Lithium Battery Research

Rechargeable Li-ion Batteries

Argonne Natl Lab

Better Batteries, Better Automobiles and a Better Environment

When Argonne National Laboratory's Michael Thackeray, Ph.D., talks about lithium ion (Li-ion) battery research, he sees the future. He doesn't quite write off the acid/lead batteries that start internal combustion engines or the nickel/cadmium cells people buy for cordless power tools and electronic gadgets, but he does see them as having run their course in terms of technological possibilities.

What's clear about Li-ion technology is that, for him, it's a thing of passion, intellectual stimulation – and massive future potential.

"Lithium ion is so versatile, and it's still evolving," says Thackeray, Argonne distinguished fellow and senior scientist at the Argonne, Ill., research facility. "Most batteries offer a fixed chemistry. With lithium ion, you can vary the materials and tailor the chemistry to achieve a range of voltages and other traits. You can achieve high voltage, high energy, long life, increased safety, smaller sizes.

"I've spent my life in the battery game and lithium ion's evolution has been like riding a wave," he continues. "It's always expanding and it hasn't broken yet." He expects the wave to keep going. "The next century will be about energy," he says. "It's an environmental, economic and strategic issue."

At present, the wave is trending toward revolutionizing transportation, moving the electric automobile closer to coming into its own. Argonne's Li-ion research is significantly expanding the capabilities of a new generation of electric-powered automobiles. Argonne hasn't invented a new battery, but Thackeray and colleagues Khal Amine, Ph.D., Chris Johnson, Ph.D., Jaekook Kim, Ph.D. (who has since left the organization) and their team have developed the technology for a new combination of battery cathode materials that manufacturers can build into their products.

The technology has been licensed to a number of companies, including General Motors, where it is helping power the hybrid-electric car Chevy Volt. The Korean firm LG Chem Ltd.'s has constructed a new plant in Michigan with the goal of producing Li-ion battery packs for electric cars. California-based Envia Systems, the international chemical giant BASF and Japan-based Toda Kogyo Corp. are all pursuing Li-ion battery development using Argonne technology.

AUTM extends its gratitude to the Better World Project sponsors.

Contributors | Promoters

University of Pittsburgh Office of Technology Management
Thomas | Horstemeyer Intellectual Property Attorneys
PARTEQ innovations advancing discovery®

“This work exemplifies the importance of research funding not just for science, but for the quality of life for all of us,” says Deborah Clayton, director of Argonne’s Technology Development and Commercialization Division. “Department of Energy funding has been translated into ‘green’ technologies that help reduce our dependence on fossil fuels, benefit the environment, make transportation more affordable and create jobs for American workers.”

Battery Basics

All batteries are one simple thing: a device that stores chemical energy and uses the flow of electrons generated by positively and negatively charged substances – made from lead, nickel, cadmium, zinc, lithium, manganese and cobalt, among others – to create electrical energy.

A battery consists of an anode (the negative electrode composed of, for example, cadmium) and a cathode (the positive electrode composed of, for example, nickel hydroxide), coupled by an electrolyte (such as an acidic or alkaline solution). The electrolyte transports ions between the electrodes during discharge of the battery, while electrons flow along a wire circuit, external to the battery, to power an electrical appliance. The reverse process occurs when the battery is being charged by an external power supply.

There are many possible combinations of anode, cathode and electrolyte materials, each producing specific features in terms of voltages, shelf and service life, reaction to extreme temperatures, safety, environmental issues, size and cost. Inexpensive nonrechargeable batteries like AA-size zinc/manganese oxide alkaline cells are well-suited for low-power needs such as television remote controls.

Devices requiring more power and long service life, such as portable drills, are more likely to use rechargeable nickel/cadmium batteries. Relatively inexpensive and rechargeable lead/acid batteries used in automobiles provide output to start internal combustion engines but would have a limited service life if used continually.

Today’s wealth of laptop computers, smartphones and other electronic devices have both benefited from and fostered the advent of Li-ion technology over recent decades. Still, the big challenge remains the dream of batteries strong enough for electric-powered automobiles. Lithium is at the center of that.

The Lithium Ion Factor

“Lithium is the lightest and most reactive metal,” notes Emilio Bunel, Ph.D., director of Argonne’s Chemical Sciences Division. “It can produce the greatest amount of electrical energy per unit weight. You can vary the formulations for many different uses, and, in fact, our Li-ion research has resulted in a portfolio of technologies.”

Serious work with lithium batteries dates back to the early 1900s, but it was the 1980s before nonrechargeable lithium batteries were a commercial reality. Developing rechargeable batteries was a more difficult matter. Recharging causes highly reactive lithium particles to accumulate on metallic lithium anodes, creating electrical shorts that can heat up the battery, risking fire and explosion. Overheating problems in the 1980s sent manufacturers looking for a new approach.

