Electronic Displays

Response to California Energy Commission
2013 Pre-Rulemaking Appliance Efficiency
Invitation to Participate

Docket Number: 12-AAER-2A; Consumer Electronics

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Summary

The information below provides direct responses to the California Energy Commission's (CEC) Invitation to Participate (ITP) for the 2013 Appliance Efficiency Pre-Rulemaking, regarding Electronic Displays including reference to several primary sources, some of which are attached separately (see References for more details). This document includes all of the questions asked in the ITP, even for those with no response.

Computer monitors account for a significant portion of electricity consumed in personal computing use as they are ubiquitous in both residential and commercial settings. We have previously conservatively estimated total annual energy consumption for computer monitors in California to be around 2,000 Gigawatt-hours per year. Power draw in on mode can vary widely, even within same screen sizes as shown in the information we provided in this response.

Primary sources of performance data for California to consider exploring energy efficiency opportunities for electronic displays include the ENERGY STAR product database. Additionally, during the development of the Version 6.0 specification, stakeholders provided energy consumption data on non-ENERGY STAR qualifying products. This dataset includes models dating back as far as May 2006 and up to April 2012. The combined product database (ENERGY STAR qualifying and non-qualifying products) includes over 3,000 computer monitor models. In our responses below, we also propose general scope and definitional language from the latest ENERGY STAR specification. Most of the shipment information was obtained from a market report published by IHS iSuppli in 2012 entitled Worldwide Monitor Market Tracker.

The California Investor Owned Utilities (CA IOUs) are also currently conducting testing to investigate the power and optical systems to determine which components and designs produce more efficient displays, as well as to collect a bill of materials for each display to be used in incremental cost analysis. We have provided some of our preliminary findings in this response. We are also looking at maximum technology scenarios such as automatic brightness control, local backlight dimming, and power factor correction in the power supply. Finally, we are exploring several emerging, potentially revolutionary technologies such as the use of organic LEDs (OLEDs). OLED technology is an emissive technology that is inherently more efficient than currently available LCD-based displays.

Table *of* Contents

1 Basic Information

1.1 Display Categories

We support the following electronic display categories in the scope of this Invitation to Participate: computer monitors, digital picture frames, professional signage (also referred to as signage displays), and electronic billboards (also referred to as digital billboards).

1.2 Product Definition and Scope

1.2.1 Computer Monitors, Digital Picture Frames, Signage Displays

Regarding definitions, the Version 6.0 ENERGY STAR® Displays Specification (referenced as "ENERGY STAR specification" throughout this letter), developed by the U.S. Environmental Protection Agency (EPA), includes the following definitions: Electronic Displays, Computer Monitors, Digital Picture Frames, and Signage Displays (EPA 2013a). We recommend using these definitions and the product category nomenclature to align with ENERGY STAR. The definitions are noted in Table 1.1 below.

Table 1.1 Product Definitions from ENERGY STAR

General Term	Definition
Electronic Display	A commercially-available product with a display screen and associated electronics, often encased in a single housing, that as its primary function displays visual information from (1) a computer, workstation or server via one or more inputs (e.g., VGA, DVI, HDMI, DisplayPort, IEEE 1394, USB), (2) external storage (e.g., USB flash drive, memory card), or (3) a network connection.
Electronic Display Product Categories	**Definition**
Computer Monitor	An electronic device, typically with a diagonal screen size greater than 12 inches and a pixel density greater than 5,000 pixels per square inch (pixels/in2), that displays a computer's user interface and open programs, allowing the user to interact with the computer, typically using a keyboard and mouse.
Digital Picture Frame	An electronic device, typically with a diagonal screen size less than 12 inches, whose primary function is to display digital images. It may also feature a programmable timer, occupancy sensor, audio, video, or Bluetooth or wireless connectivity.
Signage Displays	An electronic device typically with a diagonal screen size greater than 12 inches and a pixel density less than or equal to 5,000 pixels/in2. It is typically marketed as commercial signage for use in areas where it is intended to be viewed by multiple people in non-desk based environments, such as retail or department stores, restaurants, museums, hotels, outdoor venues, airports, conference rooms or classrooms.

Source: EPA 2013a

In Section 1 of the Eligibility Criteria of the ENERGY STAR specification, EPA includes a number of other relevant terms that would be applicable for the CEC in the potential development of efficiency measures for electronic displays.

The ENERGY STAR specification was finalized on September 4, 2012[1] and took EPA almost two years to complete with numerous stakeholders contributing to the development process, including: manufacturers, industry trade groups, non-governmental organizations, utility companies, government agencies, and other national and international stakeholders. The specification has been thoroughly scrutinized and, ultimately, accepted by this diverse group of stakeholders. Where possible, the CEC should consider aligning the framework and concepts provided in the ENERGY STAR specification with potential efficiency measures for electronic displays. Starting in

1.2.1.1 Enhanced Performance Displays

A subcategory of computer monitors that the CEC should consider within the scope is Enhanced-Performance Displays (EPDs). ENERGY STAR provides a definition for EPDs in their specification as shown in Table 1.2. This definition was developed using international standards as a foundation and supplementing additional industry and stakeholder input and data analysis.

Table 1.2 Product Definitions for EPDs

Computer Monitor Subcategory	Definition
Enhanced-Performance Displays	A computer monitor that has all of the following features and functionalities: • A contrast ratio of at least 60:1 measured at a horizontal viewing angle of at least 85°, with or without a screen cover glass; • A native resolution greater than or equal to 2.3 megapixels (MP); and, • A color gamut size of at least sRGB as defined by IEC 61966 2-1. Shifts in color space are allowable as long as 99% or more of defined sRGB colors are supported.

Source: EPA 2013a

We understand from industry that some of the enhanced capabilities of EPDs include: increased color range, better viewing angles, higher resolution, integrated accessories, and expansion potential. We also understand that there are specialized applications for EPDs for engineering, medical, architecture, and graphic design. More detailed market information for EPDs can be obtained from IHS iSuppli (IHS iSuppli 2010).

Because of these enhanced capabilities, ENERGY STAR also established power adders to the calculated On Mode power limit in order to account for additional power consumption due to enhanced capabilities based on data submitted to ENERGY STAR. While we do not have energy

[1] EPA subsequently made additional clarifications to the specification and finalized the updated Version 6 specification on January 16, 2013 (EPA 2013b).

consumption data on EPDs to share with the CEC, ENERGY STAR and industry representatives have this information. ENERGY STAR will be posting energy use data on qualified EPDs to the qualified products lists (QPLs) on their website. To date, there are already 11 product entries, representing numerous EPD models that meet the Version 6 requirements (EPA 2013c).

1.2.2 Electronic Billboards

At this time, we are not aware of an industry-standard definition for electronic, or digital, billboards. However, there are multiple groups that have developed working definitions for electronic billboards for their reports, including the Federal Highway Administration (FHA 2013), the Outdoor Advertising Association of America (OAAA 2013), and Scenic America (Young 2010). Digital billboard packages consist of three pieces: player, extender(s), and the display. The player is essentially a computer, equipped with software to generate the displayed content.

1.3 Existing Test Procedures

1.3.1 Computer Monitors, Digital Picture Frames, Signage Displays

CEC should consider the test methods outlined in the test method part of the ENERGY STAR specification. We suggest that the following sections of the test method be used: test setup (Section 4), test conduct (Section 5), and test procedures (Section 6). There are industry test procedures referenced in the ENERGY STAR method, notably:

- IEC 62301-2011: Household Electrical Appliances-Measurement of Standby Power.
- IEC 62087, Ed 3.0: Methods of Measurement for the Power Consumption of Audio, Video and Related Equipment.

The IEC 62301-2011 test procedure is used to measure the power in sleep mode while IEC 62087 is used to measure on mode power. More detailed descriptions are included in the ENERGY STAR test method. Due to stakeholder input and acceptance of the ENERGY STAR test procedures listed above, this report proposes the same test procedures.

1.3.1 Electronic Billboards

At this time, we are not aware of an industry-standard test procedure to measure the energy consumption of electronic billboards. We are looking further into the development of a test procedure.

1.4 Sources of Test Data

1.4.1 Computer Monitors, Digital Picture Frames, Signage Displays

ENERGY STAR publically posts energy consumption data for products qualified to the Version 5.1 ENERGY STAR specification. Attached, we have included the last list we have downloaded from ENERGY STAR dated May 8, 2013 (EPA 2013c). Additionally, during the development of the Version 6.0 specification, stakeholders provided energy consumption data on non-ENERGY STAR qualifying products. This dataset includes models dating back as far as May 2006 and up to April 2012. We have also included this data to our response (EPA 2012a).

1.4.1 Electronic Billboards

At this time, we are not aware of a source for comprehensive test data of electronic billboards. We are attaching anecdotal energy use information we have found regarding electronic billboards based on a study conducted by Scenic America (Young 2010). The two products identified in the red box in Figure 1.1 from the Scenic America report show the wide variation in annual energy consumption of electronic billboards of the same dimensions.

