An Assessment of Global Hydrogen Transportation Technologies and Implications for Manitoba’s Transportation Sector

Transportation: Vehicles and Refueling Working Group

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Executive Summary

The evolution of the hydrogen economy is a moving target, because the technology is still in its infancy. As a result it is difficult, if not impossible, to predict the outcome. Experts have, in the past, presented continually changing timelines for the commercial implementation of hydrogen and fuel cell technologies. A recent progress report by the U.S. Department of Energy (DoE) has put a more conservative face on this outlook. This is important in that the U.S. DoE drives U.S. government investment in fuel cell technology. In addition, other experts such as vehicle manufacturers, energy companies and fuel cell developers have all pushed back their estimates of hydrogen and fuel cell technology commercialization. Some estimates have suggested commercialization of the fuel cell vehicle within the next five to ten years, while other, more conservative estimates put commercialization at fifteen to twenty years from now. The only certainty is that the application of hydrogen to transportation will be fluid and non predictable in the near future.

The objective of this report is to assess and synthesize the market commercialization status of transportation related applications of hydrogen technologies. Specifically, the report summarizes the global fuel cell industry status, the North American competitive environment, provides an assessment of the technological/commercialization status of hydrogen and fuel cell technology for transport, and commercialization opportunities for Manitoba. The development of a strategic plan for Manitoba must focus on the natural strengths of the Region. It will be necessary to identify what innovative, technological development and university based expertise exists in Manitoba and to assess whether Manitoba’s current manufacturing capabilities coincide with the technologies being assessed.

With the development of the fuel cell, we are looking at a paradigm shift in the propulsion systems of vehicles, but it is not a shift in “real time”. Hydrogen fuel cell technology has been evolving over the past two decades and massive investment from the start is generally thought to be required to become a major high volume player in the game. The investment and the technology gap would prohibit participation in later stages of development. At this stage in the development of the hydrogen economy, massive investments have been made in the technological development phase but comparable investments have not been made in the manufacturing plant development phase. The industry is still in the pre-production phase of development.

To date, the vehicles on the road are prototype vehicles that have been built for product introduction and demonstration projects. The number of fuel cell powered automobiles at a T4 development stage (pre-production and demonstration) is under 100 worldwide and once the European bus demonstration project has its buses on the road in the next year, the total fuel cell buses in demonstration projects worldwide will be under 50.

Plant infrastructure is being built to meet near term market demand in close proximity to the technology developers. As technology improves, new plants will be built and old plants will be modified accordingly. As the technology is refined, costs of production will drop to competitive levels. With competitive prices and a strengthened market demand for zero emission vehicles, opportunities will rapidly develop across all market sectors for hydrogen-fueled vehicles.

Manitoba is capable of participating in the development of the anticipated Hydrogen Economy in the transport vehicle forum, although there is limited opportunity. The fuel cell industry in Canada has evolved mainly around clusters in British Columbia and Southern Ontario. Clusters of activity focus the Fuel Cell Producers, the Component and Material Suppliers, the Service Providers and the Fueling Infrastructure industries in common locations. The Province does have a natural advantage in bus development and manufacturing. Therefore, this sector provides the greatest opportunity. Manitoba also has participants in the Fueling Infrastructure portion of the industry. It
is essential that Manitoba make significant advances in creating a fuel cell technology base to support participation by Manitoba industry.

A second opportunity may lie in the assembly of light industrial vehicles, as the cost of the fuel cell powertrains for light duty industrial vehicles becomes cost competitive with existing power systems. Once again, Manitoba must develop the supporting technology base to participate. Although Manitoba is not participating in fuel cell development or manufacture, it does have the knowledge and experienced workers to integrate components into vehicle manufacturing enterprises, e.g., bus and agricultural implements.

To support Manitoba’s vision of becoming a key player in clean technologies and particularly hydrogen technologies it is essential that Manitoba take action as quickly as possible. Policies and incentive programs like the ones mentioned below and elaborated in section 8 are imperative for developing as a center of expertise in clean energy for transportation:

- Grow a University based research technology capability for fuel cell applications;
- Form a collaborative effort and partnership with MCI, New Flyer, and other stakeholders to focus on the application of fuel cell technology to bus manufacturing in Winnipeg;
- Promote the creation of a fuel cell bus demonstration project;
- Assess Manitoba’s capability to participate in the Hydrogen Economy with a view towards identifying the strengths and weaknesses of Manitoba’s industrial and technology base;
- Based on the results of the assessment of Manitoba’s capabilities, explore opportunities in light industrial vehicle manufacturing;
- Look at opportunities in spin off and integration technologies.

The recent 14th World Hydrogen Energy Conference (WHEC) held in Montreal from June 9 – June 13, 2002, reconfirmed the views and assessments presented in this report. The key drivers behind the hydrogen industry remain the same; improving air quality, reducing GHG emissions, decreasing dependency on foreign oil (energy security). Key players have largely remained the same with a few additions joining the industry. Several significant observations were made relating to the market development of fuel cell vehicles:

- New Investment, including both initial public offerings (IPO) and secondary offerings in alternative energy companies in North America have decreased significantly since 2000. This is a direct result of investors shying away from investing into development stage companies. Investment experts speculate whether investment levels will ever realize the 2000 levels again. This indicates that both governments and private industry will have to work together in funding the development of hydrogen and fuel cell technologies. Government policies and mandates, and subsequent government funding will be the main drivers of the industry in the future. It was stated several times that without the intervention of government, the progression of hydrogen technologies and fuel cells will not happen in the near term as they are currently not economically viable and there is no commercial need for them.
- There are still several key factors prohibiting the adoption of fuel cell technology for mass production such as cost, performance, infrastructure, and fuel sources. Major breakthroughs in each of these prohibitive areas must occur in order for there to be any
considerable advanced in the technology development and adoption. Only then will the commercialization of the fuel cell vehicles occur.

1.0 Introduction

The Province of Manitoba has a vision to become a world leader in clean energy over the next 20 years. This vision includes providing expertise, products and technology that will contribute to a cleaner energy economy, in particular a hydrogen economy derived from clean, renewable and highly efficient energy sources.

To realize this vision, Manitoba needs to focus its efforts on areas of the hydrogen development process that are compatible with the province’s strategic advantages and sets the province apart from other jurisdictions. This project is part of the initiative to assess potential hydrogen opportunities for Manitoba and for the development of a Manitoba Hydrogen Economic Development Strategy.

As input to the *Transportation: Vehicles and Refueling* working group, this project has been established to assess and synthesize the market commercialization status of transportation related application of hydrogen technologies. Specifically, this report summarizes the available information regarding applications, market potentials and commercialization opportunities for Manitoba of hydrogen-transportation technologies.
2.0 Market Drivers behind Hydrogen Vehicles

*Future Wheels*, a report released by the Northeast Advanced Vehicle Consortium (NAVC) in November 2000\(^1\), discussed the major issues related to the advancement of transportation related hydrogen and fuel cell technology and its introduction into the marketplace. The report was based on interviews with 44 global experts working in the industry and its goal was to ascertain whether there was consensus or disagreement on key issues of fuel choice and infrastructure related to transportation fuel cells. The report formed a picture of the state of the industry in 2000, and although there have been technology advances within the past two years, that picture has largely remained the same. For this reason, *Future Wheels* will be referenced often in this report, and supported by further sources.

It has been expressed time and time again, in *Future Wheels*, by private industry, and by government officials, that the ultimate goal is to run future fuel cell vehicles on pure hydrogen as opposed to hybrids and other alternative fuel vehicles. Experts unanimously agree that the continuous development and eventual commercialization of fuel cells will occur for both transportation and other uses. This being said, it is important to understand the drivers behind the hydrogen industry. Three major factors are continuously identified by industry experts as the drivers behind the development and eventual commercialization of hydrogen fuel cell technologies. They include; criteria air pollutants, global warming, global oil availability and prices (energy dependency).

**Criteria Air Pollutants**

Criteria air pollutants are an important early driver behind the development of hydrogen technologies because the fuel cell can be a zero emissions vehicle (ZEV), depending on the source of hydrogen. In North America many states have begun implementing reduced emission mandates. California is leading the way with these policies, and has issued a tough ZEV mandate to reduce air pollution. As a result of these policies, automobile companies are searching for technologies to meet the ZEV mandate and fuel cells are a solution. In urban areas air pollution is particularly acute. In *Future Wheels* one industry expert who was interviewed mentioned a report that found many sick days, health problems, and deaths were due to air pollution and billions of dollars are being spent on health care because of air pollution. Air pollution is an immediate issue and will be an initial driver for fuel cells for transportation.

**Global Warming**

Global warming, and the reduction of greenhouse gas (GHG) emissions is another key driver behind the development of hydrogen fuel cell vehicles. Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide have increased nearly 30%, methane concentrations have more than doubled, and nitrous oxide concentrations have risen by about 15%. These increases have enhanced the heat-trapping capability of the earth’s atmosphere. In a report written by Reinhold Wurster for L-B-Systemtechnik GmbH called “Hydrogen – The Ultimate Vehicle Fuel”\(^2\), Wurster states that more than 90% of all GHG experts agree that humans are influencing climate. The report goes on to say that the transport sector is one of the fastest growing contributors to human made CO\(_2\) in Europe. Experts believe fuel cells have an advantage over internal combustion (IC) engines and hybrid vehicles if the well to wheels efficiency and hydrogen generation source reduces greenhouse gas emissions. Although fuel cells will not necessarily be initially completely emissions-free and efficient, they have the potential to be. One automaker said that fuel cell electric vehicles could use fuels from renewable...
and CO₂-neutral resources most efficiently. Hence, fuel cell vehicles powered by “green” fuels can contribute to achieving CO₂-reduction targets and mitigate climate change.

Energy Diversity and Security

Oil availability and consumption, oil prices and dependence on foreign oil have been grouped together with concepts of energy diversity and security by government spokespeople and industry experts. A strong benefit of fuel cell technology is that they can use indigenous sources of energy, thereby decreasing dependence on foreign oil and helping energy security. Fuel cells offer flexibility in that they can use a variety of fuels. An additional benefit to fuel cells is that they are able to operate on fuels that are non oil-based such as renewable energy, making them a potential sustainable transportation solution.

Regardless of varying opinions on the viable lifetime of oil as an energy source, it is widely agreed that increasing supply pressure overtime will increase the attractiveness of alternative energy sources, and hence many experts believe issues concerning oil availability will help the development of fuel cells to commercialization. Opinions vary greatly among experts on the long-term availability of oil. Some experts believe that there will be enough oil for the next 280 years, while others estimated oil production will peak soon and quickly drop in global supply as developing countries expand their transportation markets. Some experts think that energy suppliers will move to different energy sources like natural gas before oil becomes a scarce commodity, and therefore energy security will not be a key issue.

Fluctuating and high oil prices might motivate Congress to pass more legislation to discourage the use of fossil fuels and hence encourage the development of hydrogen and fuel cell technologies. In the past year oil and gasoline prices have risen sharply and decreased, however these fluctuations did not observe a decrease in oil demand. Currently hydrogen fuel source prices depend largely on oil prices, as most industrial hydrogen is reformed at the wellhead. Market forces also dictate that as oil prices increases, cost pressure rises on tertiary energy sources such as natural gas and electricity – as oil prices increase natural gas and electricity will gain demand share and prices will therefore rise. A transit agency responded by saying that oil price increase is important because when prices reach over $2.35 a gallon, the issue receives a great deal of public attention. Although OPEC, and not market forces, currently dictate the price of oil, some experts believe that as oil supply decreases the costs of extracting and producing it will become prohibitive and will therefore encourage the use of alternative energy sources such as hydrogen.

Air pollution, global warming and energy security have been marked as the main drivers behind the development and eventual commercialization of hydrogen and fuel cell technologies by the respondents in Future Wheels. Secondary drivers include consumer preference for environmentally sensitive products and noise pollution reduction, however, many add that additional value beyond environmental will need to be offered in fuel cell vehicles in order to drive adoption. It has been pointed out several times that the fuel cell vehicle has to have superior performance and reliability, and needs to be competitive in price with today’s ICE cars.

Some feel that profitability is a further driver behind fuel cell development. As fuel cell technology develops, substantial cost reductions can be expected. This contrasts with ICE technology, which has essentially reached the end of its cost curve; that is to say, there are few opportunities left to radically alter the cost structure of ICE products.

Some technology companies conjecture that fuel cell deployment will occur as a result of deregulation, not regulation. Deregulation concerns stationary applications, but they feel fuel cells will be developed first in the stationary market. This will then allow money to be put back into research and development of transportation fuel cells, according to one expert. Though many
experts thought the development path and technology choices between the transportation fuel cell and the stationary fuel cell were so divergent that there were little cross platform benefits.

A variety of stakeholders are quick to point out that fuel cell drivers vary globally. For example, Europe and Japan are more concerned with climate change issues and high gasoline prices. Conversely, the United States regards criteria air pollutants as a larger issue and has therefore implemented ZEV and other similar mandates.

Conclusion

It is clear from the Future Wheels report that a wide variety of opinions exist on the market drivers that are spurring on the development of the hydrogen economy. Ultimately there will be many interrelated drivers of fuel cell development and adoption. What is abundantly clear is that the specific driver or combination of drivers will differ for each region in the world. Needs will vary across the world and the commercialization opportunities will also vary across the world.
3.0 Global Fuel Cell Industry Status

3.1 The Players

The development of the fuel cell and the balance of the powertrain for the transport market are driven by government, automotive manufacturers, a few major fuel cell developers, and major component suppliers to the automotive industry. These stakeholders have provided substantial amounts of funding directed at every stage of R&D required to advance the technologies and to put hydrogen fuel cell vehicles on the road. In most cases, international consortiums or alliances, and public/private partnerships have been formed to design, test and develop the new technology for the transport vehicle.

Government Involvement

Government funding and policy have played a pivotal role in initiating and progressing the development of the fuel cell technology in vehicles. Already, billions of dollars of both private and public funding have been invested in the industry, however as obstacles such as prohibitive costs slow development, it is evident that governments will have to create strict mandates backed by funding and initiative programs to witness any major advancements in adoption. These views have been stated by many experts in the past, and were reiterated in presentations by key stakeholders and investment companies speaking about the future of the industry at WHEC in June 2002.

Canada

In Canada Natural Resources Canada’s Hydrogen and Fuel Cell R&D Program is spearheading the fuel cell effort. The program is managed by the CANMET Energy Technology Center. There is some in-house R&D work that takes place, however the majority of it is contracted out to industry, research organizations, and universities. More specific to the development of fuel cell applications for transportation, the Canadian Transportation Fuel Cell Alliance (CTFCA) has been created as part of the Government of Canada’s Action Plan 2000 on Climate Change. The Alliance is a five-year (2001-2006), $23 million initiative geared towards encouraging advancements in hydrogen and fuel cell technologies, and greenhouse gas reductions by developing fueling infrastructure for fuel cell vehicles. The program has partnered with industry and governments to demonstrate different combinations of fuels and fueling systems. Within Manitoba, the provincial government, the University of Manitoba, as well as other industry service providers are active participants of the CTFCA.

European Union

To date the German government has been the leader in Europe for initiating and supporting hydrogen and fuel cell technology development and adoption. At WHEC in Montreal, a presenter from DaimlerChrysler provided statistics showing that Germany contributed 60% of the aggregate European fuel cell investment activity, with France following at 19%, and the balance being made up by other countries in the union. Other European countries are beginning to follow the German example by providing funding and participating in large-scale demonstration projects.

The European Integrated Hydrogen Project

The European Integrated Hydrogen Project (EIHP), started in 1989, aims to establish a coordinated approach to developing the standards, regulations and infrastructure necessary to support a hydrogen energy system. Now, in its second phase, which will run through 2004, the Project expects the following results:
• Harmonized regulations worldwide for hydrogen fueled vehicles;
• Development of procedures for periodic vehicle inspections.

The premise of the European project is that harmonized regulations and standards will provide the vehicle and infrastructure industries the necessary predictability and protection to bring hydrogen fuel cell vehicles to market. Harmonized regulations will also give many countries the legal basis to approve the operation of hydrogen vehicles on public roads and public use of refueling stations. Finally, common standards will open international markets for fuel cell vehicles.

**Japan**

Under Japan’s Ministry of Economy, Trade and Industry (METI) since 1993, the New Energy and Industrial Technology Development Organization (NEDO) has administered the WE-NET project, which conducts the research and development of hydrogen energy. The goals of the project are to provide a solution to the global dilemma of producing and utilizing energy while simultaneously preserving the environment.

**United States**

Similar programs are in place in the United States under the auspices of the U.S. Department of Energy and the Fuel Cell Council. The US DOE is the most significant source for federal government funding in the US. Among other programs, the DoE announced in February of 2002 the FreedomCAR Program to foster development of fuel cell technologies for vehicles. The Fuel Cell Council is an industry association whose members constitute one of the most significant groups of players in fuel cell development in North America. *Fuel Cell Power For Vehicles*, a report written by the US Fuel Cell Council in 2001, identifies and briefly describes the major players in the U.S. Fuel Cell Council. Major players in the U.S. Fuel Cell Council can be found in the list of industry players below.

**Major Automotive Manufacturers**

Automotive manufacturers have been instrumental in the development of fuel cells for vehicles. Although the majority of them have partnered with fuel cell developers to produce a fuel cell vehicle, both General Motors and Toyota are conducting in-house development of their own fuel cells to incorporate into their vehicles. In addition other manufacturers have invested millions, if not billions of dollars and participated in demonstrations to further their efforts in the race to develop a fuel cell vehicle.

**DaimlerChrysler – Stuttgart, Germany**

DaimlerChrysler has been a key player in moving fuel cell vehicles to the point they are at today. Already they have spent hundreds of millions of dollars on fuel cell vehicle R&D, and are dedicated to investing millions, if not billions more in the years to come to continue fuel cell technology development. With Ford, they are part owners of Ballard Power Systems Inc. and are the leaders of the next generation fuel cell vehicle and commercialization program launch.

DaimlerChrysler was the leading force behind the NECAR and NEBUS Development Project from 1994, through to 2000. They are also key investors and the bus supplier for the CUTE demonstration program in 9 European countries. As a further step in the direction of commercialization, DaimlerChrysler is now concentrating on the use of cost-effective materials.

**Ford Motor Co. – Dearborn, MI**

TH!NK Technologies is the engineering arm of Ford Motor Company that concentrates on advanced electric drive vehicles and is a leader in the development of fuel cell vehicles. In November of 2000, the group introduced the world’s first production-prototype, direct hydrogen
fuel cell vehicle, based on the Focus platform. The group has also developed prototypes of other popular Ford models that use hydrogen fuel cells, methanol fuel cells, and battery electric drives.

TH!NK Technologies is dedicated to engineering fuel cell and battery electric vehicles that produce zero tailpipe emissions and may eventually replace conventional vehicles. In 2002 Ford launched the TH!NK Road Show, touring North America, attending and hosting large-scale media events, and visiting universities and schools to promote and build awareness of hydrogen fuel cell technologies.

**General Motors – Oshawa, ON**

GM introduced the world’s first operating fuel cell vehicle in 1968, the GM Electrovan. The engineers proved that it could be done but also proved that it was not practical in 1968. In the mid 80’s Opel and GM reopened the fuel cell investigation and developed the Zafira in 1998. Also in 1998 GM formed the Global Alternative Propulsion Center, GM’s internal organization to advanced fuel cell technology. In 1999, a five-year research and development agreement was reached with Toyota.

A concept fuel cell family sedan, the GM Precept, featuring a fuel cell system vehicle with a metal hydride hydrogen storage system was introduced in 2000. Also in 2000, the HydroGen1, an Opel Zafira based fuel cell vehicle operating on liquid hydrogen was showcased around the world. GM recently unveiled AUTOnomy, a new concept vehicle that reinvents the automobile based on fuel cell technology. It is a car platform that is based on emerging technologies rather than one designed to operate on historical automobile platforms.

In pursuing the development of hydrogen technologies, GM has partnered with Toyota and with QUANTUM to collaborate on improving the range of GM fuel cell vehicles through the development of hydrogen storage, hydrogen handling and electronic control technologies for fuel cell applications. Hydrogenics has also been contracted for engineering support services.

**Toyota – Tokyo, Japan**

Fuel cell hybrid vehicles developed at Toyota convert fuel into energy nearly twice as efficiently as conventional power trains. In 1996, the automaker developed the world’s first working prototype to carry its fuel in a hydrogen-absorbing alloy. The following year, Toyota revealed a second prototype that generated its own hydrogen with an on-board methanol reformer – another world first.

Success with these prototypes convinced Toyota to complete its R&D phase and advance into its product development phase. Toyota engineers have made great strides in improving individual components vital for viable fuel cell vehicles. Toyota’s fuel cell stack, for example, occupies only 65 liters of volume but it can generate over 70 kW of energy. This exceeds the US Department of Energy’s 2004 target of 1 kW of energy per liter of volume.

Building on the success of its 1996 hydrogen absorbing alloy technology, Toyota unveiled its second-generation alloy tank at the 1999 Tokyo Motor Show. It can store 2.2 kg of gas in 100 kg of metal – a 10 % improvement over the initial design. On the vehicle development side, Toyota has developed the FCHV-5, which is based on the Highlander body and incorporates a gasoline reformer to generate the hydrogen for the fuel cell. All fuel cell related components have been located under the floor of the vehicle so as not to compromise interior cabin space. Their fuel cell bus, the FCHV-BUS1 is based on the Hino low-floor city bus HU2PMEE.

**Major Fuel Cell Developers**

The following list includes major North American and global players.
Ballard Power Systems – Burnaby, BC
Ballard is recognized as the world leader in proton exchange membrane (PEM) fuel cell technology. Its principal business is the development and commercialization of PEM fuel cells and fuel cell systems for use in selected power generation applications, including transportation, small to mid-size stationary power generation and portable power use. Ballard has been developing PEM fuel cells and PEM fuel cell systems for 17 years.

In the transportation market, Ballard has formed the Fuel Cell Alliance, a vehicular alliance, with Daimler-Chrysler and Ford. Together with their alliance partners, Ballard formed XCELLSIS, to develop and commercialize PEM fuel cell systems for cars, buses and trucks; Ecostar, to develop and commercialize electric drive trains; and Ballard Automotive, to sell fuel cells and fuel cell engines to automakers around the world.

Through the California Fuel Cell Partnership (CaFCP), Ballard is working with other organizations, including the State of California, the U.S. Department of Energy (DoE), Daimler-Chrysler, Ford, Honda, Nissan, Volkswagen and Shell, Texaco and ARCO, to test and demonstrate more than 70 fuel cell powered cars and buses in California between 2000 and 2003, while also addressing fuel and infrastructure issues.

The commercialization focus at Ballard is now on cost reduction and developing volume-manufacturing processes. Products supplied include:

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Delphi (Division of GM) – Troy, MI
Delphi Automotive Systems is working with BMW and Renault to develop solid-oxide fuel cell (SOFC) technology as an auxiliary power source for cars and trucks. Vehicles using these fuel cells will be powered by conventional IC engines. The alliance with BMW is focused on an auxiliary power source for gasoline engines while the alliance with Renault is focused on the development of diesel-fuel solid-oxide fuel cell reformers for Renault light and heavy-duty trucks.

A major benefit that the SOFC has over the PEM fuel cell that is being adopted for traction applications is that the SOFC is much less sensitive to impurities in commercial grade fuel and carbon monoxide.

