEC-500-2008-023.PDF

4.2 Notebook Computer Results

Figure 6 below presents notebook system-level electricity consumption for four notebooks. The red portion of the columns is the non-display electricity consumption. The blue portion of the columns is the electricity consumption of the notebook displays. Non-display electricity consumption differences in the notebooks ranged between 22 kWh and 9.8 kWh per year. This translates to lifetime energy savings of 67 - 29 kWh and lifetime electricity bill savings of $11.00 - $4.80.

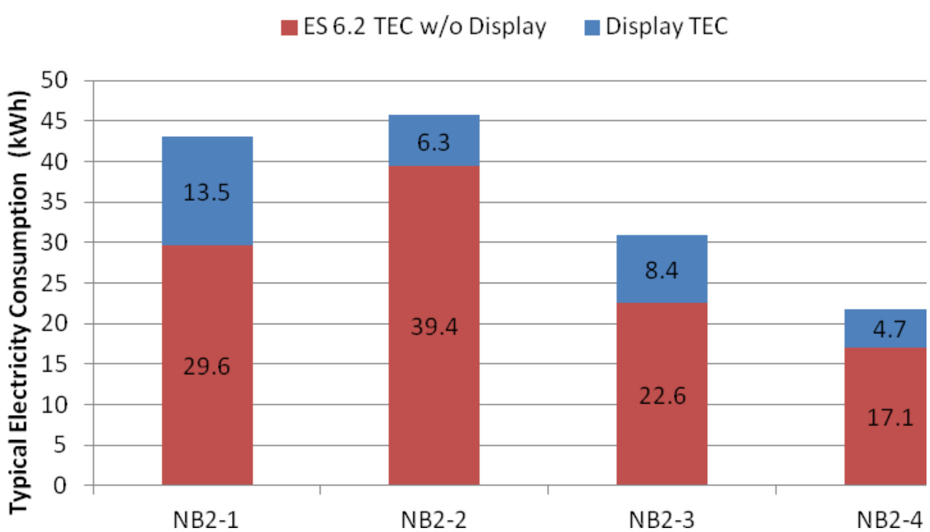

FIGURE 6: NOTEBOOK TYPICAL ELECTRICITY CONSUMPTION COMPARISON

When the impact of the display on system electricity consumption is removed, all four notebooks were considered NB2 systems as defined by ENERGY STAR Version 6.0 Draft 2. This implies that the systems were fairly similar in performance as characterized by ENERGY STAR. In reality, there were some differences in the components used in the notebooks and in the features they provide. Key differences included the use of a discrete GPU in NB2-2 and the Ultrabook form-factor of NB2-3 and NB2-4. Table 11 below describes key attributes of the notebooks.

TABLE 11: NB2-1 AND NB2-2 ATTRIBUTES

	NB2-1	NB2-2	NB2-3	NB2-4
CPU	Intel Core i5-2450M 2.5GHz	Intel Core i5-3210M 2.5GHz	Intel Core i7-3667U 2.0GHz	Intel Core i5-3427U 1.8GHz
Cores	2	2	2	2
Memory	4GB DDR3-1333MHz SDRAM	6GB DDR3-1600MHz SDRAM	4GB DDR3-1333MHz SDRAM	4GB DDR3L-1600MHz SDRAM
Storage	500GB HDD	500GB HDD	256GB SSD	256GB SSD
Graphics Processing Unit (integrated)	Intel HD Graphics 3000	Intel HD Graphics 4000	Intel HD Graphics 4000	Intel HD Graphics 4000
Graphics Processing Unit (discrete)	-	NVIDIA GeForce GT 650M 2GB DDR5	-	-
Optical Drive	CD-RW/DVD-RW	CD-RW/DVD-RW	-	-
Screen Size (inches)	15.6	14.0	14.0	13.3
Relative Motherboard Size	Medium	Large	Small	Small
Purchase Price	$585	$999	$1799	$1499

4.2.1 DISCRETE GPU IMPACT ON NOTEBOOK ELECTRICITY CONSUMPTION

The nearly 10 kWh difference in annual electricity consumption (excluding display power) between NB2-1 and NB2-2 was due, in part, to the presence of a discrete GPU. The absolute impact of the discrete GPU on NB2-2's electricity consumption was uncertain because the model of GPU in the system utilized NVIDIA's Optimus technology, which automatically switches between the integrated graphics processor and the discrete GPU depending on the graphics processing load. Figure 7 below shows the discrete and integrated graphics processor use by NB2-2. Because there was limited graphics processing load in idle test conditions, and no load in sleep and off conditions, it is likely that NB2-2 never used the discrete GPU.

