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FEATURE

Plug-in Hybrids: Electrifying Transportation

Dan Greenberg

By now you've probably seen dozens of hybrid electric vehicles (HEVs) whizzing around your town. Perhaps you own one yourself. The current best seller in that category, the Toyota Prius, boasts 60 miles per gallon (mpg) in city driving, an impressive feat considering that the average American-made compact car now gets just under 23 mpg.[1] But Felix Kramer thinks that's just a start. Kramer is the founder of the California Cars Initiative (CalCars)—a group of entrepreneurs, environmentalists, engineers, and other citizens working to spur the adoption of efficient, non-polluting automotive technologies.[2] CalCars recently modified a Prius to get well over 100 mpg. How? Well, Kramer makes it sound easy. Just add a few kilowatt-hours (kWh) of battery capacity and a plug-in charge controller, and you too can easily double or triple the fuel economy of your HEV.

Of course, what Kramer is doing is substituting the chemical energy stored in the car's gasoline tank with the chemical energy stored in the expanded battery bank that sits in the trunk. That's precisely what makes the so-called "plug-in hybrid" (PHEV) such an interesting concept for electric utility researchers and executives to ponder. The PHEV has some pretty compelling benefits going for it—namely, it has the potential to reduce both American dependence on foreign oil and transportation-related pollution at a cost that will be attractive to many consumers. And although the PHEV will surely benefit from technological developments over time, it's already a reality today. If this technology catches on, the benefits to electric utilities could become very compelling within the decade, particularly as carbon dioxide (CO_2) becomes a regulated pollutant.

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What Is a PHEV?

With their large-capacity batteries and onboard chargers that operate on standard 120-volt circuits (hence the term "plug-in"), PHEVs are something of an amalgam of the HEV and its less-successful predecessor, the battery-powered electric vehicle (EV). EVs failed in the marketplace largely because their bulky, expensive battery packs only provided enough power to take you about 80 miles, after which the batteries required a lengthy downtime period for recharging. If and when they are commercialized, PHEVs will very likely have an even shorter range on battery power—perhaps just 10 to 30 miles. But unlike the EV, PHEVs incorporate an internal combustion engine that functions as a range-extender, giving the vehicle a responsiveness and driving range equal to or better than that of a conventional car.

A PHEV can operate as a pure electric vehicle or as a "conventional" HEV, combining power from the battery with that from the internal combustion engine. For short drives, such as the commute to and from work or down to the local grocery store, the car might operate in "all-electric" mode. Once the batteries have been depleted to a predetermined level, the vehicle would automatically switch to hybrid mode, in which the internal combustion engine would both power the vehicle and maintain battery charge. Like all HEVs, PHEVs take advantage of regenerative braking to recapture some of the vehicle's kinetic energy when braking and return it to the battery. Because of their larger batteries, PHEVs can recapture and store more braking energy, further improving energy efficiency.

Currently, there are only about a dozen fully functional PHEVs in existence, most of which have been built by university research teams. Over the next few months, DaimlerChrysler will begin delivering the first of up to 40 prototype 15-passenger vans with plug-in hybrid drivetrains. These vans are the first PHEVs built and delivered to end users for public testing by a major automobile manufacturer. Field tests will be conducted by Southern California Edison, the South Coast Air Quality Management District, the Kansas City Regional Transit Authority, and the New York Power Authority, each of which provided funding for the development of the prototypes.

Although these vans have not yet achieved commercialized status, DaimlerChrysler's involvement gives the concept greater credibility in the automotive world, indicating that auto manufacturers are beginning to take a serious look at this technology. Nick Cappa, a spokesman for DaimlerChrysler has characterized the PHEV van project as "a great opportunity to develop the vehicles we foresee in the future."[3] But clearly, different manufacturers have different opinions about the technology. At Toyota, David Hermance, executive engineer for environmental engineering, strikes a less optimistic tone: "They say this is the next great thing, but it just isn't,"[4] "We keep looking at the concept, and at some point it might be feasible, but it isn't there yet."[5]

Although it would seem logical to look to auto manufacturers to develop and commercialize PHEVs, it's entirely possible that this technology will find its way to market via third-party enterprises. Having worked with CalCars on its Prius conversion in May 2005, EDrive Systems LLC (a partnership between Energy Control Systems Engineering, a California engineering firm, and Clean-Tech, a Los Angeles vehicle integrator) has announced plans to offer PHEV conversions beginning in 2006.[6] Their conversion will use lithium-ion batteries from Valence Technology Inc. of Austin, Texas (**Figure 1,** page 3).[7]

