AMD Accelerates GPU Energy Efficiency for Gaming PCs

1. Executive Summary

AMD designs Central Processing Units (CPUs), Graphics Processing Units (GPUs) and Accelerated Processing Units (APUs), as well as semi-custom processors that may incorporate 3rd party IP for products like game consoles. This study focuses on GPUs, the processors for rendering life-like graphics and video on ultra-high resolution displays. Due to visual performance demands, PC gaming applications rely heavily on state-of-the art GPUs. The newest generation GPUs execute billions of instructions every second. Beyond gaming, this level of performance helps enable many leading-edge technologies including virtual reality, digital media, and scientific applications.

The 2016 Radeon™ RX 400 Series GPUs from AMD are based on the Polaris architecture, which incorporates: the fourth-generation *Graphics Core Next (GCN)* graphics instruction set, the latest 14nm FinFET process technology, and myriad AMD proprietary power management technologies. As a technology platform, the Polaris architecture enables many new products and a spectrum of energy efficiency improvements providing up to 2.8 times the energy efficiency of previous Radeon™ graphics cards.[1] Energy efficiency is a measure of the amount of computational work a processor can perform for a given unit of energy.

This study quantifies the energy use and greenhouse gas (GHG) implications for one configuration of the new Polaris architecture. The study evaluated the flagship Radeon™ RX 480 GPU compared to the previous generation Radeon™ R9 390 GPU when used within a "gaming computer," i.e. a computer customized to rely heavily on discrete GPUs for the best possible gameplay. The two GPUs compared in this study have approximately the same performance, meaning that they produce over five trillion floating point operations per second (5 TFLOPS).[2] However, the new Radeon RX 480 GPU has a maximum power limit (also known as "thermal design power" or TDP) of 150 watts, whereas the TDP of the previous generation Radeon R9 390 GPU is 275 watts.

The study assessed electricity use based on daily usage of a gaming PC consisting of a usage profile of 4.4 hours active gaming; 2 hours of web browsing; 1.6 hours for video streaming; 1 hour of "standing by" in short idle; 3 hours of running basic programs in long idle; 6 hours in sleep mode; and 6 hours off. This test methodology is in accordance with ongoing research into the usage profile of gaming PCs.[3] The estimated GHG emissions associated with electricity consumption (sometimes also referred to as "carbon emissions") in the study were independently reviewed and validated by a third party, Pure Strategies. Pure Strategies identified the average amount of GHG emissions (measured as carbon dioxide equivalent emissions) per kilowatt-hour (kWh) of electricity generated in the countries where the majority of AMD GPU sales occurred since 2015 using the ecoinvent version 3.2 database.[4]

The study concludes that upgrading a gaming PC from a Radeon™ R9 390 GPU to a Radeon™ RX 480 GPU provides a **40 percent reduction in energy use and carbon emissions from the active gaming mode, and a 32 percent overall GHG reduction for the gaming PC daily usage model.**[5] These energy and emission improvements are derived through a combination of architectural enhancements, intelligent circuit design and enhancements from more advanced manufacturing technology.

2. Introduction

Climate change is one of the most significant issues facing humankind today. The United Nation's Intergovernmental Panel on Climate Change (IPCC) has called for global greenhouse gas (GHG) emission reductions of 60 to 80 percent below 2000 levels by 2050 to avoid significant disruption to climate patterns.[6] There is now an overwhelming consensus among climate scientists that changes observed in the atmosphere and the climate are due to GHG emissions associated with human activities.[7]

The number of digital products in use, such as notebook and desktop computers, servers, and smartphones, is growing rapidly along with the total energy they consume. Because virtually all of these products consume electricity, their use contributes to GHG emissions. AMD is committed to driving down the use of energy and associated GHG emissions from the products it designs, while also improving performance.