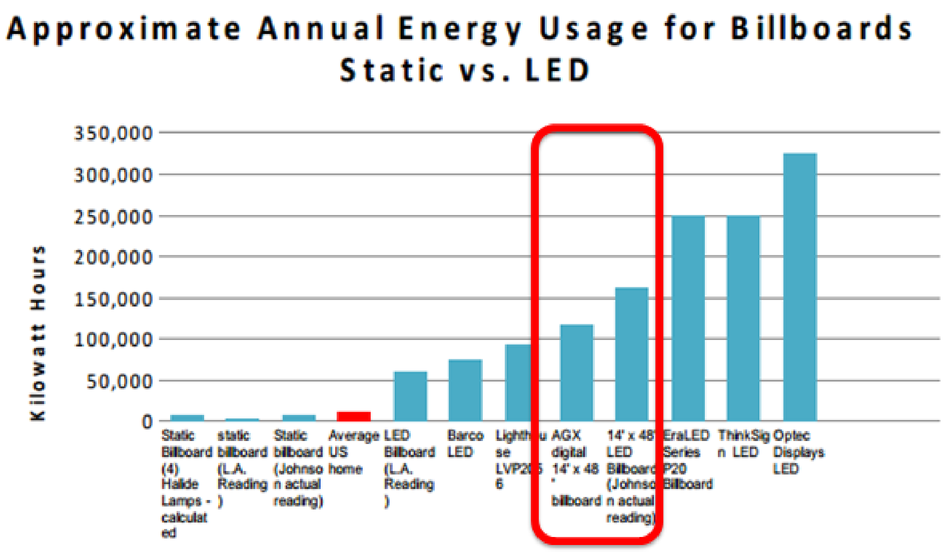

Figure 1.1 Energy Consumption of Digital Billboards

Source: Young 2010

Additionally, in the Scenic America report they state that player/fan arrangements for digital billboards typically consume between 200 and 300 watts while running (Young 2010).

1.5 Existing Standards and Standards under Development

1.5.1 Computer Monitors

At this time, we are not aware of any state with an existing standards or potential standards under development for computer monitors. According to the Collaborative Labeling and Appliance Standards Program (CLASP) Standard and Labeling Database, several other countries have minimum energy performance standards for computer monitors (CLASP 2013).

1.6 Product Lifetime – Computer Monitors

The design life for computer monitors is estimated to be four-years based on an energy consumption study conducted by Lawrence Berkeley National Laboratory (LBNL 2011).

1.7 Product Development Trends – Computer Monitors

The following market information trends are summarized primarily from an IHS iSuppli market study (IHS iSuppli 2012). We understand from industry that IHS iSuppli is a reputable, trusted, and accurate source for market information regarding computer monitors.

1.7.1 Screen Size

Figure 1. and 1.3 show general shipment trends in the U.S. between 2011 and 2016 for business and consumer sectors by screen size bin. As shown, screen sizes between 23- and 25-inches are expected to be the most shipped size categories moving forward.

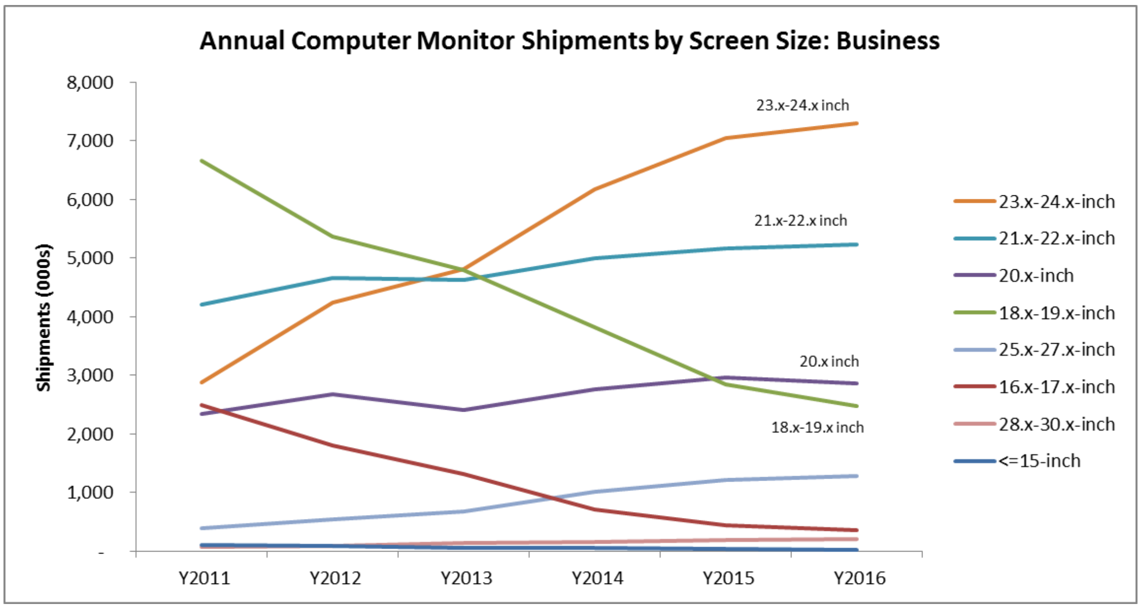

Figure 1.2 Annual Computer Monitor Shipments by Screen Size: Business
Source: IHS iSuppli 2012

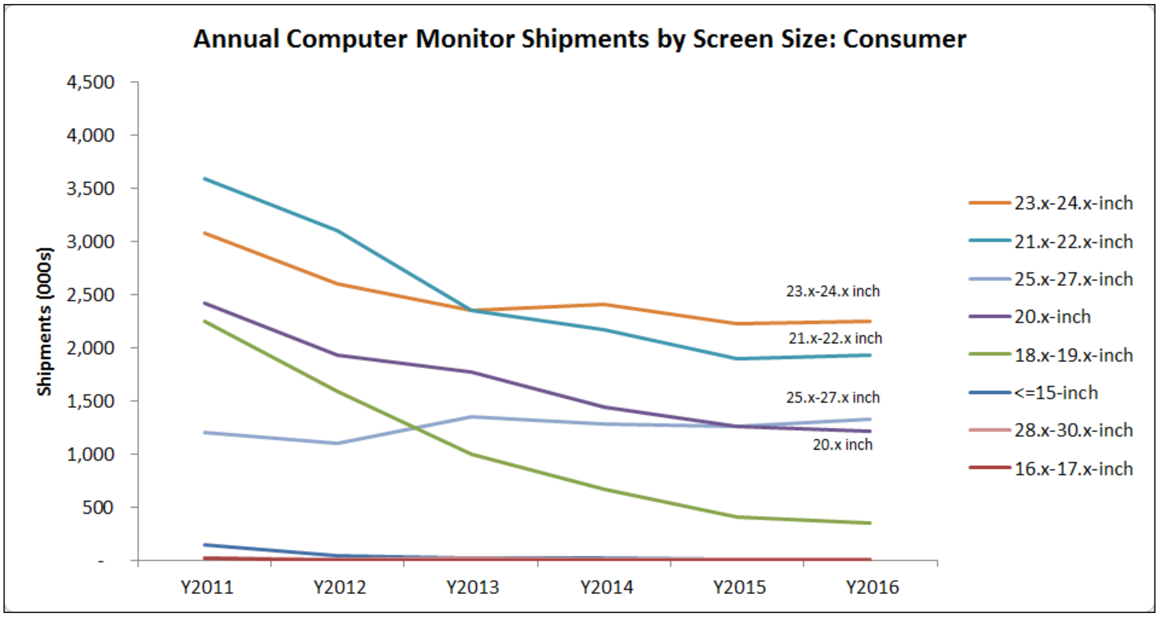

Figure 1.3 Annual Computer Monitor Shipments by Screen Size: Consumer
Source: IHS iSuppli 2012

1.7.1 Resolution

There are many different resolutions for computer monitors. Table below lists most of the resolution types for monitors considered in this report. Also listed in the table are the number of vertical pixels, horizontal pixels, total native resolution in megapixels, and aspect ratio. The aspect ratio is the width (horizontal) to height (vertical) ratio.

For purposes of this analysis, resolutions are binned in categories that align with market data.

Table 1.3 Resolution Categorizations for Computer Monitors

Resolution Bin	Total Native Resolution (MP)
<=XGA	0 – 0.786
>=UXGA	1.920 – 2.074
>=WUXGA	2.304 and higher
SXGA	1.311
WSXGA	1.296 (16:10 aspect ratio)
WXGA	1.024
WXGA+	1.764 (16:10 aspect ratio)

Based on the market information and displays in the Figure 1.4 below, since 2011, there have been increasing shipments of larger resolution monitors (≥WUXGA = 2.304 MP and higher).

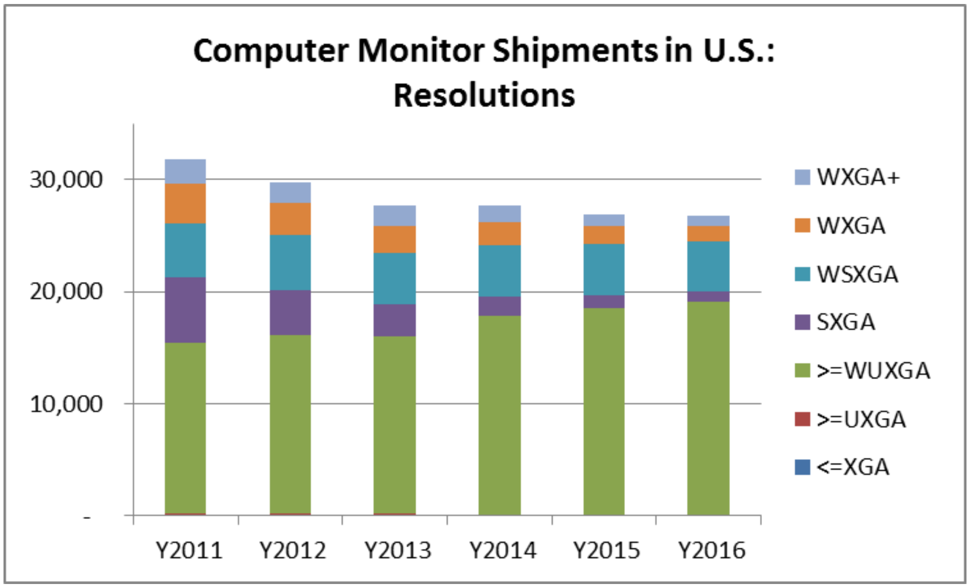

Figure 1.4. Computer Monitor Shipments in U.S.: Resolutions
Source: IHS iSuppli 2012

1.7.1 LCDs and Backlight Source

Liquid crystal display (LCD) monitors make up a vast majority of the overall computer monitor market today. A major transition from cathode ray tube (CRT) monitors to LCD took place in the early 2000s. No CRT monitor shipments have been reported since 2010. Other self-emissive flat panel display types available on the market, aside from LCDs, include plasma display panels and organic light emitting diodes (OLEDs).

