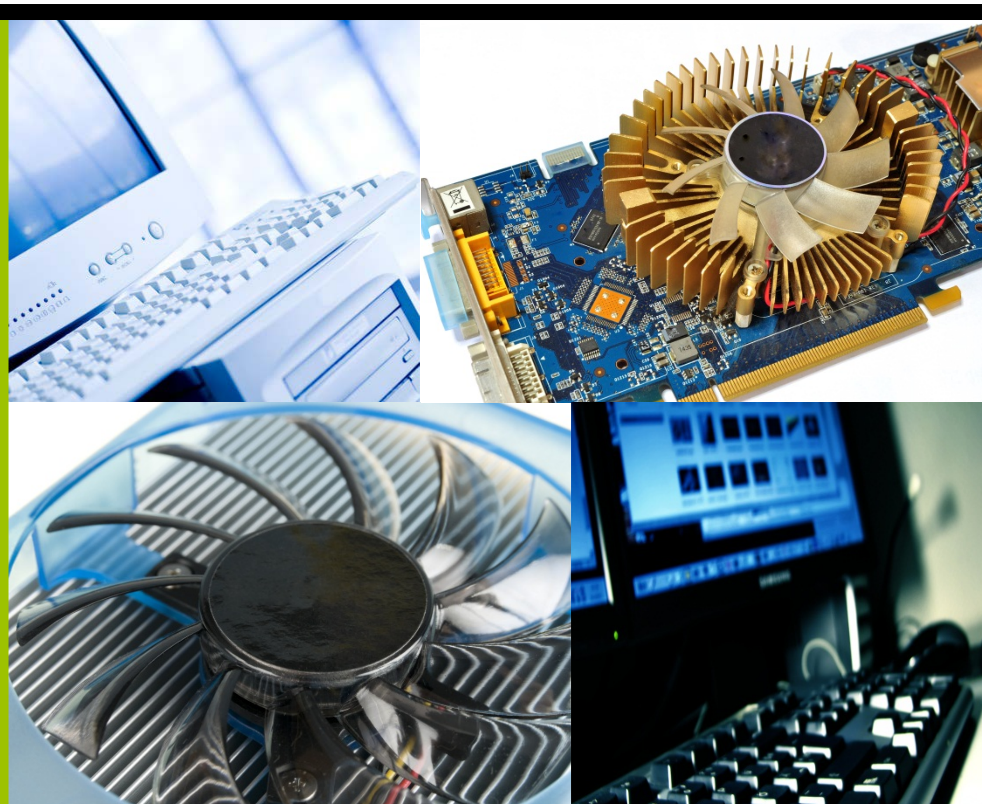

The Impact of Graphics Cards on Desktop Computer Energy Consumption

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Executive Summary

In 2012, the Collaborative Labeling and Appliance Standards Program (CLASP) and the Natural Resources Defense Council (NRDC), in collaboration with Ecova, initiated an innovative study designed to provide policy makers with data on discrete graphics card energy consumption in desktop computers. This data was gathered to support the establishment of effective energy consumption allowances (or “adders”) for graphics cards in the Version 6.0 ENERGY STAR computer specification, as well as in other labeling initiatives and mandatory standards that use the ENERGY STAR computer specification as a framework.

Graphics card adders impact energy saving. Overly lenient graphics card adders can provide a significant excess allowance of energy consumption for the rest of the computer system, which enables less energy efficient computers to meet efficiency requirements for standards and labeling programs. On the other hand, overly stringent graphics card adders may restrict market access for efficient computers that require cards for graphics-intensive applications (e.g. computer gaming). Setting graphics card adders at appropriate levels will ensure that standards and labeling programs support the market for energy efficient computers while excluding inefficient models.

Stand-alone graphics cards are typically measured and evaluated independently from the computer systems in which they are used; system-level power demand impacts are then derived by applying a power conversion factor. This traditional approach does not account for the impact of the graphics card on other components in the computer system, which may be significant in some cases.

This study employed a novel approach for measuring the power impact of discrete graphics cards; the net power impact of the cards was determined by measuring the difference in system-level power demand between a computer with the card and the same computer without the card, using integrated graphics. This approach provides a more accurate assessment of the net power impact of a discrete graphics card on a computer system.

Ecova tested 12 discrete graphics cards that were selected from six ECMA-383[1] graphics categories and represent over one-third of the desktop discrete graphics card models introduced on the U.S. market in 2011. The six computer systems in which the cards were tested represented a wide range of market segments, including Mainstream, Performance, High Performance, and Very High-end/Enthusiast[2] segments. While it was not in the scope of this study to evaluate the impact of the cards on all computer configurations on the market, the selected configurations were chosen to represent a range of performance levels across a representative sample of the primary desktop computer market segments.

Key findings from the study are as follows:

1. **The power impact of each discrete graphics card varied significantly from computer to computer**, indicating that a number of system-specific factors other than the card itself impact system power demand when a discrete graphics card is installed;

[1] International standard for measuring the energy consumption of personal computing products - http://www.ecma-international.org/publications/standards/Ecma-383.htm

[2] Information Technology Industry Council Comments on Energy Star Computers Version 6, March 10 2011 Kickoff Meeting. Available at: http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/ITI_Comments_4.pdf

2. **Power demand in idle mode generally increased as discrete graphics card frame buffer bandwidth increased;** however, there were large differences between cards;
3. **A new technology called ZeroCore Power Technology, which was featured in one high-end card, dramatically reduced power demand** when the computer was in idle mode; and,
4. **The additional power needed to operate a second discrete graphics card was approximately 25 percent less** than that required for the first card in a particular host computer.

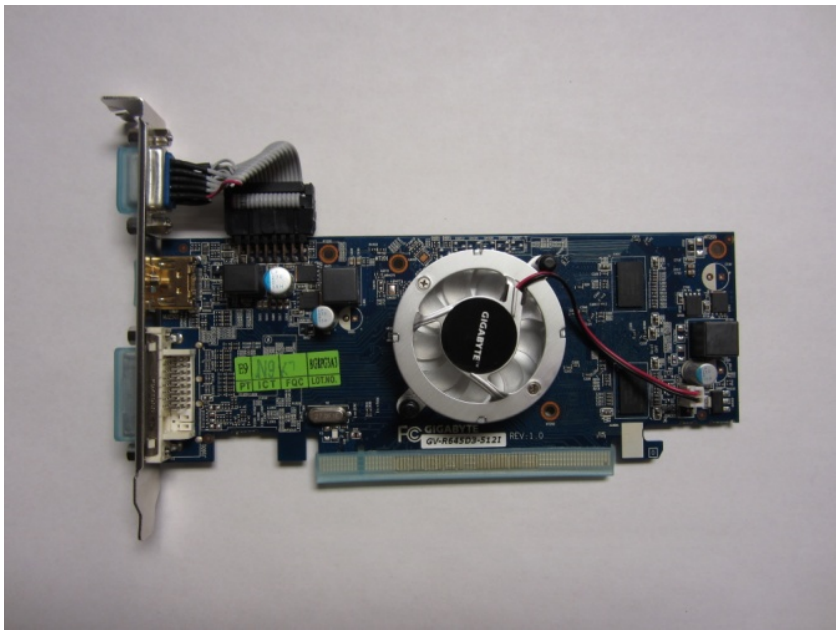
Based on the findings listed above, we recommend the following modifications to the process of determining effective adders for discrete graphics cards:

1. **Graphics card adders should be set using system-level test data** rather than individual card-level power;
2. **A linear regression across all data points allows adders to be determined more accurately than a category-by-category approach**, given the limited number of data points available in each category;
3. **Innovative technology can significantly reduce discrete graphics power demand in idle mode** in the near-future; thus, adder levels should be regularly updated to adapt to the current deployment of new low-power idle technology; and,
4. **Additional and ongoing testing using a methodology similar to the one presented in this study** should be employed to assess graphics cards newly introduced on the market.

1. Introduction

Discrete graphics cards (dGfx) are add-in graphics-processing cards that interface with a computer's motherboard through an expansion slot (typically a PCI bus) and differ from integrated graphics (iGfx), which are assimilated into the motherboard or processor (CPU). Discrete graphics cards include specialized graphics processing units (GPUs) that are designed to accelerate the display of graphical images on computer screens. They are often used for graphics-intensive applications such as computer gaming, video editing, and computer-aided design.

Photo 1: A discrete graphics card, photo taken by Ecova



The addition of a discrete graphics card to a computer often results in a large increase in the energy consumed by the overall system. As such, additional energy consumption allowances (or "adders") for discrete graphics cards are a critical component of computer energy efficiency specifications. Adders aim to make energy efficiency specifications performance-neutral by providing power or energy allowances for specific capabilities. Overly lenient graphics card adders can provide a significant excess allowance of energy consumption for the rest of the computer system, which enables less energy efficient computers to meet efficiency requirements for standards and labeling programs. On the other hand, overly stringent graphics card adders may restrict market access for efficient computers that require cards for graphics-intensive applications (e.g. computer gaming). Setting graphics card adders at appropriate levels will ensure that standards and labeling programs support the market for energy efficient computers while excluding inefficient models.

A representative sample of graphics card energy consumption is needed to set appropriate graphics card adders. The Version 6.0 ENERGY STAR computers dataset contains a limited number of configurations equipped with recent discrete graphics cards, and, in most cases, does not include data from a baseline configuration (i.e., the exact same system without the card), which is necessary to evaluate the additional power required for the graphics card to function.

This study provides a representative dataset demonstrating the impact of discrete graphics cards on the power demand of desktop computers while in idle mode, to support the process of setting effective graphics adders in the Version 6.0 ENERGY STAR computers specification. This data can also be used by other labeling initiatives or mandatory standards programs that use the ENERGY STAR computer specification as a framework.

2. Background

2.1 Scope

This study applies to discrete graphics cards for desktop computers; notebook computers require a different test approach due to their higher levels of integration and customization. Notebook graphics are also much more efficient than desktop graphics due to battery life considerations. The study therefore focuses solely on desktop computers, which offer the greatest opportunity for energy savings from discrete graphics among various types of computers.

Some desktops have more than one discrete graphics card to increase performance. To help set adders for additional discrete graphics cards beyond the first, the study also includes testing of configurations with multiple discrete graphics cards in the same system.

Finally, this study focuses on consumer-grade graphics cards (e.g. for computer gaming) as opposed to professional-grade graphics cards. The latter are designed primarily for workstations and represent a small share of the market relative to graphics cards on personal computers.

2.2 Computer Energy Use

Although 2011 sales of desktop computers were about half those of notebooks in mature markets, and their unit sales are projected to marginally decline over the next four years, desktops still use over three times as much energy as notebooks on a per unit basis. As a result, aggregate desktop energy use is projected to remain higher than that of notebooks through the year 2016, as illustrated in Figures 1 and 2.

Figures 1: Computers Sales[3]

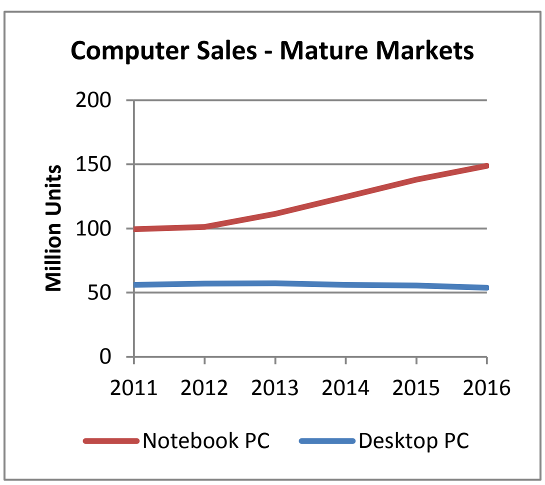
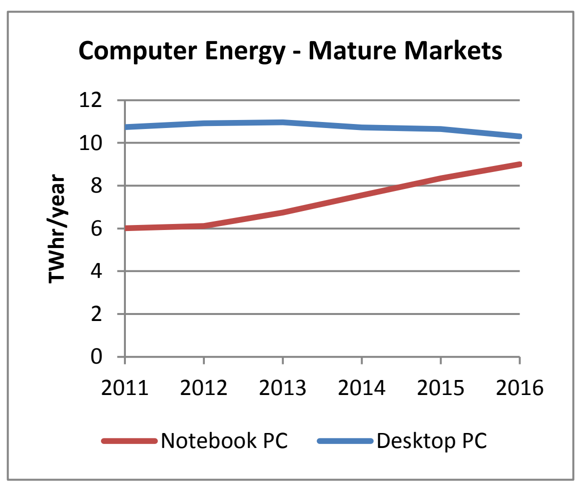


Figure 2: Computer Energy[4]



[3] IDC June 2012: http://www.idc.com/getdoc.jsp?containerId=prUS23549112

[4] Annual energy use of new computers sold each year, based on ENERGY STAR Computers v5 energy limits and duty cycle. This includes all computers sold, whether ENERGY STAR-qualified or not.

