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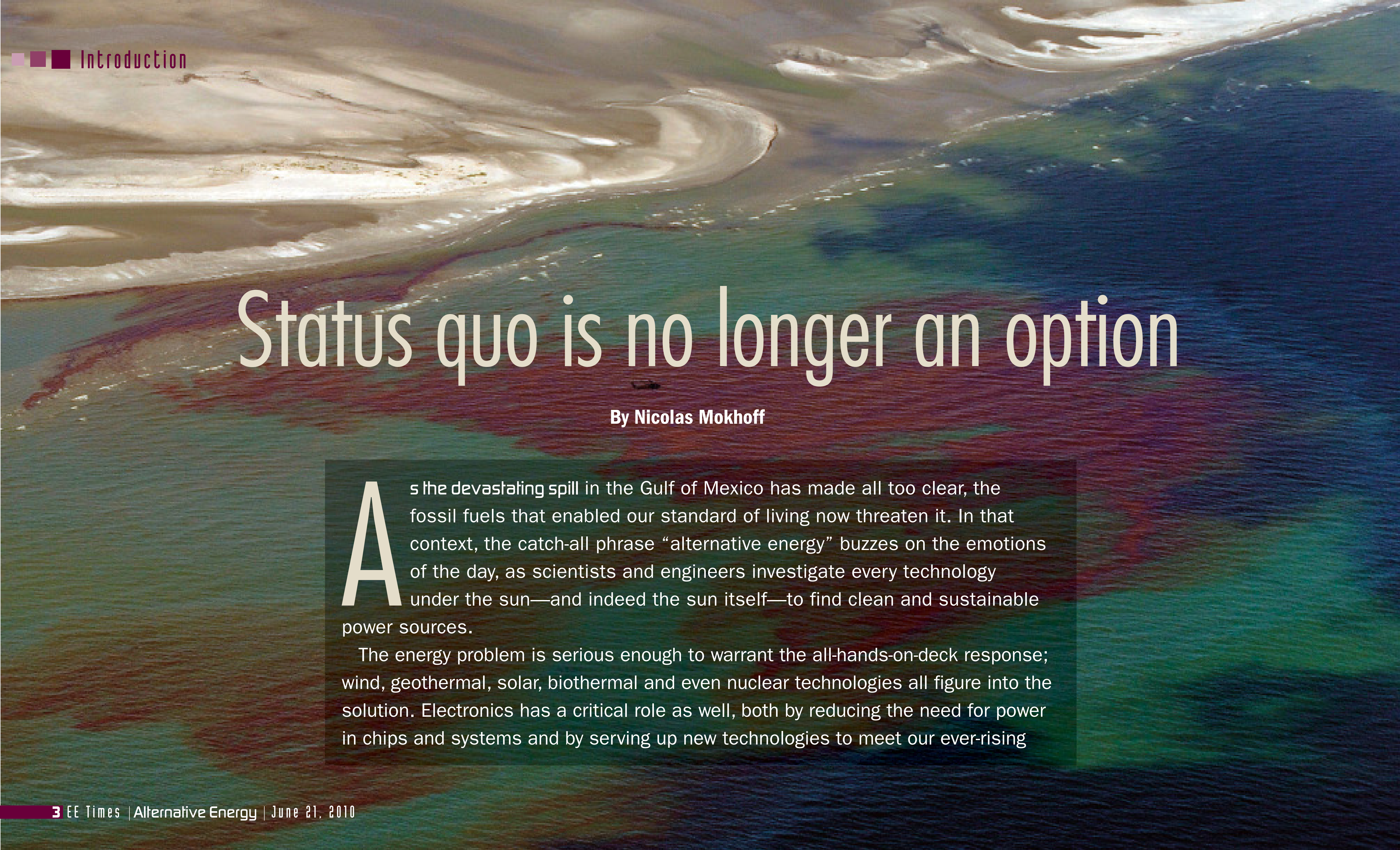


Status quo is no longer an option

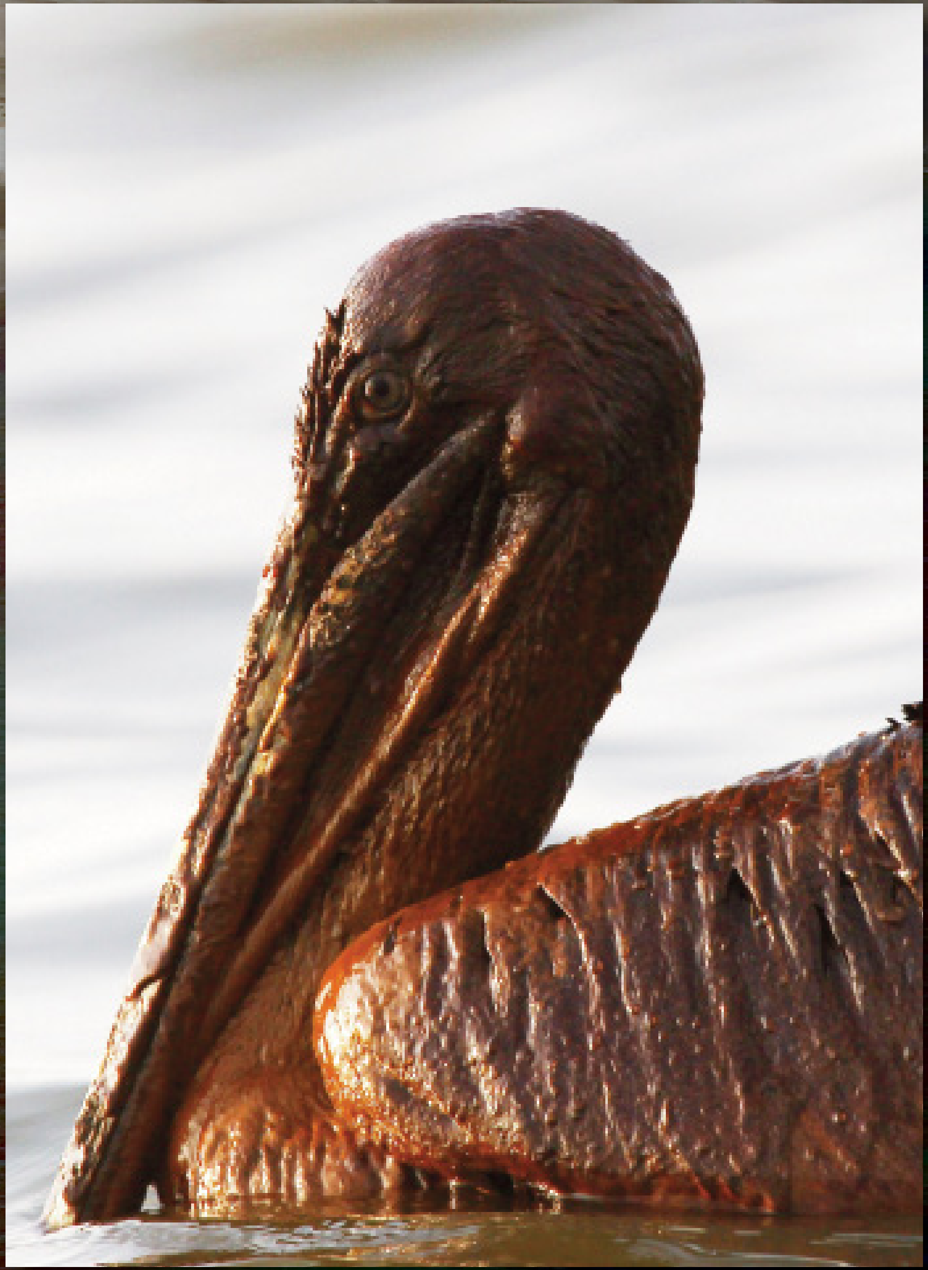
By Nicolas Mokhoff

As the devastating spill in the Gulf of Mexico has made all too clear, the fossil fuels that enabled our standard of living now threaten it. In that context, the catch-all phrase “alternative energy” buzzes on the emotions of the day, as scientists and engineers investigate every technology under the sun—and indeed the sun itself—to find clean and sustainable power sources.

The energy problem is serious enough to warrant the all-hands-on-deck response; wind, geothermal, solar, biothermal and even nuclear technologies all figure into the solution. Electronics has a critical role as well, both by reducing the need for power in chips and systems and by serving up new technologies to meet our ever-rising energy needs.

The ecological disaster in the gulf is the result of an April 20 explosion aboard a drilling rig that subsequently burned for two days and sank, causing an undersea pipe to rupture. U.S. Interior Secretary Ken Salazar, in remarks on the federal government's response to the spill, noted that President Obama "has been talking about the need for a comprehensive energy plan that includes a range of sources, such as solar power and wind, with oil and gas as part of that portfolio," according to a CNN report.

During the 2008 campaign, Obama had voiced lofty goals for U.S. energy policy under his envisioned administration. Policy statements are the politicians' bailiwick; when real solutions are required, engineers are called upon. Salazar noted that "the best scientists in the world" are working on the response to the crisis in the gulf. And technologists worldwide are working to kick humanity's petroleum habit.



For many developing energy technologies, it will be the control electronics that will provide practical results, measured in saved watts, lower current and clever voltage schemes. This special issue explores the innovations that will offer both short- and long-term energy solutions.

A recent technical training event held by Arrow Electronics and Texas Instruments offered insight into how chip vendors

are addressing alternative energy requirements in the short term. For example, components are being developed for RF systems that adhere to evolving powerline communications standards.

Other solutions include:

- power management and battery-charging ICs that provide dynamic power management to charge the battery while still charging the system;
- autonomous self-powered systems and sensors based on energy-harvesting techniques;
- energy management methods that maximize solar energy system efficiency;
- a mix of processing elements and discrete components for optimizing system performance in smart grid systems; and
- power management components to support the use of LEDs in general display lighting.

Appliances that work more efficiently can slash energy usage and costs. Toward that end, a single-phase motor efficiency controller being developed by Las Vegas-based Power Efficiency Corp. is intended to keep the motor running at a constant operating speed but reduce the current and voltage when it detects lighter-than-usual capacity, as in the case of a sparsely loaded washing machine. When the load on the motor increases, the controller would boost power to avoid a stall.

This "cruise control" for electric motors, in a device smaller than a business card, could reduce the machines' electricity consumption by as much as 25 percent, according to the company.

