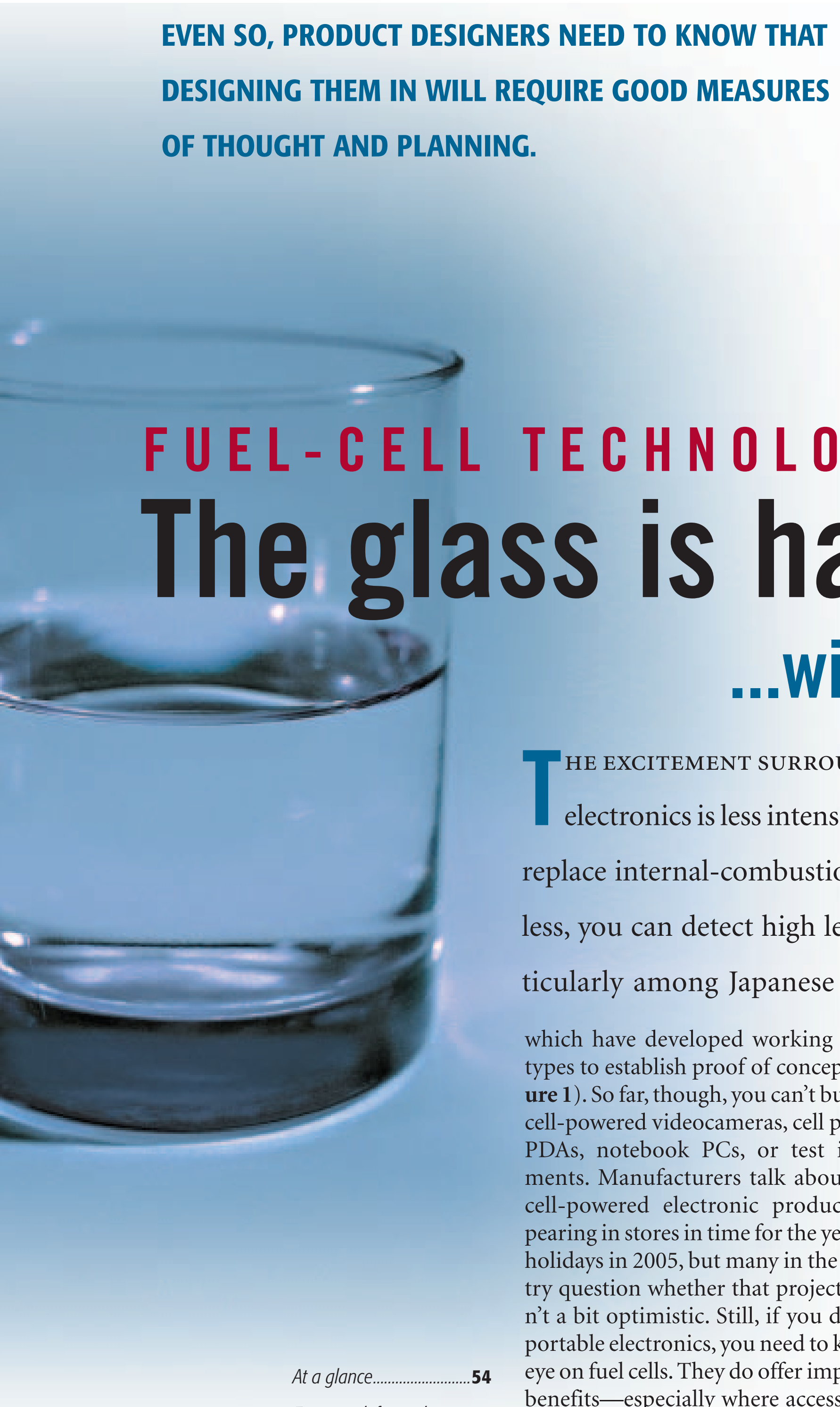
By Dan Strassberg, Contributing Technical Editor

FUEL CELLS FOR PORTABLE AND HANDHELD ELECTRONIC PRODUCTS HAVEN'T EVEN REACHED INFANCY. EVEN SO, PRODUCT DESIGNERS NEED TO KNOW THAT DESIGNING THEM IN WILL REQUIRE GOOD MEASURES OF THOUGHT AND PLANNING.



