

# Comparing Data Center Batteries, Flywheels, and Ultracapacitors

## White Paper 65

Revision 2

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### > Executive summary

Most data center professionals choose lead-acid batteries as their preferred method of energy storage. However, alternatives to lead-acid batteries are attracting more attention as raw material and energy costs continue to increase and as governments become more vigilant regarding environmental and waste disposal issues. This paper compares several popular classes of batteries, compares batteries to both flywheels and ultracapacitors, and briefly discusses fuel cells.

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## Introduction

Data centers require energy storage devices to address the risk of interruptions to the main power supply. Energy storage applications can be divided into three major functional categories:

1. **Power stability** – When the power supply coming into the data center is unstable (e.g., power surges and sags), stored energy can be used as needed to balance out disturbances and assure a clean power supply to the load.
2. **Power bridging** – When switching from one source of power to another (e.g., utility power to generator power), stored energy can be used (from seconds to hours) to assure consistent power.
3. **Energy management** – This is the cost-optimizing strategy of *charging* stored energy when energy cost is low, and *using* stored energy when energy cost is high. This energy storage application is not discussed in this paper.

Although many varieties of energy storage technologies are available today, this paper will limit its analysis to those that are most applicable to data centers. Although some storage technologies can function across a range of applications, most are limited in their specific application because of economic considerations.

The three technologies that qualify for practical use in data centers—batteries, flywheels, and ultracapacitors—are the subject of this paper (see **Figure 1**).

The intention of this paper is neither to provide detailed technical descriptions nor to compare in-depth TCO scenarios of energy storage alternatives. This paper attempts to simplify the analysis of energy storage alternatives by providing a relative comparison of mainstream and emerging energy storage technologies.

Energy **generation** means access to a *constant* or near constant source of electricity so that the data center's IT load (servers, storage devices, communications devices) can continue to run and perform critical activities. Most data center owners depend upon a local utility to supply energy. The utility captures energy either by burning fossil fuels, splitting atoms, or tapping a nearby dam. That raw energy is converted to "shaft horsepower" which is utilized as the prime mover to rotate a generator thus converting physical energy into electricity. The utility then distributes the electricity to business and home consumers across a network of power lines and transformers.

A small minority of businesses purchase alternative energy generation sources such as wind, solar or thermal power units. More often, diesel, gasoline or natural gas generators (also known in the industry as "distributed generation") are purchased to power buildings and data center sites in the event of a utility outage. Organizations such as hospitals and universities sometimes generate their own primary power (i.e., they build their own power generation plant for day-to-day operations) independent of the commercial utility and will use the utility

### > What this paper covers

This paper covers energy storage technologies that are available today and have practical use in data centers – each suited to different needs:

- Batteries
- Flywheels
- Ultracapacitors

This paper does not cover:

- Energy storage for portable devices such as laptops
- Technologies not economical or not mature enough to be practical (e.g., compressed air, superconducting magnetic energy) in a typical data center environment

**Fuel cells** often come up in energy discussions, but they are energy *generation*, not energy *storage*

## Energy storage and energy generation defined

Related resource  
**White Paper 64**

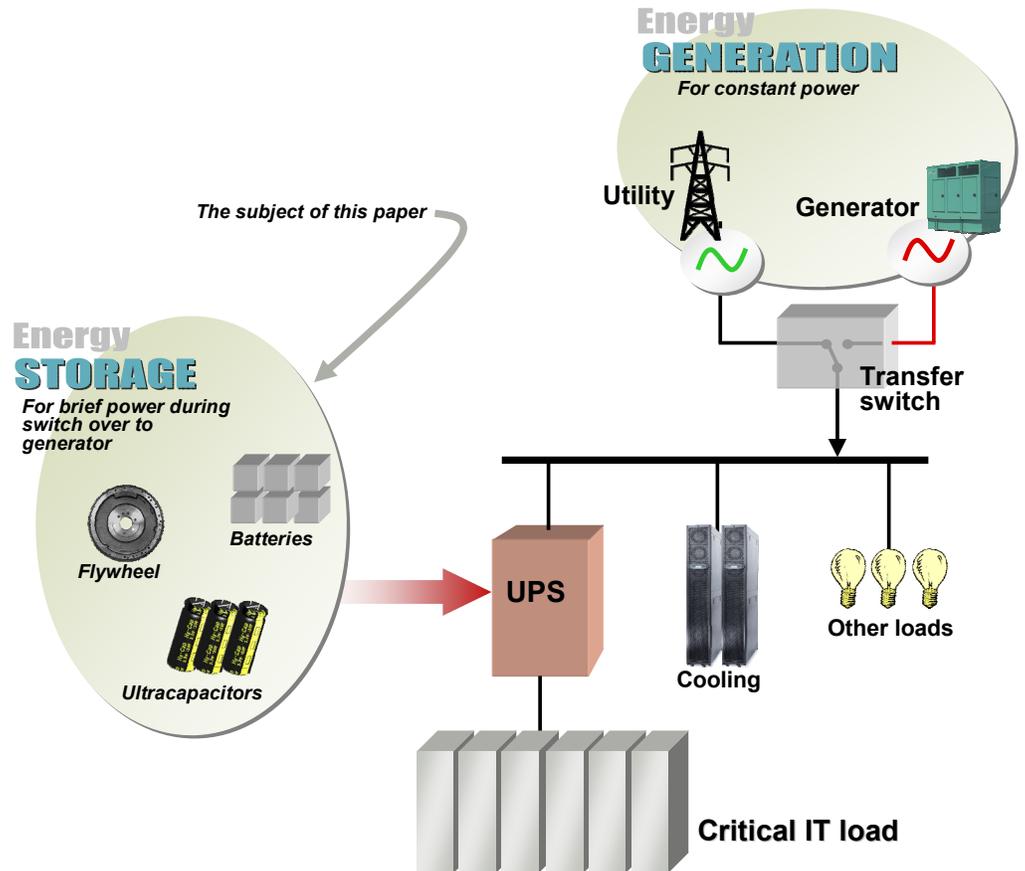
Alternative Power  
Generation Technologies for  
Data Centers and Network  
Rooms

