

Server Research Project

Efficient Power Supplies for Data Center and Enterprise Servers

February 2008 – Final Report

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Executive Summary

Ecos and EPRI's research into the energy efficiency and power quality characteristics of power supplies presently used in servers revealed ways in which power consumption could be reduced, as well as increase the load capability of the servers. Banks of servers (also known as "data centers" or "server farms") are utilized in a number of applications, including corporate campuses, government offices and educational institutions, and usually run 24/7. This widespread use presents a great opportunity for reducing energy usage by improving operating efficiency.

The research project focused on single output power supplies since market research showed that they are typically the type employed in enterprise and data center environments in a redundant configuration. Forecasts project that server power supply sales, of all types, will more than double over the course of five years.

Testing protocols for this project were adapted from existing measures and modified to test the unique properties of server power supplies. We communicated with technical representatives from power supply manufacturers to identify the priorities for the server power supply test protocol, incorporating data center architecture, such as that power supplies are typically higher power (230 volt input) and used in redundant systems that include more than one power supply for backup. Key stakeholders from power supply and computer manufactures were included in the review process to refine the final protocols.

Server power supplies from a wide variety of manufacturers and server OEMs were tested. The units were high-volume products, consisting of a representative sample of market ready and emerging technology products. Correspondence with industry stakeholders indicated that the vast majority of enterprise/data server power supplies are single output, so analysis focused on this type of power supply unit. During testing, we found that over-sizing was still prevalent, especially in redundantly powered servers: averaging 33 percent under max CPU load and 20 percent under idle, the most common operating condition for most servers. These results confirmed that identifying criteria for lower load conditions is essential to characterize the efficiency of redundant power supplies when servers are operating at or near their idle state. These lower load conditions, as compared to desktop power supplies previously evaluated by the 80 PLUS program, indicate that the server power supply's power factor requirement would need to be lower than the 0.9 mark for desktops.

A rating system was developed to rank efficiency and power factor requirements for server power supplies. The system is in three levels, in increasing efficiency: 80 PLUS Servers Bronze, 80 PLUS Servers Silver and 80 PLUS Servers Gold. 80 PLUS Servers Bronze specifications are achievable by existing products, but will pose a near-term challenge to the marketplace. 80 PLUS Servers Silver and Gold are largely in alignment with Climate Savers' 2008-2009 and 2009-2010 levels, respectively. It is important to note that efforts are currently underway to ensure complete harmonization with groups such as Climate Savers, and along with those collaborative efforts the 10% load criteria identified in this report will most likely be dropped in order to focus on power factor values and further alignment on the 80 PLUS Servers Bronze-level criteria.

Duty cycles for three server types (volume, mid-range, and high-end) were used to estimate efficiencies at each Bronze, Silver and Gold level. Energy savings estimates at each level were converted to the data center level by accounting for associated UPS and cooling savings, as well as a range of assumed product lifetimes from four to six years.

It is recommended that four actions be taken: (1) Implement proposed server power supply efficiency targets and criteria; (2) conduct marketing and launch an awareness campaign; (3) create a third party testing clearinghouse program; and, (4) implement an incentive rebate program. These measures would promote further research into server power supply efficiency and work to garner support from the industry.

Introduction

With funding from a group of electric utility and energy efficiency organizations, industry experts from Ecos Consulting (Ecos) and EPRI have completed research into the energy efficiency and power quality characteristics of power supplies utilized by high-density, rackable and blade servers in data centers.

Businesses and other organizations use banks of servers (often called data centers or “server farms”) to provide Web-based applications and to process transactions electronically. Most office buildings, as well as other types of commercial and institutional buildings, house servers that are addressed by this project. Utility customers that can benefit from this program include:

- ▶ Data centers or server farms
- ▶ Corporate campuses
- ▶ Government offices
- ▶ Banks and other large financial institutions
- ▶ Telecommunications buildings
- ▶ Universities and public school districts

The high-density servers used by these customers present significant challenges to utility managers because they represent a very concentrated 24/7 load that is coincident with customer and system peak. This load includes a very large cooling component – an issue that is widely recognized by utilities, customers and the server manufacturing industry alike.

Efforts to improve power supply efficiency – along with other server efficiency and cooling efficiency efforts – help address the load issue these servers represent, responding to electric utilities’ desire to reduce energy use and peak demand associated with high-density banks of servers. A near-term opportunity exists to improve the efficiency of server power supplies, since they can waste 20 percent to 30 percent of the useful power associated with a data centerⁱ. Amory Lovins, CEO of the Rocky Mountain Institute (RMI), summarized the opportunity in a recent interview:

“When customers realize that heat equals downtime, they will tend to favor manufacturers with efficient equipment. Ten Celsius degrees cooler doubles your mean time between hardware failures. [And] customers realize that saving a watt in the data center is around 20-30 bucks at six cents a kilowatt hour. And the power supply is in many ways the most important efficiency opportunity in the server because of the compounding heat and energy losses from it.”ⁱⁱ

The project addresses the server power supply energy efficiency opportunity with the following steps:

- 1) **Develop a draft test procedure:** The server research project team (Ecos and EPRI) developed a standardized test procedure for measuring the efficiency of multi-voltage output computer power supplies operating in a non-redundant fashion (see www.efficientpowersupplies.org). This procedure – referenced by the ENERGY STAR[®] Version 4.0 Computer Specification – is sufficient for desktop-derived server applications. We revised and enhanced the procedure to address the servers not covered by the existing procedure: high-end servers with power supplies that tend to have single voltage outputs and operate redundantly.
- 2) **Refine test procedure in response to stakeholder input:** Our team worked with industry stakeholders to get feedback on the draft test procedure and industry support for the revised document.

- 3) **Test broad spectrum of available units and develop efficiency specification:** The project team tested a broad range of server power supplies to represent key manufacturers and product types, ensuring accurate analysis of a market with broad potential savings ranges. We recommend two tiers of energy-efficiency specifications for server power supplies, though a third could be added in the future if manufacturers make sufficient progress achieving the first two levels.
- 4) **Recommend a market approach for promoting the most efficient products:** This task included packaging the server power supply specification and providing program recommendations. The project provided recommendations regarding the appropriate combination of customer education, marketing and financial incentives needed to shift the market toward a preference for these energy-efficient products.

Market Assessment

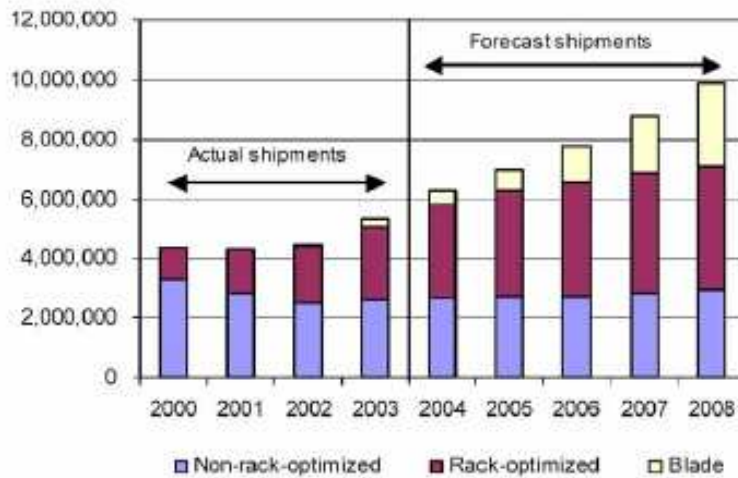
We began the research project’s market assessment by identifying the types and characteristics of power supplies most commonly used in data center and enterprise servers. A power supply is a device that converts high-voltage AC electricity into lower voltage DC electricity used by electronic devices. For the purposes of this project, server power supplies were split into two main categories: single output and multiple output, based on the number of voltage outputs. Single output power supplies are designed to provide one DC voltage level on one output voltage bus (often 12 volts or 48 volts), while multiple output power supplies provide more than one DC voltage level or bus (often 12 volts, 5 volts, and 3.3 volts). Table 1 shows the common characteristics for each power supply type based industry feedback and over 30 server power supplies submitted by manufacturers for testing.

Table 1: Power Supply Characteristics

Server Power Supply Output Category	Characteristics
Multiple Output	<ul style="list-style-type: none"> ▶ Multiple output voltages ▶ Typically run on “low line” or 115 volts AC ▶ Commonly non-redundant ▶ Usually have standardized connectors ▶ Used in desktop-derived servers
Single Output	<ul style="list-style-type: none"> ▶ Frequently run on “high line” or 230 volts AC ▶ Commonly configured redundantly ▶ Usually have custom connectors and “voltage sense” feedback systems ▶ Mounted in IT/telecom rack

Previous research, and the existing 80 PLUS® program, focused on multiple output power supplies used in desktop computers and desktop-derived (pedestal) servers, which are typically in a non-redundant configuration. This segment of the market is represented in Figure 1 by the non-rack-optimized servers – approximately 35 percent of the server market. This research project focused on single output power supplies since they are typically the type employed in enterprise and data center environments. In a data center environment, these power supplies are usually configured redundantly, so that two power supplies power a single server or server bank (either sharing the load 50-50, or with one bearing the load and the other idling). If one power supply fails, the other one will assume the full load to protect the server from unnecessary downtime. Servers used in enterprise and data center environments are typically utilized in rack-optimized or blade-based architectures.

