PORTABLE POWER: FEATURES ABOUND, THANKS TO NEW

JUST TWO YEARS AGO, LITHIUM-ION CELLS MAY NOT HAVE MET YOUR SYSTEM'S POWER REQUIREMENTS. BUT TAKE ANOTHER LOOK; YOU MIGHT BE PLEASANTLY SURPRISED BY WHAT'S AVAILABLE NOW.

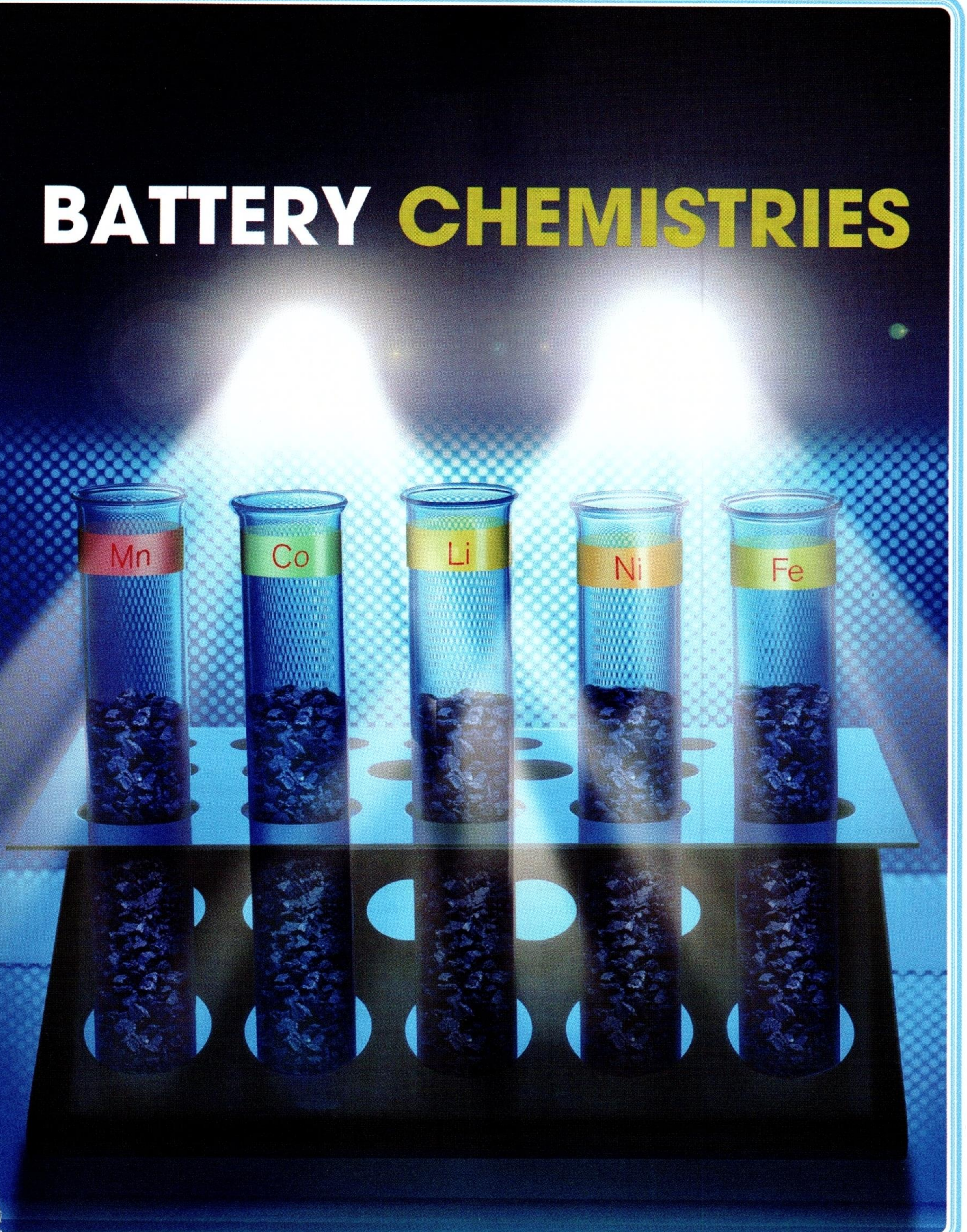
BY MARGERY CONNER • TECHNICAL EDITOR

Things are changing in the usually stodgy world of lithium-ion batteries. Two years ago, the laptop-battery market was the driving force in energy- and power-usage profiles for lithium-ion-battery packs (**Reference 1**). Now, cordless power tools rival laptops in lithium-ion-battery-market share. In 2005, judging by laptop features, laptop-computer vendors ranked the four main characteristics of a lithium-ion battery in descending order: energy storage, speed of power delivery, cost, and safety. A fifth, environmental impact, or "greenness," didn't even make the cut.

