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# Flywheel FAQ

**Q** ***About the flywheel frequently asked questions (FAQ)***

**A** This FAQ is not about presenting a flywheel technology 101. We will not brandish any equations or attempt any technical discussion about how a flywheel works or how one uses it. This FAQ is for sharing our opinions on a few persistent issues that surround energy storage for transportation applications.

**Q** ***You ask, "why are you still using chemicals for energy storage?" Isn't the obvious answer to your cheeky question "because it is the best overall solution?"***

**A** We would argue that chemical batteries are perhaps the best understood solution for charge sustaining hybrids but not necessarily the best overall solution. There are several intractable problems encountered if one selects a chemical storage device. Some of these problems can include capacity fade, power fade, efficiency fade, insufficient life, insufficient cycle tolerance, temperature sensitivity, the on-going risks associated with high voltage exposure for either maintenance personnel or first responders, risk of thermal runaway, the requirement for cell balancing or conditioning, the inability to right-size the storage system to suit the exact requirements, hazardous material content, and end of life disposal issues.

**Q** ***What do you mean by "charge sustaining hybrid?"***

**A** Charge sustaining is a hybrid vehicle control scheme that seeks to approximately preserve the state of charge in the energy storage device. This is in contrast with a charge depleting hybrid, also called a plug-in hybrid, where the state of charge in the energy storage device is depleted at least for a period before switching to a charge sustaining mode of operation. Charge sustaining hybrids are significantly more common than charge depleting hybrids. In a charge sustaining hybrid the energy storage device performs essential roles in capturing braking energy, launch assist, reducing engine transient power demands, and providing an overall reduction in fuel consumption. We advocate flywheels for charge sustaining hybrids only—especially charge sustaining hybrids with a high degree of hybridization (i.e., the ratio of storage device power to total drive power). We do not advocate flywheels for charge depleting hybrids, plug-in hybrids or pure electric vehicles.

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**Q** ***Why is it that $/kWh is not a useful ratio?***

**A** The ratio of cost ($) to total energy storage (kWh) is not a useful comparative point unless one can use all the stored energy in the device. For example, in the case of a pure electric vehicle, more stored energy is desirable and would be used to extend the driving range of the vehicle. Whereas in the case of a charge sustaining hybrid passenger vehicle, any more than 0.15 kWh of stored energy produces a diminishing return—it is excess that is not used [1]. In this case, the $/kWh ratio can result in misleading information and incorrect conclusions about the relative cost of energy storage devices. Similarly, in a hybrid transit bus, 0.75 kWh is sufficient for most routes, but typically the batteries store ten to fifteen times more than this. So, which is cheaper: A) a battery with a useable 5% SOC range that costs $1500/kWh, or B) a battery with a useable 75% SOC range that costs $15000/kWh?

| | Battery A | Battery B |
|---|---|---|
| **Required useable energy (kWh)** | 0.75 | 0.75 |
| **Permissible state of charge (SOC) range** | 5% | 75% |
| **Total stored energy (kWh)** | 15.0 | 1.0 |
| **Cost ratio ($/kWh)** | 1500 | 15000 |
| **Total cost ($)** | 22500 | 15000 |

So, while battery A is ten times cheaper on a $/kWh basis, the actual cost is 50% greater than battery B. Since one pays for energy storage devices with actual $ instead of with $/kWh, it seems a prudent buyer would question paying a 50% premium for all that unused energy storage capacity. This would be akin to buying a round the world airline ticket for a local flight because it is cheaper by the mile.

**Q** ***What is capacity fade?***

**A** Typically, as a battery or ultra-capacitor ages, its ability to store energy is reduced. This is particularly problematic for ultra-capacitors, which don't store much energy in the first place. By end of life, as much as 30% of the original storage capacity can disappear. This is less of a problem for batteries since battery packs in charge sustaining hybrids are already vastly oversized in energy storage capacity (this relates to "right sizing" and the issue of $/kWh as a meaningful measure each discussed elsewhere in this FAQ). Flywheels are not subject to capacity fade.

**Q** ***What is power fade?***

**A** Typically, as a battery ages, the maximum rate at which it can charge or discharge is reduced. This is less problematic for ultra-capacitors which generally have higher power capabilities than required for hybrids (this relates to "right sizing" discussed elsewhere in this FAQ). Flywheels are not subject to power fade.

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**Q** ***What is efficiency fade?***

**A** Typically, as a battery or ultra-capacitor ages, the amount of energy returned vs. the amount put in is reduced. This is due to a rise in the equivalent series resistance of the device—more of the input energy is turned into heat. In the case of batteries or ultra-capacitors, equivalent series resistance can rise by as much as 50% by end of life. Flywheels are not subject to efficiency fade.