Figure 1: Historical and Forecast Adoption of Pedestal, Rack-Optimized and Blade Servers



Source: IDC, 2004 as shown in Humpreys, John and Jessica Yang, IDC White Paper sponsored by Rackable Systems. Server Innovations: Examining DC Power as an Alternative for Increasing Data Center Efficiency and Reliability, August 2004

In North America, the Darnell Group Inc. forecasts that server power supply sales will more than double over the course of five years, from 3.2 million in 2006 to 7.2 million units in 2011, as shown in Table 2.

Table 2: North America AC-DC Server Power Supply Market (millions of units)ⁱⁱⁱ

Server Type	2006	2007	2008	2009	2010	2011
Enterprise Servers	0.2	0.2	0.2	0.2	0.2	0.2
Servers	2.4	2.8	3.1	3.6	4.0	4.6
Blade Servers	0.6	0.9	1.2	1.6	2.0	2.4
Total	3.2	3.9	4.5	5.4	6.2	7.2

Test Procedure Development

The existing test procedure for desktop products is well established and accepted throughout the power supply industry. To establish an effective test protocol for servers, we chose to build on the existing test protocol, yet modify the protocol to test the unique properties of server power supplies.

We contacted technical representatives from power supply manufacturers and computer manufacturers. As a result of these conversations, we identified the priorities for the server power supply test protocol. These priorities are to test for:

- ▶ Universal input voltage – test at 115 volts and 230 volts AC
- ▶ Test at extremes of load range (0%, 5%, 10%, 20%, 50% and 100% of nameplate rating)
- ▶ Test for power factor (PF) at each load point
- ▶ No redundant mode testing (testing done at low load conditions to simulate load sharing)
- ▶ Segregate data into:
 - ▷ Redundant and non-redundant designs
 - ▷ Multi-output voltage
 - ▷ Single output voltage - low (below 20 volts DC)
 - ▷ Single output voltage - high (above 20 volts DC)

The rationale for these priorities is that server power supplies are typically higher power and used in systems that include more than one power supply. This higher power system requires a higher input voltage to maintain a reasonable input current. Server systems typically operate at 230 volt input. In addition, these systems use multiple supplies to deliver the load and are referred to as load sharing and redundant systems. Some systems may have up to six power supplies sharing a single load in a redundant configuration. That is, if one fails, another can absorb the failed unit's share of load.

The cost of duplicating all of these configurations in the lab would have been significant, so we tested each unit individually. Typically, the redundant power supplies (N+1 or 2N configurations) operate at lower loading levels. Hence, to account for redundancy of the power supplies, the team decided to test the power supplies at lower loading levels such as five percent and 10 percent of the nameplate output power rating. The efficiency test results identify the units that are capable of redundant operation, and segregating the data does not unfairly judge the units that contain additional circuitry for this feature.

Multi-output power supplies have higher internal losses due to the overhead and lower output voltages these units must provide, and typically are not used in redundant configurations. Therefore, the test data for multi-output power supplies should be judged against performance of similar units. Single output units are usually redundant-capable and used in a system referred to as a distributed system. This means the server utilizes DC-DC converters internally to convert the voltage supplied, but these internal converters are not a part of this research. They remain a promising opportunity for additional energy savings, but were beyond the scope of this research.

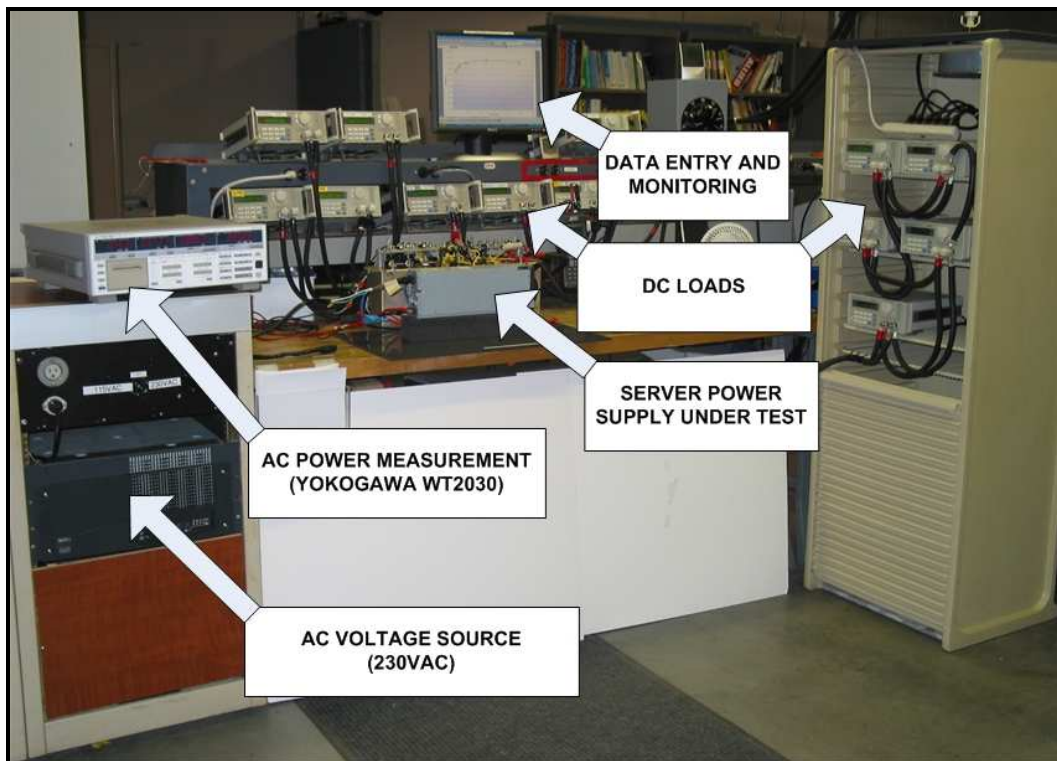
Single output power supplies deliver a voltage that can be used internal to the server to power the DC-DC converters. The voltage provided is usually 12 volts or 48 volts, although it is not limited to these voltages. A power supply delivering 48 volts has an efficiency advantage over one delivering 12 volts. It is reasonable to separate the units delivering a low voltage from those delivering a high voltage to fairly compare efficiencies.

Once we identified all of the differences between the existing desktop test protocol and the newly developed server power supply test protocol, every effort was made to include the key stakeholders from

power supply and computer manufacturers. This resulted in a review by these stakeholders via e-mail, phone correspondence, and Webinar to gather both verbal and written comments. As a result, we included significant comments in the final version of the test protocol and made a number of changes to the proposed approach as a result.

The EPRI laboratory has a dedicated test bench setup to test the efficiency of server power supplies. The test bench consists of high accuracy AC and DC power measurement devices, DC electronic load banks capable of handling 3 kW or more, and a 10kVA, 230 volts AC voltage source. Figure 2 illustrates the test setup.

Figure 2: Server Power Supply Test Setup at EPRI Laboratories



The server power supplies, unlike desktop power supplies, often have unique DC power connectors. Since the mating connectors are not readily available in the market, EPRI requested that the participating server power supply manufacturers send a mating connector along with the power supply. This helped tremendously to allow EPRI to quickly test the power supplies on schedule and deliver the test results to the sponsors of this project.

EPRI conducted the tests in a similar fashion to its desktop power supply tests. The power supplies were warmed up at no load for 15 minutes and standby measurements were taken with no load on the principal output rails. The power supplies were loaded at the following load points: 5%, 10%, 20%, 50% and 100%. The loading conditions were calculated based on the server test protocol developed which primarily was built upon the **Generalized Internal Power Supply Efficiency Test Protocol Rev 6.2^{IV}**.

At each loading point, vital measurements such as AC power, voltage, current and power factor and the DC output power for efficiency calculation were taken and recorded. The power supply was then loaded to the next higher loading level and allowed to thermally stabilize for a period of 15 minutes. Measurements were then taken as outlined above and this process was continued until the 100 percent loading point was reached.

