FUEL CELL TECHNOLOGY

A Clean, Reliable Source of Stationary Power


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ABOUT THIS SERIES

This briefing paper is one of four in a series of papers on fuel cells and hydrogen technologies produced by Clean Energy States Alliance (CESA) in the spring of 2010. These papers are part of a larger education and outreach initiative by CESA to inform and engage state policymakers about the benefits of fuel cells, their use in critical power applications, and model state policies to support them as well as information about hydrogen production and storage:

- *Fuel Cell Technology: A Clean, Reliable Source of Stationary Power*
- *Stationary Fuel Cells and Critical Power Applications*
- *Advancing Stationary Fuel Cells through State Policies*
- *Hydrogen Production and Storage: An Overview*

For further information on CESA's hydrogen and fuel cell activities, and to download all four reports, please visit *www.cleanenergystates.org/JointProjects/hydrogen.html*.

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Introduction

For many years, the focus of the emerging "hydrogen economy" has been on the use of hydrogen fuel cells for vehicles. While federal and state government and automakers still continue to invest in and promote policies to create the "hydrogen highway," private businesses and government agencies are increasingly deploying fuel cells for stationary power applications. Stationary fuel cells are a technology that is commercially available, reliable, suitable to a wide variety of applications, declining in costs, and with federal and state support, becoming more affordable.

Technical Background

A fuel cell is a device that converts the chemical energy of a fuel (usually hydrogen derived from natural gas or biogas) and an oxidant (air or oxygen) into electricity. In principle, a fuel cell operates like a battery. Unlike a battery, however, a fuel cell does not run down or require recharging (although cell stacks may need periodic replacing). It will produce electricity and heat as long as fuel and an oxidant are supplied. The fuel cell itself has no moving parts—making it a quiet and reliable source of power (see Figure 1). A fuel cell stack is a chemical power generator "sandwich" that consists of three parts: an anode, a cathode, and an electrolytic material in the middle. There are several kinds of fuels cells, and each works slightly differently. In general terms, at the anode, hydrogen atoms enter and their electrons are separated so that the hydrogen ions (protons) pass through the electrolyte, while the negatively charged electrons pass through an external electrical circuit as direct current (DC) that can power useful devices. Whether the hydrogen ions combine with the oxygen at the cathode or at the anode, together hydrogen and oxygen form water that is drained from the cell. The chemical reactions for a molten carbonate fuel cell are shown below:

Figure 1:
How a Molten Carbonate Fuel Cell Works

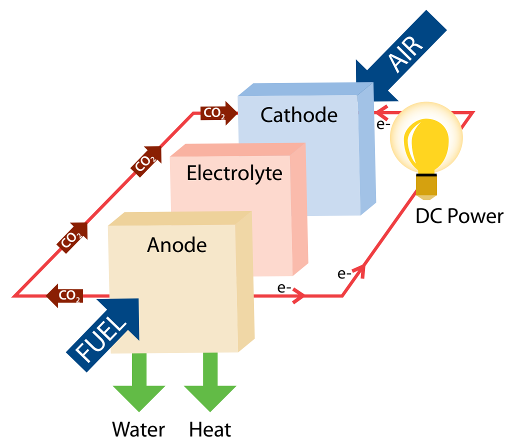

Table 1: Comparison of Fuel Cell Operating Characteristics

Fuel Cell Type	Operating Temp. (F)	System Size	Electrical Efficiency	CHP Efficiency*	Applications	Key Advantages
PEM	122–212	<250 kW (typically 5–10 kW)	25–35%	70–90% (low grade heat)	Backup Power	Low temperature, quick startup
Phosphoric Acid	302–392	50 kW–1 MW (typically 250 kW module)	>40%	>85%	Distributed Generation	Tolerance to hydrogen impurities
Molten Carbonate	1112–1292	50 kW–1 MW (typically 250 kW module)	45–47%	>80%	Distributed Generation	High efficiency, fuel and electrolyte flexibility
Solid Oxide	1202–1832	<1 kW-3 MW	35–43%	<90%	Utility-scale; large distributed generation	High efficiency, use of solid electrolyte

*Assumes use of by-product heat

Source: U.S. Department of Energy Hydrogen Program

Anode Reaction: $CO_3^{2-} + H_2 => H_20 + CO_2 + 2e^-$
Cathode Reaction: $CO_2 + 1/2O_2 + 2e^- => 2H_2O$
Overall Cell Reaction: $H_2 + 1/2O_2 + CO_2 = H_2O + CO_2$

