Skyrocketing oil prices have put renewable energy sources in the spotlight. One of the most promising of these, fuel cells, produces power without pollution. Despite the promise, the fuel cell industry faces daunting challenges–the current high cost of fuel cells, the technological need for higher power density and smaller size, and environmental concerns–to make it all work.

Fuel cells:

Will they rule or ruin the world?

By Karen Hawthorne and Jennifer Coombes

For about a decade, the scenario has gone like this: After a long day at the office, you park your car in the garage and plug it into your house. It powers up your stove for dinner, your washer and dryer to tackle that pile of laundry, and generates excess electricity that feeds back into the grid. Problems like blackouts and polluting car exhaust are things of the past.

Is this long-promised glimpse of a cleaner, brighter fuel cell future still in the cards? Well, it's looking more and more likely, although there are numerous challenges ahead, industry experts say, and controversy over the technology's true environmental impact.

What is a fuel cell, anyway?

Fuel cells are devices that harness the chemical energy in hydrogen, the fuel, and convert it into the kinetic energy we know as electricity. Think of it like a battery, having an anode and a cathode, which not only stores power but generates it, as long as the fuel is being supplied. With fuel cells, there are very low to zero emissions of such harmful substances as nitrogen dioxide, sulphur dioxide, carbon dioxide and carbon monoxide. The only by-products of the process are water and heat. NASA has used the technology since the 1960s to power spacecraft. And the by-product is pure enough for astronauts to drink.

As an efficient, clean source of energy, fuel cells can take the place of both batteries and engines to power vehicles, and a range of consumer electronics, including mobile phones and laptops. The low noise and high power quality of fuel cells make them ideal for use in hospitals and IT centres. They can even power residential grids.

Powered by a hydrogen fuel cell, the Hydrogenics GEM car is a small, neighbourhood electric vehicle. The GEM car can reach speeds of 25 km/h and is environmentally friendly, since water is the only emission.

"If you can generate electricity locally, more efficiently and in an environmentally friendly way, you can minimize transmission problems," says Christopher Cheh, PhD, P.Eng., the University of Toronto, Mississauga's director of the Centre for Emerging Energy Technologies. "These new fuel cell technologies are much more environmentally friendly than coal-fired power. They have tremendous potential."

One benefit of the technology is flexibility. A fuel cell can be small and portable or larger and permanent. To produce a usable amount of electricity, multiple fuel cells are combined into a fuel cell stack, and the electricity generated can be increased or decreased by altering the number of cells in the stack. In addition to the stack, a fuel cell system requires its support network for such operations as injecting fuel gases, managing a critical water balance, conditioning the output power, and monitoring and controlling the system's temperature and pressure.

"Fuel cells are highly scalable and offer some very interesting design freedoms," says Pierre Rivard, P.Eng., president and CEO of Hydrogenics Corporation in Mississauga, one of the leading companies in the industry. "The same technology can be used in a variety of applications. The same power module can be used to run a forklift or provide backup power to a data centre. Also, it is highly versatile…the fuel cell component of a system can be sized to the maximum power that is required."

Long-term gains

Experts contend that the cost to convert to a fuel cell-driven economy may initially be high, but over time it will significantly reduce the costs of maintenance, repair, and fuel compared to conventional technologies. If we can use the resulting heat from a stationary fuel cell system, for example, to warm a house during the winter, the fuel cell becomes even more cost effective.

"The industry knows if you step out into the future, at some point we will be running out of fossil fuels," says Fuel Cells Canada's Ry Smith, P.Eng., who manages the Hydrogen Village Partnership in the Greater Toronto Area, a collaboration of industry, government and academe established in 2003 to map out and implement the commercialization of hydrogen and fuel cell technology in the GTA as a model for the rest of Canada. "Also, at some point, the pollution loading from the use of hydrocarbon fuels will become intolerable, and we'll need to move away from hydrocarbons as a fuel source. The somewhat scary thing about it is, if we don't work now in the early stages, the transition will be very abrupt and very disruptive to society as a whole, so an overall market development program is essential for a smooth takeoff."