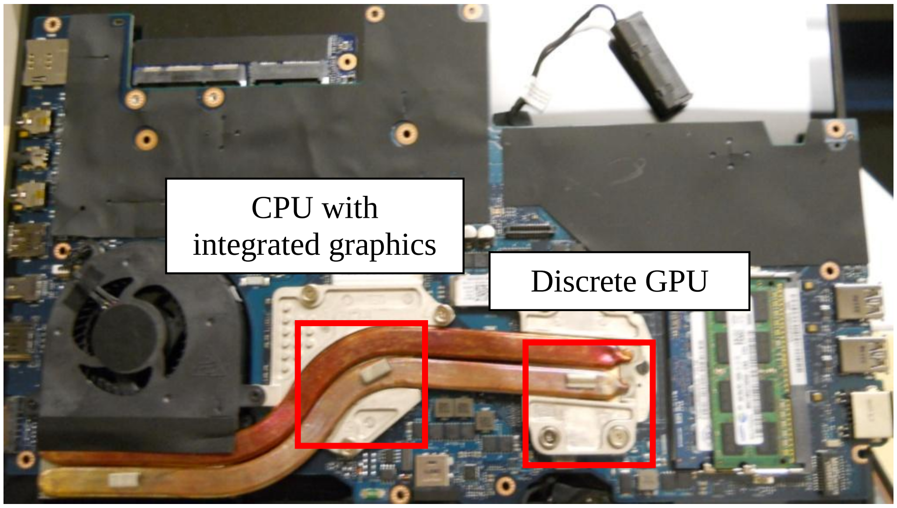

FIGURE 7: DISCRETE AND INTEGRATED GRAPHICS IN NB2-2 (UNDER HEAT SINKS)

The original intent of selecting NB2-2 for testing was to force the discrete GPU to be used in idle conditions to evaluate the impact of a discrete GPU on the system. However, during testing it became clear that forcing the discrete GPU to be in an on state was impossible in idle mode. As such, it was impossible, with the current setup, to separate the impact of actively using a discrete GPU from the impact of having the ability to use (or simple the presence of) a discrete GPU.

4.2.2 COMPACT DESIGN IMPACT ON NOTEBOOK ELECTRICITY CONSUMPTION

Ultrabooks are marketed as very portable systems with long battery life. Given the design premium placed on long battery life in Ultrabooks, the relatively small electricity consumption of NB2-3 and NB2-4 compared to NB2-1 and NB2-2 is expected. There is an inherent market driver for efficient design in Ultrabooks, even more so than in more mainstream laptops.

NB2-3 and NB2-4 both used SSDs, which have been shown to generate electricity savings in desktops (reducing annual electricity consumption on a system level by nearly 15%). The difference in annual electricity consumption between the two notebooks that used standard spinning HDDs and the two that used SSDs was slightly more than 15%. Because both NB2-3 and NB2-4 used a semi-integrated SSD (similar to mini-SATA in form factor but not identical), it was impossible to develop specific savings estimates associated with the specific drives. Changing the SSDs in these notebooks to isolate their contribution to consumption differences was impossible because other drives could not use the custom connection.

Beyond specific component choices such as storage drives, the level of system integration in the NB2-3 and NB2-4 is surprisingly large compared to the NB2-1 and NB2-2 systems. The motherboards in these systems were less than one third the size of NB2-2's motherboard. Figure 8, 9 and 10 below compare NB2-2, NB2-1, and NB2-3 motherboard sizes. The pictures are approximately the same scale.

FIGURE 8: NB2-2 MOTHERBOARD (LARGE SIZE)

FIGURE 9: NB2-1 MOTHERBOARD (MEDIUM SIZE)

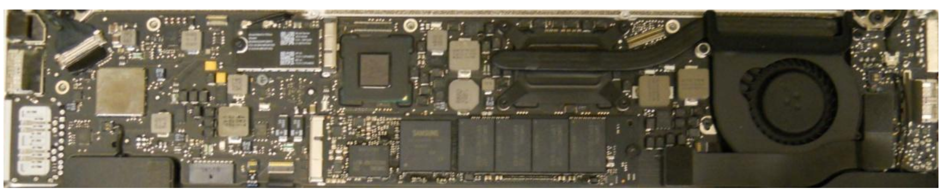

FIGURE 10: NB2-4 MOTHERBOARD (SMALL SIZE)

Several components in NB2-3 and NB2-4 were integrated directly onto the motherboard. The memory was wired directly to the board instead of being connected via dual in-line memory module (DIMM) ports, and the hard drive used a custom connection to integrate directly with the motherboard. While the impact of these design choices on system annual electricity consumption is unclear, compact motherboards and integrated design inherently drives more efficient design as component thermal dissipation becomes more critical.

