Biomass/Biowaste Fed Fuel Cells

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October 2004

Sponsored by

Ohio Biomass Energy Program

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Introduction

In November of 2002, a report on "Biomass Fed Fuel Cells" was prepared for the Ohio Biomass Energy Program (1). It focused on biomass in general and outlined the systems that might be used to convert these renewables into energy using fuel cells. The practical advantages of this approach were outlined, where energy efficiency would be improved, distributed power generation and fuel flexibility could be achieved, air and water pollution would be reduced and greenhouse gas emissions would be significantly reduced. We would like to update that study with particular emphasis on the addition of biowaste as an energy source. Fuel cells will still convert the biowaste decomposition gases into electricity and heat. Much of the material from the earlier report will be updated and included so the reader will not have to switch back and forth.

Biomass provides a renewable, domestic hydrocarbon source that can be used to generate power (2, 3, and 4). In 2002, there was about 10 giga W of electricity generated from biomass and this is expected to double by 2010. Principal systems currently use internal combustion engines (ICEs) or steam turbines. Microturbines are growing in use for small systems. Wood is the main fuel source at about 60%, municipal solid waste (MSW) was a third and other sources such as municipal waste water and landfill gas were 5%. One of the most interesting new approaches is to convert biomass to hydrogen and then use that hydrogen and air to produce electricity in fuel cells. This system produces minimal pollution and reduces greenhouse gases. Pure water and carbon dioxide are the only by-products of the fuel cell. The carbon dioxide produced is consumed in the next biomass production cycle. Since the fuel cell process is also more efficient than combustion in the production of electricity, less CO2 is produced per kilowatt of electricity generated.

Possible biomass derived hydrogen sources are: landfill gas (LFG), anaerobic digester gas (ADG) from municipal waste treatment plants, and gasifiers fed with solid agricultural or municipal waste, forest by-products or energy crops (5). However, one of the largest potential sources is biowaste. This includes confined animal farms such as egg farms, megadairies, fish farms, feed lots, etc. Also included in this would be food processing waste and waste oils both cooking and industrial. In most cases the current alternative uses for the biowaste is not of high value, if it has any net positive value at all. Biowaste is usually in a slurry form suitable for fermentation and is available on a consistent and continuous basis. Current technology for solid biomass conversion to hydrogen is gasification to producer or synthesis gas (SynGas), followed by reformation of the SynGas to hydrogen. The product hydrogen is then fed to the fuel cell. Gasifiers, digesters, reforms and fuel cells are all available, proven technology. This system is capable of producing electricity from any biomass source. However the logistics and the economics have to be demonstrated. This is a very complex issue involving public policy and regional economics as well as long term technology demonstration. Environmental impacts, fit

with the local power grid, premium for reliability all need to be considered. The conversion of biomass to methanol or ethanol and then subsequently to hydrogen will not be considered since they are now high value feedstocks. This could be an option where biomass feed transportation is required to a central power generation system. The co-production of other commercial products and the reduction of waste disposal volume and toxicity will also have a positive impact

Biomass is varied in composition, distribution, availability and cost. In most cases the biomass resource is either a by-product or a waste product. It must be available on a continuous basis and in the near vicinity of the electricity generating plant. It is estimated that there are 400 million dry tons/year of biomass available in the US. It takes roughly 1.5 tons of dry biomass to produce a mega watt of electricity. An acre of trees could produce 25-50 tons over the life cycle of the trees. One cow produces about 5 tons dry biomass per year plus methane. One quad (10^{x12} BTUs) of energy requires 55 million tons of biomass. The US uses about 100 Quads of energy with biomass currently supplying 3 quads, mostly in the pulp and paper industry. Biomass represents currently about 50% of the renewable energy produced. It provides six times the energy of wind, solar and geothermal combined. However wind is growing at 25% per year. Solar is cost limited and geothermal is resource limited.

Biomass

Biomass is not the most ideal hydrocarbon source for hydrogen. It has a much higher oxygen content than conventional fuel cell feeds like natural gas or gasoline. This results in double the available hydrogen from the hydrocarbons as compared to biomass. Biomass sources under consideration are SynGas from solid biomass fed gasifiers and anaerobic digestion using landfills, municipal waste water treatment plants, biowaste (animal and plant) and other organic containing material.

