Cleaner Energy, Greener Profits:

Fuel Cells as Cost-Effective Distributed Energy Resources

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Executive Summary

The electric power industry is undergoing major changes that are reshaping the traditional roles of utilities, creating opportunities for new technologies, and redefining the scope and character of government regulation. These changes are arising out of the interaction of several driving forces:

- An emerging technological shift could offer distributed generation sources economic benefits unavailable to traditional, centralized sources of electricity.
- Regulatory and public policy support is growing for competition over traditional forms of cost-of-service regulation of electric utilities.
- The restructuring of the electric power industry and the emergence of the digital economy are causing power markets to diverge into two groups of customers—those who demand a low-cost commodity, and those who demand electric service with a high level of reliability and are willing to pay for it.
- Increased energy security concerns are revealing the vulnerability of centralized power supply infrastructure to disruption by accident or sabotage.
- Stricter environmental constraints on power production are inevitable, as electric generation produces a large share of local and global pollution.

The electric power industry is responding to these forces by experimenting with a host of business strategies: flexible pricing for large customers; increased power purchases by utilities; separation of generation, transmission, and distribution assets; diversification into non-regulated energy-service businesses; aggressive efforts to contain costs; and corporate restructuring. Emerging from these experiments is a less tightly integrated, more diversified and, above all, much more competitive power industry. It is an industry that, during the next decade, will continue to shift from the traditional centrally focused "generation-transmission-distribution" companies into a more heterogeneous structure. The new industry will be made up of companies fulfilling various traditional roles, including independent power producers, electric service providers, energy brokers and marketers, transmission operators, and local distribution companies.

One of the most promising and exciting distributed generation (DG) options is fuel cell technology, which converts fuel to electricity at high efficiency, without combustion, and with negligible emissions. Several different fuel cell technologies are under development and commercialization for various stationary and vehicular applications. How quickly and how profitably will fuel cell technology be implemented in the electric power industry? The answer depends largely on how well the economic benefits of DG are recognized and captured in the increasingly competitive electricity market.

New and improved DG technology is making it more feasible and less expensive to produce power near the customer. Also, new technologies for the control, switching and storage of electricity are enabling the transition to DG by improving system efficiency and reliability. Falling costs of fuel cells will make them increasingly competitive with conventional power sources, approaching the point at which these options can compete directly against central generation costs. Already, careful study of the economics of power delivery suggests that cost-effective applications are emerging. Because costs of fuel cells and other DG technologies are dominated by manufacturing economies of scale—the more units one makes, the less expensive each unit is—these early markets can lead to commercialization paths that will bring fuel cells into mainstream use in both stationary and mobile applications.

The main benefits of such DG technologies as fuel cells can be divided into five categories:

- Small scale and modularity provide added value by offering the ability to put in place as little or as much generating capacity as needed. The value derived from this increased flexibility, called option value, is based on shorter lead-time and decreased risk of overbuilding, which reduce financial cost and risk.
- DG sources can provide substantial cost savings if they are sited where and when they can prevent or defer pending investments in utility distribution capacity.
- A related benefit is engineering cost savings from reduced losses, improved voltage levels and power factors, and longer equipment life.
- By providing an independent power source near the customer, DG can improve the reliability of electric service to critical customer loads. Premium reliability can have a very high value in such sensitive industries as data centers, semiconductor fabrication facilities ("fabs"), and many conventional businesses as well. Although the growth of the digital economy is driving demand for increased premium power reliability, this growth does not translate into large increases in total electric demand.
- Finally, fuel cells are among the cleanest DG technologies, and their environmental benefits allow them to be sited very flexibly. This siting flexibility makes it more feasible to capture other DG benefits, such as rapid construction, premium reliability, distribution cost savings, and use of waste heat, which depend on the proper siting of DG sources in relation to customer loads. Thus, promising near-term applications exist in emission-limited areas (such as large concentrated urban centers) where there are premium reliability needs, costly distribution constraints, or both.

Fuel cells can be cost-effective in these applications even at their present costs, if the DG benefits can be captured. Thus, the near-term commercialization path for fuel cells appears to include grid-connected fuel cell systems in commercial buildings, communication provider facilities, and other facilities that need high reliability and low emissions. The most cost-effective applications will be in locations where existing distribution capacity is insufficient to serve expected demand growth, leading to costly expansion investments.

A longer-term commercialization path for fuel cell technology will integrate these stationary applications with the potential for fuel cells in cars, trucks and buses. Cars parked at these facilities during the day offer the potential to generate large amounts of electricity during peak-demand hours from the fuel cells that are onboard, paid for, but otherwise idle. These fuel cell vehicle-generators could connect to the facilities' electric infrastructure to deliver into the grid the electricity generated onboard.

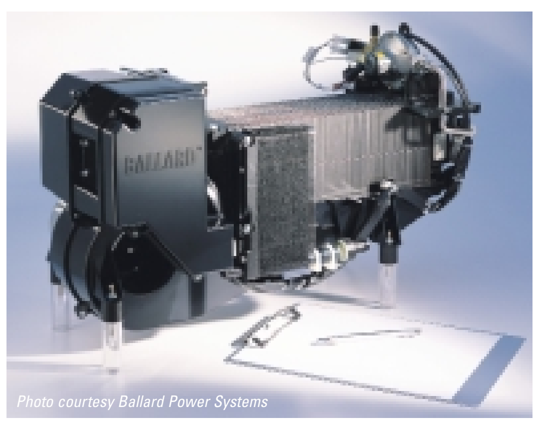


Photo courtesy Ballard Power Systems

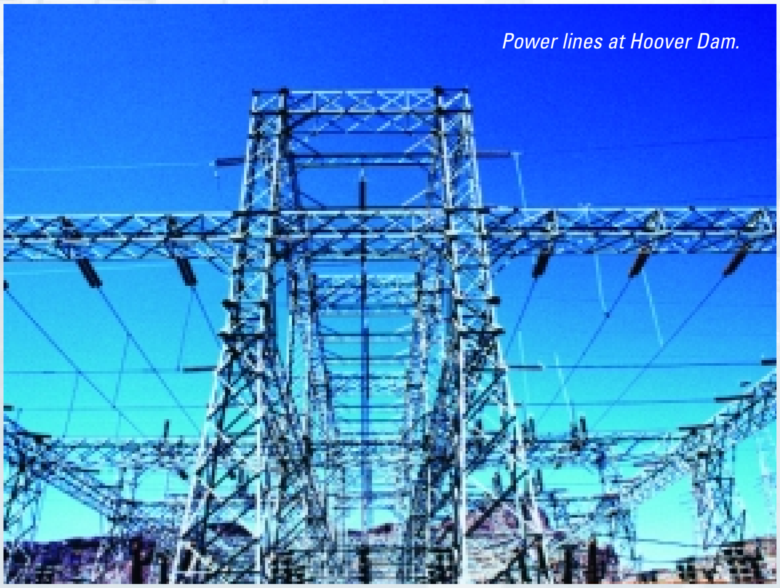
The Nexa™ power module, manufactured by Ballard Power Systems, is a commercial fuel cell product for portable applications. It is capable of generating up to 1.2 kilowatts of DC power.

For more information about fuel cells and how they work, see www.rmi.org/sitepages/pid537.php

Introduction: Why is energy back in the news?

It has been more than twenty years since energy has been a frequent topic of news headlines. Today, however, we hear frequent references to a new "energy crisis." Some aspects of the energy debates of the 1970s have changed little since they disappeared along with long lines at the gasoline pumps, while other aspects have changed dramatically. Concern about energy security related to oil imports from the Persian Gulf is due to the familiar fact that global oil reserves are concentrated in that region, and to gradually increasing U.S. demand after steep reductions in the early 1980s.[1]

This concern has prompted calls for developing fossil fuel reserves in highly sensitive areas of the U.S., such as the Arctic National Wildlife Refuge, based on the premise that such domestic energy supplies cannot be subject to embargo by a foreign power. However, it is difficult to imagine a less secure strategy than further reliance on the Trans-Alaska Pipeline, which could be permanently disabled by a wintertime attack on a single key point along its 800-mile, indefensible length.[2] Similar vulnerabilities have been identified in the U.S. domestic natural gas supply system.[3]


Power lines at Hoover Dam.

The centralized infrastructure for electric power supply in the U.S. is also vulnerable to interruption by accidental failure or intentional sabotage. High-voltage transmission lines each carry more than 1000 MW of power through hundreds, even thousands, of miles of remote, undefended territory. Nuclear power plants, although relatively well protected against accidents, may be vulnerable to aggressive acts of sabotage, which could release large amounts of radioactive contamination and severely endanger the general public.

Other forces in the energy market combined to cause a short-term crisis in the restructured California electricity market. Extreme electric price volatility during 2000–2001 was caused by the failure of the now-abandoned market structure, in which utilities were required to buy power through a central Power Exchange. A handful of wholesale power suppliers could choose to sell to this market, to other customers, or not at all. This unequal competition guaranteed that California paid the highest prices in the entire system, and prices skyrocketed. This structure also discouraged utilities from entering long-term contracts that would tend to stabilize prices. The result was high prices, deteriorating reliability, and not enough competition to stimulate increased supply.

Like the proposed solutions to oil supply insecurity, conventional wisdom regarding the California electricity debacle is contradicted by simple facts. One often hears that California built no power plants in the 1990s due to environmental regulation. In fact, additions to the state's generation capacity exceeded 4000 MW, all non-utility-owned and small (about 20 MW on average), and more capacity could have been added without environmental opposition.[4]

More importantly, funding for many of California's utility-sponsored energy-efficiency programs was severely reduced or eliminated during 1995–2000. The energy savings that were foregone could have prevented the 2000–2001 crisis.[5] Instead, voluntary demand reductions from energy efficiency, behavioral conservation, and peak-load management saved 12% of California's peak demand in the first half of 2001, thus ending the recent crisis.[6]

While restructuring was predicted to lower prices, this tends to occur only when genuine competition is introduced in a market with excess capacity, such as the airline industry of the 1980s, or with rapid technological progress, such as the telecommunication industry of the 1990s. Meanwhile, electric retail markets are diverging into those that demand a low-cost commodity and those that demand high-reliability service. Electricity can no longer be treated as a homogenous commodity. Instead, it is an essential service whose reliability is fundamental to the prosperity and security of modern industrial society.

Thus, as energy security concerns create headlines again, today's security problems are not about a lack of energy supply, but rather a highly centralized and vulnerable energy supply infrastructure with volatile and unpredictable prices. In the electric power industry, one solution to this vulnerability is distributed generation (DG). Meanwhile, the renewed interest in energy has attracted the financial industry's attention to several energy technologies as promising investment opportunities.[7] The technologies include such DG options as fuel cells and microturbines, as well as such electric storage and backup options as flywheels, ultracapacitors, and superconductors. Regardless of the accuracy of popular explanations for the new "energy crisis," the clear need for cleaner, more reliable power sources is creating a growing market interest in DG.

Today's security problems are not about a lack of energy supply, but rather a highly centralized and vulnerable energy supply infrastructure.

[1] The U.S. new vehicle fleet continues to comply with the Corporate Average Fuel Economy (CAFE) standards. However, the steady shift from predominantly passenger cars to light trucks, vans and sport-utility vehicles, which face a 25% lower CAFE standard, has caused a gradual erosion of overall fuel economy. Combined with increasing vehicle ownership, this has accelerated growth in oil demand.

[2] See Lovins, A.B. and L.H. Lovins, "Fool's Gold in Alaska," *Foreign Affairs*, July/August 2001, www.rmi.org/sitepages/pid171.php.

[3] For example, a small group of saboteurs could cut off the majority of the natural gas supply to the Eastern U.S. for several months in one evening's work without leaving Louisiana. See Lovins, A.B. and L.H. Lovins, 1982. *Brittle Power*, Brick House Publishing, www.rmi.org/sitepages/pid533.php.

[4] Contracts for another 1400 MW of natural gas-fired and wind power were canceled by Federal regulators because the $50/MWh price was considered too high, although it is less than what the state is now (2001) paying for long-term contracts and a small fraction of recent market prices. Recently, a 600 MW combined-cycle plant near Silicon Valley was opposed by local interests including neighboring Cisco Systems.

[5] See Lovins, A.B., "California Electricity: Facts, Myths, and National Lessons," Worldwatch Institute State of the World Conference, July 2001, http://www.rmi.org/images/other/E-WorldwatchPPT.pdf.

[6] See Natural Resources Defense Council, 2001. "Energy Efficiency Leadership in a Crisis: How California Is Winning," www.nrdc.org/air/energy/eeca/eecalinx.asp.

[7] "…at the innovative end of the stodgy electricity industry…Energy Technology (ET) ranges from micropower such as fuel cells and microturbines to renewables and snazzy software, such as that used for sophisticated metering. Much of this has been in development for years, but recently ET seems to have become almost as fashionable among investors as the Internet once was." *The Economist*, 19 April 2001.

Fuel cells: A small, clean, reliable power source

For more information about fuel cells and how they work, see www.rmi.org/sitepages/pid537.php

Fuel cell technology is one of the promising sources of distributed electric generation, although the technology is hardly new. The British physicist Sir William Grove made the first fuel cell, which he called the gaseous battery, in 1839. A fuel cell is essentially a battery that can be recharged by addition of a chemical fuel, rather than the reverse flow of electric current. The most efficient fuel cells run on pure hydrogen and oxygen, and the only by-product of such a fuel cell is hot water. Until recently, the technology has been developed mainly for use in submarines and spacecraft. The oxygen tank that exploded on Apollo 13 was there to supply a fuel cell.

