Canadian Fuel Cell

Commercialization Roadmap

Canada PricewaterhouseCoopers Fuel Cells Canada™

Direct Methanol Fuel Cell DaimlerChrysler NeCar5

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To obtain additional information about the Canadian Fuel Cell Commercialization Roadmap, please contact:

Annie Desgagné
Energy and Marine Branch
Industry Canada
2000-300 West Georgia Street
Vancouver, BC V6E 6E1

Tel.: (604) 666-1426
Fax: (604) 666-8330
E-mail: **desgagne.annie@ic.gc.ca**

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March 2003

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Industry Message

Worldwide, the fuel cell and hydrogen industries are poised to provide major improvements in efficiency, greenhouse gas emissions, urban pollution and quality of life. For Canada specifically, the chance to exploit the global leadership position of our companies in making these changes is significant, but to do so, strong leadership by both industry and government is urgently required.

An important first step is now complete with the publication of this Roadmap. For the first time industry, government and academia have come together in a cooperative effort to identify the roadblocks and chart the path for the commercialization of hydrogen and fuel cell technologies. The relationships between all stakeholders have been deepened and broadened and the basis for further cooperation has been established. We thank all the participants from industry, government and academia who have given of their time and effort to make this report the success it is.

For us, the path forward is clear. Together with government, we must develop a comprehensive National Strategy to confront the remaining challenges, identify the public and private resources that are required to achieve those results and implement a timetable and set of milestones that will provide clear measures of success.

The remaining challenges are significant. For success both new fueling supply technologies, and new power generation technologies — the fuel cell — need to arrive in the market at about the same time. Both face enormous competitive barriers from well-established incumbent technologies. In addition, the new technologies lie largely in the hands of the private sector and, therefore, a route must be found to directly finance the continuing need for research and development.

Support for this industry must be dedicated, direct and sustained. This is not short term quick fix science, but the prizes are not short term either. The fuel cell industry has already considered the unique role that Government can play to complement the billions of dollars being invested by the private sector. We are ready to take the next major steps in converting those plans into action.

Not surprisingly, the major conclusions of this Roadmap do not differ from those identified in other jurisdictions. The difference is that in our case, Canada already has the nucleus of leading technologies in Canadian companies while others take strong actions to catch up.

Governments in the EU, Japan and the US are now committing over $7 billion in the next three to five years to this development. These jurisdictions realize that without massive government support the new technologies are not competitive with the enormous base of

installed capital and technology serving current energy markets, nor can they attract the private capital so essential for accelerated growth and adoption. The most recent US Department of Energy Fuel Cell Report to Congress (February 2003) makes this very clear:

> "Industry is investing heavily to develop and deploy fuel cell systems. Industry's goal is to provide customers with clean, energy-efficient technology that performs as well as, if not better than, the commercially available product and at comparable cost. However, major technical and institutional barriers must be overcome. Because of the high cost and risk involved with overcoming these barriers, no single company or consortia of industry partners could be expected to make the huge investments that would be required."

Where are we? Canadian companies are global leaders in most facets of these new technologies — from hydrogen production and storage, through fuel cell development and testing capabilities. Commercial products, particularly in the portable and backup power applications are already available. The technology is no longer only the stuff of dreams, it is here, now! As spokespersons for this exciting new industry we believe that Canada is in the best possible position to exploit and benefit from the development for the broadest interests of all citizens. Whether the results take the form of new high value added jobs, export revenue or, most importantly, cleaner air and a major contribution to turning back the effects of global warming, Canada, because of its early national commitment to support these technologies, stands to be amongst the leaders of tomorrow. Our strong cadre of leading international companies puts us amongst the leaders today and offers a strong technology portfolio for exploitation tomorrow.

We would like to thank the many delegates from industry, government and academia that cooperated in the development of the Roadmap. The result illustrates the benefits of continued broad collaboration. This successful Roadmap process has identified, for the first time the path to commercialization for Canadian companies. With a sense of urgency, we look forward to further discussions with the federal government to put in place a complete plan to realize on those objectives.

We urge you to read this document, consider the recommendations, and act.

Sincerely

Ronald W. Britton
President and CEO
Fuel Cells Canada

Government Message

Fuel cell technologies represent a tremendous opportunity for Canada. From improving the quality of the air we breathe, to reducing the emissions that cause climate change and playing a significant role in helping to meet the reduction targets under the Kyoto Protocol, the introduction of fuel cell technologies holds the potential to improve the lives of all Canadians. Fuel cells offer many possibilities — from running our vehicles, to powering our hospitals, to heating our homes. Through the continuing development of this innovative sector, Canada will be able to take significant steps towards achieving both our environmental and economic goals.

We are already an acknowledged leader, with many Canadian companies at the forefront, working to deliver the benefits of fuel cells technologies to Canada and the world.

The Canadian Fuel Cell Commercialization Roadmap is an essential step toward ensuring that these critical technologies are brought to market and support Canada's globally competitive fuel cell community. Through our collaboration and successful completion of this Roadmap we have established a strong working relationship with all partners in the fuel cell challenge — industry, governments and the academic community.

The Roadmap for Canada provides a pathway to accelerate full-scale commercialization of fuel cell technology by Canadian companies and for immediate action to be undertaken. Implementation of the recommendations that accompany the Roadmap is critical in maintaining our global leadership position.

We would like to acknowledge the effort and dedication of the participants in producing this excellent report. Through our long-standing partnerships with industry and the research community, we will ensure Canada remains a global leader in this critical technology.

Canada

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Buses powered by Ballard® fuel cell engines successfully completed two years of field testing in 2000. During these tests in Chicago, Illinois, USA and Vancouver, British Columbia, Canada, 6 buses carried more than 200,000 passengers and traveled over 118,000 kilometers (73,000 miles).

Executive Summary

The Canadian Fuel Cell Commercialization Roadmap is an industry-led planning process supported by the Government of Canada and facilitated by Industry Canada. Its objective is to accelerate full-scale commercialization of fuel cell technologies by Canadian fuel cell companies.

This Roadmap has been developed through the participation, input and assistance of many leaders in industry, government and academia. It represents a critical step in identifying the commercialization challenges and in selecting the strategies and actions that will allow Canadian stakeholders to successfully meet these challenges.

The Roadmap reinforces the need for collaboration among government, industry and academia if Canada is to retain its leading position and realize the many economic, social and environmental benefits that fuel cell technology can provide for our country.

The Opportunity

The potential market for fuel cells and related products is enormous. Global demand is projected to reach $46 billion by 2011 and the potential for 2021 could exceed $2.6 trillion.[1]

Canada has been a world leader in the research and development of fuel cell and hydrogen technology — spanning most fuel cell types, components and systems supply, systems integration, fueling systems and fuel storage, along with engineering and financial services.

There are currently 17 companies across Canada whose primary focus or goal is fuel cell production and/or system integration. In addition many other companies are active in the sector supplying to the fuel cell producers, focusing on fueling infrastructure, or providing services to the fuel cell industry.

The Vancouver area, with its cluster of fuel cell companies, suppliers, infrastructure developers and service providers, has arguably the largest concentration of fuel cell expertise in the world. Fuel cell industry clusters are also growing in the Calgary, Toronto, Kingston and Montreal areas.

[1] Fuel Cells Canada and PricewaterhouseCoopers, *Fuel Cells – The Opportunity for Canada, June 2002.*

However, Canada's position at the forefront of this new industry is not guaranteed. The superior efficiency of fuel cell technology and its environmental and social benefits have attracted the attention and investment of governments and industry in most industrialized countries.

Other countries have accelerated their investments through targeted policies and program support, and through strategic corporate and research alliances. This global investment includes:

United States: The federal government proposes spending $2.7 billion over the next five years on hydrogen and fuel cell research and development, and advanced automotive technologies.[2]

European Community: The EC plans to spend $3.3 billion from 2003 to 2006 on renewable energy — mostly hydrogen and fuel cells.

Japan: The government plans to spend over $380 million a year on fuel cell research, development and commercialization.

Canada must redouble its activity and investment to retain its position as a world leader.

The time to act is now. Leveraging our existing market leadership position will require the immediate commitment and investment by industry and government.

Fuel cell technology represents a tremendous opportunity for Canada. It will enhance the overall competitiveness of our economy by providing significant growth in knowledge-based jobs, new opportunities for other key industry sectors, and a platform for growth in high value exports.

Through the export of fuel cell technology, products and applications, Canada can also play a critical role in reducing greenhouse gas (GHG) emissions worldwide, thereby contributing to the virtual elimination of urban pollutants, reduced health care costs and improved quality of life in the world's major cities.

The Challenges and Actions

The Canadian fuel cell industry faces a number of significant challenges on the road to commercialization. Overcoming these challenges — common to the industry as a whole, regardless of product, market focus or stage of development — will require the collaborative efforts of all stakeholders. Many of the challenges are interrelated and, therefore, need to be addressed concurrently.

Within this Roadmap, specific strategies and actions have been identified to address each challenge. These actions should, in most cases, be viewed as only a starting point, to be followed by an implementation plan that addresses each action in greater detail.

[2] All information in this report is expressed in January 2003 Canadian dollars unless otherwise noted. US dollar figures were converted to Canadian dollars using a factor of 1.57.

Stimulating Early Market Demand

The high price of new fuel cell products — reflecting higher production costs associated with small production volumes — poses a prohibitive barrier to potential purchasers. Production costs, and hence prices, will come down as demand stimulates increased production volumes. The sooner this demand is generated, the faster industry will be able to reduce costs and access new markets.

The time to act is now. Leveraging our existing market leadership position will require the immediate commitment and investment by industry and government.

Challenges

Creating More Market Awareness
Gaining More Knowledge of Markets

Actions

- Develop demonstration projects that showcase fuel cell technology, validate product reliability and output, 'ruggedize' the product and provide data necessary for commercialization
- Develop public information programs to educate policy makers, service providers, consumers and students
- Establish early purchase programs to encourage product procurement and benchmarking, allow public demonstration of the technology and provide critical early revenues for the industry

Improving Product Quality While Reducing Cost

To compete with incumbent technologies that are both widely accepted and constantly improved, the fuel cell industry must enhance product quality and reduce production costs. Product quality includes performance, reliability and durability. Reducing costs will require a combination of materials, product and process development, and design engineering. To stimulate development of an effective supply chain, fuel cell developers and systems integrators need to standardize their component specifications. Suppliers must be encouraged to service early markets with the produce and process development, design engineering and an integrated supply chain.

Challenges

Continuing to Improve Product Quality
Continuing to Reduce Costs
Developing a Coordinated Supply Chain for Fuel Cell Power Systems

Actions

- Identify product performance and cost barriers, and develop strategies to overcome them
- Increase collaborative research and development on materials, component costs and product standardization and integrate production plans/processes for major cost components to ensure cost curve reduction
- Undertake demonstration projects to support cost and performance value propositions in operating environments and create an ongoing database of proven fuel cell performance
- Establish a supply chain forum to develop a process for sharing technical information among fuel cell developers, suppliers and the research community. This will stimulate innovation and further investment in component design, obtain industry agreement on appropriate benchmarks and performance standards, identify gaps in supply chain and develop strategies for enhanced domestic capabilities; and develop component cost reduction programs.

Financing

Innovative approaches to securing capital are needed to meet the significant capital resources that Canadian fuel cell companies will require as they move products along the path toward commercialization. The cost of increasing the scope and scale of production and marketing activities severely challenges the available capital resources of most industry participants.

Challenge

Gaining Access to Capital

Actions

- Develop financial incentives for fuel cell products and services in order to reduce the risk profile of needed investments in manufacturing capability
- Identify and pursue development partners, including exploring the feasibility of strengthening geographic clusters to attract further development; provide tax incentives for research and development; and dedicate matching funds for investments

Creating Supporting Infrastructures

For some fuel cell applications — particularly in the mobile sector — supportive infrastructures will have to be developed. These infrastructures include: the availability of sufficient skilled personnel; the presence of codes and standards that allow and encourage the safe introduction of fuel cell applications and allow interconnectivity; and the development of a fueling infrastructure, where required.

Challenges

Obtaining Skilled Resources
Developing Fueling Infrastructure
Developing Codes and Standards

Actions

- Develop a human resources strategy to ensure a sufficient supply of skilled resources for the fuel cell sector; develop policies and criteria for training requirements; and undertake a national occupational analysis to identify where skills gaps may emerge as the industry grows
- Require a training component be incorporated into fuel cell demonstration projects and into early purchases involving government
- Develop curriculum material targeted at post-secondary students, teachers, academic and technical institutions
- Demonstrate fueling infrastructure systems solutions
- Ensure Canada takes a lead role in setting codes and standards for fuel, fuel cell and fueling systems

Taking the Next Step: A Collaborative Effort

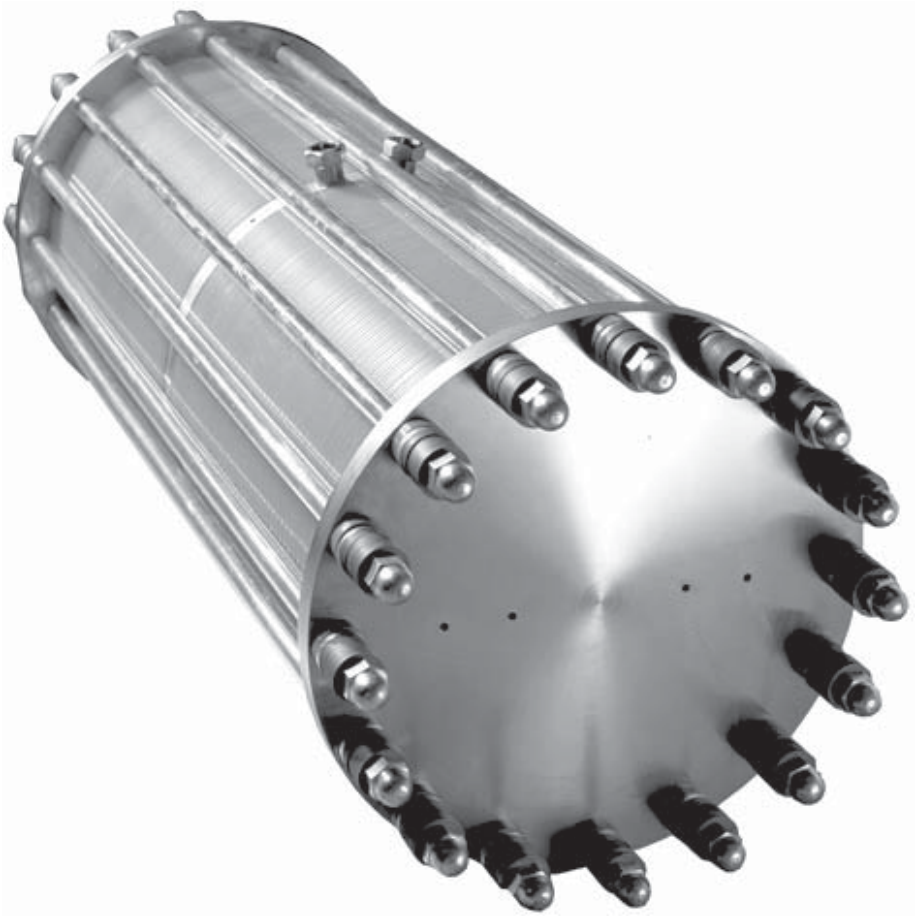
Participants in this Roadmap agree that government and industry need to work together to support demonstration projects, provide early purchaser opportunities and show leadership in overcoming the challenges facing fuel cell commercialization in Canada.

Specifically, a collaborative effort is required to:

- Develop a national fuel cell strategy within the next year which reflects the collaborative commitment of all key stakeholders
- Identify key stakeholder champions who will continually promote the Canadian fuel cell industry
- Educate government and other early users as to the long-term benefits of fuel cells and why they should demonstrate/purchase fuel cell products
- Support research and development, product development and early market products

The actions identified in this Roadmap potentially make up the key components of a national fuel cell strategy. Industry is committed to collaborating with government and the research community to develop a national fuel cell strategy, and to share the costs of implementing the actions identified.

It is imperative that this strategy is developed now, and that the actions are implemented on an urgent basis. These steps will help the development of a viable Canadian fuel cell industry, and help address Canada's climate change, health, sustainability and innovation objectives.



Vandenborre Hydrogen Systems/Stuart Energy Power Module

Introduction

Climate change technology and commercialization roadmaps are one of five initiatives within the *Climate Change Technology Development and Innovation Program*, a $19 million subcomponent of *Action Plan 2000*. The primary objectives of the Program are to:

- Accelerate development of cost-effective greenhouse gas mitigation technologies
- Build the knowledge foundation for long-term technological advances
- Build alliances and partnerships to help plan and advance research and development

These actions will contribute to meeting Canada's international commitments under the United Nations framework *Convention on Climate Change*, and to strengthening innovation in Canada.

Fuel cells and hydrogen applications can also help Canada meet its obligations under the Kyoto Protocol, which was ratified in 2002. Fuel cells and hydrogen applications provide the promise of being one of the only comprehensive long-term solutions to the reduction of greenhouse gas emissions and pollution from the transportation sector, and they will make important contributions to emission reduction from stationary power production.

Fuel cell systems are rapidly gaining worldwide attention as a feasible energy medium and power source for a variety of portable, stationary and mobile applications. Fuel cells offer significant benefits:

- Operating efficiencies at part-load and in all size configurations
- Few moving parts compared to an internal combustion engine (ICE) and potentially a high degree of reliability, lower maintenance and long operating life
- Modular design, allowing flexibility in size and efficiencies in manufacturing
- Use of a range of fuels, such as hydrogen, natural gas, methanol, propane and gasoline
- Cleaner, quieter and more efficient power production than conventional ICEs or central power stations
- Zero or low emissions, depending on the fuel used
- Use in combined heating, cooling and power purposes, further increasing the efficiency of energy production

Natural Resources Canada estimates the GHG reduction potential per average car in Canada at 4.2 tonnes/year (assuming hydrogen from natural gas). Ultimately for the existing 17 million vehicles in Canada, total replacement would result in a reduction of 71 million tones/year (CO_2 equivalent). Such a result will take a long time, but cannot be achieved by any power technologies transportation.

Significant benefits will accrue to countries that succeed in establishing a viable fuel cell industry:

- The fuel cell industry is a high value-added sector driven by innovation
- It will contribute to a strong technology driven economy in jurisdictions where it develops and supports an educated labour force with advanced skills
- Fuel cell research and development and early products are generating new areas of knowledge and expertise for the industry and its suppliers, with possible technology spin-offs
- Significant export market opportunities for fuel cells, fuel cell components, balance-of-plant, equipment required for fueling infrastructure, and intellectual property are emerging
- Strategic partnerships are being forged with companies that have recognized the benefits and market potential of fuel cells in established industry sectors such as automotive, oil & gas, utilities and electronics, as well as emerging sectors such as micro-technology
- Such partnerships result in the development of new joint ventures and alliances that create jobs and investment in the economy. These partnerships have no geographic boundaries
- A reduced reliance on central generation facilities for electricity and dependence on oil imports in import-dependent countries, thus increasing energy security

Fuel Cells and Climate Change

Fuel cell technology is seen as a viable clean air alternative to all applications of the internal combustion engine and other conventional power supply technologies.

