# Comparative Carbon Footprint Assessment of the Manufacturing and Use Phases of Two Generations of AMD Accelerated Processing Units

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By Chandramouli Venkatesan

## I. Executive Summary

Founded in 1969 and headquartered in Sunnyvale, California, Advanced Micro Devices (AMD) designs and integrates technology that powers millions of intelligent devices for gaming, immersive platforms, and the datacenter, including personal computers, tablets, game consoles and cloud servers. AMD solutions enable people everywhere to realize the full potential of their favorite devices and applications to push the boundaries of what is possible.

In 2014, announced its 25X20 energy efficiency goal to deliver at least 25 times more energy efficiency (assuming typical use as defined in Section V.c) from its mobile Accelerated Processing Units (APU) by 2020, compared to a 2014 baseline year. Accelerated Processing Units are the combination of a Central Processing Unit (CPU) and a Graphics Processing Unit (GPU) on one piece of silicon.

Energy efficiency is a measure of the amount of computational work a processor can perform for a given unit of energy. Increasing energy efficiency by 25 times would mean that a computing device using an AMD APU in 2020 could accomplish a task in one-fifth of the time, while consuming on average less than one-fifth the electricity when compared to the 2014 baseline processor. In 2015, AMD launched its 6th Generation AMD A-series APU (codenamed "Carrizo"). The energy efficiency of the Carrizo processor puts AMD ahead of the trend line needed to achieve the 25x20 goal.[i]

This study quantifies the overall life cycle greenhouse gas implications of Carrizo (A12-8800B) by comparing it to the previous generation A-Series APU, codenamed "Kaveri" (A10-7350B). Greenhouse gas emissions (also referred to as "carbon emissions") associated with major stages in the life cycle are evaluated for each processor, including wafer fabrication, assembly, test, pack, and consumer use.[ii]

The conclusion of this "carbon footprint" evaluation is that the life cycle carbon footprint of the Carrizo APU is approximately 46 percent smaller than that of the Kaveri APU. The majority of carbon emission savings come from reductions of the energy consumed in the use phase of the total life cycle (the time when the notebook computer is being used). Based on the differences observed in the use phase alone, users that upgrade to a Carrizo-based notebook computer from a Kaveri-based notebook computer can expect approximately a 50 percent smaller carbon footprint during the use phase of the product (assuming the two computers have the same components).

## II. Introduction

Climate change is arguably 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.[1] There is an overwhelming consensus among climate scientists that changes observed in the atmosphere and the climate are due to GHG emissions associated with human activities. [2]

"Carbon emissions" has become a shorthand phrase to describe a collection of gases that, when emitted to the atmosphere, accumulate and trap the sun's energy, leading to climate change. These gases are collectively referred to as GHGs. A carbon footprint study assesses the overall GHG emissions associated with the life cycle of a product or process.

The number of digital products in use, such as notebook and desktop computers, servers, smartphones, and tablets, is growing at an astounding rate along with the total energy they consume. In 2013, approximately three billion personal computers used more than 1% of total energy consumed, and 30 million computer servers worldwide used another 1.5% of all electricity, at an annual cost of $14 billion to $18 billion.[3] By 2020, its estimated the number of Internet connected devices will be 50 billion.[4] Since virtually all of these products consume electricity, their use contributes to GHG emissions.

As the global focus on climate change continues to grow, more organizations are implementing energy and carbon reduction goals and initiatives. A recent study found 60 percent of Fortune 100 companies have established public targets for reducing their greenhouse gas emissions.[5] Use of energy efficient IT products within these companies can assist in reaching these targets.

The results of this study can help companies interested in managing their carbon footprint by quantifying GHG reduction benefits of upgrading notebook (laptop) computers to the 6th Generation AMD A-Series APU from the prior generation. For example, if a commercial enterprise upgraded 100,000 Kaveri-based computers to Carrizo-based computers, based on ENERGY STAR® typical use scenario the firm could achieve reductions of 4,860,000 kWh and 3,350 metric tons of GHGs over a three year service life. The power saved would be enough to power 461 US homes for a year.[iii]

Designing energy efficient semiconductors is a major business imperative for AMD. Semiconductors are the brains of digital devices and in large part determine the overall energy consumption of the system. In the past, as new generations of semiconductors were developed, they were inherently more energy efficient because the newer products packed more transistors onto the chip, allowing them to do more work with essentially the same energy input. This trend is defined by "Moore's Law" which predicted that the number of transistors in semiconductor products roughly doubles in every generation, or about every two years. However in the early 2000's, the energy efficiency benefits stemming from the Moore's Law trend began to slow down. [6-7]

AMD engineers responded to this slowing trend with significant improvements in semiconductor design. The energy efficiency of AMD processors improved 10 fold from 2008 to 2014 (assuming typical use).[iv] Part of this improvement came from the creation of the APU itself, which combines the CPU and the GPU onto one chip. AMD conducted a carbon footprint study in 2010 that compared the first generation APU to the previous generation platform with a separate CPU and GPU and CPU, and found a 40 percent reduction in GHG emissions by combining the two processors into one piece of silicon.[8]

Recognizing the need to do even more, AMD announced a goal in June of 2014 to deliver 25 times improvement in the energy efficiency of its mobile APUs by 2020, from a 2014 baseline (assuming typical use).[v] This means a computer using an AMD APU in 2020 could accomplish a task in one-fifth of the time as in 2014, while consuming on average less than one-fifth the electricity. Using a car analogy, this rate of improvement would be like turning a 100-horsepower car that gets 30 miles per gallon into a 500 horsepower car that gets 150 miles per gallon in only six years. The 25x20 initiative represents an ambitious goal for AMD, in part because meeting this goal means that AMD APU processors will outpace the historical efficiency trend predicted by Moore's Law by at least 70 percent.[6-7]

The first processor introduced since the advent of the 25x20 initiative is the 6$^{th}$ Generation AMD A-Series APU codenamed "Carrizo," which will be used in both notebook and desktop computers. The Carrizo microprocessor represents a huge leap in energy efficiency over previous generations of AMD APU processors and puts AMD ahead of the pace needed to meet its 25x20 goal.[vi]

AMD conducted this study to estimate and compare the differences in the overall carbon footprint of Carrizo compared to its predecessor, Kaveri. The study utilized widely accepted carbon footprint assessment guidelines, and AMD subjected the analysis to a qualified third-party review to ensure alignment with these guidelines.[9] To analyze the carbon footprint of each product, this assessment includes GHG emissions estimates from each major phase of the product life cycle including wafer fabrication, assembly, test, pack, and consumer usage.

