The Future Is Now

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FUEL CELLS OFFER SUSTAINABILITY AND ECONOMIC BENEFITS.

BY DON TALEND

Given that energy sustainability and energy economics are top-of-mind among business leaders, politicians, and the public these days, hydrogen fuel cells may be viewed as a savior technology. If that statement seems hyperbolic, there is plenty of statistical evidence to support the growth of fuel cell use for both stationary and transportation applications. The growth in both application categories bodes well for business owners who seek to reduce their reliance on the electrical grid and reduce emissions from operations.

In its "Fuel Cell Technologies Market Report 2014," the US Department of Energy (DOE) reports that the fuel cell industry grew by almost $1 billion in 2014, reaching $2.2 billion in sales, up from $1.3 billion in 2013. Major increases were seen in North America and Asia Pacific revenues, spurred by fuel cells for the US material-handling market, large-scale stationary power sales by US companies, and the residential market in Japan.

The DOE report also provides an overview of how fuel cells work. Types of fuel cells include molten carbonate, solid oxide, phosphoric acid, direct methanol, and low- and high-temperature proton exchange membrane. The devices electrochemically combine hydrogen and oxygen to produce electricity, water, and heat. Unlike batteries, fuel cells continuously generate electricity as long as a source of fuel is supplied. And, unlike other energy processes, fuel cells do not burn fuel, which makes them quiet, pollution-free, and two to three times more efficient than combustion. When hydrogen is produced from nonpolluting sources, a fuel cell system is a truly zero-emission source of electricity.

The DOE identifies three market categories for fuel cell

technology: stationary power, transportation, and portable power. Stationary power is defined as any application in which the fuel cells are operated at a fixed location for primary power, backup power, or combined heat and power (CHP). Transportation applications include power for passenger cars, buses and other fuel cell electric vehicles (FCEVs), specialty vehicles, material handling equipment, and auxiliary power units for off-road vehicles. Portable power applications utilize fuel cells that are not permanently installed or are in a portable device.

That hydrogen serves as an energy carrier for fuel cells, i.e., as energy from another source is used to generate hydrogen, which stores the energy until it is used to power a fuel cell, points out the DOE. In many fueling technologies, fuel cells integrate with a fuel processor to produce a hydrogen-rich gas from a hydrocarbon-based fuel such as natural gas or propane. It is also possible to store high-purity hydrogen directly in the fuel cell.

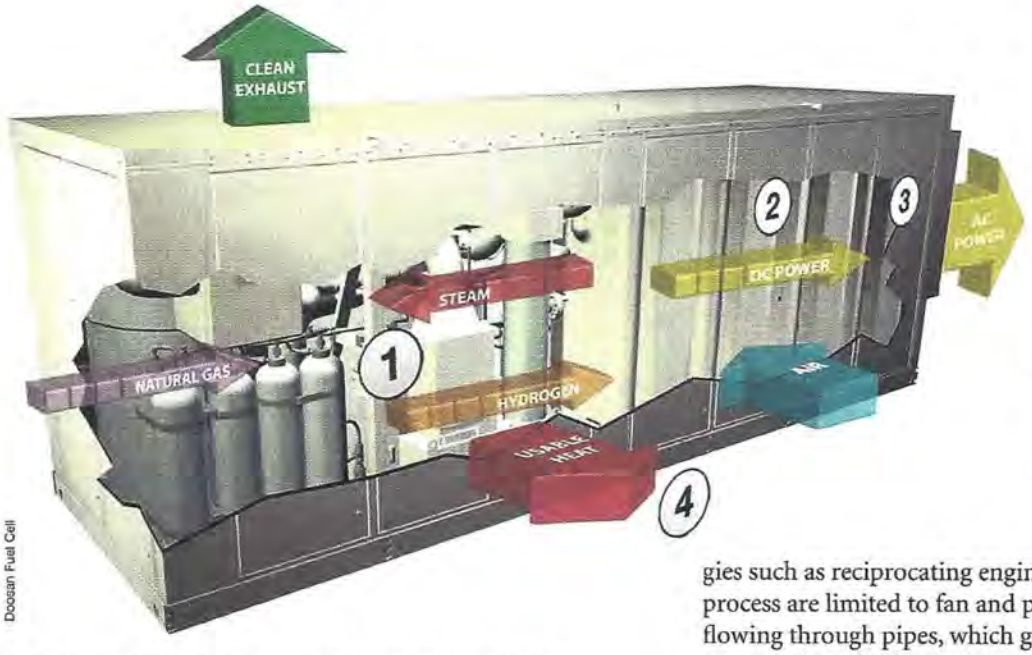
Stationary Power, Including CHP

The DOE subdivides the stationary fuel cell market category into several sizes and sectors: large-scale systems for prime power, backup power or CHP, small systems for micro-CHP (m-CHP) that suit residential or commercial operations, and prime and backup systems for remote or essential applications (e.g., data centers and telecommunications towers). Systems can range in size from several kilowatts to multiple megawatts.