In terms of greenhouse gas emissions, fuel cells offer a significant improvement over internal combustion engines. If fuel cells run on hydrogen, they produce no GHG emissions. Even on a wells-to-wheels basis, the impact on GHG emissions is expected to be up to 50 percent less than internal combustion engine technology, depending on the source of fuel for hydrogen production.

Fuel cells and the hydrogen energy pathway provide the promise of being one of the only comprehensive long-term solutions to the reduction of GHG emissions and pollution from the transportation sector. They will make important contributions to emission reduction from stationary power production as well. These critical technologies will help Canada meet its obligations under the Kyoto Protocol, which was ratified in 2002.

Fuel cell technology is versatile and has potential applications in stationary/distributed power (combined heat and power for residential and commercial buildings, uninterruptible power supplies (UPS) for telecom and commercial enterprises, backup power and emergency generators), portable power (UPS, micro fuel cells, auxiliary power units), and mobile power (cars, trucks, buses, industrial transportation, utility vehicles). Stationary and portable applications are either currently commercialized or on the verge of commercialization and can make an early contribution to Canada's GHG reductions.

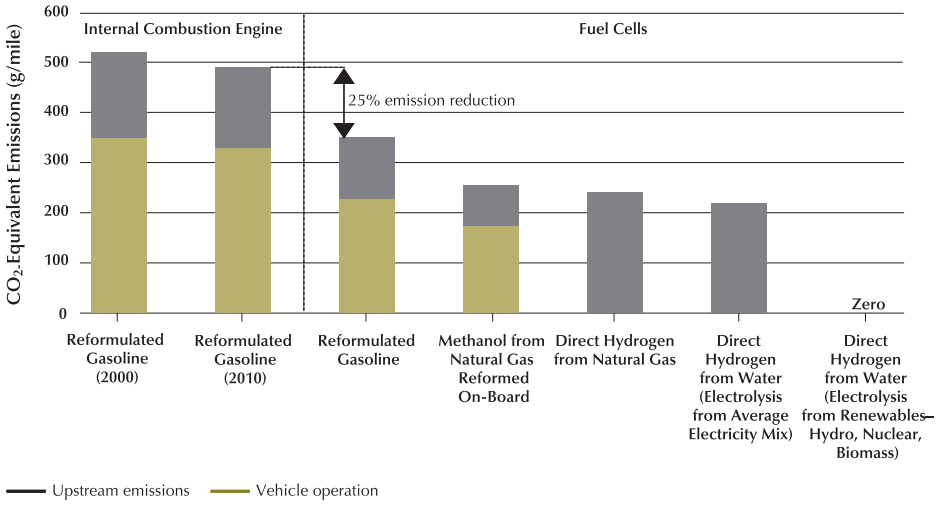
These early applications will also spur the further development of more efficient fuel cells and production methods as well as advanced materials, power-electronics, hydrogen production technologies, storage systems and balance-of-plant technology. This will result in significant cost reductions, broaden the market applications of fuel cells and accelerate GHG emission reductions. With broader market applications, there will be exponential GHG benefits as consumers replace older lower efficiency fossil fuel energy sources with fuel cells.

The largest potential for fuel cells in reducing GHG emissions is as a replacement for ICE in transportation. Transportation is the largest single source of GHG emissions in Canada, accounting for 27 percent of total emissions[3]. Many industrial countries, including Germany, Japan and the US, have established fuel cell programs as part of their commitment to GHG reduction goals and/or as a way of decreasing pollution and thus improving health conditions in their respective jurisdictions. Programs include the US FreedomCAR, the California Fuel Cell Partnership, Michigan's NextEnergy Strategy, Europe's CUTE Fuel Cell Bus Program and the Japan WE-NET Hydrogen Technologies and Fueling Infrastructure Program. Research and development to reduce costs and support demonstration projects is a key element of all these programs.

Fuel cells can operate on hydrogen or a variety of gaseous and liquid hydrocarbons. Fuel processing systems for reformation are used to produce hydrogen from hydrocarbon fuels such as natural gas, methanol, ethanol, gasoline or coal. Additionally, electrolysis is used to produce hydrogen from water using green or zero emission electricity produced from renewable resources.

While the use of fossil fuels to produce hydrogen does not promise zero emissions, reformation coupled with fuel cell technology can exploit the existing fuel infrastructure and will offer significant environmental improvements over traditional ICE systems. This is seen as an important step towards a hydrogen-driven economy.

Figure 1. Greenhouse Gas Emissions for Various Technologies and Fuel Types



Source: NRCan 2001

Through the export of fuel cell technology, products and applications, Canada's fuel cell and hydrogen sector can play a critical role in reducing greenhouse gas emissions and urban pollution for the world. By addressing pollution and climate change issues in other countries, the industry can create emissions credits for Canada. The virtual elimination of urban pollutants and emissions will lower health care costs and improve quality of life in Canada's major cities, and throughout the world.

[3] 726 Meg tonnes, NRCan 2000

It is projected that the global demand for fuel cells could reach $46 billion by 2011, with a market potentially exceeding $2.6 trillion by 2021.

Source: Fuel Cells Canada and PricewaterhouseCoopers, *Fuel Cells — The Opportunity for Canada*, June 2002.

The development of the fuel cell sector will also enhance Canada's innovative capability and the overall Canadian economy by providing significant growth in knowledge-based jobs, a more competitive automotive sector, new opportunities for other key industry sectors, and a platform for growth in high value exports.

Growing Interest in Fuel Cells

Fuel cells are already being used in some early market applications, primarily in the stationary and portable sectors, with many other applications at the demonstration stage and nearing market entry (e.g., transit buses, auxiliary power units (APUs) and laptop computers).

A growing number of global corporations are becoming involved in fuel cells, both as developers and strategic partners. Increasingly, large established manufacturers, such as DuPont, 3M and Johnson Matthey, are positioning themselves to become world suppliers of fuel cell components.

Most of the world's largest automotive manufacturers including GM, DaimlerChrysler, Ford, Toyota, Nissan, Hyundai and Honda have also recognized the importance of early fuel cell commercialization and are involved in the development of stationary fuel cells as a means of building their overall capacity in automotive fuel cell applications for the longer term.

Canada has been one of the leading countries in fuel cell research and development and commercialization over the past decade. The Canadian fuel cell industry is now focusing on securing a significant share of the emerging global market opportunities.

While the market potential is enormous across a range of applications, it is not a given that Canadian companies will make a successful transition from research and development to commercialization. A number of significant challenges need to be addressed on the path to commercialization.

These challenges are not unique to the Canadian industry. Governments and fuel cell industries in other countries face similar challenges. Recognizing the substantial benefits to be gained, these governments and industries are responding with targeted fuel cell strategies, including government/industry partnerships and strategic alliances among industry players. For example:

- The United States government proposes spending $2.7 billion over the next five years on hydrogen and fuel cell research and development and advanced automotive technologies
- In Japan, where the government provided over $275 million in support of fuel cell research and development (R&D) and commercialization in 2002, annual government spending is expected to exceed $380 million per year starting in 2003
- The European Community recently announced plans to spend $3.3 billion from 2003 to 2006 on renewable energy — mostly on hydrogen and fuel cells

Simply copying what other countries are doing will not make Canada competitive. An approach — a roadmap — is needed to build on the Canadian fuel cell industry's existing capabilities, knowledge, resources and leadership position.

Creating the Commercialization Roadmap

Roadmapping is a planning process driven by the projected needs of tomorrow's markets. It helps companies identify, select and develop clear strategies and actions that will allow them to meet future market needs.

With the support of Industry Canada, a number of established and emerging industry sectors in Canada have prepared roadmaps. Examples include: aircraft, design, manufacturing, and repair and overhaul; geomatics; medical imaging; and electrical power.

All of these roadmaps focused on overcoming specific technology issues. The Canadian Fuel Cell Commercialization Roadmap is the first to focus on commercialization challenges and solutions, while recognizing that technical challenges also need to be addressed.

Preparation of this Roadmap began in March 2002. A Steering Committee, composed of industry and government representatives, was established to oversee the process.

The Steering Committee created five Working Groups. Three of the Working Groups (Stationary, Portable and Mobile) dealt with application issues. The other two (Infrastructure and Skills) addressed issues common to all three application areas.

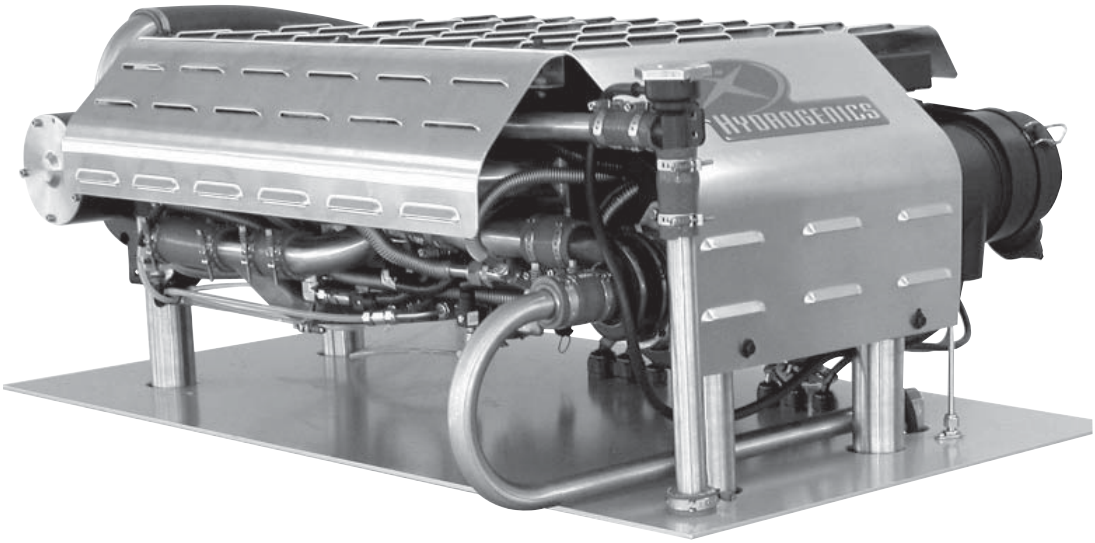
Over 45 organizations from industry, government and academia participated in developing the Roadmap (see Appendix I for a list of participants). Participants included members of both the Steering Committee and Working Groups. As well, many individuals attended one or more meetings as observers or advisors on specific topics.

In total, 28 meetings were held across Canada between June and December 2002. This included 15 all-day Working Group meetings (three per group) and eight Steering Committee meetings (see Appendix II).

PricewaterhouseCoopers acted as a resource to the Steering Committee and Working Groups, providing facilitation, administration and writing services.

The Roadmap is an important beginning point in the collaborative process, but the industry recognizes that there is much more to be done. It is proposed that the Working Groups become subcommittees of Fuel Cells Canada, a non-profit, national industry association. This would allow them to address issues of common interest, further the advancement of the Canadian fuel cell industry, and implement actions and recommendations from the Roadmap.

All financial information in this report is expressed in January 2003 Canadian dollars, unless otherwise noted. US dollar figures were converted to Canadian dollars using a factor of 1.57.



Hydrogenics Power Module

Fuel Cell Technology

A fuel cell is a device that converts chemical energy into electrical energy. Hydrogen (which can be obtained from a variety of carbon-based fuels, including methanol, natural gas, and petroleum as well as renewables) is combined with oxygen (obtained from the air) within a fuel cell to electrochemically produce electricity, water and heat.

The heart of the fuel cell consists of three primary parts: an anode, a cathode and an electrolyte. The electrical current flows from the cathode to the anode. The materials from which the fuel cell is composed determine the way in which the fuel cell produces electricity.

Major types of fuel cells include:

- Proton Exchange Membrane Fuel Cell (PEMFC)
  A specific type of PEMFC includes the Direct Methanol Fuel Cell (DMFC)
- Solid Oxide Fuel Cell (SOFC)
- Alkaline Fuel Cell (AFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Molten Carbonate Fuel Cell (MCFC)

Appendix III provides a non-technical description of how a fuel cell works and a brief discussion of each major type of fuel cell.

Different technologies are likely to be utilized in different applications, although PEMFCs and SOFCs are emerging as the leading fuel cell technologies with the broadest commercial applications.

At this stage, PEMFC technology is preferred for mobile and portable applications. In the stationary sector, it is possible that several technologies might be used in the long run, depending upon the type of application.

Currently, the Canadian fuel cell industry is most heavily focused on PEMFCs and SOFCs.

Fuel Infrastructure

Fuel cells operate on hydrogen or a variety of gaseous and liquid hydrocarbons. Electrolysis is used to produce hydrogen from water in areas where electricity is both abundant and available at a low cost. Fuel processing systems for reformation are used for hydrocarbon fuels, such as natural gas, methanol, ethanol, coal or gasoline. Hydrogen is produced by reforming hydrocarbon fuels at either a central fuel station dispensing hydrogen through distributed generation systems (off-board), or at a fuel cell location (on-board).

While the use of fossil fuels to produce hydrogen does not promise zero emissions, reformation coupled with fuel cell technology can exploit existing fuel infrastructure, and will offer significant environmental improvements over traditional internal combustion engine systems. This is seen as an important step towards a hydrogen-driven economy. No greenhouse gas emissions exist with electrolysis using renewable sources of electricity, such as hydro, wind power, photovoltaics, geothermal or nuclear power.

Current Status of the Technology

Fuel cell technology is still being refined. In many applications applied research and technology development remains a vitally important part of the industry.

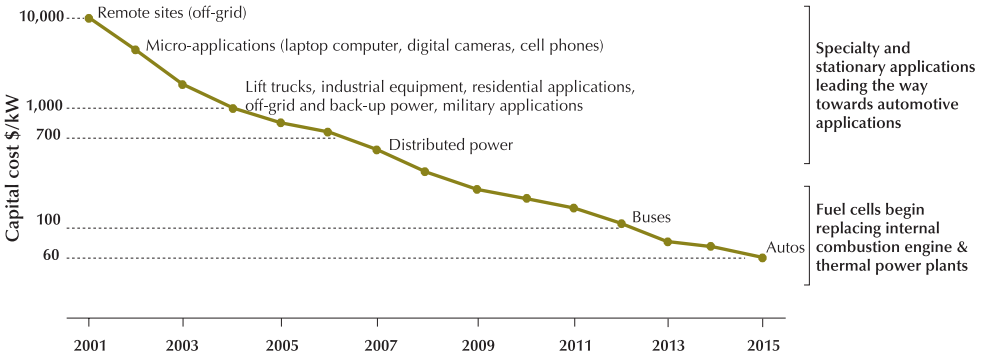
There will be winners and losers in the commercialization process as the technology develops. However, it is too early to tell which technologies will ultimately dominate in certain applications, although the future direction appears clear in some major application areas, such as PEMFC technology in fuel cell cars and SOFC technology in stationary applications.

Broad commercialization of fuel cell applications depends on reducing per unit costs. Products will be commercialized at price points that make sense. Stationary and portable applications currently lead the way, as fuel cells replace batteries in portable, stationary, light industrial and transportation applications.

In part, this reflects a technology "push" on products that have the potential to provide significant environmental benefits. Such products include fuel cell buses, military applications, auxiliary power units, remote power and automotive applications.

This initial focus will help demonstrate product performance, reliability and durability, reduce production costs, establish codes and standards, build a skilled labour force, develop a hydrogen infrastructure and create public awareness and acceptance.

Figure 2. Fuel Cells: Costs Based Market Forecast



Source: Methanex, September 2002

The Canadian Fuel Cell Industry – A Profile

Interest in fuel cells is growing rapidly as more businesses, investors and countries recognize the opportunities and benefits. This is accelerating the rate at which the fuel cell industry will commercialize globally. It is also creating a far more competitive environment.

Canada is recognized as a fuel cell industry leader, along with the US, Germany and Japan. However, many more countries are beginning to make strategic investments to create domestic fuel cell industries.

The Canadian Industry

Canada's leadership in the development and commercialization of fuel cell and related technologies covers most fuel cell types, components and systems supply, systems integration, fueling systems, and fuel storage, along with engineering and financial services.

Employment

As of October 2001, an estimated 1,800 people were directly employed by the Canadian fuel cell industry (companies whose core business is focused on fuel cell and hydrogen activities), with additional jobs supported in sectors that supply and service the industry.[4] Of the 2001 total, 76 percent were employed in Western Canada (the area west of Ontario). Employment numbers have remained relatively constant in 2002–03, reflecting a trend toward consolidation in the industry.

The Canadian workforce in the fuel cell and hydrogen sector is well educated: 78 percent of the 2001 workforce had a post-secondary education. Of that total, 55 percent held a university degree and 22 percent held a community college education.[5]

[4] PricewaterhouseCoopers and Sypher Mueller. The information compiled in this "Profile" has been obtained from three sources:
1. The PricewaterhouseCoopers Study, *Fuel Cells – The Opportunity for Canada*, June 2002.
2. The Sypher Mueller/NRCan Survey and Report, *Economic Impact of Industrial Hydrogen Activity in Canada*, June 2002.
3. Information collected by Fuel Cells Canada. Information for Sypher Mueller and for PricewaterhouseCoopers was collected in 2001 and reflects the state of the industry at that time. It is important to note that there is limited statistical information available on the Canadian fuel cell industry, and virtually none on similar activities outside of the country.

[5] Sypher Mueller/NRCan p. 14.

Revenues

Revenues reached $96.9 million in 2001. Eighty-two percent of these revenues were based on exports, with sales of equipment (77 percent) being the mainstay of the growing industry. Western Canada was responsible for 70 percent of all revenues. Total revenues for the Canadian industry are projected to reach $165.2 million by 2003 (70 percent growth).[6]

Research and Development

Continued research and development is critical to the development and commercialization of fuel cell and hydrogen products and systems. In 2001 research and development expenditures were significantly higher than revenues reaching $179 million, and representing almost $100,000 per employee. Key sources for capital research activities have come from development alliance partners. The sector is a significant player in the Canadian innovation scene. In 2001, research and development expenditures in the fuel cell and hydrogen sector were similar to that in the Canadian auto industry despite the latter's $92 billion in sales and 132,000 employees. Western Canada was responsible for 87 percent of research and development expenditures in 2001.[7]

Traditionally, much of the research and development has been carried out at the corporate level, often with support from the federal or provincial governments. Ongoing institutional research activities have been carried out at CANMET (Natural Resources Canada), the Canadian Hydrogen Institute in Trois-Rivières and more recently at the National Research Council's Institute for Fuel Cell Innovation in Vancouver. Over the years, a small number of Canadian universities have carried out research projects in fuel cell and hydrogen related topics. This activity is expected to increase over the next few years.