Back on Earth, the two main applications of fuel cells are electricity generation and powering motor vehicles. Power applications could involve central generation by utilities, industrial co-generation (of heat and electricity), or distributed generation (DG) on or near the premises of commercial or residential customers. Vehicular applications of fuel cells in cars and trucks provide a potential solution to the primary cause of urban air pollution. As we will discuss later, it is also possible to connect cars to the grid as mobile power plants when parked.

Thus, fuel cells can provide a clean, efficient and reliable power source, and they can be scaled in size to fit nearly any application. The only technical drawback of fuel cells is that hydrogen and oxygen do not readily occur on Earth in their pure forms. Oxygen can be replaced by air, which is about one-fifth oxygen, with some loss of efficiency. But obtaining a steady flow of hydrogen is more of a challenge.

There are several different types of fuel cell technologies in development today. They are differentiated by the approaches taken to obtain hydrogen from more common sources of energy, such as natural gas. Four types of fuel cells are being developed for commercial energy applications: proton-exchange membrane, phosphoric acid, molten carbonate, and solid oxide.[8] Their basic properties are shown in Table 1.

All of these fuel cell technologies are under commercial development today, although the majority of existing installations use phosphoric acid technology. Each technology promises high electric output efficiencies and virtually no emissions, and each can deliver heating energy as a by-product. Low-temperature proton exchange membrane (PEM) fuel cells are less bulky and can start instantly, making them the preferred choice for fuel cell vehicles. The higher-temperature technologies have advantages in terms of higher efficiency, more useful heat output, and the ability to use natural gas without an expensive separate fuel reformer.

Table 1.
Fuel Cell Technologies under Development and Commercialization

Fuel Cell Technology	Electrolyte	Operating Temperature	Efficiency	Fuel Requirement
PEM (proton-exchange membrane)	*Polymer*	75 C (180°F)	35–60%	*Pure hydrogen or methanol (Natural gas requires a fuel reformer)*
PA (phosphoric acid)	*Phosphoric acid*	210 C (400°F)	35–50%	*Hydrogen, but not as pure as PEM (Natural gas requires a fuel reformer)*
MC (molten carbonate)	*Molten carbonate salt*	650 C (1200°F)	40–55%	*Hydrogen, natural gas (integrated reformer)*
SO (solid oxide)	*Ceramic*	800–1000 C (1500–1800°F)	45–60%	*Hydrogen, hydrocarbons (no separate reformer)*

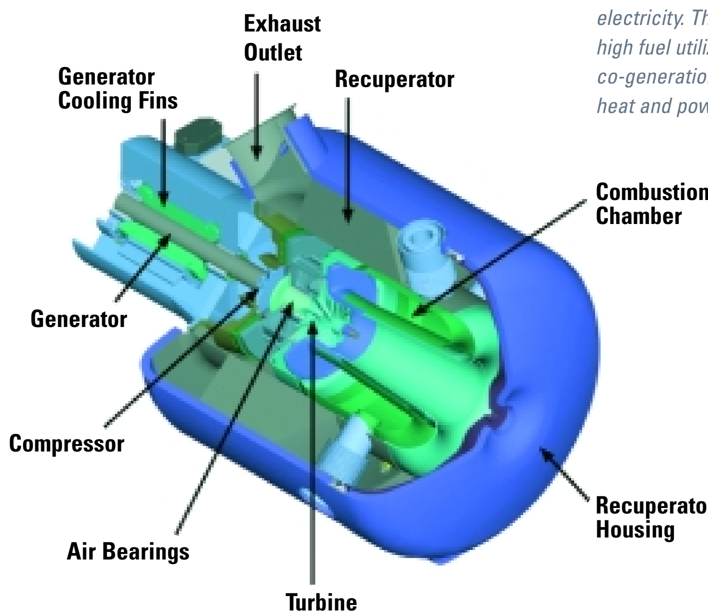
Fuel cells can run on natural gas with high efficiency, little pollution, and few moving parts. Thus, they offer a potential power source that is clean, reliable and flexible in size. The major remaining obstacle is cost. The present (2001) cost of a kilowatt (kW) of fuel cell capacity is about 7–10 times that of the combined-cycle combustion turbines that are used in today's new, central generating stations. Fuel cells are also several times more costly than small, mass-produced reciprocating gasoline or diesel engines used as backup generators.

Once they are in operation, fuel cells can be inexpensive to operate. Maintenance costs are expected to be low due to relatively few moving parts, and the high efficiency and useful heat by-product provide for low fuel costs. Fuel cells are a high-capital-cost, low-energy-cost power source. Compared to efficient central combined-cycle stations, the energy cost advantage is small,[9] so it is essential to reduce the capital cost disadvantage in order to make fuel cells competitive.

There are two ways to reduce fuel cells' capital cost disadvantage against central combined-cycle stations. The obvious way is to reduce the *cost* of fuel cells, and numerous manufacturers are working hard to achieve cost reductions in each of the fuel cell technologies now under development, as they enter high-volume production. The other way is to build the *value* side of the equation—to find additional economic benefits that fuel cells can deliver by virtue of their smaller size and greater flexibility, as well as their quiet, clean operation. We already mentioned that co-generation of electricity and heat energy is a significant benefit made possible because fuel cells can be sited near customers and in crowded urban centers.

Small DG sources can provide many other benefits, which are discussed in more detail below. They include the modularity and flexibility that come with small scale, the potential to reduce distribution grid capital and operating costs, and the ability to increase reliability for customers who need it. Finally, the environmental benefits of fuel cells are becoming ever more tangible in value. Fuel cells are just the sort of small, clean, reliable source needed to solve the new "energy crisis."

Capstone MicroTurbines™ operate on natural gas or propane. Because they can handle low energy gases, they can also convert landfill and digester gas to electricity. They can achieve high fuel utilization through co-generation, utilizing both heat and power.



[8] A fifth type of fuel cell technology, alkaline fuel cells, is used in space applications.

[9] Because fuel cells can serve electric loads directly, they can provide process heat via co-generation and are not subject to transmission and distribution losses. These advantages provide energy cost savings even compared against a combined-cycle generator with a comparable efficiency of electric generation.

What is different about today's electricity problems?

Making relatively small and remote customers pay the full cost of electricity was thought to hinder the potential development of some areas of the country.

One reason that fuel cells can help improve the economic and environmental profile of electricity supply is that the nature of energy problems has dramatically changed. In the 1970s, the supply of petroleum fuel was constrained, while today it is the security and reliability of delivered electric power that is of concern.[10]

More specifically, the problem is not even in the total supply of electric energy, but rather in the power-system capacity and its reliability to deliver electricity to meet loads, especially during times of peak demand. Unlike a liquid fuel, electricity is difficult and expensive to store; therefore, available generation and delivery capacity must be sufficient to meet the instantaneous demand. Most of the time, capacity is more than adequate. Problems occur when demand is very high, usually on hot summer afternoons, and when supply capacity decreases, due to generating station maintenance[11] or faults in the transmission and distribution (T&D) system.[12]

The traditional solution to power supply problems has been large, centralized generation stations and long, high-voltage transmission lines. This model dominated the first hundred years of development of the U.S. utility industry for several reasons. The most important reason was that the high capital costs of generation and transmission equipment created powerful economies of scale that favored large, centralized facilities. The reliability of generation equipment was relatively poor compared to distribution wires, so it made sense to connect many plants to a common T&D grid, allowing a degree of redundancy to improve system reliability.

This centralized structure made it possible to aggregate many diverse loads, reducing the total load's variation with time and allowing more generation plants to run at full capacity. Perhaps more importantly, this structure provided the technical basis for a unified power system with uniform prices among millions of diverse customers. Uniform pricing, regardless of the actual cost of service, implies a willingness to cross-subsidize certain high-cost customers at the expense of low-cost customers, such as large, steady, concentrated loads. Making relatively small and remote customers pay the full cost of electricity was thought to hinder the potential development of some areas of the country.

Finally, there was a lack of alternative technologies. Small, distributed generation sources were expensive, unreliable, noisy, and polluting. There was also a lack of the control, communication, and information technologies necessary to manage distributed sources in a way that supported, rather than jeopardized, the reliability of the power grid. Today, these technologies are increasingly available, and the historic conditions that encouraged centralized power sector development have changed as well.

[10] The fuel supply constraints of the 1970s have certainly not disappeared, however. The problem was relieved in the early 1980s by a combination of increased supply from both OPEC and non-OPEC sources, widespread fuel switching from oil to natural gas and coal, and substantial improvements in energy efficiency, including a doubling in the fuel economy of the U.S. car fleet. Oil-fired electricity generation decreased in most countries and nearly disappeared in the U.S., to be replaced by coal and nuclear power, and more recently by natural gas and wind power. With fuel shifts come new concerns, of course. Natural gas prices are the most volatile in the energy industry.

[11] When California experienced rolling blackouts in the first half of 2001, almost 30% of the state's generation capacity was off-line for maintenance. More than 10%, representing some 6000 MW of capacity, reported "unplanned" outages at generation plants owned by one of four companies.

[12] Faults can be accidental or intentional. In August 1996, an Oregon power line sagged onto a tree limb and launched a blackout to four million people in the Western U.S. A similar event could be triggered intentionally via sabotage of high-voltage transmission lines. For a full discussion of electric system vulnerabilities, see Lovins, A.B. and L.H. Lovins, 1982. *Brittle Power*, ref. 3. See also Pillar, C. "Power Grid Vulnerable to Hackers," Los Angeles Times, 13 August 2001.

Changing Trends in the Electricity Industry

The market conditions in the electric power industry have changed dramatically during the past ten years, and the forces of change have been at work for at least two decades. The industry maxim that "bigger is better" now no longer applies; bigger is no longer better all the time, or even most of the time. The reasons include industry restructuring, environmental constraints, reliability needs, new technology, the inevitable aging and deterioration of the existing power supply infrastructure, and renewed concerns about energy supply security.

The introduction of competitive electricity markets via restructuring has been a chaotic process, both in the U.S. and abroad, and the process is far from complete. Some of the chaos in the U.S. results from the lack of uniform policies or rules. In the power sector, only long-haul transmission and wholesale trade are regulated at the Federal level.[13] The rest of the industry is regulated by state-level public utility commissions or boards, resulting in 50+ different regulatory regimes and policies. At present, the status of restructuring ranges from full competition to continued full regulation, with many states somewhere in between.[14]

The effect of restructuring, however incomplete it may be, is nevertheless profound in some parts of

Workers in a network server room.

the electricity industry. Competition in power generation has begun to impose greater market discipline, such that utilities can no longer build hugely expensive nuclear and coal-fired plants with full confidence of recovering capital costs.[15] This discipline is even being applied to still-regulated utilities in the form of "performance-based" regulation. Today, producers must be confident that sufficient demand exists and that prices will support the revenues needed to justify investments in new capacity.

On the customers' side, change is coming more slowly but just as profoundly. Utilities are "unbundling" their tariffs, which previously aggregated large numbers of different customers and averaged the costs of serving them. Over time, unbundling will make it difficult to continue to cross-subsidize high-cost customers.[16] Rather,

Central power generation plants stopped getting more efficient in the 1960s, stopped getting cheaper in the 1970s, and stopped getting bigger in the 1980s.

[13] The Federal Energy Regulatory Commission (FERC) is an independent regulatory agency within the Department of Energy that regulates the transmission network and wholesale electricity sales in interstate trade. Because most bulk transmission pathways cross interstate boundaries, FERC has broad jurisdiction in the wholesale market. It has little power over retail trade or in distribution systems. FERC also licenses hydroelectric generation facilities, but it has little authority over thermal stations. Other components of the electricity supply system, including thermal generation, distribution, and retail trade, are regulated at the state level.

[14] Department of Energy (DoE), "Status of State Electric Industry Restructuring Activity," Energy Information Administration, www.eia.doe.gov /cneaf/electricity/page/restructure.html.

[15] Central power generation plants stopped getting more efficient in the 1960s, stopped getting cheaper in the 1970s, and stopped getting bigger in the 1980s, by which time unit costs were escalating rapidly. See Hirsh, R.F., 1989, *Technology and Transformation in the American Electric Utility Industry*, Cambridge Univ. Press. Since the 1980s, new central plants, many using combined-cycle gas turbines, have become smaller (<500 MW), cheaper, and more reliable, and an increasing share of new generation capacity has been <100 MW. See Lovins, A.B., *et al.*, 2002, *Small Is Profitable*, Rocky Mountain Institute, in press.

[16] Under traditional utility regulation, utilities bear an "obligation to serve," *i.e.*, they must provide the full requirements of all customers. If some customers cost more to serve than the revenues they deliver, the utility was able to recover this deficit from other, lower-cost customers through the rate-making process. With unbundling, however, it may become difficult to serve such customers without raising prices substantially or curtailing service to some degree. This situation brings the obligation to serve into question, even though it was this arrangement that allowed once-remote parts of North America to be connected to the power grid in the first place.

these customers will have to pay much higher prices and suffer lower reliability, work with the utilities to find ways to lower costs, or leave the utility grid altogether.