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Editors: Kristin Kamm and Dan Greenberg

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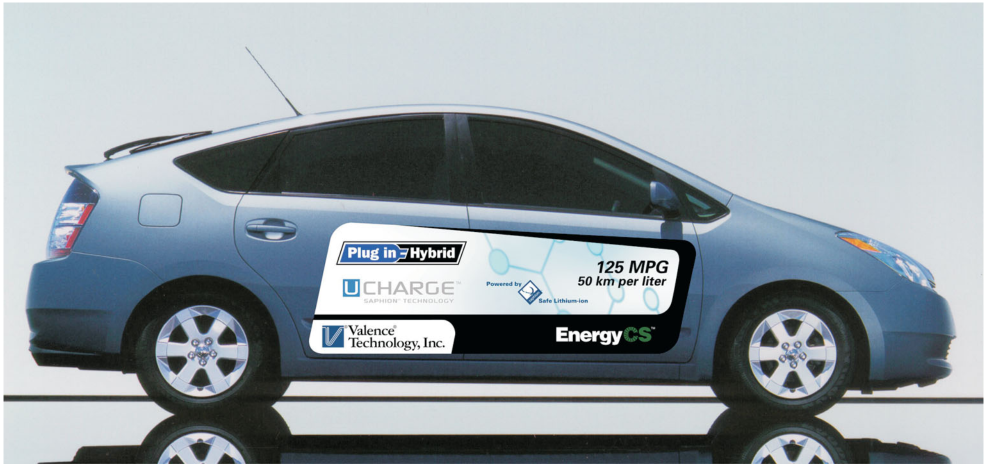
Figure 1: EDrive's converted Toyota Prius

This vehicle was converted to a plug-in hybrid electric vehicle (PHEV) by EDrive Systems LLC. The lithium-ion battery capacity gives the car a range of 35 miles without gasoline. It won first place in the Modified Hybrid Vehicle category at the 2005 Tour de Sol, achieving fuel economy of 102 mpg and using 9 kilowatt-hours of battery energy on the 150-mile course.



Courtesy: Valence Technology Inc. [7]

Potential PHEV Benefits

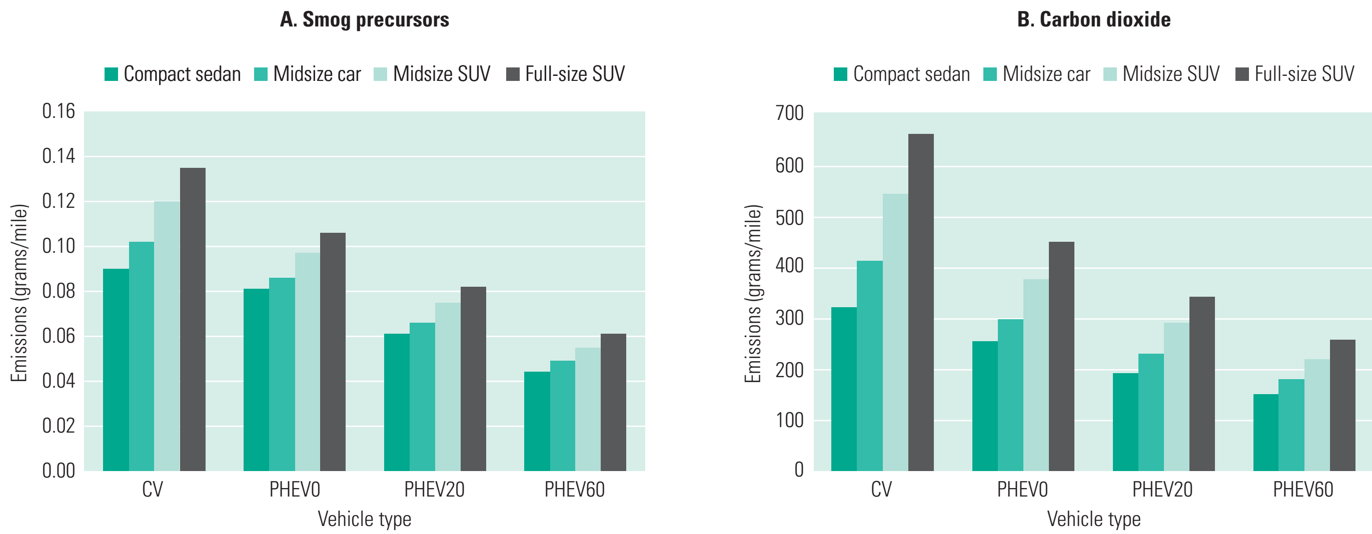
By shifting a portion of the energy consumed in the transportation sector from gasoline to electricity, PHEV technology has the potential to provide benefits to a variety of interested parties. Environmentalists and air-quality officials are most interested in reducing greenhouse gas emissions and smog precursors. National security advocates focus on the PHEV's potential to reduce America's dependence on foreign oil. Studies conducted by EPRI project that at moderate production volumes, PHEVs will offer a life-cycle cost advantage to the consumer and insulate their owners from oil price increases. Electric utility executives are also beginning to see PHEVs as an attractive off-peak load that might offer a way to reduce the costs of complying with existing and possible future environmental regulations.