**The findings show that the carbon footprint of a Carrizo-powered notebook computer is approximately 46 percent less than a Kaveri-powered notebook, assuming a three year service life, equivalent component configuration and typical usage scenario.[vii] [viii] The use phase of the processor is the largest contributor to the overall carbon footprint and the biggest differentiator between AMD's Carrizo and Kaveri APU. These results indicate that an end user upgrading to a Carrizo from a Kaveri-based notebook computer can expect 50 percent fewer GHG emissions over the service life of that Carrizo-based product, while simultaneously experiencing significantly improved computing performance and battery life.[ix]**

**III. Processor Information: "Kaveri" and "Carrizo"**

The Carrizo (A12-8800B) and Kaveri (A10-7350B) APU models evaluated in this study are comparable high-performance "A-Series" processors representing consecutive product generations. Both are manufactured using 28 nanometer manufacturing technology and have the same 2.1 GHz clock speed.[x] Despite the similarities, some of the major differences between the Carrizo APU and Kaveri APU are:

- Carrizo includes an integrated Southbridge, making it a true "system on chip" (SoC), whereas Kaveri uses a separate chip for the Southbridge ("Bolton");
- Carrizo has power-optimized "Excavator" CPU cores utilizing a high-density design library that reduces core area by 23 percent when compared to Kaveri's "Steamroller" cores implementation;

- Carrizo integrates a dedicated, ARM®-based security subsystem integrated with the system on chip, a first in APU design; and
- Carrizo is the first APU designed to meet the Heterogeneous System Architecture (HSA) 1.0 specification developed by the HSA Foundation, leading to easier programming and better performance with low power consumption; [10]

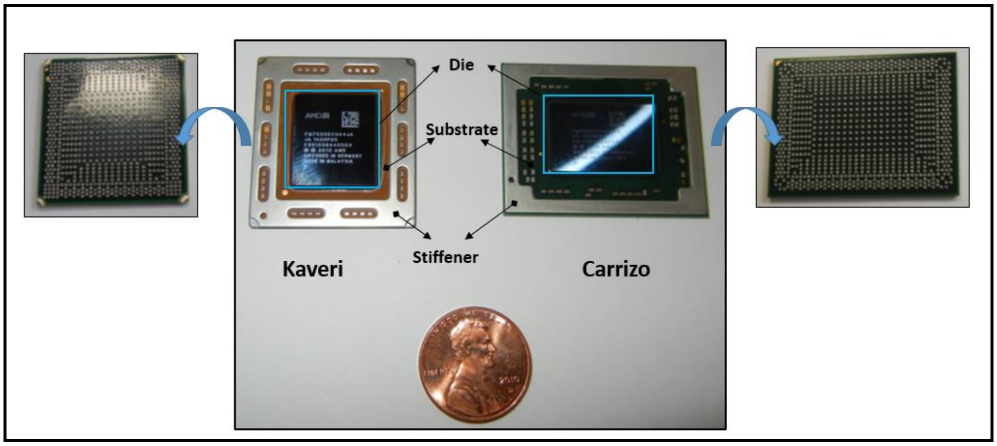


Figure 1: Kaveri and Carrizo APU (not shown in actual size)

Both processors were tested for comparative performance using Futuremark's PCMark® (version 8.2), an industry standard personal computer benchmarking tool.[11] The test procedure compares the computer performance using real-world tasks and applications that are commonly seen in both home and office scenarios. In all test scenarios, the Carrizo APU outperformed the previous generation Kaveri APU. Futuremark's PCMark® test scores for AMD's notebook reference platforms with Kaveri and Carrizo APU's are provided in Figure 2.

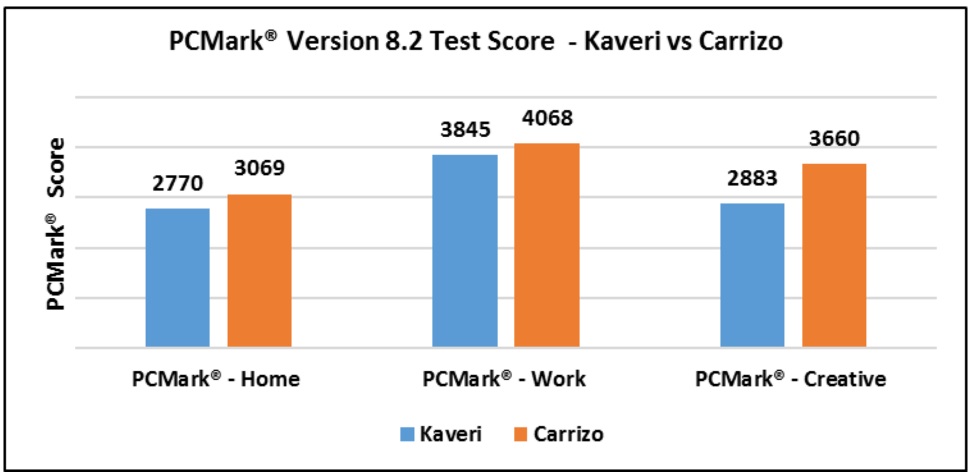


Figure 2: Test results from AMD Power and Performance Lab on PCMark® Version 8.2 [xi]

## IV. Carbon Footprint Methodology

The purpose of a carbon footprint study is to assess the overall GHG emissions associated with the life cycle of a product or process. Life cycle assessment (LCA) is a methodology to quantify the environmental impacts of product, processes, and/or system.[12] The LCA measures input materials that go into a product, energy used to make the product, its simulated real-world use, and outputs such as the finished product itself and any associated waste. In essence, a carbon footprint study is a life cycle assessment that is solely focused on greenhouse gas implications.