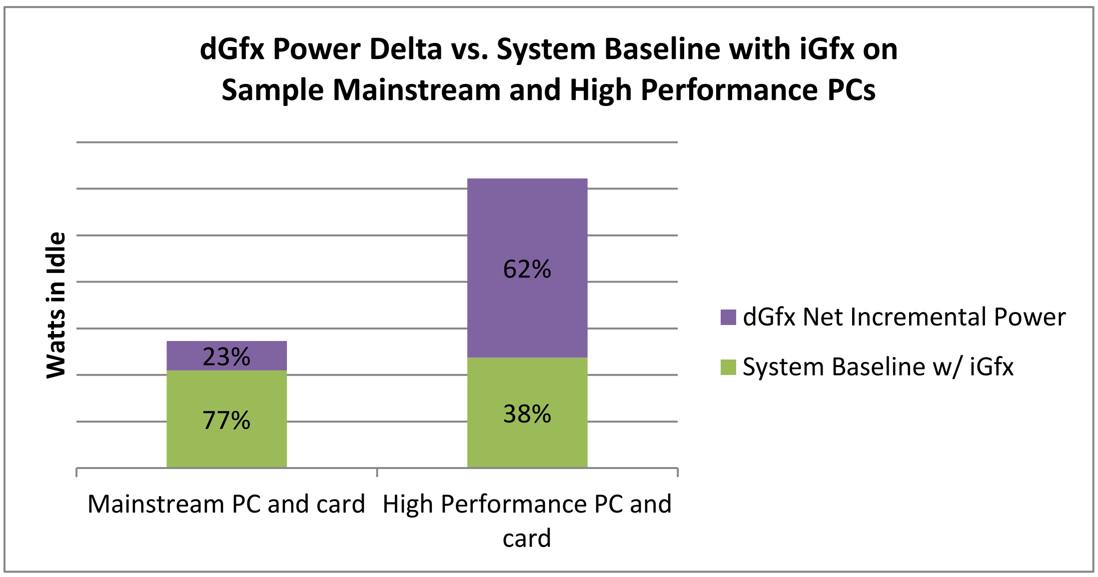
International Data Corporation (IDC) also forecasts that desktop computer unit sales will continue to grow in emerging markets over the period from 2012-2016. The high energy use of desktop computers suggests that a continued focus on desktop computer energy efficiency is necessary to reduce the global energy use of computers.

2.3 Discrete Graphics Energy Use

Desktop computers are the second highest source of electricity consumption among electronic equipment in U.S. homes, after televisions.[5] When present, discrete graphics cards can be responsible for a significant share of the host computer's energy use. Figure 3 illustrates the share of discrete graphics idle[6] power on two sample systems from the study's test data:

- A mainstream desktop computer with a low-end discrete graphics card[7];
- A high performance desktop computer with a high-end discrete graphics card[8].

Figure 3: Net Power Delta of Sample Discrete Graphics Cards on Low-End and High-End Systems



Note: Figure 3 uses data from two sample configurations. It is not meant to represent an average, but to illustrate the relative impact of discrete graphics.

In 2010, discrete graphics cards were found in between one third and one half of desktop computers on the market;[9] therefore, reducing the power demand of discrete graphics cards in idle mode is a key strategy for the reduction of the overall energy use of desktop computers.

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[5] International Energy Agency. Gadgets and Gigawatts (2009)
[6] Weighted average of Short and Long idle per Energy Star v6 draft 2 mode weightings
[7] Mainstream configuration: PC1 with GPU1 (AMD Radeon HD 6450), as described in Appendix III
[8] High-performance configuration: PC5 with GPU12 (NVIDIA GeForce GTX 590)
[9] 65-70 million desktop discrete GPUs shipped worldwide in 2010 (Mercury Research: http://www.xbitlabs.com/news/graphics/display/20101027211059_ATI_Maintains_Lead_on_Discrete_GPU_Market_Mercury_Research.html) for 145 million desktop PCs (IDC: http://www.idc.com/getdoc.jsp?containerId=prUS22861211).

3. Methodology

3.1 Overview

This study was designed to provide results that can be compared directly with (and used for the definition of) discrete graphics adders in ENERGY STAR-based specifications. The key objective was to calculate the net power impact of a discrete graphics card as the difference in power between a computer with the card and the same computer without the card. This net power impact was then converted to energy impact using the ENERGY STAR duty cycle.[10]

Laboratory testing was performed on 12 cards, featuring one GPU from each of the two main manufacturers (AMD and NVIDIA) in six of the seven ECMA-383 categories.[11] Each card was tested in six different computers selected to represent a broad range of desktop computers.[12] Each test was performed initially three times in order to identify potential testing variability. Testing was then reduced to two tests per configuration after variability was determined to be insignificant in the initial tests. The results were then analyzed. The findings are presented in Section 4.

The following sections cover the key aspects of the methodology.

3.2 System Level Testing

The study measured alternating current (AC) power of the entire computer system "at the wall."[13] This measurement provides a more accurate assessment of the impact discrete graphics cards have on the power consumption of the computer system than measuring direct current (DC) power at the component level inside the system and converting it into AC power.

Computers are integrated systems; therefore adding a discrete graphics card to a computer affects system power in more ways than just adding power used by the discrete graphics card itself. For example, plugging a discrete graphics card into a system also results in the following:

- Integrated graphics are automatically switched off in the majority of computers;
- System components, such as the CPU, motherboard and memory, consume more power in response to new demands from the discrete graphics card. This increase in power is partially compensated by the cessation of power demands from the integrated graphics card;
- Power supply load point and efficiency change in response to the difference in net DC power; and,
- In some cases, upsizing the power supply (replacing it with a unit rated at a higher maximum wattage) in order to accommodate peak power demands when the discrete graphics card is active. This impacts the efficiency curve of the power supply as well as its loading point at idle.

[10] http://www.energystar.gov/index.cfm?c=revisions.computer_spec

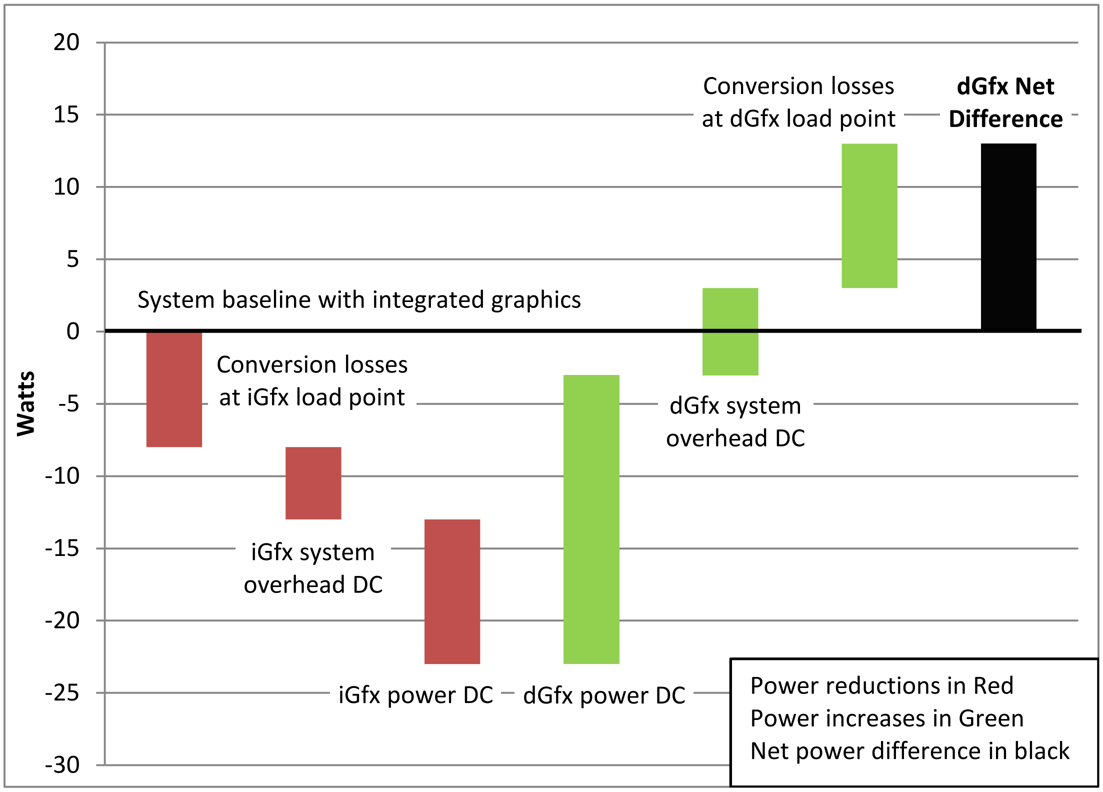
[11] ECMA-383 Standard: Measuring the Energy Consumption of Personal Computing Products - http://www.ecma-international.org/publications/standards/Ecma-383.htm. The G6 category was excluded from the study because there were very few cards of this type on the market at the time of testing.

[12] GPU12 was exempt, as it would only operate in three of the test computers.

[13] Power consumption of the computer measured at the wall electrical outlet.

The changes in net power described above are illustrated in Figure 4. This study evaluates the net impact of these effects by calculating the difference of AC power demand between a computer with the dGfx card and the same computer without the card.

Figure 4: Changes in System Power When Adding a Discrete Graphics Card[14]



3.3 Idle Mode Testing

In keeping with the ENERGY STAR Computers Version 5.2 and Version 6.0 Draft 2 specifications and test protocols, power measurements were taken in idle mode only, not active mode. The discrete graphics card net energy impacts presented throughout this study correspond to the energy requirements of the card in idle mode, when graphics processing needs are very limited and could be handled by integrated graphics.

Computer power in Off and Sleep modes was measured for Baseline configurations (computers without a discrete graphics card) for reference purposes. The power demand in Off and Sleep modes was verified not to vary between configurations with and without a discrete graphics card. Therefore power demand in Off and Sleep modes does not impact the net energy impact of discrete graphics cards.

The power impact was measured in both short idle (computer display on) and long idle (computer display in low-power mode), per the ENERGY STAR Computers revised test method dated July 21,

[14] Figure 4 shows hypothetical values to illustrate the concept, not measurements on a particular system and graphics card.

2011[15]. The net energy impact was then calculated using the mode weightings proposed in the ENERGY STAR v6.0 draft 1 and 2[16].

3.4 Test Protocol

The test approach is consistent with the ENERGY STAR computer specification test methodology[17]. Unless otherwise specified, all terms used in the test methodology are consistent with the definitions in the ENERGY STAR specification for computers. The study uses ENERGY STAR definitions for all operating modes: off, sleep and idle (short and long).

Although the ENERGY STAR test methodology requires only one test run per sample, each computer system was tested with each discrete graphics card two to three times in idle mode. Up to 3 test runs were performed for each configuration to ensure that any significant variability was detected, and tests were repeated until 2 consistent runs were obtained. Variability between test runs turned out to be marginal, and additional runs due to unexpected variability were only necessary for one configuration.

Additional details on the test methodology can be found in Appendix I.

3.5 Discrete Graphics Card Selection

Selection Criteria and Rationale

The study's objective was to select two recent cards in each of the six most common ECMA-383 graphics categories[18], with a balanced representation of the two major GPU manufacturers, AMD and NVIDIA.

A survey of discrete graphics cards offered in the desktop computer lines in four of the major original equipment manufacturers (OEMs) of desktop computers: HP, Dell, Apple and Acer, was performed. Graphics cards were categorized based on frame buffer bandwidth (GB/s) and associated ECMA-383 classification. Frame buffer bandwidth is a performance proxy for graphics cards defined by ECMA-383 for the purpose of categorization. The study's selection included the most recently-released cards identified in a market survey from both NVIDIA and AMD for each ECMA-383 category. In addition, graphics cards capable of NVIDIA® SLI™ and AMD CrossFireX™ configurations for each ECMA-383 category were selected where possible. To fill in gaps in certain performance categories in the study's OEM market survey, popular graphics cards based on third-party web sites such as Tom's Hardware and GPU Review[19] were selected. Within each ECMA-383 category cards that were most recently released and most commonly used by OEMs were selected when possible.

[15] http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/Computers_Test_Method_Rev_July_2011_Draft.pdf?abd9-54e8

[16] http://www.energystar.gov/index.cfm?c=revisions.computer_spec

[17] ENERGY STAR Computer Test Method, July 21, 2011, http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/Computers_Test_Method_Rev_July_2011_Draft.pdf

[18] ECMA graphics categories are defined at http://www.ecma-international.org/publications/standards/Categories_to_be_used_with_Ecma-383.htm

[19] See http://www.tomshardware.com/reviews/fastest-graphics-card-radeon-geforce,3085.html and http://www.gpureview.com

NVIDIA's current lineup of discrete graphics cards does not include an NVIDIA® SLI™ capable card for every ECMA-383 category. As a result, no NVIDIA® SLI™ capable cards were tested in the G1 and G2 categories. AMD/ATI offers single and CrossFireX™ configuration cards for each ECMA-383 category other than G6.

Selected Graphics Card Models

Selected graphics card are detailed in Appendix II.

The cards selected for the study cover approximately 36% of discrete desktop graphics card models released by AMD and NVIDIA in 2011. See Appendix II for the list of cards released by AMD and NVIDIA in 2011.

3.6 Test Computer Configurations

As discussed in section 3.2 System Level Testing, graphics card power demand depends not just on the card itself but also on the system it is operating in. Therefore, selecting a representative set of test computers was important to ensure the validity of the study's test results.

Tests were conducted on 6 test computers in order to represent various segments of the market, covering both the consumer and commercial markets, and a range of performance levels including Mainstream, Performance, High Performance, and Very High-end/Enthusiast. While it is not possible to accurately represent all configurations on the market, 6 configurations carefully chosen to represent different technologies and performance levels provided a representative sample of the main desktop computer market segments.

The 6 test computers included different types of technologies and efficiencies for key components including CPUs, motherboards and power supplies. Different models of these components were intentionally used across all 6 computers. Although using the same components would have enabled better control for the impact of graphics cards vs. other variables, it would not have been representative of market configurations. For adders to be meaningful it is essential that test data is as representative of the market as possible.

A more detailed explanation of the study's computer configuration process and list of detailed hardware configurations is provided in Appendix III.

Power supply configurations are not included in Appendix III, instead they are covered separately in the following section because of special requirements imposed by the study's test methodology.

3.7 Power Supply Configurations

The choice of power supply units (PSUs) required special consideration. Contrary to other components, PSUs could not be held constant for a given computer, they had to be changed depending on which graphics card was being tested. As discrete graphics can represent a significant share of a computer's active mode peak power, the PSUs used in the baseline configurations are generally not capable of supporting the higher performance cards' peak power requirements. For each test, the PSU was sized appropriately for the peak power requirements of the card being tested and its host system by following card manufacturer minimum PSU size recommendations.

The PSU could have been held constant for each computer by using a single PSU capable of supporting the highest powered card, but this would not have been representative of typical market configurations for smaller cards. Upsizing the PSU depending on the graphics card represents real design decisions made by manufacturers in the market.