Further research is needed to evaluate the energy impact of specific design choices in motherboard design.

4. CONCLUSION

Efficiency opportunities in computers can be realized through a number of different component "pathways." The results for desktop computers indicate that the greatest energy savings potential can be found in discrete graphics cards (when present), followed by storage devices and power supplies. The CPUs tested in this work generated minimal energy savings.

Previous Ecova research found that discrete graphics cards can account for up to half of a system's total energy consumption.[10] The efficiency opportunity associated with graphics cards is confirmed in the results presented here. These opportunities are associated with improvements and new designs of recent models. These improvements come from new processes such as NVIDIA's Kepler design and the incorporation of new power management features, such as AMD's "ZeroCore" technology, which shuts off power to parts of the GPU when the system is in an idle state.

Significant energy efficiency opportunities are also associated with transitioning from traditional HDDs to SSDs. SSDs contain no moving parts and have faster read-write speeds than traditional spinning HDDs. As a result, SSDs not only reduce power consumption but also increase overall system performance.

The CPUs tested in this work showed little potential for cost-effective energy savings without drastically reducing system performance either by processor under-clocking or downgrading to a slower CPU operating at lower frequencies. Many of the power management features that are driving efficiency improvements in graphics cards have already been realized in CPUs. New efficiency opportunities may only emerge through fundamental silicon process changes or architectural shifts. For example, there may be a significant opportunity in CPU efficiency as embedded computing technology used in smart phones and tablet computers is transferred to traditional desktop and notebook computers. ARM, a UK-based designer of low-energy mobile and embedded processors, has recently partnered with AMD in the design of forthcoming CPUs.

Further research is needed to fully evaluate the impact that motherboards have on overall computer efficiency. This research identifies a number of potential opportunities, including the use of more efficient FETs and voltage

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[10] See: *Assessment of Desktop Computer Graphics Card Idle Power, Preliminary Results*, March 2012, http://www.clasponline.org/en/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2012/~/media/Files/SLDocuments/2012/DesktopGraphicCardTesting/2012-3_PreliminaryResults_AssessmentOfDesktopComputerGraphicsCardIdelPower.pdf.

regulation modules as well as wider, less resistive traces on circuit boards. Such strategies may require redesign of motherboards and could not be tested in this research.

The analysis of laptop computers was more limited and less conclusive than for desktop computers. There are fewer opportunities to change components in a turnkey fashion in these products due to their high level of integration. In a sense, they present a challenge very similar to motherboards in that many efficiency opportunities may require redesign of subsystems that are soldered onto the motherboard. An evaluation of non-display power in four notebook computers identified significant differences in TEC that can most directly be attributed to differences in graphics (discrete vs. on-board), overall form factor (large vs. Ultrabook), and storage media (spinning HDDs vs. SSDs). The high degree of integration in most laptops made it difficult to evaluate the savings impacts of most features.

One of the most surprising findings of this study is that the market baseline desktop computers would qualify under ENERGY STAR's Version 6.0 Draft 2 TEC allowances. Naturally, further market analysis and testing would be required to generalize this observation across all ENERGY STAR Version 6.0 Draft 2 performance categories, but initial findings support a somewhat counter-intuitive notion: in order for a California Title 20 computer standard to generate meaningful energy savings over a typical market baseline, it might need to be at least as stringent – if not slightly more stringent – than the proposed ENERGY STAR Version 6.0 Draft 2 specification levels. For desktop computers, our analyses found that current models could be made to exceed proposed ENERGY STAR Version 6.0 Draft 2 levels by significant margins – in some cases up to 60% – in a cost-effective manner. Given this finding it will be prudent to update this report when the final ENERGY STAR Version 6 specification is available (expected in March 2013).

The results presented here indicate that there is a significant opportunity to reduce the energy consumption of desktop computers cost-effectively. This finding supports the California Energy Commission's intention to develop mandatory efficiency standards for computers in California.

