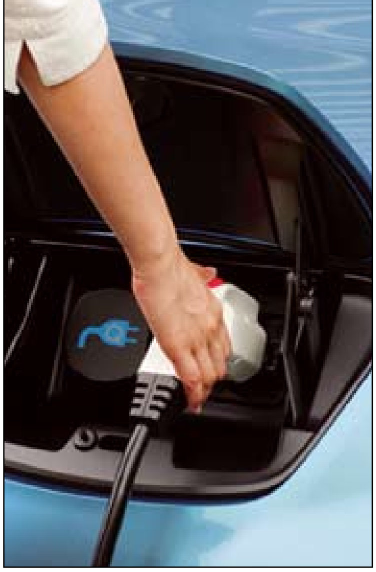


Better batteries for electric vehicles

Corinna Wu

Improved battery technology, innovative recharging strategies, and generous financial incentives are making electric vehicles more attractive to consumers than ever before.

In 1996, General Motors unveiled the EV1, an all-electric car powered by a heavy lead-acid battery. The EV1 was enthusiastically received, but a host of economic, regulatory, and technical concerns prompted GM to discontinue the car's leasing program in 2002. Instead of ushering in an era of electric cars, the EV1 was widely seen as a disappointment.

But now, thanks, in part, to major improvements in battery technology, electric vehicles are having their day in the sun. Later this year, GM will begin selling the Chevrolet Volt, a plug-in hybrid, and Nissan will begin selling the Leaf, an all-electric passenger car with a 100-mile range. In May, Tesla Motors purchased a former Toyota plant in Fremont, Calif., to begin manufacturing its all-electric Model S sedans.

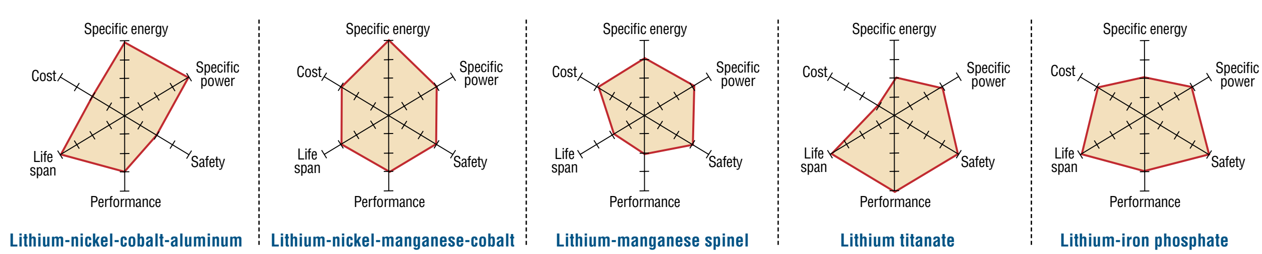
Many countries are looking toward electric vehicles for the benefits they offer in terms of energy security and the environment. Cutting the demand for gasoline would help reduce dependence on imported oil, shifting that demand to domestic electricity production. Whether electric vehicles will help reduce greenhouse gases depends on where their electric power comes from—fossil fuels or renewable sources—a mix that varies from one country to another.

What will it take to get widespread adoption of plug-in hybrids and all-electric cars? For consumers, battery-powered cars need to have a range long enough to accommodate the average commute, reasonable recharging time, and affordable cost. Continued improvements in battery technology, as well as development of an infrastructure of recharging stations, are crucial to satisfy all these demands.

Today's hybrids, such as the Toyota Prius, use nickel-metal hydride batteries, but the cars now emerging feature lithium-ion ones. The transition to lithium-ion has been driven by the differences in power needs between hybrids and plug-in hybrids. Hybrid electric vehicles (HEVs) are propelled by both an internal combustion engine and a battery that is used as a power assist; it kicks in when the engine is least efficient, such as during idling or acceleration and deceleration. Because the battery gets recharged by regenerative braking, the driver only needs to refill the gas tank, just as with a traditional car.

In a plug-in hybrid (PHEV), such as the Chevrolet Volt, the battery powers the drive train, while the internal combustion engine serves as a backup in case the battery gets depleted on the road. The driver plugs in the car to recharge the battery, a process that can take several hours. All-electric vehicles, also known as battery electric vehicles (BEVs), such as the Nissan Leaf, operate purely on a battery charge.

Lithium-ion batteries, now ubiquitous in portable consumer electronics, are attractive for vehicle applications because they are light, have a high-energy density, experience no memory effect, and can be recycled. The demands that a car puts on a lithium-ion battery, however, far exceed those of a cell phone or laptop computer. According to goals set by the U.S. Advanced Battery Consortium—whose members include Chrysler, Ford, and GM—a battery for a 40-mile range PHEV should endure 5,000 charging cycles, last 15 years at 35°C, weigh no more than 120 kg, and cost $3,400 at maximum production (100,000 units per year). "No battery meets all the mass and volume goals



The five principal lithium-ion battery technologies have different tradeoffs. In this figure, the farther the shape extends along a given axis, the better the performance along that dimension. Figure courtesy of Boston Consulting Group.

