most exalted human aspiration—"to be a member of a society that is free but not anarchical," as I. I. Rabi had put it—could indeed be satisfied. And Bethe believed that such communities were models for how larger democratic societies could operate.

All his life, whether working on nuclear weaponry, nuclear energy, nuclear test ban treaties, arms limitation treaties, or whatever assignments and responsibilities Bethe took on as a citizen with outstanding scientific and technological expertise, he believed those works would enable the US to make the planet a better and safer place for all humankind. It was with anguish and trepidation that he observed the paths taken by the present administration when addressing issues related to nuclear weaponry, the environment, test ban treaties, and scientific advice.

Few people have given so much to their discipline, their communities, and their country. Few people have done so as selflessly, sensitively, and wisely. We have all been diminished by his death.

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Ideas Generated for Transforming the Electric Infrastructure

Clark Gellings and Kurt Yeager, in their article "Transforming the Electric Infrastructure" (PHYSICS TODAY, December 2004, page 45), propose "distributed energy resources" as part of the solution to transforming and modernizing the electric power infrastructure. They recommend "small generation and storage devices distributed throughout" the system, but suggest only "fuel cells and batteries" and offer no details of how the cells and batteries could be created economically or how they would be integrated. Much more appropriate devices already exist and are currently proliferating—namely, hybrid gasoline–electric vehicles, such as the Toyota Prius.

Although nominally designed as transportation, hybrid vehicles normally perform that function for only an hour or so per day. The rest of the time they are small standby generator plants. With their capacious batteries, they could supply tens of kilowatts of instantaneous power to cover peak demands for electricity. The continuous power output of hybrids is several kilowatts, commensurate with the power required not just to drive down the highway but also to run a house.

On the power-receiving end, vehicle "docking stations" with DC-to-AC inverters and transfer circuits could turn a house, a factory, or even a community into a self-sufficient entity. Although such facilities aren't free, their cost is much less than that of the typical power station and, if mass produced, might come in under $1000 plus professional installation. Given the many power emergencies and inconveniences during this past hurricane season, I can see at least one section of the country jumping at the opportunity.

Consider what could be accomplished as the hybrid fleet size increases and its power is harnessed:

▶ Individual homeowners could sign up for voluntary disconnection from the grid. With continuous internet 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 in-