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**Q** ***What service life is required?***

**A** As with cycle tolerance, required service life is very much application dependent. In the case of passenger automobiles, a ten year service life might translate to only 5000 operating hours. This is quite reasonably within the capability of many chemical storage devices. In contrast, urban transportation vehicles easily require over 5000 operating hours per year for 12 years (transit buses) or 30 years (light rail). With this kind of intense use, battery packs require replacing several times during the life of the vehicle. With proper maintenance, flywheels are not subject to these life limitations.

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**Q** ***What cycle tolerance is required?***

**A** As with service life, required cycle tolerance is very much application dependent. Generally, most heavy vehicles and industrial equipment require significant cycle tolerance and it is well established that batteries do not well tolerate a large number of charge/discharge cycles. In order to increase the tolerance of cyclic use, batteries tend to be operated within a very narrow state of charge regime. For example, a charge sustaining hybrid transit bus might have a 15 kWh battery that operates most of the time between 45% and 50% of full charge to provide greater cycle tolerance. This leads to vastly oversized batteries (see right-sizing discussion elsewhere in this FAQ). Ultra-capacitors are known to provide greater cycle tolerance than batteries. However, even ultra-capacitors offer only 20% of the cycle tolerance that can be achieved with a flywheel.

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**Q** ***What is temperature sensitivity?***

**A** Batteries and ultra-capacitors are affected by temperature. Higher temperature reduces life and cycle tolerance, whereas lower temperature reduces capacity and efficiency. Flywheels do not exhibit these same sensitivities to temperature effects.

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**Q** ***What do you mean by "the on-going risks associated with high voltage exposure for either maintenance personnel or first responders?"***

**A** Many battery chemistries cannot be fully discharged without causing some irreparable damage to the battery pack. Even if the battery is not harmed by full discharge, a large battery pack can take many hours to fully discharge. For first responders and maintenance personnel, a battery represents a high voltage source that cannot be easily or quickly disabled. To work around the lethal voltage presented by the battery pack requires special training. On the other hand, flywheels can be fully discharged and thereby remove the high voltage exposure risk to first responders and maintenance personnel.

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**Q** ***What is the risk of thermal runaway?***

**A** Unlike lithium chemistries, flywheels present no risk of thermal runaway.

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**Q** ***What requirements are there for cell balancing or conditioning?***

**A** Batteries and ultra-capacitors usually require monitoring and intervention to balance or condition the cells. This requires additional sensors, hardware and occasionally maintenance equipment which add to the cost of using these energy storage devices. Flywheels do not require cell balancing or conditioning.

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**Q** ***What do you mean by "the inability to right-size the storage system to suit the exact requirements?"***

**A** Batteries and ultra-capacitors are produced in cells. The voltage, power and energy available in a cell are fixed. Many cells can be arranged, in series and parallel, to provide a desired DC link voltage, or power rating, or energy rating. The consequence is that for a desired rating of one there is a fixed proportion of the others. This leads to non-optimized storage systems. In contrast, with flywheels the DC link voltage, power and energy can be independently specified to provide precisely the voltage, power and energy ratings that are desired. This is because in a flywheel there are independent components that provide the fundamental performance characteristic. The DC link voltage rating is controlled by the inverter. The power rating comes from the motor/generator. The energy storage rating comes from the flywheel rotor.

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**Q** ***Is there hazardous material content?***

**A** Batteries contain hazardous materials that can be corrosive (C), flammable (F), harmful (Xn), irritant (Xi), dangerous for the environment (N) or toxic (T). For example, lithium hexafluorophosphate, an ingredient in all lithium ion batteries, is a dangerous corrosive substance that causes severe skin burns and eye damage. "The interaction of water or water vapour and exposed lithium hexafluorophosphate ($LiPF_6$) may result in the generation of hydrogen and hydrogen fluoride (HF) gas. …Breaching of the cell enclosure may lead to generation of hazardous fumes which may include extremely hazardous HF (hydrofluoric acid)" [2]. Flywheels do not contain hazardous materials.

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**Q** ***Are there end of life disposal issues?***

**A** Chemical batteries are made of…chemicals. Responsible disposal at end of life means paying for hazardous materials shipping to an appropriately equipped recycling facility in order to pay for managing end of life treatment. Flywheels are made primarily of common metals—steel, aluminum, copper—that offer high residual value at end of life.

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***References***

[1] J. Gonder *et al.*, "Lower-Energy Requirements for Power-Assist HEV Energy Storage Systems—Analysis and Rationale," NREL, PR-540-47682, 2010.

[2] A123 Systems, "Safety Data Sheet," SF000003_18, 2010.