White paper

Improving Sustainability with Flywheel UPS

Update Energy Sector Data, Environmental and Regulation Information

EXECUTIVE SUMMARY

Over the next 30 years new technologies for clean energy storage and generation will enter the global supply chain.

But today operators of energy-intensive facilities such as data centers, hospitals, and manufacturing plants may be overlooking one straightforward place to improve energy efficiency and reduce carbon emissions: their uninterruptible power supply (UPS).

Traditional UPS products waste too much electricity, emit too much carbon and from raw material to manufacture are difficult to make part of the circular economy.

Flywheel-based UPS operate with higher energy efficiency and can reduce the impact of the UPS on the environment by 90%.

This white paper will demonstrate that by combining energy efficiency and permanent energy storage, Active Power is the smart and responsible choice for the environment, saving thousands of tons of carbon over the life of the product.

SUSTAINABILITY – A GLOBAL RESPONSIBILITY

According to the International Energy Agency's World Energy Outlook 2022 report, the share of fossil fuels in the global energy mix in the Stated Policies Scenario will fall from around 80% to just above 60% by 2050.

https://www.iea.org/news/world-energy-outlook-2022-shows-the-global-energy-crisis-can-be-a-historic-turning-point-towards-a-cleaner-and-more-secure-future

What is clear is that given the scale of the installed infrastructure base the move away from fossil fuels is going to be an undertaking lasting decades.

But faced with a combination of new regulations, exposure to public opinion, and economic survival all organisations and businesses are addressing every form of waste and improving efficiency. ESG reporting is now a board level concern. And that means although it is a 30 year journey, steps must and should be taken now.

In equipment terms sustainability means the ability to last, or a capacity to endure, and then to be recycled, repurposed or reused.

CORPORATE SUSTAINABILITY

In regulatory terms one example of forthcoming regulations is the Corporate Sustainability Reporting Directive (CSRD), an EU law which requires companies to publish and report environmental impact data.

On 31 October 2022, the European Union adopted this regulation as law making it the first mandatory sustainability reporting framework with which almost all EU industrial players of any scale and activity must comply.

Aligned with the EU Taxonomy for Sustainable Activities, the CSRD will require companies to report on how their business activities impact both people and the environment.

The reporting requirements are extremely detailed and the timelines for compliance are challenging. This directive mandates that reporting starts from January 2024 for the activities of the 2023 financial year.

In the US the SEC Proposals for Major New Climate Reporting rules were revealed in March 2022.

https://www.sec.gov/news/press-release/2022-46

Under the proposed rules it is intended that companies provide detailed climate impact data just as they must report their financial performance. The proposals originally called for climate reporting from 2023. However, given the level of detail required it is thought that this is likely to be pushed back in order to provide more time for companies to prepare.

These latest moves by regulators follow a decade of new reporting regimes – by now everyone should be familiar with Scope 1, 2 and 3 emissions (even if most companies are only partially there in terms of measuring and reporting) – and the emergence of global carbon markets.

ELECTRICITY AND CRITICAL POWER

Some of the largest consumers of electricity are businesses with mission critical operations essential to the function of the business. Data centers, hospitals, and manufacturing facilities are leading industries where keeping the power on is a fundamental requirement.

Data centers, for example, are one of the most energy-intensive building types, using up to 50 times the energy of typical office space.

As a whole, data centers consume about 1% of global electricity. Due to the growth in the number of data centers over the next decade the total amount of power used by this type of digital infrastructure is expected to grow. However, individually, data centers efficiency is expected to improve dramatically. Data center operators are significant investors in Power Purchase Agreements (PPAs) for renewable energy and are investing in low carbon impact energy technologies and processes to maximize their utilization of clean power both from the grid and inside the facility. Hospitals have 2.5 times the energy and carbon emissions of commercial office space due to their energy intensive equipment and "always on" nature.[11]

The high levels of energy intensity in these types of facilities provides an opportunity to examine one of the key components in their power delivery systems – the uninterruptible power supply (UPS) – with an eye towards improving its efficiency and supporting the company's environmental goals.

