Energy Independence: On-Site Fuel Cell Systems Operating on Biofuels

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Our fuel cell is a high-temperature ceramic device that chemically converts hydrogen into electricity, requiring a little oxygen. The byproducts are water and heat. In order to turn it into something useful, we have to make our own hydrogen, generally by conversion of hydrocarbon fuels. Some impurities flow through, with production of a little carbon dioxide. Efficiency is maximized by recovering the heat and water and recycling the latter internally. We also look at the exhaust heat as a way to provide cogeneration and handle heat loads, which can cool as well as heat. And depending on the electrical loads we condition the power.

There are many types of fuel-cell systems, categorized largely in terms of scale. In Ohio, some fuel-cell companies are replacing batteries and some are replacing utilities. We chose to create new markets and carved out a 1–20 kilowatt (kW) space largely because we felt we could compete against the largest companies in the world by taking the harder, rougher road. To put it in perspective: although fuel cells have been around for decades, opinion suggests that some types are a decade away. I want to stress that the fuel cell is a disruptive technology like the telephone, the automobile and the Internet. It took the telephone 70 years to achieve 50% market penetration, over 50 years for the automobile and close to a decade for the Internet. Like these technologies, fuel cells require a paradigm shift; they have the ability to drive a megatrend.

Megatrends

Oil supplies are dwindling, whereas demand is growing. National security concerns are rising. Greenhouse gases are a problem as are waste and pollution. In this context, entrepreneurs see many opportunities, with growing interest in renewable energy in the wind, solar and clean-tech areas. Although interest in biofuels is driven largely by transportation, we see it also as a source of fuel for stationary systems. And there is now emphasis on biofuels from non-edible derivatives.

We are seeing an emphasis on incentives to reduce fossil-fuel consumption and this has resulted in money and opportunities for development of high-efficiency devices. We all know what a carbon footprint is and there are opportunities to develop businesses moving toward zero carbon and, most recently, carbon sequestration. Biochar—just emerging—is a form of on-farm carbon sequestration that I'll discuss later. And there is now an awareness of business opportunities in eliminating waste before it occurs at the site, and if you can go one step further and convert it into energy, you are addressing some of the other issues.

Technology Management, Inc.

Technology Management, Inc. (TMI) was formed in 1990 as Ohio's first fuel-cell-systems developer. Our mission is commercialization of a fuel cell that was developed originally by Standard Oil of Ohio, which we obtained. Longer term, we see this as being the heart of a device to produce power anywhere, anytime and be operated by anyone. Because we are a small business entering a large market potentially, our goal was to develop a product, which was a platform, an original equipment manufacturer (OEM) platform that could involve other products. We didn't want to be limited by the fuel-supply infrastructure or by the availability of a trained workforce or even by the logistics necessary to maintain a parts inventory. We didn't want to be limited to any specific type of fuel, so we developed flex fuel for a variety of markets, including military, commercial, residential, rural and remote. Finally, we knew we had to have a proprietary technology manufacturable at low cost and we are now pretty close. TMI is one of fewer than a dozen companies in the world that have actually put together a complete kilowatt-scale system, operated in public on ordinary fuel, *i.e.* fuel that you and I can buy in most places.

Our laboratory system is small and can be shipped overnight by common carrier (Fig. 1). It's easy to operate by one person without special tools or equipment. If you need more power you just put several together in parallel. And if it needs maintenance you ship it back, so you never have to deal with a parts inventory.