FUEL-CELL TECHNOLOGY

The glass is half full...

...with methanol fuel

THE EXCITEMENT SURROUNDING the debut of fuel cells in portable electronics is less intense than the talk about how the devices will replace internal-combustion engines in motor vehicles. Nevertheless, you can detect high levels of activity in certain quarters, particularly among Japanese notebook-PC manufacturers, some of which have developed working prototypes to establish proof of concept (**Figure 1**). So far, though, you can't buy fuel-cell-powered videocameras, cell phones, PDAs, notebook PCs, or test instruments. Manufacturers talk about fuel-cell-powered electronic products appearing in stores in time for the year-end holidays in 2005, but many in the industry question whether that projection isn't a bit optimistic. Still, if you develop portable electronics, you need to keep an eye on fuel cells. They do offer important benefits—especially where access to ac-mains power is problematic—and creating fuel-cell-powered electronic products will involve a lot more than merely designing batteries out and fuel cells in.

Although there are approximately a dozen fuel-cell types, only a few are candidates for use in portable and handheld electronic products. Some types are orders of magnitude too large and heavy and produce orders of magnitude more power than electronic applications require. In addition, open space must surround some high-power units because they operate at extremely high temperatures. In fact, nearly all of the work on fuel cells for applications in portable electronics has centered on one type: the DMFC (direct-methanol-fuel cell). Medis Technologies, a proponent of a different approach, which you can call a

DLFC (direct-liquid-fuel cell) or an AFC (alkaline-fuel cell), strongly believes that, for powering portable electronics, its technology is more practical and inherently less expensive than the DMFC.

You probably should think of fuel cells not as alternatives to rechargeable batteries, but as a complementary technology. Large numbers of portable-equipment users, who are accustomed to plugging their carry-around electronic units into ac wall sockets to recharge the batteries, will be reluctant to forgo this convenient method of refueling in favor of swapping out fuel cartridges or pouring liquid into a reservoir.

However, users who need charge life longer than that obtainable from battery-powered products of practical size and weight or who won't tote around fully charged replacement batteries and can't wait for recharging will likely be more receptive to carrying fuel cartridges or bottles of liquid fuel. This group includes many people besides mobile executives who want notebook PCs with a charge life greater than or equal to the approximately eight-hour duration of transcontinental airline flights. Others who would be receptive to fuel cartridges or liquid refueling include workers in industrial environments and warehouses, where finding sources of ac power can be inconvenient and finding time to recharge batteries is just about impossible.

AT A GLANCE

▷ Fuel cells are more likely to make gradual inroads into portable electronics than to displace batteries overnight.

▷ Unlike batteries, fuel cells can't recharge from the ac line. Therefore, fuel-cell-powered products that must also operate from ac-line power when it is available are larger, heavier, and costlier than similar products that use batteries when ac is unavailable.

▷ Designing a fuel-cell-powered version of what had been a battery-powered product involves more than just replacing the batteries with fuel cells.

▷ When you incorporate fuel cells within a densely packaged electronic product, the heat emitted by the fuel cells during operation may further complicate an already complex thermal-design problem.

▷ Failure to quickly standardize the dimensions and other key specifications of fuel cartridges for small fuel cells used in portable electronics could jeopardize the future of such power sources.

