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Desktop Graphics Cards Idle Power Measurement:
Test Approach and Component Selection Criteria

MEMORANDUM TO: THE COLLABORATIVE LABELING &
APPLIANCE STANDARDS PROGRAM (CLASP)

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Background and Purpose

This project aims to develop a representative dataset of graphics card power use in idle mode to support the setting of effective graphics adders in the ENERGY STAR v6 computers specification, as well as in mandatory standards which use the ENERGY STAR computer specification as a framework.

Graphics adders are a critical element in personal computer efficiency specifications. If they are set too high, graphics adders can provide a significant excess margin of energy consumption for the rest of the computer system, which can allow inefficient computers to meet efficiency requirements for standards and labels. On the other hand, if graphics adders are set too low it may restrict market access for efficient computers that require graphics cards for specific applications (e.g. computer gaming). Setting graphics card adders at the correct levels will ensure standards and labeling programs support energy efficient computers, while excluding inefficient models.

A representative dataset of graphics card energy consumption is needed to set appropriate graphics adders; while we expect the ENERGY STAR v6 dataset to contain a number of graphics enabled configurations, we believe that more data is needed.

The Collaborative Labeling and Appliance Standards Program (CLASP) is therefore funding the following project with collaboration from the Natural Resources Defense Council (NRDC). The project is divided into three phases:

- Phase 1: Development of a test approach to measure the idle power of discrete graphics cards;
- Phase 2: Selection of components for testing; and,
- Phase 3: Laboratory testing of discrete graphics card energy consumption.

This project will provide objective data, which can be used by policy makers to set appropriate desktop computer discrete graphics allowances. After the testing phase of this project is complete, the EPA will have a robust dataset that includes data covering a wide range of ECMA-383 categorized discrete graphics cards (12 unique cards in total, plus 10 dual-card configurations) tested across a variety of desktop computers. We expect that the availability of this comprehensive dataset will allow more accurate level setting than a smaller sample which may not be representative of the overall market. Based on the differential power consumption of the system with a discrete graphics card installed (relative to an integrated graphics option), the EPA and other agencies should be able to quantify a set of total energy consumption (TEC) graphics allowances (aka graphics "adders") for desktop computers based on their respective ECMA-383 categorized discrete graphics card.

It is our perception that proposed ENERGY STAR performance categories for potential adders for graphics cards is based on GPU performance characteristics rather than the performance characteristics of a complete graphics card. We believe that a more appropriate categorization would be based on the performance of the complete graphics card rather than the GPU alone. The same GPU can be paired with different speeds of VRAM, resulting in a variety of models of cards with different frame buffer band-widths built on the same GPU. We invite industry to comment on this potential issue.

Test Methodology

Overview

The test methodology presented here is primarily based on the ENERGY STAR test method for computers and Ecova's previous work with discrete graphics cards for NRDC. The approach will determine the differential idle-mode power demand when one adds a discrete graphics card to a desktop computer system with integrated graphics. Ecova will build six desktop PC configurations, each with a unique central processing unit (CPU) and motherboard pairing. These six configurations will be combined with a set of secondary PC components including storage drive, system memory, computer case, power supply unit (PSU), optical drive, and operating system to create six different PCs that we will identify as 'PC1', 'PC2', 'PC3', 'PC4', 'PC5', 'PC6' for testing.

Due to the nature of our project, this test approach utilizes 'build-your-own' desktop PCs rather than unique original equipment manufacturer (OEM) PC models. This approach allows us to:

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

Other than developing our desktop PC configurations in-house rather than testing specific OEM desktop PC models, our test approach complies with the ENERGY STAR computer specification test methodology wherever possible.[1] Unless otherwise specified, all terms used in our test methodology are consistent with the definitions in the ENERGY STAR specification for computers. We use ENERGY STAR definitions for all operating modes: off, sleep and idle (short and long).

Laboratory Measurements

Ecova is an EPA-recognized laboratory.[2] Equipment used for the testing phase of this project consists of high precision laboratory grade instruments. Ecova's measurement equipment is calibrated by an ISO/IEC 17025 accredited calibration laboratory. Equipment includes the following:

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

Although the ENERGY STAR test methodology requires only one run, a given PC system will be tested with each discrete graphics card three times in idle mode in single card configuration

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[1] ENERGY STAR Computer Test Method, July 21, 2011. Available:
http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/Computers_Test_Method_Rev_July_2011_Draft.pdf
[2] For detailed information see http://www.energystar.gov/index.cfm?c=third_party_certification.tpc_labs and http://l-a-b.com/accredited-labs?field_scope_text_value=ecova&title=&field_state_value=All&field_country_value=All

and two times in dual card configuration. Running multiple tests should provide a clearer understanding of the variability between runs, which should, in turn, add confidence to calculations of the consumption of a given model of card. Testing will comply 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 are likely to fall) the WT1600 has an uncertainty of less than 0.3%. The 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. On a percentage basis, the uncertainty associated with smaller differences in power demand will be larger than the uncertainty associated with greater differences in power demand.

