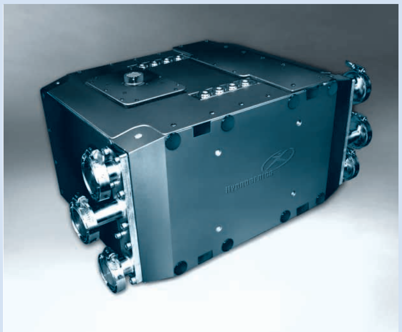
Preliminary Hydrogen Opportunities Report

Setting the Direction for Hydrogen Development in Manitoba



Fuel Cell
courtesy of Hydrogenics Corporation

Ford Fuel Cell Focus at The Forks, Winnipeg June 2002

Hydrogen Fuel Dispenser
courtesy of Kraus Global

April 2003

MANITOBA ENERGY DEVELOPMENT INITIATIVE

Manitoba
Building for the Future

PRELIMINARY
HYDROGEN OPPORTUNITIES REPORT

April 2003

- **Compiled Report of Manitoba Hydrogen Steering Committee and Working Groups**
- **Energy Development Initiative**
- **Manitoba Energy, Science and Technology**

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EXECUTIVE SUMMARY

This report summarizes the results of preliminary assessments of hydrogen-related opportunities for Manitoba. Hydrogen is often characterized as the "ultimate fuel of the future," being both clean and available without the need for foreign energy imports. The progressive movement toward a cleaner energy economy, based on hydrogen, could ultimately result in the use of a range of new technologies, products, services, as well as increased use of renewable energy sources, creating a range of new economic opportunities. It should be recognized, however, that a hydrogen future is not guaranteed and that competing technologies or technologies not yet discovered could win out in the future. It is important to monitor and stay on top of these technologies in addition to a focus on hydrogen.

In anticipation of a long-term transition to hydrogen, Manitoba has begun the process to develop a Hydrogen Economic Development Strategy, with a vision to: *Become over the next twenty years a leader in the provision of products, services and technologies that will contribute to a cleaner energy economy, particularly one based on renewable hydrogen*. As the first logical step, a series of broad-based preliminary assessments were conducted to identify hydrogen-related opportunities. This work has been coordinated through the Manitoba Government's Energy Development Initiative, but it reflects the cooperation of many participating organizations, including different departments, all three levels of government, utility, university, and industry representatives.

The objective of the preliminary assessments was to identify opportunities that could form the basis of a Hydrogen Economic Development Strategy, with a focus on identifying opportunities that would make sense for Manitoba, by creating manufacturing or service value-add, export potential, long-term high-value employment, or knowledge and skills.

Five Working Groups, operating under the auspices of the Manitoba Hydrogen Steering Committee, conducted preliminary assessments for the following five specific opportunity areas:

- Hydrogen production and movement;
- Transportation: vehicles and refueling;
- Stationary and portable fuel cell applications;
- Research/scientific centre of excellence; and
- Non-fuel and other applications.

The most obvious connection to a Manitoba clean energy future is the hydroelectric resources of the province, which when combined with water electrolysis technologies provides the ability to produce clean hydrogen. Such hydrogen may have a variety of applications including possible export. It is important to note that producing bulk hydrogen solely for the purpose of utility-scale reconversion back to electricity within Manitoba would not make sense, given significant resulting energy losses. It is clear from the results of the assessments that any opportunities for large-scale hydrogen production from water electrolysis remain very long-term in nature, and will depend on the emergence of satisfactory market conditions, and lower long-term production costs than competing processes, particularly the large-scale production of hydrogen from natural gas. If acceptable conditions can be achieved, the potential is significant. Given its current hydroelectric advantage, Manitoba could be the first jurisdiction in North America where large-scale electrolysis production of hydrogen becomes cost-efficient. The province could also become self-sufficient in transportation fuels.

The path toward a long-term hydrogen future requires identifying and pursuing early stage opportunities, to allow Manitobans to capitalize on long-term opportunities. Potentially viable opportunities in the near- to medium-term for hydrogen will involve niche applications, because of the still costly nature of hydrogen technologies. Such niche opportunities may also represent economic development opportunities in their own right. The preliminary assessments undertaken by the Working Groups identified five priority niche areas for Manitoba, including transit buses and refueling, by-product hydrogen, direct-to-DC electricity applications for fuel cells, hydrogen safety and systems design, and other possible light-duty vehicle applications.

The potential Manitoba opportunities require specific conditions to be fulfilled in order to be successful. Many of the opportunities are subject to competition from non-hydrogen technologies or are subject to significant uncertainty, particularly regarding competitive energy prices such as for natural gas. All of the opportunities will require partnerships in order to be successfully implemented, in particular accessing existing and forthcoming programs of the Federal Government. Given the preliminary nature of assessments, the opportunities will require further evaluation in order to confirm suitability.

The Working Groups and Steering Committee identified eleven specific follow-up actions:

1. Transit bus demonstration, including refueling and on-site hydrogen production.
2. Fuel cell demonstration using by-product hydrogen.
3. Development of Centre of Excellence on hydrogen.
4. Monitoring progress of proposed hydrogen system at Manitoba Hydro's Dorsey Converter Station.
5. Memorandum of Understanding (MOU) with Government of Iceland on hydrogen development.
6. Direct-to-DC electricity fuel cell demonstration for backup-power.
7. Hydrogen internal combustion engine (ICE) fleet vehicles demonstration.
8. Investigation of non-fuel applications for by-product hydrogen.
9. Investigation of niche light-duty vehicle manufacturing opportunities.
10. Electricity export opportunities linked to clean hydrogen production.
11. Evaluation of potential for identified non-hydrogen alternative energy technologies.

Given important uncertainties, not all identified actions may lead to successful outcomes. Five of these actions are given highest priority because of time sensitivity. Follow-up evaluations and development of business case or public policy justifications thus will need to be undertaken rapidly. These five actions, in no order, are described as follows:

1. <u>Fuel cell transit bus demonstration, including refueling and on-site electrolysis hydrogen production</u>.

   Transit buses and associated refueling represent a natural opportunity for Manitoba, both for near-term demonstration and long-term economic development:

   - Winnipeg is already a major manufacturing centre for buses, given the presence of both New Flyer and Motor Coach Industries, and a demonstration would help to promote advanced bus manufacturing in the province.
   - Transit bus niche application was identified in the assessments to be a priority for hydrogen fuel cells, being already furthest developed in terms of demonstration of the technology and likely to be the first vehicular application to achieve any significant market penetration, within eight to ten years.
   - Refueling would take advantage of and support the capabilities of Kraus Global as a leader in alternative gaseous refueling systems.
   - Prospective fuel cell bus demonstration project already has been proposed as part of the recent Winnipeg/Manitoba-Urban Transportation Showcase Expression of Interest.

   On the fuel production side, the implementation of a demonstration for transit buses could allow Manitoba to have the first commercially viable electrolysis hydrogen refueling station. So far economical production has not been part of other demonstrations, which have often relied on donated fuel. This aspect of the project would provide inherent economic benefits, as well as experience in the management of commercial hydrogen infrastructure.

2. <u>Fuel cell demonstration project using by-product hydrogen</u>.

   Manitoba currently has two major sodium chlorate plants producing hydrogen as a by-product. A fairly unique opportunity exists for a demonstration project using a stationary fuel cell to generate electricity from unused by-product hydrogen, which has never been previously attempted. Enough hydrogen is potentially available to allow this to lead to one of the largest fuel cell installations in the world. The project could also reduce overall electricity use by such plants, allowing increased electricity exports by Manitoba Hydro.

The lessons learned from working with by-product hydrogen are applicable to other hydrogen projects, and any specialized knowledge or products developed to allow successful implementation might be exportable. The focus of the proposed initial small-scale demonstration project would be to confirm the suitability of fuel cells in this application through extended operation (3 to 5 years). The long-term nature of testing requires as short a delay as possible in commencing the demonstration.

3. Research/Scientific Centre of Excellence.

The creation of a research/scientific Centre of Excellence was recommended, being based as a starting point on the hydrogen-related activities at the Atomic Energy of Canada Limited Whiteshell laboratories in Pinawa. The purpose of the proposed Centre would include practical hydrogen systems design for industrial applications, fundamental research, product development, prototype testing, etc. The Centre would take advantage of unique experience and facilities that have already been developed at AECL for hydrogen in their nuclear-related research, as well as growing interest and capabilities in hydrogen-related research at Manitoba universities.

A preliminary model for the proposed Centre was identified; this being a stand-alone non-profit corporation based on the successful TRLabs in the telecommunications sector. Potential stakeholders include the Province of Manitoba, University of Manitoba, University of Winnipeg, Red River College, AECL, Manitoba Hydro, and interested private sector Manitoba companies. A full cost structure for the model has not been developed, but will require involvement of the Government of Canada in setting up the Centre, particularly through the National Research Council, and in potential research funding. In addition to academic and skills development, the proposed Centre of Excellence could also provide direct economic development opportunities. As was identified in the assessments, marketable hydrogen-safety services and products could result in the near term, including potential certification testing services and spin-off product manufacturing.

The existing hydrogen program at AECL's Whiteshell laboratories is near the end of its mission, and AECL has plans to wind down its hydrogen activities at Whiteshell by the end of 2003. As such, there is a limited window of opportunity for taking advantage of these capabilities.

4. Monitoring progress of Manitoba Hydro Dorsey hydrogen project.

Manitoba Hydro is already considering the commercial implementation of a dedicated industrial-grade electrolysis system at the Dorsey Converter Station. Hydrogen produced by this system would displace imported hydrogen used as coolant, with a very high associated cost. Besides being cost efficient in its own right, it would provide relevant knowledge and experience in hydrogen production system implementation and operation, particularly for higher-value industrial-grade hydrogen.

5. Memorandum of Understanding (MOU) with Government of Iceland on Hydrogen Development.

Developing collaborative partnerships is important for hydrogen development, because of technical and financial risks, and high costs associated with hydrogen technologies and hydrogen infrastructure today. Such arrangements share risks burden, develop knowledge and experience in a cost efficient manner through leveraging, and generate profile.

Of immediate and specific relevance to Manitoba is the development of a broad collaborative partnership with Iceland. In addition to a focus on renewable energy sources and a focus on hydrogen, Manitoba and Iceland share many other important cultural and business connections. A MOU with Iceland on hydrogen development is a logical first step, potentially including:

- Promoting a closer working relationship between governments and companies in both jurisdictions on hydrogen;
- Investigating matters of mutual interest for joint initiatives on hydrogen; and
- Investigating the benefits of people and information exchanges and joint research/training initiatives.

Collaborations with other potential partners, particularly international, need to be identified and pursued.

Hydrogen Economic Development Strategy

The actions recommended by the Working Groups are important in helping to define the future directions of a Hydrogen Economic Development Strategy for Manitoba. These actions are specifically aimed at gaining experience in target niches and assessing further development directions. The nature of the Strategy will remain dynamic and will depend on confirming likely successful opportunity areas.

Recommendations

1. The Manitoba Hydrogen Steering Committee will undertake the following:

    - Proceed with implementing follow-up evaluation and business case or public policy justification for the five most time sensitive near-term actions, and undertake the other six identified actions as time permits.
    - Identify lead proponents and confirm participants in implementing actions.
    - Confirm funding requirements and sources, including beginning discussions with the Federal Government on securing appropriate funds.
    - Take responsibility for tracking developments and current events relevant to hydrogen.

2. Return to the Community and Economic Development Committee of Cabinet with a progress update.

1.0 INTRODUCTION

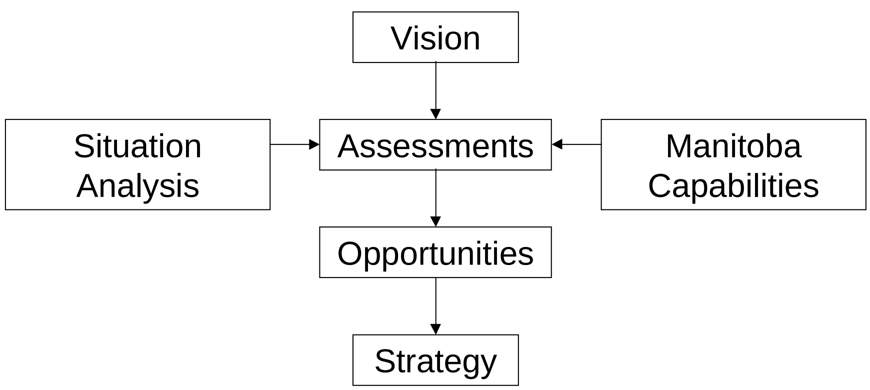
Hydrogen represents an energy carrier that is clean and can be produced without foreign energy imports, being often characterized as the "ultimate fuel of the future." While hydrogen as a commercial energy carrier is still in its development stages, there is growing interest and also growing momentum to address the technical difficulties and barriers that remain, and to move hydrogen forward to reality.

The progressive movement toward a cleaner energy economy, based on hydrogen, will result in new technologies, as well as increased use of renewable energy sources, creating new economic opportunities. In anticipation of this future, Manitoba has begun the process to develop a Hydrogen Economic Development Strategy that will allow the province to best position itself for the anticipated transition, in the near-term, medium-term and long-term. It should be recognized, however, that a hydrogen future is not guaranteed and that competing technologies or technologies not yet discovered could win out in the future. It is important to monitor and stay on top of these technologies in addition to a focus on hydrogen.

As a first logical step, a broad-based preliminary assessment was conducted to identify hydrogen-related opportunities, with the compilation of results documented in this report. This work has been coordinated through the Manitoba Government's Energy Development Initiative, which is responsible for coordinating broad energy policy and pursuing energy-related economic development for Manitoba, but it reflects the cooperation of many participating organizations, including different departments, all three levels of government, utility, university, and industry representatives.

2.0 STRATEGY DEVELOPMENT PROCESS

In order to work towards establishing an appropriate Hydrogen Economic Development Strategy for Manitoba, a logical overall process has been under way, represented as follows:



The important steps undertaken so far, leading to identification of opportunities, as well as the generic assessment methodology employed, is summarized in the following sections.

2.1 Manitoba's Hydrogen Vision

Manitoba has developed a vision to: *Become over the next twenty years a leader in the provision of products, services and technologies that will contribute to a cleaner energy economy, particularly one based on renewable hydrogen*. This vision formed the basis for the assessment activities.

2.2 Hydrogen Steering Committee

A Manitoba Hydrogen Steering Committee was formed to provide broad direction for the individual assessments of potential hydrogen opportunities for Manitoba. The Committee consists of core stakeholders with direct interest or involvement in hydrogen development. A list of Hydrogen Steering Committee members is provided in Appendix A.

Committee participants made commitments on behalf of their individual organizations and provided both human and financial resources as necessary for the individual assessments undertaken. The Committee is responsible for reporting back to the Provincial Government upon the completion of the assessments. An evaluation of the future role of the Manitoba Hydrogen Steering Committee will be undertaken to determine responsibilities and involvement in future steps, particularly for the development of a hydrogen economic development strategy.

2.3 Working Groups

A series of Working Groups was formed under the auspices of the Manitoba Hydrogen Steering Committee in order to conduct preliminary assessments. Five Working Groups have so far been actively involved in assessments for the following specific opportunity areas:

- Hydrogen production and movement (Chapter 4);
- Transportation: vehicles and refueling (Chapter 5);
- Stationary and portable fuel cell applications (Chapter 6);
- Research/scientific centre of excellence (Chapter 7); and
- Non-fuel and other applications (Chapter 8).

A list of Working Group members is provided in Appendix B.

Significant resources were committed to the conduct of the preliminary assessments, amounting to more than 500 staff-days in aggregate. The results of the Working Groups are much too detailed to be included in their entirety within this report. A synopsis of key information from each is provided in respective chapters, as indicated. A sixth working group, dealing with identification of Business Spin-offs, had been originally envisioned, but was deferred given that the nature of spin-offs would depend on opportunities identified by the other groups.

The Energy Development Initiative's Hydrogen Specialist facilitated the activities of the Steering Committee and various Working Groups, providing technical guidance, communications and linkage between Working Groups, developing assessment templates, and collating the collective assessment reports.

2.4 Preliminary Assessments

The objective of the preliminary assessments was to identify hydrogen-related opportunities that could in turn provide input for a Hydrogen Economic Development Strategy. The focus was on identifying project opportunities that make sense, that may provide a reasonable probability of economic success in specific applications, enhance environmental sustainability, and create:

- Manufacturing or service value-add;
- Export potential;
- Long-term, high-value employment; or
- Knowledge and skills.

The sequential steps involved in the generic assessment methodology used by the Working Groups are summarized as follows:

- Technology scans, including identification of key hydrogen and competing technologies, their current development status, current major players, extent of existing markets and approximate market commercialization status.
- Comparing technology options available.
- Defining estimates (or range of estimates) on the likely market commercialization timeframe, and what may represent potential major alternatives into the future.
- Identifying important trends and how they would likely impact technology development and market commercialization timeframes.
- Identifying challenges for technology development and commercialization.
- Identifying generic and specific project opportunities for Manitoba.
- Defining potential scenarios that likely could be faced in the future.
- Defining opportunity directions for development strategy for Manitoba.
- Identifying linkages to other working group opportunities.
- Identifying policy issues that need to be addressed in order to ensure success.
- Identifying strategic partners for development in Manitoba.
- Defining next steps, including the extent of resources likely required.

The intent was for Working Groups to focus primarily on "generic" opportunities within the near-term, medium-term and long-term, given that there might be differing commercial interests. At the same time, it was also desired for Working Groups to identify tangible first steps and demonstration projects as part of the overall assessment process that would lead to a better ultimate understanding of how to exploit opportunities.

2.5 Definitions

Common definitions of technology development status and market development status were adopted across all Working Groups in order to provide a common understanding. A common definition of developmental time frame was also adopted as follows:

- Near-term future, meaning within the next five years;
- Medium-term future, meaning within the next 5 to 15 years; and
- Long-term future, meaning beyond 15 years.