Delphi is also developing a PEM fuel cell for traction applications, however, the SOFC is more attractive as an APU because of its efficiency and because it does not require a cumbersome reforming process to run using existing fuels.
Teledyne Energy Systems, Inc. – Hunt Valley, Maryland
Teledyne Energy Systems, Inc. (TESI), a Teledyne Technologies Company, is a leading global provider of on-site gas and power generation systems based on proprietary fuel cell, electrolysis and thermoelectric technologies. In addition, Teledyne teamed up with former Energy Partners, a leading PEM fuel cell developer, to add PEM fuel cell stacks, PEM fuel cell power systems and fuel cell engineering services to its product offerings.
In a 1996 collaborative effort with John Deere and Company, Energy Partners converted 2 John Deere Gator utility vehicles to fuel cell power. Each vehicle is powered by a 10 kW fuel cell stack and is equipped with an 115v inverter with standard electrical outlets. The Gators are currently being retrofitted with advanced fuel cell stacks and metal hydride fuel storage beds.

Hydrogenics Corporation – Mississauga, ON
Hydrogenics designs and builds integrated PEM fuel cell systems for power generation as well as for fuel cell testing and diagnosis from their facility in Mississauga, ON. The company also operates a manufacturing facility in New York as well as an Asia-Pacific regional office in Tokyo, Japan, in response to a growing interest in their test system products and other developmental fuel cell products.

They offer system integration capabilities to clients who require design engineering and prototyping in order to integrate their proprietary technology into operational fuel cell systems or subsystems.

Hydrogenics' product specifications are divided into two main categories, Power Generation Products and Fuel Cell Test and Control Systems. In November 2001 they announced the launch of their next-generation 2002 FCATS™ product line. FCATS™ is Hydrogenics' proprietary product line of automated, industrial-grade systems for the testing and optimization of fuel cells and fuel cell stacks.

In October 2001 they became a member of the General Motors' Alliance of fuel cell commercialization companies. At the time of the signing of the corporate alliance agreement, the two companies already had a long standing working relationship in fuel cell development. A synergy had been established from teaming the strengths of GM's fuel cell expertise with Hydrogenics' operating system and system integration capabilities. Hydrogenics' FCATS™ products have been instrumental to GM's advanced fuel cell development, and indeed, the progressive product development of the FCATS™ systems has often been driven by the growing demands of GM's fuel cell program.

In addition to contributing their current core competencies to the alliance, as of December 3, 2001, Hydrogenics has undertaken a significant engineering services contract for GM at their fuel cell research facility in New York.

UTC Fuel Cells – South Windsor, CT
(Formerly International Fuel Cells), South Windsor, CT
International Fuel Cells (IFC) is the world leader in the production and development of fuel cell power plants for transportation, stationary, residential and space applications. UTC has been a supplier of fuel cell power plants since 1961. It has produced and delivered more than 500 power plants.

Today, UTC is supplying PEM power plants for traction and auxiliary power. In partnership with BMW, UTC Fuel Cells developed and delivered a PEM fuel cell auxiliary power unit. Demonstrated at the Frankfurt Auto Show in 1999 in a BMW 7 series car, this APU unit provided energy for the car’s entire on-board electrical needs including climate control.
Ford, BMW, Volkswagen, Hyundai, and other OEMs and the U.S. Department of Energy have received or are working with UFC to develop automotive power plants. In 2000, UTC Fuel Cells integrated its Series 300 ambient pressure fuel cell into a Hyundai Santa Fe sports utility vehicle as the main power plant for the vehicle. Unveiled at the CaFCP in November 2000, the car demonstrated the superiority and feasibility of UTC Fuel Cells’ ambient pressure technology.

Working with the U.S. Department of Transportation and Georgetown University, UTC Fuel Cells in 1998 integrated a 100 kW phosphoric acid fuel cell system into a full-sized bus. The bus is currently operating as a student shuttle service on the Georgetown campus. In 2000, UTC Fuel Cells signed separate development and demonstration agreements with Thor Industries, the largest maker of mid-size buses in the United States and IRISBUS, one of the largest European makers of buses.

**Nuvera Fuel Cells – Cambridge, MA**

Nuvera is a leading designer and developer of fuel processors, fuel cell stacks, and integrated fuel cell systems for stationary and transportation applications. The international firms fuel processors and PEM fuel cell stacks have been successfully tested and evaluated by major automobile and appliance manufacturers, research institutions, and industrial and energy companies.

**Ze Tek Power Corporation – Munich, Germany**

ZeTek is the European leader in zero-emission fuel cell technology. ZeTek fuel cells can be integrated into systems to supply clean, reliable and cost efficient electric power for use in vehicles, watercraft and stationary applications. ZeTek’s automotive division Ze Vco’s fleet of commercial vehicles located in Munich, Germany, exists in modest numbers, but represents several key areas of operation. The ZeVco fleet includes a Metrocab demonstration taxi and Iveco parks vehicle.

### 3.2 Major Demonstration Projects

In addition to partnerships and alliances formed by individual companies to pursue product development, there are several demonstration projects that are either on the go or have been recently completed, primarily taking place in North America and Europe and Japan. These demonstrations have been instrumental in the advancement of fuel cell applications for vehicles and larger-scale fleet demonstration will be necessary before commercialization takes place. [Appendix 1](#) gives a summary of completed and current demonstrations that have taken place.

**North America**

**California Fuel Cell Partnership – Sacramento, CA**

The California Fuel Cell Partnership (CaFCP) represents one of the most significant collaborative efforts to advance new vehicle technology. The Partnership has provided an opportunity for automobile companies and fuel suppliers to join together to demonstrate fuel cell vehicles under real day-to-day driving conditions. The CaFCP has plans to place up to 60 fuel cell passenger cars and fuel cell buses on the road between 2000 and 2003. In addition to testing the vehicles, the Partnership is examining fuel infrastructure issues and beginning to prepare the California market for this new technology.

Funding for the partnership is derived from an annual contribution of about $100,000 from each full partner. The funding is used to support efforts such as facility start-up costs, program administration, joint studies, public outreach and education. The private partners supply all
vehicles, equipment, and technical staff, and in addition work collaboratively in developing fuel cell vehicles at the Partnership’s Sacramento facilities, though each automaker leases and maintains their own workspace. Specifically, the Partnership aims to achieve four main goals:

- Demonstrate vehicle technology by operating and testing the vehicles under real-world conditions in California;
- Demonstrate the viability of alternative fuel infrastructure technology, including hydrogen and methanol stations;
- Explore paths to commercialization through identifying potential challenges and then creating solutions; and
- Increase and enhancing public awareness and opinion of fuel cell/electric vehicles, preparing the market for commercialization.

The Partnership includes the following organizations:

**Automotive**
- DaimlerChrysler, Ford, General Motors, Honda, Hyundai, Nissan, Toyota and Volkswagen

**Energy**
- British Petroleum, ChevronTexaco, Exxon Mobil, and Shell Hydrogen

**Fuel Cell Technology**
- Ballard, UTC Fuel Cells

**Government**
- California Air Resources Board, California Energy Commission, South Coast Air Quality Management District, US Department of Energy and the US department of Transportation

**Associate Partners**

**SunLine Transit Agency**, a California Fuel Cell Partner, is leading a complex integrated hydrogen demonstration project. Both renewable and fossil-based hydrogen production technologies are being evaluated, along with compressed gas storage. The ongoing testing will pave the way for the complete transition of California’s Coachella Valley transit system to hydrogen fuel cell vehicles.

In 1994, SunLine became the first public transit fleet in the world to park all its diesel buses and switched overnight to 100% clean-burning compressed natural gas (CNG). In April 2000, SunLine opened the world’s first hydrogen generation /storage/fueling facility built by a public transit agency. The facility boasts two Hythane buses (80 % CNG/20 % hydrogen), the XCELLIS ZE-bus, the nation’s first street legal hydrogen fuel cell mini-car (SunBug), three hydrogen fuel cell powered golf carts and a hydrogen powered internal combustion engine pickup. SunLine is operating this “lab on wheels” to determine the supportability, reliability, maintainability and operability of a fleet of hydrogen powered vehicles.

SunLine expects to begin conversion of its CNG bus fleet to hydrogen fuel cell buses in 2003. If all goes according to plan, SunLine and AC Transit in Northern California will each receive 10 fuel cell buses as part of the California Fuel Cell Partnership Bus Demonstration Project. For the
moment the two transit companies have been given permission to purchase four fuel cell buses. SunLine will purchase one bus, and AC Transit will purchase three from ISE Research-ThunderVolt Inc. of San Diego. The buses are equipped with fuel cells from UTC Fuel Cells, based in Connecticut. Delivery of the buses is expected in 2004.

**P3 Bus Program**

In addition to the collaborative efforts of the CaFCP, Ballard Power Systems carried out earlier work on fuel cell buses. In the 11th Canadian Hydrogen Conference Proceeding (2001) the Coast Mountain Bus Company describes the P3 Bus Program that was conducted from 1996 to 2000. In 1990 the Government of British Columbia initiated a partnership with Ballard and approved funding and resources for the integration of a first generation fuel cell engine into a shuttle bus. The shuttle bus was demonstrated at the Los Angeles International Airport. In 1996, an agreement was reached between Ballard, the BC Government and BC Transit, in which the government provided $8.6 million in funding for a project that used fuel cell buses in real-life, passenger-carrying, revenue transit services. The funding was used to build, operate, and evaluate 3 fuel cell powered buses in actual transit operations over a two-year period. A similar agreement was reached between Ballard and the Chicago Transit Authority and the entire project was named the P3 Bus Program.

A New Flyer Industries 40-foot low floor bus chassis was chosen for the project and after the fuel cell integration and testing the 3 buses began the 2-year demo phase in June of 1998.

**Europe**

Germany is headquarters for several of the key European automotive manufacturers, such as BMW and Mercedes (a DaimlerChrysler company). In addition the government of Germany has been progressive and supportive in hydrogen fuel cell research and development. As a result, the country has lead the way in terms of research, development and larger scale demonstration projects of fuel cell vehicles. The first large-scale demonstration projects date back to the early 1990’s and the country has continued as a key ambassador of this technology. A number of demonstration projects have been initiated in Europe. A paper, “Hydrogen – The Ultimate Vehicle Fuel – Hypothesis IV September 2001” identified many of the demonstration activities that are taking place. Although details of several of the projects were not available, a list of activities is provided below. In addition we can identify these activities.

- **Bavarian ICE LH2 – Bus (see below)**
  Erlangen & Munich from 1996-1998

- **Bavarian CGH2 PEMFC Bus (see below)**
  MAN, Siemens, Linde

- **Munich Airport (see below)**
  LH2 and CGH2 demonstration project

- **CGH2 ICE Van fleet**
  Hamburg

- **LH2 and LCGH2 Linde Refueling Station**
  Berlin

**Bavarian ICE LH2 Bus & Bavarian CGH2 PEMFC Bus**

In 1991 the Erlangen and Munich Governments, in cooperation with MAN bus and Linde, commenced the Bavarian Liquid Hydrogen Bus Demonstration. Hardware development and

The LH2 Bus project was soon followed by the Bavarian Fuel Cell Bus Project with commenced in 1996 and continued until 2000. This latter project was set up in 4 phases, the first phase being the design phase, the second phase being the system integration phase, and the third and fourth stages being the test and commissioning phases.

**Munich Airport H2 Project**
The opening of the new international airport of Munich, Bavaria, in 1992, presented an ideal opportunity to convert the entire airfield services; catering vehicles, aircraft tractors, waste removal trucks and passenger transport vehicles (minivans, buses, passenger cars) to hydrogen propulsion step by step, by gradually replacing existing vehicles. Planning and hardware development for the endeavor began in 1995 and the actual installation of vehicles occurred from 1997 to 2000. All the vehicles were centrally refueled from one of two parallel refueling stations; one for refueling apron vehicles with gaseous H2; and the other for refueling passenger vehicles at the terminal. Vehicles used included:

- PEMFC fork lift
- MAN low-floor bus – H2-ICE
- 3 articulated buses with advance H2 ICE
- 2 PEMFC buses
- 15 VIP cars – BMW LH2-ICE

All vehicles are now in regular operation.

**BMW – Clean Energy Project**
BMW has demonstrated its commitment to environmental sustainability through its participation in the Global Compact (an international forum for information sharing) with its “Clean Energy Project”7. For BMW, “Clean Energy” means closing the loop for zero CO2 emissions. The technical process for this is: water to hydrogen and back to water. When used in vehicles, hydrogen is converted back into vapor and returned to the atmosphere. The goals of the “Clean Energy Project” are to:

- Shift away from fossil fuels via natural gas technology towards hydrogen. (Natural gas fueled cars and hydrogen fueled cars – 750hL);
- Networking with industry partners for developing a global sustainable hydrogen infrastructure;
- “SWB Solar-Wasserstoff-Bayern Gmbh” – the largest solar-hydrogen project worldwide consisting of 15 enterprises exploring possibilities of a hydrogen based economy. The project developed into the “Hydrogen Project Airport Munich” which is the first fully automated public hydrogen filling station at the Munich airport;
- Along with nine partners and support from the European Commission, BMW founded the “European Integration Hydrogen Project” to develop a dual-approach strategy for hydrogen top down to provide assistance in framing the necessary legislation and bottom-up to develop the necessary technology;
- In 2000, BMW presented the first fleet of 15 hydrogen 750hL cars with bivalent internal combustion engines (to run on hydrogen or petrol) equipped with hydrogen fueled fuel cells instead of conventional batteries;
In 2001, BMW set off with the full fleet of hydrogen cars on the Clean Energy World Tour 2001. The tour is to globally raise awareness and build up a long-term stable political framework for a vision of a sustainable future, based on a hydrogen economy and society.

**NECAR and NEBUS Development**
In 1992 the NECAR and NEBUS Development project was initiated as a joint effort between DaimlerChrysler, Ford Motor Co., Ballard Power Systems and the German Government. Since its commencement, the project partners have poured over 900 million German Deutsche Marks ($449,800,277.50 USD) in funding and have developed and demonstrated 5 prototype cars and 2 NEBUSes, with plans for project completion in 2004. The objective was to develop and commercialize PEM fuel cell electric propulsion systems for cars and buses. The project concepts include 3 types of propulsion systems with respect to fuel supply:

- Direct hydrogen supply and on-board storage of both LH2 and CGH2;
- Methanol on-board reforming; and
- Gasoline on-board catalytic partial oxidation.

The project goals are based on commercialization of the vehicles; the number of passenger car units to be sold into the market is set at 40,000 units for 2004, 70,000 units for 2005, and 100,000 units annually starting from 2006 on. The propulsion units will be sold partially in Mercedes cars, Ford cars, and third party car manufacturers. The NEBUS demonstration and testing was planned with 27 bus units between 1999 and 2001 and with an additional 120 bus units between 2002 and 2004.

**European Fuel Cell Bus Demonstration Project**
The most recent efforts in fuel cell demonstrations were announced in 2001, making Europe a hot spot for the introduction of fuel cell buses. Three demonstration projects supported by the European Union will result in 33 fuel cell busses operating in 13 cities and 9 countries throughout Europe by 2003.

The first project, **The Fuel Cell Bus for Berlin, Copenhagen, and Lisbon II**, is being realized in co-operation with several European manufacturers and public transport operators. The project will demonstrate, for the first time, the operation of 3 fuel cell buses powered by liquid hydrogen in regular urban public transit. The project will demonstrate the long-term advantages of urban application through introduction to a wide market. Phase I of the project will be the demonstration of the fuel cell buses in 3 cities: 9 months in Berlin; 1 mo in Copenhagen; and 2 months in Lisbon. Phase II of the project assessment of the experience and information gained to determine technical improvements to the buses. A MAN N L223 low floor bus equipped with a DE NORA fuel cell (150 kW) was used.

Under the **Clean Urban Transport Europe (CUTE)** project the European Commission has awarded 18.5 million euro to nine European cities for the introduction of 27 hydrogen fuel cell buses. This project will be the first mass production test of this scale for fuel cell buses, conducted anywhere in the world.

- **EvoBus – Citaro (LH2)**

The **Ecological City Transport System (ECTOS-project)** is a combined demonstration and research project of hydrogen infrastructure and the operation of hydrogen fuel cell buses in Reykjavik, Iceland. The projects 4-year goal is to build a filling station in Iceland, with on-site production of hydrogen by electrolysis using renewable power and operate 3 buses in normal service by the Reykjavik Municipal Bus Corporation. The project was awarded 7 million euro;
2.85 million euro contributed by EU, and the remaining 4.14 million euro financed by foreign and domestic partners. The buses used will be EvoBus – Citaro LH2 with a Ballard/Xcellsis fuel cell engine.

3.3 Market Development

Background

The commercialization and adoption of hydrogen and fuel cell technologies is both complex and uncertain as a result of unknowns and barriers. There are several challenges prohibiting or slowing the development of fuel cell technologies. Depending on if and when these challenges are overcome will play a large role in determining the adoption time of fuel cell technologies for transportation. Most experts agree that market adoption of fuel cell technologies will follow an “S” curve. In a report put out by the State of Michigan, “Positioning the State of Michigan as a Leading Candidate for Fuel Cell and Alternative Powertrain Manufacturing”, authors state that fuel cells will be delivered for transportation applications after specialty applications and stationary applications. The reason for this is due to the cost sensitivity in these specific markets. In the transportation market the challenge is to deliver fuel cells with a target cost of at or below $100 per kW. Therefore experts predict that it will be at least 15 to 20 years before fuel cell vehicles gain significant market penetration.

Transit market will develop first

Despite disagreement on several issues surrounding hydrogen and fuel cell technology, experts generally agree that transit buses will be the first to adopt fuel cell technology on a broad scale. The majority believes that fuel cells will capture a significant initial market share sooner in the transit market than in the passenger vehicle market.

Respondents in Future Wheels were asked when fuel cells would be able to capture a significant initial market share of the transit and passenger vehicle markets (5% of their respective markets is considered significant). The question left it to the respondent to speak to the global market, or to the U.S., European, or Japanese markets, which would seem to be the most likely first markets for fuel cells as they have the most research and demonstration activities underway. Five percent of the transit market is a significantly different amount than five percent of the passenger vehicle market. For example, in the U.S., there are approximately 5,000 new buses sold each year; five percent of this is 250. By contrast, the passenger vehicle market in the U.S. sees 17 million new vehicles sold in a year. Five percent of this market is 850,000.

All respondents in Future Wheels believed that fuel cells will be commercially viable in the transit market before they will be in the passenger vehicle market. However, respondents varied on what they believed will be the timeframe and speed of market development. The majority of respondents predicted that fuel cell transit buses might encompass 5% of the transit market by 2008 - 2012. This view is in close keeping with the U.S. DoE and with other experts who have shared their opinions at WHEC in June 2002 and in other papers.

There are several reasons factoring into the prediction of these experts and several reasons that make buses ideal for early fuel cell adoption in transportation applications. The first is the issue of sheer numbers, as noted above. Using the U.S. as an example, it will simply be quicker to get to annual production of 250 vehicles (for transit) than to reach production of 850,000 (for passenger vehicles). A second issue is that although transit buses only make up roughly 1% of
vehicles driven in the U.S., they are concentrated in urban centers and thus contribute to a disproportionate amount of emissions in these areas. Transitionally, this makes them responsible for a disproportionate number of health cases due to air quality. For this reason, this makes them a target for ZEV mandates.

There are a variety reasons making early introduction of fuel cells to the transit market easier than the passenger vehicle market including infrastructure, cost, integration of the fuel cell onto the vehicle platform, government subsidy and regulatory drivers.

It is interesting to note the consistency surrounding the timeframe/schedule for fuel cell penetration into the transit market. Although all predictions are highly speculative, most respondents in Future Wheels and other experts since see it happening somewhere within a five to 10-year timeframe: 2005 – 2012. Some respondents cited specific drivers for these dates. For example, several experts, including a government agency, noted that California is requiring that 15% of new buses be zero emission by 2008. Since the California bus market is a significant percentage of the national market, they believe this will have a significant impact in developing the national market. Overall, experts have not cited specific reasons for selecting a particular timeframe for market penetration; nevertheless, there is an overall consensus that it may happen by 2012. This consensus may indicate that there is no serious technological “show-stoppers” to fuel cell transit vehicles.

Transit market will be easier to develop than the passenger market

The second area of consensus among experts is regarding the question of whether there will be any difference between the development of the transit market vs. the passenger market. In general, experts agreed that it would be easier to introduce fuel cells into the transit market than to the passenger market -- which is why they predicted fuel cells capturing a significant market share in transit first. However, even though the transit arena is considered easier for initial introduction, some doubt whether it will be a sustainable driver for the market of fuel cells because of the low volume numbers. The light duty vehicle market is where the large volume producing numbers are, therefore lower price producing numbers.

Although this question did not specify whether “market” referred to the global fleet, or to the U.S., Europe or Asia, in general, respondents chose to apply this question to the U.S. market. Also, in framing this question, it was generally assumed that “transit” referred to buses; however, several respondents commented that it was really the more general category of “fleet” applications, of which “transit” is a subset, that would happen first. They referred to other fleet applications such as delivery vans, taxis and other urban fleets as possible entry markets for fuel cells.

The reasons that the experts feel the transit market will be easier than passenger market is as follows;

Fuel choice: Many respondents said that direct compressed hydrogen is clearly the fuel that will be used for heavy-duty transit applications. The lack of a debate or controversy over which fuel to use will speed the introduction of fuel cell buses. Conversely, many respondents seemed to feel that the uncertainty surrounding the fuel choice for passenger vehicles would delay the development of this market. In stating that the use of direct hydrogen gives transit vehicles an advantage over passenger vehicles, the respondents are essentially acknowledging that direct hydrogen is the easiest fuel for the fuel cell to process, that this technology is farther along in development, and, therefore, that direct hydrogen fuel cell vehicles will happen first.

Transit infrastructure: Almost all respondents pointed out that another advantage for transit is the fueling infrastructure. While direct hydrogen is preferred by the fuel cell, the infrastructure is
not widely developed and is not familiar to consumers. This will not be as much of an issue for transit vehicles because they are centrally fueled. It will only be necessary to install hydrogen fueling at central bus depots; this constitutes a fairly small number of stations compared to what would be necessary to fill the needs of the passenger market. Also, buses are refueled and maintained by a skilled, dedicated staff that can be trained to safely dispense compressed hydrogen. Developing a hydrogen system that can be used safely by the general public is a more difficult task — whereas, in the transit vehicle market it is a much less onerous task. Transit operators can be trained on how to deal with hydrogen, whereas the general public has to have a seamless infrastructure experience similar or more beneficial than gasoline for the public to be interested.

Vehicle integration: Many respondents noted that a large transit vehicle offers better packaging options with regard to the fuel cell and hydrogen storage system. Fuel cell systems are still in development, and can have weight and size penalties as compared to internal combustion engine systems. Many respondents commented that this is less of an issue with the large transit bus applications, where there is more space to fit the fuel cell as well as the compressed hydrogen tanks, which need to be quite large at this point to allow the vehicle adequate driving range. In addition, the added weight of the fuel cell and hydrogen storage is less of an issue on heavy transit buses than with passenger vehicles. Recent prototype light duty vehicles have shown though that packaging and infrastructure can be addressed in a smaller vehicle.

Cost: Many respondents noted that the initial high cost of fuel cell vehicles would be less of an issue for transit applications because bus purchases are subsidized. One automaker noted that the “payback” time for buses is shorter than for passenger vehicles because they have an income. One regulatory agency commented that, in some cases, about 80% of the cost of a bus is federally subsidized, so they believe transit agencies can more easily bear the extra cost of a fuel cell powered vehicle. The passenger vehicle market, it was widely noted, is quite price sensitive. Several respondents, including one automaker, noted that consumers have not shown any inclination to pay more for “green” technology.