The major types of fuel cells—*proton exchange membrane* (PEM), *phosphoric acid*, and *solid oxide*—utilize different materials and processes and have different operating characteristics:

- PEM fuel cells are well-suited for back-up power applications at sites such as communication towers and equipment since they ramp up quickly and operate at low temperatures.
- Phosphoric acid fuel cells were a first-generation technology commercialized in the early 1980s. Their advantages for use as baseload power include high operating efficiency, particularly when waste heat is re-used, simple construction, low electrolyte volatility, and long-term operating stability.
- Molten carbonate fuel cells operate at higher temperatures and are also designed to be used as a baseload, 24/7 power source. Molten carbonate fuel cells convert gas into hydrogen within the fuel cell itself, avoiding the need for on-site storage of hydrogen or an external reformer.
- Solid oxide fuel cells are emerging as the latest fuel cell technology. Advantages of solid oxide fuel cells include an ability to reform gas within the fuel cell, the use of low-cost solid ceramic materials instead of a liquid electrolyte containing precious metals or corrosive material, and very high operating efficiency.

In addition to electric power, some stationary fuel cells also produce, as a by-product, heat that can be used for water, space, or process heating. The by-product heat can also be used to provide cooling through absorption or adsorption cooling systems technology to drive a refrigeration cycle. By capturing the waste heat from the fuel cell system, the overall thermal efficiency of the system can be very high under the right conditions. The already high 40–50% electrical efficiency that fuel cell systems offer can reach 90% in thermal efficiency, with the utilization of by-product heat.

Fuel cells can be scaled to provide power to anything from a portable electronic device such as a cell phone or a computer to large commercial, industrial and institutional facilities and even utility-scale projects. Because they are modular, multiple units can operate parallel to one another.

Applications

Fuel cells can be deployed in any setting where a reliable source of baseload, on-site power is desired and, ideally, where by-product heat can be effectively utilized. They

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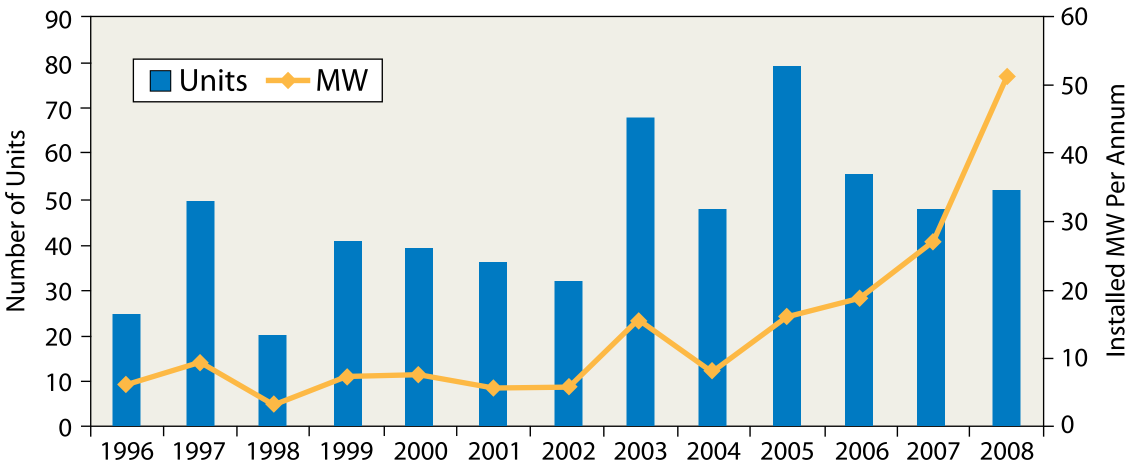
California State University, Northridge

CSUN installed a 1 MW stationary fuel cell power plant system from FuelCell Energy®. The system reforms hydrogen from natural gas to power the fuel cell and has successfully reduced the university's energy costs, improved power security through reduced reliance on the grid, created a state-of-the-art educational tool, and reduced their carbon footprint. Approximately 18% of the university's baseload power requirement is met by the fuel cells. The university further benefits from the fuel cells by utilizing by-product heat to provide 22 billion BTUs of thermal energy per year used to heat water for the campus, and by channeling residual CO_2 into an adjacent greenhouse where research on carbon dioxide plant enrichment is taking place.

Figure 2: Annual Number of Large Fuel Cell Units and MW Installed



Source:
© Fuel Cell Today, 2008 Large Stationary Survey

are also well-suited as alternatives to batteries or diesel generators for strictly back-up power applications, particularly in remote areas (such as cellular phone towers), and at critical facilities in urban areas with air quality issues.

