Energy Storage: Batteries

Many storage technologies have been considered in the context of utility-scale energy storage systems. These include:

Each technology has its own particular strengths and operational characteristics. For example, pumped hydro is best suited for large-scale bulk electrical energy storage (if suitable geographic topology, geology and environmental conditions exist). Pumped hydro generating stations have been built capable of supplying 1800MW of electricity for four to six hours.

This ClimateTechWiki description focuses on the use of batteries for energy storage. Several different types of batteries are discussed. Batteries can be used for a variety of purposes, each with their own advantages and disadvantages.

Introduction top:

Electrochemical batteries are storage media in which reversible electrochemical reactions enable storage of electrical energy as chemical potential and release of that energy on demand.

An electrochemical battery consists of two or more electrochemical cells. These cells use chemical reactions to create a flow of electrons. In other words, the chemical reactions create an electric current. The primary components of an electrochemical battery are the container, two electrodes (cathode and anode) and electrolyte material. The electrolyte is in contact with the electrodes. Discharging of a battery occurs when it is connected to a connected load: electrically charged ions in the electrolyte that are near one of the cell's electrodes supply electrons, which is called oxidation while ions near the cell's other electrode accept electrons, which is called reduction, to complete the process. The process is reversible in order to charge the battery which involves ionizing the electrolyte. An increasing number of chemistries are used for this process. Familiar ones include lead-acid batteries, nickel cadmium and lithium ion batteries (Eyer and Corey, 2010). The basic composition of a battery is illustrated in Figure 1.

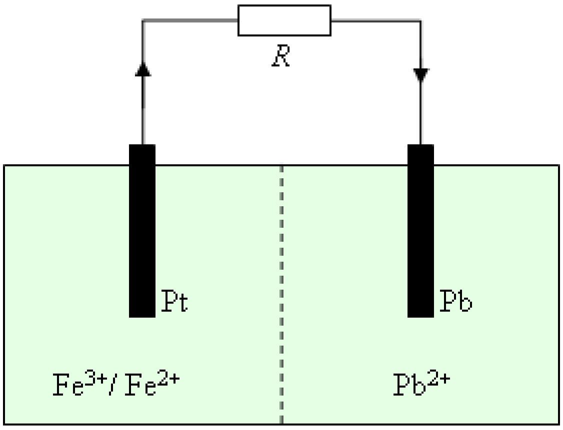


Figure 1: Simple schematic of an electrochemical battery. Note that the electrolytes are in the same container, separated by a membrane. Source: Mathworks, no date

A differentiation can be made between conventional batteries and flow batteries. Conventional batteries contain electrolyte in the same container as the cells (where the electrochemical reactions occur). Flow batteries on the other hand use electrolyte that is stored in a separate container (e.g. a tank) outside of the battery cell container, as illustrated in Figure 2. Flow battery cells are said to be configured as a 'stack'. When flow batteries are charging or discharging, the electrolyte is transported between the electrolyte container and the cell stack. Vanadium redox and Zinc- Bromine are two of the more familiar types of flow batteries. A crucial advantage of flow batteries is that the storage system's discharge duration can be increased by adding more electrolyte and additional tanks, without increasing the capacity of the battery itself. It is also relatively easy to replace a flow battery's electrolyte when it degrades (Eyer and Corey, 2010).