Test Results

We sought test samples from a wide variety of server power supply manufacturers and server OEMs. Participating server OEMs included Dell, HP, and Sun Microsystems. Participating server power supply manufacturers included Delta Electronics, TDI, FSP, AcBel, C&D Technologies, Cherokee, ColdWatt, PowerOne, Ascom Energy, and Commergy. In our outreach efforts, we took care to ensure that we received samples of server power supplies that were both indicative of high volume products currently on the market as well as emerging products with exemplary efficiency. Our resulting set of test samples is generally representative of products available on the market today.

Early in the analysis of our efficiency measurements, several facts came to light through conversations with industry stakeholders that shaped our analysis of the test data. Conversations with a variety of industry stakeholders indicated that the vast majority of enterprise/data center servers are powered by single output power supplies that are configured redundantly. As a result of this feedback, we chose to limit our data analysis and resulting specification recommendations to single output server power supplies. Although a number of multiple output server power supplies were submitted and measured, we found that these units have a design and intended use that more closely fits with the desktop-derived server portion of the existing 80 PLUS program. They are typically found in pedestal servers used for office file sharing or printer sharing rather than in enterprise-grade servers used for running Web applications or executing transactions. They are typically non-redundant and contain the same voltage outputs as most desktop power supplies. As a result, they also follow the same pattern of efficiency as desktop power supplies, and thus, it would not be fair to compare them to the single output power supplies used in data centers that are capable of slightly higher levels of efficiency.

Figure 3: No Load Power Consumption of Server Power Supplies by Size

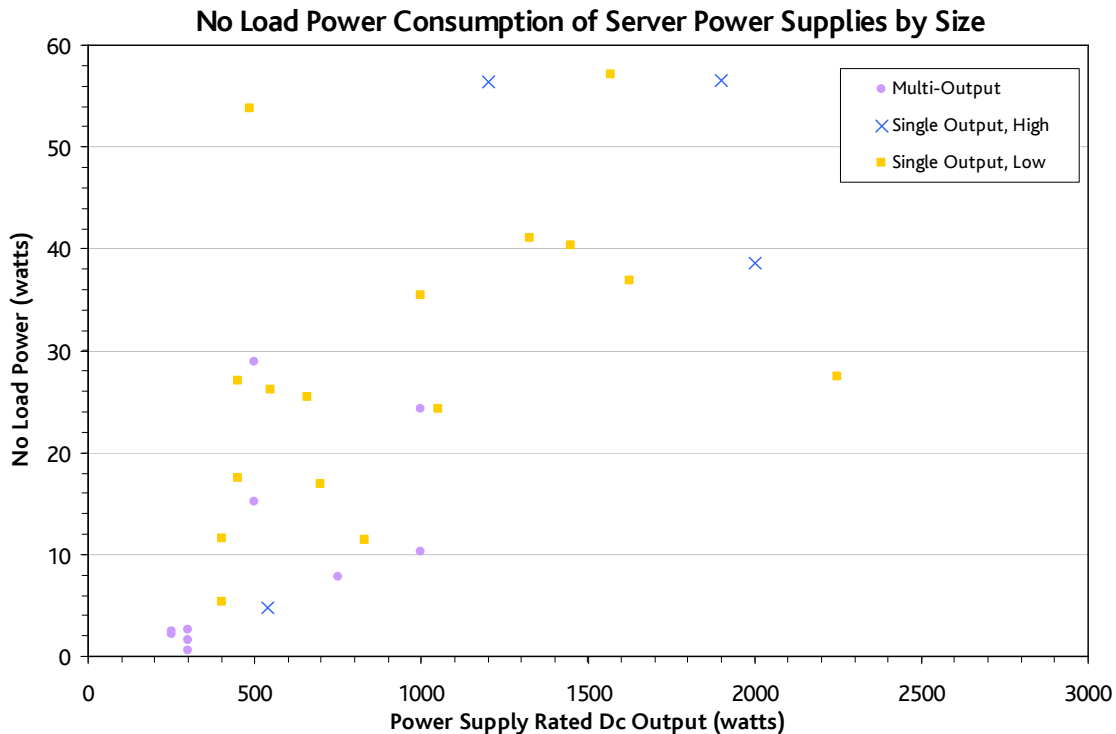
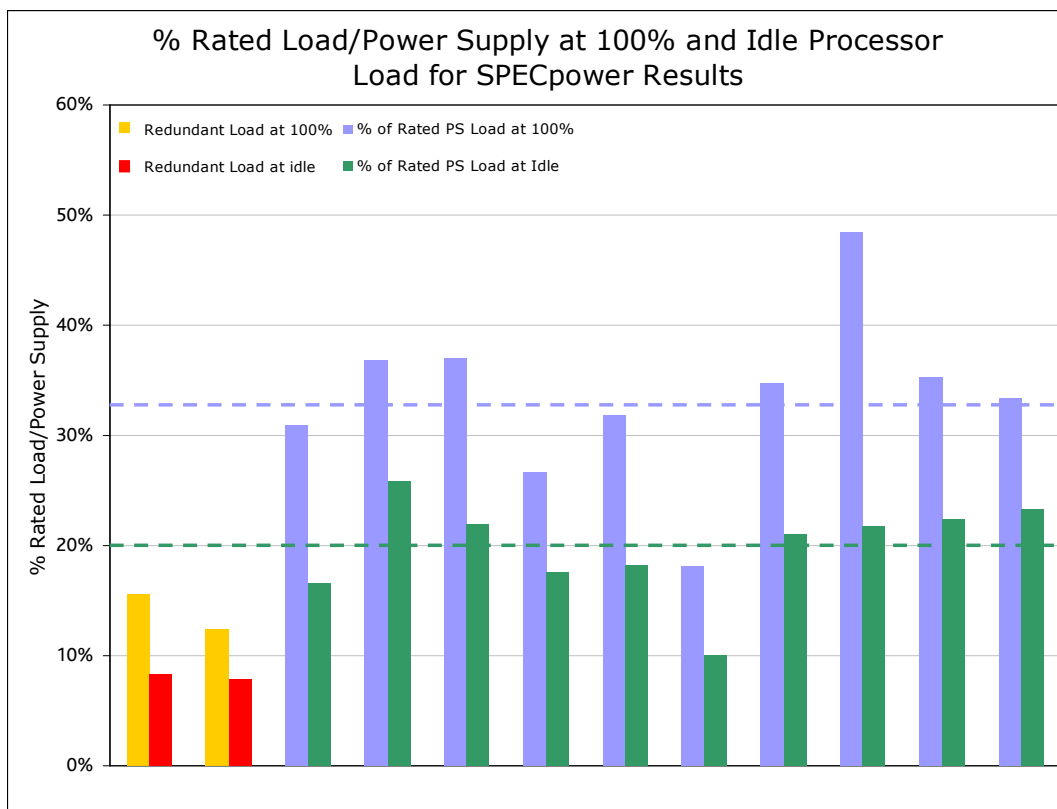


Figure 3 shows that no-load power consumption varied widely in our measurements, though some of this can be attributed to the fact that some of the power supplies required the presence of a very small load in order to operate at all. It was not possible to standardize the measurement of all the units to a single set of operating conditions. In addition, many stakeholders commented that server power supplies rarely operate in a “no load” or “standby” state. As a result, the remainder of this research effort was limited to consideration of active mode efficiency across a range of defined load conditions.

To understand which power supply load conditions are relevant for data center servers, we compared SPECpower AC power measurements made in 2007 for a variety of servers when idling and when operating at 100 percent of CPU capacity. This made it possible to determine the extent to which servers utilize the power supply capacity they are sold with. We found that over-sizing was still prevalent, especially in redundantly powered servers.

We used an iterative analysis to estimate the percentage efficiency at which those servers’ non-redundant power supplies were operating in idle and maximum CPU utilization, and then, in turn, the percentage of power supply output the resulting DC output represents. As shown in Figure 4, the servers operated at 18 percent to 48 percent (average of 33 percent) of rated power supply output at max CPU capacity. But they operated at only 10 percent to 25 percent (average of 20 percent) of rated power supply output at idle – the most common operating condition for many servers.