SynGas production from biomass uses either a solid or slurry feed to the gasifier and thus is more complex and less reliable compared to gas or liquid feeds. The gasifier producers a mixture of hydrogen, carbon monoxide, methane and carbon dioxide through a high temperature reaction that breaks down the organic material. Depending on the fuel cell used this gas may need to be further processed to eliminate the carbon monoxide and methane. Sasol in South Africa has been operating coal fed Lurgi gasifiers for several decades. During World War two, the Germans operated thousands of Lurgi gasifiers on coal to produce liquid fuels.

Biomass also has a high percentage of moisture. This reduces the efficiency of power generation by requiring heat input to bring the reactor to operating temperature and evaporate the water. However in some applications this water has great value, such as on a spacecraft where waste is being reprocessed. Biomass's lower energy content makes minimization of transportation of the feedstock a requirement. Since the power plants have a long life, these plants using biomass as a fuel makes siting a key issue. Biomass should also be readily available over the life of the processing plant and also year round.

Landfill and digester gases are anaerobic processes that produce a gas with a variable methane and carbon dioxide content. Naturally occurring bacteria attack the biomass in an oxygen-deprived environment. Work is being done to tailor the microbes to increase yield and through put. The SynGas produced is low cost. However, methane is twenty-one times worse than CO2 as a greenhouse gas and needs to be captured and disposed of. Flaring or combustion is the normal solution for methane. There are 300 LFG sites and over 400 digester sites (>1MW) already in existence. The digester route in municipal waste water treatment is also used to reduce the solids in the system. The LFG is a natural result of the decay of the landfill waste. There are only a handful of large scale demonstrations that involve use of these gases in conjunction with fuel cells. With biowaste the animal manure or organic food waste needs to be anaerobic fermented to give methane for conversion into hydrogen for feed to the fuel cell. Some bacteria can convert the hydrocarbon directly into hydrogen. However methagenisis is a potential serious problem where other microbes consume the microbial produced hydrogen. Biowaste could also be feed to a gasifier to produce SynGas which would be further processed into hydrogen.

Pyrolysis is another option for biomass/biowaste. Oil results from the high temperature treatment of biomass in the absence of oxygen. This oil can then be fed to a reformer where steam and air or oxygen are added to produce hydrogen and CO2. Pyrolysis oil would be a way to collect and concentrate biomass for a central processing plant that produces hydrogen.

Field wastes are a problem because they are seasonal. Animal wastes do not pose this problem. Large chicken farms and other confined animal operations are highly concentrated and could be a supply for ADG. This further emphasizes that siting and biomass source are key issues. Biomass and biowaste do have a number of attractive features. They can be a domestic, reliable and renewable energy source with wide distribution of availability. Wood in particular contains no sulfur and no heavy metals. Fermentation greatly reduces any emissions. Acid rain and greenhouse gases are greatly reduced and there is minimal ash. Because of biomass's volatility and reactivity, the system operating temperature and pressure can be lower, improving the efficiency and reducing the capital cost. Dedicated fast growing biomass has been proposed, where continuous harvesting is done on a year round basis. Switchgrass, poplars, and willow are three potential crops. The trees do have 50% moisture, while the grass is about 15%. A gasifier would be used and the larger the plant the more costly the biomass supply could become since hauling distances become higher.

An example of a good potential biowaste application is megadairies. Cows are confined, their waste is concentrated and the methane they produce is captured in the barns ventilation system. A recently released study (6) has identified twenty-one on-going government funded digester projects in the Great Lakes Region using dairies. The gas produced from the digesters (typically plug-flow) is fed to an ICE. However, a fuel cell based system would take both waste streams and convert them to hydrogen for a feed to an SOFC. Heat, electricity and water would be produced. The farm could use the electricity and sell the excess to the grid. Excess heat could be used for greenhouses. Greenhouse gases, particularly methane, will be reduced. The potential contamination of the ground water will be eliminated. Similar scenarios could be outline for chickens, fish, hogs, industrial food processing, etc.

Biodiesel (mixture of diesel fuel and soybean methyl ester), ethanol and methanol are all more costly than the other feeds considered here. They would work, but they also have other outlets. There would have to be very special circumstances to make them an attractive hydrogen source. In addition the overall energy efficiency is likely to be low.