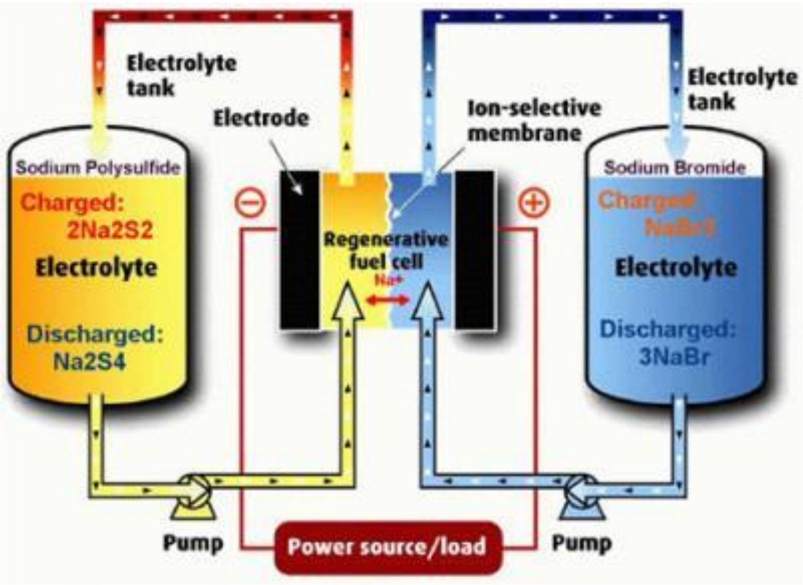


Figure 2: Schematic of a flow battery. Source: Metaefficient, no date

Flow batteries provide several advantages over conventional battery storage technologies:

a) Power/Energy Design Flexibility. Since electrolyte is stored separately from the reaction stacks, the energy storage rating (kWh) is independent of the power rating (kW). This allows for design optimization for power and energy separately, specific to each application. Therefore, flow batteries have the advantage of scalability. To increase peak power output additional battery cells need to be added. But to increase the amount of energy that can be stored, and therefore to increase the time they will operate on a full charge, can be expanded almost indefinitely by building biffer tanks and filling them with electrolyte. The result is that these batteries can be used in a wide range of roles; from small scale units to power-station scales of hundreds of MWhs.

b) Layout Flexibility. The tanks can be easily arranged to fit the available space and shape of the facility. In one demonstration, the tanks were made of rubber that conformed to the shape of basement walls in an office complex.

c) Low Standby Losses. Depending upon the application, it is possible to drain the stacks and store the charged electrolyte for long periods of time without self-discharge or pump auxiliary loads.

d) Simple Cell Management. Conventional batteries must be periodically charged at high voltages to equalize all cells to the same state of charge. This can produce undesirable levels of explosive hydrogen gas (a safety issue) and reduces the available water in the battery (a life issue). In flow batteries, however, all cells share the same electrolyte at the same state of charge, so equalization is unnecessary.

There are also some relative disadvantages of flow batteries, including:

a) Mechanical Complexity. The advantages of storing electrolyte in tanks external to the stacks are offset by the complexity of hydraulic design. Flow batteries require anolyte and catholyte pumps and associated plumbing to transport and distribute electrolyte to and from the stacks and within stacks to individual cells. Designs must address potential leaking throughout the system, and provide sufficient secondary containment in the event of leaks and spills.

b) Parasitic Losses. Electrolyte pumps draw power while the system is operating, reducing overall system efficiency.

c) Footprint. Relative to other battery technologies under consideration for T&D applications, flow batteries require a larger space. This limits their applicability in locations where space is limited.

As illustrated in Figure 3, flow batteries are considered an important technology for large scale electricity storage. Examples of such applications are load leveling at large renewable energy generation facilities. The other battery technologies can be used in applications where space is limited. An example of such an application is battery technology in electric and hybrid cars, which use lithium-ion battery technology.

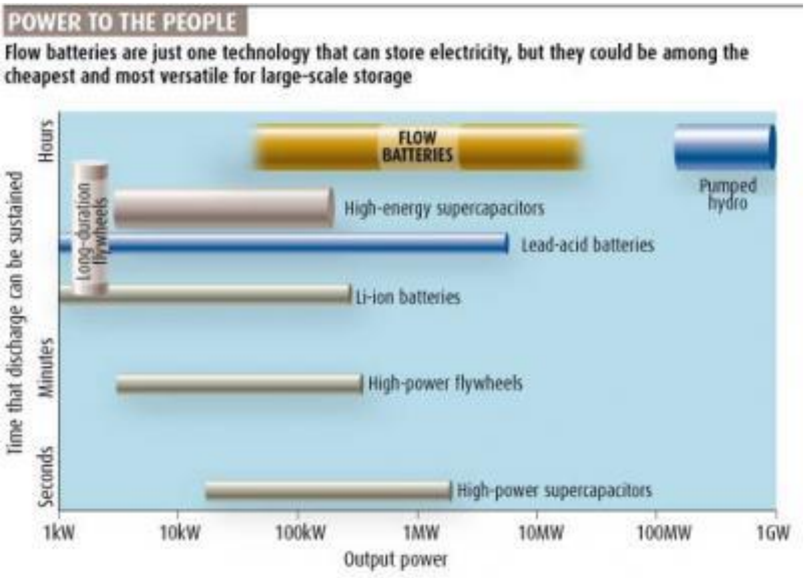


Figure 4: Comparison between several energy storage technologies, including several battery chemistries. Source: Science.org, no date