Figure 4: Estimated Server Power Supply Utilization from SPECpower Measurements



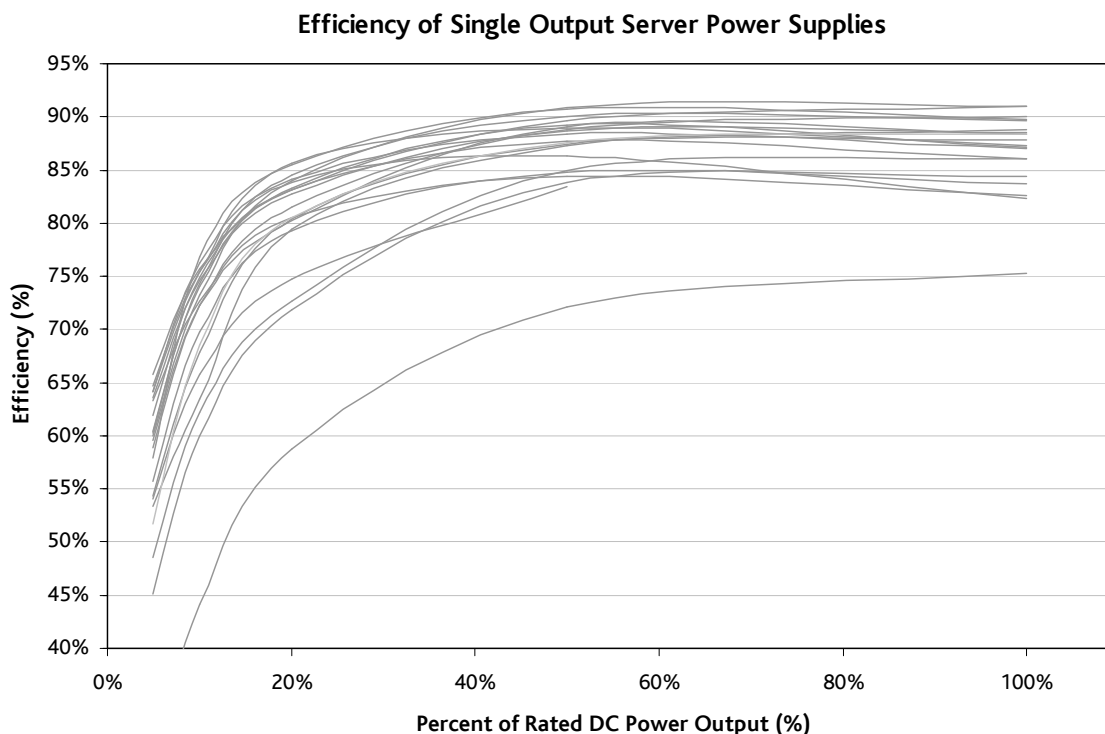
In redundant power supply configurations, the percentages of power supply output utilized dropped even further. Max CPU utilization led to loading conditions of 12 percent to 16 percent of rated power supply output. During idle, the servers utilized only 7 percent to 8 percent of the rated output of each of their redundant power supplies. Likewise, if the servers tested with SPECpower had been fitted with redundant versions of their power supplies, we would have seen loading of approximately 9 percent to 24 percent at max CPU utilization and 5 percent to 12 percent at idle. Both sets of estimates confirmed the usefulness

of having measured efficiency in the 5 percent load condition, even though we ultimately decided not to specify a minimum efficiency and power factor requirement at any load conditions below 10 percent. Our measurements did confirm that the 10 percent load condition was absolutely essential to characterizing the efficiency of redundant power supplies when servers are operating at or near their idle state.

Our efficiency measurements for single output server power supplies are shown below in Figure 5, comprising a total of 21 individual power supplies ranging in output power from 400 watts to 2,000 watts. As with other power supplies used in desktops and desktop-derived servers, efficiency varies depending on how much load the power supply is supplying compared to its nameplate or rated load. Efficiency drops off steeply below 20 percent load. A significant difference between most single output server power supplies and the multi output desktop/desktop-derived server power supplies of the current 80 PLUS program is that efficiency tends to be a few percentage points higher on average. This is because many of these server power supplies deliver power at a single, higher voltage than in multiple output supplies and incur fewer resistive losses (often referred to as I^2R losses) as a result.

As loading conditions drop below 50 percent, the spread in measured efficiencies widened considerably. With the exception of one product in the dataset, most server power supplies will achieve 83 percent to 90 percent efficiency at the 50 percent load condition; however, at the 10 percent load point, the same power supplies range in efficiency from 60 percent to 76 percent. In areas where the efficiency spread is tighter, it may seem that only minimal gains could be made in product efficiency. However, small percentage gains in these products can result in quite large energy savings, due to the high amount of power that flows through servers and their near-continuous operation.

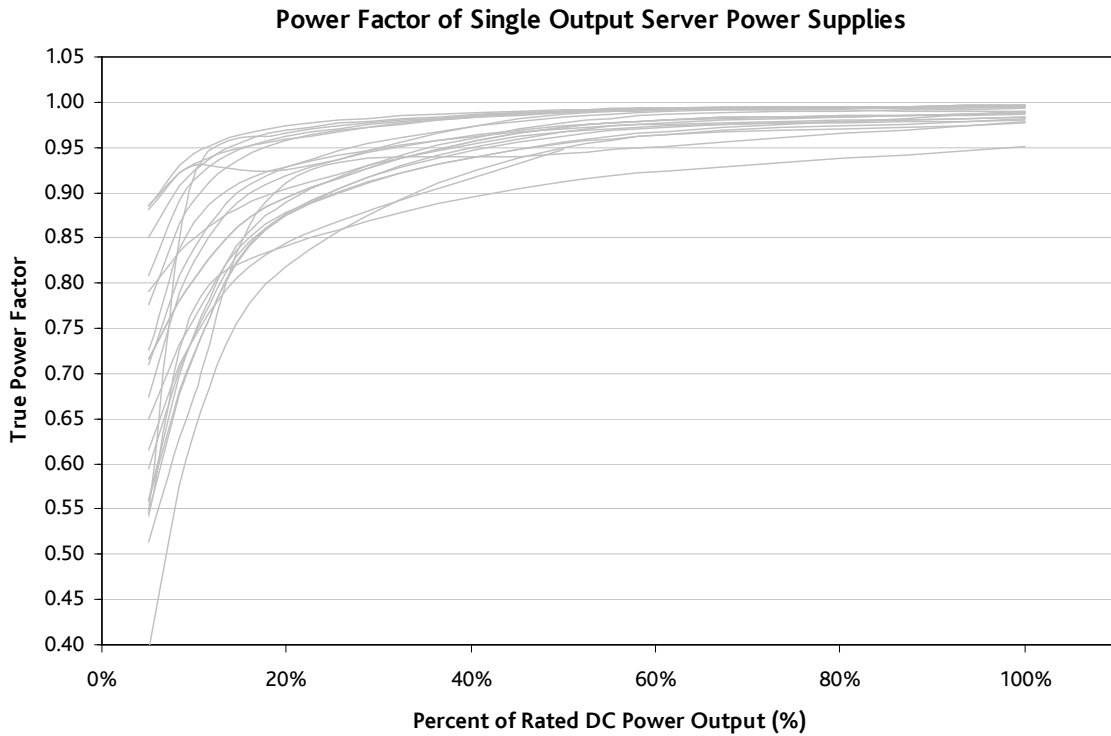
Figure 5: Efficiency of single output server power supplies



One other important factor in assessing the efficiency and performance of the server power supplies we tested was their differences in power factor. The existing 80 PLUS program for desktop and desktop-derived servers has set a precedent for addressing active power factor correction by requiring that all certified power supplies have a power factor of 0.9 or higher at full load. It became clear in our analysis of

server power supplies that such requirements would need to be extended to lower load conditions, given that server power supplies routinely operate at far lower load conditions. As shown in Figure 6, power factor can range widely at these low load levels, with only a handful of models maintaining a power factor above 0.9 when operating at 10 percent load or less. Prior studies by EPRI and Ecos have shown that improving power factor can have significant additional energy benefits in commercial buildings due to lower resistive losses in typically long runs of distribution wiring.^v

Figure 6: Power Factor of Single Output Server Power Supplies



Specification Development

The research team used an iterative process to develop a set of stringent yet readily achievable energy efficiency specifications for single output server power supplies. We began by examining the top 25 percent highest performing products in our dataset, a process quite similar to the one used by the U.S. EPA ENERGY STAR program in determining its product specifications. We examined the overall product compliance rates achieved by combining best-in-class efficiency and power factor requirements and adjusted the levels for both to arrive at an overall compliance rate of approximately 20 percent. This level of stringency (“80 PLUS Servers Bronze”) ensures that existing products can readily meet the specification, but the target will still pose a near-term challenge to the marketplace.

We then increased the efficiency and power factor requirements by several percentage points across the board to create a second, more stringent “aspirational” specification level (“80 PLUS Servers Silver”). While no single current product met all of its criteria, a few of the measured products met the individual levels that comprise the specification, indicating that it should be achievable with design modifications to current products. This helps to create an incentive for manufacturers to advance beyond today’s designs, and largely aligns with Climate Savers’ 2008-09 levels.

Our third level (“80 PLUS Servers Gold”) was set even higher, and represents a stretch goal for manufacturers to achieve in the future with further advances in power conversion technology, largely aligning with Climate Savers’ 2009-10 levels. These three specifications are described in Table 3.