LCD monitors use a backlight as a light source. The backlight source can vary from cold cathode fluorescent lamps (CCFLs) to more energy-efficient light emitting diodes (LEDs). For LED-backlit monitors, the LEDs could be arranged behind the entire LCD panel ("full-array") or arranged only along the edge of the LCD panel ("edge-lit") and can illuminate the screen using light guides. Figure 1.5 shows shipment trends in the U.S. of computer monitors by backlight type.

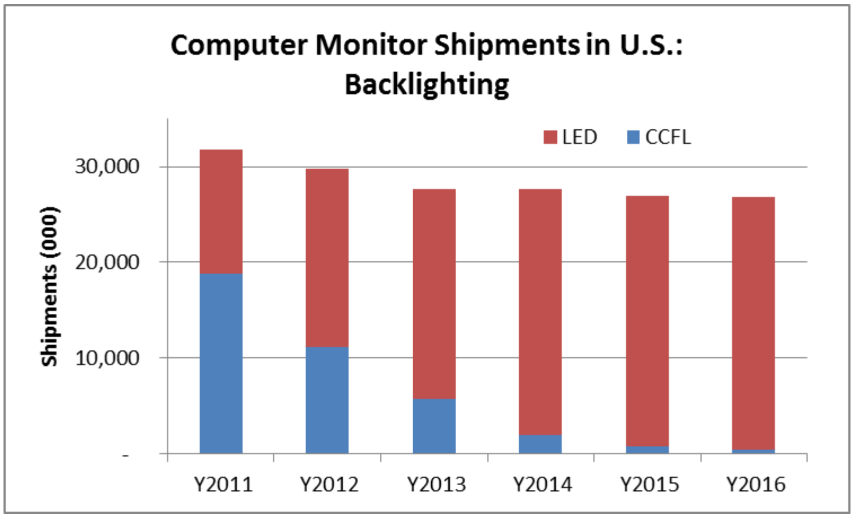

Figure 1.5. Computer Monitor Shipments in U.S.: Backlighting
Source: IHS iSuppli 2012

2 Operations

2.1 How should the energy efficiency of standalone display devices be measured or bench marked (e.g., energy/area, energy/pixel, etc.)? Why?

Energy efficiency of computer monitors, digital picture frames, and signage displays should be benchmarked using power in watts), screen area in inches-squared, and screen resolution in megapixels. This approach aligns with the ENERGY STAR specification and is industry-accepted and is recognized and understandable to consumers, who typically make purchasing decisions based on screen size (as opposed to number of pixels).

After considering an approach for on mode requirements based on just screen size (as is established in the Title 20 energy conservation standard for TVs) and power, further analysis showed that resolution does not necessarily scale linearly with screen size. Given different applications for different screen resolutions, incorporating resolution into the requirement would ensure availability of models at most popular screen resolutions.

2.2 How does display resolution impact power draw?

The higher resolution monitors will typically consume more power due to the increased brightness of the backlight and additional controllers required for higher resolution displays. The CA IOUs are currently analyzing test results and will have more technical information to share regarding the effect of resolution on power draw with CEC in the coming months.

2.3 How does display brightness impact power draw?

In order to brighten a display, the backlight unit would have to be brightened which requires more power. Additionally, different types of optical films may be added to increase the screen brightness. Further discussion is provided on optical films in Section 4.

2.4 What are the modes of operation?

Electronic displays have three primary power modes: on, sleep, and off. On mode occurs when the display is on and displays an image. Sleep mode is a temporary low power state entered after a period of inactivity (e.g., for a monitor typically 15 minutes when power management is enabled). Off mode is the lowest power mode and is reached when the user powers down the display by manually switching it off. Display on mode power draws depend most strongly on display technology, screen size, and resolution. All three power modes are described in terms of watts (W). Below are the power mode definitions included in the ENERGY STAR specification (EPA 2013a).

2.4.1 On Mode

The power mode in which the product has been activated, and is providing one or more of its principal functions. The common terms, "active," "in-use," and "normal operation" also describe this mode. The power in this mode is typically greater than the power in sleep and off modes.

2.4.2 Sleep Mode

The power mode the product enters after receiving a signal from a connected device or an internal stimulus. The product may also enter this mode by virtue of a signal produced by user input. The product must wake on receiving a signal from a connected device, a network, a remote control, and/or an internal stimulus. While the product is in this mode, it is not producing a visible picture, with the possible exception of user-oriented or protective functions such as product information or status displays, or sensor-based functions.

- Note: Examples of internal stimuli are a timer or occupancy sensor.
- Note: A power control is not an example of user input.

2.4.3 Off Mode

The power mode in which the product is connected to a power source, and is not providing any On Mode or Sleep Mode functions. This mode may persist for an indefinite time. The product may only exit this mode by direct user actuation of a power switch or control. Some products may not have this mode.

2.5 What is the typical usage profile (duty cycle)?

Since these residential and commercial segments have very different operating hours, is it necessary to segregate their duty cycles. Both residential and commercial duty cycles are shown in Table 2.1 below. The residential duty cycle is derived from an industry study (Fraunhofer 2011). The commercial duty cycle is derived from another study (Navigant 2009). There are a number of different studies that look at duty cycles for computer monitors, but the two noted here provide the most recent and robust results.

Table 2.1 Duty Cycle for Computer Monitors by Sector

Sector	On (hrs/day)	Sleep (hrs/day)	Off (hrs/day)
Residential	6.4	9.9	7.7
Commercial	6.8	11.2	6.0

Sources: Fraunhofer 2011; Navigant 2009

In order to calculate the operating hours per year for computer monitors in commercial setting, we needed to estimate the number of work days in the year. If we assume an average of five workdays a week and account for 20 day of paid time off (10 days of vacation/sick time and 10 holidays), the average worker is at work 240 days annually. We assume the computer monitor would be off the 125 days a worker is not in the office. The average annual operating hours for computer monitors, by mode, in both residential and commercial settings are displayed below in Table 2.2. As usage patterns differ depending on the application, we determined a shipment-weighted average of total hours a year in each mode based on the 2012 shipments by sector to U.S. and Canada.

Table 2.2 Calculated Annual Hours in Power Mode for Computer Monitors by Sector

	On (hrs/yr)	Sleep (hrs/yr)	Off (hrs/yr)
Residential	2,336	3,614	2,811
Commercial	1,632	2,688	4,440
Shipment-Weighted Averages	1,939	2,983	3,838

2.6 What are the typical factory default settings (e.g. power management, brightness, refresh rate, etc.)?

A majority of the models available on the market today meet the currently effective Version 5.1 ENERGY STAR specification (further discussion in Section 8 below). Power management requirements under the Version 5.1 specification state the following:

- Products shall offer at least one power management feature that is enabled by default, and that can be used to automatically transition from On Mode to Sleep Mode or Off Mode (e.g., support for VESA Display Power Management Signaling [DPMS], enabled by default).
- Products that generate content for display from one or more internal sources shall have a sensor or timer enabled by default to automatically engage Sleep or Off Mode.

EPA updated power management requirements in the Version 6.0 specification to also include the following:

- For products that have an internal default delay time after which the product transitions from On Mode to Sleep Mode or Off Mode, the delay time shall be reported.

- Computer monitors shall automatically enter Sleep Mode or Off Mode within 15 minutes of being disconnected from a host computer.

2.7 What is the maximum and minimum power draw during active mode across various display sizes?

2.7.1 Computer Monitor On Mode Dataset – Overall

Combining the products listed on the ENERGY STAR QPL (EPA 2013c) and including the products data used in the development of the Version 6.0 specification development process (EPA 2012a), the overall dataset of computer monitors between 0 and 350 inches-squared is displayed in Figure 2.1.