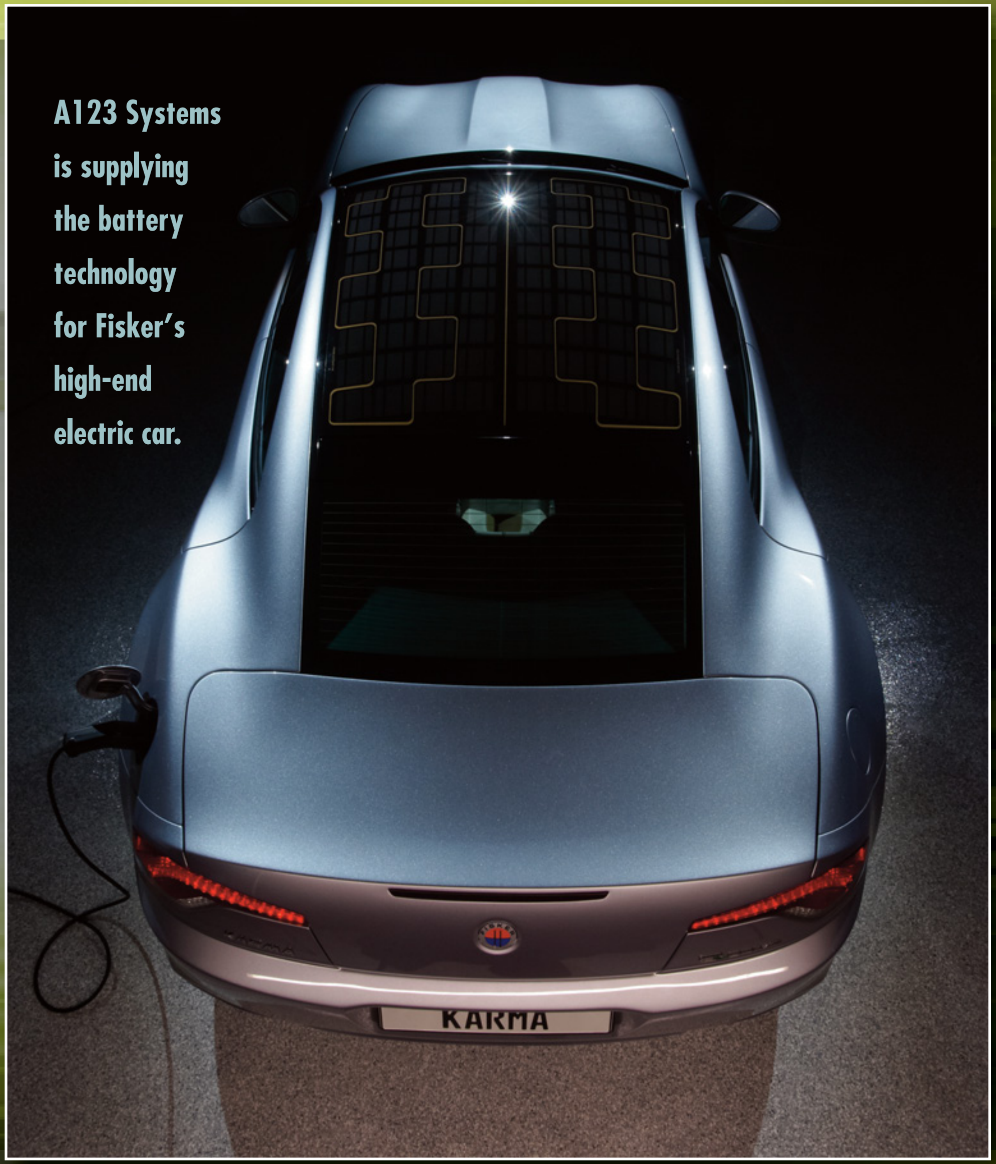
"Energy efficiency is the low-hanging fruit of energy solutions," said Steven Strasser, chairman and CEO of Power Efficiency. "It is much less expensive, destructive and time-intensive to reduce energy demand through efficiency than to increase energy supply through new power plants and transmission lines."

With the massive oil slick in the gulf underscoring our need for options, alternative energy R&D is in full swing. ▪

Batteries are expanding beyond today's notebook computers and cell phones to the coming generation of electric vehicles and, further out, to giant energy storage systems for the smart grid. Much of the activity centers on lithium ion, but researchers are exploring a range of other chemistries.

"It's a pretty exciting time for the deployment of energy storage systems, particularly for the grid, since systems are emerging that we didn't have a few years ago, [with] lithium-ion and flow batteries and other chemistries finding their way out of the labs," said Dan Rastler, a battery specialist with the Electric Power Research Institute (EPRI), a nonprofit R&D group supported by electric utilities.

"Our goal by 2015 is to have proven capabilities and options that can be deployed by our

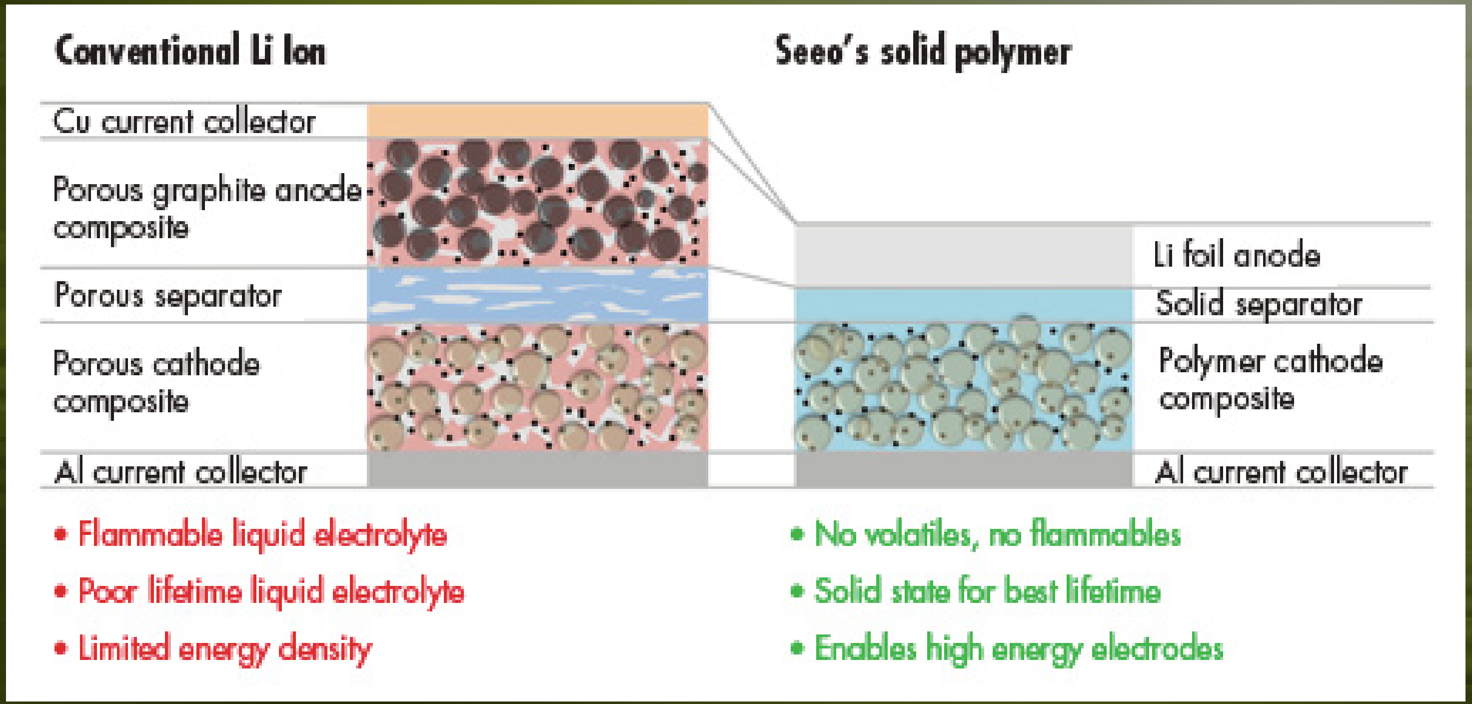


A123 Systems is supplying the battery technology for Fisker's high-end electric car.

industry," Rastler said.

The excitement has attracted entrepreneurs such as microprocessor veteran Atiq Raza, interim chief executive of lithium-ion battery startup Seeo (Berkeley, Calif.). As an entrepreneur in residence at cleantech firm Khosla Ventures, Raza is also exploring such options as an energy storage system that combines batteries and ultracapacitors.

"There is a tremendous need in the world to make batteries with higher energy density, safety and a high-speed way of charging and discharging," Raza said. "So we need two kinds of batteries: one with at least 10 times the energy



Seeo uses a solid polymer electrolyte to improve the safety, energy density and charge cycle life of its lithium-ion battery.

The Xtreme Power system provides a comprehensive solution for more efficient use of power generation, transmission and distribution resources.

density we have today, and a battery or ultracap that allows fast charging and discharging."

Work in lithium-ion batteries is "the most exciting of all the activities," said Rastler of EPRI. "It's the battery of choice for plug-in hybrids and EVs, so there's a significant amount of capital investment going into factories to make lithium-ion batteries for vehicles, and the OEMs that make these batteries are very interested in using that capacity to serve stationary apps on the grid."

One of EPRI's goals in 2010 is to complete a feasibility study examining that thesis, he said. "We are very interested in this big wave of lithium ion for transportation, and we want to see if everything is lined up like we think it is."

Tesla Motors sparked the enthusiasm for big lithium-ion batteries by creating a pack powerful enough to fuel a car. The Tesla Roadster uses 6,831 standard laptop 18650 lithium-ion cells to create a 900-pound battery pack that can propel the car an estimated 245 miles per charge. The battery has an estimated lifetime of 100,000 miles.

Tesla's innovation was finding a way to wrap what Raza called "an efficient refrigerator" around the massive pile of lithium-ion cells. The package safeguards the powerful pack from the kind of thermal-runaway problems that have caused laptops, battery factories in Canada and Japan, and even a UPS plane on the tarmac to go up in flames.

A handful of top battery makers are following Tesla's lead to power other electric vehicles emerging this year. NEC has developed the battery for the Nissan Leaf, and LG Chemical is supplying the pack for the Chevy Volt.

Many believe the next big step is a move to new variants of the lithium-ion chemistry and to so-called prismatic cells—typically flat, 2 x 4-inch rectangles that can be more efficiently packaged into big batteries. "That's what's being used for the

Tesla Motors developed a proprietary Li-ion battery that proved the technology could power an electric-only car.

Leaf and the Volt, and that pathway we think will be more mainstream," said Rastler.

A123 Systems, a U.S. battery startup that garnered a billion-dollar market cap when it went public last year, is pursuing a variety of cell designs, including 18650s and prismatics. The company will be a test case for whether the near-term hopes for lithium-ion batteries in EVs will be a springboard for an even larger market in smart grid storage.

Jason Forcier, vice president of the automotive group at A123, noted the market in 2009 for lithium-ion batteries in transportation "was basically nothing" but is expected to grow to a whopping $70 billion by 2020.

On the grid

A variety of smart grid applications are emerging for energy storage, each with its own requirements. The most commonly cited app is for backing up energy from solar farms for use at night or for balancing voltage levels during cloudy periods.

Rastler of EPRI foresees other apps, spanning a range from residential systems of a few dozen watts that back up rooftop solar panels to megawatt banks used to regulate frequency on the grid or balance wholesale supply and demand. In the middle, trailers with hundreds of kilowatts of storage could back up neighborhood transformers.

Market watcher ABI Research estimates there is already more than 128 GW of energy storage currently attached to the power grid worldwide, increasing to nearly 150 GW by 2015.

Raza also foresees rapid growth for wireless basestations, many of which will need battery backup. "If you count all the energy requirements for all these applications, they actually exceed even the automotive requirements," he said.

Engineers are fine-tuning lithium-ion chemistries and packages for those apps. But the technology has its limits. For example, researchers are working on grid-scale systems capable of supplying megawatts of energy for as long as 4 hours, a feat still out of reach for lithium ion.

In addition, lithium ion's cost, especially in the large packs, is still high, for several reasons. Electronics are needed to control the battery's heat and compensate for uneven charging of individual cells. Manufacturing volumes for the large batteries are still low. And the energy density of lithium ion is low relative to traditional energy sources.

Raza notes the battery in the Volt is expected to have an energy density of 80 kilowatt-hours per kilogram. That's head and shoulders above the 25 kWh/kg of today's lithium batteries, but it's almost laughable compared with the 12,000 kWh/kg energy density of a tank of gasoline.

Rastler said improvements on many fronts should ultimately get car- and grid-scale lithium ion down to the $300 **per kilowatt-hour** costs of today's laptop batteries. Car-sized lithium-ion batteries cost about $750/kWh today.

"We think costs could come down 50 percent and energy density could double in next five years," said Forcier of A123. "A lot of that is driven by volume manufacturing, better materials and better mechanical configuration of cells."

This is Xtreme Power's Dynamic Power Resource. The company's proprietary PowerCell storage technology sits in one side of the crate; the monitoring and management controls sit in the other. Dynamic Power Resources are uniquely compact; other storage mechanisms require massive amounts of land. As is shown here, the Dynamic Power Resource is roughly the size of a shipping container.

A123 makes its own chemical powders and uses ion phosphate to eliminate the extra oxygen that causes thermal runaway.

Raza's startup Seeo is taking the novel approach of using a solid polymer rather than a liquid electrolyte. The new material opens the door to a battery that is safer, supports more charge cycles and has greater energy density, Raza claims, but it is still in a prototype phase.

Lead acid comeback?

A host of other approaches are in the works for energy storage on the grid. Rastler said advanced versions of the workhorse lead acid battery are in development as storage for solar farms, including a solid-state lead acid battery from Xtreme Power and one from another company that uses ultracapacitors.

Three or four companies are working on zinc-air batteries for the grid. Some utilities have already installed energy systems based on sodium sulfur batteries. General Electric has used sodium nickel metal chloride batteries in electric buses in Europe and is working on versions for utilities, Rastler said.