Industry Structure

Worldwide, the fuel cell and hydrogen industry is at the nascent stage. The structure of the industry reflects this early stage of development, as does the lack of statistical information and analyses of this new industry. The Sypher Mueller/NRCan study found that the major activities of respondent firms could be divided into the following areas:

- Engineering services – 36 percent
- Hydrogen production equipment – 29 percent
- Testing equipment – 25 percent
- Fuel cell stacks – 25 percent
- Electrical components – 21 percent [8]

In Canada and elsewhere, the industry is characterized by a relatively low number of small (mostly under 500 employees) companies engaged exclusively (over 50 percent of revenues derived from the fuel cell and hydrogen related activities) in the sector, with a much larger range of companies involved to a much smaller degree in the supply of parts, systems and services.

This profile builds on the analysis developed by PricewaterhouseCoopers.[9]

[6] Sypher Mueller/NRCan pp. 7–11
[7] Ibid., p. 12
[8] Ibid., p. 6
[9] PricewaterhouseCoopers pp.25–29

The several interrelated layers in the Canadian fuel cell industry can be described as follows:

- Companies, whose primary focus or goal is **fuel cell production and/or system integration,** many of which have formed strategic international alliances or are pursuing such alliances
- **Major suppliers to the fuel cell producers,** a number of which are selling to both foreign and Canadian companies
- Companies that are focused on **fueling infrastructure**
- **Providers of services** to the fuel cell industry

There is a symbiotic relationship among the various players and layers of the industry. The number and intensity of the inter-relationships are growing as the industry grows in scope and scale. Of significant interest is the increasing number of large domestic and international corporations that are beginning to participate in the sector. The entry of these stakeholders confirms the long-term growth potential for the sector, and provides the manufacturing, marketing and management experience needed for the industry to successfully mature.

It has already been noted that most Canadian fuel cell industry revenues are derived from export sales. While this reflects the realities of the large overseas markets and their support for new technology adoption, it is important to note that foreign market opportunities are directly related to targeted government support for the introduction and early purchase of these new technologies. In recent years, the same degree of support has not been available in Canada.

Fuel Cell Producers and Systems Integrators

There are 17 companies in Canada whose primary market focus or goal is fuel cell production and/or system integration.

Figure 3. Fuel Cell Producers and Systems Integrators

COMPANY	CITY	PROVINCE	APPLICATIONS		
			Stationary	Portable	Mobile
Aluminum Power	Toronto	ON			●
Angstrom Power	North Vancouver	BC		●	
Astris Energi	Mississauga	ON			●
Ballard Power Systems	Burnaby	BC	●	●	●
Cellex Power Products	Richmond	BC	●		
DuPont Canada	Kingston	ON	●	●	●
Energy Visions	Mississauga/Calgary	ON/AB	●	●	●
Fuel Cell Technologies	Kingston	ON	●		
Global Thermoelectric	Calgary	AB	●		●
GreenVOLT Power	Orillia	ON	●		
Hydrogenics	Mississauga	ON	●	●	●
Kinectrics	Toronto	ON	●		
MagPower Systems	Delta	BC	●	●	
Palcan Fuel Cells	Burnaby	BC		●	●
PEM Technologies	Vancouver	BC		●	●
PowerDisc Development	Chilliwack	BC			●
Siemens Canada	Mississauga	ON	●	●	

Source: Fuel Cells Canada, January 2003

Reflecting the current situation throughout the world, most of these companies are relatively small, falling into the Canadian definition of small and medium sized enterprises as having under 500 employees. The larger companies usually have fewer than 500 employees engaged in fuel cell and related activities. The exception to this situation is Ballard Power Systems. Most of its approximately 1,100 employees are directly employed in activities related to fuel cells and/or systems development and integration.

Many of these producers have formed domestic and international strategic alliances with companies in other industries that will be users of fuel cell technology. These alliances and partnerships provide actual (or potential) access to the financial resources, and the technical, manufacturing and marketing skills required as the industry moves into the commercialization of products and systems.

Figure 4. Suppliers, Service Providers and Fueling Infrastructure*

PARTS AND SYSTEMS SUPPLIERS	FUEL CELL SERVICE PROVIDERS
Advanced Measurement Systems	Alberta Research Council
Agile Systems	Auto21 Networks of Centres of Excellence (NCE)
Azure Dynamics	Automotive Parts Manufacturers' Association
Cimtex Industries	BC Ministry of Competition, Science & Enterprise
FuelMaker	Business Development Bank of Canada
Greenlight Power Technologies	Canadian Hydrogen Association
Kinectrics	Centre for Automotive Materials and Manufacturing (CAMM)
NORAM	Chrysalix Energy Management
Pathway Design & Manufacturing	Colliers International
Pivotal Power	Dundee Securities
PrecisionH2	Environment Canada
QuestAir Technologies	Fuel Cells Canada
SatCon Power Systems Canada	Gowlings
SMC Pneumatics (Canada)	GrowthWorks
SRE Controls	Heating, Refrigeration and Air Conditioning Institute of Canada
Technologies M4	Heliocentris Energy Systems
TeleflexGFI Control Systems	HSBC Bank Canada
Teleflex (Canada)	Human Resource Development Canada
Transformix Engineering	Hydrogen Research Institute
Turbo Genset	Hydro-Québec CapiTech
Tyco Electronics	Industry Canada (Energy & Marine Branch)
Universal Dynamics	Institute for Integrated Energy Systems
Westaim Ambeon	Ipsos-Reid (North American Energy Division)
Xantrex Technology	James Hoggan and Associates
Zetacon	Korn/Ferry International
FUELING INFRASTRUCTURE	KPMG
BC Hydro	Marsh Canada
Duke Energy	McCarthy Tétrault
Dynetek Industries	National Bank Financial
Enbridge Gas Distribution	National Defence
ENRG	National Research Council Canada
General Hydrogen	Natural Resources Canada; TEAM and CANMET Energy Technology Centre
HERA Hydrogen Storage Systems	Ontario Ministry of Enterprise, Opportunity & Innovation
Kraus Group	PricewaterhouseCoopers
Methanex	Public Works & Government Services Canada
Ontario Power	TD Securities
Praxair	Technology Partnerships Canada
Stuart Energy Systems	TISEC
Vandenborre Hydrogen Systems	Transport Canada
	University College of the Fraser Valley
	Ventures West Management
	Western Economic Diversification

* Some companies are involved in more than one area.

Suppliers, Service Providers and Fueling Infrastructure

Many more firms and organizations in Canada besides fuel cell producers are involved in the fuel cell industry. This includes a number of companies focused on developing the fueling infrastructure.

Some of these firms are closely aligned with one or two of the producers, but most are involved with many of the industry's players. Many of these companies also provide parts, systems and/or services to foreign as well as domestic stakeholders.

A brief profile of the companies and organizations listed above is contained in Appendix IV.

Industry Clusters

Michael Porter, a leading authority on industry cluster theory, has described clusters as "critical masses in one location with unusual competitive success in specific fields."[10] Successful clusters usually include a wide range of organizations and agencies, and include, among other characteristics:

- The presence of at least one anchor tenant or player
- Linkages among firms and their supporting technological infrastructure
- Proximity to supportive educational, financial, business and institutional resources
- Self-sufficiency in key inputs, including skilled employees, components and systems, engineering, marketing and financial resources
- Access to government institutions and resources

Fuel cell and hydrogen industry clusters are at an early stage (mature industry clusters are often considered to have at least 15,000 employees). However, it is clear that such clusters are indeed growing in Canada, and that these clusters provide a core capability that can, with aggressive policy and program support from government and accelerated participation by industry, continue to ensure Canada's leading role in this developing industry.

Clusters of fuel cell companies, suppliers, infrastructure developers and service providers exist in the Vancouver area, and are growing in the Calgary, Toronto, Kingston and Montreal areas. All have localized fuel cell and infrastructure developments with considerable growth potential.

Vancouver

BC, specifically the lower mainland around Vancouver, is home to the earliest corporate fuel cell development activities in Canada. With more than 1,200 workers directly employed in the fuel cell and hydrogen industries, the area has arguably the largest concentration of fuel cell expertise in the world. It is also an excellent example of the dynamics of cluster building, whereby the existence of core capabilities can enhance growth in a new industry.

The Vancouver cluster developed from the early activities of Ballard Power Systems. Founded in 1982, the company now has approximately 1,100 employees, 300 of which are located outside the province. Ballard has established relationships with a variety of local suppliers and customers, who themselves have established relationships with others in the region. Some employees from Ballard Power Systems have moved on to found new corporations, while others now work for other companies and organizations in the area.

[10] Porter, Michael, *Clusters and the New Economics of Competition*, Harvard Business Review (Nov–Dec 1998) p. 80.

Demonstration projects allowed significant progress to be made in data collection, knowledge of product performance, and in testing the robustness of products as they were prepared for commercial production.

Ballard Power Systems, and the region, remain largely focussed on PEMFC technology, however other complementary core competencies are focussed increasingly important. These include: parts and systems development, systems integration, fueling infrastructure systems development, engineering, consulting and financial services.

Government support was critical to the early success of the Vancouver cluster. Recognizing the long-term benefits of fuel cell technology, both the federal and provincial governments provided early financial support to the industry. Critically, support was extended not just for research and technology development, but also for demonstration projects. These demonstration projects allowed significant progress to be made in data collection, knowledge of product performance, and in testing the robustness of products as they were prepared for commercial production. Although the region continues to benefit from some limited support for demonstration activities, this support ends in 2003 and there is no currently agreed replacement or continuation.

As the industry has grown, it has attracted services to the region. Local venture capital companies have increased their interest and commitment to the industry and specialized financial institutions have been established. Given the size of the industry in the Vancouver region, it was an appropriate site for the headquarters of Fuel Cells Canada, as well as the headquarters of the National Research Council's Institute for Fuel Cell Innovation. As national institutions, both of these organizations provide services and support industry stakeholders across the country.

University activity has been a part of the cluster development in the region. For many years, the major activities occurred at the Institute for Integrated Energy Systems (IESVic) at the University of Victoria, which has a graduate program in fuel cell technology and core research facilities. Research activities are also carried out at Simon Fraser University in Burnaby. Recently, the University of British Columbia has joined the industry, establishing a small facility and hiring staff recently graduated from the University of Victoria.

Critical activities in BC include:[11]

- Focus on PEMFC technology
- Core technology developers/integrators: Ballard Power Systems, Palcan Fuel Cell Company, Cellex Power Products, Angstrom Power, PEM Fuel Cells
- Suppliers of specialized products and systems: QuestAir Technology, Pathway Design and Manufacturing, Greenlight Power Technologies, Cimtex Industries, Xantrex Technology, Azure Dynamics
- Fueling infrastructure and storage: General Hydrogen, Methanex, BC Hydro (Powertech), ENRG (PFC eFuels)
- Government institutions: Western Economic Diversification, Industry Canada, National Research Council, BC Ministry of Competition, Science & Enterprise
- Universities: University of Victoria (IESVic), University of British Columbia, Simon Fraser University, University College of the Fraser Valley
- Specialized services: NORAM Engineering and Constructors, Keen Engineering, Fuel Cells Canada, Chrysalix Energy Management, Ventures West Management, GrowthWorks
- Testing facilities: BC Hydro (Powertech), National Research Council's Institute for Fuel Cell Innovation
- Research and development organizations: National Research Council's Institute for Fuel Cell Innovation, British Columbia Research Inc. (BCRI)

Many of these companies and institutions also have significant relationships with other domestic and international stakeholders.

[11] For a list of some critical cluster activities see: *Vancouver's Key Private Sector Industries for Clustering*, Vancouver Economic Development Commission, July 2002. p13.

Calgary

The Calgary area also has the potential to build a fuel cell cluster. Anchor capabilities include Global Thermoelectric, a leading developer of small (5 kW) solid oxide fuel cells, and Dynetek Industries, a leading supplier of cylinders for compressed hydrogen. In addition, Advanced Measurement Systems supplies testing units for Global Thermoelectric. The University of Calgary has respected capabilities in research, as does the Alberta Research Council, where Energy Visions is developing its direct methanol fuel cells.

Toronto

Core fuel cell technology and commercialization capabilities in the Toronto area include Hydrogenics (PEMFC) and Kinectrics (fuel cell integration). The area is also home to Stuart Energy Systems, a major developer and supplier of hydrogen infrastructure systems. As important is the huge potential in the supply industry, both present suppliers (Agile Systems, FuelMaker, SatCon Power Systems Canada, SRE Controls, TeleflexGFI Control Systems, Zetacon), and the many volume manufacturers of parts and components to allied industry sectors, such as automotive, aerospace and defence, white goods, electrical supply and information technology. Local universities have excellent research capabilities. The University of Toronto, McMaster University and others have small but long-standing programs related to fuel cells and hydrogen supply development. Enbridge Gas Distribution has extensive experience in HVAC systems and is able to provide recommendations in product integration.

Kingston

Kingston is the home of Fuel Cell Technologies, a leading integrator of small scale (5 kW) SOFC systems. The company has also developed proprietary aluminium air fuel cell technology. Kingston is the centre of DuPont Canada's fuel cell development. DuPont has a global mandate to develop flowfield plates and membrane electrode assemblies for PEMFC and direct methanol fuel cells. Transformix Engineering develops and supplies power electronics for fuel cells. The city also has long-standing research and testing capabilities at the Royal Military College and is developing research capabilities at the Centre for Automotive Materials Manufacturing (CAMM) which is connected to Queen's University. It provides university-level automotive engineering education as well as considerable investment in automotive research and development, including fuel cells and hydrogen technology. Industry stakeholders have recently organized and incorporated an alternative energy industry organization to foster growth of a fuel cell industry cluster in the area.

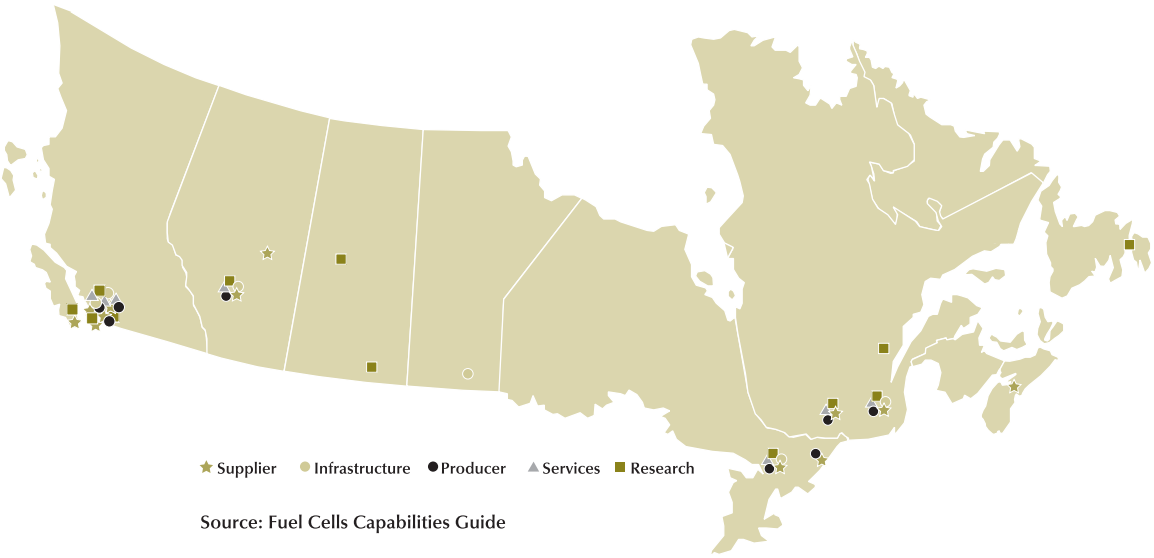
Montreal

Montreal has significant activities related to hydrogen fueling and storage. This developing capability originated in the 1980s with the interest of Hydro-Québec in the huge potential for supplying Europe with hydrogen. While Hydro-Québec remains interested in the industry, companies such as HERA Hydrogen Storage Systems, Vandenborre Hydrogen Systems and Hydro-Québec CapiTech now carry the flag for the hydrogen supply industry. Nearby, the Canadian Hydrogen Institute at the Université du Québec à Trois-Rivières provides world-renowned research facilities and capabilities for the industry. The region has benefited from support by the provincial and the federal governments — especially for research in hydrogen storage technologies.

The Importance of Clusters

Clusters provide the critical mass needed to sustain the fuel cell industry in Canada. As other countries and regions try to lure producers and suppliers to their jurisdictions, clusters will become even more important as the "glue" that keeps the Canadian industry together. Clusters will also accelerate technology and commercialization development due to their potential to pool skills and talents and to focus efforts. In Canada, many stakeholders integral to the various clusters have considerable relationships with one or more industry players in the other regions, as well as relationships with alliance partners and suppliers in other parts of the world. Considerable scope exists within the larger Canadian fuel cell and hydrogen industry for the kind of dynamic relationships that will support industry acceleration across the country. The early evidence from demonstration programs in BC indicates that these inter-regional relationships may be an integral part of the developing industry across the country.

Figure 5. Clusters of Fuel Cell Companies



Source: Fuel Cells Capabilities Guide

International Competitors

Other jurisdictions are challenging Canada's leadership position in fuel cell development and commercialization. Recognizing the substantial benefits to be gained from success, government and industry stakeholders in other countries have developed policies and programs that aggressively support fuel cell development and market access for their own companies and institutions.

United States

The US government proposes spending $2.7 billion over the next five years for hydrogen and fuel cell research and development and advanced automotive technologies.

- Freedom Fuel Initiative will develop technologies for hydrogen production and the distribution infrastructure needed to power fuel cell vehicles and stationary fuel cell power sources.
- FreedomCAR Initiative is a partnership with automakers to develop technologies needed for mass production of safe and affordable hydrogen-powered fuel cell vehicles.

In addition, individual states have established their own incentive programs to promote alternate energy sources:

- California: Incentives, emission targets and demonstration activities
- Michigan: NextEnergy program will provide funding of $79 million over next three years, plus a 700-acre tax-free research zone
- Ohio: Fuel cell initiatives totalling $162 million over three years
- Connecticut: Clean Energy Fund provided approximately $15 million in 2002

Japan

The government provided over $275 million in 2002 to support fuel cell research, development and commercialization. This spending is expected to exceed $380 million per year beginning in 2003.

European Community

EC will spend $3.3 billion from 2003–2006 on renewable energy, mostly hydrogen and fuel cells. This is a significant increase from the 1999–2002 period, when the average annual spending on fuel cell research, development and demonstration was $140 million.

The European Economic Union's 6th Framework Program (2002–2006) identifies the following research, technological development and demonstration activities pertaining to sustainable development:

- Estimated $2.5 billion will be dedicated to fuel cells and hydrogen initiatives
- Target of five percent of EC road transport to be hydrogen-powered by 2020
- Targets for fuel cell cost reductions in stationary power of less than $1,650/kW
- Focus on identifying actions necessary for vibrant fuel cell industry and sustainable hydrogen economy, with ability to target additional expenditures of up to $4.3 billion

Germany

Current annual funding for fuel cell and hydrogen initiatives totals approximately $58 million. Germany's Investing into the Future Program (ZIP) has committed $99 million during the next three years to help fund 44 R&D projects involving fuel cells for stationary and mobile applications.