Emission reductions. The potential for emission reductions via an electrified transportation sector has long been of interest to air-quality officials and others in California, which is home to some of the most vexing air-quality problems in the U.S. The HEV Working Group—a coalition of representatives from EPRI, the utility and automotive industries, the U.S. Department of Energy (DOE), other regulatory agencies, and university research organizations—published a pair of analyses in 2001 and 2002 that investigated the potential benefits of HEVs and PHEVs.[8] The group evaluated emissions throughout the full fuel cycle (from extraction through the refining/conversion process and out the vehicle tailpipe) for conventional vehicles (CVs), hybrid vehicles without plug-in capability, PHEVs with a 20-mile all-electric driving range, and PHEVs with a 60-mile all-electric range.

The results of the two studies indicate that hybrids offer substantial reductions in both CO_2 and ozone precursors (nitrogen oxides and hydrocarbons), and that the amount of reduction increases as a vehicle's battery capacity increases (**Figure 2,** page 4).[9] Notable assumptions underlying these results were that both the conventional and hybrid vehicles

Figure 2: Emissions reduction benefits of hybrid and plug-in hybrid vehicles

Assuming that the electricity to recharge plug-in hybrid electric vehicle (PHEV) batteries will be generated off-peak by gas-fired combined-cycle power plants, PHEVs appear to offer substantial emissions benefits for both smog precursors (A) and carbon dioxide (B), even relative to hybrid electric vehicles that lack any plug-in capability.



Notes: CV = conventional vehicle with an internal combustion engine only; PHEV0 = a hybrid electric vehicle with no plug-in capability; PHEV20 = a PHEV with a 20-mile all-electric range; PHEV60 = a PHEV with a 60-mile all-electric range.

Source: Platts; data from EPRI [9]

met California's standards for super-ultra-low-emissions vehicles when operating on gasoline, that the PHEVs would be recharged during utility off-peak hours, and that the additional load posed by the PHEVs would be served by combined-cycle power plants burning natural gas.

Although those assumptions appear to be reasonable for California, it's not clear whether they would apply equally well to other regions of the U.S. that rely on different sets of generating resources and have different environmental regulations. Currently, no detailed analysis of the potential emissions impact of PHEVs outside of California has been published, but an analysis by Argonne National Laboratory indicates that based on the emissions characteristics of the average kilowatt-hour generated in the U.S., PHEVs could reduce CO_2 by at least 36 percent and nitrous oxides by at least 30 percent as compared with conventional vehicles.[10]

Reduced oil imports. To Frank Gaffney, founder of the Center for Security Policy, a conservative Washington think tank, the potential for PHEVs to reduce U.S. dependence on foreign oil easily trumps any environmental benefit. Gaffney told *The New York Times*, "If you're thinking about [PHEVs] as an environmental issue first and foremost, you're missing the point."[11] He went on to characterize reducing dependence on foreign oil as "a national security emergency." The Center for Security Policy is one of several prominent organizations and individuals with seemingly divergent political agendas that have recently banded together to form the Set America Free Coalition, with the stated goal of weaning the U.S. from its dependence on foreign oil. Not surprisingly, the coalition has come out as a major supporter of PHEVs and other alternative-fuel vehicles.[12]