Feasibility of technology and operational necessities top:

Each battery technology has its own unique set of electrochemical reactions, materials, and electrical characteristics.This wide variety of attributes leads to tremendous diversity in battery types and uses. This CTW description will cover two battery systems which are expected to play a particularly big role in utility scale battery energy storage systems:

- The Vanadium Redox Battery
- The Regenysys Battery

Vanadium Redox Battery

The Vanadium Redox Battery (VRB) is a flowing-electrolyte battery that lends itself to high capacity, high cycle count requirements necessary for utility-scale transmission and distribution (T&D) electricity storage applications. The battery uses the commercially produced metal vanadium. The VRb is also sometimes referred to as a fuel cell or a reversible fuel cell (EPRI, 2002).

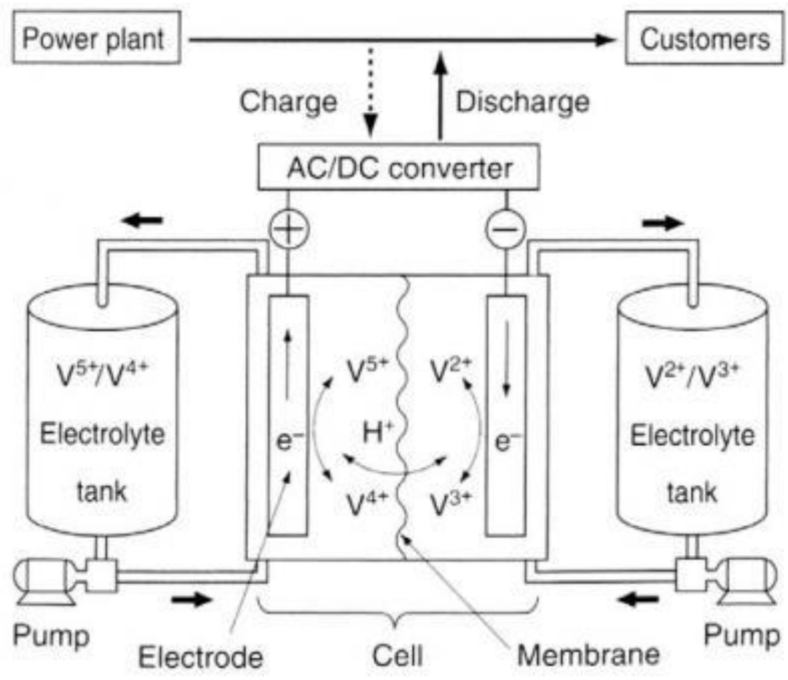


Figure 5: Schematic of the functioning of a VRB system (click image to enlarge). Source: EPRI, 2002

One of the additional advantages of the VRB on top of the advantages of flow batteries in general is that many of the failure modes associated with other batteries are avoided in the simple and elegant VRB electrochemistry. Moreover, the reactions do not require elevated temperatures and there are no electro deposited solids of the active substance (EPRI, 2002).

The VRB is an emerging energy storage technology that is entering the commercialization phase of development. The basic electrochemistry research is essentially complete, and the leading manufacturers have demonstrated full-scale gridconnected systems in Japan, South Africa, and North America. However, true commercial, standardized, volume-produced products are not yet available in the marketplace.(EPRI, 2002).

The round trip efficiency is restricted due to transformer losses during charge and discharge, Power Conversion System (PCS) losses during charge, battery DC losses and pumping losses. The efficiency of this system is around 70 % (EPRI, 2002).