Major potential biomass sources are wood wastes (particularly uniform sized wood chips), briquetted wood wastes, agricultural waste (field, food processing or animal), municipal sludge, landfills or any cheap hydrocarbon. Large quantities of used frying oil and food processing waste are available in concentrated and continuous supply. Island wastes could have additional positive economics. Hawaii imports all its fuels while producing significant agricultural waste. Soybean has oil, protein, hulls and residual plant matter. This system does not need organic matter if a gasifier is used to process the carbon containing material. This system could be used in third world or remote areas. Power lines are not necessary.

Biomass/Biowaste to Hydrogen

Gasification: The biomass/biowaste must be converted to hydrogen to feed the fuel cell. NREL sponsored a study to evaluate current gasifier technology for conversion of biomass to SynGas(7). The gasifier produced SynGas is fed into the first stage of the fuel processor where the reactor uses elevated temperature, a catalyst and pressure along air or oxygen and moisture to give a mixture of carbon dioxide, carbon monoxide and hydrogen. Initial reactor temperatures are between 500C and 850C, depending on the feed material and the operating conditions. The type of fuel cell will determine what further gas treatment may be required. Fluidized bed, upflow and down flow gasifiers are being tested. Proton exchange membrane (PEM) fuel cells which operate at 80 C require very low carbon monoxide levels (<10ppm), while solid oxide fuel cells (SOFC) which operate at 1000 C do not. The basic gasifier designs have been around since before World War II. They were used by the Germans during the war and are now currently being used in South Africa at Sasol with a coal feed. When using air, a low Btu gas is produced which contains about 15% the energy of natural gas. When using oxygen a higher Btu gas is produced with about 40% of natural gas' value. The difference is nitrogen from the air dilutes the product gas. Since they are using solid feed, the gasifiers are typically circulating or fluidized beds. Size and uniformity of the feed is important. Wood chips or pellets/briquettes are the most desirable. Pellets/briquettes add cost, but they do simplify feeding the gasifiers and reduce the moisture content of the feed. They would also allow longer distance transportation. Slurry feeds can also be utilized where the water is removed before the feed is introduced into the gasifier.

Biomass gasification demonstration projects are currently underway in Sweden, UK, Italy, Hawaii and Vermont. They range from 10 MW to 50 MW. The SynGas and heat are used to produce electricity using microturbines or ICEs. There are no projects that couple the gasifier output with a fuel cell. All fuel cell/biomass demos use digester gas as a methane source followed by a fuel processing system that removes impurities and converts the methane to hydrogen.

Production of SynGas is generally a two step process. The biomass is initially converted into a low or medium Btu gas. Depending on the feed and conditions, significant char can be formed.

This char can then be treated with steam and oxygen to give more hydrogen. For PEMs this gas is then fed to a shift reactor where steam and air/oxygen are added to convert more CO and char to hydrogen and CO_2. Some commercial gasifier designs are the IGT, Lurgi and Texaco gasifiers where,

Producer gas: Biomass + air = CO (20%) + H_2 (20%)+ CO_2 (6%) + N_2 (50%) + CH_4(5%).
Synthesis gas: Biomass + O_2 = CO (40%) + H_2 (40%) + CO_2 (15%) + CH_4 (5%)

SynGases are then fed to a water gas shift reactor to maximize hydrogen and eliminate carbon monoxide for feed to a PEM.

$$CO + H_2O = CO_2 + H_2.$$

Hydrogen yields when coupled with a shift reactor can approach 70%. The reactors typically do not use platinum-based (PGM) catalysts. Only the final reactor in a PEM fuel processor, a preferential oxidation (PrOx) reactor uses PGMs to drive the CO below 10 ppm.

Fixed bed and circulating bed gasifiers are used because of the solid fuel feed. These are the same type for gasifiers perfected for use with coal feed. Lawrence Livermore did a lot of work in the mid-sixties with Texaco on its use on municipal solid waste (MSW). Slurry preparation drew most of the attention. Lab scale simulations using the slurry were encouraging. With specific types of biomass, upflow or downflow gasifiers are used.