Societal vs. market drivers: Many respondents stated that the transit market is driven more by societal concerns, such as air pollution, noise pollution, and other environmental issues, than the passenger market is and that this gives an advantage to fuel cells. Transit agencies are under more pressure to consider the environmental and societal impact of their vehicles, and fuel cells will seem more attractive as an option for dealing with air pollution, toxins, greenhouse gases, and noise pollution.

Regulatory drivers: This category is related to the issue of societal drivers. Several experts commented that, for buses that operate in cities, fuel cells would be particularly attractive because urban governments are banning or limiting gasoline cars in their city centers. One automaker noted that this could be particularly important in driving the European market.

While most respondents thought that infrastructure for transit will make it easier to develop this market, some also noted that the transit market alone will not drive down the costs of fuel cell systems because the fleet numbers are too low. At 5000 new vehicles a year in the U.S., the transit market won’t provide the necessary economies-of-scale to make the cost of fuel cell systems competitive with internal combustion engines. Therefore, many experts feel that the early transit applications will be valuable primarily as test beds for this new technology, not as market drivers. An industry consultant commented that it will be best to put the early fuel cell buses into difficult driving routes to derive the most benefit out of these early “test beds”. This knowledge will be applicable to fuel cell systems for passenger vehicles as well as transit.

Other important information that might shed light on the situation is that fuel cell buses are currently priced at 4 or 5 times the cost of today’s diesel buses. It appears that in the near to
medium future, this cost split will not narrow because, as mentioned above, production volumes are not nearly high enough. The only markets that will be able to support fuel cell buses are the jurisdictions driving air pollution reductions and imposing ZEV policy, such as California. Currently, the alternative fuel and hybrid buses are meeting those standards. For example Sun Line Valley has switched their entire fleet to CNG. The CUTE European Bus Demonstration project is the largest scale demo of buses. The delivery of those buses is not scheduled until 2003 and so it will be another 2 – 3 years away from any assessment on the outcome of the demo and the performance of the buses in real operating conditions.

**Timeframe for passenger market penetration**

As for passenger vehicles, there less of a consensus on when fuel cells might achieve a significant market share. Respondents agreed it would take longer than for transit and most seemed to agree that five- percent penetration was at least ten years away, but actual predictions varied. Of the auto manufacturers, most predicted it would happen after 2010. One automaker predicted between 2010 and 2015; one said it would be between 2010 and 2020; and one said simply that it would be after 2010. One automaker did not make any specific prediction, but said that, following commercial introduction of fuel cell vehicles, it would probably take a five to eight years starting phase to make the public aware of the advantages of fuel cell vehicles.

As for the other respondents, two energy companies predicted that it would be sometime after 2010, as did an alternative fuel company and two fuel cell companies. Others feel it is further away: a hydrogen supplier and a hydrogen generation technology company feel that it will happen closer to 2020, and an alternative fuel company said it will be far past 2010. A regulatory agency was one of the few who thought it might happen earlier than 2010; this respondent predicted it could happen around 2008 – 2010.

**Cost Comparison of Vehicles**

In February 2002 a report was prepared for the US. DoE by Arthur D. Little, Inc., titled “Guidance for Transportation Technologies: Fuel Choice for Fuel Cell Vehicles” 9. The report was written to help the Department set targets for its direct hydrogen program, and focused on the timeframe around which fuel cells are now projected to become ready for mass-market introduction. In its assessment it considered emissions and cost comparisons of IC engine, hybrid electric, and fuel cell vehicles. The report projected that because of energy efficiencies and high cost, fuel cell vehicles would not begin market penetration before 2010 and beyond.

The report’s calculations revealed that even the most economical hydrogen fuel chains are expected to be over two time more expensive than gasoline, on a $/GJ basis due to capital cost of complex systems, transportation and distribution costs, and high feedstock costs. According to the report alternative fuels, especially hydrogen will require a significant upfront investment. Taking into account possible variations in fuel cost; electricity hydrogen and ethanol are likely to be substantially more expensive than gasoline, as shown in the following graph.

**Graph 3.3.1: Sensitivity Analysis – Fuel Cost (LHV)**
Conventional fuels are by far the least expensive fuels on an energy content basis, thus keeping fuel cell vehicles uncompetitive with ICE vehicles. Predictions were made, that only after easy-to-produce oil resources were used up, would conventional fuel prices begin to rise significantly, and this is not expected until well after 2010.

As for the vehicles themselves, performance of the fuel cell stack remains the key barrier in achieving comparative cost with hybrid electric or conventional vehicles. Current fuel cell vehicle power unit cost is 2 – 3 times the DoE/PNGV target of $45/kW. Costs of owning a fuel cell vehicle would be $1,000 - $2,000 higher than that of conventional ICE vehicles on account of the high initial vehicle cost. Based on the report’s scenario analysis, factory costs of future fuel cell vehicles will likely be 40-60% higher than conventional vehicles. While ICE vehicles typically cost $50/kW, the current cost of fuel cell technology is running at $1,000 to $1,500/kW.

U.S. Department of Energy Planning Timeline

Appendix 2, “Accelerated Timeline to Establish the Capability of Hydrogen Fuel Cell Vehicles”, issued in 2001, highlights the U.S. Department of Energy’s view of the development and commercialization timeline for fuel cell vehicles. The Department has become more conservative in its estimation of fuel cell commercialization than in previous years. This year the DoE released two documents; one in February of 2002, entitled “A National Vision of America’s Transition to a Hydrogen Economy”, and the second being The Fuel Cell Report to the Congress – April 2002. The former is a broad scope outlook of the future hydrogen economy as a whole, and estimates that the market introduction of personal vehicles will not occur until around 2030, as shown in Appendix 3. As can be seen in the following table, the current view generally reflects the timelines identified in the Future Wheels report. However, it is significant to note that commercialization only really is forecast to begin beyond 2012, a full decade away.

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<th>Phase 1</th>
<th>Feasibility Demonstrations</th>
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<td>Phase 2</td>
<td>Controlled Fleet</td>
<td>2004 – 2008</td>
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<td>Demonstrations</td>
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<td>Phase 3</td>
<td>Commercial Fleet</td>
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<td>Commercialization</td>
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A growing number of press articles support this view that the market commercialization of the personal passenger vehicle is considerably downstream. On March 16, 2002 the National Post printed an article that had the following comment from General Motors:
“Gas and diesel-powered cars won't disappear for another 50 years.”

GM has spent hundreds of millions of dollars and now has 250 employees working at developing hydrogen fuel cell powered cars. However, there is currently little consumer demand for alternatives to traditional fossil fuel powered vehicles and there are many regulatory, technical and financial hurdles to overcome on the way to a hydrogen-based transportation system.

A recent article in the London Times ran with the header:

“British Government does not see Hydrogen as fuel for 20 + years”

The government is facing a battle with leading car manufacturers over the future after deciding that fossil fuels will not be phased out for at least another 50 years. Ministers have rejected a proposal to convert Britain’s cars to hydrogen by 2025, and called on manufacturers to develop more efficient models powered by gasoline or diesel. Mr. Jamieson, the Minister for Transport, said that renewable sources of hydrogen would not be available on a large enough scale for road transport until after 2050. He is therefore refusing to support a national network of hydrogen filling stations. The general belief is that the hybrid vehicle will be the focus for the short to intermediate term.

Taking into account the above information, it is necessary to stress that there is no certainty as to the timeframe of commercialization of either bus or personal vehicles markets. In a report written by PricewaterhouseCoopers for the Government of Canada, “Fuel Cells: The Opportunity for Canada” in June 2002, they state that in order for the industry to reach its potential, pricing must become competitive with incumbent sources of power. The authors of the report project that pricing for fuel cells systems will meet incumbent pricing by 2008. The report goes on to say that analysts expect stationary fuel cells to be the first to significantly penetrate the market starting in 2006/07. Transportation fuel cells will only begin to gain broader market acceptance by 2010/11. Even at this level, analysts are only projecting a penetration of less than two percent of the new vehicle market by 2011.

3.4 14th World Hydrogen Energy Conference: Update

In June of 2002, members of the Transportation: Vehicles and Refueling Working Group attended the 14th World Hydrogen Energy Conference held in Montreal. The event extended for five days with plenary sessions in the mornings and parallel presentations in the afternoon on a wide variety of topics pertaining to hydrogen and fuel cell technology. Participants and presenters came from all over the globe, however there were strong contingents from Canada, Germany, Japan and the U.S.

The conference served to revalidate the points that have already been made in this report. The Conference held a feeling of general enthusiasm with some pessimism as to the future of the hydrogen industry. Transportation applications seemed to be the central focus of the conference, concentrating on the challenges ahead, namely cost and distribution of hydrogen fuel. Some of the presenters brought some interesting points to light.

Revalidating previously made points

It has been difficult to obtain information regarding the hydrogen vehicle industry that is more recent than one or two years old. WHEC served to revalidate the status of the main drivers, key players and technology. Several presentations reiterated the drivers behind fuel cell and hydrogen technology to be air pollution, reducing GHG emissions, and solidifying energy security
and reducing dependence on foreign oil. In the wake of events on September 11, 2001, energy security seemed to be a hot topic and the main issue in the U.S. DoE.

Government is a major player in the North American, European and Asian fuel cell industry, playing a large role in policy and funding, as well as information sharing. The vehicle manufacturers, fuel cell developers, and major component suppliers to the automotive industry mentioned in section 3.1 have for the most part remained unchanged. One point that is important to make, and that was made previously is that fact that the fuel cell industry timeline is hard to predict because it is government driven and not economics driven.

Technology has of course improved, with the main R&D focus on kW output of fuel cells, storage, handling and infrastructure, and sources of hydrogen energy such as biomass, solar and wind. However, along with the improvements the same challenges still remain of prohibitive costs, hydrogen infrastructure and transportation, and the need for a universal revamping of safety codes and standards. In addition the technology is still far from being commercially ready.

Key take aways

There were several key points that several of the presenters made continuously throughout the five days that need to be included in this report.

- New investment (including IPOs and secondary offers) in the alternative energy industry has decreased significantly over the past two years. In 2000 new investments in North America were close to 1.6 billion U.S. In 2001 new investments dropped to roughly 600 million, and in 2002 to date, new investments in North America are at 100 million USD. This is basically a result of investors not wanting to invest in development stage companies.

- In order to ensure the continued growth and success of hydrogen and fuel cell technologies for transportation, governments will have to initiate more policies and mandates, and subsequent funding. Without these it will not be economically feasible for private investors to progress the technology development.

- There will need to be a major breakthrough in reducing cost, reliability, and performance of fuel cell vehicles for their ensured success.

- There will have to be major breakthrough in production, transportation, handling and distribution of hydrogen in order for the industry to progress and in order to see the adoption of fuel cell vehicles.

Conclusions

The preponderance of opinion suggests that the transit market will provide the test bed with the automotive market following. As the transit market is the only significant transport sector that Manitoba currently participates in, it is obvious that Manitoba should be exploring every opportunity to become a player in the development of fuel cell powered buses.

Of note to this report is the absence of any discussion on the applicability to the long haul truck, marine and rail sector of the marketplace. All of our research work on fuel cell development suggests that the truck, and marine sectors will follow the developments in the bus and automotive markets. We found no indication of any implementation in the rail industry in the next
two decades. The marketplace has sorted out the rational introduction of fuel cell technology to the transportation marketplace.
4.0 The North American Competitive Environment

The “Hydrogen Economy” has been identified in the United States as the long-range goal for achieving a more emission-free environment and making the U.S. less dependent upon other regimes for energy supply. Fuel cells have been under intense development for over a decade and are still a long way from full commercialization. Some writers talk about the shift in energy sources from fossil fuels to hydrogen as a “paradigm” shift, however, it is one that is taking place over an extended period of time. Implementation has had to wait for the market drivers needed to generate the investment for research and development and then for technological breakthroughs to develop technologies that work and can be produced at a low cost in a manufacturing environment.

Consequently, the current focus on emissions reduction is improvement to existing technologies, particularly for transport vehicles. A total of 24 states in the U.S. have established and developed financial incentive programs to promote for cleaner transportation technologies, over and above what the federal law requires. These incentives primarily focus on alternative fueled vehicles but in some cases provide for fuel cell vehicle development. In most cases the incentives for fuel cell implementation are in the power supply market for the installation of stationary fuel cell power plants for commercial use.

In several jurisdictions, the base economy of the state is driven by the design, development and production of automobiles and other transport related activities. These states have taken specific measures to ensure that their companies participate in the new economy. To not do so could spell economic disaster for the state in the future. Both Michigan and Ohio have evaluated their capability to participate in the “Hydrogen Economy” and have developed action plans to ensure that their states are players in the future.

4.1 Michigan

In August 2001 the state of Michigan issued a report titled “Positioning the State of Michigan as a Leading Candidate for Fuel Cell and Alternative Powertrain Manufacturing”. The report was written in hopes of identifying “key market trends in new powertrain technologies (including fuel cell) and hybrid electric vehicles – a critical enabler for automotive fuel cell application – and assist the State in identifying critical actions to position itself as a strong candidate for potential automotive fuel cell manufacturing investment.”

The following quote is taken from the executive summary to this report.

"Many industry participants believe that fuel cell technology had the potential to replace the ICE as the primary source of propulsion for automotive applications. Although there are significant hurdles yet to be overcome in the development of a cost-effective automotive fuel cell and a viable infrastructure, the implications for the automotive industry and the State of Michigan could be truly profound. There are 10 engine plants and 5 transmission plants in Michigan and nearly 27,000 people are employed in these facilities. The development of a cost-competitive automotive fuel cell would likely make many of those powertrain facilities obsolete."

In developing its strategy for the future, Michigan has analyzed the new processes for developing and manufacturing hydrogen fuel cell vehicles in relation to the existing technologies available in Michigan. In order to position Michigan as a leading candidate for fuel cell and alternative powertrain manufacturing, the following recommendations were made:

- Create a Michigan Advanced Automotive Powertrain Technology Alliance;
• Investigate the feasibility of creating a power electronics “Center of Excellence”;  
• Establishing a Michigan Hydrogen Infrastructure Working Group;  

• Promoting the demonstration and testing of prototype fuel cell vehicles and supporting the commercialization of fuel cells for advanced vehicles and stationary applications; and  

• Conducting an economic study to determine the most appropriate financial incentives for the development and commercialization of fuel cell and other advanced technology vehicles.

On April 2002, Governor John Engler unveiled NextEnergy – a comprehensive economic development plan to make Michigan a world leader in the research, development, and commercialization manufacture of alternative technologies such as hydrogen fuel cells. These technologies include mobile applications to power cars and trucks, stationary uses for homes and factories and portable needs such as laptop computers, cell phones and PDAs.

Engler’s energy blueprint proposes the creation of a 700-acre, tax-free NextEnergyZone in York Township near Ann Arbor, building the NextEnergy Center there and attracting alternative energy companies from around the world to the zone, making it a cluster of energy innovation.

Highlights of the blueprint include:

• **NextEnergy Center** – a state-of-the-art facility affiliated with the University of Michigan will serve as a comprehensive clearinghouse and information resource on alternative industry-university collaborative research and commercialization projects.

• **Michigan NextEnergyZone** – a 700-acre state owned site that will become the focus of the alternative energy cluster of innovation. In addition to being designated a tax-free Renaissance Zone, companies that locate there will receive a tax rebate based on the jobs they create in the zone.

• **National alternative Energy Program** – Designed to complement the work of the NextEnergyCenter, the national program could act as a type of Underwriters Laboratory for the development of industry standards, certification systems and to identify research gaps and needs.

• **NextEnergy Tax Incentives** – Exemptions from the SBT and personal property tax for companies, or activities within companies, whose primary focus is alternative energy research, development of manufacturing.

• **Spurring NextEnergy Demand** – Steps include an exemption from the sales and use tax of any purchase of stationary and vehicular devices using alternative energy technologies.

• **NextEnergy Leadership Council** – Governor Engler will appoint national experts to this panel to provide critical advice on the implementation of our NextEnergy agenda and on issues ranging from research investments to questions about intellectual property.

• **NextEnergy Demonstration Microgrids** – These microgrids powered by fuel cells or other alternative energy technologies would demonstrate that these solutions are viable.
• **International NextEnergy Conference** – Michigan will host this event where industry and academic leaders can share innovations and work with government officials to new energy policy initiatives.

Complete text of NextEnergy can be found at [www.nextenergy.org](http://www.nextenergy.org)

### 4.2 Ohio

A report written in November 2001 by the Weatherhead School of Management called “Opportunities for Creating a Fuel Cell Industry in Ohio”\(^\text{14}\), observes that a realignment brought about by emerging fuel cell technology will be profound, not only for consumers but equally so for industry and regions where these new industry activities will eventually cluster. Change inevitably brings with it opportunities for the quick and agile. States will need to be nimble if they wish to capture the job growth and new wealth that business activities are going to create. Because of its research presence in electrochemistry and its manufacturing expertise in specialty materials, components and control instruments, Ohio is well suited to become a national leader in fuel cells. However, the report suggests that although Ohio is populated with several world-class materials and component suppliers, it currently lacks a fuel cell manufacturing facility. This void constitutes an important leak in the commercialization system. As a result, fuel cell technology engineered at Ohio R&D labs is likely to flow out of the state and enrich firms and workers in other communities.

To participate in this growth this report recommends five policy strategies:

- Growing the R & D base;
- Creating a fuel cell institute;
- Workforce training;
- Fostering a more supportive regulatory environment;
- Increasing the visibility of Ohio’s competitive assets.

Several states have initiated monetary programs designed to advance fuel cell development and implementation.

### 4.3 Connecticut

The Connecticut Clean Energy Fund solicited and received 31 proposals in response to its Fuel Cell Initiative Request. In its first year the fund is expected to pay out $ 6 million to support these applications.

The Clean Energy Fund invests in enterprises and other initiatives that promote and develop sustainable markets for energy from renewables and fuel cells that will benefit ratepayers. This program is targeted at electrical generation projects as the funding comes entirely from electrical ratepayers in Connecticut.

### 4.4 Texas

In 2001 the State of Texas enacted a bill to create the Texas Fuel Cell Commercialization Initiative. The original concept called for the allocation of $ 95 million to competitively promote and facilitate the accelerated commercialization of clean small-scale fuel cell power generation
and small combined heat and power fuel cell systems. This bill was not implemented as planned. The funding has not been allocated and the program has been reduced to undertaking a study. We were advised that Texas is leaving all activity related to transportation vehicles to projects already in existence such as the California Fuel Cell Partnership and other federal projects to progress the development of the fuel cell vehicle.

*The former noted State programs are specifically focused on fuel cells or hydrogen based fuel.*

### 4.5 State Incentives for Cleaner Transportation Technologies

Many states are more focused on cleaner transportation technologies than fuel cell implementation and have developed a broad range of programs to stimulate investment in and conversion to cleaner transportation technologies, as seen in Appendix 13. A report titled “*State Incentives for Cleaner Transportation Technologies,* September 2001†”, prepared for the U.S. Environmental Protection Agency assessed these incentives as follows:

#### Federal Alternative Fuel Vehicles (AFV)

The federal government offers several tax incentives to promote AFV’s:

- A federal income tax deduction is available for the purchase of new qualified OEM clean fuel vehicles or for the conversion of a vehicle so that it can use clean-burning fuel ($2,000 for auto’s; $5,000 for a truck or van between 10,000 & 26,000 pounds; $50,000 for a bus or truck over 26,000 pounds);

- An income tax credit is available for the purchase of qualified electric vehicles and hybrid electric vehicles. (10% of cost to max of $4,000);

- A tax deduction of up to $100,000 per location is available for qualified clean fuel refueling property or recharging property for EV’s.

#### Blue Sky Engine Series

EPA has established voluntary emission standards for non-road and marine diesel engines. Engines that meet these standards are usually at least 40 % cleaner than current regulations require and are given the Blue Sky Series label. State and local governments have started to offer incentives aimed at promoting use of the Blue Sky Series engines.

A number of other federal programs targeted at advancing clean technologies are summarized in table include:

- Voluntary Diesel Retrofit Program
- Partnership for a New Generation of Vehicles
- Advanced Vehicle Technologies Program (AVY)
- U.S. Advanced Battery Consortium
- Clean Cities Program
The majority of the state incentive programs rely on monetary reward to promote cleaner transportation technologies. These types of programs generally seek to offset the higher cost associated with purchasing or operating an energy efficient or low emission vehicle. Monetary incentives may be structured as a tax incentive, a grant, or a reduction in fees. Most monetary incentive programs typically fall into one of four categories:

- AFV purchase incentives,
- Emission-reduction (non-AFV) incentives,
- Fuel purchase incentives, and
- Infrastructure development incentives.

State AFV purchase incentives generally include a selection of the following incentives:

- Individual income tax credit or deduction
- Retail sales tax reduction or exemption
- License or tilting fee reduction
- Corporate tax credit or deduction
- Grants or rebates to individuals
- Grants or rebates to local governments
- Grants to small businesses
- Low interest loans to local governments

A recent report by the National Conference of State Legislatures provides an assessment of the effectiveness of state incentives in promoting market penetration by AFV’s16. The report finds that use of AFV’s has grown since incentive programs were adopted over the past ten years, but that AFV’s still account for only a tiny share of the total on-road transportation sector. Between 1992 and 1999, the consumption of alternative fuels grew from 0.17 % to 0.22 % of all transportation fuels, while the AFV population grew from 0.13 % to 0.19 % of the total U.S. vehicle population. The report also notes that AFV incentives may have encouraged advancement in new clean transportation technologies, but it is difficult to measure this impact.

The conclusions to the report on State Incentives observed that state programs are generally effective at promoting new technological advancements in the transportation sector only when they fund R&D efforts or partner with private industry. Because of the large amount of funding needed for these efforts, only large states like California or New York are typically involved. Both of these states are effectively supporting demonstrations of new cleaner transportation technologies. The CaFCP is the most significant joint venture between a state and the private sector to develop new transportation technologies, though its success is yet to be determined.

### 4.6 FreedomCAR Program

FreedomCAR, the new cooperative automotive research (CAR) partnership between the U.S. Department of Energy and USCAR, will be replacing the current Partnership for a New
Generation of Vehicles (PNGV), initiated in 1993. The PNGV program emphasized R&D programs to triple automobile fuel efficiency. Since the initiation of the PNGV the situation has changed and the National Research Council Peer Review recommended restructuring the program because of significant developments and achievements in related fields such as declining fuel economies because of SUVs and significant R&D progress.