In this context, a carbon footprint study quantifies the GHG emissions associated with the energy expended to make a product, along with the energy that is used to operate the product during its useful life. For example, making a passenger car requires energy to create the raw materials and assemble the vehicle, but the car also uses energy (e.g., gasoline) for operation.

This carbon footprint analysis includes the energy used across the life cycle of two generations of AMD APUs, and converts the energy used into the associated GHG emissions. There are several types of gases that are included in the definition of GHGs. Carbon dioxide ($CO_2$) is the predominant contributor to climate change and, in addition to $CO_2$, there are several other compounds associated with climate change (i.e., $SF_6$, $CH_4$, $N_2O$, HFCs, HFEs and PFCs). Each of these compounds has a different potency or "global warming potential" (GWP). The GWP measures the contribution of each GHG in terms of its carbon dioxide equivalent, or $CO_2$-e. This is a common method to normalize the potency of these materials. [1, 13] For example, the global warming potential of methane (CH4), the second most prevalent GHG, is 25 times greater than that of $CO_2$, thus its GWP is 25. [xii]

This study was conducted in accordance with the Product Life Cycle Accounting and Standard from World Resource Institute, in collaboration with World Business Council for Sustainable Development.[9] The standard is, in turn, based on the International Standards Association (ISO) 14044 standard, which sets forth requirements and guidelines for LCA analysis, including the following components:

- Goal and scope
- Life cycle inventory analysis
- Life cycle impact assessment
- Interpretation, reporting and critical review [14-15]

This carbon footprint study includes all of these components, and underwent third party critical review performed by EarthShift for adherence to the adopted standard and methodologies. The critical review process description and comments are provided in Appendix A.

### a. Goal and Scope of AMD's Microprocessor Carbon Footprint Study

The goals of this carbon footprint study are to quantify and compare the AMD Kaveri and Carrizo APUs, in terms of energy use and carbon dioxide equivalent emissions ($CO_2$-e), throughout the product life cycle of each processor. The scope of this study, which is often referred to as the LCA boundary, is illustrated in Figure 3.[xiii]

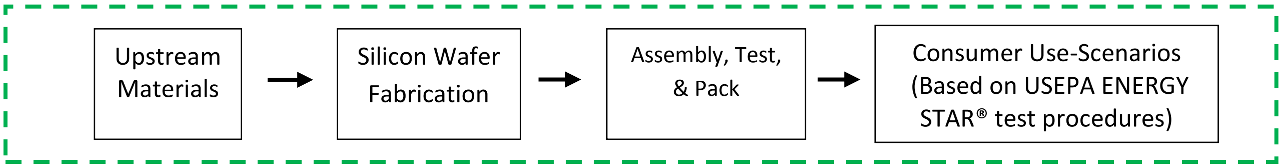


Figure 3: Carbon Footprint Assessment Boundary for Kaveri versus Carrizo APU

The boundary of this carbon footprint assessment includes GHGs associated with wafer fabrication (energy and upstream materials), assembly, test and pack operations (energy and upstream materials), as well as consumer energy use. Out of scope for this study are the manufacturing and assembly of other components in the final notebook computer, such as the motherboard, display, and keyboard. Adjustments were incorporated into the study to assure that other energy consuming components in the computer were identical in order to evaluate the difference associated with the processors only.

In accordance with the Product Life Cycle Accounting and Standard, a criterion of one percent of total life cycle GHG emissions was applied by AMD as the cutoff for inclusion in the study. This means any life cycle phase that was less than or equal to one percent of the total life cycle GHG emissions for either processor was not included in the study's final comparative assessment. For this reason, the GHG emissions associated with transportation and the end-of-life (EOL) of the processors are not included in the final assessment.[xiv]

The study includes direct emissions (GHG emissions direct to the atmosphere) from onsite processes, as well as indirect emissions (GHG emissions associated with offsite electricity generation) for wafer fabrication and assembly, test, and pack (ATP) operations. Additionally, GHG emissions are included from the upstream supply chain (e.g., materials used in the manufacturing process) and downstream product use (e.g., the electricity consumption of notebook computers over a three year service life). The study is based on data from 2014 and 2015 provided at the facility level for both the wafer fabrication and ATP phase (see Section V).

### b. Functional Unit

A functional unit is the quantifiable unit used to measure the carbon footprint across the phases of a product life cycle. For this assessment, the functional unit is kilograms of $CO_2$-e per APU over a three year service life of a notebook computer. Two major assumptions used to calculate this functional unit include a three year service life for a typical notebook computer, and the typical notebook computer use scenario specified by the EPA ENERGY STAR® program.[16] Details and publicly available references for these assumptions, as well as a sensitivity analysis, are discussed in Section VI.

## V. Life Cycle Inventory: GHG Emissions, Boundary, Data Sources and Assumptions

### a. GHG Emissions from the Wafer Fabrication Phase

Semiconductors are fabricated on silicon wafers in cleanroom fabrication facilities through a photo-lithography process that can include a series of more than 200 complex steps. The operation uses multiple process chemicals and gases, some of which can contribute to GHG emissions.[8]

In this study, wafer fabrication GHG emissions are calculated based on annual GHG emissions data collected in 2014 from a foundry facility that manufactures both the Kaveri and Carrizo APUs. The direct (onsite) GHG estimates for wafer fabrication are based on the use and GHG emissions of refrigerants and other process gases. The GWP emission factor for each refrigerant and process gas was sourced from the IPCC Fourth Assessment Report (100 yr. time horizon).[13] The indirect (offsite) GHG emission estimates are based on GHG emission factors from the local electricity and natural gas providers. Lastly, "upstream" supply chain GHG emissions are estimated based on the energy used to make the materials in the manufacturing process. This study includes approximately all 40 chemicals used in the wafer manufacturing process.[xv]

GHG emissions from all of these sources were allocated to AMD products by dividing the total GHG emissions from the wafer manufacturing facility by the product specific "Manufacturing Index" (MI). The MI is calculated by taking the number of wafers manufactured per year, multiplied by the square centimeters of silicon in the finished product, multiplied by the number of "mask layers" (photolithography masks).

