Efficiency Improvement Opportunities in PC Monitors: Implications for Market Transformation Programs

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Executive Summary

This report presents the results of an analysis, commissioned by the U.S. Department of Energy, of personal computer (PC) monitors efficiency in support of the Super-efficient Equipment and Appliance Deployment (SEAD) initiative.[1] SEAD aims to transform the global market by increasing the penetration of highly efficient equipment and appliances. The objective of this analysis is to provide the background technical information necessary to improve the efficiency of PC monitors and to provide a foundation for the voluntary activities of SEAD participating countries.

We assess the market trends in the energy efficiency of PC monitors that are likely to occur without any additional policy intervention and estimate that PC monitor efficiency will likely improve by over 40% by 2015 with saving potential of 4.5 terawatt-hours [TWh] per year in 2015, compared to today's technology. We discuss various energy-efficiency improvement options and evaluate the cost effectiveness of three of them, at least one of which improves efficiency by at least 20% cost effectively beyond the ongoing market trends. We assess the potential for further improving efficiency taking into account the recent development of universal serial bus (USB) powered liquid crystal display (LCD) monitors and find that the current technology available and deployed in them has the potential to deeply and cost effectively reduce energy consumption by as much as 50%. We provide insights for policies and programs that can be used to accelerate the adoption of efficient technologies to further capture global energy saving potential from PC monitors which we estimate to be 9.2 TWh per year in 2015.

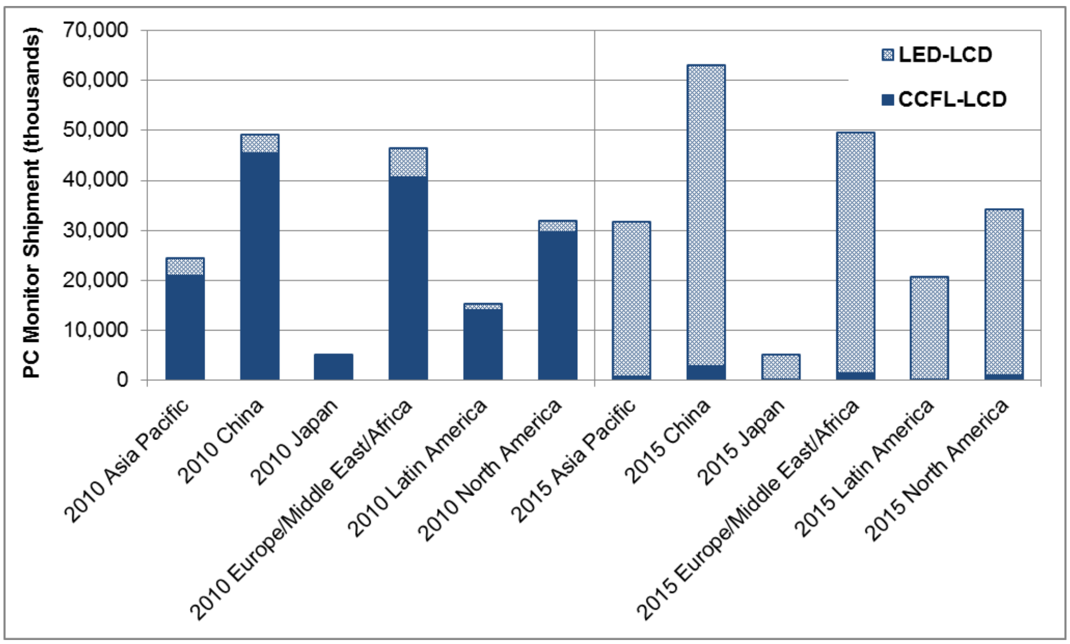
Motivation for this Study

The total global electricity consumption of personal computer (PC) and monitor stocks, including notebook computers, in the residential sector was estimated to be about 140 terrawatt hours [TWh] in 2008, and of the electricity consumption, monitors are estimated to account for 30-40 TWh (IEA 2009). Among the key components of a PC system, displays (i.e., monitors) are responsible for a significant portion of energy

