Batteries

In their application to green technology batteries are systems for storing electrical energy in chemical form for use in vehicles or to provide temporary power to compensate for intermittency of electricity generation. They store energy in the form of chemical bonds, and release it as electricity. With limited ability to store large amounts of energy they are the weak link in all-electric vehicle applications, but are needed to replace oil that causes global warming and is in finite supply. Batteries can also be applied to load-leveling of intermittent but renewable electric power sources such as wind and solar, and to future hybrid power sources, mixing on-board energy storage with power picked up by a moving vehicle.

There are two classes of batteries – single-use batteries such as those in flashlights that are discarded after they are exhausted, and rechargeable storage batteries that convert chemical to electrical energy and back again for many cycles. Here only high-capacity storage batteries will be considered, because these are the designs that will contribute to future fossil-fuel-free energy management systems.

Principles of Operation

All modern batteries are based on the same general principle: two metals termed electrodes, with different electronegativity (affinity for electrons, the carriers of electrical charge), are immersed in a fluid that conducts electricity. Electrons flow from one metal to the other when the circuit is completed with an external load that connects the two metals outside the battery. This is the definition of a single cell; as the term 'battery' implies, several cells are usually connected in series to yield practical amounts of power. The word 'battery' was first applied to electrical storage by Benjamin Franklin when he realized that a single cell could not provide a significant amount of power. He combined cells in series, creating a battery of storage devices by analogy to a battery of cannons.

To recharge a battery the current flow is reversed; an external voltage, a difference in charge at positive and negative terminals, is applied so that the flow of ions within the battery reverses and renews the potential energy stored in the battery's electrodes. There are always losses, however; not all of the energy stored in the battery can be released, because some of it is lost as heat or in incomplete or secondary chemical reactions. Similarly, not all of the charging energy is available from the recharged battery.

In theory a storage battery can be charged and discharged for an infinite number of cycles, because the chemical reactions are reversible. In practice, though, recharging never restores a battery to exactly its original condition. Discharge involves degrading one of the electrodes and depositing material on the other. At recharge the material returns to the original electrode, but the structure of the restored electrode will be less regular than it was in its previous charged condition. Crystal structures will leave gaps and clumps of material on the electrode, and some of the material will fail to attach to the electrode and be lost. Over many charge/discharge cycles this reduces the capacity of the battery. Deep discharges usually reduce the life of a battery because of these losses.

Each type of battery has a characteristic voltage, or difference in charge at its positive and negative terminals, determined by the chemistry of its cells. The familiar ‘dry cell’ battery used in flashlights has a cell voltage of 1.5 volts. The electrodes are a carbon rod as the anode (positive terminal) and the zinc casing as the cathode (negative terminal). The cell isn’t really dry; the electrolyte solution saturates a paper matrix or is stabilized as a gel, so that no fluid flows as the battery is used in various orientations.

The most commonly known and widely distributed storage battery, the lead-acid battery found in all motor vehicles, golf carts, etc., has a cell voltage of a bit more than 2 volts. Like most storage batteries it is a ‘wet cell’, in this case using dilute sulfuric acid as the electrolyte fluid. In the standard 12 volt automobile battery, six cells are linked in series; the negative terminal of one cell is connected to the positive terminal of the next one, so that the voltages add. This scheme reflects Franklin’s original concept, cells connected together in a battery of cells. For high-current applications, several such batteries can be connected in parallel to keep voltage the same while increasing the volume of current (amperage) available.

A problem with all storage battery types is the available energy density, the amount of energy that the battery can store for each kilogram of weight or for each liter of volume. The lead-acid battery is a mature technology, and the materials that make it up are plentiful and inexpensive, but its energy density is low. It takes nearly a ton of lead-acid batteries to provide the energy stored in one gallon of gasoline, weighing about four kilograms. Earlier electric vehicles using these batteries were limited to a reliable range of about 60 miles (95 km), and achieved that range only because electric motors are so much more efficient than gasoline or diesel engines.

Newer battery chemistries offer higher energy densities for electric automobiles, but none exceed the lead-acid standard by more than an order of magnitude. Nickel metal hydride batteries in the Toyota Prius manage power from a gasoline engine, equivalent to an all-electric range of a few miles. Nickel-cadmium batteries have good recharge characteristics but are more expensive, and cadmium, like lead, is a toxic heavy metal. At present lithium-ion batteries offer the highest power density, allowing an all-electric range of about 100 miles (160km). The third-lightest element in the universe, lithium makes much lighter batteries possible, and is relatively plentiful, but most of it is imported. Battery technology is under intensive research,, however, after languishing for decades.

Applications

Interest in battery technology has exploded in recent years with the realization that practical electric energy storage will be essential when societies face limitations in fossil fuels, only a few years in the future. Alternatives are needed because the world consumes about 1000 barrels of oil every second, an unsustainable rate. More than half of the recoverable oil that was originally in the ground has already been extracted, a resource that accumulated over millions of years. Oil has enabled the earth’s population to quadruple during the 20th century, something that has never happened before and will never happen again. Those people depend on oil for modern farming, transportation and industry. But the earth has been pretty well explored for oil already (deep ocean beds are not geologically suited to oil deposits). The coming decline will be faster than the rise because the population, and therefore the demand, is so much larger. Global warming demands reduced fossil fuel use in any case.

