The race for better batteries

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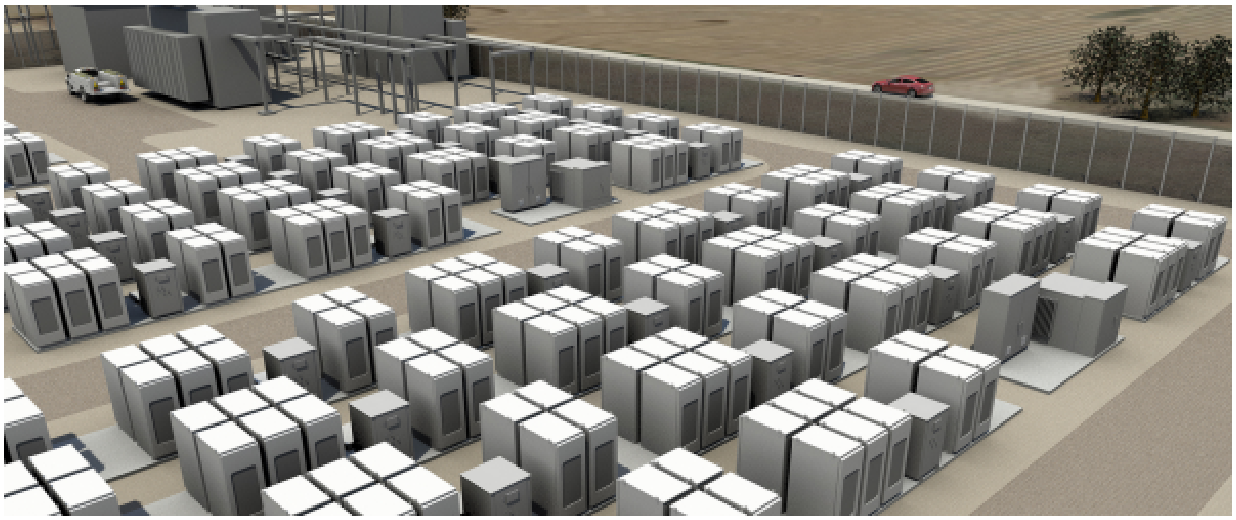

Tesla’s utility scale Powerpack batteries

"The worldwide transition from fossil fuels to renewable sources of energy is under way…" according to the Earth Policy Institute's new book, The Great Transition.

Between 2006 and 2012, global solar photovoltaic's (PV) annual capacity grew 190 percent, while wind energy's annual capacity grew 40 percent, reported the International Renewable Energy Agency. The agency projects that by 2030, solar PV capacity will be nine times what it was in 2013; wind power could increase five-fold.

Electric vehicle (EV) sales have risen 128 percent since 2012, though they made up less than 1 percent of total U.S. vehicle sales in 2014. Although today's most affordable EVs still travel less than 100 miles on a full battery charge (the Tesla Model S 70D, priced starting at $75,000, has a 240-mile range), the plug-in market is projected to grow between 14.7 and 18.6 percent annually through 2024.

The upward trend for renewables is being driven by concerns about climate change and energy security, decreasing solar PV and wind prices, rising retail electricity prices, favorable governmental incentives for renewable energy, the desire for energy self-sufficiency, and the declining cost of batteries. Growing EV sales, also benefitting from incentives, are affecting economies of scale in battery manufacturing, helping to drive down prices.

Sun and wind energy are free, but because they are not constant sources of power, renewable energy is considered "variable"— it is affected by location, weather and time of day. Utilities need to deliver reliable and steady energy by balancing supply and demand. While today they can usually handle the fluctuations that solar and wind power present to the grid by adjusting their operations, as the amount of energy supplied by renewables grows, better battery storage is crucial.

Batteries convert electricity into chemical potential energy for storage, and back into electrical energy as needed. They can perform different functions at various points along the electric grid. At the site of solar PV or wind turbines, batteries can smooth out the variability of flow and store excess energy when demand is low to release it when demand is high. Currently, fluctuations are handled by drawing power from natural gas, nuclear or coal-fired power plants; but whereas fossil-fuel plants can take many hours to ramp up, batteries respond quickly, and when used to replace fossil-fuel power plants, they cut CO_2 emissions. Batteries can store output from renewables when it exceeds a local substation's capacity and release the power when the flow is less, or store energy when prices are low so it can be sold back to the grid when prices rise. For households, batteries can store energy for use anytime and provide back-up power in case of blackouts.

