PEM Fuel Cells For Distributed Generation

By Stephen Lasher; Robert Zogg, P.E., Member ASHRAE; **Eric Carlson; Patrick Couch; Matthew Hooks; Kurt Roth, Ph.D.,** Associate Member ASHRAE; and **James Brodrick, Ph.D.,** Member ASHRAE

When used in distributed generation (DG) applications, fuel cells have the potential to save energy and reduce emissions depending on the fuel-cell technology used,[1,2] and their inherent fuel-flexibility could help address energy shortage issues through energy diversity.[3] In addition, fuel cells have the potential to be quieter, more reliable, and have lower maintenance costs than most technologies used for DG.

Similar to batteries, fuel cells are electrochemical devices that convert chemical energy directly into electric power. Unlike batteries, both the cathode and anode reactants of a fuel cell are constantly replenished by air and fuel, respectively. Some of the fuel cell technologies under consideration for DG applications include solid oxide, molten carbonate, phosphoric acid, and polymer electrolyte membrane (PEM) fuel cells. This article addresses PEM fuel cells (PEMFC). Subsequent articles will discuss other fuel cell options.

In a PEMFC both the anode and cathode are comprised of platinum-based electrocatalysts supported on carbon particles. The electrolyte is a polymeric membrane that conducts protons. PEMFCs operate at lower temperatures than other fuel cells (i.e., 60°C to 90°C [140°F to 194°F] vs. 200°C to 1000°C [392°F to 1,832°F]), which limits their combined heat and power applications. PEMFCs likely will not be able to provide the high waste heat temperatures required for absorption cooling and, in most cases, space heating. On the other hand, their fast startup, simplicity of operation, zero emissions (when operating on hydrogen [H_2]), and potential for low capital and maintenance costs have attracted interest for DG applications.

How Will PEMFCs Be Fueled?

Ideally, PEMFCs can operate on a H_2-rich fuel (i.e., "reformate") generated from fossil fuels such as coal, natural gas, gasoline and landfill gas, or alcohols in conjunction with fuel processing. In practice, PEMFCs require very clean H_2 to prevent poisoning of platinum catalysts from impurities, such as carbon monoxide (ppm levels) and sulfur compounds (ppb levels). For this reason, ultra-pure (>99.999%) H_2 is the fuel of choice for PEMFC systems.

Investigators are evaluating several H_2 production, transportation, and storage options that eventually could meet the demands of future H_2 vehicles and stationary PEMFC systems. This includes both large-scale, central H_2 production options (typically 50 to 500 tons per day [TPD] H_2 output) and small-scale, distributed production options (typically < 3 TPD H_2 output).

Leveraging the benefits of large central H_2 production options for distributed PEMFC power systems will require an extensive H_2 delivery network between and within cities and towns, and along highways. Transportation options include compressed gaseous H_2 delivery via tube trailers or pipelines, and liquid H_2 or chemical hydride delivery via trucks, barges, or rail.

Alternatively, H_2 generation can occur on a smaller scale at or near the point-of-use to avoid storage and transportation from a central plant. Potential distributed production options include natural gas steam methane reforming and grid-based water electrolysis.

The DOE has developed cost models to estimate the required H_2 selling price for various production options for fueling future H_2 vehicles. Models and documentation are available on the DOE-supported H2A Web site: www.hydrogen.energy.gov/h2a_analysis.html. As can be seen in *Figure 1*, H_2 production costs of at least \$1.75/kg can be expected, even assuming high H_2 demand. Delivery for central plant options would likely increase the cost by at least \$0.50/kg to \$2.25/kg or \$17/MMBtu (HHV).

Although central coal gasification is projected to be the lowest-cost production option in the long-term, it will not likely be economical for metro-area-based H_2 demands of less than about 100 TPD (enough to generate 69 MWe or fuel 200,000 H_2 vehicles) due to the poor scalability of production and large-scale delivery of H_2. Therefore, coal gasification and other central plant options are not expected to fuel stationary PEMFC systems until significant H_2 demand (e.g., from H_2 vehicles or PEMFC power systems) develops.

Instead, distributed H_2 production via on-site reforming will be the most attractive nearer-term option for stationary PEMFC systems. This process would likely use natural gas as the feedstock because it is relatively easy to reform to H_2 and readily available at or near most DG sites, and potential sites, in the U.S.

Energy and Emissions Considerations

PEMFCs efficiently convert H_2 to electricity (40% vs. 30% for DG technologies using conventional fuels). On the other hand, generating (and in some cases storing and transporting) H_2 is relatively inefficient compared to conventional fuels. Therefore, the overall primary energy efficiency and greenhouse gas (GHG) emissions from PEMFC power systems that operate on H_2 produced via distributed natural gas reforming are not significantly better—and can be worse—than conventional DG technologies or the electric power grid.[4]

In addition, demand for natural gas has increased significantly and its cost has increased sharply in recent years, due in large part to greater use for power production. Therefore, incremental demand for natural gas will likely require additional liquefied natural gas (LNG) imports, which have higher emissions and energy security concerns than domestic natural gas.