In some of the assessments, the term "integration" has been used relating to opportunities. In general terms, integration is defined as the linking of a variety of components to merge their functional characteristics and technical requirements into a single final product that performs optimally. Integration is relevant to the adaptation of fuel cell technologies for new applications, and includes the development of specialized knowledge and additional products or components necessary to operate successfully in the new application, and at the same time add significant value to a final overall product or system.

Hydrogen quantities are expressed in volume units of normal cubic metres (Nm^3), which refers to volume at normal conditions of one atmosphere pressure and 0ºC, or in mass units of metric tonnes. Note that one tonne equals 1,000 kilograms (kg), and is equivalent to approximately 11,100 Nm^3.

2.6 Energy Prices

All prices are presented in real 2002 Canadian dollars. In the preliminary assessments conducted the following unit energy prices were used:

- Natural gas input price of 23.5¢ per standard m^3 or approximately $6.20 per GJ based on higher heating value (HHV).
- Electricity input price of 3.0¢ per kWh.

Reasons for using these unit energy prices in all calculations are as follows:

- Prices reflect published 2002 energy rates within Manitoba, specifically Centra Gas' High Volume Firm rate class for natural gas, and Manitoba Hydro's General Service Large rate class for electricity.
- Prices reflect what is currently available at a retail level to any user according to standard terms and conditions and without any subsidy.
- Prices reflect mid-range size for hydrogen production facilities that could be implemented within Manitoba.

The prices of energy employed do not necessarily represent the cost of servicing a new energy load (e.g. costs of new dam development). This is a factor in any large-scale production scenario. Rates too may be subject to change in the future, with electricity rates particularly dependent on export conditions and revenues, which are uncertain. In any detailed analyses, site-specific energy prices will need to be considered.

3.0 HYDROGEN APPLICATIONS – PAST, PRESENT AND FUTURE

In assessing hydrogen opportunities for Manitoba, it is important to understand relevant past and present experience with hydrogen, as well as prospective directions into the future. These topics are addressed in the following sections.

3.1 Our Hydrogen Past

While hydrogen has been promoted as highly futuristic, its use as a fuel is not really new, particularly within Manitoba. In the latter part of the 1800s, the gasification of coal was commercialized and broadly implemented, providing "manufactured gas" or "town gas" for streetlights and other heating applications. Perhaps unknown to many, this synthetic gas mixture was composed primarily of hydrogen and carbon monoxide.

Winnipeg too had a manufactured gas plant, located at what is today the Operations Centre of Centra Gas on Sutherland Avenue. Up until about 1955, when the TransCanada Pipeline was first implemented, significant portions of Winnipeg were supplied from this plant. The availability of natural gas, at a lower cost and with higher energy content, brought the demise of manufactured gas. Unfortunately much of the practical knowledge of dealing with large quantities of hydrogen-containing gas has also since passed away. Nevertheless it is important to recognize that in the not too distant past, hydrogen use was a fairly mundane and everyday feature of life.

The experience of the transition from manufactured gas to natural gas is relevant to a hydrogen future:

- Initial natural gas pipeline was not built on speculation, but rather connected and used existing systems, for example gradually incorporating the distribution network of pipes already in place for the manufactured gas. Consistent experience also occurred in England with the advent of natural gas from the North Sea.

- Capacity was expanded incrementally, as consumption increased. The existing TransCanada Pipeline is not a single line, but rather a series of parallel pipes.

- Unforeseen problems occurred, requiring adaptation. The older manufactured gas piping network consisted to a large extent of simple cast iron, with oakum caulk used at joints. The highly moist nature of the synthetic gas actually helped the caulk to seal. When high quality and very dry natural gas was introduced, the caulk dried out causing leaks, and necessitating the ultimate change over to steel pipe for the natural gas.

3.2 Our Hydrogen Present

The current hydrogen situation, both on an international and local basis, is described in the following sections.

3.2.1 Current Hydrogen Production

Cited specific data on hydrogen production and utilization is not entirely consistent between sources, but the following general information is understood:

- Current total annual worldwide hydrogen consumption is in the range of 400 to 500 billion Nm^3. Of this quantity, approximately 97% is represented by captive or internal production and only about 3% is provided from merchant sources, the latter being supplied by industrial gas companies such as Air Products and Chemical, Praxair, and Air Liquide.

- Total consumption in North America is approximately 80 billion Nm^3, which is of course dominated by the U.S. and represents in the range of 16% to 20% of the total world volume. Merchant sources provide in the range of 6% to 10%, which is a significantly higher proportion than for the world overall.

Current major established hydrogen production technologies in order of priority are:

- Steam methane reforming (SMR), which represents more than 80% on a world basis and which is described in more detail in Chapter 4;

- By-product hydrogen gas primarily from petrochemical, chloralkali, and sodium chlorate production, which represents approximately 18%; and

- Deliberate electrolysis, which represents a small volume compared to the above.

3.2.2 Current Hydrogen Applications

The four largest-scale uses of hydrogen, as follows, account for more than 95% of all world consumption:

(1) Ammonia Synthesis - Ammonia production is the largest single consumer of hydrogen in the world. It involves the catalytic conversion of hydrogen and nitrogen gas by the reaction:

$$2\ N_2 \text{ (nitrogen)} + 3\ H_2 \text{ (hydrogen)} \rightarrow 2\ NH_3 \text{ (ammonia)}$$

Ammonia and derivative fertilizers, including urea and ammonium nitrate products, are major input commodities for agricultural crop production in North America, and as such are extremely important for the Manitoba economy. The vast majority of this hydrogen is captive production using steam methane reforming.

(2) Petroleum Refining - This is the second largest lumped consumer of hydrogen, but involves a wide variety of processes, including hydrocracking (simultaneously breaking down large hydrocarbons and adding hydrogen), hydrotreating (adding hydrogen), catalyst regeneration, desulfurization, and heavy oil upgrading. Within North America, new hydrogen requirements for petroleum refining applications tend to be provided from merchant sources.

(3) Methanol Synthesis - Methanol is produced catalytically by reaction of "synthesis gas":

$$CO \text{ (carbon monoxide)} + 2\ H_2 \text{ (hydrogen)} \rightarrow CH_3OH \text{ (methanol)}$$

Methanol is typically produced from natural gas via on-site steam reforming and recombination. Although methanol can be used as a fuel, including potentially fuel cells, its current primary applications are in the manufacture of resins (e.g. phenol-formaldehyde resins used for furniture) and other organic chemicals (e.g. input chemical in polyester production).

(4) Other Syntheses - Reasonably significant quantities of hydrogen are used in aggregate by other petrochemical and inorganic synthesis processes for hydrogenation. This includes non-vegetable oil for soap, insulations, plastics, ointments and other specialty chemicals, including aniline dyes and hydrogen peroxide.

Besides these major uses of hydrogen, there are diverse minor applications summarized in the following table in no order or priority:

Minor Uses of Hydrogen		
Metals Processing	Pharmaceuticals	Metal Welding and Cutting
Microelectronics Processing	Aerospace (Rocket Fuel)	Analysis and Laboratory
Float Glass	Utility Generator Cooling	Synthetic Diamonds
Edible Fats and Oils	Nuclear Corrosion Prevention	Deuterium Production

3.2.3 Market Growth Trends

Overall, the hydrogen market is continuing to grow, however, the nature of that growth is non-uniform. Both ammonia and methanol are mature markets, even possibly declining. On the other hand, demand for hydrogen in the conventional oil refinery industry is anticipated to continue growing rapidly (10% to 15% annually) due to a number of factors.

These factors include aging refinery plants, consistently diminishing quality of crude oil, and increasingly strict environmental requirements, such as diesel fuel desulfurization, all of which increase hydrogen demand. This market growth has also been accompanied by general increases in merchant market prices for hydrogen.

3.2.4 Current Market Prices

Merchant hydrogen prices are highly variable, depending on purity requirements, form of delivery, volume, location and length of contract. In early 2001, the typical U.S. market prices were as follows (in Canadian dollars):

- Compressed hydrogen gas (tube trailer supplied) in the range of 90¢ to $1.30 per Nm^3, translating to $10,000 to $15,000 per tonne, F.O.B. production plant.
- Liquid hydrogen in the range 60¢ to 90¢ per Nm^3 equivalent, translating to $6,000 to $10,000 per tonne, F.O.B. production plant.
- Pipeline hydrogen gas (where available) in the range 10¢ to 40¢ per Nm^3 equivalent, translating to $1,000 to $4,000 per tonne, delivered.

3.2.5 Current Manitoba Situation

Manitoba already has a “hydrogen economy" summarized as follows:

- Simplot Chemical in Brandon has the largest hydrogen production capacity in Manitoba. This plant is the single largest consumer of natural gas within the province, used primarily for the production of hydrogen, via steam methane reforming (described in Chapter 4). The hydrogen in turn is used internally as a building block for the production of nitrogen fertilizers, including anhydrous ammonia, urea, ammonium nitrate and other derivatives. This is important to the Manitoba economy, given the prominence of the agriculture industry.

- Manitoba Hydro is a user of industrial grade hydrogen (99.95%+) as a coolant in high-speed generators and synchronous condensers, which are large rotating machinery used to support the transmission of electricity. Manitoba Hydro is the largest industrial grade consumer in the province.

- Atomic Energy of Canada Limited (AECL) is also a user of industrial bottled hydrogen, to support hydrogen-related fire safety research at their Whiteshell Laboratories in Pinawa.

- Two Manitoba companies have by-product hydrogen production from their sodium chlorate plants. Sodium chlorate, which is used in the production of chlorine dioxide for pulp and paper bleaching, is produced electrochemically from purified salt solutions. Approximately 1 kg of hydrogen is produced for every 18 kg of sodium chlorate. Based on approximate maximum aggregate sodium chlorate capacities for these plants, maximum by-product hydrogen production capacity is in the range of 10,000 tonnes to 20,000 tonnes annually.

Specific current hydrogen production and consumption figures for individual companies within Manitoba are not publicly disclosed.

3.3 Our Hydrogen Future

The future directions on hydrogen, including development trends, major drivers, major challenges and uncertainties common to all applications are summarized in the following sections.

3.3.1 Future Hydrogen Applications

Much of the excitement surrounding hydrogen is as a result of fuel cells. A variety of definitions have been used to describe such technologies. Most broadly, fuel cells can be considered as electrochemical devices that:

- Convert the potential energy of a controlled chemical reaction directly into electricity; and

- Continuously supply the reactants, or fuel, used by the cell from an external source.

Fuel cells are similar to batteries, and similar terminology is typically used to describe the structure and operation of fuel cells. In contrast, however, batteries involve a self-contained package of electrochemical reactants with no external fuel supply, and as such have a limited life before they must be discarded or recharged. Fuel cells at least in principle can be operated indefinitely as long as fuel is provided.

The fuel cells of practical interest today rely on the reaction of hydrogen with oxygen or air to form water as the final product. Despite the popular impression of a modern high-tech aura, the concept of the hydrogen fuel cell is quite old, with the initial discovery in 1838 by Grove in England. Hydrogen fuel cell technology came to initial public prominence more than 30 years ago in the 1960s with application as a power source for space missions.

Hydrogen fuel cells are also often popularly considered as a single technology. Rather, there are six different classes of hydrogen-related fuel cell systems, each with different operating characteristics, each with different strengths and weaknesses, some involving hydrogen molecularly bonded to other compounds. These different classes are:

- Alkaline fuel cells (AFC);
- Phosphoric acid fuel cells (PAFC);
- Proton exchange membrane fuel cells (PEM), also known as polymer electrolyte fuel cells (PEFC), also including reversible fuel cells (RFC);
- Solid oxide fuel cells (SOFC);
- Molten carbonate fuel cells (MCFC); and
- Direct methanol fuel cells (DMFC), also known as direct alcohol fuel cells (DAFC).

Major common characteristics of hydrogen fuel cells include:

- Conversion of gaseous hydrogen fuel energy to electricity, with cell efficiency in the range of 20% to 70% depending on fuel cell type;

- Further potential to recover by-product heat, depending on the type of system;

- No direct emissions of smog-forming by-product pollutants such as nitrogen oxides (NOx);

- Few moving parts, all external to the cell;

- Electrical output in the form of direct current (DC); and

- No direct carbon emissions.

The major future applications envisioned for hydrogen involve:

- Transportation vehicles, particularly involving fuel cell technologies, which are described in Chapter 5;

- Stationary and portable electricity generation, also primarily involving fuel cells, which are described in Chapter 6; and

- Non-fuel and other applications, which are described in Chapter 8.

Of these three areas, transportation has the greatest potential implications in terms of the quantity of hydrogen required, assuming in the long-term future that all vehicles adopt hydrogen fuel cells. Given the assumptions for North America of 260 million vehicles, annual travel in the range of 12,000 to 20,000 km per vehicle, and overall average fuel cell vehicle consumption of 1.5 kg hydrogen per 100 km, total annual hydrogen requirements would be in the range of 500 to 600 billion Nm^3. This value is in the range of 6 to 8 times greater than current North American hydrogen production. If Manitoba's undeveloped hydroelectric resources, approximately 5,000 MW, were converted to hydrogen via electrolysis at current standard efficiency, 70%, the resulting total production capacity would be 8 billion Nm^3 or between 1% to 2% of the above estimated North American requirements for transportation fuels.

3.3.2 Hydrogen Development Trends

There are significant investments and growing involvement of major players including governments, companies and research organizations in hydrogen. Annual expenditures on hydrogen activities are now in the hundreds of millions of dollars worldwide. Example actions include the following:

- All the world's major automobile manufacturers, including Daimler/Chrysler, General Motors, Ford, Toyota, Honda and others, are actively involved in development of hydrogen fuel cell powered cars. Daimler/Chrysler for example, already a significant investor in Ballard, has committed to spend more than $1 billion over the next ten years on fuel cell vehicle development. General Motors recently unveiled a new multi-million dollar fuel cell research facility. The major Japanese manufacturers, including Toyota, Honda and Nissan, have all recently committed to have fuel cell powered vehicles available in less than two years. BMW has continued uniquely to pursue the application of hydrogen internal combustion engines (ICE) for its luxury vehicles, which it has committed to having commercially within four years.

- Major energy suppliers, including Shell and BP, are already working on supply infrastructure. Shell Hydrogen for example is supporting the development of hydrogen demonstration infrastructure in Tokyo, California, Iceland and the Netherlands, as well as several major investments, including a recent commitment to participate in a $100 million international investment fund targeted at hydrogen technologies.

- Number of hydrogen technology companies continues to burgeon. Ballard has continued to maintain a prominent position, but there are now more than fifty different companies worldwide who are actively involved in fuel cell development, as well as a variety of component suppliers, including such large firms as Dupont and 3M.

- Research and development expenditures on hydrogen fuel cell technologies in Canada alone are currently around $180 million and anticipated to grow to around $360 million by 2003, according to Fuel Cells Canada.

- Iceland has announced a major national commitment to move entirely to hydrogen within the next 30 to 50 years, positioning itself as a hydrogen "pilot" for the world. Although Iceland is a small country, they have attracted the interest of several major companies, including both Shell Hydrogen and Daimler/Chrysler to support this endeavor.

A surprising finding, given growing interest and involvement with hydrogen, has been that relatively few jurisdictions, particularly within North America, have like Manitoba conducted any sort of coordinated multi-stakeholder approach to identify appropriate opportunities or to develop a strategy. The most prominent have included Michigan, Ohio and Texas.

3.3.3 Major Hydrogen Drivers

There are four major drivers that have spurred development of hydrogen, three primarily affecting markets and one involving technology. These are summarized as follows:

- <u>Energy and infrastructure security</u>. The readily available petroleum reserves of the world are finite, are being now depleted, and eventually will run out. Based on information from the Manitoba Petroleum Branch, it is anticipated that world oil production will likely reach its peak within the medium-term (next 5 to 15 years), after which annual production levels will steadily decline. There is significant debate as to how long petroleum, on which the economies of the world are now so dependent, will last as a significant energy contributor. Specific estimates vary greatly but in general show a rough time frame of 50 to 100 years, essentially within a life span, although some smaller quantities of oil will likely continue to be produced for much longer, depending primarily on price. Of perhaps greater concern is ownership of remaining reserves. Since the early 1980s, non-OPEC reserves have been depleted most rapidly, such that as time progresses an ever increasing proportion of remaining petroleum will be under the control of OPEC, with associated potential for instability as occurred in 1973 and 1979. Given in particular the terrorist attacks of September 11, 2001, security is the most important energy issue for the United States, both in terms of security of energy supply and security of energy infrastructure. Hydrogen represents a solution. Hydrogen can be produced without the need of imported energy from outside North America, and the infrastructure for production and distribution of hydrogen would be inherently less vulnerable to attack.

- Urban air quality improvement. This is a major driver in large urban areas, particularly in the Southwest and Northeast United States and in Europe. Air quality is becoming increasingly important in developing countries, where urbanization is most rapid and where air quality problems due to smog and other air pollutants are becoming most acute. Hydrogen offers the potential of clean energy, with water being its only by-product and eliminating the creation of smog pollutants.

- Greenhouse gas (GHG) emissions reduction. Addressing climate change issues in general requires the implementation of increasingly more efficient and cleaner energy technologies. Fulfilling reduction requirements under the Kyoto Protocol, now ratified by Canada, imposes specific targets. Even without Kyoto, there would still need to be improvement. For example, while the United States formally withdrew from the Kyoto process, their effort and commitment of resources towards cleaner technologies has remained. Hydrogen, if produced from clean sources, offers the potential of energy without carbon dioxide or other greenhouse gases.

- Fuel cell technology improvements. The realistic advent of a hydrogen-based energy economy will to a large extent depend on the commercial success of fuel cell technology. The technology has now improved, both in terms of efficiency and costs, and is beginning to venture into commercial reality. This prospect has brought significantly greater business attention to the technology.

An important feature of the three drivers affecting markets (energy security, air quality and greenhouse gases) is that they are all complementary. Making improvements on the basis of one inherently will result in improvements toward the others.

