Ion Drive: A Visit to EnerDel[1]

Timothy F. Slaper: Director of Economic Analysis, Indiana Business Research Center, Kelley School of Business, Indiana University

It seems apparent that removing oil dependency from our economy will require removing the gas tank from cars and that batteries will largely replace those gas tanks. The type and source of those batteries, however, remains an open question. Will the United States become as dependent on importing batteries from Asia as it is dependent on importing oil now? Perhaps not. Indiana is home to EnerDel, the only U.S. manufacturer producing commercial-scale, automotive-grade lithium-ion battery systems. The company formed when Ener1 (its parent company) acquired the lithium-ion battery operations of Delphi Corporation. Its goal is to obviate the need for gasoline to power vehicles, either by reducing the gasoline required for operation via hybrid electric vehicles (HEV) and plug-in hybrids (PHEV) or by eliminating the need for gasoline entirely with fully electric vehicles (EV). The goal for the latter vehicle, charging in as little as fifteen to twenty minutes a day, is in sight, subject to the availability of fast-charging stations. This article provides an inside view of EnerDel, based on a personal visit.

Most lithium-ion battery manufacturing in the United States is limited to the assembly of bulky battery packs. These manufacturers import their batteries from Asia, bundle them into big boxes, and then adapt the software and electronics to integrate the battery packs into the vehicle. EnerDel, on the other hand, offers fully integrated electric power systems with the components largely manufactured in the United States.

EnerDel has two plants just north of Indianapolis. When I met Derrick Buck, director of battery system integration, I was checking out a prototype hydrogen-electric hybrid car. The car sat next to a stand reminiscent of the old-style gasoline pump, the uncluttered, slender iconic ones from the early days of the internal combustion engine, with a hose draped on one side. The hose in this case is a high-voltage electric cord. "With that charging station, we can recharge this vehicle in about eighteen minutes," says Buck. Buck is a Purdue University graduate and a fourth-generation auto engineer. Like the other two engineers I would meet that day, he is a Hoosier with decades of experience in the auto industry.

Buck gave me an overview of EnerDel's lithium-ion battery pack, which differs from the nickel metal hydride (NiMH) batteries used on earlier models of HEVs. The lithium-ion was chosen for several reasons. Lithium is the third lightest element and the lightest metal. It provides superior energy and power density. The development of the lithium-ion battery over the last two decades revolutionized the mobile phone industry. Without dramatically smaller size and cost, it is unlikely the ubiquitous cell phone would have gained widespread adoption.

Right out of the gate, it was clear that product design, capabilities, and manufacturing were difficult to tease apart. "We integrate multiple chemistries for specific applications with a prismatic cell design and stacking architecture for superior performance, longevity, and safety," Buck explains. "Not only do we get better energy density, but these vehicular batteries are superior in safety and dependability." EnerDel's battery chemistry has led to improved battery stability and overcoming the thermal problems that occurred in earlier vintages of lithium-ion batteries. The batteries can also work dependably over a broad range of temperatures, currently as cold as -22 degrees Fahrenheit.

Many Advantages

Combined with computer and electronic hardware and software, the lithium-ion chemistry is capable of quick acceleration, regenerative braking (transferring the braking energy back into the vehicle battery) and longer range. Adjusting the chemistry, hardware, and software also provides the manufacturer the flexibility to make batteries for specific applications. The energy needs for electric vehicles are not one-size-fits-all. HEV cells focus on power, providing ultra-high discharge capacity, with more than a 50 C-rate continuous discharge possible (meaning an entire battery would discharge in just over a minute). EV cells, on the other hand, offer higher energy density for longer range combined with good power characteristics.

In addition to advances in battery chemistry, EnerDel cells have prismatic design, in contrast to the cylindrical form most of us are accustomed to. The basic idea is that rather than rolling up the battery innards and placing them in a cylinder, they are stacked like a deck of cards and put into a foil-like pouch. The flat cell is significant for two reasons, energy density—space between the cylinders can consume about 20 percent of the battery pack volume—and surface area that dissipates heat. Moreover, the shape reduces transportation volume, makes assembly easier, and increases the number of cooling options in the automobile.