"There's the whole chicken and egg thing," says Todd Bednar, P.Eng., a senior advisor with the Sector Competitiveness Branch, Industry Division, at the Ministry of Economic Development and Trade. "The classic question, especially from a transportation perspective, [is that] you have fuel cell vehicles but you need hydrogen infrastructure, you need hydrogen infrastructure to have fuel cell vehicles. Well, both have to go hand in hand."

Bednar is working with the ministry's Ontario Fuel Cell Innovation Program, launched last January to help fund the work of Ontario companies to move fuel cell technologies to the manufacturing stage.

There are some specific technology challenges to overcome, Bednar says: "Cost is one thing. This is an emerging technology and the applications are being discovered. The manufacturing costs of fuel cell units themselves have got to come down, whether PEM-based [proton exchange membrane], or high-temperature solid oxide fuel cells. Also the reliability of fuel cells has to be improved, especially the lower temperature operating fuel cells [PEM]."

Environmental impact

But is a technology that promises to power our cars, homes and businesses with just one clean by-product–water–sound too good to be true? For the moment, it is.

Despite the promise of fuel cells, they do not come without controversy. Central to the controversy is the process of getting enough hydrogen to run them and, in particular, the environmental issues surrounding the production of hydrogen. The so-called clean credentials of hydrogen are eliminated if its production is from sources that pollute.

Because hydrogen makes up about three quarters of the mass of the universe, it's quite an appealing candidate to become the wonder fuel of the future. When the whole life cycle of hydrogen is considered, however, that's not yet the case. Despite being plentiful, hydrogen has to be derived from raw material, and that raw material until recently has mostly been fossil fuels like oil, coal and natural gas. In fact, over 90 per cent of hydrogen used today is produced by the combustion of fossil fuels, a process that sends massive quantities of carbon dioxide and other pollutants into the atmosphere–in some cases, even more than using the fossil fuels directly. To top it off, hydrolysis requires electricity, which is often generated primarily from fossil fuels and other conventional energy sources. Clearly, the production techniques of hydrogen need greater focus.

Enter renewables

That said, strides are being made in Ontario, the rest of Canada, and around the world toward a sustainable hydrogen future through the development of clean ways to manufacture hydrogen. For instance, hydrogen can be produced from carbon-free or carbon-neutral energy sources. "Part of the beauty of the technology is that hydrogen can be made in different ways from different raw materials," says Hydrogenics' Rivard.

In the meantime, industry analysts suggest that a successful transition to the hydrogen economy will require extracting hydrogen from fossil fuels with more environmentally sensitive processes. For example, CO_2 capture and storage decreases the amount of damage to the atmosphere. Atlantic Hydrogen Inc. is leading a consortium comprising the University of New Brunswick in Fredericton, Energy Reaction Inc. and PrecisionH2 Power Inc., of Montreal, Enbridge Inc., and Hydrogen Engine Centre, of Iowa, that has demonstrated a technology to produce hydrogen and remove solid carbon from natural gas without releasing greenhouse gases. The consortium has produced a bench-scale model of their trademarked CarbonSaver technology and is working on a larger-scale prototype. Until even cleaner methods are available on a large scale, this seems like a step in the right direction.

Another positive step is the use of renewable electricity generation techniques, such as wind and solar, to power the actual process of hydrolysis. One of the companies making strides in applying renewable electricity to hydrogen production is Hydrogenics. The company's HyLYZER refueling station is fueled by wind energy from the turbine at Exhibition Place in Toronto. Part of Toronto's Hydrogen Village project, the station is capable of producing about 65 kg of hydrogen a day for stationary or mobile applications. If used for vehicles, that's enough hydrogen for roughly 20 vehicles. Says Rivard, "When hydrogen comes from renewable sources, like in this particular system, we benefit from completely clean energy."

Hydrogenics has also teamed up with Prince Edward Island Energy Corporation to lead a consortium of industry and government partners to develop the Prince Edward Island (PEI) Wind-Hydrogen Village Project, Canada's first wind-hydrogen village demonstration. The initiative will demonstrate how wind energy and hydrogen technologies can work together to offer clean, sustainable energy in real life. The energy from the project will be used to power the North Cape Interpretive Centre Complex, the Atlantic Wind Test Site, homes and other buildings in the North Cape area.

Next steps in the project will include a hydrogen refueling station in Charlottetown to support three hydrogen shuttle buses used in the city, and a variety of fuel cell utility vehicles.