[1] As one of the initiatives in the Global Energy Efficiency Challenge, SEAD seeks to enable high-level global action by informing the Clean Energy Ministerial dialogue. In keeping with its goal of achieving global energy savings through efficiency, SEAD was approved as a task within the International Partnership for Energy Efficiency Cooperation (IPEEC) in January 2010. As of April 2011, the governments participating in SEAD are: Australia, Brazil, Canada, the European Commission, France, Germany, India, Japan, Korea, Mexico, Russia, South Africa, Sweden, the United Arab Emirates, the United Kingdom, and the United States. More information on SEAD is available from its website at http://www.superefficient.org/.

consumption in a PC system, accounting for 15-35% of the system's consumption (IEA 2009, Delforge 2011, Horowitz 2011). The wide range of estimates for the share of PC energy consumption attributable to monitors is because average unit energy consumption (UEC) of a PC varies highly with the system specifications and power management scheme applied to the system.

An assessment of efficiency improvement opportunities for Pc monitors is needed for three reasons - *first*, to correct market failures such as uncaptured economic and environmental benefits available from PC monitor energy consumption reduction through cost-effective[2] efficiency improvements, and s*econd,* to account for the ongoing large scale transition from cold cathode fluorescent lamp (CCFL) backlit liquid crystal display (CCFL-LCD) monitors to light emitting diode (LED) backlit LCD (LED-LCD) monitors in designing market transformation programs such as standards, labels or incentives in a timely manner. LED-LCD monitors are likely to be at least 50% and 90% of the PC monitor shipments in 2012 and 2015 respectively (DisplaySearch 2011a). *Third,* information and communications technology (ICT) appliances such as PCs, laptops and monitors are internationally traded, used in a similar manner globally and subject to internationally recognized energy efficiency specifications such as ENERGY STAR (Waide 2011). Hence the results of this analysis are likely to be applicable in several countries.



Source: DisplaySearch, 2011a

Figure 1. Actual (2010) and Forecasted (2015) Shipments Showing Market Transition by Region and Screen Technology

Objective and Scope

The objective of this analysis is to identify potential PC monitor efficiency improvements and their incremental costs, as well as to provide initial global and country-specific estimates of total energy savings potential. The overarching goal is to provide relevant and appropriate information to support design of appropriate policy programs that will accelerate the penetration of super-efficient PC monitors.

[2] In this analysis, cost-effectiveness is defined as cost of conserved electricity (CCE), the annualized investment in more expensive equipment or component needed to provide a unit of energy saved (kWh), less than electricity price.

This paper focuses on LCD monitors which are expected to dominate worldwide sales, amounting to an expected 99% of global PC monitor shipments by 2015 (DisplaySearch 2011a). In this paper, we assess recent technology trends and their impact on the energy efficiency of PC monitors, and related efficiency improvement programs. However, detailed program design questions are out of the scope of this paper. We also assess technologies that can improve the efficiency of PC monitors beyond this trajectory in a cost-effective manner, and provide insights on policies that can accelerate their adoption. We consider efficiency improvement options that are technically feasible, practical to manufacture, and could be realized in the short term (over the next three years) as the rapid evolution of technology in the display market makes a forecast over a longer time scale highly uncertain and therefore not very useful from a policy perspective.

Data Sources and Analysis Method

We obtained the data for this paper primarily from the following sources: a review of the literature including technical reports, DisplaySearch reports, the ENERGY STAR data base, international conferences, technical exhibitions and interviews with manufacturers and experts in the field.

Analysis Results

A. Efficiency improvement options and trends

Efficiency improvement options which also lead to concurrent improvement in other desirable product characteristics (e.g. LED backlighting leads to thinner/lighter monitors and better picture quality in color reproduction capability and contrast ratio) or leads to reduction in overall costs (e.g. high transmittance LCD panels require fewer optical films or backlight lamps) - are more likely to be adopted on their own without additional policy intervention compared with options which predominantly improve only efficiency. Table 1 summarizes LCD monitor efficiency-improvement options.