Singapore

The government has established the Singapore Initiative in Energy Technology Program (SINERGY), which aims to make Singapore a leading player in the development of alternative energy technology. SINERGY is part of the government's effort to promote more clean energy R&D and test-bedding activities for automotive and stationary power applications.

Hydrogenics HyUPS™ fuel cell power generator is a stationary power product developed to meet critical backup power needs across multiple markets.

Stakeholders

The Canadian Fuel Cell Commercialization Roadmap initiative, facilitated by Industry Canada and Fuel Cells Canada, is ensuring that industry, government and academia jointly develop strategies and an action plan to accelerate the commercialization of fuel cells and hydrogen technologies by Canadian companies.

Appendix IV identifies key government and business stakeholders, some of whom will play critical roles in implementing this report's recommended strategies.

Fuel Cell Industry

Fuel Cells Canada (FCC), a non-profit, national industry association, represents the Canadian fuel cell industry. It is the prime source of services and support to Canadian corporations, educational institutions and business alliances promoting, developing and deploying fuel cell and related products and services in Canada. FCC currently has 52 members, including all major Canadian fuel cell companies.

The Canadian fuel cell industry includes companies involved in: systems integration; design, manufacture and distribution of fuel cell components; manufacturing systems; fuel and fueling systems, storage, integration and development; test/sensor equipment; control systems; and engineering service supply. FCC estimates that about 1,800 people are employed by companies whose core business is focused on fuel cell and hydrogen activities (more information is provided in the previous section and in Appendix IV).

Many partnerships are being formed, both among Canadian companies and between Canadian companies and foreign companies. A number of these partnerships are among companies along the fuel cell industry value chain, including those in established industries such as automotive and other original equipment manufacturers (OEMs). These partnerships allow Canadian companies to leverage the resources they can bring to the table in the Roadmap implementation process.

Government

Governments have played an important role in the development of the Canadian fuel cell and hydrogen industry. From 1982–2002, government support to the fuel cell industry totalled approximately $179 million in grants, contributions and loans. This funding has supported activities on a project-by-project basis in all regions and across all technologies. Overall policy objectives guiding support have been related to innovation, clean technologies, energy efficiency and greenhouse gas abatement. Current and potential involvement of government departments includes:

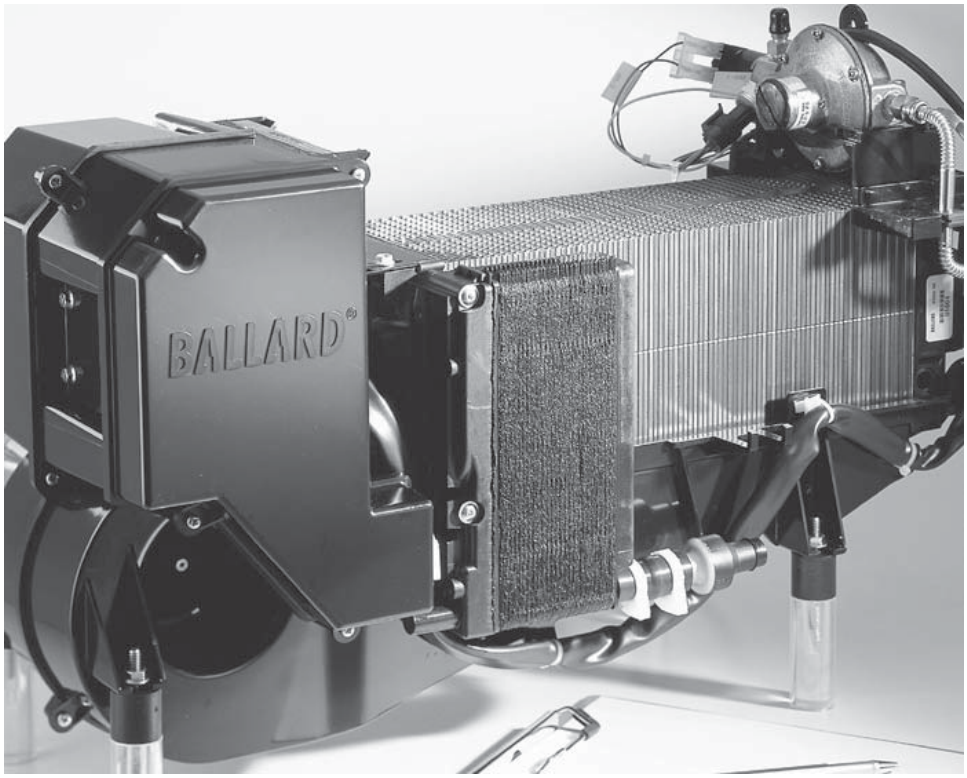
- **BC Ministry of Competition, Science & Enterprise** works to advance policies and regulations that enhance the development of the national fuel cell industry centered in BC; promotes investment in the fuel cell industry in BC; provides a supportive research and workforce training infrastructure in the province's universities and other advanced education institutes for the expansion of fuel cell industry capabilities; promotes the use of fuel cells as an enabling technology for climate change.
- **Department of National Defence** supports R&D activities through early adoption of fuel cell technology.
- **Environment Canada** performs emissions testing (GHG, Criteria Air Contaminants (CACs) and toxics); lifecycle analysis and technology assessments.
  - **Climate Change Action Fund/Technology Early Action Measures** provides funding for a variety of demonstration projects across the country.
- **Human Resources Development Canada**, through The Labour Market Services area in BC, is examining the feasibility of developing a human resource plan identifying the skilled labour requirements needed to sustain the growth of fuel cell industry clusters in BC and Canada. This entails research of data identifying key areas of demand and potential gaps in the supply of skilled labour.
- **Industry Canada** is leading the development of the Canadian Fuel Cell Commercialization Roadmap; funds Fuel Cells Canada and Western Demonstration Program through Western Economic Diversification; funds commercialization activities through Technology Partnerships Canada.
- **Natural Science & Engineering Research Council** provides funding for research chairs and targeted projects in partnership with industry and government; provides project and student training support.
- **National Research Council Institute for Fuel Cell Innovation** provides technical (investigative and collaborative R&D) and partnership programs (technology intelligence and partnership assistance to spin-offs and spin-ins) for fuel cell research.
  - Fuel cell testing and demonstration program provides $20 million in incremental funding to train people for the fuel cell sector and showcase innovative Canadian technologies and companies.

- **Natural Resources Canada** funds and performs research and development; supports Canadian Transportation Fuel Cell Alliance; provides technical and policy advice; develops codes and standards; conducts education and public outreach.
  - **Canadian Transportation Fuel Cells Alliance** is a $23 million program to encourage the development and application of a fueling infrastructure for vehicles.
  - **Climate Change Action Fund/Technology Early Action Measures** provides funding for a variety of demonstration projects across the country.
  - **CANMET** partners with industry and other federal and provincial agencies to develop and deploy new transportation technologies.
- **Public Works Government Services Canada** is an early purchaser and user of technology.
- **Technology Partnerships Canada** advances and supports government initiatives by investing strategically in research, development and innovation in order to encourage private sector investment, and so maintain and grow the technology base and technological capabilities of Canadian industry. It has provided financial support to Canadian fuel cell and hydrogen businesses to develop innovative products and processes.
  - $19 million investment in fuel cells research and development at **DuPont Canada**.
- **Transport Canada** provides policy framework and safety regulations.
- **Western Economic Diversification Canada** has provided support to the fuel cell and hydrogen sector since 1990 and continues to partner closely with Fuel Cells Canada, Industry Canada, the National Research Council, the Provinces of BC and Alberta, and other industry stakeholders to identify and collaborate on initiatives to support and accelerate the growth of the fuel cell sector.
  - **Western Economic Partnership Agreements** (Western Economic Diversification & BC government) has distributed $13 million for demonstration projects carried out in BC, along with some support to FCC.
- **AUTO21 Networks of Centres of Excellence** has been provided with $23 million federal support, with matched industry funding, for partnering academic and industry applied research programs, including fuel cell technologies.

Academia

Post-secondary institutions have a significant role to play in the development of the fuel cell and hydrogen industries. As the sector grows, so too will the demand for pre-competitive scientific research and for trained personnel at all levels. Currently, the major demands are for highly trained scientific and technical research personnel in private and public sector research facilities. As fuel cell and hydrogen products are commercialized, the demand for repair, maintenance and skilled production personnel will overtake the current demands for scientific researchers.

- **Canadian universities** conduct research on fuel cells and specialized courses, and degrees directly related to the technologies.
  - AUTO21 (**University of Windsor**)
  - Centre for Automotive Materials Manufacturing (**Queen's University**)
  - Hydrogen Research Institute (**Université du Québec à Trois-Rivières**)
  - Institute for Integrated Energy Systems (**University of Victoria**)



Nexa™ power module, the world's first volume-produced proton exchange membrane (PEM) fuel cell module designed for integration into a wide variety of stationary and portable power generation applications.

Markets

Markets for fuel cells are diverse and the revenue potential is substantial.

The automobile sub-segment is projected to make up 94 percent of the mobile units sold in 2011.

Although these markets will not be constrained by geographic borders, developed regions such as Europe, North America and Japan are expected to be the early adopters for a number of reasons, including:

- Energy costs
- Large consumer demand
- Environmental pressures to change energy consumption behaviour
- Advanced regulatory environments
- Consumer awareness and willingness to be early adopters
- Willingness to pay a premium for energy reliability and security

During the early part of the projected time horizon, much of the demand is expected to come from institutional and government buyers willing to pay a premium to support the fuel cell industry's development and promote alternative energy sources. This includes demonstrating the benefits for society and the environment, as is already being done in Japan and Europe.

Longer-term uses, particularly for stationary and portable power, could be extensive in underdeveloped countries with less access to conventional energy sources and infrastructure.

The following series of figures shows the projected demand by market segment and timeframe.

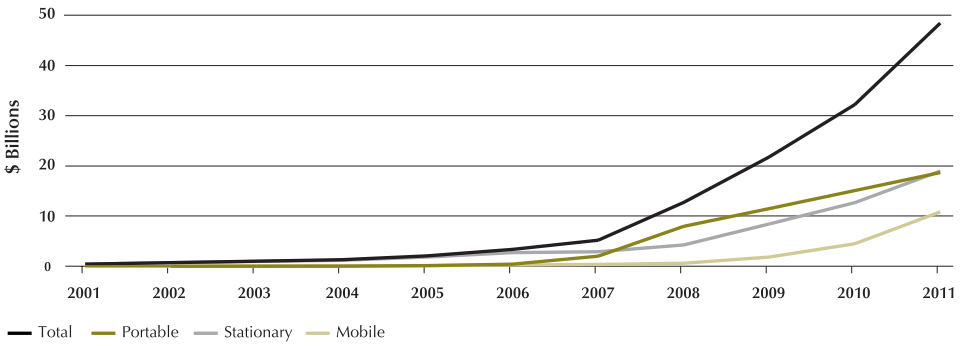
Figure 6. Global Fuel Cell Systems Estimated Demand

Units/MW

Market Segment	2001	2003	2005	2007	2009	2011	CAAG* 2003–2011	CAAG* 2007–2011
Stationary (MW)	75	225	675	2,025	7,088	15,947	70%	67%
Portable ('000 Units)	0	50	2,000	50,000	290,000	470,000	214%	75%
Mobile (Units)	10	3,523	7,608	31,680	275,520	1,610,080	115%	167%

Source: PricewaterhouseCoopers
* Cumulative Average Annual Growth

Figure 7. Global Fuel Cell System Market Projections



Source: PricewaterhouseCoopers

Figure 8. Global Fuel Cell Systems Estimated Demand

$ (millions)

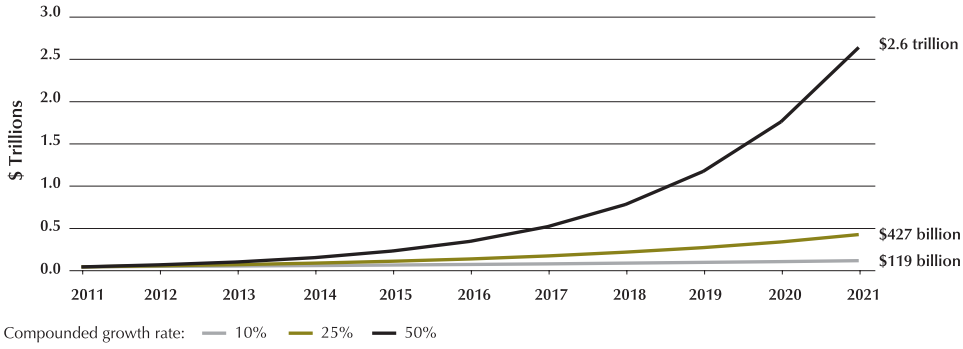
Market Segment	2001	2003	2005	2007	2009	2011	CAAG* 2003–2011	CAAG* 2007–2011
Stationary	$397	$886	$1,747	$2,734	$ 7,974	$17,940	46%	60%
Portable	0	3	94	1,875	10,875	17,625	193%	75%
Mobile	1	79	123	311	1,746	10,257	84%	140%
Total Market	$398	$968	$1,963	$4,920	$20,595	$45,822	62%	75%

Source: PricewaterhouseCoopers
* Cumulative Average Annual Growth

Growth rates for the industry are projected to average in excess of 60 percent between 2003 and 2011. While detailed projections were not taken beyond 2011, all indications show that the market will continue to grow at high levels beyond this point.

For the period 2007 to 2011, the industry is projected to grow at a 75 percent compounded average annual rate. The figure below illustrates the impact of a 10 percent, 25 percent and 50 percent compounded average annual growth rate to 2021.

Figure 9. Estimated Global Demand to 2021



Source: PricewaterhouseCoopers

Market Stages

The long-term potential of fuel cells is generally recognized, but the immediate challenge is identifying and securing early adopters of the technology. For most companies, the move into mass markets will be a gradual process.

Defining Commercialization

For many technology companies, including those in the fuel cell industry, the line between product development and commercialization is a grey area. For the purposes of this Roadmap, commercialization is defined as the third of a three-phase new product process.[12]

Pre-development – From the idea stage up to, but not including, product development

Development and testing – Product development, as well as in-house and customer tests of the product

Commercialization – Market launch and production start-up

The commercialization phase is divided into four stages related to market development.

Demonstration – Fuel cells are produced in small numbers for demonstration purposes. This phrase illustrates market-readiness in specific applications in terms of product quality which includes performance, reliability and durability.

Early Markets – Fuel cells are produced for sale in early adopter markets. These early adopters will be sophisticated buyers who have specific needs, such as performance and reliability, that are best met by fuel cells. These buyers are also prepared to pay a premium price. Early markets require the development of full-scale manufacturing capabilities and the development and implementation of supply chains.

Mid-Markets – Fuel cells are produced in larger numbers for markets that are beyond early adopters but not yet mass markets. Price will be a more important consideration in the purchase decision in the mid-markets than in the early markets. Buyers will still tend to be relatively knowledgeable in their purchase decision. Manufacturing capabilities are similar to the early markets stage.

Late Markets – Fuel cells are sold in large volumes to mass markets and are widely accepted by consumers. Buyers will be less sophisticated in their product knowledge. Price will be the major factor in the purchase decision for most buyers, with reliability and performance having been clearly proven in the early and mid-markets.

These commercialization stages reflect a typical fuel cell company, based on application area and unit size (see Table 1). Ranges are intended to be general and specific applications will differ. Every product will proceed through the four stages in a somewhat different way.

[12] Adapted from Robert G. Cooper, *Winning at New Products*

Table 1. Commercialization Stages for a Typical Fuel Cell Company*

Annual Number of Units Sold

Stationary

STAGE	UNIT SIZE		
	<25 kW	25–150 kW	>150 kW
Demonstration	10–100	10	10
Early Markets	1,000	100–1,000	10–100
Mid-Markets	1,000–10,000	1,000–10,000	100–1,000
Late Markets	10,000	10,000	1,000

Portable

STAGE	UNIT SIZE		
	<25 W	25–100 W	>100 W
Demonstration	100–1,000	100	10–100
Early Markets	1,000–10,000	1,000–10,000	1,000
Mid-Markets	10,000	10,000	10,000
Late Markets	100,000	100,000	10,000–100,000

Mobile

STAGE	UNIT SIZE		
	<25 kW	25–125 kW	>125 kW
Demonstration	10–100	100	10
Early Markets	1,000	1,000	100
Mid-Markets	10,000	10,000	1,000
Late Markets	10,000–100,000	100,000	10,000

* This table shows the number of units that a typical fuel cell company might sell in a year at each market stage. It does not show what the industry as a whole might sell annually.

Current Market Position of Canadian Fuel Cell Companies

Currently, a variety of Canadian fuel cell products are in the demonstration and early market stages of commercialization (see Table 2).

Many more products are expected to move from development and testing to early market commercialization within the next two to five years.

Canadian companies are involved in not only fuel cell production and systems integration but also in many support services and functions (see Table 2). For example, Canada is the world leader in fuel cell test station development and marketing, with over 300 units sold in the past 10 years. As fuel cell production increases, so too will the demand for test stations. Canada is well positioned to continue to dominate this market. Market success for fuel cells will lead to after-market diagnostic testing, which will extend the product lines of these companies.