COST: INITIAL AND FUEL

Then there is the issue of cost. Fuel-cell manufacturers insist that, when they produce DMFCs and DLFCs in quantity, they will be competitive in cost with Li-ion (lithium-ion) batteries. There is little argument that the cost of refueling will be reasonable; the expendable materials—methanol for DMFCs; KOH (potassium hydroxide) for Medis' DLFCs—are inexpensive. (Medis identifies its consumable material as KOH, but chemists who don't work for the company suspect that Medis may be keeping secret the material's true composition.) And the cost of disposable cartridges—which a few manufacturers say constitute the only practical way of refueling small fuel cells or transporting small quantities of fuel—will probably be modest. But manufacturers are not yet mass-marketing commercial products, so it is difficult to gauge the accuracy of assertions of the low cost of the nonexpendable hardware. For example, Medis insists that DMFC proponents grossly understate the cost of addressing several issues that can make or break DMFC technology's suitability for powering portable electronics. Medis boasts that its DLFC technology presents no such issues.

You may be tempted to ask what prevents portable-equipment designers from building products that users can either recharge from the ac line *or* refuel by exchanging cartridges or adding liquid fuel. The answers are size, weight, and cost. Although several fuel-cell manufacturers have proposed an FCS (fuel-cell system) that you could substitute for a notebook PC's Li-ion battery (**Figure 2**), and Intel—among others—has proposed an FCS that would fit into a PC's removable-drive bay, these approaches are not without drawbacks. For example, a transcontinental traveler could wind up having to carry the PC's external "brick" power supply (to recharge the battery overnight to prepare for a day of presentations to customers) as well as the FCS and additional fuel cartridges (for use on the plane). Also, the traveler with the drive-bay FCS would have to forgo viewing a DVD movie while in flight because the PC can't simultaneously accommodate an optical drive and a fuel-cell power source.

The potential complexity of such situations certainly raises the question of why you shouldn't consider a technology other than fuel cells for powering electronic products over extended periods when access to ac mains is problematic. The ubiquitous (usually nonrechargeable) alkaline cell is a candidate for lower powered devices, such as PDAs. However, in applications such as notebook PCs that require more energy, you would have to replace alkaline batteries at inconveniently short intervals. Thus, the bulk and cost of the replacement batteries discourage alkaline cells' use in applications that require more than a few watt-hours per charge.

Furthermore, you may not be justified in expecting the first fuel-cell-powered electronic devices to run significantly longer on a supply of fuel than do rechargeable-battery-powered devices on fully charged batteries. Fuel-cell manufacturers expect their devices to initially exhibit rather modest running-time advantages over Li-ion batteries. These manufacturers insist, however, that the advantage will grow over time and that, a few years after their introduction, fuel cells will enjoy an advantage of at least 2-to-1 and perhaps more than 3-to-1 over batteries of the same *volume*. Moreover, say the fuel-cell manufacturers, if you compare fuel cells with Li-ion batteries of the same *weight*, the fuel cells' advantage will be significant even at the outset; DMFCs and DLFCs weigh less than Li-ion batteries of the same size.

BATTERY IMPROVEMENTS: ON THE HORIZON?

Another relevant area of controversy is whether rechargeable batteries have reached a performance plateau, and if so, how long they will remain at that plateau before making further advances. Compared with ICs—the traditional EE benchmark for the pace of technological innovation—battery technology has always evolved at a glacial pace. Indeed, the progression in less than a decade from NiCd (nickel-cadmium), to NiMH (nickel-metal-hydride), to Li-ion chemistry may have marked a significant acceleration of innovation in rechargeable batteries. However, fuel-cell manufacturers look for a "reversion to the mean";

that is, they expect 10 or 15 years of stability in battery technology before the next major innovation. Battery manufacturers suggest that their fuel-cell counterparts are engaging in wishful thinking—that new battery chemistries and batteries designed for much more rapid charging will appear in much less than 10 years. Neutral observers say that they are optimistic about significant progress in batteries within the next *two* years, but regard the likelihood as approximately 50%.

Clearly, rapid progress in batteries could impact—and might even derail—fuel cells' future in portable electronics. A small, light, reasonably priced battery capable of powering a notebook PC for eight hours and recharging from full discharge to full charge in, say, 90 seconds could seriously dampen fuel-cell manufacturers' optimism. Such a scenario is not altogether absurd. If a suitable battery chemistry existed, it would probably be possible to limit the peak charging current during a 15-minute quick charge to less than 50A. Some consider AliP (advanced lithium-polymer to be a candidate for this task. Whereas 50A is not a current to trifle with, currents this great are starting to become common in electronic systems, though so far only rarely in systems the size of notebook PCs. Moreover, if you were to limit the battery to a capacity typical of batteries for PCs manufactured in 2001, you probably could limit the peak quick-charge current to less than 20A.

