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Comparative Assessment of Residential Energy Supply Systems That Use Fuel Cells
(Executive Summary)

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Comparative Assessment of Residential Energy Supply Systems That Use Fuel Cells
(Executive Summary)

by

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SRI INTERNATIONAL

COMPARATIVE ASSESSMENT OF RESIDENTIAL ENERGY SUPPLY SYSTEMS THAT USE FUEL CELLS

EXECUTIVE SUMMARY

What Are Fuel Cells?

Fuel cells are devices capable of converting the chemical energy stored in a fuel directly into electrical energy without a step involving combustion. Hydrogen contained in the fuel is chemically combined with oxygen from the air to produce water and an electric current that can be regulated and used. Fundamentally, the process is just the inverse of the electrolysis of water into its component parts, a process often demonstrated in high school chemistry classes. Practically, a fuel cell consists of two electrodes, a catalyst used to promote the chemical reaction, and an electrolyte (a chemical substance that conducts electricity) separating the electrodes. As might be suspected, a device of such fundamental simplicity was first conceived long ago—in 1839 by Sir William Grove, a British jurist.

Are Fuel Cells Commercially Available Today?

Although old in concept, as practical devices for producing electricity in significant amounts, fuel cells are in their infancy. For space missions, fuel cells have been shown to be ideal power sources, partly because they convert on-board stores of hydrogen and oxygen to electrical power without producing excessive heat or vibration-producing mechanical motion. In fact, they provided electrical power in Gemini and Apollo spacecraft, but were still considered novel and exotic devices.

Made in limited quantities, and to extreme reliability standards, fuel cells for space craft are understandably expensive. Nevertheless, much has been learned from the space program about fuel cells and that knowledge is beginning to find earthbound applications in much-improved and less costly devices.

More than 60 small (12.5 kW) fuel-cell power plants were field tested in 1972 and 1973. A 40-kW device was demonstrated in 1975, and now work is underway to demonstrate a 4.5-MW fuel cell in the Consolidated Edison (New York) utility system by 1980. Fuel-cell technology has come a long way and is nearing commercial readiness.

Do Fuel Cells Possess Attractive Attributes?

Much of the present interest in fuel cells derives from their unusually low environmental impact and their high efficiency. Because no combustion is involved, even fuel cells that use common fuels produce very low emissions of nitrogen or sulfur oxides; the emissions are many times below federal standards. Moreover, fuel cells generally consume no water and operate very quietly.

As a result of its environmental good- neighborliness, a fuel-cell power plant can easily be located very near the power demands it serves, thereby lessening the need for high voltage electric transmission lines.

The ability to site fuel-cell power plants locally is much enhanced by their modular design (which allows off-site manufacturing) and their rapid installation. Accordingly, electric power utilities may soon have commercially available a device that enables system expansion in small increments.

How Might Fuel Cells Fit into Electric Power Systems?

Besides being suitable for small, dispersed, locally sited power stations, fuel cells can easily operate in applications that require output to follow demand closely. In fact, electric utility interest in fuel cells often centers on mid-1980s deployment for load-following. Again, because of their cleanliness, fuel cells may be installed in buildings or residential complexes where the combined production of electric power and heat could be used to satisfy heating and cooling demands in an integrated (or "cogeneration") fashion. The fuel-cell-derived electricity would be used to operate heat pumps to provide cooling and supplemental heating.

Can Fuel Cells Use Coal or Coal-Derived Fuels?

Fuel cells, like most fuel-consuming devices are indifferent to the origin of the fuel—as long as in final form it conforms to the chemical requirements of the device. Accordingly, natural gas, petroleum products, or similar fuels are perfectly acceptable in fuel cells provided that the fuels are first reformed to hydrogen and carbon dioxide and that harmful sulfur contamination is removed before the fuels enter the fuel cell proper.

Fuel cells, therefore, can have a place in a largely coal-based U.S. energy future.

What Are Leading Coal-Based Alternatives to Fuel Cells?

Already, U.S. electrical power is largely generated in coal-fired plants and the federal government is pushing for even more in an effort to save relatively scarce and expensive oil and natural gas for other uses. Larger, conventional coal-fired power plants, often located in remote areas and connected to urban load centers by high voltage transmission lines, certainly provide a well-proven alternative to electric power generated from fuel cells.