Several types of gas and liquid fuels have been tested in the lab:

- Natural gas
- Propane
- Kerosene
- JP-8 (jet fuel)
- Diesel

- Ethanol
- Biodiesel
- Digestor biogas (simulated)
- Ammonia
- Vegetable oils (soy and corn oil)
- Used cooking oil

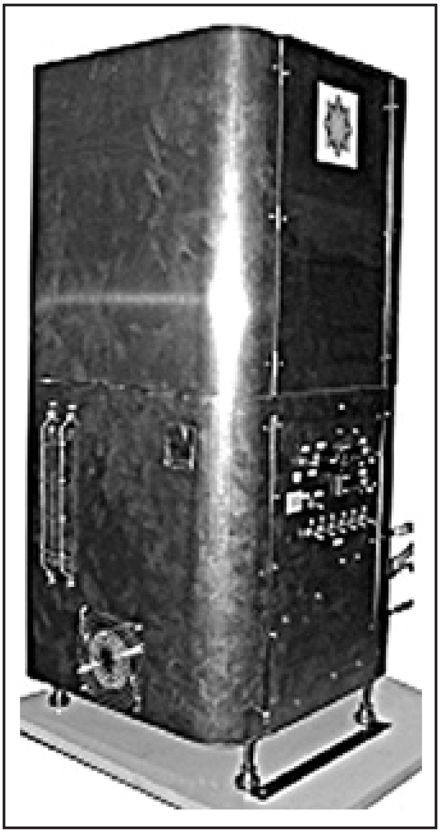

Figure 1. The 1-kW unit.

The upper group is fossil-based and the lower ones are renewable biofuels. You can switch between liquid and gas fuels on the fly, which starts to distinguish what our device can do from others. Its simplicity of design means that it can be manufactured like an appliance. Our target is to reduce the 1-kW unit from its current size of 16”×16”×32” (Fig. 1) to 13”×13”×28”.

Because it is a generic product and technology, it has multiple product-embodiment opportunities. Three have emerged over the last decade:

- an anti-idling device for trucks; we are pursuing this market
- remote rural use, as part of sustainable agriculture
- military

In September 2007 at the Farm Science Review, thanks to funding from the Ohio Soybean Council and USDA and some help from the Ohio Agricultural Research and Development Center (OARDC), we demonstrated the 1-kW solid-oxide fuel cell system operating on soybean oil. To our knowledge, this was the first demonstration of direct electricity generation from soybean oil. It also has been proven on corn oil, and we have done it on used cooking oil. We are looking to get our hands on jatropha and some of the other non-edible oils. Basically, the fuel cell is not fussy about what it converts.

What a Kilowatt Can Do

Most people don’t know what 1 kW can do. It’s larger than the base load of the average US home. We can scale it up by putting more together and it can augment solar and wind installations that charge battery banks.

It doesn’t produce carbon monoxide which allows its safe use as a heat source indoors. In addition to producing electricity at about a 35% efficiency, if you can use the heat an efficiency of 90% is achievable. It’s quiet and it’s clean and may be located in the barn, in the chicken coop or in the home. Distributed power generation is an exciting megatrend that will change the way we think about personal energy generation in the next few decades.

The fuel cell is very different from engines and turbines. To achieve the fuel cell's high efficiency, engines and turbines have to be much larger, which is one of the reasons we came in at the kilowatt scale. With the same hardware you can operate with liquid or gas, which is not the case with many other devices, and you can even switch between fuels on the fly. This opens up the whole idea of independent energy generation, whether it's fitted into the grid or independent of it. And it opens up serving markets and regions where power is unreliable or faulty or doesn't exist. With multiple 1-kW modules combined, mission-critical applications are feasible: cell-phone tower, law-enforcement, fire-protection, airport, *etc*., support.

Figure 2 shows the fuel cell that we acquired from SOHIO/BP. It uses no precious materials and is featureless and symmetric, which means it's easy to manufacture in high volumes. The 2-inch diameter cell is full commercial scale and can be nested in various groupings for a range of power products.