and stand-by generators as a backup. For more details on power generation methods for data centers, see White Paper 64, *Alternative Power Generation Technologies for Data Centers and Network Rooms*.

Energy **storage**, on the other hand, supplements overall data center availability by providing a stored, *potential* source of energy (such as batteries) in the event of interruption to the normal electrical flow. Energy storage addresses the challenges of a rapid switchover to an alternative power source when a power disturbance occurs, and the stable delivery of power to the load until the disturbance is resolved.

**Figure 1**

Energy storage in the context of the data center power path



A data center's stored energy system should demonstrate the following characteristics:

- Instant availability of supply power to the critical load via the UPS in the event of sags, spikes, complete utility failure, or any other power disturbance that requires a switch-over to a backup power source
- Proper sizing to supply the critical load that is normally supported by the utility via the UPS
- Sufficient operating time for backup power to come online (typically the time required for a generator to start up)

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**White Paper 154**

Electrical Efficiency  
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## Energy storage efficiency

When discussing energy storage efficiency, it is important to define what is meant by the term "efficiency". The definition of energy storage system efficiency has to be consistent with the way efficiency is defined for the entire data center. Data center efficiency is measured as the ratio of total data center input power to IT load power. (see White Paper 154, *Electrical Efficiency Measurement for Data Centers for more details*). This metric is called the Power

*Usage Effectiveness (PUE) measurement.* A higher PUE number means lower efficiency. A perfect efficiency would be equal to 1.

The key element, when it comes to energy storage efficiency, is the amount of energy required to keep the energy storage equipment charged. In the case of a flywheel, for example, energy is required to keep the flywheel spinning (this is called standby loss). In the case of batteries, energy is required to provide the batteries with a float charge (this is called trickle charge loss). In both cases, the energy that constantly feeds these devices to keep them in a state of readiness is lost forever. These losses will have an impact on overall data center efficiency percentage because, as per our definition, this energy never makes it to the IT load.

If we compare the two technologies in this context, the batteries are likely to be more efficient because it takes more energy to keep a flywheel spinning than it does to supply the batteries with float charge. The typical full load standby loss of a flywheel can range from 0.2% (0.002) to 2% (0.02) of the flywheel's full load kW rating, depending upon the flywheel technology. By comparison, the average trickle charge loss of a battery is 0.2% (0.002) of the UPS's full load kW rating. The efficiency gain in this case could be as high as 1.8 percentage points in favor of the battery. Assume that a 1 MW data center can consume 177 million kW-hrs of energy – equal to \$17 million over the 10-year lifetime of the data center – (or 4300 cars worth of carbon). Therefore, over the lifetime of the data center, an inefficient flywheel compared to a battery system could cost the data center owner up to as much as an extra \$306,000 (1.8% x \$17 Million).

Some flywheel technologies such as high speed composite, frictionless vacuum-encased flywheels can demonstrate higher efficiencies. However, they are usually limited in capacity (e.g., up to 250 kW) and reserve time (only a few seconds compared to many minutes of battery reserve at ratings up to a megawatt). Flywheels that are integrated into a UPS system can be more efficient than flywheels purchased as stand-alone assemblies. When flywheels and UPS are integrated, specific losses are reduced to 0.5%. This is because control power, fan power, and other losses are shared by the flywheel and UPS.