Designing energy efficient semiconductors is a major business imperative for AMD. Through its 25x20 energy efficiency initiative, the company has recently achieved outstanding results from its 6th and 7th Generation A-Series APUs for both energy efficiency and carbon emission reduction.[8-9] Now the company has made similar strides with discrete GPUs – achieving up to 2.8 times the energy efficiency from the latest discrete GPU products when compared to AMD graphics chips of only two years ago.[1]

Accelerating energy efficiency in gaming PCs is important. With each new generation, CPUs and GPUs provide increasingly realistic, life-like experiences including ultra-high resolution and the appearance of seamless action through faster frame-rates. Sometimes these performance advances have required higher levels of power consumption. The energy efficiency breakthroughs included with the Polaris architecture changes this paradigm. Gamers can get the performance for immersive gaming experiences while conserving power and reducing their carbon footprint.

AMD engineers have focused on driving Polaris GPU energy efficiency improvements through new chip architecture and circuit design.[10] Additional gains are realized by transitioning to smaller transistors as a result of manufacturing "process shrink." This means that additional energy efficiency is achieved when circuits are packed into a smaller area of silicon due to advanced manufacturing processes, and electrical signals have a shorter path to travel.

Collectively, the new Polaris architecture and advanced circuit design, along with process technology, efficiently delivers exceptional graphics and compute performance for a variety of applications. These improvements are included across the entire Polaris architecture-based Radeon™ RX 400 Series of GPUs.

To assess the real-world impact of these improvements, AMD compared the energy and carbon footprint of a gaming PC equipped with a new Polaris-architecture graphics card – the AMD Radeon RX 480 – to a gaming PC running with the prior generation AMD Radeon R9 390 graphics card. Both graphics cards have similar performance insofar as both produce more than 5 TFLOPS of computing power. This translates into similar results for the two products on 3DMark – a performance benchmark for graphics applications. The main difference between these similarly equipped PCs is the advanced energy efficiency improvements in the Radeon RX 480 card. By upgrading to the Polaris architecture from the prior generation GPU, a PC gaming enthusiast can maintain a familiar level of excellent gaming performance while reducing the annual energy use and carbon emissions from active gaming by up to 40 percent, and by up to 32 percent for typical daily system usage, respectively.[5]

3. Processor Technical Information

Fifty years into the evolution of Moore's Law, each new generation of semiconductors has offered more transistors and thus, more functionality. At the same time, the power and energy benefits that come along with new process technology, known as "Dennard scaling," have slowed down. To keep pace with the demand for greater graphics processing performance without correspondingly increasing energy consumption, engineers must increasingly improve semiconductor architecture, including better circuits and more innovative power management techniques.

The Graphics Core Next (GCN) instruction set has proven a solid foundation for high performance across the entire graphics ecosystem, from integrated notebook solutions, to leading edge game consoles, and high-end discrete graphics cards for VR and PC gaming. The Polaris architecture builds on the success of GCN, systematically increasing performance, enabling a more responsive experience and increasing energy efficiency. The three critical innovations powering the Polaris architecture are a new process technology, novel architecture, and creative circuit design techniques that draw on AMD's long expertise in CPU design.

Among the key improvements with the Polaris architecture:

- The product is made with the latest FinFET 14 nanometer process.[11] This change improved the generational performance per watt of the Polaris architecture by up 1.7 times.[12]
- The inclusion of AMD proprietary clocking, transistor gating, and circuit design build on this to push the performance per watt of the Polaris architecture to a peak of up to 2.8 times products shipped just two years ago.[1]
- The Polaris architecture also offers up to 15 percent additional performance-per compute unit, many of which are ganged together in parallel as the fundamental building blocks of the Polaris architecture.[13]

These three characteristics are incorporated across the AMD Polaris architecture-based family of GPUs, including the Radeon™ RX 460, Radeon™ RX 470 and Radeon RX 480. Additional technical details including changes over the previous generation in the memory interface, compute units and geometry engines, are available on the AMD Polaris architecture website.[14]

4. Scope and Methodology of this Study

A typical gaming PC was assembled by AMD to measure and compare the electricity consumption from using a new Radeon RX 480 graphics card versus the previous Radeon R9 390 graphics card. The only difference in hardware components during the tests was the GPU. The software driver was different because, at the time of the study, no single driver supported both GPUs, however this change has no effect on power consumption.