Biomass pyrolysis involves feeding material to a high temperature reactor without air or oxygen. Significant (25%) char is formed along with lots of tars. These can be further react with high temperature steam to produce hydrogen and a mixture of CO and CO_2. The pyrolysis oil could also be transported to another site.

Biological: Another general approach is biological and includes anaerobic digestion (LFG & ADG), fermentation or photolysis. The products of these processes are usually fed to a reformer to complete the conversion to hydrogen. The biological route uses an 8-10% slurry, typically in a plug flow digester. It does not produce carbon monoxide, greatly simplifying the fuel processing chain. A typical land fill gas (LFG) composition is 60% methane and 40% CO_2. EPA regulations require the gas from landfills to be burned or used, since methane is twenty one times worse than CO_2 as a greenhouse gas. Numerous LFG sites are still just flared. Digesters in municipal water treatment plants convert about 40% of the waste stream solids to gas using either batch or continuous digesters. The anaerobic digester gas (ADG) is about 60% methane, 35% CO_2 and 5% N_2. ADG can also be produced from animal waste and food processing waste. In some cases microbes can be used to produce hydrogen directly, but they are slow and easily poisoned. However this does eliminate the reformer unit from the process. It is possible to combine light and a catalyst to produce hydrogen from a dilute biomass slurry, but the process is slow and the conversion efficiency is low.

Hydrogen Fed Fuel Cells

Fuel cells were first demonstrated in 1839 by William Grove. Most commonly fuel cells combine hydrogen and oxygen and release energy in the form of electricity without combustion. Water and heat are the only by-products. They are quiet, non-polluting, highly efficient, and reliable. Siting is not a problem. The first significant use was as a power source on NASA space missions (Apollo and Gemini) in the sixties. Karl Kordesch ran a car for two years here in Ohio in the early 1970's. Fuel cell cost and hydrogen availability have always been major issues. Progress has been made on both fronts. The use of fuel cells to provide green power is continuing to grow (8). Today there are three major applications: stationary, transportation and portable.

There are six types of fuel cells, operating with different electrolytes and at different temperatures. Today the effort is principally on solid oxide fuel cells (SOFCs) and proton exchange membrane (PEM) fuel cells. Both fuel cell stacks are bipolar in design which means that failure of one element in a 250 element stack will shut down the whole system. Since five years is the target life, reliability is essential. PEMs(80C) are targeted at vehicles, portable and small stationary applications like residential. SOFCs target the stationary and distributed power market. SOFCs, because they operate at 1000 C, generate waste heat that can generate additional power and increase the overall efficiency to near eighty percent. Alkaline (100 C) were used in the space program, but are very expensive due to the heavy use of nickel. Phosphoric acid fuel cells (PAFC) currently have all the large commercial installations. Each module is about 250 kW. They are low temperature (200C), but rapidly losing favor to PEMS. UTC PAFCs have demonstrated 40,000 hours of operation, but require a large amount of platinum catalyst on the electrodes. Molten carbonate fuel cell (MCFC) which operates at 650 C suffers from maintenance problems. Direct methanol fuel cells continue to draw interest, where methanol replaces hydrogen as the fuel. It does suffer from efficiency robbing crossover and poor fuel electrode performance. A coal-fired power plant has efficiencies in the low thirties, a combined cycle gas fired plant can approach forty percent and an internal combustion engine (ICE) is in the twenties. SOFCs can approach 80%, while PEMs with combined cycle are near 60%.

For vehicles the original idea was to have on-board reformers to produce hydrogen from gasoline or diesel fuel. However size and cost constraints now dictate that at least initially central fueling stations will be used to supply hydrogen directly to the vehicle. The fuel station itself will have a large hydrogen generation system, which could use biomass as a hydrogen source. Residential and portable applications are not probable consumers of biomass derived hydrogen. If a complete hydrogen economy and infrastructure evolves similar to our natural gas system, then biomass hydrogen would have to compete on a cost basis. Hydrogen is a challenge if it is not used on site. It is very low density, and explosive. At ambient temperature and pressure hydrogen has an energy density of 2.8 wh/l, while gasoline is 9100 wh/l. Hydrogen storage as a hydride or pressure improves this. Currently a maximum of 10,000 psig has been approved, but that still is about half the energy density of gasoline. Hydrogen is a highly fugitive gas. Current natural gas and liquid pipelines are not suitable to transport hydrogen.