Figure 1

This proof-of-concept model of a fuel-cell-powered notebook PC from NEC uses bottles, as opposed to plug-in cartridges, to supply the methanol fuel.

If you think about powering portable electronics, you realize that the target is moving quickly—and usually in the wrong direction. Despite constant improvements in process technology, which reduce the power that ICs require to deliver a given level of performance, users' demands for products with ever-more-complex feature sets result in an almost constant need to increase battery capacity. Only rarely have advances in the architecture of processors tailored for mobile applications, such as Intel's Pentium M, temporarily reversed this trend. In any event, the trend suggests that achieving eight-hour runtime in a 2008-model notebook PC will require significantly more energy than achieving the same runtime in a 2004 model.

ULTRACAPACITORS

The combination of fuel cells and ultracapacitors—small devices that, for their size, store prodigious amounts of energy (**Figure 3**)—appears to be a marriage made in heaven. Without a convenient method of storing energy to supply such peak loads as disk-drive spin-up, PCs, videocameras, and other electronic systems that present varying loads could require fuel cells sized to their peak, rather than their average, power demands. Typically, in the absence of an energy reservoir that can meet the peak demand, a product might need a fuel cell four or five times the size of one that could supply its average power needs, even though little or no change would occur in fuel usage, which mainly depends on the fuel cell's energy output.

Ultracapacitors with capacitance of many farads, 2.7V working voltage, internal resistance of no more than a few milliohms, and useful life of at least five years are off-the-shelf items today. An energy reservoir for a notebook PC whose

FOR MORE INFORMATION...

Worldwide, more than 1000 companies are developing fuel cells and fuel-cell components. Not all are working on products that you can use in small-portable-electronic applications. This box lists a few of the companies that are working on fuel cells or components suitable for portable electronics as well as several companies that manufacture ultracapacitors that you can use with fuel cells. A good resource for locating additional companies is the Interactive map of US fuel-cell companies listed below under Fuel-cell industry Web sites. **Reference 2** lists additional companies.