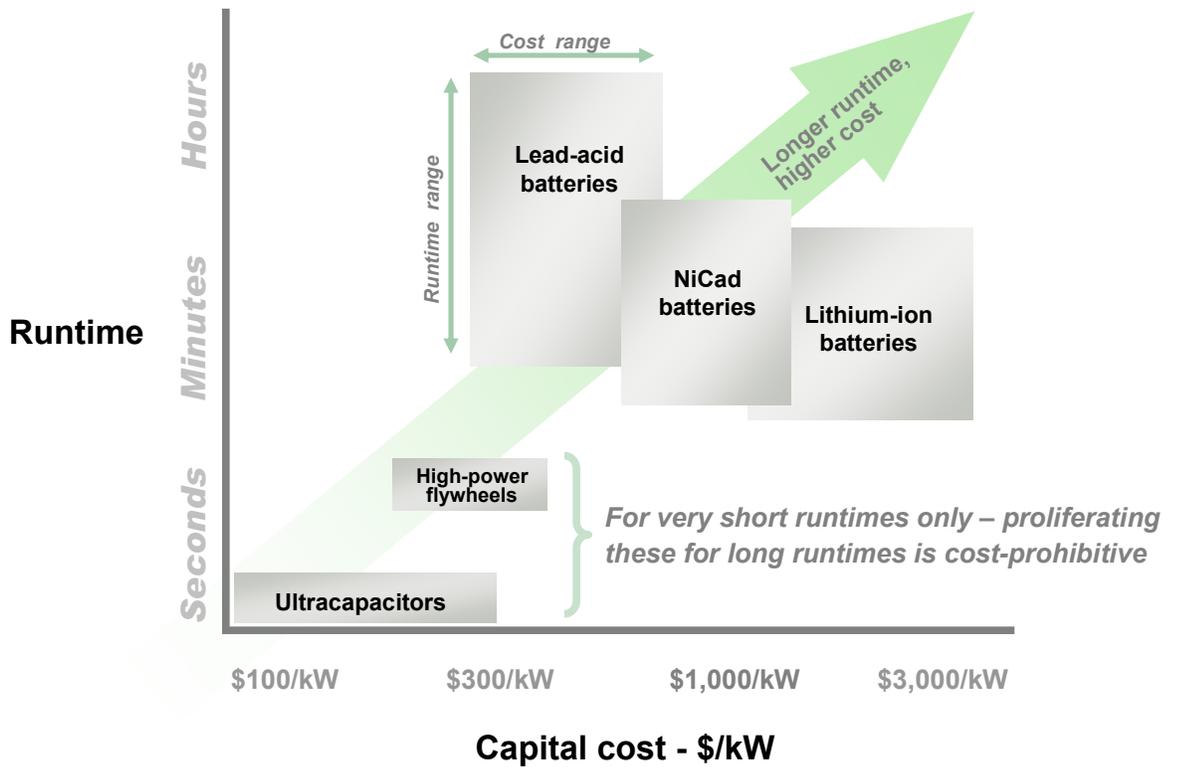
## Energy storage cost

**Figure 2**<sup>1</sup> shows a comparison of capital cost for energy storage solutions. While capital cost is an important financial parameter, it should be recognized that the total cost of ownership (which includes operational and maintenance costs) is a much more meaningful index for analysis. For example, while the capital cost of lead-acid batteries is relatively low, they may not necessarily be the least expensive option for environments experiencing frequent outages of short duration. Under such circumstances, lead-acid batteries will likely experience a shortened life span. **Figure 2** is intended to provide an overview cost comparison of different energy storage solutions – it should only be used as a general guide and not as detailed data.

<sup>1</sup> **Figure 2** is derived from data presented courtesy of the Electricity Storage Association <http://www.electricitystorage.org> accessed December 6, 2007

**Figure 2**

Capital cost vs. runtime for energy storage methods



## Factors that influence the business decision

Related resource  
**White Paper 154**

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Centers

Data center professionals investing in energy storage solutions should consider the following:

- Efficiency** – Data center efficiency is defined as the following ratio: watts to the IT load / watts to the data center. If 100 watts of power are coming into the data center and only 60 of those watts makes it to the IT load, then that data center is 60% efficient (see White Paper 154, Electrical Efficiency Measurement for Data Centers for more information). Low efficiency of energy storage devices increases the overall energy cost of the data center.
- Criticality of the IT load** – Does the data center support global banking transactions where millions of dollars in revenue can potentially be lost if the computer system goes down, or does the data center support applications less critical in nature (such as the computer supporting the local public library)? Answering the criticality question will help determine how much runtime is required when a power outage occurs. Required runtime, in turn, becomes an important factor in determining the type of energy storage to be deployed. Larger data centers are sometimes divided into criticality zones, each of which may require a different energy storage approach.
- Budget** – When evaluating energy storage options, a number of factors need to be considered that will directly impact the budget. In some cases, government incentives will nudge consumers of energy towards particular “green” technologies. Upfront costs also need to be considered (see Figure 2). Some energy storage solutions are modular and can spread cost over a number of years (e.g., removable / replaceable battery cartridges). Other solutions re-

### > What is “cycle life?”

Cycle life is the number of charge / discharge cycles that can be accomplished during the lifetime of the device. It is an estimate, and depends upon an assumption of an average “depth” of discharge.

The cycle life specification provides a way of comparing energy storage methods and deciding which is best for the power characteristics of the installation.

quire an upfront payment with excess capacity so that the solution can prove viable over the long term as the buyer's energy storage requirements grow.