The same selection principles utilized in the selection of CPUs and motherboards were applied to the selection of PSUs: a range of PSU efficiencies representative of current PSUs in the market were selected. These PSUs were matched to the computer system, so that the combination of computer system and PSU power rating and efficiency represents configurations commonly found in the market. To account for the need to upsize PSUs for the highest powered cards, a set of PSUs of comparable efficiency were selected for each test computer. Detailed PSU models and efficiencies can be found in Appendix IV.

Using a different PSU in the baseline and in the discrete graphics card test is legitimate and representative of design practices in the market. However, it raises two questions regarding the accuracy of the test results in this study:

1. Are differences in power supply conversion losses a significant factor in the reported discrete graphics card net impact values?
2. Did upsizing certain PSUs result in significant differences in power compared to using the Baseline PSUs?

A detailed analysis of these two questions is presented in Appendix IV. In summary, changes in power supply conversion losses were responsible for less than one fifth of the incremental discrete graphics card power. The increase in power supply losses is nearly proportional to the increase in DC power demand by the system. The power supply efficiency increases slightly as load increases, but this effect is relatively minor compared to the increased losses due to higher load.

The other four fifths of the AC power impacts result from system power changes due to the discrete graphics card, not to differences in PSU conversion losses. Moreover this ratio was very consistent across cards, varying between 15 and 19 percent, indicating that power supplies did not introduce significant variability in test results.

Regarding the impact of PSU upsizing, the study’s analysis shows that the incremental power due to PSU upsizing is on average only 2% of the discrete graphics card net power impact. This means that PSU upsizing introduced negligible variability on the discrete graphics card net impacts reported in the project results.

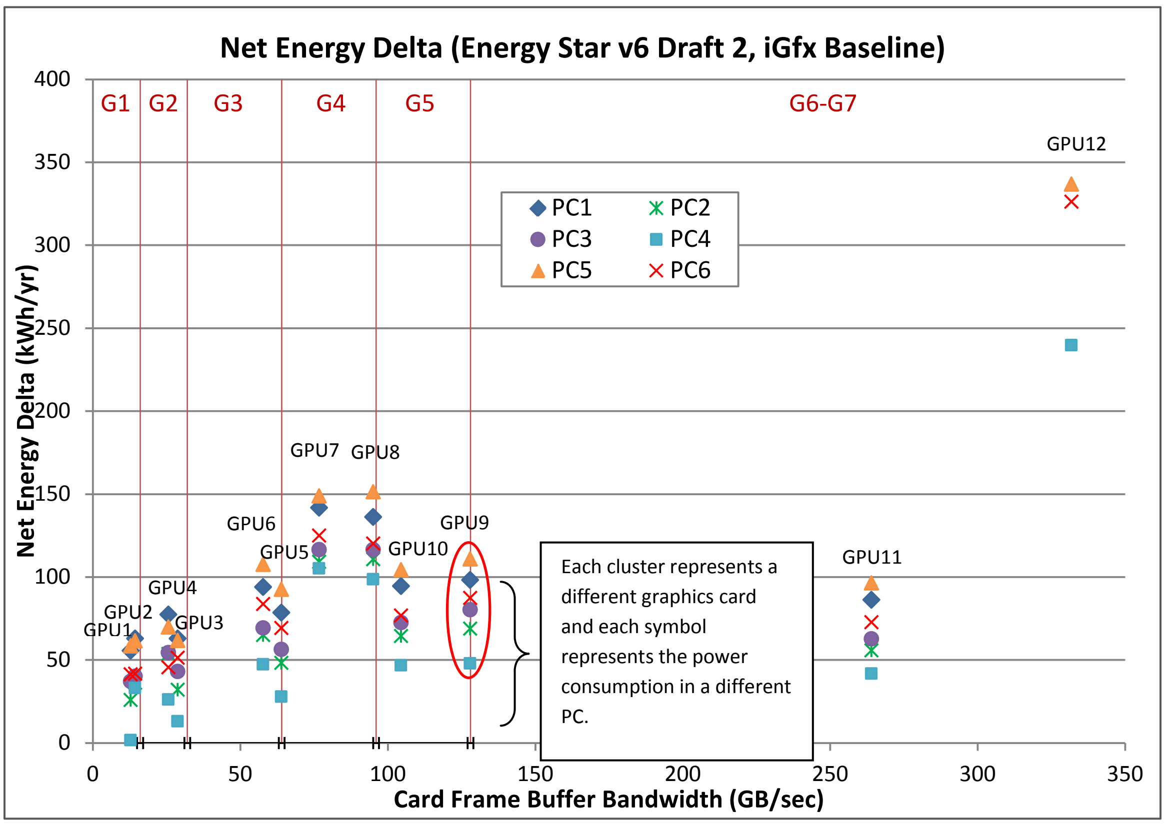
4. Data Analysis & Key Findings

This section presents an analysis of the net annual energy impacts for each card[20]. Policy recommendations follow in Section 5.

4.1 Single Card Test Results

Figure 5 shows the net energy impacts of single card configurations per card and per test computer. The x-axis represents the card frame buffer bandwidth, with higher values generally corresponding to higher graphics performance[21]. The y-axis represents the difference in idle power between the system using the discrete graphics card, and the baseline system using integrated graphics.

Figure 5: Net Energy Delta (Version 6.0 ENERGY STAR Computers Draft 2, iGfx Baseline)



Notes:

1. GPU12 (NVIDIA GeForce GTX 590) has only 3 data points because it would only run in 3 of the 6 test computers due to its high power requirements.
2. GPU1 on PC4 uses only 1.6 kWh/yr. This reflects the fact that increased power demand from adding GPU1 is almost completely compensated by the reduction in power from switching off PC4 integrated graphics.

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[20] The study's test data and analysis is available at http://www.clasponline.org/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2012/Impact-of-Graphics-Cards-on-Desktop-Computer-Energy-Consumption

[21] There are other factors to graphics performance, but frame buffer bandwidth is a simple and generally accepted proxy for the purpose of graphics card categorization.

Figure 5 illustrates the following facts:

1. **Power demand of individual graphics cards varies from computer to computer**

   Differences in energy consumption across test computers for a given card are represented by the vertical spread in clusters on the chart. The spread of energy consumption across test computers is generally consistent for all cards, meaning each card generally increased computer power demand by the same amount across each of the computer systems tested. This confirms that the net energy delta for a system with a discrete graphics card is due to power changes in the system in addition to power consumed by the card itself. Table 1 below provides more analysis on this point.

2. **Computer power demand generally increases with graphics card frame buffer bandwidth**

   As discrete graphics card frame buffer bandwidth increases, so does the computer's energy consumption. However this is not always the case, as shown by the two G5-category cards, which require less additional power than the G4-category cards, even though they have a greater frame buffer bandwidth as shown on Figure 5;

3. **One of the cards tested (GPU11) delivers a dramatically better idle power to performance ratio than the others**

   GPU11 and GPU12 are both G7 cards. The difference in energy consumption may be explained by new technology used by GPU11. GPU11 is an AMD Radeon HD 7970, the first card on the market to feature ZeroCore Power Technology designed to radically reduce card power demand in idle mode. This suggests that new energy efficiency technology may substantially decrease graphics card power demand in idle mode once this technology is rolled out to a large number of cards. Recent NRDC market research indicated that AMD and NVIDIA had already rolled out low-power idle technology to 11 new cards across 4 ECMA categories in the first half of 2012[22].

Table 1 below presents the same data as Figure 5 in table format with color coding to highlight high and low values. It shows that some computer systems, such as PC5, consistently used more additional energy to run the discrete graphics cards than other computers. This is likely due to the fact that PC5's integrated graphics are highly efficient in idle mode, resulting in lower baseline power and therefore a higher power difference when using discrete graphics.

By the same token, some computers consistently used less additional energy to run the discrete graphics cards than other computers. PC4 in particular consumed significantly less additional energy. This appears to be due to high integrated graphics power demand in idle mode compared to the other computers. This limits the energy reduction from switching off the integrated graphics when the discrete graphics card is added. PCs 2, 3, and 6 appear closer to the average and may be more representative of the average computer.

[22] Radeon HD 7970, Radeon HD 7950, Radeon HD 7870, Radeon HD 7850, Radeon HD 7770, Radeon HD 7750, GeForce GTX 680, GeForce GTX 690, GeForce GTX 670, GeForce GTX 630, GeForce GTX 640,

Table 1: Net Energy Delta (ENERGY STAR v6.0 Draft 2 duty cycle, iGfx Baseline)

kWh/yr	PC1	PC2	PC3	PC4	PC5	PC6	Average
iGfx	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
GPU1	55.6	25.9	37.1	1.6	58.5	41.4	**36.7**
GPU2	62.9	36.3	40.1	33.0	61.5	41.7	**45.9**
GPU3	62.9	32.1	43.1	12.9	61.7	51.3	**44.0**
GPU4	77.3	53.7	54.5	26.1	69.8	45.5	**54.5**
GPU5	78.4	48.2	56.4	27.8	92.6	69.3	**62.1**
GPU6	94.0	65.1	69.3	47.3	107.7	83.8	**77.9**
GPU7	141.7	109.1	116.4	105.0	148.9	125.0	**124.4**
GPU8	136.1	110.6	116.4	98.6	151.3	120.1	**122.2**
GPU9	98.1	68.8	80.2	47.8	110.9	87.5	**82.2**
GPU10	94.5	64.4	72.6	46.7	104.4	76.9	**76.6**
GPU11	86.3	55.8	62.7	41.6	96.4	72.7	**69.3**
GPU12				239.7	336.8	326.3	**300.9**

Note: The color scales indicate comparative energy use change among the computers tested for a given graphics card (GPU) compared to baseline integrated graphics; red indicates the highest change in energy consumption, followed by orange, yellow, light green, and green indicated the lowest.

4.2 Average by Card

To facilitate the use of test results for policy purposes, the average of the net energy impacts on the computer system across test computers was calculated to derive a single value per card. The average was calculated across the 4 median PCs, excluding the systems yielding the lowest (PC4) and highest (PC5) values overall. While PC4 is a valid market configuration, including it in the average could have penalized computers with effective integrated graphics power management. PC5 yielded the highest power impacts overall and was excluded to balance out the exclusion of PC4 and ensure that the average is representative of the median of the test sample. Table 2 gives average results per card, for both ENERGY STAR v6.0 Draft 2 and ENERGY STAR v5 mode weightings.

Table 2: Average Test Results for Each Graphics Card

Card	GPU	Card Frame Buffer Bandwidth[1] (GB/s)	ECMA-383 (v3)[2]	Energy Delta E* v6 Draft 2[3] (kWh/yr)	Energy Delta E* v5[4] (kWh/yr)
GPU1	AMD Radeon HD 6450	12.8	G1	40.0	33.1
GPU2	NVIDIA GeForce GT 520	14.4	G1	45.3	35.8
GPU3	AMD Radeon HD 6570	28.8	G2	47.3	39.0
GPU4	NVIDIA GeForce GT 440	25.6	G2	57.8	45.5
GPU5	AMD Radeon HD 6670	64.0	G3	63.1	51.6
GPU6	NVIDIA GeForce GTS 450	57.7	G3	78.1	63.4
GPU7	AMD Radeon HD 6770	76.8	G4	123.1	102.3
GPU8	NVIDIA GeForce GTX 460	95.0	G4	120.8	99.5
GPU9	AMD Radeon HD 6850	128.0	G5	83.7	68.7
GPU10	NVIDIA GeForce GTX 550	104.5	G5	77.1	62.6
GPU11	AMD Radeon HD 7970	264.0	G7	69.4	69.0
GPU12	NVIDIA GeForce GTX 590	331.8	G7	326.3	278.5

Notes:

1. Card Frame Buffer Bandwidth: a proxy for graphics card performance as defined by ECMA-383 at the link below.
2. ECMA-383 (v3): discrete graphics categories as defined at : http://www.ecma-international.org/publications/standards/Categories_to_be_used_with_Ecma-383.htm
3. Energy Delta E* v6 Draft 2: average difference across the 5 test computers between system Typical Energy Consumption (TEC) with the card and Baseline system TEC without the card (using integrated graphics). This TEC value is a weighted average of short and long idle values according to ENERGY STAR Computers v6.0 draft 2 (45% Off, 5% Sleep, 15% Long Idle, 35% Short Idle).
4. Energy Delta E* v5: Same as previous but based on Short idle only and using the ENERGY STAR Computers v5 idle weighting of 40%. ENERGY STAR v5 idle corresponds to Short idle for desktops and Long idle for notebooks and integrated desktops. The blue color code indicates Energy Star v5 throughout this report.

4.3 Average by ECMA Category

Table 3 provides the average net energy consumption increases by ECMA category. It averages values for the 2 cards tested in each computer and category.

Table 3: Average Test Results by ECMA Category

ECMA-383 (v6)	Energy Star v6 draft2 kWh/yr	Energy Star v5 kWh/yr
G1	42.6	34.4
G2	52.5	42.3
G3	70.6	57.5
G4	122.0	100.9
G5	80.4	65.7
G7 (GPU11)	69.4	69.0
G7 (GPU12)	326.3	278.5

Note that category average values do not necessarily represent a recommended adder value for that category. Depending on the policy program, more stringent values may be warranted. Chapter 6 proposes policy approaches using lower values than the averages in Table 3.

Energy Star v5 values are different from Energy Star v6.0 because of different mode weightings in the two versions of the specification. For programs based on the ENERGY STAR v5 framework, program managers should use the ENERGY STAR v5 values.

4.4 Dual Card Test Results

Dual-card configurations, and more generally multi-card configurations, refer to computers that use more than one discrete graphics card. These configurations are used to increase graphics performance: either by providing higher performance than a single card could, or by providing equivalent performance at a potentially lower price than that of a single card.

