Nexant Chem Systems

PERP Program – New Report Alert

February 2004

Nexant's ChemSystems Process Evaluation/Research Planning program has published a new report, ***Fuel Cells for Transportation (02/03S5)***.

Introduction

Transportation is the largest single segment of the energy sector, accounting for 19 percent of global energy demand and over one-quarter of total U.S. demand and two-thirds of U.S. petroleum demand. Fuel cells offer the potential for higher efficiency vehicles using non-petroleum based fuel with much lower greenhouse gas emissions. For these reasons, transportation has been a major target market for the development of fuel cells as a replacement for the internal combustion engine.

This report assesses the status of development, the potential for future improvements and the market outlook for fuel cell vehicles. Fuel cells offer the advantage of higher energy efficiency than conventional internal combustion engines. However, electric hybrids of internal combustion engines are an alternative for increasing energy efficiency in vehicles. These hybrids are already commercially available, and this report concludes that fuel cells will be a higher cost alternative, even at current projections of future performance levels to 2015.

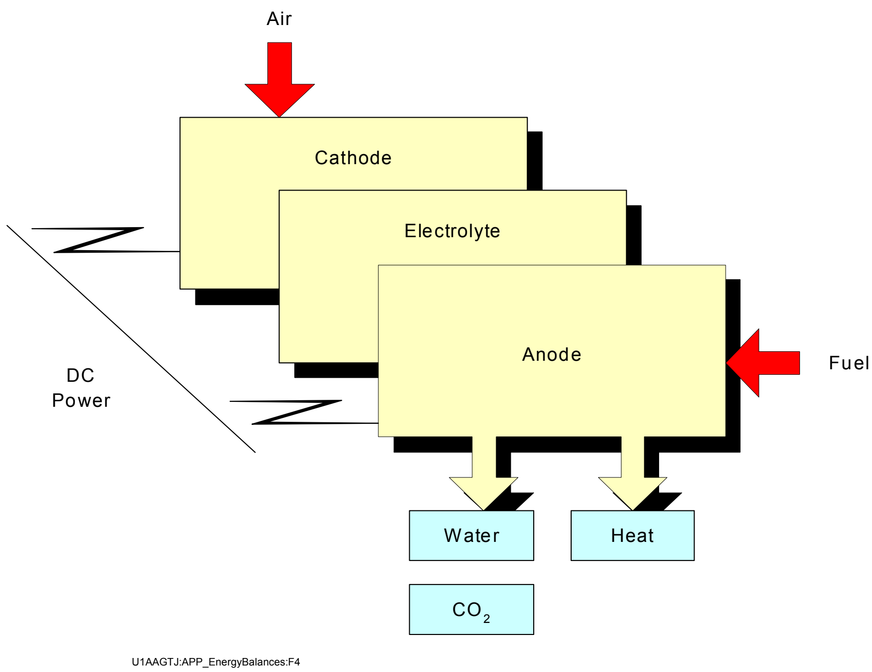
Generically, a fuel cell uses an electrochemical process to generate electrical power through catalytic oxidation of a fuel. Figure 1 on the next page illustrates a generic fuel cell operation.

In its simplest chemical form, the fuel cell catalytically oxidizes hydrogen using the following steps:

1. Hydrogen molecules adsorb on the surface of the anode catalyst
2. The hydrogen molecule is split, with the two resulting atoms being ionized to H+ ions (protons) and the residual electrons conducted away through an electrical circuit
3. Protons desorb from the anode catalyst and diffuse through an electrolyte layer to the cathode, driven by potential and diffusion gradients
4. At the cathode oxygen molecules are adsorbed and split into individual atoms
5. The oxygen atoms accept free electrons from the electrical circuit to form O^{2-} ions
6. Finally, two protons combine with the O^{2-} ions to form water, which desorbs from the cathode

A voltage potential develops across the cell, due to the concentrations of hydrogen ions at the anode and oxygen ions at the cathode. This, combined with the free electrons that are available to travel through the external circuit result in the fuel cell providing useful power, derived from the energy available in the oxidation process. Individual cell voltages are quite low for larger scale practical applications, so a number of cells are connected in series to drive the load.

Figure 1
Fuel Cell Operation



Fuel Cell Technologies

There are four major types of fuel cells currently under development with mass market potential:

- Two low temperature types –
  - Proton exchange membrane (PEMC)
  - Phosphoric acid (PAFC)
- Two high temperature types –
  - Solid oxide (SOFC)
  - Molten carbonate (MCFC)

The two types with greatest potential application in vehicles are PEMC and SOFC.