Regenesys Battery

The Regenesys battery is a polysulfide-bromine flow battery and is also sometimes called a regenerative fuel cell. The system was developed during the early 1990s. While often seen as a redox-like system, Regenesys is not truly a redox system since both the positive and negative reactions involve neutral species (EPRI, 2002). The discharge reaction at the positive electrode is:

$NaBr3 + 2Na^+ + 2e \rightarrow 3NaBr$

and that at the negative is:

$2Na_2S_2 \rightarrow Na_2S_4 + 2Na^+ + 2e$

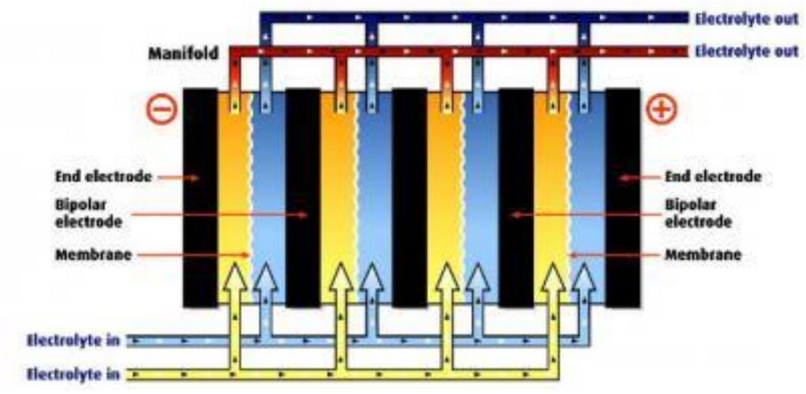


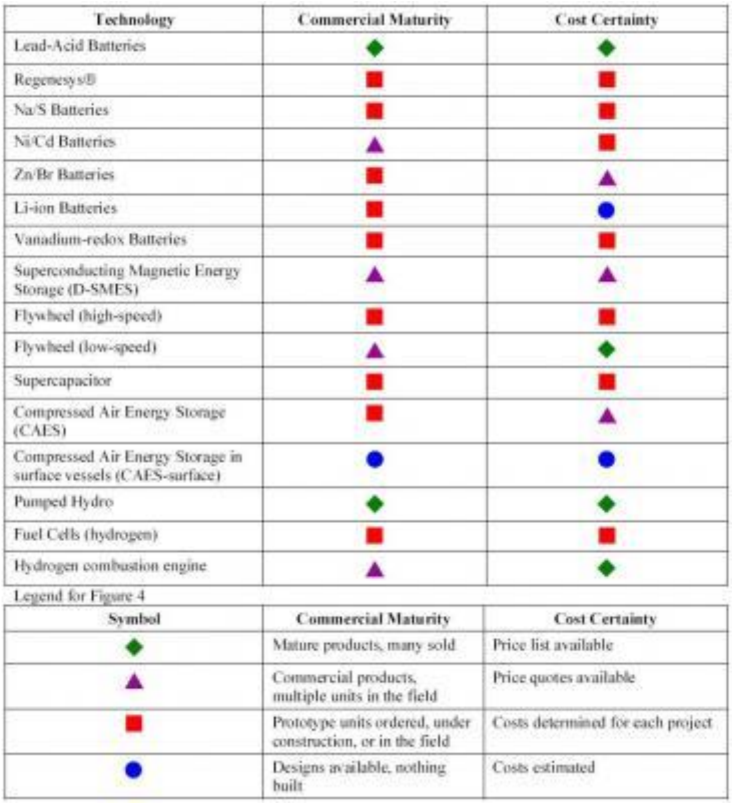
Figure 6: An example of a Regenesys system. Source: EPRI, 2002

The characteristics expected for a 100 MWh/10MW Regenesys energy storage facility are identified by the developer of the technology. For instance, the expected space requirements are 1 hectare (2.5 acres) or less which corresponds to a footprint of slightly less than 1 kWh/square foot. This is not very different from the total site area for a single story plant based on flooded lead-acid cells (EPRI, 2002).

The round-trip efficiency of such a facility is estimated o be around 60-65 %. Higher discharge rates than the nominal rates of discharge will reduce the efficiency to 50-55%. The lifetime of the plant is expected to be 15 years. A performed Environmental Impact Assessment for the technology indicates that a Regenesys plant will be environmentally benign.

Status of the technology and its future market potential top:

The following figure compares the commercial maturity of several energy storage systems. Clearly, out of the battery technology systems, only the lead acid battery system has reached full commercial maturity and cost certainty. The other technologies are still under development. At King Island, Australia, a prototype VRB facility has been installed which functions as a back-up to the island's wind farm.