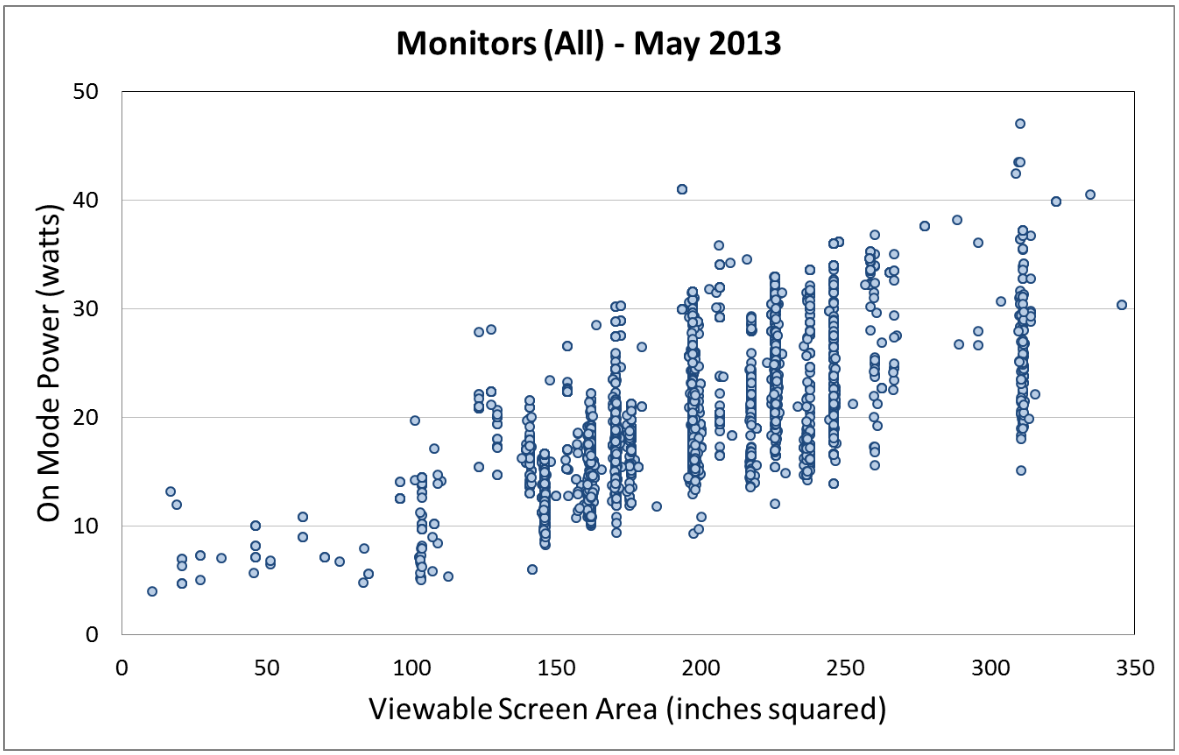

Figure 2.1 Computer Monitor On Mode Power Consumption: 0-350 in-sq

Figure 2.1 shows wide variation in the on mode power consumption among screen sizes. To examine this spread in on mode across similar screen sizes, box plots were developed for the dataset and shown in Figure 2.2. The box plots display the maximum, third quartile, median, first quartile, and minimum on mode power consumption values for some popular screen size categories. Table 2.3 lists the numeric values for these box plots as well as the mean and number of products for each screen size category. For each screen size, there are wide ranges in on mode power consumption for each size category. Energy conservation standards could potentially remove the lowest-performing (in regards to power consumption) products within a size category from the market, while still ensuring a large selection of models that perform the same utility.

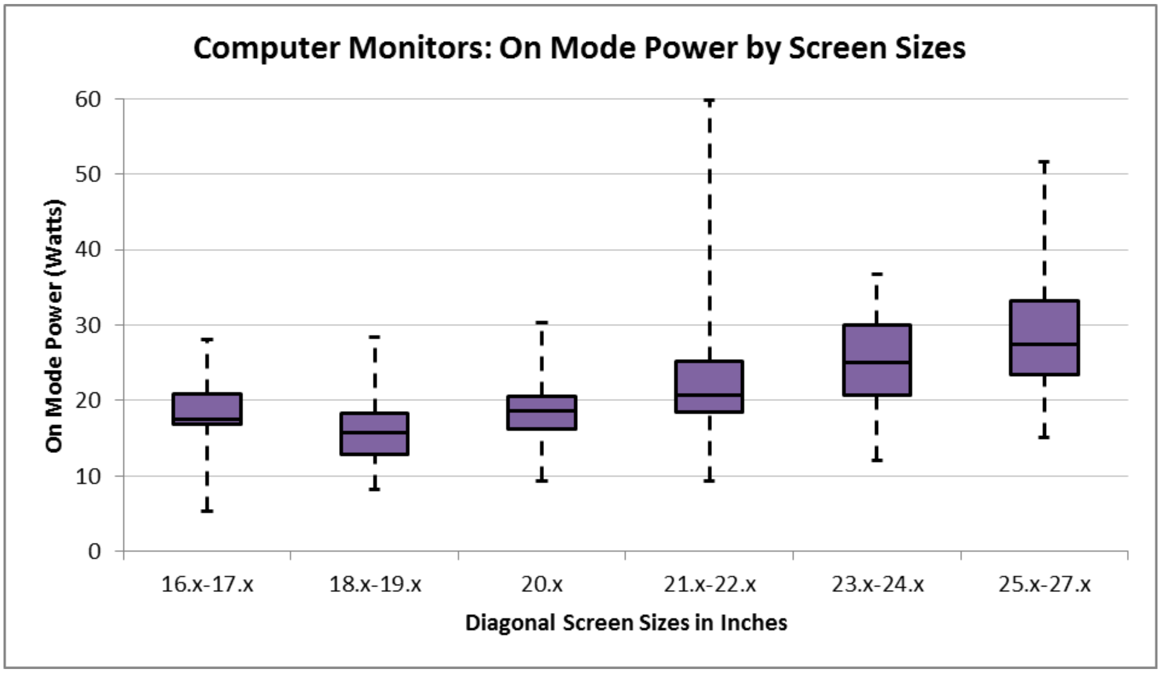

Figure 2.2 Computer Monitor On Mode Power Consumption Box Plots

Table 2.3 Computer Monitor On Mode Power Consumption Box Plot Values

On Mode Power Box Plots						
Screen Size Bins:	16.x-17.x	18.x-19.x	20.x	21.x-22.x	23.x-24.x	25.x-27.x
Minimum	5.3	8.2	9.4	9.3	12.1	15.1
First Quartile	16.8	12.8	16.3	18.5	20.7	23.5
Median	17.5	15.8	18.7	20.8	25.0	27.5
Third Quartile	20.9	18.3	20.5	25.2	30.0	33.2
Maximum	28.1	28.5	30.3	59.9	36.8	51.7
Mean	18.1	15.8	18.8	22.0	25.3	28.6
Count	162	840	367	876	899	174

2.7.2 Computer Monitor On Mode Dataset – CCFL Backlight

Figure 2.3 show the on mode power consumption of those models reported to use CCFL backlighting. The spread in on mode power does not seem to be as wide for this subset of monitors.

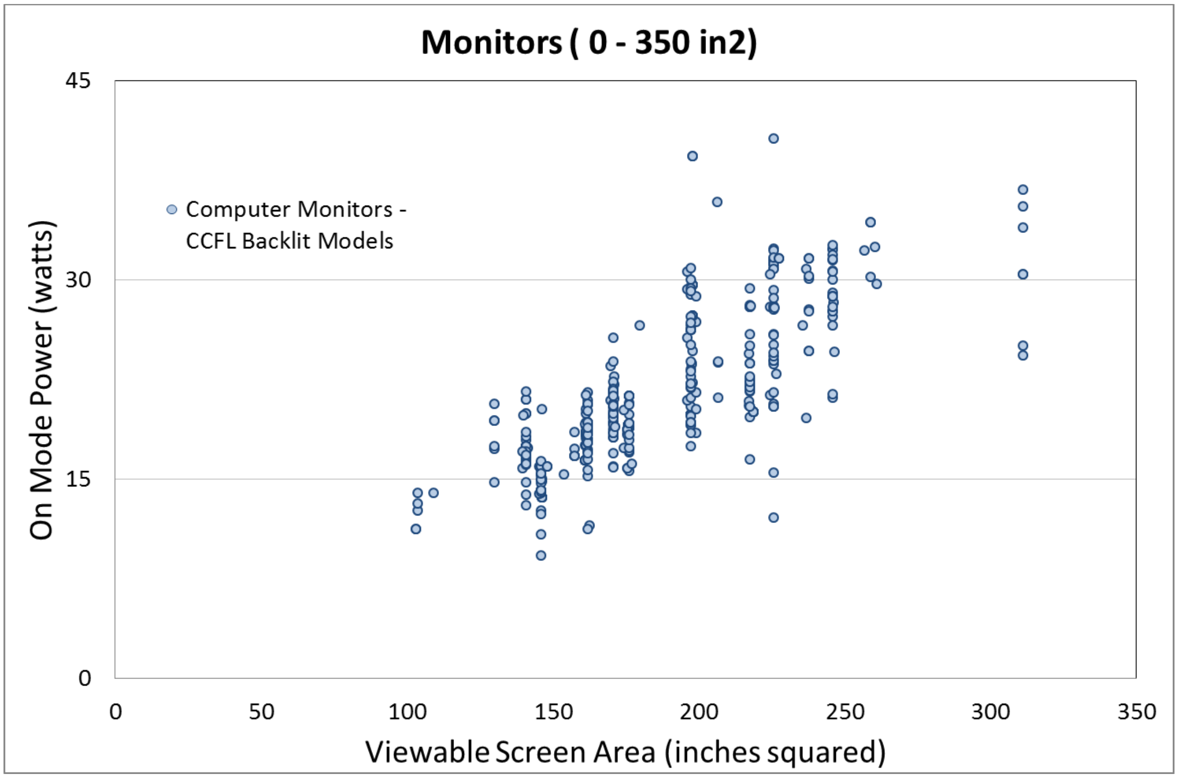

Figure 2.3 Computer Monitor On Mode Power Consumption: CCFL Backlighting

2.7.3 Computer Monitor On Mode Dataset – LED Backlight

Figure 2.4 show the on mode power consumption of those models reported to use LED backlighting. The spread in on mode power for LED units appears to be wider that CCFL monitors. Further discussion on features that can affect the power draw of a monitor, beyond just backlighting, is provided in Section 4.