Table 3: 80 PLUS Servers Bronze, Silver, and Gold Specification Levels

Specification Level	Requirement	% of Rated Load			
		10%	20%	50%	100%
80 PLUS Servers Bronze	Efficiency	74%	83%	87%	83%
	Power Factor	0.7	0.8	0.9	0.9
80 PLUS Servers Silver	Efficiency	77%	85%	89%	85%
	Power Factor	0.75	0.85	0.9	0.9
80 PLUS Servers Gold	Efficiency	80%	88%	92%	88%
	Power Factor	0.75	0.85	0.9	0.9

Figure 7 and Figure 8 show the Bronze and Silver specification levels, respectively, compared to our existing dataset. For the 80 PLUS Bronze specification chart, the three compliant products tested so far are shown in blue.

Figure 7: 80 PLUS Servers Bronze

Efficiency of Single Output Server Power Supplies and 80 PLUS Servers Bronze Efficiency Levels

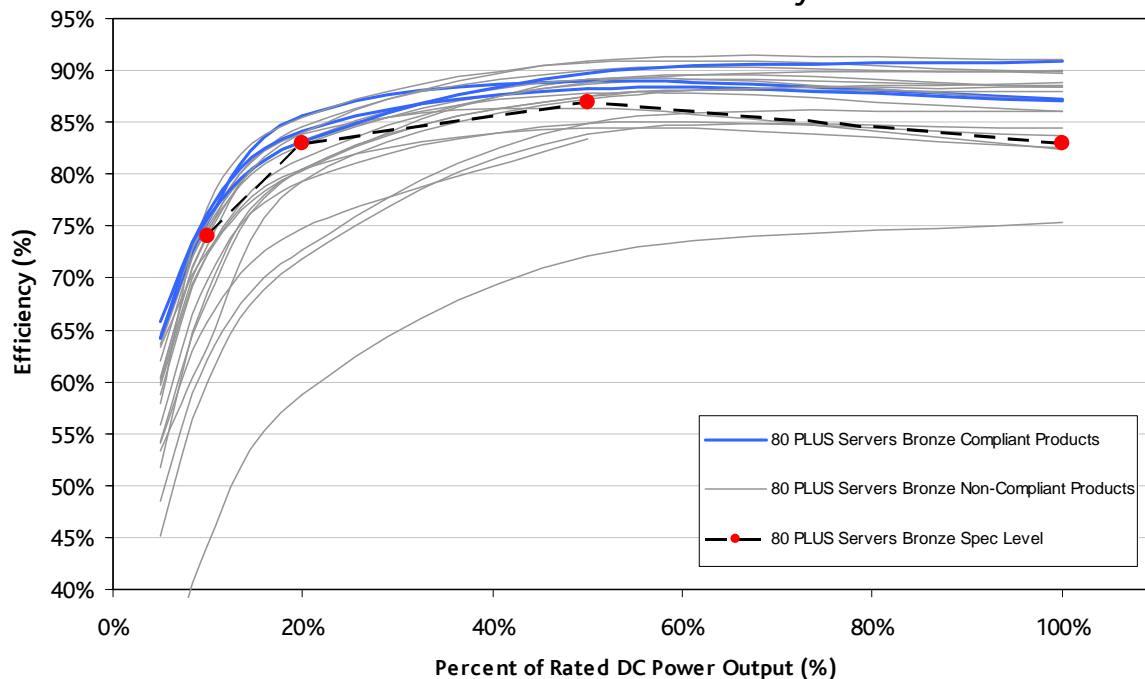
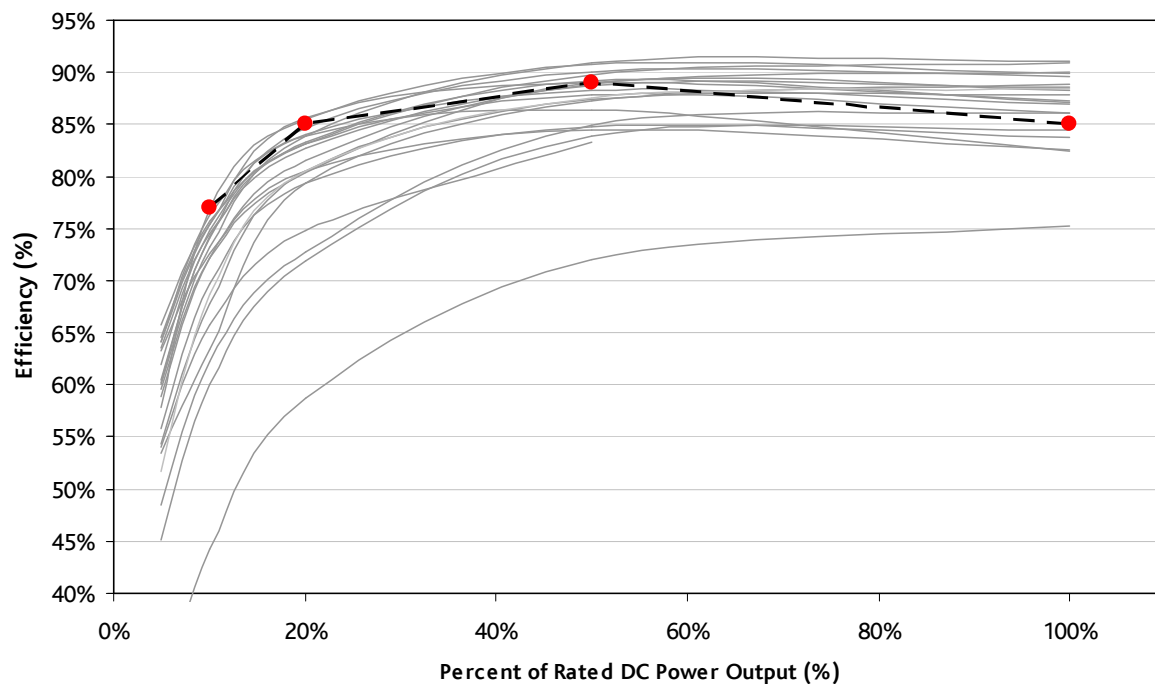


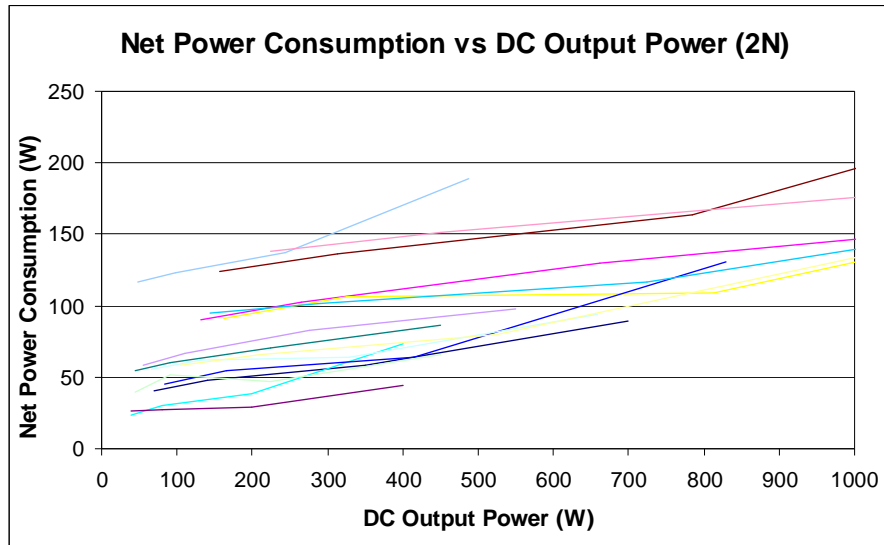
Figure 8: 80 PLUS Servers Silver

Efficiency of Single-Output Server Power Supplies and 80 PLUS Servers Silver Efficiency Levels



We evaluated one other form of specification: net power supply consumption. This metric simply subtracts DC output power from AC input power across the range of DC output power levels a server typically experiences between its idle and max CPU operating states. Redundant power supplies tend to exhibit a higher net consumption than non-redundant ones and even within a given level of redundancy and at a given DC load condition, net consumption can vary by more than 100 watts as illustrated in Figure 9.

Figure 9: Net Power Supply Consumption



For a given level of desired redundancy, manufacturers can reduce net consumption via a combination of improving overall power supply efficiency, flattening the efficiency curve at low load conditions, or more closely sizing the power supply to the anticipated load. This type of a performance-based specification may have substantial merit in future efficiency programs for servers themselves (where associated power supply sizes have already been specified), but requires further evaluation and is beyond the scope of our effort to assess and specify power supply efficiency without regard to power supply size.