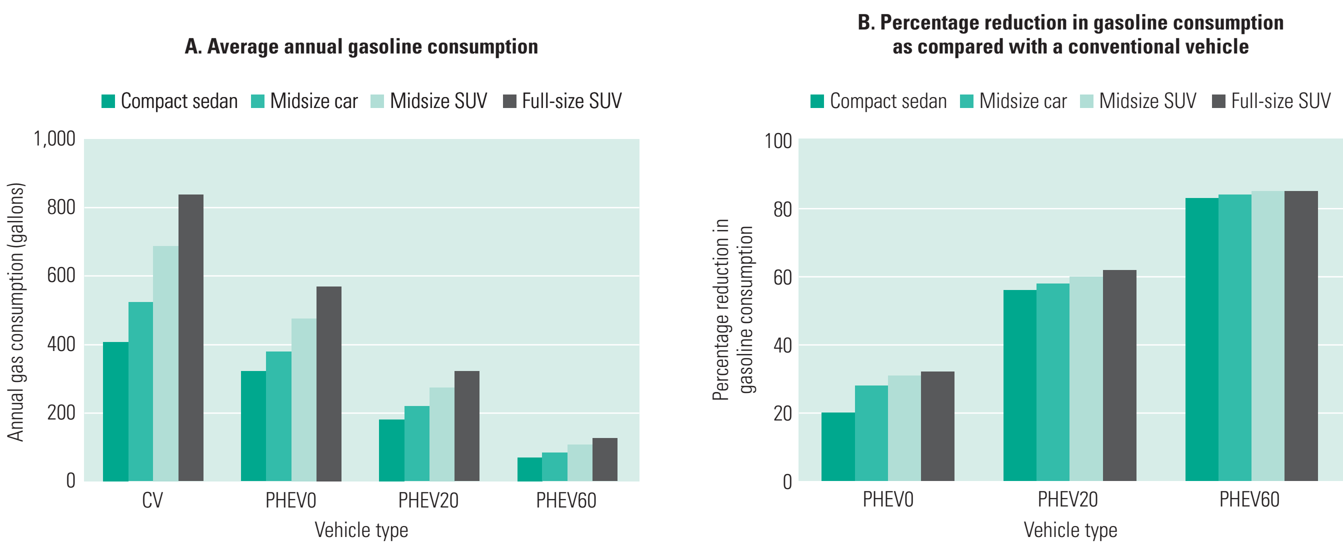
The HEV Working Group simulated the fuel consumption of HEVs and PHEVs using data on commuting distances from 400 survey respondents to determine annual mileage and the fraction of those miles that the PHEVs would run in all-electric mode. Assuming an average driving schedule and nightly recharging, the reduction in gasoline consumption is quite large, and as one would expect, it increases as the all-electric range expands (**Figure 3**).[13]

Off-peak load growth. The additional load that PHEVs might one day represent would deliver an obvious benefit to electric utilities. Just how big that load might be will depend on the number of PHEVs on the road, the size of their batteries, and when their owners choose to recharge those batteries. Each of these factors is open to speculation. Since PHEVs don't yet exist as a commercial product, there are no measured data revealing actual consumer preferences when faced with the choice between a CV, an HEV, and a PHEV. However, studies by the HEV Work Group and the DOE have evaluated the stated preferences of consumers who have been asked to consider their interest if they had this choice (**Table 1,** page 6).[14]

As a very rough estimate, if we assume that 5 percent of the 17.2 million cars and light trucks that the U.S. Energy Information Administration estimates will be sold in 2010[15] are PHEVs with a 20-mile electric range, that on average they can travel 4 miles per kilowatt-hour of grid electricity delivered, and that on an average day they are driven 15 miles in all-electric mode, the total annual load would amount to 1.17 million megawatt-hours (MWh). If the vehicles are recharged over a 10-hour period, the average load would amount to just over 320 megawatts (MW) on a national basis.

Figure 3: Annual gas consumption versus degree of hybridization for four vehicle types

Due to their improved fuel efficiency, hybrid electric vehicles (HEVs) without plug-in capability offer a substantial reduction in gasoline consumption relative to conventional vehicles. Assuming an "average" driving schedule and nightly charging of plug-in hybrid (PHEV) batteries, simulations by the HEV Working Group indicate that gasoline consumption by four vehicle types could result in greater reductions if HEVs were equipped with additional battery capacity (A). Relative to conventional vehicles, gasoline consumption is reduced by about 60 percent for PHEVs with a 20-mile all-electric range and by more than 80 percent for PHEVs with a 60-mile all-electric range (B). (For these calculations, all cars are assumed to travel 13,322 miles per year.)