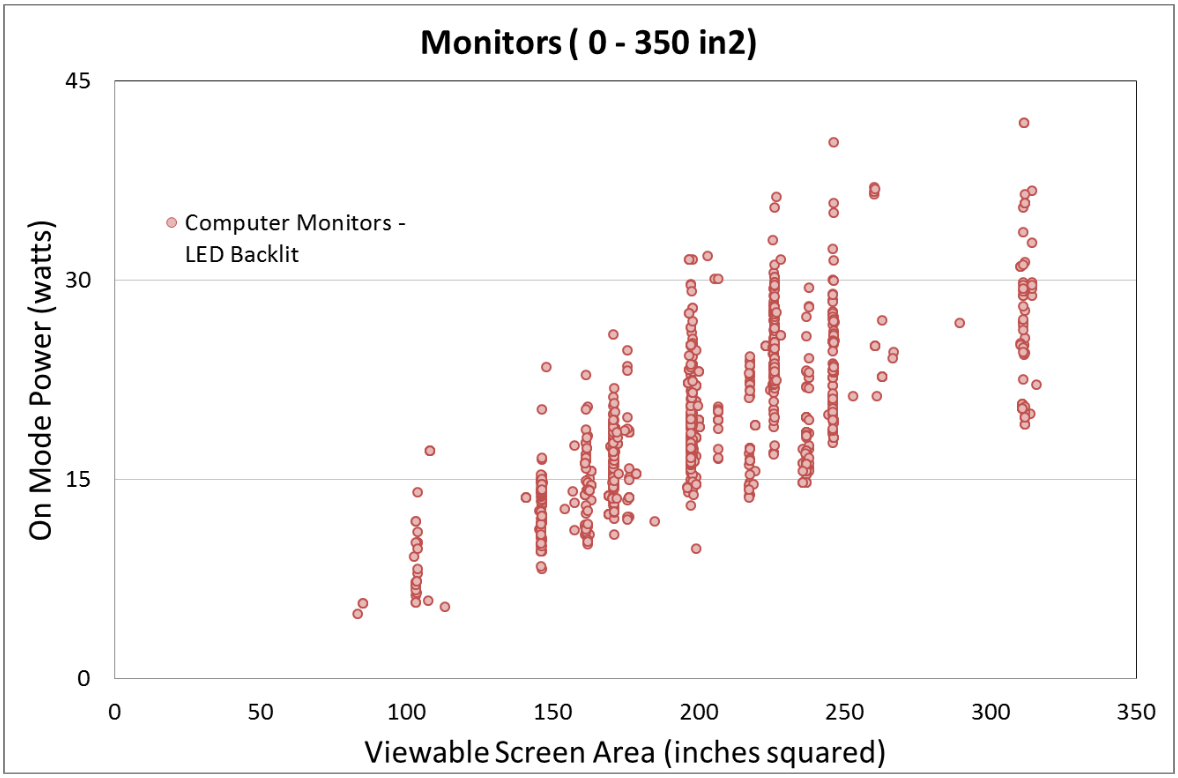

Figure 2.4 Computer Monitor On Mode Power Consumption: LED Backlighting

2.8 What is the maximum and minimum sleep/standby mode power draw?

To examine this spread in sleep mode across similar screen sizes, box plots were developed for the dataset and shown in Figure 2.5. As with the on mode box plots, the sleep mode box plots display the maximum, third quartile, median, first quartile, and minimum sleep mode power consumption values for some popular screen size categories. Table 2.4 lists the numeric values for these box plots as well as the mean and number of products for each screen size category. For each screen size, there are relatively narrow ranges in sleep mode power consumption.

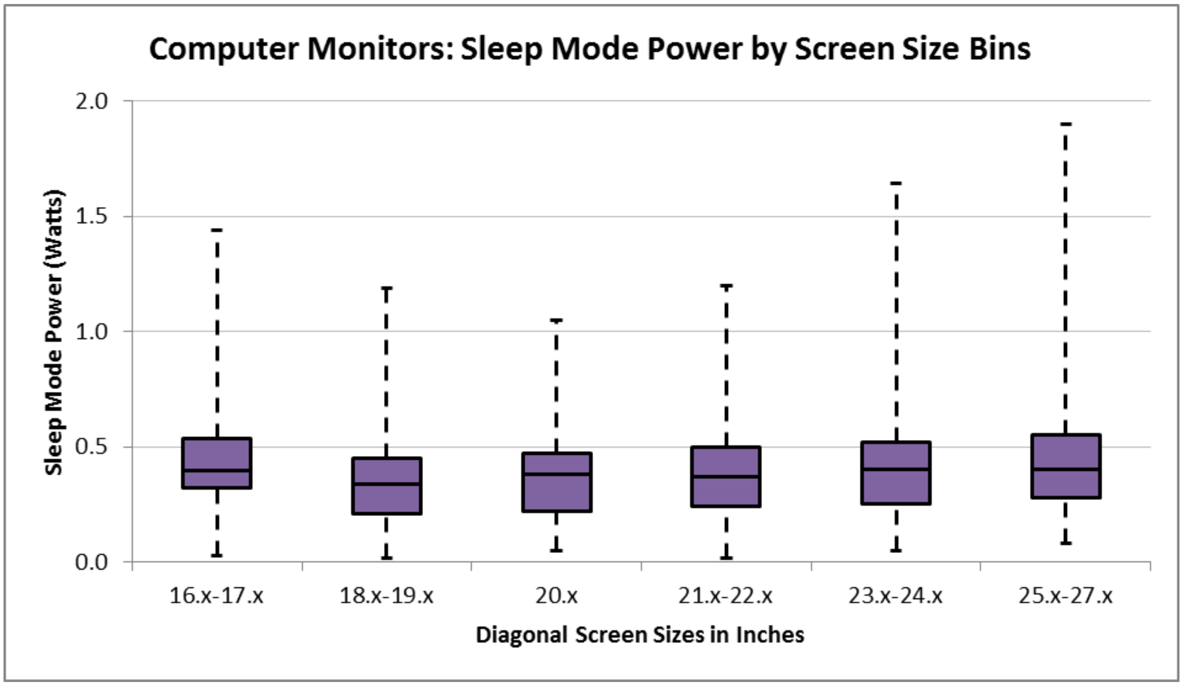

Figure 2.5 Computer Monitor Sleep Mode Power Consumption Box Plots

Table 2.4 Computer Monitor Sleep Mode Power Consumption Box Plot Values

Sleep Mode Power Box Plots						
Screen Size Bins:	16.x-17.x	18.x-19.x	20.x	21.x-22.x	23.x-24.x	25.x-27.x
Minimum	0.0	0.0	0.1	0.0	0.1	0.1
First Quartile	0.3	0.2	0.2	0.2	0.3	0.3
Median	0.4	0.3	0.4	0.4	0.4	0.4
Third Quartile	0.5	0.5	0.5	0.5	0.5	0.6
Maximum	1.4	1.2	1.1	1.2	1.6	1.9
Mean	0.4	0.3	0.4	0.4	0.4	0.4
Count	116	709	324	752	782	152

2.9 What is the maximum and minimum power draw with no input data signal (i.e., when the computer is off but the monitor is on)?

We would expect the power draw to be similar to the power draw in when the monitor is in a sleep state. However, the preliminary results of some of the testing we have done show, shown in Table 2.5, there are some computer monitors with large power draws when the monitor is on but there is no input signal from a source or the source is in a sleep state. This is most likely due to the fact that for those monitors the backlight remained on to display a message on the screen that there was no input signal.

Table 2.5 Computer Monitor Power Testing: Source Signal and Low Power Modes

Monitor	Port	Power after disconnecting source (W)	Power with source in sleep (W)	Power of monitor in sleep (W)
19" CCFL-LCD 1	VGA	19.1	0.3	0.2
19" LED-LCD 2	VGA	0.2	0.2	0.1
19" LED-LCD 3	DisplayPort	0.3	1.3	0.3
22" LED-LCD 1	DVI	0.3	0.3	0.2
22" LED-LCD 2	VGA	0.2	0.2	0.1
22" LED-LCD 3	DVI	0.3	0.3	0.2
25" OLED (professional monitor)	HDMI	44.6	42.0	0.5
27" LED-LCD 1	DisplayPort	0.3	0.3	0.3
27" LED-LCD 2	HDMI	0.3	0.3	0.2
27" CCFL-LCD 3	DisplayPort	79.6	1.4	0.7

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2.10 Do power management (e.g. auto power down) operations change depending on connection type (e.g. DVI, HDMI, etc.)? If so, how?

We do not expect large differences in power management operations depending on connection type. However, we do not have any test data to confirm this.

3 Energy Consuming Features

3.1 What built-in energy consuming features are typically included in displays (e.g. cameras, USB charging ports, speakers, etc.)?

For the computer monitors we tested, we found the following features that potentially add to the energy consumption of the unit.

- High Resolution
- USB charging port (power draw when charging a device)
- Touch screen (enabled through a USB port)
- Additional ports (HDMI, USB, DisplayPort, etc.)

Although not found in the units we tested, we would expect to find the following features in other units could increase a computer monitor's energy consumption.

- Camera/microphone – With increased remote working environments, it is possible that many more monitors will include a built-in camera and microphone. This option is currently available at a comparable price to standard monitors (Amazon 2013).
- Integrated speakers.
- 3D.
- Ambient backlighting (Engadget 2013).

3.2 How much energy does each feature use?

Through our testing, the following preliminary power draw values were observed for certain energy-consuming features.

3.2.1 High Resolution

Comparing the power draw of two 27" LCD monitors, a 2.07 megapixels (1920 pixels by 1080 pixels) panel and the other with a 3.69 megapixels (2560 pixels by 1440 pixels) panel, we found a more than 50% increase in plug load after normalizing for other components. An increase in pixels results in increased power draw from various components including:

- Backlight unit (BLU) – More pixels mean more blocking of light by the thin-film transistors (TFTs) which supply power to sub pixels. Therefore, in order to pass through the same amount of light as a panel of the same size with fewer pixels, a higher resolution monitor will need more light output from its BLU.

- LCD controller - Extra power is needed secondarily in the LCD panel to control extra pixels.

- Signal processing - A small amount of extra power is needed for extra signal processing on the monitor's main board.

3.2.2 USB Charging Port - Power draw when charging a device

For two monitors with USB charging capability, we used a dummy load (fixed resistor) of 2.25 watts to represent a charging device. The resulting plug load impact was around 3 watts and shown in Table 3.1.

Table 3.1 USB Charging Power Draw

Monitor	Plug Load Power Draw	Plug Load Power Draw with 2.25W Charging Load
27" LED-LCD	22.4W	25.3W
22" LED-LCD	19.6W	22.8W

3.2.3 Touch screen (enabled through a USB port).

We measured the incremental power draw of enabling the optical touch screen system of a 22” LED-LCD monitor. The resulting plug load impact was approximately 1 watt. There was no measureable impact on panel transmissivity, meaning that this feature is not expected to require an increase in backlight output.

3.3 How much does each cost the manufacturer to include on a per-unit basis?

Most feature costs are not included in any market cost data reports which we relied on for our analysis.