Estimates for GHG emissions from wafer fabrication, from direct, indirect and upstream (materials) sources, are provided in Table 1. The results indicate the overall GHG emissions for the wafer fabrication stage are twelve percent less for Carrizo than Kaveri. The primary reason for this difference is a reduction in mask layers of Carrizo compared to Kaveri.[xvi] The reduction in mask layers indicates fewer manufacturing steps which is assumed to be roughly proportional to less GHG emissions.

| Description | Kaveri (KV) Kg $CO_2$-e/die | Carrizo (CZ) Kg $CO_2$-e/die | Percent (%) Change from KV to CZ |
|---|---|---|---|
| Total wafer fabrication emissions [includes direct, indirect and upstream emissions] | 5.86 | 5.15 | -12.0 |

Table 1: Wafer fabrication GHG emission estimates for Kaveri and Carrizo

### b. GHG Emissions from the Assembly, Test, and Pack (ATP) Phase

After the wafer fabrication process, the finished silicon wafers are shipped to the AMD ATP facility where they are cut into die and assembled on to the substrate along with a stiffener layer. The completed product (chip) is then tested on specialized equipment and prepared for shipping. Similar to the wafer fabrication process, the GHG emissions from the ATP process are calculated based on facility level data from 2014 and estimated in accordance with the GHG Protocol Corporate Accounting and

Reporting Standard.[17] The GHG emissions estimates associated with the AMD ATP site are also published in the AMD Corporate Responsibility Report. [18]

The GHG emissions from the ATP process come from three sources: direct (onsite) GHG emissions from equipment that uses fuels and refrigerants, indirect (offsite) emissions from electricity generation, and the upstream energy and GHG emissions associated with the materials used to make the product. To estimate direct (onsite) GHG emissions, AMD tracks fuel combustion and fugitive emissions of refrigerants (e.g., HFCs) in a corporate database. These data are converted into GHG emission estimates using emission factors provided by chemical manufacturers and the IPCC Fourth Assessment Report (100 yr. time horizon). [19, 22-23]

To estimate indirect (offsite) GHG emissions from electricity generation, AMD tracks metered electricity data from the AMD ATP facility located in Penang, Malaysia in a corporate database. These data are converted into GHG emissions using emission factors provided by the local electricity provider.[xvii] Additional "upstream" GHG emissions estimates were calculated for twelve substrate and stiffener materials used in the ATP process, some of which require relatively high energy and direct GHG emissions to manufacture (e.g., palladium, gold, nickel, tin, copper, and silver).[xviii] The GHG emission factors associated with these materials were based on the Eco-Invent version 3 database, IPCC Fourth Assessment Report (100 yr. time horizon) and other sources. [13, 19-20]

The GHG emissions associated with the AMD ATP facility and the upstream materials it uses were allocated to each product by dividing by the number of each processor tested and assembled at the site in 2014. As shown in Table 4, the GHG emissions from the ATP stage for each processor are nearly identical.  The ATP process steps are approximately the same for Kaveri and Carrizo, as confirmed through consultations with factory engineers at the AMD Penang ATP facility.[xix] However the materials used as inputs to the ATP stage for Kaveri and Carrizo APU differ slightly, as evidenced by the difference in each processor's weight, 4.2g and 4.6g respectively.

| Description | Kaveri (KV) Kg $CO_2$-e/APU | Carrizo (CZ) Kg $CO_2$-e/APU | Percent Change from KV to CZ |
|---|---|---|---|
| Total GHG emissions from the ATP phase [direct, indirect, and upstream GHG emissions] | 2.02 | 2.03 | 0.50 |

Table 2: ATP process-based GHG emissions for Kaveri and Carrizo APU

### c. GHG Emissions Associated with the Consumer Use Phase

The inclusion of GHG emissions associated with the consumer use phase is consistent with previous semiconductor carbon footprint analyses.[8,21] To calculate the energy consumption associated with the consumer use phase, we used the "typical use" scenario from the US EPA ENERGY STAR® standard, version 6.0.[16] Generally speaking, ENERGY STAR® is a voluntary energy labeling program that provides consumers and institutions with energy consumption information for a wide array of products including notebook and desktop computers. The standard is similar to those adopted by Japan, New Zealand and the European Union. ENERGY STAR® defines "typical use" as the amount of time the computer is in a particular mode when used by a "typical" operator. These modes are defined by the associated energy consumption, as measured in watts (see Table 3). The energy consumption in each mode is multiplied by the amount of time the computer is in that mode, to calculate the annual typical energy consumption (TEC). The ENERGY STAR® formula is shown in Figure 4. More information on the test standard and procedure can be found at the EPA ENERGY STAR® website.[16]

Kaveri and Carrizo APUs were tested using the EPA ENERGY STAR® guidelines by the AMD Power and Performance Lab. These tests were based on an optimized AMD reference platform for notebook computers. The results of these tests are presented in Table 3.

| Use Mode Description | ENERGY STAR® Duty Cycle Percent (%) of Time ($T_i$) | Power at wall (W) ($P_i$) | |
|---|---|---|---|
| | | Kaveri | Carrizo |
| Off mode | 25 | 0.89 | 0.40 |
| Sleep mode | 35 | 1.13 | 0.50 |
| Long Idle mode | 10 | 6.08 | 1.92 |
| Short Idle mode | 30 | 8.46 | 4.06 |