Batteries have not been fully integrated into the mainstream power system because of performance and safety issues, regulatory barriers, the resistance of utilities, and cost. But researchers around the world are working on developing better and cheaper batteries.

Every battery consists of two terminals made of different chemicals (usually metals)—a positively charged cathode and a negatively charged anode—and the electrolyte, the chemical medium that separates the terminals. When a battery is connected to a device or an electric circuit, chemical reactions take place on the electrodes, causing ions (atoms with a positive electrical charge) to flow from the anode through the electrolyte to the cathode. Electrons (particles with a negative charge) want to move to the positive cathode too, but because the electrolyte blocks them, they are forced to do so via the outside circuit, creating the electric current that powers the device. After all the electrons move to the cathode, the battery dies. In rechargeable batteries, electricity from an outside source can reverse the exchange, but since the chemical reaction is not perfectly efficient, the number of times a battery can be recharged is usually limited.

Batteries vary in their attributes. The charge time determines how long a battery takes to get back to its charged state. Energy density is the amount of energy that can be put into a battery of a given size and weight, which matters depending on application. Cycle life refers to how many times a battery can be recharged before it drops below 80 percent of its ability to hold a charge, which is when it begins to be depleted. Other aspects of a battery include its toxicity, recycleability and how easily it can be kept in its required temperature range. Cost has been the major limiting factor for widespread use.

EVs at a public charging station in San Francisco

There are many kinds of batteries available today, and depending on the function a battery serves, many different requirements for storage capacity, charging and discharging performance, response time, maintenance, safety and cost. Here are a few examples of battery types.

Lead-acid batteries are already used worldwide to support renewable energy. Many have a short cycle life and last only 3 to 4 years. Nickel cadmium batteries have good cycle life and can discharge quickly, but the materials are more expensive than those in lead acid batteries. Lithium-ion batteries have high energy density for their size, which is why they are widely used for consumer electronics and electric vehicles. They are good for short discharge cycles and high power, but because of the energy density and combustibility of lithium, they can potentially overheat and catch fire. Sodium-sulphur batteries, with molten salt as the electrolyte, must operate at high temperatures, but can discharge for six hours or more.

Flow batteries, with the chemicals to produce electricity dissolved in water in separate tanks, can be charged and discharged limitlessly and can provide steady energy over time. Because the use of bigger tanks allows flow batteries to store more energy, they have great potential to help the grid deal with utility-scale electricity storage.

Battery researchers are trying to advance existing technologies and develop novel ones, as well as enhance materials and manufacturing processes. They are manipulating chemicals and experimenting with new ones, trying to improve the scale of batteries, the duration of their discharge, their efficiency, response time, sustainability and cost, as well as addressing safety issues. Japan and the United States are global leaders in the use of battery storage, with China and Germany close behind. India, Italy and South Korea are also implementing battery storage.

Some examples of new batteries being developed include Japan's dual carbon battery that charges 20 times faster than ordinary lithium-ion batteries with comparable energy density, doesn't heat up, and is fully recyclable. Researchers at Stanford University are using nanotechnology in a pure lithium battery to hopefully triple the energy density and decrease the cost four-fold. At the University of Illinois at Chicago, lithium ions have been replaced with magnesium ions, which can move twice as many electrons; this allows the battery to be recharged more times before degrading. The Joint Center for Energy Research at Argonne National Laboratory is researching technologies other than lithium-ion that can store five times more energy at one-fifth the cost.

Eric Isaacs, a Columbia University Ph.D. candidate in Applied Physics, is studying how to improve cathode materials. Featured in the 2015 Earth Institute Student Research Showcase, his research focuses on lithium iron phosphate as a candidate for cathode material. It has high energy density and can be heated to hotter temperatures, so it is safer than typical lithium-ion batteries; and since iron is abundant, it could potentially be used to produce a cheaper and more sustainable battery.

But Isaacs explained that the basic material is unstable when it's partially charged, and "playing tricks" in processing it to help stabilize it lowers the energy density. His research aims to understand and remedy the instability, and could also eventually help identify and evaluate other new materials for cathodes.

Over $5 billion has been invested in battery development over the last decade. Bill Gates has backed MIT's liquid metal battery, made up of two common molten metals separated by a molten salt that is cheap, easy to assemble and long-lasting. The venture capital firm Kleiner Perkins Caufield & Byers invested in an aqueous-ion battery, an updated saltwater battery being developed at Carnegie Mellon with potential to become the cheapest non-toxic and long-lasting battery for homes and hospitals. Khosla Ventures is behind Berkeley Lab's dry lithium battery that uses porous material and has two to three times the energy density of today's liquid lithium battery.