3.4 How common are they?

Monitors with these features are readily available in the current marketplace. At this time, we do not have comprehensive information to provide to CEC.

4 Energy Saving Features and Technologies

4.1 What energy saving technologies or features are currently included in displays?

For the computer monitors we tested, we found the following currently-available technologies and features that have the potential to reduce energy consumption.

- Backlighting – Switching from cold-cathode fluorescent lamps (CCFLs) to more efficient LEDs to backlight LCD monitors decreases energy use. The efficiency of LED backlight units is itself also expected to improve as a result of developments in advanced LED structure, phosphors, thermal management, and beam angles.
- Reducing number of backlight lamps – manufacturers can reduced the total number of CCFL lamps used in backlighting CCFL monitors thereby reducing the unit’s power consumption.
- Reflective polarizer – Using a reflective polarizer in a film stack is a low cost means to recycle improperly polarized light rather than letting it be lost as absorbed heat. This improvement increases LCD transmissivity which enables the use of a less powerful backlight unit (BLU).
- Highly efficient power supply – As power supply efficiency increases for a given load, the power draw of the plug load decreases.
- High LCD panel transmissivity – LCD transmissivity is the ratio of screen-normal light measured out the front of the LCD panel to the screen-normal light measured out the front of the film stack. LCD panels typically block more than 90% of light coming from the BLU, making small improvements in panel transmissivity significant to overall monitor efficiency improvements.
- Auto power down (APD) – Some monitors will sense through its connection with its video source that the video source is no longer transmitting. Typically, this brings the monitor into a very low power state.

- "Eco" setting – Many monitors include an "Eco" or other energy saving mode setting accessible via a picture settings menu. This will decrease the overall energy use of the monitor, usually through lowering the brightness of the backlight.
- Automatic brightness control (ABC) – A technology used to adjust display brightness to room illumination. Lower room lighting results in decreased display brightness, decreasing energy use.
- Backlight dimming – There are two types of backlight dimming possible with displays, global dimming and local dimming. With global dimming, the entire BLU is at the same brightness, but can be dimmed to the level required by the brightest pixel being displayed at that point in time. Local dimming can result in greater energy savings by dimming individual zones of the backlight.
- Occupancy sensor – This feature allows the monitor to enter a low power state if it does not detect a user within a given time period.

4.2 How much energy does each save?

Through testing, we found the following preliminary power savings for the above features and technologies.

4.2.1 LED Backlighting

In addition to switching from cold-cathode fluorescent lamps (CCFLs) to more efficient LEDs to backlight LCD monitors, there are a range of LED lamp efficacies (measured in lumens per watt) currently utilized (see Table 4.1).

Table 4.1 LED Backlight Efficacy

Monitor	LED efficacy (lm/W)
19" LED-LCD 2	69
22" LED-LCD 1	107
22" LED-LCD 2	104
27" LED-LCD 1	86
27" LED-LCD 1	107

This data represents a 55% difference in efficacy from the least efficient to the most efficient lamps. Given that a monitor's backlight unit (BLU) typically accounts for about 50% of its power budget, lamp selection will have a significant impact on monitor energy use.

4.2.2 Reflective Polarizer

Through detailed teardown and measurement tests, we found different approaches to the use of optical films in monitors. When we theoretically added a reflective polarizer to an already efficient model, it increased overall efficiency by 23%.

4.2.3 Highly Efficient Power Supply

When we theoretically replaced the existing power supply (measured to be 80% efficient) of an already efficient monitor with an 85% efficient power supply, it increased overall efficiency by nearly 6%.

4.2.4 High LCD panel transmissivity

In the comparison of two 22" LED-LCD monitors, one model, which uses in-plane switching (IPS) panel technology, transmitted over 50% more light than the other model, which uses twisted nematic (TN) panel technology.

4.2.5 Auto power down (APD)

Of the units we tested, 6 of the 10 units incorporated some sort of power down capability.

4.2.6 "Eco" setting

Of the units we tested, 6 of the 10 units included an energy saving mode which decreased power draw by an average of 32%.

Table 4.2 Energy Saving Setting Power Draw

Monitor	Default Setting (W)	Energy Saving Setting (W)	% Energy Savings
19" LED-LCD 1	19.21	14.48	25%
19" LED-LCD 3	20.85	14.01	33%
22" LED-LCD 1	28.42	17.23	39%
22" LED-LCD 3	17.08	12.06	29%
27" LED-LCD 1	38.56	27.91	28%
27" LED-LCD 2	21.77	12.88	41%

4.2.7 Automatic brightness control (ABC)

Of the units we tested, one of the 10 monitors utilized ABC. With a room illuminance of 10 lux measured at the display's ABC sensor, a 50% power reduction was realized with ABC activated.

4.2.8 Backlight dimming

Instantaneous power measured using the IEC video test clip shows how power of the backlight and other components scales to the content displayed. **Error! Reference source not found.** shows a power log in default mode with the video clip. Figure 4.2 shows a power log in backlight dimming mode with the video clip. In its default mode, the backlight unit was constant; it did not scale power to picture content. In its backlight dimming mode, however, backlight power scaled to average picture level of the test clip, reducing power by 35%.

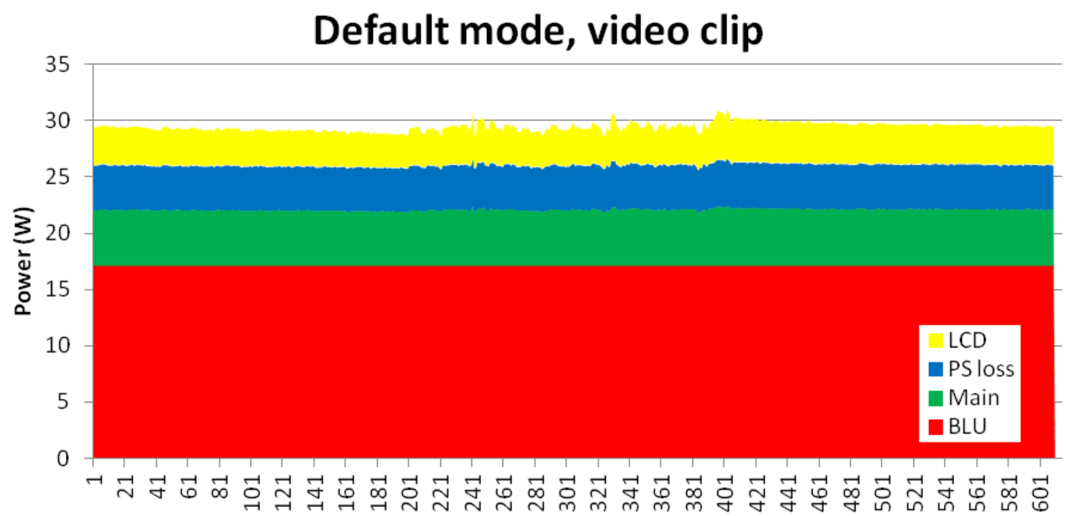

Figure 4.1 Default Mode Power Log

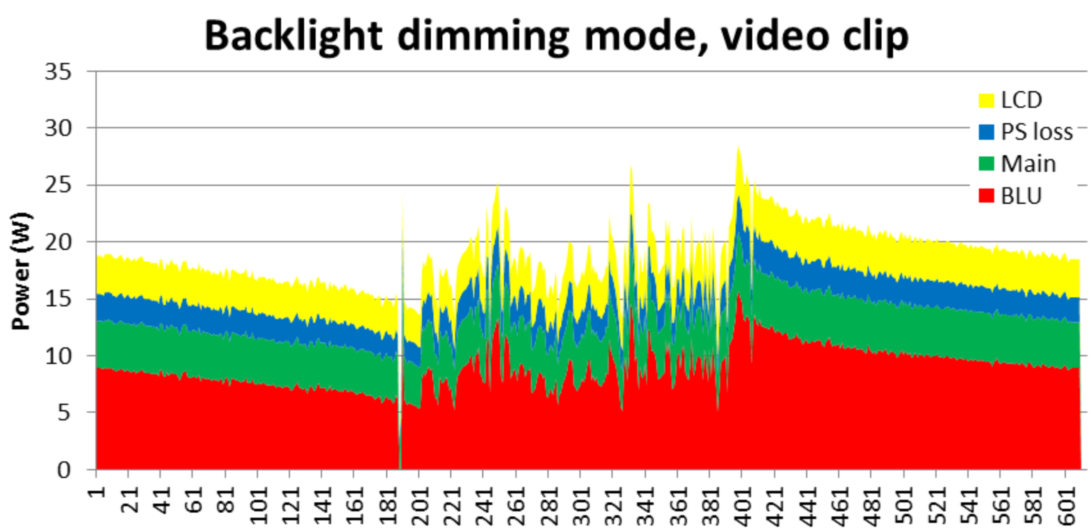

Figure 4.2. Dimming Mode Power Log

4.2.9 Occupancy sensor

This optional feature was found in one of the 10 units tested. The sensor could be set to either a backlight dimming state or a backlight off state after a user specified amount of time. The resulting power draw savings were 71% and 95% respectively.

4.3 How much does each cost the manufacturer to implement on a per-product basis?

We are currently conducting a cost-analysis that would provide answers on the cost to implement some of the features on a per product basis. We should have more information to share in the coming weeks.

4.4 How common are they?

Monitors with these features are readily available in the current marketplace. We have noted the prevalence of these features in the computer monitors we tested. At this time, we do not have comprehensive market information to provide to CEC.

Regarding ABC, based on the ENERGY STAR Qualified Products List, over 130 different models ship with ABC enabled by default. We would expect many more models to have ABC as an optional feature and is not enabled by default.

4.5 Which energy saving technologies or features could potentially be incorporated in displays?

Technologies or features that could be incorporated into displays, or more widely implemented, may include the following:

- More widespread implementation of ABC, backlight dimming, and occupancy sensors.
- Organic light emitting diode (OLED) display technology.
- Quantum dots (DigiTimes 2013).
- Higher LCD panel transmissivity.