Biomass benefit

Several current North America projects involve extracting hydrogen from biomass. For example, at Pennsylvania State University, Bruce Logan, a professor of environmental engineering, is the inventor of an electrically assisted microbial fuel cell, based on a process that uses a small amount of electricity to enable bacteria to get about four times as much hydrogen directly from any biodegradable organic matter than with fermentation alone. The researcher admits that biomass probably can't sustain a global hydrogen economy, but it may offset the costs of wastewater treatment and provide a contribution to nations able to harness hydrogen as an energy source.

Robert Johnson, president and CEO of Purolator, introduced a fuel cell hybrid electric vehicle into Purolator's Toronto curb-side delivery fleet. The delivery vehicle has been developed in conjunction with Hydrogenics Corporation, Azure Dynamics Corporation, Industry Canada and Natural Resources Canada.

Fuel cell-powered forklifts were introduced at the General Motors plant in Oshawa in a test pilot earlier this year.

That view is shared by David Bagley, associate professor of civil and architectural engineering, University of Toronto; Hydromantis, an environmental consulting and software firm in Hamilton; and Ontario Centres of Excellence Inc. (OCE). The team is developing a similar process to create an energy benefit from the wastewater treatment process. Their project converts organic materials in wastewater into hydrogen through an anaerobic microbial process.

"When engaging in projects, the OCE really works to focus on the solution and tries to avoid putting the technology first. That's what was really interesting about us engaging in this project," says Michael Fagan, P.Eng., director of business development, Earth and Environmental Technologies, Ontario Centres of Excellence Inc. "There is a huge need in water treatment to address the energy issue because it's the single biggest cost. Anything they can do to offset that is obviously of significant and immediate benefit to the municipalities, who are the problem owners."

The fuel cell battery hybrid design of the Hydrogenics MIDI bus has the capacity to at least double the range achieved by battery power. Ideal for European cities, the bus is expected to receive German road certification by the end of the year.

According to Hugh Monteith, P.Eng., senior consultant at Hydromantis, "David Bagley and graduate student Ioannis Shizas found that there is roughly nine times the energy coming into a wastewater treatment plant than is needed to run the plant. The question is, 'How do we capture that energy?' Their idea was to use bacteria to convert some of the waste into hydrogen, which could then be consumed to address the energy issue."

"It was very much a solution-focused initiative," adds Fagan. "This project solved an intermediate problem and is working towards a long-term solution."

At Solar Hydrogen Energy Corporation (SHEC labs) in Saskatoon, a similar project is using biomass from landfills or wastewater as the main ingredient for the production of hydrogen. The new wrinkle here is that the process derives all of its energy from solar power. The company has demonstrated a dry fuel hydrogen generation system that consists of a solar mirror array, a solar concentrator and shutter system, and two thermo-catalytic reactors that convert methane and carbon dioxide into hydrogen.

As opposed to traditional hydrogen production methods that result in a net increase of carbon dioxide in the atmosphere, when biomass is converted to methane and then combusted, the carbon dioxide released into

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the atmosphere is only what was used to grow the biomass in the first place through photosynthesis. The process is completely renewable because this cycle can continue indefinitely.

Jamie Bakos, P.Eng., manager of environmental services at Toronto's Giffels Associates, is providing engineering support for the SHEC labs project. "Biomass conversion represents the greatest opportunity to meet Canada's need for renewable energy in the next 10 to 20 years. Not to knock any of the other energy forms out there, as a mixture of renewable energy forms is very important, but the opportunity for biomass is much greater than solar and wind energy due to the load factor, the amount of time during each day that the energy is available to do work. Biomass is constantly available, rather than available only when it's windy or only when it's sunny, and we still get tremendous environmental benefits since we're emitting far less CO_2 than fossil fuels," he says.

There are lots of codes and standards to install a boiler, but very few to install a hydrogen production facility," says Bakos. He says engineers often want to go back to what is completely proven, and with this technology they don't necessarily have all the answers. "If we want to bring hydrogen technologies to the marketplace, we have to use our best judgment and engineering skills."