Before walking around the plant, the conversation turned to company strategy and manufacturing processes. Buck could not contain his enthusiasm for the EnerDel battery and the womb-to-tomb design considerations, not surprising considering he is the director of battery system integration. However, all the EnerDel engineers pride themselves as one of the few firms, if not the only American firm, that produces an application-specific, fully integrated system of hardware and software that allows a battery to communicate with the vehicle and monitor the performance of each individual cell and the overall pack.

The EnerDel product strategy embraces the entire battery lifecycle: how the batteries will be serviced, replaced, and reused, together with how the cells will be decomposed and their materials recycled. The modular design of the battery pack allows for the quick pinpointing and replacing of troublesome cells. The service technician identifies the sub-pack (containing dozens of cells) that needs to be replaced, disconnects it, pulls it out, and replaces it with a new one. The entire process would take about fifteen minutes. He then sends the toolbox-sized sub-pack back to EnerDel for repair or replacement of the faulty cell.

Eventually, battery performance declines with age. While the aging batteries may lack the C-rate for the automobile acceleration, the ability to hold 80 percent of the originally specified power can be used for stationary applications. For example, the battery can be deployed to store electricity for peak loads on the power grid. In other words, the batteries would provide the smart grid of the future the ability to smooth electricity demand and generation. Large banks of older batteries can store the electricity generated by wind farms for later use. Households can use a smaller bank of a few units—no bigger than a linen closet—to pull from the power grid when electricity is cheaper and discharge when electricity is more expensive.

A Question of Scale

How many of these battery packs can this facility produce? It depends on whether they are EV or HEV units. The present facility, running with two shifts six days a week can produce about 16,000 EV packs a year, double that if they are for HEV applications. The HEVs don't have the power requirements of fully electric. I did some quick math: If Toyota sold about 160,000 units of the Prius in 2008 in the United States, that would mean facilities ten times the size of the EnerDel plants in Indianapolis if EnerDel was the sole source. It boggles the mind to consider scaling up to produce the number of battery pack units to meet the Obama administration's goal of one million fully electric vehicles on the road by 2015. How would an EnerDel, and those firms that supply rather boutique material inputs, fulfill that demand?

Battery production needs a lot of space; the combined square footage of the Indianapolis plants total 127,000. It also requires a lot of sophisticated, fantastically expensive, and highly proprietary capital equipment.

EnerDel is still tweaking the battery chemistry—they have a separate production lab for R&D to keep production models separate from prototypes—but production engineering and high-volume manufacturing appear to be the dominant challenges.

The federal government has stepped in to help address these challenges. EnerDel, along with several other Indiana companies[2] and dozens across the country, was identified to receive federal grants for R&D and to increase manufacturing capacity for manufacturing "green cars." Unlike most federal R&D grants that tend to focus on primary research and science, these funds will enable EnerDel to transition to high-volume production. EnerDel, recipient of the largest grant to a firm in Indiana, gained possession of its $118.5 million grant on March 3, 2010.[3] Even though the company did not have the cash in hand, the firm made plans to spend it. In January, EnerDel announced its investment plan to lease and equip a new manufacturing facility in Hancock County.[4]

I asked Sean Hendrix, director of program management and battery management systems development, if this R&D seed funding for EnerDel and other advanced automobile companies would be sufficient to surmount the threat from Chinese battery manufacturers. He wasn't sure "threat" was the right term[5] but did note that the Chinese government has spent liberally on R&D for green technologies and that they have also spent considerable resources "tooling up the academics" that would train the next generation of green technology engineers and scientists. Like manufacturers in the United States, China has the challenge of taking proven technologies to mass-volume commercialization.

The Manufacturing Process

The building blocks of the batteries, the innards of the cells, are better described as building wafers. The first series of steps combine a thin foil—much thinner than the foil in your kitchen drawer—of either aluminum or copper, with various active materials such as manganese or mixed oxides for cathodes. The mixing room contains something of a vastly scaled up Home Depot paint-mixing machine to prepare the coating for the foil. The chemical slurry looks like thick black paint. This paint is, for want of a better term, "sprayed" onto the copper or aluminum foils—the mechanics of the application is a closely held secret. The foil then goes through a long, tunnel-like drying machine that bakes the paint to the foils.

Following that, the next series of steps turns the specialty-coated foil into battery electrodes. The foil is unspooled and squeezed between two large, precision rollers to ensure that the material on the foil is perfectly flat. (The slightest bump, not even visible to the naked eye, would potentially short the battery when the sheets are stacked.)