"The issue with existing batteries is that they suck," said Elon Musk, Tesla's CEO when the company launched its new Powerwall and Powerpack products at the end of April. Tesla's solution is the Powerwall, a rechargeable lithium-ion battery, 7 inches thick and 3 feet by 4 feet, that can be mounted on a wall. The 7kWh version sells for $3,000, the 10kWh costs $3,500, and they are guaranteed for 10 years. Up to nine of them can be stacked in a home, providing up to 90 kWh of power. The 10kWh model could power the average American home, which uses about 30kWh per day, for 8 hours, according to one analyst. 38,000 Powerwalls units were reserved the first week after the launch, and they are already sold out until mid-2016.

Solar plant in the Mojave. Credit: Akradecki

The Powerpack is a 100 kWh battery for utility scale use, which can be combined to "scale infinitely," said Musk. Ten thousand Powerpacks would produce 1GW of electricity. To move the world to sustainable energy and curb climate change, Musk envisions a scenario where 160 million Powerpacks could enable the United States to transition to renewable energy; 900 million Powerpacks could make it possible to make all electricity generation in the world renewable.

"The goal is complete transformation of the entire energy infrastructure of the world," said Musk.

To produce the Powerwall, Powerpack and its electric vehicle batteries,Tesla is building a $5 billion "gigafactory" in Nevada, the first of many. The factory will produce the energy it needs from geothermal, solar and wind and one expert projected that it will actually generate 20 percent more than it needs.

In the U.S., battery storage is already used in places like Notrees, Texas, where thousands of lead-acid batteries store wind energy. In Laurel

Mountain, W.Va., a lithium-ion battery storage plant with 32MW of capacity is so far the largest in the world. Southern California Edison has the nation's biggest battery storage system, with plans for an additional 264 MW of storage, using Tesla batteries. California's large utilities are required to collectively add 1,325 MW of storage by 2024.

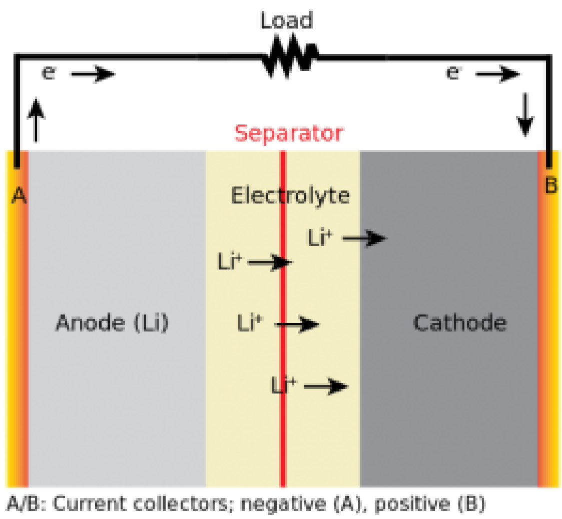

Diagram of a lithium-ion battery

A battery that costs $100 per kWh is the Holy Grail for battery researchers around the world. Electric vehicle batteries cost between $300 and $410 per kWh in 2014; analysts generally agree that batteries must reach $150 per kWh or less for those vehicles to be competitive with gasoline-powered vehicles. The cheaper the battery, the more electricity can be stored, and the farther the car can go on a charge.

Last year, the cheapest utility scale batteries cost $700 or more per kWh. The Tesla Powerpack is currently estimated to cost $250 per kWh, with the "gigafactory" expected to cut battery prices by 30 percent. The

Advanced Research Project Agency-Energy (ARPA-E) is funding 21 different grid-scale battery technologies, hoping to lower battery costs to $100 per kWh, the point at which storage becomes competitive with conventionally generated electricity.

According to the International Renewable Energy Agency, annual battery storage capacity is expected to grow from 360MW to 14GW between 2014 and 2023. Global sales of light duty electric vehicles are projected to go from 2.7 million in 2014 to 6.4 million in 2023. With so many striving for a significant battery breakthrough, more economies of scale and improved manufacturing processes, the world just might see a $100 per kWh battery within the next few years.

BASF experiments with cathode materials to improve lithion-ion batteries

Provided by Earth Institute, Columbia University

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