3.3.4 Major Challenges and Uncertainties

The implementation of hydrogen-related technologies faces a number of major hurdles. Challenges common to all applications, and for which work is underway to address, include the following:

- High capital cost of fuel cell technologies. In order to be realistically implemented, fuel cells must become competitive by decreasing costs by a factor of 3 to 10 times, depending on the fuel cell and market application considered.

- Technology development risk. As in the case of any new technology, fuel cell and associated technology development is costly, with a high risk of financial failure.

- Need for support. Like any new renewable or alternative energy source, there is a need for support to overcome financial risks (e.g. favourable tax treatment or incentives).

- Lack of hydrogen infrastructure. This represents the classic chicken and egg dilemma.

- Safety concerns. Public perception of safety has continued to remain a major issue for hydrogen.

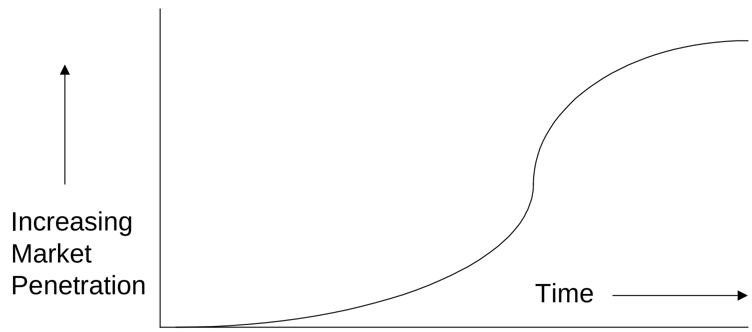
- Codes and standards. Generalized codes and standards exist for transportation and handling of hydrogen and for mechanical/electrical design of hydrogen systems. There is, however, rather limited industrial experience in applying these standards. The interpretation and adaptation of applicable codes and standards for specific applications remains a challenge. As experience is gained and more applications emerge, refinements and additions to existing codes and standards may be needed. As well, there are gaps in the data on hydrogen behaviour needed to conduct proper functional and safety analysis hydrogen systems.

- No differentiation in value of hydrogen by source. Clean hydrogen does not yet appear to command any premium for applications.

While there is a growing recognition that hydrogen probably represents the ultimate fuel of the future, there are two major uncertainties affecting development in all application areas:

(1) Timing. The pattern of adoption of hydrogen-related technologies is relatively predictable, based on past experience in technology development. Implementation will likely follow a typical “S”-shaped adoption curve, as illustrated below. As such, hydrogen technologies in general are expected to be adopted slowly to start, to at some point in time rapidly take off once sufficient market confidence has been achieved, and lastly to taper-off as they become mature. Estimates of timeframes for specific applications are discussed later in individual chapters. The precise timing of adoption, however, will be dictated by market forces and is uncertain.

Generalized Technology Adoption “S” Curve



(2) Technology. There is not one single technology for hydrogen, but rather a myriad of potential hydrogen-based and supporting technologies currently under development, as well as many non-hydrogen technologies, many offering similar benefits. What will represent the ultimate “winners” in the overall market and in individual specific niches is uncertain. A mixture of “winners” will likely result. The nature of uncertainty also varies between applications, for example:

- For transportation vehicle applications (Chapter 5) the dominant prospective technology considered for both heavy duty and light duty applications appears to be the proton exchange membrane (PEM) fuel cell, while the form of fuel feedstock and storage to be employed for passenger vehicle applications is uncertain, and indeed may involve implementation of several different options.

- For grid-connected stationary power fuel cell applications (Chapter 6) the dominant prospective fuel is likely to be natural gas, while the dominant type of fuel cell is uncertain.

4.0 HYDROGEN PRODUCTION AND MOVEMENT

While hydrogen is the most abundant element, it is not normally available in a pure gaseous form. In order to be used as a gas, the hydrogen must first be manufactured, then purified if necessary, stored and finally moved as required to its final point of use. The assessment of these aspects and identification of associated projects and opportunities are described in the following sections.

4.1 Purpose of Working Group

The purpose of the working group was to assess a series of related technology areas, including production, purification, storage and movement of hydrogen gas, and to recommend potential opportunities and demonstration projects.

4.2 Overview of Current Situation

Through its evaluation, the Working Group prepared detailed assessments of hydrogen production, purification, storage and movement technologies, including current technical and market development status, as well as likely future prospects in a Manitoba context. Highlights of the evaluation are provided.

4.2.1 Production Technologies

Hydrogen gas can be produced from diverse materials containing hydrogen, with a sampling provided as follows:

Potential Sources of Hydrogen		
Water (H_2O)	Methanol (CH_3OH)*	Hydrogen sulfide (H_2S) Associated with natural gas
Methane (CH_4) Natural gas or biogas	Ethanol (CH_3CH_2OH)*	Deep ocean vent discharge
Other hydrocarbons	Ammonia (NH_3)*	By-product hydrogen
Coal	Biomass	
* Manufactured or recovered from another source material		

A range of processes has been identified that could be potentially used for the production of hydrogen. Currently, however, there are only two key competing technologies that are at a commercially ready status, and that will likely continue to be the dominant competing technologies into the medium- to long-term (5 to 15 years). These are:

1. Steam methane reforming (SMR), involving thermal decomposition of methane from natural gas with steam, to form hydrogen together with by-product carbon monoxide and/or carbon dioxide; and

2. Electrolysis of water, involving the application of DC electricity to split water into constituent hydrogen and oxygen gas.

Steam methane reforming, as noted in Chapter 3, dominates current world hydrogen production (80%+) and is still the lowest cost process for large-scale, bulk production, even within Manitoba. The process, however, results in by-product carbon oxides, which are undesirable from a greenhouse gas emissions perspective, if not captured. It also requires the consumption of finite fossil fuel, which is unsustainable in the long term. These carbon disadvantages are well recognized, and carbon sequestering is currently a major focus for a variety of research groups, particularly in the U.S. The resulting carbon oxides also represent detrimental poisons for certain types of fuel cells, necessitating extensive purification prior to use of the hydrogen (Section 6.2.1 discusses contaminant tolerance of fuel cells).

Although use of steam methane reforming continues the reliance on hydrocarbons as a fuel source, it may be considered as a bridge to a time when cleaner hydrogen can be produced economically. There are other related thermal conversion technologies, such as partial oxidation or autothermal reforming, and other hydrocarbons can also be considered as source materials for hydrogen. None, however, can achieve anything near the same high yield ratio of hydrogen-per-carbon as steam methane reforming, which is why it continues to dominate at large-scale.

Electrolysis has been well recognized as a means to produce hydrogen without byproduct carbon oxides, and when using a clean electricity source, such as wind, solar or hydroelectricity, the entire process is carbon-free. Electrolysis also offers other advantages. It produces the highest purity hydrogen of any commercially available technology, requiring little if any post-purification for fuel cells. Contaminants typically consist of trace quantities of oxygen, nitrogen and water vapour, which are all benign for the operation of fuel cells.

While well known to be more costly than steam methane reforming at large-scale, there is data suggesting electrolysis to be a less costly approach for the production of hydrogen at small-scale, as illustrated in the following table using current Manitoba energy prices:

Technology	Cost per Tonne Hydrogen (1,000 kg)	
	Large-Scale	Small-Scale
Steam Methane Reforming	$1,200 per tonne	$8,000 per tonne
Electrolysis	$2,400 per tonne	$6,400 per tonne
Capacity Range	15,000 to 150,000 tonnes/year	50 to 150 tonnes/year
Inclusions	No distribution or dispensing	Dispensing included

The reason for this change in economics is largely because the capital equipment requirements of steam methane reforming remain relatively fixed and do not readily scale down to small production. On the other hand, electrolysis technology is modular in nature, so that capital costs readily scale down and become cheaper, with the transition occurring for production capacity under around 500 tonnes annually. This is important for the economic viability of dispersed applications, such as will likely occur during the introductory development of hydrogen consuming appliances and vehicles. Not all information sources, however, are consistent with these findings and a more specific detailed evaluation needs to be undertaken to confirm the economic advantage of electrolysis at small-scale.

The on-board and off-board reforming of methanol and ethanol are under development. These may represent potential options.

Gasification of coal and biomass are important to mention, particularly given that coal gasification is one of the oldest processes for production of hydrogen. Gasification technology, whether for deliberate production of hydrogen or hydrogen as a by-product, suffers from a number of technical problems. These include a relatively poor mass yield of hydrogen, which contributes to the costly nature of the process; variable quality of output gas product, particularly when a system is fed non-homogeneous inputs; extensive purification requirements given the relatively uncontrolled nature of the process leading to diverse and varying contaminants, which also adds significantly to cost; and potential to produce environmentally detrimental by-products under certain conditions. The production of heat or fuel for generation of electricity are likely better applications for this technology.

A variety of other hydrogen production technologies are under development. Some of the more promising technologies involve supercritical conversion processes, including direct solar-thermal conversion of water, and are worth monitoring. Other technologies, including direct photolysis and biological conversion, are not likely to be realistic until the long-term future.

4.2.2 Purification Technologies

Purification of hydrogen is important depending on the hydrogen source and ultimate application. For fuel cell applications, purification is less important for hydrogen derived from electrolysis, but is critical for hydrocarbon-based processes. For high-value hydrogen, such as semiconductor applications, extensive purification is still required even for electrolysis-derived product.

The dominant commercialized purification technologies for hydrogen employ adsorption, including both pressure swing adsorption and vacuum swing adsorption. Adsorption involves the selective adherence of gas molecules to a solid matrix material, allowing separation. Solvent absorption and membrane technologies, including organic polymer, ceramic and metal membrane systems, are also available at commercially ready status. The highest purity hydrogen is obtained using palladium metal membranes, although this is expensive.

4.2.3 Storage and Movement Technologies

Compressed gas storage is currently the dominant commercially available storage technology, although it is subject to the problem of relatively low energy densities. Storage at around 350 atm (5,000 psig) is now reasonably common, with systems now becoming available at 700 atm (10,000 psig). Liquefaction is an established storage technology for hydrogen to increase energy density. Liquefaction, however, requires a costly infrastructure, results in a net loss of energy of as much as 20% to 40%, although with the possibility to partially recover energy during regasification. Gradual evaporation results in progressive loss of hydrogen over time. Liquefaction also introduces a variety of additional safety and materials concerns given the extremely low temperatures involved. A number of other technologies, including metal hydride storage and carbon nanotubes are under development for storage, however, these still are still constrained by weight to volume limits and are not likely to be realistically available until well into the long term.

Movement of compressed gaseous hydrogen and liquid hydrogen by truck and rail are well-established technologies and practiced by industrial gas supply companies. Hydrogen pipelines have been commercially implemented, and it is possible to overcome such problems as embrittlement. The constraint for pipelines is strictly economic, and most tend to be very short, with the longest in the world no more than about 400 km. It is only feasible to consider the construction of a hydrogen pipeline when there are adequate markets to support the resulting large throughput. Existing hydrogen pipelines are privately owned and are not common carrier, as is the case with natural gas. As such, information on cost, performance, and reliability issues specific for hydrogen are typically not released into the public domain. Unfortunately, existing models for pipelines tend to be based on natural gas, and are not directly transferable to hydrogen.

4.3 Major Trends and Uncertainties

A variety of important trends have been identified that will potentially impact both the development of technology and commercialization:

- Governments and industry are looking to hydrogen as one means to reduce and ultimately eliminate pollution, requiring ultimately the production of hydrogen from clean energy sources.

- Existing hydrogen market bulk prices are determined primarily by natural gas prices, given the dominance of steam methane reforming. There appears to be no price differentiation based on sourcing of hydrogen. In particular, there are not yet any premiums available for clean-derived hydrogen.

- Grid-connected stationary fuel cell applications for sizes over about 200 kW will likely be dominated by natural gas as fuel with either internal or external reforming, and will be primarily linked to natural gas distribution systems. Remote applications of fuel cells are subject to different considerations, as described later in Chapter 6 under Stationary and Portable applications.

- Hydrogen market volumes for vehicle applications will continue to be relatively small and dispersed into the medium term (next 5 to 15 years), being focused on selected fleets with dedicated refueling systems, likely developing on a distributed production model. Electrolysis is ideally suited to the distributed production model. Research is currently under way to develop cost-efficient systems for steam methane reforming at small scale, but it is uncertain whether cost targets can be achieved. The technology appears to remain more expensive than electrolysis at small scale.

- Any movement toward centralized, large-scale production, whether by steam methane reforming or electrolysis, with distribution of hydrogen by truck or even pipeline networks, is uncertain and will depend on two major factors: (1) adequate market acceptance and volume demand to support large production facilities; and (2) cost-efficient bulk distribution systems.

- Timing for significant adoption and implementation of hydrogen remains uncertain. Likely dominant production technology into the future also remains uncertain (e.g. will it be centralized vs. distributed production; will it be electrolysis vs. steam methane reforming production?). The key factor determining both the timing and technology questions is the future price of natural gas. Although the price of natural gas is expected on average to rise in the future, as noted in the next point, natural gas pricing is highly volatile and difficult to predict.

- For the purpose of this report, overall energy use in North America is assumed to increase at a relatively constant rate, with average energy prices for natural gas and electricity also assumed to increase at a relatively constant rate, as for example predicted by the U.S. Department of Energy's Energy Information Administration. Such predictions, however, would be significantly impacted by unanticipated events, including volatile energy price spikes or serious short-term moves by the U.S. to divorce itself from foreign petroleum sources.

4.4 Issues

Major potential negative and positive issues associated with hydrogen production and associated technologies have been identified as follows:

4.4.1 Production Technologies

Negative
- Getting the production of hydrogen to be cost effective with other fuels.
- Lack of incentives or premiums for renewable derived hydrogen.
- Lack of reliable information on fuel requirements, performance and cost of hydrogen technologies.
- Lack of market pull.
- Lack of government incentives for early market adopters of distributed production systems.
- Lack of consistent definitions of hydrogen product quality/purity.
- Lack of technical and financial expertise and frameworks to engage hydrogen energy.

Positive
- Opportunities for demonstration projects involving electrolysis, firstly to gain experience with the technology, secondly to showcase clean hydrogen production, and thirdly to confirm predicted costs at small-scale.
- Potential to gain research and development expertise.
- Potential to develop cost-efficient approaches for niche applications (e.g. buses).
- Potential export of electricity for production of clean hydrogen at distributed sites in export markets, but with need for associated premium for clean fuel production.

4.4.2 Purification Technologies

Negative
- Lack of consistent definitions of hydrogen product quality/purity.
- Lack of information regarding performance and technology limitations.

Positive

- Opportunity for developing improved separation and purification methods and materials.
- Use of Manitoba materials for purification technologies (e.g. lithium, sodium and particularly nickel to be used in metal hydrides).

4.4.3 Storage and Movement Technologies

Negative

- Low energy density presents a significant challenge for hydrogen storage to be cost efficient and to gain market acceptance.
- Lack of safety acceptance (unsafe hydrogen images of “Hindenburg fire” and “hydrogen bomb”).
- Lack of obvious transition strategy for centralized fuel production, particularly as relates to fuel distribution, and the possible use of gasoline, methanol or others as interim fuels.
- Lack of clear understanding of relative economics of transporting hydrogen vs. other energy forms.

Positive

- Opportunity for research and development for improved storage technologies.
- Opportunity for demonstrations to show safe handling of hydrogen and thus to enhance public acceptance.
- Opportunity for low cost, effective compression technologies or high-pressure electrolysis systems to reduce costs.
- Opportunity for demonstration of hydrogen transportation to show cost effectiveness and safety.
- Ability to capitalize on compressed gas tank, trailer manufacturing and dispensing competencies that could participate in near term demonstrations of movement and end use storage for gaseous hydrogen in the transportation sector.

4.5 Hydrogen Production Opportunity Scenarios

A series of six different possible opportunities were identified for the production of hydrogen. The largest contributing hydrogen fuel requirement is assumed to be transportation applications, primarily buses and passenger cars, and the described scenarios are based on such demand. The scenarios are outlined in the following sections.

4.5.1 Small-Scale Distributed Production of Clean Hydrogen in Manitoba by Electrolysis to Support Demonstrations

A near-term opportunity exists in Manitoba for production of hydrogen via small-scale electrolysis to support early vehicular demonstration projects.

The first likely opportunity is the refueling of transit buses, which is described further in Section 5.5.1. For production capacity in the range of 50 to 150 tonnes per year, which is sufficient to support approximately three to eight transit buses respectively, the resulting cost of hydrogen is approximately $6,400 per tonne dispensed, as noted earlier including capital cost recovery. There is a need for further study to confirm costs and the potential advantage for electrolysis at small-scale.

Additional potential exists for the provision of hydrogen to support demonstrations of hydrogen-based light duty vehicles, as described in Section 5.5.2.

4.5.2 Export of Electricity for Small-Scale Distributed Production of Clean Hydrogen Fuel in Export Markets

Total numbers of fuel cell and other hydrogen-powered vehicles are anticipated to remain relatively small throughout the medium-term (next 5 to 15 years), being focused initially on demonstration fleet vehicles using their own dedicated refueling systems. Over that time period, small-scale distributed production facilities will likely be scattered across North America to match the corresponding fleet demands. Electrolysis could be the predominant production approach, given convenient availability of electricity and water, scalability of the technology, high purity of hydrogen and likely lower cost compared to steam methane reforming, if lower price or off-peak power is available, the latter applicable outside Manitoba.

Into the long-term future (15+ years), when compared to other clean electricity sources such as wind or photovoltaics, and even relative to nuclear, hydroelectricity will likely remain the lowest cost source of clean renewable electricity for small-scale production of carbon-free hydrogen fuel via electrolysis. An opportunity may exist starting in the near-term to promote exports of Manitoba electricity, for the production of clean hydrogen fuel under the following conditions:

- Premiums need to be obtained;
- Legislated requirements for clean hydrogen need to be implemented in user jurisdictions (similar to Renewable Portfolio Standards for electricity generation);
- Markets need to be found and reached; and
- Implications of open access rules (e.g. reciprocity regarding access to retail customers) need to be addressed.