Notes: CV = conventional vehicle with an internal combustion engine only; PHEV0 = a hybrid electric vehicle without plug-in capability; PHEV20 = a PHEV with a 20-mile all-electric range; PHEV60 = a PHEV with a 60-mile all-electric range.

Source: Platts; data from EPRI [13]

Table 1: Consumers' stated preferences for PHEVs

In a study published by EPRI, the HEV Working Group surveyed 400 consumers (A), investigating their vehicle preferences among four vehicle types under four different gas price scenarios. Only the base case for PHEVs with a 20-mile electric range (PHEV20s) is shown here. The U.S. Department of Energy's survey (B) assessed the preferences of 281 consumers intending to purchase a new vehicle within three years. This survey assumed an incremental cost of $4,000 for a PHEV20 version of five different types of vehicles. The results from both surveys indicate significant consumer preference for a PHEV over a conventional car, particularly when faced with high gas prices.

A. HEV Working Group survey

	Percentage interested in purchasing PHEV20s	
Vehicle type	Gas at $1.65/gallon	Gas at $3.00/gallon
Compact sedan	12.7	19.5
Midsize car	34.5	46.6
Midsize SUV	29.8	45.6
Full-size SUV	39.6	57.0

B. U.S. Department of Energy survey

	Percentage interested in purchasing PHEV20s	
	Gas at $1.50/gallon	Gas at $2.50/gallon
Average interest across five types of vehicles	15	21

Source: Platts; data from EPRI and U.S. Department of Energy [14]

The Cost Challenge

The hybrid vehicles available on the market today come at a price premium of at least $2,000. Adding the battery capacity, charger, and controls to convert one to a PHEV costs substantially more. For example, the lithium-ion battery pack for EDrive's prototype Prius conversion with a 35-mile electric driving range cost about $15,000.[16] (EDrive expects this price to come down to between $5,000 and $7,000 if the vehicles are being produced in modest volumes.)

Incremental costs of this magnitude clearly take the conversions beyond the reach of the majority of the car-buying public. However, two trends suggest that PHEVs may be able to achieve life-cycle cost parity with CVs in the not-too-distant future. First, field experience has demonstrated that the nickel metal-hydride batteries used in electric vehicles will last longer than had previously been assumed, meaning that if these batteries were used in PHEVS instead of lithium-ion batteries, it would likely be possible to manufacture PHEVs that wouldn't require battery replacement during their assumed 10-year, 150,000-mile life.[17] Second, HEV market penetration is expected to exceed 1 million units worldwide by 2010. This volume of production should drive down the cost of motors, controllers, and other electrical hardware, thereby reducing the cost of any hybrid design.

In 2004, EPRI published an evaluation of life-cycle costs for HEVs and PHEVs that concluded that "nickel metal-hydride batteries designed for PHEV applications and incorporating the design and materials advances of the last three to five years should meet PHEV performance and cycle life requirements and, in mass production, also the cost goals for PHEVs to capture substantial shares of the automobile market."[18] Assuming a medium-volume production level of 100,000 units per year, the EPRI analysis found a net present value benefit exceeding $1,000 for PHEV20 versions of both a midsize car and a full-size SUV relative to conventional vehicles. At 100,000 units per year, the EPRI analysis estimated incremental costs of about $4,000 and $6,000 for PHEV20 versions of the midsize car and SUV, respectively.

These incremental first costs would certainly present a barrier for a large portion of the potential market. But given the emission and oil-consumption benefits PHEVs appear to offer, it's easy to imagine local, state, or federal governments offering tax incentives, similar to the ones being offered for HEVs today. Moreover, where electric utilities are required to reduce or offset their emissions of ozone precursors or CO_2, it may someday be advantageous for utilities to offer rebates or attractive financing arrangements (perhaps for the battery alone) to gain credit for PHEV emissions reductions. Indeed, some see this as the primary benefit PHEVs offer to utilities.

Market Development

Given the diverse environmental, national security, and economic benefits this technology may deliver, it's no surprise that a variety of parties are promoting its adoption. Perhaps the most ambitious effort is that being spearheaded by the municipal utility serving Austin, Texas. At the direction of its city council, Austin Energy is developing an incentive plan to encourage the purchase of PHEVs.[19] The plan will include rebates on PHEV purchases; a commitment by city government to purchase PHEVs for its fleet; and an effort to obtain commitments from local businesses as well as environmental and consumer groups to purchase plug-in hybrids if the automobile companies manufacture them.