Ever more stringent environmental constraints, locally and globally, have become a fact of life. The public demands environmental quality just as much as it demands more and better food, clothing, housing, transportation, and recreation. Electricity production accounts for two-thirds of U.S. emissions of SO_2 and one-third of NO_X and CO_2, the main cause of global climate change.[17] Despite dramatic reductions in the rate of emissions from such sources as cars, most urban areas must continue to reduce emissions in order to maintain, let alone improve, air quality. And despite the political convenience of arguments that the threat of climate change is uncertain, it is now clear that the uncertainty concerns only the rate and distribution of climate change, not its existence.[18]

Growth of the digital economy translates foremost into widespread and growing demand for premium-reliability power.

An even more sudden change is the emergence of the digital economy, which is alive and growing despite the failure of numerous "dot-com" firms. The growth in data traffic is remains brisk, and the demand for bandwidth (a measure of capacity to transfer information) is estimated to be more than doubling each year.[19] The core of the digital economy is not in the "dot-com" sector, but in a variety of well-established and fast-growing businesses, including telephone networks, Internet service providers, wireless communication providers, semiconductor fabrication plants ("fabs"), software firms, online brokerages, Internet portals, data warehousing centers, web-hosting companies, and more. All these businesses need extremely reliable electricity.

Businesses in the digital economy are not simply inconvenienced by a power outage; they can be crippled by even a brief outage. Thus, the growth of the digital economy translates foremost into widespread and growing demand for premium-reliability power. Contrary to some widely cited claims, this demand does not translate into large increases in total electricity demand, because each generation of electronic equipment is ever more energy-efficient, and because electronic commerce reduces the need for other, more energy-intensive activities such as transport.[20] However, the number of customers that need premium-reliability power and are willing to pay for it will continue to grow in response to economic needs and heightened concern about energy security.

The traditional utility solution of centralized generation and long-haul transmission was dictated, to a large degree, by the then-available technology capable of delivering adequate reliability at acceptable cost. This technology included steam turbines, miles of high-voltage wire, huge trans-

[17] Each type of emissions leads to different environmental impacts. Oxides of nitrogen (NO_X) are the main precursor in the formation of ground-level ozone and urban smog. Sulfur dioxide (SO_2) causes direct damage to human health, agricultural crops, and materials, and it is the main precursor in the formation of acid rain. Carbon dioxide (CO_2) is not considered a pollutant under the Clean Air Act, in fact it is a nutrient; however, it is the most important of the greenhouse gases, which cause global climate change.

[18] The latest report from the Intergovernmental Panel on Climate Change (IPCC), a consensus of nearly 1000 scientists worldwide, concludes: "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system. There is new and stronger evidence that most of the warming observed in the last 50 years is attributable to human activity. Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate. Human influences will continue to change atmospheric composition throughout the 21st century." IPCC Working Group I, *Third Assessment Report, Summary for Policy Makers, 2001*, www.ipcc.ch.

[19] One recent estimate of data traffic projected Internet traffic growing from 350,000 terabytes (trillion bytes) per month in 1999 to 16 million terabytes per month by 2003, and that streaming media accounts for 10% of all Internet traffic. Ryan Hankin Kent, "Internet Traffic Report," 18 January 2000. www.rhk.com. It is clear that growth has slowed, but not stopped, in the past year, and there is overcapacity of bandwidth, causing financial distress for many telecommunications firms. Even if only 15% of existing capacity is now used, a resumption of such traffic growth could employ all available capacity within two years.

formers, electromechanical switches and circuit breakers, and so on. Today, however, the emergence of new technologies in power generation, storage, switches, and controls has changed the situation, if not the thinking of utility engineers.

Today, small gas turbines can be as clean and efficient (counting their co-generated heat) as large generation stations, and fuel cells even more so. Advanced flywheels and superconducting storage technology offer reliability improvements. Solid-state switching equipment can eliminate many of the power quality problems introduced by the traditional grid. Finally, intelligent control and communication technology can coordinate the whole system, integrating both central and distributed generation sources, as well as premium-reliability service for some customers, and real-time pricing and customer load control for others. Utilities have been slow to adopt these new technologies and to exploit DG, but it can be done.[21]

Another important change in the power supply system is simply the effect of time. Our aging T&D system is strained: its condition deteriorating, its capacity inadequate, and its technology outdated. Power reliability suffers as a result. The majority of power outages originate in the T&D system—as a result of interference from trees, animals, cars, and even solar electromagnetic storms.

The need to maintain reliability for all customers, to greatly improve it for some, and to capitalize on new technology would together suggest substantial investment in the T&D system. In the 1990s, however, uncertainty about restructuring caused utility investment in T&D to decline, creating a growing backlog of unmet needs.[22] Today, these needs present an opportunity to address T&D planning and design using a least-cost approach, selecting the best buys first. Considering the massive capital investments needed for conventional T&D solutions, DG technologies and aggressive end-use efficiency improvements offer the potential for substantial cost savings, while meeting reliability and energy security needs faster.

Today, small gas turbines can be as clean and efficient as large generation stations, and fuel cells even more so.

[20] Many claims of explosive Internet-related electricity demand growth can be traced to Huber, P. and M.P. Mills, "Dig More Coal—the PCs are Coming," *Forbes,* 31 May 1999. The authors assert, for example, that a "typical computer and its peripherals require about 1,000 watts of power." In fact, the average PC and monitor use about 150 watts of power in their active mode, falling to 50 watts or less in energy-saving mode. Laptop computers use under 30 watts, and all computers are getting more energy-efficient because of technical improvements driven by the growing market for portable equipment. New flat screens use about a quarter of the energy of traditional video display terminals. Huber and Mills conclude that the Internet accounts for 13% of U.S. electricity demand, and that "…it's now reasonable to project that half of the electric grid will be powering the digital-Internet economy within the next decade." These projections appear to result directly from the authors' erroneous assumptions about individual equipment power demand, extrapolated to the entire population of Internet-related hardware. Technically consistent estimates based on real measurements show that all office, communications and networking equipment account for about 3% of U.S. electricity demand, and that its growth is largely offset by continuous efficiency gains. Kawamoto, K., *et al.*, 2001. *Electricity Used by Office Equipment and Network Equipment in the U.S.*, Lawrence Berkeley National Laboratory, LBNL technical report number 45917. See also http://enduse.lbl.gov/projects/infotech.html for a review of the whole debate. For more background on the Huber/Mills claims, see www.fossilfuels.org/electric.htm. For a summary of energy efficiency gains from the Internet, see www.cool-companies.org/energy.

[21] For example, such utilities as Entergy and Wisconsin Public Service have installed distributed superconducting magnetic energy storage (D-SMES) units in distribution substations to solve voltage-related problems, ensure power reliability, and increase the power transfer capability of the existing grid. Duke Power and Salt River Project have installed dynamic voltage restorer (DVR) units at sensitive industrial customers' facilities to correct momentary voltage sags, and Florida Power has installed DVRs at distribution substations to protect the power quality on entire distribution feeder lines.

[22] Since 1992, planned investment in U.S. electric transmission capacity has fallen by about half. One measure of the vulnerability of the transmission system is the ten-fold increase between 1997 and 2000 in occurrence of transmission loading relief (TLR) procedures. TLR procedures are curtailments in interstate power transfers that cause potential transmission facility overloads. These events do not necessarily result in customer load curtailment, but their frequency indicates the degree of strain on the system and the need for increased capacity. North American Electric Reliability Council, *Reliability Assessment 2000–2009*, www.nerc.com.

Fuel Cells Light Times Square Showpiece

The Condé Nast Building, at 4 Times Square in Manhattan, is equipped with two 200-kilowatt fuel cells, which can provide eight percent of the building's power requirements.

© Jeff Goldberg/Esto
courtesy of Fox & Fowle Architects

Two fuel cells generate 400 kW of electricity for the Condé Nast Building, the Durst Organization's new signature building at 4 Times Square in Manhattan. The company installed the fuel cell system in February 2000 to supplement the building's primary power requirements. **During a blackout, the system can operate independently of the utility grid** to maintain power to critical mechanical components and external landmark signage on the building's facade.

In addition to electricity, the fuel cells generate thermal energy at the rate of nearly one million Btu per hour, which feeds the building's perimeter heating. Harnessing the combined heat and power raises the total energy efficiency of the system to 87%. Because the fuel cells make no more noise than a standard air conditioner, the units at 4 Times Square were installed inside the building, several floors above street level.

The Durst Corporation chose fuel cells as the power source for this urban environment, where air quality is a significant concern and reliable power is vital. **These units are powered by natural gas and produce minimal emissions.** By operating in parallel with the utility grid, the organization has an extremely reliable, environmentally friendly system. The model PC25™ fuel cell systems were developed by International Fuel Cells, Inc. (IFC), and were manufactured by IFC's sister company, ONSI Corp.

Durst views this installation—which also integrates solar cells into the building's south and west façades—as a groundbreaking achievement, with similar opportunities on the horizon. **"We already have begun planning another mid-town project where fuel cell technology is likely to be appropriate,"** Durst executives said. The company expects that new data centers, which require highly reliable power supplies and are sensitive to even minor power fluctuations, to be especially good candidates for fuel cell technology.

Small is profitable: the economic benefits of distributed generation

The result of all of these changes, in an industry not accustomed to rapid change, is the new "energy crisis." Like the energy crisis of the 1970s, this one will retreat from the headlines as prices return to normal levels, even if the underlying causes are not resolved. Still, a crisis usually teaches us lessons and leads to new opportunities, and this one is no exception. One lesson is that there is no single panacea for electricity problems, as we learned earlier with nuclear power. Rather, we must examine the full range of technical and business opportunities in electricity generation, delivery, and use.

For example, it is clear that power generation plants are getting smaller, and that distributed generation (DG) is here to stay. Below, we address the benefits of DG, and specifically fuel cells. Another part of the story is that the T&D grid needs refurbishing and upgrading, but not necessarily with simply more wires and transformers. The best solutions will involve a smart combination of these traditional technologies, together with targeted energy-efficiency measures and properly sited DG, storage, switching, controls, and communications technologies. Utilities and regulators continue to overlook myriad cost-effective end-use efficiency opportunities—usually the best and quickest buy of all—but that's another story.[23]

Jeremy Heiman photo

Transformers at the Hopkins Substation in rural Colorado step down 230,000 volts to 115,000 volts. The substation, owned by Xcel Energy, has a capacity of 100 megawatts.

As set out above, the benefits of distributed generation include several general categories:

- Option values from small scale, modularity, short lead time, and high flexibility
- Distribution capacity cost deferral if correctly sited in time and place
- Electrical engineering cost savings from reduced losses and from ancillary services
- Utility and customer reliability benefits, including premium-power service
- Environmental benefits from emission costs and siting advantages

Within each of these categories of benefits, discussed below, there can be a range of different benefits to utilities, their customers and society. Each benefit tends to be highly technology- and site-specific. They do not necessarily apply equally or at all to every individual DG case.

[23] In most commercial, industrial, and institutional facilities, there are abundant opportunities to save 70% of the energy and cost for lighting, fan, and pump systems, 50% for electric motors, and 60% in such areas as heating, cooling, office equipment, and appliances. Whole-system design may also reveal opportunities for downsizing, combining, or eliminating some building energy systems, obtaining multiple benefits from single expenditures and achieving far greater cost savings than indicated by measure-by-measure analysis. See A.B. Lovins, 1996. "Negawatts: Twelve Transitions, Eight Improvements and One Distraction," *Energy Policy*, April 1996, www.rmi.org/images/other/E-Negawatts12-8-1.pdf. Moreover, the productivity gains resulting from the installation of more efficient building design may dwarf the money saved directly on energy. See, for example, Romm, J.J. and W.D. Browning, 1998. "Greening the Building and the Bottom Line," Rocky Mountain Institute, www.rmi.org/sitepages/pid174.php.

Option values

When central power generation costs were an order of magnitude cheaper than small generation, there was no reason to consider DG if a connection to the grid was available. Today, however, new technology has brought the cost of DG within the range of that of central generation, even as the cost of central combined-cycle generation has fallen. With DG costs approaching the competitive range, it makes sense to sharpen the financial economics pencil and explore the economic benefits of small scale and high flexibility.

Because electricity is prohibitively expensive to store in large quantities, it is like a commodity with a short shelf life, such as milk. Imagine if one could only buy milk in 100-gallon barrels, and that it took several days for an order to arrive. We would no doubt be sure to order earlier than necessary to avoid running out; we would often have an excess of milk; and a lot of milk would be unused and spoiled because of its short life. Wouldn't it be more efficient to get milk in 1-gallon bottles at a local store? We would save so much from reduced spoilage that we could afford to pay a higher unit price for the milk. This premium, based on the *option* to buy as little or as much as we need, just when we need it, is the "option value" that comes from small size and flexibility.