Baseline Test Methodology

Baseline tests across our six PC configurations, each with integrated graphics capability, will be conducted prior to installing discrete graphics cards to investigate power consumption variation across CPU and motherboard pairings. These baseline values will be used to determine the differential power use of each discrete graphic card, installed across all systems. Using the ENERGY STAR July 21st, 2011 test method and proposed definitions for short and long idle, our baseline test approach will include the following:

ENERGY STAR 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.)

Full ENERGY STAR Tests

In addition to measuring idle power, a complete ENERGY STAR test that also measures the sleep and off mode power consumption for each of the six PC configurations will be conducted once. This will allow for the development of a more complete power consumption profile for the six test PC configurations. Sleep and off mode measurement will be limited to the six PC configurations with no discrete graphics card installed. We will not test off and sleep power in discrete graphics card configurations because we do not anticipate the choice of graphics card to influence sleep and off-mode power consumption.[3] Computers will be tested with Wake-on-LAN (WOL) enabled for all tests. Using the ENERGY STAR test method, off and sleep power measurements will include the following:

ENERGY STAR Off Mode testing

After updating component software drivers, computers shall be tested for Off Mode.

1. With the computer in Off Mode, set the meter to begin accumulating true power values at a frequency greater than or equal to 1 reading per second.
2. Accumulate power values for 5 minutes and record the average (arithmetic mean) value observed during that 5 minute period.

ENERGY STAR Sleep Mode testing

After updating component software drivers, computers shall be tested for Sleep Mode.

1. Place the computer in Sleep mode.
2. Reset the meter (if necessary) and begin accumulating true power values at a frequency greater than or equal to 1 reading per second.
3. Accumulate power values for 5 minutes and record the average (arithmetic mean) value observed during that 5 minute period.

Graphics Card Test Methodology

After baseline and ENERGY STAR testing is completed, each of the 12 graphics cards identified in Phase II will be tested across all six PC systems in single-card configuration. All power measurements will be taken in idle mode. Three separate tests will be performed for each graphics card/ PC configuration. As with our baseline testing, the graphics card testing will use the ENERGY STAR, July 21st, 2011 test method for measuring short and long idle mode:

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[3] We may test this with 2-3 discrete graphics cards to confirm, but this is not formally included as part of the test methodology.

Energy Star 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.)

Multi-Card Test Methodology

We will test multi-capable cards in both single and multi-card configurations. There will be 10 multi-capable cards and 2 systems capable of utilizing these NVIDIA® SLI™ and AMD CrossFireX™ configurations. Each unique configuration will be tested two times. This work will help define "additional graphics" adders, i.e. adders for additional discrete graphics beyond the first discrete GPU. Multi-card testing will also use the ENERGY STAR July 21st, 2011 test method 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, we will set the hard drive to spin down after 12 minutes of testing.[4]
- 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, we will set the display to shut down after 12 minutes of testing [4]
- All tests will be conducted with an active Ethernet network connection with full network connectivity.[5]
- All component drivers will be updated via the manufacturer's website prior to testing.[6] The laboratory technician will install NVidia and AMD/ATI's control panel software and record graphic card settings for each test. The laboratory technician will check the control panel 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.
- We will use default (as shipped) Windows 7 operating system settings unless otherwise specified.[6] A summary of Windows 7 power management settings we plan to use is included below:

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[4] 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.
[5] 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.
[6] 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.

Table 1. 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[7]
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

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[7] 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)

Data Reporting

The tables below illustrate how the data collected in the testing phase will be reported. While the ultimate format in which the data will be presented is still to be determined, the information presented in the tables below will be included in any final format. Note that additional descriptors associated with each test and PC-build will also be recorded and reported (e.g. power supply make and model, power management settings, memory make and model, etc.)