Several companies are working on flow batteries that could pump electrolyte from giant tanks through battery cells. Such designs could scale to utility requirements, supplying megawatts of power for up to 10 hours, simply by creating larger electrolyte tanks.

Chemistries being used for flow batteries include zinc chlorine and iron chrome. EPRI hopes to demonstrate a zinc bromine flow battery this summer.

Batteries cannot handle some of the biggest bulk energy storage jobs on the grid. For example, researchers are exploring ways of using compressed air for energy storage to back up big wind farms. ▪

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Today, even the most advanced wireless devices are designed to be periodically tethered to their rechargers with a power cord. In the near future, however, all your wireless devices—phone, laptop, Bluetooth headset, remote controls, game joysticks and more—will be powered by energy beacons that will beam directly to devices, effectively cutting the last power cord. Even light bulbs will eventually be powered wirelessly.

Nikola Tesla pondered the dream of wireless energy transfer as long ago as 1899, but only recently has the concept become technologically feasible, according to Massachusetts Institute of Technology professor Marin Soljacic. In 2007, Soljacic demonstrated how resonant magnetic coupling can wirelessly transfer energy. His work inspired Intel's 2008

Top: Fulton Innovations' eCoupled wireless inductive coupling with intelligent resonant frequency tuning optimizes power transfers to Apple's iPhone.

Bottom: Car-mounted recharging stations will use Fulton Innovations' eCoupled wireless inductive coupling with intelligent resonant frequency tuning.

demonstration of a wirelessly illuminated light bulb.

Intel, which likens the technique to a singer's breaking a glass by hitting a pitch that matches the resonant frequency of the glass, has discovered that resonant coupling works best at an optimal distance—a "sweet spot." Details will appear in next month's *IEEE Transactions on Industrial Electronics*.

"Intuitively, you would think that the closer the coils, the more efficient the coupling," said Intel Research principal engineer Joshua Smith. "Not true. Depending on the size of the coil and the frequency being used, there is an optimal distance where very high efficiency is achieved."

Intel is investigating how to tune the coupling in real-time in order to keep wirelessly powered devices in the sweet spot, with an eye toward developing control systems that would automatically ensure optimal resonant coupling.

MIT's Soljacic, whom Intel cites in its research, has founded a company, WiTricity Corp. (Watertown, Mass.), that has licensed its patented technology to about two dozen OEMs. Some of the licensees plan to introduce products later this year. Most are concentrating on recharging apps for mobile consumer devices, but some WiTricity licensees are aiming higher. At this year's Consumer Electronics Show, for example, Haier Group (Qingdao, China) demonstrated an untethered

32-inch flat panel TV that wirelessly received both HDMI data and WiTricity power.

"Our OEMs run the gamut from consumer electronics to industrial and military applications," said WiTricity CEO Eric Giler. "At the low end of the power spectrum, there are all these mobile devices that need to be recharged, as well as low-power devices that use disposable batteries—like keyboards and mice, for example—that we can power wirelessly. And at the high end, we have been able to deliver 3 kW to a plug-in electric automobile."

WiTricity hopes to offer solutions for every device type that uses batteries today—and, like Intel, it aspires to cast wireless energy transfer into silicon.

"We are actively engaged with a number of chip manufacturers who are planning to produce WiTricity-enabled chips," said Giler. "These well-known semiconductor companies will put everything an OEM needs onto one chip, except for the resonator and some of the power electronics."

Several other patented technologies will compete with resonant magnetic coupling. Duracell's myGrid, using technology licensed from WildCharge, cleverly arranges a conductive grid so that it will always match the electrode spacing of the user-added "warts" on a mobile device. Lay down a wart-equipped mobile device anywhere on the pad, and its electrodes will

WiTricity's resonant magnetic coupling offers efficiencies as high as inductive coupling, but at distances of up to several feet. Here, the technique wirelessly powers an LCD TV in a prototype demonstrated by Haier Group Co. (Qingdao, China) at CES 2010.

make contact and begin charging, enabling wireless power transfer from the myGrid electrode to the wart electrode at almost 100 percent efficiency.

Also already in the marketplace are inductive charging pads made by Powermat USA (Commerce Township, Mich.), a joint venture between Michigan-based HoMedics and Israel's PowerMat Ltd.

"We now have over 40 patents applied for and are achieving from 80 to 92 percent efficiency," said Powermat vice president David Kelly. "We are working on solutions that transmit both the power and the data to devices wirelessly, and we have aspirations to recharge electric cars someday too."

Duracell's myGrid wireless recharger allows handheld devices to be laid in any orientation on its surface. Energy is transferred with nearly 100 percent efficiency as a result of the direct-contact conductive connection.

Powermat's inductive technology works much as a transformer does: Coils of wire on the transmit side set up a magnetic field that induces a current in the receiver's coil, which is attached to its battery. Mobile phone users merely replace their existing battery and door with a Powermat version that includes the receiver coil from which current is induced by the transmit coil in the Powermat. The upside is the relatively high efficiencies that can be achieved with wireless power transfer by induction, but the downside is that mobile devices have to be positioned with millimeter precision to achieve those high efficiency marks.

Powermat claims to have delivered more than 750,000 units since introducing its technology late last year. Those kinds of numbers have attracted rivals, principally Fulton Innovation (Ada, Mich.), whose eCoupled technology also uses inductive coupling.

Fulton claims its approach is superior because it includes an intelligent resonant frequency tuning system that optimizes power transfers in real-time to achieve up to 98 percent efficiency. Fulton has attracted such big-name partners as Bosch, Energizer, Motorola and Texas Instruments.

For a roundup of companies working on inductive wireless power technologies, visit the Wireless Power Consortium, a trade group whose 30-plus members are working toward an open standard.

Another promising method for wirelessly powering household devices uses near-infrared laser diodes. According to developer PowerBeam Inc. (Mountain View, Calif.), the invisible, eye-safe power beams can be precisely aimed at devices, such as wall-mounted TVs, to eliminate unsightly cords. On the receiving end, a solar-cell like receiver converts the incident laser beam

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into electricity.

"We use long-IR laser diodes on the transmit side that can be beamed over long distances, up to 30 feet," said PowerBeam co-founder Christopher Surdi.

PowerBeam offers three evaluation kits for designing real applications: a 100-mW kit for sensors, a 2.5-W kit for small mobile devices and a 10-W kit for powering appliances. The company targets OEMs that develop wireless sensors, keyboards, mice, mobile phones, speakers, TVs and signage.

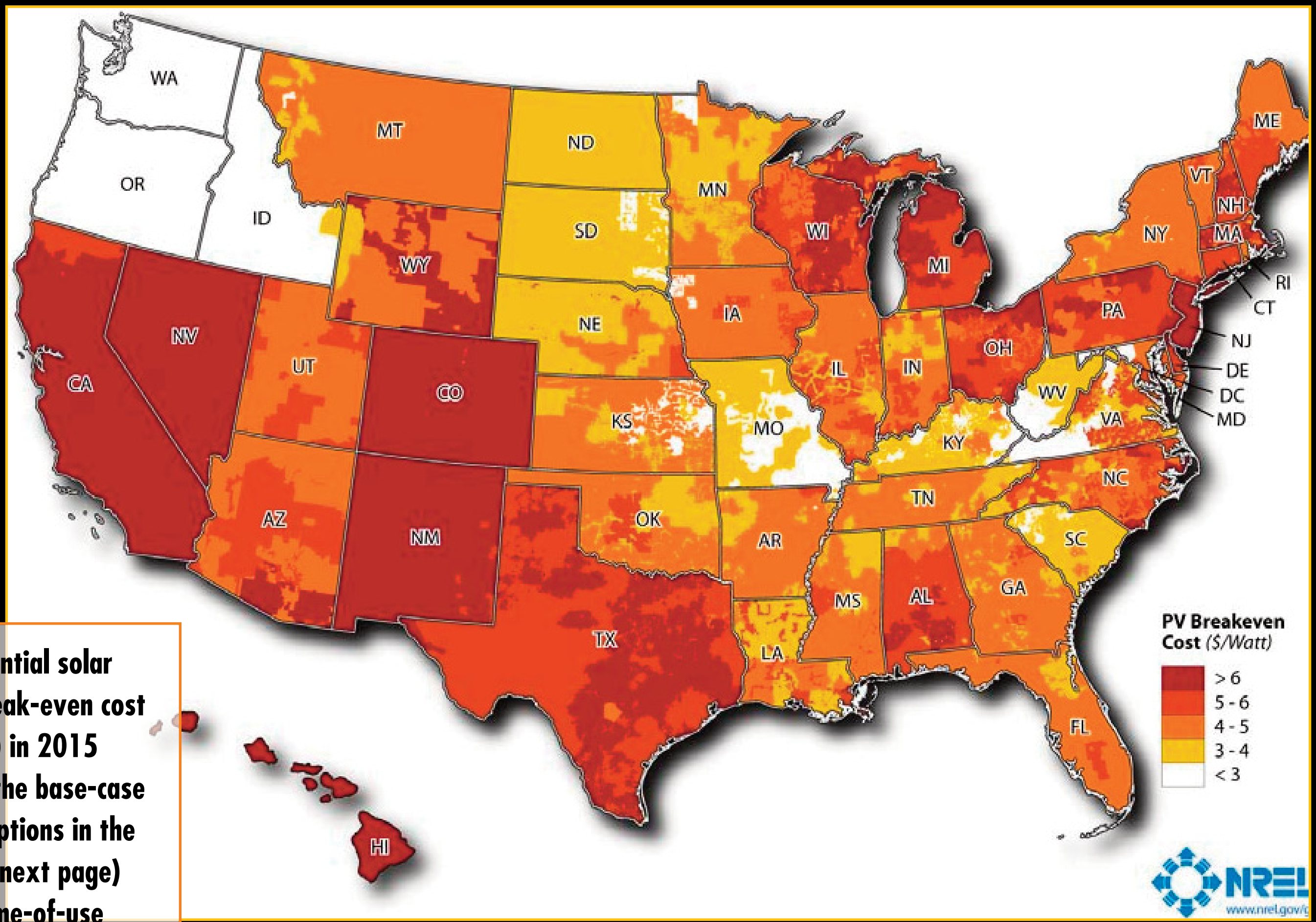
Its systems are completely safe, according to Surdi, because they automatically turn off whenever the beam is interrupted.

Inductive coupling with resonant frequency tuning can recharge almost any battery-operated handheld device, including remote controls, merely by laying them on a special pad.

Another wireless power transfer method taps RF to achieve distances as far as PowerBeam's but without requiring line-of-sight connections. Powercast Corp. (Pittsburgh) says its Powerharvester receiver chips can either recharge batteries or eliminate them altogether. A single RF power beacon can transfer energy to any number of receiver chips within its broadcast range, which can be hundreds or even thousands of feet.

The downside of RF is that FCC regulations cap transmitters at 5 W. That restriction, in turn, limits the amount of power transferrable to devices to the milliwatt range.

As a result, the RF approaches are suitable only for specialized applications such as wireless sensor networks. ▪



Residential solar PV break-even cost ($/W) in 2015 using the base-case assumptions in the table (next page) and time-of-use rates in all states.

I predict solar PV not only will see high growth in utility, commercial and residential applications but will also expand at a rapid rate for off-grid industrial and consumer apps. Already, off-grid solar applications such as solar lighting, solar traffic controls and signage, and consumer charging devices are becoming more common.

One strong reason for growth of the solar PV industry will be energy policy. While federal energy policy is largely lacking (with the exception of tax credits), it is a different story at the state level. States are enacting what are known as RPS (renewable portfolio standards) policies—mandates that a particular percentage of energy be produced via renewable sources by a particular date. Eleven states have already enacted RPS requirements of 20 percent or higher by 2020. Six more states have requirements of 20 percent

PV sensitivity cases in 2015. The values in the table are not intended to represent all possible scenarios but were chosen to provide a reasonable range of values for each parameter.

[a]O&M values were based on inverter replacements at 10 and 20 years (2025 and 2035). Solar program goals (base case) assumed $297/kW in 2025 and $280/kW in 2030. Energy Information Administration values used were $947/kW and $960/kW for 2025 and 2030, respectively.