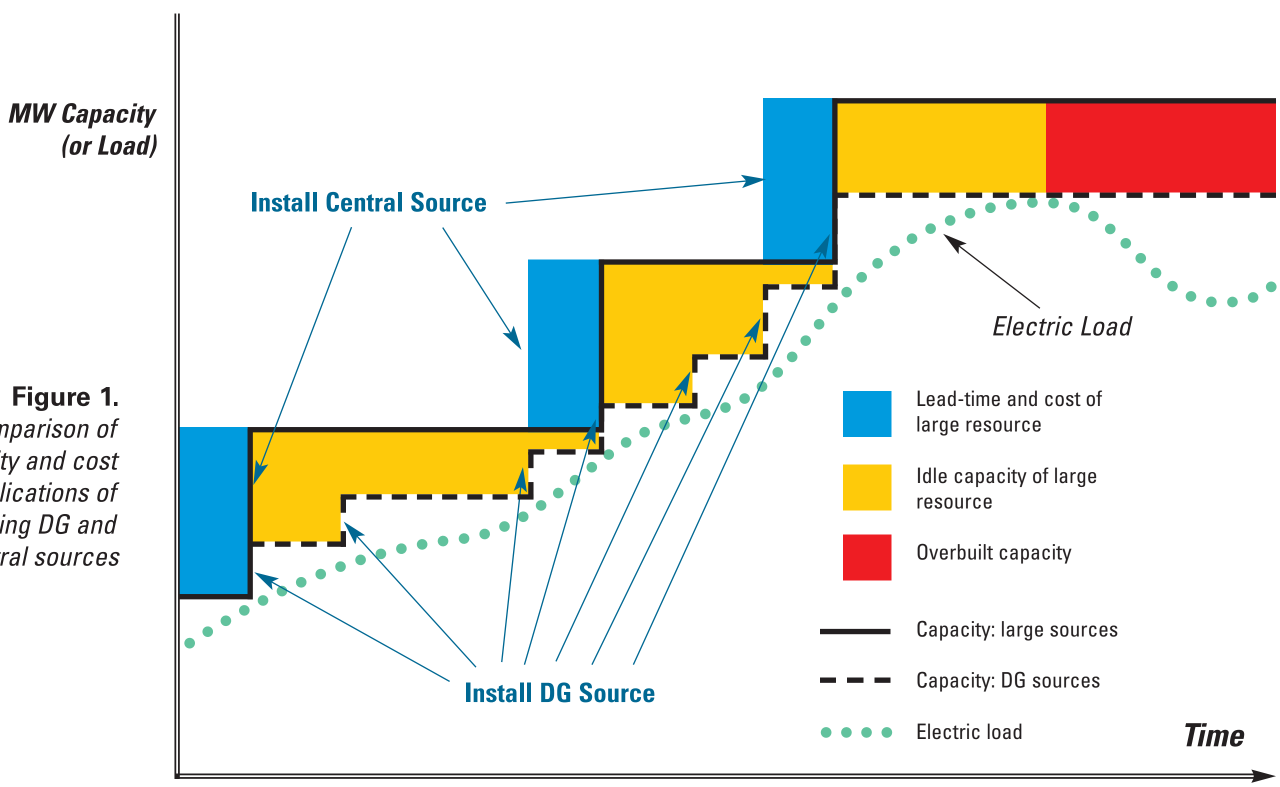


Figure 1. *Comparison of capacity and cost implications of adding DG and central sources*

The central source is available in large capacity increments and has a long lead-time. The DG source is available in flexible capacity increments and has a short lead-time. Option value benefits of DG compared to the central source include 1) increased lead-time and cost of central sources, 2) increased cost of idle capacity that exceeds existing load, and 3) increased cost of overbuilt capacity that remains idle.

This option value applies even more powerfully to electricity generation. Central generation plants, as well as T&D capacity, are "lumpy" investments; *i.e.* they come in large increments. Often, a large unit is built to meet demand that is expected to exceed existing capacity by only a small amount. This leads to excess capacity that remains idle but still incurs costs. Smaller units can reduce the need to overbuild to meet expected but uncertain demand growth. Traditional utility regulation rewarded overbuilding, but the financial discipline of a competitive market will surely penalize producers with idle capacity.

In addition, the modularity that accompanies small scale can improve the rate of response to demand changes. If new customers suddenly require unexpectedly large amounts of power, then small, modular DG units can usually enter service faster than large central stations. The short lead-time of smaller units is thus an advantage in responding to demand changes without building unnecessary idle capacity (see Figure 1).

Short lead-time also reduces the carrying costs of plants under construction, which can reduce the present-value cost of the plant itself. As in the milk example above, reducing the lead-time also reduces the incentive to overbuild, as it is easier and less expensive to increase capacity in response to demand growth when it occurs.

As an example of the economic benefits of small scale and short lead-time, consider a perfect DG resource, which can be built in exactly the increments needed to meet annual load growth, with a one-year lead-time. In contrast, a central generation source would have a longer lead-time. Also, because the central source is larger than the annual increments of load growth, some of its capacity remains idle after it is built, until the load growth catches up.

Table 2 shows the increase in the net-present-value cost of the central source, compared to the DG source with the *same unit ($/kW)* cost. For instance, if the central source has a capacity equal to six times the annual load growth, and a four-year lead-time, it carries a 45% cost premium compared to a DG source with equal unit cost. Thus, DG could cost 45% more per kW and still have the same net-present-value cost as the central source.

Size	Large Resource Lead-Time (years)				
Ratio	1	2	3	4	5
1	0%	5%	10%	16%	22%
2	5%	10%	16%	22%	28%
3	10%	15%	21%	27%	34%
4	15%	20%	27%	33%	40%
5	20%	26%	32%	39%	46%
6	25%	32%	38%	45%	53%
7	31%	37%	44%	52%	60%
8	36%	43%	50%	58%	66%
9	42%	49%	57%	65%	73%
10	48%	55%	63%	72%	81%

Table 2.
*Net Present Value Benefit of a Small Resource with 1-year Lead-Time**

* Compared to a resource of *equal unit* cost, but with a longer lead-time and larger capacity. The size ratio is the resource capacity as a multiple of annual load growth. The small resource can be deployed in exactly the quantity needed to meet annual load growth. Thus, the large resource must begin construction earlier (depending on its lead-time) and stay overbuilt until load catches up. Both of these consequences increase its net present value compared to the small resource.

The comparisons shown in Table 2 are based on an assumption of certain load forecasts. The inherent uncertainty of load forecasting further increases the benefits of the DG source. Load uncertainty increases the risk that the central source will remain overbuilt and unable to recover its costs. If load growth stagnates, the DG source will still be sized correctly, while it becomes possible that the central source will remain oversized indefinitely and unable to recover its costs. Thus, a full probabilistic analysis of the risk-adjusted costs of competing generation options will show even greater benefits for DG.[24]

Worse yet, if expected demand growth does not materialize at all, then overbuilding large, lumpy generating stations is even more costly. The added flexibility provided by small scale and short lead-time does not eliminate the risk of overestimating demand, but does reduce its potential cost substantially. Small scale and short lead-time mean that less capacity is under construction at a given time, thus reducing the cost penalty for delaying the completion of that capacity if demand slows unexpectedly.

With restructuring, and especially performance-based regulation, there is greater pressure on electric suppliers to control capital expenditures, and it is becoming feasible to use varying customer price structures, based on the cost of service.

[24] For many more detailed examples, see Lovins, A.B., *et al.*, 2002. *Small Is Profitable*, Rocky Mountain Institute, in press.

[25] For example, one analysis showed that the cost of refurbishing distribution lines could more than double the cost of service for about 25% of the rural electric cooperatives in the U.S., giving these coops and their customers ample incentive to use DG. See Hoff, T.E. and M. Cheney, 2000. "An Historic Opportunity for Photovoltaics and Other Distributed Resources in Rural Electric Cooperatives," www.clean-power.com

Distribution cost deferral

So far, we have compared DG to large, central generating stations. This appears to be the relevant comparison for firms and policy makers that deal with generation capacity only. However, DG can also offset costs in the T&D system, providing additional financial benefit to the utility. Until recently, most utilities treated T&D costs as unavoidable components in the expansion of the generation network, based on engineering rules of thumb designed to maintain accepted system reliability criteria. Also, traditional regulation prevented utilities from charging different prices to different customers, for example charging more distant customers proportionately for higher distribution costs. Instead, utilities were forced to subsidize high-cost customers at the expense of others.

With restructuring, and especially performance-based regulation, there is greater pressure on electric suppliers to control capital expenditures, and it is becoming feasible to use varying customer price structures based on the cost of service. These changes open the door for distribution utilities to take action to reduce costs, or increase revenues, in high-cost areas that they were traditionally expected to subsidize. DG can play a major role in this strategy, but first utilities need to identify the areas where potentially high costs are expected and to target DG (and energy efficiency) specifically to those areas.

It is important to note that, like generation, T&D expenditures are "lumpy." Moreover, distribution capacity is actually utilized even less of the time than generation capacity, as shown in Figure 2, because being closer to the load, it serves fewer customers whose loads are less diversified. This means that these large, lumpy distribution investments are idle much of the time. Thus, deferring such investments can yield significant cost savings.[25]

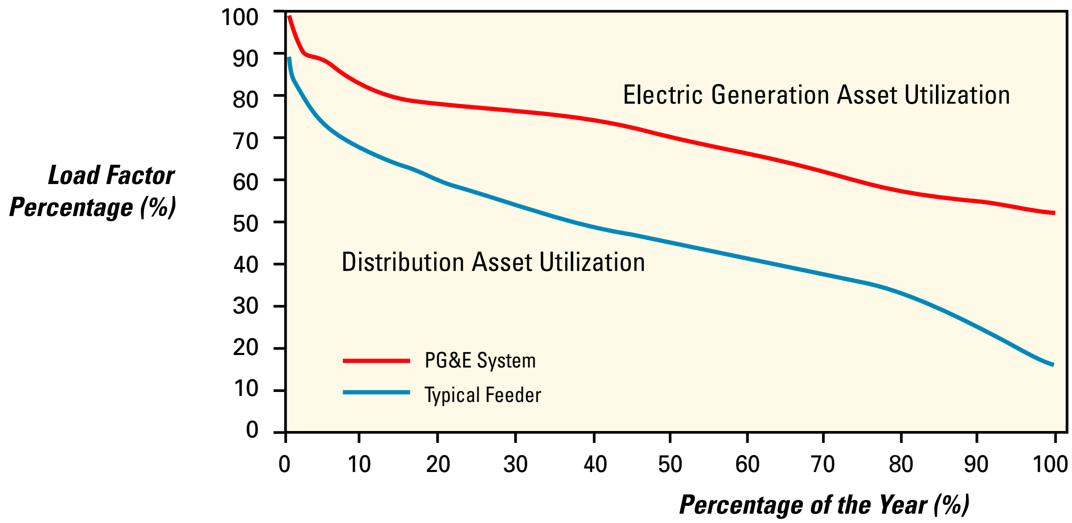


Figure 2. *Comparison of load duration curves for a distribution feeder vs. generation*[26]

Recent analytic advances in determining utilities' area- and time-specific (ATS) costs more accurately have important implications for the siting and design of DG sources. This method has been applied by numerous electric utilities in the U.S. and Canada, and its use has been adapted to utilities in Brazil, Hong Kong, Israel, the Philippines, and South Africa.

The most important innovation of the ATS method is to distinguish the marginal distribution capacity cost (MDCC) from the familiar system-level utility capacity and energy costs. Unlike the system-level utility costs, which are most sensitive to generation and bulk transmission costs, area-specific costs largely depend on distribution and local transmission capacity costs. As a result of pursuing this kind of analysis, a distribution utility may discover an option to choose the least-cost means to serve incremental demand from a significantly expanded list of resources:[27]

- Develop small-scale *DG facilities* located near the source of load growth,[28]
- Use *differentiated prices* to encourage customers to limit demand during peak hours,[29]
- Promote *energy efficiency or peak load management* for customers or uses that drive the peak demand,[30]
- Rely entirely on central-grid power, and incur the costs of *new T&D capacity* to transport the power to customers with new and/or increasing loads.

[26] A load duration curve shows the fraction of the time that the load is equal to or less than a given fraction of its annual maximum. The area under the curve is the load factor, an indication of the utilization of the supply resource. Generation resources see a much higher load factor than most distribution resources, because they serve all customers and see the maximum load diversity. The data are from Pacific Gas and Electric Co, as reported in Feinstein, C.D., 1993. "An Introduction to the Distributed Utility Valuation Project," Electric Power Research Institute, EPRI TR-102461.

[27] The comprehensive approach to least-cost distribution planning is sometimes labeled local integrated resource planning (LIRP), which is a promising application of the ATS costing method. For case studies, see E SOURCE, *Local Integrated Resource Planning: A New Tool for a Competitive Era*, November 1995, www.esource.com. New applications, in the restructured environment, are called energy "resource investment strategy" (ERIS) in RMI's parlance.

[28] Swisher, J.N., 1998. *Using Area-Specific Cost Analysis to Identify Low Incremental-Cost Renewable Energy Options: A Case Study of Co-Generation Using Bagasse in the State Of São Paulo*, Global Environment Facility, Washington DC.

[29] Electric Power Research Institute (EPRI), 1994. *Designing Profitable Rate Options Using Area- and Time-Specific Costs*, EPRI report TR-104375.

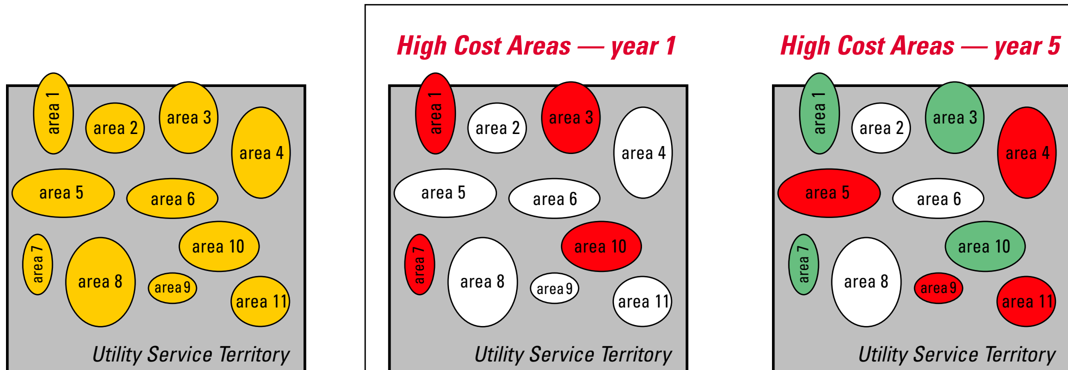
[30] Swisher, J.N. and R. Orans.1996. A New Utility DSM Strategy Using Intensive Campaigns Based on Area-Specific Costs. *Utilities Policy*, vol. 5, pp. 185-197.