Current Fuel Cell Market

There are currently several hundred large fuel cell installations in the United States. In 2009, the U.S. market grew by 40%. Globally, 30 to 50 megawatts (MW) of fuel cell capacity are being installed annually (see Figure 2) with a projected 213 MW of new installed capacity in 2013. Projects are also getting larger, with the average fuel cell installation growing to about 1 MW, up from 250 kilowatts (kW) in 2005.

Costs

Costs for stationary fuel cell installations have dropped from about $600,000 per kW in the 1970s (when fuel cells were developed for NASA) to about $4,500 per kW today for the most widely deployed technologies. This is higher than the capital costs for fossil-fuel based distributed generation such as diesel generators and gas turbines. But it is lower than the capital costs of other distributed clean energy technologies such as solar photovoltaics. The U.S. Department of Energy's goal is to reduce this cost to about $400 per installed kW by 2020 for solid oxide fuel cell technology. It has formed the Solid State Energy Conversion Alliance (SECA), a government-industry partnership to achieve that goal. Like renewable energy technologies, fuel cells are eligible for the 30% federal Investment Tax Credit and for direct financial subsidies, in some states, lowering their capital costs considerably.

Because fuel cells can operate as a continuous, baseload source of power (unlike solar or wind which are intermittent), these capital costs can be spread out over far more kilowatt-hours (kWh) produced, especially when the by-product heat is captured and re-used. UTC Power projects that its PureCell® 400 kW unit will be able to produce power at 16¢/kWh (with 50% heat utilization), and at 14¢/kWh (with 100% heat utilization), before any federal or state subsidies. The capital costs of fuel cells can also be transferred through third-party ownership, in which a manufacturer or financial intermediary owns the system, realizes the tax benefits and sells energy to the host facility under a fixed price contract.

Table 2: Comparative Capital Costs for Distributed Generation Technologies

Technology	Cost ($/kW)
Diesel Generator	$800–$1,500
Reciprocating Gas Engine	$1,800–$2,000
Stationary Fuel Cells (1–200 kW)	**$2,500–$4,500**
Wind Turbine (50 kW–100 kW)	$1,500–$5,000
Solar Photovoltaics (1–100 kW)	$6,000–$8,000

Benefits of Fuel Cells

Stationary fuel cells have considerable benefits both to the facility where they are installed and to the public at large. These benefits will multiply as the costs of fuel cells continue to decline relative to grid power and the number of installations increases.

User Benefits

Reliability

Fuel cells are well suited for primary power applications, providing both an extremely reliable and high-quality source of on-site power. This reliability makes them ideal for public safety facilities such as emergency dispatch

United States Postal Service, San Francisco CA

The 680,000 square foot facility is a major postal service hub, processing 7.5 million pieces of mail per day. With the assistance of a third-party energy service provider, the facility installed a 250 kW fuel cell to provide a portion of both its power and space heating needs. The fuel cell complements a 285 kW, roof-mounted solar photovoltaic system that provides maximum output during periods of peak demand. The facility received financial support from both the California Self-Generation Incentive Program (SGIP) which provides incentives of $2,500 per kW for natural-gas fuel cells, as well as the U.S. Department of Defense Climate Change Fuel Cell Program.

centers, police and fire stations and hospitals. For private facilities such as computer server farms, data centers and laboratories where even momentary losses of power or voltage changes can disrupt computers and sensitive equipment, fuel cells deliver the sustained power quality needed, with grid power acting as a backup. Even non-critical facilities such as office buildings, retail stores and hotels can benefit from a grid-independent source of power that can also displace other fuels for heating, cooling and refrigeration.

Siting

While fuel cells have some local siting challenges, in general they are easy to site relative to other distributed generation technologies because they can operate emission-free, are quiet and compact. In some states such as California, they are completely exempt from permitting requirements. Fuel cell technologies that directly utilize natural gas (or biogas) avoid any local concerns over on-site hydrogen storage.

Remote Operation

Fuel cells can be operated and monitored remotely. This is important for fuel cells installed as backup power in remote locations such as telecommunications towers.

Baseload Clean Energy

Many businesses and public facilities are installing solar photovoltaics as a way of providing on-site clean energy. Fuel cells' high efficiency and ability to produce constant power makes them a good complement to solar.

Energy Cost Hedge

The installation of fuel cells can insulate businesses from unpredictable and rising electricity costs. While fuel cells still require hydrogen or natural gas as an input, these costs might rise less quickly than electricity, particularly in the event of state, regional, or federal carbon legislation.