DoE and industry partners agree that public/private partnerships are the preferred approach to R&D, however the cooperative effort must be refocused in order to:

- Aim at longer range goals with greater emphasis highway vehicle contributions to energy and environmental concerns;
- Move to more fundamental R&D at the component and subsystem level;
- Assure coverage of all light vehicle platforms;
- Maintain some effort on nearer term technologies that offer early opportunities to save petroleum;
- Strengthen efforts on technologies applicable to both fuel cell and hybrid approaches; e.g., batteries, electronics, and motors

FreedomCAR will accelerate the development of affordable fuel cell-powered vehicles and renewable fuels, a long-term goal of USCAR researchers. The program has a budget of $150 million. Secretary of Energy, Abraham stated that the new partnership has been created “to promote the development of hydrogen as a primary fuel for cars and trucks as part of our effort to reduce American dependence on foreign oil.” A more detailed look at FreedomCAR’s technology-specific 2010 goals can be found at [http://www.cartech.doe.gov/freedomcar/technical-goals.html](http://www.cartech.doe.gov/freedomcar/technical-goals.html)

### 4.7 Canada

Due to the success of Ballard Power Systems Inc. in B.C., significant research in hydrogen technologies and large-scale demonstration projects, such as the Euro-Quebec project in the 1990’s, Canada has positioned itself as a leading nation in fuel cells and hydrogen technologies. Most of the fuel cell industry in Canada is clustered in four provinces: B.C., Alberta, Ontario and Quebec. Activities in these clusters are as follows:

<table>
<thead>
<tr>
<th>Regional Cluster</th>
<th>Activities</th>
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<tbody>
<tr>
<td>BC</td>
<td>Focused on PEMFC technology</td>
</tr>
<tr>
<td></td>
<td>Ballard Power Systems leading to cluster development</td>
</tr>
<tr>
<td></td>
<td>Service companies and organizations (e.g., venture capital) specific to the fuel cell industry becoming established</td>
</tr>
<tr>
<td>Alberta</td>
<td>Currently at an embryonic stage</td>
</tr>
<tr>
<td></td>
<td>High interest in fueling infrastructure from major companies</td>
</tr>
<tr>
<td>Ontario</td>
<td>Companies developing PEMFC and SOFC technology</td>
</tr>
<tr>
<td></td>
<td>Clustering being led by Fuel Cell Technologies, Hydrogenics and DuPont Canada</td>
</tr>
<tr>
<td></td>
<td>Centre of Canadian Automotive manufacturing area</td>
</tr>
<tr>
<td>Quebec</td>
<td>Close proximity to US automotive manufacturers</td>
</tr>
<tr>
<td></td>
<td>Has attracted subsidiary of US fuel cell company H Power</td>
</tr>
</tbody>
</table>
A non-exhaustive list as of fuel cell development companies (prepared in December 2000) can be found in Appendix 14. Notably absent from the list is Manitoba, however, Kraus Global is heavily involved in fueling infrastructure.
4.8 Alberta Study

The Province of Alberta has recognized the potential impact on the provinces economy with the development of fuel cell technology. Key ripple effects are anticipated in the following areas:

- Lower growth demand for gasoline with potentially offsetting heightened demand for natural gas as a source of hydrogen;
- A diminution on demand for traditional centralized, large-scale power plants with an offsetting growing focus on distributed power supported by fuel cells; and
- A concurrent reduction in investments for the expansion of centralized electricity grids, as the attractiveness of such investments diminishes.

A confidential report titled “The Alberta Fuel Cell Industry: Strategy Options for Growth”\(^{17}\), has identified a range of strategy options for the province to implement to facilitate its ability to participate in the integration of fuel cell technologies in our economy as follows:

- Demonstration projects;
- Distributed generation projects as catalysts;
- Incentives to promote energy efficient buildings using fuel cells;
- A fuel cell liaison;
- The Canadian Venture Exchange as a financing vehicle;
- A web presence for fuel cell applications in Alberta;
- A university based research & development institute;
- A private sector research and development laboratory;
- A refundable corporate income tax credit; and
- Fuel cell associated educational technology tax incentives.

The report states that by adopting a somewhat pro-active stance, while being fully cognizant of the limitations and risks currently characterizing the fuel cell market, the Province could reap benefits by assuming the role of an early market leader. The Province then becomes a developer and supplier of technology, rather than a positioning itself behind the curve, essentially as a consumer.

Conclusion

Most jurisdictions in North America have recognized the opportunities that will flow through the growth of the fuel cell industry. Jurisdictions that will be affected by a powertrain shift to fuel cells are taking steps to ensure that they participate in the future development of the industry. As identified above, the growth will likely take place around the geographic clusters that are now developing. For Manitoba to participate in future fuel cell development, it is essential that the provincial government complete the development of a fuel cell strategy for Manitoba and invest in
its development. For Canada, it is essential that investment be focused on the fuel cell industry to ensure that Canadians will not lose out as foreign competition exploits the opportunities.

5.0 Technical Assessment/Commercialization Status in the Transport Industry

5.1 Technology Status and Market Adoption Status Definitions

Fuel cell technology has been in development stages since the 70’s and yet, the technology has still not been perfected or come close to commercial production. The development and commercialization of this technology has been both hindered and helped by market drivers. The project calls for the assessment of the technology in terms of its “Technology Status” and its “Market Adoption Status”. The assessment has been based on standard definitions for the current state of the technological development and market adoption as follows:

Technology Status Definitions (Five Stages):

- **T1. Idea Concept Formulation Stage:** Concept for product defined based on valid scientific knowledge. No working model but potential exists.

- **T2. Research Stage:** Technical R&D undertaken. A product defined (although may not yet be finalized), including form (how it will work) and functionality (what benefits it provides). End results is a working unit of some kind although not necessarily at final scale, and also without regard to cost or efficiency.

- **T3. Development Stage:** Product is refined to reach or be substantially within reach of defined cost and performance goals. End point is working prototype system and working design at least for alpha unit to be used for testing under real market conditions.

- **T4. Pre-production and Demonstration Stage:** Test units in demonstration that prove technology will work under actual condition for anticipated market. Include alpha and beta test units. Honing and refinement of technology may be undertaken although often related to manufacturing. End point is product prepared for release to markets under commercial conditions.

- **T5. Matured Product Stage:** Product is available in form that can be released to market. Readiness in this regard does not necessarily imply that it is acceptable to a market, only that it is available.

Current adoption and commercialization status of different application markets will vary significantly. Implementation of a selected technology, if accepted by a specific market, likely will follow an “S”-shaped curve, but acceptance and timing of adoption will be dictated by market forces and are both uncertain.

Market Adoption Status Definitions:

- **M1. Innovators/Technology Enthusiasts:** Selected market group committed to new technology, with less regard to economics or risks of the moment.

- **M2. Early Adopters/Visionaries:** Adopters who identify competitive advantage in application of new technology, despite still relatively high risk associated with technology.
- M3. Critical Niches: Technology begins to prove itself such that perceived risks are less than potential benefits. Attainment of 5% to 15% market penetration within niche markets that lead to broader market recognition (not just awareness but propensity to purchase) and broader adoption of the technology.
- M4. Early Majority/Pragmatists: Large group that begins to adopt technology once benefits are proven and risks are tolerable.
- M5. Late Majority/Conservatives: Relatively risk-adverse segment that adopts a new technology only after a significant proportion of the market has adopted it.
- M6. Lagging market/Tradition Bound: Lagging segment that is highly suspicious of change and likely to adopt when there is no other choice.

5.2 Light Duty Applications

Light Duty Vehicles/Cars

In discussion with several industry experts it is evident that the automotive manufacturers are the key drivers of hydrogen and fuel cell technology development for vehicular use. According to Fuel Cell Power for Vehicles\(^\text{18}\), roughly 60 million new cars are sold worldwide every year. Several automotive industry leaders are speculating that fuel cell vehicles could account for 20 to 25 percent of new car sales within the next 20 to 25 year. That would mean a potential annual market of 12 to 15 million vehicles, and billions of dollars for the automotive companies. As alluded to earlier in the discussion, the key automotive manufacturers (DaimlerChrysler, Ford, General Motors, Honda, Hyundai, Nissan, Toyota, and Volkswagen) are spending billions of dollars in a race to bring fuel cell vehicles to the marketplace. Some companies are making promises to deliver their first fuel cell vehicles by 2004.

Through extensive research, a few things have become evident; every major automotive manufacturer has formed alliances and partnerships with other manufacturers, fuel cell developers and government agencies. Each of these alliances has made significant headway in fuel cell vehicle development. While not one of these groups has a fuel cell vehicle available on the commercial market and market adoption status is at the M1 to M2 stage, each has at least one vehicle in the T3 to T4 stage of technical development. Appendix 4: Sample Of Fuel Cell Vehicles In Development, gives a good indication of each companies fuel cell vehicle efforts.

DaimlerChrysler

Over the next four years DaimlerChrysler will invest more than $1.4 billion to develop fuel cell technology. As mentioned earlier in the report, DaimlerChrysler has been the leading force behind the NECAR Development Project, and unveiled NECAR 1, a hydrogen fueled fuel cell mini-bus, in 1994. The NECAR 2, released in 1996, used a hydrogen-fueled fuel cell power train in a Mercedes-Benz van. The NEBUS was presented in 1997 as the first fuel cell powered bus. Also introduced in 1997, NECAR 3 was the world’s first fuel cell car fueled by methanol. In 1999, the company unveiled NECAR 4, a compact car using LH2. The last of the series to be released was NECAR 5, released in November 2000. The technological successor of the NECAR 3 reaches peak velocities of more than 150 kilometers per hour. In this car the complete drive system inclusive of the methanol reformer is located in the under-side of the Mercedes-Benz A-Class. Compared with the NECAR 3 it is 50% more efficient, and only half as big and weighing 300 kilograms less. As a further step in the direction of commercialization, DaimlerChrysler is now concentrating on the use of cost-effective materials.
**Ford Motor Co.**
Ford Motor Company introduced the world’s first production-prototype, direct-hydrogen powered fuel cell vehicle in November 2000, the Focus FCV, based on the Focus platform. The Focus FCV has a direct hydrogen powertrain configuration. Ecotrac Electric Drive Systems and XCELLIS supply the electric motor and fuel cell engine respectively.


**General Motors**
At the 2002 Detroit Motor Show, General Motors displayed the mockup of concept fuel cell vehicle, the AUTOnomy. The vehicle consists of two basic parts – a four-wheeled chassis platform that is meant to house the drivetrain essentials, and the body. It has also been developing the HydroGen 1, an Opel Zafira minivan platform, as well as, doing work on a gasoline-reforming, fuel cell S-10.

**Honda**
Honda has been developing its FCX-V since 1999 when it first released its FCX-V1. It has since modified and improved upon the first prototype, and in April 2002, Honda confirmed that it plans to make roughly 20 FCX-V4 hydrogen fuel cell cars available by 2003 in Japan.

**Nissan**
Nissan has completed initial development and has begun driving tests of a fuel cell vehicle equipped with a methanol reformer. The Nissan Fuel Cell Vehicle adopts a high-efficiency neodymium magnet synchronous traction motor combined with lithium-ion batteries that enable the vehicle to achieve optimum electric power by switching between a fuel cell-powered driving mode and a battery-powered driving mode.

**Toyota**
Toyota has chosen the Highlander SUV as a platform for its fuel cell vehicle and uses its own fuel cell technology to power its vehicles. The vehicle has been named FCHV and has reached its 5th design stage.

**Volkswagen**
In April 2002, Volkswagen and Paul Scherrer Institute release information on their joint efforts to produce a low-cost hydrogen fuel cell. The fuel cell incorporates new membrane use, which is cheaper to manufacture and is integrated with the Jetta platform. Volkswagen is also doing work developing ultra capacitors.

**Assessment**

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<tr>
<th>Technology Status</th>
<th>T3 – T4</th>
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<tr>
<td>Market Adoption Status</td>
<td>M1 – M2</td>
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**Hybrid and Alternative Fuel Vehicles**
Another interesting observation is that hybrid and alternative fuel vehicles (AFV) appear to be the start of an evolution towards fuel cell vehicles. Some experts believe they are clearly only an interim to fuel cell vehicles, while other think they are a long-term technology. Several experts predict that once fuel cells emerge to the market, they will be preferred over hybrid electric vehicles. According to *Future Wheels*, after internal combustion engine hybrids, there could be a larger contribution from the electric system and less from the ICE. Some companies are currently looking into hybrid fuel cells to see if the battery could help improve the performance of pure fuel cell systems. The question remains how long hybrids and AFVs will dominate the market before fuel cells take over. Will hybrids remain a long-term technology or are they just an interim? Many experts believe that the length of their run in the market will depend on several factors such as the hybrid’s environmental performance, the fuel cell’s commercial timing and infrastructure.
development, and consumer acceptance of both technologies. Some experts say that hybrids are both a long-term technology and an interim step. They are a great transition technology, but they will be around for a long time because they use the existing infrastructure and are similar to what the general public is used to. Appendix 5, Sample of Hybrid Vehicles, and Appendix 6, Sample of Alternative Fuel Vehicles, give an overview of Hybrid and alternative fuel vehicles being developed or currently on the market.

### Scooters & Bicycles

The market potential for pollution free, two wheeled vehicles is enormous. There are an estimated 100 million motorized two-wheeled vehicles in use worldwide. The greatest concentrations are in Asia. Worldwide scooter production is estimated to be above 17 million a year and use is expanding globally. According to an article published by Eye for Fuel Cells¹⁹ in November of 2001, an estimated 10 million noisy, polluting scooters were sold in China in 2000 and an estimated 3 million in India. According to Palcan Fuel Cells, “Research has determined that electric bikes are the world’s largest and fastest growing electric vehicle market. Battery powered scooters, which target an even larger potential market by replacing polluting 2 stroke engines, have had little impact due to both limited range and lack of recharging infrastructure. Fuel cells, with their superior performance, are expected to make electric scooter and bikes into a multibillion-dollar industry.”

#### Bicycles

In the fall of 2001, Italian bike makers, Aprilia unveiled its prototype fuel cell bicycle. The bike is powered by a fuel cell produced by the Manhattan Scientifics, Inc in Germany, and stores compressed hydrogen in a two-liter canister housed in the frame. The bike was named invention of the Year 2001 by Time Magazine. Time said, "Fuel cell technology, which uses pollution free hydrogen gas to generate an electric current, could ignite electric bike sales. The bike has a top speed of 20 mph, weighs 20 % less than regular electrics and travels twice as far, about 43 miles before it needs more gas. The bike is estimated to be available in 2003 for approximately $2,300.

### Scooters

In November 2001 Manhattan Scientifics Inc. unveiled a fuel cell powered electric scooter, powered by the company’s 3000 kW fuel cell. Production models of the scooter are expected to have a range of 120 miles and attain a top speed of 35 miles per hour. The concept vehicle uses Manhattan Scientifics’ unique and proprietary fuel cell technology developed by its German unit NovArs Gmbh. The fuel cell system, including all electronic, valve and fans, weighs slightly less than 6 kg. The weight of the fuel vessel is only 4.3 kg.

In January 2002, India’s state owned Scooters India Ltd., announced that it is working on a zero emission fuel cell technology based vehicle. The scooter is slated to be launched in 2003 and the project is being financed largely by the Ministry of Non-conventional Energy Sources.

On April 17, 2002, Palcan Fuel Cells, out of Vancouver, reported it had entered into an agreement with Italy’s Celco Profil S.R.E. to jointly develop fuel cell power systems for the European scooter, electric vehicle and portable power industries. The initial demonstration
program will use the existing Celco electric scooter as the development platform. The objectives are to integrate the Palcan PalPac fuel cell power system with Celco’s battery operated scooter designs, and successfully demonstrate commercial performance of the system to major European scooter vehicle manufacturers. The initial products from this joint agreement are expected to be demonstrated in Europe sometime in the fall of 2002.

These recent announcements and prototype unveilings demonstrate that fuel cell scooters are at their beginning stages of development and commercialization. Essentially these companies are marrying low output fuel cells that are already available to existing vehicle designs. The potential market is huge in India and Asia as these vehicles are a primary mode of transportation. However, as was indicated in one of the articles, the new products will have to meet or exceed the performance of existing products to gain market acceptance. Appendix 7, Fuel Cell for Bicycles Applications, and Appendix 9, Hydrogen Fuel Cell Applications for Scooters, give brief summaries of worldwide progress in these two-wheeled applications of fuel cells.

Assessment
Technology Status  T3
Market Adoption Status  M2

5.3 Medium/Heavy Duty Applications

Buses

Although automotive manufacturers have been the leaders in developing fuel cell technology for transportation related applications, the majority of the demonstration projects have occurred in bus technology. In a report evaluating hydrogen fuel cell buses, the author, the National Renewable Energy Laboratory, explains that buses make up less than 1% of the total vehicles operated in the U.S., however, their concentrated use in the urban environments result in disproportionate public health impacts. The California Air Resources Board (CARB) identified buses as a major cause of human exposure to emissions of diesel particulate matter. Several factors make transit buses the ideal vehicles for fuel cell demonstrations: they typically operate in highly urbanized areas where pollution is a problem; they are centrally fueled; they are highly visible; and they are government subsidized.

Several prototype fuel cell buses have been demonstrated in Canada, Europe and the U.S. in recent years and several more demonstration projects are underway both in North America and Europe.

There are several bus manufacturers, fuel cell developers, electric powertrain specialists and government agencies forming alliances and cooperating in efforts to develop viable fuel cell buses for real life use. These demonstrations projects have been summarized in section 3.2 of this report and a snapshot of each demo can be seen in Appendix 1. These demonstrations have allowed manufacturers and developers to improve the technology significantly, and as mentioned previously, buses will most likely be the first fuel cell vehicles to market.

Assessment
Technology Status  T3-T4
Market Adoption Status  M1-M2

Railways

A fundamental point about rail transportation must be noted in the assessment of a fuel cell locomotive. The railway locomotive presents the most energy and emission efficient mode of moving freight today. Although significant improvements are expected in the truck engine, the lower rolling resistance of steel on steel will make rail transport less polluting because less energy per ton mile is required.

The leading research reports on fuel cell locomotives clearly identify that fuel cell technology will only be applied to the locomotive when the fuel cost and operating efficiency of fuel cell locomotives meets or exceeds the existing diesel-electric technology. Railways in North America, are bottom line driven and will not invest in technology that increases operating costs. Fuel cell locomotives are several decades away from matching the efficiencies of the diesel-electric locomotive.

A report from the International Union of Railroads questioned whether any energy efficiency gains can be obtained from fuel cells when considering the full energy chain. This study examined the total energy chain including the production of the hydrogen for the fuel cell. In the European context, much of the energy required to produce the fuel is fossil fuel driven. In North America, only a few geographic areas have abundant hydro (renewable resource) energy. In fact, the primary areas driving emission reduction in the United States are energy deficient. This report reaffirms that fuel pricing is the determining factor for the economic viability of fuel cell vehicles but it also raises the problem of fuel pricing being politically driven in many jurisdictions.

Our survey of the North American rail industry that included rail system operators, locomotive engine manufacturers, the Canadian and American railway associations and the leading fuel cell developer in Canada, indicated that they are not pursuing the application of fuel cells in locomotives. At the present time, the industry is not planning on initiating specific activity on this application in the near future. The industry generally believes that with time and money the engineering hurdles could be surmounted and a fuel cell locomotive could be built. However, the practical limitations of fuel cell locomotive implementation will preclude significant activity in the short and medium term.

**Assessment**

**Technology Status** T1

**Market Adoption Status** 0

**Marine**

A study was prepared by the U.S. Coast Guard Research and Development Center22 in September 1999 titled, “Marine Fuel Cell Market Analysis – September 1999”. The study argues that marine applications will proceed as a “fast-follower” shortly behind land applications of fuel cells. Marine market penetration of FC technology will depend on the rate at which land applications of fuel cells can be made technologically and economically competitive to primarily diesel engines as prime movers for propulsion and ship service generators. Most importantly for early adopters, market penetration will depend on emerging environmental requirements (e.g., emissions credits, regions with local air quality problems, etc.).

The Executive Summary of the report summarizes the marine fuel cell development;
“In partnership with the U.S. Navy and other Federal agencies, the U.S. Coast Guard has been investigating the feasibility of using fuel cells to provide shipboard electric power. Studies have been conducted which demonstrate the feasibility of reforming marine diesel to generate electric power using current fuel cell technology. Due to their higher efficiency, fuel cells can generate power using 25-30% less fuel than existing marine diesels or gas turbines. While it appears technically feasible to implement such technology, the future development of such systems for shipboard use remains an issue.”

A large database of ships in service and future construction was analyzed. In addition, interviews of naval architects, ship builders and ship owners/operators were conducted. The main goal of the survey analysis was to see if a significant market potential for fuel cell power applications could be identified for the years in the study forecast period. The interviews yielded two primary insights:

- Naval architects and ship builders generally espouse a position of technical orthodoxy. Some have not considered fuel cells at all, while others are waiting to see how rapidly such propulsion systems become commercially available.

- Ship operators said that relative cost, energy efficiency, and complexity are indirectly important. The two factors that drive their acquisition choice for any new technology are:
  - Increased productivity
  - Increased competitive advantage

If fuel cell technology can be made commercially justifiable with unit power output between 250 kW and 500 kW, the study concludes that the marine market potential for fuel cells could be tens of thousands of units sold by the year 2015.

The original authors of this study have been interviewed for the purpose of this study and it was determined that not a great deal of progress has been made in the ensuing 2 years. Indications have been made that problems are occurring with the PEM fuel cell in the maritime environment and that further research may focus on solid oxide fuel cells. Appendix 9 gives an overview of the marine applications research and development of fuel cells.

**Assessment**

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**Submarines**

In March 2002, Kowaldtswerke-Deutsche Werft AG (HDW) christened U31, the first of four 212A Class submarines. Destined for the German Navy, U31 is scheduled commissioning on March 30, 2004. HDW in Kiel and Thyssen Nordseewerke in Emden are currently constructing the four boats. The new class 212 submarine developed by HDW has an air-independent propulsion system using a hydrogen fuel cell. HDW is reported to be the first shipyard in the world to offer a fuel cell propulsion system ready for series production. The Italian Navy has followed the lead of the German Navy and is building two class 212 boats at the Fincantieri shipyard in Italy.

**Assessment**

<table>
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<tr>
<th>Technological Status</th>
<th>Market Adoption Status</th>
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<tr>
<td>T4</td>
<td>M3</td>
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</table>
Ferries
In March 2002, the San Francisco Water Transit Authority (WTA) announced it was awarded a $100,000 Federal grant to design the first fuel cell powered commuter ferry in the world. The vessel links Treasure Island with San Francisco and the East Bay. This project is a big step in extending zero emission fuel cell technology from cars to buses to boats. This grant will fund the design, cost estimates and final drawings for the fuel cell powered vessel, expected to be completed by Summer 2003. With this grant the region has the potential to put a fuel cell powered boat in the water within the next three years.

Small Boats
Several companies have initiated demonstration projects involving the installation of fuel cell propulsion systems in small boats. One example is the Hydra, a 12 m wooden passenger launch built in Germany. The fuel cell is built by ZeTek and is their “Europ 21” alkaline cell stack of 5 kW that drives an Ocosachs electric motor. Top speed is about 6 knots with a range of 50 miles on a single charge. ZeMar (ZeTek’s marine subsidiary) is working hard to overcome snags that still inhibit the adoption of fuel cells, issues mainly of cost, bulk, service life limitations and fuel storage.

At the 12th Annual U.S. Hydrogen Meeting in March 2001, a hydrogen-powered water taxi was shown for the first time. The boat is an open, 18-foot tri-hull, powered by a 40 kW surplus solar gas turbine developed by Winstead B. Weaver. The development program was paid for by DCH Inc. The turbine acts to recharge the battery system, which in turn drives an electric motor. 400 cu. Ft of gaseous hydrogen are carried in two light weight IMPCO tanks at 3600 psi to power fuel cells for the boat’s electronics. The boat is operated on Casaic Lake, CA, and will be upgraded to all-fuel cell propulsion. The boat was demonstrated through California. DCH hydrogen technology will also be deployed in other water taxis that will debut in Hong-Kong, as well as in Iceland.

Assessment
Technological Status T3
Market Adoption Status M2

5.4 Specialized Applications

Aviation (See Appendix 10, Fuel Cell Developments for Aviation Applications)

NASA Glenn Research Center
Zero CO2 Research Project - The goal of the Zero CO2 Research Project is to reduce or eliminate the environmental impact of subsonic air breathing propulsion systems. The project will develop enabling technologies for a hydrogen-fueled air breathing propulsion system.