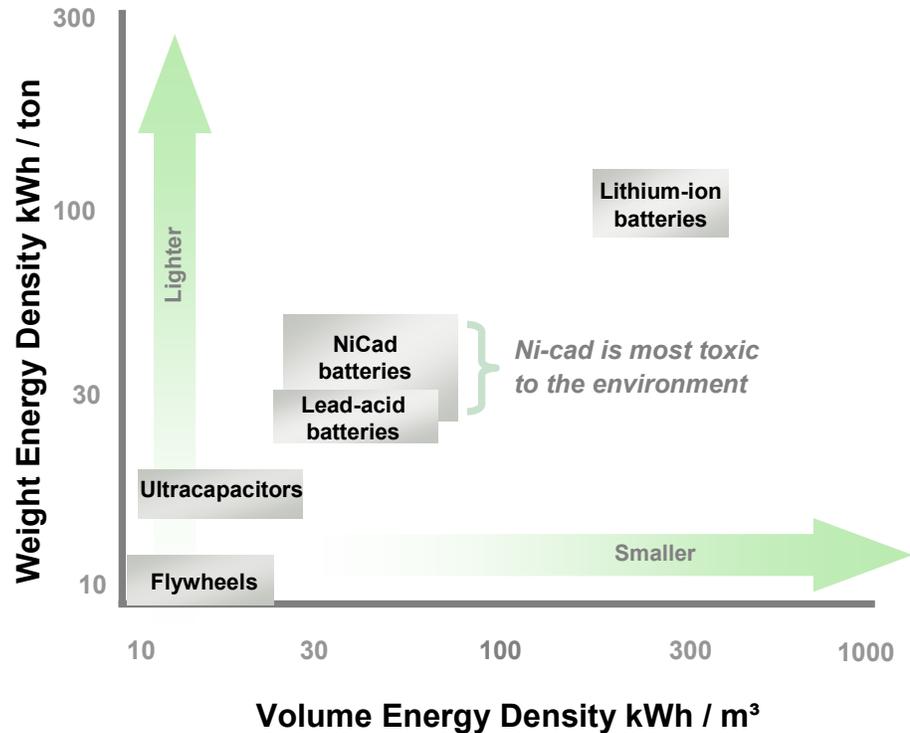
- **Cycle life** – Short cycle life increases the total cost, since the storage device needs to be replaced more often. The present value of this expense needs to be considered along with the capital cost and operating expenses to obtain a better picture of total cost of ownership.
- **Size and weight** – The various energy storage solutions are designed differently from each other and have unique physical characteristics. Batteries, for example, are heavy and can consume considerable floor space. Weight can be an issue if the energy storage solution is placed on a floor that is above grade. The as-built floor may not be strong enough to bear the weight. These solution characteristics need to be taken into consideration (see **Figure 3**<sup>2</sup>). Much of the data center floor space may already be dedicated to racks and the energy storage solution may require an adaptable form factor in order to fit into the allotted space i.e. stacking batteries vertically.
- **Stability / availability of power from the primary source (usually the utility)** – What is the performance record of the nearby utility? Are frequent but short outages typical, or is the utility source stable most of the time with an occasional prolonged blackout? Are power surges and sags rare or commonplace? The answers impact which kind of energy storage solution or combination of solutions is best able to support the load.
- **Energy storage operating environments** – The physical environment of the energy solution is an important consideration. Will the energy storage equipment reside inside the building or in an outdoor enclosure? What is the typical temperature and humidity range of the environment? These environmental characteristics can impact the functionality and anticipated life span of the selected energy storage solution.
- **Safety** – Federal safety regulations, state and local fire codes, hazardous materials management, and emergency response planning all need to be considered. Can the energy storage solution be secured with an emergency power off (EPO) system in case of fire? Since people are interacting directly with or working near energy storage equipment, provisions need to be made for operation, storage, and removal of materials. For example, what if a maintenance person accidentally drops a tool across opposing bus bars on a battery system and triggers a short circuit and arc flash? What if a rotating flywheel were to break apart? Would it crash through its casing and cause harm to nearby personnel?
- **Maintenance** – Some energy storage solutions have many moving parts. This could imply a higher maintenance cost over time, since moving parts wear out faster than non-moving parts. However, chemical reaction and corrosion can influence the functionality of non-moving parts such as internal plate connections. Battery systems vary in their maintenance and monitoring requirements. Vented lead-acid batteries require regular inspection, connection verification, and water additions. VRLA batteries and sealed lithium batteries do not need water addition.

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<sup>2</sup> **Figure 3** is derived from data presented courtesy of the Electricity Storage Association <http://www.electricitystorage.org> accessed December 6, 2007

**Figure 3**

Technology size and weight comparisons



## Data center energy storage technologies

### Batteries

In the simplest terms, a battery is an electrochemical device that stores energy and then supplies it as electricity to a load circuit. Batteries are typically organized in strings and can be connected in series, in parallel, or in combination of both, to provide the required operating voltage and current.

The way batteries are architected can impact the overall reliability of the battery solution. If the system design is organized in single strings, the possibility exists for a cell reversal condition. This can occur unexpectedly due to battery degradation or manufacturing defect. When one cell in a series string has a much lower capacity than the other cells in the string, the lower capacity cell can become driven into a reverse condition by the remaining good cells in the string. Fortunately, most UPSs available today are configured with parallel battery string architecture. If one string were to malfunction, the other string would continue to support the load. The equivalent in a flywheel would be a second, redundant flywheel system operating in parallel.