Public Benefits

Environmental

Stationary fuel cells result in dramatically reduced on-site air pollution relative to back-up diesel generators. They can also result in reduced emissions relative to grid power depending on the source of generation that is displaced. This is due to the use of natural gas or biogas as the source of hydrogen, the high conversion efficiency of fuel cells, and the absence of particulate emissions. Fuel cells are driven by electrochemistry, not combustion. As a result, fuel cells emit only trace amounts of NOx. Because fuel cells are intolerant of sulfur, the fuels used have to be de-sulfurized, and thus fuel cells emit no SOx. If the direct fuel input is hydrogen, then only water vapor is generated in the exhaust. Because of the high electrical efficiency of fuel cells, the amount of CO_2 emitted per kWh of electricity generated is lower than from conventional fossil-fuel generation. Avoided emissions are further increased when the facility is configured to utilize the waste heat from the fuel cell. Table 3 compares the emissions profile of a fuel cell versus other forms of distributed and central power generation.

Table 3: Comparative Emissions Profiles of Fuel Cells vs. Distributed and Central Generation

Generation Technology	NOx (lbs/MWh)	SO2 (lbs/MWh)	Particulate Matter (lbs/MWh)	CO2 (Tons/MWh)
Fuel Cells	0.01	0.001	None	0.49*
Diesel Generators	5.9-17.1	0.3-0.5	0.74-3.0	0.75-0.9
Combined Cycle Natural Gas	0.11	0.022	0.067	0.50
Pulverized Coal	0.69	1.41	0.28	0.97

*Assumes internal conversion of natural gas to hydrogen within the fuel cell. CO_2-equivalent emissions would be reduced or eliminated if biogas or a renewable source of hydrogen were used.

Source: National Fuel Cell Research Center

Sierra Nevada Brewing Co, Chico, CA

The Sierra Brewing Company wanted to find a reliable and affordable way to power its state-of-the-art brewing facility that was also environmentally-friendly. Its solution was a combined heat and power, 1 MW fuel cell power plant that provides nearly all of the brewery's baseload power needs and the by-product heat and steam are used in the brewing process as well as other heating needs. This system not only lowers the overall energy cost at the plant, but also eliminates air pollutant emissions. When the fuel cells generate more power than is needed, Sierra Nevada sends the excess electricity into the grid and receives net-metering credit.

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Dublin San Ramon Services District Regional Waste Water Treatment Facility, Pleasanton, CA

Two 300 kW fuel cells were installed at the DSRSD regional wastewater treatment plant. This fuel cell system was designed to use the biogas generated by the wastewater treatment process as their renewable fuel source. The fuel cells also generate heat that is used to pre-heat waste sludge, optimizing the anaerobic digestion process. The fuel cell helps reduce the demand on the local power grid by providing as much as 50% of the facility's required power. Because the facility is utilizing biogas, it was eligible for a larger $4,500/kW incentive from California's SGIP.


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Sheraton New York Hotel

As part of a major renovation, the 1,750-room Sheraton New York Hotel installed a 250 kW fuel cell. This was the first hotel in New York to do so. The unit provides 10% of the electrical load of the hotel and, due to the hotel's large and constant hot water needs, effectively utilizes the system's waste heat to supplement natural gas in its boilers. The system received financial support from NYSERDA, New York State's energy research and development administration, which also manages its clean energy fund.

Avoided Generation and Transmission Costs

Like other distributed generation technologies, fuel cells displace utility purchases of wholesale electricity on the margin and during peak demand periods. The cumulative effect of fuel cells with other distributed generation resources can also defer the need to build both additional generation and distribution system upgrades.

Public Safety and Security

When power blackouts occur, the need to maintain critical public facilities and services ranging from police and fire dispatch to hospitals to water pumping and wastewater treatment is essential. Fuel cells provide a reliable way to ensure that these facilities stay up and running.

Table 4: Build-Up of Fuel Cell Value in California

VALUE	¢/kWh
Job Creation Potential	0.11–0.26
Health Benefits*^	2.34–2.54
Avoided CO_2 Emissions*	0.11–2.21
Other Avoided Emissions (NOx*^, SO2*, VOC*, PM10^, CO*^, Hg)	0.11–1.90
Increased Reliability/Power Quality/Blackout Avoidance	<0.01–0.22
Grid Support	0.03–0.40
Avoided Losses (Generation, T&D, Related Emissions)	0.26–0.64
Avoided Distribution Cost (All Costs Allocated to Peak)	0.06–0.97
Avoided Transmission Cost (All Costs Allocated to Peak)	0.01–0.24
Avoided Water Use	0.00–0.26
Avoided Fossil Fuel as a Price Hedge*^	0.36–0.96
Avoided Generation Fuel Cost*^ (Efficiency Gain + Cogen Credit + 30% Renewable Fuel Use)	1.28–7.03
Avoided Generation Variable O&M Cost	0.00–0.25
Avoided Generation Capacity Fixed Operation & Maintenance Cost	0.22–0.29
Avoided Generation Capacity Capital Cost (93% Effective Load Carrying Capacity)	1.71–2.31
RANGE OF TOTAL FUEL CELL VALUE	**6.6–20.5¢/kWh**