4.6 How much energy does each save?

4.6.1 Widespread implementation of ABC, backlight dimming and occupancy sensors.

Through our online market research and review of recent ENERGY STAR qualified product lists, we have found only very limited implementation of these energy savings features. As noted in the above responses, we were able to test for power draw savings and found significant energy savings potential.

4.6.2 Organic light emitting diode (OLED) display technology.

Because they do not require a backlight or filters, OLED displays theoretically have the potential to use less energy than LCD displays. Our testing of an available 25" OLED monitor showed much higher average plug load power draw than the highly efficient 27" LED-LCD tested (58W vs. 22W). This was expected as the OLED display was an early generation model, not the product of a mature and efficient manufacturing process such as that of the 27" LED-LCD. In addition, the

OLED display was designed for professional editing usage, incorporating fans and other heat protecting features to account for a duty cycle with greater time spent in active mode.

To account for these differences, we compared component level measurements between the two monitors and estimated the power draw of an OLED with more efficient processing and display controls that would be in line with a more mass produced product that is also designed for a more typical consumer duty cycle. This results in a modeled OLED display that uses 2-3 more watts than the LED-LCD display. With future improvements in the manufacturing process and OLED lighting efficiency, it is possible OLED displays will achieve the theoretical energy use advantage over LCDs.

4.6.3 Quantum dots

Quantum dots are very tiny particles that can emit light at very specific wavelengths. Used in conjunction with an LCD panel's color filter, they can theoretically produce red, blue and green light more efficiently and with a greater color gamut than current displays (LEDs Magazine 2011). The increased efficiency comes in part from using current (blue light emitting) LEDs without a phosphor coating that creates white light. At least one manufacturer has begun implementing this technology and offered currently by multiple suppliers: QD Vision and 3M (CNET 2013a; QD Vision 2013; 3M 2013).

4.6.4 Higher LCD panel transmissivity

Efficient approaches to reduce backlight demand include:

- *Increasing pixel effective area by reducing the area of thin film transistors (TFTs) that block light (Figure 4.3).* Recently, Sharp has recently introduced its indium gallium zinc oxide (IGZO) thin film transistor (TFT) technology which takes up less space than traditional amorphous silica TFTs. In addition, this technology reportedly saves energy through the reduction of screen refreshes required for still images when compared to amorphous silica TFT technology (CNET 2013b).

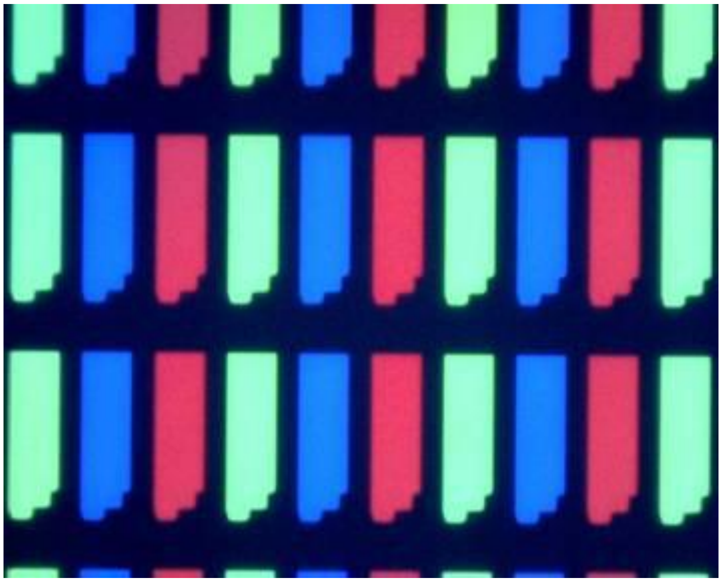

Figure 4.3 Micrograph of a twisted nematic LCD panel, an LCD type that is commonly used in computer monitors[2]

- *Adding additional sub-pixel colors beyond red, green and blue.* In TVs, some manufacturers have implemented yellow or white sub-pixels to create a panel that reportedly transmits light more efficiently (Sharp 2010). We would expect this approach could be adapted for computer monitors as well.
- *Matching LCD technology to content and application***.** As mentioned above, we found an IPS LCD to transmit 50% more light than a TN LCD. However, the measured efficiency of the panel depends on how the panel is tested. IPS panels align liquid crystals to an open position when voltage is applied, while TN panels will remain open until a voltage is applied, blocking light from passing through. So, using a test clip with more dark images than light images (such as the IEC video test clip) provides an advantage to the IPS technology. Additionally, TN panels have a narrower viewing angle which works well for an individual at a workstation, but is less optimal when a monitor is used as a television with multiple viewers. Therefore, matching IPS LCD technology to larger monitors intended for more television type usage (darker images, wider viewing angle) and TN technology to other monitors intended for more traditional computing type usage (white backgrounds, smaller viewing angle) makes sense from an energy standpoint.

4.7 How much does each cost the manufacturer to implement on a per-product basis?

We are currently conducting a cost-analysis and should have more information regarding manufacturer cost to implement to share with CEC in the coming weeks.

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[2] Each green, blue and red block is a subpixel that, when open, lets colored light out of the front of the display. Black areas are TFTs and structural material. The less space occupied by TFTs and structural material, the more light passes through the panel.

5 Control Features

5.1 What features can improve overall display efficiency by changing the duty cycle or lowering the power draw of the equipment (e.g., activity sensor, power management, automatic brightness control)?

Occupancy sensors, power management, and automatic brightness controls features can all potentially lower power draw of displays if implemented properly.

5.2 Please explain how these features save energy.

5.2.1 Occupancy Sensor

An occupancy sensor, which forces the display to go into a lower power mode when no one is in front of the display, is one potential feature that can be more widely adopted and save energy.

5.2.2 Power Management

In general, computer monitors go into sleep mode after a certain time period of user inactivity. Users can fit their preferences using the operating system settings, and the savings from this option depends on computer usage patterns.

5.2.3 Brightness Control

Employing technology to dim the backlight lamps behind the required part of the screen based on dynamically changing pictures on the screen can lead to reducing the backlight electricity consumption. The simplest dimming option is to dim the whole backlight by a universal amount varying by frame, global dimming. Another option is to dim part of the backlight area depending on input image. This can be achieved via: a) one-dimensional, partial, or line dimming, or b) two-dimensional, or local, dimming. However, various dimming strategies are not employed as much with computer monitors (in relation to TVs) because of the typically static nature of the content.

5.2.3.1 Automatic Brightness Control

Starting with the Version 5.0 Displays specification, ENERGY STAR first included a credit for computer monitors which offered an ABC feature enabled by default. EPA recognized the benefits of offering consumers full-featured products, higher luminance settings tend to negate the power consumption reductions achieved through improved component efficiency. ABC technology could offset the effects of these higher default settings by automatically modulating the luminance of displays under variable ambient lighting conditions. In addition to offering significant energy savings, this feature could also improve the user viewing experience. At the time, there was no product data or understanding exactly how the ABC feature was being, but the use of this feature had the *potential* to save energy for consumers *if implemented properly* by reducing the screen brightness automatically in lower light conditions, thereby reducing the power consumption. By including a credit, ENERGY STAR was trying to incentivize the use of ABC.

Based on recent testing conducted by the U.S. Department of Energy (DOE) in support of their televisions test procedure rulemaking, the ABC response on most TVs today does not follow the theoretical ABC response based on room illumination (DOE 2013). In other words, very few tested TVs with the ABC feature showed a gradual response of TV brightness (luminance) due to increasing room brightness (illluminance); therefore, it appears that ABC is not being properly implemented so as to save energy for consumers. Significant power savings can be achieved when the ABC response curve is gradual rather than a binary response. Additionally, DOE testing even showed evidence of the ABC test being "gamed" so as to achieve the greatest credit without regard to actual picture quality.

In recent testing conducted, DOE concluded that ABC sensors may become saturated by non-visible light. This seems to point to a potential flaw in the design of some ABC sensors resulting in the ABC feature to not function correctly and thus not result in energy savings. While all of DOE's testing has focused on ABC sensors on TVs, it can be reasonably concluded, given the overlap of manufacturers and suppliers for both displays and TVs, these problems with ABC implementation apply to computer monitors as well.

5.3 How much do they cost to implement into a display on a per- product basis?

We are currently conducting a cost-analysis and should have more information to share in the coming weeks.

5.4 What impact would proper implementation of these efficiency features have on the energy consumption of displays?

Please refer to some of the preliminary results presented in Section 4.2 above.

5.5 Are consumers receptive to these control features?

Occupancy sensors and power management features are being employed in computer monitors currently manufactured. We assume this is in response to consumer demand for these features.

6 Market Characteristics

The following market information is summarized from a 2012 IHS iSuppli market study.

6.1 What are the annual California shipments for 2009 to 2012 as well as projected for 2013 to 2015 by display category?

Even though desktop computer shipments are projected to stabilize and eventually decrease slightly in the coming years (IDC 2013), global computer monitor shipments are expected to experience continuous growth through 2016 (IHS iSuppli 2012). This growth is largely driven by shipments in China, India, and Russia. Generally, growth is also driven by monitor upgrades, increased adoption of larger screen sizes and higher resolutions, use with notebook computers, and dual or multiple

monitor use. However, due to a variety of economic factors in the United States, computer monitor shipments in California are expected to decline slightly. Pressure to reduce deficit spending in 2013 result in reduced government and education spending in the U.S. while the private sector purchasing is expected to accelerate in 2013 (IHS iSuppli 2012).
Error! Reference source not found. shows annual computer monitor shipments in California from 2011 to 2016. Shipments in California to the business sector typically have been and are expected to be between 60 to 70% of overall shipments between 2011 and 2016. Numbers for this figure were calculated using national numbers from the IHS iSuppli market report (IHS iSuppli 2012) and assuming the stock in California was 13 percent of the overall U.S. stock. This percentage is the same percentage of California's share of the total U.S. gross domestic product (GDP).