Discrete graphics cards capable of operating in multi-card configuration are also known as SLI for NVIDIA technology and CrossFireX for AMD technology. Testing was conducted on a smaller number of graphics cards and a smaller number of computers than for single card configurations, because not all cards and test computers supported multi-card configurations. Dual card tests were only performed in PCs 4 and 6 and on ten cards (excluding GPU2 and GPU4) as other cards and computers did not support dual-card configurations. A summary of the additional energy required to run a second discrete graphics card is summarized in Table 4.

Table 4: Dual Graphics Card Energy Deltas: Results by Card (kWh/yr)

		PC4			PC6		
ECMA Category	GPU	Single Card d(iGfx)[1]	Dual Card d(single card)[2]	Dual Card d(iGfx)[3]	Single Card d(iGfx)[1]	Dual Card d(single card)[2]	Dual Card d(iGfx)[3]
1	GPU1	1.6	25.4	27.0	41.4	26.2	67.6
2	GPU3	12.9	23.1	36.0	51.3	27.3	78.5
3	GPU5	27.8	29.7	57.5	69.3	31.6	100.9
3	GPU6	47.3	57.6	104.9	83.8	55.2	138.9
4	GPU7	105.0	78.0	183.0	125.0	93.2	218.2
4	GPU8	98.6	106.6	205.2	120.1	131.1	251.3
5	GPU9	47.8	56.2	104.0	87.5	64.4	151.9
5	GPU10	46.7	58.5	105.2	76.9	82.4	159.3
7	GPU11	41.6	33.0	74.7	72.7	47.4	120.1
7	GPU12	239.7	277.3	517.0	326.3	296.0	622.3

Notes:

1. Single Card d(iGfx): Energy delta between single card and integrated graphics
2. Dual Card d(single card): Energy delta between the second card and the first one
3. Dual Card d(iGfx): Energy delta between the second card and integrated graphics

As illustrated by GPU1 in PC4 (Table 4), dual graphic card adders for PC4 are skewed by the fact that there is little difference between PC4's power demand with integrated graphics versus a single graphics card, because its integrated graphics card consumes a large amount of power in idle mode. Therefore, when the second graphics card is added to PC4, it consumes significantly more additional power than the first. This makes PC4's additional power for a second card abnormally high and not representative of the average computer.

PC6 is more representative of an average computer. The additional power needed to run a second graphics card is lower than that required for the first card. Second cards require on average 73% of the power of the first card on PC6.

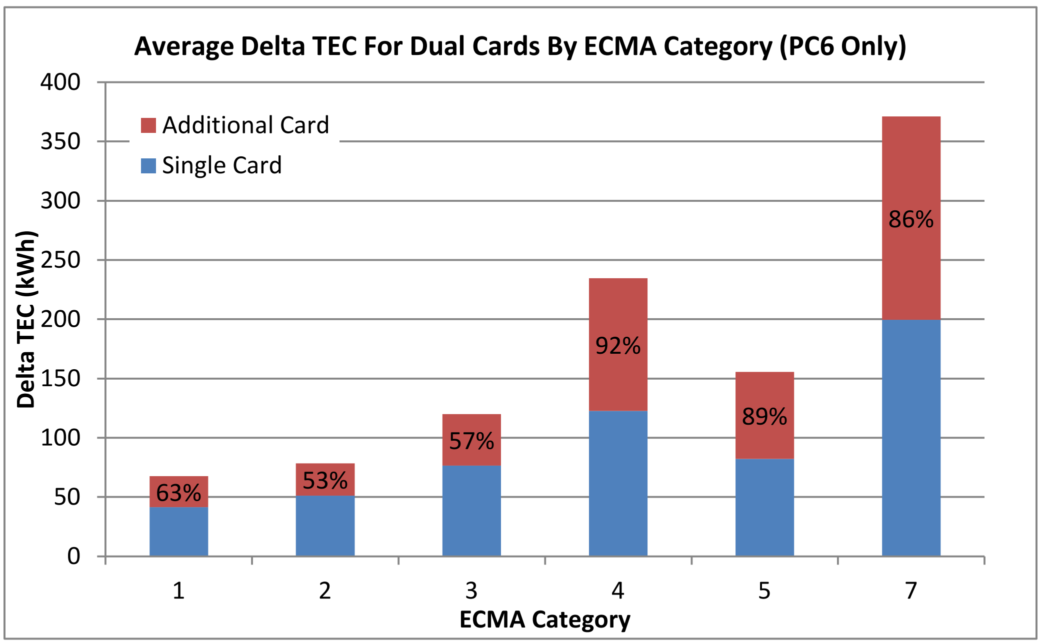
Some cards recently released in the market are capable of powering down the second card almost completely in dual card mode[23], however none of the cards tested in this study had that capability.

[23] http://blogs.amd.com/play/2012/01/30/power-efficiency-is-making-a-difference/

Table 5: Energy Delta (kWh/yr) for Dual Cards by ECMA Category for PC6

ECMA Category	Average Single Card d(iGfx)	Average Dual Card d(single card)	Second card as % of first card
1	41.4	26.2	63%
2	51.3	27.3	53%
3	76.6	43.4	57%
4	122.6	112.2	92%
5	82.2	73.4	89%
7	199.5	171.7	86%
		Average	73%

Figure 6: Average Energy Delta for Dual Cards by ECMA Category for PC6



Note: Table 5 and Figure 6 use ENERGY STAR v6.0 Draft 1 formulae. ENERGY STAR v5 shows similar ratios with different absolute values.

5. Recommendations

5.1 Setting Adders for Discrete Desktop Graphics Cards

The methodology of the study was designed so that test results are directly comparable to, and usable for the definition of, ENERGY STAR graphics adders.

Considerations for Setting Adders

Allowance Leakage: The annual typical energy consumption approach enables flexibility to implement the most cost-effective way to meet a standard. However, when adders represent a significant share of typical energy consumption (TEC), as is the case with graphics and display adders, rapid technology evolution can result in a large unwarranted allowance for the rest of the system, which could result in the qualification of relatively inefficient computers. We refer to this situation as "allowance leakage". It is an unintended consequence of the flexibility that the TEC approach provides, and can reduce the effectiveness of TEC-based standards if not managed appropriately.

Market Bias: Base TEC limits are set at the level that achieves a certain pass-rate in a given category after applying adders. When categories contain both systems with and without discrete graphics (as in ENERGY STAR v5.0 and v6.0 draft 2), setting adders too high will give systems that use discrete graphics an advantage over those that don't, resulting in a potential bias towards systems that benefit from the overly high adders. The reverse is also true for adders that are set too low.

Market bias can be avoided or minimized by separating systems that use discrete graphics from those that don't, and/or by ensuring that adders are set at an appropriate level.

Stringency of Adders

Making specific adder recommendations is not the purpose of this study. Adder levels will need to be set by programs based on independent analysis and assessment of test data. We provide here general guidance to standards and labeling program managers on how the results of this study can be utilized.

Recommendations are based on the following guiding principles:

- The stringency of adders depends on the objectives and the type of program being considered;
- Adders should be set at a certain percentile of the test dataset, including this study and any other complementary data source that uses a methodology consistent with this study;
- Adders should be no less stringent than the median of the test dataset, in order to minimize allowance leakage and market bias;
- The energy efficiency of discrete graphics is evolving rapidly as evidenced by the ZeroCore Power technology used by the AMD Radeon HD 7970 card. Program managers should take that evolution into account by setting adders slightly lower than their program qualification target rate to ensure the standards meet their objectives when in effect.

Table 6 below puts forth target percentile ranges for adder levels based on the study's test data and the guiding principles listed above.

Table 6 - Target Percentile of Dataset for Adder Setting

Program Type	Program Qualification Target	Set Adders in Following Percentile Range of Dataset
	Top 10% of market	**5^{th}-15^{th}**
	Top 25% of market	**20^{th}-30^{th}**
	Top half of market	**40^{th}-Median**
	Top 75% of market	**Median**

Use a linear regression based on frame buffer bandwidth to set adders

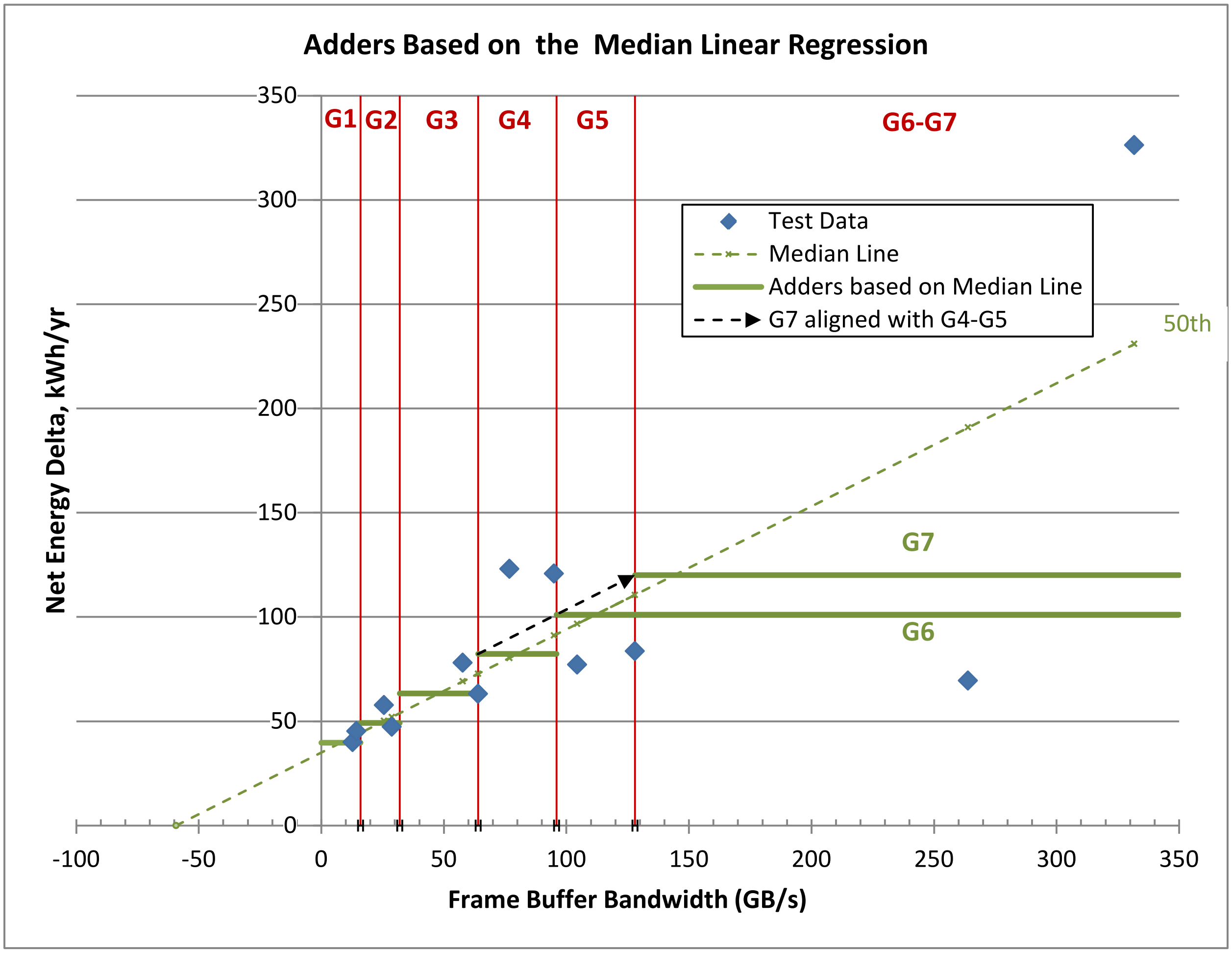
The approach of setting graphics card adders by taking the average or a target percentile of data points within each graphics category has limitations: the number of data points in each category is limited not just by testing costs and time, but also by the limited number of products available on the market in each category at any given time. As a result the target percentile for each category is very sensitive to the data available, which increases the risk of setting adders at inappropriate levels.

The alternative "linear regression" approach uses test data points across all graphics categories to establish the median and other percentile lines for the entire data set. The benefits of using a linear regression is that the adder levels are based on more test data, making the levels less vulnerable to outliers. Adders based on linear regression are illustrated in Figure 7 below.

Category adders are then calculated as follows:

- G1 through G5 are set at the mid-way point of the linear regression in each category;
- G6 is set equal to the G5 adder, following the approach by EPA in ENERGY STAR Version 6.0 Draft 2; and,
- G7 is aligned with the G4 and G5 adders, so that the difference between the G4 and G5 adder is equal to the difference between the G5 and G7 adder.