* Indicates inclusion of Cogen Credit
^ Indicates inclusion of Digester Gas Credit

Source: National Fuel Cell Research Center, UC-Irvine, 2008.

The results in Table 4 are associated with a two-year study conducted by National Fuel Cell Research Center, in collaboration with fuel cell manufacturers, which sought a mechanism for quantitatively and comprehensively establishing the monetary value of fuel cells beyond traditional cost measures. The NFCRC examined the spectrum of costs from avoided generation to health benefits, and estimated the overall societal value of fuel cells to be in the range of 6–20 cents per kWh generated.

Coming Soon: Fuel Cells for Your Home

While fuel cells in the United States are today targeted towards commercial use, in Europe and Japan, they are beginning to be manufactured and sold for the residential market. In Japan, residential fuel cells, about the size of a refrigerator, are being sold for $30,000 ($15,000 after government subsidy). To date, about 5,000 of the units have been installed. But, with mass production, analysts expect the cost to drop to about $5,000 within five years and one in four homes in Japan to have them by 2050. Beyond reducing dependency on the electric grid, converting natural gas into electricity (with the waste heat being used for space and hot water heating) would save homeowners a considerable amount in energy costs and also reduce the net carbon emissions of a home.

Google and eBay, Mountain View, CA

Google and eBay are among the companies that have been beta-testing the solid oxide fuel cells recently introduced by Bloom Energy. These companies use huge amounts of consistent electricity to power their server farms and need to provide extensive back-up systems to keep them running in case of power outages. The fuel cells can serve both needs by providing a reliable source of baseload power.

UTC POWER

Whole Foods Market, Dedham, MA and Glastonbury, CT

The Whole Foods store in Dedham, Mass., opened in Fall 2009, generates approximately 90 percent of its power on-site with a 400 kW fuel cell unit, installed by UTC Power. In addition, the 60,000 square foot store is heating 100 percent of its water using the technology. This followed the installation of a fuel cell in March 2008 at its store in Glastonbury, CT. According to Whole Foods, the store's energy costs are 30 percent lower with fuel cells than they were before installing them. The capture and use of the heat generated by these fuel cell units in cooling and heating is the key to making the economics work for these installations. For Whole Foods, the fuel cells were installed with minimal investment outlays. UTC Power owns and operates the fuel cell units and sells the power to the store. Each installation was also supported by large grants from the states' clean energy funds.

Conclusions

Fuel cells are coming into widespread commercial use for stationary applications, and their combination of reliability, efficiency, and low environmental impact make them an outstanding distributed generation technology for a range of applications. As the technology improves and costs decline, more businesses and public institutions should turn to fuel cells as a source of both primary and backup power.

However, as with other clean energy technologies, states play an important role in accelerating their adoption through both public policy and financial support. Policies such as including fuel cells as eligible resources in state renewable portfolio standards, encouraging or requiring the use of fuel cells in critical public facilities, and adopting uniform siting guidelines are important steps. In addition, providing financial incentives through state clean energy funds can help businesses overcome the first cost hurdles of installing fuel cells. These policy recommendations are reviewed in greater depth in an accompanying briefing paper, "Advancing Stationary Fuel Cells through State Policies."

Clean Energy States Alliance (CESA) is a national nonprofit coalition of state clean energy funds and programs working together to develop and promote clean energy technologies and markets. CESA provides information sharing,technical assistance services and a collaborative network for its members by coordinating multi-state efforts, leveraging funding for projects and research, and assisting members with program development and evaluation.

Many states across the U.S. have established public benefit funds to support the deployment and commercialization of clean energy technologies. More than twenty states are actively participating in CESA membership activites. Though these clean energy funds, states are investing hundreds of millions of public dollars each year to stimulate the technology innovation process, moving wind, solar, biomass, and hydrogen technologies out of the laboratory and toward wider use and application in business, residential, agricultural, community and industrial settings. State clean energy funds are pioneering new investment models and demonstrating leadership to create practical clean energy solutions for the 21st century.

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