Proton Exchange Membrane Fuel Cells (PEMC)

Proton Exchange Fuel Cell technology (PEMC) uses a polymer membrane as an electrolyte. PEMC have gotten the most attention as fuel cells for vehicles. The primary advantages of PEMC are its low operating temperature and prospects for reasonable cost. The membrane operates as a conductor of hydrogen ions to allow the formation of an electrochemical cell, and eliminates the problems associated with liquid electrolytes. The electrochemical cell operates under the following chemical reactions:

$$\text{Anode:} \quad H_2 \longrightarrow 2H^+ + 2e^-$$

$$\text{Cathode:} \quad O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

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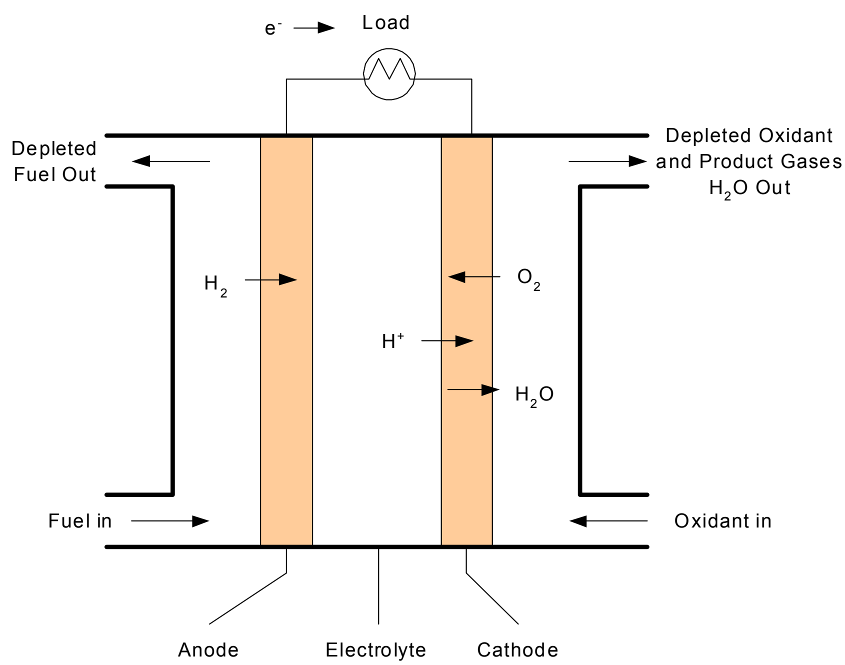
Figure 2 is a simple schematic of a PEMC.

Figure 2
Proton Exchange Membrane Fuel Cell (PEMC)



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Hydrogen is either supplied directly as the fuel or is generated from conventional hydrocarbon or alcohol fuels with a reformer.

PEMC operates at a relatively modest 80°C, which allows relatively quick start up, but the heat dissipated by the system is of very low grade. The PEMC fuel cell is currently very sensitive to chemicals impurities on the fuel side, but research is focusing on improving its tolerance for catalyst poisons.

For applications with fuels other than hydrogen it is necessary to include upstream reformers to produce hydrogen that the cell can use. In PEMCs, it is also essential that the upstream fuel processing systems remove carbon monoxide to very low levels since it also acts as a catalyst poison. These additions add to the size, complexity, cost and weight and reduce the dynamic response times of the fuel cell system as well.

Solid Oxide Fuel Cells (SOFC)

Solid Oxide Fuel Cell technology (SOFC) is also being developed for use in vehicles. Despite its higher operating temperatures, SOFC offers some advantages over PEM technology. SOFC fuel cell is based on a solid ceramic electrolyte and hence eliminates the issue of electrolyte loss associated with liquid electrolytes. To obtain adequate ionic conductivity in the ceramic, it is necessary to operate at around 1,000°C. Hence, it is possible to reform the fuel within the fuel cell itself, and also use the exhaust gases in power generation.

Within the SOFC fuel cell the electrochemical reaction proceeds as follows, with the oxide ion O^{2-} providing the ionic charge transfer.

Anode: $H_2 + O^{2-} \longrightarrow H_2O + 2e^-$

$CO + O^{2-} \longrightarrow CO_2 + 2e^-$

$CH_4 + 4O^{2-} \longrightarrow 2H_2O + CO_2 + 8e^-$

Cathode: $O_2 + 4e^- \longrightarrow 2O^{2-}$

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The current direction of development is for SOFC auxiliary power units (APUs), rather than SOFCs as replacements for the internal combustion engine. There is a trend to electrification of vehicle accessories, such as power steering and brakes, windows, heated seats, heated windshields, and air conditioning. These applications account for as much as one-third of total vehicle energy consumption.

The SOFC APU is a high efficiency electrical generator that runs with the engine on or off. It can operate using conventional petroleum fuels with a simple partial oxidation reforming process. It has less stringent requirements for reformate quality (using carbon monoxide directly as a fuel) and is less sensitive than PEMCs to contaminants such as sulfur.