5. Appendices

5.1 Appendix – Efficient Desktop Component Detail

DT1 Desktop Computer Components Tested

CPUs	Storage	PSUs	GPUs	Motherboards
AMD E2-3200 2.4GHz	Seagate Barracuda SATA 7200RPM 500GB	FSP Group FSP300-60GHS-R 300W		
AMD A4-3300 2.5GHz	Western Digital Caviar Green 500GB	Seasonic SS-300ES 300W		
AMD Athlon II X2 260 3.2GHz	Western Digital Scorpio Black 500GB	Seasonic SS-300TGW 300W		
Intel Core i3-2120 3.3GHz	Seagate Momentus XT Hybrid HDD/SDD 500GB			
Intel Core i3-3220T 2.8GHz	Samsung 830 Series 256GB			

DT3 Desktop Computer Components Tested

CPUs	Storage	PSUs	GPUs	Motherboards
Intel Core i5-2500 3.3GHz	Hitachi Deskstar 7K1000 1TB (x2)	OCZ Fatal1ty 550W	AMD Radeon HD 6850 (G5)	Foxconn 2ADA (H61)
Intel Core i5-3330 3.0GHz	Hitachi Deskstar 7K2000 2TB	Sunbeam PSU-ECO650 650W	AMD Radeon HD 6870 (G7)	MSI Z68A-G43 G3 (Z68)
Intel Core i7-3770 3.4GHz	Western Digital Caviar Green 2TB	Sparkle Power FSP600-80ETN	AMD Radeon HD 7850 (G7)	ASUS P8Z77-I (Z77)
Intel Core i5-3450S 2.8GHz			NVIDIA GTX 660 (G7)	ASUS P8Z68-V (Z68)
Intel Core i5-3550 3.3GHz			NVIDIA GTX 650 (G4)	ASRock Z68 Extreme7 Gen3 (Z68)

5.2 Appendix - Economic Assumptions

Desktop Computer Lifetime: 4 years

Notebook Computer Lifetime: 3 years

Discount Rate: Built into rates

California Electricity Rates:

TABLE 12: ASSUMED CALIFORNIA ELECTRICITY RATES

YEAR	RESIDENTIAL	COMMERCIAL	INDUSTRIAL
2014	$ 0.17	$ 0.17	$ 0.11
2015	$ 0.16	$ 0.16	$ 0.11
2016	$ 0.17	$ 0.17	$ 0.12
2017	$ 0.17	$ 0.17	$ 0.11
2018	$ 0.17	$ 0.17	$ 0.12
2019	$ 0.18	$ 0.18	$ 0.12
2020	$ 0.18	$ 0.18	$ 0.12

TABLE 13: CAGRS USED FOR DIFFERENT COMPONENTS

COMPONENT	COMPOUND ANNUAL GROWTH RATE (%/YEAR)
CPU	-10.1%
GPU	-14.5%
HDD 3.5"	-11.2%
HDD 2.5"	-20.1%
SSD	-53.2%
PSU	0.0%

5.3 Appendix - Desktop Computer Build Attributes

DT1-1 Builds – Medium Performance Desktop Computer

Attribute	Baseline	Cost Effective Efficient Build (2015)
CPU	AMD E2-3200 2.4GHz	AMD A4-3300 2.5GHz
Cores	Dual Core	Dual Core
Memory	2x2GB DDR3-1600MHz SDRAM	2x2GB DDR3-1600MHz SDRAM
Storage	Seagate Barracuda SATA 7200RPM 500GB	Samsung 830 Series 256GB
Graphics Processing Unit	AMD Radeon HD 6370D (int)	AMD Radeon HD 6370D (int)
Power Supply Size	OEM 300W	FSP Group FSP300-60GHS-R 300W

DT1-2 Builds – Medium Performance Desktop Computer

Attribute	Baseline	Cost-Effective Efficient Build (2015)
CPU	Intel Core i3-2120 3.3GHz	Intel Core i3-2120 3.3GHz
Cores	Dual Core	Dual Core
Memory	2x2GB DDR3-1333MHz SDRAM	2x2GB DDR3-1333MHz SDRAM
Storage	Hitachi Deskstar 7K1000.C 500GB	Seagate Momentus XT Hybrid HDD/SDD 500GB
Graphics Processing Unit	Intel HD Graphics 2000 (int)	Intel HD Graphics 2000 (int)
Power Supply Size	OEM 300W	Seasonic SS-300TGW 300W