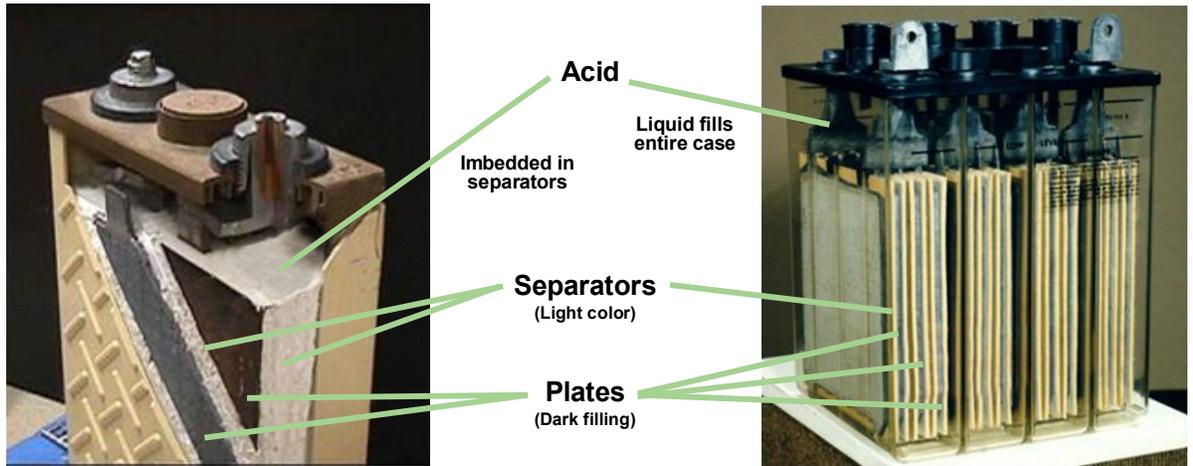
Battery systems are treated as short-term to medium-term sources of stored energy, capable of supporting a critical load for minutes or hours (see **Figure 2**). Runtime (power capacity) can be increased by adding more battery strings. Battery systems can be the primary source of backup power, but they usually support the load until an alternate source of power is available (such as a standby generator). The Electricity Storage Association (ESA) estimates that the sales of industrial batteries, as might be used in data center applications, amounts to \$5 billion each year (see **Table 1** for a comparison of popular battery types)<sup>3</sup>.

<sup>3</sup> [http://electricitystorage.org/technologies\\_applications.htm](http://electricitystorage.org/technologies_applications.htm) (accessed January 6, 2008)

**VRLA**

**Flooded**

**Figure 4**  
*Typical lead-acid battery*



Batteries are often installed in cabinets next to a UPS, but can also be set up in racks or on shelves in dedicated battery rooms. The batteries most commonly associated with UPSs are sealed valve-regulated lead-acid (VRLA) batteries mounted in the UPS or in one or more adjoining cabinets. Of the batteries described in **Table 1**, some have numerous subcategories of battery types. Lithium batteries, for example, are available in a number of varieties such as lithium-ion and lithium-polymer.

**Table 1**

Comparison of battery types

	Flooded / vented lead-acid	Valve regulated lead-acid	Nickel cadmium	Lithium-ion	Ni-MH
<b>Environmental Impact</b>	Lead and acid must be safely disposed of Electrolyte must be contained	Lead and acid must be safely disposed of Spill resistant	Considered even more toxic than lead-acid. Highly controlled disposal required.	Considered less toxic than either lead/acid or nickel cadmium	Not toxic
<b>Current Cost (relative to other batteries)</b>	Low	Low	High	High	Moderate
<b>Cost trend</b>	Upward (lead prices)	Upward (lead prices)	Downward (projected 50% lower by 2010)	Downward (projected 40% lower by 2010)	Downward
<b>Discharge / Recharge Characteristics</b>	Fast discharge / slower recharge	Fast discharge / slower recharge	Fast discharge / fast recharge	Fast discharge / fast recharge	Fast discharge / fast recharge
<b>Gravimetric Energy Density* (Wh / kg)</b>	30-40	15 - 40	35 - 55	90 - 200	43 - 70
<b>Volumetric Energy Density** (Wh / L)</b>	60-80	55-80	30 - 150	230 - 500	83 - 170
<b>Gravimetric Power Density*** (W / kg)</b>	180 - 200	75 - 415	50 - 150	750 - 1250	250 - 1100
<b>Broad Field Performance History</b>	More than 100 years	20 years	15 - 20 years	Less than 5 years	Less than 5 years
<b>Life Expectancy Range</b>	15 - 20 years	3 – 10 years	10 years	6-20 years	5 to 15 years
<b>Operating Temperature Range</b>	60°F to 77°F (15°C to 25°C)	60°F to 77°F (15°C to 25°C)	-4°F to 140°F (-20°C to 60°C)	-40°F to 140°F (-40°C to 60°C)	-4°F to 140°F (-20°C to 60°C)

\* Gravimetric Energy Density (Specific Energy) - The ratio of energy output to weight (watt-hrs / kg)

\*\* Volumetric Energy Density - The ratio of energy output to volume (watt-hrs / liter)

\*\*\* Gravimetric Power Density (Specific Power) - Power output per unit weight (watts / kg)

Each battery type has distinct advantages and disadvantages. For purposes of general comparison, four types of common batteries have been highlighted in **Table 1**: Lead-acid (both flooded and VRLA), nickel cadmium, lithium-ion, and nickel-metal hydride batteries (Ni-MH).

Lead-acid batteries are the most common data center batteries (over 10 million UPSs use them) and are either of the flooded (also known as vented or wet cell) or VRLA type (see **Figure 4**). In data centers, VRLA batteries are the most common type of lead-acid battery. Flooded lead-acid batteries are almost always located in separate battery rooms, isolated from the loads they support, and are often used in UPS applications above 500 kW. Because the electrolyte within flooded batteries is open to the air, flooded lead-acid batteries are subject to more stringent environmental regulations.