[b]Avoided cost assumes that PV offsets only the fuel cost of a mix of combined-cycle and single-cycle gas turbines with a composite heat rate of 8,000 BTUs/kW, with no credit received for capacity or T&D losses. For further discussion of avoided fuels, see "Quantifying avoided fuel use and emissions from photovoltaic generation in the western United States" in *Environmental Science and Technology* (Denholm, Margolis and Milford 2009). We used the projected natural gas price in 2015 from the Energy Information Administration's "2009 Annual Energy Outlook" which results in a national average avoided cost of 5.4 cents/kWh.

<table>
<tr><th colspan="2" rowspan="2">Base Case</th><th colspan="2">Finance</th><th colspan="2">Technical</th><th colspan="2">Electricity</th><th colspan="2">Policy</th></tr>
<tr><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th></tr>
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<tr><td>Discount rate</td><td>5%</td><td>7%</td><td>4%</td></tr>
<tr><td>Interest rate</td><td>5%</td><td>7%</td><td>4%</td></tr>
<tr><td>Loan type</td><td>30-yr. home equity</td><td>15-yr. home</td><td rowspan="2">Base</td></tr>
<tr><td>Evaluation period</td><td>30 years</td><td>25 years</td></tr>
<tr><td>Solar resource location</td><td>Largest utility</td><td colspan="2" rowspan="10">Base</td><td>Lowest</td><td>Highest</td></tr>
<tr><td>Orientation</td><td>S-25deg – fixed</td><td>Flat</td><td>Base</td></tr>
<tr><td>Derate</td><td>77%</td><td>82%</td><td>86%</td></tr>
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<tr><td>Electric cost location</td><td>Largest utility</td><td>Lowest</td><td>Highest</td></tr>
<tr><td>Net Metering[b]</td><td>Full retail net metering</td><td>Avoided cost</td><td>Base</td></tr>
<tr><td>CO^2 cost</td><td>$25/ton</td><td colspan="2" rowspan="2">Base</td><td>$0</td><td>$50/ton</td></tr>
<tr><td>Incentives</td><td>Federal ITC (30%)</td><td>None</td><td>Base</td></tr>
</table>

by 2025, and 10 states are targeting slightly lower percentages by around 2020. I therefore believe that utility solar PV will see a significant spike after 2015. It is much easier and quicker to construct a solar power facility, particularly one near the load, than it is to establish facilities for various other renewable power sources.

As for residential PV, in many heavily populated areas of the country where electric rates are high, the cost of solar PV electricity is already at parity with the grid. National Renewable Energy Labs (NREL) has completed an in-depth study of grid parity for residential installations. By 2015, the estimate of what grid parity will look like, assuming a cost of $3.50/W installed solar, is shown in the map on the previous page.

Without a doubt, the cost of solar PV has hindered mass adoption; the cost of utility-scale solar PV is still measurably higher than that for coal and nuclear power generation. A key assumption for the NREL data cited above is that the cost for residential installed solar will be $3.50/W in 2015. Current installed costs are at around $6 to $8/W. How will we achieve the $3.50/W cost number for residential? And how will utility-scale solar become more cost-competitive with coal and nuclear power generation?

Barclays Capital estimates a 50 percent rise in solar PV shipments for each of the next four years. Solar applications for both utility and residential power generation and for off-grid industrial applications have caught the attention of the semiconductor industry. The opportunity is now significant enough for semiconductor companies like STMicroelectronics and others to begin development of integrated

Solar PV has many desirable features; it is clean and renewable, and it can be used for both utility-scale and residential applications.

devices specifically designed for PV applications. This is key, not only as an indication that PV is gaining acceptance, but also as an enabler of the cost, efficiency and reliability improvements that promote further market adoption.

The decline in crystalline silicon prices due to oversupply and the recession has caused severe pressure on module makers to reduce manufacturing costs. While painful, the trends in the industry have lowered costs to the end customer, keeping demand strong. Meanwhile, research continues to show the potential for significant cost reductions for next-generation thin-film PV materials. New transformerless topologies for central inverters are 1 to 2 percent more efficient than previous designs, a huge improvement. Microinverters and dc optimizers are also making significant improvements in system-level efficiency. These topologies and system architectures, as well as improvements in efficiency and cost reduction, are driven by EEs.

Solar PV will be an area of continued innovation and opportunity for EEs in the years to come. ■

Heather Robertson is solar technology director for Avnet Electronics Marketing.
http://em.avnet.com/solar

Photovoltaics research at IMEC

The Interuniversity Microelectronics Center set up an integrated processing facility for organic photovoltaics in 2009 and has also extended its pilot line for silicon solar cells. IMEC holds an extended patent portfolio relating to solar technology.

Recently, IMEC granted Silicon Valley startup Solexel a nonexclusive license on selected patents for the development and commercialization of next-generation high-efficiency thin-film photovoltaic arrays and solar modules. The licensed technology involves a method for depositing a thin film of monocrystalline material on a substrate.

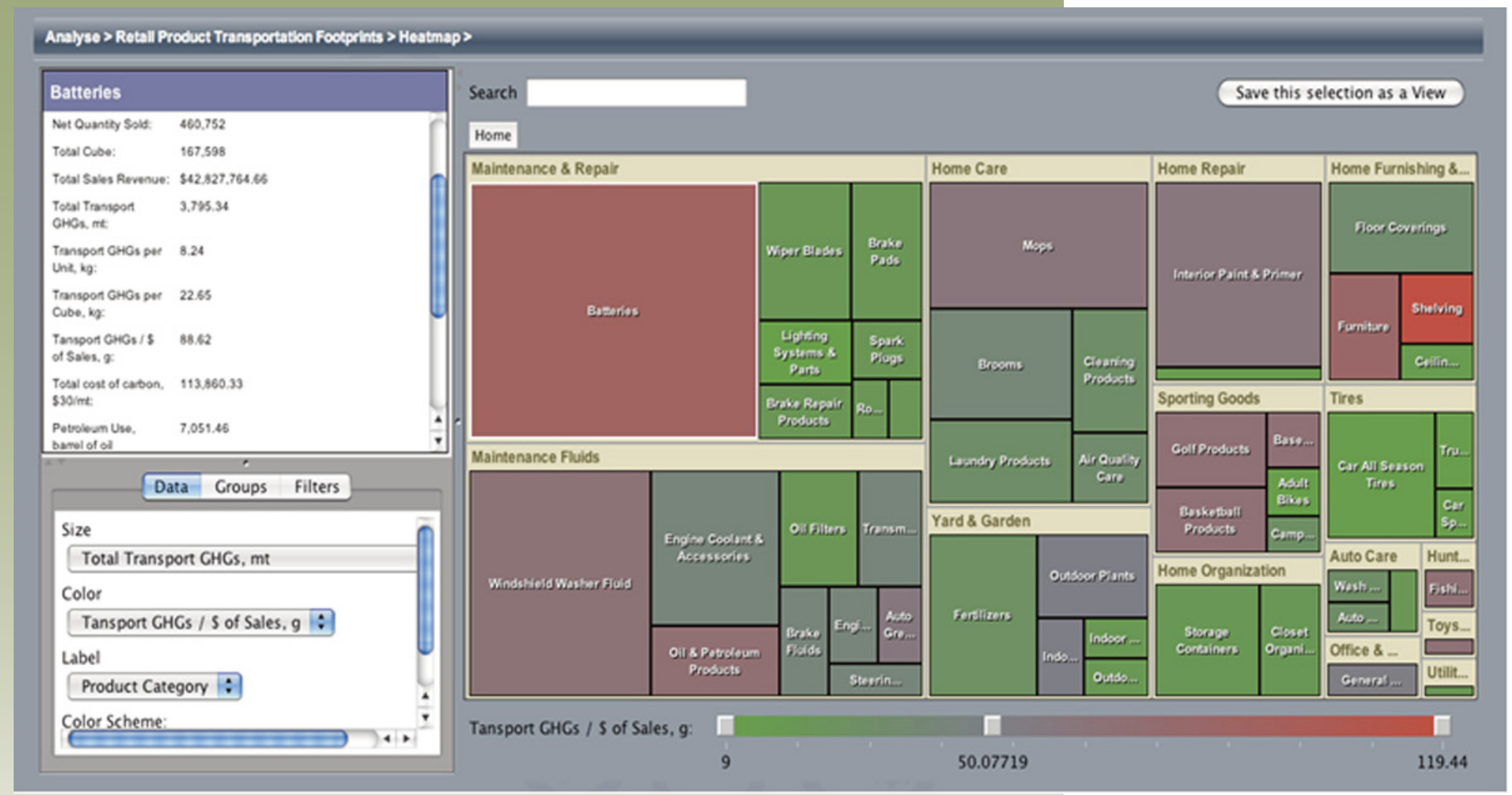
To increase the efficiency of the resulting solar device, the method advocates depositing a porous silicon layer between the substrate and the thin film. The layer has both light-reflecting and light-diffusing properties, helping to confine the incoming light in the thin-film layer and thereby improving the efficiency of the cell.

— Nicolas Mokhoff

material extraction, through processing and manufacturing, all the way to final disposal and recycling.

Demand for greater disclosure is occurring through a variety of programs, such as the carbon footprint labeling initiatives and producer take-back laws in Europe, Wal-Mart's Product Sustainability Index, and a seemingly endless array of "green product" certification schemes.

The regulatory landscape for product environmental compliance has reached such a level of complexity that manual environmental reporting processes and spreadsheet tools are no longer sufficient for effective risk management. Advanced product analytics technology and processes are increasingly necessary to keep up with current requirements while



Advanced product-analytics tools are increasingly necessary. PTC Insight analyzes carbon-footprint impacts throughout the supply chain.

meeting those of future regulations and standards without costly disruption. The good news is that these solutions can be leveraged in a strategic progression beyond compliance and into the environmental performance management of your entire product portfolio.

Most product designers, especially in the electronics industry, optimize design for the product's usage phase by improving energy efficiency, durability, reliability and safety. Those design decisions have environmental implications in the production and disposal phases of a product's life cycle, however, and sometimes the trade-offs can overwhelm the benefits of the design.

Materials with quite similar performance characteristics sometimes have vastly different impacts during their original production. Further, seemingly simple choices, such as gluing parts in an assembly, can make a product unrecyclable. A notable example of unintended consequences was the recent discovery that when the use of fertilizer and transportation fuel is taken into account, North American corn-based ethanol may actually require more fossil fuel than the gasoline it displaces.