Boeing
In November 2001 Boeing announced plans to develop and test an electrically powered demonstrator airplane as part of a study to evaluate environmentally friendly fuel cell technology for future Boeing products.

Boeing believes that fuel cells and electric motors will not replace jet engines on commercial transports but they could one day replace gas turbine auxiliary power units. Replacing the auxiliary power unit is their ultimate goal but first they are going to learn more about fuel cells by powering a small airplane and as the technology matures, use fuel cells to power an aircraft electrical system.
E-plane
FASTec and Advanced Technology Products of Golden, Colorado unveiled the plans to develop the first electric powered plane, E-plane, at the Osh Kosh air show in Wisconsin, July, 2001. The innovative research and education project focuses on designing, building and testing a 2-place general aviation airplane powered by DC electricity from fuel cells and advanced rechargeable batteries. When completed, the plane will be used in worldwide education programs to demonstrate emerging technologies such as fuel cells, electric drive systems and advanced materials and propeller technology.

The E-plane is being developed around an all carbon French built Lafayette III, donated by American Giles Aircraft of Dijon France. The plane is being developed in three stages. The first stage (expected to be completed in 2002) will equip the plane with advanced high energy, lithium-ion batteries powering a UQM 53 kW brushless permanent magnetic electric motor. By 2003, the plane is expected to be equipped with a combination of batteries and a 10-15 kW fuel cell and have a range of 250 miles. In its final form, it will fly solely on the power of a PEM fuel cell with a 500-mile range.

Assessment
Technological Status  T1
Market Adoption Status  M1

Industrial Fuel Cell Vehicles (See Appendix 11, Light industrial Fuel Cell vehicles)

A consortium of seven organizations was formed to develop and validate a light industrial vehicle powered by a fuel cell with on-board storage of hydrogen fuel as a metal hydride. The consortium consisted of:

- Deere & Company    IFCV manufacturing and sales
- Energy Partners    PEM fuel cells
- Westinghouse Savannah River Co  Metal hydride hydrogen storage
- Teledyne Brown Engineering  Hydrogen generator design and sales
- University of South Carolina –    Performance modeling & testing, H2 storage
- Center for Electrochemical Engineering  refueling testing
- York Technical College    IFCV validation testing
- Southeastern Technology Center  Project management and integration

Work began in August 1998 with the first of two prototype vehicles, Gator 1, being assembled and undergoing testing at the time of the latest report (summer 2000). The vehicle has been displayed at a number of venues and undergone testing. Lessons learned from this experience are being factored into the design of the second vehicle. One of the problems with the potential market penetration of the vehicle identified in January 2000 was the potential cost of the vehicle versus the competitive market. The cost estimates ranged from $13,000 to $19,000 per vehicle depending on manufacturing volume versus the cost goal of $5,000 per vehicle.

The Gators are currently being retrofitted with advanced fuel cell stacks and metal hydride fuel storage beds.

Golf Carts / Utility Vehicles
Astris Energi Inc has developed and demonstrated the world’s first fuel cell golf cart. Astris has been engaged in alkaline fuel cell development for 17 years. The new engine for the golf cart has been designed for use in a wide range of utility vehicles that can be utilized in airports, manufacturing plants, retirement communities, etc. The hydrogen fuel for the cart is contained in a small canister behind the seat of the cart and is sufficient to run the cart for three days of normal use.

On August 23, 2001 Astris announced a partnership with ACE Golf Cars, a division of ACE Concept, Inc, Indian Wells, California for the establishment of a joint venture for other small vehicles.

Whistler Inc’s Carbon-X fuel cell powered golf car marks the company’s entry into fuel cell projects across many industries. (December 10, 2001) The golf car, introduced by Whistler’s Voltairis Fuel Cell division is powered by an advanced proton exchange membrane fuel cell developed by Anuvu Inc. Voltairis Fuel Cell is bringing the technology demonstrated in this golf cart to commercial production and developing strategic relationships with original equipment manufacturers to build fuel cell powered products.

Voltairis is developing a commercial production capacity for Carbon-X fuel cells in the 1-25 kW range. With the planned pilot fuel cell manufacturing plant, Voltairis will begin volume production of Carbon-X fuel cell systems for 12 volt to 96 volt mobile and portable equipment applications in 2002.

**Assessment**

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<th>Technological Status</th>
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<td>Market Adoption Status</td>
<td>M2</td>
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**Mining** *(See Appendix 12, Fuel Cell Mining Applications)*

**Fuel Cell Propulsion Institute**

The mission of the Fuel Cell Propulsion Institute, an international consortium of 32 universities, national laboratories and corporations is development and evaluation of fuel cell vehicles and fuel infrastructure for applications with high commercialization potential. Because mining and tunneling have the highest near term potential, the Institute is focusing on underground applications. The consortium has built the world's first fuel cell underground vehicle, a mining and tunneling locomotive, which was displayed at MINExpo 2000. In January 2001 the consortium commenced a transnational project of the U.S., Canada and Mexico that will develop and evaluate the largest fuel cell vehicle yet built. A fuel cell battery hybrid is an underground mine loader, weighing 26 thousand kilos, developing 300 kW of peak power and storing 30 kg of hydrogen onboard as a metal hydride.

**Locomotive**

The lead partners in the locomotive project are:

- RA Warren Equipment, North Bay, ON – base locomotive & vehicle design
- Nuvera Fuel Cells, Cambridge, MA – fabrication of the stacks
- Sandia National Laboratories – power plant development & hydride storage
- Atlas Copco Wagner, Portland, OR – vehicle integration & aboveground evaluation site
- MSHA, Arlington, VA – safety evaluation
- CANMET, Ottawa, ON – underground productivity evaluation

The base vehicle for the project is a commercial four-ton battery locomotive manufactured by consortium member RA Warren Equipment. The vehicle employs a 52 cell lead-acid battery, series traction motors with interpoles, smart motor controller, double-enveloping gear drive,
hydraulically assisted disc brakes and unitized body/chassis. The power plant uses a PEM fuel cell. No traction battery is employed and the vehicle is thus a pure fuel cell vehicle.

The fuel cell locomotive will match or exceed the battery vehicle in performance while having greater availability. Its calculated power and tractive effort are equal or greater. Vehicle operating time on a full hydride charge is eight hours, versus a practical battery operating time of six hours.

Under the direction of the Canada Centre for Mineral and Energy Technology (CANMET), the locomotive will be evaluated while working in four underground metal mines.

**Assessment**

**Technological Status**  T2  
**Market Adoption Status**  M1

**Loader**

The loader project, started in January 2001, will develop and evaluate the largest fuel cell vehicle yet built. The four-year project cost is estimated at US $ 12.6 million, with expected contributions from both the US department of Energy (US$4 million) and Natural Resources Canada (US$ 1 million). The new loader will cost 25 % more than conventional machines but is expected to chop as much as 30 % from mine ventilation costs as it reduces the need for expensive systems designed to expel emissions from diesel operations.

**Assessment**

**Technological Status**  T1  
**Market Adoption Status**  M1

A primary driver of the commercialization of mining technology is the dramatic savings that accrue to the elimination of emissions problems in mines and tunnels and the elimination of support systems such as tethers for underground equipment.

**Powerball International, Inc**

January 24, 2002 – Powerball International, Inc. reported that it has signed on to produce a version of their patented hydrogen generation system for use as an emergency backup fuel supply for a hydrogen powered mining vehicle, code named ZEUS. The zero emissions utility solution (ZEUS) mining vehicle project is under the direction of the Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health. The objective of this research project is to demonstrate the technical and economic feasibility of using hydrogen as an alternate, zero emission fuel that could reduce the exposure of underground miners to diesel particulate matter. The vehicle used in this project is an EIMCO 975 utility truck, which is an articulated four-wheel drive, general purpose vehicle with a hydrogen converted internal combustion engine and a 10,000 lb payload capacity.

**Off-Road/Farm Equipment**

Although many fuel cell developers see off-road/farming equipment as a possible application for fuel cells, there has been little to no work done on developing the technologies. Many experts agree that off-road/farm equipment manufacturers will adopt the technology once it has been developed in other mobile applications such as passenger vehicles and buses. The reason for this links back to the key drivers of fuel cell technology; air pollution, GHG emissions and energy security. The development of hydrogen and fuel cell technology presents the most challenges in the transportation sector. The widespread use and commercialization of mobile fuel cell technologies will be determined by the successful integration of these technologies in the
transportation sector. Until this happens the industry will not see any significant development in these offshoot sectors.

5.5 Auxiliary Power Unit Applications

In addition to propulsion, another promising fuel cell application is as auxiliary power units (APU). Fuel cells are ideal for use in tractor-trailers as APUs, in that they can provide power for devices needed for driver comfort when stationary rather then letting the truck idle. Similarly, Jeep (DaimlerChrysler) has used it in its prototype Jeep Commander for auxiliary power, and BMW is also using fuel cells for auxiliary power in its 7 Series Hydrogen car.

In August 2001, the U.S. Department of Energy (DoE) selected four new government-industry projects as the vanguards of a $500 million, 10-year effort to produce low-cost fuel cells that will eliminate current cost barriers. Among the four companies chosen, the team of **Delphi Automotive Systems** was chosen. Their proposal is to develop and test a solid oxide fuel cell design that can be mass produced at a low cost for automotive and truck auxiliary power units, distributed power generation and military markets. They will demonstrate a 5 kW system that operated on common fuels. The University of Utah will participate on a consultant basis. The DoE will provide $74.6 million and Delphi and its partners will contribute $60.9 million.

**Diesel Truck Auxiliary Power Units**

ITS-Davis is playing a central role in helping to pioneer perhaps the most important early application of fuel cells in vehicles -- to power truck auxiliary power units, especially during extended idling. Working with Freightliner and others, ITS-Davis demonstrated an operational system on a heavy-duty truck, and conducted analytical studies demonstrating large emissions and energy savings at a competitive cost. [http://www.americanfreightliner.com/fuel%20cells.htm](http://www.americanfreightliner.com/fuel%20cells.htm)

This particular program demonstrates that the development of the APU is clearly in its early stages. The State of Oregon is promoting use of the Business Energy Tax Credits for heavy-duty vehicle auxiliary power units. Program staff have approached Freightliner about using the credits to install the units in new truck tractors, but have not been successful so far. There is little demand for the devices, in part because drivers are unfamiliar with them and because of a downturn in the new truck market.

The APU clearly has an early market potential in both the light duty and the heavy duty markets, however, as Martin Hammerli pointed out in his presentation to the CIT Outlook Conference in April 2002, current APU’s are too costly for implementation. The technology is very new and as we can see from the U.S. DoE’s commitment to research funding, is a clear focus for the near future.

**IdaTech**, a subsidiary of IDACORP, formed an agreement with **Atwood Mobile Products Inc.**, a subsidiary of Dura Automotive Systems Inc. in February 2001 to develop a portable fuel cell system for the recreational vehicle (RV) industry. The two companies intend to develop a an onboard electrical power system, including related power control equipment, that is quiet, produces little vibration or pollution and is specifically tailored for the portable platform of an RV. The end product will be a fully integrated system that RV manufacturers worldwide can install in their vehicles.
Likewise Cummins Onan indicated that they are currently developing a PEM fuel cell auxiliary power unit (APU) for recreational vehicles. Currently they are working on a demonstration unit, which would place this development at roughly the T3 to T4 stage.

**Assessment**

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<th>Technological Status</th>
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<tr>
<td>Market Adoption Status</td>
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### 5.6 On-board Storage Systems

Dr. Jensen of the University of Hawaii, in a 1999 presentation to the Hydrogen Technical Advisory Committee, explained that a major difficulty in the utilization of hydrogen as a fuel is the problem of onboard hydrogen storage. High pressure and cryogenic hydrogen storage systems are impractical for vehicular applications due to safety concerns and volumetric constraints. This has prompted an extensive effort to develop solid hydrogen storage systems for vehicular application. Metal hydrides, activated charcoal and carbon nanotubes have been investigated as hydrogen carriers. Unfortunately, despite considerable research efforts no material has been found suitable for reasons of carrying capacity and low cost required for vehicular use. (Source: HTAP April 1999 meetings)

#### On Board High Pressure Storage Systems

Two companies lead the research and development march toward commercialization of FCV hydrogen storage containers made with polymer composites. One is QUANTUM technologies WorldWide Inc a wholly owned subsidiary of IMPCO Technologies Inc of Irvine, California which manufacturers its trademark TriShield Type IV hydrogen storage cylinders. The other, Dynetek Industries Ltd of Calgary, Canada offers its trademark DyneCell cylinder for hydrogen storage. Both companies offer hydrogen tanks at 5000-psi storage capacity and are testing to 10,000 psi. Both are also drawing from substantial experience in the manufacture of cylinders for compressed natural gas (GNG) that are used in natural gas powered vehicles.

**QUANTUM Technologies Worldwide Inc.**

In February 2001, IMPCO renamed its Technology and Automotive OEM Division QUANTUM Technologies WorldWide Inc. IMPCO has spent $100 million over the last seven years designing and engineering fully-integrated gaseous fuel system technology with a total platform focus – including its own storage cylinder and component testing, validation, certification and crash testing.

QUANTUM, which produces the Type IV TriShield cylinder, announced being the first to market with a hydrogen storage tank capable of a 5000 psi compressed hydrogen fill, with a TriShield cylinder and hydrogen fuel system installed on Hyundai’s Santa Fe fuel cell SUV. QUANTUM has set a performance record of 11.3 % hydrogen storage by weight in a proof-of-concept (POC) 5000 psi cylinder, and has demonstrated hydrogen storage at 10000 psi.

On February 27, 2002, QUANTUM announced that it has achieved a major milestone by receiving German TUV regulatory approval for its 10,000 psi TriShield hydrogen storage cylinder. This higher pressure means that operating time is increased by 118 % compared to that with a standard 3600-psi tank. An alliance formed in April 2000 with ATK Thiokol Propulsion allows QUANTUM to capitalize on Thiokol’s innovative composite conformable hydrogen fuel storage tank technology. In May 2001, the companies opened a jointly operated advanced hydrogen storage testing facility in Promontory, Utah. Certification of a 65-liter volume conformable tank to NGV2-2000 specification
developed by Thiokol was recently announced. This is the first 5000-psi conformable tank to meet these specifications. QUANTUM has the rights to commercialize this technology and to integrate the conformable tanks into OEM fuel systems under development in North America and European markets.

**Dynetek Industries**  
Founded in 1991, Dynetek manufactures DyneCell cylinders with 200, 250 and 350-bar storage capacity. Dynetek is the only cylinder manufacturer to offer a 5075-psi storage cylinder capacity tank (versus 5000 psi) to meet the requirements of a European original equipment manufacturer. The first DyneCell hydrogen storage cylinders were delivered in 1997 to Ballard Power Systems for roof mounting on six fuel cell powered transit buses that were field tested in Chicago and Detroit.

Dynetek is involved in 16 FCV projects with seven different automotive OEMs. Milestones among these projects include:

- Five of eight FCV’s rolled out at the CaFCP headquarters dedication utilized Dynetek hydrogen tanks – three Ballard buses, Nissan’s Xterra SUV and Ford’s Focus FCV;
- Multi year agreement with Ford for the supply of DyneCell tanks for all its fuel cell programs. Ford has tested the tanks in its P2000 FCV prototypes;
- German bus maker MAN Technologie has used DyneCell hydrogen storage cylinders for an experimental ICE and a hybrid bus;
- Delivery to DaimlerChrysler of the first 350 bar hydrogen storage system that will be roof mounted on 30 fuel cell buses to be operated in Europe.

### 5.7 Hydrogen Fueling Trailers

**Powertech Labs** of Surrey, British Columbia and **Dynetek Industries Ltd.** in Calgary have been working jointly to develop a lightweight tube trailers to transport hydrogen in a high-pressure container. Powertech Labs, a subsidiary of BC Hydro has initiated the Canadian Hydrogen Infrastructure Program to demonstrate the technical feasibility of high-pressure gaseous hydrogen fueling stations. In Phase 3 of the project their objective is to transport hydrogen from a centralized production unit to a satellite fueling station. To accomplish this Dynetek Industries has integrated its lightweight, carbon-fiber hydrogen containers onto a standard flat deck trailer, which acts as a mobile hydrogen fueling station. Two trailers have already been built, the first trailer with a carrying capacity of 28 kg of hydrogen; the second, much larger trailer can transport 82 kg of hydrogen.

The Hydrogen Refueling Trailer was recently used as a filling station at the Challenge Bibendum 2001 held in California. Both trailers are currently being used in the Vancouver area for hydrogen testing programs. The larger trailer is also used at fuel cell car rallies in the United States.

In Mississauga, Ontario, Stuart Energy Systems has produced a Community Fueler Portable 450 (CFP-450). It is based on a single trailer, in order to be transported easily. The CFP-450 was demonstrated in June 2002 at WHEC held in Montreal.

### 5.8 Competitors of the Hydrogen Fuel Cell
The Vandium Energy Storage System (VESS) technology was developed and patented at the University of New South Wales (UNSW), Sydney, Australia. Pinnacle VRB, an Australian company, purchased the technology from UNSW in 1998 and has been actively pursuing an international commercialization program introducing VESS technology into stationary and mobile markets worldwide.

VESS uses the chemistry of Vanadium to store electrical energy as chemical energy. The technology has been under development for over 10 years and large scale, grid connected units have been under continuous demonstration in Japan for over two years.

The VESS uses a Vanadium Redox Flow Battery (VRB), a device that is built entirely from recyclable plastics and operates essentially as a rechargeable fuel cell. During discharge, electricity is generated as the Vanadium ions present in the electrolytes change valence states, as they are pumped through the electrochemical cells. During charging, the cell reactions are reversed and the valiancy of the Vanadium ions in the electrolytes is restored. These electrochemical reactions are 100% reversible and the Vanadium electrolytes never need replacing.
6.0 Readiness to Compete

In assessing their States ability to compete in the emerging hydrogen economy, Michigan has made an assessment of the components that contribute to the design, development and manufacture of fuel cell powered vehicles. Ohio has assessed its strengths and weaknesses by industrial sector.

The powertrain configuration for fuel cell powered vehicles is comprised of three basic subsystems: the fuel storage/reformer module, the fuel cell and the electric drivetrain. In addition, an electronic control network and a balance of plant (BOP) system are required. The critical components of the powertrain system include:

6.1 Fuel Storage/Reformer Module

Current research efforts for hydrogen storage have focused on three main methods. Possible storage options include high pressure, liquefying at extremely low temperature and the use of metal hydride storage powders. Current processes are focusing on the storage of high-pressure hydrogen onboard the vehicle. QUANTUM Technologies Worldwide Inc. and Dynetek Industries have been identified as leading the research in this area in North America. (Refer to section 5.5.)

Liquified Hydrogen

DaimlerChrysler’s NECAR 4 incorporates a cryogenic liquefied hydrogen storage system. However, the energy required for the liquefaction process greatly decreases the overall fuel efficiency of the technology. And, as with compressed hydrogen, many safety and distribution barriers remain.

Metal Hydrides

The third option for onboard storage is the storage of hydrogen in solid form by using metal hydrides. These metal alloys are in a loose powder form. Hydrogen gas enters the storage unit and is absorbed into the powder. Relative to alternative hydrogen solutions, metal hydrides are more easily and possibly more safely stored. One of the barriers to metal hydrides is weight: metal hydride storage of hydrogen may be six to ten times that of liquid hydrogen storage. Toyota’s initial fuel cells were powered with hydrogen from metal hydride storage although the latest models are based on fuel reformation.

Reformation

The alternative to storing hydrogen onboard is the onboard extraction of hydrogen from gasoline, methanol or other similar hydrogen rich fuels. There are three basic reformulation designs currently under consideration: partial oxidation (POX), steam, and autothermal (ATR). Early developmental advances may suggest that steam reformers are more advantageous for use with methanol, while POX and ATR reformers are more adaptable to gasoline, methane and ethane (SAE 2000-01-0003, p.17).

A recent report titled *Bringing Fuel Cell Vehicles to Market – Fuel Alternatives* suggested that timely and efficient fuel reforming technology development might be the most difficult challenge to
early fuel cell vehicle commercialization. Based on the information available at the present time, our conclusions suggest that reformation technology has not been developed beyond the prototype demonstration application.

6.2 Fuel Cell Technology

The proton exchange membrane (PEM) fuel cell stack is comprised of four basic elements: membrane electrode assembly (MEA), the bipolar plates, and the end plates. Aside from the technical hurdles being overcome by the fuel cell companies, the manufacturers of the materials that form the components of the fuel cell stack must also be addressed. The MEA consists of an electrolyte membrane, the anode and the cathode, the catalyst and the gas diffusion/current collector. Dupont and 3M are two of the relatively few companies that have established capability to provide complete MEA’s. The fuel cell stacks are likely to be manufactured by those specialized companies that have developed the technology.

Balance of Plant (BoP)

In addition to the fuel cell stack, there are several external components, known as the balance of plant (BoP), that complete the fuel system. Included in this group of external components are the thermal loop to remove heat from the fuel cell and an air compressor to increase airflow into the cell. These components have some similarity to components currently being manufactured for internal combustion engines such as radiators, heater cores, air compressors, and solenoids. These components are likely to be produced by the existing OEM suppliers.

6.3 Electric Drivetrain

The electric drivetrain will likely be comprised of four components: a DC/DC converter, an inverter, an AC motor and transmission system and a battery or ultracapacitor for power storage. The automobile manufacturers can produce the electric drivetrain and transaxle components. The power electronics system (comprised of the DC/DC converter, the power inverter, and the control electronics for the electric drivetrain, fuel cell and fuel system) is a critical element. Power electronics is not traditionally an automotive industry strength. Defense and aerospace research has lead to the creation of centers of expertise for power electronics far from the traditional automotive industry.

Conclusion

The coming hydrogen economy has had slow beginnings and there has been enormous change since research and development took off in the early 90’s. Nonetheless the majority of companies conducting research in fuel storage, reforming modules, fuel cell technologies, and electric drivetrain technologies have are well established and have acquired a great deal of expertise in their areas. In order to participate in one or more of these design or manufacturing areas in the coming hydrogen economy, existing technological capabilities are necessary. Another approach to participating in the industry is to create an environment where local companies can become leading experts in the development and manufacture of specialized components required to assemble a fuel cell power system for vehicles.
The report *Opportunities for Creating a Fuel Cell Industry in Ohio*\textsuperscript{24} summarized the skill requirements and Manufacturing characteristics for the four fuel system components for the fuel cell powertrain:

<table>
<thead>
<tr>
<th>System Components</th>
<th>Manufacturing Characteristics</th>
</tr>
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<tbody>
<tr>
<td>Fuel Cell Stack</td>
<td>Will likely be produced by specialist companies who have developed the technology. Fuel cell production requires knowledge in electrochemistry and materials sciences.</td>
</tr>
<tr>
<td>Fuel Cell System</td>
<td>Automotive component suppliers will need to shift production skills to accommodate designs that incorporate fuel reformers. Some retraining will be required.</td>
</tr>
<tr>
<td>Balance of Plant system</td>
<td>Components are similar to those currently produced by automobile manufacturers and its supplier industries.</td>
</tr>
<tr>
<td>Electric Drivetrain</td>
<td>Automobile manufacturers can produce the electric drivetrain and transaxle components, however, power electronics require skills that are not traditionally found in the auto industry.</td>
</tr>
</tbody>
</table>

Ohio also created a “Fuel Cell Industry Scorecard” to assess its Readiness to Compete.