The most important energy requirement for laptops and other consumer-electronics products, such as cell phones and MP3 players, is energy-storage capacity. At a minimum, users want to be able to watch a feature movie on their laptops during cross-country flights. Second is the ability to quickly charge the device; laptop users are an impatient bunch. Third is cost: Users see battery packs as commodities rather than features that vendors can charge for. Granted, a laptop user will pay more for increased battery-powered work time, but this increased cost is often the result of clever circuit design and component selection rather than the inclusion of a battery pack with a higher energy capacity. Safety comes next. Although a basic level of safety is a given, some level of failure is acceptable. Manufacturers signaled their acceptance of a certain failure level when they began designing with lithium-ion cells, whose failure mode can be catastrophic.

Standard lithium-ion batteries use a cobalt oxide for the cathode. There are several permutations of this cobalt alloy, such as nickel-manganese cobalt, but the key ingredient is cobalt, which makes for the highest energy storage in the battery. Unfortunately, it also goes hand in hand with a volatile chemistry. Lithium-cobalt chemistries are highly combustible, and cell puncture or drawing too much current can trigger thermal runaway or even a fire. Although uncommon, lithium-ion-cell failures were the cause for

BATTERY CHEMISTRIES



the massive recall of products from Dell, Apple, and others.

Battery manufacturers recognize, however, that applications other than consumer devices, such as laptops and cell phones, have different profiles, and these applications have driven different features requiring different battery chemistries. The first challengers to laptops as drivers for battery technology were cordless-power tools. Power tools still require adequate energy capacity, but they also need large bursts of power at a high current rate. Power-tool users will pay a premium for eliminating the need for an extension cord annoyingly following them all over their work sites or shops. In the past, power-tool designers could get by with battery chemistry such as nickel cadmium, which is adequate for energy storage and can sustain large currents. But Europe's recently enacted ROHS (restriction-of-hazardous-substances) regulations ban most electronic equipment using heavy metals, such as cadmium. So, manufacturers can no longer sell products with "non-green" nickel-cadmium-battery packs. A new requirement for cordless power is also battery-charge- and discharge-cycle life, because users discard most consumer-electronics battery packs after three years, whereas power-tool users keep their equipment longer.

Battery companies A123 Systems, Valence Technology, Altair Nano, and E-One Moli Energy have each developed a lithium-ion chemistry that uses an iron-phosphate-based cathode. By eliminating the use of cobalt, iron-phosphate batteries sacrifice high energy density, but they gain the ability to support higher current and, thus, greater power. They also have no thermal-runaway problems. So, lithium-iron-phosphate batteries became available just as ROHS regulations went into effect. Power tools introduced a new power-usage profile into battery options and enabled other applications. Robin Tichy, PhD, technical-marketing manager at battery-pack-design house Micro Power, gives this example of how applications with common power-usage profiles can leverage battery technology: "Applications that have motors tend to fit the same high-power/high-current capability of power tools. Now, engineers can make a battery-powered version of a motorized application." For example, Valence's lithium-iron-phosphate-battery packs power new versions of the motorized Segway personal-mobility device.

All battery manufacturers are eyeing the enormous market potential of EVs (electric vehicles), HEVs (hybrid EVs), and PHEVs (plug-in HEVs). Unlike laptops, the No. 1 battery characteristic for any vehicle is safety. Although consumers will tolerate cell-phone or laptop battery packs' overheating and the—rarely—ensuing fire, they won't accept the potential explosion of tens of kilowatts and the resulting disaster in an EV. So, although lithium-ion-cobalt batteries are attractive for their energy-storage capability, their tendency to have thermal runaway has all but ruled them out for mainstream EVs and HEVs. An exception is the Tesla Motors' Roadster, which has a range of more than 200 miles and an acceleration of 0 to 60 mph in 4 seconds. Although it will use a lithium-ion-cell battery pack, the pack has elaborate power-control and -monitoring electronics. In addition, the high-end-performance car selling for more than $95,000 doesn't target typical consumers (**Reference 2**).

EVs rely completely on their batteries to store energy and use it to power their motor-driven wheels. HEVs rely on a combination of an internal combustion engine and a battery-powered motor. With the need to rapidly charge and discharge the battery, HEVs and PHEVs are closer in many ways to power tools than to laptops. PHEVs' energy requirements need to meet only a minimum energy capacity, in contrast with laptops, in which more is always better. PHEVs put energy density at the bottom, rather than the top, of their battery-features list.