Precision machines cut the electrodes into sheets about the size of letterhead stationery, but half as thick as a sheet of paper. From there, the electrodes will be stacked in an ultra-clean, ultra-dry environment.

The next series of steps assemble the electrodes into battery cells. Automated stacking machines pick up an anode, cathode, and a super-thin polymer separator and stack them in a series. The anode/cathode sandwich is then inserted into a metallic, silvery pouch and hermetically sealed on three edges. The last manufacturing step fills the cell with an electrolyte and seals the last side of the cell. The completed cell is about a fourth of an inch thick.

Before assembly into battery packs, the cells are tested. After leaving the assembly room, the cells are charged for the first time in what is called the formation process, and then the cells are aged. Only by aging can the cells be monitored to determine whether they meet all specifications. Once the cells have passed the final quality check, they are ready for assembly into the packs that will power a vehicle. The vehicle battery packs are built from sub-packs built from modules of about a dozen cells.

The flat cells are stacked into modules, and these, in turn, are assembled into sub-packs. Depending on the energy requirement for the vehicle, the final battery casing may consist of a couple of sub-packs or many. Fully electric vehicles require greater C-rates and thus need twice the number of sub-packs as a hybrid. The six sub-pack battery casings for EVs dominated the shop floor when I visited. As the sub-packs are grouped together in the final casing, the electronic hardware and software that monitors cell health and status and integrates the batteries with the power requirements of the vehicle are also installed.

The modular nature of the complete battery package has several advantages for both the manufacturer and consumer. On the manufacturing side, the voltage for the sub-pack is low enough that high-voltage gear isn't needed for the technicians until the last stage of assembly. For the consumer, a sub-pack can be removed and replaced in a couple of minutes should a cell go bad. Moreover, an 80-pound sub-pack is easier to ship back to the plant for diagnostics and repair than a complete, welded battery assembly that can weigh 600 pounds.

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Once EVs and HEVs have sufficient market penetration, and once EnerDel ramps up production to help meet the million vehicles or more in global annual unit sales, cell production and battery pack assembly can be geographically separated. While I did not discuss this with the EnerDel team, I could foresee a time when the cells would be manufactured in Indiana and then would age en-route to assembly facilities closer to the vehicle assembly and customer.

Who Killed the Electric Car?

Hendrix chuckled at my question and said, "It doesn't matter. What matters is that without that first foray into electric cars in the 1990s, the battery technology would not be as developed today. We have several of the folks who worked on that project. They were the pioneers."

Hendrix then talked about who composed the talent pool from which to draw to expand capacity, namely anyone with battery technology education or experience. "Auto industry experience is best. As a Hoosier, I'd like to hire regionally, but the talent is global." Buck agreed that they need to look globally for engineering talent.

Hendrix also talked about EnerDel's relationship with universities in the state like Purdue, Rose-Hulman, and Indiana University–Purdue University Indianapolis (IUPUI) and how engineering curriculum can be modified for the needs of the transforming industry: "We want these graduates to be ready to work on advanced batteries on their first day."

Whether the designers and engineers of the original electric car, GM's EV1, had the palpable enthusiasm of the team at EnerDel, I don't know. But if they could bottle their zeal, it would power the auto industry for a very long haul.

Notes

1. Most of this article was originally published as "Batteries of a Different Shape" by *Progressive Engineer*, an online magazine covering all disciplines of engineering in the Unites States: www.progressiveengineer.com/features/EnerDel.htm. It is reproduced with permission.
2. While six Indiana businesses (and a group of universities) were awarded grants for electric vehicle battery and component manufacturing in August 2009, they would not actually see the money for some time. According to information on the Department of Energy's Energy Efficiency and Renewable Energy website, awardees of funds for Congressionally Directed Projects must apply for their funds upon being selected to receive them. Remy, Inc. received final approval to use its $60.2 million on May 24, almost ten months after President Obama originally announced the grants in a speech in Elkhart (www.insideindianabusiness.com/newsitem.asp?id=41832).
3. www.wishtv.com/dpp/news/business/enerdel-receives-$18.5m-stimulus-grant-.
4. www.insideindianabusiness.com/newsitem.asp?ID=39737.
5. In late May, EnerDel announced a joint venture with China's largest auto parts producer, enabling EnerDel to break into the Chinese auto market: www.insideindianabusiness.com/newsitem.asp?id=41900.