Table 2. Current Market Postition of Canadian Fuel Cell Companies

Stationary

STAGE	UNIT SIZE <25 kW	25–150 kW	>150 kW
Demonstration	**Ballard** Nexa PEMFC (1.2 kW) **Ebara Ballard** PEMFC co-generation system (1 kW) **Fuel Cell Technologies** SOFC co-generation system (5 kW) **Hydrogenics** HyUPS PEMFC backup power system (25 kW) **Palcan** 3 kW regenerative power system with integrated fuel cell and photovoltaic	**Ballard** Nexa PEMFC (1.2 kW) scalable to 60 kW **Hydrogenics** HySTAT power generator (50 kW)	**Kinectrics** engineering and BOP integration for 250 kW SOFC CHP power plant
Early Markets	**Ballard** Nexa PEMFC (1.2 kW)	**Ballard** scalable Nexa (1–60 kW)	

Portable

STAGE	UNIT SIZE <25 W	25–100 W	>100 W
Demonstration		**Energy Visions** Hybrid DMFC/ Battery Demonstration	**Ballard** Nexa PEMFC (1200 W) scalable to 0.060 W **Hydrogenics** HyPORT CTM PEMFC power generator (0.005 W) **Hydrogenics** HyPORT PEMFC power generator (5 kW)
Early Markets			**Ballard** Nexa PEMFC (1,200 W)

Mobile

STAGE	UNIT SIZE <25 kW	25–125 kW	>125 kW
Demonstration	**Hydrogenics** HyPM 20 kW power module **Hydrogenics** HyPM-LP2 20 kW power module, scalable to 125 kW **Hydrogenics** HyPORT-E Regenerative APU (5 kW) **Palcan** 0.5 kW Fuel cell powered bicycle **Palcan** 3 kW APU **Palcan** 1.5 kW–2 kW fuel cell powered scooter	**Ballard** PEMFC mark 902 module and HY 75 fuel cell engine	**Ballard** Mark 902 PEMFC power module and HY 205 kW fuel cell heavy duty engine
Early Markets		**Ballard** Mark 902 PEMFC power module and HY 75 fuel cell engine	**Ballard** Mark 902 PEMFC power module and HY 205 kW fuel cell heavy duty engine

Table 2. Current Market Postition of Canadian Fuel Cell Companies (cont'd)

Fuel Cell Support Products and Services*

Demonstration	**DuPont** – value added flow field plates for PEMFC and DMFC applications
	Dynetek – mobile hydrogen fueling station, 5,000 psi stationary hydrogen storage, hydrogen storage cylinders for fuel cell vehicles
	Hera – metal hydride canister capability
	Kinectrics – design engineering and systems integration services for the pre-commercialization demonstration of 250 kW SOFC from Siemens Westinghouse
	Praxair – hydrogen distribution capability (cylinders)
	QuestAir – H-3200™ hydrogen purification PSA systems
	HyQuestor – large-scale hydrogen purification
	Stuart Energy – personal fuel appliance hydrogen fuelers
	Xantrex – inverters and controls
	Ballard – hydrogen and natural gas Gensets to support fuel cell infrastructure
Early Markets	**DuPont** Nafion® – membranes, membrane-electrode assemblies, flow field plates
	General Hydrogen – Hydricity™ fueling systems
	Greenlight – fuel cell test stations
	Hydrogenics – FCATS, FCVAS and IMPACT fuel cell test and control systems
	Methanex – MCELL fuel service package – modular fuel storage and handling system provides multiple fuel solutions (methanol, methanol/water blends to high purity hydrogen)
	QuestAir – H-6100 ultra compact hydrogen purification unit for stationary power fuel processing systems
	QuestAir – C-9100 ultra compact hydrogen purification unit designed for onboard fuel processing systems
	QuestAir – C-7100 gas management system for high temperature fuel cells (MCFC or SOFC)
	Stuart Energy – bus and community hydrogen fuelers
	Xantrex – inverters and controls

* Includes: systems integration; design, manufacture and distribution of fuel cell components; manufacturing systems; fuel and fueling systems, storage, integration and development; test/sensor equipment; control systems; and engineering service supply.

Markets Drivers

The market drivers for fuel cell products will differ as products move through the market stages (see Table 3). These drivers can be divided into two broad types:

Macro drivers are primarily tied to government policies, legislation and incentives. Pollution reduction, greenhouse gas amelioration, the need for energy security, and the need to reduce healthcare costs will continue to be critical macro drivers for widespread adoption of fuel cell technologies. It is assumed that government legislation and regulations will become increasingly important as fuel cell technology improves, especially in mobile applications.

Micro drivers are related to the needs of the market and the ability of the fuel cell industry to meet these needs. In the demonstration phase, product quality, performance and the need to be seen as a first purchaser can be significant drivers. As products move through each market stage other micro drivers such as proven product quality, cost competitiveness (compared to incumbent technologies) and mass production capabilities come into play.

Table 3: Fuel Cell Markets and Drivers*

Small Stationary Fuel Cells (<25 kW)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Environmental and health interest by North American governments Foreign government environmental regulations Government technology, energy and innovation policies Energy security	Product quality Unique capabilities Lifecycle cost Continuous energy availability Ability to supply product Partnerships	PEMFC emergency back-up power SOFC co-generation power PEMFC and SOFC off-grid primary power	Single family homes Small telecommunications facilities Government (e.g., small public buildings) Small commercial buildings Recreational properties (e.g., cabins)
Early Markets	Now–2015	Above, plus... Introduction of North American government environmental policies and regulations Energy conservation	Above, plus... Economically viable niche uses Convenience Quality power	Above	Above
Mid-Markets	2005–2020	Above, plus... Increased North American government environmental policies and regulations Government fiscal incentives	Above, plus... Proven quality Profits for suppliers	Above, plus... PEMFC and SOFC energy storage	Above, plus... Small residential subdivisions Small multi-family buildings Small off-grid communities in developed countries
Late Markets	Post 2010	Above, plus... Widely mandated North American government environmental policies and regulations New sources of energy demand	Above, plus... Cost competitive Mass production capabilities	Above	Above, plus... Small off-grid communities in developing countries

*Information provided by Working Group participants

Table 3. Fuel Cell Markets and Drivers (cont'd)

Medium Stationary Fuel Cells (25–150 kW)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Environmental and health interest by North American governments Foreign government environmental regulations Government technology, energy and innovation policies Energy security	Product quality Unique capabilities Lifecycle cost Continuous energy availability Ability to supply product Partnerships	PEMFC emergency back-up power SOFC co-generation power PEMFC and SOFC off-grid primary power	Telecommunications facilities Data centres Government (e.g., larger public buildings) Commercial buildings Larger recreational properties (e.g., lodges)
Early Markets	Now–2015	Above, plus... Introduction of North American government environmental policies and regulations Energy conservation	Above, plus... Economically viable niche uses Convenience Quality power	Above	Above, plus... Small hospitals Small remote industrial operations (e.g., mines)
Mid-Markets	2005–2020	Above, plus... Increased North American government environmental policies and regulations Government fiscal incentives	Above, plus... Proven quality Profits for suppliers	Above, plus... PEMFC and SOFC energy storage	Above, plus... Larger residential subdivisions Large multi-family buildings Larger off-grid communities in developed countries
Late Markets	Post 2010	Above, plus... Widely mandated North American government environmental policies and regulations New sources of energy demand	Above, plus... Cost competitive Mass production capabilities	Above	Above, plus... Larger off-grid communities in developing countries

Table 3. Fuel Cell Markets and Drivers (cont'd)

Large Stationary Fuel Cells (>150 kW)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Environmental and health interest by North American governments Foreign government environmental regulations Government technology, energy and innovation policies Energy security	Product quality Unique capabilities Lifecycle cost Continuous energy availability Ability to supply product Partnerships	PEMFC emergency back-up power SOFC co-generation power PEMFC and SOFC off-grid primary power	Major telecommunications facilities Large data centres Government (e.g., larger public buildings) Large commercial buildings and developments (e.g., shopping centres)
Early Markets	Now–2015	Above, plus... Introduction of North American government environmental policies and regulations Energy conservation and efficiency	Above, plus... Economically viable niche uses Convenience Quality power	Above	Above, plus... Large hospitals Wastewater treatment plants Electroplating plants Large remote industrial operations (e.g., mines, sawmills)
Mid-Markets	2005–2020	Above, plus... Increased North American government environmental policies and regulations Government fiscal incentives	Above, plus... Proven quality Profits for suppliers	Above, plus... PEMFC and SOFC energy storage	Above, plus... Major residential subdivisions Large off-grid communities in developed countries
Late Markets	Post 2010	Above, plus... Widely mandated North American government environmental policies and regulations New sources of energy demand Capital cost avoidance for new conventional energy facilities (e.g., hydroelectric)	Above, plus... Cost competitive Mass production capabilities	Above	Above, plus... Large off-grid communities in developing countries Large on-grid communities

Table 3. Fuel Cell Markets and Drivers (cont'd)

Small Portable Fuel Cells (<25 W)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Government technology and innovation policies	Product quality Unique capabilities Weight reduction Ability to supply product Partnerships	Battery replacement Handheld devices (e.g., personal digital assistants)	Military Small electronics OEMs
Early Markets	Now–2015	Above	Above, plus... Economically viable niche uses	Above, plus... Battery chargers	Above, plus... General public
Mid-Markets	2005–2020	Above	Above, plus... Proven quality Profits for suppliers Mass production capabilities	Above, plus... Cameras Hearing aids Portable electronics (e.g., CD players) Cell phones Toys Small power tools	Above
Late Markets	Post 2010	Above	Above, plus... High reliability Cost competitive	Above, plus... Medical devices (e.g., pacemakers)	Above

Table 3. Fuel Cell Markets and Drivers (cont'd)

Medium Portable Fuel Cells (25–100 W)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Government technology and innovation policies	Product quality Unique capabilities Weight reduction Noise reduction Ability to supply product Partnerships	PEMFC laptop computer battery replacements Wearable power	Military Laptop computer OEMs General public
Early Markets	Now–2015	Above	Above, plus... Economically viable niche uses	Above	Above
Mid-Markets	2005–2020	Above	Above, plus... Proven quality Profits for suppliers Mass production capabilities	Above, plus... Other electronics battery replacements Larger power tools	Above
Late Markets	Post 2010	Above	Above, plus... Cost competitive	Large toys	Above

Large Portable Fuel Cells (>100 W)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Government technology and innovation policies	Product quality Unique capabilities Weight reduction Noise reduction Ability to supply product Partnerships	Generators Wearable power (military)	Military Industry General public
Early Markets	Now–2015	Above	Above, plus... Economically viable niche uses	Above, plus... Road sign illumination Wearable power (commercial)	Above, plus... Government (e.g., highways) Commercial (surveyors)
Mid-Markets	2005–2020	Above	Above, plus... Proven quality Profits for suppliers Mass production capabilities	Above, plus... Wearable power (recreation)	Above
Late Markets	Post 2010	Above	Above, plus... Cost competitive	Above, plus... Large power tools (e.g., chainsaws, leaf blowers)	Above

Table 3. Fuel Cell Markets and Drivers (cont'd)

Small Mobile Fuel Cells (<25 kW)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Environmental and health interest by North American governments Foreign government environmental regulations Government technology, energy and innovation policies	Product quality Unique capabilities Ability to supply product Partnerships	Truck and other vehicle auxiliary power units Aircraft auxiliary power units Two-stroke engine replacements (e.g., electric bicycles, motors scooters) Small materials handling equipment (e.g., forklifts, pallet movers) Airport indoor people movers Golf carts Personal mobility devices (e.g., electric wheelchairs)	Government Military Truck OEMs Commercial truck fleets Aircraft OEMs Airlines Airports Golf courses Industrial operations (e.g., warehouses) Bicycle and motor scooter OEMs
Early Markets	Now–2015	Above, plus... Introduction of North American government environmental policies and regulations	Above, plus... Economically viable niche uses Fleet fueling infrastructure	Above	Above, plus... General public in narrow range of applications (e.g., motor scooters, golf carts and bicycles)
Mid-Markets	2005–2020	Above, plus... Increased North American government environmental policies and regulations Government fiscal incentives	Above, plus... Proven quality Profits for suppliers Standardized platforms Wider fueling infrastructure	Above, plus... More types of two-stroke engine replacements (e.g., small snowmobiles and ATVs)	Above, plus... General public in wider range of applications (e.g., small snowmobiles and ATVs)
Late Markets	Post 2010	Above, plus... Widely mandated North American government environmental policies and regulations	Above, plus... Cost competitive Mass production capabilities Broad fueling infrastructure	Above, plus... More two-stroke engine replacements (e.g., motorcycles and small boats)	Above, plus... General public in broad range of applications (e.g., motorcycles, small boats)

Table 3. Fuel Cell Markets and Drivers (cont'd)

Medium Mobile Fuel Cells (25–150 kW)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Environmental and health interest by North American governments Foreign government environmental regulations Government technology, energy and innovation policies Energy security	Product quality Unique capabilities Ability to supply product Partnerships	Small buses Passenger vehicles Light duty commercial trucks Utility vehicles (e.g., grounds maintenance) Materials handling equipment (e.g., forklifts)	Public transit operators Automobile OEMs Small truck OEMs Utility vehicle OEMs Government fleets (e.g., Post Office) Military Commercial truck fleets Industrial operations (e.g., warehouses)
Early Markets	Now–2015	Above, plus... Introduction of North American government environmental policies and regulations	Above, plus... Economically viable niche uses Fleet fueling infrastructure	Above	Above
Mid-Markets	2005–2020	Above, plus... Increased North American government environmental policies and regulations Government fiscal incentives	Above, plus... Proven quality Profits for suppliers Standardized platforms Wider fueling infrastructure	Above, plus... Small off-road industrial vehicles (e.g., loaders, haulers) Increasing selection of fuel cell passenger car and truck models	Above, plus... Mining and forestry operations Passenger car and truck fleet operators
Late Markets	Post 2010	Above, plus... Widely mandated North American government environmental policies and regulations	Above, plus... Cost competitive Mass production capabilities Broad fueling infrastructure	Above, plus... Broad selection of fuel cell passenger car and truck models Pleasure boats	Above, plus... General public

Table 3. Fuel Cell Markets and Drivers (cont'd)

Large Mobile Fuel Cells (>150 kW)

STAGE	TIMING	DRIVERS		MARKETS	
		Macro	Micro	Uses	Users
Demonstration	Now–2010	Environmental and health interest by North American governments Foreign government environmental regulations Government technology, energy and innovation policies Energy security	Public awareness Product quality Unique capabilities Ability to supply product Partnerships	Buses Military vehicles (e.g., Hummers, troop transport) Submarines Surface ships	Public transit operators Military Marine research institutions
Early Markets	Now–2015	Above, plus... Introduction of North American government environmental policies and regulations	Above, plus... Economically viable niche uses Fleet fueling infrastructure	Above	Above
Mid-Markets	2005–2020	Above, plus... Increased North American government environmental policies and regulations Government fiscal incentives	Above, plus... Proven quality Profits for suppliers Standardized platforms Wider fueling infrastructure	Above, plus... Heavy duty commercial trucks Large off-road industrial vehicles (e.g., loaders, haulers) Heavy duty trucks	Above, plus... Commercial truck fleets Mining and forestry operations Passenger car fleet operators
Late Markets	Post 2010	Above, plus... Widely mandated North American government environmental policies and regulations	Above, plus... Cost competitive Mass production capabilities Broad fueling infrastructure	Above, plus... Locomotives Large pleasure boats Ships	Above, plus... Railways General public Shipping lines

Product Uses and Users

Demonstration/Early Markets

Governments are important early adopters of fuel cell technology at the demonstration and early markets stages. Federal leadership in market introduction can be key in assuring a successful commercial launch of new energy technology, providing a bridge between relatively expensive advanced pilot programs and cost-competitive commercial offerings.

Government early adoption could cover stationary, portable and mobile applications of fuel cell systems. The applications could include buses, motor vehicle fleets, military applications, industrial uses, residential fuel cells for powering government, community and other buildings, and power generation in Canada's remote communities.

In the US, the military has traditionally been an early adopter of new technologies. It has already shown an interest in a number of fuel cell applications. The military has the resources to both evaluate and adopt new technologies that can improve performance and meet specialized needs, making it a prime candidate for the early markets stage.

Initial fuel cell markets will generally be for specialized products (see Table 3). Most buyers will be sophisticated users who have special operating performance needs and an interest in lifecycle costs — high cost is not a critical impediment to purchase. The ability of the product to meet performance requirements will have been shown through earlier demonstrations.

To gain early market customers, fuel cell producers may have to sell products at well below manufactured cost. In return, however, they will gain market share and profile. This is a proven strategy to commercialization.

Mid and Late Markets

To reach the mid-market stage and remain commercially viable, producers must be able to sell at a profit. Competitive pricing against incumbent technologies will become an important factor. The types of application and markets will broaden as products become more competitive with incumbents while providing additional benefits. The customer base will expand into the broader population — particularly for mobile applications — and different fuel cell technologies will serve the same application.

Most fuel cell products will to go through all four stages. However, the rate at which products move through the different stages will vary by application.

A significant number of Canadian fuel cell products are already in the demonstration and early markets stages (see Table 2). Moving more Canadian products from research and development to demonstration and early markets during the next three years (2003–2005) will be critical if Canada is to retain its competitive edge over foreign fuel cell producers.

A number of products are also expected to enter the mid-market stage during this period, and some products with widespread applications will enter the late market stage. The mobile sector is expected to lag behind the portable and stationary application sectors by about five years in late market applications, given the challenges in making fuel cell cars competitive with ICE cars on both a performance and, most importantly, cost basis. This cost competitiveness is critical to attracting a significant share of the general consumer automotive market in the long-term.

Paralleling this progress will be a need for fuel supply infrastructure and unit costs to reach a competitive level with conventional fuels such as gasoline and natural gas. This is a complication that further restricts rapid commercialization, and therefore it must be addressed with equal priority.

Palcan Fuel Cell Bike using PalPac™ Power Products

Commercialization Challenges

A number of significant challenges must be addressed on the road to commercialization. These challenges — common to the industry as a whole, regardless of product, market focus or stage of development — will require the collaborative efforts of all stakeholders to ensure the successful commercialization of the Canadian fuel cell industry. Many of the challenges are also interrelated and, therefore, need to be addressed concurrently.

The challenges are summarized as follows (see Table 4 for specific criteria for each challenge and the milestones associated with each market stage). Given the current emergent position of the Canadian fuel cell industry, the Roadmap challenges focus on demonstration and early markets.

Stimulating Early Market Demand

The high price tag of new fuel cell products — reflecting higher production costs associated with small production volumes — poses a prohibitive barrier to potential purchasers. Production costs, and hence prices, will come down as demand stimulates increased production volumes. The sooner this demand is generated, the faster industry will be able to reduce costs and access new markets. A concerted effort is required to jumpstart the market and provide the early production volume critical to cost reduction. This effort will require an aggressive program of demonstration projects, trial opportunities and first-purchase incentives to create greater awareness of user requirements, confirm the benefits of fuel cell technology and overcome the uncertainty associated with first use.

Challenges

Creating More Market Awareness
Gaining More Knowledge of Markets

Improving Product Quality While Reducing Cost

To compete with incumbent technologies that are both widely accepted and constantly being improved, the fuel cell industry must improve product quality (performance, reliability and durability) and reduce production costs. Depending on the product and application, fuel cell costs must be reduced from one to ten times the current cost. This will require a combination of materials, product and process development, and design engineering. Critical to cost reduction is an integrated supply chain that ensures the availability of high quality materials and components at competitive prices. To stimulate development of an effective supply chain, fuel cell developers and systems integrators need to standardize their component specifications, and suppliers must be encouraged to service early markets with the design, engineering and maintenance support critical to system developers, integrators and first users.

Challenges

Continuing to Improve Product Quality
Continuing to Reduce Costs
Developing a Coordinated Supply Chain for Fuel Cell Power Systems

Financing

Innovative approaches to securing capital are needed to meet the significant capital resources that Canadian fuel cell companies will require as they move products along the path toward commercialization. Partnerships and strategic alliances are being used to leverage some of these necessary resources. However, the costs of increasing the scope and scale of production and marketing activities required for successful commercialization severely challenges the available capital resources of most industry participants.

Challenge

Gaining Access to Capital

Creating Supporting Infrastructures

For some fuel cell applications — particularly in the mobile sector — supportive infrastructures will have to be developed. These infrastructures include: the availability of sufficient skilled personnel; the presence of codes and standards that allow and encourage the safe introduction of fuel cell applications and allow interconnectivity; and the development of a fueling infrastructure, where required.