THE ROLE OF THE UPS

Most of the power in a data center, hospital, or manufacturing plant flows through a UPS. The UPS is in place to condition incoming power and provide backup power to the critical load in case of a power disturbance or outage. The choice of UPS and energy storage is critical as it can impact not only capital and operating expenditures, but a facility's overall carbon emissions. With a variety of products available, it's easy to overlook the fact that UPS systems can have a dramatic effect on energy use as energy efficiency can vary widely from product to product. An energy efficient UPS plays a key role in supporting sustainability efforts and decreasing overall power consumption and carbon emissions.

There are three prevalent types of UPS available: static double conversion UPS with batteries; static parallel online UPS with integrated flywheel; and rotary UPS with diesel generator. Each UPS operates in a unique way and relies on a different type of energy storage.

STATIC DOUBLE CONVERSION UPS

A static double conversion UPS relies on power electronics and some form of energy storage, such as lead-acid batteries, to condition incoming power and protect the critical load. A double conversion UPS converts unconditioned incoming power twice — first from AC to DC and then DC back to AC — to provide a clean output voltage to the load. This architecture uses a significant amount of power to continuously perform these conversions, lowering its overall efficiency to approximately 94-96%.

Historically, the most common energy storage deployed in mission critical facilities for static UPS is valve-regulated lead acid (VRLA) batteries. This type of battery is composed of lead (roughly 70%), which is a toxic component, acid, and plastic, and must be replaced every 4-6 years, increasing its overall carbon footprint.

PARALLEL ONLINE UPS

Active Power offers a static parallel online UPS with an integrated flywheel for its energy storage. A parallel online UPS continuously samples and corrects the input voltage through inductors and inverters to provide a clean output sine wave to the load. In the event of a power disturbance or outage, the UPS disconnects from the input and utilizes its built-in flywheel as energy storage until either the utility input is reestablished or a transfer to a generator is made.

A flywheel UPS is field proven to protect against all nine IEEE-defined power disturbances while operating at an efficiency of up to 98%. Ultimately, the parallel online topology is a simpler design with fewer components that is inherently more efficient while providing the same protection as a double conversion UPS.[12] Additionally, the flywheel energy storage never has to be replaced during the 20-year design life of the UPS, inherently lowering its overall carbon footprint.

ROTARY UPS

A rotary UPS utilizes rotating components, such as a motor-generator, to condition power and protect the critical load. The most common design is the engine-coupled rotary UPS, in which the motor is mechanically coupled to a generator set through a short duration flywheel. This design does not require the use of other energy storage options, such as batteries. However, since a rotary UPS has to spin a motor, it wastes more power and has lower efficiency of approximately 93-96%. Similar to a flywheel UPS, it does not require battery replacements, but due to its lower efficiency, it has a higher carbon footprint than other static UPS.

CARBON IMPACT OF UPS

When it comes to total carbon footprint calculations of UPS systems, there are two types of carbon emissions that should be evaluated: operational carbon emissions, which is determined by the energy efficiency of the UPS and its cooling requirements, and embedded carbon emissions, which takes into account the amount of carbon required to manufacture the UPS and its energy storage device.

Let's take a look at how efficiency, cooling requirements, and energy storage choice play a role in measuring carbon emissions of different UPS systems.

OPERATIONAL CARBON EMISSIONS

Operational carbon emission is the carbon emitted as a result of the operation of a UPS and its use of electricity. UPS's have critical functions that are not energy-free to provide; nonetheless, a more efficient UPS will waste less power and generate less heat, which will reduces carbon emissions.

ENERGY EFFICIENCY

By definition, UPS efficiency is the ratio between output power to input power. UPS efficiency is a consequence of a combination of fixed losses (e.g., fans, control power, energy storage charging, etc.) and variable losses driven by the load and the system design of the UPS. Most UPS vendors publish an efficiency curve showing expected efficiency across a variety of rated loads and specific load types (i.e., linear / resistive vs. non-linear). For typical UPS loads in the 50-75% range, a conventional double conversion UPS with batteries and rotary UPS are both approximately 95-96% efficient, compared to an integrated flywheel UPS which is approximately 96-97.5% efficient.[13] See Figure 2 below for efficiencies across typical loads.