GPU	**Radeon RX 480**	**Radeon R9 390**
Monitor	Nixeus NX-VUE24A (144Hz)	Nixeus NX-VUE24A (144Hz)
Software	Radeon™ Software 16.20 RC20	Radeon™ Software 16.6.1 Beta
Motherboard	Asus Z97-A/USB 3.1	Asus Z97-A/USB 3.1
CPU	Intel Core i5-4690K	Intel Core i5-4690K
Memory	16GB DDR3-2133	16GB DDR3-2133
Solid State Drive	Samsung 850 Pro (512GB)	Samsung 850 Pro (512GB)
Hard Drive	2TB Seagate Barracuda 7200RPM HDD	2TB Seagate Barracuda 7200RPM HDD
Operating System	Windows® 10 x64 (build 10586)	Windows 10® x64 (build 10586)
*x*PU Power Management	All CPU/GPU P-States and C-States enabled	All CPU/GPU P-States and C-States enabled

Table 1: Gaming system configurations for comparing GPUs

The same energy tests were conducted with both systems cycling through seven typical use operating modes of a gaming PC. Daily use assumptions are based on previous research and consist of a profile of 4.4 hours active gaming; 2 hours of web browsing; 1.6 hours for video streaming; 1 hour of short idle; 3 hours at long idle; 6 hours in sleep mode; and 6 hours off.[15] To measure the power used in each mode, a kilowatt meter read the power draw (watts) from the wall outlet, and converted the power to kilowatt hours. If the wattage measurement varied significantly in a given operating state, as it did while web browsing and gaming, then the electricity consumed was calculated over a one hour period to measure kilowatt hours. The hourly electricity consumption per mode was multiplied by the typical number of hours per day in that mode, and then multiplied by 365 days per year to estimate the annual electricity consumption (kWh). While 4.4 hours of active gaming by a PC user every day may not be representative of most gamers, using this weighted daily average to represent PC use over of time is consistent with previous studies. [16-17]

In the active gaming mode, PC electricity consumption is a calculated 40 percent lower with the Radeon RX 480 GPU compared to the R9 390 GPU. Since active gaming consumes more electricity than all other modes combined, the improvements in this mode stand to represent the greatest environmental benefit and energy cost savings. Web browsing and video streaming are the next two highest categories of electricity use, and in those states the gaming PC with the Radeon RX 480 GPU uses a calculated 33 percent and 17 percent less electricity, respectively. Electricity use from the lower power states, categorized as long and short idle, increased marginally, to a calculated 6 percent and 1 percent respectively with the RX 480 GPU. While idle electricity use represents a small percentage of total electricity use, optimizing it is a focus area for AMD in forthcoming GPU products. In the sleep and off states, there was no observed difference in electricity consumption between the GPUs.

Typical Use Scenario		R9 390	RX 480	Percent (%) Change in Annual kWh from R9 390 to RX 480
Operating State	Hours Per Day	Annual Electricity Use (kWh)	Annual Electricity Use (kWh)	
Active Gaming (3DMark 2013 loop)	4.4	642.4	385.4	-40%
Video Streaming (1080p, YouTube/Netflix)	1.6	88.2	73.6	-17%
Web Browsing (Manual *or* Peacekeeper benchmark)	2.0	87.6	58.4	-33%
Long Idle (standby)	3.0	69.1	73.6	6%
Short Idle (active hard drive)	1.0	33.0	33.3	1%
Off	6.0	3.0	3.0	0%
Sleep	6.0	5.8	5.8	0%
Annual Electricity Use (kwh)		929	633	-32%

Table 2: Gaming use profile, power draw and estimated annual energy use

5. Sensitivity Analysis

The primary assumption and source of uncertainty in this analysis was the hours per day a gaming PC spends in each use mode, due to the differences in electricity consumption. This study utilized the typical daily use case profile of gaming PCs from a previous study (4.4 hours active gaming; 2 hours of web browsing; 1.6 hours for video streaming; 1 hour of short idle; 3 hours at long idle; 6 hours in sleep mode; and 6 hours off).[18] To test the sensitivity of this use case scenario, alternative scenarios were evaluated whereby the 4.4 hours per day in active gaming mode was increased and decreased by up to two hours (45 percent). The additional time in the gaming mode was added and subtracted from each of the six other modes, resulting in twelve alternative scenarios. Varying the gaming mode by up to 2 hours resulted in up to a 3 percent increase and 6 percent decrease from the original overall finding (32 percent annual electricity and carbon emissions decrease) from upgrading the Radeon R9 390 GPU to the Radeon RX 480 GPU. This means that varying the length of time in gaming mode in the use case scenario by plus or minus 45 percent resulted in a calculated range of 26 percent to 35 percent overall energy and carbon savings from the upgrading to the new GPU.