<table>
<thead>
<tr>
<th>Component</th>
<th>Assessment</th>
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<tr>
<td>Research &amp; Development</td>
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<tr>
<td>Material Suppliers</td>
<td>Strong</td>
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<tr>
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</tr>
<tr>
<td>System Developers</td>
<td>Average</td>
</tr>
<tr>
<td>System Installation</td>
<td>Average</td>
</tr>
</tbody>
</table>

Application Market:
- Transportation Market: Weak
- Portable Devices: Weak
- Stationary Power Generation: Average

Creating opportunities for Manitoba industries necessitates a complete evaluation of Manitoba’s capabilities in relation to the skill requirements of participating in the hydrogen revolution. Manitoba will have to select those niche markets where it can potentially excel and invest in the development of knowledge and technological skills and expertise necessary to bring the opportunity to fruition.
7.0 Commercialization Opportunities for Manitoba

7.1 Light Duty Applications

Automobiles

It is clearly evident that a vast amount of research has taken place in the development of fuel cell technology for the application to the automotive market around the world. To date, none of that R&D activity has taken place in Manitoba and the Province currently lacks the technical expertise to participate. Review of the steps being undertaken by U.S. States to protect their position in the development and manufacture of the future automobile suggests that R&D, component manufacture and OEM assembly plants will not likely relocate to Manitoba. The primary capabilities, technologies and facilities will locate in natural clusters as the auto industry is structured today.

The June 2002 draft report “Fuel Cells: The Opportunity for Canada” clearly identifies BC and Southern Ontario and to some degree, Quebec as the only locations where industry clusters have developed sufficiently to participate in development and manufacturing. The ability of Manitoba to participate in this market would be entirely dependent upon the development of critical niche technologies and significant investment in the exploitation of those technologies. One such niche area could be cold weather testing of fuel cell vehicles.

Bicycles and Scooters

The market for bicycles and scooters is extremely large and will likely see significant growth of fuel cell powered vehicles. However, the market lies in Asia and India. The market drivers for the purchase and use of these vehicles in North America are vastly different from Asia and India. They will not likely become a prime mover of people in our economy. It is highly unlikely that Manitoba could participate in this market.

7.2 Medium/Heavy Duty Applications

Bus

The bus industry is the one significant transport sector where Manitoba has the technology and the manufacturing capability to participate in the manufacture of fuel cell powered buses. Although the prime R&D and component manufacture of critical components such as the powertrain system will take place elsewhere, Manitoba is a center for bus design and assembly. Motor Coach Industries specializes in the manufacture of highway vehicles and New Flyer Industries specializes in the manufacture of transit vehicles. This presents Manitoba with the opportunity to develop a technology base for the application of fuel cell powertrain technology to the bus industry.

One factor that could very likely dampen Manitoba’s efforts to participate in the development of fuel cell buses is a new “Buy America” policy implemented by the U.S. Government. Currently in the U.S. the “Buy America” policy applies to transit bus purchases involving federal funds. This is already a well known and critical issue for Manitoba’s bus manufacturers; however, it is exacerbated in the case of advanced fuel cell buses, given that fuel cell technologies today are largely Canadian in origin.
Railways

Development of fuel cell propulsion for the rail industry is not foreseeable in the near future. Although Manitoba is a center for rail transportation, technology development takes place in the existing main motive power development centers in North America. They are driven by the lead manufacturers General Electric, General Motors, Alstom, Bombardier, etc. who do not have a R&D or manufacturing presence in Manitoba.

Marine

Marine applications can be subdivided into several categories; ship propulsion power, specialized applications such as submarines, small boat applications and auxiliary power unit applications.

Manitoba has no marine industry and is not likely to create one. We have no immediate market for large or small vessels. Our research has determined that the main marine industry will operate in a fast-follower mode to the automotive industry. Consequently, the technological expertise will remain in the automotive industry in the near future. The only opportunity seen for the near future is the potential market for auxiliary power units on board vessels.

Off Road/Farm Equipment

To date there has been no significant research done in off-road (farm equipment) applications of hydrogen. The transportation sector has presented more challenges than other applications due to its complexity. Most experts agree that once adoption of fuel cell technologies occur in buses and passenger vehicles, other applications such as off-road will follow.

7.3 Specialized Applications

Airplanes

The aviation market is only on the drawing boards at this time for propulsion systems and do not present an opportunity for Manitoba. As with the marine industry, the nearer term opportunities lie in the development of auxiliary power units.

Industrial Fuel Cell Vehicles

The application of fuel cell technology to the light industrial vehicle is still in its infancy. Several organizations have developed concept vehicles such as the Gator 1 & 2 and unveiled fuel cell powered golf carts. Largely these applications involve marrying existing fuel cells to existing vehicles. We have not been able to identify any manufacturing and distribution operations involving light industrial vehicles. Logic suggests that this application will not become fully commercialized until the production and operating costs are completely competitive with existing technology. The market is now adequately served by existing technology.

The application of fuel cell technology to industrial vehicles could present an opportunity for Manitoba manufacturers in specialized niche markets. Capitalizing on these opportunities would require the development of technical expertise in the province and support to our manufacturing companies to explore these opportunities.
Mining

The most promising application of fuel cell technology in the near term is in mining. The market driver for developing this technology is profit. Although the vehicles themselves will be more expensive than existing technology, the ability to eliminate fuel emissions from the mine or tunnel will eliminate a major capital and operating cost of mine operation, the ventilation system.

The first prototype locomotive is in test phase and the first mine loader is in a 4-year design and build phase. Manitoba is not involved in this market today and will not likely be able to participate in the future. The industry is highly specialized and development will take place where existing technology and manufacturing capability already exist.

Hydrogen Fuel Trailers

Another opportunity for Manitoba’s OEM’s might be in the manufacturing of trailers to transport high-pressured, carbon-fiber hydrogen storage cylinders. Currently hydrogen is transported in steel tube trailers, however there are several drawbacks to this mode. As the hydrogen market grows, the need to transport substantially larger amounts of hydrogen will also grow, meaning transporting at higher volumes, and transitively, higher pressures. Transporting hydrogen in the steel tube trailer is not cost effective, as steel tubes need increasingly thick walls to hold higher pressured hydrogen. The ticker the steel tubes are the heavier they become until they are too heavy to be pulled by trailers.

As mentioned earlier in section 5.6, Dynetek is developing lightweight carbon-fiber tubes to store hydrogen. They have worked jointly with Powertech labs to build a lightweight trailer to carry these tubes and are currently investigating trailer manufacturers they can team with to build more of these trailers.

As the R&D in the hydrogen infrastructure progresses there will be more and more of a need for these lightweight trailers. Manitoba has several trailer manufacturers, mainly experienced in building flat-deck trailers, grain trucks and gravel trucks. Several of these manufacturers were contacted, and it was discovered that none of them had experience with building trailers for the transport of dangerous goods. However every company that was contacted said they would be willing to work jointly with a company such as Dynetek to design and integrated hydrogen trailer.

A list of the companies contacted and their phone numbers have been provided in Appendix 15.

7.4 Auxiliary Power Unit Applications

We have identified future opportunities in both the marine and air industries for auxiliary power unit applications. The automotive industry has already developed auxiliary power units for demonstration vehicles. The fuel cell developers have been developing power units for small applications and portable power generation for decades. It is our expectation that the auxiliary power unit will be the first fuel cell application that will achieve commercial application in vehicles in the near future.

Once again, fuel cell developers around the world have been focused on creating these small power units. Any Manitoba opportunity would have to be focused on a licensed manufacturing operation. To create this opportunity, technological expertise would have to be developed in the province.
8.0 Manitoba Policy Initiatives

As stated in Michigan’s “Positioning the State of Michigan as a Leading Candidate for Fuel Cell and Alternative Powertrain Manufacturing”, many industry leaders and experts are certain that fuel cell technology has the potential to replace the ICE as the primary source of propulsion for transportation applications. As with the implications of this to Michigan's automotive industry, similarly the effects of this to Manitoba’s bus manufacturing industry could also be profound. Manitoba must identify critical actions to position itself as a strong candidate for potential fuel cell bus manufacturing. Manitoba must undertake a number of aggressive measures if it expects to create an environment where Manitoba industry can participate in the emerging hydrogen economy. Based on our review of the current status of developments with respect to transport vehicles we suggest that Manitoba consider the following steps:

- **Grow a University based research technology capability for fuel cell applications:** In order to participate in the coming hydrogen economy it is necessary to have knowledge and expertise in the area. In the U.S. several universities, such as UC Davis and Georgetown University, have extensive R&D programs in place working alongside industry. The University of Manitoba's Faculty of Engineering is a well-established faculty with the capabilities of developing a similar program to produce experts in the field.

- **Promote information sharing and form a collaborative effort and partnership among industry stakeholders such as MCI, New Flyer, Manitoba Hydro, University of Manitoba's Engineering Department, and Kraus Global:** As seen, partnerships and alliances such as the CaFCP are vital for the progression of the industry. Forming cohesive groups such as this promotes information sharing and parallel growth that benefits all stakeholders.

- **Promote the creation of a fuel cell bus demonstration project with emphasis on real-condition, and cold weather technical testing:** Manitoba has the industry components necessary to host such a demonstration project. In housing such a project it could potentially help develop the level of knowledge and expertise stated in the first recommendation.

- **Assess Manitoba’s capability to participate in the Hydrogen Economy with a view towards identifying the strengths and weaknesses of Manitoba's industrial and technology base:**

- **Based on the results of the assessment of Manitoba’s capabilities, explore opportunities in light industrial vehicle manufacturing.**

- **Look at opportunities in spin off and integration technologies.**
### 9.0 Appendices

#### 9.1 Appendix 1: Sample of Demonstration Projects

**SAMPLE OF DEMONSTRATION PROJECTS FOR EUROPE, NORTH AMERICA**

### EUROPE

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Project Leader</th>
<th>Partners</th>
<th>Timeline</th>
<th>Location</th>
<th># of Vehicles</th>
<th>Bus Platform</th>
<th>Project Description</th>
<th>Vehicle Technical Data</th>
<th>$ Allocated</th>
<th>Tech Status</th>
<th>Market Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bavarian Bus Project</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Concept - Conventional low-floor city bus will be equipped with a fuel cell system, delivering electricity to an electric drivetrain. H2 stored on-board vehicle in compressed gaseous form. Phase I: 1996-1998 - Conceptual design; Phase II: 1998-1999 - System integration; Phase III: 2000 - Test and commissioning to prepare the test operations.</td>
<td>Bus model: MAN low-floor bus; Fuel cell: Siemens AG Power Generation, 4 modules, 120 kW, 400 V at max output; H2 storage: MAN Technologie AG, on-board storage, 1530 L capacity; Fuel type: CGH2; Operating range: 200 - 300 km</td>
<td>N/A</td>
<td>T2</td>
<td>M1</td>
</tr>
</tbody>
</table>

### NORTH AMERICA

<table>
<thead>
<tr>
<th>Name of Demo Project</th>
<th>Project Leader</th>
<th>Partners</th>
<th>Timeline</th>
<th>Location</th>
<th># of Vehicles</th>
<th>Bus Platform</th>
<th>Project Description</th>
<th>Vehicle Technical Data</th>
<th>$ Allocated</th>
<th>Tech Status</th>
<th>Market Status</th>
</tr>
</thead>
</table>
### NECAR and NEBUS Development Program

<table>
<thead>
<tr>
<th>Name of Demo Project</th>
<th>Project Leader</th>
<th>Partners</th>
<th>Timeline</th>
<th>Project Location</th>
<th># of Vehicles</th>
<th>Bus Platform</th>
<th>Project Description</th>
<th>Vehicle Technical Data</th>
<th>$ Allocated</th>
<th>Tech Status</th>
<th>Market Status</th>
</tr>
</thead>
</table>
### SAMPLE OF DEMONSTRATION PROJECTS FOR EUROPE, NORTH AMERICA - Continued

<table>
<thead>
<tr>
<th>Name of Demo Project</th>
<th>Project Leader</th>
<th>Partners</th>
<th>Timeline</th>
<th>Location</th>
<th># of vehicles</th>
<th>Bus Platform</th>
<th>Project Description</th>
<th>Vehicle Technical Data</th>
<th>$ Allocated</th>
<th>Tech Status</th>
<th>Market Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell Bus for Copenhagen, Berlin, Lisbon II</td>
<td>Senate of Berlin, Germany; Management: MVV InnoTec; several European manufactures, and public transit operators as well as JOULE/ THERMIE/ENERGIE of European Commission</td>
<td>Berlin, Germany, Copenhagen, Denmark; Lisbon, Portugal</td>
<td>Oct-98 - 2000 (integrated as part of regular fleet)</td>
<td>BERLIN, GERMANY, COPENHAGEN, DENMARK; LISBON, PORTUGAL</td>
<td>3 MAN</td>
<td>Concept - Demonstrate for the first time, the operation of a fuel cell bus powered by LH2 in regular urban public transit. Objective - To demonstrate the long-term advantages of urban application through introduction to a wide market. Phase I: demo FC bus in 3 cities. Initially bus will be tested for 9 months in Berlin, 1 mo in Copenhagen, 2 months in Lisbon. Phase II: Analysis and technical improvements.</td>
<td>Bus model: The bus is a MAN NL223 low floor bus; Fuel cell: DE NORA; System integration: Air Liquide DTA; FC consists of 5 stacks at 30 kW - drive module with 150 kW; H2 Storage: on-board storage, 700 L capacity;</td>
<td>Funded by partners and THERMIE Program funding. 11 Million DM (40% of project cost) co-financed by European Commission</td>
<td>T4</td>
<td>M1- M2</td>
<td></td>
</tr>
<tr>
<td>Clean Urban Transport for Europe (CUTE)</td>
<td>DaimlerChrysler</td>
<td>several manufacturing companies, fuel cell producing companies, government agencies and European Commission (EC)</td>
<td>Oct-01 - Ongoing</td>
<td>Amsterdam, Netherlands; Barcelona, Spain; Hamburg, Germany; London, UK; Luxembour; Madrid, Spain; Porto, Portugal; Stockholm, Sweden; Stuttgart, Germany</td>
<td>27 EvoBus (Mercedes)</td>
<td>Concept - 9 cities will begin demonstrating fuel cell buses in 2003. The project will be the first volume production test of this scale for FC buses. H2 will be produced through different methods in order to provide data for efficiency comparison.</td>
<td>Bus model: Limited production series EvoBus (Mercedes-Benz), Citaro fuel cell urban buses. Fuel cell: Ballard/Xcellis, 205 kW; Fuel storage: on-board, compressed gas cylinders containing CGH2 @ 350 bar; Max speed: 80 km/hr; Range: 200 km</td>
<td>18.5 million euro awarded to 9 countries by European Commission as part of CUTE program</td>
<td>T4</td>
<td>M1- M2</td>
<td></td>
</tr>
<tr>
<td>Ecological City Transport System (ECTOS)</td>
<td>Icelandic New Energy (Iceland)</td>
<td>Shell Hydrogen, DaimlerChrysler, Norsk Hydro, Vistorka (EcoEnergy Ltd.) - owned by a group of Icelandic companies, EC and others including University of Iceland, Reykjavik Municipal Bus Corp.; Tech Institute of Iceland</td>
<td>Oct-01 - Ongoing</td>
<td>Reykjavik, Iceland</td>
<td>EvoBus (Mercedes)</td>
<td>Concept - 4 year, combined demo and research looking at infrastructure and operation of fuel cell buses. Phase I: 2 yrs - building H2 infrastructure; on-site production of H2 by electrolysis; creating maintenance facilities; training staff; prep for bus arrival etc. Phase II: 2 yrs - operating buses in normal bus routine; Infrastructure used to power 3 fuel cell buses in normal service for 2 years; gauge how they will cope with day-to-day oper. conds. Buses being delivered 2003</td>
<td>EvoBus (Mercedes-Benz) Citaro Bus Fuel Cell provided by Ballard/Xcellis</td>
<td>Total Funding: 7 million euro. 2.85 million euro from EU. Remaining 4.14 million euro by domestic and foreign partners (50%/50%).</td>
<td>T4</td>
<td>M1- M2</td>
<td></td>
</tr>
</tbody>
</table>
## SAMPLE OF DEMONSTRATION PROJECTS FOR EUROPE, NORTH AMERICA - Continued

### NORTH AMERICA

<table>
<thead>
<tr>
<th>California Fuel Cell Partnership</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of Demo Project</strong></td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Thunder Power Fuel Cell Bus Partnership</td>
</tr>
<tr>
<td>Hythane Bus Project</td>
</tr>
<tr>
<td>AC Transit/SunLine Transit Agency Compressed Hydrogen Buses</td>
</tr>
</tbody>
</table>
### Sample of Demonstration Projects for Europe, North America - Continued

#### Georgetown University Advanced Vehicle Program

<table>
<thead>
<tr>
<th>Name of Demo Project</th>
<th>Project Leader</th>
<th>Partners</th>
<th>Timeline</th>
<th>Location</th>
<th># of Vehicles</th>
<th>Bus Platform</th>
<th>Project Description</th>
<th>Vehicle Technical Data</th>
<th>$ Allocated</th>
<th>Status</th>
<th>Market Status</th>
</tr>
</thead>
</table>

#### Xcellsis/Ballard Zero-Emission Fuel Cell Bus Project

<table>
<thead>
<tr>
<th>Name of Demo Project</th>
<th>Project Leader</th>
<th>Partners</th>
<th>Timeline</th>
<th>Location</th>
<th># of Vehicles</th>
<th>Bus Platform</th>
<th>Project Description</th>
<th>Vehicle Technical Data</th>
<th>$ Allocated</th>
<th>Status</th>
<th>Market Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xcellsis ZE-bus</td>
<td>SunLine Transit Agency AC Transit (Oakland, CA)</td>
<td>CaFCP</td>
<td>Oct-99 - Nov-01</td>
<td>Thousand Palms, Oakland, CA</td>
<td>1</td>
<td>NewFlyer (modified Phase II bus)</td>
<td>Zebus was 1st demo vehicle to be delivered to CaFCP for one year testing program with SunLine Transit Agency. The ZE-bus completed 13 months test at SunLine</td>
<td>205 kW PEM FC (Xcellsis). Bus uses central engine that provides traction power and drives at the same all auxiliary components.</td>
<td></td>
<td>T4</td>
<td>M1 - M2</td>
</tr>
</tbody>
</table>
### SAMPLE OF DEMONSTRATION PROJECTS FOR EUROPE, NORTH AMERICA - Continued

<table>
<thead>
<tr>
<th>Name of Demo Project</th>
<th>Project Leader</th>
<th>Partners</th>
<th>Timeline</th>
<th>Project Location</th>
<th># of Vehicles</th>
<th>Bus Platform</th>
<th>Project Description</th>
<th>Vehicle Technical Data</th>
<th>$ Allocated</th>
<th>Tech Status</th>
<th>Market Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTA Zero-Emission Electric Transit Bus Program - Phase I</td>
<td>Electric Fuel Transportation Corp.</td>
<td>Several strategic partners</td>
<td>1998 - Jul-00</td>
<td>Community College of Southern Nevada</td>
<td>1</td>
<td>NovaBus Corp</td>
<td>Concept - Demo Electric Fuel's patented zinc-air FC system's performance on full size bus. Bus maintained and operated by Community College of Southern Nevada.</td>
<td>Bus utilizes all-electric, battery/battery hybrid propulsion system.</td>
<td>DOT allocated $2 million</td>
<td>T2</td>
<td>M1</td>
</tr>
<tr>
<td>FTA Zero-Emission Electric Transit Bus Program - Phase II</td>
<td>Electric Fuel Transportation Corp.</td>
<td>Several strategic partners</td>
<td>Jan-01 - Ongoing</td>
<td>Community College of Southern Nevada</td>
<td>1</td>
<td>NovaBus Corp</td>
<td>Concept - focus on conducting evaluations of system and vehicle performance; enhancing all-electric propulsion system; incorporate ultracapacitors and associated interface. The project concluded that bus meets all requirements for a transit bus.</td>
<td>Bus utilizes all-electric, battery/battery hybrid propulsion system.</td>
<td>DOT approved funding for 50% of project cost up to $1.5 million</td>
<td>T3</td>
<td>M1</td>
</tr>
</tbody>
</table>
### 9.2 Appendix 2: Accelerated Timeline of Hydrogen Fuel Cell Vehicles

**Accelerated Timeline to Establish the Capability of Hydrogen Fuel Cell Vehicles**

<table>
<thead>
<tr>
<th>Year</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feasibility Demonstration</td>
<td>Controlled Fleet Demonstrations</td>
<td>Commercial Fleet Demonstrations</td>
<td>Commercialization Phase</td>
</tr>
<tr>
<td>2001</td>
<td>Test FC vehicle performance and feasibility (CaFCP)</td>
<td>Demonstrate use of FC vehicles under real-world conditions</td>
<td>Demonstrate commercial viability of FC fleet vehicles</td>
<td>Investment to establish manufacturing plants and sales/service</td>
</tr>
<tr>
<td>2004</td>
<td>1 site - CaFCP</td>
<td>5 - 8 sites - varying climates</td>
<td>2 or 3 states (networked sites)</td>
<td>Investment for 25 - 50 % of all stations H2 capable</td>
</tr>
<tr>
<td></td>
<td>&lt; 50</td>
<td>~ 500</td>
<td>~ 5000</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>Demonstrate H2 fueling station and analyze fuel options</td>
<td>Onsite generation from multiple feedstocks</td>
<td>Sufficient stations to provide consumer convenience</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Primarily trucked in liquid form</td>
<td>Renewable &amp; fossil fuels</td>
<td>Most cost effective sources by region</td>
<td></td>
</tr>
<tr>
<td></td>
<td>~ 3</td>
<td>5 to 10</td>
<td>20 to 30</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>Share management responsibilities, Fuel Chain Analysis, Education</td>
<td>Purchase vehicles, Cost share and operate H2 fueling stations, Data collection &amp; dissemination, Coordination of International codes and standards, Education</td>
<td>Vehicle subsidy, Cost shared infrastructure, Education</td>
<td>Legislated incentives to consumers &amp; industry, Exercise capability for national energy security</td>
</tr>
<tr>
<td></td>
<td>Operate vehicles and H2 stations Primary Funding</td>
<td>Vehicle design, engineering &amp; integ. Cost share fueling stations Identify service requirements Complete codes &amp; standards</td>
<td>Cost share fueling stations Gauge consumer acceptance Maintenance capability</td>
<td>Commercialization Phase begins</td>
</tr>
</tbody>
</table>

*Source: United States Department of Energy*
## 9.3 Appendix 3: Overview of the Transition to the Hydrogen Economy

### Overview of the Transition to the Hydrogen Economy

<table>
<thead>
<tr>
<th>Year</th>
<th>Public Policy Framework</th>
<th>Production Processes</th>
<th>Delivery</th>
<th>Storage Technologies</th>
<th>Conversion Technologies</th>
<th>End-Use Energy Markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Outreach and acceptance</td>
<td>Electrolysis using renewable and nuclear</td>
<td></td>
<td></td>
<td>.Fuel Cells .Advanced combustion</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>Public confidence in hydrogen as an energy carrier</td>
<td>Gasification of Coal</td>
<td>Onsite&quot;distributed&quot; facilities</td>
<td>Solid state (hydrides)</td>
<td>Mature technologies for mass production</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td>Biophotocatalysis</td>
<td></td>
<td>&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2040</td>
<td></td>
<td>Photolytics to split water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Source:** *A National Vision of America's Transition to a Hydrogen Economy - To 2030 and Beyond*
### 9.4 Appendix 4: Sample of Fuel Cell Vehicles in Development