DT3-1 Builds – Medium Performance Desktop Computer

Attribute	Baseline	Cost Effective Efficient Build (2015)
CPU	Intel Core i5-2500 3.3GHz	Intel Core i5-3330 3.0GHz
Cores	Quad Core	Quad Core
Memory	2x4GB DDR3-1333MHz SDRAM	2x4GB DDR3-1333MHz SDRAM
Storage	2xHitachi Deskstar 7K1000.C 1TB	Western Digital Caviar Green 2TB
Graphics Processing Unit	AMD Radeon HD 6850 (G5)	NVIDIA GTX 660 (G7)
Power Supply Size	OEM 600W	Sunbeam PSU-ECO650 650W

DT3-2 Builds – Very High Performance Desktop Computer

Attribute	Baseline	Cost Effective Efficient Build (2015)
CPU	Intel Core i7-3930K 3.2GHz	Intel Core i7-3930K 3.2GHz
Cores	Hex Core	Hex Core
Memory	4x4GB DDR3-1333MHz SDRAM	4x4GB DDR3-1333MHz SDRAM
Storage	Seagate Barracuda SATA 7200RPM 2TB	Western Digital Caviar Green 2TB
Graphics Processing Unit	AMD Radeon HD 6870 (G7)	NVIDIA GTX 660 (G7)
Power Supply Size	OEM 875W	Sparkle Power FSP600-80ETN

5.4 Appendix – Additional Power Supply Research

SPECIAL COST CONSIDERATIONS FOR POWER SUPPLIES

Our initial component selection process used retail prices on aftermarket PSU to establish incremental costs. We examined the average retail prices of replacement PSU with similar capacities (nameplate output wattage) and efficiency compared to the units used in our baseline and efficient system builds.

We confirmed this analysis using a more detailed secondary analysis and robustly establish trends between PSU efficiency and cost. Market research firm iSuppli first conducted a tear-down engineering analysis of six PSUs in the 350 to 400W range to examine how bill of materials (BOM) costs varied with efficiency. Their original analysis showed that, on average, BOM costs rose about $0.77 for every percentage point improvement in efficiency within a given efficiency range (roughly between 65% and 88% efficiency). In other words, a PSU with a measured efficiency of 81% costs about $0.77 more to produce than a similarly sized PSU with 80% efficiency.

The efficiency data used by iSuppli's analysis came from manufacturer-reported values, often at 50% of the PSU's rated load. To provide more accurate and relevant efficiency data, Ecova augmented the iSuppli analysis by re-testing the PSUs at a range of lower load points (10, 15 and 20%) that better reflect real-world usage (details on power supply testing provided below). We then re-fit the cost vs. efficiency trend line using Ecova's measured efficiency data and the corresponding iSuppli BOM costs. Using this curve, we were able to determine the typical increase in BOM costs associated with PSU efficiency.

ADDITIONAL POWER SUPPLY EFFICIENCY RESULTS

We evaluated PSU savings opportunities through two approaches: 1) evaluating system level electricity consumption in the same fashion as other components and 2) a bench test of AC-DC conversion efficiency coupled with tear-down engineering analysis by iSuppli to establish relationships between efficiency and BOM costs.

The system-level measurements and cost-effectiveness analysis showed that, despite the significant progress in transforming the PC power supply market made by programs like 80 PLUS and ENERGY STAR, cost-effective savings associated with PSU efficiency can still be realized on a system level. Figure X below illustrates the gap in efficiency between OEM power supplies available in our baseline systems (black) and more efficient models ultimately determined to be cost-effective (green). As shown by the graph on the right, less efficient OEM power supplies can consume anywhere from 5 to 9W more power through conversion inefficiencies. The relatively large lifetime savings associated with power supply measures—anywhere from around 50 to 120 kWh—can justify incremental costs of about $8 to $20 at current California electric rates to achieve payback during the lifetime of the device.