B. Cost-effectiveness Analysis

We focus on assessing the cost effectiveness of adopting reflective polarizer films which reduce energy consumption by 20%-30% and are unlikely to be widely adopted in the market in the absence of any market transformation policy action. We estimate CCE for using a reflective polarizer in each product class of monitors. The selected product groups have a CCE with a range of $0.08 per kWh and $0.10 per kWh. The deployment of reflective polarizers can be encouraged in a cost effective manner to improve PC monitor efficiency because the CCEs are less than the average residential electricity prices of many countries.

Although efficient LCD panels required for DC powered monitors would cost more than the average LCD panels available today, the final LCD monitor set can be manufactured without many electronic components typically required in AC powered PC monitors such as power cord and AC/DC converter, leading to further cost reduction in packaging and shipping. DC monitors are likely to be cost effective and provide savings on the order of approximately 50% from current levels as long as the incremental cost for efficient LCD panels is less than about 4%-5% of the LCD monitor price.

Ambient light sensors are commercially available and their material cost does not vary with screen size or resolution. Although ambient light sensors might enable TVs and PC monitors being used at home to reduce energy consumption, it is difficult to more accurately determine the average effect of ambient light sensors on energy consumption of a PC monitor because sufficient data on the varied lighting conditions where PC monitors are used across regions and sectors is not available. Table 2 summarizes the CCE ranges and savings estimates of the technical options.

Table 1. LCD Monitor Efficiency Improvement Options

Components		Improvement options	Notes
Backlight Unit	Backlight source	• CCFL to LED transition	• Cost increase • Adopted by manufacturers due to improved product quality • Expected to be accelerated by economies of scale and technological learning (BAU[b])
		• High LED efficacy	• Cost reduction in the long term (BAU) • Technical barrier in thermal management and short term cost increase from adoption of much higher efficiency LEDs (i.e., high power LEDs) than BAU
	Optical films	• Optimized combination of films	• Trade-offs in material cost, ease of manufacture, and efficiency (BAU)
		• Reflective polarizer (DBEF[a])	• Cost increase, proprietary technology
LCD Panel		• Improvement in panel transmittance by optimizing pixel design, functional layers, e.g., polarizer, color filter, and data line	• Proprietary technology • R&D investment required but driven by cost reduction (BAU)
Power management		• Brightness control based on computer usage patterns	• Efficiency improvement varies with settings and usage patterns. (BAU)
		• Brightness control based on ambient light condition	• Efficiency improvement varies with settings and ambient light condition
		• Brightness control (local dimming) based on image signals	• Efficiency improvement varies with manufactures' design scheme. The use of local dimming in PC monitors is more limited than in TVs.
Other		• Low voltage DC powered monitors (e.g., USB-powered monitors)	• High-efficiency LCD panel required • Cost increase for the LCD panel but likely cost neutral for the monitor set

[a] Dual brightness enhancement film produced by 3M

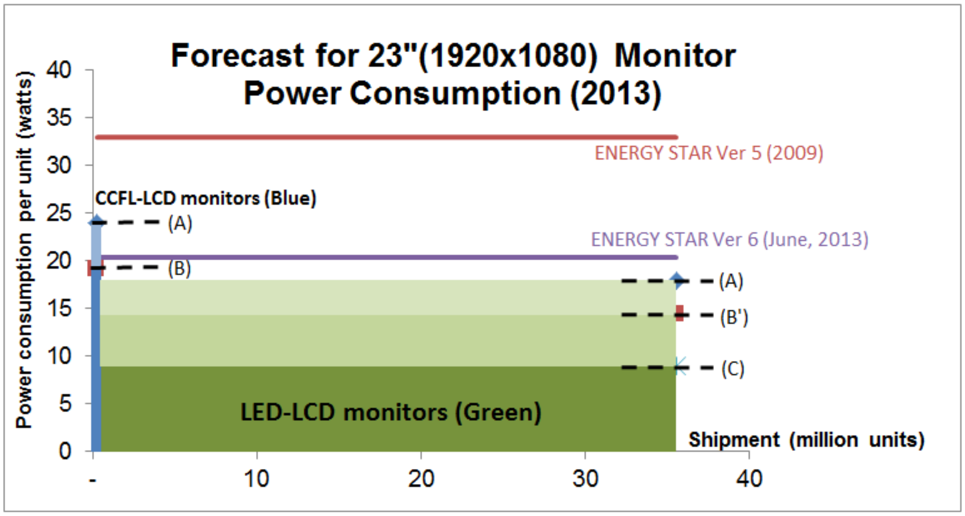
Table 2 Cost of Conserved Electricity (CCE)[a] for 23-inch LED-LCD Monitors