An analysis of **Table 1** would point to multiple advantages for lithium-ion batteries. However, in two key categories (cost and field performance history) lead-acid batteries currently

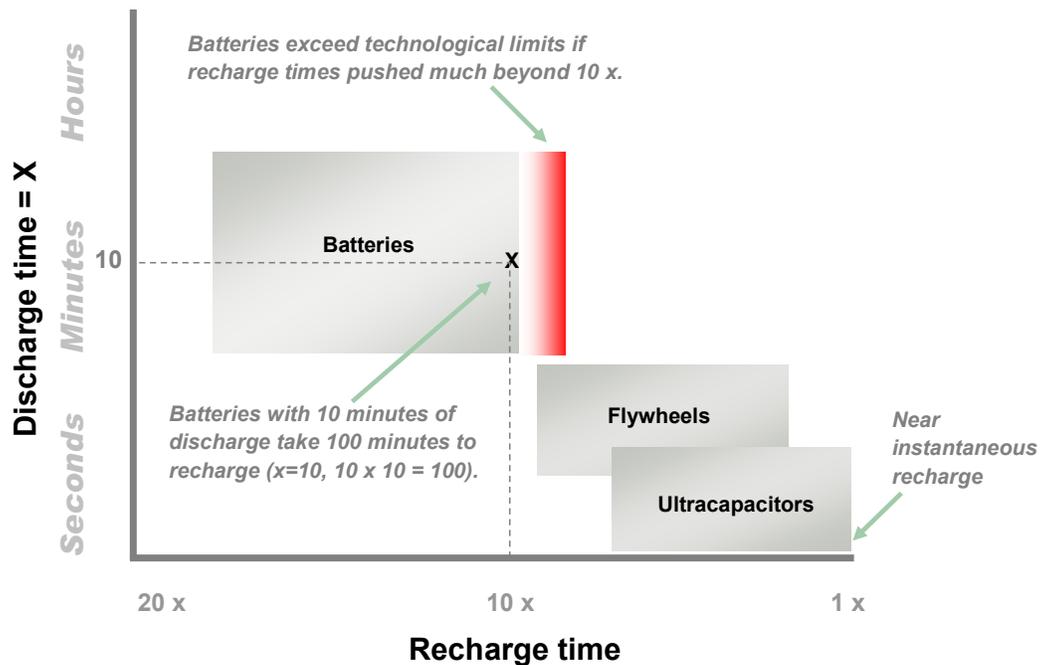
command very significant advantages. A look forward into the near future implies that lithium-ion batteries may soon (within the next five years) offer a compelling business case for a switch from lead-acid to lithium-ion.

### Flywheels

A traditional flywheel is a heavy wheel that stores kinetic energy when rotating. When the AC input power fails, the flywheel system operates as an AC generator (via the DC to AC inverter) and uses the kinetic energy of the flywheel to supply the output voltage. The wheel is spun by a series of motors. During a power failure, the flywheel provides power to the load while the generators start up. After a very short period of time (seconds), the kinetic energy from the flywheel dissipates.

**Figure 5**

Comparison of energy storage technology discharge / recharge times



Flywheels are sometimes confused with rotary UPSs. The definition of a rotary UPS is any UPS whose output sine wave is generated by rotating mechanical motion. Like static UPSs, rotary UPSs provide clean stable power to the load and bridge the gap in power when an outage occurs (see White Paper 92, *Comparison of Static and Rotary UPS* for more information). In some cases, both rotary and static UPSs use batteries as an energy storage source. In other cases, they use a flywheel as a replacement for batteries. In yet other cases flywheels are used in conjunction with batteries, particularly in situations where frequent short runtimes are required.

The principal advantages and disadvantages of flywheels are included in the box below.

Batteries usually provide five to 15 minutes of backup power, while a flywheel can typically supply from 8 to 15 seconds of backup at full power (see **Figure 2** for a general comparison). The extended battery runtime allows for both humans and software to perform emergency procedures to safeguard data. For this reason, flywheels are often used in conjunction with a standby generator for longer runtime. However, this could present an environmental issue, because many communities have emissions regulations that limit how many hours a diesel generator can run. Consideration must be given to the “bridge time” before a generator starts and is ready to accept load.

 Related resource  
**White Paper 92**  
*Comparison of Static and Rotary UPS*

If used with a battery-based UPS, a flywheel can handle all short duration power disturbances, leaving the batteries only for extended outages and thereby extending battery life. A flywheel can also work with a rotary UPS in conjunction with a motor / generator and act as an alternative to a battery-based UPS.

In a power-bridging capacity, both flywheels and batteries support the load until the generator starts. However, with the longer runtime of batteries it is possible to program the generator to start only when an outage exceeds a specific duration. Flywheel systems, in most cases, do not have this luxury, and the generator must start for every outage no matter how short. This is a disadvantage because once the generator starts, it will run for a minimum period of time no matter how long or short the utility outage. Running a generator should be avoided whenever possible (except as required for monthly maintenance), because of noise and exhaust emissions issues.

Storage of kinetic energy in rotating mechanical systems such as flywheels is attractive where very rapid absorption and release of the stored energy is critical. However, rapid recharge can require high power to power both the UPS and the flywheel simultaneously. Few applications exist where high power capacity and short charging cycles are the primary consideration. Where fast recharge is not required, flywheels typically are charged at approximately 10% rated output, which is comparable to battery-backed UPS systems.