Jesse Hayes, PureCell product manager for Doosan Fuel Cell, reports that fuel cell technology is well-suited to many commercial, institutional, and industrial applications. Doosan designed its PureCell phosphoric acid fuel cell for stationary power CHP applications. The Doosan PureCell Model 400 is rated for 440 kW with multiple unit installations ranging from 880 kW to 30 MW. The scalability of the Model 400 is a good fit for facilities such as hospitals, data centers, corporate campuses, college campuses, pharmaceutical, and other manufacturing processes. The Model 400 operates on natural gas and generates 440 kW of clean electricity and 1.7 million BTU per hour of usable heat.

Fuel cells offer ultra-low emissions due in part to high-efficiency chemical processes rather than combustion and the use of natural gas fuel—the cleanest fossil fuel resource. Fuel cells are an efficient, continuous-duty, and ultra-low emission distributed energy resource. The PureCell product line is designed to use phosphoric acid fuel cell technology to achieve fast-ramping dispatch capability and the ability to transition to a critical power mode at up to 400 kW in less than five seconds in the event of a utility outage. These two aspects of the Model 400 suit clean technology microgrids. Additionally, fuel cells provide continuous dispatchable power, unlike wind and solar systems, which have intermittency issues.

The development of the Model 400 and its predecessor, the Model 200, focused on durability of the core technology, the cell stack. Doosan's decision to utilize the medium-temperature



Doosan Fuel Cell

In the Doosan Model 400 fuel cell, the fuel processor, i.e., reformer, (1) converts (reforms) natural gas to a hydrogen gas using byproduct water steam to feed the fuel cell stack, (2) where hydrogen and air are combined in an electrochemical process that produces direct current (DC) electricity, pure water and heat. The power conditioner (3) processes DC power provided by the fuel cell stack into grid-interactive, high-quality alternating current power output. An integral heat recovery system (4) can heat facility water for purposes such as space heating, domestic hot water, and cooling in conjunction with an absorption chiller.

phosphoric acid architecture resulted in the Model 200's five-year stack life, which was subsequently increased to 10 years with the introduction of the Model 400 in 2009.

Fuel cell-powered CHP systems provide baseload electric power and heating to a facility; when a fuel source also powers cooling applications, the system is referred to as trigeneration. According to Doosan, combined use of heat and power can deliver 90% system efficiency. In non-CHP applications, nearly two-thirds of the energy used to generate and distribute electric power is wasted in the form of heat discharged to the atmosphere. Most of Doosan's installed global fleet is made up of CHP applications, Hayes reports.

Using fuel cells for stationary power carries several significant benefits. For one, fuel cells are a clean power source. Doosan's PureCell systems, for example, operate on low-emissions natural gas and qualify for four to six Leadership in Energy and Environmental Design (LEED) points. The combustion-free electrochemical process that occurs in powering fuel cells results in ultra-low emissions of pollutants such as NO_x, SO_2, carbon monoxide, volatile organic compounds, particulate matter—significantly below that which occurs in utility-generated power and reciprocating engines.

The system's emissions fall well below the California Air Resources Board (CARB) 2007 limits for distributed generation. This means that fuel cells are considered such a clean technology that the South Coast Air Quality Management District in Los Angeles has ruled that they do not require clean air permits.

Hayes points out that other technologies used for CHP require air permits, which are sometimes difficult to obtain, and they also need exhaust gas treatments to process unburned hydrocarbons and prevent formaldehyde emissions. "Their exhaust gas cleanup systems take up space, are complex, and have extra moving parts for urea pumps. Tanks and maintenance on those systems is needed. Fuel cells are inherently clean and do not need exhaust gas treatment."

In addition, fuel cells generate minimal noise pollution. Fuel cells do not have moving parts, e.g., pistons and cylinders, as technologies such as reciprocating engines do. Noise from the PureCell process are limited to fan and pump operation or natural gas flowing through pipes, which generates 60 dBA or less at 10 meters, about the level of normal conversation. Hayes points out that many other technologies require the construction of soundproof enclosures.