Table 2. Key Data Reporting Attributes For Graphics Card Idle Power Measurements

PC Build	GPU	Graphics Card	Card Frame Buffer Bandwidth	ECMA Category	Average Idle Power	Variability in measurements and measurement instrumentation accuracy
PC that the graphics card was tested in	GPU contained within the graphics card under test	Make and model of graphics card under test	Frame buffer bandwidth associated with the graphics card under test	ECMA graphics card performance category	Average idle power value for the three test runs	This field will quantify the variability in individual measurements and associated measurement instrumentation accuracy

Table 3. Key Data Reporting Attributes For Differential Graphics Card Idle Power Calculations

PC Build	GPU	Graphics Card	Card Frame Buffer Bandwidth	ECMA Category	Average Differential Idle Power	Variability in measurements and measurement instrumentation accuracy
PC that the graphics card was tested in	GPU contained within the graphics card under test	Make and model of graphics card under test	Frame buffer bandwidth associated with the graphics card under test	ECMA graphics card performance category	Average differential idle power value (PC with discrete graphics card compared to baseline PC)	This field will quantify the variability in individual measurements and calculations and the associated measurement instrumentation accuracy

Raw Data

Raw instantaneous power demand measurements for the duration of all tests will be recorded in Microsoft Excel format. While these data will not be explicitly reported in detailed form, they will be retained in electronic form should further analysis of data be needed at a later date. All raw data will be available to CLASP and NRDC.

Component Selection Criteria

Overview

Ecova will build six PC configurations, each with a unique central processing unit (CPU) and motherboard pairing. These six configurations will be combined with a set of secondary PC components including storage drive, system memory, computer case, power supply unit (PSU), optical drive, and operating system to create six different PCs that we will identify as 'PC1', 'PC2', 'PC3', 'PC4', 'PC5', 'PC6' for testing.

The following goal and criteria were used to develop the CPU and motherboard pairings for the PCs in which the discrete graphics cards will be tested. Secondary components and the specific discrete graphics cards that will be tested are also defined.

To design appropriate PC configurations, the project began with an overall goal which in turn led to a short series of requirements. These then led to the final hardware selections.

Goal

The project is tasked with the following:

> *Determine the change in idle-mode power consumption 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 PCs that approximately parallel the mainstream, performance, enthusiast and very high-end enthusiast PCs as defined by industry proposed

ENERGY STAR 6.0 performance categories for desktop computers (See Table 2).[8]

b. Select motherboards and CPUs that reflect most recent technology at price points that match the four categories above.

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:

- PC Construction – General plans for building PCs 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.

PC Construction

As noted earlier, due to the nature of our project this test approach utilizes 'build-your-own' desktop PCs rather than unique original equipment manufacturer (OEM) PC models. This approach allows 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), if we so choose.

CPU

Desktop CPUs from the world's two largest manufacturers, Intel and AMD, will be utilized. To better reflect market share, the tests will cover four Intel and two AMD CPUs.[9] 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 4). These segments are: Entry, Mainstream, Performance, High Performance, Very High-end/Enthusiast. An entry level desktop configuration will be excluded from this project because this low performance category seems to be becoming less relevant in today's market, particularly for configurations with discrete graphics. Given the project's timing and funding constraints, this category is considered the lowest priority and will be excluded from scope. Note that we believe that some category definitions as they stand in the current proposal to ENERGY STAR[10] may mischaracterize certain machines. For example,

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

[9] 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/
[10] http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/computer/ITI_Comments_4.pdf

the AMD Llano A8 CPU has four cores and would place a desktop in the DT2 performance category despite being marketed as a mainstream CPU. As such, we provide both the proposed ENERGY STAR 6.0 classification and our own classification in the final table that describes the proposed desktops.

As the project scope is limited to only six PCs, only two categories will include multiple PCs. To support multiple card testing (SLI and CrossFireX cards), the tests required at least two PCs at the High-Performance or Enthusiast category. This leaves one other PC category that could contain multiple PCs. 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.

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 AMD-based PC with multiple graphic card support to compare multiple card performance across Intel/AMD. Without a true AMD competitor to Intel's i7, this last PC would use AMD's fastest solution, the Phenom II x4: placing this PC in the High Performance category.

Table 4. Proposed ENERGY STAR 6.0 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 PC configurations will contain an integrated graphics processing solution, but this can be 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 1). Because of this trend, we propose testing four PC configurations with graphics integrated directly into the CPU die and the remaining two with graphics integrated on the motherboard. *We are only planning to test systems that have some form of integrated graphics.* The nature of our testing requires an integrated graphics option to serve as the baseline for each of the six PC configurations.
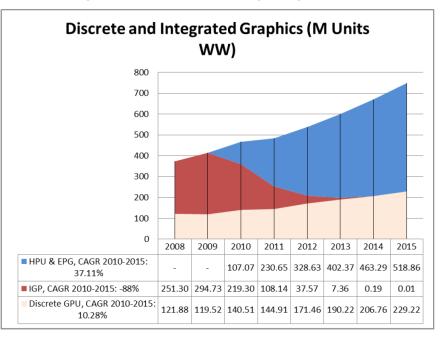
Figure 1. Embedded processor graphics (EPG) overtakes integrated graphics processors (IGPs) by 2014.