Option	Savings potential	CCE ($/kWh)
Reflective Polarizer	20-30%	0.070-0.104
Efficient LCD Panel	10-20%	0.077-0.256 [b] (indicative)
USB-powered monitor with efficient LCD panel and reflective polarizer	50%	< 0.100
Ambient Light Sensor	5-20%	0.017-0.114

[a] Assumptions: discount rate=5%, economic lifetime=6 years, daily usage=5 hours
[b] Based on the estimated incremental costs for efficient LCD panels (i.e., $1.7-$9) where the USB-powered monitor is cost-effective.

C. Insights for Market Transformation Programs

As LED-LCD monitors are expected to account for more than 80% of global PC monitor shipments from 2013 onward, energy efficiency programs need to account for the performance of LED-LCD monitors. In 2015, the share of LED-LCDs is expected to be 97% in the market. Thus, potential levels for future standards and incentives will have to be more aggressive than the ENERGY STAR Version 6 levels in order to impact efficiency further beyond these levels. Fig. 2 shows an example of possible power consumption levels for standards, labeling and incentive programs.



(A) Estimated average power consumption in a BAU scenario
(B), (B') Power consumption possible with reflective polarizers - (B): possible level for standards or entry level of labeling program
(C) Power consumption possible with USB-powered DC monitor with reflective polarizer (i.e., possible level for advanced levels of labeling or incentive programs)
Each shaded area represents total power consumption by global shipments in the corresponding scenario.

Fig. 2 Possible Levels for Standards, Labeling and Incentive Programs

D. Global Savings Potential for Efficiency Improvements in PC Monitors

To estimate global savings potential, we selected ten product categories identified by screen size and resolution. The selected product groups represented 84% of the global PC monitor shipments in 2010 and are expected to account for about 93% of the market in 2012 (DisplaySearch 2011a). First, we estimated the baseline on-mode power consumption for each of the product categories based on the ENERGY STAR data. We assumed that average daily usage at on-mode is 5 hours for all monitors, and estimated the unit energy consumption (UEC) per year for all the selected products by multiplying the power consumption for a product with the annual usage. Based on the shipment data for each product type, we estimate total consumption for year by multiplying the UEC for a product with the projected shipments of that product.

This analysis compares future PC monitor energy consumption for three major scenarios: a base case with efficiency improvement expected in BAU (Base Case), an efficiency case and a super efficiency case with two sub-cases; one is the case with one cost-effective efficiency improvement option (i.e., reflective polarizer) and the other is the case with the technology as energy efficient as USB-powered monitors. In addition to the three major scenarios, we include one additional case which assumes a market transition from CCFL-LCD to LED-LCD in the LCD technology with no further efficiency improvement within each technology from 2011 onward in order to give the reader a sense of the rapid improvement in PC monitor efficiency expected even in a BAU scenario.

If in every year the efficient designs discussed in this paper reach 100% of the product groups analyzed, i.e., about 90% of the whole market, the total energy savings potential would be about 4.1 to 9.2 TWh per year in 2015, and up to 55.1 TWh during their lifetime. Fig. 3 shows the results of forecasted global PC monitor electricity consumption in on-mode. The energy savings potential contributed from 2012-2015 PC monitor shipments by each scenario and corresponding policy programs are summarized in Fig. 4.