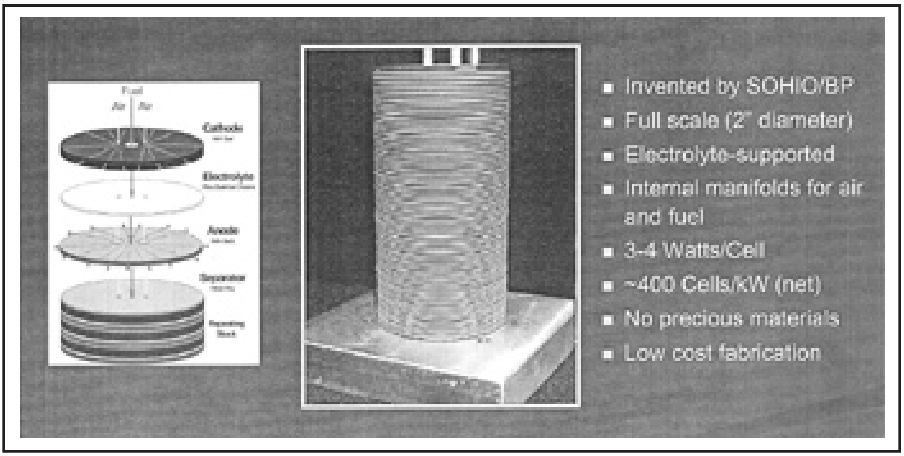

Figure 2. Simple, low-cost cell and stack design.

Integration with Biofuels

Fuel cells can be added to the biofuels discussion to open new areas that, for the moment, I'm going to call energy-independence. I'll describe four provocative scenarios.

Farm Waste to Bioenergy

The first scenario deals with conversion of farm waste to bioenergy. In the center of Fig. 3 is a small digestor ("biogas plant") of which millions are in existence. They take organic material in the forms of agricultural residues and animal, plant, human and food waste, producing methane and ammonia if urine is involved. The fuel cell converts the methane and ammonia into heat and electricity and the solids can be used as fertilizer.

Figure 4 is illustrative of the potential for energy independence. With integration of a fuel cell, the manure produced by a herd of 400 to 500 cows would allow a dairy farm to be energy-sufficient. Methane from the digestor goes to the fuel cell (not ours in this illustration) with the heat being fed to the various buildings. Electricity from the fuel cell provides power to the main house and to the farm. Solids from the digestor can be composted and/or used for dry bedding for the cattle and the nutrient-rich stream has various uses, including as liquid fertilizer. The carbon dioxide from the fuel cell can be can be captured and utilized.

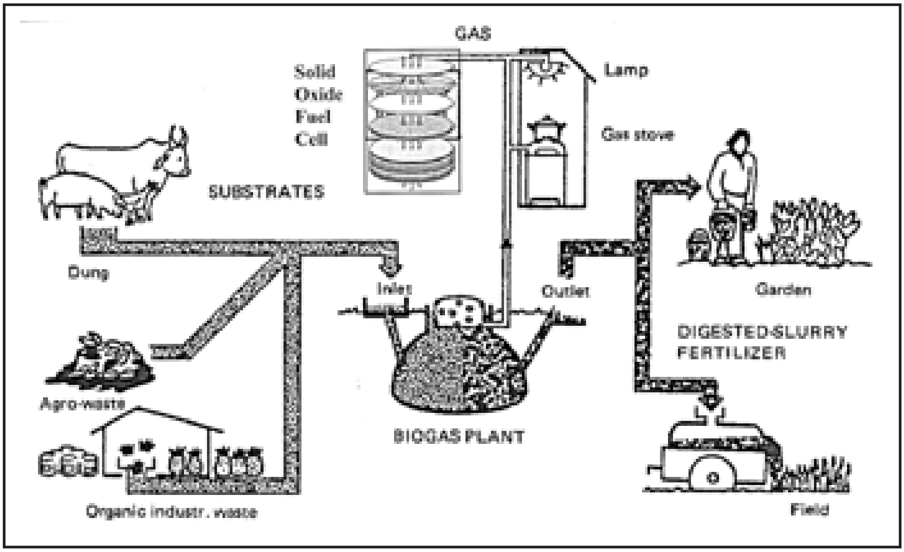

Figure 3. Organic waste conversion to electric power via a fuel cell.