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Lithium-ion battery pack in the all-electric Nissan Leaf. © 2010, Nissan.

today, so we make amendments to the vehicle architecture itself to make it pleasing to the customer" and to accommodate the battery, said Mark Verbrugge, director of the Materials and Processes Laboratory at the General Motors Research and Development Center in Warren, Mich.

Advances in the materials that make up the cathode, anode, and electrolyte have helped to increase the performance of lithium-ion batteries and bring down their cost. Conventional lithium-ion batteries have cathodes made of lithium cobalt oxide ($LiCoO_2$), but because of safety issues, researchers have moved toward using other materials in vehicle batteries.

Ensuring safety is one of the most important factors in developing cathode and electrolyte materials. Notorious incidents of laptop computers bursting into flames prompted several massive recalls of lithium-ion batteries. Certain battery chemistries are prone to thermal runaway, which occurs when excess heat from a short circuit or overcharging accelerates reactions inside the cell, producing even more heat. Those chemistries typically offer higher energy density, though, so other system-level safety measures are incorporated to reduce the risk of overheating.

The batteries used in the Chevrolet Volt, manufactured by LG Chem in South Korea, have cathodes made of a layered manganese oxide. The Nissan Leaf uses lithium manganese spinel batteries manufactured by Nissan and NEC. Several companies are working with lithium nickel manganese cobalt oxide (NMC) cathodes. A123 Systems supplies car companies such as Fisher Automotive with its batteries based on nanoparticles of lithium iron phosphate ($LiFePO_4$). "There are several basic lithium battery chemistries that are vying to be one of the successful automotive battery chemistries," said Yet-Ming Chiang, professor of ceramics at the Massachusetts Institute of Technology and founder of A123. "I think it's quite clear that there will be more than one winner in this area."

Increasing the energy stored will require increasing the voltage of the batteries, the capacity of the electrodes, or both, said Michael Thackeray, senior scientist at Argonne National Laboratory. "The voltage of conventional lithium-ion batteries is 3.5 to 4 volts, which is already quite high." Thackeray and colleagues have nearly doubled the capacity using composite electrode structures rich in manganese and nickel that can accommodate much more lithium. They have to be charged to about 4.5 volts to achieve the high capacity, Thackeray said.

Improvements can be made in anode materials, as well. Lithium-ion battery anodes are typically made of graphite, and a solid-electrolyte-interface layer forms on the surface. If recharging is too fast, that layer tends to hinder the movement of lithium ions, said John Goodenough, Virginia H. Cockrell Chair of Engineering at the University of Texas at Austin, who identified and developed the iron phosphate cathode materials used in the first commercial lithium-ion batteries. That puts a limit on the rate of recharge, but "I think that will be solved in the relatively near future," Goodenough said. He adds that the next materials development might be in solid electrolytes to replace the organic liquids used now.

In addition to work on specific materials, design innovations can make the architecture of batteries more efficient, said Chiang. "In many batteries, 50% or less of the available volume and mass are used for active material," he said. Because ion transport is slow, electrodes are designed to be very thin. "Is it possible to design much thicker electrodes that are much denser in the active materials but still have the necessary transport characteristics?" Chiang wonders.

The typical consumer in the market for an electric vehicle might not know a cathode from an anode, but he or she will take notice of a car's range, its recharging time, and its cost. Developing an infrastructure of recharging and battery switch stations can help allay those common worries about driving BEVs. A driver would be able to stop at a station and get a depleted battery switched for a freshly charged one in a matter of minutes. Batteries will improve in many ways, "but it doesn't look like you're going to have five-minute charging for lithium-ion," said Michal Wolkin, head of battery technology at Better Place in Palo Alto, Calif., a company dedicated to developing global electric vehicle networks.

In addition, Better Place would own the battery, and consumers would purchase a service plan for it as they would for a cell phone. That would cut $12,000 from the price of a BEV, Wolkin said. Adding in federal and state tax credits could lower the price enough to attract more consumers.

Many countries, including the United States, China, Israel, Denmark, and Japan, are putting policies in place to boost the market for PHEVs and BEVs. China plans to build 75 charging stations this year and is offering consumers in five cities subsidies of up to $8,800 for buying a BEV or PHEV. In Denmark, electric vehicles are exempt from the 180% tax placed on new cars. Japan's Ministry of Economy, Trade and Industry wants 50% of all new domestic car sales to be hybrids or electric vehicles by 2020 and is rolling out incentives to make it happen. The Renault-Nissan Alliance, Better Place, and others are working to supply the cars and to build the infrastructure needed to make electric vehicles practical. Soon, more and more drivers will be "filling up" with electrons instead of petroleum. □

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