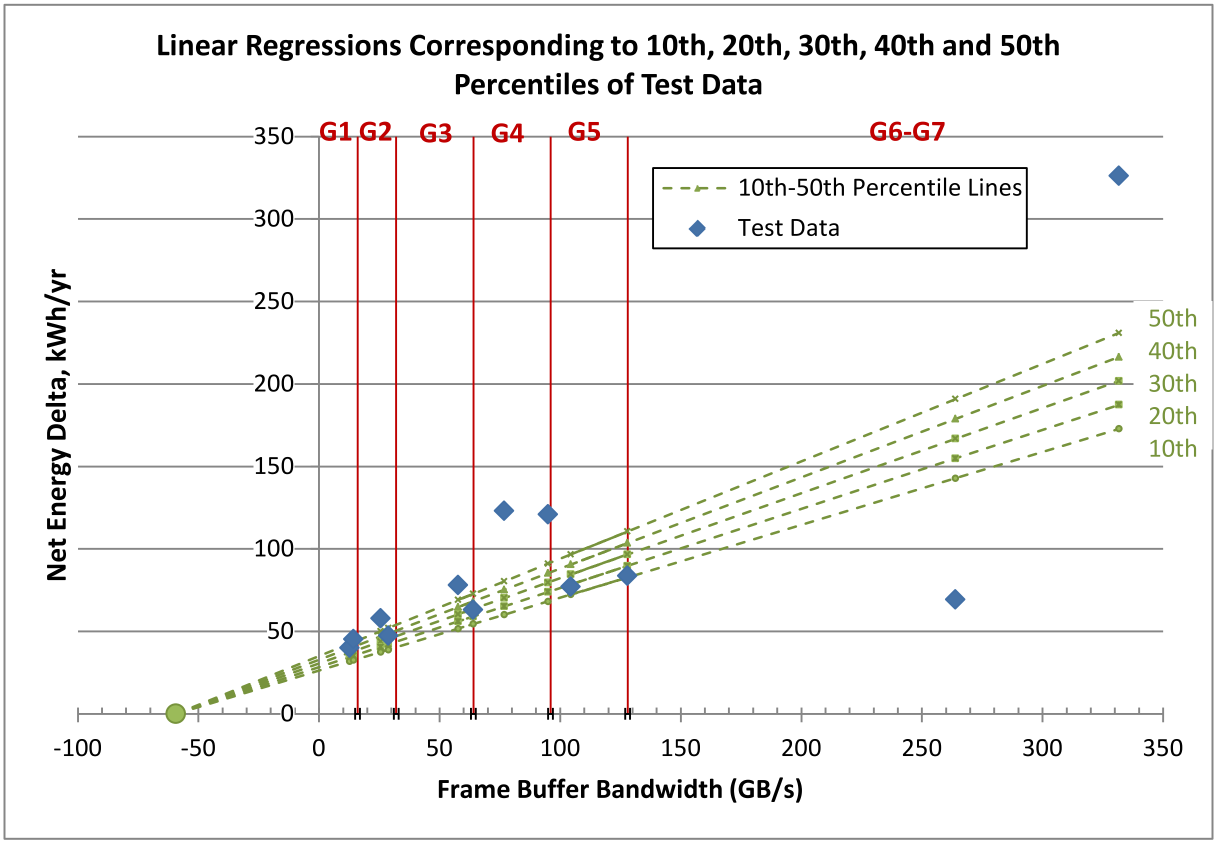
Figure 7: Adders Based on the Median Linear Regression



Setting adders by ECMA category creates a "stair-step" pattern. This can create incentives for higher frame buffer bandwidths, e.g., movement to the right on the graph from each category to utilize the higher adders at higher bandwidths. Note that we are not proposing to set graphics adder as a linear function of frame buffer bandwidth. While this would have the benefit of avoiding the discontinuities implicit in stair-steps, it would provide no absolute upper limit at high frame buffer bandwidths, and it could unfairly disadvantage some graphics card designs over others. Frame buffer bandwidth is an accepted performance proxy for the purpose of categorization, however it is not meant to be used as a pure performance metric.

To set adders based on lower percentiles, a similar approach can be followed using lower percentile lines such as those illustrated in Figure 8 below. These percentile lines are calculated by pivoting the median line around its x-intercept point so that only a given percentage of test data points is below or on the line. For example, the 25th percentile line is such that 25 percent of the data points are below or on it, and 75 percent above it. The median, 40th, 30th, 20th and 10th percentile lines are shown in Figure 8.

Figure 8: Linear regressions corresponding to 10th, 20th, 30th, 40th and 50th Percentiles of Test Data



Adders for each category can then be calculated in the same manner as illustrated for the median line above.

The line equations and corresponding adder values for each percentile line are given in Tables 7 and 8 below:

Table 7: Target Adder Levels (kWh/yr) Per Target Percentile – Energy Star v6.0

Percentile	Line Equation	G1	G2	G3	G4	G5	G6	G7
50th	y = 0.5905x + 35.0	40	49	63	82	101	101	120
40th	y = 0.5533x + 32.8	37	46	59	77	95	95	112
30th	y = 0.5162x + 30.6	35	43	55	72	88	88	105
20th	y = 0.4791x + 28.4	32	40	51	67	82	82	97
10th	y = 0.4420x + 26.2	30	37	47	62	76	76	90

Table 8: Target Adder Levels (kWh/yr) Per Target Percentile – Energy Star v5.0

Percentile	Line Equation	G1	G2	G3	G4	G5	G6	G7
50th	y = 0.5270x + 27.2	31	40	52	69	86	86	103
40th	y = 0.4921x + 25.4	29	37	49	65	81	81	96
30th	y = 0.4572x + 23.6	27	35	46	60	75	75	89
20th	y = 0.4224x + 21.8	25	32	42	56	69	69	83
10th	y = 0.3875x + 20.0	23	29	39	51	63	63	76

Managing the Impact of Breakthrough Innovation in Low-Power Graphics Technology

One of the two G7 cards tested shows dramatically lower energy use in idle mode than the other one (70 kWh vs. 326 kWh). This card, the AMD Radeon HD 7970, was the first card on the market to feature AMD's "ZeroCore Power" technology, which radically reduces idle power. This is very promising for the energy efficiency of computers using discrete graphics, however it creates a significant risk for the effectiveness of the ENERGY STAR Computer Specification.

The magnitude of the power reduction in idle mode enabled by AMD's ZeroCore Power technology makes the allowance leakage issue much more acute than with other cards in the test sample: any computer featuring the Radeon HD 7970 card could get a very large free allowance, enabling less efficient machines to qualify. ZeroCore Power and other similar technologies will likely become much more prevalent over the next 12-18 months, creating an increasingly large loophole in specifications based on legacy cards, and rendering them potentially ineffective once the majority of the discrete graphics market has adopted the technology. Ten other cards with low-power idle capability had been released by June 2012. This suggests that the market is rapidly adopting this type of technology.

This is an issue not just because overly high adders fail to encourage more efficient discrete graphics, but because they make the overall standard ineffective for computers with discrete graphics (fortunately this issue does not affect computers with integrated graphics).

In order to address this issue, program managers may consider using the following approach:

1. In the short-term, set adders based on the latest cards released in the market.
2. Closely monitor the market for the deployment of low-power idle technology, and conduct additional testing as necessary;
3. Revise adders as soon as there are multiple cards utilizing this technology in each category.

5.2 Setting Adders for Additional Graphics Cards (Beyond the First Card)

The study's dual card test results presented in section 4.4 indicate that additional discrete graphics cards do not use as much incremental power as the first card. Additional cards have different effects on system power demand from the first card: for example the card may not create as much incremental activity in CPU and memory as the first card. On the other hand, the energy use of integrated graphics is only avoided once by the first card. Test results indicate that the net effect of these two factors is that the second card uses less additional power than the first one by approximately 25%, as illustrated by Table 5 and Figure 6 in section 4.4.

This 25% ratio is based on testing on a single computer. This limited test data attaches a significant level of uncertainty to this ratio. Additional testing of dual-card configurations would be ideal. Alternatively, additional data from industry on this issue would also help strengthen this study's findings on this point.

The study did not test configurations with more than two discrete cards; therefore the incremental energy use of additional cards beyond the second card was not assessed. However, configurations with more than 2 cards are rare and in the absence of specific data, it seems reasonable to assume that their incremental power demand in idle is similar to that of the second card, for the same reasons.

5.3 Setting Adders for Discrete Notebook Graphics Cards

Notebook discrete graphics cards were not tested; therefore no recommendations are made on graphics adder values for notebooks, however interested readers are referred to the methodology proposed by EPA in ENERGY STAR v6.0 draft 2 to convert desktops graphics adders into notebook graphics adders by applying a ratio of 38%.[24]

[24] Slide 8 of EPA's presentation at the May 23, 2012 stakeholder meeting: http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/V6_D2_EPA_Presentation.pdf?7506-3135

6. Conclusion

This study used a unique approach to determining the system-level power impacts of computer discrete graphics cards. The traditional approach is based upon the internal DC power of the card and applies a power conversion factor to derive the AC power of the card. Instead the impact of a card was measured at the system level on a sample of host computer systems and the results were averaged out.

The study shows that incremental power demand due to the card varies significantly between host computers. This indicates that there are a number of factors other than the card itself that lead to increases in net system power demand. As a result, adders should be set on the basis of the net effect of all these factors.

The test sample of 12 cards and 6 test computers is representative of the 6 main graphics categories and of both major GPU manufacturers. It covers over a third of the desktop discrete graphics cards introduced on the market in 2011. Target adder values are provided based on the study’s test results.

The study also identified the emergence of a new technology with radically lower power demand in idle mode. This technology is very promising for the efficiency of desktop computers with discrete graphics. It also means that programs using adders based on legacy technology may quickly become obsolete due to allowance leakage. To address this issue interested parties are encouraged to conduct additional and ongoing testing using this study’s methodology to assess cards newly introduced on the market, and policy makers should rapidly adjust their programs to adapt to the deployment of new low-power idle technology.

This study’s methodology provides robust values from which to set graphics adders. As a result, standards and labeling program managers are encouraged to consider the recommendations made in this report when setting graphics adders.

7. Appendices

Appendix I – Test Methodology

Test Equipment

Testing was performed at an EPA-recognized, accredited test laboratory at Ecova, Inc.[25]. Equipment used for the testing phase of this study consists of high precision laboratory grade instruments. Ecova's measurement equipment is calibrated by an ISO/IEC 17025 accredited calibration laboratory. Equipment includes the following:

- Chroma Programmable AC Power Source 61602
- Yokogawa WT1600 Digital Power Meter

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

1. 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.
2. 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.

The Yokagawa WT1600 digital power meter exceeds ENERGY STAR instrumentation measurement accuracy requirements for computer testing. With power measurements at 115 volts, 60Hz in the 50 to 500 watt range (where most of the idle power measurements for desktop computers fell) the WT1600 has a measurement uncertainty of less than 0.3%. The propagated measurement uncertainty associated with calculating differences in power demand (which requires two measurements) can range between 0.5 W if idle power measures are near 70 W and 1.1 W if idle power measurements are near 200 W.

Energy Star Idle Mode Test Procedure

The standard ENERGY STAR Computers Test Procedure[26] was adjusted as follows:

1. Prior to testing, configure power management to trigger long-idle behavior (e.g. shutting down the screen and hard drives) at approximately 12 minutes.
2. Switch on the computer and begin recording elapsed time, starting either when the computer is initially switched on, or immediately after completing any log in activity necessary to fully boot the system.
3. Once logged in with the operating system fully loaded and ready, close any open windows so that the standard operational desktop screen or equivalent ready screen is displayed.
4. After 5 minutes or less after the initial boot or log in, set the meter to begin accumulating true power values at a frequency greater than or equal to 1 reading per second for approximately 12 minutes. This constitutes the short-idle measurement.
5. Accumulate power values for 8 to 10 additional minutes to capture long-idle measurements. (Note: both short and long-idle power measurements were captured in a single run.)

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[25] For accreditation 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

[26] http://www.energystar.gov/ia/partners/product_specs/program_reqs/Computers_Program_Requirements.pdf?1bf5-bee9

Multi-Card Test Methodology

Multi-capable cards were tested in both single and multi-card configurations. There were 10 multi-capable cards and 2 systems capable of utilizing these NVIDIA® SLI™ and AMD CrossFireX™ configurations. Each unique configuration was tested three times. Multi-card testing also used the ENERGY STAR July 21st, 2011 test method[27] for measuring short and long idle mode:

Idle Mode testing

1. Prior to testing, configure power management to trigger long-idle behavior (e.g. shutting down the screen and hard drives) at approximately 12 minutes.
2. Switch on the computer and begin recording elapsed time, starting either when the computer is initially switched on, or immediately after completing any log in activity necessary to fully boot the system.
3. Once logged in with the operating system fully loaded and ready, close any open windows so that the standard operational desktop screen or equivalent ready screen is displayed.
4. After 5 minutes or less after the initial boot or log in, set the meter to begin accumulating true power values at a frequency greater than or equal to 1 reading per second for approximately 12 minutes. This constitutes the short-idle measurement.
5. Accumulate power values for 8 to 10 additional minutes to capture long-idle measurements. (Note: both short and long-idle performance will be captured in a single run.)

Other Test Conditions and Documentation

Each of the following comes directly from the ENERGY STAR test method unless otherwise noted.

- Desktop computers shall be configured with a standard mouse, keyboard and external display.
- Primary hard drives shall not be power managed ("spun-down") during short-idle testing unless containing non-volatile cache integral to the drive (e.g. "hybrid" hard drives or similar non-removable disk caching architectures). For long idle testing, set the hard drive to spin down after 12 minutes of testing.[28]
- The computer display power management settings shall be set to prevent the display from powering down to ensure it stays on for the full length of short-idle testing. For long idle testing, set the display to shut down after 12 minutes of testing [28]
- All tests will be conducted with an active Ethernet network connection with full network connectivity.[29]
- All component drivers will be updated via the manufacturer's website prior to testing.[30] The laboratory technician will install NVidia and AMD/ATI's control panel software and record graphics card settings for each test. The laboratory technician will check the control panel

[27] http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/Computers_Test_Method_Rev_July_2011_Draft.pdf?abd9-54e8

[28] This requirement does not come directly from the ENERGY STAR test method. We have specifically selected the 12 minute point for spinning down the hard drive as an ideal time to start long idle behavior.

[29] If there is significant variability in the instantaneous power measurements during the test runs the project team may disable the Ethernet connection to reduce variability.

[30] This requirement does not come directly from the ENERGY STAR test method. We have added this since we will utilize custom-built machines that will need certain software updates prior to testing.

software to ensure no settings have been automatically changed when installing a new card, and will confirm that default settings are chosen.