Table 3: Power at wall in each mode on AMD reference platform with Kaveri and Carrizo APU

Energy Star® Typical Energy Consumption (TEC) Calculation ($E_{TEC}$) for Notebook Computers

Notebook $E_{TEC} = (8670/1000) \times \sum (P_i)(T_i)$

- Notebook $E_{TEC}$ = Typical Energy Consumption of reference notebook with Kaveri and Carrizo APU (kWh/year)
- 8670/1000 = 365 days/year x 24 hours/day (conversion factor to convert hourly energy consumption to annual)
- ($P_i$) = $P_{off}$, $P_{Sleep}$, $P_{Long\ idle}$, and $P_{Short\ idle}$ = Power consumption in each mode
- ($T_i$) = $T_{off}$, $T_{Sleep}$, $T_{Long\ idle}$, and $T_{Short\ idle}$ = Percent time the product annually spends in each mode

**Total Energy Consumption = $E_{TEC}$ x notebook service life**

Figure 4: Energy Star® Typical Energy Consumption (TEC)

To measure and compare the energy consumption of the Kaveri and Carrizo APUs only, all of the other components in the reference notebook computer (e.g., memory, display, etc.) were inventoried and any differences accounted for in the calculations.[xx] This assessment (conducted by the AMD Power and Performance Lab) identified two differences in AMD's reference systems for Kaveri and Carrizo: The amount of memory and the efficiency of the AC power adapter. The Kaveri reference notebook computer has 4GB of system memory, whereas the Carrizo platform has 2GB of system memory. Therefore, the additional power consumed by the extra 2GB of memory in the Kaveri-based notebook was deducted from Kaveri's test results on total energy consumption. The energy used by the Carrizo-based notebook was slightly less due to a more efficient AC power adapter. These energy savings were added to Carrizo's total energy consumption (see Table 4). These two adjustments neutralize the variability stemming from different components in the reference platforms and thus isolate comparison of energy consumption of the Kaveri and Carrizo APUs. Table 4 outlines these adjustments, shows the typical energy consumption per year, and compares $CO_2$-e emissions from electricity generated to power these computers over their service life.[22] Based on this analysis, the Carrizo APU results in 50 percent less energy and GHG emissions than the Kaveri APU in the use phase.

| Description | Unit | Kaveri | Carrizo |
|---|---|---|---|
| Typical Energy Consumption (TEC) based on EPA ENERGY STAR® test standard (using AMD reference platform) | kWh/year | 33.0 | 14.8 |
| TEC after adjusting for differences in system memory and AC power adapter efficiency | kWh/year | 32.2 | 16.0 |
| TEC over a three year service life | kWh/3 years | 96.6 | 48.0 |
| GHG emission factor considered for electricity use | Kg CO2-e/kWh | 0.69 | |
| Total use phase GHG emissions over a three year service life | Kg $CO_2$-e/ APU over three years | 66.6 | 33.1 |
| Total use phase percentage change of energy and GHG emissions, from Kaveri to Carrizo | Percentage | -50.2 | |

Table 4: Use phase GHG emissions for Kaveri and Carrizo APU based notebook computers

### d. Transportation and End-of-Life Phases

The GHG emissions associated with the transportation phase of the life cycle are estimated using a proxy transport model in lieu of actual transportation data.[xxi] This simulation model utilized the assumption that finished 300mm wafers are shipped from the manufacturing foundry to the AMD ATP facility in Penang, Malaysia. After the finished APU package is assembled, the study assumed that it is shipped from Penang, Malaysia to an original equipment manufacturer, several of which are in Shenzhen, China.

The GHG emissions associated with transportation can vary depending on the mode of transport, weight of the product, and distance travelled. This study assumed that air freight transportation was used for all shipping[xxii]. Based on these assumptions, the estimated GHG emissions estimate from this stage is 0.03 Kg $CO_2$-e/ APU.[xxiii] Because the transportation-based GHG emission estimate is less than one percent of the total life cycle GHG emissions estimate, this stage was excluded from the final analysis.

The end-of-life (EOL) phase for an APU is when the product is discarded for disposal or recycling. The analysis of the GHG emissions associated with this phase relied upon previous semiconductor carbon footprint studies.[23-26]An APU is one part of a notebook computer that, if not reused or refurbished, can be recycled for the value of its elemental materials (e.g., gold). A previous study estimated the GHG emissions from the landfill disposal of a 1.7 kg subject notebook to be 300g $CO_2$-e.[23] By relying on this estimate, this analysis concluded that the EOL phase is less than one percent of total life cycle GHG emissions estimate, therefore this phase was excluded from the final analysis.

## VI. Results and Interpretation

A primary finding of this study is that the life cycle carbon footprint of AMD's Carrizo APU is approximately 46 percent smaller than the Kaveri APU. The consumer use phase of the life cycle is the largest segment of the overall carbon footprint for each product – ranging between 80 and 90 percent of the overall GHG emissions estimate. When comparing the consumer use phase only, the Carrizo APU carbon footprint is 50 percent smaller than the Kaveri APU over a three year computer service life. At the wafer fabrication stage, which represents approximately eight and twelve percent of the total life cycle GHG emissions for Kaveri and Carrizo, respectively, this study found that the production of the Carrizo APU resulted in twelve percent less GHG emissions compared with Kaveri. The result is likely due to fewer masking layers in the chip architecture, which in turn reduces manufacturing steps and associated energy use and GHG emissions.