Another environmental benefit of using fuel cells is water savings. The PureCell system, for example, is designed to operate in water balance, with no consumption or discharge of water in normal operations. In contrast, central power generation requires a substantial amount of fresh water to cool the turbine generators, resulting in the use of millions of gallons of water at a typical plant.

Providing Control Over Economics

The benefits of fuel cells for stationary power go beyond sustainability and positively impact economics. For one thing, fuel cells provide utility cost control. "If someone purchases a fuel cell system, they take control of their energy costs," says Hayes. "In places where electricity is five cents per kilowatt-hour, you're likely burning coal to get that power. Where utilities are pressed to do better with their emissions, increases in costs are borne by the rate payers." He adds that customers with high electric rates can adopt

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fuel cells to reduce their reliance on the grid for their power and control their energy costs.

Hayes notes that fuel cells have not yet been produced in mass quantities. When that happens, the economies of scale will help reduce equipment costs. "If we look at the solar industry, there are huge quantities of panels being made and prices are coming down drastically—the same will be true of fuel cells," he says. Initial investment is a barrier in the Midwest, where coal-fired power plants are plentiful and electricity costs five to six cents per kilowatt-hour.

"With electric rates that low, it's hard to convince someone to sign off on a project that will make electricity cost 10 cents per kilowatt-hour, even if it's orders of magnitude cleaner," he continues. "But, if you look at the handful of more progressive states, they have clean energy portfolio standards or incentive programs, such as net metering, that include fuel cell technologies. I'll agree that natural gas is not a renewable fuel, but it is the cleanest possible fuel resource, coupled with an ultraclean technology in fuel cells. If you shift the conversation from renewable technologies to ultraclean technologies, one, it addresses the intermittency and non-dispatchability issues of solar and wind, and it allows us to use the right mix of technologies to address a broader energy sustainability need. One of the benefits of our fuel cells is that they have a very high-capacity factor, so we generate roughly six times more energy as an equivalently sized solar panel throughout the course of a year."

Doosan provides proposals for projects with relatively short payback periods where local or state incentive funding is favorable, Hayes says. "There is a misconception that fuel cells aren't economical. If you've got five-cent electricity and no state clean energy incentives, you could be looking at a 10- to 15-year payback for a fuel cell. In some states and locations, electric rates are well above 10 cents and our projects fall in the three- to six-year payback range."

The goal is achieving cost parity without incentives, Hayes adds. "In areas that have incentives and are more conscious of the carbon dioxide footprint, we develop projects typically in the three- to six-year payback range."

When Doosan's bid has a six-year payback and is competing against a natural gas reciprocating engine with a five-year payback, Hayes touts the impressive value proposition of fuel cells as an advanced CHP solution. Advanced CHP utilizing fuel cells are well-suited to emergency power applications because they reconnect to emergency loads in less than five seconds, unlike most lean-burn natural gas reciprocating engines used for CHP.

"When a company is looking to replace an emergency generator or build a facility and put in an emergency generator, it's a capital equipment purchase that's often required by law," points out Hayes. "Now they can buy one product that gives them both everyday cost savings and critical power. That's a complete paradigm shift for the power industry."

Stationary power is also a major market for Air Products and Chemicals, a supplier of industrial gases, including liquid and gaseous SmartFuel hydrogen for fuel cells, and fueling infrastructure solutions. In the stationary power space, Air Products focuses on providing direct hydrogen fuel sourcing to fuel cells for primary power, backup power/uninterruptible power supply (UPS), peak-shaving, and grid stabilization for applications in which as much as 1 MW of power is generated.

Fuel Cells, Solar Are Complementary

Hayes does not believe that fuel cells and solar energy are competing technologies in every case. In some parts of the country, the two technologies can be used in a complementary fashion. The Northeast, where he is based, is a good example. During the winter, many facilities have heat loads, lighting loads, and process loads. In the summer, they have air-conditioning loads, which are considerable. Summer is also one of the best periods for solar generation; on hot, sunny days, solar power can help to offset peak loads like refrigeration or air conditioning. Meanwhile, fuel cells can accommodate base loads most economically.

"In periods of high peak demand, electric bills can get pretty high," says Hayes. "There's a load duration curve that shows the power profile of a company over the course of a year, and the shape of that curve reveals a lot of information about the most effective way to control electric rates. If we can fit a fuel cell in that curve, we can drop that curve down by 440 kilowatts per unit. On one corporate campus, we installed a two-megawatt fuel cell system alongside a 375-kilowatt solar system.