Avista
1-509-228-6500
www.avistalabs.com

Ballard Power Systems
1-313-583-5980
www.ballard.com

Direct Methanol Fuel Cell Corp
1-626-296-6310
www.dmfcc.com

DuPont
www.dupont.com
1-800-441-7515
1-302-774-1000

Energy Visions Inc
1-905-764-9457
www.energyvi.com

Fujitsu Microelectronics America Inc
1-408-737-5600
www.fma.fujitsu.com

Intel
1-800-628-8686
www.intel.com

Maxwell Technologies
1-858-503-3300
www.maxwell.com

Medis Technologies
1-212-935-8484
www.medistechnologies.com

Motorola
1-866-289-6686
www.motorola.com

MTI MicroFuel Cells
1-800-828-8210
1-518-533-2222
www.mtimicrofuelcells.com

Neah Power Systems
1-425-424-3324
www.neahpower.com

NEC USA Inc
1-212-326-2502
www.nec.com

NessCap
011-82-31-219-0682
www.nesscap.com

STMicroelectronics
1-781-861-2650
www.st.com

Texas Instruments
www.ti.com
1-800-336-5236

Toshiba
www.toshiba.com

WL Gore
1-800-311-3060
1-800-757-4673
www.goreelectronics.com

FUEL-CELL INDUSTRY WEB SITES

Bewag Fuel Cell Innovation Park
www.fuelcellpark.com

Eye for Fuel Cells
www.eyeforfuelcells.com

Fuel-Cell Information Center
www.fuelcells.org

Fuel Cell Today
www.fuelcelltoday.com

Fuel Cells Canada
www.fuelcellscanada.ca

Hydrogen Fuel-Cell Investor
www.h2fc.com

Interactive Map of US Fuel-Cell Companies
www.fuelcells.org/fcdevel.htm

fuel cells or batteries produce 10.8V (a common nominal-terminal voltage in Li-ion PC batteries) could consist of four 6F ultracapacitors in series—probably with a high-value resistor in parallel with each to ensure equal voltages across the four devices. In OEM quantities, the total cost of these four ultracaps would be less than $10—and, possibly, less than $5. During a 90-sec refueling or battery change, this energy reservoir would limit to approximately 1V the change in the unregulated dc voltage applied to the input of an operating PC's dc/dc power supply, thus enabling the computer to continue running without a break.

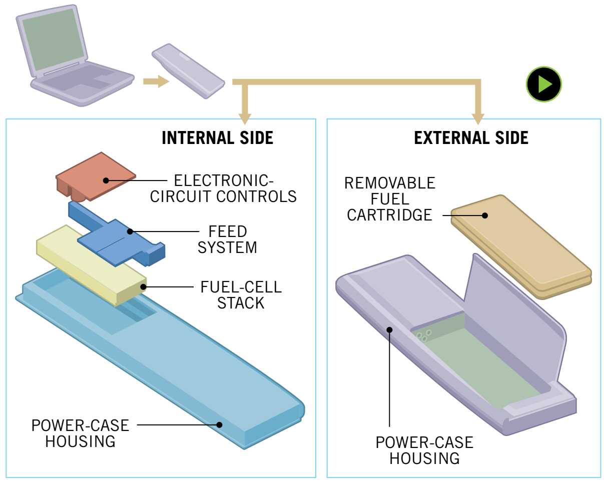


Figure 2 Neah Power Systems speculates that a fuel-cell power system for notebook PCs might replace existing Li-ion batteries. The left and right pictures show different views of the same object. In the right-hand picture, the fuel-cartridge compartment is on top, even though, in normal use, it would be on the PC's bottom surface.

In notebook PCs and other consumer products, even a $5 cost increase is significant, so product manufacturers will think long and hard before including the energy reservoir. In a product such as the PC whose user can choose either battery- or fuel-cell power, the energy reservoir might be part of the fuel-cell-based power-source assembly that accepts fuel cartridges and plugs into the drive bay. With that arrangement, customers who choose not to use fuel-cell power don't pay for the energy reservoir. However, the energy reservoir might benefit both battery and fuel-cell users because it could allow nonstop operation of the PC during both battery swaps and fuel-cartridge installation. The location of the energy reservoir is just one example of the many subtle and not-so-subtle architectural issues with which product designers must grapple if they are to make a successful transition to fuel-cell power.

Some DMFC manufacturers say that this DMFC-system block diagram (**Figure 4**) makes the system appear much more complex than necessary, which could explain why proponents of alternative fuel-cell systems use the diagram to make a case for their approaches. Of particular note are the three electromechanical components: a pump and two blowers for cooling. These electromechanical elements have finite life, are relatively costly, make a certain amount of noise, and have no counterparts in batteries for portable electronics.

MAKING FUEL CELLS WORK

A key component of a DMFC system is the PEM (proton-exchange membrane). A figure of merit for a PEM is the power the fuel cell can deliver divided by the PEM area. According to Neah Power Systems, competitors' PEMs produce insufficient power per unit area. Neah based its approach on IC-lithography and -fabrication technology. The technology uses microscopic holes etched into a silicon membrane, increasing the PEM's effective area by more than an order of magnitude (**Figure 5**).

Even if the fuel cells themselves need no active cooling devices, such as blowers, the presence of fuel cells in small, portable electronic products seems certain to present some cooling-related packaging challenges. Batteries in portable electronic systems exhibit little temperature rise, even when you charge them. On the other hand, fuel cells, when delivering power, dissipate at least as much power as they deliver to loads. In other words, a DMFC is no more than approximately 50% efficient in converting into electric power the energy the cell's internal chemical reaction releases. In products such as notebook PCs, which already present thermal-design challenges, the additional heat load that accompanies conversion from battery- to fuel-cell power is a most unwelcome byproduct.