4.5.3 Large-Scale Hydrogen Production in Manitoba for Vehicles and Other Applications

If hydrogen and fuel cell vehicles achieve significant market growth and penetration, likely in the longer-term, a need will develop for low-cost larger-scale hydrogen production to support their fuel requirements. A long-term opportunity may exist to produce this hydrogen fuel via electrolysis, using the province's hydroelectric resources. Necessary conditions in this case include:

- Cost of bulk-scale hydrogen production via electrolysis needs to be lower than steam methane reforming of natural gas;
- Sufficient numbers of fuel cell vehicles need to be available to support large-scale fuel production, as would occur once fuel cell vehicle market penetration within Manitoba reaches the critical range of 5% to 15%;
- Distribution infrastructure costs need to be sufficiently low to ensure approximate price neutrality with gasoline; and
- Long-term solution needs to be found to address fuel tax such that hydrogen is not burdened, but at the same time funding for transportation infrastructure is not compromised (discussed further in Chapter 11 under Policy Issues).

It would be technically possible for Manitoba to produce sufficient hydrogen via electrolysis to fulfill the province's own transportation fuel requirements, assuming all vehicle are fuel cell powered. Given the assumptions of 800,000 vehicles, which is approximately the number registered in 2002, annual travel in the range of 12,000 to 20,000 km per vehicle, and overall average fuel cell vehicle consumption of 1.5 kg hydrogen per 100 km, the necessary electrolysis production capacity would range from 1,000 MW to 2,000 MW. This value is within the predicted available unused hydroelectric resources for the province, approximately 5,000 MW.

Reaching fuel price neutrality with conventional gasoline for hydrogen from any source will depend on:

- Price of conventional gasoline fuel;
- Fuel consumption levels for conventional vehicles; and
- Fuel cell vehicle hydrogen consumption levels.

Assuming overall average fuel cell vehicle consumption of 1.5 kg hydrogen per 100 km versus a relatively efficient conventional vehicle mileage of 8 Litres per 100 km (30 miles per US gallon), hydrogen becomes roughly price neutral at approximately $3,500 per tonne. This is compared to present gasoline prices of around 68¢ per Litre, including taxes. The use of a relatively efficient benchmark for conventional vehicles makes sense given anticipated future improvements in fuel efficiency. However, average fuel consumption per vehicle within Manitoba is now much less efficient, being currently more than 12 Litres per 100 km (less than 20 miles per US gallon) overall, translating to a much higher comparable hydrogen price.

Much will depend on future trends in the price of conventional fuel. If conventional gasoline prices rise, whether through market pressures due to supply shortage or environmental requirements, hydrogen becomes more attractive. The same is true for other alternative energy sources.

If retail gasoline prices remain relatively stable, large-scale production of hydrogen within Manitoba could be feasible as long as the costs of distribution and dispensing achieved are sufficiently low in order not to exceed the threshold hydrogen cost level of $3,500 per tonne, and fuel tax can be suitably addressed. On the other hand, it likely would not be economical to continue considering small-scale production, given much higher costs per tonne, whether from electrolysis or steam methane reforming.

Steam methane reforming now enjoys a significant cost advantage over electrolysis for bulk-scale hydrogen production, given current energy cost structures. Based on a retail electricity rate of 3¢ per kWh, natural gas retail costs would need to increase to more than $15 per GJ (HHV), more than twice the current level, in order for electrolysis production to become the least costly option. In the long-term future, the relative economics between electrolysis and steam methane reforming will be determined primarily by the future price of natural gas, which is difficult to predict with certainty. Electrolysis could become more attractive if the relative cost of natural gas were to increase sufficiently more as a result of market pressures from increased consumption, volatility or environmental requirements.

The benefits of using Manitoba hydroelectric resources in the long-term future to supply hydrogen to support all vehicles within the province include:

- Potential local economic development;
- Potential reduction or elimination of emissions from fuel production; and
- Potential reduction or elimination of the significant provincial energy deficit for transportation fuels, which is currently in the range of $0.5 to $1.0 billion annually.

These benefits, however, would need to be weighed against disadvantages, including:

- Potential lost revenue of forgone exports of electricity; and
- Significant potential costs of infrastructure and new generation capacity, which would be likely needed to support new large-scale hydrogen fuel production.

4.5.4 Long-Term Export of Hydrogen

If hydrogen markets develop to a significant extent, likely in the longer-term future, it may be possible to consider export of hydrogen on a bulk basis. In order to be achieved it would be necessary to fulfill the following conditions:

- Sufficient prospective markets need to be developed to justify the large quantities involved;
- Prices for bulk hydrogen production via electrolysis need to be lower than comparable bulk steam methane reforming, with sufficient additional margin to cover the cost of transportation; and
- Bulk exports of electrolysis-produced hydrogen need to of higher value than the lost revenue from selling the electricity directly into export markets.

The value of export market electricity is increasingly tied to North American natural gas prices, such that as natural gas prices rise, so too do electricity prices. The future predicted value of export electricity by Manitoba Hydro is approximately 6¢ to 7¢ per kWh in 20+ years. At this value, natural gas prices would have to increase to more than $27 per GJ (HHV) for production costs to be matched, but without including any rate of return or shipping costs. As noted in the last section, the cost of natural gas into the future remains a major uncertainty. Electrolysis production of hydrogen in Manitoba could become potentially viable if the relative cost of natural gas were to increase sufficiently as a result of market pressures from increased consumption, volatility or environmental requirements.

Hydrogen transport costs also remain uncertain because large-scale, long-distance exports have not been undertaken anywhere in the world. Transport options include:

- Gaseous or liquid hydrogen tankers, whether truck or rail based;
- Pipeline; or
- Electrical bulk transmission with large-scale electrolysis production near the point of use.

A detailed economic analysis of these various transport modes would be necessary to ensure the most cost-efficient method is pursued.

One transport possibility to consider for the long-term is adaptation of the TransCanada pipeline network, including for example dedication of one component pipe to transport of hydrogen or Hythane mixture. This could become possible as existing natural gas throughput drops due to the inevitable decline in natural gas production by the Western Sedimentary Basin. However, hydrogen adaptation and infrastructure deterioration issues, particularly due to age, would need to be addressed.

4.5.5 Production and Export of Industrial Grade Hydrogen from Manitoba

Industrial-grade hydrogen for non-fuel applications generally has a higher value than would be applicable for fuel. A separate possibility starting in the near- to medium-term may be the production of high purity hydrogen within Manitoba via electrolysis for export, primarily to mid-west U.S. markets. In this regard it is important to note that Manitoba Hydro is already in the process of considering the on-site production of hydrogen at its Dorsey Converter Station, displacing imported hydrogen, with a very high value, used as coolant.

Necessary conditions in this case include:

- Sufficient prospective markets need to be identified and developed to justify the quantities involved; and

- Prices for high-purity hydrogen produced via electrolysis within Manitoba need to be lower than the comparable costs of hydrogen in consumer markets, whether derived from industrial-grade steam methane reforming with gas purification or from electrolysis, and with sufficient additional margin to cover the cost of transportation.

Being able to exploit this opportunity would provide familiarity with hydrogen production and movement that could be applied to fuel applications later in the future.

4.5.6 Utilization of By-Product Hydrogen

Two Manitoba companies, as outlined earlier, now produce significant quantities of by-product hydrogen via sodium chlorate manufacturing, representing a near-term opportunity for these companies and prospective hydrogen users. Necessary conditions in this case include:

- Sodium chlorate producers need to be interested, either directly involved in marketing hydrogen or willing to make excess hydrogen available at a reasonable cost;
- Applications need to be identified and developed that are appropriate to the quantity and quality of hydrogen available; and
- Value of hydrogen in selected applications needs to be sufficient to cover costs of movement and any purification required, as well as a reasonable return.

The economic application of byproduct hydrogen is much different than for deliberate electrolysis, given that the cost of production has already been essentially covered. In this case, finding an economically feasible opportunity only requires covering the cost of the transport and storage infrastructure, purification if required, and an appropriate market-based compensation to the sodium chlorate producer. In this case, it is more likely that a potential site-to-site movement of hydrogen would be involved to a specific end-use, rather than any kind of common-carrier pipeline.

Being able to exploit this opportunity would provide familiarity with hydrogen production and movement that could be applied to fuel applications in the future. A number of specific high-value non-fuel uses for by-product hydrogen, that may be applicable in the near-term, are described in Section 8.5.1. The alternative use of by-product hydrogen for on-site electricity production via stationary fuel cell technology is described in Section 6.5.1.

5.0 TRANSPORTATION: VEHICLES AND REFUELING

The most high-profile future application of hydrogen is transportation, including heavy-duty buses, light-duty passenger automobiles, and various other transportation modes. The assessment of these aspects and identification of associated opportunities are described in the following sections.

5.1 Purpose of Working Group

The purpose of the Working Group was to assess hydrogen vehicle applications and refueling, including a broad array of transportation modes. Given the potential gray area between production and refueling, particularly for on-site installations, the Working Group focused downstream of the “nozzle,” but included dispensing and mobile storage trailers to support refueling. The Hydrogen Production and Movement Working Group addressed stationary production and storage issues upstream of the “nozzle,” as outlined earlier in Chapter 4.

5.2 Overview of Current Situation

The Transport Institute of the Asper School of Business at the University of Manitoba (UMTI) was engaged as a consultant to support the Working Group. A final report by UMTI is available at their internet site: http://www.umanitoba.ca/transport_institute/. Through the course of its evaluation, the Working Group prepared detailed assessments of all broad vehicular applications, categorized into three groups: heavy duty road vehicle applications, light duty road vehicle applications and other applications. Highlights of the detailed evaluation are provided in the following sections.

5.2.1 Heavy Duty Applications

There is general agreement that due to issues such as central refueling infrastructures, easier vehicle integration, subsidized costs, regulatory drivers, and location of vehicle use, transit buses clearly represent a priority application for hydrogen, not just in terms of heavy duty applications, but indeed for transportation overall:

- Fuel cell transit buses have been tested in more demonstration projects than any other heavy or light duty vehicle. By the end of 2003, upwards of 30 buses are expected to be in demonstration in European countries and approximately six buses are planned to be on North American roads. None-the-less, fuel cell buses still require significant research and development, with real challenges coming from the vehicle drive-train and integration, and high vehicle costs.

- Transit buses represent a much smaller and specialized niche when compared to larger volume markets such as passenger vehicles. Total sales of new transit buses are approximately 5,000 annually, compared to passenger vehicle sales of more than 17 million annually for North America.

- Focus is predominantly on proton exchange membrane (PEM) fuel cell systems, although various other technologies are also under consideration, including other fuel cells, metal-air cells (described in Section 6.2.3), Hythane (mixture of hydrogen and natural gas as fuel), and direct hydrogen internal combustion engines (ICE).

- Focus is also predominantly on gaseous hydrogen as fuel, rather than any on-board reforming options, this being specifically driven by urban air quality issues, particularly in the U.S. southwest, U.S. northeast, Europe, and Asia.

The cost of fuel cells for transportation applications in general is still now very high, in the range of $5,000 to $20,000 per kW. As illustrated in the following table, the target cost for fuel cells in bus applications is higher than for light-duty applications, and the likely cumulative production experience needed in order to reach the target cost is significantly smaller, although progress in fuel cell cost reduction for buses will continue to depend to a degree on progress for light duty applications:

Application	Approximate Target Cost for Fuel Cell	Likely Cumulative Production Volume to Reach Target Cost
Heavy Duty (e.g. bus)	$250 per kW	5 to 6 thousand
Light Duty (e.g. passenger car)	$50 per kW	1 to 2 million

Fuel cell transit buses are anticipated to reach mature demonstration status within the near-term (within the next five years), with the total number of fuel cell buses in North America by 2005 anticipated in projections by the U.S. Department of Energy to be about 150. Significant market penetration, reaching levels of 5% to 15% of new bus sales, is not expected until at least 2010-2012, although much sooner than is anticipated for light duty vehicles.

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

5.2.2 Light Duty Applications

The passenger vehicle application represents by far the largest single prospective market for hydrogen as a fuel and is highly publicized in the media. All the major world automobile manufacturers are now involved in development activities, at least at or beyond prototype stage. Priority appears focused on PEM fuel cell technology as the main propulsion unit over the long term. There is also some consideration and development of the use of auxiliary power units (APU), which could potentially involve PEM, but also solid oxide fuel cell (SOFC) or molten carbonate fuel cell (MCFC) technology.

The passenger vehicle application is not nearly as close to commercial use as the transit bus application described above. This is due to a variety of practical issues, as were noted, but also a result of the general approach being pursued by the automobile manufacturers, this being to maintain “fuel invisibility” to the user even for the incorporation of significant technological advances into new vehicle models. As such, they are not likely to introduce well developed fuel cell vehicles to broad markets until these products can be equally priced and provide comparable drivability to their gasoline-based vehicles.

A notable exception in many regards is BMW, who has selected to focus on hydrogen ICE, using liquid hydrogen as the fuel form. BMW’s approach is much more near-term, being already at an advanced demonstration stage, and with commercial-ready product anticipated within the near-term (within the next five years). However, BMW’s approach by its nature is also highly niche, oriented to a very narrow high performance, luxury vehicle market, and as such will never contribute to significant overall market penetration by hydrogen.

While there appears to be a strong focus on PEM technology, there is substantial divergence in the prospective fuel choices to provide hydrogen. The main fuel options being considered include gaseous hydrogen, liquid hydrogen, methanol (both on-board and off-board reforming), ethanol, and gasoline. Several exotic sources have also been considered, including ammonia and sodium borohydride. The extreme nature of the divergence and uncertainty on fuel choice is emphasized by deliberately stated policies of neutrality regarding the selection of fuel that have been adopted by a number of key agencies involved with fuel cell development or fuel cell promotion. These include Natural Resources Canada, Fuel Cells Canada, the U.S. Department of Energy, and the California Fuel Cell Partnership.

The timeframe for commercial implementation for fuel cell passenger automobiles is also uncertain. Divergence on this issue is emphasized by varying reported projections. Within the past year, for example, different statements by General Motors alone, as reported in the media, have suggested that practical fuel cell vehicles may be available in as few as 10 years or as long as 50 years. The U.S. Department of Energy has issued a four-phase time-line requirement for the industry, with set milestones:

- Feasibility demonstration, involving likely less than 50 vehicles and lasting until 2004.
- Controlled fleet demonstrations, involving upwards of 500 vehicles and lasting until 2008.
- Commercial fleet demonstrations, involving upwards of 5,000 vehicles and upwards of 30 refueling stations until 2012; followed by
- Initial commercial releases.

Ford has also suggested the projection for initial release of commercial-ready fuel cell vehicles by 2012. The timeframe for fuel cell vehicles to achieve significant market share, in the range of 5% to 15% of total new unit sales, will be further into the long-term future.

5.2.3 Other Transportation Applications

A diverse range of other possible applications was also reviewed, and summarized as follows:

- Bicycles and scooters. Several manufacturers are working on these products, now at prototype to demonstration stage, with primary intended markets in Asia.

- Golf carts and small people movers. Several manufacturers now have products at demonstration stage.

- Forklifts, ice grooming machines (e.g. Zambonis), and other indoor-use vehicles. Although such applications represent a distinct opportunity, there appears to be relatively little direct activity in this area by others.

- Mine vehicles. There are three major consortia currently engaged in underground vehicles, although still a relatively early stage of development. Despite high costs, hydrogen fuel cell vehicles offer enormous benefits in mining applications, due to avoided ventilation. Given rigorous safety requirements the development process will however be very slow.

- Trains. There is little current interest among railways for hydrogen-based systems, given the efficiency and low cost of diesel-electric technology now in use.

- Marine vessels. These are expected to be a fast follower to fuel cell buses and automobiles. The priority application is submarines, taking advantage of only benign emissions of water from fuel cells.

- Airplanes. Liquid hydrogen is already well established as an aerospace fuel for rockets and shuttles. Likewise fuel cells began in and are well established for space vehicles. The application of fuel cell technology to commercial aircraft is still, however, at a very early stage.

5.2.4 Major Competing Technologies

Development of hydrogen and fuel cell technologies for vehicles is not being undertaken in isolation. Alternatives include:

- Continued improvements in conventional ICE vehicles, which are already well established in the market and still have substantial cost advantages for consumers.

- Alternative fuels in modified ICE vehicles, particularly natural gas and ethanol, but also possibly including Hythane (hydrogen and natural gas mixture).

- Hybrid electric vehicles, both gasoline-electric and diesel-electric.

Hybrid vehicles, in particular, represent both an interim step and a direct competitor to fuel cells. Fuel cells offer a major efficiency advantage over the conventional ICE, with the former approaching around 50% while the latter is no more than about 20% in practical terms. These values do not take into account an exhaustive evaluation of the entire fuel chain. Hybrid vehicles, however, have already demonstrated fuel efficiencies approximately double that of conventional vehicles, significantly diminishing the prospective advantage of the fuel cell.

In addition, hybrid vehicles are much further along in development. There are already three commercially available hybrid gasoline-electric passenger vehicles in the market -- the Toyota Prius, the Honda Insight and Civic Hybrid, with a variety of others, such as the Ford Escape, expected in production within the near term. At least two bus manufacturers have hybrid diesel-electric system now in pre-production.

While hybrid vehicles are considered a direct competitor for fuel cells, they can also represent a potential bridging technology. Given the configuration of hybrids, an ICE could be progressively replaced in such vehicle models by a fuel cell as the prime mover. Already some of the research is focused on hybrid fuel cell vehicles.

Commercially available compressed natural gas ICE vehicles provide a potential pathway to demonstrate hydrogen transportation refueling infrastructure. Since these vehicles can be adapted to use Hythane or gaseous hydrogen, hydrogen-refueling systems can be developed in the near-term. Gaseous-hydrogen capable ICE vehicles, including pickup trucks and passenger cars, already can be obtained through special order from manufacturers.

5.3 Major Trends and Uncertainties

A variety of important trends have been identified that will potentially impact both the development of technology and commercialization:

- In the wake of the September 11, 2001 terrorist attacks, it has become evident that the key driver behind the development of hydrogen and fuel cell transportation technology for the U.S. is energy security.