"The solar part of it addresses their peak load during the day; together, the two mimic the typical usage of a facility," continues Hayes. "As long as they keep the fuel cell below that load, that fuel cell is perfect at just dropping the curve, and then solar does a great job of clipping the top off of that curve. On sunny days, the complementary nature of these two technologies is good."

Verizon has embraced fuel cells and solar, by installing 21 PureCell Model 400 power plants that provide a total of 8.4 MW of power and 60 million kWh of electricity at its locations in California, New York, and New Jersey. The projects are part of a major fuel cell and solar energy initiative in 20 states intended to allow Verizon to generate more than 70 million kWh of its own clean energy, eliminate more than 10,000 metric tons (MT) of CO_2, and cut its carbon intensity in half by 2020. To date, Verizon has reduced CO_2 and NO_x emissions by an estimated 5,376 MT and 18 MT, respectively, and saved 27 million gallons of water in nine fuel cell installations that are currently utilizing both fuel cells and solar power.

CBS Studio Center in Los Angeles uses Doosan Fuel Cell's PureCell Model 400.

Doosan Fuel Cell

From Buses to Scooters

Fuel cells are a less mature technology for transportation, but their use is arguably more high-profile than in the stationary power realm, given the considerable impacts of globalization, science, and geopolitics on refined petroleum prices. Fuel cells have been demonstrated and used in light-duty passenger cars, buses, material handling vehicles, boats, planes, scooters and other specialty vehicles, and also on-board internal combustion engine or other alternative-fueled or battery-electric vehicles as range extenders or auxiliary power units.

In April 2014, BMW, Daimler, Honda, Hyundai, and Toyota combined to launch the HyFive project, agreeing to deploy 110 fuel cell electric vehicles in several European cities. The £31 million ($49 million) program will also develop hydrogen refueling stations in London, Denmark, and Austria. Japan announced that it will offer a rebate of at least ¥2 million ($18,165) to customers purchasing FCEVs and will make FCEVs the official car of its ministries and other government offices. China mandated that electric cars, including FCEVs, comprise at least 30% of government vehicle purchases by 2016.

Hydrogen fuel cell cars are the only alternative to gasoline-powered cars —including battery electric cars—that have the potential to have the same range, performance and refueling time of a conventional automobile. Air Products provides integrated systems that include hydrogen compression, storage and dispensing, and delivery of liquid or compressed gas. The company is participating in several hydrogen energy demonstration projects around the world. One example was supplying and fueling hydrogen buses in Beijing for the 2008 Olympic Games. Air Products has permanent stations or temporary installations for technology demonstration for two to 200 buses. The stations can accommodate fleets with HICE (Internal Combustion Engines running on hydrogen) or hydrogen fuel cell vehicles.

In the material handling space, Air Products focuses on the benefit of increasing customers' productivity by eliminating the need to change, recharge, and maintain lead-acid forklift batteries. Vehicles using fuel cells need refueling once or twice per day, a process that takes three to five minutes, and emissions are limited to water. The company provides the hydrogen supply and fueling infrastructure for fuel cell power packs for forklifts, automated guided vehicles, and other material-handling vehicles. Air Products has one hydrogen fueling station designed for facilities that will use up to 100 kilograms (kg) of hydrogen per day and another for facilities that will use more than 100 kg of hydrogen per day. The latter station suits customers that expect to grow over time or have large peak demand periods for fuel. Each station can have multiple dispensers installed and all stations have backup options.

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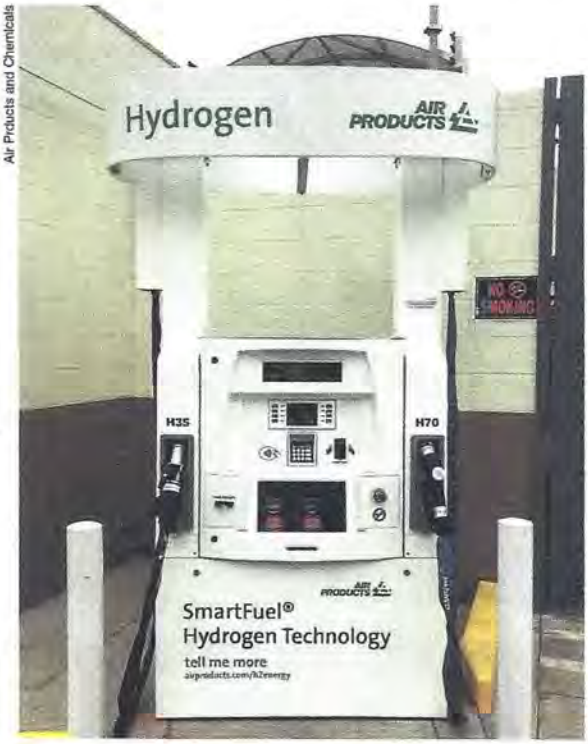
Infrastructure Growth Mirrors Transportation

