connections common, a utility could almost instantaneously request that customers go off-line and revert to their hybrid-vehicle power source if part of the utility's generating or transmission capacity fails.

- ▶ Even without notice from the utility, homeowners would have a backup generator in the event of a power failure, and the neighborhood would have sources of emergency power.
- ▶ Much of the time that the vehicle isn't at home, it is likely to be at work. If tens or hundreds of employees' cars are available to provide instantaneous emergency power, diffusion furnaces won't even hiccup, and the wheels of industry will continue to turn.

These benefits can be provided economically, given that hybrid vehicles are already being produced and purchased in record numbers. Cooperation from vehicle manufacturers is what is needed, primarily in including control software that will allow the batteries to provide power and be recharged through external instruction and power demand. That software, plus a power connector, should be sufficient on the vehicle. Neither should affect its cost noticeably.

We're all accustomed to the necessity of installing an uninterruptible power source for each computer. Maybe it's time to consider installing a UPS for the house as well.

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In their interesting article on the electric infrastructure, Clark Gellings and Kurt Yeager got most of it right. However, in 1879, three years before Thomas Edison's Pearl Street Station, the first electric company opened in San Francisco. It provided electric energy to arc-light customers.

Edison did his best to prevent the commercialization of alternating current. Through an agent, he staged cruel public demonstrations electrocuting dogs, cats, horses, and even an elephant, to show that AC was unsafe. He even purchased AC apparatus to construct the first electric chair at Auburn Prison in New York. It was Nicola Tesla's polyphase AC, promoted by George Westinghouse, that made possible the large transmission systems of today. Edison's direct-current systems were largely obsolete by 1940.

Over the past 100 years, efficiencies of generators have steadily increased because of scale economies.[1] The efficiency of Edison's generators in 1882 was estimated to be only 8%. It took the building of transmission lines and the increase in unit sizes up to 500 000 kW or more over 70 years to boost the efficiency to 38% for coal-fired steam turbines.

These economies could only have been realized by connecting giant generating stations to thousands of small loads over a very wide area, using transmission lines to reach substations at many load centers and then distribution lines between the substations and the small loads. The principal reason for constructing and operating transmission systems is to permit the use of giant generators, which are more efficient in converting coal to electricity, use far less fuel per kilowatt, and have far lower costs per kilowatt of generating capacity.

Now, however, the relatively tiny 250-kW molten-carbonate fuel cell is more efficient than even the largest central station, particularly when transmission and distribution losses are taken into account and the high price of natural gas relative to coal makes gas no longer as useful for generating base-load energy. Base-load generators, which are on line most of the time, have the more expensive generating capacity per kilowatt but have the lowest fuel costs per kilowatt hour. Even though they constitute only about 40% of all generating capacity, they supply 80% or more of all kilowatt hours. Intermediate and peaking generators that use more fuel per kWh supply the remainder when the base-load generators are being fully used.

With mass production, fuel cells' hardware cost will drop dramatically, perhaps 20% with each doubling of production, and the full fuel-cell energy cost—including the costs of both fuel and hardware—will become competitive with that of central-station power from the grid.

Moreover, apart from their cost advantages, fuel cells can provide highly reliable power. They can cut toxic pollution emissions by some 99% and greenhouse gases by a lower percentage, and can do away with the transmission lines snaking through wilderness or through Connecticut suburbs.

The fuel cost of electric power from giant central stations has been so low over the past 100 years that, even after paying all the costs of transmission and distribution, central-station power has been the most economical. With the advent of the fuel cell, that fuel-efficiency advantage of large central stations over small ones has disappeared. The costs of new transmission and distribution that are necessary if large central stations remain the source of power are skyrocketing—from an average of $500 per kilowatt cost of all those currently installed to about $1500 per kilowatt for those installed in the last few years before control of transmission no longer gave control of the market.

I think that distributed generation with fuel cells will likely be the direction that our power supply will take for the future.

Reference

1. For more information, see W. E. Brand, three-part article in *EV World*. See part 1 at http://evworld.com/view.cfm?section=article&storyid=587, part 2 at =594, and part 3 at =595.

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Gellings and Yeager reply: We thank Wallace Brand and Richard Factor for providing additional insights about the electric infrastructure. A few points deserve clarification.

Several electric ventures did, indeed, open in the US and the UK in the late 1870s and early 1880s before Thomas Edison's Pearl Street Station. However, we highlighted Edison since his was the first true utility "system" of substantial size, serving multiple functions and users.

The efficiency of the transmission system has increased over the years, largely through the use of higher-voltage AC transmission lines and, in a few selected situations, high-voltage DC transmission. Little has changed in transmission technology, though, except for a few applications of power electronics, and growth in demand continues to exceed the rate of capacity expansion.

The cost of electricity steadily declined in real terms from the birth of the industry to about 1970. Most of that cost reduction came from increases in power-plant size and efficiency—a trend that has slowed over the past 30 years and has been more than offset by fuel cost increases and the cost of retrofitting coal-fired power plants with environmental controls such as selective catalytic reduction and flue gas scrubbers.

The average fuel efficiency of central-station power does continue to increase, albeit slowly. The increase is mostly due to the recent addition of new plants, based on combustion turbine technology, that are only slightly more efficient than the average fleet of existing plants. Regrettably, the recent run-up in natural gas prices has rendered many of these plants uncompetitive. And so far, the costs of small generation devices such as fuel cells remain marginally competitive at best, despite their potential efficiency advantages, and they should be considered a complement to, not a replacement for, central-station generation.

The solution to our electric energy needs may include fuel cells—but realistically it will also require increasing the utilization efficiency of electricity and use of advanced nuclear reactors, cleaner combined-cycle coal combustion, and renewable energy resources.

Adapting hybrid vehicles to become plug-in hybrid vehicles is an exciting potential way to reduce overall energy needs even further, reduce emissions, and provide the lowest vehicle life-cycle costs to consumers. Several such vehicle configurations are being demonstrated in the US and Europe.

Today's power system remains the most complex machine ever invented by humankind. Adapting it to meet tomorrow's needs will require a portfolio of solutions and renewed investment. No matter how well-intended, efforts to promote individual solutions outside the context of a robust portfolio only distract and delay the essential comprehensive effort.

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Radioactive Sources May Enter US Illegally

I thought the article "Detecting Illicit Radioactive Sources" by Joseph McDonald, Bert Coursey, and Michael Carter (PHYSICS TODAY, November 2004, page 36) was a good presentation of current and future techniques for detecting radioactive material passing through legal ports of entry. However, passage through legal entry points is not the only pathway for illicit radioactive material to enter the US.

The US–Mexico border is almost 2000 miles (3200 km) long. Hundreds of thousands of illegal aliens cross that border into the US each year. It might be difficult to shield strong gamma emitters to the point where an individual could carry a significant quantity. However, the shielding or containment needed for beta or alpha emitters, including special nuclear materials, is light enough that a few individuals could safely carry enough material for a radioactive dispersal device or an improvised nuclear device.

Hundreds of metric tons of illegal drugs are smuggled into the US each year via land, sea, and air pathways. Larger quantities of illicit radioactive materials could enter the US by these routes.

I fully support the efforts to secure our legal ports of entry. They are a necessary part of our security. But I think this article may give a false sense of security by failing to mention these alternate entry pathways for illicit radioactive sources. Questions about the likelihood of terrorists using legal or illegal entry pathways, and about how illegal entry pathways could be patrolled need to be addressed.

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