- Urban air quality issues represent a key driver behind the development of hydrogen fuel cell transportation technologies, particularly with California leading the way in terms of requirements for cleaner emission vehicles. California recently enacted legislation empowering the California Air Resources Board (CARB) to develop performance standards for the reduction of carbon dioxide emissions from vehicles. Other jurisdictions in the U.S. have also begun to adopt requirements developed by CARB.

- Climate change is a recognized global threat in the United States and Canada. Despite the fact that the U.S. has withdrawn from Kyoto, American federal and state governments are still providing incentives and regulatory pressures to reduce greenhouse gas emissions. As a result American industries, academics and research institutes have assumed the lead in North American research and development, and demonstration of fuel cell technologies for vehicles.

The majority of research in fuel cell transportation technology has focused around the PEM stack; however, a significant amount of work and consideration has also centered around the SOFC and MCFC for vehicle applications, particularly as auxiliary power units (APUs). The major uncertainty in the adoption of fuel cell transportation technology is the fuel choice for passenger fuel cell vehicles. This has resulted from the broad range of fuel options and cost uncertainties.

5.4 Issues

Major potential negative and positive issues associated with vehicular applications have been identified as follows:

Negative

- Lack of fueling infrastructure.

- Limited availability of fuel cell vehicles.
- High costs of fuel cell vehicles.
- “Buy America” requirements for U.S. bus purchases.
- Lack of incentives or premiums for renewable derived hydrogen.
- Developing or acquiring manufacturing integration capabilities involving fuel cells.

Positive

- Kraus Global capabilities on refueling systems.
- Bus manufacturing capabilities in Manitoba, including New Flyer and Motor Coach Industries.
- Opportunity for demonstration projects involving fuel cell vehicles, firstly to gain experience with the technology, secondly to provide a promotional showcase for local technologies.
- Leading trend toward fuel cells in transit buses.
- Diverse range of additional niche opportunities with little current activity (e.g. indoor vehicles).
- Development of research and development expertise.
- Manufacturing hydrogen-refueling trailers.

5.5 Transportation Application Opportunity Scenarios

A series of four different scenarios were identified that could represent prospective vehicle-related opportunities. The scenarios are outlined in the following sections.

5.5.1 Transit Buses and Demonstration

The application of fuel cells to buses in a demonstration project is an obvious generic opportunity for Manitoba, given that:

- Transit buses represent a leading early application for hydrogen fuel cells, being already furthest developed in terms of demonstration of the technology and likely to be the first vehicular application to achieve any significant market penetration, within eight to ten years.

- Winnipeg is already a major manufacturing centre for buses, given the presence of both New Flyer and Motor Coach Industries, and is already recognized effectively as the “bus capital” of North America. A demonstration would help to promote advanced bus manufacturing in the province.

- Refueling would take advantage of and support the capabilities of Kraus Global as a leader in alternative gaseous refueling systems.

- A fuel cell bus demonstration project already has been proposed as part of the recent Winnipeg/Manitoba-Urban Transportation Showcase Expression of Interest.

Necessary conditions for a transit bus demonstration project include:

- Active involvement of bus manufacturer;

- Active involvement of transit system operator;

- Availability of technical competency to support service and operation of fuel cell buses;

- Financial assistance, given the known high capital cost of fuel cell buses compared to conventional;

- Infrastructure for production of hydrogen and refueling;

- Understanding of implications of “Buy America” legislation (discussed in Chapter 11); and

- Defined project plan, including objectives, performance benchmarks, media strategy to profile project and system for monitoring and evaluation of results.

Hydrogen fuel production to support this project is described earlier in Section 4.5.1. Given stable and low cost retail electricity rates, Manitoba could be the first jurisdiction in which it is possible to have hydrogen production that could be price neutral to conventional diesel fuel and at the same time allows for the reasonable recovery of costs for the production infrastructure. Achieving competitiveness with conventional diesel on a price per km basis in the bus application will depend on:

- Price of conventional diesel fuel, which is anticipated to generally increase due to stricter environmental requirements and increasing U.S. reliance on imported petroleum;

- Hydrogen consumption for fuel cell buses, which has been continuing to improve; and

- Fuel and other taxes, which needs to be systematically addressed, as discussed later in Chapter 11 under Policy Issues.

Achieving hydrogen consumption levels in the range of about 7-kg to 9-kg per 100 km is necessary for the price of hydrogen to be approximately equal to that of retail diesel fuel in 2002. Fuel consumption by fuel cell buses is still more than 12 kg per 100 km. The timeframe for achieving the desired level of fuel consumption is uncertain, but may be reached within three to five years, if past improvement trends continue. Also important on an interim basis would be some sort of relief from fuel taxes. For example for initial demonstration projects involving relatively small numbers it may be appropriate to consider an exemption from fuel taxes, as is currently the case for compressed natural gas.

Given a need for associated infrastructure, an opportunity exists to promote Manitoba in the near-term as a demonstration centre for hydrogen bus technologies, or potentially for the export of complete demonstration packages to other jurisdictions. Although the primary focus is on fuel cell applications, an important interim measure, particularly given the limited availability of fuel cell buses into the near future, is the possible use of converted ICE buses running on gaseous hydrogen. Availability of byproduct hydrogen in Brandon may also represent an interim opportunity to support hydrogen powered vehicles.

5.5.2 Light-Duty Vehicle Opportunities

Potential exists for demonstrations of hydrogen-based light duty vehicles including:

- Hydrogen internal combustion engine (ICE) vehicles in the near-term, as an interim measure; and

- Fuel cell commercial or government fleet vehicles in the medium-term, as sufficient number of vehicles start to become available.

Necessary conditions for a light duty fleet demonstration project include:

- Active involvement of fleet operator;

- Availability of hydrogen-ready vehicles either through purchase or lease arrangements at reasonable price;

- Availability of technical competency to support service and operation of vehicles;

- Partnerships, in particular to increase vehicle market purchasing power;

- Availability of infrastructure for production of hydrogen and refueling; and

- Defined project plan, including objectives, performance benchmarks, media strategy to profile project and system for monitoring and evaluation of results.

A near-term demonstration opportunity exists for selected numbers of adapted light duty hydrogen or Hythane ICE vehicles. Such vehicles can already be obtained in the market and a small number could be used to demonstrate both the operation of vehicles themselves, promoting hydrogen, and the associated refueling infrastructure. In this case it would not be yet possible to attempt to match pricing with conventional fuels.

The further development path for light-duty vehicles toward fuel cells will likely involve a focus on fleet applications prior to any public commercial release. As such, opportunities exist in the medium-term for the early adoption of fuel cell vehicles for fleet demonstrations and the further promotion of Manitoba as a demonstration hub for hydrogen. Various public and private-sector organizations within the province operate significant light-duty fleets, which could be suitable for inclusion in fuel cell fleet demonstrations. These include various Provincial Departments, the City of Winnipeg, Manitoba Hydro, Manitoba Public Insurance, Manitoba Telecom Services, Shaw Cable and Videon, etc.

At the same time, government in general can help to influence to some extent both the speed and direction of market development by exercising purchasing power. The availability of fuel cell vehicles even for fleet applications is still a number of years away, however, policies can be developed in the near term to establish desired target purchase timelines and commitments for fuel cell vehicles. Such action is even more effective through collaboration with multiple jurisdictions. There may be strong receptivity to such an approach, particularly in adjoining states through such organizations as the Red River Clean Cities Coalition and other ongoing inter-jurisdictional consultations.

5.5.3 Other Hydrogen Integration Opportunities

Given the diversity of transportation applications, a variety of integration opportunities may be available, incorporating hydrogen and fuel cell technologies into niche applications, including:

- High-pressure gaseous hydrogen storage trailers, particularly for refueling applications.
- Light industrial vehicles, including golf carts, people movers, etc.
- Indoor industrial vehicles, such as forklifts, ice grooming machines (e.g. Zambonis), etc.

Necessary conditions that would need to be fulfilled in this case include:

- Confirmation of potential available markets for specific products to justify consideration; and
- Development of necessary capabilities for local manufacturing or integration.

5.5.4 Alternative Technology Opportunities

Opportunities may also be available with regard to alternative technologies, such as hybrid-electric vehicles. As noted in Chapter 6 under the Stationary and Portable Applications Working Group, a variety of electrical technologies were identified, such as advanced batteries suitable for hybrid vehicles, that may represent potential opportunities in their own right, particularly using Manitoba-based materials such as high-grade nickel or other minerals. Such technologies need to be evaluated further in the context of broader renewable energy strategy development in Manitoba.

6.0 STATIONARY AND PORTABLE FUEL CELL APPLICATIONS

Aside from transportation vehicles, the other major potential application of fuel cells, and thus for hydrogen, is the production of electric power in stationary and portable units. The assessment of these aspects and identification of associated opportunities are described in the following sections

6.1 Purpose of Working Group

The purpose of the working group was to assess the application of hydrogen powered fuel cells and competing technologies for stationary and portable power applications.

6.2 Overview of Current Situation

Through its evaluation, the Working Group prepared detailed assessments of stationary and portable applications, the range of available fuel cell technologies for such applications, and major competing non-hydrogen technologies. In each case, the Working Group determined current technical and market development status, as well as likely future prospects. Highlights of the detailed evaluation are provided in the following sections.

6.2.1 Stationary Fuel Cell Applications

Hydrogen fuel cells represent an alternative to combustion generation and other technologies, offering the potential of much higher fuel-to-electrical conversion efficiencies and lower emissions. Five of the six classes of fuel cells are potentially applicable to stationary applications. These are:

- Alkaline fuel cells (AFC);
- Phosphoric acid fuel cells (PAFC);
- Proton exchange membrane fuel cells (PEM), including reversible fuel cell versions (RFC);
- Solid oxide fuel cells (SOFC); and
- Molten carbonate fuel cells (MCFC).

Only two of these hydrogen-related technologies, the AFC and PAFC, are now available in a commercially ready form for stationary applications. The AFC represents the original fuel cell, but tends to be considered an antiquated technology, given both technical limitations (e.g. requiring virtually pure hydrogen feed and involving large amounts of platinum catalyst) and high resulting costs. The PAFC is the most commercially advanced, with typical unit capacity sizing of 200 kW. The two most successful applications of PAFC appear to be primary power for data centres, where a power outage has a high consequence, and the use of so-called “free” fuel, particularly reformed biogas from wastewater treatment plants. The PAFC units are expensive, with package unit capital costs in the range of $6,000 to $7,000 per kW based on natural gas fuel supply, more expensive for such fuel as biogas. More importantly, the cost of both AFC and PAFC systems is not anticipated to decline in the future, and these technologies will likely become less popular as other more cost efficient fuel cells become available in the market.

The PEM technology is now almost commercial, with limited offerings of small-sized units running on pure hydrogen gas, but only to select customers. Costs for initially available PEM units are still very high, in the range of $15,000 to $20,000 per kW. These costs are predicted to decline due to increased volume and manufacturing improvements, although PEM manufacturers in the past have tended to be overly optimistic about cost reductions. PEM technology remains relatively sensitive to contaminants, such as carbon monoxide, requiring sufficient purification of hydrogen gas feed and associated costs.

An interesting variant on the PEM is the reversible fuel cell (RFC). One version, produced by Proton Energy Systems and undergoing field use testing has the significant advantage of fast (i.e. 1 microsecond) fuel cell startup time. Another system offers high-pressure (i.e. 140 atm or 2,000 psig) electrolysis.

Within the next five years, the SOFC and MCFC systems are anticipated to reach full commercial-ready status. Both are still at a demonstration stage today. Compared to PEM, both offer higher operating temperatures, potentially larger sizes, better tolerance of carbon oxide contaminants, and the ability to incorporate internal reforming of natural gas. Given these characteristics, both are more readily suited to combined heat and power (CHP) applications, particularly running on natural gas. This is a distinct advantage for stationary applications, given the prominent general trend towards cogeneration in industry.

Within the next five years, it is anticipated that fuel cells likely will be used or demonstrated in a variety of commercial building and institutional applications in North America. These include data processing and telecommunications centres, telecommunications towers, hospitals and other institutions, airports, hotels, office buildings, and educational facilities. In all cases the focus is on primary or backup power, and most commonly using reformed natural gas as the source of hydrogen. Some limited residential demonstrations likely will be implemented within the next five years, but more significant residential and industrial applications are not anticipated until longer into the future.

A variety of utility-related applications for fuel cells also have been identified, including peaking deferral, spinning or non-spinning reserve and local area security. Fuel cells for such applications are currently expensive and at present are likely uneconomic in many jurisdictions. Therefore in the near- to medium-term (5 -15 years) such utility applications do not make sense within Manitoba.

6.2.2 Portable Fuel Cell Applications

At present, there are only a few hydrogen fuel cell systems at a full commercially ready status for portable applications. Most of the work for portable fuel cell systems has been based on PEM technology. In recent media, there has been significant focus on the Ballard/Coleman AirGen 1.2 kW portable unit. There continued, however, to be delays in the release of this product, which is really a moveable version of a backup power PEM unit fueled by contained pure hydrogen gas, described in the last section, in this case targeted as an extended backup power supply for home offices.

Much of the work on portable units has been targeted at military applications, for which performance characteristics, including quiet operation, are more critical than cost. Such systems are anticipated to be commercially ready within the next two to four years.

For portable electronic devices, the focus appears to be primarily on stand-alone power supply units into which portable devices could be plugged. Such systems are anticipated to be commercially ready within five years. A major focus also appears to be the use of methanol rather than pure hydrogen gas to overcome energy density issues. In the shorter term, methanol would be reformed for use in a PEM system. The DMFC, which is still at an early stage of development, is particularly suited for smaller sized portable devices, obviating the need for a methanol reforming system. It will likely become commercially ready for such applications within the next 5 to 15 years.

A major identified marketing limitation of hydrogen gas or methanol powered fuel cells for portable electronics (e.g. cell-phones and computers) will be restrictions on transporting flammable liquids and gases, particularly relating to commercial airlines. Such problems may be addressed by using sufficiently dilute methanol in water as a fuel source, however, at the expense of size and weight. This measure may not be fully acceptable to airline security authorities.

6.2.3 Competing Technologies

For stationary and portable power applications there is a wide diversity of competing technologies. A number of these, although not using hydrogen as fuel, offer similar benefits to hydrogen-related fuel cells and even may be considered as potential opportunities in their own right.

For stationary power applications, the major competing technologies are efficient industrial gas turbines, reciprocating engines and microturbines, particularly fueled by natural gas. These technologies are already well established, have relatively low emission levels including reduced NOx output (fuel cells will still be lower), have electrical conversion efficiencies somewhat lower than fuel cells but still reasonable, are readily adaptable to combined heat and power (CHP) to increase overall energy efficiency, are available in a broad range of sizes, and have much lower installed-capital costs than fuel cells, in the range of only $500 to $2,000 per kW. Reciprocating engines are already common in Manitoba, particularly for backup power. Niche applications are already being implemented within the province for industrial gas turbine technology, at Manitoba Hydro's Brandon Station, and microturbine technology, at the City of Winnipeg.

Batteries involve a very broad category of packaged chemical systems used to produce DC power, including both disposable (termed primary) and rechargeable (termed secondary) technologies. They are applied to everything from micro-sized electronics, such as hearing aids, to large-scale applications. The latter include backup DC power installations for telecommunications, electrical utility protection and control systems, and megawatt-scale storage for short-term electrical system control or longer-term load leveling.

Batteries have several limitations and problems, and thus represent a prospective substitution market for fuel cells, although this will be difficult. Current battery technologies tend to suffer from limited energy densities, short life span, deteriorate with age, high lifecycle electricity cost, and a variety of environmental, fire and exposure hazards. Lead-acid batteries for example, which are used extensively for backup DC power, are extremely heavy, contain hazardous materials, including corrosive liquid and heavy metal, and pose an explosive threat due to venting of errant generated hydrogen.

At the same time, batteries also are a developing opportunity, representing a very large, highly competitive market. Of particular importance is the still rapidly growing portable electronics market (i.e. cellular telephones and portable computers). There is continued pressure for lighter, higher energy batteries to support this market. A wide range of opportunities exists for advanced battery development, particularly based on Manitoba-derived minerals such as high-grade nickel, zinc, lithium and others.

Hydrogen is not the only fuel cell medium. There are also a variety of newly developed alternative energy technologies that may make sense to pursue within Manitoba, including the following:

- Metal-Air Cells - This technology involves the oxidation of a selected metal as fuel, currently including zinc, aluminum or magnesium, and offers the potential for extremely high energy density, low weight, long storage periods, low ongoing maintenance, operation at ambient temperature conditions and improved safety, given the benign nature of resulting oxides. These cells may be manufactured in two forms, as fuel cells or batteries. As fuel cells, they consume metal as long as it is supplied, in the same manner as a hydrogen fuel cell. A regenerator may be coupled with the cell for "recharging". The spent fuel also may be swapped with fresh metal for recycling. As a battery, they may be disposed of when the metal is consumed, in exactly the same manner as any disposable primary battery. Units may be applicable for a broad range of portable devices, as well as battery backup, especially for remote locations. The zinc-air battery appears to be the most commercially ready product, particularly for portable applications. Zinc is also the third most important metal to the Manitoba economy, after nickel and copper.

- Carbon Cells - This complex technology involves the oxidation of input carbon ultimately to carbonate ions, producing electricity. The chemical species involved in the reactions are all benign, which is advantageous. The end product carbonate ion also means that the technology theoretically should not produce any net carbon dioxide, however, in actual practice carbon dioxide release is still a problem.

- Redox Flow Cells - This technology involves reversible electrolyte solutions, typically at larger scale for the storage of electricity. There are currently three available systems: (1) vanadium redox flow; (2) sodium polysulfide based system (under trade name Regenesis); and (3) zinc-bromine based system. Of particular importance may be the potential application to leveling of intermittent electricity sources, such as wind, solar and other renewables, where redox flow cells offer high-energy storage efficiencies, upwards of 85%. A closed-cycle hydrogen electrolysis-fuel cell system by contrast is only in the range of 40% to 45%. These technologies also offer significant performance advantages in utility applications, including voltage and frequency support.