Challenges

Obtaining Skilled Resources
Developing Fueling Infrastructure
Developing Codes and Standards

Table 4. Fuel Cell Industry Commercialization Challenges and Milestones

Stimulating Early Market Demand

CHALLENGES	MILESTONES			
	Demonstration	Early Markets	Mid-Markets	Late Markets
Creating More Market Awareness				
Including: • Fuel cell technology • Uses • Costs • Performance/capabilities • Benefits (e.g., environmental) • Safety • Availability	High-level value propositions defined and confirmed with early users Partners and participants in market demonstrations secured by companies	Acceptance of value propositions for early applications by early users	Broader market acceptance of value propositions for wider range of applications	Very broad public acceptance of value propositions for wide range of applications
Gaining More Knowledge of Markets				
Including: • Segments • Needs and applications • Size and growth • Early versus late adopters • Pricing • Competing technologies	Partners and participants in market demonstrations clearly identified	Early markets defined, entry strategies developed and early adopter customers secured	Mid-markets defined, entry strategies developed and broad range of customers secured	Late markets, defined, entry strategies developed and a broader customer base secured

Improving Product Quality While Reducing Costs

CHALLENGES	MILESTONES			
	Demonstration	Early Markets	Mid-Markets	Late Markets
Continuing to Improve Product Quality				
Including: • Closing technology gaps for: - Performance - Reliability - Durability - Longevity - Safety - Environmental standards	Extensive testing completed for all parts of system Minimum performance criteria achieved	Quality improvements made relative to incumbent technologies Some criteria approaching incumbent technologies Product certification achieved	Quality approaching incumbent technologies for most criteria	Quality equal to or better than incumbent technologies in most or all criteria
Continuing to Reduce Costs				
Including: • Purchase • Lifecycle, including maintenance and disposal • Components and materials • Installation and integration • Manufacturing • Sales and distribution	Demonstrated ability to continue to reduce costs	Costs coming closer to incumbent technologies across some criteria Costs acceptable to niche market users Supply chain formed	Costs approaching incumbent technologies across more criteria Secure supply chain in place	Costs equal to or better than incumbent technologies in most or all criteria

Table 4: Fuel Cell Industry Commercialization Challenges and Milestones (cont'd)

Financing

CHALLENGES	MILESTONES			
	Demonstration	Early Markets	Mid-Markets	Late Markets
Gaining Access to Capital				
Including: • General operating • Applied research and product development • Skilled resources • Demonstrations • Facilities • Production • Distribution • Machinery and equipment	Partners/customers secured to cost share in demonstration projects and continue applied research and product development	Financing secured to begin low volume production and initial sales and marketing programs and continue applied research and product development	Financing secured to increase production volumes and sales and marketing programs and improve manufacturing technologies	Financing secured to undertake high volume production and sustained wide-scale sales and marketing programs

Creating Supporting Infrastructures

CHALLENGES	MILESTONES			
	Demonstration	Early Markets	Mid-Markets	Late Markets
Obtaining Skilled Resources				
Including: • Engineering • Science • Industrial design • Technology commercialization • Technicians • Trades	Sufficient skilled technical resources secured to support demonstration projects and continue applied research and product development	Skilled technology commercialization, production, and service and support resources secured	Sufficient skilled resources secured to meet growing production (including machinery and equipment manufacturing) and servicing needs	Sufficient skilled resources secured to meet mass production and servicing needs
Developing Infrastructure				
Including: • Fuel type • Fuel delivery • Fuel storage • Fuel processing • Packaging • Quality • Availability	Solutions are identified and confirmed with early adopters	Infrastructure in place for initial applications	Broader infrastructure in place approaching that of incumbent technologies	Very broad infrastructure in place similar or better than for incumbent technologies
Developing Codes and Standards				
Including: • Fuel • Infrastructure • Storage • Balance of plant • Interconnectivity • Disposal	Appropriate codes and standards determined, including which standard bodies will develop them	Appropriate technology codes and standards adopted	Appropriate manufacturing codes and standards adopted Appropriate skills certification standards adopted	High quality assurance standards adopted

Strategies and Actions

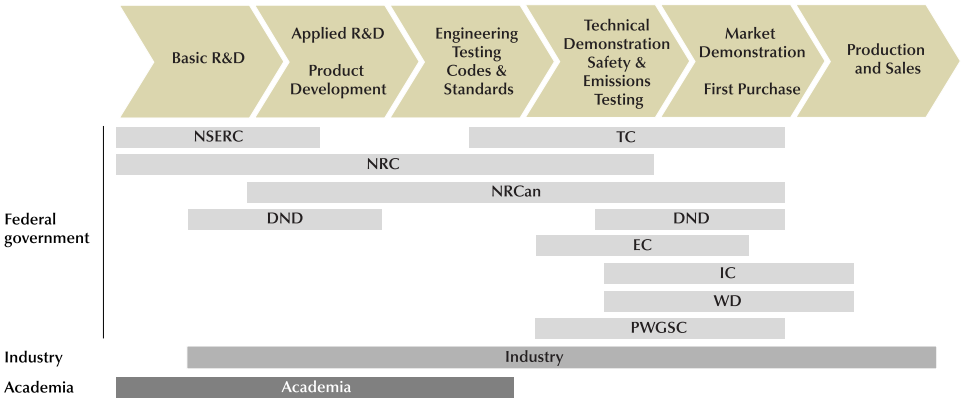
A comprehensive set of strategies and actions has been identified to address the challenges and achieve the desired outcomes identified by participants in this Roadmap.

A key desired outcome is the establishment of a national fuel cell strategy that focuses on maintaining Canada's competitiveness in the face of growing global competition. This Roadmap is, in many ways, the first step toward establishing such a national strategy.

Desired Outcomes

- A national fuel cell strategy, reflecting the collaborative commitment of all key stakeholders, is developed within the next year (see Table 5)
- Stakeholder champions are identified who will continually promote the Canadian fuel cell industry
- Government and other early users understand the long-term benefits of fuel cells and why they should demonstrate/purchase fuel cell products (e.g., a clean technology that will help Canada achieve targets established under the Kyoto Protocol)
- Financial assistance is made available for research and development, product development and early market products

FIGURE 10. STAGES OF DEVELOPMENT



Source: Industry Canada

Actions for Success

To achieve these desired outcomes, strategies and actions have been identified for each challenge (see Table 5 for specific strategies and actions for each challenge). These actions should, in most cases, be viewed as only a starting point, to be followed by an implementation plan that addresses each action in greater detail. The timing of each action focuses on what needs to be done within the next several years to commercialize the Canadian fuel cell industry. This timeframe is viewed as the most critical period if the industry is to remain competitive on a global scale.

The key actions identified for each challenge are summarized below. Given the current emergent position of the Canadian fuel cell industry, the Roadmap's recommended actions focus on demonstration and early market stages of commercialization.

Stimulating Early Market Demand

- Develop demonstration projects that showcase fuel cell technology, validate product reliability and output, 'ruggedize' the product and provide data necessary for commercialization
- Develop public information programs to educate policy makers, service providers, consumers and students
- Establish early purchase programs to encourage product procurement and benchmarking to allow public demonstration of the technology and to provide critical early revenues for the industry

Improving Product Quality While Reducing Cost

- Identify product performance and cost barriers, and develop strategies to overcome them
- Increase collaborative research and development on materials, component costs and product standardization; integrate production plans/processes for major cost components to ensure cost curve reduction
- Undertake demonstration projects to support cost and performance value propositions in operating environments and to create an ongoing database of proven fuel cell performance
- Establish a supply chain forum to develop a process for sharing technical information among fuel cell developers, suppliers and the research community. This will stimulate innovation and further investment in component design, obtain industry agreement on appropriate benchmarks and performance standards, identify gaps in supply chain and develop strategies for enhanced domestic capabilities, and develop component cost reduction programs

Financing

- Develop financial incentives for fuel cell products and services in order to reduce the risk profile of needed investments in manufacturing capability
- Identify and pursue development partners, including exploring the feasibility of strengthening geographic clusters to attract further development, provide tax incentives for research and development, and dedicate matching funds for investments

Supporting Infrastructures

- Develop a human resource strategy to ensure a sufficient supply of skilled resources for the fuel cell sector; develop policies and criteria for training requirements; and undertake a national occupational analysis to identify where skills gaps may emerge as the industry grows
- Require that a training component be incorporated into fuel cell demonstration projects and early purchases involving government
- Develop curriculum material targeted at post-secondary students, teachers, academic and technical institutions
- Develop fueling infrastructures that demonstrate fueling solutions
- Ensure Canada takes a lead role in setting codes and standards for fuel, fuel cells and fueling systems

Table 5. Canadian Fuel Cell Commercialization Strategies

Stimulating Early Market Demand

Creating More Market Awareness

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	High-level value propositions defined and confirmed with early users Partners and participants in market demonstrations secured	Create a high domestic and international profile for the Canadian fuel cell industry and technology	Continue to support FCC in its role as lead organization representing and promoting the Canadian fuel cell industry	FCC, with member participation	Ongoing
			Complete development of fuel cells education kit for distribution to schools and other interested parties	FCC with Industry Canada	2003
			Participate in industry trade and investment shows and government missions	FCC and individual companies	Ongoing
			Promote the Canadian industry and fuel cell products through Canadian embassies and trade office world-wide, including distribution of an information package targeted at foreign investors and users	Federal and provincial governments, with FCC and its members	2003 onward
			Continue to work on plans for "Vancouver - Whistler Hydrogen Highway" demonstration project	FCC, with BC and Federal governments	Ongoing
			Develop program for, and maintain a portfolio of, other high profile public demonstrations including a showcase location demonstrating key sustainable technologies (fuel cells, electolyzers, hydrogen purification, storage, fuelling solutions).	FCC, with member participation	2003
		Create a common value proposition framework and guide for use by Canadian industry in domestic and international markets, including a consistent message on the general benefits of fuel cell technology in quantifiable terms	Develop Terms of Reference and conduct study to development framework and guide, with user input	Industry Canada, with FCC and its members	2003
			Value proposition framework distributed to and adopted by industry	Individual companies	2003 onward

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Stimulating Early Market Demand (cont'd)
Creating More Market Awareness (cont'd)

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	High-level value propositions defined and confirmed with early users Partners and participants in market demonstrations secured	Secure government partners to cost share in market demonstrations and early applications	Develop detailed business case for industry/government demonstrations	Industry Canada, with FCC and its members	2003
			Develop government policies and programs for demonstration projects	Federal government	2004
			Submit proposals for specific product and application demonstration projects	Individual companies	2004 onward
			Build on NRCan/DOE research relationship to gain access to their programs	NRCan	
		Secure OEM/end user partners to cost share in market demonstrations and early applications	Develop proposals for specific product and application demonstration projects	Individual companies	Ongoing
			Work through Brand Canada and other government assistance programs to establish contact with potential partners	Individual companies, with Investment Partnerships Canada and other government agencies	Ongoing
		Secure military partners to cost share in demonstrations of technology and applications	Submit proposals directly to Canadian, US and other defence departments for specific product and application demonstration projects	Individual companies	Ongoing
			Work with Canadian and US defence departments through Technology Partnerships Canada to explore feasibility of entering into Defence Development Sharing Agreements	Individual companies, with Technology Partnerships Canada	Ongoing

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Stimulating Early Market Demand (cont'd)

Creating More Market Awareness (cont'd)

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Early Markets	Acceptance of value propositions for early applications by early users	Ensure broad use of value proposition framework by Canadian companies in marketing products	Consistently apply value proposition framework to each product and market application	Individual companies, with FCC	Ongoing
		Secure government as an early adopter of fuel cell technology in a range of applications	Develop business case for government as an early adopter	FCC, with member participation	2004
			Develop government policies and programs for fuel cell product procurement	Federal government	2005
			Develop sales proposals for specific products and applications	Individual companies	2005 onward
		Subsidize products for high profile users and locations to encourage early adoption	Identify target markets with high profile users and locations and pursue them	Individual companies	Ongoing
			Undertake detailed study of early adopter markets for fuel cells	FCC and Industry Canada, with the Federal Fuel Cells Coordinating Committee	2003
		Develop leasing programs for early adopters to help off-set high upfront purchase costs and reduce risk in certain applications	Develop leasing proposals and pursue with leasing companies	Individual companies	2004 onward
			Develop fuel cell producer leasing programs	Individual companies	2004 onward
			Explore feasibility of government involvement in leasing programs for fuel cells (e.g., risk management and insurance fore users)	Industry Canada, NRCan	2003
			Identify and pursue users most receptive to lease concept	Individual companies	2004 onward
		Facilitate use of stationary fuel cells as sources of electricity to the grid	Explore the feasibility of creating legislative frameworks to open electricity markets and allow users of energy to install fuel cells and connect then to the grid as independent sources of supply	Governments	2006 onward
			Explore the feasibility creating Electricity Market Rules that favour 'clean' energy technologies	Governments	2006 onward

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Stimulating Early Market Demand (cont'd)

Gaining More Knowledge of Markets

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	Partners and participants in market demonstrations clearly identified	Develop a detailed understanding of the initial markets for each fuel cell application (e.g., segments, needs, size, pricing)	Undertake individual market studies	Individual companies	Ongoing
			Collect and disseminate publicly available market information, including through use of website	FCC, with member participation	2003
			Roll Canadian Fuel Cell Commercialization Roadmap Working Groups into FCC as subgroups in order to continue information sharing process	FCC, with member and other stakeholder participation	2002
			Undertake market research utilizing government programs, such as the International Trade Personnel Program	Individual companies, with government international trade agencies	Ongoing
			Obtain good third party research	Individual companies	Ongoing
			Clarify the requirements of potential users for the industry to use as targets	FCC, with member participation	2003
Early Markets	Early markets defined, entry strategies developed and early adopter customers secured	Develop a detailed understanding of the mid-markets for each fuel cell application	Same actions as above	Same leaders as above	Ongoing, as products move towards mid-market entry

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Improving Product Quality While Reducing Costs

Continuing to Improve Product Quality

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	Extensive testing completed for all parts of system Minimum performance criteria achieved Demonstrated ability to continue to improve quality	Expand product testing capabilities of the Canadian fuel cell industry	Harmonize testing procedures and standards for components	NRC	2004
			Create more industry/research institution partnerships for testing	NRC	2004
			Undertake more independent third party testing	Individual companies, with independent testing organizations	Ongoing
			Encourage more testing by OEMs	Individual companies	Ongoing
			Use the Canadian Centre for Housing Technology as a test centre for relevant products	Individual companies, with CMHC, NRCan and NRC	Ongoing
		Develop benchmarks and standards (e.g., product specifications for Canadian and foreign technologies) and create shared data base for Canadian fuel cell industry and suppliers thereto.	Develop Terms of Reference and conduct data baseline framework study	NRC, with FCC and its members	2003
			Obtain industry agreement on appropriate benchmarks and standards	NRC, with FCC and its members	2003
			Build data base through testing and demonstration projects	NRC	2004
			Develop process for sharing of technical information among Canadian companies and academia	FCC, with member and other stakeholder participation	2003
			Create supplier forum	FCC and members	2003
Early Markets	Quality improvements made relative to incumbent technologies Some criteria approaching incumbent technologies Product certification achieved	Move towards standardization of key components of fuel cell systems	Conduct study on supply chain harmonization for the Canadian fuel cell industry	NRCan, with FCC and its members	2005
			Identify gaps in Canadian supply chain and develop strategies for enhancing domestic capabilities	Federal government, with FCC and its members	2005

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Improving Product Quality and Reducing Cost (cont'd)

Continuing to Reduce Costs

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	Demonstrated ability to continue to reduce costs	Determine life cycle costs for each segment — stack, balance-of-plant and fuel storage system	Undertake life cycle cost studies for key products and applications and share results	Individual companies with NRC	Ongoing
		Target research on continued cost reduction methods and technologies	Identify key components where costs need to be reduced to meet product costs market will bear	Individual companies with NRC	Ongoing
			Undertake more research on component costs and standardization	Individual companies with NRC	Ongoing
		Reduce use of exotic materials	Review CLiMRI (Canadian Lightweight Materials Research Initiative) Program and similar programs (e.g. AUTO21 NCE) to determine applicability to fuel cells	NRC	2003
			Conduct further research on fuel cell materials	NRC HVAC	Ongoing
			Research supply chains	Individual companies	Ongoing
		Identify costs that the market will bear in each application	Include as part of early market studies	Individual companies	Ongoing
			Undertake demonstration projects to show costs in operating environment	Individual companies	Ongoing
			Benchmark users and alternative technologies	NRC	2003
Early Markets	Costs coming closer to incumbent technologies across some criteria Costs acceptable to niche market users Supply chain formed	Increase production volumes	Develop production plans to allow smooth transition from demonstration into early market stage	Individual companies	Ongoing
			Review how other technology industries have moved into production and develop fuel cell industry model	Industry Canada	2004
		Make greater investments in component development	Develop component cost reduction programs based on product costs market will bear	Individual companies	Ongoing
			Develop supply chains	Individual companies	Ongoing

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Financing

Gaining Access to Capital

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	Partners/customers secured to cost share in demonstration projects and continue applied research and product development	Identify potential funding sources	Prepare comprehensive guide for Canadian fuel cell companies on private and public sector sources of funding	FCC, with member participation	2003
			Making collected information on industry available to banks, VCs and other funding sources wanting to know more about fuel cells	FCC, with member participation	Ongoing
			Determine role for government in helping bring larger investors and partners to the table and build relationships	Industry Canada	2003
		Identify demonstration partners willing to bear part of cost	Incorporate into market studies and strategies	Individual companies	Ongoing
			Develop business case, including potential benefits from early adoption		
		Identify development partners (equity and strategic), including OEMs and end users	Incorporate into market studies and strategies	Individual companies	Ongoing
			Develop business case, including potential revenue stream from early markets		
Early Markets	Financing secured to begin low volume production and initial sales and marketing programs and continue applied research and product development	Introduce comprehensive set of financial incentives for the Canadian fuel industry and fuel cell users	Develop business case based on benefits to Canada and industry needs and submit to government	FCC, with member participation	2004
			Develop government policies and programs for fuel cell financial incentives	Industry Canada	2004

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Creating Supporting Infrastructures

Obtaining Skilled Resources

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	Sufficient skilled technical resources secured to support demonstration projects and continue applied research and product development	Undertake in-house training programs to meet immediate needs	Continue with programs already in place and build new ones based on projected short-term needs	Individual companies	Ongoing
		Develop a national plan for meeting long-term skills demand in the Canadian fuel cell industry	Undertake national occupational analysis	HRDC, with FCC and member participation	2003
			Identify skills required at each step along the supply chain	HRDC, with FCC and member participation	2003
		Ensure that fuel cell demonstration projects or early purchases involving government incorporate a training component	Develop policies and criteria for training requirements	Industry Canada, NRCan, PWGSC	2003
			Develop plans for incorporating training component into government demonstration and early market sales	Individual companies	2003 onward
Early Markets	Skilled technology commercialization, production, and service and support resources secured	Import management skilled in technology commercialization	Develop innovative strategies to attract outsiders to work in Canadian fuel cell industry	FCC and members with HRDC	2004
			Build program to search for required skills based on industry identification of need	HRDC, with FCC and member participation	2004
		Augment current management skills in commercialization	Send current management to Executive Development and other courses that teach business skills	Individual companies	Ongoing
		Develop nation-wide information dissemination program for career opportunities in fuel cells	Develop material targeted at post-secondary students and teachers and create ongoing promotional campaign	FCC and its members, with HRDC	2005 onward
			Develop material targeted at those post-secondary academic and technical institutions considered most likely to support creation of fuel cell courses and, ultimately, programs	FCC and its members, with academic and technical institutions	2005 onward
		Develop nationally accepted certificate for fuel cell trades people	Create plan for how certification program should be structured and develop appropriate standards	HRDC, with FCC and member participation	2005