“The Japanese put a lot of work into lithium batteries,” notes chemist Chris Johnson. “They needed them for their electronic devices. In 1991, Sony came out with anodes that used lithium-carbon materials instead of metallic lithium [to overcome heating problems]. It just knocked people back – everyone went *wow*!

AUTM extends its gratitude to the Better World Project sponsors.

Contributors	Promoters
University of Pittsburgh Office of Technology Management; Thomas Horstemeyer Intellectual Property Attorneys	PARTEQ innovations advancing discovery®

It was the following year that Johnson started working on Li-ion battery technology – the first person at Argonne to focus on it. "I came right after getting my doctorate at Northwestern in electrochemistry – a pretty broad field," he notes. "They assigned me to work on the technology. It became a career. And now we have a full team focused on it."

Born and raised in South Africa, Michael Thackeray joined Argonne in 1994 after 20 years at his native country's Council for Scientific and Industrial Research. The previous 12 years he had focused on room temperature lithium batteries. One day Thackeray's bosses told him, "You can do any research you want but we're shutting down lithium battery research," he notes, adding that there wasn't a sufficient market for the technology in South Africa. At a conference in Toronto, he met an Argonne scientist who suggested he move to the American research facility. "It's worked out incredibly well," he says.

In the early 1980s, Thackeray was involved in breakthrough research on manganese spinel cathodes. Spinel has a cubic structure that is stable, safe in terms of heat issues and provides space for fast Li-ion flow. Although the basis of the Japanese breakthrough in the early 1990s was lithium cobalt oxide, a different material, manganese spinel proved to be a reliable, inexpensive material and is used today in many commercial batteries.

The Hi-Tech Analytical Factor

"Lithium cobalt oxide has been a very successful cathode material, but it's expensive," says Argonne Distinguished Fellow and Senior Materials Scientist Khal Amine. He joined the laboratory in 1998 after studying and working in France, Belgium and Japan. "Lithium cobalt oxide is widely used in small batteries for consumer electronics, but its cost makes it impractical for the very large batteries used in automobiles." Electric cars initially relied on manganese spinel. It offered a long lifecycle at a relatively low cost, but the downside was that the cars weren't getting the level of energy they needed.

"Lithium-carbon anode technology had progressed significantly," Amine notes. "The bottleneck was in the cathode. We looked at it intensively and invented something different – a cathode material that offers more capacity and power and is longer-lasting, safer and more affordable."

"Intensively" meant using Argonne's Advanced Photon Source synchrotron facility to study the workings of lithium batteries at the atomic level – and in real-time. From there, they developed a formula for lithium/manganese/nickel cathodes with a very low amount of cobalt. The new combination offers a significant increase in battery energy, significantly lowers the risk of overheating and retains the low cost of manganese technologies.

For drivers, the breakthrough can mean significant advantages in terms of cost, convenience and capability. For the public as a whole, it offers the prospect of a cleaner environment and less dependence on foreign fossil fuel supplies.

"For hybrid-electric cars like the Chevy Volt, lithium ion technology provides as much as a 100-percent increase in energy storage capacity, with longer operating times between charges," says Jeffrey Chamberlain, Ph.D., strategic leader of Argonne's energy storage initiative.

"The 400-pound battery in today's Volt enables you to go 35 to 40 miles on electric energy before recharging is needed," he notes. "That's the typical journey for 75 percent of all commuters, so it works for a lot of people." In fact, it works for Chamberlain, who drives a Volt to Argonne each day in his own commute.

AUTM extends its gratitude to the Better World Project sponsors.

Contributors	Promoters
University of Pittsburgh Office of Technology Management; Thomas Horstemeyer Intellectual Property Attorneys	PARTEQ innovations advancing discovery®

Still Farther to Go

Michael Thackeray regards the current technology as only the first generation of new Li-ion possibilities. “We expect that the next generation will nearly double the current levels,” he says. “The goal is always to increase voltage, energy capacity and battery life and to put it all in smaller and smaller containers – safely.”

That’s the goal in the foreseeable future. In the long view, Thackeray sees an entirely new version of Li-ion technology – a hybrid with lithium/oxygen batteries in which lithium reacts with oxygen in a controlled way. It could offer 5 to 10 times the energy of current Li-ion technologies.

“That’s a long way off, but based on past experience, it’s feasible,” says Anthony Burrell, Ph.D., head of Argonne’s Energy Storage Department.

“Argonne has the technical resources for this work, and our success has been a combination of the right people and the right facilities. Mike, Khal and Chris are the best people in the world at this. I’m proud of these guys.”

– Ralph Fuller, Better World Report, 2013

AUTM extends its gratitude to the Better World Project sponsors.

Contributors	Promoters
University of Pittsburgh Office of Technology Management; Thomas Horstemeyer Intellectual Property Attorneys	PARTEQ innovations advancing discovery®