6.3 Major Trends and Uncertainties

A variety of important trends have been identified that will potentially impact both the development of technology and commercialization:

- Transmission grid capacity constraints, particularly in the U.S., represent a continuing concern that could limit the shipment of electricity between regions.

- Continuing customer concerns, particularly in the U.S., with the quality and quantity of delivered power.

- Continuing application of natural gas as fuel of choice for stationary electricity generation in North America, with projected annual growth of 6% to 8% over the next 20 years. This growth will likely be dominated by large industrial gas turbine installations.

- Continuing application of combined heat and power (CHP) or cogeneration, also predominantly using natural gas, in North America with projected annual growth of greater than 2% over the next 20 years.

- Continuing growth of distributed generation of electricity over the next 20 years in North America, although still small as a proportion of overall electricity generation.

- Continued trend in portable applications toward both smaller and more power hungry devices and thus a growing demand for lighter, higher energy-density sources of power for these devices.

There is uncertainty in the timing of future commercial implementation of hydrogen fuel cells, as well as their ultimate future power costs, which will depend both on production volumes achieved and possible manufacturing improvements. In addition to this uncertainty, energy commodity prices have a history of stability punctuated by severe price spikes of varying duration. Since most abundant, cheap fuels are fossil in origin, fuel cells may also become competitive without any change in their cost structure if the prices for conventional fuels rise sufficiently.

6.4 Issues

Major potential negative and positive issues associated with hydrogen fuel cell technology applications to stationary and portable applications have been identified as follows:

Negative

- Significant net energy loss in using an electrolysis-fuel cell storage cycle for leveling of wind, solar and other intermittent electricity sources (total efficiency in range of only 40% to 50%). The application of hydrogen fuel cells to leveling of intermittent electricity generation sources was reviewed but is likely to be dominated by competing technologies.
- Specific niches are not obvious, and effort is required to quantify opportunities.
- Continuously delayed product announcements.
- High costs of materials and manufacturing for fuel cells of all types.
- High current capital costs for fuel cell purchase.
- Long-term durability and reliability of new fuel cell systems at commercial scale appear promising, but are still uncertain.
- Consumer perceptions of cost, benefits and safety.
- Restrictions on combustible gases and liquids for airline travel affecting fuel cell sources for portable electronic devices.
- Handling and implications of exhaust water.
- PAFC technology is currently only available as a bundled system, including expensive natural gas reforming and purification systems.
- Lack of incentives for fuel cell use, such as subsidies.
- Excessively long startup time for all fuel cells at low temperatures.

- Problem of water freezing in fuel cell systems at low temperatures, however, likely solutions exist.
- Toxicity of methanol if used as a fuel source.
- Poor electrical load following characteristics (i.e. slow response to rapidly changing demand).

Positive

- Opportunity for demonstration projects involving fuel cells, firstly to gain experience with the technology and secondly evaluate methods of cost-efficient operation.
- Byproduct hydrogen applications at sodium chlorate producers, where quantities of hydrogen are already physically available without the need for extensive cleanup.
- Direct-to-DC applications of fuel cells, avoiding losses associated with conversion to AC and back to DC again.
- Consumer perception of leading edge, clean technology: cleaner fuels, cleaner exhaust and quieter operation.
- Growing number of call centres and data storage centres within Manitoba.
- Practical systems design to ensure safety and reliability in the handling of hydrogen.
- Streamlined hydrogen design codes.
- Research and development of non-hydrogen technologies (e.g. metal-air cells, redox flow cells, carbon cells, microturbines, etc.) that may be superior to hydrogen in some applications.
- Opportunity to become prepared for the eventual crossover point, when hydrogen based systems may be technically, economically and strategically feasible so that Manitoba can build quickly on that preparedness.

6.5 Stationary and Portable Opportunity Scenarios

A series of three different scenarios were identified that could represent prospective projects or opportunities for stationary and portable applications.

6.5.1 By-Product Hydrogen

A potential opportunity exists within Manitoba to make use of unused by-product hydrogen from sodium chlorate production for the generation of electricity using fuel cells. There are two advantages, firstly the availability of fuel already on-site, and secondly the reduced capital cost of the fuel handling system, through elimination of fuel processing and pretreatment. A portion of the by-product hydrogen is used at both these plants as boiler fuel, offsetting their requirements for natural gas, however, excess quantities that cannot be used are vented.

The necessary conditions for this opportunity are:

- Sodium chlorate manufacturers need to be involved;
- Fuel cell must be able to tolerate minor chlorine contamination; and
- Fuel cell cost for a commercially installed unit in this application must be less than $3,000 per kW.

A major consideration in using the by-product hydrogen is the presence of trace amounts of chlorine gas. Discussions with fuel cell manufacturers confirm that PEM technology would likely be the most suitable of available systems, potentially being able to tolerate this contaminant without significant problems. Although the cost of PEM technology is still a factor of three to six times higher than the necessary cost target, manufacturers have suggested that it may be achievable in the medium-term. SOFC technology is in general more tolerant to contaminants, however, discussions with manufacturers indicated it is likely less suitable to the presence of trace chlorine. SOFC could still be applicable if hydrogen were purified, but at increased cost.

If maximum capacity for by-product hydrogen were used entirely in fuel cells, electricity generation would amount to the range of 15 MW to 25 MW. Although relatively small compared to other generation projects, such as northern dams, the use of by-product hydrogen, if fully implemented, could represent one of the largest installations of fuel cells in the world. On an interim basis, it may also be possible to consider the use of a hydrogen-capable reciprocating engine generator system. Although efficiency of such units is significantly less than fuel cells, this approach could make sense if it all the waste heat could be used.

The use of by-product hydrogen is effectively a one-time opportunity to set up generating capacity. Electricity production could increase if sodium chlorate production was expanded, and the knowledge associated with the application may be exportable.

6.5.2 Direct-to-DC Stationary Applications

Fuel cells produce DC output. An efficient way to use stationary fuel cells is the direct-to-DC application, avoiding DC-to-AC and possible further AC-to-DC conversion losses and costs. The most prominent direct-to-DC application is backup for telecommunications, call centres, and data storage centres. The sodium chlorate application, described above, is also direct-to-DC, given that output from a fuel cell could be redirected back to selected DC sodium chlorate production cells.

Manufacturers of fuel cells have begun to focus more on this area, particularly targeting the telecommunications industry; however, it still represents a potential opening. Expertise and possible additional products or software developed to adapt fuel cells to direct-to-DC applications could be potentially exportable.

The necessary conditions for this opportunity are:

- Technical suitability needs to be confirmed through testing in specific applications;
- Fuel cell and hydrogen costs in combination need to be sufficiently low in order to achieve total energy storage costs of no more than about $150 per kWh, comparable to conventional battery storage systems; and
- Additional benefits, including improved safety and reduced installation size and mass, need to be quantified and confirmed.

6.5.3 Other Technology Opportunities

One significant conclusion of the Working Group was that other promising energy technologies exist besides hydrogen fuel cells. Although not necessarily involving hydrogen, they may offer similar end-use benefits, including improved efficiency and reduced pollution, and may offer economic development opportunities, for example involving high-value application of Manitoba materials such as zinc or nickel. Identified technologies include advanced batteries, metal-air cells, and redox flow cells. Such technologies need to be evaluated further in the context of broader renewable energy strategy development in Manitoba.

7.0 RESEARCH/SCIENTIFIC CENTRE OF EXCELLENCE

Hydrogen as a commercial energy carrier is still in its development stages. Many technical questions and challenges that are critical to the commercialization of hydrogen technology are unanswered or have widely varying answers.

7.1 Purpose of Working Group

The purpose of this working group was to consider:

- How to coordinate and encourage hydrogen research in the province;
- How to be able to connect this research community with the private sector to ensure a common focus; and
- Whether and how some kind of research/scientific Centre of Excellence could be established to facilitate this function.

7.2 Assessment Process

A somewhat different assessment process is employed for this working group than in the case of the other working groups. Three types of information were assembled in order to evaluate the potential for a Centre of Excellence:

(1) Activities currently under way elsewhere in Canada, in order to ensure uniqueness of any proposed centre, avoiding duplication, and determining appropriate potential interfaces for collaboration.

(2) Capabilities that exist within Manitoba, forming the basis for any proposed centre.

(3) Key research gaps, providing a focus for the operation of any proposed centre.

Each of these areas is discussed separately in the following sections.

7.2.1 Activities Elsewhere in Canada

Major activities elsewhere in Canada are summarized as follows:

1. Vancouver Cluster Centering around Fuel Cell Technology Centre (FCTC)

   As part of the National Fuel Cell Research and Innovation Initiative, launched jointly by NRC, NRCan, and NSERC in August 1999, the NRC Fuel Cell Program was formed and has established the Fuel Cell Technology Centre (FCTC) at NRC's Innovation Centre facility in Vancouver, B.C.

   This centre is located near the campus of UBC and is the designated core of a Network Centre of Excellence on fuel cells. It includes appropriate hydrogen-safe laboratory space, although relatively small-scale in nature, and NRC research staff dedicated to this research area. In its structural administration and operation, FCTC is much like the Institute for Biodiagnostics (IBD) located in Winnipeg.

   Also included within this cluster of activities in Vancouver are the following:

   - Fuel Cells Canada, a non-profit corporation, that acts as a fuel cell industry association and is involved in information exchange, lobbying and other related activities. Its stated mission is to advance Canada's fuel cell industry and currently involves membership of 46 companies and organizations. Although it is open to any Canadian stakeholder, it primarily involves a number of B.C.-based companies such as Ballard and Questair.

- Canadian Institute for Market Intelligence (CIMI), an academic-based collaboration involving NRC. It is focused on developing and providing competitive intelligence via NRC to Canadian small and medium sized companies. One of CIMI's key activity areas is fuel cells and related technologies.

The primary focus of all these activities in Vancouver is fuel cells themselves, which is natural given Ballard's dominant presence in B.C. There is also extension into specific applications and infrastructure given the importance of these issues.

2. Cluster in Quebec Centered Around L'institut de Recherche sur l'Hydrogene (IRH)

Activity in Quebec is centered around the L'institut de Recherche sur l'Hydrogene, at the Universite de Quebec a Trois-Riviere, which was founded in 1996. This group involves physics and engineering research that is more fundamental in nature, involving such areas as metal hydrides storage, but also includes support work relating to codes and standards issues. For example, Tapan Bose, Director of IRH, is involved on behalf of Canada in the Technical Committee (TC) 197 of the International Organization for Standardization (ISO). Hydro Quebec is also significantly involved.

3. Other University Groups

A number of universities have reasonably significant concentrations in specific areas relevant to hydrogen. A non-comprehensive overview, including identified areas of apparent focus (where known), is as follows:

- University of Victoria (fuel cells)
- University of Toronto
- Royal Military College (reformer technologies)
- McMaster University
- University of Calgary (currently fuel cell catalyst chemistry, but also had previously maintained a research chair in hydrogen)

There is some additional work relevant to hydrogen at other universities, but it has not tended to be as concentrated. A wide range of plans and proposals involving hydrogen-related centres of excellence and other academic collaborations are also under discussion across Canada.

7.2.2 Profile of Manitoba Capabilities

In order to support the assessment of this Working Group, as well as others, IRAP engaged the Prairie Centre for Business Intelligence (PCBI) to conduct a brief investigation and to identify relevant institutional and corporate players within Manitoba who are currently involved with hydrogen activities in some way.

PCBI's results are sufficiently exhaustive to provide a clear overview of hydrogen research and business within the province, even if a few possible activities may have been missed. The overall characterization is as follows:

- Hydrogen research is conducted within Manitoba, with a variety of activities that would fall under the hydrogen umbrella;

- Hydrogen research and business activities cover a number of diverse technical areas; and

- Research activities have tended to be fragmented and isolated from one another, and thus uncoordinated from an overall perspective.

Although it would also be useful to understand Manitoba capabilities that might have some relevance in the future, it was not practical to extend PCBI's investigation to this greater degree, given limitations of both time and resources.

There is one major area of research strength within the province, as identified by PCBI's evaluation, this being the hydrogen safety and mitigation research programs conducted by Atomic Energy of Canada Ltd. (AECL) at its Whiteshell Laboratories in Pinawa. AECL's developed resources in Pinawa include:

- Important existing body of practical knowledge on behaviour of hydrogen and on safe hydrogen systems design.

- Group of professional and technical/support staff engaged in hydrogen safety R&D.

- Unique large-scale infrastructure for the safe testing of hydrogen under a top level quality assurance program.

AECL's work is focused on nuclear safety, largely under contracts from nuclear utilities to address potential safety and licensing issues associated with accidental hydrogen generation (from metal-water reactions) under adverse conditions in nuclear reactors where venting to atmosphere is strictly precluded. The developed background knowledge and activities at Whiteshell are also applicable to hydrogen in broader industrial applications, and thus of potential benefit to a developing hydrogen industry in Manitoba. Because of the commercial proprietary nature and narrow application on nuclear safety, AECL's hydrogen activities in Pinawa have remained largely unknown outside nuclear circles. Although relevant experience and capabilities have been built up at Whiteshell, it also important to note that the hydrogen program is near the end of its mission and AECL has plans to wind down hydrogen activities at Whiteshell by the end of 2003. As such, there is a limited window of opportunity for taking optimum advantage of these capabilities.

At the University of Manitoba and University of Winnipeg there are strong generic programs, for example in Mechanical/Industrial Engineering and Chemistry, that have the potential for being directed to hydrogen research, and where there is growing interest and capabilities. There is also a potential to strengthen capabilities, for example by funded research chairs.

7.2.3 Key Research Gaps

From the investigations of other working groups, two broad areas of gap have emerged, summarized as follows:

(1) Cluster of problems and issues described as "codes, standards, safety, certification, etc." is a major recurring theme, not just in other Working Groups but also in general discussions and development of hydrogen outside Manitoba. Generalized codes and standards exist for transportation and handling of hydrogen and for mechanical/electrical design of hydrogen systems. There is, however, rather limited industrial experience in applying these standards. The interpretation and adaptation of applicable codes and standards for specific applications remains a challenge. As experience is gained and more applications emerge, refinements and additions to existing codes and standards may be needed. As well, there are gaps in the data on hydrogen behaviour needed to conduct proper functional and safety analysis hydrogen systems.

(2) Various gaps in knowledge of hydrogen systems behaviour impede hydrogen implementation. Such areas include materials interaction, separation performance, testing, pipeline losses, risk mitigation, and cold weather performance. Again, what is really at issue is a lack of practical experience with hydrogen systems. Practical pipeline pressure drop losses for hydrogen is a specific example. This information, which does exist within private hands, is fundamental to questions of hydrogen transportation, particularly when comparing to other possible energy transport modes, such as natural gas pipelines or HVDC electricity transmission lines. Theoretical prediction can be undertaken but is inadequate because of non-linearity.

The kind of experience and expertise developed at AECL in safe hydrogen systems design and practical hydrogen data development is relevant to begin addressing both of these gap areas, and thus would represent an important starting point for further research.

7.3 Funding Sources for R&D

A variety of potential funding sources may be available. It was felt important that the development of any funding proposal should be targeted, and should follow any decision on what is most appropriate as the purpose and function of a proposed Centre of Excellence.

Key factors necessary for a successful proposal to granting agencies include the following:

- Unique niche;
- Long-term plan;
- Industrial involvement; and
- Collaboration.

The involvement of academic staff is important not just for collaboration but also to be able to gain access to specific funds -- for example, the Natural Sciences and Engineering Research Council of Canada (NSERC).

7.4 Proposed Centre of Excellence Opportunity

Based on its preliminary review, the Working Group recommends the creation of a scientific/research Centre of Excellence based as a starting point on the activities at AECL's Whiteshell laboratories in Pinawa, spinning out to non-nuclear hydrogen applications.

7.4.1 Purpose

The proposed purpose of the Centre is to focus on hydrogen systems design, including:

- Providing a focal point for hydrogen research development activities and providing support to other development activities within the province;
- Undertaking selected research activities, including both pure and applied research;
- Linking to other research collaborations, involving researchers within Manitoba, but also potentially outside Manitoba;
- Providing relevant training opportunities for research and professional staff, as well as the development of broader training programs; and
- Developing commercial spin-offs within Manitoba for potentially marketable service and product opportunities.

This proposed purpose is unique relative to other academic centres within Canada, and also would allow the two broad research gap areas to be addressed.

7.4.2 Proposed Model

The precise form of the proposed centre may change, based on the results of further more detailed review, but at this time the working group makes the preliminary recommendation for the proposed Centre to be a non-profit corporation, modeled on the successful TRLabs in the telecommunications sector. This would involve:

- Establishing a standalone, non-profit corporation, with equal voting share opportunities offered to Manitoba stakeholder organizations.
- Eligible Manitoba stakeholders could include Province of Manitoba, University of Manitoba, University of Winnipeg, Red River College, AECL, Manitoba Hydro, and interested private sector Manitoba companies.

8.0 NON-FUEL AND OTHER HYDROGEN APPLICATIONS

Hydrogen has a variety of non-fuel applications, typically with much higher value than can be obtained for fuel. The assessment and identification of such opportunities is presented in the following sections.

8.1 Purpose of Working Group

The last active working group, called Hydrogen in Existing Processes, was responsible for assessments covering two major areas:

- Understand how hydrogen is used in industrial processes globally and in Manitoba and what existing sources of hydrogen are available in the province (e.g. waste gas from chemical production); and
- Identify potential future opportunities for hydrogen involving non-fuel applications and other miscellaneous opportunities that might otherwise be missed through the other working groups.

8.2 Overview of Current Situation

Through its evaluation, the Working Group prepared detailed assessments of existing applications of hydrogen. Highlights of this evaluation were incorporated into Chapter 3.