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Creating Supporting Infrastructures (cont'd)

Obtaining Skilled Resources (cont'd)

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Early Markets	Skilled technology commercialization, production, and service and support resources secured	Encourage multi-disciplinary approach to engineering with a fuel cell focus	Identify industry and academic champions to promote concept	FCC and its members, with academic and technical institutions	2005
			Identify disciplines required and knowledge base	FCC and its members, with academic and technical institutions	2005
		Encourage fuel cell based project learning	Develop program for fuel cell product competitions and secure industry sponsors	FCC and its members, with academic and technical institutions	2004
		Encourage the development of fuel cell courses and, ultimately, programs at selected universities and technical schools	Facilitate linkages between industry and academic champions	FCC and its members, with academic and technical institutions	2003 onward
			Conduct study on industry needs and required courses and programs to meet needs, current offerings and gaps	FCC and its members, with academic and technical institutions	2004
			Identify most appropriate institutions to develop courses and programs	FCC and its members, with academic and technical institutions	2004
			Incorporate fuel cell elements into existing courses, including use of instructors / lecturers from industry	FCC and its members, with academic and technical institutions	2004 onward
		Expand co-op/internship programs at fuel cell companies	Continue with programs already in place and build new ones based on projected long-term needs	Individual companies	Ongoing
		Make Canada an international centre of fuel cell education	Undertake a study of current and potential international market opportunities for fuel cell training and education	FCC and its members, with academic and technical institutions	2004
			Develop courses and programs based on need and market internationally	Academic and technical institutions	2005 onward

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Creating Supporting Infrastructures (cont'd)

Developing Infrastructure

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	Solutions are identified and confirmed with early adopters	Create infrastructure development plan for introduction of fuel cells into Canadian market	Develop Terms of Reference for plan and undertaker study	NRCan	2003
			Develop appropriate government policies and programs in support of plan	NRCan	2004
		Resolve fuel storage and distribution issues for mobile fuel cell vehicles	Investigate storage options	Individual companies	Ongoing
			Continue with 10,000 psi storage projects	NRC	Ongoing
			Test multiple pathways to providing hydrogen	Individual companies	Ongoing
		Undertake high profile demonstration projects with an infrastructure component	Continue to work on plans for "Vancouver–Whistler Hydrogen Highway" demonstration project	NRCan	Ongoing
Early Markets	Infrastructure in place for initial applications	Provide clean fuel tax subsidies for hydrogen users	Develop the business case and present to government	FCC and its members	2004
		Provide incentives for hydrogen producers	Develop business case and present to government	FCC and its members	2004
		Establish network of hydrogen labs in proximity to key fuel cell clusters in Canada	Examine feasibility of concept, including partners and funding options	NRC, NRCan	2003
			Develop program and implementation strategies	NRC, with identified partners	2004
		Widely publicize infrastructure milestones to markets as they are achieved	Provide research results and input to OEMs and other key users of technology	Individual companies	Ongoing
			Develop information dissemination program for infrastructure milestones	FCC, with member participation	2003 onward

Table 5. Canadian Fuel Cell Commercialization Strategies (cont'd)

Creating Supporting Infrastructures (cont'd)

Developing Codes and Standards

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
Demonstration	Appropriate codes and standards determined, including which standards bodies will develop them	Coordinate with US and other countries on codes and standards development and harmonization	Review work to date, including who is involved and what has been done, and plan future actions	NRCan	2003
			Explore opportunities to coordinate with US Fuel Cells Council, the National Hydrogen Association, the European Integrated Hydrogen Project and other organizations on dealing with US and Canadian regulators	FCC and its members	2003
		Link demonstration projects to codes and standards development	Ensure codes and standards are incorporated into demonstration proposals	Individual companies with demonstration partners	Ongoing
			Build standard framework for demonstration projects on how codes and standards are to be addressed	NRCan	2003
		Work with others who are developing a codes and standards information clearing house	Participate in development of clearing house and ensure that Canadian companies contribute to and benefit from it	FCC and its members	2003 onward
			Develop process for keeping FCC aware of fuel cell codes and standards work being undertaken by Canadian companies and organizations	FCC and its members	2003
Early Markets	Appropriate technology codes and standards adopted	Educate Canadian regulatory authorities at all levels across the country on codes and standards adopted	Develop program for disseminating information on fuel cell codes and standards	FCC and its members	2004
			Publicize high profile demonstration projects and early adopters as examples of applied codes and standards	FCC and its members	2004 onwards

Table 5a. The Need for Public Policy and a National Fuel Cell Strategy

STAGE	MILESTONE	STRATEGIES	ACTIONS	LEADER	TIMING
	Fuel cell champions created in federal and provincial government	Build case for national strategy and government support	Develop program for targeting provincial governments as an initial step in driving a national strategy	FCC, with member participation	2003
			Showcase workable products in high profile locations	FCC, with member participation	Ongoing
			Continue publicity campaign targeted at building awareness among key decision makers	FCC, with member participation	Ongoing
			Use FCC developed industry materials to communicate consistent key messages	FCC, with member participation	Ongoing
			Undertake comprehensive study of what other countries are doing	FCC and its members, with Industry Canada	2003
			Develop a public outreach program	FCC and its members, with government	2003
		Identify and pursue strategic champions in government, industry, academia and markets (early adopters)	Develop program for how champions will be targeted and pursued on a coordinated basis	FCC and its members	2003
			Prepare supporting material and research to continue education of secured and potential champions.	FCC and its members	2003 onward
		Encourage coordination among federal, provincial and municipal institutions, academic and research institutions, and industry to ensure all are moving in the same direction with a common purpose and vision	Develop coordination plan	Federal government agencies	2003

Conclusion

This Roadmap is intended to assist stakeholders in addressing the major challenges facing fuel cell commercialization in Canada. It underscores the significant role that government, industry and academia must play if Canada is to remain a leader in commercializing fuel cell technology in the face of growing international competition.

A clear message of this Roadmap is that action must be taken now. Competition is intensifying, and only those companies and countries that have a clear plan for commercialization will emerge as winners.

Action is Needed Now

The next two to three years will be particularly critical for Canada's fuel cell industry. Quality must be improved, costs must be reduced and demonstration activities must be increased if the industry is to be able to deliver commercial products for market entry. This will require a collaborative effort, with government and industry working together to support demonstration projects, providing early purchaser opportunities and showing leadership not only in fuel cell technology, but also in addressing Canada's climate change, health, and sustainability and innovation agendas.

Next Steps

This Roadmap is but a first step. The next steps must include:

- Developing a national fuel cell strategy within the next year
- Preparing an implementation plan, including estimates of the costs of carrying out the recommended actions. Implementing this plan in the shortest possible time will require collaboration of industry, government and academia
- Integrating the Roadmap Working Groups as committees of Fuel Cells Canada
- Implementing the Roadmap Communication Strategy in conjunction with FCC

This Roadmap will also need to be reviewed and updated on a regular basis. To respond to changing conditions, key stakeholders must agree on an appropriate timeline for reviews. As well, a performance-monitoring plan must be developed to track progress in achieving the desired commercialization.

Methanex methanol storage tanks

Appendices

Appendix I

Steering Committee and Working Group Participants

Alberta Research Council
Shawn Gervais*

Angstrom Power
Ged McLean
Bruce Rea

Automotive Parts Manufacturers' Association
Patrick Curran
Gerry Fedchun

Ballard Power Systems
Stephen Kukucha*
Heather McKay
Bruce Rothwell
Debby Harris

BC Ministry of Competition, Science & Enterprise
Stephen Brydon

BC Hydro
Allan Grant

Cellex Power Products
Subhash Aggarwal
David Pfeil

Centre for Automotive Materials and Manufacturing
Floyd Tuler

Chrysalix Energy Management
Christine Bergeron

DuPont Canada R. & B. D. Centre
Peter Andrin

Dynetek Industries
Robb Thompson

Enbridge Gas Distribution
Walter Matias*
Terry Whitehead

Energy Visions
Wayne Hartford

Environment Canada
Steve McCauley
Lynne Patenaude

Fuel Cell Technologies
Barbara Haines

Fuel Cells Canada
Chris Curtis*
Annie-Sylvie Desaulniers
Dave Shepherd

General Hydrogen
Darren Sokoloski

Global Public Affairs
Alan Cocksedge

Greenlight Power Technologies
Dave Chapman

Heating, Refrigeration and Air Conditioning Institute of Canada
Martin Luymes

Human Resources Development Canada
Richard DeBeck

Hydrogenics
Jane Dalziel*
Jason Goodhand
Kevin Harris
Pierre Rivard

IESVic, University of Victoria
Taco Niet

Industry Canada
Bruce Bowie*
Annie Desgagne*
Patrick Roy

Kinectrics
Diane Cote
Ivor Da Cunha
Young Ngo
Robert Stasko
Ralph Watts*

Korn/Ferry International
Kevin McBurney

Methanex Corporation
Ron Britton (now FCC)*
Paul Daoust
Dominique Kluyskens
Kevin Maloney

NRC DND
Ed Andrukaitis

National Research Council Institute for Fuel Cell Innovation
Rod McMillan
Maja Veljkovic*

Natural Resources Canada, CANMET Energy Technology Centre
Nick Beck
Debra Haltrecht
Rodney Semotiuk
Rob Brandon

NORAM Engineering & Constructors
Malcolm Cameron
George Cook*

Ontario Ministry of Enterprise, Opportunity and Innovation
George Mandrapilias
Robert Tmej

Palcan Fuel Cells
Jim McBeth
John Shen

Powertech Labs
Yoga Yogendran

PricewaterhouseCoopers
Simon Berry
Alastair Nimmons
Eric Vance
John Webster

SatCon Power Systems Canada
Vince Scaini

SMC Pneumatics (Canada)
Ryan Benn
Brian Davis

Sofinov Société Financière d'Innovation
Luc Charron

Stuart Energy Systems Corporation
Matthew Fairlie

Technology Partnerships Canada
Dennis Rue

TeleflexGFI Control Systems
Lindsay Worden

Transport Canada, Research and Development
Michael Ball

University College of the Fraser Valley
Duncan Jeffries

AUTO21, University of Windsor
Peter Frise

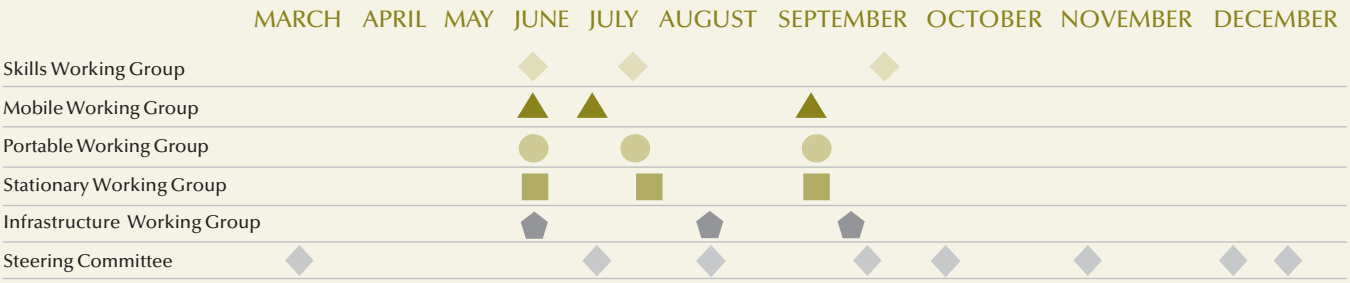
Western Economic Diversification Canada
Ardath Paxton Mann
Franco Zanatta

Xantrex Technology
Konrad Mauch
Mossadiq Umedaly

* Also Steering Committee Member

Appendix II

Steering Committee and Working Group Meetings – 2002



Appendix III

How a Fuel Cell Works and Fuel Cell Types

The following is a non-technical explanation of how a fuel cell works and major fuel cell types.

How a Fuel Cell Works

A fuel cell is a device that converts chemical energy into electrical energy. Hydrogen (which can be obtained from a variety of carbon-based fuels including methanol, natural gas and petroleum or renewables) is combined with oxygen (obtained from the air) within a fuel cell to electrochemically produce electricity, water and heat.

The heart of the fuel cell generally consists of three primary parts: an anode, a cathode and an electrolyte. The electrical current flows between the cathode to the anode. The materials from which the fuel cell is composed determine the way in which the fuel cell produces electricity.

Cells

A basic Proton Exchange Membrane Fuel Cell (PEMFC) has hydrogen protons migrating from the anode through the electrolyte to the cathode. A platinum coating at the anode acts as a catalyst and helps to split the hydrogen molecules into positively charged protons and negatively charged electrons. The electrolyte membrane allows only the protons to pass through it to the cathode. The electrons cannot pass through this membrane and, as a result, they flow (in the form of an electrical current) through an external circuit to get to the cathode, thus creating electricity. Oxygen supplied at the cathode then combines with the protons to form water.

A basic Solid Oxide Fuel Cell (SOFC) gets its name from the wafer-thin ceramic that makes up the electrolyte. Oxygen ions migrate through the electrolyte from the cathode to the anode, where they combine with available protons. An SOFC typically uses perovskites and nickel-based compounds as catalysts.

Stacks

Individual fuel cells are typically combined into a fuel cell "stack". The number of fuel cells in the stack determines the total voltage. The surface area of each cell determines the total current. Multiplying the voltage by the current yields the total electrical power generated, typically measured in kilowatts (kW).

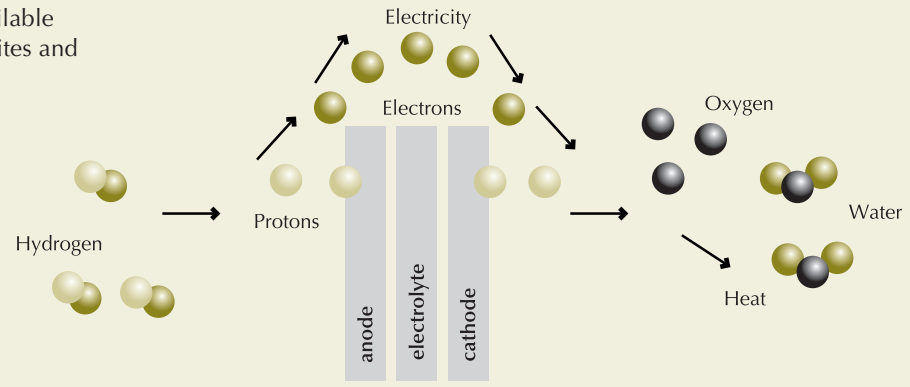
Balance-of-Plant

Producing usable electrical power from a fuel cell requires more than just a fuel cell stack. In addition to the stack, a fuel cell system includes many components for functions such as: injecting fuel gases; managing a critical water balance; conditioning the power output and monitoring and controlling all the required system parameters (e.g., temperature and pressure). Without this supportive operating system, the fuel cell stack cannot produce usable power.

Fuel Cell Types

The types of fuel cells include:

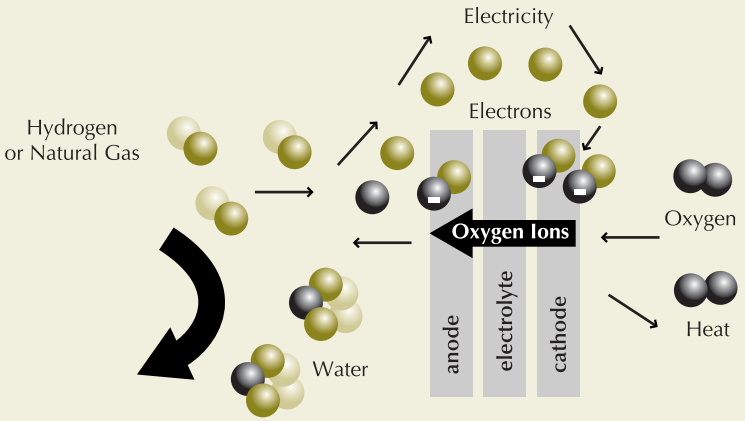
Proton Exchange Membrane Fuel Cell – It operates at a relatively low temperature, which means it warms up quickly and does not require expensive containment structures. Platinum is typically used as a catalyst in this type of fuel cell. Constant improvements in engineering and materials used in the PEMFC have increased the power density to a level where a device about the size of a small piece of luggage can power a car. Cyclability adds to the advantages of PEMFCs. They are the leading fuel cell technology for use in transportation applications.



Proton Exchange Membrane Fuel Cell

Direct Methanol Fuel Cell (DMFC) – It is a small PEM fuel cell that uses unreformed methanol to provide hydrogen to the fuel cell. DMFC developers are currently addressing an issue referred to as methanol crossover where unreacted methanol within the fuel cell reduces the fuel cell's performance. Potential uses for DMFCs include portable and micro applications such as lawn mowers, laptop computers and mobile phones.

Solid Oxide Fuel Cell (SOFC) – It may be used in both utility (250 kW) and small-scale (1 to 50 kW) stationary power systems. Because this type of fuel cell operates at very high temperatures (650 to 1000°C), all SOFC systems co-generate electrical and thermal power. This co-generation attribute gives SOFC systems the advantage of maximizing overall efficiency. The heat that SOFCs produce as part of their electro-chemical reaction can be used to advantage: in the case of a utility application, to produce steam to drive turbines that generate more electricity; in all SOFC applications, to provide heat for space/hot water heating; and eventually, to run thermally-driven cooling systems. No matter how the heat is used, the co-generation capability of an SOFC system makes it highly efficient. SOFC's attributes eliminate the need for fuel reformers, water management systems and precious metal catalysts.



Solid Oxide Fuel Cell

Alkaline Fuel Cell (AFC) – It has been used in the US space program since the 1960s. The AFC is very susceptible to contamination and requires pure hydrogen and oxygen. It is also very expensive, so this type of fuel cell is unlikely to be widely commercialized.

Phosphoric Acid Fuel Cell (PAFC) – It has potential for use in small stationary power generation systems. It operates at a higher temperature than the PEMFC, so it has a longer warm-up time. This makes it unsuitable for use in cars.

Molten Carbonate Fuel Cell (MCFC) – It is also best suited for large stationary power generators. It operates at high temperatures and can generate steam that can be used to generate more power. It has a lower operating temperature than the SOFC, which makes the design less expensive because the materials used do not have to withstand extremely high temperatures.

Appendix IV

Profiles of Canadian Companies in the Fuel Cell Industry

Fuel Cell Producers and Systems Integrators

Aluminum-Power Inc. has developed an aluminium air fuel cell that has the potential to revolutionize the mobile electronics and automotive industries. A breakthrough technology that offers high, sustained power over extended periods.