Direct Methanol Fuel Cells (DMFC)

Direct methanol fuel cells have been demonstrated, but economic viability still needs to be demonstrated. DMFCs are a development primarily of PEMC technology that allows the direct use of methanol as a solution in water in the fuel cell rather than hydrogen from a reformer. As such, it is possibly the most promising fuel cell technology for portable applications. Since the DMFC runs directly on methanol, the system does not need either the reformer or carbon monoxide elimination processes that are necessary in a PEMC application. This considerably simplifies the system design. Current DMFC technology, however, cannot match the power density of a PEMC cell, due to lower cell voltages and current densities. Development is also needed to prevent fuel cross-over from the anode to the cathode, as well as to eliminate certain corrosion issues that arise from the chemical by-products.

Fuel Cells in Vehicles

As an alternative to internal combustion engines, fuel cells for transport applications offer significantly higher fuel efficiencies. Like a battery-powered electric vehicle, a fuel cell electric vehicle produces very little or no tailpipe emissions and has the driving range and convenience of a conventional gasoline-powered engine.

With good design these systems will exhaust essentially only a mixture of air, carbon dioxide and water vapor. The fuel cell vehicle will also be far quieter than the equivalent internal combustion based model, an advantage that would benefit many built up urban areas.

Fuel cell vehicle (FCV) technology is currently in the development stage. Although fuel cell applications for buses have been implemented for demonstration purposes, special emphasis is on development for light-duty vehicles since these vehicles offer the greatest potential in energy and environmental benefits.

There are still major challenges ahead in the development of fuel cells, and progress has been slower than expected. However, recent advances have increased the confidence that technology development is unlikely to be an ultimate barrier to adoption of fuel cells. Most fundamental challenges remaining are “chicken-egg” in nature:

- Cost Reduction – The general view is that costs need to be reduced by 50 to 70 percent. In any development scenario for a new technology, especially where modularity is a key feature or possibility, achieving economy of scale in OEM production systems enables lower costs, which in turn encourages market growth.

- Infrastructure Development – It will be critical to create enough of an infrastructure quickly, or leverage or integrate with existing systems (as for any alternative fuel vying to be a general fuel in private passenger vehicles) so as to provide consumers with a sufficient level of comfort in being able to readily refuel upon demand. Focus groups have shown that most consumers in an urban setting on the average require 25-30 percent of refueling stations to carry the alternative fuel before they will buy a car that uses it. This hurdle percentage increases to 50 percent in a rural setting.

Other important detailed challenges facing industry in overall fuel cell development, and especially fuel cells for vehicles and other mobile or portable applications, are discussed in the report.

Fuel Selection Issues

The choice of fuel for fuel cell vehicles is still very uncertain. Presently, hydrogen, methanol and “simplified” gasoline are being considered.

A ranking of the key characteristics of methanol, hydrogen and gasoline that are expected to influence the selection of fuels for fuel cells are summarized in Table 1.

Table 1
Ranking Of Key Characteristics Of Fuels For Vehicle Fuel Cells

Ranking	Energy Density	Convenience of Phase In	Environmental Benefits	Demonstrated Technology
1	GFC	GFC	HFC	MFC
2	MFC	MFC	MFC	HFC
3	HFC	HFC	GFC	GFC

MFC-Methanol Fuel Cell, GFC-Gasoline Fuel Cell, HFC-Hydrogen Fuel Cell

Fuel Cell Market Assessment in Automobiles

The largest potential market for fuel cell vehicles is the automobile. PEMs have been investigated extensively for this application due to their low weight and operating temperature. However, the estimated current cost of PEM's are in the order of $300 per KW at commercial scale. The baseline assumptions for this estimate are a 50 KW fuel cell with a multi-fuel capability reformer, and a PEM fuel cell. The fuel cell efficiency is estimated at 54.3 percent and overall efficiency is assumed to be 36.5 percent.

Platinum and the electrolytic membrane are the two major components of fuel cell system costs. Platinum availability is also an issue for PEM fuel cells.

To be competitive in the marketplace, the required cost and performance characteristics of PEMFCs have been estimated, as summarized in Table 2.

Table 2
PEMFC Cost and Performance Requirements for Competitiveness

System	Efficiency (%)	Cost ($ per KW) *(2010)*	Cost ($ per KW) *(2015)*
Direct Hydrogen Fuel Cell Power System (Including storage)	60	45	30
Reformer-based Fuel Cell Power System -Clean hydrocarbon or alcohol fuel -30 second startup -Satisfies emission standards	45	45	30

This report also provides detailed discussion of the following topics:

- Distribution infrastructure for hydrogen and methanol as fuel cell energy sources
- Current fuel cell production costs
- Future projected PEMFC performance and cost characteristics.

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