Ultimately, an end user that replaces a Kaveri-based notebook computer with a Carrizo-based notebook will save approximately 49 kWh and 34 kg of GHG emissions over the three year service life of the computer. Table 5 presents the major findings of this carbon footprint assessment.

| Description | Kaveri (KV) | | Carrizo (CZ) | | Delta |
|---|---|---|---|---|---|
| | GHG Emissions ($KgCO_2$-e/APU) | Percent (%) of the Total Life Cycle | GHG Emissions ($KgCO_2$-e/APU) | Percent (%) in Total Life Cycle | Percent (%) Change from KV to CZ |
| Wafer Fabrication | 5.9 | 7.9 | 5.2 | 12.8 | -12.0 |
| ATP | 2.0 | 2.7 | 2.0 | 5.0 | 0.5 |
| Use | 66.6 | 89.4 | 33.1 | 82.2 | -50.2 |
| Total | 74.5 | 100 | 40.3 | 100 | -45.8 |

Table 5: Total GHG emissions from Kaveri and Carrizo APU

## VII. Sensitivity Analysis

There are two primary sources of uncertainty in this assessment: parameter uncertainty and scenario uncertainty. For the parameters used in this study, if direct measurements were not available, then inputs from other published studies or best engineering judgments from relevant professionals were utilized. As examples, wafer fabrication GHG emissions data were provided by the foundry engineers, and process steps for ATP operations are provided by AMD engineers. To identify upstream materials from the supply chain, this study used the AMD "bill of materials" and then estimated the corresponding GHG emissions for each material based on emission factors.[20]

The other primary source of uncertainty stemmed from the scenarios assumed in this study, mainly how a notebook computer is used and for how long. The use phase represents the majority of overall energy consumption and GHG emissions in this study, which is aligned with other previous studies.[8, 21]

To test the sensitivity of the use phase scenarios, this study tested the impact to the overall GHG estimates by varying these assumptions. For example, this study assumed that the service life of a notebook computer is three years, based on industry norms and a previous life cycle assessment study.[21] By changing the assumed service life to two years and four years, the variation in the GHG estimates was less than two percent (see Table 6).

| Service Life Scenarios for GHG Emissions Estimate Difference | Percent (%) Change in Absolute Value | Delta (%) |
|---|---|---|
| Three (3) year service life (base case) | 45.8 | 0.0 |
| Two (2) year service life | 44.1 | -1.7 |
| Four (4) year service life | 46.9 | 1.1 |

Table 6: Total GHG emissions sensitivity based on service life

Another important use phase assumption is the percentage of time a notebook computer is in different power consuming modes. This study followed the EPA ENERGY STAR® test parameters for standard use phase scenarios.[xxiv] For example, the EPA standard assumes that a notebook computer is in the "short idle" mode 35 percent of the time. (This mode uses more energy than others because the storage drive is active as the computer completes workloads). To test the sensitivity of these assumptions, the use phase scenario was modified by changing the percentage of time that the notebook computer spends in each mode using a spectrum of ten thousand possible use phase scenarios. The difference in the life cycle GHG emission estimates from all these scenarios has a median of 49 percent, which is similar to the conclusion of this study.[xxv] The results of this sensitivity analysis are presented in Figure 5.

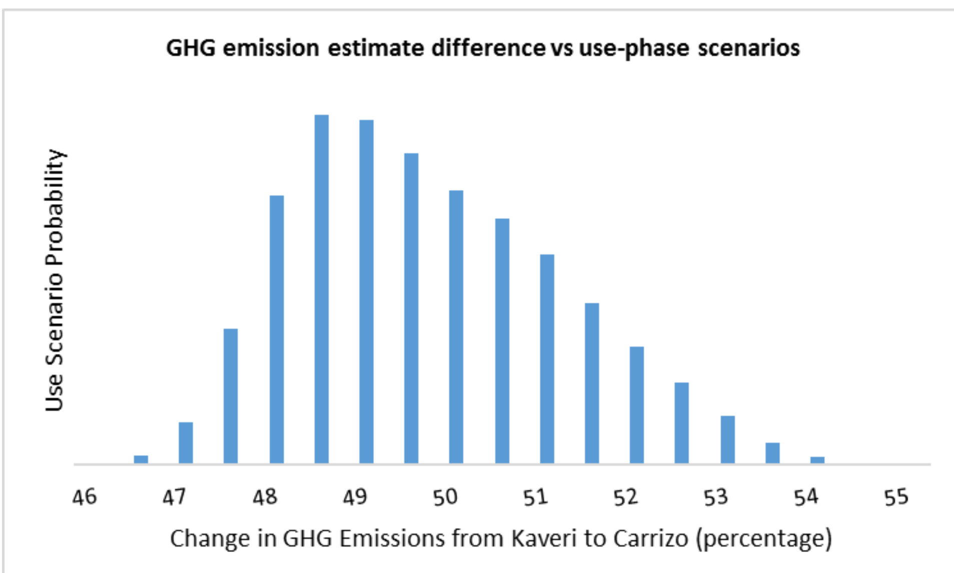


Figure 5: Use phase scenario probability vs GHG emissions estimate difference (%) with variations in off, sleep, long and short idle modes for a simulation of 10,000 random use cases[xxvi]

Additional sensitivity analyses were conducted to assess the variability from assumptions regarding GHG emissions associated with upstream materials used in wafer manufacturing and ATP phases. Varying the total GHG estimates from these phases of the study by five and twenty percent resulted in less than one percent variation in the overall GHG emissions comparison between the Kaveri and Carrizo APUs.

## VIII. Conclusion

This study found that the life cycle carbon footprint of AMD's Carrizo APU is 46 percent less than the Kaveri APU. The majority of the difference in the life cycle GHG emission estimates comes from lower energy consumption in the use phase of the Carrizo product.