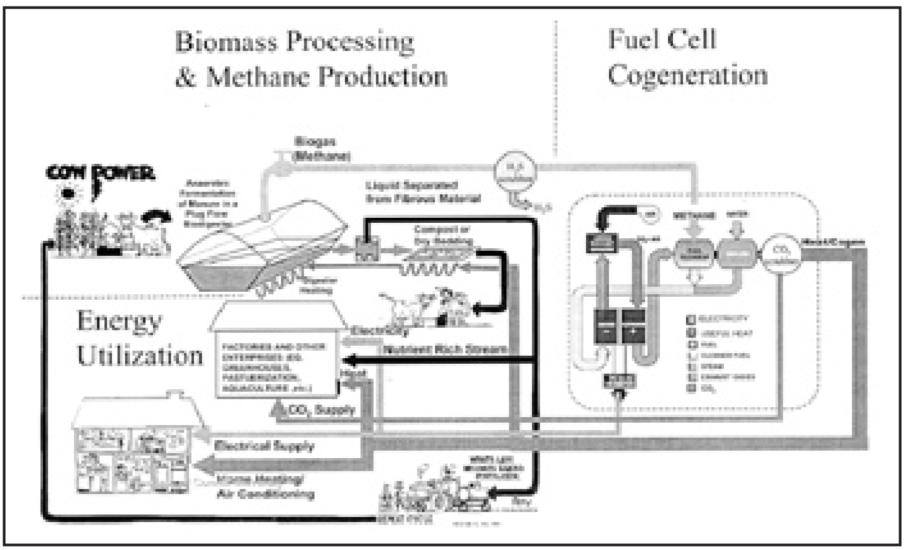

Figure 4. Energy independence from cow manure
(http://www.cowpower.cornell.edu)

Biomass to Energy

For the second scenario—biomass to energy—Fig. 5a provides a blueprint for what will emerge from the OARDC. The second column from the left shows various types of conversion. At the top are fermentation and anaerobic digestion and the middle shows mechanical extraction, *i.e.* screw presses to squeeze oils out. In the lower section are thermochemical gasification and pyrolysis; slow pyrolysis is now being explored at a number of institutions, including Cornell and Ohio State. Biochar is a form of carbon sequestration; up to 30% of the carbon that goes into a slow pyrolysis process can thus be sequestered. It has physical properties that enhance soil—helping retention of moisture and certain nutrients—and is considered to have commercial value. We come in at the third column. Each of the biofuels can be converted by the solid-oxide fuel cell into renewable energy and heat.

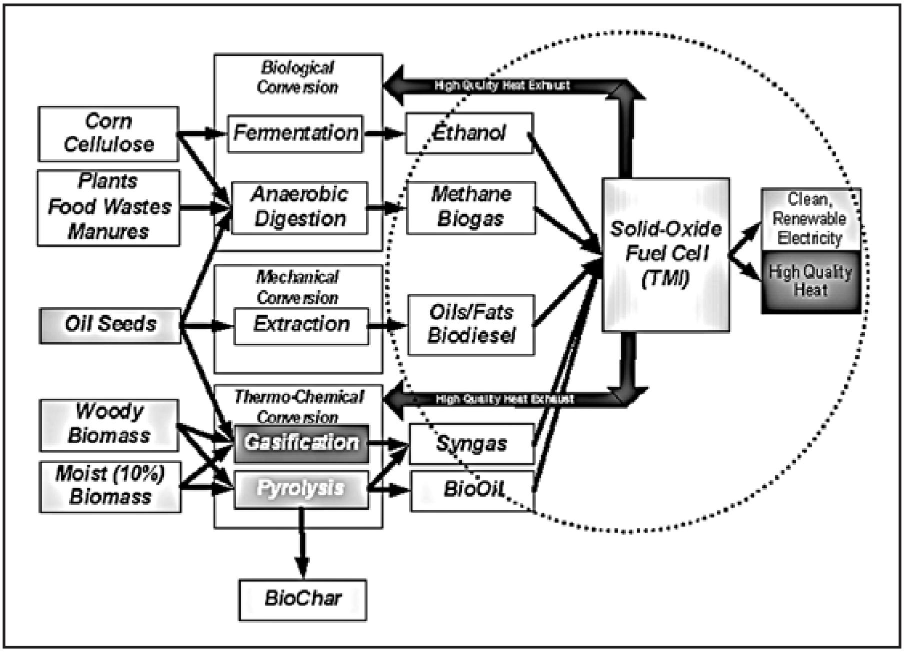

Figure 5a. The Ohio State Biomass to Energy Program (courtesy of Floyd Schanbacher).