Energy Usage and Savings Estimates

By comparing the average efficiencies of power supplies above and below each specification level, it was possible to estimate the energy savings that would result from market adoption of our proposed specifications. We established a business and a high performance duty cycle for each of the three server types (volume, mid-range, and high end) for which national average annual energy use estimates exist, from Dr. Jonathan Koomey (shown in Table 4).^{vi}

Table 4: Server Unit Energy Consumption Estimates by Product Type and Usage Model

Usage Model	Volume Servers		Mid-Range Servers		High End Servers	
	Share	Unit kWh/yr	Share	Unit kWh/yr	Share	Unit kWh/yr
Business	95%	1,875	50%	3,995	25%	66,649
High Performance	5%	2,998	50%	6,880	75%	67,485
Weighted Average	-	1,932	-	5,438	-	67,276
Koomey Est.	-	1,923	-	5,426	-	67,568

The methodology for calculating these estimates is straightforward, but still subject to uncertainty due to a variety of factors:

- ▶ Continuing evolution of power supply and server technology
- ▶ The increasing popularity of virtualization (allowing greater utilization of existing equipment)
- ▶ Changing forecasts for growth in sales of each server category
- ▶ The lack of published data on real-world duty cycles for large numbers of servers in data centers

In addition to the findings from the SPECpower server measurements described earlier in Figure 4, Ecos and EPRI^{vii} also analyzed the duty cycles for a number of servers in operation at Lawrence Berkeley National Laboratories and corporate facilities in 2005. As Figure 10 indicates, the average non-redundantly powered server never exceeded 40 percent of rated power supply output or fell below 30 percent of rated power supply output. Redundant configurations operated almost exclusively between 15 and 20 percent of the rated output of each power supply. Similarly, as Figure 11 indicates, it was clear that high performance servers tended to utilize a higher percentage of power supply output than business servers, even when both are operated non-redundantly.

Figure 10

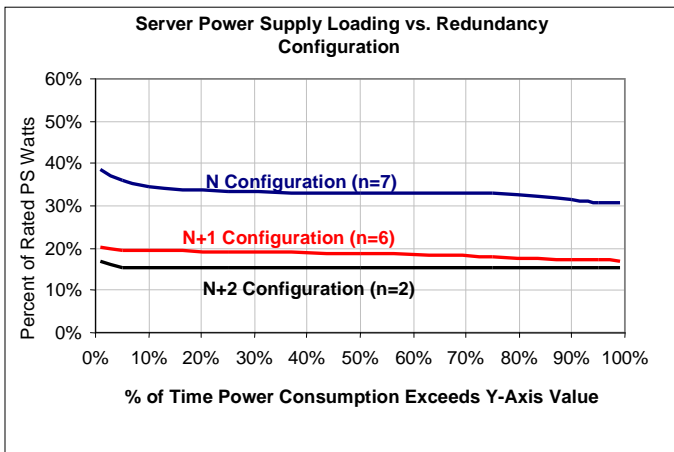
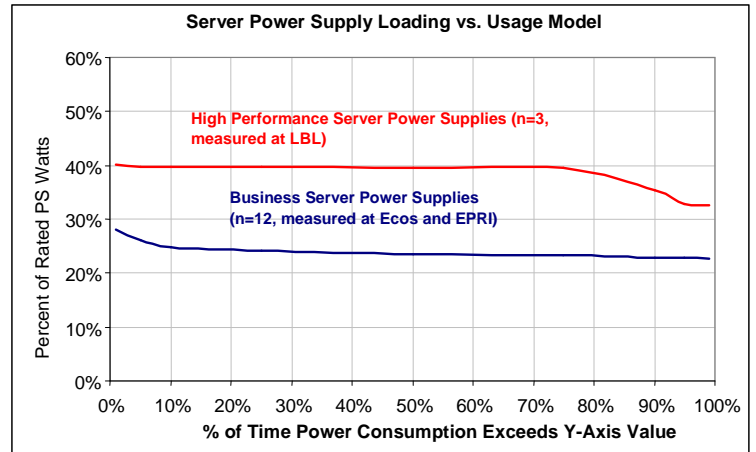


Figure 11



Because of the growth of blade server technology and virtualization in data centers, we estimated that even redundantly powered mid-range and high end servers spend more time in the 30 percent to 40 percent range of rated power supply output than the 2005 Ecos and EPRI measurements indicate. These measurements provide some basis for estimating duty cycles, power supply sizing, and a mix between business and high performance applications for each server type that yields weighted average energy consumption estimates similar to Koomey's. More research is clearly needed to verify actual operating patterns in data centers, particularly with larger servers and in high-performance applications.

Table 5 through Table 10 illustrates the methodology used to develop savings calculations for the 80 PLUS Servers Bronze specification:

Table 5: High Performance Volume Servers

Server Type	PS Redundancy	Output Voltage	Max DC Load	Power Supply Size	# of Power Supplies	Proportion of Power Supply's Maximum DC Power Output Rating						Totals						
Volume	2N	single	210 watts	550 watts	2	Stand By	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		
Application																		
High Performance Computing																		
Power Supply Operating Hours																		
Proportion of Year							5%	10%	55%	30%								100%
Operating Time (hr/yr)	-	1,315	2,192	4,821	438	-	-	-	-	-	-	-	-	-	-	-	-	8,766
DC Output Power per PS (watts)	-	55	110	165	220	275	330	385	440	495	550							
Total DC Energy Use (kWh/year)	-	145	482	1,591	193	-	-	-	-	-	-	-	-	-	-	-	-	2,411
Base Case																		
Average Measured Efficiency	-	68.7%	79.2%	81.6%	84.0%	86.4%	86.4%	86.4%	86.4%	86.3%	86.3%	86.3%						
AC Input Power (watts)	74	160	278	404	524	636	764	891	1,019	1,147	1,275							342
Power Supply Consumption (kWh/year)	-	66	127	359	37	-	-	-	-	-	-	-	-	-	-	-	-	588
Total Computer Consumption (kWh/year)	-	211	609	1,950	229	-	-	-	-	-	-	-	-	-	-	-	-	2,998
80 PLUS Servers Bronze																		
80 PLUS Measured Efficiency	-	76.1%	84.6%	86.2%	87.8%	89.4%	89.3%	89.2%	89.0%	88.9%	88.8%							
AC Input Power (watts)	74	145	260	383	501	615	739	864	988	1,114	1,239							322
Power Supply Consumption (kWh/year)	-	46	88	255	27	-	-	-	-	-	-	-	-	-	-	-	-	415
Total Computer Consumption (kWh/year)	-	190	570	1,846	219	-	-	-	-	-	-	-	-	-	-	-	-	2,826
																	Savings =	173

Table 6: Business Workload Volume Servers

Server Type	PS Redundancy	Output Voltage	Max DC Load	Power Supply Size	# of Power Supplies	Proportion of Power Supply's Maximum DC Power Output Rating						Totals						
Volume	2N	single	210 watts	550 watts	2	Stand By	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		
Application	Business Workload																	
Power Supply Operating Hours																		
Proportion of Year		10%	55%	30%	5%												100%	
Operating Time (hr/yr)	-	5,698	2,192	876	-	-	-	-	-	-	-	-	-	-	-	-	8,766	
DC Output Power per PS (watts)		55	110	165	220	275	330	385	440	495	550							
Total DC Energy Use (kWh/year)		627	482	289	-	-	-	-	-	-	-	-	-	-	-	-	1,398	
Base Case																		
Average Measured Efficiency	-	68.7%	79.2%	81.6%	84.0%	86.4%	86.4%	86.4%	86.3%	86.3%	86.3%							
AC Input Power (watts)	19	160	278	404	524	636	764	891	1,019	1,147	1,275						214	
Power Supply Consumption (kWh/year)	-	285	127	65	-	-	-	-	-	-	-						477	
Total Computer Consumption (kWh/year)	-	912	609	354	-	-	-	-	-	-	-						1,875	
80 PLUS Servers Bronze																		
80 PLUS measured efficiency	-	76.1%	84.6%	86.2%	87.8%	89.4%	89.3%	89.2%	89.0%	88.9%	88.8%							
AC Input Power (watts)	19	145	260	383	501	615	739	864	988	1,114	1,239						197	
Power Supply Consumption (kWh/year)	-	197	88	46	-	-	-	-	-	-	-						332	
Total Computer Consumption (kWh/year)	-	824	570	335	-	-	-	-	-	-	-						1,730	
																	Savings =	145