These results indicate that an end user upgrading to Carrizo from a Kaveri-based notebook computer can expect 50 percent fewer GHG emissions over the three year service life of the Carrizo processor, while simultaneously experiencing significantly improved computing performance and battery life.[xxvii] This carbon footprint study also helps companies interested in managing their carbon footprint by quantifying GHG reduction benefits of upgrading notebooks to the 6$^{th}$ Generation AMD A-Series APU from the prior generation. For example, if a commercial enterprise upgraded 100,000 Kaveri-based notebook computers to Carrizo-based notebooks, they could achieve reductions of 4,860,000 kWh and 3,350 metric tons of GHGs over a three year service life. The power saved would be enough to power 461 US homes for a year.[xxviii]

## IX. Disclaimer



## X. End Notes

[i] AMD's 25X20 energy efficiency webpage, http://www.amd.com/en-us/innovations/software-technologies/25x20
[ii] The third party critical review of this study was conducted by EarthShift (http://www.earthshift.com) in accordance with the Greenhouse Gas Protocol Life Cycle Accounting and Reporting Standard (http://www.ghgprotocol.org/files/ghgp/Product%20Life%20Cycle%20Accounting%20and%20Reporting%20Standard.pdf). A record of reviewer comments and AMD responses can be requested by emailing CorporateResponsibility@AMD.com.

[iii] Based on ENERGY STAR® typical use tests conducted by AMD lab, and after adjusting for differences in system memory and AC power adapter efficiency, switching from one Kaveri notebook (32.2 kWh per year) to Carrizo notebook (16.0kWh per year), saves 16.2 kWh per year, or 48.6 over the three year service life. When multiplied by 100,000 notebook conversions from Kaveri to Carrizo, the savings is 4,860,000 kWh over the three year service life. EPA's Carbon Equivalent Calculator estimates this is equal to 3,350 metric tons of GHGs, eight million miles of driving and electricity for 461 US homes for a year. http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results. The average US electricity rate of $0.102 is from the US Energy Information. Administration. http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a
[iv] AMD's 25X20 energy efficiency website, http://www.amd.com/en-us/innovations/software-technologies/25x20
[v] AMD's 25X20 energy efficiency website, http://www.amd.com/en-us/innovations/software-technologies/25x20
[vi] AMD's 25X20 energy efficiency website, http://www.amd.com/en-us/innovations/software-technologies/25x20
[vii] Three year useful life is a common industry assumption and is included in Boyd, S. B. (2011), *Life-cycle assessment of semiconductors*, Springer Science & Business Media.
[viii] ENERGY STAR® typical use scenario assumes the notebook is in off mode 25 percent of time, sleep mode 35 percent, long idle 10 percent and short idle 30 percent. https://www.energystar.gov/index.cfm?c=computers.pr_crit_computers
[ix] Testing conducted by AMD Performance labs on optimized AMD reference systems. PC manufacturers may vary configuration yielding different results. Basemark CL performance is used to represent CPU performance; the AMD FX-8800p (35W) scored 86 while the AMD A10-8700P processor scored 58. CZN-23Battery testing by AMD Performance labs using reference platforms based on an AMD 6th Generation Processor featuring an AMD FX-8800P platform, 2x4GB DDR3-1600, 256GB SSD, Windows 8.1, Driver 15.100 lasting 10.2 hrs The comparison system consisted of an AMD FX 7600P with 2x4GB DDR3-1600, 256GB SSD, Windows 8.1, 14.200.1004 drivers. Jan 15, 2015 lasting 7.1 hrs. Testing done with a 50 kw/hr battery with Varibright mode set to aggressive, and airplane mode enabled, with MobileMark12. CZN-14
[x] Specifications for "Kaveri" system: A10-7350B APU, 2x 4GB, DDR3L-1600, 1Rx8 for 19W, 256 GB 6GB/s SATA, Windows 8.1, GPU Driver 13.350.0.0. "Carrizo" system: A12-8800B APU, 2x 2GB, DDR3L-1866, 1Rx16 for 15W, 256 GB 6 GB/s SATA, Windows 8.1 Pro Build 9600, GPU Driver 15.100.1020.0.
[xi] Typical-use Energy Efficiency as defined by taking the ratio of compute capability as measured by common performance measures such as SpecIntRate, PassMark and PCMark, divided by typical energy use as defined by ETEC (Typical Energy Consumption for notebook computers) as specified in Energy Star Program Requirements Rev 6.0 10/2013. "Kaveri" system: A10-7350B APU, 2x 4GB, DDR3L-1600, 1Rx8 for 19W, 256 GB 6GB/s SATA, Windows 8.1, GPU Driver 13.350.0.0. "Carrizo" system: A12-8800B APU, 2x 2GB, DDR3L-1866, 1Rx16 for 15W, 256 GB 6 GB/s SATA, Windows 8.1 Pro Build 9600, GPU Driver 15.100.1020.0.
[xii] EPA website, Overview of Greenhouse Gases - http://epa.gov/climatechange/ghgemissions/gases/ch4.html
[xiii] Data on wafer manufacturing, including upstream materials and energy used in operations, provided by EHS engineer at the foundry. Data on ATP, including upstream materials and energy used in operations, provided by AMD Penang. Data on ENERGY STAR® testing provided by AMD Power and Performance Lab using AMD reference notebook system.
[xiv] Transportation and end-of-life phases were assessed but not included in final carbon footprint comparison due to not meeting the one percent criteria for inclusion. In the transportation emissions estimation, the distance and mode of transportation is included but not product packaging. Data on the estimated calculations can be provided by requesting the study's supplemental materials document from CorporateResponsibility@AMD.com.
[xv] Wafer manufacturing data is provided by the EHS engineer at the foundry facility. Some additional data and information, like emission factors, can be provided by requesting the study's supplemental materials document from CorporateResponsibility@AMD.com.
[xvi] The ten percent reduction in mask layers from AMD's Kaveri to Carrizo processors reflects the twelve percent reduction in overall wafer manufacturing GHG emissions.

