UNDERSTANDING STORAGE PERFORMANCE

The fundamental metrics used to define a storage technology for most electricity grid systems include:

- Energy storage capacity [kWh or Ah];
- Charge and discharge rates [kW or A];
- Lifetime [cycles, years, kWh_{life}];
- Roundtrip efficiency [%];
- Initial capital costs [$/kW, $/$kWh_{cap}$, and $/$kWh_{life}$];
- Operating costs [$/MWh, $/kW x yr]; and

For mobile systems and systems in which space is at a very high premium, the physical size (m^3) of the system may also be important:

- Energy density [Wh/kg and Wh/m^3] and power density [W/kg and Wh/m^3].

Energy Storage Capacity

Energy storage capacity is the amount of energy that can be stored at a given time [kWh]. Some batteries will assume an operating voltage [V] and provide energy capacity in a different form [Ah, where kWh = V × Ah / 1,000]. The useful energy capacity will often be less than the stated total capacity based on a number of factors described below.

For some battery technologies, the capacity will appear less if power is pulled out quickly and greater if power is pulled out slowly. Many technologies also have restrictions on how much of the storable energy may be used. Overdischarging some technologies (in particular, lead-acid batteries) can shorten their lifetime.

Charge and Discharge Rates

Charge/discharge rates are measures of power (kW) indicating the rate at which energy is added/removed from a storage system. Some systems will assume an operating voltage (V) and provide the charge/discharge rates as a current in amperes (A) [where kW = V × A / 1,000]. For many technologies these rates will not be constant values at all times; in practice, they will change with how much energy is in storage and how long power has been continuously removed/added to storage. However, at a high level they can be discussed with nominal values that are representative. The charge rate is lower than the discharge rate for most technologies. Typically, a storage system will be described in terms of its discharge rate, as in Figure 1.

Lifetime

Every storage technology has a limited lifetime. Some technologies measure lifetime according to how much they are charged and discharged [cycles], while other technologies will lose functionality due to time passing [years] and yet others have lifetimes limited by total energy throughput [kWh_{life} or Ah_{life}].

As they age, most storage technologies will suffer from degraded performance.

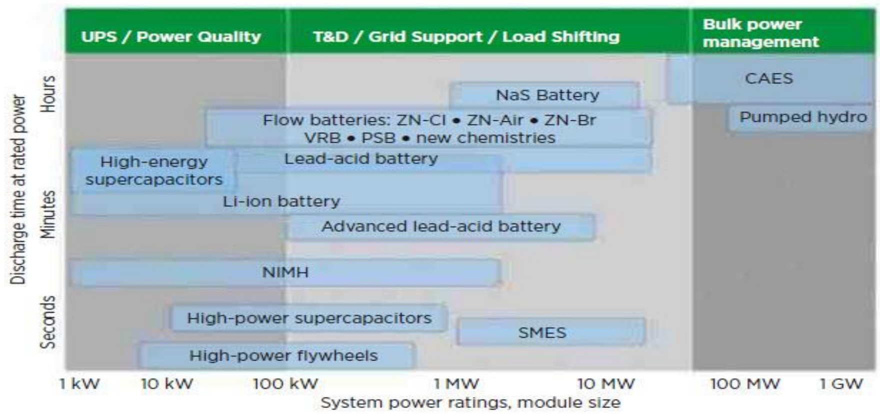

Figure 1: Sum mary of major storage technologies by discharge rate for different scales of application (adapted from Rastler, 2010)

Roundtrip Efficiency

Every storage technology will require more energy to charge than can be discharged. This loss of energy is typically expressed as a percentage known as roundtrip efficiency [%], which is the ratio of energy discharged from storage to the energy input into storage. There will be some energy losses during the process of storing the energy and some energy losses when converting the stored energy back into electricity. These both contribute to the roundtrip efficiency.

Roundtrip efficiency affects the costs of storage. A less efficient storage system will require more electricity to store the same amount of electricity supplied than a more efficient storage system. For example, if it costs $0.50/kWh to generate electricity and 20% of that is lost in the storage system, then the effective cost per delivered kWh is $0.625/kWh – plus the cost of the storage system (A more detailed sample calculation demonstrating the impact of roundtrip efficiency on costs is given in Appendix B).

Initial Capital Cost

The capital costs provided here are estimates based on professional experience and informal surveys of publicly available prices. They are intended to provide a high-level understanding of the issues and are not intended as cost inputs into a design. Costs for a specific system will vary across a wide range of factors. These factors include system size, location, local labor rates, market variability, intended use of the storage system, local climate, environmental considerations and transport/ access issues.[2]

It is important to recognize that installing storage will impose additional costs, commonly called balance-of-system (abbreviated BoS) costs. These include safety equipment (e.g. fuses, current fault protection), in-verters/rectifiers, system controllers, remote monitoring equipment and supplemental sensors. The needed equipment will vary considerably, depending on the specifics of the electricity system. BoS equipment can have a large impact on the total system cost, ranging anywhere from 100% to 400% more than the costs of the storage technology alone (See Appendix B for an example calculation that illustrates BoS costs).