This study is not a full life cycle assessment (LCA) of the carbon footprint associated with the Radeon RX 480 GPU. Full LCA includes product system inputs (such as energy) and system outputs (such as carbon emissions) from multiple stages of the product life, including raw material extraction, wafer manufacturing operations, and end of life.

Previous AMD LCA studies have shown that approximately 80%-90% of the carbon footprint of a microprocessor occurred when it was in use and consuming electricity.[19-20] Thus, the scope of this study was deliberately limited to electricity use (and associated carbon emissions) for the use of GPUs in a

gaming PC. Furthermore, the variation in the carbon footprint from non-use phases was found to be minimal in these prior studies. Because the impacts of other lifecycle stages are expected to be small and have less variation compared to the "use phase," they were excluded from this study.

6. Results and Interpretation

Users who upgrade a gaming PC from the AMD Radeon R9 390 GPU to the new AMD Radeon RX 480 GPU can reduce their annual electricity use and carbon emissions by 40 percent from active gaming, and 32 percent across all use modes. The associated annual savings per gaming PC amounts to 296 kWh, $37 USD and 204 kg of carbon emissions. Over a 3 year service life, total savings per gaming PC amounts to approximately 888 kWh, $112 USD (at current electricity prices) and 613 kg of carbon emissions.[21]

This study extrapolated the hypothetical energy, carbon and cost savings if the approximately 15.8 million "Performance" class GPUs sold in 2015[22] were assumed to achieve the same potential savings calculated in this study by switching from the Radeon R9 390 GPU to the Radeon RX 480 GPU. While this scenario is unrealistic, the extrapolation was performed to better understand the potential total cost and carbon savings that could be achieved in the market. To make the calculation[23] more realistic, we assumed the most conservative use case scenario from the study's sensitivity analysis, which reduced the hours per day of active gaming by 45 percent to 2.2 hours (instead of 4.4 hours) and increased long idle "stand by" computer use to 5 hours (instead of 3 hours). This extrapolation shows the theoretical total annual savings would be approximately 2.8 billion kWh, which equals $350 million USD saved, and avoids 1.9 million metric tons of CO2 emitted to the atmosphere. Stated another way, the theoretical annual energy savings would be enough to power electricity for 289,000 US homes.[24]

About AMD

For more than 45 years AMD has driven innovation in high-performance computing, graphics, and visualization technologies — the building blocks for gaming, immersive platforms, and the datacenter. Hundreds of millions of consumers, leading Fortune 500 businesses, and cutting-edge scientific research facilities around the world rely on AMD technology daily to improve how they live, work, and play. AMD employees around the world are focused on building great products that push the boundaries of what is possible. For more information about how AMD is enabling today and inspiring tomorrow, visit the AMD (NASDAQ: AMD) website, blog, Facebook and Twitter pages.

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[1] Testing conducted by AMD Performance Labs as of May 10, 2016 on 3DMark 11 and 3DMark Firestrike using a test system comprising of an i7-4600M, 8GB, AMD Radeon driver 16.20. AMD Radeon R9 M280X (14CUs) scored 5700 and 3500 with a board power of 82W. AMD Radeon RX 480M (16CUs) scored 7200 and 4070 with a board power of 35W. Using Performance/Board power, the resulting average across the 2 different titles was a perf per watt of 2.8X vs the Radeon R9 M280X. RX-5

[2] A "FLOPS" (or floating-point operations per second) is a unit of measure for computing speed. A "teraflops" represents a trillion floating-point operations per second.

[3] Mills, N. (2015). "Taming the Energy use of gaming computers" http://evanmills.lbl.gov/pubs/pdf/Taming-the-Energy-Use-of-Gaming-Computers.pdf Accessed 20 June 2016.