Such measures alone won't generate the level of market pull that would entice an automobile manufacturer to deliver a PHEV product, so Austin Energy has embarked on a campaign to encourage the governments of the 50 largest cities in the U.S. to replicate its efforts. At the same time, EDrive Systems, CalCars, and other groups are working to demonstrate PHEVs' benefits, stimulate market demand, and provide at least an interim way of meeting that demand until the automobile manufacturers commit to producing PHEVs. We expect to see such commitments materialize before the decade is out.

NEWS

Heat Pump Clothes Dryer: Efficient but Expensive

Ira Krepchin

Heat pump clothes dryers have been available for a number of years in Europe, but the high price tag and slow drying time (up to two hours for loads half the size of those typically tumbling around inside standard dryers in North American homes) have kept them from making inroads in the U.S. Prototypes of a new design developed by Tiax LLC—a consulting firm based in Cambridge, Massachusetts—with funding from the U.S. Department of Energy have cut the drying time in half. However, high costs may still keep the units from making significant market inroads in residential markets.

Heat pump clothes dryers are essentially conventional tumble dryers with the heating element replaced by a small heat pump. The system removes moisture from the exhaust air by cooling it, then rewarms the air and recirculates it back into the dryer. In conventional dryers, all the air is vented from the home, whereas in the Tiax design most of the air is recirculated and only 20 percent is vented to protect the compressor and to trap lint.

Potential benefits of heat pump clothes dryers include reduced energy use and lower power demand compared with electric resistance dryers.

Potential benefits include reduced energy use and lower power demand compared with electric resistance dryers. There should also be less wear on fabrics due to lower operating temperatures. Tiax project manager Peter Pescatore tells us that the prototype, tested on a wide range of loads, used 40 to 50 percent less energy than conventional electric resistance clothes dryers.[20]

The Tiax researchers were able to make drying time comparable to, or less than, that of conventional dryers by increasing both air temperature and the airflow rate. A conventional electric dryer uses air at an inlet temperature of more than 300° Fahrenheit (F). Existing heat pump dryers typically use air at 140°F, which results in increased drying time. The Tiax concept uses a different refrigerant, R-134a, in an R-22 compressor, which enables an increase in inlet air temperature to

180°F—not enough to increase wear on fabrics, but when combined with an oversize blower that more than doubles the airflow, it was enough to cut drying time in half.

The remaining challenge is the high cost: The extra parts—including the compressor, evaporator, condenser, and an oversize blower—add up to about $150. And with extra assembly time and retail markup, the increment to the consumer could be $300 or more. For the typical home, where 7 to 10 loads are dried each week, the energy savings would result in a payback period of six years or more, depending on utility rates. Pescatore says the design would have a quicker payback in light commercial applications such as coin-operated laundries, inns, and dormitories, where the machines process many more loads per week.

Tiax's manufacturing partner, which prefers to remain unnamed, is continuing to work on the design and may introduce the new appliance first in Europe sometime in 2006 and then later in the U.S. for the light commercial market.

For more information, contact Peter Pescatore at Tiax, tel 617-498-5000.

SpeciFlow Makes Outdoor Airflow Measurement Less Expensive

Kristin Kamm

Many commercial and industrial buildings lack equipment to measure the amount of outdoor ventilation air brought in to the building. That's because it's difficult to accurately and cost-effectively measure airflow rates, especially at outdoor air intake locations where space is limited and nonuniform airflow conditions exist. But bringing in too little outdoor air results in poor indoor air quality, and bringing in too much results in wasted energy for conditioning the excess air.

A new technology, called SpeciFlow™, can take accurate airflow measurements in nonuniform conditions, is compact, and costs less than the airflow measurement technologies commonly used in buildings today. Federspiel Controls LLC, a developer of building systems control technologies, created SpeciFlow and patented it in 2003. In early 2005, Greenheck Fan Corp., a manufacturer of ventilation equipment, commercialized a control damper that uses the SpeciFlow technology.

SpeciFlow technology, which consists of sensors, electronics, and software, is unique in that it can be inexpensively integrated with high-performance control dampers. Greenheck's product, called the IAQ-42, is a control damper that has pressure sensors right on the damper blades. A microcontroller circuit computes the airflow rate based on the pressure difference across the damper blades, the position of the damper blades, and the temperature of the air flowing through the damper. The microcontroller circuit also opens or closes the damper blades so that the airflow rate through the dampers is close to the setpoint at all times. The IAQ-42 compensates for the effects of temperature and altitude on air density, which can vary by as much as 15 percent from standard conditions.