## Ultracapacitors

A capacitor is an electric circuit element used to store an electrical charge temporarily. In general, it consists of two metallic plates separated and insulated from each other by a nonconductive material such as glass or porcelain.

An ultracapacitor (also known as a supercapacitor) is a double-layer electrochemical capacitor that can store thousands of times more energy than a common capacitor. It shares characteristics with both batteries and conventional capacitors, and has an energy density (the ratio of energy output to its weight) approaching 20% of a battery. In other words, a battery would have to be 80% heavier than the ultracapacitor in order to produce the equivalent energy output.

This means that an ultracapacitor could be a suitable battery replacement in situations where a long runtime is not required. For example, consider an application in an environment where frequent outages last for less than two minutes. In such an environment, battery deterioration is excessive due to the high frequency of the outages. In this case, a UPS with 40 minutes of battery runtime could be replaced with a UPS and ultracapacitor that provides approximately

### > Flywheels

#### Advantages:

- Fast recharge after use
- Makes more economic sense for applications of 500 kW or above
- Wide operating temperature range (0° to 40° C or 32° to 104°) compared to batteries
- Lifetime of more than 15 years
- Have a power density advantage over batteries when less than a minute of runtime is acceptable
- In larger applications, may have smaller footprint than batteries (e.g., > 50 kW)

#### Disadvantages:

- Maintenance cost
- Short runtime translate into longer generator runtimes (noise, fuel consumption, pollution)
- Flywheels function with the assistance of a complex set of multiple controls which represent potential single points of failure
- Complexity of installation
- Efficiency losses to maintain flywheel rotation (during normal operation)
- Can have a larger footprint than batteries in small applications (e.g., <50 kW)

two minutes of runtime. This would result in a highly reliable energy storage system that would require little or no maintenance.

This ultracapacitor solution (without a battery required) would be effective for applications that reside in remote sites where regular battery maintenance is impractical or even impossible.

The ultracapacitor is also a solution where ambient temperatures make it difficult to keep batteries inside the recommended operating range without compromising battery capacity and lifetime. Ultracapacitors are safer for the environment since they contain fewer hazardous materials. However, if an ultracapacitor is burned, toxic and corrosive gases from within the electrolyte would be released into the atmosphere.

Ultracapacitors, still in an emerging phase of development, are a very promising power-bridging technology for short backup applications such as fuel cell start up. Ultracapacitors are used primarily for peak load shaving due to their very fast charge and discharge cycles. While small electrochemical capacitors are well developed, large ultracapacitors with energy densities over 20 kWh/m<sup>3</sup> are still under development.

The following are the principal advantages and disadvantages of ultracapacitors:

**> Ultracapacitors**

<b>Advantages</b>	<b>Disadvantages</b>
<ul style="list-style-type: none"> <li>• Can process a large number of charge and discharge cycles without suffering wear</li> <li>• Satisfactory operation in a wide range of temperatures</li> <li>• Relatively small in size and weight for short discharge times (seconds)</li> </ul>	<ul style="list-style-type: none"> <li>• High cost for longer runtimes (minutes to hours)</li> <li>• Can only store low quantities of energy (short runtimes)</li> <li>• Very short history in data center environments (less than 10 years) – no extended performance data</li> </ul>

## Additional considerations

In the broader spectrum, the ecological qualities of an energy storage solution should be assessed over its entire lifecycle. This embraces the notion of an “ecodesign” concept. For example in the manufacturing phase of a product, how much energy is required to make the product? How much energy is required to transport the product? Are the raw materials supplied to manufacture the product environmentally friendly? How does the manufacturing facility itself affect its environment? What about proper disposal of the product at end of life? All these questions are an important aspect of determining the carbon “footprint” of a solution.

A closer look at battery solutions provides an interesting perspective. Battery manufacturing is highly mature. Modern factories are ISO14000 certified, which means that the waste, and the consumption of energy and water are monitored and under control. Batteries are made of very few components, which makes the manufacturing process simple (if compared to flywheels, for example). Lead-acid battery recycling practices are also very mature and in excess of 90% of all stationary lead-acid batteries are recycled. This is a higher recycle rate than either paper or aluminum.<sup>4</sup> (See White Paper 36, *Data Center VRLA Battery End-of-Life Recycling Procedures*).

Once a battery is delivered from the manufacturing site, what are its life characteristics during operation? How much energy is consumed to achieve a targeted level of performance? In

<sup>4</sup> <http://www.batterycouncil.org/LeadAcidBatteries/BatteryRecycling/tabid/71/Default.aspx> accessed March 15, 2010

 Related resource  
**White Paper 36**  
*Data Center VRLA Battery End-of-Life Recycling Procedures*

the case of a battery, the energy required to maintain the charge of a battery is negligible. At the end of life, how is the energy storage solution disposed of? How easy is it to dismantle the installation and to dismantle the product? How much energy and resource is required for safe removal? How easy is it to recycle the materials?

Residual energy can still be present in “spent” energy storage devices such as batteries and ultracapacitors. Safety precautions need to be taken when disposing of such materials in order to avoid inadvertent shock.