[4] Pure Strategies used emission factors from the ecoinvent version 3.2 database (2014) http://www.ecoinvent.org/database/ecoinvent-32/new-data-in-ecoinvent-32/new-data-in-ecoinvent-32.html. The weighted average of emission factors from the top ten countries where AMD GPUs were sold from January 2015 through June 2016 (USA, Germany, UK, China, Australia, Russia, Canada, Sweden, France, and Poland) was 0.69 kg CO2e/kwh.

[5] In active gaming mode (tested on 3D Mark 2013 loop benchmark), the R9 390 GPU draws 0.40 watts versus the RX 480 GPU draws 0.24 watts. Multiplied by 4.4 hours per day, 365 days per year, the R9 390 GPU consumes 642 kWh annually in gaming mode, whereas the RX 480 GPU consumes 385 kWh annually in gaming mode, a 40 percent reduction. Accounting for watts drawn across all use modes, and the corresponding time in each mode (4.4 hours active gaming; 2 hours of web browsing; 1.6 hours for video streaming; 1 hour of short idle; 3 hours at long idle; 6 hours in sleep mode; and 6 hours off), the R9 390 GPU consumes 929 kWh annually versus the RX 480 consumes 633 kWh annually, a 32 percent reduction.

[6] 2007: Technical Summary. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.] Barker T., I. Bashmakov, L. Bernstein, J. E. Bogner, P. R. Bosch, R. Dave, O. R. Davidson, B. S. Fisher, S. Gupta, K. Halsnæs, G.J. Heij, S. Kahn Ribeiro, S. Kobayashi, M. D. Levine, D. L. Martino, O. Masera, B. Metz, L. A. Meyer, G.-J. Nabuurs, A. Najam, N. Nakicenovic, H. -H. Rogner, J. Roy, J. Sathaye, R. Schock, P. Shukla, R. E. H. Sims, P. Smith, D. A. Tirpak, D. Urge-Vorsatz, D. Zhou.
http://www.ipcc.ch/pdf/assessmentreport/ar4/wg3/ar4-wg3-ts.pdf

[7] Cook, J., Nuccitelli, D., Green, S. A., Richardson, M., Winkler, B., Painting, R., & Skuce, A. (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature. http://iopscience.iop.org/article/10.1088/1748-9326/8/2/024024;jsessionid=A0164C0085DFF0CD7774BFCC16FA7F90.c1

[8] http://www.amd.com/en-us/innovations/software-technologies/25x20

[9] Venkatesan, M. (2015). "Comparative carbon footprint assessment of the manufacturing and use phases of two generations of AMD Accelerated Processing Units" http://www.amd.com/Documents/carbon-footprint-study.pdf

[10] AMD Polaris architecture website. http://www.amd.com/en-gb/innovations/software-technologies/radeon-polaris

[11] FinFETs are field effect transistors (FETs) that get their name because the transistor gate wraps around the transistor's elevated channel, or "fin." It's a way to better insulate the circuits in semiconductors that both improves performance and decreased electricity loss or "leakage."

[12] Based on AMD internal data generated in AMD performance labs as of May 2016, measurements of capacitance, voltage frequency, leakage and power data show up to 1.7x performance/watt on 14nm vs 28nm FINFET technology. Final performance/watt results on AMD products using 14nm FinFET technology may vary and will depend on various factors including but not limited to clock speed, voltage, and various AMD proprietary technologies. RX-17

[13] Testing conducted by AMD performance labs as of May 18, 2016 on the Radeon RX 480 and Radeon R9 290 on a test system comprising Intel Core i7-5960X, 16GB DDR4-2666, Gigabyte X99-UD4, Windows 10 x64 (build 10586), Radeon Software Crimson Edition 16.5.2using Ashes of Singularity, GTA V, Project Cars, Witcher, and Assassin's Creed Syndicate, All games tested at 1440p. Radeon RX 480 graphics (150W TGP/36 CU) vs. Radeon R9 290 graphics (275W TGP/40 CU) scores as follows: Ashes of the Singularity (44.19 FPS vs 46 FPS); GTA V (66.23 FPS vs. 66.44 FPS); Project Cars (48.99 FPS vs. 45.99 FPS); Witcher 3 (50.78 FPS vs. 50.13 FPS); Assassin's Creed Syndicate (50.51 FPS vs. 45.78 FPS). Average FPS of above game scores: 52.14 (Radeon RX 480) vs. 50.06 (Radeon R9 290). Discrete AMD Radeon™ GPUs and AMD FirePro™ GPUs based on the Graphics Core Next architecture consist of multiple discrete execution engines known as a Compute Unit ("CU"). Each CU contains 64 shaders ("Stream Processors") working in unison (GD-78). CU efficiency formula = average FPS/# of CUs. Test results are not average and may vary.