- Computers will be tested with Wake-on-LAN (WOL) enabled for all tests.
- Default (as shipped) Windows 7 operating system settings shall be used unless otherwise specified.[30] Windows 7 power management settings are as follows:

Table 9: Proposed power management settings

Windows 7 Option	Proposed Settings
Turn off display	12 min
Put computer to sleep	30 min
Turn off hard disk	12 min
Wireless Adapter settings *(options include: max performance, low power saving, med power saving, and max power saving)*	max performance
Allow hybrid sleep	on
Hibernate after	never
Allow wake timers	enabled
USB selective suspend setting	enabled
PCI Express Link State Power Management *(specifies the Active State Power Management (ASPM) policy to use for capable links when the link is idle. Other options include 'off' and 'max power saving')*	moderate power savings
Put GPU to sleep	never[31]
Min processor state	5%
System cooling policy	active
Max processor state	100%
JavaScript Timer Frequency	max performance
When sharing media	prevent idling to sleep
When playing video	optimize video quality

[31] Certain GPU's may be tested in a setting that allows for the graphics card to be powered down in idle state (e.g. the AMD HD7970)

Appendix II – Graphics Card Models

Table 10. Discrete Graphics Card Models and Characteristics

ECMA-383 (v6)	Manu.	GPU Model	Date of Release	Card FBB (GB/s)	Max GPU Power (W)	Manufacturer Recommended PSU Power (W)	SLI/CrossFire X Capability	Price ($)	Graphics Card and Product Link	Quantity
G1	ATI/AMD	Radeon HD 6450	Apr '11	12.8	18	400 (500 for dual)	2-way	47	Gigabyte GV-R645D3-512I	2
G1	NVIDIA	GeForce GT 520	Apr '11	14.4	29	300	none	55	MSI N520GT	1
G2	ATI/AMD	Radeon HD 6570	Apr '11	28.8	44	400 (500 for dual)	2-way	70	Sapphire 100323L	2
G2	NVIDIA	GeForce GT 440	Feb '11	25.6	65	300	none	80	EVGA 01G-P3-1441-KR	1
G3	ATI/AMD	Radeon HD 6670	Apr '11	64.0	66	400 (500 for dual)	2-way	97	Sapphire 100326L	2
G3	NVIDIA	GeForce GTS 450	Sep '10 /Mar'11	57.7	106	400	2-way	120	Gigabyte GV-N450-1GI	2
G4	ATI/AMD	Radeon HD 6770	Jun '11	76.8	108	not listed	2-way	107	PowerColor AX6770 1GBD5-H	2
G4	NVIDIA	GeForce GTX 460	Jul '10	95.0	160	450	2-way	79	Galaxy 60XMH6HS3HMW GeForce GTX 460 GC Edition	2
G5	ATI/AMD	Radeon HD 6850	Oct '10	128.0	127	500	2-way	145	HIS H685FN1GD Radeon HD 6850	2
G5	NVIDIA	GeForce GTX 550	Mar '11	104.5	116	400	2-way	145	EVGA 01G-P3-1556-KR	2
G7	ATI/AMD	Radeon HD 7970	Jan '12	264.0	250	500	2-way	550	DIAMOND 7970PE53G Radeon HD 7970	2
G7	NVIDIA	GeForce GTX 590	Mar '11	165.9	365	700	4-way	750	EVGA 03G-P3-1596-AR	2
									Total:	**22**

The test sample represents 36% of AMD and NVIDIA cards released in 2011 (not including configuration variations such as different memory configurations). This ratio does not include the two 2010 cards and the 2012 card. The 2010 cards were chosen because there were no 2011 models meeting the category requirements. The 2012 card was chosen in order to evaluate the potential of AMD's "ZeroCore Power" technology.

Model	Date Released	In Study	
Radeon HD 6850	22-Oct-10	Y	
GeForce GTX 460	15-Nov-10	Y	
…			
Radeon HD 6290	7-Jan-11		
Radeon HD 6750	21-Jan-11		
Radeon HD 6350	7-Feb-11		
Radeon HD 6450	7-Feb-11	Y	
Radeon HD 6570	7-Feb-11	Y	
Radeon HD 6670	7-Feb-11	Y	
Radeon HD 6990	8-Mar-11		
Radeon HD 6790	4-Apr-11		
Radeon HD 6770	28-Apr-11	Y	
Radeon HD 6410	20-Jun-11		
Radeon HD 6530	20-Jun-11		
Radeon HD 6550	20-Jun-11		
Radeon HD 6320	15-Aug-11		
Radeon HD 6370	1-Nov-11		
Radeon HD 6930	Dec-11		
GeForce GTX 560	25-Jan-11		
GeForce GT 440	1-Feb-11	Y	
GeForce GTX 550	15-Mar-11	Y	
GeForce GTX 590	24-Mar-11	Y	
GeForce GT 520	12-Apr-11	Y	
GeForce GT 530	14-May-11		
GeForce GT 545	14-May-11		
GeForce GTX 560	17-May-11		
GeForce GTS 450	1-Sep-11	Y	
GeForce 510	29-Sep-11		
Radeon HD 7970	9-Jan-12	Y	
	2011	9	36%

Appendix III – Test Computer Configurations

Overview

Six computer configurations were built, each with a unique central processing unit (CPU) and motherboard pairing. These six configurations were combined with a set of secondary computer components including storage drive, system memory, computer case, power supply unit (PSU), optical drive, and operating system to create six different computers identified as 'PC1', 'PC2', 'PC3', 'PC4', 'PC5', 'PC6' for testing.

The following goals and criteria were used to develop the CPU and motherboard pairings for the computers in which the discrete graphics cards were to be tested. Secondary components are also defined.

Goal

The project was tasked with the following:

> *Determine the change in idle-mode power demand when replacing integrated graphics on a computer with a discrete graphics card solution across a representative but constrained set of contemporary computers and discrete cards.*

Given the wide variation in computer components and discrete graphics cards, a comprehensive test of every possible configuration is logistically impossible, so careful selection of components becomes critical.

Requirements for Meeting the Goal

Before selecting specific components, the project first developed the following requirements to achieve the goal (presented in order of importance):

1. Include major market components for CPU and integrated graphics
    a. Include both Intel and Advanced Micro Devices (AMD) processors.
    b. Include integrated graphic solutions on CPU and on motherboard.
    c. Include single card and multiple card configurations.

2. Capture a range of low to high performance computers available in late 2011.
    a. Develop computers that approximately parallel the mainstream, performance, enthusiast and very high-end enthusiast computers as defined by industry proposed ENERGY STAR 6.0 performance categories for desktop computers (See Table 11).[32]
    b. Select motherboards and CPUs that reflect most recent technology at price points that match the four categories above.

[32] Information Technology Industry Council Comments on Energy Star Computers Version 6, March 10 2011 Kickoff Meeting. Avalable: http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/ITI_Comments_4.pdf

General Hardware Design

Based on the goals and requirements for the project, Ecova developed motherboard and CPU pairings presented in this document. This includes discussion of:

- Computer Construction – General plans for building computers specifically for this testing.
- CPU – Plans and considerations for selection of CPU manufacturers and performance levels.
- Integrated Graphics – Plans and considerations for whether integrated graphics will be provided on the motherboard or CPU.
- Motherboards – Plans and considerations for motherboard selection.

Computer Construction

As noted earlier, due to the nature of the project the test approach utilizes 'build-your-own' desktop computers rather than unique original equipment manufacturer (OEM) computer models. This approach allowed us to:

1. Easily swap out discrete graphics card quickly in a laboratory setting.
2. Preserve the option to control or vary different secondary components, such as hard disk drive (HDD) and power supply unit (PSU), as needed.

CPU

Desktop CPUs from the world's two largest manufacturers, Intel and AMD, were utilized. To better reflect market share, the tests covered four Intel and two AMD CPUs.[33] CPU performance capabilities and number of internal cores were chosen to fit appropriately into one of the targeted computer market segments that parallel the ENERGY STAR 6.0 categories for desktops proposed by industry. These market segments have their own hardware and performance requirements (Table 11). These segments are: Entry, Mainstream, Performance, High Performance, Very High-end/Enthusiast. An entry level desktop configuration was excluded from this project because this low performance category is becoming less common in today's market, particularly for configurations with discrete graphics. Given the project's timing and funding constraints, this category was considered the lowest priority and was excluded from scope.

As the project scope is limited to only six computers, only two categories will include multiple computers. To support multiple card testing (SLI and CrossFireX cards), the tests required at least two computers at the High-Performance or Enthusiast category. This leaves one other computer category that could contain multiple computers. Selecting this category first requires considering the CPU capabilities available to consumers.

As of December of 2011, Intel was shipping CPUs that span the range of low performance to high performance. These appear in all-in-one systems and in both reduced-size and full tower form factors. In these systems, on-die graphics are available for both low and high end computing solutions, although high-end systems are generally paired with discrete cards.

[33] As of Q2 2011, Intel's overall worldwide CPU share is approximately 79.3 percent, while AMD's is 20.4 percent. From http://www.engadget.com/2011/08/02/amds-market-share-tiptoes-higher-intel-still-ruler-of-the-roos/

In contrast, a survey of performance reviews and major vendors shows that AMD is less present as an Enthusiast / Very High End solution. On comparative benchmarks, the AMD Phenom II x4 (which is not the latest AMD CPU) remains the most commonly recommend performance AMD solution, and in OEM configurations, the Phenom II x4 also appears to be performance choice for AMD. However, the Phenom chip does not provide on-die graphics; in fact AMD only provides on-die solutions to the All-in-one, Laptop, and Mainstream markets (via the Fusion). To include an AMD CPU with an on-die solution means that the test configurations must include an AMD Fusion, which logically fits in the Mainstream category.

Beyond this, the test suite still requires an AMD-based computer with multiple graphics card support to compare multiple card performance across Intel/AMD. Without a true AMD competitor to Intel's i7, this last computer uses AMD's fastest solution, the Phenom II x4: placing this computer in the High Performance category.

Table 11. Proposed ENERGY STAR 6.0 Draft 2 Desktop Categories

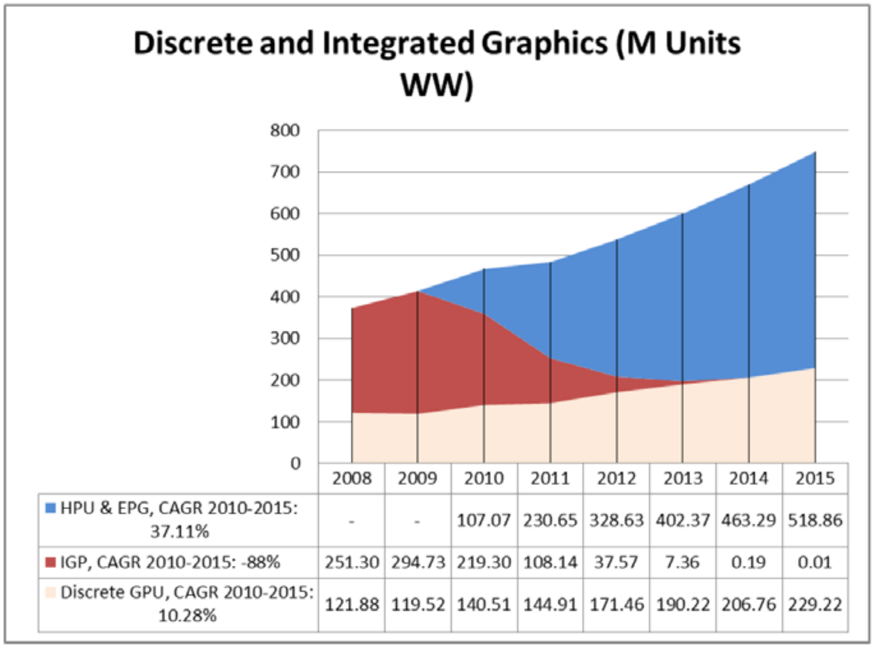
Category	DT 0	DT 1	DT 2	DT 3	DT 4
Market *	Entry	Mainstream	Performance	High Performance	Very High-end/Enthusiast
Cores	N/A	cores ≤ 2 (less than or equal to 2 cores)	≥3 cores (greater than or equal to 3 cores)	≥4 Cores (greater than or equal to 4 cores)	≥4 Cores (greater than or equal to 4 cores)
Channels of memory	Ch mem = 1 (1 Channel of memory)	Ch mem = 2 (2 Channels of memory)	≥ 2 channels (more than or equal to 2 channels of memory)	≥2 Channels (more than or equal to 2 channels of memory)	≥2 Channels (more than or equal to 2 channels of memory)
Base memory (min)	1GB	2GB	2GB	≥4 GB	≥4 GB
Base Graphics	iGfx (integrated graphics)	iGfx (integrated graphics)	iGfx (integrated graphics)	dGfx ≥ G5 based on 7-class dGfx classes (any additional dGfx allowed)	dGfx ≥ G5 based on 7-class dGfx classes (any additional dGfx allowed)
Graphics Adders	dGfx ≤ G7 (less than or equal to G7)	dGfx ≤ G7 (less than or equal to G7)	dGfx ≤ G7 (less than or equal to G7)	≥G6 (greater than or equal to G6)	≥G6 (greater than or equal to G6)
PCIe					≥2 PCIe slots/end points of x8 or x16 configuration
PSU Rating					≥500W
Form Factor	Both Traditional & Integrated DT	Both Traditional & Integrated DT	Both Traditional & Integrated DT	Both Traditional & Integrated DT	Traditional (with expansion slots)

Source: Information Technology Industry Council Comments on Energy Star Computers Version 6, March 10 2011 Kickoff Meeting. Available at: http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/ITI_Comments_4.pdf

Integrated Graphics

Each of the six computer configurations contained an integrated graphics processing (IGP) solution, either integrated on the motherboard or on the CPU die (often called embedded processor graphics, or EPG). Jon Peddie Research suggests that EPG devices will almost entirely replace the IGP market by 2014 (Figure 9). Because of this trend, four computer configurations were selected with graphics integrated directly into the CPU die and the remaining two with graphics integrated on the motherboard. *Only systems that have some form of integrated graphics were tested.* The nature of the study's testing requires an integrated graphics option to serve as the baseline for each of the six computer configurations.

Figure 9. Embedded processor graphics (EPG) overtakes integrated graphics processors (IGPs) by 2014.