Wind electricity is already cost-competitive with fossil fuels in many locations, and is growing rapidly. European experience has shown that the intermittence of wind can be compensated by fossil fuel or hydroelectric sources up to about 20% of the power mix; after that, the power becomes difficult to manage. It becomes necessary to store energy for later use, smoothing out the uneven production from wind and solar. Giant flywheels can store power for a short time, running generators when other sources fail. Scaling this source up to commercial power generation is problematic, and has never been tried. Solar installations in deserts, that heat a fluid to run a generator, can become more stable if excess heat acquired in the middle of the day heats molten salts that run the generators a few hours later, at evening peaks. The salts can be heated to far above the boiling point of water, resulting in a high energy density. Another solution uses excess wind or solar power to fill a reservoir that can be emptied into hydroelectric turbines when more power is needed. As this non-battery solution is not an option at most sites, an alternative is large-capacity, stationary storage batteries in the bases of the wind turbines themselves. For this application weight and volume do not limit battery design – cost per kw stored is the only criterion.

All of these alternatives smooth out power but incur losses from storing, holding and releasing their energy. If the electrical power is then applied in a function such as charging an electric vehicle, it is stored and released twice before doing useful work.

One future vision is electric vehicles that plug into a smart grid for long periods of time; when extra power is available, for instance from wind and solar, the batteries would be charged. When things are in equilibrium, charging would continue only for an additional fee, but when more power is needed than the generation sources can provide, power from the storage batteries in millions of vehicles supplements the main supply. The technique has never been tried, however, and compensation of vehicle owners for degrading their batteries is an unresolved issue.

There are two existing visions of how users of electric vehicles can recharge their batteries, a critical issue because of relatively short ranges of battery-powered vehicles and long recharging times. First is the conventional approach, recharging at owners' homes. Overnight charging would be preferred because of the time needed to recharge. Faster charges are possible for some battery types, but they require specialized equipment and might still take several hours.

Home charging would be supplemented by charging stations in parking garages, businesses, and even parking meters to extend the practical range of a daily round trip to more than half of the vehicle's battery range. This option imitates the model that has developed around internal combustion engines using fossil fuel. Fixed stations store fuel to fill the tanks of vehicles in a few minutes. With battery-powered vehicles, however, the model works poorly because of long charging times. Drivers still would be limited to the distance they can travel on batteries charged at home, making long continuous trips impossible.

The second vision is to 'refuel' quickly by swapping exhausted batteries for fresh ones at a specialized exchange facility. The approach requires vehicles designed from the start to allow swap of a particular battery configuration, and enough exchange facilities to maintain the flexibility to which drivers are accustomed. The approach is being tested first in Israel, which has the advantages (for battery swapping) of small size, seldom-crossed borders and sensitivity to dependency on oil. Another small country with a progressive energy policy, Denmark, will provide a European test bed, and several other small demonstration projects are proposed.

The battery swap strategy promises to overcome the two disadvantages of battery-powered vehicles, short range and long recharging times. No new technology is required; indeed, demonstration battery exchange facilities are already in operation. Robots pull out a 600-pound (270 kg) battery from beneath a vehicle and replace it in three minutes. A disadvantage is that a large and expensive infrastructure is required, and the battery format of the vehicles must match that of the exchange facility and the replacement battery pack. Battery geometry and format are still under development, though. If the format becomes fixed before the technology is mature, it could be permanently handicapped, as happened with the qwerty keyboard, the VHS video tape, and even the PC.

A third alternative, not yet in development, is based on the energy model used in all successful long-range electric vehicles. These vehicles obtain their power while in motion, from overhead wires or ‘third rails’. Most are rail vehicles that complete an electrical circuit by using the rails to ground the vehicle. Electric buses, also called trackless trolleys, use two overhead wires to complete their electrical circuit. Without batteries, these vehicles are dependent on power obtained while in motion. Such a scheme for private vehicles would require a power and a ground connection that could take the form of a third rail with two sides, and a grip-like device extending out from the vehicle.

Alternatively vehicles can pick up alternating current from an overhead catenary system or from coils in the road. Such one-wire systems require alternating current and some current management equipment in the vehicle; essentially the wire provides positive and negative sources alternating sixty times per second. Freeway lanes along the median could incorporate such power sources; small battery packs would propel vehicles to and from the freeway, which in normal use is not more than a few miles. Drivers would never have to stop for refueling; the idea of stopping to load up on energy would become a thing of the past.

Other models may emerge for powering electric vehicles; research and development in these areas is just beginning.

See Also: Alternative Propulsion; Energy Conservation ; Energy Storage; Plug-in Hybrid; Zero Emission Vehicle

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