Simple choices like gluing an assembly can make a product unrecyclable

A methodology called life cycle assessment (LCA) takes such factors into account before their implications can ripple through the product life cycle. In a typical product LCA, a process map is created for all material and energy

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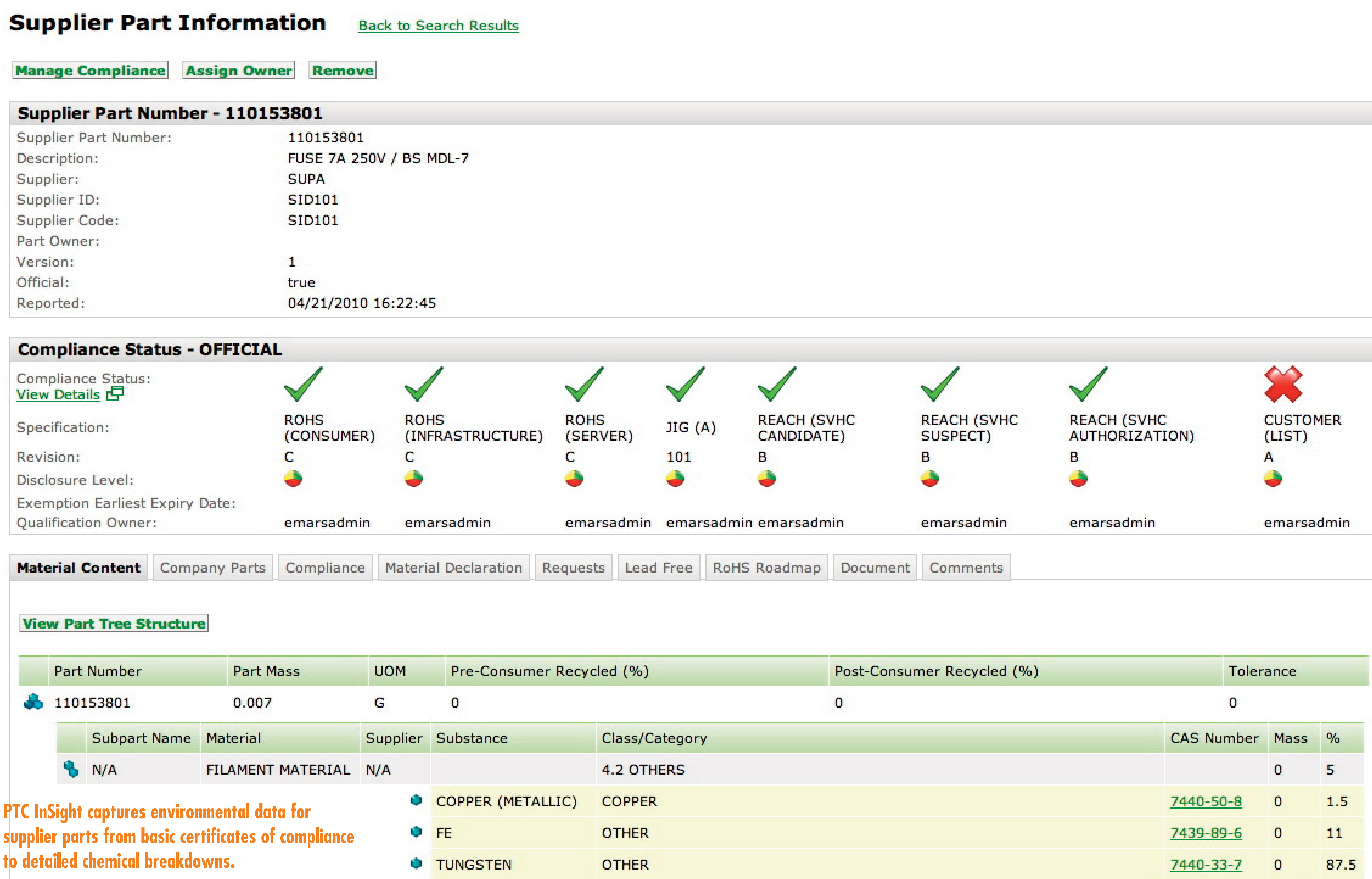

PTC InSight captures environmental data for supplier parts from basic certificates of compliance to detailed chemical breakdowns.

consumed or released over the life of the product, “from cradle to grave.” That might include everything from the tailings created while mining ore to the harmful chemicals that could leach into landfills as a discarded product decomposes.

Clearly, direct measurement of each and every process in a product’s life cycle would lead to an intractable data collection problem, so the most detailed LCAs to date have been performed for common raw materials, processes and commodities. Using the averaged data from those LCAs, a base of assumptions is built for modeling complex products (built with the examined materials and processes) across a number of parameters of interest. For instance, an investigation might consider the carbon

Tools for treading lightly

The process of predicting, measuring and improving a product’s environmental performance is becoming increasingly important to the success of manufacturers across all industries.

PTC recently acquired Planet Metrics to help build out PTC design solutions for environmental compliance and green design. Planet Metrics’ software predicts a product’s carbon footprint and environmental impact.

The move expands the PTC InSight Product Analytics solution, enabling manufacturers and retailers to model, analyze and optimize a product’s carbon emissions and energy use throughout the value chain, from concept to end of life. The Planet Metrics software includes an exhaustive, normalized database of environmental profiles and combines both analytics and intuitive heat map displays to identify high-impact “hot spots” in materials, packaging, supply chain, transportation and disposal.

PTC also offers Insight Environmental Compliance software for managing and improving product and supply chain environmental performance. Read more here.

— Nicolas Mokhoff

footprint for a kilogram of a particular aluminum alloy or the energy consumed in manufacturing a typical surface-mount resistor.

Laws like WEEE, RoHS and especially REACH have forced manufacturers to improve their understanding of the materials present in the parts and commodities they use. Much of the data acquired for environmental compliance—and many of the processes used to collect and apply it—is also necessary for the calculation of the environmental impact of a product over its life cycle.

Scalable technology is now available for integration into existing PLM and ERP systems

Once a company begins to track and manage the material content of its products, life cycle environmental impact factors can be applied to those materials. When a product's bill of materials is then analyzed for material breakdown, it can be graded for compliance with various regulations and assessed for upstream and disposal environmental impacts at the same time. By combining those results with the design performance of the product's use phase, a full life cycle trade-off analysis can be performed.

The collection and management of such data are not trivial tasks, but they are increasingly necessary if a company hopes to continue selling into large regional markets. Scalable technology is now available for integration into existing PLM and ERP systems to facilitate the process. When the mandatory

Steps

1. Select Report Options
2. Add or Edit Parts
3. Review Material Completeness
4. Generate Report
5. **View SOC Report**

Current Selections

BOM Name: EPHONE
Company Part: 0611040E78
Organization Code: N/A
Description: MOBILE PHONE
Revision: C0
BOM Revision Date:
Saved BOM Version: 3
Creation Date: 01/27/2009 15:07:50
Source: BOMCONFIG

The PTC InSight program generates product compliance reports in numerous formats.

Step 5. View Substance(s) of Concern Report

Specification:	EU RoHS
Item Qualification Status:	QUALIFIED
Report Option:	SoC Report
Report Created By:	bgreen
Date Report Generated:	06/03/2010 13:18:02

Company Part	Description	Toxic and Hazardous Substances or Elements					
		LEAD (Pb)	MERCURY (Hg)	CADMIUM (Cd)	HEXAVALENT (Cr(VI))	POLYBROMINATED BIPHENHYLS (PBBS)	POLYBROMINATED DIPHENYL ETHERS (PBDES)
0611040E78	MOBILE PHONE	X	X	X	X	X	X
135-8248-01	BATT COVER	X	X	X	X	X	X
15-7683-01	IC,TPS62000,DC-DC CONV,0.9-5.0V,600MA,MSOP10	O	O	O	O	O	O
235-7549-01	SEC IC UNIT A3EE7	X	X	X	X	X	X
246-4567-01	ANT COVER ABB	O	O	O	O	O	O
301-0141-01	PKG BAG BUBB-10MM PE 3SS	X	X	X	X	X	X
357-6785-02	CAP CE .027UF 10V 5%SM 0603PASSIVE	X	X	X	X	X	X
357-6786-01	RES 120 OHM 3%	X	O	O	O	O	O
357-7555-01	ALM CAS COV TOP	X	X	X	X	X	X
357-7556-03	CHIP COMP AC77B	X	X	X	X	X	X
357-7557-01	ALM CAS COV BOT	X	X	X	X	X	X
357-9564-01	METAL WIRE	X	O	O	O	O	O
468-2574-01	LABEL INT ASY	X	X	X	X	X	X
468-8245-01	OUTER COVER	X	X	X	X	X	X
468-8246-01	SCREEN LCD	X	X	X	X	X	X
468-8247-01	BUTTON PAD SHEET ABB	X	X	X	X	X	X

Records [1 - 15] / 24 « Previous 1 ... 1 2 ... 2 Next » 15 rows/page

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O Indicates that the content of the toxic and hazardous substances in all the homogenous materials of the part is below the concentration limit requirement

X Indicates that the content of the toxic and hazardous substances in at least one homogenous material of the part exceeds the concentration limit requirement efforts are further leveraged into a product environmental performance strategy, the financial returns can extend beyond cost avoidance to include potential top-line revenue growth.

The financial returns can extend beyond cost avoidance to include top-line revenue growth

Mindful of that progression, leading manufacturers such as Apple now publish on their Web sites the material breakdown, life cycle environmental impacts and generational improvements for each of their products. Toshiba has developed a holistic index to grade, rank and improve all of its products on the balance of environmental impact and customer value. And Seagate provides "full material disclosure" on its products, offering data that goes well beyond the information mandated by regulations or willingly published by its competitors.

These companies are rewarded for their leadership through enhanced brand image, inclusion in programs like the Dow Jones Sustainability Index, better views into material and commodity price sensitivity, and the peace of mind and breathing room that come with being prepared for compliance with new regulations in advance of their implementation. ▪

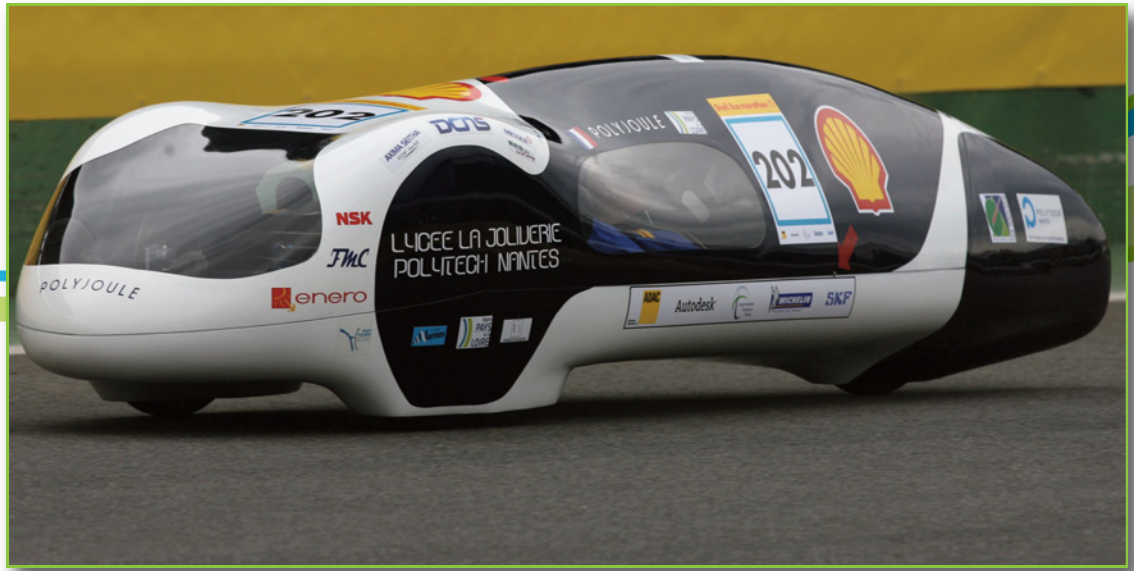
Nathan Taylor oversees the life cycle assessment product strategy for PTC InSight, assisting manufacturers in the development of strategies and processes for green product development.

ntaylor@ptc.com

High-school and college students came from across the Americas to push the boundaries in the 2010 Shell Eco-marathon Americas.

On the streets of downtown Houston, 42 student teams showed fuel-efficient vehicles designed, built and tested with the aim of traveling the farthest distance using the least amount of energy. The team from Laval University (Quebec) took home the grand prize for the second year in a row.

For the Prototype category, teams entered futuristic, highly streamlined vehicles focused on maximizing fuel efficiency through innovative design elements, such as drag reduction. For the UrbanConcept category, teams entered more "road worthy" fuel-efficient vehicles. For both categories, teams used conventionally



Team Polytech Nantes participated in the Shell Eco-marathon Europe with its Polyjoule entry, a hydrogen-powered prototype. (Team No. 202) available fuels such as diesel, gasoline and liquid petroleum gas, as well as alternative fuels such as hydrogen, biomass and solar.

The Purdue Solar Racing team won last year's Solar Car category of the Eco-marathon, achieving the equivalent of 4,913 miles per gallon. The Purdue team this year achieved 2,487.5 mpg in the Prototype category, according to Mark Singer, global project manager for the Shell Eco-marathon.

The team from Mater Dei High School in Evansville, Ind.,

Brian Thompson, left, a Purdue University mechanical engineering student and vice president of Purdue Solar Racing, and team president Ted Pesyna, also a mechanical engineering student, competed in Houston in March in the Shell Eco-marathon Americas. (Purdue University photo/Andrew Hancock) took the UrbanConcept grand prize for the second consecutive year with a vehicle that achieved 437.2 mpg.

The Prototype entries included 28 vehicles powered by combustion engines, five by fuel cell/hydrogen technology, two by solar power and two by diesel fuel.