One consistent result of ATS analysis is that T&D costs vary widely in time and place, creating large variations in MDCC values. Thus, ATS costing allows targeting of DG projects—like a rifle, not a shotgun—in areas where the *distribution utility costs are relatively high*. Where DG capacity can defer new T&D capacity, it has an economic *deferral value* to the grid.

In theory, higher utility costs mean higher value for DG alternatives, potentially allowing more attractive investments in such sources as fuel cells. By selectively targeting projects to minimize utility costs, it should be possible (albeit still difficult in practice) to improve the terms that the utility offers for privately produced power from DG sources.

If utilities know what their area-specific costs are, they will know *where and when* their costs are significantly higher than the system average. The timing is important, because cost estimates must be forward-looking. Thus, high-cost areas can move around in *space and time* (see Figure 3). Some utilities have many such areas, while others will have few if their general level of excess distribution capacity is relatively large.

Figure 3.
Comparison of conventional DG siting to targeted (ATS-based) approach



Conventional approach:
Based on system-level costs, all areas look the same…

Based on area-specific costs:
Some high cost (red) areas are attractive for DG now, but these areas become low-cost (green) areas later.

Using information from existing utility system costing studies, which include detailed ATS analysis of many distribution planning areas within several utilities, one can estimate the range of the potential MDCC values. The following example gives estimates of the range of value that DG could provide for deferral of utility T&D capacity investment.

A study of four U.S. utilities illustrates the variation in MDCC by time and location, both within and between different utilities. This study estimated MDCC values in 378 utility planning areas across four utilities in four different states. The four utilities vary from each other by location, customer mix, load profile and size.[31]

In this study, the MDCC was estimated as a lifecycle value over 20 years. For example, an MDCC of $500/kW means that a 1-kW reduction for 20 years (or approximately the life of a fuel cell) is worth $500. For a 3-kW fuel cell, the value would be $1,500. Figure 4 compares the distribution of MDCC for each of the utilities. This chart shows the MDCC for the different utility planning areas as a percentage of utility load. For example, 50% of Utility 1's load occurs in areas with an MDCC of $300/kW or more.

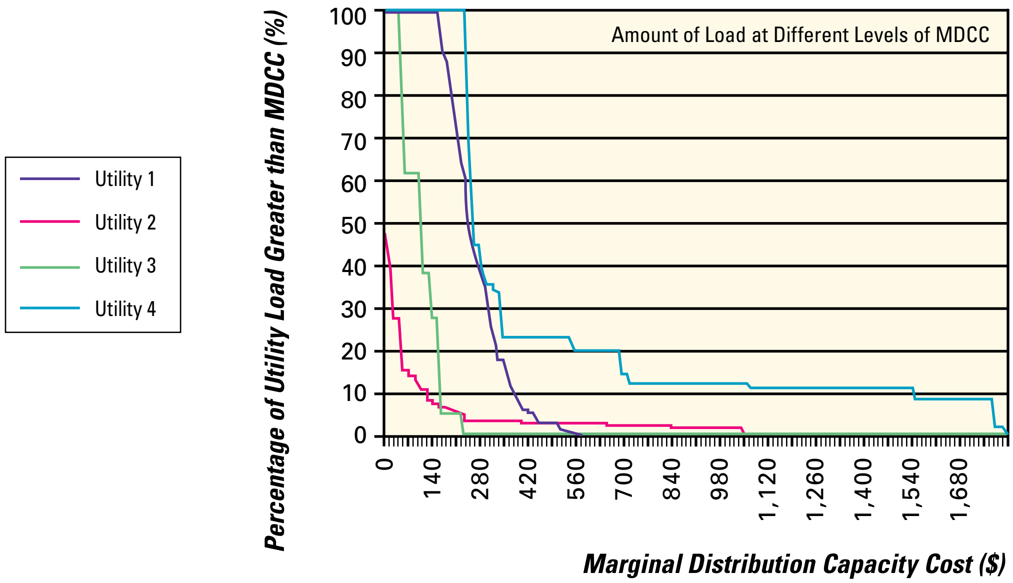


Figure 4.
Distribution of MDCC Values for Four Utilities

From Figure 4 we see that the MDCC variations can be dramatic: 50% of Utility 2's planning areas have zero MDCC over the 20-year planning horizon, while 50% of Utility 4's planning areas have MDCC values greater than $320/kW. The MDCC distributions vary substantially by utility. The MDCC for Utility 3 ranges from $50/kW to only $182/kW, while the range for Utility 1 is from zero to over $1,000/kW. The mean MDCC varies from $73/kW for Utility 2 to $556/kW for Utility 4.

This high-level ATS cost survey shows the range of MDCC and an assessment of the potential value of T&D deferral applications, with the following conclusions:

- The value of deferring distribution capacity investments, indicated by the MDCC values, varies widely by area; it also fluctuates considerably over time. Thus, the DG "targets of opportunity" are moving targets.
- The MDCC value range is $0/kW (wrong area) to over $1000/kW, with many areas at $200–400/kW. In terms of DG, each 1-kW reduction achieved in T&D load would be worth $200–400 in utility cost deferral for these areas.
- DG must target certain distribution planning areas at certain times to capture deferral value.
- The DG source needs not meet the entire load of an area to defer planned distribution capacity. In fact, the maximum DG capacity that would be needed to defer capacity in *all* high-cost areas would be less than 10% of the total existing load.
- To achieve any deferral value, DG must displace the area load growth for at least one year. The minimum DG size is therefore in the range 500–2500 kW for most areas, though this could be the sum of multiple smaller units in the same area.
- The local peak demand drives the MDCC value. Compared to the system peak, this area peak may occur at different times and be caused by different customers or loads.

[31] Heffner, G., C.K. Woo, B. Horii and D. Lloyd-Zannetti, 1998. Variations in Time- and Area-Specific Marginal Capacity Costs of Electricity Distribution, *IEEE Transactions on Power Systems*, vol. 13, pp. 560–565.

DG offers potentially significant benefits above and beyond the value of generated energy alone.

The MDCC value determines the cost-effectiveness of DG in terms of the *capital cost* that can be avoided per kW of DG, provided that the DG source is available during the critical high-cost area-peak hours. Avoiding this cost can help pay for the investment in a DG source such as fuel cells. The low *energy* cost of high-efficiency fuel cell technology may provide some savings in terms of the cost of purchased energy from the grid, but this may not be a very important advantage in such applications.

Although DG is often considered as an alternative to utility grid service,[32] the types of economic benefits described above actually accrue most directly to the utility. Therefore, some form of cooperative partnership with the utility is essential to capture this value. Operating DG independently from the grid would avoid the incremental cost of expansion as well, but it would also lose the benefit of using the existing utility investments.[33]

As this example of ATS cost analysis demonstrates, DG offers potentially significant benefits above and beyond the value of generated energy alone. Improved precision in capturing and quantifying such benefits—a product of greater experience, better analytics, and increased awareness—will only accelerate the identification of profitable options for deployment of fuel cells and other distributed generation options.

Electrical engineering cost savings

In addition to capacity deferral value, DG can provide economic benefits to distribution utilities by reducing costs in the operation and maintenance of T&D systems. These potential electrical engineering benefits include:

- *Reduction of Losses.* DG can reduce system losses by reducing the current flow from the transmission system through the transformers and conductors on the distribution system. DG-based loss reduction also reduces the distribution utility's total installed capacity (and corresponding cost) as seen by the transmission system.
- *Voltage Support.* DG can support voltage in areas of the distribution system that suffer large drops at high loads, replacing voltage regulators and line upgrades. Voltage support is provided by injecting power into the system at the DG site, thereby reducing the current and corresponding voltage drop from the substation to the area. DG can also regulate voltage by balancing fluctuating loads with generation output.
- *Reactive Power Support.*[34] DG can help balance reactive power flows on a distribution system with both real and reactive power injection. Real power injection reduces current in the conductors, which is a major source of reactive power demand that is typically treated with banks of capacitors. Improved reactive power flow (as indicated by a higher power factor) reduces current and losses on transmission and distribution components, and helps control system voltage.

[32] See, for example, Hoff, T., *et al.*, 1997. "Distributed Generation and Micro-Grids," Proceedings of the 18th Annual North American Conference of the US Association for Energy Economics, www.clean-power.com.

[33] Remote power systems are one market niche for DG technologies. However, their economic benefits are limited by high fuel costs, limited reliability, lack of thermal loads, and poor matching of output with loads.

[34] Reactive power is a measure of energy stored in the oscillating inductance and/or capacitance of a power delivery system with no net gain or loss. Reactive power is indicated by the power factor, which is the ratio of real power supplied (kW) to the apparent power (kVA) and is equal to the cosine of the phase-angle between the supply voltage and current. Reactive power demand (measured in kVAR) increases the current needed from the power system, which increases system losses, and can also cause a voltage drop in T&D lines. To reduce these effects, electric utilities use reactive-power compensation and may pass on the cost of compensation to the user in the form of a penalty for power factors low enough to require compensation.

- *Equipment Life Extension.* DG can provide value for equipment life extension in aging facilities, especially if transformers and feeder lines are under heavy loading. If DG is used to keep loading levels on these facilities below a predefined de-rated value, the DG source can defer the transformers' or lines' replacement costs.

Another advantage is that fuel cells are direct current power sources. Like certain other DG technologies, fuel cells rely on an inverter to convert DC power into AC power. Correctly designed inverters are well suited to provide voltage and reactive power support in a distribution system. This can offset costs of capacitor banks, voltage regulators, and other equipment. Additional modest cost savings result from extending the life of transformers and feeder lines.

In a typical "problem area" that utility engineers regularly face, the value of these savings would be in the range of $100–200/kW, although in extreme cases this value could exceed $500/kW. Loss reductions resulting from injection of DG into the distribution grid tend to be modest but can have significant value. Again, in a typical "problem area," this value would be in the range of $5–10/MWh.

As in the case of deferral value discussed above, the resulting cost savings will generally accrue directly to the distribution utility. Most such savings take the form of reduced internal utility expenditures and are difficult to track without the utility's cooperation. Reductions in losses, and to some extent the need for reactive power, can be observed to some degree from the utility's purchases of ancillary services in restructured markets.

Reliability benefits

One of the most exciting prospects for DG technology is the potential to provide valuable benefits in terms of improved customer reliability. It is widely acknowledged that one consequence of the emergence of the digital economy is the need for premium-reliability power in facilities operated by a wide range of businesses.[35] A customer's cost for a power outage, and thus the value of preventing the outage, is clearly increasing. The outstanding questions are then:

- *How much is premium-reliability power worth?*
- *Which customers are willing to pay for premium-reliability power?*
- *To what extent can DG provide the needed reliability?*
- *How can the reliability benefits be captured for the DG owner?*

The value of customer reliability, which reflects the avoided cost of power outages, is difficult to estimate and appears to be changing rapidly.[36] DG-provided reliability can reduce inconvenience, discomfort, direct costs, and opportunity costs from lost sales or production. The sum of these indicates value of service (VOS). VOS estimates vary widely, from low values for residential customers to more than $1000 per outage, even momentary, for commercial customers. Home offices probably have much higher VOS values than other residential customers do, and this market segment is growing as broadband service permeates the residential market.

Most existing VOS studies are still based on surveys of traditional industries, where sustained loss of refrigeration or prime movers could incur

DG sources such as fuel cells can respond to problems caused by momentary interruptions faster than can conventional standby generators.

[35] "…the growing societal reliance on technology is transforming the rare power outage from an inconvenience into something more serious…this phenomenon is real, will intensify geometrically, and presents the greatest near-term opportunity for new power technology." Merrill Lynch, "Power Technologies: There's Gotta Be a Better Way," research report, June 2000.

[36] Outage cost estimation is an entire academic field by itself. A good discussion of customer outage costs can be found in R. Billinton and R. Allan, 1996. *Reliability Evaluation of Power Systems*, Plenum Press.

substantial costs. Today, however, even the briefest outage could be crippling to many digital-economy businesses. The rapid pace of technological change and the new business models evolving in the information and telecommunications industries make these customer reliability benefits the most difficult DG benefits to quantify at present.

Anecdotal data indicate that many customers believe that brief interruptions can cost them between $40,000 and $200,000, and some manufacturers, such as pharmaceutical and semiconductor companies, consider their outage cost to be on the order of millions of dollars per hour.[37] Internet-based businesses require extremely high levels of reliability, which may reflect VOS values that are orders of magnitude higher. In some cases such values are backed by contractual terms and insurance policies.[38] Some examples are listed in Table 3.