Bakos feels the critical issue slowing down the hydrogen economy is that, except for those used for niche markets like laptops and cell phones, fuels cells are a bit slow to come down in price. Even if fuel cells take a little longer to appear than expected, says Bakos, "we can still produce clean, renewable hydrogen to use in traditional internal combustion engines and wait for the even bigger payoff with fuel cell cars. That way, not only are we not adding CO_2 to the atmosphere from hydrogen production, but we're now offsetting fossil fuels

According to Bakos, another challenge is that this technology is new, so engineers don't have enough experience with it yet.

Following completion of a demo unit in Tempe, Arizona, SHEC labs is now gearing up for what–as far as they know–is the first commercial-scale dry fuel reformation process, at a landfill site in Canada.

Bakos is quick to note that there are all kinds of issues in working with hydrogen and fuel cells in general. "While hydrogen is a wonderful energy carrier, there are problems with it, too, simply because it's so light. We have to find innovative ways to store and transport it, he says. One of those innovative ways is looking at injecting hydrogen into natural gas itself, right into the pipeline system similar to the way a cleaner product like ethanol is added to gasoline right now.

According to Bakos, another challenge is that this technology is new, so engineers don't have enough experience with it yet. "Engineering is about codes and standards and ultimately protecting the public, and the standards for hydrogen are still developing. that would be used to drive those internal combustion engines."

Despite the challenges, however, he feels that fuel cells are the greatest payoff for the environment ultimately.

Fagan's take on fuel cells in general mirrors Bakos' optimism, and that of the majority of industry experts, for that matter. While he believes there's a lot of hype now surrounding fuel cells, he's also convinced there's a future for them.

Although hydrogen and fuel cells do not yet offer sufficient short-term, end-user benefits to justify their higher costs compared to conventional technologies, the question is, with ever-dwindling fossil fuel supplies, and the pollution their use causes, do we even have a choice?

Testing the waters

The fuel cell dates back to its discovery in 1839 by William Grove, a Welsh judge who pursued science as a hobby. Through the years, Canadian government, industry and academe have been actively engaged in dozens of important hydrogen and fuel cell demonstration projects. Here is a sampling of projects that feature Canadian engineering.