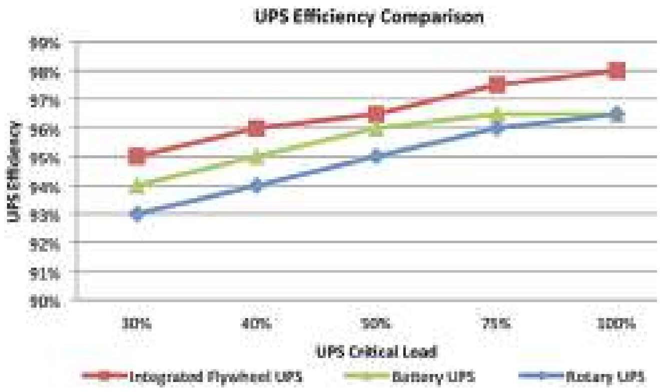

Figure 2. UPS Efficiency Comparison

Since large amounts of power are flowing through the UPS, efficiency plays a significant role in the electricity usage and carbon emissions of a UPS over the life of the product. A difference of only 1-2 points in efficiency can have a dramatic impact in the overall power consumption and consequent carbon emissions. A UPS that is 95% efficient requires 1053 kW of electricity to provide 1000 kW of electricity to its load (1 / 0.95). That additional 5.3 kW is lost by the UPS as it performs its internal critical functions. If this wasted 5.3 kW could be reduced or eliminated, that would translate into lower costs and lower emissions for the user.

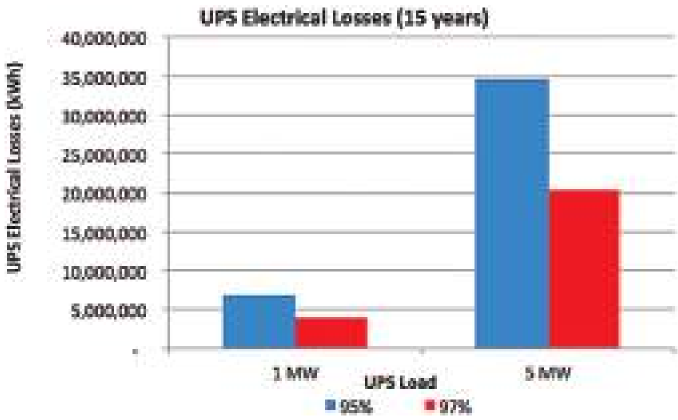

Figure 3. UPS Electrical Losses In kWh

In the example above, a 2% improvement in energy efficiency of the UPS can reduce the electricity usage of a 1 MW facility by more than 2.8 million kWh over 15 years of operation, while a 5 MW facility can reduce energy usage by over 14 million kWh over that same period. This will result in a significant impact on both operating cost[14] and carbon emissions, as calculated below.

COOLING

Higher energy efficiency also has a secondary benefit: further reducing the cooling load on the facility. UPS energy losses generate heat into the surrounding room. That heat must be cooled to keep the facility and equipment within their operating parameters. A general rule of thumb is that it takes 0.3 kW of cooling to dissipate 1 kW of heat losses. Thus, for every kilowatt saved by choosing a more efficient UPS, total savings increases by 1.3 kW. Significant energy savings and low carbon emissions can be realized by choosing a UPS with energy storage that can operate in higher ambient temperatures and has lower heat dissipation.

Flywheels have a number of other, related advantages. UPS batteries must be kept at 77 degrees Fahrenheit (25 degrees Celsius) to maximize their useful life, requiring additional cooling equipment and in some cases dedicated battery rooms. One advantage of a flywheel and rotary UPS is that they can operate in environments of up to 104 degrees Fahrenheit (40 degrees Celsius) with no degradation in performance.

This wide ambient temperature operating range offers flexibility that enables operators to deploy the UPS in spaces where existing cooling cannot be expanded or is unavailable, such as right on a manufacturing floor. Active Power flywheel UPS systems reduce, and in some cases eliminate, the need for additional cooling provisioning or expansion, effectively lowering overall power consumption and carbon emissions.