Technology	Commercial Maturity	Cost Certainty
Lead-Acid Batteries	◆	◆
Regenesys®	■	■
Na/S Batteries	■	■
Ni/Cd Batteries	▲	■
Zn/Br Batteries	■	▲
Li-ion Batteries	■	●
Vanadium-redox Batteries	■	■
Superconducting Magnetic Energy Storage (D-SMES)	▲	▲
Flywheel (high-speed)	■	■
Flywheel (low-speed)	▲	◆
Supercapacitor	■	■
Compressed Air Energy Storage (CAES)	■	▲
Compressed Air Energy Storage in surface vessels (CAES-surface)	●	●
Pumped Hydro	◆	◆
Fuel Cells (hydrogen)	■	■
Hydrogen combustion engine	▲	◆

Legend for Figure 4

Symbol	Commercial Maturity	Cost Certainty
◆	Mature products, many sold	Price list available
▲	Commercial products, multiple units in the field	Price quotes available
■	Prototype units ordered, under construction, or in the field	Costs determined for each project
●	Designs available, nothing built	Costs estimated

Figure 8: Comparison in the commercial maturity and cost certainty of several energy storage technologies for utility scale storage, including several battery energy storage systems.(click image to enlarge) Source: Schoenung and Hasselzahn, 2003

How the technology could contribute to socio-economic development and environmental protection top:

Due to the large variety of battery types, many different functions can be performed. Especially flow batteries, which can be scaled appropriately to the application, have a wide variety of application possibilities. Several of the benefits of these functions are discussed here. In addition, others can be found in the other energy storage ClimateTechWiki descriptions.

a) Support the role out and deployment of renewable energy technologies.

As illustrated in Figure 7, battery technology can support the functioning of intermittent renewable energy sources, in this case wind. Especially flow batteries, which can store large quantities of energy are suitable for such large scale applications. The implementation of battery energy storage in wind farms and solar farms reduces the problem of intermittency of the energy source. In other words, the technology can store energy when the demand is low but production is high, and release this energy when production is low but demand is high. This supports the economics of renewable energy technologies. Subsequently, this technology supports environmental protection due to the increased use of renewable energy technologies.

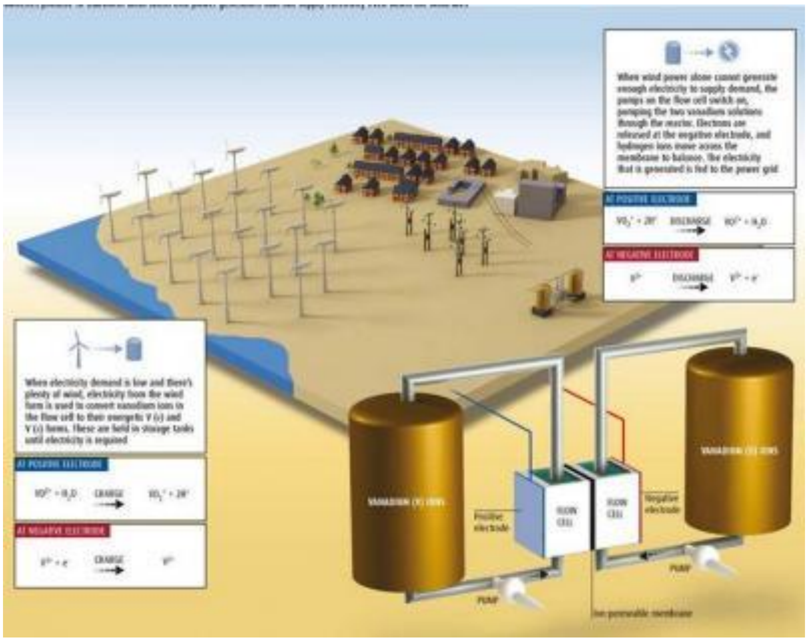


Figure 7: Illustration of wind farm stabilization through the use of a VRB (click image to enlarge). Source: Science.org, no date

b) Load leveling

Batteries have the capacity to realize load leveling. Base load plants are more efficiently used when they can generate electricity on a continous basis. Battery technology might provide this option. Currently, at high demand, additional power plants need to be started to cover the additional demand. These power plants are shut down during periods of low demand.