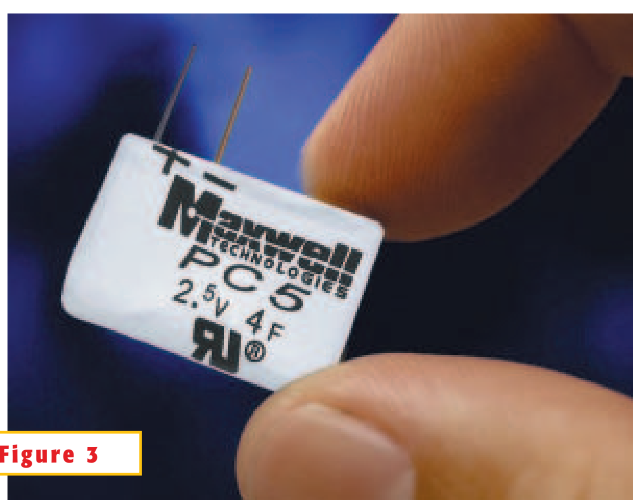


Figure 3 This 4F ultracapacitor from Maxwell measures 17×24×4.5 mm and weighs 5.5g. According to the manufacturer, although officially rated at 2.5V, such units last for many years and do not fail catastrophically when operated at 2.7V. Thus, four units in series act as a 1F energy reservoir, which supplies peak-current demand in a fuel-cell system that replaces a 10.8V, three-cell Li-ion battery.

Another unwelcome aspect of fuel cells is transportation of the fuel. Under US government and international regulations, airline passengers cannot bring methanol, the fuel for DMFCs, onboard commercial airliners. DMFC manufacturers are confident that, once they demonstrate the safety of transporting methanol, especially in small cartridges, the rules will change. A related issue is standardization of the cartridges. The PC industry has a poor record of standardizing disposable supplies. Nevertheless, users need standardized fuel cartridges in much the same way that they need standard alkaline batteries. Lack of standardization greatly diminishes the likelihood of your quickly obtaining a replacement fuel cartridge when and where you need it and probably results in higher prices. Although the cartridges might embody proprietary technology, which could, for example, allow different manufacturers' cartridges to provide different running times, production of fuel cartridges whose dimensions and contents are unique to product models appears to benefit nobody except the cartridge suppliers, and it might not benefit even them.