So-called "combined-cycle" electrical power generation—a conventional boiler and steam turbine generator supplemented by a high-temperature gas turbine—is an improving technology gaining considerable attention among utilities. Certainly, by the time fuel-cell systems are perfected sufficiently to allow commercial deployment, combined-cycle systems will already be in use and fuel-cell systems will have to compete with them.

Much of the U.S. space heating demand is met by the combustion of natural gas. Because so many consumer-owned heaters are already in place, gas utilities have strong incentive to supplement natural gas supplies with coal-derived substitutes that would not require alteration of either consumer appliances or habits.

Synthetic natural gas, (SNG) derived from coal, then, offers strong competition for the electric heating role a fuel-cell/heat pump combination could play in the market place.

Can Fuel Cells be Compared with the Alternative Technologies?

Because fuel cells must compete with so many electric power and heat-producing fuel and technology combinations, the relative advantages and disadvantages of fuel cells have proven difficult to discern clearly. Consequently, as a part of its mission to preserve and enchance environmental quality, the U.S. Environmental Protection Agency commissioned this study precisely to learn more about what might be expected from fuel cells when actually deployed in utility systems.

To address this question, SRI International conceptually designed twelve energy systems able to provide residential heating and cooling using technologies projected to be available toward the end of this century. Only a few systems used fuel cells. As in most comparisons, some constraints were imposed to eliminate unnecessarily confusing complexities while providing a uniform framework for comparison. Accordingly, all systems use western coal as the primary energy resource, and all residences are assumed to have identical heating and cooling demands typical of the mid-continent United States. After winnowing out the clearly least attractive combinations, we selected five systems and compared them in great detail.

For all the comparisons, we examined the entire chain of the system, starting with the coal mine and ending with the heating and cooling of residences, to be sure that the claimed environmental advantages of the fuel cells at the point of electric power generation did not distract us from some important environmental impacts elsewhere in the system. Our five surviving systems, four of which use heat pumps for heating and cooling are:

- System 1—A coal-fired power plant supplies electricity and a coal gasification plant supplies SNG to residences; electricity powers air conditioners and SNG is burned in gas furnaces.
- System 2—A 26-MW fuel-cell power plant fueled by coal-derived SNG supplies electricity to residences with heat pumps.
- System 3—A 26-MW fuel-cell power plant fueled by coal-derived naphtha supplies electricity to residences with heat pumps.
- System 4—A combined-cycle power plant fueled by coal-derived fuel oil supplies electricity to residences with heat pumps.
- System 5—A 100-kW fuel-cell power plant fueled by coal-derived SNG, sited in a housing complex, supplies electricity to townhouses with heat pumps; heat recovered from the fuel cell supplies supplemental space heating and hot water.

Of these five, the first one most resembles the existing order in the utility industry, and the fourth constitutes an already evident evolutionary change of the industry.

What do the Comparisons Show?

The scorecard for the various systems is mixed--no single system stands out as superior in all the attributes that will ultimately decide which systems will be deployed. Nevertheless, some very interesting facts emerge about energy systems that use fuel cells.

Which System Costs the Consumer More?

The three fuel-cell systems provide heating and cooling to our standard residences at considerably higher cost that the two more conventional systems. In fact, the annual energy bill to a consumer using System 5 is over 63% higher than for one using System 1, the most conventional and lowest cost option. The order of cost, from the least expensive system to the most expensive, is 1,4,2,3,5.

Are There Differences in the Capital Investment Required?

The scorecard for the capital intensiveness of the five systems largely follows the pattern of the annual cost to consumers. In order, from least to most capital intensive, are Systems 1, 4, 3, 2, 5. Because capital is itself a scarce resource, utilities most likely will show most interest in Systems 1 and 4.

Which Has the Best System Performance?

Because all five systems contain at least one element not yet proven in commercial service, such things as reliability, the degree of redundancy needed in a system, and the ability to integrate smoothly the new devices into a system are difficult to assess, more so than for most other comparison attributes. We judge, however that, overall, the most conventional system is most likely to give the best performance. System performance, from best to worst comes in this order: Systems 1, 2, 4, 3, 5.

Which System is Most Efficient?