8.3 Major Trends and Uncertainties

A variety of important trends have been identified that will potentially impact both the development of technology and commercialization:

- Trend toward increasingly stricter environmental regulations for industries (particularly toxic-related controls such as under the Canadian Environmental Protection Act), and direct associated trend toward "cleaner or greener" production technology. The use of hydrogen-based processes offers in many cases the potential to reduce adverse environmental impacts.
- More subtle background trend of consumers demanding end-use products with reduced environmental effects. For institutions and companies this is manifested in "green" procurement programs. This trend will translate to more "environmentally friendly" products and processes; however, given the derived demand and product-specific nature of changes, the exact resulting impacts are uncertain beyond generalities. Hydrogen-based products have the potential to provide environmental benefits. Environmental benefits were described in Chapter 5 and Chapter 6 for vehicular, and stationary and portable power applications respectively, but are also relevant for other products and applications.

- Development of new technologies and new products. Again, given the product-specific nature of changes, the exact resulting impacts are uncertain beyond generalities.

8.4 Opportunity Identification and Rating

Given the diversity of potential opportunities for non-fuel use of hydrogen, the Working Group conducted a brainstorming session. This brainstorming session involved 11 participants from diverse backgrounds, including government, industry and university.

A total of 50 ideas were generated from the brainstorming session, which were categorized into eight groups as follows:

- Building block products
- Processing applications
- Environmental applications
- Mobile devices
- Appliances
- Safety systems and services
- Other services
- Other hydrogen-using systems

A complete list of identified opportunities, broken down into these categories, is provided in Appendix C.

In order to develop a shorted-list of possibilities, with likely promise for Manitoba, all the ideas were subsequently rated by members of the Working Group using a simple criterion-based approach.

First the individual ideas were categorized according to when they would likely come to fruition, whether that would be:

- Near-term (within next five years);
- Medium-term (next 5 to 15 years); or
- Long-term (beyond 15 years).

Each of the ideas was then rated in terms of potential using nine equally weighted criteria:

- Economic impact potential - How big a positive impact will this opportunity likely make, in terms of manufacturing value-add, exports, knowledge value, etc., and how important is it to Manitoba?
- Environmental improvement potential - How big a positive impact will this opportunity likely make in terms of environmental improvement?
- Technology or service capabilities match - How well does the opportunity involved match technology and/or service capabilities within Manitoba?
- Available market match - How appropriate is the market or potential market involved to be serviced from Manitoba?
- Competitive advantage - How unique is the opportunity for Manitoba (i.e. is not easily duplicated elsewhere)?
- Resources required to bring to fruition - How reasonable are the resources necessary to bring this opportunity to fruition?
- Social impact potential - How big a positive impact will this opportunity make in terms of employment and community development?
- Risk and uncertainty - How manageable are the uncertainties and risks involved with this opportunity?
- Linkage to other areas - How much will the opportunity leverage into other areas (i.e. linkage to other working groups)?

8.5 Hydrogen Opportunities

The highest rated hydrogen opportunities were identified for each of the three prospective time periods as described in the following sections.

8.5.1 Near-Term Opportunities

The near-term opportunities with greatest likely promise all fell within two groups: (1) safety-related systems and services, which were highest ranked and primarily linked to spin-off capabilities from AECL's research in Pinawa and (2) building block product applications.

The three highest-rated safety-related systems and services opportunities, which could potentially be exploited as spin-offs of the proposed Centre of Excellence, are:

- Services related to hydrogen safety technology and expertise, including support for regulations and standards, information for the insurance industry, certification, and imbedding safety into developing products, that could potentially be sold both within and outside Manitoba on a fee-for-service, royalty or some other basis;
- Product technologies to safely consume fugitive emissions of hydrogen; and
- Hydrogen detection products.

The three highest-rated building block product applications are:

- Hydrogen for upgrading food and feed products, such as treatment of canola meal to address phenolic content or possible treatment of grains for inactivation of fusarium mycotoxins, the latter in particular in conjunction with ethanol production;
- By-product hydrogen for ammonia production, potentially on an augmenting basis; and
- By-product hydrogen for hydrogen peroxide manufacturing.

8.5.2 Medium-Term Opportunities

The three highest-rated medium-term opportunities are:

- Small-scale catalytic thermal devices for clean heat (appliance application);
- Hydrogen for manure control or manure management (environmental application); and
- Lawnmowers, using hydrogen as fuel (mobile devices).

8.5.3 Long-Term Opportunities

The two highest-rated long-term opportunities are:

- Catalyst research, development and commercialization, based on available mineral materials in Manitoba; and
- Vanadium deposit development for potential production of redox flow battery electrolyte.

9.0 EMERGING OVERALL DIRECTIONS

Five recurring themes emerged from the analyses conducted by the various working groups:

(1) Focus on leveraging unique Manitoba resources and capabilities;

(2) Focus on niche applications;

(3) Focus on developing collaborative partnerships;

(4) Need to address gaps in practical experience with hydrogen technologies; and

(5) Need for appropriate near-term actions to capitalize on limited window of opportunity.

Each is discussed in more detail in the following sections.

9.1 Unique Resources and Capabilities

As determined by the Working Groups, Manitoba already possesses a number of unique resources and capabilities that are relevant or potentially relevant to hydrogen, but that up until now have never been considered under a unified umbrella. These include:

- Bus manufacturing capabilities of New Flyer and Motor Coach Industries, both in Winnipeg;
- Refueling system capabilities of Kraus Global in Winnipeg;
- Knowledge of hydrogen and sophisticated testing facilities developed by AECL in Pinawa;
- Specialized hydrogen storage vessel capabilities using electron-beam cured composites by Acsion in Pinawa;
- Growing academic interest and capabilities for hydrogen and associated technologies at Manitoba universities and colleges;
- Near-term availability of renewable hydrogen as a by-product of sodium chlorate production at two industrial plants;
- Hydrogen production at Simplot Chemical in Brandon for fertilizer products, which are important to the agriculture economy; and
- Existing and undeveloped hydroelectric resources of the province together with the infrastructure of Manitoba Hydro providing the capability and flexibility to produce renewable hydrogen in the long-term future if it becomes economically feasible.

In the continuing progress toward a cleaner energy economy, it is important to formally seek to leverage these resources and capabilities, including the following:

- Formally recognize and coordinate the cluster of activities relevant to hydrogen as the "Manitoba Hydrogen Industry".
- Emphasize high-value applications.

9.2 Niche Applications

Much of the current focus on hydrogen technologies has been specifically on fuel cell stacks, the actual energy conversion devices themselves. It is clear from the Working Groups that the prospect of Manitoba building or acquiring its own fuel cell stack manufacturing industry would be impractical. The learning curve to compete with existing players is simply too steep and the resource requirements are too costly.

At the same time, a wide variety of opportunities appear to be available for the utilization of fuel cells and hydrogen technologies for specific applications, particularly niche applications. Bringing fuel cells to fruition ultimately will require applications, and in the near- to medium-term these will be niche applications, because of the costly nature of the technology.

Priority niche focus areas identified by the Working Groups are summarized as follows:

- Transit buses and refueling. Transit buses and associated refueling represent a natural opportunity for Manitoba, both for near-term demonstration and in production because of the manufacturing infrastructure already in place. In this case experience in the adaptation and utilization of fuel cells in buses will be needed.

- By-product hydrogen. The availability of by-product hydrogen from chlorate production provides multiple opportunities, the production of stationary electricity including an associated demonstration to prove the technology and other possible high-value applications that could lead to a hydrogen movement technology demonstration. Lessons learned from working with by-product hydrogen are applicable elsewhere.

- Direct-to-DC. This application, particularly for backup power is a near-term possibility for fuel cells, with significant applications within and outside Manitoba. Alternative backup systems will need to be considered.

- Hydrogen safety and systems design. Developing practical and safe hydrogen systems is intrinsic to all applications. The proposed Centre of Excellence represents a distinct opportunity given the lack of understanding on safe but practical hydrogen handling.

- Other light-duty vehicle applications. A broad range of possibilities exists that could be potentially exploited, including small fleet vehicles, golf carts, people movers, and indoor vehicles such as forklifts.

9.3 Collaborative Partnerships

There are technical and financial risks, and high costs associated with hydrogen technologies and hydrogen infrastructure today. As such, collaborative partnerships represent an important component of all actions to be undertaken. Such arrangements share risk burden, develop knowledge and experience in a cost efficient manner through leveraging, and generate profile.

Although partnerships are generally important, of specific relevance to Manitoba is the development of a broad collaborative partnership with Iceland. As noted earlier, Iceland has already made a strong commitment to hydrogen, and is positioning itself as a hydrogen economy pilot. Both jurisdictions already have a strong focus on renewable energy production, and both represent effectively unique energy "islands," Iceland literally and Manitoba more figuratively being the lowest electricity cost and highest proportion renewable jurisdiction in North America.

Manitoba and Iceland share more in common than hydrogen. Manitoba has a large Icelandic community dating back to the late 19^{th} century, and Iceland already maintains an ambassador level representative (General Consul) in Manitoba. Municipal level arrangements already exist with Winnipeg and Reykjavik designated as sister cities. There are also four existing agreements with Iceland involving the University of Manitoba.

A Memorandum of Understanding (MOU) with Iceland on hydrogen development is a logical first step. Collaborations with other potential partners, particularly international, need to be identified and pursued.

9.4 Hydrogen Experience Gaps

In order for Manitoba to compete in a future hydrogen industry, a pool of knowledge is required, firstly in terms of the handling of hydrogen and design of practical hydrogen systems, and secondly in integration for specific applications. The experience needed to be able to successfully pursue hydrogen-related opportunities largely does not yet exist. There are gaps.

The lack of experience was most acutely identified by the Vehicles and Refueling Working Group where the issues associated with integration of fuel cells into buses or other light industrial vehicles are complex and challenging. Specific means to address the experience gaps include the following:

- Recommended creation of a Centre of Excellence, which will include taking advantage of the enormous experience base is practical hydrogen systems safety and design already present at AECL. This opportunity deals broadly with hydrogen, but may not address specific application issues (e.g. integration of fuel cell drive trains in buses).

- Implementation of demonstration projects, as discussed further in Chapter 10.

- Additional application-targeted activities, for example specifically addressing issues associated with adapting fuel cells or fuel cell vehicle drive trains into buses.

9.5 Window of Opportunity

The broad commercialization of hydrogen is not anticipated for a number of years and, as such, it may be too easy to succumb to the temptation to simply wait and see. However, all the identified niche opportunities, as noted above, exist largely because the resources of existing players are limited. As commercial development continues and attention on hydrogen technologies grows, potential openings that show promise ultimately will be seized by others. The window of opportunity for all these niche areas, in terms of being able to achieve economic development benefits within Manitoba, in all cases is likely to be less than five years, even shorter in such cases such as the proposed Centre of Excellence based on AECL's capabilities in Pinawa.
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Developing opportunities takes time. Inappropriate applications waste time and resources. Judicious planning and actions are needed today in order to be prepared when commercial opportunities finally develop. In order to maintain momentum, a series of near-term actions and projects have been recommended by the various Working Groups, as summarized in Chapter 10. These include a number of potential demonstration projects aimed ultimately at gaining experience in key target application areas and assessing further development directions.

10.0 NEXT STEPS

Eleven actions were identified, including five potential demonstration projects and other follow-up activities. These actions are summarized as follows, with any relevant linkages and requirements for follow-up evaluations indicated in each case:

1. <u>Transit bus demonstration including refueling and on-site electrolysis hydrogen production system</u> (Transportation: Vehicles and Refueling, and Hydrogen Production and Movement Working Groups)

   Manitoba has proven bus manufacturing capabilities and also has a unique opportunity to be able to produce clean hydrogen for small-scale fuel cell bus demonstration at a cost competitive to conventional fuel. The objectives of the bus and refueling component of the project include:

   - Showcase bus and refueling technologies;
   - Demonstrate refueling and operation under real conditions, including winter operation; and
   - Promote Manitoba as a demonstration centre for hydrogen-related bus technologies.

The objective of the fuel production component would be to demonstrate small-scale trial commercial electrolysis fuel production. This would involve delivery of hydrogen at competitive costs, with cost recovery to sustain the production infrastructure over an extended period (i.e. at least five to eight years or longer).

The priority focus is on fuel cell buses. However, it may be desirable to also consider the use of hydrogen-based internal combustion engines as an interim step, or inclusion of a limited number of additional hydrogen ICE cars or trucks within the same project, as described later under Action #6.

Follow-up involves two components:

- Detailed follow-up evaluation of potential for transit bus and refueling system aspects.
- Detailed follow-up evaluation to confirm costs and benefits of electrolysis-based hydrogen production to supply fuel for a transit bus demonstration.

2. Demonstration of fuel cell for stationary power using by-product hydrogen
(Stationary and Portable Applications, and Hydrogen in Existing Processes Working Groups)

Implementation of fuel cells for this application would be staged. The first stage would involve demonstration testing on a partial scale with objective to confirm long-term suitability of fuel cell technology and performance.

Detailed follow-up evaluation of the by-product hydrogen application is required to confirm costs and benefits, including determining prospective interest of fuel cell manufacturers and confirming contaminant concentrations. PEM technology appears to be most suitable to this application, but needs to be confirmed.

3. Follow-up assessment and proposal preparation for Centre of Excellence
(Research/Scientific Centre of Excellence Working Group)

The follow-up evaluation includes confirming the validity and desirability of the proposed Centre, confirming prospective participants, and identifying most appropriate funding sources and specific collaborative opportunities.

4. Continued monitoring of progress of industrial-grade hydrogen production at Manitoba Hydro, Dorsey
(Hydrogen Production and Movement, and Hydrogen in Existing Processes Working Groups)

Manitoba Hydro is already considering implementation of a dedicated industrial-grade electrolysis production system as a stand-alone commercially justified project at its Dorsey Converter Station. This would represent a major hydrogen project, including the development of relevant knowledge and experience.

5. Memorandum of Understanding (MOU) with Government of Iceland on hydrogen development
(Hydrogen Steering Committee)

The intent of a MOU with Iceland is multiple, potentially including:

- Promoting a closer working relationship between governments and companies in both jurisdictions on hydrogen;
- Investigating matters of mutual interest for joint initiatives on hydrogen; and
- Investigating the benefits of people and information exchanges and joint research/training initiatives.

6. Direct-to-DC application demonstration of fuel cell technology
(Stationary and Portable Applications Working Group)

A small-scale fuel cell would be implemented using pure hydrogen gas as fuel to provide backup for a direct-to-DC application. Priority installations would be call centres, telecommunications or data centres. Detailed follow-up evaluation is required to confirm costs and benefits of the project.

7. Hydrogen ICE fleet vehicle demonstration
(Transportation: Vehicles and Refueling Working Group)

A near-term demonstration opportunity exists for a limited number of adapted light-duty hydrogen ICE vehicles, potentially in the range of three to five. The purpose would be specifically to demonstrate both the visible operations of hydrogen-powered light-duty vehicles and suitable light-duty refueling infrastructure. Given the much smaller amounts of fuel used by such vehicles, it might be possible to piggyback on the hydrogen production infrastructure necessary for buses, as outlined earlier.

Detailed follow-up evaluation is required to determine scope, costs and benefits of this project, which are uncertain at this time.

8. Investigation of application opportunities for by-product hydrogen
(Hydrogen in Existing Processes, and Hydrogen Production and Movement Working Groups)

Application opportunities for by-product hydrogen are important in themselves, with particular emphasis on high-value products, but also leading to potential for a demonstration project focused on economic movement of hydrogen. No specific project is yet identified. Preliminary assessment of by-product hydrogen applications is necessary, including non-fuel and other energy opportunities.

9. Investigation of specific niche light-duty vehicle integration opportunities
(Transportation: Vehicles and Refueling Working Group)

Further investigation and evaluation of other prospective light-duty vehicle integration opportunities is necessary to identify specific opportunities.

10. Investigation of near-term and long-term electricity export opportunities linked to clean hydrogen production (Hydrogen Production and Movement Working Group)

This activity will be undertaken by Manitoba Hydro.

11. Evaluation of potential for non-hydrogen alternative energy technologies as part of broader renewable energy strategy (Stationary and Portable Applications Working Group)

Non-hydrogen technologies identified for further evaluation include advanced batteries, metal-air cells, carbon fuel cells, and redox flow cells. Although possible competitors to fuel cells in certain applications, they may represent economic development opportunities in their own right. Evaluation of these technologies is important to consider as soon as possible under the umbrella of a broader renewable energy strategy.

11.0 POLICY ISSUES

Through the course of the assessments by the Working Groups, a number of important policy issues were identified as follows:

1. "Buy America" Legislation. Currently in the United States, "Buy America" legislation applies to bus purchases involving U.S. federal funding from the Federal Transit Administration (FTA). The legislation in general terms requires 60% of all components and sub-components to be of U.S. origin as well as final assembly to be conducted in the U.S. For transit bus purchases in the U.S., the FTA typically provides the large majority of funding, around 80%. "Buy America" does not apply if U.S.

federal funding is not used and this is known to have occurred. It is possible to apply for waivers on the basis of public interest, non-availability, or significantly lower cost, although waivers are discretionary in nature and provide no precedent for further action.

"Buy America" is already a well-known issue for Manitoba's bus manufacturers. It is exacerbated in the case of advanced fuel cell buses, given that fuel cell and many related technologies today are largely foreign to the U.S. in origin, many indeed are Canadian. As such, this U.S. policy could represent a constraint limiting the extent of future possible hydrogen technology related activities for transit buses within Manitoba. Important observations are as follows:

- Given that "Buy America" involves the practices of a foreign government, any actions attempting to address or modify such a policy would have to come through the Government of Canada, however, only if the Government of Canada first could be interested in pursuing such action.
- It is unlikely the U.S. Government could be motivated to modify "Buy America" by any intervention or lobbying of the Government of Canada, based on past experience.
- Manitoba bus manufactures have adapted to "Buy America", and may not be receptive to any intervention by the Government of Canada for modification, given that "Buy America" creates barriers to Mexican and off-shore competitors.
- Manufacturing of additional individual components within Manitoba intended for transit buses can be considered on a component by component basis, for example via waiver, but needs to consider on a long term basis the implications of "Buy America."