For instance, in the night, demand is lowered to such a point that it is below the base load capacity of the base load power plants. Therefore, several base load power plants need to reduce their production and are therefore less efficiently used. As illustrated in image ... battery technology is capable of allowing base load power plants to continue at full operation even when demand is low, and then supply that electricity when demand is high. This increases the efficient use of these power plants. Subsequently, fewer fossil resources are required and the need to construct additional power plants is reduced.

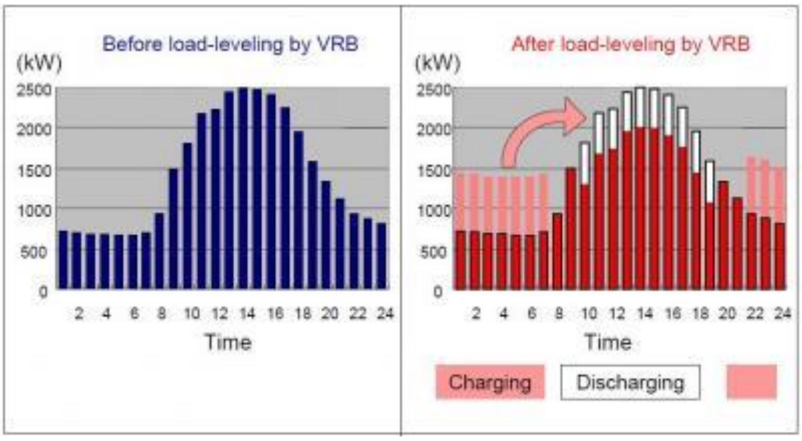


Figure 3: An example of a VRB installation to realize load leveling.

c) Transmission deferral

When growing demand for electricity approaches the capacity of a transmission system, transmission providers (wires company) currently add new lines and transformers. Since load grows gradually, new facilities are larger than necessary at the time of their installation, and there is an under-utilization of the new transmission assets during the first several years of operation. To defer the purchase of a new line and/or transformer, a wires company could instead install a battery energy storage plant close to the load center and discharge the energy storage plant as necessary (e.g., shave peaks at the sub-station) to keep from overloading existing transmission assets. The deferral can be made until the load warrants purchase of conventional transmission upgrades (EPRI, 2002).

d) power reliability and power quality

A variety of loads--ranging from modest industrial installations to substations of significant capacity--require energy to provide power quality and backup power. This energy is used for a variety of conditions such as when momentary disturbances require real power injection to avoid power interruptions. In the case of industrial customers, a local source of power may be required when there is an interruption of power from the utility. This power source may function until the power feed from the utility is restored, until a reserve generator is started, or until critical loads are shut down in a safe manner. In the case of a substation, a variety of momentary disturbances such as lightning strikes or transmission flashovers cause power trips or low voltages. The total energy storage requirement is greater and there may be a need power flow separation to insure continuous power to important customers (EPRI. 2002).

Contribution of the technology to protection of the environment top:

As with all storage technologies, every charge/discharge cycle results in some loss of energy due to system inefficiencies. For typical grid-connected applications, this means that from a global perspective, there may be increased air emissions associated with the generation of this lost energy. Of course, for renewable energy applications, there are no air emissions considerations, and in some applications, the battery technology serves to increase the utilization of renewable sources. In addition, battery energy storage saves resources due to more efficient use of power plants and delays investments in additional transmission infrastructure.

Financial requirements and costs top:

Costs of battery systems depend on the required capacity, both in terms of power as in terms of required discharge times.

The following figure clearly illustrates that the required discharge times severely influences costs of a battery energy storage system.