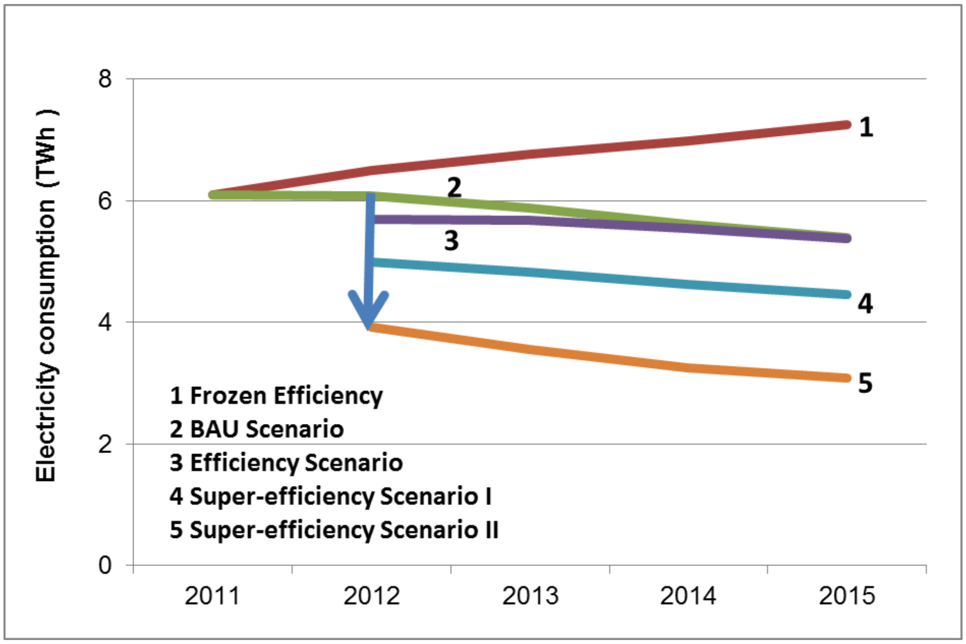
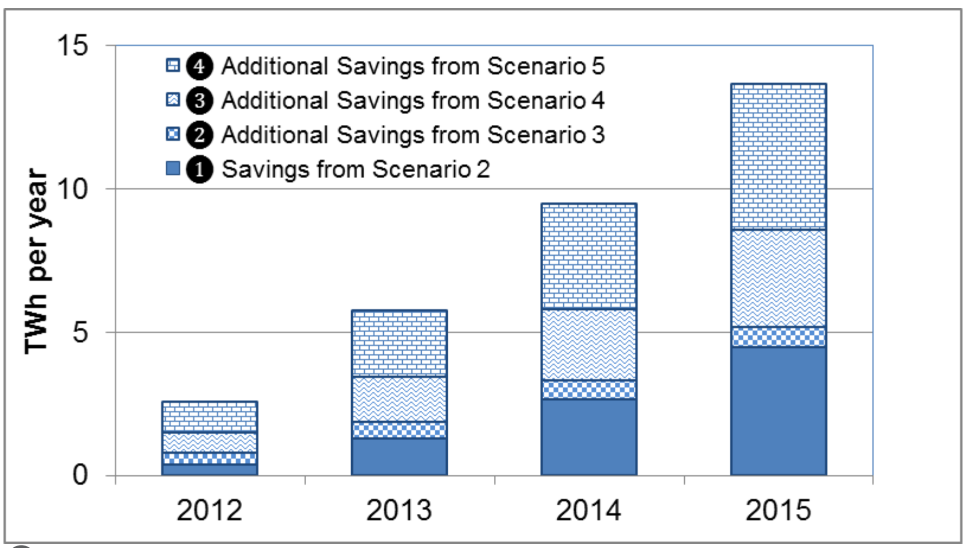


Figure 3. Global PC Monitor Electricity Consumption Forecast for Annual Shipment



➊: Possible savings by BAU improvement.

➋: Possible savings by standards.

➌+➍: Possible savings by incentives and labeling programs.

Figure 4. Global PC Monitor Savings Potential