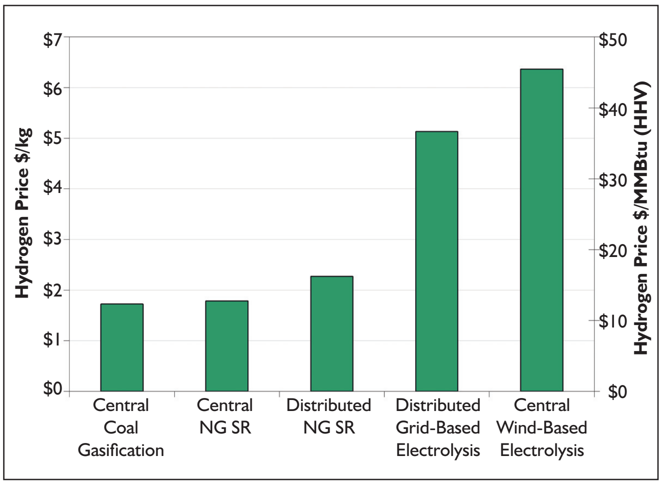

Figure 1: Required hydrogen selling price for production only.

Despite the primary energy challenges, PEMFC have potential to significantly reduce criteria pollutant emissions compared to conventional DG power systems. PEMFC do not produce nitric oxide (NO_x) and sulfur oxide (SO_x) emissions, the latter because of the required sulfur cleanup in the fuel processing step.

When operating on pure H_2, they also do not emit hydrocarbons, carbon monoxide, particulate matter, or other emissions at the point of use. These low emissions can greatly facilitate siting relative to conventional DG power systems.

Cost Challenges

Fuel costs are the largest component (more than 70%) of the overall cost of generating electricity for most combustion-based DG applications.[5] The potential for higher efficiency and resulting lower operating costs of fuel cells are primary reasons for their development for DG applications. TIAX analysis has shown that fuel costs must be \$10/MMBtu (HHV) or less to be competitive with the electric power grid and achieve break-even economics with electricity at \$0.09/kWh (assuming 40% HHV efficiency [*Figure 2*]).

However, generating ultra-pure H_2 is costly. Cost projections based on DOE H2A models for distributed natural gas-based H_2 production assuming H_2 will probably not cost less than \$2.25/kg or \$17/MMBtu (HHV) (*Figure 1*). Distributed H_2 production costs presented here are based on the H2A models for transportation applications that have been modified by excluding capital and operating costs associated with storage, compression, and dispensing to H_2 vehicles.

This distributed H_2 production cost translates into an equivalent cost of electricity of at least \$0.13/kWh based on fuel costs alone (assuming 40% HHV efficiency). This does not include capital, replacement, or other operating and maintenance costs for the fuel cell power system. In the near-term, stationary PEMFC power systems are projected to have higher capital costs than combustion-based DG systems, adding to the overall cost of electricity.

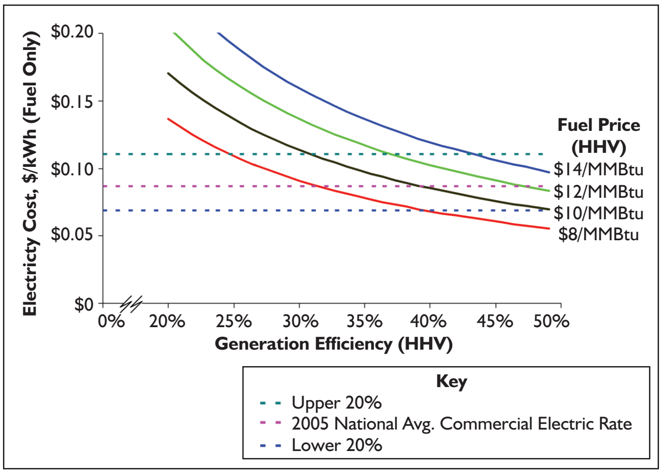

Figure 2: Maximum fuel price for baseload DG operation.

Promising DG Markets

Although the economic viability of PEMFC power systems for most DG applications hinges on the development of an extensive hydrogen infrastructure, some smaller but more promising nearer-term stationary power applications exist.

Among these applications, high-value backup power could be the most attractive. End-users in the telecom, finance, health-care, emergency response, retail and services industries may be willing pay a premium for reliable backup power. In these applications, on-site reforming or hydrogen storage could fuel the PEMFC power system. Although the cost of this system will exceed that of alternatives, the reliability and ease of siting due to near-zero emissions, could make PEMFC systems more attractive than conventional backup power systems.

Another promising application is to use a PEMFC to generate power at locations that have low-cost or "negative value" H_2-rich fuel available. For example, certain chemical processes result in large-scale (5 to 10 TPD) flaring of H_2-rich gas (e.g., chlor-alkali plants). A few demonstration efforts are underway to capture this opportunity H_2 for storage and resale and/or for fueling PEMFCs to generate power. Because the H_2 is a byproduct of another process, the economics of using the H_2 in PEMFCs improves.

A promising future application for stationary PEMFCs is as part of a "Hydrogen Energy Station." Energy stations would be locations with distributed H_2 production to provide fuel to H_2 vehicles and stationary PEMFC power systems. This integrated design could meet the needs of groupings of residential or commercial customers. Benefits might include early fuel infrastructure support for zero emissions vehicles (ZEV) and cleaner electricity production. Energy Stations could result in a more sustainable environment and a potential economic benefit via emission trading programs.

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Stephen Lasher and Eric Carlson are principals with TIAX LLC in Cambridge, Mass. Robert Zogg, P.E., and Kurt Roth, Ph.D., are associate principals with TIAX. Patrick Couch and Matthew Hooks are technologists at TIAX. James Brodrick, Ph.D., is a project manager in the Building Technologies Program, U.S. Department of Energy, Washington, D.C.