The most common methods for measuring airflow require a separate airflow measuring station as well as uniform flow conditions. But SpeciFlow works well in outdoor air intakes because the way its pressure sensors are configured on the damper makes it insensitive to the nonuniform flow conditions that exist there. Greenheck product literature lists the accuracy of the IAQ-42 as 5 percent of reading for face velocities of 1.5 to 10.0 meters per second.

Other technologies that work in nonuniform flow, such as hot water anemometers, are more complex and more expensive. Having the airflow monitoring and measuring gear integrated with the mechanical component that modulates flow makes SpeciFlow smaller and more compact than technologies that require a separate airflow measuring station. The Greenheck product is also less expensive because some of the components exist as part of the damper and the damper does not need to be custom-made—it's a stock damper that Greenheck already manufactures.

For more information, contact Clifford Federspiel, principal at Federspiel Controls, at tel 510-418-3392 or e-mail cf@federspielcontrols.com, or visit www.federspielcontrols.com.

RETROSPECTIVE

Whatever Happened to LED Lighting?

Ira Krepchin

When it comes to light-emitting diode (LED) technologies, just about everyone in the lighting industry wants to know when LEDs will be efficient enough and cheap enough for general illumination. The answer to that question is probably not for at least five years, mainly because of high costs (see **Table 2**) and low efficiency.[21] But researchers and manufacturers are pushing LEDs into an expanding number of niche markets.

The most successful early applications for LEDs have been those in which they replace filtered incandescent bulbs, as in traffic signals and exit signs. That's because the filtering of the light emitted makes an already inefficient incandescent source even less efficient. The efficacy of a typical incandescent lamp is about 17 lumens per watt (lm/W). To produce colored light with that lamp, an absorptive filter is used, which reduces the efficacy to 1 to 5 lm/W. In contrast, the color of the light that LEDs generate is based on the materials of construction. Modern, high-brightness red LEDs operate with an efficacy of 15 to 30 lm/W, which makes them much more efficient sources of red light than filtered incandescent lamps. Other leading applications at the moment include outdoor signs and lighting the contours of buildings, where LEDs are replacing neon.

Other properties of LEDs are also playing a role in applications now under development. These attributes include their ability to be used in conjunction with other light sources, their consistent operation at cold temperatures, their small size, and their ability to control various properties of the light emitted.

Two products that have emerged from the California Energy Commission's Public Interest Energy Research (PIER) program show how LEDs can work with other sources. These two new products were developed through the PIER Lighting Research Project, which is managed by Architectural Energy Corp.

The first product is a hybrid incandescent/LED outdoor fixture for exterior and walkway lights in residential and commercial locations. Existing fixtures typically use incandescent lamps because they are small and inexpensive. But these lamps tend to burn all night long, leading to high energy use. And they burn out quickly, which compromises security until the lamps are replaced.

Table 2: Cost of different light sources

It currently costs far more to produce 1,000 lumens of light with an LED source than it does with other light sources.

Light source	Cost ($/1,000 lm)
Incandescent, 40 watts	25
Fluorescent, F32T8	1
Metal halide, 175 watts	2
CFL, self-ballasted	20
LED	150

Notes: CFL = compact fluorescent lamp; LED = light-emitting diode; lm = lumen. Includes replacement costs over 20,000 operating hours; does not include costs of energy.

Source: Platts; data from Vic Roberts [21]

LEDs have the potential to cut lighting energy use by 50 percent or more, without reducing the display's ability to catch the customer's eye.

A new product from Shaper Lighting features a 5-W amber LED that runs continuously during the night paired with an incandescent lamp that only operates when the occupancy sensor detects motion. The area is then flooded with warm, bright light for a few minutes, after which the sensor turns the incandescent lamp off. The LED array continues to run. If the LED runs continuously over a 10-hour nighttime period, and the 75-W incandescent lamp is only on for 1 hour per night, the savings would amount to 228 kWh per year as compared with a continuously burning incandescent.