The principal price bases for comparing technologies are the prices per amount of power that the storage can deliver [$/kW] and costs per amount of energy capacity [$/kWh$_{cap}$]. Figure 2 shows a graphical representation of costs for selected storage technologies.

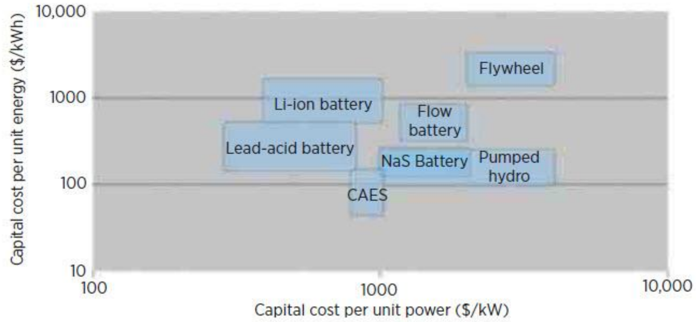

Figure 2: Init ial capital cost per unit power versus capital cost per unit energy for selected storage technologies (Adapted from ESA, accessed 10 Dec. 2011)

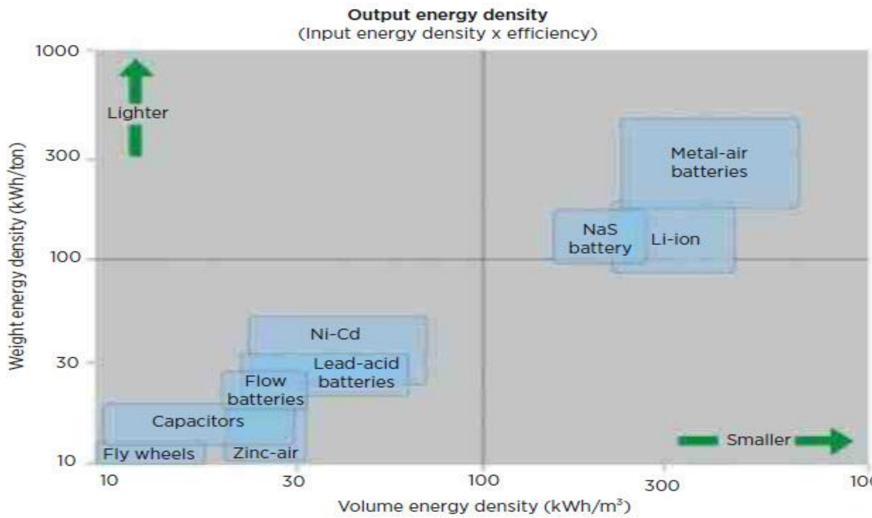

Figure 3: This plot shows a summary of major storage technologies by volume and weight energy densities (adapted from ESA, accessed 10 December 2011).

When looking at costs, it is also important to consider the expected lifetime of the technology because frequent replacement will increase costs of the storage system. To capture the entire lifetime cost, the capital cost of the battery is divided by the total expected lifetime energy throughput [$/kWh$_{life}$]. The lifetime cost of storage provides insight into the cost of storing a kWh of electricity and indicates the expected additional cost for each unit of electricity stored (see Table 1 below). The costs presented here (in U.S. dollars) represent an average installation and do not include site-specific factors such as tarif s, taxes and shipping costs.

Operating Costs

Technologies require ongoing operation and maintenance to remain at peak performance. In reality, a number of factors will influence ongoing O&M costs, including how often the storage equipment is used, ambient temperatures, handling of the equipment, adherence to the recommended maintenance schedule, quality of installation, protection from overcharging, protection from overdischarging, the rate at which the equipment is cycled and the quality of the storage equipment. For simplicity, all of these factors are bundled in a typical annual cost based on the size of the equipment [$/kW x yr]. Estimates of these annual costs are provided in Table 1.

Energy and Power Density

In a stationary power system, the weight of the batteries is generally less important than their functionality. In some mobile applications and some site-specific locations, the size and weight of the storage technology is important. In these cases, it is useful to consider the capacity per weight [kWh/ton] or capacity per volume [kWh/m^3]. As these factors increase, the required size of the system decreases at equal energy storage; that is, storage technologies will be smaller and lighter if they have high weight and volume energy densities. These are summarized in Figure 3.

Source: http://decarboni.se/publications/electricity-storage-and-renewables-island-power-guide-decision-makers/2a-understanding-storage-performance