General Motors' PHEV concept car, the Chevy Volt, will have an all-electric range of 40 miles. Most daily trips in the United States fall within this range, meaning that much of the car's travel will be all-electric. To support this 40-mile range, the Volt will have a 16-kW lithium-iron-phosphate battery. Like most other batteries, lithium-ion batteries operate best within a state-of-charge window: Rather than charge the battery to its theoretical maximum charge and then run it down to a total discharge, the Volt will charge each night from its ac outlet plug to 80% of its theoretical maximum and then discharge down to 30% of its maximum, resulting in a 40-mile range. Once the battery discharges to 30%, then the car's 1-liter internal combustion engine starts, but, rather than directly powering the wheels, the engine generates electricity to keep the battery charged at its 30% level (**Reference 3**). Lithium-iron-phosphate batteries provide "good-enough" energy capacity and have thousands of cycles of rapid charge and discharge currents, making them an enabling technology for PHEVs. For these vehicles, power capacity trumps energy.

Similarly, the battery for an HEV needs to provide power at the expense of energy storage. In city traffic, a battery is constantly charging or discharging, and reliance on the battery for an extended range is rare. A familiar example of an HEV is the Toyota Prius, which debuted in 2004 and is the most common hybrid on

AT A GLANCE

- Laptops are no longer the dominant application driving lithium-ion-cell development.
- Lithium-ion cells with cobalt cathodes provide high energy capacity; cells with iron phosphate provide high power and can sustain high charge and discharge rates.
- Cordless-power tools are big players, with electric cars coming on strong and driving research dollars.
- You can optimize for either energy or power—but not both.

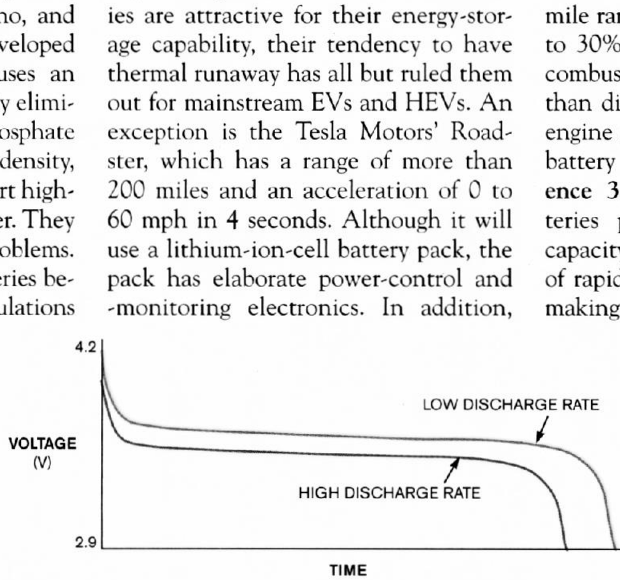


Figure 1 The curve for lithium-ion batteries illustrates a complex relationship based on discharge rate, age, temperature, and other factors.

the road today. The Prius uses a parallel-hybrid configuration, meaning that either the battery or the internal combustion engine can power the wheels. In practice, the battery mainly acts as a power assistant and harvester for the Prius' acceleration/deceleration: It can power the car in EV-only mode for only about two miles. The battery-use profile of such a hybrid places a premium on power, rather than energy, because the car uses the battery to frequently and quickly charge and discharge, rather than to fully charge and then power the car for a long trip. The Prius uses a nickel-metal-hydride battery, which in 2004 was the optimum battery chemistry for repeated rapid charge and discharge cycles.

Toyota is not standing still regarding new battery technologies, but it doesn't appear nearly as confident about lithium-ion-battery development as GM is. Toyota announced this year that it would introduce a hybrid with lithium-ion batteries in 2009, but later said that safety concerns about lithium ion would delay the introduction until 2011. Although Toyota has not provided any details about the type of lithium-ion-battery chemistry it's working on, the safety concerns seem to imply that lithium-ion cobalt is at least one of the chemistries it is investigating. This chemistry is also a strength of Toyota's current hybrid-battery-pack supplier, Panasonic. However, lithium-ion-cobalt batteries' strength is energy storage rather than power storage, so Toyota may lag behind GM in its PHEV-battery development.