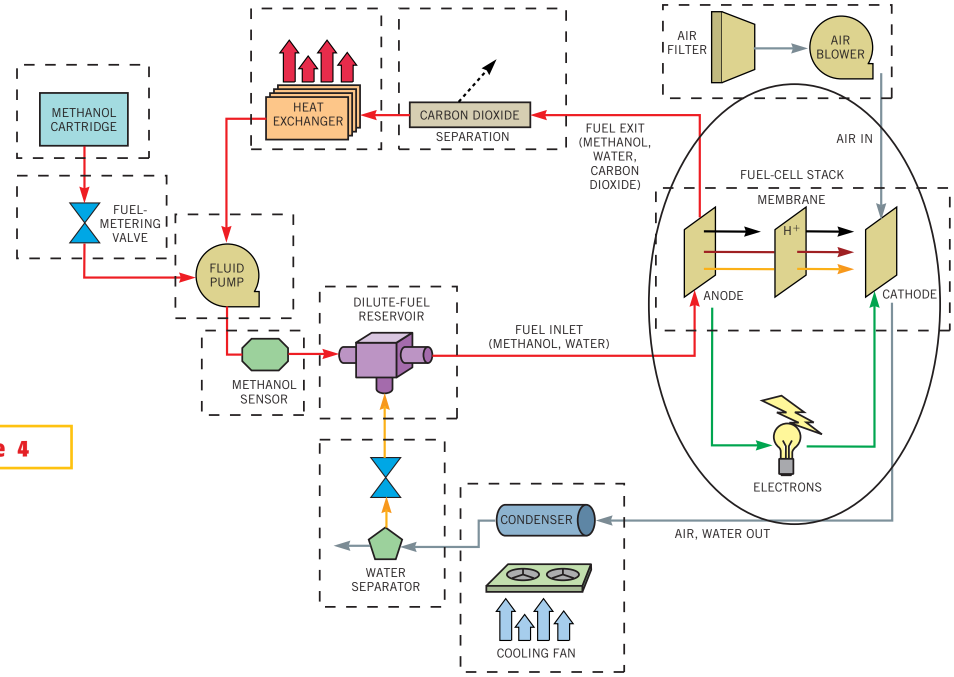


Figure 4

Although several manufacturers of direct-methanol fuel cells criticize this figure for making DMFCs appear too complex and expensive, the figure does reveal some of the technical challenges in designing a working system. Apparently, though, some DMFC systems don't need all of the functional blocks shown (courtesy Intel and Medis).

It should by now be obvious that the introduction of fuel cells into portable electronics raises infrastructure issues that the industry can effectively deal with only if many companies cooperate. Fuel cells are unlikely to take the electronics industry by storm overnight. Several companies recommend—and at least one is already pursuing—a phased approach. Phase 1 will see the introduction of fuel-cell-powered battery chargers. These units need not fit inside any existing product. In the case of notebook PCs, they will connect via the standardized connectors that you now use to connect to ac-powered "brick" supplies and will provide power to recharge batteries when ac power is unavailable. Phase 2 is likely to see the introduction of fuel-cell-powered units, such as that in **Figure 2**, which can replace existing batteries. Phase 3 might see the introduction of fuel-cell-based power systems that fit into notebook PCs' standardized removable-device bays. Phase 4 could see the introduction of electronic products that integrate more—and perhaps all—of the fuel-cell power system except for the plug-in fuel cartridge.

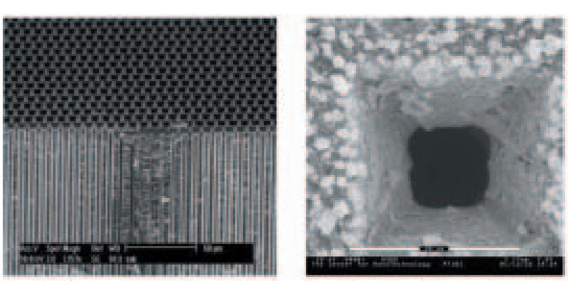


Figure 5 **Neah Power Systems uses 3-D IC-lithography and -fabrication technology to give its silicon proton-exchange membranes surface areas at least an order of magnitude greater than those of equal-sized membranes that other methods use. Neah says that its direct-methanol fuel cells owe their outstanding performance to the membranes.**

Based on Medis' announcement of a fuel-cell-based battery charger for handheld devices, such as PDAs, Phase 1 has already begun. The unit, whose volume is approximately equal to that of a 12-oz soft-drink can, uses the company's DLFC technology. In view of a complaint you often hear from videocamera owners—that whenever they want to use their cameras, the batteries are discharged and no ac outlet is handy—a device of this sort, capable of recharging videocamera batteries, would quickly find a receptive audience. □

References

1. Titus, Jon, "Fuel cells," *ECN,* March 2004, pg 27.

2. PricewaterhouseCoopers LLP, *2003 fuel-cell industry survey: A survey of 2002 financial results of North American public fuel-cell companies*, www.pwc.com/ca.

3. You can find a list of companies that exhibited fuel cells and related products at the recent Hannover Fair in Germany at the Web version of this article at www.edn.com.

Author's biography

Contributing Technical Editor Dan Strassberg holds a bachelor's of science in electrical engineering from Rensselaer Polytechnic Institute (Troy, NY) and a master's of science in electrical engineering from the Massachusetts Institute of Technology (Cambridge). He is a life member of the IEEE and of the NSPE (National Society of Professional Engineers). You can reach him at StrassbergEDN@att.net.

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