2. Sustainable Transportation. Sustainable transportation can be complex in its complete definition, but includes both the concepts of reducing environmental effects and of ultimately using renewable sources of energy for motive power. Sustainable transportation and the fuel pricing signals and other tools required to achieve this goal are important for both transportation and energy policy development. An important resulting premise is that for clean fuels to enter the marketplace, the full cost of dirty fuels and associated combustion technologies must be borne by the users, and not society in general. Otherwise, users of clean and renewable fuels like hydrogen are forced to pay the full cost of being clean while at the same time competing with "subsidized" dirty fuels. Several issues related to sustainable transportation were identified through the course of the assessments:

   - Fuel Taxes. Existing transportation fuel taxes are an established source of significant revenue for government, particularly relative to the support of transportation infrastructure, and any policy that deals with future fuels must deal with this issue. It was identified that achieving price neutrality in the near term for hydrogen relative to conventional fuels for applications such as transit buses will depend on having no motive fuel taxes, whether provincial or federal, applied to hydrogen, and further no GST or PST applied to electricity used to produce hydrogen. The issue of immediate concern is how to ensure that fuel taxes do not compromise Manitoba's ability to participate in early initiatives for developing hydrogen-based economic opportunities. This needs to be addressed through some sort of "relief requirements" during the demonstration phase so early users are not penalized. One possibility is an interim tax exemption, as is currently the case for compressed natural gas used as fuel, which may be acceptable so long as the number of hydrogen-powered vehicles remains relatively small.
   - Interim Fuel Incentive for Transit Application. It was identified that achieving fuel price neutrality for transit buses will depend primarily on increasing the efficiency of on-board fuel cells to reduce hydrogen fuel consumption levels. It may take to some time in order to reduce sufficiently fuel consumption to desired economical levels. Further incentives for transit buses may be needed on an interim basis until sufficient hydrogen fuel economy is achieved.
   - Fuel Incentives on Hydrogen to Recognize Clean Nature. Additional incentives may be appropriate to consider, both at the provincial and federal level, for renewably derived hydrogen to recognize lower greenhouse gas and other pollutant emissions, as well as contributing to national energy security and reduction of the provincial energy deficit.

- Fuel Cell Vehicle Procurement. The commercial availability of light duty fuel cell vehicles is still a number of years into the future, but prototype vehicles will be available for road testing much sooner. Purchasing policies promoting future fuel cell purchases or leases could be implemented in the near term. This includes development of possible target timelines and purchase commitments.

3. Industry Assistance. In order to help promote both the adoption of new technologies by private sector companies, and economic development, a variety of targeted measures may be needed to assist the industry, including the following:

   - Recognition of Hydrogen Industry. Manitoba already has hydrogen activities, although not under a single umbrella. Measures could include a formal recognition of the industry, as well as possible incentives to assist in establishment of a Hydrogen Industry Association.

   - Encouragement for Skills and Experience Development. There is a currently an experience gap in the application of hydrogen technologies, particularly skills related to integration. Appropriate incentives would allow companies to upgrade experience to help address this issue.

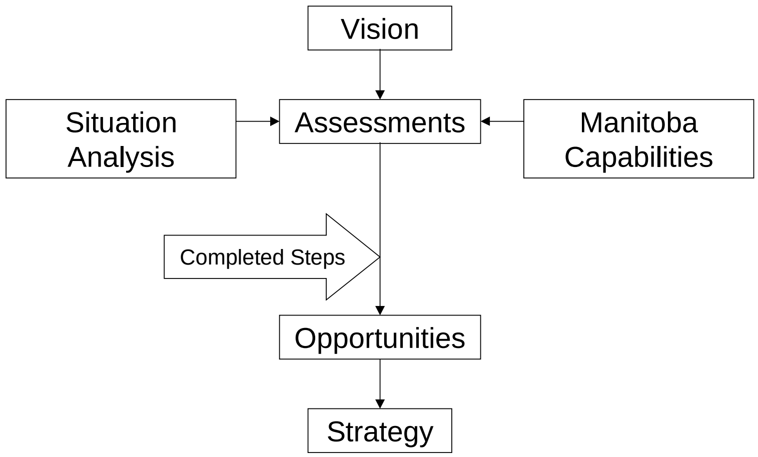
   - Accelerated Capital Cost Allowance (ACCA) to Assist with Technology Risks for Corporations. Many initial applications of hydrogen related systems will be public sector, however, the intent is to have commercial implementation as soon as practical. Given the relatively high existing capital costs, the risks of implementing fuel cell technologies, including stationary, portable and vehicular applications, may continue to be unattractive for companies. This could be enhanced by appropriate accelerated capital cost allowance incentives, for example by providing accelerated write-offs for all hydrogen-related equipment under the current Class 43.1 (i.e. 30% on declining balance CCA). Given the importance and risks associated with hydrogen, it may be possible to justify even more advantageous ACCA rates, for example comparable to the old Class 34 that had been applied for a limited time period to cogeneration systems (i.e. 50% on declining balance CCA). The setting of ACCA rates is under Federal jurisdiction, but encouragement should be provided to achieve an improved position.

4. Development of Broader Renewable Energy Strategy. The assessments undertaken on hydrogen opportunities are intended to lead towards the development of a formal Hydrogen Economic Development Strategy, which in turn is one component of a broader renewable energy strategy. Initiating such a broader framework is important regarding a number of non-hydrogen technologies identified through the course of the assessments that may represent economic development opportunities in their own right.

12.0 CONCLUSIONS AND RECOMMENDATIONS

12.1 Preliminary Assessment Process Completion

Preliminary assessments of potential hydrogen-related opportunities for Manitoba have been completed. This work represents a major step forward toward the development of a Hydrogen Economic Development Strategy for Manitoba, as illustrated in the following diagram:



Actions identified by the Working Groups are important in helping to define the future directions of a Hydrogen Economic Development Strategy for Manitoba, gaining experience in target niches and assessing further development directions. The nature of the Strategy will remain dynamic and will depend on confirming likely successful opportunity areas

The completion of the preliminary assessment process by itself represents an important opportunity, providing Manitoba a leadership position within Canada on hydrogen. Other jurisdictions within Canada and elsewhere may have more existing economic activity related to hydrogen, but surprisingly few jurisdictions within North America, and none in Canada, appear to have undertaken a similar broad-based systematic process for opportunity assessment or strategy development.

12.2 Long-Term Hydrogen Potential

The most obvious connection to a Manitoba clean energy future for transportation and portable power is the hydroelectric resources of the province, which when combined with water electrolysis technologies provides the ability to produce clean hydrogen. It is clear from the results of the assessments that any opportunities for large-scale production from water electrolysis remain very long-term in nature, and will depend on the emergence of satisfactory market conditions, and lower long-term production costs than competing processes, particularly the large-scale production of hydrogen from natural gas. At large-scale, hydrogen from natural gas today enjoys a significant cost advantage.

If acceptable conditions can be achieved, the potential is significant. Given its current hydroelectric advantage, Manitoba could be the first jurisdiction in North America where large-scale electrolysis production of hydrogen becomes cost-efficient. Assuming in the long term future that all vehicles in North America are powered by hydrogen fuel cells, the undeveloped hydroelectric resources of Manitoba, around 5,000 MW, if converted to hydrogen could provide between 1% to 2% of all transportation fuel requirements. This could also allow Manitoba to become self-sufficient for transportation fuels.

12.3 Priority Niches in the Near- and Medium-Term

The path toward a long-term hydrogen future requires identifying and pursuing early stage opportunities, to allow Manitobans to capitalize on long-term opportunities. Potentially viable opportunities in the near- to medium-term for hydrogen will involve niche applications, because of the still costly nature of hydrogen technologies, particularly fuel cells. Five priority niche areas for hydrogen were identified by the Working Groups:

- Transit buses and refueling. Transit buses and associated refueling represent a natural opportunity for Manitoba, both for near-term demonstration and in production because of the manufacturing infrastructure already in place.

- By-product hydrogen. The availability of by-product hydrogen from sodium chlorate production provides multiple opportunities. First is the possible production of electricity using stationary fuel cells, which if fully implemented for all byproduct hydrogen would represent one of the largest fuel cell installations in the world. Other high-value non-fuel applications may also be possible, potentially leading to a hydrogen movement technology demonstration. Lessons learned from working with by-product hydrogen are applicable elsewhere.

- Direct-to-DC electricity. Fuel cells produce DC electricity. A near-term opportunity is the use of fuel cells to provide DC directly for applications where it is required, such as in backup power for telecommunications. This approach avoids unnecessary and inefficient conversion to AC and back to DC again. There are significant applications within and outside Manitoba. Alternative technologies will need to be considered.

- Hydrogen safety and systems design. Developing practical and safe hydrogen systems is intrinsic to all applications. A research/scientific Centre of Excellence has been proposed, using as a starting point the existing unique capabilities at AECL's Whiteshell laboratories in Pinawa, spinning out to non-nuclear hydrogen applications. This represents a distinct opportunity given the lack of understanding on practical hydrogen handling.

- Other light-duty vehicle applications. A broad range of possibilities exists that could be potentially exploited for the application of fuel cells, including small fleet vehicles, golf carts, people movers, and indoor vehicles such as forklifts or ice grooming machines.

The potential Manitoba opportunities require specific conditions to be fulfilled in order to be successful. Many of the opportunities are subject to competition from non-hydrogen technologies or are subject to significant uncertainty, particularly regarding competitive energy prices such as for natural gas. All of the opportunities will require partnerships in order to be successfully implemented, in particular accessing existing and forthcoming programs of the Federal Government. Given the preliminary nature of assessments, the opportunities will require further evaluation in order to confirm suitability. In all cases, the window of opportunity in order to achieve economic development benefits is likely to be less than five years, even shorter in some cases.

12.4 Actions

A series of eleven actions were identified by the Working Groups and Steering Committee including five potential demonstration projects. These projects are ultimately aimed at gaining experience in target niches and assessing further development directions. Not all may necessarily lead to successful outcomes, given uncertainties.

Five actions are given highest priority because of time sensitivity. These are the transit bus demonstration, by-production fuel cell hydrogen demonstration, proposed Centre of Excellence, the Dorsey hydrogen production project, and implementation of a MOU with Iceland on hydrogen development. Follow-up evaluations and development of business case or public policy justifications thus will need to be undertaken rapidly for these. All the identified actions are summarized as follows:

Action	Benefits	Comments
1. Transit bus demonstration, including refueling and on-site hydrogen production	Advanced bus manufacturing and refueling system manufacturing, with associated potential export. Potential for first commercially viable bus refueling station in world, with experience in management of commercial hydrogen infrastructure.	
2. Fuel cell demonstration using by-product hydrogen	Potential for one of the largest fuel cell installations in world, with potential exports of specialized knowledge and any developed technology.	
3. Centre of Excellence (Proposed as multi- shareholder non-profit corporation based on TRLabs model).	Spin-off of unique experience and capabilities currently at AECL to non-nuclear application. Includes potential for commercial products and services.	
4. Monitoring progress of proposed hydrogen system at Dorsey Converter Station	Additional experience and capabilities with hydrogen will result if project implemented.	Project already being considered separately by Manitoba Hydro for commercial reasons.
5. Develop MOU with Iceland on Hydrogen Development	Information sharing, joint development of skills and experience, joint projects and international profile.	
6. Direct-to-DC electricity demonstration for backup-power	Potential export of specialized knowledge and any developed technology.	
7. Hydrogen ICE fleet vehicles demonstration	Small number of vehicles specifically to showcase practical operation (may be linked with transit bus refueling demonstration).	
8. Investigation of non-fuel applications for by-product hydrogen.	Value-added opportunities that may lead to hydrogen movement demonstration.	
9.Investigation of niche light duty vehicle opportunities	Identification of light-duty applications that could make sense to exploit in Manitoba.	
10. Electricity export opportunities linked to clean hydrogen production	Potential value-add for electricity in near-term associated with on-site hydrogen production outside Manitoba.	Will be undertaken by Manitoba Hydro
11. Evaluation of potential for identified non-hydrogen alternative energy technologies	Manufacturing or other opportunities for identified non-hydrogen technologies.	Needs to be considered as part of broader renewable energy strategy development.

12.5 Recommendations

1. The Manitoba Hydrogen Steering Committee will undertake the following:

   - Proceed with implementing follow-up evaluation and business case or public policy justification for the five most time sensitive near-term actions, and undertake the other six identified actions as time permits.
   - Identify lead proponents and confirm participants in implementing actions.
   - Confirm funding requirements and sources, including beginning discussions with the Federal Government on securing appropriate funds.
   - Take responsibility for tracking developments and current events relevant to hydrogen.

2. Return to the Community and Economic Development Committee of Cabinet with a progress update.

APPENDIX ‘A’

MANITOBA HYDROGEN STEERING COMMITTEE
Represented Organizations
Atomic Energy of Canada Ltd.
City of Winnipeg
Community and Economic Development Committee of Cabinet
Kraus Global
Manitoba Energy, Science and Technology
Manitoba Executive Council
Manitoba Hydro
Manitoba Transportation and Government Services
Natural Resources Canada
Red River College
University of Manitoba
University of Winnipeg

APPENDIX 'B'

MANITOBA HYDROGEN WORKING GROUPS

Hydrogen Production and Movement
Represented Organizations
Manitoba Hydro (Leader)
Manitoba Energy, Science and Technology
NRC Industry Research Assistance Program (IRAP)
Prairie Centre for Business Intelligence
Manitoba Transportation and Government Services
University of Manitoba
Atomic Energy of Canada Ltd.
Acsion

Research/Scientific Centre of Excellence
Represented Organizations
Atomic Energy of Canada Ltd. (Leader)
Manitoba Energy, Science and Technology
University of Manitoba
University of Winnipeg
Manitoba Hydro
NRC Industry Research Assistance Program (IRAP)
Nexen Chemicals
Manitoba Executive Council

Transportation: Vehicles and Refueling
Represented Organizations
Manitoba Transportation and Government Services (Leader)
Natural Resources Canada
City of Winnipeg
Kraus Global
Manitoba Hydro
New Flyer Industries Ltd.
University of Manitoba
Atomic Energy of Canada Ltd.
Manitoba Energy, Science and Technology

Hydrogen in Existing Processes (Core Group)
Represented Organizations
Manitoba Energy, Science and Technology (Leader)
Manitoba Hydro

APPENDIX 'B'

MANITOBA HYDROGEN WORKING GROUPS (Cont'd)

Stationary & Portable Fuel Cell Applications
Represented Organizations
Manitoba Hydro (Leader)
Manitoba Energy Science and Technology
Manitoba Transportation and Government Services

APPENDIX 'C'

Summary of Non-Fuel and Other Opportunity Ideas Generated at Brainstorming Session (No Priority Order)	
Category	**Idea Description**
Building Block Products	Hydrogen peroxide manufacturing
	Specialty food ingredient production (i.e. sorbitol as sweetener)
	Hydrochloric acid and other inorganics production
	Hydrogenated vegetable oils
	Hydrogen for upgrading food and feed products, such as upgrading canola meal unusable because of phenolics content
	Hydrogen as a building block for pharmaceutical and nutraceutical products
	Renewable hydrogen for augmenting ammonia production
	Asymmetric catalytic reduction
	Petroleum/hydrocarbon upgrading, including hydrogenation using "renewable" hydrogen and co-transport of petroleum/hydrogen
Processing Applications	Minerals processing of magnesium
	Plasma-based processing of metals and minerals
	Deuterium gas for electronics applications (chip hardening)
	Ceramics production
Environmental Applications	Hydrogen after-burning for stack emissions, including VOC control by rapid combustion and mobile asphalt facilities emissions
	Reductive processing of hazardous waste materials, including remediation
	Hydrogen for manure control or manure management
	Promotion of Brandon as possible community Centre of Excellence for eco-industrial
Mobile Devices	Hydrogen buoyancy applications, including rigid airships, and hydrogen as simultaneous fuel and buoyancy provider
	Lawnmowers
	Snowblowers
Appliances	Hydrogen powered thermal appliances
	Cooling using special hydrogen properties including hydride-based cooling systems, enhanced heat transfer using hydrogen, possible absorption approaches, combined cooling and fuel for automobiles (hydrogen as a coolant), replace refrigerants
	Small scale catalytic thermal devices for clean heat
Safety Systems and Services	Services involving safety technology and expertise, developing regulations and standards, information to the insurance industry, and embed safety into developing products
	Small volume production systems, infrastructure to test small commercialization
	Hydrogen consumption technologies
	Risk management or assessments
	Development of instrumentation for controls and safety
	Hydrogen detection products
	Natural gas and mercaptans including cleaning systems to remove mercaptans (sulfur) which are toxic or poisonous to reformers or fuel cells, and alternative non-sulfur odourants
	Flame arrestors for safety in pipelines
Other Services	Service development expertise for hydrogen purification – electrolytic/chlorine cleanup
	Modeling of plasma (thermal fluids) with virtual reality
	Detailed computer modeling (hydrogen processes)

Summary of Non-Fuel and Other Opportunity Ideas Generated at Brainstorming Session (No Priority Order)	
Category	**Idea Description**
Other Hydrogen-Using Systems	Hydrogen for nanotechnology as activators in mechanical devices
	Medical imaging applications, including hydrogen for MRI magnet cooling
	Modified atmosphere packaging with hydrogen or deuterium, including food products, computer chips, medical related
	Catalyst research, development and commercialization, using Manitoba-based exotic materials
	Welding and related applications, including oxygen – hydrogen welding, hydrogen explosive welding (controlled detonation), and metal deposition for welding (high temperature flame)
	Other applications including Virology Lab - something that could be enhanced or replaced, applications at the Canadian Mint? - coolant, presses, applying metal finishes, garment or tanning industry?
	Special detonation applications such as landmine clearing
	Deliberate embrittlement applications – turning metal into powder for special applications, decorative or functional characteristics
	Deliberate use of diffusion processes - where is diffusion valuable?
	Hydrogen activated luminescent devices (non-fuel cell)
	Influence of hydrogen on the microbials that fix nitrogen (nitrogen fixation)
	Aeronautics/space applications - rocket fuel – Churchill
	Hydrogen as a carrier - add it to stabilize and then remove it
	Inorganic membranes
	Vanadium development for redox flow battery electrolyte production