To what extent can DG enhance reliability, and why haven't utilities taken advantage of this resource in the past? The answer depends, to a large degree, on how reliability is defined. Utility grid design focuses on providing a uniform level of reliability under conditions of peak demand. Traditional generation system design aims for an outage probability of 0.0003, or 99.97% reliability (3.5 "nines"). This level is achieved, despite the 90–95% reliability of generation plants, by having excess *reserve capacity* available.

Table 3.
Examples of digital economy businesses that need premium power

Business Sector	Example Companies
Telephone networks	*AT&T, MCI*
Internet service providers	*AOL, Juno*
Wireless communications	*Sprint, Palm*
Semiconductor manufacturers	*Intel, Motorola*
Software firms	*Microsoft, Oracle*
Online brokerages	*Schwab, E-Trade*
Internet portals	*Yahoo, Lycos*
Data centers	*Relera, Verio*
Retail electronic commerce	*Amazon, EBay*
B2B electronic commerce	*Commerce One, I2*
B2B equipment vendors	*Cisco, Sun*

Because the majority of outages is caused by faults in the distribution system, from interference by trees, animals, cars, etc., rather than by generation, the true reliability is about 99.9% (3 "nines"). Even at this level, it is difficult for a DG system to improve peak availability beyond that of a wires-only system. To do so, the DG capacity would have to serve the entire peak load at a high level of reliability.

However, if most of the reliability value is associated with lower loads, and in particular with specific, critical loads, then DG can improve reliability beyond that of a wires-only solution by *reducing the probability of losing critical loads*. For these loads, DG can increase the reliability to more than five "nines," and higher with additional redundancy.

Thus, such DG sources as fuel cells can provide customer reliability services that wires alone cannot. DG can provide protection of critical

[37] E SOURCE, *Distributed Generation: A Tool for Power Reliability and Quality*, Report DE-5, November 1998, www.esource.com.

[38] For example, Sure Power is selling 1-MW grid-independent power supply systems for critical loads, based on the ONSI fuel cell technology and flywheel storage. Sure Power contractually guarantees 99.9999% (six nines) reliability, which is backed by a $5 million insurance policy. With expensive technology and extreme redundancy, this product is clearly aimed at a premium-price market niche.

loads from sustained outages far beyond what a typical uninterruptible power supply (UPS) can provide, and it can respond to problems caused by momentary interruptions faster than can conventional standby generators.[39]

To increase reliability value, a fuel cell system must use highly reliable components, redundancy of multiple components, or both. Because more and better components increase costs, there is a trade-off between reliability value and capital cost. Also, the fuel cell system must be operated and maintained to ensure its availability when outages occur. Some quantity of hydrogen storage can mitigate the risk of fuel-supply failure, either from component failure or interruptions in natural gas supply. The latter risk can also be further mitigated by bottled gas as an on-site backup supply.

Unlike the value provided by distribution capacity deferrals or engineering cost savings, customer reliability benefits provide value directly to the customer. This means that DG developers have the opportunity to market DG reliability benefits (and other values to the extent possible) directly to the customer.[40] Therefore, it is not as necessary to secure the cooperation of the utility to capture the value of customer reliability benefits. Utility cooperation may still be necessary to arrange the grid interconnection in a way that supports, and doesn't interfere with, the use of DG to enhance customer reliability.

An incorrect connection between a DG source and the grid can endanger system stability, the utility's equipment, and the safety of utility personnel in the field. Utilities have therefore developed strict rules to prevent incorrect connections.[41] On the other hand, utilities make relatively little effort to encourage proper connections to DG sources. This hesitancy is partly due to the view that DG is a relatively untested approach to solving traditional utility planning problems. Another part of the problem is the cultural bias of engineers and planners in a utility working culture, where the default reaction to new technologies in the distribution system is to question their safety and reliability.

Existing DG sources are typically connected in one of two configurations:

- *Emergency standby*—In this configuration, the DG source operates only when the grid is not available. Depending on the quality of power electronics and the quantity of energy storage installed, the host facility may or may not lose power as its power supply switches between the grid and the DG source.
- *Parallel*—In this configuration, the DG source operates most of the time, with the grid providing backup power. The DG source might even export surplus power to the grid. In the case of a grid outage, however, the DG source must "trip," or disconnect, in order to prevent problems for the utility as it restores service.

The challenge for a fuel cell system designer is that a cost-effective system requires *both* the reliability benefits of standby operation and the energy savings of parallel operation. A critical issue for DG sources is the possibility of "islanding," when a fault in the grid separates a gener-

An essential part of the uninterruptible power supply at Cajun Networks in Baton Rouge is this array of batteries. Though the batteries would only be required to provide power for a matter of seconds before the diesel generators activate in response to a power outage, they hold enough power to sustain server operations for 16 hours.

39 Conventional standby generators are not capable of responding to instantaneous power interruptions. Rather, they rely on a battery-powered uninterruptible power supply (UPS), together with fast-response power electronics to provide ride-through power until the generator can carry the load.

40 For example, the flagship Condé Nast building on Times Square in New York uses a combination of fuel cells, solar photovoltaics, and doubled energy efficiency to attract tenants at premium rents, using the advantage that the building's two most reliable power sources are located within the building itself.

41 Typical utility interconnection rules can require detailed engineering studies, utility-grade switches, batteries, dedicated isolation transformers, fault-current-limiting reactors and other protection equipment, and possibly automated control, monitoring and telemetry equipment. E SOURCE, *Shifting the Balance of Power: Grid Interconnection of Distributed Generation*, Report DE-8, October 1999, www.esource.com.

While conventional generators are less expensive than fuel cells, the potentially high value of service for fast-growing market segments such as data centers suggests that customers could be willing to pay a cost premium for high-reliability power.

ating source from the rest of the system, stranding it on an electrical "island."[42]

DG sources need to operate in an island mode to serve loads during a grid outage. Present utility practice, however, discourages any sort of islanding. Moreover, utility connection requirements for DG vary widely and tend to be complex and costly.[43] To help reduce DG connection and protection costs by making the requirements more predictable, the Institute of Electrical and Electronic Engineers (IEEE) is working to develop a national Standard for Interconnecting Distributed Resources with Electric Power Systems, which is expected to be published during 2002.[44] In Texas, the PUC has issued a fairly simple and transparent interconnection standard for generation sources less than 10 MW.[45] This is a step in the right direction, but the standard does not provide for islanding DG sources.

Capturing the potential reliability benefits of DG, without sacrificing the benefits of parallel operation, requires further development of standard practices, in cooperation with distribution utilities. This goal should be achievable with existing technology, as long as the DG source is not exporting power to the grid. The latter operating mode has practical and cost constraints, due to the need to avoid system instability in case of a grid outage. Although technically possible, it appears impractical to try *both* to export and to island.[46]

The rapid pace of technological change makes the customer reliability benefits of DG the most difficult to quantify, but potentially the most important, at least for commercial customers. Capturing this reliability value requires robust design of a fuel cell or other DG system, redundancy of key components, and provision for islanding during a system outage without sacrificing the benefits of parallel operation. These requirements are technically feasible to meet, but further harmonization and standardization of design practices are needed.

Of course, fuel cells are more expensive than traditional standby generators and battery-based UPS systems. However, batteries provide only a limited duration of support, they tend to lose capacity over time, and they have high maintenance and space requirements. While conventional generators are less expensive than fuel cells, the potentially high VOS for fast-growing market segments such as data centers suggests that customers could be willing to pay a cost premium for high-reliability power, if fuel cells can offer other advantages.

[42] An island is "any part of the distribution system, consisting of both generation and load, that operates without interconnection with the bulk power system." Dugan, R. and G. Ball. 1995. *Engineering Handbook for Dispersed Energy Systems on Utility Distribution Systems*. Final Report, Electric Power Research Institute. EPRI TR-105589.

[43] National Renewable Energy Laboratory (NREL), 2000. *Making Connections: Case Studies of Interconnection Barriers and their Impact on Distributed Power Projects*, NREL/SR-200-28053.

[44] This standard, IEEE SCC 21 P1547, will include requirements for the performance, operation, testing, safety, and maintenance of DG interconnections.

[45] Texas Public Utility Commission, "Interconnection of On-Site Distributed Generation," November 2000.

[46] A compromise solution might involve separate DG sources, one sized and designed not to export power but to island during a grid outage, and the other designed to export but to trip in case of an outage.

Environmental benefits

We have shown that DG can provide significant economic benefits from deferring capacity investments and reducing engineering costs in the distribution system, and that DG can provide premium reliability to customers. If several of these benefits can be realized in individual applications, fuel cells can provide significant value in the distribution system, potentially becoming competitive with central generation sources even at elevated capital costs.

However, other DG technologies, such as reciprocating engines, small turbines, and microturbines, can provide similar benefits. With a typical size range of 1–5 MW, DG sited near a substation for distribution support would be a good fit for new combustion turbines, which have fuel-to-electricity efficiencies as high as 42%. In the size range less than 100 kW, DG sited near loads and at the end of feeders might be candidates for microturbines.[47]

Both of these turbine technologies have lower costs than fuel cells, at least at present. Reciprocating engines are even cheaper. How, then, can fuel cells find a large enough market niche to enter this market and build sales volume in order to reduce costs? The answer depends, among other factors, on the regulatory feasibility of siting DG sources, based on environmental, safety and land-use requirements.

Depending on the location, the DG technology and the project size, the siting rules and regulations for a DG project could include permits designed for building construction (building codes and noise standards), as well as permits designed for power generation plants (land use and air emissions), or both. Several state commissions are now working to clarify and simplify these requirements for siting future DG projects.

The Craig Station, owned by the Tristate Generation and Transmission Association, has a total net capacity of 1,264 megawatts. The plant, which cost $1.2 billion to construct, burns more than 3 million tons of coal annually.

Conventional DG technologies, such as reciprocating engines, are a familiar component of many commercial and institutional building sites. However, most of the conventional DG implemented to date is designed for emergency standby generation, operating only a few, if any, hours per year. Most jurisdictions explicitly exempt such applications from many of their existing siting and permitting requirements, except fire and safety criteria.

Operating conventional DG technologies for more hours, whether for grid voltage support, meeting peak demand, or reliability services, is a different matter. In populated areas, there is particular resistance to the noise emitted by reciprocating engines. It is unlikely that DG sources will be allowed permitting exemptions if they are to be operated for purposes other than emergency standby generation.[48] As a result, several

[47] Small, conventional combustion turbines are based on the technology used in aircraft propulsion engines, driving an AC generator, and they range in capacity between 500 kW and 10–20 MW. Microturbines are derived from aircraft auxiliary power units, producing DC power with an inverter, and commercial units are in the 30–70 kW capacity range, with 300-kW models in development.

[48] On the contrary, some generators that exceeded their permitted hours during California's electricity emergencies were threatened with prosecution.

New DG emission standards under consideration in California and Texas will make it difficult for turbines to meet the permitting standards, and nearly impossible for reciprocating engines.

states are developing standard building and electric code language to govern the siting of DG sources. These code provisions will likely favor clean DG sources such as fuel cells.

The other crucial aspects of DG siting are land use and air quality permits, which generally fall under state-level and Federal regulations. For residential and commercial DG applications, land-use permitting should not be a major problem, as DG will generally be installed in a building or at least on an existing site, which would trigger relatively few new siting requirements.

Air emissions and air quality permitting are much more serious challenges for conventional DG technologies. Existing air quality regulation, under the Clean Air Act and its most recent amendments of 1990, are designed for large, central generating stations. Conventional DG technologies installed for emergency standby power are generally exempt from this process. In most jurisdictions, however, existing standby generators will probably have to re-apply for permits or exemptions before they can operate in a peak-shaving or grid-support mode.

Under the Clean Air Act, implementation of air quality standards for seven so-called criteria[49] pollutants is managed at the state level according to a State Implementation Plan. Some states such as California are broken down into regional air quality management districts (AQMDs). The reason for this is that the applicable emission standards vary, depending on whether an area is in compliance with the air quality standards for a particular pollutant under the Clean Air Act. If not, the area is a *non-attainment* area. The critical pollutant for which most urban centers in the U.S. are non-attainment areas is oxides of nitrogen (NO_X).

In non-attainment areas, all large new sources such as generating plants are subject to a New Source Review (NSR) under the Clean Air Act. DG sources are generally too small to trigger NSR activity. However, many potential DG applications will be in non-attainment areas for NO_X. In these areas, DG will receive increasing scrutiny with regard to air emissions. This is bad news for reciprocating engines, and probably for small gas turbines, but it is good news for fuel cells and renewable sources.

New DG emission standards under consideration in California and Texas will make it difficult for turbines to meet the permitting standards, and nearly impossible for reciprocating engines.[50] The California standards, however, incorporate credit for use of waste methane (from landfills and water treatment plants) as fuel and for efficiency gains from co-generation of heat and power, encouraging these sources.[51]

Fuel cells and renewable technologies, on the other hand, should have little difficulty meeting these standards. For example, the AQMD in Southern California, where emission standards are the tightest in the country, explicitly exempts fuel cells from permitting requirements, even in base-load applications.

[49] The Federally regulated “criteria pollutants” are: sulfur dioxide (SO_2), oxides of nitrogen (NO_X), carbon monoxide (CO), particulate matter (PM), ozone (O_3), lead (Pb), and air toxics. Note that ground-level ozone, a principal constituent of urban smog, is produced primarily by secondary reactions in the atmosphere, involving NO_X and other directly emitted pollutants. Legislation has been proposed but not enacted (as of late 2001) to add CO_2 as a criteria pollutant.