**SAMPLE OF FUEL CELL VEHICLES IN DEVELOPMENT**

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Year shown</th>
<th>Fuel Type</th>
<th>Fuel Cell Developer</th>
<th>Vehicle Technical Data</th>
<th>Tech Status</th>
<th>Mkt. Adoption Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daimler-Chrysler</td>
<td>Jeep Commander</td>
<td>SUV</td>
<td>2000</td>
<td>Methanol</td>
<td>Ballard/Xcellsis</td>
<td>Motor/Tran: EPIC electric minivan production units; Power source: FC battery pack</td>
<td>T3</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>NECAR (Mercedes-Benz 180 van)</td>
<td>van</td>
<td>1993</td>
<td>CGH2</td>
<td>Ballard/Xcellsis</td>
<td>Max speed: 110 km/h; Range: 250 km; power: 50 kW. H2 tanks on roof.</td>
<td>T2</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>NECAR 2 (Mercedes-Benz V-Class)</td>
<td>Minivan</td>
<td>1995</td>
<td>CGH2</td>
<td>Ballard/Xcellsis</td>
<td>Significant reduction in volume and weight of FC system</td>
<td>T2</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>NECAR 3 (Mercedes A-Class)</td>
<td>car</td>
<td>1997</td>
<td>Methanol</td>
<td>Ballard/Xcellsis</td>
<td>1st vehicle in world with on-board methanol fuel reforming. Max speed: 120 km/h;</td>
<td>T3</td>
<td>M1 - M2</td>
</tr>
</tbody>
</table>
### SAMPLE OF FUEL CELL VEHICLES IN DEVELOPMENT - Continued

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Year shown</th>
<th>Fuel Type</th>
<th>Fuel Cell Developer</th>
<th>Vehicle Technical Data</th>
<th>Tech Status</th>
<th>Mkt. Adoption Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daimler-Chrysler</td>
<td>NECAR 4 (Mercedes A-Class)</td>
<td>car</td>
<td>1999</td>
<td>liquid hydrogen</td>
<td>Ballard/Xcellsis</td>
<td>Breakthrough - compact car that runs on pure H2 and offers room for 5 pasgs. + luggage. Max speed: 145 km/h; Power: 70 kW</td>
<td>T3</td>
<td>M1 - M2</td>
</tr>
<tr>
<td></td>
<td>NECAR 5 (Mercedes A-Class)</td>
<td>car</td>
<td>2000</td>
<td>Methanol</td>
<td>Ballard/Xcellsis</td>
<td>Further development of NECAR 3. Max speed: 150 km/h; 50% more efficient than NECAR 3 and only half as big and weighs 300 kg less. Ballard 900 stack; power: 75 kW</td>
<td>T4</td>
<td>M2 - DC planning to introduce fuel cell cars to mkt. in 2004</td>
</tr>
<tr>
<td>DMFC</td>
<td>one person vehicle</td>
<td>2000</td>
<td>Methanol</td>
<td></td>
<td>Ballard/Xcellsis</td>
<td></td>
<td>T3</td>
<td>M1</td>
</tr>
<tr>
<td>Sprinter (Mercedes)</td>
<td>van</td>
<td>2001</td>
<td>hydrogen</td>
<td>Ballard/Xcellsis</td>
<td>Delivered to Hamburg delivery service, Hermes</td>
<td>T3-T4</td>
<td>M1-M2</td>
<td></td>
</tr>
<tr>
<td>Hyundai Santa Fe</td>
<td>SUV</td>
<td>2000</td>
<td>hydrogen</td>
<td></td>
<td>Ballard/Xcellsis</td>
<td>Methanol reforming. Will perform the steam reforming and membrane purification in single system.</td>
<td>T3</td>
<td>M1</td>
</tr>
</tbody>
</table>
### SAMPLE OF FUEL CELL VEHICLES IN DEVELOPMENT - Continued

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Year shown</th>
<th>Fuel Type</th>
<th>Fuel Cell Developer</th>
<th>Vehicle Technical Data</th>
<th>Tech Status</th>
<th>Mkt. Adoption Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P2000 SUV</td>
<td>SUV</td>
<td>1999</td>
<td>Methanol</td>
<td>concept only</td>
<td>FC: PEM Ballard Mark 900 series. Fuel pressure: 3600 psi; Max speed: 128 km/h; Range: 160 km; power: 67 kW</td>
<td>T1</td>
<td>M1</td>
</tr>
<tr>
<td>Focus FCV</td>
<td>car (Focus)</td>
<td>2000</td>
<td></td>
<td>compressed hydrogen</td>
<td>Ballard/Xcellsis</td>
<td>same as FCV except FC: Polymer Electrolyte FC with methanol reformer, Ballard Mark 901</td>
<td>T4</td>
<td>M2 -expected for fleet availability in 2004</td>
</tr>
<tr>
<td>Focus FC5</td>
<td>car (Focus)</td>
<td>2000</td>
<td></td>
<td>Methanol</td>
<td>Ballard/Xcellsis</td>
<td>Max Speed: 124 km/h; Polymer Electrolyte FC with methanol reformer, Ballard Mark 901; power: 65 kW</td>
<td>T4</td>
<td>M1 - M2</td>
</tr>
<tr>
<td>Mazda Premacy</td>
<td>car (sedan)</td>
<td>2000</td>
<td></td>
<td>Methanol</td>
<td>Ballard/Xcellsis</td>
<td></td>
<td>T4</td>
<td>M1 - M2</td>
</tr>
</tbody>
</table>
### SAMPLE OF FUEL CELL VEHICLES IN DEVELOPMENT - Continued

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Year shown</th>
<th>Fuel Type</th>
<th>Fuel Cell Developer</th>
<th>Vehicle Technical Data</th>
<th>Tech Status</th>
<th>Mkt. Adoption Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Motors</td>
<td>Fuel Cell Precept</td>
<td>car</td>
<td>2000</td>
<td>hydrogen</td>
<td></td>
<td>Methalhydride storage</td>
<td>T2</td>
<td>M1 - info N/A</td>
</tr>
<tr>
<td>AUTOonomy</td>
<td>concept car</td>
<td></td>
<td>2002</td>
<td></td>
<td></td>
<td>2 parts: four-wheeled chassis platform; body attached to chassis by mechanical locks. Universal docking connection that links body to control drive-by-wire systems. Chassis houses powertrain (FC, hydrogen storage system etc.)</td>
<td>T1 - T2</td>
<td>M1</td>
</tr>
<tr>
<td>Opel HydroGen 1</td>
<td>Minivan (Opel Zafir)</td>
<td>2000</td>
<td>Hydrogen</td>
<td></td>
<td>Range: 500 m +;</td>
<td>T3</td>
<td>M1 - M2</td>
<td></td>
</tr>
<tr>
<td>Gen III Processor</td>
<td>Pickup (chevy S-10)</td>
<td>2001</td>
<td>Gasoline</td>
<td></td>
<td>Truck reforms gasoline onboard. World's 1st gasoline FCV; 25 kW</td>
<td>T2</td>
<td>M1</td>
<td></td>
</tr>
<tr>
<td>Automaker</td>
<td>Vehicle Type</td>
<td>Vehicle Mode</td>
<td>Year shown</td>
<td>Fuel Type</td>
<td>Fuel Cell Developer</td>
<td>Vehicle Technical Data</td>
<td>Tech Status</td>
<td>Mkt. Adoption Status</td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
<td>--------------</td>
<td>------------</td>
<td>--------------</td>
<td>---------------------</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>-------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Honda</td>
<td>FCX-V1</td>
<td>car</td>
<td>1999</td>
<td>hydrogen</td>
<td>experimental</td>
<td></td>
<td>T2</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>FCX-V2</td>
<td>car</td>
<td>1999</td>
<td>Methanol</td>
<td>experimental</td>
<td></td>
<td>T2</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>FCX-V3</td>
<td>car</td>
<td>2000</td>
<td>hydrogen</td>
<td>Honda</td>
<td>Honda FC used. Had slower acceleration and lower max speed. Experimental model</td>
<td>T3</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>FCX-V4</td>
<td>car</td>
<td>2001</td>
<td>hydrogen</td>
<td>Ballard/Xcellsis</td>
<td>H2 storage: 5000 psi; power 60 kW; FC: Ballard PEM; max speed 87 mph; Range: 185 m. Achieves performance of traditional mass-produced vehicles</td>
<td>T4</td>
<td>M2</td>
</tr>
<tr>
<td>Nissan Motor Co.</td>
<td>Xterra</td>
<td>SUV</td>
<td>2000</td>
<td>Methanol</td>
<td>UTC</td>
<td></td>
<td>T3</td>
<td>M1</td>
</tr>
<tr>
<td>Renault</td>
<td>Laguna Estate</td>
<td>car (station wagon)</td>
<td>1998</td>
<td>liquid hydrogen</td>
<td>UTC</td>
<td></td>
<td>T2</td>
<td>M1</td>
</tr>
<tr>
<td>Automaker</td>
<td>Vehicle Type</td>
<td>Vehicle Mode</td>
<td>Year shown</td>
<td>Fuel Type</td>
<td>Fuel Cell Developer</td>
<td>Vehicle Technical Data</td>
<td>Tech Status</td>
<td>Mkt. Adoption Status</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------</td>
<td>--------------</td>
<td>------------</td>
<td>-----------</td>
<td>---------------------</td>
<td>---------------------------------------------------------------------------------------</td>
<td>-------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Toyota</td>
<td>FCHV-3 SUV</td>
<td>2001</td>
<td>hydrogen</td>
<td>Toyota</td>
<td></td>
<td>body based on Highlander SUV; power: 90 kW. Regen braking.</td>
<td>T2</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td>FCHV-4 (Fuel Cell Hybrid Vehicle) SUV</td>
<td>2001</td>
<td>hydrogen</td>
<td>Toyota</td>
<td></td>
<td>Based on FCHV-3 and Highlander SUV, FCHV-4 is 1st Toyota FCV on US road. Completed totally in-house.</td>
<td>T2- T3</td>
<td>M1- M2</td>
</tr>
<tr>
<td></td>
<td>FCHV-5 SUV</td>
<td>2001</td>
<td>CHF</td>
<td>Toyota</td>
<td></td>
<td>FCH that generates electricity from hydrogen derived from Clean Hydrocarbon Fuel (CHF), using Toyota's CHF reformer</td>
<td>T4</td>
<td>M1- M2</td>
</tr>
<tr>
<td></td>
<td>FCHV-BUS1 Bus</td>
<td>2001</td>
<td>hydrogen</td>
<td>Toyota</td>
<td></td>
<td>Low-floor city bus, powered by high pressure hydrogen FCH system, dev. Jointly with Hino Motors. Range: 300 + km; power: 90 kW,</td>
<td>T3</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Jetta (Bora) HY .POWER car</td>
<td>2002</td>
<td>hydrogen</td>
<td>VW and Paul Scherrer Institute (PSI)</td>
<td></td>
<td>VW and PSI jointly developed a low-cost hydrogen FC. FC was developed with ultra capacitors to store engine's electrical energy. Electric motor rated at 75 kW. Incorporates new membrane use which is cheaper to manufacture</td>
<td>T3</td>
<td>M1</td>
</tr>
</tbody>
</table>
## 9.5 Appendix 5: Sample of Hybrid and Electric Vehicles

### SAMPLE OF HYBRID AND ELECTRIC VEHICLES - AUTOS AND BUSES

#### AUTOS

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Power</th>
<th>Development Stage</th>
<th>Technology Status</th>
<th>Mkt. Adoption Status</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>DaimlerChrysler</td>
<td>Dodge ESX-3 car</td>
<td>Diesel/Electric concept</td>
<td>T1</td>
<td>M1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Durango SUV</td>
<td>Gas/Electric in production</td>
<td>T4</td>
<td>M1-M2</td>
<td></td>
<td></td>
<td>10 DaimlerChrysler Electric Powered Interurban Commuter (EPIC) minivans join the fleet of Xpress Shuttle Vehicles at Los Angeles Airport</td>
</tr>
<tr>
<td></td>
<td>EPIC Minivan EV</td>
<td>EV</td>
<td>in development</td>
<td>T4</td>
<td>M1-M2</td>
<td></td>
<td>Max Road Speed: 40 km/hr Turf Speed: 24 km/hr (tires rated for road and turf). Recharge Time: 8 hours using a household 110-volt AC connection. Fast charge capability is being developed for these vehicles.</td>
</tr>
<tr>
<td></td>
<td>GEM car</td>
<td>EV</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prodigy Hybrid Electric car</td>
<td>Diesel/Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
<td>Max Speed: 120 kph (75 mph). Range: 117.5 km (73 m). Available only in select locations. Approx. 50 dealers who are certified to sell in US and Canada.</td>
</tr>
<tr>
<td></td>
<td>Ranger EV Pickup</td>
<td>EV</td>
<td>in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td>NiCd Batteries, Top Speed: 56 mph (90 km/hr). Range: 53 m (85 km). Can store 11.5 kWh. Can be charged in 4-6 hrs to 80%</td>
</tr>
<tr>
<td></td>
<td>Think City car</td>
<td>EV</td>
<td>production ready (2002)</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td>Range: 30 m (48 km). Power: 72 volt battery. Charging time: 4-8 hrs. Speed: (dual forward speed modes) Drive mode: 25 mph (40 km/hr), Turf mode: 15 mph (24 km)</td>
</tr>
<tr>
<td></td>
<td>USPS Truck pickup/van</td>
<td>EV</td>
<td>in production</td>
<td>T3-T4</td>
<td>M1-M2</td>
<td></td>
<td>Being tested in a number of locations across US. Max speed: 100 kph (61 mph). Range: 85 km (50 m)</td>
</tr>
<tr>
<td></td>
<td>Volvo Integrated Starter Generator Hybrid</td>
<td>car</td>
<td>Gas/Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td>Auxiliary energy/power source.</td>
</tr>
<tr>
<td></td>
<td>Volvo Power Split Hybrid car</td>
<td>Gas/Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Volvo Trucks Hybrid Class 8</td>
<td>Heavy Truck</td>
<td>Diesel/Electric concept</td>
<td></td>
<td>M1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### SAMPLE OF HYBRID AND ELECTRIC VEHICLES - Continued

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Power</th>
<th>Development Stage</th>
<th>Technology Status</th>
<th>Mkt. Adoption Status</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Motors</td>
<td>Chevy Triax</td>
<td>car/SUV</td>
<td>Gas/Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EV-1</td>
<td>car</td>
<td>EV in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hybrid Electric</td>
<td>Hybrid Electric Bus</td>
<td>bus</td>
<td>Diesel/Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parallel Hybrid</td>
<td>Parallel Hybrid Full size Pickup</td>
<td>pickup</td>
<td>Gas/Electric concept ready for production '04</td>
<td>T4</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precept</td>
<td>Precept</td>
<td>car</td>
<td>Diesel/Electric concept</td>
<td>T1-T2</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Series Hybrid</td>
<td>Series Hybrid</td>
<td>car</td>
<td>designed to operate with lithium polymer battery pack</td>
<td>T1-T2</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-10 Electric</td>
<td>S-10 Electric</td>
<td>pickup</td>
<td>EV in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Honda</td>
<td>EV Plus</td>
<td>car</td>
<td>EV in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td>Most fuel efficient 5 seater sedan</td>
</tr>
<tr>
<td></td>
<td>Insight</td>
<td>car</td>
<td>Gas/Electric in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Civic Hybrid</td>
<td>Civic Hybrid</td>
<td>car</td>
<td>Gas/Electric in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spocket</td>
<td>Spocket</td>
<td>car/pickup</td>
<td>Gas/Electric concept</td>
<td>T2</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toyota</td>
<td>e.com</td>
<td>car</td>
<td>EV concept</td>
<td>T2</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>HV-M4</td>
<td>SUV</td>
<td>Gas/Electric concept</td>
<td>T2</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prius</td>
<td>car</td>
<td>Gas/Electric in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RAV4 EV</td>
<td>SUV</td>
<td>EV in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nissan</td>
<td>Altra EV</td>
<td>Minivan</td>
<td>EV in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hypermini</td>
<td>car</td>
<td>EV concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diesel Hybrid Light Truck</td>
<td>pickup</td>
<td>gas/electric production ready</td>
<td>T3-T4</td>
<td>M1</td>
<td>CNG Engine/Capacitor/Electric-drive motor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tino</td>
<td>car/Minivan</td>
<td>Gas/Electric in production</td>
<td>T4-T5</td>
<td>M1-M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renault</td>
<td>Koleos</td>
<td>car/Minivan/SUV</td>
<td>Gas/Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bombardier</td>
<td>NV</td>
<td>car</td>
<td>EV in production</td>
<td>T4</td>
<td>M1-M2</td>
<td></td>
<td>Has small combustion engine as back up for emergency situations</td>
</tr>
<tr>
<td>Subaru</td>
<td>Elten Custom</td>
<td>car</td>
<td>Gas/Electric or Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td>Has small combustion engine as back up for emergency situations</td>
</tr>
<tr>
<td>Suzuki</td>
<td>EV Sport</td>
<td>car</td>
<td>Gas/Electric or Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pu-3 Commuter</td>
<td>car</td>
<td>Gas/Electric concept</td>
<td>T2-T3</td>
<td>M1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### SAMPLE OF HYBRID AND ELECTRIC VEHICLES - Continued

#### BUSES

<table>
<thead>
<tr>
<th>Automaker/ Busmaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Power</th>
<th>Development Stage</th>
<th>Technology Status</th>
<th>Mkt. Adoption Status</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Flyer Industries</td>
<td>Transit Bus</td>
<td>Diesel Electric</td>
<td>Diesel/Electric</td>
<td>in development</td>
<td>T4</td>
<td>M2</td>
<td></td>
</tr>
<tr>
<td>Orion Buses</td>
<td>Transit Bus</td>
<td>Diesel Electric</td>
<td>Diesel/Electric</td>
<td>in development</td>
<td>T4</td>
<td>M2</td>
<td></td>
</tr>
</tbody>
</table>

**Glossary of Abbreviated Terms**

AC = Alternate Current
EV = Electric Vehicle
### 9.6 Appendix 6: Sample of Alternative Fuel Vehicles

#### SAMPLE OF ALTERNATIVE FUEL VEHICLES - AUTOS AND BUSES

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Type</th>
<th>Vehicle Mode</th>
<th>Fuel Type</th>
<th>Range</th>
<th>Stage of Development</th>
<th>Tech Status</th>
<th>Mkt. Adoption Status</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMW</strong></td>
<td>Series 7 car</td>
<td>car</td>
<td>Hydrogen</td>
<td>TBD</td>
<td>in development</td>
<td>T3</td>
<td>M1</td>
</tr>
<tr>
<td><strong>DaimlerChrysler</strong></td>
<td>Dodge Ram van, maxi van, wagon</td>
<td>CNG Dedicated</td>
<td>van 368 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mini van</td>
<td>E85 FFV</td>
<td>E85 512 km Gas 640 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
<td></td>
</tr>
<tr>
<td><strong>Ford Motor Co.</strong></td>
<td>FFV (Taurus, Ranger, Explorer)</td>
<td>car/pickup/SUV</td>
<td>E85 FFV</td>
<td>variable</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Bi-Fuel F-150</td>
<td>Pickup</td>
<td>CNG Bi-Fuel</td>
<td>CNG 192 km Gas 512 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Bi-Fuel F-150</td>
<td>Pickup</td>
<td>LPG Bi-Fuel</td>
<td>LPG 400 km Gas 624 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Bi-Fuel Super Duty</td>
<td>Pickup</td>
<td>CNG Dedicated</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Dedicated CNG (Crown Vic., Econoline, F-Series)</td>
<td>car/pickup/van</td>
<td>CNG Dedicated</td>
<td>variable</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Volvo S80 Bi-Fuel</td>
<td>car</td>
<td>FFV</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
</tbody>
</table>
### SAMPLE OF ALTERNATIVE FUEL VEHICLES CONTINUED

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Name</th>
<th>Vehicle Mode</th>
<th>Fuel Type</th>
<th>Range</th>
<th>Stage of Development</th>
<th>Tech Status</th>
<th>Mkt. Adoption Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Motors</td>
<td>Chevy Silverado GMC Sierra</td>
<td>Pickup</td>
<td>CNG Bi-Fuel</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Chevy Silverado GMC Sierra</td>
<td>Pickup</td>
<td>CNG Dedicated</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Chevy Bi-Fuel Cavalier</td>
<td>car</td>
<td>CNG Bi-Fuel</td>
<td>CNG 176 km, Gas 576 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Chevy S-10 GMC Sonoma</td>
<td>Pickup</td>
<td>E85 FFV</td>
<td>E85 640 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Chevy Express GMC Savana</td>
<td>van</td>
<td>CNG Bi-Fuel</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Chevy Tahoe GMC Yukon</td>
<td>SUV</td>
<td>E85 FFV</td>
<td>E85 464 km, Gas 544 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td></td>
<td>Chevy Suburban GMC Yukon XL</td>
<td>SUV</td>
<td>E85 FFV</td>
<td>E85 464 km, Gas 544 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td>Honda</td>
<td>Civic GX</td>
<td>car</td>
<td>CNG Dedicated</td>
<td>320 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td>Mazda</td>
<td>B3000</td>
<td>Pickup</td>
<td>E85 FFV</td>
<td>E85 368 km, Gas 480 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td>Saab</td>
<td>Variable Compression</td>
<td>car</td>
<td>not determined</td>
<td>concept</td>
<td>T2</td>
<td>M1</td>
<td></td>
</tr>
<tr>
<td>Toyota</td>
<td>GNG Camry</td>
<td>car</td>
<td>CNG Dedicated</td>
<td>432 km</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td>Volkswagen</td>
<td>Jetta (Bora) Turbo Direct Injection</td>
<td>car</td>
<td>SunFuel (super-clean synthetic diesel)</td>
<td>in development</td>
<td>T4</td>
<td>M1-M2</td>
<td></td>
</tr>
</tbody>
</table>
## SAMPLE OF ALTERNATIVE FUEL VEHICLES CONTINUED

### ALTERNATIVE FUEL BUSES

<table>
<thead>
<tr>
<th>Automaker</th>
<th>Vehicle Name</th>
<th>Vehicle Mode</th>
<th>Fuel Type</th>
<th>Range</th>
<th>Stage of Development</th>
<th>Technology Status</th>
<th>Mkt. Adoption Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Flyer</td>
<td>Low Floor Bus Bi-Fuel</td>
<td>Transit bus</td>
<td>CNG, LPG</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td>Orion</td>
<td>40 ft. Bus CNG Dedicated</td>
<td>Transit bus</td>
<td>CNG Dedicated</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
<tr>
<td>NABI</td>
<td>40 ft. Bus Bi-Fuel</td>
<td>Transit bus</td>
<td>CNG, LPG</td>
<td>TBD</td>
<td>in production</td>
<td>T5</td>
<td>M1-M2</td>
</tr>
</tbody>
</table>

**Glossary of Abbreviations**

- **CNG** = Compressed Natural Gas
- **E85** = 85% Ethanol, 15% Gasoline
- **FFV** = Flexible Fuel Vehicle
- **LPG** = Liquefied Petroleum Gas (Propane)
- **SUV** = Sport Utility Vehicle
- **TBD** = To Be Determined
9.7 Appendix 7: Fuel Cell for Bicycle Applications