The UrbanConcept entries included six vehicles powered by combustion engines, two by diesel fuel, one by fuel cell/hydrogen and one by solar power.

Videos of Eco-marathons across the globe can be seen here. ▪

Racers eye right formula for plug-in hybrids

By Nicolas Mokhoff

The fourth annual Formula Hybrid International Competition took place in May at the New Hampshire Motor Speedway in Loudon. Founded and run by Thayer School of Engineering at Dartmouth, the competition features high-performance hybrid race cars built by teams of undergraduate and graduate engineering students.

The purpose of the event is to give engineering students the opportunity to work across disciplinary boundaries while engineering and developing a plug-in hybrid electric race car. But the competition is also a way to test out alternative energy technologies for transportation based on innovative ideas from a new generation of engineers.

Formula Hybrid competitors design, build and race open-wheel, single-seat plug-in hybrids. The cars must conform to a formula that emphasizes drive train innovation and fuel efficiency in a high-performance application.

Thirty teams were registered this year, including groups from Canada, China/Taiwan, Italy and Russia.

Along with demonstrating their vehicles' fuel efficiency, teams needed to show ample consideration for the use of sustainable materials in the design and construction of their cars. A summary of this year's results can be found at

Catch a video from the 4th Annual Formula Hybrid International Competition

Click the button above to launch the video

Investiture 2010 Awards Thayer School of Engineering Dartmouth

Click the button above to launch the video

Graybar, a distributor of electrical and communications products, is one of the sponsors of the Formula Hybrid competition, hosted by the Thayer School of Engineering at Dartmouth College. In the May event at New Hampshire Motor Speedway in Loudon, 30 participating teams of undergraduate and graduate engineering students designed, built and raced single-seat hybrid cars, emphasizing high-performance fuel efficiency.

Photos/videos are courtesy of Dartmouth's Thayer School of Engineering.

formula-hybrid.org.

The hybrid event is modeled after Dartmouth's earlier Formula SAE competition. Like their Formula SAE predecessors, the Formula Hybrid competitors must consider the design, acceleration, handling and endurance of their vehicles and abide by a long list of rules.

This year, a fourth day was added to give teams extra time to pass safety inspections. "The students are dealing with high-voltage electrical systems," said Doug Fraser, director of the Formula Hybrid project, "so our safety rules are very stringent."

The emphasis of the Formula Hybrid Competition is on the engineering of the hybrid drive system and vehicle suspension to maximize performance in three areas: acceleration, autocross and endurance.

Day one of the competition was devoted to electrical and mechanical technical inspections, which continued into day two, overlapping with the design and marketing presentation events. Day three featured the acceleration runs, the autocross competition and the design finals. Day four featured the endurance event, followed by the awards ceremony.

The most challenging competition is the endurance event. All vehicles begin this portion of the competition with their accumulators (batteries or capacitors) having been fully charged from the grid, as would be the norm for a plug-in hybrid vehicle.

Student teams can choose to maximize their accumulator

Shell Eco-marathon Europe 2010 - A Record Smashing Ending

Click the button above to launch the video and see the race!

capacity, as in the Chevrolet Volt, or to run a smaller system, as in the Toyota Prius. These are complex decisions, requiring extensive engineering analysis, according to Fraser.

When designing and building their vehicles, the student teams immerse themselves in the following disciplines:

- high-power electronics such as motors, generators, controllers, and dc-dc converters;
- mechanical systems, including suspension, steering, braking, chassis design, body design and ergonomics;
- race strategy and management;
- computerized systems control;
- data acquisition;
- internal combustion engines, including intake and exhaust systems, fuel management, and ignition systems;
- regenerative electric/hydraulic braking systems; and
- project management.

Sponsors of the competition included the Society of Automotive Engineers, the IEEE, New Hampshire Motor Speedway, SolidWorks, Plug In America, Toyota, General Motors and Chrysler. ■

Nasty pond scum or clean biofuel?

By Nicolas Mokhoff

The first person to propose algae as a clean energy source probably got more than a few funny looks. But researchers have been investigating algae's biofuel potential, with promising results, since 2006. Here, National Instruments describes its work with Solix Biofuels to demonstrate the technology's viability.

The Engines and Energy Conversion Laboratory (EECL) at Colorado State University teamed with entrepreneurs three years ago to form Solix Biofuels with the goal of delivering scalable, cost-effective technology for producing algae-based fuel. Since its foundation, Solix Biofuels has refined multiple generations of the Algal Growth System (AGS) technology now operating at the Coyote Gulch Demonstration Facility in southwestern Colorado.

A biofuel is a solid, liquid or gaseous fuel derived from recently deceased biological material. Biofuels pose a CO_2-reducing alternative to petroleum-based fuel. And because algae grows 50 to 100 times faster than conventional food crops, biofuels produced from the tiny organisms hold promise as a readily scalable alternative energy solution.

Algal Growth System (AGS) technology is in place at the Coyote Gulch Demonstration Facility in Colorado.

> Algae grows 50 to 100 times faster than conventional crops, promising a readily scalable biofuel solution

The challenge for the AGS automation system was to develop data acquisition and controls to manage and control the growth process. National Instruments developed a data acquisition system and control platform that is flexible enough for R&D yet sufficiently rugged for industrial deployment to serve Solix Biofuels' needs.

Solix uses an NI Compact FieldPoint programmable automation controller and LabView to monitor and control its process systems and manage the recorded data, and uses the LabView Datalogging and Supervisory Control (DSC) Module and NI DIAdem data management software to store and process the data and make it available for detailed analysis.

Compact FieldPoint systems gather all the required input data from sensors and execute proprietary control algorithms to deliver the required nutrients to the algae as it grows.

Algae-based biofuel could play a leading role in addressing greenhouse gas emissions. "We expect our strategic partnership with NI will continue to support our expansion as we deploy our systems on an increasingly large scale," said David Rausen of Solix Biofuels. ■

The challenge for AGS automation was to develop data acquisition and controls to manage the growth process.

Eli Sherman, Solix senior controls and instrumentation engineer, stands next to one of the basin control panels.

Fitness monitor is a sleek study in design consequences

By Patrick Mannion

The Fitbit combines wireless technology, microelectromechanical systems and cutting-edge algorithms in a sleek package for monitoring personal fitness. In addition to storing end users' stats, the unit holds lessons for any designer and aspiring inventor looking to turn an idea into a viable, competitive product.

From conceptualization and market differentiation to component selection and system design, the Fitbit is an intriguing study in design choices and consequences.

The device itself tracks calories burned, steps taken, distance traveled and sleep quality using 3-D motion sensing combined with wireless. It then converts that data into useful information about daily activities. When the user comes within 15 feet of the base-station (which is connected to

a PC USB port), all data is silently uploaded in the background to the Fitbit.com Web site, which sorts the data, performs calculations on such elements as the calories burned, and updates the user profile that resides on the site. (*Fitbit.com* also hosts user forums and features a repository of information on nutrition.)

When we tried to purchase the $99 product in mid-March, we learned it was on back-order until June. But the company was gracious enough to send *EE Times* three units in time for a scheduled teardown at the Embedded Systems Conference in early April (watch the video here).

Couch-potato inspiration

The Fitbit idea started with company CEO James Park's fascination with the Nintendo Wii and its melding of sensors and software.

"I was out of shape myself," he said, "so I wanted to combine the best aspects of sensors and software to promote activity."

The market for fitness devices was already dominated by Garmin, Nike and Polar, whose devices include many of the Fitbit's capabilities, along with GPS support. Park recognized this competition early on and altered his strategy a bit, opting to target sedentary users who wanted to get in shape rather than active people looking to maintain or increase their fitness level.

That meant focusing on form factor. "We found that those [users who] were geared toward being fit were more open to obtrusive devices" than their couch-potato counterparts, said Park. "Compared with the [typical] pedometer, we're 40 percent smaller—and wireless. We also focused on differentiated data."

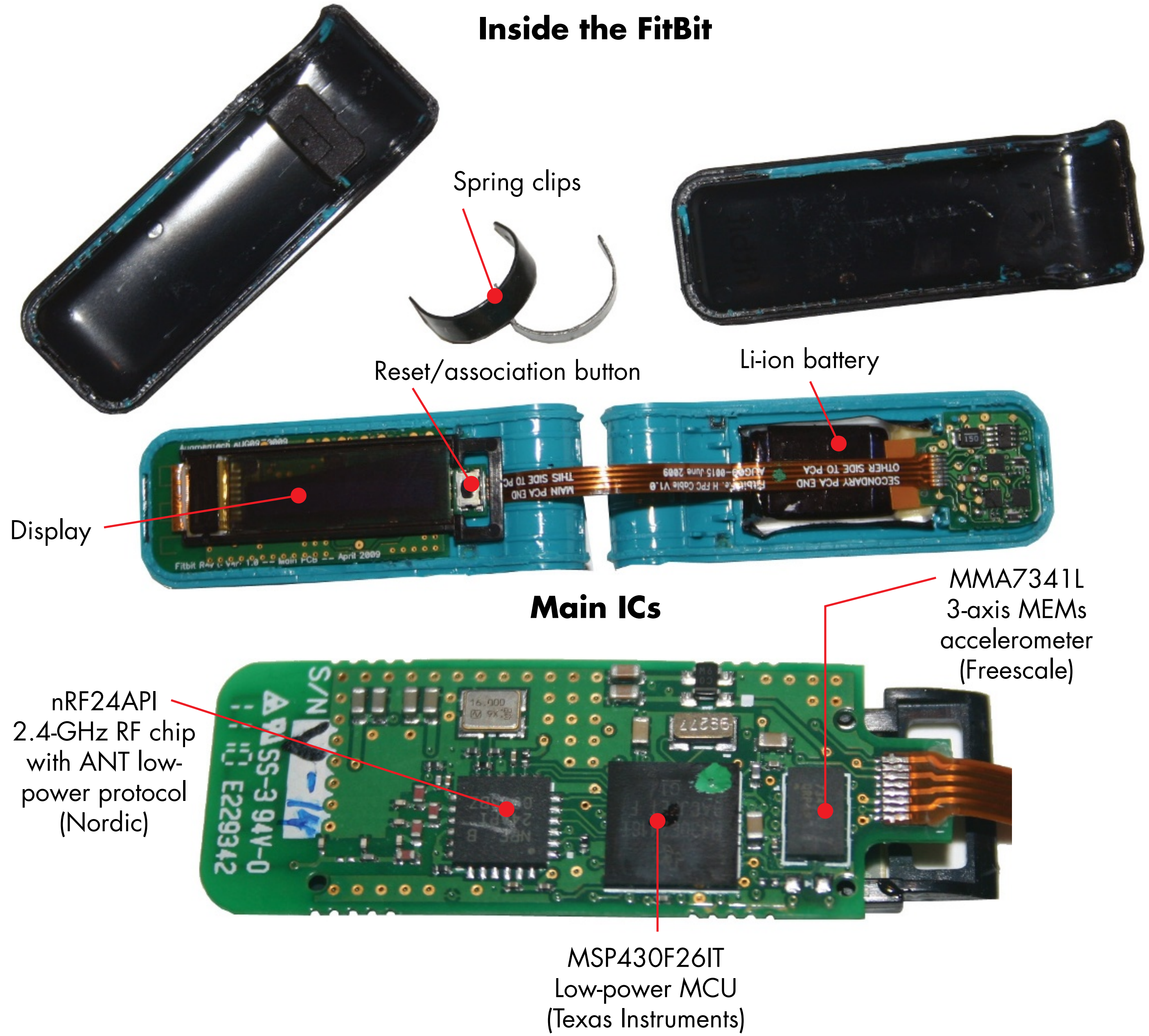
Park advised other developers to "get as much validation from potential customers as possible. There are too many NRE [nonrecurring engineering] costs" involved in developing a product to risk rolling out a device that won't suit the market.

But Park also advises designers

not to get too bogged down in analysis. A few months spent talking to customers, hosting focus groups and playing with the product's shape and size based on that early input should be sufficient, he said.

As is often the case, two factors that were critical to the device's success—form factor and wireless capability—also proved to be the two biggest hurdles to achieving that success. The algorithms used to process the incoming data are where much of the company's intellectual property lies, but implementing those algorithms in a device measuring 2 x 0.75 x 0.3 inch proved problematic, mostly because of the decision to go wireless.