Biomass gasifier produced syngas can be considered like a natural gas or methane as a feed to existing reformer systems. In these systems, a reformer converts the gas into hydrogen and more carbon dioxide using steam and temperature. Shift reactors can then further increase the hydrogen and reduce the carbon monoxide levels. For PEMs there is a strict requirement on

carbon monoxide levels (<10 ppm). This requires an autothermal reactor (ATR), two water gas shift reactors (WGS) and a partial oxidizer (PrOx) for final CO clean-up. There is also a sulfur removal step commonly using zinc oxide powder. An SOFC, since it is not CO sensitive, can use a much simpler reforming system. A single ATR is feasible. SOFCs also use CO as a fuel. Its fuel electrode in not poisoned by CO like the fuel anode in a PEM. Some SOFC systems can actually do the reforming inside the fuel cell stack with the proper choice of fuel. They are also more tolerant of sulfur.

Table 1 gives a comparison of the two technologies, which are quite different. Two membrane electrode assemblies (MEA) sandwich an ion exchange membrane in a PEM. The PEM operates at low temperature, uses precious metal catalysts, and is sensitive to poisons like carbon monoxide and sulfur. The polymer separator is an expensive perfluro sulfonate. Humidity control is challenging. The membrane can not dry out or it will lose its conductivity. The current is carried by the protons generated at the anode. The SOFC has two ceramic oxide electrodes that sandwich a ceramic membrane. To obtain sufficient conductivity the SOFC operates at high temperature, but it is not affected by catalyst poisons and does not use either PGM catalyst or expensive polymer separators. Here the current is carried by the oxide ion generated at the cathode. Handling ceramics during manufacturing and thermal cycling during start-up and operation are concerns for the ceramics integrity. SOFCs also provide the option of using their high temperature waste heat in a co-generation system to produce more electricity in stationary applications. This heat can also be used as process heat.

Table 1
Fuel Cell Comparison

	PEM	**SOFC**
Operating Temp	80 C	1000 C
CO Requirement	<10 ppm	None
Fuel Cell Catalyst	0.5 mg/cm2 PGM	Non-PGM oxides
Catalyst Poisons	Sulfur, Halides Carbon Monoxide	Sulfur Halides
Separator	Nafion	YSZ (ceramic oxide)
Control Issues	Water Mgt Start-up Fuel Processing Start-up PEM	No water mgt Start-up and cycle – Thermal
Co-generation	Low Grade Heat	High Grade Heat

Efficiency		
w/ CoGen	60%	80%
Current Density	0.6 ma/cm2	0.6 ma/cm2

The precious metal use at current loadings is a problem for PEMs. At ten- percent penetration of the automotive market worldwide, the current PGM requirements would equal the current PGM supply. Admittedly, one of the largest uses of PGMs is in automotive catalyst, so some of the current automotive PGM will be freed up. Increased PGM recycle will also help. That still leaves the economic challenge of platinum at $600/T.O and supply controlled by Russia and South Africa.

Applications

There are three broad applications for fuel cells: transportation, stationary and portable. The potential market size is in the same order of magnitude for each application and is billions of dollars per year for each. Hydrogen sourcing is an issue for each. For the near future, transportation will use hydrogen from a central source and thus fleets and urban applications are favored. Biomass could feed the central station. Urban sources could be ADG, waste oil/rendering plants and MSW. Automotive systems are designed for a 75 KW output. Most likely initial use will be in fleets, locomotives and large off-highway equipment. All have high duty cycles, fixed routes and central maintenance.

Stationary will use a system that contains a reformer that generates hydrogen on site with natural gas as the fuel source. They will tend to be 250 KW modules that can be ganged together to produce more power. Today uninterruptible or back-up power and distributed power are the two main markets. Uninterruptible power is important for hospitals, computer farms, and telecommunications networks. Power losses for banks and financial markets can run into millions of dollars per hour. The National Power Institute estimated that there were an average of 290 major power fluctuations in 2002 and it cost $30 billion. Distributed power is best in remote locations or adding to the grid where a new large fossil fuel plant would be a problem. New power lines do not have to be built and grid overload is reduced and grid reliability is increased.