Vendors of lithium-iron-phosphate batteries recognize this variation in power-versus-energy-capacity needs of EVs and HEVs. For example, A123 has introduced two battery types rather than a one-size-fits-all device. The 32113 M1 Ultra high-power cell targets HEVs, and the 32157 M1 HD cell uses a higher-energy-electrode design that provides greater battery-only range for PHEVs. Both battery types will deliver more than 10 years and 150,000 miles in engineered automotive-battery packs. A123 is providing batteries for the GM Saturn Vue PHEV-development program, which may reach production status as early as 2009. Users will be able to plug in the PHEV-version Vue at night, but the EV range is only approximately 10 miles.

Figure 2 The XO laptop will cost $100 to $200 and use alternative forms of power to help in the education of children in developing countries.

New battery chemistries and capabilities are not the only changes in portable power; the surrounding electronics are also improving and becoming more complex. Accurate fuel gauging has for years been the Achilles' heel of lithium-ion batteries. Lithium ion has an unpredictable discharge profile: You don't know how much charge remains because it varies, depending on the discharge rate, temperature, and life of the cell (**Figure 1**). Addressing that problem, Texas Instruments recently introduced a the bq27500 battery-fuel-gauge IC incorporating the company's Impedance Track technology, which directly measures the effects of discharge rate, temperature, age, and other factors on cell impedance. The technology, which TI claims offers 99% accuracy, uses these parameters to calculate the remaining battery capacity and full-charge capacity (**Reference 4**).

Battery-fuel-gauge ac-curacy is more important in medical devices than in any other application. Portable medical devices require a series of warning flags indicating a countdown to when the battery will discharge, with a highly accurate countdown beginning at 30 minutes before the battery will die. In the past, portable medical devices have used sealed-lead-acid backup batteries because they have a predictable constant-slope discharge. However, Micro Power puts lithium-ion-battery packs into medical devices because the Impedance Track technology allows a highly accurate gauging of the battery.

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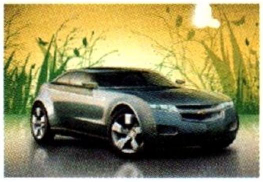
Alastair Johnson, vice president of marketing and sales for Valence, cautions that designers often overlook the broader issue of battery-management electronics. “For one hybrid-bus manufacturer that we work with, the batteries are as much as 25% of the total cost of the vehicle, which puts battery costs second only to the drive-system costs. Designers need to protect the battery system from any kind of stress. The better your battery-management system is at monitoring and carrying out small adjustments on your pack, the better your extension of the life of the battery, and the better the protection of the customer's ROI [return on investment].”



The Chevy Volt PHEV will have a range of 40 miles traveling on its battery alone.

Even as laptops cease to be the single dominant driver of battery requirements, the laptop itself is changing. Take, for example, the OLPC (One Laptop Per Child) organization's design effort. Its developers initially conceived the idea to provide $100 laptops to children in Third World countries, and the project has had to overcome an almost-overwhelming array of technical challenges. For example, how do you power a laptop in areas without reliable power utilities? The designers have come up with several options, both solar- and human-powered, which the OLPC's XO laptop makes feasible (**Figure 2**). It consumes 2W of nominal power—a tenth of today's standard laptop, according to the OLPC organization. OLPC asserts that the first alternative-energy source for the XO will be flexible thin-film solar panels from ECD Ovonics, rather than the more efficient but less rugged and more expensive silicon/crystalline-based solar panels. OLPC uses the phrase “virtually indestructible” when describing the panels, always a desirable feature for equipment that children use. The laptops will come with a manual crank from Freeplay and a lithium-iron-phosphate-battery pack from Gold Peak and BYD Batteries

What's ahead for batteries? Lithium

derivatives may not be the final word on energy density and safety. ZPower, which is developing a silver-zinc battery for the consumer market, demonstrated a prototype version powering a laptop at the recent Intel Developer Forum in the all-day section on computing. ZPower claims that its batteries will have an energy density of 200 Whr/kg and be completely nonflammable, with no nasty ingredients to end up in landfills. But silver is one of the most expensive battery materials. To offer these batteries at only a 20% or so premium over lithium ion, the company will establish a trade-in policy for its batteries and effectively recycle all of the silver, according to ZPower President Ross Dueber, PhD.

And portable energy storage is no longer limited to batteries. For example, Medis offers a liquid borohydride-powered microfuel cell, the 24-7 Power Pack, which can recharge small consumer electronics, such as cell phones and MP3 players. You activate the device by squeezing it, and it supplies 1W at 3.8 to 5V, enough to power an MP3 player for 60 to 80 hours. The small, recyclable power pack sells for $19.99. EDN

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