Figure 5b illustrates the near-term vision at OARDC. Wet biomass at the top is converted in two 800-gallon anaerobic digestors and at the bottom dry biomass is converted in a small gasifier, developed at the University of North Dakota. Both are small so that they can be matched with our 1-kW fuel cell; this system is applicable to many small-scale operations and is also scalable.

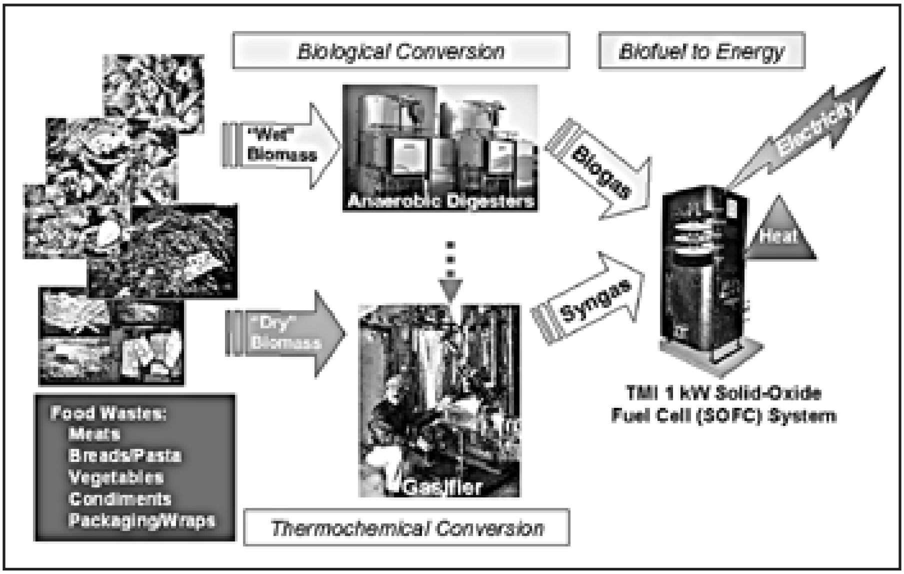

Figure 5b. The Ohio State Biomass to Energy Program (courtesy of Floyd Schanbacher).

Several other possible applications exist for combined heat and power (CHP). We can take wastes from dairy-, hog-, chicken-farm and food-processing operations put them through a digestor or gasifier and feed the electricity and heat to onsite buildings, greenhouses, fish farms or water-treatment plants (from which, sewage gas can be utilized). Again, mission-critical operations needing mobile power—disaster relief for example—can be served by this small-scale fuel cell in conjunction with biofuels and other fuels.

Biomass to Energy—Global Markets

Consumption of electricity in the United States is expected to increase by over 40% by 2030. However, this increase is relatively small when compared with the projected increase for the world as a whole (Fig. 6).

As described above, there is potential to develop agricultural and rural applications here in the United States, and with care we may put ourselves on a trajectory to move into the largest market for power generation. Interviewing people in developing countries revealed lack of enthusiasm for electricity generation *per se*. On the other hand, they do care about clean water and refrigeration. Fuel cells produce electricity and heat, from which production of clean water and refrigeration isn't rocket science. It simply involves thinking smaller about technologies that already exist. We need to start thinking outside of the box beyond just biofuels and beyond just bioenergy to solve problems meaningful to society as a whole.