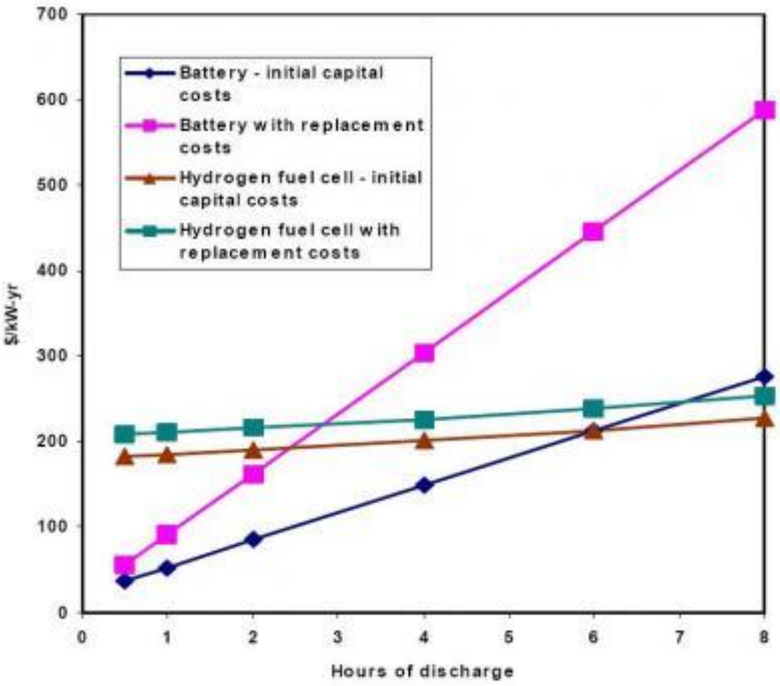


Figure 9: Battery carrying costs compared to fuel cell systems. (click image to enlarge) Source: Schoenung and Hasselzahn, 2003

Component costs compared to other energy storage technologies are illustrated in figure 10 and 11.

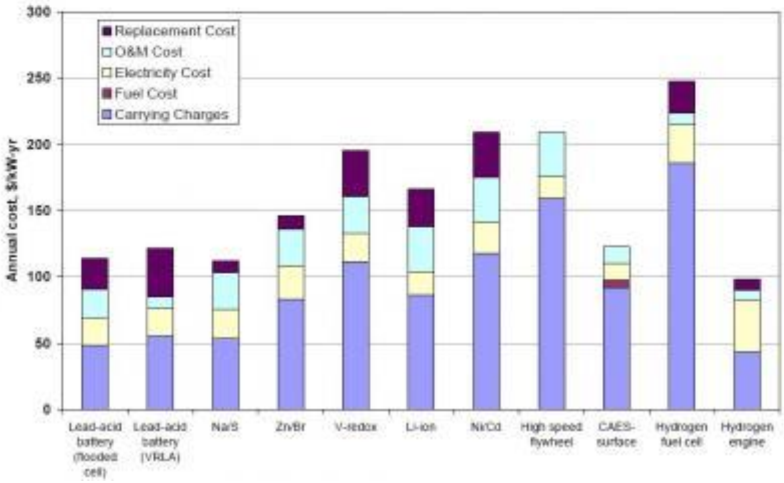


Figure 10: Components costs of several battery systems and several other energy storage technologies based on a 1 hour discharge (click image to enlarge) Source: Schoenung and Hasselzahn, 2003

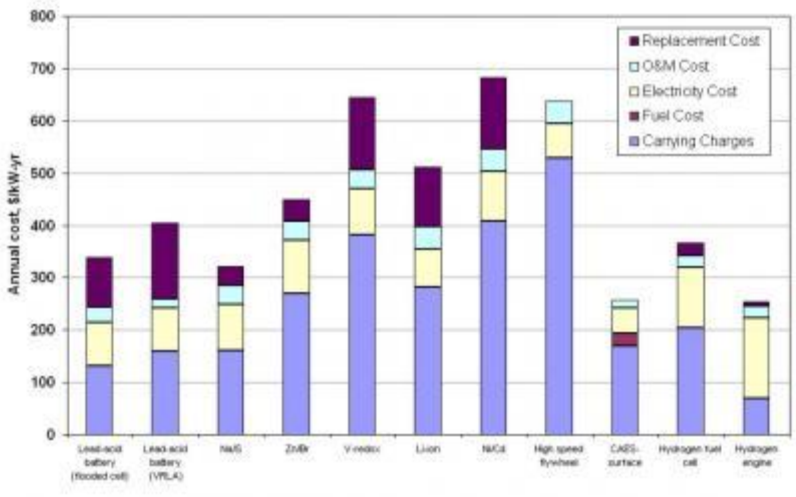


Figure 11: Component costs of several battery systems and several other energy storage technologies based on a 4 hour discharge (click image to enlarge) Source