	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 PC configurations sharing the same proposed ENERGY STAR performance category, motherboards will be chosen from the same manufacturer to eliminate any ambiguity in our data that could be manufacturer specific. However, we will vary the motherboard manufacturer 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 will correspond to the CPU manufacturer (i.e., Intel CPUs will be paired with motherboards equipped with Intel chipsets) and will be selected relative to the performance of the CPU. This will ensure that the key components of each PC are fairly representative of the market.

Of the six motherboards, two will also be 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 will support dual channels of memory.
- All motherboards selected will be 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) will not dictate motherboard selection as these features tend to correspond with the motherboard chipset.

Discrete Graphics Cards

Selection Criteria and Rationale

We surveyed discrete graphics cards offered in the desktop computer lines in four of the major OEMs of desktop computers: Hewlett-Packard, Dell, Apple and Acer. Graphics cards were categorized based on frame buffer bandwidth (GB/s) and associated ECMA-383 classification. Our proposed selection includes the most recent cards identified in our market survey from both NVIDIA and AMD/ATI for each ECMA-383 category. In addition, we selected graphics cards that are capable of NVIDIA® SLI™ and AMD CrossFireX™ configurations for each ECMA-383 category where possible. To fill in gaps in certain performance categories in our OEM market survey, we selected popular graphics cards based on third-party web sites such as Tom's Hardware and GPU Review.[11] Within each ECMA-383 category we selected cards that were most recently released and most commonly used by OEMs when possible.

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 will be tested within the G1 and G2. AMD/ATI offers single and CrossFireX™ configuration cards for each ECMA-383 category with G6 being the exception.

Selected Graphics Card Models

Our specific proposed card selections are detailed in the table on the following page.

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

![ecova logo]

ECMA-383 (v6)	Manu.	GPU Model	Date of Release	Card FBB (GB/s)	Max GPU Power (W)	Manufacturer Recommended PSU Power (W)	SLI/CrossFireX Capability	Price ($)	Graphics Card and Product Link	Quantity Needed
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	66	400 (500 for dual)	2-way	97	Sapphire 100326L	2
G3	NVIDIA	GeForce GTS 450	Sep '10 /Mar'11	57.73	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	95.04	160	450	2-way	79	Galaxy 60XMH6HS3HMW GeForce GTX 460 GC Edition	2
G5	ATI/AMD	Radeon HD 6850	Oct '10	128	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	250	500	2-way	550	DIAMOND 7970PE53G Radeon HD 7970	2
G7	NVIDIA	GeForce GTX 590	Mar '11	331.8	365	700	4-way	750	EVGA 03G-P3-1596-AR	2

Total: 22

Secondary Components

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

Power supply unit (PSU)

PSUs will vary in efficiency for each PC configuration in order to represent the range of power supplies that one would expect to find in PCs similar to our custom built PCs. The baseline tests for all PCs, with integrated graphics only, will be performed using a 300 watt PSU. Some PCs may require multiple sizes of PSUs to support the testing of graphics cards that have a larger power demand. As larger power supplies are needed for a given PC/graphics card combination, the efficiency badge of the PSU will be held constant for a given PC build.

Memory

Memory will vary for each of the six PC configurations. In general, as PC performance increases so will memory size and speed. Memory latency will also decrease as PC performance increases. In addition, motherboard specifications will also dictate the size and speed of memory that we will utilize for each PC configuration.

Storage

For each of the six PC configurations, the same storage (hard disk drive) make and model will be used. We believe that it is unlikely that choice of storage drive will have a significant impact on the graphics card idle power demand.

Optical drive

For each of the six PC configurations, the same optical drive make and model will be used. We believe that it is unlikely that choice of optical drive type and speed will have 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 PC configurations, the same computer case make and model and associated cooling system will be used.[12] We believe that it is unlikely that choice of computer case will have a significant impact on the graphics card idle power demand.

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[12] Each computer will be tested in the same room under ENERGY STAR required temperature and humidity conditions.

Selected Configurations

Our specific proposed component selections are detailed in the table on the following page.