[50] State of California Legislature, Senate Bill 1298, September 2000; Texas Natural Resource Conservation Commission, “Air Quality Standard Permit for Small Electric Generating Units,” draft summary document, November 2000.

[51] Waste methane is also an attractive fuel for fuel cell applications. For example, King County, in Washington State, is installing a 1-MW fuel cell system from Fuel Cell Energy to convert methane-rich digester gas from municipal wastewater treatment to electricity, while minimizing air emissions.

It is important to note that these proposed regulations and other permitting requirements govern the siting of DG sources, not their operation. Stringent *siting* criteria will make it more difficult for other DG technologies to compete with fuel cells in providing *capacity*, where the other technologies would otherwise have a cost advantage (i.e., their cost per kW is less than fuel cells). The relative ease with which fuel cells can be sited confers a significant time, and therefore financial, benefit on this technology.

Once a DG source is sited, its *operating* cost may not be very important, because such applications as capacity deferral and grid support require relatively few operating hours per year. The *capacity*, not the *energy*, is the source of value. The lower energy costs of fuel cells provide no economic advantage if high capacity costs prevent their installation in the first place. Even if conventional DG technologies have to buy expensive emission credits to operate, or even pay carbon taxes in the future, their lower capacity costs will prevail in applications that require few operating hours, *but only if they can obtain siting permits*.

Thus, air emissions benefits are most likely to help fuel cells compete in terms of *initial siting and permitting, where fuels cells have a capacity-cost premium*, rather than in operation, where fuel cells already have an energy-cost advantage. This advantage will be most important in urban areas that are non-attainment for NO_X, as in most of California and cities in other states.

Police Pioneers with Fuel-Cell Powered Precinct

A fuel cell provides on-site power to the New York Police Department's 22nd precinct station in Central Park. Supplying 200 kW of electricity, the fuel cell brings consistent and reliable electricity to a site that had been routinely disrupted by power shortages.

Prior to the fuel cell's installation, the power supply to the 148-year-old station had been so limited by antique underground power lines that at times not all of the computers, photocopiers and other office equipment could be operated simultaneously. "There was never enough juice to power the air conditioners, the lights, the computers," said Capt. James O'Neill. "It was a very difficult work situation. It wasn't a wonderful work environment." The building was originally built as a stable and later converted to a police precinct station. **Increasing the capacity of the underground power lines would have required an expensive and disruptive excavation operation within Central Park.**

Beyond increasing officer comfort, the fuel cell contributes to the precinct's effectiveness as a police station. The added power permitted the Police Department to install computer-modem booking and fingerprinting equipment. Excess electricity recharges the electric vehicles used by police to patrol Central Park. **The fuel cell is quieter and more efficient than conventional engine generators, saving fuel and preserving the quiet of Central Park.**

Note that renewable DG technologies have emissions benefits similar to those of fuel cells, and this will help with siting of these technologies as well. Among the renewable DG sources, however, photovoltaic (PV) generation has capacity costs comparable to or higher than those of pilot-produced (as opposed to mass-produced) fuel cells. Moreover, PV produces energy during fewer hours of the year, and the peak-hour availability of PV energy is not as high as that of fuel cells, even though the maximum PV output often coincides with peak demand.

Wind turbines provide far less expensive generation today than either PV or fuel cells, but their availability may not be sufficient at a given site, limiting their potential for distribution cost deferral. Furthermore, the siting constraints of wind turbines, based on both visual impact and the wind resource, are generally not compatible with a DG siting strategy near urban loads and/or substations.

Molten Carbonate Fuel Cell Powers a Hospital in Germany

MTU Friedrichshafen GmbH, a German unit of DaimlerChrysler Corp., recently began operating a 250-kW molten carbonate fuel cell power plant at the Rhon-Klinikum Hospital in Bad Neustadt in May 2001. **The power plant is connected to the internal power supply system of the hospital, and it also provides heat for steam production. It contains a Direct Fuel Cell® (DFC), so named because it can use natural gas or other hydrocarbon fuels directly, without first converting the fuel to hydrogen.** It was manufactured by FuelCell Energy and was configured as a hospital power plant by MTU.

"This is another important step for us and our partners at MTU in rolling out field trials at customer sites," said Jerry D. Leitman, FuelCell Energy president and CEO. "The MTU team has taken the time to benefit from the experience of running their first unit at the University of Bielefeld. They are working closely with the technical staff at Rhon to build on that experience, and I am confident that this extra effort will produce even better results at the hospital."

According to Dr. Rolf A. Hanssen, board chairman of MTU Friedrichshafen, fuel cells are poised to take on a major role for electric power generation. **"Step by step, fuel cells will take over the functions that current power plants and engines assume now."**

Hospitals represent a promising application of DFC power plant technology because of their high electrical demand, steady load profile and heat requirements. The DFC offers additional advantages, including quiet operation, virtually no pollution, and very high efficiency. The DFC produces high-quality electricity, which is required for computer systems and sensitive medical devices used by hospitals. **The power plant placed into service at Rhon also generates approximately 170 kW equivalent of waste heat, which is used to produce high-pressure steam for sterilization and air conditioning.**

The bottom line

We have identified many sources of economic benefits of distributed generation,[52] but it is important to observe that not all of these benefits necessarily occur together in the same applications. Moreover, all of these benefit values are highly site- and technology-specific, and their evaluation often requires rather detailed technical and economic analysis. We can study an example based on experience with estimating these benefits.

Although it is difficult to generalize the economic benefits of DG, their magnitude appears to be significant. A hypothetical example might include the design attributes listed in Box 1. A fuel cell DG system of this type would provide the following illustrative benefits:

- *Electric energy value*—Regardless of DG benefits, the energy produced by a fuel cell system would be worth about $100–150/kW-year, assuming the system is sized to provide base-load power and operate almost continuously.
- *Thermal energy value*—Especially in a commercial application, the waste heat recovered from the fuel cell can provide fuel savings of about $100–150/kW-year.
- *Option value*—In an area with fast but uneven growth, the added cost of overbuilding generation that could be avoided by widespread use of DG is about $50–200/kW-year.
- *Deferral value*—In a high-cost area, with distribution capacity constraints and moderate growth, the deferral value would be about $50–200/kW-year, assuming that these areas are targeted with sufficient DG capacity to defer capacity expansion.
- *Engineering cost savings*—In a "problem" distribution area, properly cited DG can avoid the cost to re-conductor feeders, add capacitor banks, and install voltage regulators, worth about $50–150/kW-year. Reductions in losses are worth about $25/kW-year.
- *Customer reliability value*—In a commercial application with a high value of service, a highly reliable DG system that reduces outage risk for critical loads provides a reliability value of $25–250/kW-year, depending on the customer value of service.
- *Environmental value*—The environmental benefit of fuel cells' low emission rate is unlikely to be realized directly, but it makes fuel cells easier to site than other DG, and this can reduce both lead-time and financial risk.

In addition to the energy values, any one of the other DG values make the *total DG value* reach about $300–500/kW-year or higher. In an area where all these benefits are realized, the total DG value could reach about $600–1000/kW-year or higher. Note that the ability of the DG system to realize these benefits depends on certain design features listed in Box 1, including co-generation, need for reliability, and proper utility interconnection.

[52] For a very comprehensive compilation of such benefits, see Lovins, A.B., *et al.*, 2002. *Small Is Profitable*, Rocky Mountain Institute, in press.

Box 1.
Design Parameters for an Example Fuel Cell DG System

Customer Type: The customers include at least one commercial account, which will value reliability benefits and have uses for thermal energy recovered from co-generation.

Utility service: Utility service is needed for natural gas supply and backup electricity. Non-firm electric service is acceptable if it avoids utility standby capacity charges and allows collection of utility capacity deferral value.

Local grid layout: Customers can assign critical (high-reliability) loads, which should be on separate circuits and controlled by a central generation and load control system.

Fuel cell configuration and sizing: Fuel cell stacks are centralized for economies of scale, reliability and co-generation. Total size should be 100–150% of the minimum monthly average load. Several smaller units are more reliable for critical loads than one large unit, and would probably be worth the increased cost.

Fuel reformer: The reformer is centralized for economies of scale. It should be sized for the average fuel cell output plus any additional hydrogen uses. Reformer reliability is a key constraint on system performance and value, and should be as high as possible.

Hydrogen storage: Hydrogen storage improves system reliability, provides flexibility in reformer sizing, and adds potential for other uses.

Battery storage: Battery size needs to be sufficient only for transient control and short-term backup and surge control in islanding mode.

Co-generation: Waste heat at the commercial facility is recovered and used.

Customer UPS: Customers with critical loads require UPS systems to maintain service during a grid outage, when the system switches between grid and island mode. If the critical loads are substantial and their load factor is high, this function can be met by a separate fuel cell unit, possibly sharing the central reformer.

Generation and load control: A smart central control system is essential to manage the operation of the generator, monitor the utility supply, and control loads, especially in response to a grid outage. In case of an outage, the control system must instantly switch to the island mode and disconnect non-critical loads in order to protect critical loads.

Standby generation: An engine generator is the cheapest and most practical way to back up non-critical loads and provide a voltage source. It will soon be practical to use only grid-tied fuel cells and battery or flywheel storage, dispensing with the standby generator.

Utility grid connection: A one-way, import-only utility connection saves connection cost, and utilities consider it safer and more reliable. Islanding is essential to provide premium reliability to critical customer loads.

The relationship between these benefit values and the allowable costs for fuel cell systems depends on our assumptions about fuel cell financing. Conventional commercial financing requires about 20% annual cost recovery, while a 30-year residential mortgage would require only about 10% annual cost recovery.

Using these ratios, a DG value of $400/kW-year would translate in to an allowable capital cost of $2000/kW with commercial financing, or $4000/kW with mortgage financing. A DG value of $800/kW-year would translate into an allowable capital cost of $4000/kW with commercial financing. The $2000/kW value is considered achievable in the near future by fuel cell manufacturers, while the $4000/kW value is commercially achievable today, or nearly so. This means that with proper design and siting, fuel cell DG systems can be cost-effective today, based on the value of their distributed benefits.

In many cases today, however, the mechanism for capturing these benefits for the DG owner is not obvious. Some DG advocates present DG as an alternative to utility service, suggesting that customers can profit most from supplying their own electricity independently. However, this strategy would need to be justified without all the DG benefits that would be difficult to capture without any utility connection.

Because of the need for utility data to evaluate DG benefits, and because these benefits tend to accrue most directly to the utility, it is hard to imagine capturing most of their value without some degree of cooperation with the incumbent distribution utility. While the traditional bias of many utility planners is to discourage DG, this barrier can be reduced with experience and collaborative work toward technical and procedural standards, such as the Institute for Electrical and Electronic Engineers interconnection standard mentioned earlier.

DG proponents cannot expect to win every argument, however. Even when ATS analysis clearly demonstrates high avoided costs of distribution capacity, and potential benefits from DG, there may also be other, more conventional solutions. Indeed, ATS analysis can help utilities find less expensive approaches to implementing traditional T&D upgrades and expansion.

Similarly, distributed benefits are also provided by end-use technologies, which can eliminate or defer the need for T&D upgrades by strategically reducing or shifting peak customer loads. Targeted demand-side management (DSM) programs to reduce the area peak load can be part of the least-cost design to relieve distribution constraints.[53] These programs range from such tariff structures as curtailable rates and real-time pricing to equipment rebates and direct installation programs. While this approach has practical limitations to implementing programs with sufficient scale and speed to defer distribution capacity, both DG and DSM can contribute to a least-cost distribution planning solution.

The ability of utilities to implement such least-cost solutions, as well as their interest in DG, will depend on the future regulatory treatment of distribution investments. One promising approach being considered in several states is performance-based regulation (PBR). PBR links the utility's earnings to its performance in reducing the customers' cost of service. Another approach is local integrated resource planning (LIRP), where distribution utilities must prove that proposed grid investments are more cost-effective than other solutions including DG and targeted DSM.[54] Depending on the regulatory design details, these approaches can provide incentives for cost-effective DG.

[53] Swisher, J.N. and R. Orans. 1996. A New Utility DSM Strategy Using Intensive Campaigns Based on Area-Specific Costs. *Utilities Policy* 5:185–197.

[54] LIRP is now mandated in New York State. One relevant application of DG in New York is a 200-kW ONSI fuel cell that the New York Power Authority installed at the New York City Police Department station to avoid a costly and environmentally sensitive distribution upgrade, while minimizing emissions. See E SOURCE, *Distributed Generation for System Capital Deferral*, Report DE-12, September 2000, www.esource.com.

Early markets and commercialization paths

One early market niche with substantial distributed benefits would be the high-cost distribution "hot spots," indicated by ATS cost analysis, particularly those in areas with emission constraints.

There appears to be significant value in siting DG where it can defer distribution investments, reduce utility engineering costs, and improve customer reliability. These values can equal or exceed the basic energy value of the DG source, making such DG technologies as fuel cells attractive in many areas. The ability of DG owners to capture these enhanced values depends on the tariff structures and regulatory treatment of distribution utilities. In any case, cooperation with these utilities will probably be necessary to capture the greatest value from DG.

Fuel cells are well suited to provide these distributed benefits, despite the lower present capital costs of competing technologies. To compete successfully against small gas turbines and engines in urban applications, fuel cells must be far cleaner and quieter, and they are. To compete successfully against such renewable sources as solar and wind, fuel cells must be highly reliable and dispatchable, *i.e.*, able to start up and operate at any time, and they are. Thus, to the extent that the distributed benefits of DG can be captured, fuel cells have great potential.