	2008	2009	2010	2011	2012	2013	2014	2015
HPU & EPG, CAGR 2010-2015: 37.11%	-	-	107.07	230.65	328.63	402.37	463.29	518.86
IGP, CAGR 2010-2015: -88%	251.30	294.73	219.30	108.14	37.57	7.36	0.19	0.01
Discrete GPU, CAGR 2010-2015: 10.28%	121.88	119.52	140.51	144.91	171.46	190.22	206.76	229.22

Source: Jon Peddie; http://jonpeddie.com/media/presentations/an-analysis-of-the-gpu-market/

Motherboard

For computer configurations sharing the same ENERGY STAR performance category, motherboards were chosen from the same manufacturer to eliminate any ambiguity in the data that could be manufacturer specific. However, motherboard from different manufacturer were used across different tiers of performance (i.e. proposed ENERGY STAR category) to allow for an appropriate mix of manufacturers and associated energy use implications (if any).

Motherboard chipsets correspond to the CPU manufacturer (i.e., Intel CPUs were paired with motherboards equipped with Intel chipsets) and were selected relative to the performance of the CPU. This ensured that the key components of each computer were fairly representative of the market.

Of the six motherboards, two were also capable of utilizing multiple (two or more) discrete graphics cards from either AMD or NVIDIA. These multiple-card technologies are commonly known as ‘SLI’ when referring to NVIDIA based graphics options and ‘CrossFireX’ when referring to AMD/ATI based graphics options. These two motherboards will be paired with an EPG integrated graphics option.

Other features:

- All motherboards support dual channels of memory.
- All motherboards selected are equipped with common features such as integrated audio and networking.
- Additional motherboard features (such as SATA and USB communication interfaces as well as memory capacity) do not dictate motherboard selection as these features tend to correspond with the motherboard chipset.

Secondary Components

Ecova built six computer configurations with unique central processing unit (CPU) and motherboard pairings as previously defined. These six configurations were combined with a set of secondary computer components including power supply unit (PSU), memory, storage, optical drive and computer case to create six different computers. The following criteria were used to develop secondary component selections for the computers in which the discrete graphics cards will be tested.

Power supply unit (PSU)

See separate discussion in section 4.7 of the main report.

Memory

Memory varies for each of the six computer configurations. In general, as computer performance increases so does memory size and speed. Memory latency also decreases as P computer performance increases. In addition, motherboard specifications also dictates the size and speed of memory that was utilized for each computer configuration.

Storage

For each of the six computer configurations, the same storage (hard disk drive) make and model were used. We believe that the choice of storage drive had no significant impact on the graphics card idle power demand.

Optical drive

For each of the six computer configurations, the same optical drive make and model was used. We believe that the choice of optical drive type and speed had no a significant impact on the graphics card idle power demand. This device should not be active during short and long idle mode testing.

Computer Case

For each of the six computer configurations, the same computer case make and model and associated cooling system was used.[34] We believe that the choice of computer case had no significant impact on the graphics card idle power demand.

Detailed Test Computer Configurations

The specific test computer configurations are detailed in Table 12 on the following page.

[34] Each computer was tested in the same room under ENERGY STAR required temperature and humidity conditions.

Table 12: Test Computer Configurations

Test PC	PC1	PC2	PC3	PC4	PC5	PC6
Market Class	Entry	Slim	Basic Commercial	Budget Gaming	Performance	Enthusiast Gaming
Proposed ENERGY STAR Category	DT1 Mainstream	DT2 Performance	DT2 Performance	DT3 High Performance	DT3 High Performance	DT4 Enthusiast
CPU Manufacturer	Intel	AMD	Intel	AMD	Intel	Intel
CPU Performance	Intel Core 2 Duo E7600 Wolfdale 3.06GHz (Dual-Core)	AMD A8-3850 Llano 2.9GHz (Quad-Core)	Intel Core i5-2300 Sandy Bridge 2.8GHz (Quad-Core)	AMD Phenom II X4 960T Zosma 3.0GHz (Quad-Core)	Intel Core i5-2500K Sandy Bridge 3.3GHz (Quad-Core)	Intel Core i7-2600K Sandy Bridge 3.4GHz (Quad-Core)
Type of Integrated Graphics	integrated on motherboard (IGP)	integrated into CPU die (EPG)	integrated into CPU die (EPG)	integrated on motherboard (IGP)	integrated into CPU die (EPG)	integrated into CPU die (EPG)
Motherboard	GIGABYTE GA-G41MT-S2P LGA 775 Intel G41	MSI A75A-G35	MSI P67A-C43 (B3) LGA 1155 Intel P67	ASUS Sabertooth 990FX Socket AM3+	ASUS P8Z68-V PRO/GEN3 LGA 1155 Intel Z68	ASRock Z68 Extreme7 Gen3 LGA 1155 Intel Z68
Power Supply Unit 1	Non-80+ 300W Athena Power AT30	80+ Bronze 300W SeaSonic SS-300ES	80+ Gold 300W TBD	Non-80+ 300W Athena Power AT30	80+ 300W FSP Group FSP300-60GHS-R	80+ 300W FSP Group FSP300-60GHS-R
Power Supply Unit 2 (as needed)	Non-80+ 450W Coolmax CX-450B	80+ Bronze 450W COOLER MASTER GX 450W RS450-ACAAD3	80+ Gold 450W Rosewill CAPSTONE Series CAPSTONE-450	Non-80+ 550W Ultra LSP550 550-Watt	80+ 550W OCZ Fatal1ty 550W	80+ 650W Sunbeam PSU-ECO650
Power Supply Unit 3 (dual-card only)	None	None	None	80+ 1000W Thermaltake TR2 RX TRX-1000M	None	80+ 1000W Thermaltake TR2 RX TRX-1000M
Channels of Memory	2	2	2	2	2	2
Base Memory	2GB	2GB	2GB	4GB	4GB	8GB
Memory Model	Crucial 2GB DDR3 SDRAM DDR3 1066 (PC3 8500)	G.SKILL NS 2GB DDR3 SDRAM DDR3 1333 (PC3 10600)	Kingston HyperX 2GB DDR3 1333 (PC3 10600)	G.SKILL Ripjaws Series 4GB (2 x 2GB) DDR3 SDRAM DDR3 1600 (PC3 12800)	CORSAIR DOMINATOR GT 4GB (2 x 2GB) DDR3 DDR3 1866 (PC3 14900)	G.SKILL Ripjaws X Series 8GB (2 x 4GB) DDR3 SDRAM DDR3 2133 (PC3 17000)
Storage	Western Digital Caviar Blue 500GB HDD	Western Digital Caviar Blue 500GB HDD	Western Digital Caviar Blue 500GB HDD	Western Digital Caviar Blue 500GB HDD	Western Digital Caviar Blue 500GB HDD	Western Digital Caviar Blue 500GB HDD
Optical Drive	ASUS 24X DVD Burner	ASUS 24X DVD Burner	ASUS 24X DVD Burner	ASUS 24X DVD Burner	ASUS 24X DVD Burner	ASUS 24X DVD Burner
Computer Case	Antec Nine Hundred Two V3	Antec Nine Hundred Two V3	Antec Nine Hundred Two V3	Antec Nine Hundred Two V3	Antec Nine Hundred Two V3	Antec Nine Hundred Two V3
Multi-Card Capable	No	No	No	Yes	No*	Yes
Operating System	Windows 7	Windows 7	Windows 7	Windows 7	Windows 7	Windows 7

Appendix IV – Power Supply Configurations and Efficiencies

Power Supply Models

Table 13: Power Supply Models

PSU ID	Mfr / Model	80-PLUS Category	Power Rating (W)
PSU1	COOLMAX CA-300 300W ATX	Non-80+	300
PSU2	SeaSonic SS-300ES	80+ Bronze	300
PSU3	FSP AURUM GOLD 400	80+ Gold	400
PSU4	COOLMAX CA-300 300W ATX	Non-80+	300
PSU5	FSP Group FSP300-60GHS-R	80+	300
PSU6	FSP Group FSP300-60GHS-R	80+	300
PSU7	Coolmax CX-450B	Non-80+	450
PSU8	COOLER MASTER GX 450W RS450-ACAAD3	80+ Bronze	450
PSU9	Rosewill CAPSTONE Series CAPSTONE-450	80+ Gold	450
PSU10	Ultra LSP550 550-Watt	Non-80+	550
PSU11	OCZ Fatal1ty 550W	80+	550
PSU12	Sunbeam PSU-ECO650	80+	650
PSU13	Antec CP-1000 1000W	80+	1000
PSU14	Antec CP-1000 1000W	80+	1000

PSU1 and PSU 4, PSU5 and PSU6, and PSU13 and PSU 14 are the same and were purchased in duplicate in order to enable parallel testing to reduce testing time.

Computer - Power Supply Combinations

Table 14: Computer-Power Supply Combinations

		PSU Tier A			PSU Tier B			PSU Tier C		
PC ID	**PC Market Class**	**ID**	**Power rating (W)**	**Efficiency Rating**	**ID**	**Power rating (W)**	**Efficiency Rating**	**ID**	**Power rating (W)**	**Efficiency Rating**
PC1	Entry	PSU1	300	Non-80+	PSU7	450	Non-80+			
PC2	Slim	PSU2	300	80+ Bronze	PSU8	450	80+ Bronze			
PC3	Basic Commercial	PSU3	400	80+ Gold	PSU9	450	80+ Gold			
PC4	Budget Gaming	PSU4	300	Non-80+	PSU10	550	Non-80+	PSU13	1000	80+
PC5	Performance	PSU5	300	80+	PSU11	550	80+	PSU13	1000	80+
PC6	Enthusiast Gaming	PSU6	300	80+	PSU12	650	80+	PSU14	1000	80+

PSUs 1-6 were used for baseline tests and low-power discrete graphics cards. PSUs 7-12 were used for higher power cards and dual-card tests. PSU13 and 14 were used for GPU 12 due to its high peak power requirements.

Detailed computer-GPU-PSU combinations are available in the study spreadsheet.

Influence of Power Supply Efficiency on Test Results

The changes in power supply conversion losses between configurations with and without the discrete graphics card is legitimate and representative of market reality, however it raises two questions regarding the accuracy of the test results in this study:

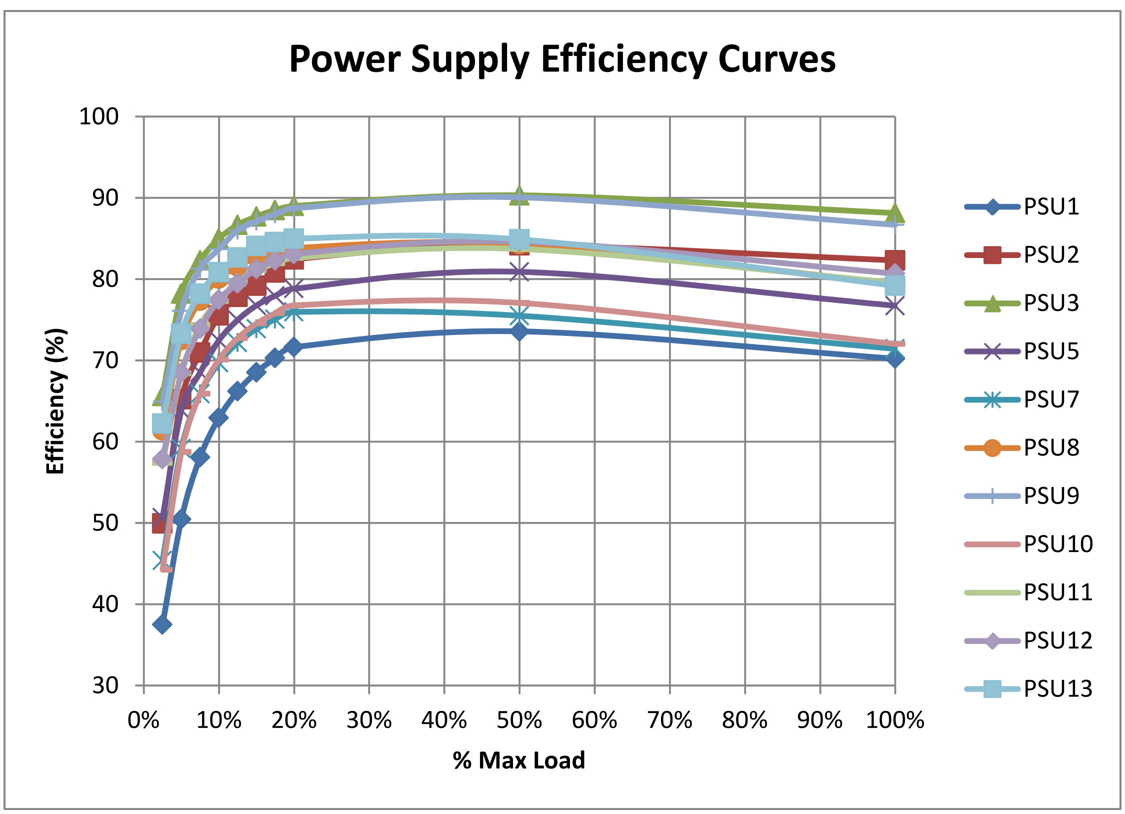
1. Are the power supply effects a significant factor in the reported discrete graphics card net impact values? If they were, power supply choices could introduce significant variability in the measurements, independently from the discrete graphics card.
2. While upsized PSUs of comparable efficiency with baseline PSUs were selected, did upsizing the PSU introduce significant variability in the net TEC impact results?

To answer these questions, with Intel's, Ecova and EPRI's help, the power supplies used for the project were benchmarked to determine their efficiency profile. This data was used to back-calculate the following quantities:

1. System DC power for both baseline systems (with iGfx) and with the discrete graphics card;
2. Hypothetical discrete graphics card AC power using the baseline PSU. This is hypothetical because such a computer may not be able to operate the discrete graphics card at peak load. It is only calculated to allow the comparison between the baseline operating load point and that of the upsized PSUs.

Figure 10 shows power supply efficiencies as measured by Intel and EPRI:

Figure 10: Power Supply Efficiency Curves



Figures 11 and 12 illustrate the changes in load point of the PSUs, and the corresponding PSU efficiencies. The charts below cover only GPU1 for clarity. Charts showing all GPUs are available in the project data file[35].