Compared with a tethered USB connection, wireless has clear user-experience advantages, assuming the nuances of device-to-basestation



association have been worked out. But the attendant impact of wireless on design time, cost and power consumption must be weighed carefully, particularly with such a small form factor, said Park.

"Going wireless definitely affected the mechanical design, and there were layout issues given the small board and the closeness of he metallic components," said Park. "It did require a lot of adjustments to make sure it worked."

To get the design done, the team leaned on Nordic, which supplied the nRF24AP1 single-chip 2.4-GHz transceiver with embedded ANT wireless personal area network protocol. According to Mike Paradis, sales manager at ANT Wireless, approaching Nordic was one of the best decisions Park and his team could have made. "The initial [RF] design was very rudimentary; Nordic was very helpful once they got involved," Paradis said.

The importance of the component vendor to any design cannot be overstated, whether it be for the RF, main processor or other components. "That was one of the big decisions we made as a small company," said Park. "Some vendors are great, and it's not a function of size, as small or large [vendors] can be responsive. Others can be complete black holes."

Paradis advises designers to accept vendors' help when it's offered. "Go to the people who are the leaders; they have all the use cases," he said. "For example, Nordic has a complete reference design for a keyboard and mouse—just make your own form factor."

ANT, for its part, offers the complete low-power protocol, and the ANT File System already has critical issues covered, such as device association without a user interface, Paradis said.

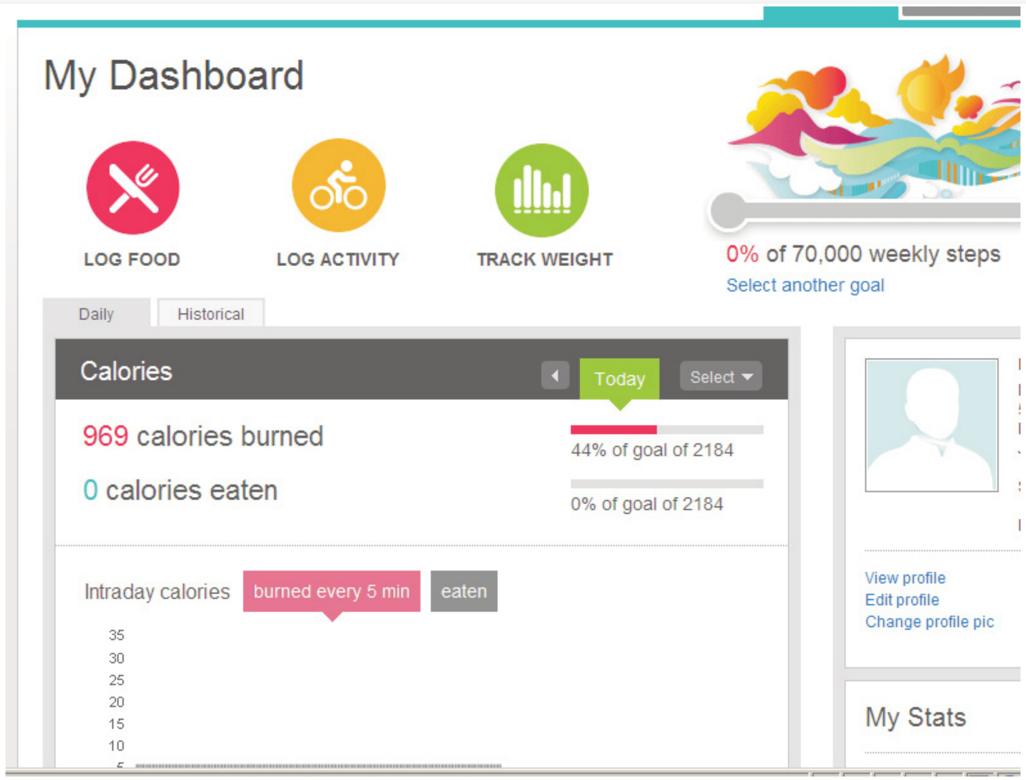
Main processor

When it came time to select the main processor upon which the algorithm would run, "a lot of it was educated guesses," Park conceded. "We had only a vague notion of the power requirements of the software algorithm." By this time, Park had divided the team into separate groups: RF, firmware and I/O display, and algorithm development.

The team did know they had to minimize processing power consumption, so during their search for a microcontroller vendor in 2007, they initially narrowed the choice to two: Texas Instruments and Atmel. The team ultimately picked TI's MSP430F2416T, a 16-MHz MCU with a 12-bit A/D converter and the precise mix of flash and RAM—92 kbytes and 4 kbytes, respectively—that the system needed, said Park.

As is so often the case, the team had selected a chip with which it was familiar. In *EE Times'* recent "2010 Embedded Market Study," 48 percent of the respondents said they stick with familiar chips when they have the opportunity to do so for new designs, citing the ecosystem and tools as the prime reasons for that choice.

In this year's study, TI was by far



Personal fitness data is analyzed and uploaded in the background to the user's profile on *Fitbit.com.*

the favorite based on ecosystem, at 17 percent. Freescale and Microchip came in second and third, respectively, at 10 and 9 percent.

Digital not always better

The third and final piece of the component puzzle was the choice of three-axis MEMS accelerometer. While designers have a knee-jerk tendency to go digital, Park suggests they take a closer look at analog devices, which he said are sufficient for most applications, without the added cost and complexity of a digital option.

For the Fitbit, power consumption was a priority, along with noise levels, as the algorithm is particularly sensitive to noise, said Park. As a result, the team opted for the older-model MMA7341L three-axis accelerometer from Freescale.

"We had worked with an ADI [Analog Devices Inc.] part but chose [the Freescale device] as it was cheaper, smaller and had lower noise," said Park, adding that the newer model is half the size of the version chosen at the time.

Consequences

While each design feature and component selection choice had its own clear set of issues, benefits and consequences, some of the consequences reverberated down the line to manufacturing.

For example, the MCU came in a microBGA package, and it turned out the contract manufacturer Fitbit wanted to use couldn't handle the pitch size.

In addition, the push to minimize weight went all the way down to the pc board, which ended up being only 0.5 mm thick. The team had to take extra steps to reinforce the board, since its fragility was affecting yield.

These were just some of the issues the team faced in making a workable, production-worthy design.

The final product is light and easy to use, meeting design goals—but it's also easy to lose. Talk about unintended consequences.

After a 3-mile trial run on a wooded trail with the kids to test the Fitbit, I returned home to find it missing. I drove back to the trail, ran it again—faster, this time, since it was getting dark—but to no avail. The Fitbit was gone.

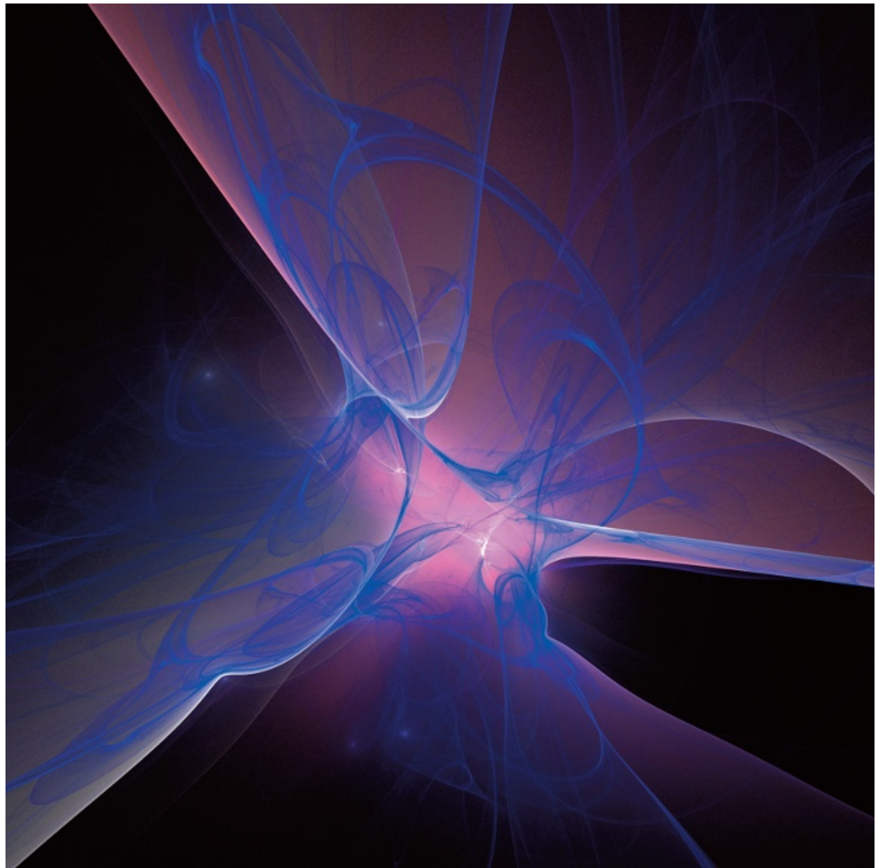
But I ran 6 miles that day, so I guess it the Fitbit did make me fitter! (Park chalked up the problem to the clip design, which he said is being reworked.) ■

Ambient energy stands ready to serve

By Tony Armstrong

With electronic circuits now capable of operating at microwatt power levels, it is feasible to power them from nontraditional sources. Hence the rise of energy harvesting, which provides the power to charge, supplement or replace batteries in systems where battery use is inconvenient, impractical, expensive or dangerous.

Energy harvesting can eliminate the need for wires to carry power



or to transmit data. It can power smart wireless sensor networks to monitor and optimize complex industrial processes, remote field installations and building HVAC systems. And otherwise wasted energy from industrial processes, solar panels and internal combustion engines can be harvested for useful purposes.

Ambient energy sources include light, heat differentials, vibrating beams, transmitted RF signals and any source that can produce an electrical charge through a transducer. Such "free" energy sources can be converted into electrical energy by using a suitable transducer, such as a thermoelectric generator (TEG) for heat, a piezoelectric element for vibration, a photovoltaic cell for sunlight (or indoor lighting) and even galvanic energy from moisture. These energy sources can be used to power electronic components and systems autonomously.

Despite their complexity, energy-harvesting systems have already been deployed in transportation infrastructure, wireless medical devices, tire pressure sensing and building automation. In building automation systems, elements such as occupancy sensors, thermostats and light switches can eliminate the power or control wiring normally associated with their installation and instead use localized energy harvesting. A wireless network using an energy-harvesting technique can link sensors in a building to reduce HVAC and lighting costs by turning off power to nonessential areas when the building is vacant. The cost of enabling energy-harvesting electronics is often lower than that for running supply wires, so there is an economic gain to be had by adopting a harvested power technique.

Many of the advantages of a wireless sensor network disappear if each node requires its own external power source. Though power management developments have enabled electronic circuits to operate longer for a given power supply, that approach has its limitations. Energy harvesting provides a complementary approach, powering wireless sensors nodes by converting ambient energy into usable electricity.

Typical node

A typical energy-harvesting configuration or wireless sensor node comprises four blocks (see **Figure 1**): an ambient energy source; a power conversion component to power the rest of the node; a sensing component that links the node to the physical world, along with a computing component, comprising a microprocessor or microcontroller that processes measurement data and stores the data in memory; and a communications component, consisting of a short-range radio for wireless communications with neighboring nodes and the outside world.

Examples of ambient energy sources include a thermoelectric generator (TEG) or thermopile attached to a heat-generating source

Power supply (or battery)	Discharge rate
	Battery dimensions
	Supply voltages
	Type of electrode material used
	Dc/dc efficiency
Sensors	Physical to electrical signal conversion
	Complexity of supporting components
	Signal sampling
	Signal conditioning
A/D conversion	Sampling rate
	Aliasing
	Dither
Microprocessor	Core operating frequencies
	Operating voltages
	Power proportional to process and computational load
	Ambient temperature
	Application code
	Peripheral utilization
Radio	Modulation scheme
	Data rate
	Transmission range
	Operational duty cycle

Table 1. Various elements affect the power consumption characteristics of an energy-harvesting system.