Portable applications are small size (<10W). Use in computers, data devices and military are near term. Users would carry hydrogen in a refillable or disposal cartridge. These applications are far less cost sensitive. Lifetime and weight/volume are key issues. Other applications are auxiliary power, where a truck, RV or boat runs its electricals off the fuel cell while the main engine is shut off. Likely an on-board reformer will use the diesel fuel. Back-up power supplies are also attractive applications. However they would not use biomass derived hydrogen. A biomass based system would need to operate continuously. There are numerous military applications for fuel cells, but they would not use biomass as fuels except for large stationary. One potential application is kitchen waste where the power and pure water would be of value to a deployed force.

The target cost for each application varies significantly. Table 2 outlines current costs. A gasoline engine costs about $35/KW. The target for stationary is about $500/KW and portable is about $2500/KW. Current costs for fuel cell systems are above $2500/KW. United Technologies has sold about 200 units since 1995. They are 200 KW phosphoric acid (PAFC) systems and most are continuing to run. 40,000 hours has been demonstrated on their systems. Plug Power has recently commissioned over 1000 PEM residential unit (10KW). There are about 15 fuel cell buses, mostly with compressed hydrogen and Ballard PEMs. Otherwise everything is one or two units. Ballard is the leading player in PEMs and Siemens Westinghouse is the leader in SOFCs.

Table 2
Fuel Cell Costs

Application	Target Cost	Current Cost
Stationary Coal Fired		$1000/KW
Stationary SOFC	$500/KW	$2500/KW
Stationary PEM	$1000/KW	$4000/KW
Vehicle Diesel		$25/KW
Vehicle Gas		$35/KW
Vehicle PEM	$35/KW	$10,000/KW
Portable PEM	$2500/KW	$5000/KW

Current major demonstration projects for biomass fed fuel cells include the Columbia Boulevard Fuel Cell Plant in Portland, Oregon. Here a waste water digester uses biomass solids to produce methane. The methane is converted to hydrogen using a reformer and the resultant hydrogen is then fed to a UTC phosphoric acid fuel cell. The system is rated at 200 KW and cost $1.3MM to install in 1999. It is still running producing about 175 KW. The only major challenge has been a ten fold higher H2S level that required more scrubbing. They are looking at microturbines as an alternative. Previous to that in 1994, a similar system was installed in Penrose, CA and ran for about six weeks. It was then moved to Groton, CT were it ran for several more months. Plants are also operating using ONSI (UTC) fuel cells in Cologne, Germany, Deer Island, MA (recently decommissioned), Calabasis, CA, and Yonkers, NY (1997) using digester gas as a hydrogen source. One of the more interesting is Saporo Beer which has an ADG fed PAFC. An MCFC is running in King City, WA on biogas feed and several other sites are being built, including one here in Ohio.

There are a number of sites that convert biomass (ADG and LFG) into gaseous fuels that are then burned in microturbines or industrial diesels. Pollution and efficiencies are their challenges.

Economics

The principal source of biomass fuel is likely to be wood. Pulpwood is used as a standard and costs about $60/green ton or $4/Mbtu. Fuel oil is $9/Mbtu and natural gas is $7/Mbtu for residential, but is less than half at large utilities. Capital costs for wood burning systems are higher due to fuel handling and storage. A plant will use about 5 ovendry tons of wood/MW/day. For Biowaste, it is likely the feed cost will be low and handling simpler since it will likely be a slurry already. If disposal and/or pollution are issues for the biowaste, that should improve the attractiveness of this option.

Table 3 gives a rough breakdown of a PEM fuel cell system. Natural gas and SynGas from a biomass fed gasifier are similar in impurity levels and thus would have similar processing requirements. The key cost components are the precious metal catalyst and the membrane separator.

Table 3
PEM Stack Costs

Size	70 KW	Car
Stack Area	15 m2	
Catalyst	0.5 mg/cm2 2.5 TO	Platinum $600/troy ounce $1500/stack
Membrane	$600/m2	Nafion $9000/stack
Bipolar Plates	Low	Metal or Graphite
Stack Cost Unit Cost	$11,000 $1570/KW	Materials only

Table 4 gives a breakdown of the total system. The stack is by far the largest cost component due to the membrane and PGM catalyst. The fuel processor would not be included in automotive use, but would be in the cost of the fuel.