**FUEL CELL FOR BICYCLE APPLICATIONS**

<table>
<thead>
<tr>
<th>Company</th>
<th>Concept</th>
<th>Prototype</th>
<th>Technological Status</th>
<th>Market Adoption Status</th>
<th>Target Market</th>
<th>Market Conditions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aprilia (Italy)</td>
<td>Manhattan Scientifics NovArs division in Germany</td>
<td>Fuel-cell technology, which uses pollution free hydrogen gas to generate an electric current used to power a bicycle (ie. Electric bicycle)</td>
<td>T3</td>
<td>M2</td>
<td>AsiaEurope - high population density areas</td>
<td>Potential market for pollution free, two-wheel vehicles is enormous, an estimated 100 million two-wheel motorised vehicles in use world-wide.</td>
<td>Planned to be available in 2003 at a cost of US$2,300.</td>
</tr>
</tbody>
</table>
## 9.8 Appendix 8: Hydrogen Fuel Cell Applications for Scooters

### HYDROGEN FUEL CELL APPLICATIONS FOR SCOOTERS

<table>
<thead>
<tr>
<th>Company</th>
<th>Concept</th>
<th>Prototype</th>
<th>Technological Status</th>
<th>Market Adoption Status</th>
<th>Target Market</th>
<th>Market Conditions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manhattan Scientifics (German Division)</td>
<td>Fuel cell powered electric scooter.</td>
<td>Powered by a 3000 watt fuel cell. Production models of the scooter are expected to be able to be capable of covering 120 miles on a fuel up and attain a top speed of 35 miles per hour. The fuel cell system, including all electronic, valves and fans weighs slightly less than 6 kg.</td>
<td>T3</td>
<td>M2</td>
<td>Asia/Europe - high population density areas</td>
<td>Worldwide scooter production is estimated to be above 17 million a year and use is expanding globally. In the UK, scooter sales increased by 40% despite the bad weather. Similar growth in Germany and Italy. An estimated 10 million noisy scooters were sold in China in 2000 and 3 million in India.</td>
<td></td>
</tr>
<tr>
<td>Scooters India Ltd.</td>
<td>Zero-emission fuel cell technology based vehicle.</td>
<td></td>
<td>T2</td>
<td>M2</td>
<td>Asia/Europe - high population density areas</td>
<td>Worldwide scooter production is estimated to be above 17 million a year and use is expanding globally. In the UK, scooter sales increased by 40% despite the bad weather. Similar growth in Germany and Italy. An estimated 10 million noisy scooters were sold in China in 2000 and 3 million in India. Slated to be launched in 2003.</td>
<td></td>
</tr>
<tr>
<td>Palcan Fuel Cells (Vancouver) Celco Profil S.R.E (Italy)</td>
<td>Jointly develop hybrid fuel cell-battery power system for the European scooter, electric vehicle and portable industries (with peak power of up to 10 kw).</td>
<td></td>
<td>T2</td>
<td>M2</td>
<td>Europe</td>
<td>Worldwide scooter production is estimated to be above 17 million a year and use is expanding globally. In the UK, scooter sales increased by 40% despite the bad weather. Similar growth in Germany and Italy. Initial products from this agreement are expected to be demonstrated within 6 months in Europe.</td>
<td></td>
</tr>
</tbody>
</table>
## 9.9 Appendix 9: Fuel Cell Development for Marine Applications

**FUEL CELL DEVELOPMENT FOR MARINE APPLICATIONS**

<table>
<thead>
<tr>
<th>Company</th>
<th>Concept</th>
<th>Prototype</th>
<th>Technological Status</th>
<th>Market Adoption Status</th>
<th>Target Market</th>
<th>Comments</th>
</tr>
</thead>
</table>
| **Howaldtswerke-Deutsche Werft AG (HDW)**  
Siemens (Germany)  
Fincantieri (Italy) | A submarine fitted with an air independent propulsion system using a hydrogen fuel cell. | 1,840 ton German and Italian U212-class submarines. Submarine will consist of nine PEM fuel-cell modules each nominally rated at 34 kw, to yield approximately 300 kw. The system is predicted to yield 14 days submerged endurance and the ability to run up to 8 knots on fuel cells alone. The four 212A class submarines have been christened U31. | T4 | M3 | Military | Siemens is working on a next-generation PEM module rated at 120 kw, and two of these will be incorporated into HDW’s 1,860 ton U214 boats, planned as export successors to the U212 series. Such technological advances has the capability of improving their inherent stealth. Naval application only. |
| **Water Transit Authority (San Francisco, CA)** | First fuel cell powered commuter ferry in the world. | The ferry will carry 49 passengers from San Francisco to Treasure Island (and back). A one way trip is approximately 2 miles. The ferry will travel at a speed of 12 knots. | T1 | M1 | Urban centres with major commercial centres and residential areas separated by a body of water (i.e., River or bay). | The design, cost estimates and final drawings for the fuel cell powered vessel is expected to be completed by summer 2003. The region has the potential to put a fuel cell powered boat in the water within the next three years if funds are available for actual construction. |
| **Etaing GmbH (Germany)**  
ZeTek (Britain) | Silent, non-pollution propulsion in small boats. | Hydra, a 4.3 ton passenger launch built in Germany relies on an alkaline fuel cell for silent, non-polluting propulsion. The boat is able to carry two dozen passengers. Top speed is about six knots and cruising range on a single charge of hydrogen fuel is some 50 miles (80 km) | T3 | M2 | | This summer ZeTek plans to base a fuel cell narrow boat demonstrator on the Thames. A 5 kw fuel cell will drive a 21 kw Lynch electric motor to propel this 21.3 meter craft via conventional stern gear and propeller. There will be enough power left over for domestics and to drive facilities ashore such as a mobile exhibition. |
| **U.S. Coast Guard Research and Development Centre** | Zero-emission U.S. Coast Guard Fleet | U.S. Coast Guard Cutter | T2 | M0 | | Potential if development follows land based implementation. |
### 9.10 Appendix 10 : Fuel Cell Development for Aviation Applications

**FUEL CELL DEVELOPMENT FOR AVIATION APPLICATIONS**

<table>
<thead>
<tr>
<th>Company</th>
<th>Concept</th>
<th>Prototype</th>
<th>Technological Status</th>
<th>Market Adoption Status</th>
<th>Target Market</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nasa Glenn Research Centre</td>
<td>Zero CO2 Research Project</td>
<td>The goal of the project is to reduce or eliminate the environmental impact of subsonic air breathing propulsion systems. The project will develop enabling technologies for a hydrogen-fueled air breathing propulsion systems.</td>
<td>T1</td>
<td>M1</td>
<td>Aviation Industry</td>
<td>On going research project. Development is projected to take it's course of the next three years.</td>
</tr>
<tr>
<td>Boeing (Madrid)</td>
<td>Will develop and test an electrically powered demonstrator plane as part of a study to evaluate environmentally friendly fuel cell technology for future Boeing products.</td>
<td>Modify a small single-engine airplay by replacing its engine with fuel cells and an electric motor that will turn a conventional propeller.</td>
<td>T1</td>
<td>M1</td>
<td>Aviation Industry</td>
<td>Boeing believes that fuel cells and electric motors will not replace jet engines on commercial transports but they could one day replace gas turbines auxiliary power units. Test flights are scheduled to begin in early 2004. Nasa, fuel-cell makers, the automotive industry and several European universities are also supporting the project.</td>
</tr>
<tr>
<td>Fastec (US)</td>
<td>Advanced Technology Products (US)</td>
<td>The innovative research and education project focuses on designing, building, and testing a safe, practical 2-place General aviation airplane powered by DC electricity from fuel cells and advanced rechargeable batteries, that can take off, fly over 250 miles on a single charge and land safely.</td>
<td>T1</td>
<td>M1</td>
<td>Aviation Industry</td>
<td>There are three key development stages. First the plane will be equipped with advanced high energy, lithium-ion batteries flown, with a 100-mile range. Then, the batteries will be augmented with a 10-15 kw PEM fuel cell, and will have a 250 mile range. In its final form, it will fly solely on the power of a PEM fuel cell with a 500 mile range. The last stage of the project is likely to occur sometime in 2004.</td>
</tr>
</tbody>
</table>

The "E-plane" is being developed around an all-carbon French built 2 place Lafayette III, donated by American Ghiles Aircraft of Dijon France. The new airplane will be powered by a UQM 53 kw brushless permanent magnet electric motor.
9.11 Appendix 11 : Fuel Cell for Utility Vehicles

**FUEL CELL FOR UTILITY VEHICLES -- Light Industrial Vehicle powered by fuel cell**

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>APPLICATION</th>
<th>LOCATION</th>
<th>TECHNOLOGY STATUS</th>
<th>MARKET ADOPTION STATUS</th>
<th>COMMERCIALIZATION</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whistler Inc.</td>
<td>Carbon-X Fuel cell powered Golf Car</td>
<td>Sacramento, California</td>
<td>T4</td>
<td>M2</td>
<td>Planned commercial testing by late 2002</td>
<td></td>
</tr>
<tr>
<td>John Deere, Energy Partners, Southeastern Technology Center, and more</td>
<td>Gator</td>
<td>N/A</td>
<td>T3</td>
<td>M2</td>
<td>Demonstration units currently being tested</td>
<td></td>
</tr>
</tbody>
</table>


## 9.12 Appendix 12: Hydrogen Cell for Mining Applications

### HYDROGEN FUEL CELL FOR MINING APPLICATIONS

<table>
<thead>
<tr>
<th>COMPANY</th>
<th>APPLICATION</th>
<th>LOCATION</th>
<th>TECHNOLOGY STATUS</th>
<th>MARKET ADOPTION STATUS</th>
<th>COMMERCIALIZATION</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuelcell Propulsion Institute</td>
<td>Mine Locomotive</td>
<td>Denver, Colorado</td>
<td>T2</td>
<td>M1</td>
<td>Going through a several year testing phase</td>
<td>Displayed at MINExpo 2000, and Cdn. Institute of Mining Expo May 2001</td>
</tr>
<tr>
<td>Fuelcell Propulsion Institute</td>
<td>Mine Loader</td>
<td>Denver, Colorado</td>
<td>T1</td>
<td>M1</td>
<td>4 year design and build phase</td>
<td></td>
</tr>
<tr>
<td>Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health (NIOSH)</td>
<td>Zeus</td>
<td>Spokane, Washington</td>
<td>T2</td>
<td>M2</td>
<td>Demonstration project</td>
<td></td>
</tr>
</tbody>
</table>
## 9.13 Appendix 13: Sample of State Policies Targeting Fuel Cells

### SAMPLE OF STATE POLICIES TARGETING FUEL CELLS

<table>
<thead>
<tr>
<th>State</th>
<th>Fuel Cell Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arkansas</td>
<td>Income tax credit up to 50% of firms' expenditures on design, development, and production of fuel cells, including vehicle applications.</td>
</tr>
<tr>
<td>California</td>
<td>State loans, grants, and research funding for the development of the fuel cells (aimed at efficiency and cost effectiveness). Pending legislation would make buses with fuel cells exempt from sales tax.</td>
</tr>
<tr>
<td>Connecticut</td>
<td>State funding for research and development of fuel cells (totaling $1,125,000). Legislation requires electricity providers to obtain a portion of their supply from renewable sources (including fuel cells). A portion of the electric bill subsidizes fuel cell research. Tax incentives for fuel cell vehicles, including sales tax exemption for purchase of and conversion to fuel cell vehicles. Clean Energy Fund (CEF) supports applications of fuel cells and renewables, including $2 mil to South Windsor, CT for a fuel cell emergency generator. CEF is also $6 mil in first-year funding for research through its Fuel Cell Initiative. The Connecticut legislature recently announced that it would fund six eminent scholar positions in fuel cell related disciplines.</td>
</tr>
<tr>
<td>Maine</td>
<td>Fuel cell vehicles projects are eligible for grants and low-interest loans from the state. Fuel cell vehicles are exempted sales tax on the portion of the cost that exceeds the cost of comparable gasoline vehicles. Electric providers must obtain 30% of their supply from renewable sources, including fuel cells.</td>
</tr>
<tr>
<td>Maryland</td>
<td>Fuel cells larger than 2 kW are exempted from sales tax. Fuel cell vehicles have excise tax exemptions. Facilities powered by fuel cells are exempted from &quot;competitive transition charges&quot;.</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>The state's Technology Park Corp. supports fuel cell technology through grants, loans, equity investment and customer rebates for R&amp;D, public information, and market development. Fuel cells are considered renewable sources for electric utility &quot;renewable portfolio standards.&quot; The Renewable Energy Trust Fund funds research in renewable energy and fuel cells. Funding consists of $150 mil per year from 1998-2003, and $20 mil per year after that.</td>
</tr>
</tbody>
</table>
SAMPLE OF STATE POLICIES TARGETING FUEL CELLS -- Continued

<table>
<thead>
<tr>
<th>State</th>
<th>Fuel Cell Programs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan</td>
<td>Developed a comprehensive plan to encourage the development of a automotive fuel cell industry.</td>
</tr>
<tr>
<td>New Jersey</td>
<td>Fuel cells are considered renewable sources for electric utility &quot;renewable portfolio standards&quot;, and are eligible for state funding as part of &quot;demand side management&quot; to lower the costs of market transformation.</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Fuel cell projects for electric utilities are eligible for funding from a ratepayer-funded program administered by the state.</td>
</tr>
<tr>
<td>Ohio</td>
<td>On-site fuel cell operators are eligible for &quot;net metering&quot; (selling excess power to the electric utility).</td>
</tr>
<tr>
<td>Oregon</td>
<td>Fuel cell owners receive a $1,500 tax credit, and are eligible for &quot;net metering&quot;.</td>
</tr>
<tr>
<td>Rhode Island</td>
<td>A state electric tax of 2.3 mills per kW-hr funds demand-side management and renewable energy programs, which include fuel cells. The tax expires in 2002.</td>
</tr>
<tr>
<td>Texas</td>
<td>Created the Fuel Cell Commercialization Initiative.</td>
</tr>
<tr>
<td>Vermont</td>
<td>Fuel cells with a capacity smaller than 15 kW are eligible for &quot;net metering&quot;.</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Fuel cells are considered renewable sources for electric utility &quot;renewable portfolio standards&quot;.</td>
</tr>
</tbody>
</table>

### 9.14 Appendix 14: The Fuel Cell Industry in Canada

#### THE FUEL CELL INDUSTRY IN CANADA

<table>
<thead>
<tr>
<th>Company or Entity</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASA Automation Systems Associates</td>
<td>Fuel cell testing equipment</td>
</tr>
<tr>
<td>Azure Dynamics</td>
<td>Hybrid electric vehicle control systems</td>
</tr>
<tr>
<td>Ballard Power Systems</td>
<td>PEM fuel cells -- Numerous major partners</td>
</tr>
<tr>
<td>BC Hydro</td>
<td>Hydrogen production and infrastructure</td>
</tr>
<tr>
<td>BC Gas, BCG eFuels</td>
<td>Natural gas for fuel cells + NG combustion Alliance with Westport Innovations</td>
</tr>
<tr>
<td>Blue Energy Canada</td>
<td>Tidal energy: electricity from Davis turbine</td>
</tr>
<tr>
<td>Cellex</td>
<td>PEM fuel cell application products</td>
</tr>
<tr>
<td>CFS Alternative Fuels</td>
<td>Liquefaction of landfill gas to liquid natural gas</td>
</tr>
<tr>
<td>Methanex</td>
<td>Develop methanol as a fuel for fuel cells</td>
</tr>
<tr>
<td>Nunavut Environmental</td>
<td>Renewable hydrogen energy for Nunavut</td>
</tr>
<tr>
<td>QuestAir</td>
<td>Gas purification (hydrogen + oxygen) Alliance with Ballard Power Systems</td>
</tr>
<tr>
<td>Placan Fuel Cells</td>
<td>PEM fuel cell systems (Asian market focus)</td>
</tr>
<tr>
<td>Xantrex</td>
<td>Power conversion electronics</td>
</tr>
<tr>
<td>XCELSIS</td>
<td>Fuel cell engines using Ballard fuel cells Owned by Ballard</td>
</tr>
<tr>
<td>Westport Innovations</td>
<td>Direct injection Natural Gas engines</td>
</tr>
<tr>
<td>Institute for Integrated Energy Systems</td>
<td>R&amp;D Fuel cell technology</td>
</tr>
<tr>
<td>University of Victoria</td>
<td>R&amp;D Fuel cell technology</td>
</tr>
<tr>
<td>NRC Innovation Center</td>
<td>Labs for fuel cell technology R&amp;D + testing</td>
</tr>
</tbody>
</table>
### THE FUEL CELL INDUSTRY IN CANADA -- Continued

#### Alberta

<table>
<thead>
<tr>
<th>Company or Entity</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynetek Industries</td>
<td>High-pressure hydrogen storage tanks</td>
</tr>
<tr>
<td>Global Thermoelectric</td>
<td>High temperature Solid Oxide Fuel Cells (SOFC)</td>
</tr>
<tr>
<td>Snow Leopard, Ehtyl Tech</td>
<td>Extraction of hydrogen from sour gas (H2S)</td>
</tr>
<tr>
<td>Xogen</td>
<td>Innovative water electrolysis technology</td>
</tr>
<tr>
<td>University of Calgary</td>
<td>Charir in Hydrogen Technology</td>
</tr>
</tbody>
</table>

#### Saskatchewan

<table>
<thead>
<tr>
<th>Company or Entity</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHEC Labs (Solar Hydrogen Energy Corporation) <a href="http://www.solar-h.com">http://www.solar-h.com</a></td>
<td>Proprietary hydrogen production technology from water and sunlight</td>
</tr>
</tbody>
</table>

#### Ontario

<table>
<thead>
<tr>
<th>Company or Entity</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astris Energy</td>
<td>Alkaline fuel cells</td>
</tr>
<tr>
<td>Energy Ventures</td>
<td>Direct methanol fuel cells (DMFC)</td>
</tr>
<tr>
<td>Enbridge Consumer Gas</td>
<td>Natural gas distribution</td>
</tr>
<tr>
<td></td>
<td>Alliance with Global Thermoelectric</td>
</tr>
<tr>
<td>Fuel Cell Technologies</td>
<td>Solid oxide fuel cells, Aluminum-air systems</td>
</tr>
<tr>
<td>Fuel Maker</td>
<td>Natural gas compressors for refuelling stations</td>
</tr>
<tr>
<td>Green Volt Power</td>
<td>Alkaline fuel cells</td>
</tr>
<tr>
<td>Hydrogenics</td>
<td>PEM fuel cells + fuel cell testing equipment</td>
</tr>
<tr>
<td>Ontario Power Generation</td>
<td>Demonstration program of SOFC with Siemens Westinghouse</td>
</tr>
<tr>
<td>Ontario Hydro Technologies</td>
<td>Support development of Canadian Electric Vehicle infrastructure standards</td>
</tr>
<tr>
<td>Stuart Energy Systems</td>
<td>Electrolyzers to refuel Fuel Cell Vehicles</td>
</tr>
<tr>
<td>University of Toronto</td>
<td>Center for Hydrogen and Electrochemical studies</td>
</tr>
<tr>
<td>Royal Military College, Kingston</td>
<td>Fuel processing, hydrogen and fuel cell research</td>
</tr>
</tbody>
</table>
### THE FUEL CELL INDUSTRY IN CANADA -- Continued

#### Quebec

<table>
<thead>
<tr>
<th>Company or Entity</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRYO-NOR</td>
<td>High tech containers for liquid hydrogen</td>
</tr>
<tr>
<td>H Power Enterprises of Canada</td>
<td>PEM fuel cell systems: residential + portable</td>
</tr>
<tr>
<td>Hydrogen Systems</td>
<td>Electrolyzers</td>
</tr>
<tr>
<td>Hydrogenal</td>
<td>Hydrogen production plant (in part electrolysis) Owned by air Liquide and Hydro-Quebec</td>
</tr>
<tr>
<td>Hydro Quebec, IREQ, LTEE</td>
<td>Various researches and projects in fuel cells, hydrogen and electrolysis</td>
</tr>
<tr>
<td>Hythane-Tech</td>
<td>Hythane (natural gas + hydrogen) technology for the conversion of city buses to hythane</td>
</tr>
<tr>
<td>Technologies M4</td>
<td>Electric drive train technology for electric vehicles</td>
</tr>
<tr>
<td>Tektrend</td>
<td>Development of techniques for analysis and testing for gas pressure tanks</td>
</tr>
<tr>
<td>Hydrogen Research Institute, UQTR (Universite du Quebec a Trois-Rivieres)</td>
<td>Researches on hydrogen storage and safety issues</td>
</tr>
<tr>
<td>University of Sherbrooke</td>
<td>Chair in Electro catalysis</td>
</tr>
</tbody>
</table>

#### Northwest Territories/Yukon

<table>
<thead>
<tr>
<th>Company or Entity</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand Alone Energy</td>
<td>Remote power generation using fuel cells</td>
</tr>
<tr>
<td>Yukon Energy Corporation</td>
<td>Remote power generation using fuel cells</td>
</tr>
</tbody>
</table>
9.15 Appendix 15: Trailer Manufacturers in Manitoba

**Arne’s Welding Ltd.**
835 Mission Street  
Winnipeg, MB R2J 0A4  
Tel: (204) 233-7111  
Product Description: Dump trailers, low bed trailers, customized trailers, trailer parts and accessories

**Cancade Company**
1615 – 12th Street  
Brandon, MB R7A 7L1  
Tel: (204) 728-4450  
Product Description: Truck bodies, grain trucks, gravel trucks, farm trailers,

**Ft. Garry Industries**
2525 Inkster Blvd.  
Winnipeg, MB  
Tel: (204) 586-8261  
Product Description: Flat deck trailers, grain trailers, truck bodies, truck parts, trailers

**Grain Master Manufacturing Ltd.**
Tel: (204)-224-1697  
Product Description: Grain trucks, trailers

**Millcosteel Ltd.**
315 Park Ave. E  
Brandon, MB  
Tel: (204) 726-9639  
Product Description: Commercial trailers, industrial trailers, farm trailers
9.16 Appendix 16 : Members of the Working Group

Members and Affiliation:

1. John Spacek, Chair, Manitoba Transportation & Government Services
2. Terry, Zdan, Manitoba Transportation & Government Services
3. Robert Parsons, Energy Development Initiative, Department of Energy, Science and Technology
4. Rodney Semotiuk, Natural Resources Canada
5. Dr. Mal Symonds, Faculty of Engineering, University of Manitoba (Alternate: Dr. Jack Cahoon)
6. Joe Cattani, IRAP, NRC, Industry Canada
7. Paul Zanetel, New Flyer
8. Greg Zador, City of Winnipeg (Alternate Andrew Cowan)
9. Gordon Maher, Manitoba Hydro
10. Consultant: Doug Duncan, University of Manitoba Transport Institute
11. Connie van Rosmalen, University of Manitoba Transport Institute
10.0 References


7 www.unglobalcompact.org and www.unglobalcompact.org/un/gc/unweb.nsf/content/bmw.htm


14 Gregory M. Stoup, *Opportunities for Creating a Fuel Cell Industry in Ohio*. Center for Regional Economics Issues, Weatherhead School of Management, Cleveland, OH. November 2001


22 *Marine Fuel Cell Market Analysis – September 1999*. Prepared by the U.S. Coast Guard Research and Development Center, 1999


24 Gregory M. Stoup, *Opportunities for Creating a Fuel Cell Industry in Ohio*. Weatherhead School of Management, Cleveland, OH, 2001