In addition, the LED source has an expected life of 50,000 hours, or more than 13 years at 10 hours of operation per night. The incandescent lamp has a much shorter life, about 1,000 hours, but reduced on-time means that it should last a long time without burning out—almost three years at 1 hour per night.[22]

The second product is a bathroom lighting fixture, developed in cooperation with the California Lighting Technology Center at the University of California, Davis; the Sacramento Municipal Utility District; MetalOptics/SpecLight; and The WattStopper. The new fixture features fluorescent lighting, an integrated motion sensor, and an orange LED nightlight with battery backup. The LED, which draws less than 1 W, doubles as a safety light during power outages. It provides sufficient light for people to safely move about without affecting their night vision. UC Davis is filing a patent application and negotiating with manufacturing partners to license the fixture.[23]

Three more projects that are being developed at the Lighting Research Center (LRC) in Troy, New York, also point to the wide variety of applications possible for LEDs. The first is a lighting system for refrigerated display cases. These cases typically use fluorescent lighting, but fluorescent lamps have several problems in that application—in cold temperatures, their light output decreases significantly and lamp life is shorter. In addition, because the lamps are typically placed near a door hinge, only about 60 percent of the light is directed toward the merchandise inside, and shadows make it hard to see merchandise deep within the case.

The LRC design features LEDs distributed on the shelves, which provides a more even illumination. In addition, LED output is not affected by cold temperatures. The LRC estimates that when the efficacy of the LEDs reaches about 38 lm/W, the LED solution will be more efficient than fluorescents. Field tests in a store in Albany, New York, showed that customers liked the way the cases looked with the LED lighting.[24] The project is funded by the New York State Energy Research and Development Authority, and the LRC is collaborating with GELcore, Golub Corp., and Tyler Refrigeration.

Another application takes advantage of the small size of LED sources, which makes it possible to produce very low profile fixtures. With funding from PIER and Otis Elevator Co., the LRC is collaborating with Otis to develop a new elevator illumination system. Elevators now typically use halogen bulbs that require at least 8 to 10 inches of vertical clearance. The system produced by LRC enabled Otis to build an elevator cab at least 2 inches shorter than standard, leading to a significant reduction in the weight of the cab and the amount of materials required to build it.[25]

A third project the LRC is working on is for retail display lighting. The team found that LEDs had the potential to cut lighting energy use by 50 percent or more, without reducing the display's ability to catch the customer's eye. Most retailers use halogen PAR and MR lamps due to their good color rendering qualities. Stores also typically use very high illumination levels to create a large contrast between the objects on display and the general background within the product display area. Past research has shown that other variables, such as color variations, can also draw increased attention.

The LRC's approach calls for the continued use of halogen lamps for displayed items, so as not to lose the color quality, in combination with LEDs to provide background color. That approach reduces the level of halogen lighting throughout a store's display area without sacrificing the attention-grabbing function of the displays. In an LRC laboratory study, and in field tests at three clothing stores in the Los Angeles, California, area, researchers also found that viewers preferred the colored background to a white background.[26]

Looking farther into the future, researchers at Rensselaer Polytechnic Institute (RPI) expect that the ability to control such properties as spectral content, emission pattern, polarization, color temperature, and intensity will open up a whole range of new uses for LED lighting. RPI researchers E. Fred Schubert and Jong Kyu Kim offer two examples: developing lighting that can adjust color temperature in ways that will improve health, mood, and productivity; and gaining the ability to control the spectral composition of "grow lights," enabling the energy-efficient cultivation of fruits and vegetables out of season or in climates where they would not ordinarily grow.[27]

A number of challenges remain for developers of LED lighting systems. In addition to improving efficiency and cutting costs, they must develop standards and practices so that lighting designers know how to apply the technologies and get consistent results. Over the next decade, we expect the lure of technology and the improving performance of LEDs to continue to expand their market presence.

The ability to control such properties as spectral content, emission pattern, polarization, color temperature, and intensity will open up a whole range of new uses for LED lighting.

Notes

1 2005 EPA Fuel Economy Datafile (accessed June 1, 2005), from www.fueleconomy.org/feg/download.shtml.

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3 Nick Cappa, spokesman for DaimlerChrysler, as quoted by John Carey, "Giving Hybrids a Real Jolt," *BusinessWeek* (April 11, 2005).

4 David Hermance, executive engineer for environmental engineering, Toyota Corp., as quoted by Danny Hakim, "Hybrid-Car Tinkerers Scoff at No-Plug-In Rule," *New York Times* (April 2, 2005).

5 David Hermance, as quoted by John Carey [3].

6 "EDrive Systems Launches New Plug-In Hybrid Technology; Technology Allows Hybrid Owners to Fuel Cars from a Home Electrical Outlet," press release, EDrive Systems LLC (May 2, 2005).

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