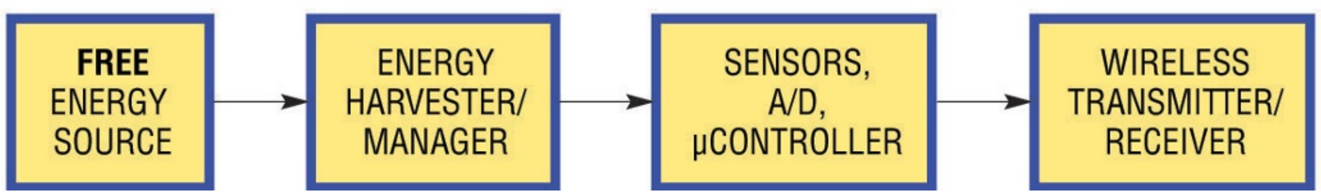


Figure 1: The four main blocks of a typical energy-harvesting system or wireless sensor node.

(such as an HVAC duct) and a piezoelectric transducer attached to a vibrating mechanical source (such as a windowpane). In the former case, a transducer can convert small temperature differences into electrical energy; in the latter, the piezoelectric device can accomplish the same conversion with mechanical vibrations or strain.

Once the electrical energy has been produced, it can be converted by an energy-harvesting circuit and then modified into a suitable form to power the downstream electronics. Thus, a microprocessor can wake up a sensor to take a reading or measurement.

The collected data can then be manipulated by an analog-to-digital converter for transmission via an ultralow-power wireless transceiver.

Integrated solutions

Integrated circuits are available that can overcome the deficiencies of current discrete energy harvester solutions.

The LTC3109 is a dc/dc converter and power manager IC that takes a “systems level” approach to solving a complex problem. It converts the low-voltage source and manages the energy between multiple outputs.

The part can harvest and manage surplus energy from extremely low-input-voltage sources such

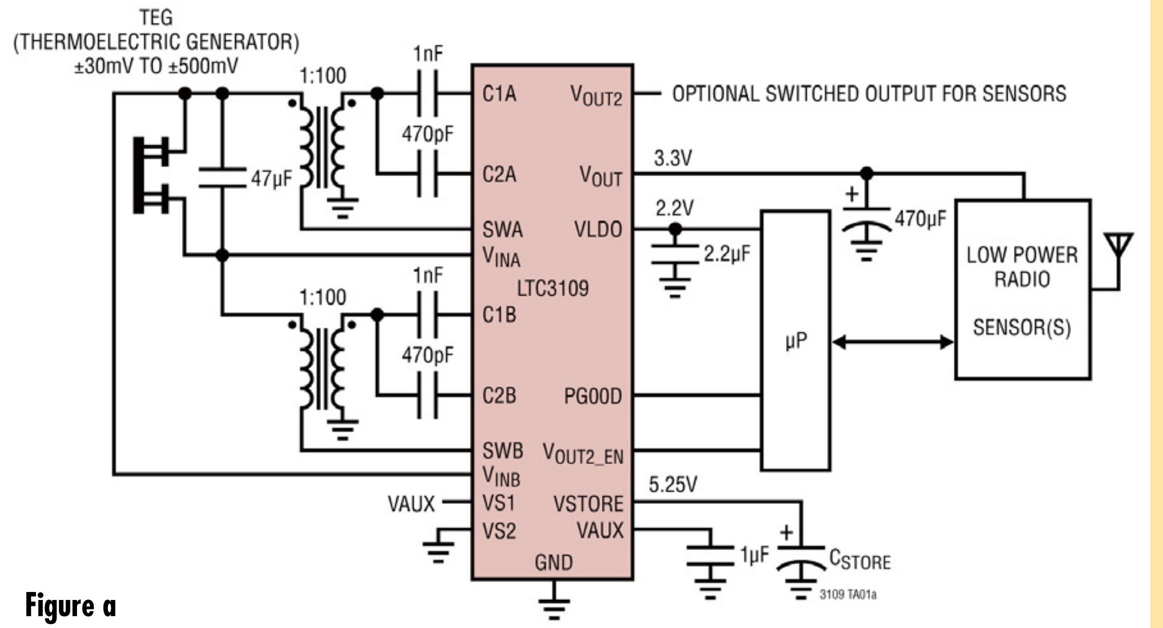


Figure a

Of course, the energy provided by the energy-harvesting source depends on how long the source is in operation. Therefore, the primary metric for comparison of scavenged sources is power density, not energy density. Energy harvesting is generally subject to low, variable and unpredictable levels of available power, so a hybrid structure is used that interfaces to the harvester and to a secondary power reservoir. The harvester, because of its unlimited energy supply and deficiency in power, is the energy source of the system. The power reservoir, either a battery or a capacitor, yields higher output power but stores less energy, supplying power when required but otherwise receiving a charge from the harvester.

Radio sensors for building automation systems are a key area

as thermoelectric generators, thermopiles and even small solar cells. It operates from input sources as low as 30 mV, regardless of polarity.

The circuit shown in **Figure a** uses two compact step-up transformers to boost the input voltage source to the LTC3109, which then provides a complete power management solution for wireless sensing and data acquisition. It can harvest small temperature differences and generate system power instead of using traditional battery power.

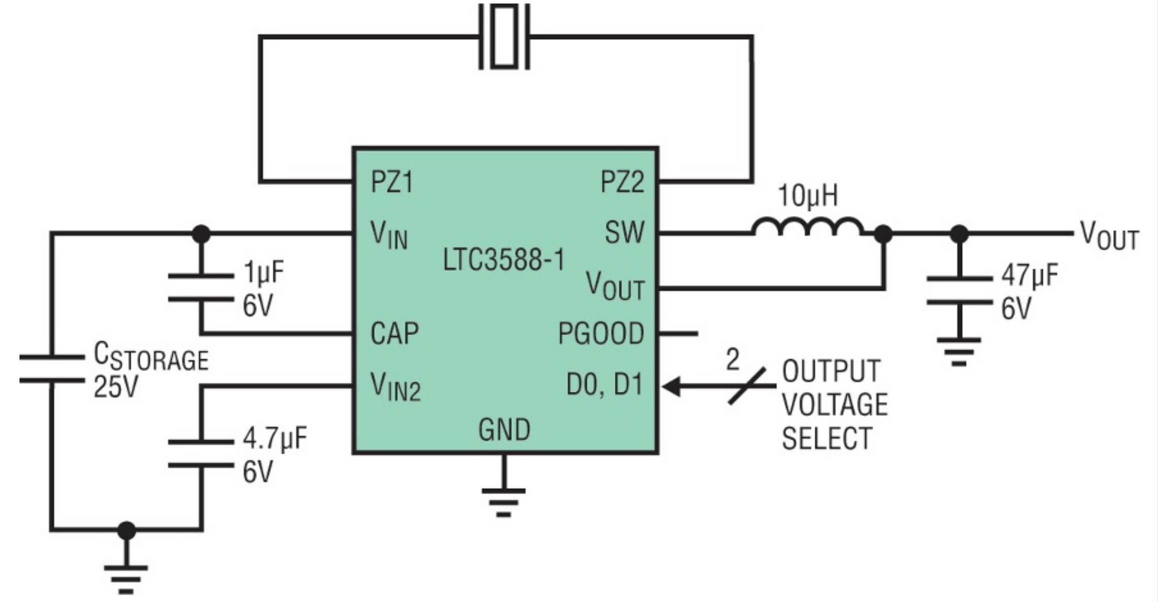


Figure b

of application for energy-harvesting systems.

Consider the breakout of energy usage in the United States. Buildings are the No. 1 user, accounting for 38 percent of total energy consumption, closely followed by the transportation and industrial segments, at 28 percent each.

Moreover, building energy use can be categorized into commercial and residential consumption, representing 17 and 21 percent, respectively. A further breakdown of the residential figure reveals that heating and cooling account for 76 percent of total energy consumption in that domain.

With energy usage forecast to double between 2003 and 2030, energy savings of up to 30 percent could be attained via building automation.

The LTC3588-1 in **Figure b** is a complete energy-harvesting solution optimized for low-power energy sources, including piezoelectric transducers. Piezoelectric devices produce energy either by compression or by deflection of the device. These piezoelectric elements can produce hundreds of microwatts/cm^2 depending on their size and construction.

The chip operates from an input-voltage range of 2.7 V to 20 V, suiting it for a wide array of piezoelectric transducers, as well other high-output-impedance energy sources.

— Tony Armstrong

Find more online

Click links below

Linear Technology application and product-brief videos

Texas Instruments: Energy harvesting basics, applications, solutions

"Freescale green energy power converter eases apps"

"ST, Micropelt launch energy-harvesting kit"

Intel/National Semiconductor: "NeuralWISP: An Energy-Harvesting Wireless Neural Interface with 1-m Range"

Ambient energy sources

State-of-the-art and off-the-shelf energy-harvesting technologies, for example in vibration energy harvesting and indoor photovoltaics, yield power levels in the milliwatts under typical operating conditions. While such power levels may appear restrictive, the operation of harvesting elements over a number of years can render the technologies broadly comparable to long-life primary batteries in terms of both energy provision and the cost per energy unit provided.

Further, systems incorporating energy harvesting will typically be capable of recharging after depletion. The same cannot be said for systems powered by primary batteries.

As already discussed, ambient

ENERGY SOURCE	TYPICAL ENERGY LEVEL PRODUCED	TYPICAL APPLICATION
Small solar panels	Hundreds of mW/cm² (direct sunlight)	Handheld electronic devices
Small solar panels	Hundreds of μW/cm² (indirect sunlight)	Handheld electronic devices
Seebeck devices (which convert heat energy into electrical energy)	Tens of μW/cm² (body heat)	Remote wireless sensors
Seebeck devices	Tens of mW/cm² (furnace exhaust stack)	Remote wireless actuators
Piezoelectric devices (which produce energy by either compression or deflection of the device)	Hundreds of μW/cm²	Handheld electronic devices or remote wireless actuators
RF energy from an antenna	Hundreds of pW/cm²	Remote wireless sensors

Table 2. Energy sources and the amount of energy they can produce.

energy sources include light, heat differentials, vibrating beams, transmitted RF signals and just about any other source that can produce an electrical charge through a transducer. Successfully designing a completely self-contained wireless sensor system requires readily available power-saving microcontrollers and transducers that consume minimal electrical energy from low-energy environments. Low-cost and low-power sensors and microcontrollers have been available for a couple of years, and ultralow-power transceivers have just recently become commercially available.

The laggard in this chain has been the energy harvester.

Existing implementations of the energy-harvesting circuit typically consist of low-performing discrete configurations, usually comprising 30 components or more. Such designs have low conversion efficiency and high quiescent currents, compromising end-system performance.

The low conversion efficiency will increase the amount of time required to power up a system, which in turn increases the time interval between taking a sensor reading and transmitting the data. A high quiescent current limits how low the output of the energy-harvesting source can be, since it must overcome the current level needed for its own operation before it can supply power to the output.

Power management is the key aspect to enabling remote wireless sensing, but it must be implemented starting at the concept of the design. System designers and planners have to prioritize their power management needs from the onset in order to ensure efficient designs and successful long-term deployments. ▪

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On the Web: Reports from the front

EE Times' *far-ranging coverage of alternative energy technology includes this sampling of analytical articles and videos posted in the past half-year.*

Click on headlines under the topics to open links.

ARPA-E

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Batteries

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Nanocomposite said to boost lithium batteries by 5X

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Video: Just add CNT ink to make paper battery

Fuel cells

Portable fuel cell market to reach $2.3 billion in 2016, says analyst

Fuel-cell powered aircraft prepares for take-off

Researchers integrate fuel cells on chip level

Fuel cells get $49M in stimulus funds

Energy harvesting

ST, Micropelt launch energy-harvesting kit

Linear unveils piezoelectric energy harvester

MIT researchers simplify energy harvesting circuits

EnOcean raises $11.5 million for energy harvest business

ESC panel to debate wireless sensor networks

Piezoelectric scheme seeks to reap the wind while driving

Embedded Systems Conference videos

ESC panel: Deploying the smart grid

ESC keynote: Better Place's Jason Wolf on electric vehicles

The electric car is now: Our interview with Jason Wolf