Table 7: High Performance Midrange Servers

Server Type	PS Redundancy	Output Voltage	Max DC Load	Power Supply Size	# of Power Supplies	Proportion of Power Supply's Maximum DC Power Output Rating						Totals						
Mid-Range	2N	single	400 watts	1000 watts	2	Stand By	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		
Application	High Performance Computing																	
Operating Hours																		
Proportion of Year		5%	14%	33%	48%												100%	
Operating Time (hr/yr)	-	438	1,227	2,893	4,208	-	-	-	-	-	-	-	-	-	-	-	8,766	
DC Output Power per PS (watts)		100	200	300	400	500	600	700	800	900	1,000							
Total DC Energy Use (kWh/year)		88	491	1,736	3,366	-	-	-	-	-	-	-	-	-	-	-	5,681	
Base Case																		
Average Measured Efficiency	-	68.7%	79.2%	81.6%	84.0%	86.4%	86.4%	86.4%	86.3%	86.3%	86.3%							
AC Input Power (watts)	74	291	505	735	952	1,157	1,389	1,621	1,853	2,085	2,318						785	
Power Supply Consumption (kWh/year)	-	40	129	391	640	-	-	-	-	-	-						1,200	
Total Computer Consumption (kWh/year)	-	127	620	2,127	4,006	-	-	-	-	-	-						6,881	
80 PLUS Servers Bronze																		
80 PLUS measured efficiency	-	76.1%	84.6%	86.2%	87.8%	89.4%	89.3%	89.2%	89.0%	88.9%	88.8%							
AC Input Power (watts)	74	263	473	696	911	1,118	1,344	1,570	1,797	2,025	2,253						746	
Power Supply Consumption (kWh/year)	-	28	90	278	468	-	-	-	-	-	-						863	
Total Computer Consumption (kWh/year)	-	115	580	2,014	3,834	-	-	-	-	-	-						6,544	
																	Savings =	337

Table 8: Business Workload Midrange Servers

Server Type	PS Redundancy	Output Voltage	Max DC Load	Power Supply Size	# of Power Supplies	Proportion of Power Supply's Maximum DC Power Output Rating						Totals						
Mid-Range	2N	single	400 watts	1000 watts	2	Stand By	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		
Application	Business Workload																	
Operating Hours																		
Proportion of Year		55%	20%	20%	5%												100%	
Operating Time (hr/yr)	-	4,821	1,753	1,753	438	-	-	-	-	-	-	-	-	-	-	-	8,766	
DC Output Power per PS (watts)		100	200	300	400	500	600	700	800	900	1,000							
Total DC Energy Use (kWh/year)		964	701	1,052	351	-	-	-	-	-	-	-	-	-	-	-	3,068	
Base Case																		
Average Measured Efficiency	-	68.7%	79.2%	81.6%	84.0%	86.4%	86.4%	86.4%	86.3%	86.3%	86.3%							
AC Input Power (watts)	74	291	505	735	952	1,157	1,389	1,621	1,853	2,085	2,318						456	
Power Supply Consumption (kWh/year)	-	439	184	237	67	-	-	-	-	-	-						927	
Total Computer Consumption (kWh/year)	-	1,403	886	1,289	417	-	-	-	-	-	-						3,995	
80 PLUS Servers Bronze																		
80 PLUS measured efficiency	-	76.1%	84.6%	86.2%	87.8%	89.4%	89.3%	89.2%	89.0%	88.9%	88.8%							
AC Input Power (watts)	74	263	473	696	911	1,118	1,344	1,570	1,797	2,025	2,253						424	
Power Supply Consumption (kWh/year)	-	303	128	169	49	-	-	-	-	-	-						649	
Total Computer Consumption (kWh/year)	-	1,268	829	1,221	399	-	-	-	-	-	-						3,717	
																	Savings =	278

Table 9: High Performance High End Servers

Server Type	PS Redundancy	Output Voltage	Max DC Load	Power Supply Size	# of Power Supplies	Proportion of Power Supply's Maximum DC Power Output Rating						Totals						
High End	various	single	1000 watts	2200 watts	8	Stand By	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		
Operating Hours																		
Proportion of Year			10%	15%	75%												100%	
Operating Time (hr/yr)	-	-	877	1,315	6,575	-	-	-	-	-	-	-	-	-	-	-	8,766	
DC Output Power per PS (watts)		220	440	660	880	1,100	1,320	1,540	1,760	1,980	2,200							
Total DC Energy Use (kWh/year)		-	3,086	6,943	46,284	-	-	-	-	-	-	-	-	-	-	-	56,313	
Base Case																		
Average Measured Efficiency	-	68.7%	79.2%	81.6%	84.0%	86.4%	86.4%	86.4%	86.3%	86.3%	86.3%							
AC Input Power (watts)	296	2,561	4,445	6,470	8,378	10,180	12,220	14,263	16,307	18,352	20,399						7,699	
Power Supply Consumption (kWh/year)	-	-	811	1,565	8,797	-	-	-	-	-	-						11,172	
Total Computer Consumption (kWh/year)	-	-	3,897	8,508	55,081	-	-	-	-	-	-						67,485	
80 PLUS Servers Bronze																		
80 PLUS measured efficiency	-	76.1%	84.6%	86.2%	87.8%	89.4%	89.3%	89.2%	89.0%	88.9%	88.8%							
AC Input Power (watts)	296	2,314	4,162	6,126	8,018	9,842	11,827	13,818	15,815	17,817	19,826						7,349	
Power Supply Consumption (kWh/year)	-	-	563	1,113	6,429	-	-	-	-	-	-						8,105	
Total Computer Consumption (kWh/year)	-	-	3,648	8,055	52,714	-	-	-	-	-	-						64,418	
																	Savings =	3,067

Table 10: Business Workload High End Servers

Server Type	PS Redundancy	Output Voltage	Max DC Load	Power Supply Size	# of Power Supplies	Proportion of Power Supply's Maximum DC Power Output Rating						Totals						
High End	various	single	1000	2200 watts	8	Stand By	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%		
Operating Hours																		
Proportion of Year			10%	20%	70%												100%	
Operating Time (hr/yr)	-	-	877	1,753	6,136	-	-	-	-	-	-	-	-	-	-	-	8,766	
DC Output Power per PS (watts)		220	440	660	880	1,100	1,320	1,540	1,760	1,980	2,200							
Total DC Energy Use (kWh/year)		-	3,086	9,257	43,199	-	-	-	-	-	-	-	-	-	-	-	55,541	
Base Case																		
Average Measured Efficiency	-	68.7%	79.2%	81.6%	84.0%	86.4%	86.4%	86.4%	86.3%	86.3%	86.3%							
AC Input Power (watts)	296	2,561	4,445	6,470	8,378	10,180	12,220	14,263	16,307	18,352	20,399						7,603	
Power Supply Consumption (kWh/year)	-	-	811	2,087	8,210	-	-	-	-	-	-						11,108	
Total Computer Consumption (kWh/year)	-	-	3,897	11,343	51,409	-	-	-	-	-	-						66,649	
80 PLUS Servers Bronze																		
80 PLUS measured efficiency	-	76.1%	84.6%	86.2%	87.8%	89.4%	89.3%	89.2%	89.0%	88.9%	88.8%							
AC Input Power (watts)	296	2,314	4,162	6,126	8,018	9,842	11,827	13,818	15,815	17,817	19,826						7,254	
Power Supply Consumption (kWh/year)	-	-	563	1,484	6,001	-	-	-	-	-	-						8,047	
Total Computer Consumption (kWh/year)	-	-	3,648	10,741	49,200	-	-	-	-	-	-						63,589	
																	Savings =	3,060

Converting these estimates of savings per power supply into savings at the data center level takes into account associated UPS and cooling savings, as well as a range of assumed product lifetimes from four to six years. Every watt of “at-the-plug” savings provides an additional estimated savings of:

- ▶ 0.3 watts, through reduced cooling loads
- ▶ 0.1 watts, through reduced losses in the facility’s UPS

Total savings estimates are calculated in Table 11.

Table 11: Summary of Energy Savings Estimates

Specification Level	Server Class	Annual Energy Savings per PSU (kWh)	Lifetime Energy Savings per PSU (kWh)	Total PSUs per Server	Annual Energy Savings per Server (kWh)	Lifetime Energy Savings per Server (kWh)	Annual Savings North America (gWh)
Bronze Level	Volume	73 – 86	292 – 516	2	146 – 172	584 – 1,032	6,242 – 11,031
	Mid-Range	139 – 168	556 – 1,008	2	278 – 337	1,112 – 2,032	465 – 851
	High-End	382 – 383	1,528 – 2,298	8	3,058 – 3,065	12,232 – 18,390	293 – 441
Silver Level	Volume	84 – 152	336 – 912	2	168 – 303	672 – 1,818	7,183 – 19,432
	Mid-Range	206 – 297	824 – 1,782	2	413 – 594	1,652 – 3,564	692 – 1,493
	High-End	671 – 667	2,684 – 4,002	8	5,334 – 5,365	21,460 – 32,004	515 – 768
Gold Level	Volume	113 – 195	452 – 1,170	2	226 – 391	904 – 2,346	9,662 – 25,076
	Mid-Range	267 – 398	1,068 – 2,388	2	534 – 796	2,136 – 4,776	894 – 2,001
	High-End	916	3,664 – 5,496	8	7,324 – 7,328	29,312 – 43,944	703 – 1,054

In Table 12, estimates for demand reduction potential illustrate the range of reductions expected per power supply in business and high performance use.

