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Improving the Lithium-Ion Battery

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Researchers tweak electrode chemistry to boost energy capacity and lower costs.

Global demand for electric vehicles has exploded in recent years. More than 740,000 electric vehicles were on the road in January 2015, a number expected to reach several million by 2020.

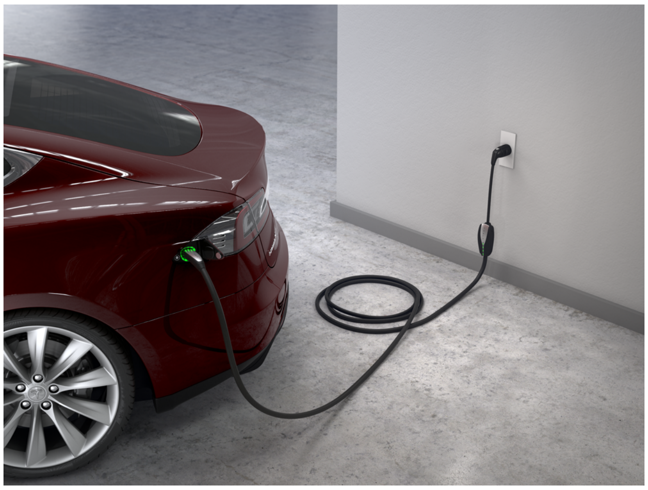
Lithium-ion batteries will likely power all of those cars. Other battery technologies such as lithium–sulfur and magnesium-ion are in the works, but none are close to dethroning lithium-ion. "Lithium-ion is pulling away, and everything else is in the rearview mirror", says Yet-Ming Chiang, a materials science and engineering professor at Massachusetts Institute of Technology.

Lithium-ion batteries have come a long way since Sony first sold them in 1992 for consumer electronics. Today, they hold more than double the energy by weight. Also their cost per kilowatt-hour has dropped to $300, a third of what it was in 2008. But to get electric vehicles into the driveways of more people, manufacturers will need cheaper batteries with a 300-plus-mile driving range.

Achieving that range from a single charge requires a battery with high energy density. Researchers are pushing for such densities by tinkering with the battery's electrode chemistries.

Inside a typical lithium-ion cell, an electrolyte-soaked separator sits between an anode and cathode. Ions flow from the anode to the cathode during discharge and shuttle back when the battery recharges. The anode in present-day batteries is typically made of graphite, while the electrolyte is a lithium salt in an organic solvent.

The cathode can be made from various lithium-containing materials and largely determines a battery's performance. The energy stored in the cathode depends on the material's charge-storage capacity and the voltage it needs to absorb and release lithium ions, explains Vincent S. Battaglia, head of the electrochemical technologies group at Lawrence Berkeley National Laboratory. So researchers' goal is to develop cathode materials with high capacities and voltages.



An all-electric Tesla Model S charges its batteries while plugged into a wall outlet. Credit: Tesla Motors.

This can be tricky, he says. Any new electrode material has to be stable but also work well with other battery components. One example of a stability problem is collapse of the cathode material's crystal structure when lithium ions flow out of it. This can reduce the electrode's lithium-storage capacity over time or cause it to break down. As for issues with other battery components, if a cathode operates at too high a voltage, it can oxidize and decompose the liquid electrolyte. Other unwanted reactions between the cathode and electrolyte can lead to corrosion of the cathode or deposition of current-reducing layers on its surface.

Batteries in cell phones and laptops use lithium cobalt oxide cathodes, which have a high energy density of 150–190 Wh/kg. But the material's high price tag and low stability make it unsuitable for the large battery packs needed in electric vehicles. So researchers have in recent years made stable cathode materials by replacing some of the cobalt with elements like nickel and manganese.

One promising material is lithium nickel manganese cobalt (NMC). It has an energy density of 140–180 Wh/kg and can be charged twice as many times as lithium cobalt oxide before losing its capacity. A typical electric vehicle battery goes through 1,500 cycles. Electric cars such as the Nissan Leaf and BMW i3 use NMC batteries.

Published: July 13, 2015

DOI: 10.1021/acscentsci.5b00223
ACS Cent. Sci. 2015, 1, 161–162

The Tesla Model S, meanwhile, runs on lithium nickel cobalt aluminum oxide (NCA) batteries made by Panasonic. This new cathode material boasts an energy density greater than 240 Wh/kg, but it is relatively expensive and requires oversized liquid-cooled battery packs to prevent overheating.

The hunt for new cathode materials now involves tweaking the composition of existing materials. Most efforts are focused on the next generation of NMC materials. The auto industry's thrust is to increase the nickel content in NMC compounds, because nickel allows the cathode to operate at a high voltage, Chiang says. Current NMCs have equal parts by weight of nickel, manganese, and cobalt, but the industry is now looking at ratios of 5-to-2-to-3 or 6-to-2-to-2.

Researchers at Argonne National Laboratory and Oak Ridge National Laboratory, meanwhile, are trying to improve a lithium- and manganese-rich NMC cathode that promises 280 Wh/kg energy density but currently suffers from a voltage drop over time.

While cathodes take up a large share of research, scientists are also looking at new anode chemistries. Major battery makers as well as some startups want to swap graphite anodes with silicon, which has 10 times the charge-storage capacity. Silicon swells drastically when it absorbs lithium ions, so the anodes degrade after a few hundred recharge cycles. Researchers are trying to limit the swelling with tricks such as combining silicon with graphite or graphene, embedding it in protective coatings, or using silicon nanostructures. A few research groups are also looking at anodes made of pure lithium metal and of graphene.

It is hard to predict which lithium-ion battery chemistry will increase the driving ranges and lower the costs of electric vehicles. But it is clear that chemists have their work cut out for them. "A battery is more than just a collection of materials: It's a system", Chiang says. "The materials have to work together. That's one of the most challenging aspects of battery development."

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DOI: 10.1021/acscentsci.5b00223
ACS Cent. Sci. 2015, 1, 161−162