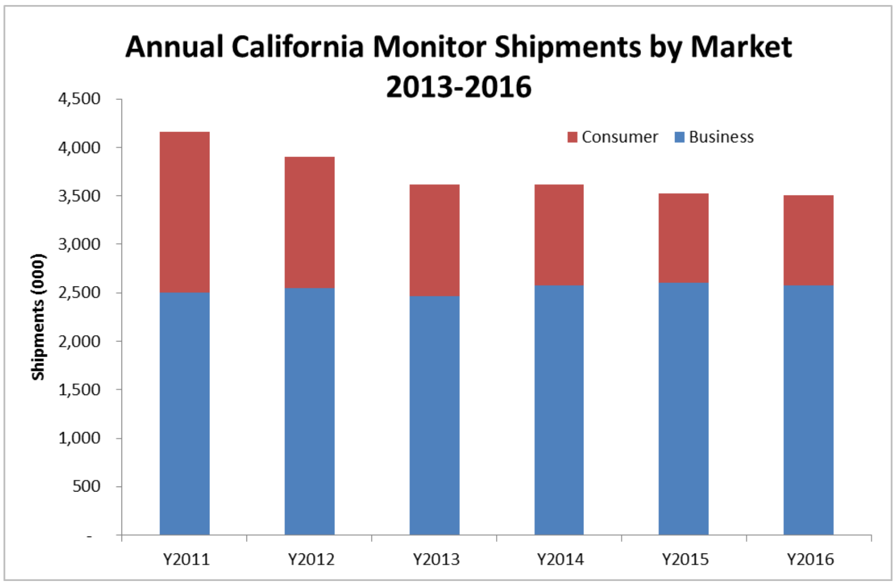

Figure 6.1 Annual California Monitor Shipments by Market
Source: Calculations based from shipment data from IHS iSuppli 2012

6.2 What are the typical sizes in the market for each display category?

Figure 1. and 1.3 above show computer monitor shipment trends in the U.S. between 2011 and 2016 by screen sizes for business and consumer sectors. For other product categories, please refer to the ENERGY STAR QPL for typical sizes (EPA 2013c).

6.3 What percent of shipments in each display category has automatic brightness adjustment controls?

Regarding ABC, based on the ENERGY STAR Qualified Products List, over 130 different models ship with ABC enabled by default (EPA 2013c). We would expect many more models to have ABC as an optional feature and is not enabled by default. However, we do not have comprehensive market information to cite here.

6.4 What percent of shipments in each category has an easily accessible off switch that reduces power draw to zero?

At this time, we do not have comprehensive information to provide to CEC, though a number of the monitors we tested had an easily accessible off switch that reduced the power draw to near zero.

6.5 What is the percent of shipments in the market across the typical sizes and resolutions for each display category?

Please refer to our responses in Section 1 above regarding shipment trends.

6.6 What is the percent of shipments by backlight technology (e.g. CCFL, LED [edge & array], OLED or other)?

Please refer to our responses in Section 1 above regarding shipment trends. Regarding LED backlit computer monitors, we do not have comprehensive market information on the LEDs are set-up in the BLU.

6.7 How many small businesses are involved in the manufacture, sale, or installation of these products?

At this time, we do not have comprehensive information to provide to CEC.

7 Installed Base Characteristics

7.1 What is the current California installed base for displays by category?

The current installed stock and energy use of computer monitors in California is outlined in the following Table 7.1 for both residential and commercial applications and based from two industry studies looking at the residential and commercial sectors nationwide (Fraunhofer 2011; TIAX 2010). Numbers for this table were calculated using national numbers and assuming the stock in California was 13 percent of the national stock. This percentage is the same percentage of California's share of the total U.S. gross domestic product (GDP). Regarding energy use, we have previously conservatively estimated total annual energy consumption for computer monitors in California to be around 2,000 Gigawatt-hours per year. Based on two nationwide energy consumption field studies (TIAX 2010; Fraunhofer 2011), total annual energy consumption for computer monitors in California could be as high as 5,000 Gigawatt-hours per year.

Table 7.1 Total Stock and Energy Use in California by Sector – Computer Monitors

Sector	Total Stock (000)	Total Energy Use (GWh/yr)
Residential	17,030	1,650
Commercial	20,800	3,510
Total	37,830	5,160

Sources: Fraunhofer 2011; TIAX 2010

7.2 What are the typical sizes in the installed base for each display category?

The installed stock of computer monitors in California by size category in 2015 is outlined in the following Table 7.2. Numbers for this table were calculated adding the annual U.S. shipments from 2011 through 2014 (IHS iSuppli 2012). California shipments were determined by assuming the stock was 13 percent of the national stock. This percentage is the same percentage of California's share of the total U.S. gross domestic product (GDP).

Table 7.2 Installed Base in California by Size Bin in 2015 – Computer Monitors

Size Bin	Installed Base (000)	Percentage
<=15-inch	146	<1%
16.x-17.x-inch	1,811	5%
18.x-19.x-inch	7,566	23%
20.x-inch	5,059	15%
21.x-22.x-inch	8,367	25%
23.x-24.x-inch	8,129	24%
25.x-27.x-inch	2,124	6%
28.x-30.x-inch	134	<1%
Total	33,336	

Source: IHS iSuppli 2012

7.3 What percentage of the installed base do these typical sizes account for by display category?

Please refer to Table 7.2 for information on percentage of each size bin over the total installed base for computer monitors.

8 Other

8.1 What are the current market drivers initiating the improvement of display efficiency?

The primary driver regarding efficiency of displays is the ENERGY STAR program. In addition to the ENERGY STAR specification that is designed to identify the top 25% of energy efficient products within a product category, ENERGY STAR also recently launched a Most Efficient categorization for computer monitors. ENERGY STAR Most Efficient is a new program element to identify and advance highly efficient products in the marketplace. This effort identifies the most efficient products among those that qualify for the ENERGY STAR in particular product categories. Recognition criteria were established to ensure that products that receive this recognition demonstrate efficiency performance that is truly exceptional, inspirational, or leading edge consistent with the interests of environmentally-motivated consumers and early adopters (EPA 2013d).

8.2 How are consumers identifying the most efficient products on the market?

ENERGY STAR and ENERGY STAR Most Efficient are the two primary distinctions consumers are identifying the most efficient computer monitors on the market today. EPEAT® is another distinction that helps purchasers identify, among many other attributes, efficient computer monitors (EPEAT 2013).

8.3 What is the market share of displays that meet ENERGY STAR 5 and 6 criteria?

Figure 8.1 shows that in 2010, the first full year of the ENERGY STAR Version 5 specification, the market penetration of models that met the Version 5 specification was 43%. In 2011, the second full year of the Version 5 specification, the market penetration jumped up to 85% (EPA 2011; EPA 2012b). All major manufacturers are ENERGY STAR partners, so we estimate ENERGY STAR partners cover the whole market of computer monitors sold in the U.S. It is important to note that the response rate from manufacturers was 93% and 89% for 2010 and 2011, respectively. Therefore, the ENERGY STAR market penetration information is not reflective of the entire market. However, based on observations of available products, we expect these market penetration estimates to be a reasonable estimate.

In 2013, we assume that approximately 90% of models shipped meet ENERGY STAR 5. Given a historically rapid uptake of ENERGY STAR specification requirements and the number of qualifying models that meet the Version 6 requirements, we would expect an uptake in the first year of the Version 6 specification similar to when Version 5 was introduced, or approximately 40%. The Version 6 specification will take effect on June 1, 2013.

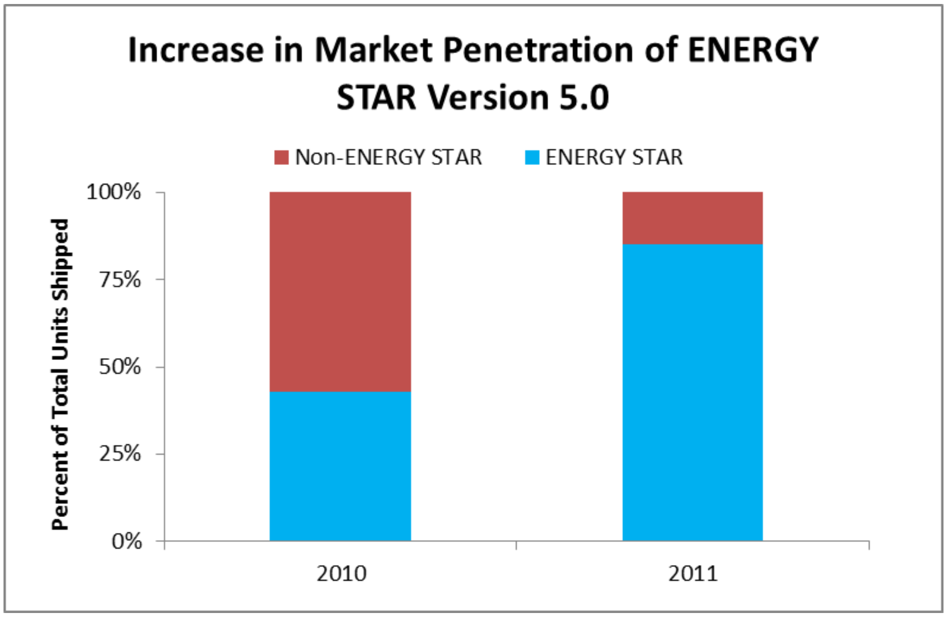

Figure 8.1 Market Penetration of ENERGY STAR Version 5 Specification
Source: 2012 ENRGY STAR

While ENERGY STAR has been effective in moving the market towards improved efficiency, there still remains significant variability in on mode power draw for monitors that provide similar utility (see Section 2 figures).

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(References attached separately are highlighted in grey)

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