Figure 11: PSU Load Points for GPU1[36]

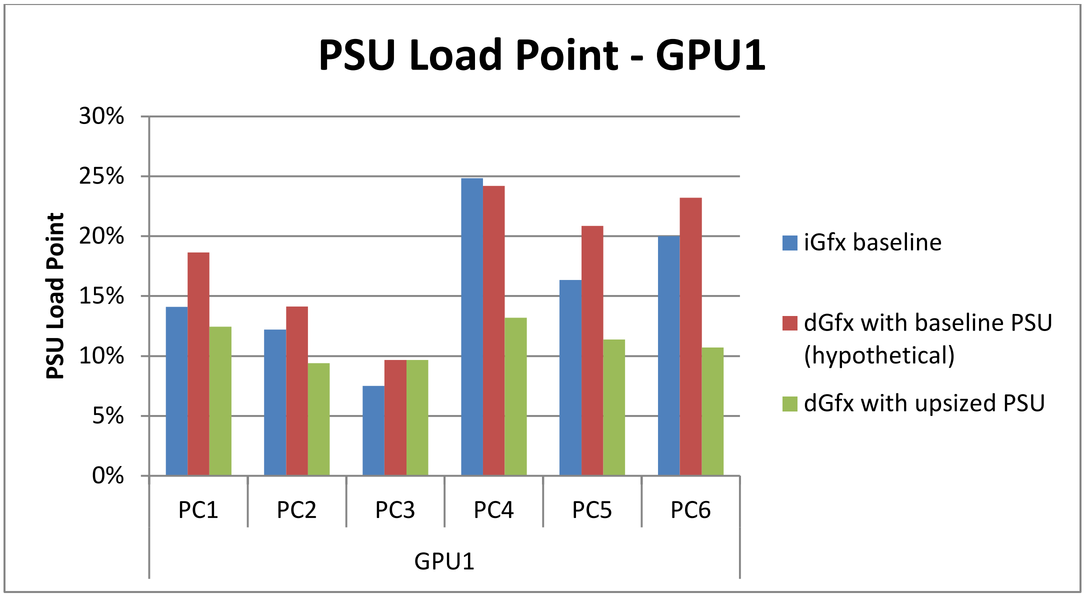
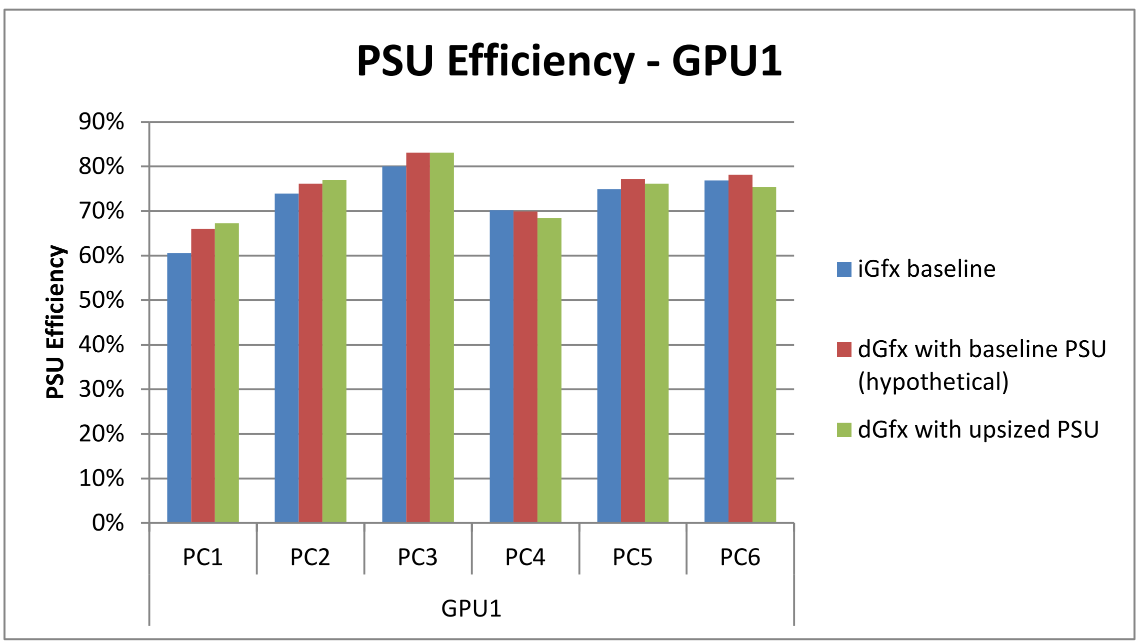


Figure 12: PSU Efficiencies for GPU1



[35] http://www.clasponline.org/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2012/Impact-of-Graphics-Cards-on-Desktop-Computer-Energy-Consumption

[36] Note that the PSU on PC3 was not upgraded because the baseline PSU was able to support the discrete graphics card at peak power. All other PCs had their PSU upgraded.

Figure 12 shows that PSU upsizing had a relatively minor and mixed impact on PSU efficiencies: the efficiency of upsized PSUs at discrete graphics card idle load point were slightly higher or slightly lower than the efficiency of the baseline PSU, depending on each computer-discrete graphics card-PSU configuration. Overall, the chart does not indicate outsized impacts from PSU upsizing.

The impact of overall PSU conversion losses and of PSU upsizing, averaged across all 5 test computers (excluding PC4), are shown on Figures 11 and 12:

Figure 13: Contribution of PSU conversion losses to discrete graphics card adders

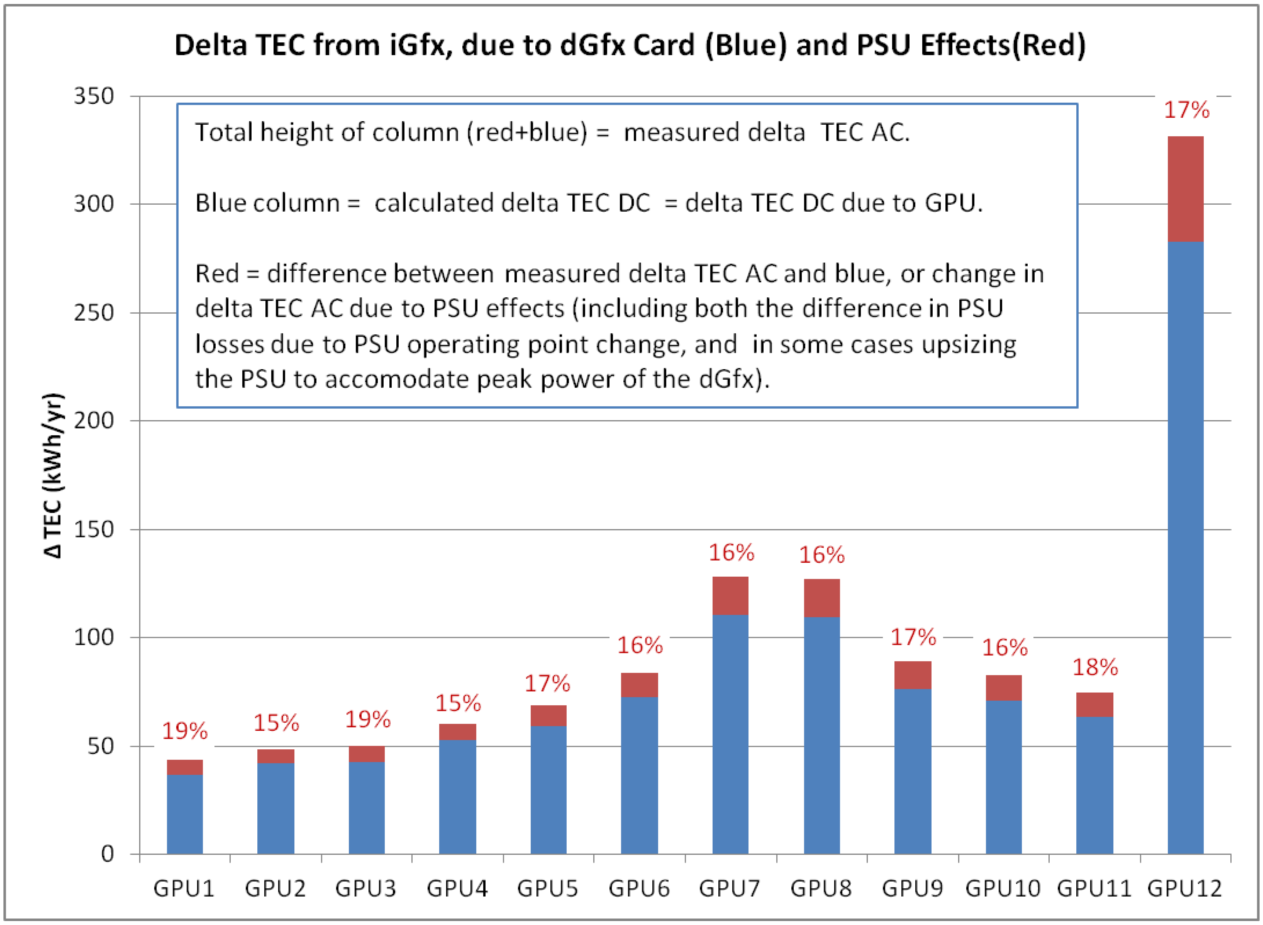


Figure 13 shows that on average, 17% of the net discrete graphics card impact is due to changes in conversion losses in the PSU when adding a discrete graphics card. The vast majority of the TEC delta comes from internal power changes due to the discrete graphics card, not to differences in conversion efficiency.

Figure 14: Effect of PSU Upsizing Alone (Excluding Changes in DC Power and PSU Operating Point)

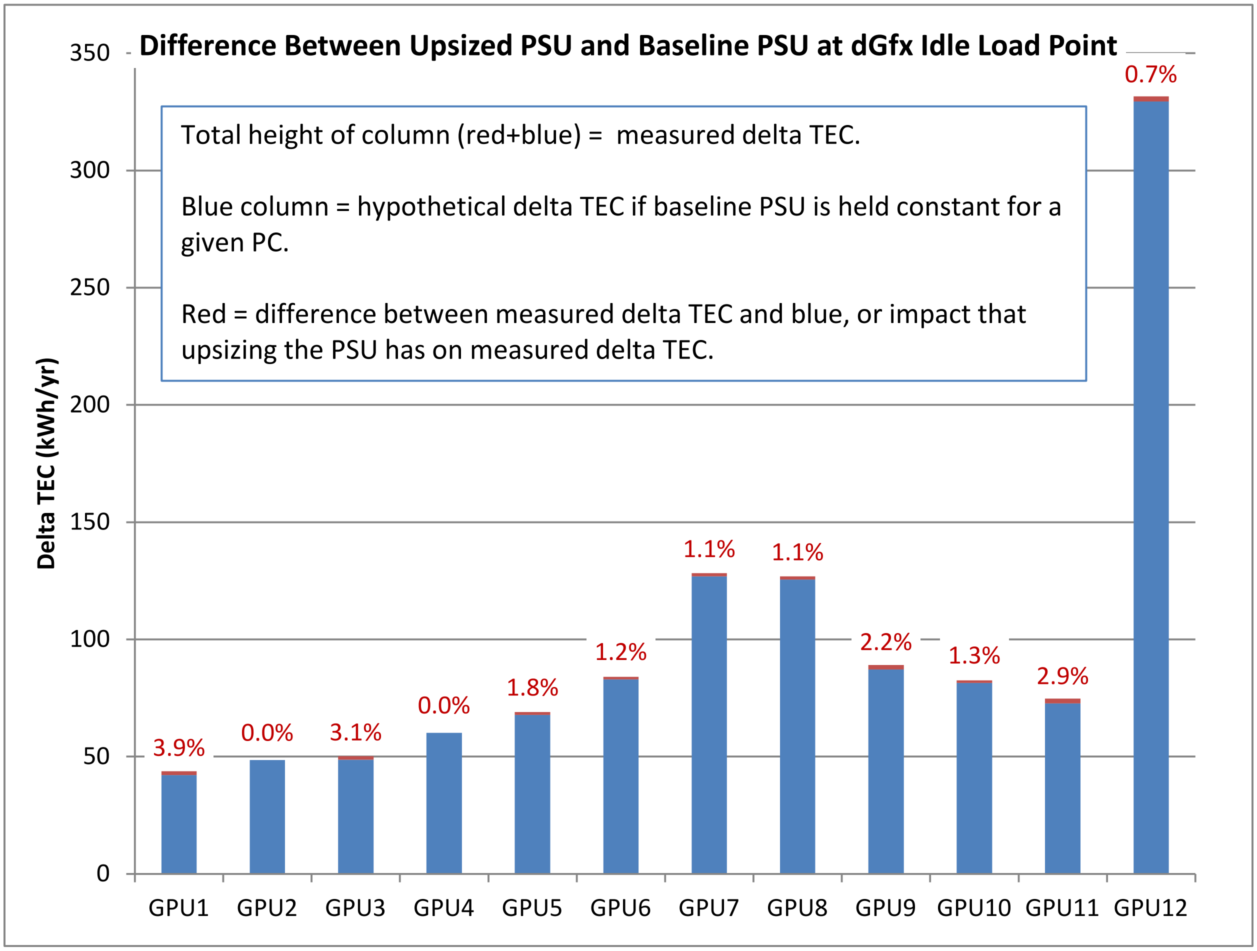


Figure 14 shows that the variability of delta energy due to PSU upsizing is on average 2%. As seen previously on Figure 12, the variability is higher with a mix of positive and negative impacts at the computer-GPU configuration level, but the 2% average means that PSU upsizing introduced negligible variability on the discrete graphics card net impact values reported in the project results.

Appendix V – Detailed Test Data and Analysis

A spreadsheet containing detailed test data and analysis can be found at http://www.clasponline.org/ResourcesTools/Resources/StandardsLabelingResourceLibrary/2012/Impact-of-Graphics-Cards-on-Desktop-Computer-Energy-Consumption