CARBON EMISSIONS FROM UPS INEFFICIENCY

The amount of carbon emitted by electricity production varies widely around the world, driven by the carbon intensity of the mix of fuel sources supplying the facility. Coal is generally the highest CO_2 emitting fuel source per kWh generated at 0.94kg, followed natural gas at 0.55kg, while nuclear, hydro, and renewable sources emit almost no carbon.[15]

Based on the global average mix of fuel used, each kWh of electricity generated emits approximately 0.53kg of carbon. This amount can vary widely by country and within countries. The US, still heavily dependent on coal and emits around 0.69kg of CO_2 per kWh generated.[16] Australia and China, with an even higher mix of coal, emit more kg of CO_2 per kWh at 0.84 and 0.77kg, respectively. Countries with abundant hydroelectric (Sweden, Brazil) or nuclear power (France) emit far less CO_2. See Table 1 below.[17]

COUNTRY	KG CO_2 / kWh
United States	0.69
World Average	0.53
United Kingdom	0.46
France	0.08
Sweden	0.03
Germany	0.46
Netherlands	0.41
Mexico	0.45
China	0.77
Singapore	0.50
Australia	0.84
Brazil	0.09

Table 1. CO_2 Emissions per country

At US levels of carbon intensity, Active Power's flywheel UPS reduces operational carbon emissions from losses by 2,145 metric tons or 43% compared to a conventional battery UPS for a 1 MW critical load, as shown below in Table 2.

CARBON EMISSION SAVINGS	ACTIVE POWER	BATTERY UPS
Critical Load	1 MW	1 MW
UPS Efficiency	97.5%	96%
15-year kWh wasted (inefficiency + cooling)	4,043,077	7,117,500
Carbon emissions factor	0.69	0.69
15-year carbon emissions from losses (metric tons)	2,789	4,911
Active Power 15-year carbon emission savings (metric tons)	2,121	
Active Power 15-year carbon emissions from lossessavings (%)	43%	

Table 2. Carbon emissions savings calculation

The carbon emissions savings scale up dramatically as the size of the UPS and critical load increase. Table 3 and Figure 4 below show that the Active Power flywheel UPS can reduce carbon emissions by over 21,000 metric tons over 15 years for a 10 MW facility.

CARBON EMISSIONS SAVINGS (METRIC TONS) – 15 YEARS			
	Active Power	Battery UPS	Savings
1 MW Load	2,789	4,911	2,122
5 MW Load	13,945	24,555	10,610
10 MW Load	27,890	49,110	21,220

Table 3. Carbon emissions savings by load

Figure 4. 15 Year carbon emission savings

EMBEDDED CARBON EMISSIONS

Embedded carbon is the carbon emitted during production of a component from its raw materials, such as lead or iron, and is represented as kg of CO_2 per kg of material. The embedded carbon of a component is determined from the chemical composition of the raw materials used, the embedded carbon of the different elements, and the weight of the materials.

The primary difference between the types of UPS from an embedded carbon perspective comes from their energy storage. Lead-acid batteries are comprised of lead (~70%) and sulfuric acid encased in a plastic container.[18] Based on the chemical composition and their embedded carbon, [19] each kilogram of a lead-acid battery has a total embedded carbon of 1.14 kg of CO_2, as shown in Table 4 below.

LEAD-ACID BATTERY	CONTENT (%)	EMBEDDED CO_2 (KG CO_2/KG)
Inorganic lead / lead compounds	72%	1.33
Sulfuric Acid	20%	0
Fiberglass separator	2%	1.35
Container plastic	5%	3.1
	Weighted average	1.14

Table 4. Embedded carbon of lead-acid battery

Flywheels are made out of aircraft grade steel (4340 or 4330M) and enclosed in a ductile iron housing. Both are overwhelmingly composed of iron.[20] As calculated in Table 5 below, each kilogram of material in the flywheel and housing has an embedded carbon content of 2.2 kg of CO_2.