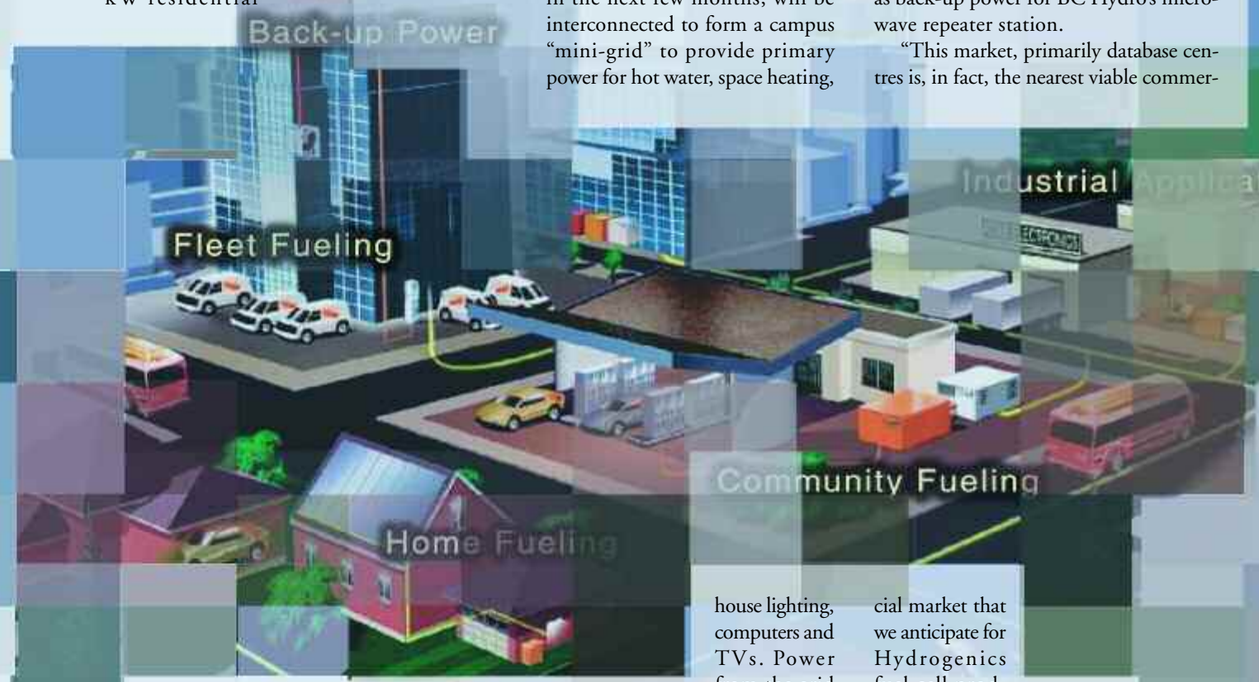
Fuel cell buses

Because the size of fuel cells remains an issue, many test vehicles with fuel cells have been large. Common test subjects have been delivery and fleet vehicles and motor homes. A fuel cell bus field trial was demonstrated in Vancouver and successfully completed in July 2000. BC Transit purchased three fuel cell bus engines from XCELLSIS Fuel Cell Engines Inc., now a part of industry pioneer Ballard Power Systems in Burnaby, BC. BC Hydro produced the hydrogen used to power the fuel cells using off-peak electricity.

Currently, there are 33 buses powered by Ballard heavy-duty fuel cell engines operating on the streets of nine major European cities, and in Iceland and Australia. These buses carry passengers in daily service in each city as part of a two-year field trial. The project organizers, Clean Urban Transport for Europe (CUTE), announced in July that the buses had collectively covered 760,000 km–equivalent to a return trip between the Earth and the Moon.

Home power

Natural Resources Canada entered into a $260,000 partnership with Fuel Cell Technologies Ltd. (FCT) in Kingston to install the first residential fuel cell in Canada last February at the Canadian Centre for Housing Technology at the National Research Council's Institute for Research in Construction in Ottawa. A virtual family made routine domestic power demands so performance and integration data could be gathered. The 5 kW residential solid oxide fuel cell had excess power



"93 per cent of the day and was importing power 7 per cent of the day when, for example, in the evening you're cooking and running the dryer at the same time. Then, the fuel cell doesn't have enough power. But most of the day we were actually exporting power," says John Stannard, PhD, P.Eng., FCT president and CEO. These systems can generate electricity and heat at the single household level, providing a viable alternative, or supplement, to large power generating stations. FCT has sold several of these systems outside Canada.

"In the near to mid-term, the larger part of the market that is accessible is stationary fuel cells," says Stannard. "It makes sense. The solid oxide fuel cell can use a wide range of fuels, and it has a high temperature waste heat that you can use to heat a house, heat a factory, and provide heat for other processes."

The University of Toronto, Mississauga, is retrofitting a 12-unit block of its townhouse style student residences with four 5 kW solid oxide fuel cells from FCT. The units, expected to be installed in the next few months, will be interconnected to form a campus "mini-grid" to provide primary power for hot water, space heating, house lighting, computers and TVs. Power from the grid will supplement the system, which will also, at times, export power to the grid and to other parts of the campus.

"So far this technology has been applied only one unit at a time for any one location, so this is a first," says Christopher Cheh, PhD, P.Eng., the University of Toronto, Mississauga's director of the Centre for Emerging Energy Technologies, who is the project manager for the student residence project. "FCT has the capability for remote monitoring, but our intention is to have on-site people from the school's engineering faculty run the system."

Back-up power

The National Research Council's Institute for Fuel Cell Innovation (NRC-IFCI) is a site for demonstration projects in sustainable development. The first phase, in partnership with the British Columbia Institute of Technology, integrates solar technology with a Hydrogenics electrolyzer module to produce hydrogen for NRC-IFCI labs and power a fuel cell backup–a Ballard Nexa RM system–for the building. The same Ballard system is also being tested for use as back-up power for BC Hydro's microwave repeater station.

"This market, primarily database centres is, in fact, the nearest viable commercial market that we anticipate for Hydrogenics fuel cell products. We also are putting this technology into back-up power for cell tower sites," says Pierre Rivard, P.Eng., president and CEO of Hydrogenics Corporation.

Fleet vehicles

Purolator's fuel cell hybrid delivery van and on-site hydrogen refueling system initiative kicked off this past May, using Hydrogenics PEM electrolysis technology. This is the first step toward replacing the company's conventional diesel-powered vehicles with zero-emissions fuel cell vehicles.