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 Z68A-G43 (G3) LGA 1155 Intel Z68	ASUS M5A88-V EVO AM3+ AMD 880G	ASUS P8Z68-V PRO/GEN3 LGA 1155 Intel Z68	ASRock Z68 Extreme7 Gen3 LGA 1155 Intel Z68
Power Supply Unit 1	Non-80+ 300W COOLMAX CA-300 300W ATX	80+ Bronze 300W SeaSonic SS-300ES	80+ Gold 400W FSP AURUM GOLD 400	Non-80+ 300W COOLMAX CA-300 300W ATX	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 (as needed)	None	None	None	80+ 1000W Antec CP-1000	80+ 1000W Antec CP-1000	80+ 1000W Antec CP-1000
Channels of Memory	2	2	2	2	2	2
Base Memory	2GB	2GB	2GB	4GB	4GB	8GB
Test PC	PC1	PC2	PC3	PC4	PC5	PC6

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 Home	Windows 7 Professional	Windows 7 Professional	Windows 7 Home	Windows 7 Home	Windows 7 Home

*PC5 is technically capable of utilizing multi-card configurations but we do not plan to test any in this test PC. All dual-cards will be tested in PC4 and PC6.

Glossary

All definitions are from the ENERGY STAR v5 computer program requirements unless otherwise noted.

AMD CrossFireX™. CrossFireX harnesses the power of two or more discrete graphics cards working in parallel to dramatically improve gaming performance.[13]

Desktop Computer. A computer whose main unit is designed to be located in a permanent location, often on a desk or on the floor. Desktop computers are not designed for portability and are designed for use with an external display, keyboard, and mouse. Desktop computers are intended for a broad range of home and office applications.

Discrete Graphics Processing Unit (GPU). A graphics processor with a local memory controller interface and local graphics-specific memory.

Off Mode. The lowest power mode which cannot be switched off (influenced) by the user and that may persist for an indefinite time when the appliance is connected to the main electricity supply and used in accordance with the manufacturer's instructions. For systems where ACPI standards are applicable, Off Mode correlates to ACPI System Level S5 state.

Idle Mode. The mode in which the operating system and other software have completed loading, the product is not in Sleep Mode, and activity is limited to those basic applications that the product starts by default. There are two forms of idle that comprise Idle Mode.

    a) Long Idle: The mode where the UUT has been inactive for a period of time (e.g., 15 minutes after OS boot or after completing an active workload or after resuming from sleep) and the screen has blanked but the UUT remains in the working mode. All default power management features should have engaged (e.g., display is off, hard drive may have spun-down) but the UUT has not entered Sleep Mode.

    b) Short Idle: The mode where the UUT has been inactive for a brief period of time (e.g., 5 minutes or less after OS boot or after completing an active workload or after resuming from sleep), the screen is on and set to as shipped brightness, and Long Idle power management features have not engaged (e.g., the hard drive is still spinning and the UUT is not entering Sleep Mode, ACPI G0/S0).

NVIDIA® SLI™. SLI technology is a revolutionary platform innovation that allows you to intelligently scale graphics performance by combining multiple NVIDIA graphics solutions in an SLI-Certified motherboard.[14]

Sleep Mode. A low power mode that the computer enters automatically after a period of inactivity or by manual selection. A computer with Sleep capability can quickly "wake" in response to network connections or user interface devices with a latency of less than or equal to 5 seconds from initiation of wake event to system becoming fully usable including rendering of

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[13] From http://sites.amd.com/us/game/technology/Pages/crossfirex.aspx
[14] From http://www.slizone.com/page/slizone_learn.html

display. For systems where ACPI standards are applicable, Sleep Mode most commonly correlates to ACPI System Level S3 (suspend to RAM) state.

Wake On LAN (WOL). Functionality which allows a computer to transition from Sleep Mode or Off Mode to an Active State of operation when directed by a network Wake Event via Ethernet.

Full Network Connectivity. The ability of the computer to maintain network presence while in Sleep Mode or another low power mode of equal or lower power consumption ("LPM") and intelligently wake when further processing is required (including occasional processing required to maintain network presence). Presence of the computer, its network services and applications, is maintained even though the computer is in a LPM. From the vantage point of the network, a computer with full network connectivity that is in LPM is functionally equivalent to an idle computer with respect to common applications and usage models. Full network connectivity in LPM is not limited to a specific set of protocols but can cover applications installed after initial installation. Also referred to as "network proxy" functionality.

   a) Network Proxy - Base Capability. To maintain addresses and presence on the network while in LPM, the system handles IPv4 ARP and IPv6 NS/ND.
   b) Network Proxy - Remote Wake. While in LPM, the system is capable of remotely waking upon request from outside the local network. Includes Base Capability.
   c) Network Proxy - Service Discovery/Name Services. While in LPM, the system allows for advertising host services and network name. Includes Base.
   d) Network Proxy - Full Capability: While in LPM, the system supports Base Capability, Remote Wake, and Service Discovery/Name Services.