FLYWHEEL	CONTENT (%)	EMBEDDED CO_2 (KG CO_2/KG)
Iron, Fe	95.5%	1.91
Nickel, Ni	1.83%	12.4
Chromium, Cr	0.8%	5.4
Manganese, Mn	0.7%	3.5
Carbon, C	0.4%	0
Molybdenum, Mo	0.25%	32.2
Silicon, Si	0.2%	13.5
	Weighted average	2.22

Table 5. Embedded carbon of flywheel

While the embedded carbon to produce 1 kg of flywheel is higher than that needed to produce 1 kg of lead-acid battery, the amount of material needed by the flywheel is far lower. Active Power's UPS requires roughly 3,000 kg of steel to provide energy storage for 1 MW of UPS, embedding 6,700 kg of carbon. Nearly 15,000 kg of lead-acid batteries – with 16,750 kg of embedded carbon – is needed for that same load. In short: flywheels need nearly 80% less weight, and 40% less embedded carbon, than one set of lead-acid batteries. And since batteries will typically require three replacements over the life of the UPS, another 45,000 kg of batteries will be used, representing another 50,000 kg of embedded carbon. Over the lifetime of the UPS, flywheels will embed 90% less carbon than lead-acid batteries.

	BATTERIES (LEAD ACID)	CLEANSOURCE FLYWHEEL (4340 STEEL)
Embedded carbon emissions (CO_2/kg)	1.14	2.23
Energy storage for 1 MW	6 x Battery cabinets	2 x 750 kVA Flywheels
Total energy storage weight (kg)	14,693	3,084
Total embedded carbon (kg CO_2)	16,750	6,785
15 Year replacements	3	0
Total lifecycle embedded carbon (kg CO_2)	67,002	6,785

Table 6. Embedded carbon comparison

In this example, a 1 MW load is powered by two 750 kVA UPS: two battery UPS with 5 minutes of runtime or two integrated flywheel UPS. The flywheel UPS reduces embedded carbon emissions by nearly 10 times or 60 tons of CO_2 versus a battery-based UPS.

FLYWHEEL VS BATTERIES

The use of lead acid batteries for energy storage also causes other environmental concerns because they are comprised mostly of hazardous materials. Federal law requires that all lead acid batteries be treated as universal waste under the Code of Federal Regulations, Title 40 – Protection of Environment, Part 273 – Standards for Universal Waste Management. The improper disposal of lead acid batteries is prohibited, and it is the responsibility of the owner/end-user to ensure an appropriate and legally acceptable method of disposal. Lead is a toxic heavy metal and therefore improper disposal can be hazardous to the environment, leading to the pollution of drinking water and food sources. Some jurisdictions require extensive reporting and permitting prior to the installation of a new lead-acid battery installation, due to fire and hazardous material concerns.[21]

Lead-acid batteries are one of the most recycled consumer products in the world. More than 99% of lead in batteries ends up being recycled, and typically new batteries are composed of over 60% recycled lead.[22]

But even though lead acid batteries are highly recyclable products, new lead has to be produced, and smelting facilities require a tremendous amount of power and resources to keep up with current demands. In the 1 MW example above, over 58,000 kg of lead-acid batteries will need to be deployed over 15 years. Since 70% of the battery is lead, the site will store 41,000 kg of lead over its life. If 60% of that lead comes from recycled sources, it still leaves 16,000 kg of new lead that will need to be mined, smelted and transported to the facility to provide its energy storage.

Conversely, flywheels are made out of almost 100% steel, which is not toxic. Steel is the most recycled material in the world, more than all other materials combined. In 2012 steel had a recycling rate of 88%.[23] In fact, two-thirds of newly produced steel is made from recycled steel.