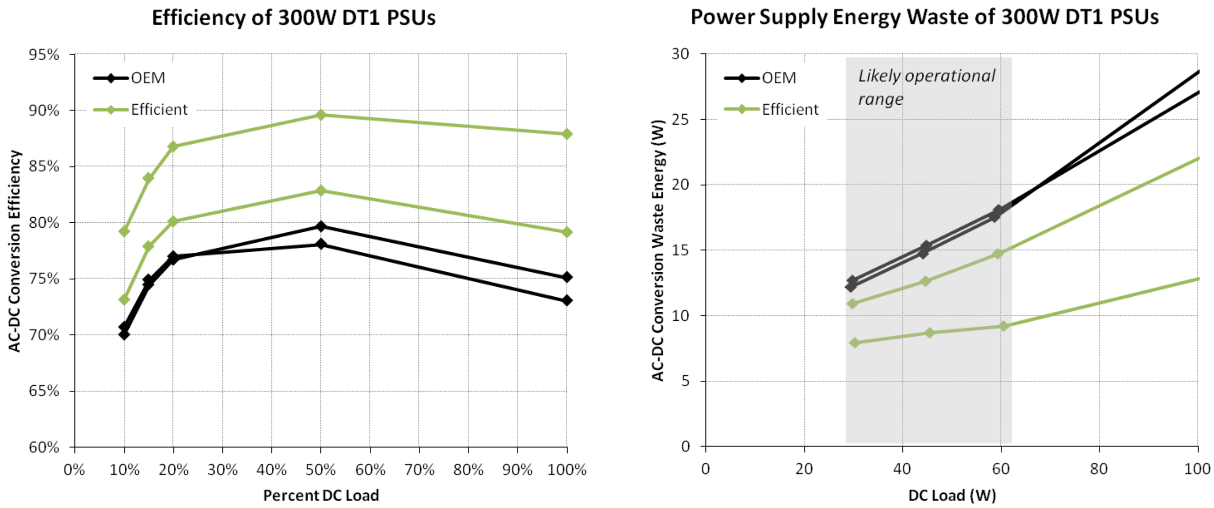

FIGURE 11: MEASURED EFFICIENCIES (LEFT) AND WASTE ENERGY (RIGHT) FOR 300W DT1 PSUS

We used a secondary tear-down analysis to more closely examine relationships between cost and efficiency at the component level and corroborate incremental cost assumptions. Using a combination of iSuppli's BOM tear-down investigation and Ecova's lab measurements of power supply efficiency, we were able to derive a rough relationship between BOM costs and efficiency under typical operating conditions (assumed here to be about 15% of the power supply's rated DC load). The data follow a linear trend, shown in Figure 12.

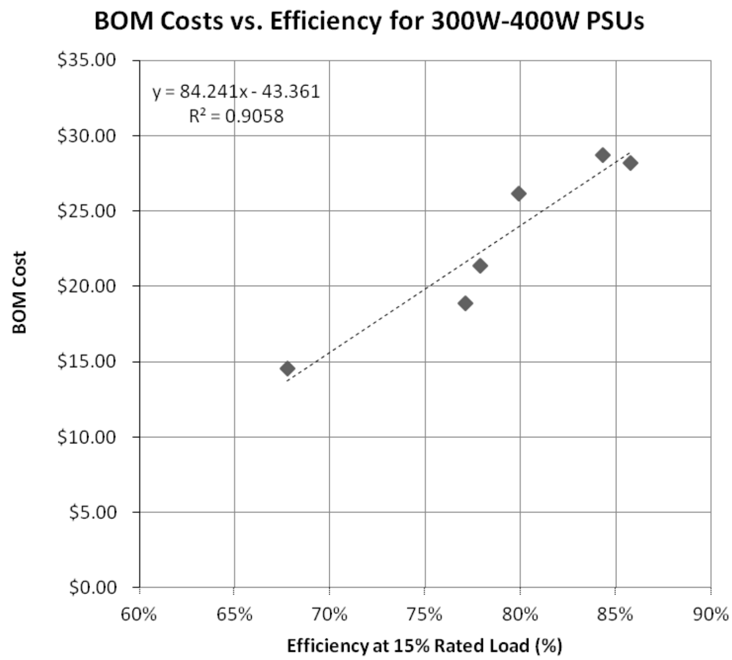

FIGURE 12: BOM COSTS VS. EFFICIENCY FOR 300W-400W PSUS

From the trend line above, we were able to infer what the incremental BOM costs of our more efficient power supplies should be to check against our retail cost approach. To do this, we applied a 250% retail markup to the incremental BOM costs predicted by the trendline to put them in terms of retail dollars.11 The findings from this bottom up analysis confirm the PSU selections based on the retail approach.

[11] The 250% markup estimate was developed via dialogue with power supply manufactures who participate in the 80+ PSU efficiency labeling program which Ecova runs in collaboration with the Electric Power Research Institute.