Table 4
System Breakdown PEM

Fuel Production Gasifier or Digester	10%
Fuel Processing Reformers Gas Clean-up	15%

Fuel Cell Stack	55%
MEAs	
Bipolar Plates	
Power Conditioning	10%
Balance of Plant	10%

For a biomass/biowaste fuel the system is composed of: 1. an initial biomass processing section that produces fuel gas; 2. a fuel processing section which produces the pure hydrogen; 3..the fuel cell stack which converts hydrogen and air into electricity, water and CO2; and 4. the energy conversion section that the electrical and heat conversion section that produces usable energy. The major cost components in a low temperature fuel cell are the precious metal catalysts that are used to facilitate the low temperature reactions at the anode and cathode. These platinum group metals (PGMs) are also used in some of the fuel processing reactors. The other costly component in a PEM is the Nafion or Nafion-like membrane which is a perflouro sulfonate ion exchange resin. In an SOFC, these two components are not used. Cheaper ceramic oxides are used. However, SOFC manufacture is more challenging. Because of the SOFC's better tolerance for feed impurities and the fact that the biomass fed systems will be stationary; this will like be the system of choice to couple with biomass generated hydrogen. As mentioned earlier the target cost for an SOFC is $400/KW for the DOE's SECA program.

Miscellaneous

Work at the University of Wisconsin since 2001 has shown the ability to convert glucose and alcohols directly to hydrogen by a fixed bed catalytic route.

Sponge iron (high surface area, high reactive iron) has been investigated for production of hydrogen from biomass. This would replace the shift reactor. The gas is low CO in one set of experiments and would be suitable for direct feed to a PEM. In addition, the sponge iron could store the synthesis gas. Subsequently this gas could be treated with steam to release the hydrogen.

Direct-fed methanol fuel cells are a target for transportation and portable applications. Here methanol replaces hydrogen as the feed to the anode. Substitution of methanol for gasoline in the transportation fuel distribution chain would be possible. For portable use the packaging would be simpler and the energy density would be higher. Several companies are currently developing direct methanol fed fuel cells (DMFCs). Methanol is not widely used because it's a catalyst poison for a low temperature fuel cell, reducing performance and shortening life. Crossover to the catholyte compartment reduces the efficiency.

Low temperature, supercritical conversion of biomass is also under evaluation.

Worldwide R&D of fuel cells was>$2 billion. Finally there are over 800 firms claiming some affiliation with fuel cells. Ballard has the largest effort followed by GM.

Hybrid vehicles will maintain a solid, growing niche in the transport sector. US sales in 2002 were 20,000 units of the Impact and the Prius. Honda introduced the Hybrid Civic recently and expects to sell 30,000 units. Ford has recently introduced its hybrid SUV, the Escape and projects 20,000 to 40,000 units. Toyota is now selling a redesigned Prius for about $25,000. Acceptance has been very good. There are a number of other hybrid projects nearing completion and ready for introduction. Significant penetration by hybrids will make it more difficult for a fuel cell vehicle. However for biomass/biowaste this is not a direct concern.

A biowaste blog has been set up to bring you the latest information. If you would like to contribute to the blog, forward the information to Tom Gilligan at gc_group@comcast.net. The blog can be accessed at: http://makingchange.typepad.com/biowaste. Another valuable source is the Ohio Biomass Energy Program quarterly Newsletter, available on the Program website in the electricity section of www.puco.ohio.gov

Conclusions and Recommendations

Many potential markets for biomass/biowaste fed fuel cells appear attractive without significant government intervention. First would be distributed power, where biomass is readily available. Examples are: logging operations, landfill gas. The second would be auxiliary power using waste. Examples might be a large farm with confined animals, food processing waste, pulp mill black liquor, municipal waste treatment, or any waste process with a high value co-product.

Of great assistance in promoting the use of biomass/biowaste fed fuel cells would be a 200 kW demonstration project using either an SOFC or a PEM. Solid feed to a gasifier followed by reformation and then the fuel cell would be the most comprehensive, since it could handle any feed. Coupling a digester to the front end to process biomass/biowaste slurries or biowaste would also be of great interest.

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21 Oct 04