Lithium Battery Takes to Water—And Maybe the Road

Playwright Arthur Miller had his own formula for the death of a salesman, but here's one that might work just as well: a showroom full of $60,000 electric cars whose top speed is 50 miles per hour when the air conditioner is on and whose batteries are prone to smoke or catch fire if ruptured. Some transportation researchers say that sale-killers like those are one possible outcome of the very work that aims to improve performance of electric vehicles (EVs): the development of advanced batteries. These "superbatteries" improve on the range of standard lead-acid batteries and withstand repeated recharging better—but often at the cost of chemical stability or high peak current. And, says Daniel Sperling, director of the Institute of Transportation Studies at the University of California, Davis, advanced batteries "could be so expensive that they will kill off the market [for EVs] rather than expand it."

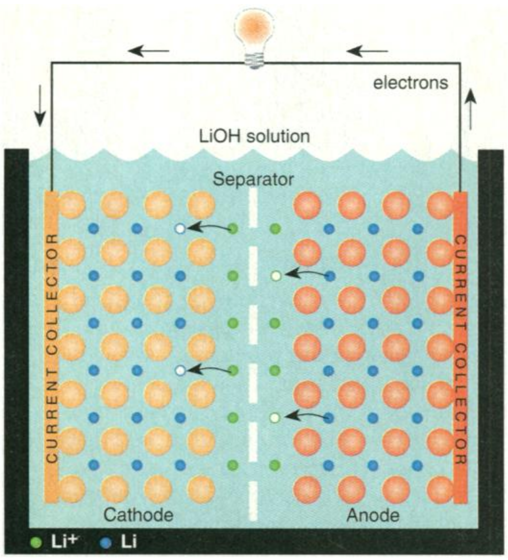
But on page 1115 of this issue, Wu Li and Jeffery Dahn of Simon Fraser University in British Columbia and D.S. Wainwright of Moli Energy report steps toward improving the low current, high cost, and instability of one electric-vehicle contender: the lithium-ion battery. By chemically taming the highly reactive lithium in the battery and replacing the complex electrolyte of earlier versions with a simple water solution, the work "could really simplify the whole field of rechargeable lithium-ion batteries," says George Blomgren, a senior technology fellow at Eveready Battery Company. With further refinement, Dahn and his colleagues believe, aqueous lithium-ion batteries could gain a strong position among EV contenders.

Lithium emerged as a promising material for rechargeable batteries in the mid-1970s, when researchers realized that individual cells based on lithium could produce a higher voltage than nickel-cadmium (NiCad) or lead-acid cells. Higher voltage opened the possibility of lighter batteries for, say, portable electronic equipment, because fewer cells would have to be linked to make a usable battery. What's more, a higher voltage cell can store more energy, which translates to longer operation per charge for a given battery weight.

But these potential benefits came at a high cost. Because lithium reacts violently with moisture, the batteries can burn when damaged, and they have to use nonaqueous electrolytes, generally lithium salts dissolved in organic compounds. Unfortunately, such electrolytes usually have high resistance to the power-producing flow of current. And their effectiveness rapidly degrades in contact with water and air, which means the batteries must be manufactured with purified materials under carefully controlled conditions, then hermetically sealed.

The first lithium-ion cells made use of lithium metal for the negative electrode and an "intercalation" compound, which usually has a lattice structure, as the positive electrode. As such a cell produces current, lithium atoms give up electrons at the negative electrode, yielding positive ions that travel through the electrolyte to the positive electrode. There they intercalate (reversibly insert themselves) into the other electrode. Because the lithium ions effectively "fall" toward the intercalation compound, which has a much greater affinity for them than does the metal, electrons are driven through the external circuit to the positive electrode, where they are returned to the lithium ions.

The flow can be reversed to recharge the battery when a voltage is applied to the external circuit, pushing the ions back up the electrochemical hill and redepositing them on the lithium metal of the negative electrode. Repeated recharging, however, brought out the flaw in these first lithium batteries, says Dahn. Instead of arraying themselves in unbroken layers, the replated lithium ions eventually formed a microscopic "fur" whose high surface area apparently made it unstable enough to burn. In 1989, Moli Energy, a pioneer in the field, had to recall thousands of lithium batteries after several of them began spewing smoke or flames.



The wet look. Lithium and a water electrolyte—ordinarily a reactive mixture—peacefully coexist in the new lithium-ion battery.

SOURCE: BRIAN WAY AND JEFFERY DAHN ILLUSTRATION: C. FABER SMITH

Since then, several companies have solved the fur problem by using intercalation compounds at both electrodes. That keeps the batteries safe (providing they aren't ruptured), but lithium's reactivity still forced battery designers to use nonaqueous electrolytes, with attendant high cost and low current. As a result, these batteries are unlikely to power anything larger than camcorders and cellular phones, says Howard Saunders of the Westinghouse Science and Technology Center in Pittsburgh.

Dahn and colleagues' strategy for overcoming this deficiency is to restrain the lithium so it can't react with water, then use a simple electrolyte consisting mainly of distilled water. The feat required two kinds of safeguards: manganese oxide–based intercalation compounds that bind the lithium more tightly than the carbon in earlier lithium-ion batteries, and lithium hydroxide dissolved in the electrolyte. Since lithium hydroxide is exactly what results when lithium reacts with water, loading the electrolyte with the compound in effect saturates the system, ruling out further reactions.

The development is "a big plus as far as safety goes," says Saunders, and it opens the way for the development of lithium batteries that would generate larger currents. The disadvantage is that because water breaks down at the high voltages of earlier lithium cells, Dahn and his colleagues had to lower the cell voltages—and hence their energy densities—to values only slightly better than those of NiCad batteries. But those drawbacks may be offset the new battery's relatively low cost. Its aqueous electrolyte should make it much cheaper to manufacture than nonaqueous systems, and its manganese-based electrodes should reduce materials costs by as much as a factor of 10 over nickel-based cells, Dahn estimates.

Still, the savings may not show up for a while in a practical battery. "It took 10 years for alkaline cells to be perfected, even though the chemistry is fairly straightforward," says Duward Shriver of Northwestern University. And Dahn himself notes that there may not even be a pressing need for a car-sized lithium-ion battery: For his own daily commute of less than 50 miles, he says, a lead-acid–powered car might suffice—"as long as it didn't cost me a hundred thousand." Somewhere down the road, though, his work may mean that EV salesmen won't need to get by on just a shoeshine and a smile anymore.

–James Glanz

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