CATEGORY	FLYWHEEL	LEAD ACID BATTERIES
Life	20 years	4-6 years
Degradation	None	Frequent use and high temperatues degrade lifespan
Maintenance	Limited	Extensive
Monitoring	Built-in UPS	Separate costly system
Operating Temperature	Up to 40C (104F)	Must be kept at 25C (77F)
Footprint	Compact, enclosed	2-3x larger
Safety	Built-in features	Requires external safety systems
Reliability	Very high (12x)	Most common reason for data centre outage
Hazardous materials	None	Lead, Sulfuric

Table 7. Flywheel vs battery comparison

Lead acid batteries are the most vulnerable part of a UPS and the leading cause of load loss in data centers.[24] Even with the latest improvements to battery technology, they require advanced and constant monitoring to minimize the inherent risk of downtime.

There are many considerations and precautions that must be observed to ensure proper safety and battery functionality, such as:

- HYDROGEN DETECTION
- SPILL CONTAINMENT TRAYS
- TEMPERATURE CONTROLLED STORAGE (25°C OR 77°F)
- DEDICATED BATTERY ROOMS WITH SPECIAL VENTILATION
- SPECIAL LIFTING / INSTALLATION TOOLS
- EMERGENCY EYE WASH STATIONS
- PERSONAL PROTECTIVE EQUIPMENT (PPE) DURING MAINTENANCE
- FLOOR ANCHORING AND LOADING RESTRICTIONS
- SHORTEST CABLE DISTANCE TO MINIMIZE VOLTAGE DROP

Batteries in general are cumbersome and an outdated energy storage solution for highly sophisticated data centers and other mission critical applications. They are extremely unreliable, their average lifespan is about half of their design life (i.e., a 10 year battery needs to be replaced after 4-6 years), and are highly affected by usage (discharge/recharge) and environment. Lead acid batteries also require extensive quarterly or semi-annual maintenance to check loose or corroded connections, voltage and resistance levels, and visual inspections for any damages.

CONCLUSION

Environmental awareness and responsibility are spreading throughout industry. Many major global companies are committed to reduce carbon emissions with a variety of programs and initiatives, including energy efficiency programs, switching to renewable energy, and updating equipment. While renewable energy production is expanding at a very fast rate, we will continue to rely on fossil fuels for many years to come, increasing the importance of pursuing products that can support these sustainability efforts.

Active Power is committed to provide a sustainable solution for our customers and the environment. In anticipation of the dramatic increase in power consumption by data centers and all other industries over the next five years, businesses must consider implementing green initiatives throughout their facilities. The flywheel UPS is a key product to help businesses lower their overall power consumption and minimize their carbon footprint.

Active Power flywheel UPS is able to reduce embedded carbon emissions by approximately 10 times and operational carbon emissions from losses by 40% with high efficiency, lower cooling requirements, and permanent energy storage over the life of the product. These inherent characteristics make Active Power's flywheel UPS products an ideal solution for customers to achieve their sustainability goals and lower their overall carbon footprint.

10, 11, 12 Missing footnotes
13 Active Power UPS efficiency from data from www.activepower.com. Competitor efficiency averaged from leading battery UPS manufacturers. See Active Power white paper 114, High Efficiency UPS Systems for a Power Hungry World.
14 See Active Power white paper 119, Evaluating Total Cost of Ownership for UPS Systems
15 U.S. EIA, FAQ, https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11.
16 U.S. EPA, GHG Equivalencies Calculator, https://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references.
17 International Energy Agency, CO2 Emissions from Fuel Combustion, 2012,
18 See e.g., B.B. Battery, Material Safety Data Sheet, Valve Regulated Lead-acid Rechargeable Battery,
19 Embedded carbon derived from Circular Ecology, Inventory of Carbon and Energy (ICE), http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html#.VuMFp_krJaQ.
20 AZO Materials, AISI 4340 Alloy Steel, http://www.azom.com/article.aspx?ArticleID=6772
21 See, e.g., Santa Clara Fire Department, Stationary Storage Battery Systems, http://www.santaclaraca.gov/home/showdocument?id=11764.
22 Battery Council International, http://batterycouncil.org/?page=Battery_Recycling.
23 American Iron and Steel Institute (SteelWorks), http://www.steel.org/sustainability/steel-recycling.aspx
24 Emerson Network Power, Battery Maintenance Solutions for Critical Facilities (e-book),

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