Table 12: Summary of Demand Impact Estimates

Specification Level	Server Class	Demand Reduction per PSU (Watts)	Annual Demand Reduction North America (kW)
Bronze Level	Volume	8 - 10	85,512 – 106,890
	Mid-Range	16 - 19	6,704 – 7,961
	High-End	44	1,056
Silver Level	Volume	10 - 17	106,890 – 181,713
	Mid-Range	24 - 34	10,056 – 14,246
	High-End	76 - 77	1,848
Gold Level	Volume	13 - 22	138,957 – 235,158
	Mid-Range	30 - 45	12,570 – 18,855
	High-End	105	2,520

Project Recommendations

The findings of this project have culminated in the following set of recommendations to drive increased efficiencies in the server power supply industry. These recommendations include a set of proposed efficiency targets and criteria; elements for implementing a marketing and awareness campaign; a program offering to serve as an independent, third party testing clearinghouse for server power supplies; and, an incentive rebate program offering.

Proposed Server Power Supply Efficiency Targets and Criteria

As mentioned previously in this report, to effectively spur the power supply industry to adopt ever-increasing efficiencies in upcoming design cycles, the project team proposes the release of three simultaneous sets of efficiency and power quality targets, as outlined in Table 13.

Table 13: Summary of Proposed Specification Levels

Specification Level	Requirement	% of Rated Load			
		10%	20%	50%	100%
Bronze Level	Efficiency	74%	83%	87%	83%
	Power Factor	0.7	0.8	0.9	0.9
Silver Level	Efficiency	77%	85%	89%	85%
	Power Factor	0.75	0.85	0.9	0.9
Gold Level	Efficiency	80%	88%	92%	88%
	Power Factor	0.75	0.85	0.9	0.9

The Bronze, Silver, and Gold branding associated with each would confer marketing value to the manufacturers that pay for the third party certification to those levels. The more common approach in efficiency specification development has been to adopt single levels of efficiency that rise over time as technology improves. However, the pace of innovation is never uniform across an industry or its individual suppliers – some are always seeking additional market differentiation on the basis of efficiency. Those who can leapfrog current specifications to achieve the higher levels of efficiency immediately would benefit from the opportunity to be recognized for their achievement, just as their customers and utilities would benefit from the resulting additional energy savings.

Although the proposed Bronze specification is more stringent than Climate Savers’ 2007-08 levels, the Silver and Gold Levels align exactly with Climate Savers’ 2008-09 and 2009-10 efficiency levels for 20 percent, 50 percent, and 100 percent load. Likewise, Climate Savers is evaluating the inclusion of power factor requirements identical to those proposed here for 20 percent, 50 percent, and 100 percent. If ENERGY STAR were to adopt similar levels as well in its forthcoming server specification, the alignment between independent testing efforts, utility programs, industry-led voluntary specifications, and government specifications would strongly encourage power supply manufacturers to develop the most efficient possible products.

Marketing and Awareness Campaign

There are several marketing and awareness strategies that the project team strongly recommends for consideration in order to effectively encourage more efficient power supply design in the marketplace.

Based on test result and savings data, as well as industry partner input, it is highly recommended that an 18 month to 24 month product testing, publication, and awareness campaign be initiated upon completion of this project to continue the forward progress of more efficient power supply design with industry partners. We propose a combined budget of approximately \$600,000, drawn from at least five utility and regional efficiency group sponsors across North America, to launch this effort. In order to effectively implement an education and awareness campaign to help transform the market toward a preference for energy-efficient server power supplies, the following strategies have been identified as elements to be deployed for achieving this goal:

- ▶ **ENERGY STAR server specification:** Utilities should work closely with ENERGY STAR to encourage adoption of stringent power supply efficiency and power quality requirements. This includes attendance in meetings, submission of independent test data, and commenting on specification drafts.
- ▶ **Industry event attendance:** The project team proposes to participate actively in a set of industry meetings and conferences over the coming months to publicize these specifications, promote certified products, and encourage participation by manufacturers. These conferences include Digital Power Forum, Applied Power Electronics Conference, and Uptime Institute. These efforts will positively impact the submittal of power supply samples in the near term, as industry partners begin to design their products to this new set of criteria.
- ▶ **Industry outreach and engagement:** Continued outreach and dialogue with industry partners, power supply and computer manufacturers alike will be vital to the successful transition to more efficient design in the power supply industry. We recommend that these efforts continue over the next 18 to 24 months to ensure that the power supply industry embraces this new efficiency criteria, plans their next generation product designs to these specifications, and continues to recognize 80 PLUS as the industry leader in internal power supply testing and certification, thereby submitting samples for certification at a steady rate. Program staff will also make every effort to engage with related initiatives by Climate Savers and the Consortium for Energy Efficiency, with the goal of developing one comprehensive set of efficiency criteria for the industry to reference and aspire to achieve.
- ▶ **Website development:** To ensure successful launch of the server power supply program, an 80 PLUS website overhaul would need to occur to differentiate this initiative from the existing 80 PLUS program. Branding strategies would also be developed, complementing changes to the website, and clearly articulating to all stakeholders the form factors of power supplies and server types covered under the new program.

Third Party Testing Clearinghouse Program

Over the course of the past four years, 80 PLUS has become the recognized industry leader in independently testing and certifying the energy efficiency and power quality of internal power supplies. Dialogue with industry partners during the course of the server research project reconfirmed this concept, as industry partners became increasingly interested in the efficiency targets being established by project staff. We recommend that a similar testing and certification program be initiated as soon as possible to facilitate the testing of server power supplies. Ecos has secured additional laboratory space to support this effort, and is prepared to purchase the testing equipment needed to augment EPRI's present testing capabilities. This will reduce the lag time between product submittal and completion of finished test reports.

The immediate launch of this program offering accomplishes several goals of the project:

- ▶ Specifically addresses the majority of power supplies being utilized in volume server markets, being single output, redundant configurations
- ▶ Complements the existing desktop program, covering a broad range of redundant and non-redundant power supply configurations between the two initiatives

- ▶ Establishes a consistent and comprehensive test protocol across the entire industry, via independent, third party certification

The initial step for launching this initiative is to publish the finalized test protocol on the 80 PLUS website, and continue outreach to industry partners to solicit samples for testing and certification. There will be particular emphasis in working with industry partners to obtain samples that are utilized in volume server markets. We recommend that utility and efficiency group sponsors fund the initial round of product testing (approximately 15 to 20 models). The results of that work and the measurements made to date will be used to promote the program at industry events, encouraging power supply and server manufacturers to submit their own samples and fund the subsequent testing of products.

Incentive Rebate Program Offering

Based on programmatic experience and project research to date, an incentive rebate program is one option worth consideration to influence the industry toward increasing power supply efficiencies. It is worth noting however that tracking utility incentives would be complex, and per unit rebates would be relatively low in order to maintain the program's cost effectiveness. This would indicate that the more powerful driver of customer decisions to choose more efficient server power supplies for their data centers may turn out to be information – the knowledge that a particular product choice has been verified to reduce energy use, save money and reduce heat, thereby enabling greater racking density with improved reliability. To the extent financial incentives could have influence, this scenario would most likely occur with a smaller number of customers weighing a purchase decision of thousands of servers.

If individual utilities are interested in employing tiered financial incentives to accelerate installations of power supplies at the Silver and Gold levels on a case by case basis with individual data centers, Ecos could work with those utilities to structure such a program. Although the recommended approach is to support a strongly marketed branding program, this option would be of most value to those sponsors where data centers represent a major fraction of load growth. This type of program offering would be evaluated per request of the utility sponsor to identify the savings potential and appropriate rebate levels, given their rate structure and the design of the data center itself.

ⁱ <http://www.dell.com/downloads/global/power/ps2q07-20070270-PowerTCO.pdf>

ⁱⁱ http://searchdatacenter.techtarget.com/qna/0,289202,sid80_gci1248873,00.html

ⁱⁱⁱ Darnell Group Inc. 2006. *AC-DC Power Supplies Global Market Forecasts and Competitive Environment*

^{iv} <http://www.efficientpowersupplies.org/methods.asp>

^v See http://www.efficientpowersupplies.org/pages/Latest_Protocol/Power_Factor_Report_CEC_500-04-030.pdf

^{vi} Dr. Jonathan Koomey, *Estimating Total Power Consumption by Servers in the U.S. and the World*, Final report, February 15, 2007. Per-server energy consumption estimated from Koomey's Table 4 values for total direct electricity consumption of servers and the installed base of servers, by category, for 2005.

^{vii} M Ton and B Fortenbery, Ecos Consulting and Electric Power Research Institute. *High Performance Buildings: Data Centers, Server Power Supplies*. Lawrence Berkeley National Laboratory, 2005.