When making a comparison of system efficiency, we were careful to account for energy losses at every step in proceeding from the coal mine to the heated and cooled residence. All fuel-cell systems are considerably more efficient than the most conventional system, System 1. Indeed, System 5 is 75% efficient, while System 1 is only 41% efficient. Systems 2, 3, and 4 possess nearly equal efficiencies in the 64% to 67% range. This attribute is particularly important because it shows that the systems using fuel cells required less coal to accomplish the same end—a virtue that, besides conserving resources, carries over into lessened environmental impact.

What About Air Quality?

Because maintenance of air quality around electric power generation plants is a vexing and costly problem, the relative scores for this indicator could prove especially important to utilities in the years ahead. We weighted equally pollutants emitted at the fuel production site and the fuel consumption site (both overwhelm the emissions from fuel transportation). Again, all three systems using fuel cells are superior to the two more conventional systems, with System 5 being the cleanest and System 1 emitting the most pollutants. In order, from least to most polluting are Systems 5, 2, 3, 4, 1.

Are There Differences in Water Quality?

For this indicator we weighted equally effluents and water consumption at the fuel production and the fuel consumption locations.

All three fuel-cell systems are cleaner than the two more conventional systems. Again, System 5 is the cleanest, but this time System 4 degrades water quality the most. In order of cleanliness are Systems 5, 2, 3, 1, 4.

How Do They Compare on Solid Waste?

Most solid waste for this set of five systems is produced as ash in converting the coal to a more useful energy form. Consequently, scores in this category essentially mirror the overall system energy efficiency ratings—the most efficient System 5 also produces the least solid waste and the least efficient System 1 produces the most solid waste. Systems 2, 3, 4 are nearly tied, and produce about the same intermediate quantities.

What About Land Use, Noise and Aesthetics?

The three parameters are closely linked because aesthetics and human exposure to noise produced are greatly affected by location and the amount of land occupied or disturbed. Overall, least obtrusive is System 5 and the most obtrusive is System 1.

Is There a Pattern in the Comparison?

A striking pattern emerges when we assemble the scores for all categories of comparison. The fuel-cell systems are the most costly—to build and install as well as in end-use cost to consumers—but are the most environmentally benign and consume the least coal to get the heating and cooling job done.

We expected from the outset of this study that the fuel cells themselves would be clean compared to alternatives, but our finding that entire fuel-cell systems from resource extraction to final demand offer overall environmental benefits is new.

Will Fuel Cell Systems Actually Be Used?

How the trade-off between environmental cleanliness and economic cost will be valued in the next several decades will prove crucial to the question of whether fuel-cell systems resembling those we have examined will actually be deployed in meaningful numbers. One thing is certain: Fuel-cell systems possess a mixture of attributes much different from the more conventional electric power systems. As a result, U.S. utilities will have available an important new electric power option in the years ahead.

Full analysis is available in the 500-page report: "Comparative Assessment of Residential Energy Supply Systems That use Fuel Cells," Environmental Protection Agency, Report No. 600/7-79-105b, 1979.

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16. ABSTRACT The report gives results of a comparison of residential energy supply systems using fuel cells. Twelve energy systems, able to provide residential heating and cooling using technologies projected to be available toward the end of this century, were designed conceptually. Only a few systems used fuel cells. All systems used Western coal as the primary energy source, and all residences were assumed to have identical heating and cooling demands typical of the mid-continent U.S. After screening, five systems were analyzed in detail. The entire energy cycle, from coal mine to end use, was examined for costs, efficiency, environmental impact, and applicability. The five energy systems are: (1) a coal-fired power plant supplying electricity and a coal gasification plant supplying SNG; (2) a 26-MW fuel-cell power plant fueled by coal-derived SNG supplying electricity; (3) a 26-MW fuel-cell power plant fueled by coal-derived naphtha supplying electricity; (4) a combined-cycle power plant fueled by coal-derived fuel oil supplying electricity; and (5) a 100-kW fuel-cell power plant fueled by coal-derived SNG, sited in a housing complex, supplying electricity to heat pumps, with heat recovered from the fuel cell supplying supplemental space heating and hot water. Results indicate that the fuel cell systems are most costly, most efficient, and have least environmental impact.

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Fuel Cells	Coal Gasification	Stationary Sources	10B	13H
Energy Conversion	Coal	Substitute Natural Gas		21D
Techniques	Naphthas		10A	07C
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