Achieving this potential demands that fuel cell costs fall sharply. Lower costs depend, in turn, on increased production rates. And accelerated production requires substantial demand from early market niches. Several promising niches are suggested by the ATS cost analysis and consideration of customer reliability demands.

One early market niche with substantial distributed benefits would be the high-cost distribution "hot spots" indicated by ATS cost analysis, particularly those in areas with emission constraints. Because both distribution constraints and emission constraints are likely to occur in urban areas, there should be many areas that meet these criteria at any given time. As discussed earlier, the main challenge for the DG owner is to capture the distribution benefit that accrues most directly to the utility.

Perhaps the best opportunity for maximum distribution support and cost savings is portable DG. In this strategy, fuel cells could be mounted on trucks or rail cars, which would be sited temporarily in distribution hot spots on a seasonal or annual basis. Employing the DG source in multiple areas makes it possible to capture their combined deferral value while paying the cost of only one DG system. Several utility companies have been experimenting with portable DG programs, mostly using conventional combustion technologies.[55] Switching to fuel cell technology would preempt the likely environmental restrictions on this approach, while the cost is spread over multiple areas, and system benefits are increased by the ability to deploy in the highest-value locations.

The other highly promising market, albeit a difficult market to quantify, is serving commercial customers with premium reliability needs. Again, this market is especially attractive for fuel cells in areas with emission constraints, and these areas also tend to correspond to areas with a high concentration of premium-reliability customers. The advantage of this market is that the DG owner can charge the customer directly, without depending on the utility to identify attractive areas or to capture the benefits of DG.

Although the real value that customers are willing to pay for premium reliability is still rather uncertain, there is now ample evidence that this value can be sufficient to justify investments in

[55] The Salt River Project (SRP) in Phoenix, AZ has a program to deploy mobile gas turbines at substations where loads are approaching capacity. SRP can rotate generator units among eight different substations, depending on distribution system needs, thus deferring investments in substation capacity expansion.

[56] Fuel cells can give semiconductor fabs several benefits: reliable power without massive battery UPS, waste heat for process heat and cooling, ultra-pure hot water (replacing a costly process input), on-site hydrogen supply (displacing an expensive process reagent), and emission reduction credits.

DG. Where emission constraints exist, fuel cells could emerge as the technology of choice. Once the interested customers have been identified, the main challenge for the DG owner will be convincing the customers that sufficiently high levels of reliability can be achieved using DG technology. The technical sales pitch will probably have to include performance guarantees, supplemented by contractual terms and insurance.

Thus, the near-term commercialization path for fuel cells appears to be grid-connected fuel cell systems in commercial buildings, communication providers, semiconductor fabs,[56] and other facilities that have coincident needs for high reliability and low emissions. The most cost-effective applications will be in locations with high avoided costs, as indicated by distribution constraints or ATS cost analysis.

Fuel Cell Power Helps Bank Make Money

A fuel cell system that boasts 100 to 1,000 times greater reliability than conventional electric sources helps a 200,000-square-foot credit card operations and processing facility serve customers better and more profitably. First National Bank of Omaha chose fuel cells to power its computer system, which processes over $100 million in transactions every day.

The system produces reliable power 99.9999% (six "nines") of the time, according to the bank. Typical electricity backup plans employ a combination of utility grid power and back-up generators to guarantee three "nines." **A conventional uninterruptible power supply system would experience about 60 minutes of downtime a year, while the fuel cell system at First National Bank is designed for less than 3 seconds/year of downtime.**

"Being a large credit card processor, doing $6 million an hour in transactions, our computers have to work," said Dennis Hughes, director of property management for the bank. **All told, U.S. businesses lose an estimated $29 billion a year from computer failures due to power outages.** "For example, if a consumer goes into the Gap to make a purchase and the First National Bank of Omaha's computer system is down, the Gap will be unable to make the sale. The Gap not only loses the sale, but may also lose their customer due to poor customer service," said Hughes.

In addition to meeting the redundancy requirements of the building, the life-cycle cost of fuel cells proved to be lower than that of an alternate UPS system. **Also, the clean power of fuel cells contributes to the bank's image of environmental awareness.** Natural gas powers the system of four fuel cells, which produce 800 kW of electricity. Waste heat is used to displace heating that would typically come from coal- or oil-burning boilers.

Does the system really work? **"About two weeks ago, we had a series of brownouts,"** said Hughes. **"The fuel cells were able to reconfigure and there was no loss of power. They kept right on chugging away with no disruption."**

Once vehicles have been thoroughly electrified, and fuel cells have found widespread cost-effective applications in buildings and industry, the shift to fuel cell vehicles will be greatly simplified.

A longer-term commercialization path for fuel cell technology will integrate these stationary applications with the potential for fuel cells in cars, trucks and buses.[57] The most promising fuel cell technology for vehicular applications is the proton exchange membrane (PEM) fuel cell, due to its relatively low temperature and fast response to changes in load. Because PEM fuel cells require relatively pure hydrogen fuel, a fuel reformer must be used to convert such fossil fuels as gasoline or natural gas.

The expense of adding a reformer to every fuel cell vehicle could be avoided by using hydrogen as the fuel. This strategy makes the fuel cell smaller, more efficient, and more durable, and it avoids the problems of an onboard reformer.[58] However, it also requires an infrastructure to refuel vehicles with hydrogen.

This is where the fuel cell-powered buildings fit in nicely. The cars parked near these facilities during the day bring with them the potential to generate large amounts of electricity during peak-demand hours from the fuel cells that are onboard but otherwise idle. These fuel cell vehicle-generators could connect to the local electric infrastructure to deliver electricity generated onboard into the grid, providing high-value peaking power and such additional electrical engineering benefits as voltage support and reactive power.

Meanwhile, the vehicles could be refueled with hydrogen made at the same site. If the stationary fuel cell systems use fuel reformers themselves, *i.e.*, they use PEM or similar technology, the reformers could be sized to accommodate the additional needs of the vehicle-generators. If they use high-temperature fuel cells, which require no fuel reformers, then hydrogen-producing reformers could be added or hydrogen could be made by electrolysis at night using off-peak electricity. Either way, the drivers of the vehicles would receive a "vehicle-to-grid" (V2G) electricity generation credit against the cost of their fuel bill.[59]

This scenario is one of several plausible commercialization paths for fuel cells in both vehicles and stationary applications. The advantages of fuel cells in vehicles are their outstanding fuel economy (double that of combustion engines), high reliability, minimal noise, and near-zero emissions. The use of fuel cells in cars, trucks, and buses also suggests a transition to electric-drive vehicles. This transition has already begun, beginning with the introduction of integrated alternator/starter motors, electric steering, and higher-voltage onboard electrical systems.[60] This step will be followed eventually by electric brakes and shock absorbers, and finally an all-electric drive train.

[57] Lovins, A.B. and B.D. Williams, 1999. "A Strategy for the Hydrogen Transition," 10th U.S. Hydrogen Meeting, Vienna, VA, 7–9 April, www.rmi.org/images/other/HC-StrategyHCTrans.pdf.

[58] The problems include the need for fast warm-up and response time, wide dynamic range, minimum weight, and durability in a harsh operating environment. Another problem with an onboard reformer is that is does not operate very much of the time (less than 2% even in a hybrid configuration), compared to a stationary reformer with hydrogen storage. The latter approach may even be less expensive than maintaining the existing gasoline infrastructure capacity. See Thomas, C.E., "Hydrogen Infrastructure: Less Costly than Gasoline?" Aspen Clean Energy Roundtable VIII, Aspen CO, October 2001.

[59] V2G generation is best suited to operation during periods of peak demand, when the value of energy generated, reserve capacity and ancillary services such as voltage support and reactive power is highest. A recent study estimates that the value of these benefits could exceed $2000/year for a 40-kW fuel cell vehicle in California. See Kempton, W., *et al.*, 2001. "Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California," University of California, Davis report, UCD-ITS-RR-01-03. For details about V2G strategies, see www.udel.edu/V2G/.

The results of these changes will include improved fuel economy, emissions, reliability, safety, and functionality. If integrated with state-of-the-art body design and materials, as illustrated by Rocky Mountain Institute's Hypercar™ synthesis, these changes could revolutionize the automobile and the industry that builds it.[61] This revolution could even remove the car from environmental and consumer advocates' most-wanted lists.

Concept Hypercar vehicle.

As these changes occur, the vehicles' power plant will shift from the conventional engine to hybrid electric motors, which are already on the market in models from Toyota and Honda.[62] In time, it will be a rather simple and natural transition to replace the combustion engine in the hybrid motor with fuel cell technology. Note, however, that this transition to electric-drive vehicles has little to do with today's battery-powered electric vehicles, which serve mainly to transport batteries for short distances.

Once vehicles have been thoroughly electrified, and fuel cells have found widespread cost-effective applications in buildings and industry, the shift to fuel cell vehicles will be greatly simplified. Although much of the current interest among technologists and investors concerns fuel cells in vehicles, it appears that more cost-effective applications of fuel cells will appear sooner in buildings. There, the advantages of fuel cells in modularity, siting flexibility, reliability, and emissions can win customers in the near term, setting the stage for additional applications in the future.

Fuel cell technology will not solve the short-term "energy crisis" mentioned at the beginning of this article. However, fuel cells and other DG technologies, which can provide cost-effective power with low emissions, offer an important part of a long-term solution that can prevent crises in the future. If electricity markets and utility planning are structured to reflect accurately the economic benefits of DG, and to combine them with end-use efficiency and load management, then these short-term measures can provide a bridge to a clean, resilient, and economical energy system to meet the diverse needs of society.

[60] The integrated alternator-starter is used in hybrid electric vehicles now in production, and it is under development for combustion-driven vehicles. Electric steering is already built into production vehicles by Fiat and Volkswagen. Just as the automobile industry shifted from 6–7 volts to 12–14 volts in the 1950s, the transition to 36–42 volt electrical systems will lead the transition to next-generation vehicles. The standard voltage (36-volt battery, 42-volt bus) has been adopted by the Society of Automotive Engineers and the MIT Global Consortium on Advanced Automotive Electrical/Electronic Components and Systems.
This standard is used in present electric vehicles and is under development for combustion-driven vehicles.

[61] The Hypercar is an ultralight, advanced-composite, low-drag, hybrid-electric vehicle conceived by Rocky Mountain Institute. Now spun off from RMI as a for-profit start-up, Hypercar, Inc. (www.hypercar.com) is developing the design, and manufacturing processes for the integration of these design principles and technologies. See also Lovins, A.B., 1996, "Hypercar℠ Vehicles: The Next Industrial Revolution," International Electric Vehicle Symposium, Osaka. For a more technical treatment, see Lovins, A.B., *et al.*, 1997. *Hypercars: Materials, Manufacturing, and Policy Implications*, Rocky Mountain Institute, www.hypercarcenter.org.

[62] Hybrid car sales in 2001 are expected to reach 20,000 in the U.S. and 35,000 worldwide.

Fuel Cells and Hypercar™ Vehicles

The Hypercar™ is an ultralight, advanced-composite, low-drag, hybrid-electric vehicle conceived by Rocky Mountain Institute. A PEM fuel cell would power a Hypercar™ vehicle using pure hydrogen, without the need for a chemical reactor/reformer to derive the hydrogen onboard from natural gas or a liquid fuel.

Norm Clasen photo

Hypercar, Inc. has come up with an SUV crossover design which, at just under one ton in weight, is powered by a mere 35 kW PEM fuel cell. Running on 7.5 lbs (3.4 kg) of compressed hydrogen gas stored in three tanks, the aptly named "Revolution" has a range of 330 miles (530 km), double what conventional steel vehicle prototypes can get. This equates to 99 mpg (2.4 L/100 km)! Taking advantage of its advanced composite structure and the reduction in size of the power train as well as the reduction in the volume of fuel required to attain its range, the "Revolution" boasts room for five adults and up to 69 ft^3 (2.0 m^3) of cargo space, and performs just like a normal car. For more information on this prototype in development, see www.hypercar.com.

From an engineering design standpoint, storing hydrogen onboard in pressurized tanks has advantages: by eliminating the reformer, it significantly reduces weight, cost, complexity, fuel consumption, and emissions. The only real disadvantage of onboard hydrogen storage—bulk—is solved by the Hypercar concept, since Hypercar vehicles' lower fuel requirements enable the storage tank to shrink to the size of a conventional fuel tank.

Fuel cell vehicles will be very efficient, quiet, low in emissions, compatible with renewable energy sources, reliable and durable (since they have almost no moving parts), and adaptable to a wide variety of auto designs. Efficiency is expected to be about 50 percent in automotive use. Fuel-cell-powered vehicles could also run as power generators when parked, providing valuable electricity to the grid during times of peak demand.

Almost all the automakers have shown prototype fuel-cell-powered vehicles. Most of these prototypes have been quite heavy, requiring large (and therefore expensive) fuel-cell power plants, which has led some observers to predict that it may take 15 to 20 years for fuel cells to become economical.

Yet Hypercar vehicles could accelerate the adoption of fuel cells, because the Hypercar vehicle's lighter weight and much lower power requirements for its size would require far less fuel-cell capacity than a heavy, high-drag conventional car. This should make fuel cells affordable in Hypercar vehicles years earlier than in conventional vehicles.

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