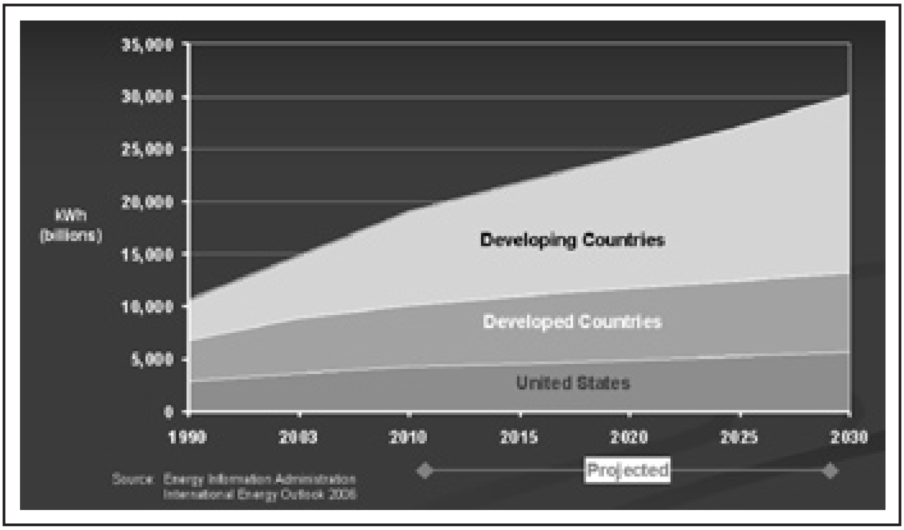

Figure 6. Global electricity consumption.

Beyond Bioenergy

The World Health Report of 2005 (WHO, 2005) provided these statistics:

- 1.1 billion people do not have access to improved water supply sources
- 2.4 billion people do not have access to any type of improved sanitation facility
- 2 million people die every year due to diarrhea diseases; 90% are less than 5 years of age
- 88% of diarrhea disease is attributed to unsafe water supply, inadequate sanitation and hygiene

The third and fourth bullets are particularly alarming, when you compute how many children under 5 die every hour from diarrhea, resulting from dirty water. The following quote highlights the non-obvious potential impact of modern technology.

> *We shall not finally defeat AIDS, tuberculosis, malaria, or any of the other infectious diseases that plague the developing world until we have also won the battle for safe drinking water, sanitation and basic health care.*
>
> —Kofi Annan, United Nations Secretary-General (2001)

We read about teams of doctors working across the developing world, but there is little they can do to prevent deaths from poor sanitation. This is an engineering problem. It's a problem that biofuels, bioenergy and engineers can solve. One kilowatt, which is what our system produces, can pump water from rivers or wells into sand filters; we don't need high-tech purification systems. We can add ultraviolet light, with just 10 or 15 watts of power, and provide heat to treat water to complement the work of doctors being sent overseas by the World Bank, USAID, Gates Foundation, church groups, *etc*.

Reference

World Health Organization (WHO) (2005) The World Health Report. Geneva: WHO.

BENSON LEE is the founding CEO of Technology Management, Inc. (TMI), a Cleveland-based developer of modular, solid-oxide fuel-cell (SOFC) systems for kilowatt-scale, "on-the-farm," rural and mobile applications. Developed originally by SOHIO/British Petroleum, the system operates on a range of liquid and gas fuels and is designed for operation and maintenance by end-users without special tools, equipment or access to a trained service workforce. To identify cost-effective biomass-waste-to-energy applications in agriculture, TMI has formed collaborations with the Colleges of Agriculture at Cornell University and the Ohio State University. The current system prototype—using biomass-derived fuels such as ethanol and transitional fuels such as natural gas—is being engineered to begin field-testing.

Mr. Lee received his BEE and master's certificate in engineering from Cornell University. He has specialized in product development and commercialization throughout his career, starting with IBM and Westinghouse, and continuing as a fulltime entrepreneur. He is a trustee (emeritus) of Cornell and is on the board of Cornell's Center for Sustainable Global Enterprise at the Johnson School of Management. In Cleveland, he serves on the boards of the Cleveland Foundation, the Ohio Fuel Cell Coalition and the Nance School of Business at Cleveland State University.