[xvii] 0.56 KgCO2-e/kWh emission factor was provided from the electricity supplier for AMD Penang - Tenaga Nasional Berhad [electricity mix from coal - 35%, gas - 53%, distillates - 0.6%, and Hydro - 10.3%]
[xviii] Supplemental materials available upon request at CorporateResponsibility@AMD.com. Requires identification of requestor and application of data, and potentially other requirements like a non-disclosure agreement (NDA).
[xix] AMD Facility engineer, YY Low in Penang, provided data and advisement in June-July 2015.
[xx] AMD reference systems may be adjusted from one Generation to the next based on changes in customer interests and available technology. Kaveri and Carrizo reference systems differed in memory size and power adapter efficiency.
[xxi] Model that estimates distance and GHG emissions from air freight transportation, based on known points of origin and the assumed point of destination.
[xxii] AMD logistics providers confirm air freight is primary mode of transport for products. Additional estimated ground freight calculations requires assumptions based on type of vehicle, location and distance.
[xxiii] Transport emissions equals the weight of the product (in tons) times distance traveled in air freight (in kilometers) times KgCO2-e emissions per ton-kilometer.
[xxiv]ENERGY STAR® typical use scenario assumes the notebook is in off mode 25 percent of time, sleep mode 35 percent, long idle 10 percent and short idle 30 percent.
https://www.energystar.gov/index.cfm?c=computers.pr_crit_computers
[xxv] AMD conducted an analysis to generate the energy use from 10,000 different use case scenarios that vary the assumptions in the ENERGY STAR® formula to reflect various energy use conditions due to changing the amount of time in each mode (e.g., off, short idle, long idle or sleep). Additional sensitivity analysis materials can be requested at CorporateResponsibility@AMD.com.
[xxvi] The sensitivity analysis varied the ENERGY STAR® typical use scenario to 10,000 other potential use cases. The analysis showed results if the percentage of overall time spent in long idle changed from 10 percent to a range of 10 to 50 percent, short idle from 30 percent to 30 to 90 percent, off from 25 percent to 10-25 percent, and sleep mode from 35 percent to 10-35 percent. The range of possible GHG emission reductions was 46 to 54 percent.
[xxvii] AMD lab measurements on 3.3 GHz Lab measurements on "Carrizo" 15WFX-8800P, 2x2GB DDR3L 1Rx16 SO-DIMMs, 14" 1366x768 Samsung LTN140AT29 display, 100 nits, 2.5" MM550 SSD, vari-bright enabled, 2.5" SATA SSD. "Kaveri" 19W reference design FX-7500, 2x4GB DDRL 1Rx8 SO-DIMMs, 14" 1366x768 CMO, vari-bright enabled, 2.5" SATA SSD. Cinebench single-thread and multi-thread test results for frequency, instructions-per-clock and benchmarked performance.
[xxviii] Switching one Kaveri notebook to Carrizo notebook saves 16.2 kWh per year, or 48.6 over the three year service life. When multiplied by 100,000 notebook conversions from Kaveri to Carrizo, the savings is 4,860,000 kWh over the three year service life. EPA's Carbon Equivalent Calculator estimates this is equal to 3,350 metric tons of GHGs, eight million miles of driving and electricity for 461 US homes for a year.
http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results. The average US electricity rate of $0.102 is from the US Energy Information Administration.
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## Appendix A: Final Critical Review Statement

EarthShift
*Building pathways to sustainability*

| | |
|---|---|
| **Date:** | August 4, 2015, August 18, 2015 and September 11, 2015 |
| **Study Reviewed:** | Comparative Carbon Footprint Assessment of the Manufacturing and Use Phases of Two Generations of AMD Accelerated Processing Units |
| **Reviewer:** | Shelly Martin, EarthShift |
| **Panel Decision:** | This study was found to be in compliance with the GHG Protocol's Product Standard. There were no unresolved issues upon completion of this critical review. |
| **Applicability of Study Results:** | The results of this carbon footprint are only representative of the AMD APU Carrizo and Kaveri. The results are not intended to make direct comparisons between other APU systems because of differences in the performance characteristics of each system. |

**Critical Review Summary**

EarthShift was commissioned by AMD to conduct a third-party critical review of this product carbon footprint assessment.

The study report and supporting documents were critically reviewed to determine if:

- The methods used to carry out the product carbon footprint are consistent with the international standards (GHG Protocol's Product Life Cycle Standard);
- The methods used to carry out the product carbon footprint are scientifically and technically valid;
- The data used are appropriate and reasonable in relation to the goal of the study;
- The interpretations reflect the limitations identified and the goal and scope of the study; and
- The study report is transparent and consistent.

Since the study is intended to be used to make public claims about the environmental impacts associated with the APUs, the review also considered whether the product carbon footprint assessment report is compliant with the specific reporting requirements of the GHG Protocol Product Life Cycle Standard for studies intended to be communicated to any third party.

The reviewer' responses have been should appear as a supplemental appendix for reference.

**Final Review Statement**

The reviewer concluded that the study is in compliance with the GHG Protocol's Product Life Cycle Standard to be communicated to a third party. There are no outstanding methodological or technical issues upon completion of this review, and the general findings of the reviewer are summarized below. More detailed comments on the study methodology and technical assumptions, including the study team's responses, can be found in the supplemental appendix.

***Are the methods used to carry out the product carbon footprint consistent with the international standards (GHG Protocol's Product Life Cycle Standard)?***

The reviewer found that the study is consistent with the GHG Protocol's Product Life Cycle Standards, and in particular, the reporting requirements to be communicated to third parties. The methodology is clearly described, and all modeling assumptions are documented and explained. Sensitivity analyses were conducted to verify key assumptions and the results of sensitivity analyses did not vary significantly from the primary results, generally supporting the study conclusions.

***Are the methods used to carry out the product carbon footprint scientifically and technically valid?***

The reviewer found that the method used, the IPCC Fourth Assessment Report (100 year time horizon), is scientifically and technically valid.

***Are the data used appropriate and reasonable in relation to the goal of the study?***

The reviewer found that the data used are appropriate with respect to the study objectives.

***Do the interpretations reflect the limitations identified and the goal and scope of the study?***

The reviewer found that the interpretation of the results reflects the limitations identified and the sensitivity analyses provided support the conclusions.

***Is the study report transparent and consistent?***

The reviewer found that the study report is transparent and consistent. A high-level of detail is provided in the description of the product systems, key assumptions, and data used.