Strong growth in hydrogen station infrastructure that supports expected growth in commercial FCEV deploy-

ments by automakers should continue in the coming years, according to the DOE. Public policy is supporting funding commitments that will enable the number of hydrogen fueling stations to grow across the United States, Europe, and Asia. Additionally, hydrogen energy storage is increasingly viewed as a way to utilize surplus energy produced by wind or solar technologies. This renewably generated hydrogen can be injected in natural gas pipelines for widespread distribution or used for fuel cell power generation or hydrogen vehicle fueling.

The H2USA partnership was announced in 2013 to accelerate the rollout of a US hydrogen infrastructure for FCEVs and has grown to more than 30 businesses and organizations, including the US DOE, automakers, fuel cell suppliers, materials and component manufacturers, and energy companies. Japan's Ministry of Economy, Trade, and Industry Hydrogen/Fuel Cell Strategy Council announced plans to introduce and expand hydrogen and fuel cell technologies there. The European Union adopted new rules to ensure an increase in the commissioning of publicly accessible refueling points adhering to common standards in member states that opt for hydrogen fueling infrastructure by the end of 2025.

Air Products stations are involved in about 1 million hydrogen fills per year, and the company has been involved in more than 200 hydrogen fueling projects in the United States and 20 countries. The company provides hydrogen fueling at 700 bar (10,000 psi) with its high-pressure distribution systems and retail hydrogen fuel dispenser, which is designed to mirror traditional consumer gasoline fueling and payment practices. Hydrogen for these stations can be delivered to a site via truck or pipeline, produced by natural gas reformation, biomass conversion, or by electrolysis, including electrolysis driven by renewable energy sources such as solar and wind.



Air Products SmartFuel hydrogen fueling station

Future Looks Bright

Without a doubt, fuel cells have a bright future in the aforementioned applications, due to factors playing in favor of this technology.

The January 2015 issue of *Hydrocarbon Processing* reported that rising natural gas production is facilitating growth in both fuel cells that supply stationary power and the utility grid, and expanding applications in light-duty fuel cell electric vehicles. Stationary fuel cell applications will use both natural gas, and methanol as fuel. Currently, fuel cell technology accounts for 2 million MWh of electricity generated in the US, according to the Fuel Cell and Hydrogen Energy Association.

Hayes believes that natural gas increasingly will be used to power fuel cells. "The natural gas industry is growing and natural gas is becoming much more safe and abundant," he says. "We have this great resource, and we'll be building natural gas infrastructure for years and years."

On its own, solar power has a major shortcoming: relatively low power output per square foot of panels. But, as the word gets out about the relative benefits of fuel cells and solar power, Hayes sees the adoption of that combination growing. He has seen projects in which solar power would require 4 acres, compared with a 20-by-40-foot pad for fuel cells.

It's clear that fuel cells have a bright future in the transportation area. In addition to several countries' public policies intended to facilitate the growth of vehicular fuel cell use, automakers such as Toyota are embracing the technology. In late 2015, Toyota unveiled the Mirai, which runs on hydrogen power like that supplied by Air Products. The campaign launching the new model was educational in nature and was inspired by the 1980s film *Back to the Future* in which a trash-fueled car transports its two stars back in history and into the future. A *Fueled by the Future* video explains how companies like Air Products are turning trash into hydrogen to fuel cell cars like the Mirai. Another video, *Behind the Science,* covers the technology in more detail. Both videos, available at **https://ssl.toyota.com/mirai/fueledbyeverything.html,** show an Air Products steam methane reformer that produces large quantities of hydrogen and an Air Products SmartFuel hydrogen fueling station.

In California, Air Products is supplying fueling stations with hydrogen made from eligible renewable sources. At least 33% of the hydrogen dispensed at the company's automotive fueling stations in the state is renewable, complying with California's hydrogen infrastructure program. Also, the company has developed and successfully demonstrated other renewable production technologies that can produce hydrogen, including the conversion of biogas from municipal wastewater to hydrogen. Feedstock sources such as agricultural, food, and brewery wastes, in addition to landfill gas, all contain hydrogen and can be used to produce renewable fuel. According to Air Products, converting all of these available streams to hydrogen could provide fueling for up to 200 million fuel cell vehicles in the US and make sustainable energy independence possible. **BE**

Don Talend *is a frequent contributor to Business Energy.*