In the realm of batteries, ISO certified (9002 and / or 14001) service-providers can collect spent batteries, and manage the

associated follow-up documents related to industrial wastes. The battery recycling channel, or industry, is well organized, established, and efficient.

### > What about fuel cells?

Although they are an energy *generation* system as opposed to an energy *storage* system, fuel cells often come up as a topic in any discussion involving energy alternatives.

Several types of fuel cells exist, but the most common for IT applications is the proton exchange membrane (PEM) technology. The fuel is typically pure hydrogen, although some fuel cells include reformers to convert other fuels into hydrogen. A fuel cell reaction is silent and clean and it produces no waste or by-products other than water.

Unlike a battery which has a finite capacity (before requiring recharge), a fuel cell can operate as long as it is supplied with fuel. This means that runtime is only limited to the number of hydrogen tanks that can be physically (and economically) stored on site. Since a fuel cell takes some time to start before it can take on the critical load, a power-bridging technology is often required (such as a battery, flywheel, or ultracapacitor) as part of the entire solution.

#### Advantages:

- Clean – no hazardous materials
- Silent and vibration free
- Lightweight and compact
- Few moving parts

#### Disadvantages:

- Does not eliminate need for bridging technology
- Complex site preparation to accommodate
- High cost of processing, transporting, storing hydrogen (or other) fuel

**Table 2***Energy storage technology comparison*

	Batteries	Ultracapacitors	Flywheels
<b>Typical runtime</b>	5 minutes to 8 hours	10 seconds to 1 minute	1 second to 1 minute
<b>History in the marketplace</b>	Long (many decades)	Short (a few years)	Longer for low speed, short for high speed
<b>Operating conditions</b>	Narrow temperature range	Wide temperature range	Wide temperature range
<b>Environmental impact</b>	Harmful (lead) if not recycled, hydrogen release on recharge	Harmful if burned	Harmful (circuit boards) if not recycled
<b>Safety</b>	Significant government and local regulations for management of lead and acid	Requires high voltages to operate	Encasements may be required for higher rpm flywheels (in case of breakage while spinning)
<b>Power range</b>	Up to multiple megawatts	Up to tens of thousands of kilowatts	Up to multiple megawatts
<b>Reliability</b>	Moderate (higher for shorter runtimes)	High	Moderate (higher for newer technologies)
<b>Maintenance</b>	Moderate for VRLA Higher for vented / flooded	Moderate	Moderate for carbon fiber Higher for older technology
<b>Recharge time</b>	10 x discharge time	Seconds	Seconds or minutes
<b>Number of deep charge/ discharge cycles</b>	Up to 3,000	Up to 1 Million	Unlimited (assuming maintenance)

In the future, new energy storage technologies are expected to play an increasingly important role in shifting patterns of energy consumption away from scarce to more abundant and renewable primary resources.

## Conclusion

The landscape of alternative energy storage is gaining more recognition. When selecting an energy storage solution, the first step is to determine the criticality of the data center operation; i.e., what would be the consequence of an unplanned IT equipment shutdown? A less critical operation may be able to tolerate an occasional shutdown as long as it can “ride through” the momentary power interruptions that make up the majority of power outages. A more critical operation may require a longer stored energy reserve.

As new energy storage technologies emerge, a fundamental question should be posed: What is the benefit of instituting a longer runtime (e.g., 15 minutes) as opposed to a short runtime (30 seconds)? If no benefit exists, flywheels, ultracapacitors, and smaller battery systems can represent a huge savings.

Why, then, aren't data center professionals abandoning their batteries in droves and replacing them with flywheels, ultracapacitors, and smaller battery systems? In some cases, buyers of energy storage solutions cite issues such as cost, mechanical moving parts with lower reliability, or the inability to meet length of life goals. However, additional reflection leads to the conclusion that it is people, human beings, and not just pieces of equipment, that are ultimately responsible for the success or failure of the data center.

As computer operations become more and more critical, the majority of data centers today require longer UPS runtimes, and, as a result, batteries continue to outperform flywheels and ultracapacitors in terms of cost, reliability and availability. Despite the growth of alternative technologies, the view over the next few years is that batteries will still remain the principle resource for energy storage in the data center.

For most data center professionals, time to react and respond to a problem or emergency is perceived to be at a premium during a crisis situation. Extra time during an emergency might allow a human to correct the problem such as discovering that an auto switch was erroneously left in a manual position. In addition, since most data centers are equipped with monitoring software, when a fault occurs, an automatic data center backup copy is launched. After the backup copy, the remaining battery time is used to launch a safe server shutdown. The servers are stopped cleanly and restarted immediately when power returns. From a data center operator's point of view, the more time to resolve an issue, the better. Since batteries currently provide people with more time to react, they are favored and take on the role as the primary energy storage mechanism in the data center.

As power generation and storage technologies combine (e.g., fuel cells combining with ultracapacitors) and manufacturers strive to introduce cost effective and cleaner hybrid solutions to the marketplace, choices for viable data center energy storage technologies will increase.



## About the author

**Stephen McCluer** is a Senior Applications Engineer for external codes and standards compliance at Schneider Electric. He has 25 years of experience in the power protection industry, and is a member of NFPA, ICC, IAEI, ASHRAE and the IEEE Standards Council. He serves on a number of committees with those organizations, is a frequent speaker at industry conferences, and has authored technical papers and articles on power quality topics.

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