[14] AMD Polaris architecture website. http://www.amd.com/en-gb/innovations/software-technologies/radeon-polaris

[15] Mills, N. (2015). "Taming the Energy use of gaming computers" http://evanmills.lbl.gov/pubs/pdf/Taming-the-Energy-Use-of-Gaming-Computers.pdf Accessed 20 June 2016.

[16]Mills, N. (2015). "Taming the Energy use of gaming computers" http://evanmills.lbl.gov/pubs/pdf/Taming-the-Energy-Use-of-Gaming-Computers.pdf Accessed 20 June 2016.http://evanmills.lbl.gov/pubs/pdf/Taming-the-Energy-Use-of-Gaming-Computers.pdf

[17] Short, J.E. (2013) How much media: report on American consumers, Institute for Communications Technology Management, Marshall School of Business, University of Southern California, 42 pp.
http://www.marshall.usc.edu/faculty/centers/ctm/research/how-much-media Accessed 22 June 2016.

[18] Mills, N. (2015). "Taming the Energy use of gaming computers" http://evanmills.lbl.gov/pubs/pdf/Taming-the-Energy-Use-of-Gaming-Computers.pdf Accessed 20 June 2016. http://evanmills.lbl.gov/pubs/pdf/Taming-the-Energy-Use-of-Gaming-Computers.pdf

[19] Jain, S. (2011). "A comparative assessment of the carbon footprint of AMD Fusion™ products with the previous generation products".
https://www.amd.com/Documents/APU%20Carbon%20Footprint%20white%20paper%20FINAL%201%2021%2011.pdf

[20] Venkatesan, M. (2015). "Comparative carbon footprint assessment of the manufacturing and use phases of two generations of AMD Accelerated Processing Units" http://www.amd.com/Documents/carbon-footprint-study.pdf

[21] Based on an average emission factor of 0.69 kg CO2e/kwh (Pure Strategies) and $0.1258 per kWh from the US Energy Information Administration

[22] Jon Peddie Research's Add-in-Board Quarterly Market Report. Fourth quarter 2015, graphics board shipments and market activity (Pp 24). Performance GPUs are priced at $100-249, and approximately 15.8 million were sold in 2015.

[23] The alternate use case in the sensitivity analysis showing the least delta for annual electricity savings was 2.4 hours active gaming; 2 hours of web browsing; 1.6 hours for video streaming; 1 hour of short idle; 5 hours at long idle; 6 hours in sleep mode; and 6 hours off. In this case the gaming PC with the R9 390 GPU consumes 683 kWh annually, instead of 507 kWh annually with the RX 480 GPU, a difference of 176 kWh (25.6 percent reduction). 176 kWh x 15.8 million = 2,784,307,600 kWh per year x $0.1258 cents per kWh (US Energy Information Administration) = $350,265,896 USD. 15,800,000 GPUs per year x 0.12 MTCO2e per gaming PC = 1,921,172 MTCO2e. 2,784,307,600 kWh per year equals electricity to power 289,946 US homes for one year (US EPA Greenhouse gas equivalency calculator)

[24] The annual kWh savings from operating a gaming PC with a Radeon R9 390 versus a Radeon RX 480 is 296 kWh (929 kWh – 633 kWh). Annual per PC savings times the number of Performance GPUs sold in 2015 equals 4.7 million kWh. US EPA carbon equivalency calculator used to estimate equivalent number of US homes powered. Estimated carbon emissions from the average emission factor of 0.69 kg CO2e/kWh (from Pure Strategies). Energy costs are the US national residential average of $0.1258 per kWh from the US Energy Information Administration.