Angstrom Power Inc. is a Vancouver-based developer of micro-structured fuel cells targeting a variety of applications. Angstrom was formed to commercialize technology developed at the University of Victoria by Dr. Gerard McLean and is applying micro-fabrication techniques to create a fuel cell system using novel architecture and manufacturing techniques. Initial target applications could include battery replacement and portable power.

Astris Energi Inc., a developer of mobile and stationary power systems, has developed 1.5 kW portable power systems, 2–3 kW units to power a wide variety of small vehicles and a 4 kW system that could provide electricity, heat and hot water for residences. All are AFC systems.

Ballard Power Systems Inc. is recognized as the world leader in developing, manufacturing and marketing zero-emission proton exchange membrane (PEM) fuel cells. Ballard is commercializing fuel cell engines and components for the transportation market, electric drives for both fuel cell and battery powered electric vehicles, power conversion equipment for microturbines and other distributed generation technologies, fuel cell power generation equipment for markets ranging from portable power products to larger stationary power generation products and is a Tier 1 automotive supplier of friction materials for power train components.

Cellex Power Products Inc. is a leading developer of fuel cell based power products for use in premium power applications. Cellex develops proprietary system and component technology and integrates third-party fuel cell stacks, fuel processors and other components into commercial products. Specifically, Cellex is developing products to be used as power sources for industrial vehicles. Cellex was founded in 1997 and is based in Vancouver, BC.

DuPont Canada has been conducting intensive technology research in PEM fuel cells since the mid-1990s, and it has distinct materials and fuel cell technology expertise to improve fuel cell stacks from the inside out. In 2001, DuPont formed a Fuel Cell Business Unit to pursue growth opportunities in PEM fuel cells. DuPont Canada has the specific business mandate within the global DuPont Fuel Cell business for the marketing, development and production of fuel cell conductive flowfield plates and value-added functionality that can be built from flowfield plates. The company has created pilot development and fuel cell test facilities at its Research and Business Development Centre in Kingston, Ontario.

Energy Visions Inc. was formed in 1996 and focuses on portable fuel cell or battery applications. It aims to develop cost effective materials and manufacturing technology. With the Alberta Research Council, it is currently working to build commercial 250 W and 2.5 kW prototypes of its direct methanol fuel cells (DMFC). EVI believes the DMFC under development offers significant competitive advantages for portable and stationary applications.

Fuel Cell Technologies Ltd. has specialized in the research and development of fuel cell systems since 1994. The company's core business is the production of modularized SOFC power systems in the 1–50 kW range to provide electricity and heat for stationary applications such as homes, remote sites and small commercial and industrial enterprises. This power system incorporates the Siemens Westinghouse Power Corporation tubular cell stack technology that has been successfully demonstrated in large-scale systems in recent years. The 5 kW system is scheduled for field demonstrations in early 2003. FCT's research and production facilities are located in Kingston, Ontario.

Global Thermoelectric Inc. is involved in the development of SOFC technology. The company's goal is to become the leading supplier of scalable SOFC product, focusing on residential cogeneration, automotive and small-scale commercial applications. In July 2000, the company announced its first significant strategic alliance by aligning with Enbridge to approach the Canadian market. Enbridge is Canada's largest gas distributor and is committed to the rapid introduction of fuel cell technology.

GreenVOLT Power has developed a Saltwater-Air-Magnesium fuel cell product, the SAM-Cell™ PM-120, in response to increased public demand for a portable, light, simple, independent, long lasting and inexpensive electrical 12 Volt DC power supply unit. In the fall of 2002, all assets of GreenVOLT Corp were purchased by the Rama Wheel Corporation of Orillia, Ontario. Substantial commercial alliances are now being completed by Rama Wheel to facilitate the launch of GreenVOLT fuel cell products.

Hydrogenics Corporation is dedicated to the design and development of commercial PEM fuel cell systems for transportation, stationary and portable power applications. With its first commercial product line of fully integrated fuel cell test systems, Hydrogenics has established a leadership position in the fuel cell balance-of-plant and operating system technology. Hydrogenics' 95,000-square-foot headquarters and R&D facility is located in Mississauga, Ontario. The company also has Asia-Pacific operations in Tokyo, Japan, and European operations in Gelsenkirchen, Germany. Hydrogenics is a member of the GM alliance of fuel cell commercialization companies.

Kinectrics Inc., formerly part of the utility company Ontario Hydro, is now an independent company active in the design, specification and procurement of balance of plant for stationary and residential fuel cells. It has facilities for the testing of single cells and stacks. Kinectrics is currently constructing and operating a prototype 250 kW SOFC CHP plant, made by Siemens Westinghouse. In addition, the company is helping Fuel Cell Technologies develop a 5 kW SOFC residential CHP system. Kinectrics offers complete testing facilities for solid oxide fuel cell components and stacks.

MagPower Systems Inc. has developed a magnesium-air fuel cell, MagGen, which is designed to be a primary, alternative and emergency power source. Current development also includes a unit designed in a joint development with BC Hydro, which will recharge 125-volt lead acid batteries and in some areas replace them altogether. The extended product line is anticipated to include a fully automated system for the home, an efficient and economical primary power source for third world countries, a primary power source for boats and a power source for all back-up applications that currently use lead-acid batteries.

Palcan Fuel Cells Ltd. has developed technologies for prototyping, manufacturing and testing PEMFC stacks and systems, operated on pure hydrogen and air and ranging from 100 W to 5 kW. Palcan is also developing and manufacturing unique rare earth metal hydride hydrogen storage products. A three-way fusion of these products with electronics will produce an integrated power system series of products branded under the name Palpac Power Systems. This system will initially be targeted at the electric bike, small electric vehicle and portable power market.

PEM Technologies is a Canadian company specializing in the development and commercialization of PEM fuel cell technologies. A PEM fuel cell scooter has been successfully developed. A PEM fuel cell motorcycle and a PEM fuel cell forklift are currently in development for demonstration. PEM has also developed low-cost, high-quality key components such as a bipolar plate, membrane and catalyst for fuel cell applications.

PowerDisc Development Corporation Ltd. is a research and development company focused on the development and commercialization of PowerDisc engines, proprietary PEM fuel cell stacks and hybrid propulsion systems utilizing the PowerDisc engine. The company is working closely with the National Research Council of Canada under the National Fuel Cell Program and several complimenting companies to develop its products. PowerDisc's product line will consist of a variety of PowerDisc engines ranging from 20–200 kW, PEM fuel cell stacks and hybrid propulsion systems.

Siemens Canada Limited and Westinghouse belong to the pioneers of fuel cell technology. Activities in the Siemens corporate research labs started back in 1962. In 1984, a 100 kW alkaline fuel cell developed by Siemens was successfully tested in a submarine. Siemens continues to be one of the leading companies in fuel cell research, development and manufacturing of SOFC technology. With SOFC demonstration projects well under way in Canada and elsewhere in the world, Siemens Solid Oxide Fuel Cell technology holds a leading position.

Parts and Systems Suppliers

There are a number of other companies in Canada who derive a significant share of their revenue from the sale of products and services to the fuel cell producers. Some rely exclusively on the Canadian fuel cell producers as their market, while others also have an export component, selling to fuel cell producers in other countries.

Advanced Measurement Systems Inc. specializes in fuel cell testing. The company manufactures fully customized test systems to meet each customer's individual requirements. The test system measures fuel-cell characteristics such as voltages, current, humidity, temperature and gas flows into a fuel cell. The system also controls all aspects of the test environment.

Agile Systems Inc. has applied its digital power expertise to the fuel cell marketplace, integrating control and power management to produce the most advanced inverter technology. The company uses digital processing to produce a power management solution that is small, smart, connected and versatile.

Azure Dynamics Corp. is an innovative company that has developed proprietary hybrid electric vehicle technology for retrofit and new vehicle power trains in the light and medium duty commercial vehicle category. Azure's proprietary adaptive control systems achieve optimal efficiency and vehicle performance while also making significant reductions in emissions and energy consumption.

Cimtex Industries Ltd. is a full-service manufacturer of machined and fabricated metal and plastic components for a range of industries including aerospace, telecommunications and other advanced technology manufacturing. The company's services include prototype design and development, machining, fabrication, assembling and testing.

Dynetek Industries Ltd. develops, produces and markets Advanced Lightweight Fuel Storage Systems™ for storing compressed natural gas for low emission vehicles, and compressed hydrogen for zero emission fuel cell vehicles. The company's products are marketed under the Dynecell brand name and sold in 20 countries worldwide.

FuelMaker Corporation has over 15 years experience in high-pressure, gaseous fueling systems around the world. It custom engineers fast-fill or time-fill fleet fueling systems for electrolytic and reformer based hydrogen, and natural gas and hydrogen compression and storage systems for stationary power/fuel cell applications.

Greenlight Power Technologies Inc. (a division of Hydrogenics) is a leading global supplier of testing and diagnostic equipment to the fuel cell industry. Its current product line includes test stations for fuel cell stacks, components, fuel reformers, electrolysers and fuel cell systems. Its commercially available testing technology is used in testing stationary, portable and automotive fuel cell applications in the PEM, molten carbonate and solid oxide chemistries.

HERA Hydrogen Storage Systems Inc. develops hydrogen storage products based on metal hydrides for use in fuel cell, hydrogen fueled internal combustion engines and other hydrogen applications. Metal hydrides provide a compact and low-pressure storage solution for mobile, stationary, portable, military and other power applications.

NORAM specializes in the development, commercialization and supply of electrochemical processes. The privately owned company is a major shareholder of BC Research, a technology incubator located at the University of British Columbia. NORAM is focused on stationary power applications for fuel cells.

Pathway Design & Manufacturing Inc. is a custom supplier to the fuel cell industry, specializing in the design and manufacture of plastic products. With a full-service machine shop in-house, Pathway offers tooling, prototyping, production machining services as well as injection moulding and vacuum forming.

Pivotal Power Inc. offers power electronics engineering solutions to the fuel cell industry with inverters and converters products in the range of 1 W to 20 kW.

Praxair Inc.'s range of supply options including cylinders, high-pressure bulk gas delivery, liquid hydrogen delivery, onsite production and pipeline supply. All are designed to provide an economical, flexible, reliable and safe supply for hydrogen users.

PrecisionH2 is developing non-thermal fuel processor technology for onsite hydrogen production in distributed natural gas applications.

SatCon Power Systems Canada Ltd.'s products include DC/AC and DC/DC power converters for distributed generation applications, including fuel cells ranging in size from 10 kW to 3 MW.

SMC Pneumatics (Canada) Ltd. is committed to aiding and participating in the development of fuel cell applications. Its products and R&D structure allow SMC to continually provide collaborative solutions designed to improve fuel cell systems, fuel cell manufacturing automation systems and related test equipment.

SRE Controls Inc. is a major supplier of controllers for industrial electric vehicles. SRE designs, manufactures and sells power electronic motor controllers for traction motor control, lift and pump motor control and steering control.

QuestAir Technologies Inc. develops, designs, manufactures and sells complete gas separation systems. Proprietary technologies, modular manufacturing methods and proven expertise enable the company to produce compact, high efficiency hydrogen purifying units for the fuel cell industry.

Technologies M4 Inc. delivers solutions for highly integrated power electronics, controls and electric generator units offering superior power density, efficiency, controllability and reliability to meet power quality needs, as well as for distributed and mobile power generation applications.

TeleflexGFI Control Systems Inc. is a full-system service supplier of alternative fuel systems and components for hydrogen, natural gas and propane applications. The company provides high-pressure hydrogen components to original equipment manufacturer customers involved in compressed hydrogen storage for fuel cell vehicular and stationary storage.

Teleflex (Canada) is seeking to be a leader in balance-of-plant component design and manufacturing for the fuel cell industry. The company is one of the few western Canadian manufacturing companies that can produce engineered, high volume, precision machined products that meet the strictest quality demands.

Transformix Engineering Inc. designs and builds testing, quality control, material handling and assembly equipment for the automotive, pharmaceutical, food & beverages, consumer packaging and hi-tech industries. The company is working with fuel cell companies in developing fuel cell related products.

Turbo Genset provides technology solutions for distributed power, transportation and industrial systems. The company's high-speed motor/generators can be coupled directly to turbo machinery, such as compressors and gas turbines, to meet the needs of a range of applications, including fuel cells.

Tyco Electronics Ltd. is the world's largest passive component supplier, with brand names like AMP, Raychem, Elcon, Agastat, P&B, Schrack, Hartman, CII Technologies and Dulmison.

Universal Dynamics provides outsourced engineering and software development services to fuel cell related companies. This includes plant facility power and hydrogen distribution infrastructure, testing and data acquisition/ analysis software systems, and custom development of automated manufacturing machinery.

Vandenborre Hydrogen Systems Inc. designs and builds H_2 Igen based fuel stations, including production, compression, dispensing and storage. Typical applications are heat treating, cooling of power generators, fuel cells, electronics, fuel stations and renewable energy solutions.

Westaim Ambeon is a leader in composite material technologies for advanced power generation and electronic applications. A new catalyst materials group within the division is aiming to apply its capabilities in composite materials to assist in achieving the required material breakthroughs for the fuel cell industry in components like fuel reformers, membrane electrode assemblies and SOFC anodes.

Xantrex Technology Inc. develops, manufactures, markets and supports leading advanced power electronic and control products for distributed power, mobile power and programmable power markets.

Zetacon's Z2000 power platform can be configured as a power converter, inverter, generator or sensor-less motor controller. The Z2000 allows customers to take advantage of advanced high performance power technology without a high investment in power electronics infrastructure.

Fuel Cell Service Providers

A number of organizations are service providers to the fuel cell industry, including some that are exclusively focused on the industry.

Alberta Research Council provides innovative science and technology solutions for the current and emerging needs of their customers. ARC develops and commercializes technologies to give clients a competitive advantage. A Canadian leader in innovation, ARC provides solutions globally to the energy, life sciences, agriculture, environment, forestry and manufacturing sectors.

AUTO21, The Automobile of the 21st Century, is a national research initiative administered through the University of Windsor. It is supported by the federal government through the Networks of Centres of Excellence.

Automotive Parts' Manufacturers' Association promotes the Canadian manufacturing of automotive parts, systems, components, materials, tools, equipment and supplies, and the provision of services used in the automotive industry and in particular for the original equipment market. It also engages in activities that support the welfare of association members.

BC Ministry of Competition, Science & Enterprise is focused on establishing and expanding partnerships with entrepreneurs, businesses and organizations throughout British Columbia in order to build a strong private-sector-driven economy; fostering an innovation culture for science and technology; and developing national and international investment and trade relationships.

Business Development Bank of Canada meets the special needs of businesses at every stage of development. BDC Investment Group's venture capital and subordinated financing provides flexible, innovative financial instruments designed for companies whose assets are primarily intangible.

Canadian Hydrogen Association is a non-profit association of universities, research organizations and small businesses. It promotes the use and development of hydrogen energy, hydrogen energy systems and technologies that are environmentally friendly.

Centre for Automotive Materials and Manufacturing (CAMM) provide leadership and a framework to transform university research and education into opportunities for the automotive sector. CAMM is a partnership of industry, university and the Ontario provincial government. Fuel cells are a major area of CAMM's research and development program, with applications that include transportation, portable and stationary systems.

Chrysalix Energy Management is an early-stage private equity venture capital firm focusing on the fuel cell industry. It is a joint venture of Ballard Power Systems, BASF Venture Capital, The BOC Group, Duke Energy, The Mitsubishi Corporation and Shell Hydrogen.

Colliers International has developed industry-specific technical expertise for the fuel cell industry to ensure our clients receive appropriate and cost effective real estate solutions.

Dundee Securities Corp. is an independent, fully integrated, research-driven investment dealer with extensive institutional and retail distribution capabilities. The company provides value-added research and advisory services, concentrating on sectors where it has specialized knowledge and expertise.

Environment Canada's mandate is to preserve and enhance the quality of the natural environment, including water, air and soil quality; conserve Canada's renewable resources, including migratory birds and other non-domestic flora and fauna; conserve and protect Canada's water resources; carry out meteorology; enforce the rules made by the Canada-US International Joint Commission relating to boundary waters; and coordinate environmental policies and programs for the federal government.

Fuel Cells Canada, a non-profit national industry association, is the prime source of services and support to Canadian corporations, educational institutions and business alliances that promote, develop and deploy fuel cell and related products and services in Canada.

Gowlings LLP, one of Canada's largest national law firms, provides a broad range of legal and intellectual property agency services for clients in the fuel cell industry.

GrowthWorks Ltd. is a recognized leader in venture capital and fund management, with expertise in raising and investing capital. GrowthWorks' funds under management have made investments in 300 small and medium-sized businesses in Canada, primarily in emerging sectors.

Heating, Refrigeration and Air Conditioning Institute of Canada is a non-profit trade association of manufacturers, wholesalers and contractors in the Canadian heating, ventilation, air conditioning and refrigeration industry. Member companies provide products and services for indoor comfort and essential refrigeration processes.

Heliocentris Energy Systems is a world leader in providing fuel cell and hydrogen technology systems for education, outreach and demonstration. Its products range from inexpensive demonstration products for middle schools and junior high schools to powerful computer-interfaced fuel cell systems for colleges and universities.

HSBC Bank Canada is the seventh largest bank overall in Canada, with 160 branches. HSBC Bank Canada is a principal member of the HSBC Group, one of the world's largest banking and financial services organizations.

Human Resources Development Canada's objective is to enhance employment, encourage equality and promote social security in Canada. The Labour Market Services Division focuses on the development of a collaborative planning and research process involving private firms and public institutions with the objective of creating a human resource plan for the industry needed to commercialize the technology and maximize the local economic benefits.

Hydrogen Research Institute is an R&D unit of the Université du Québec à Trois-Rivières. Its research activities focus on storage, safety and use of hydrogen and fuel cells.

Hydro-Québec CapiTech is the wholly owned venture capital arm of Hydro-Québec. CapiTech invests in companies offering energy related products and services that can increase the performance of Hydro-Québec's business units. Hydro-Québec CapiTech has invested directly and indirectly in more than five fuel cell companies and related enabling technologies.

Industry Canada (Energy & Marine Branch) facilitated the Canadian Fuel Cell Commercialization Roadmap, undertakes sector analyses, develops a fuel cell awareness session and works with the fuel cell industry to respond to the federal government's Innovation Strategy.

Institute for Integrated Energy Systems at the University of Victoria develops new technologies and perspectives to overcome barriers to the widespread adoption of

sustainable energy systems. Its area of expertise includes modelling, design and testing of fuel cells, cryofuels, energy systems analysis and energy policy development.

Ipsos-Reid (North American Energy Division) provides in-depth industry knowledge and an understanding of the complete range of issues facing companies in the energy sector.

James Hoggan and Associates is one of Canada's leading public and investor relations firms, with specific expertise in the alternative energy sector. Current clients include Ballard Power Systems, Stuart Energy Systems, QuestAir Technologies, Fuel Cells Canada and the California Fuel Cell Partnership.

Korn/Ferry International has provided global executive search services for a number of fuel cell companies.

KPMG LLP is the professional services firm of choice for many of Canada's fuel cell leaders. KPMG helps its clients achieve their strategic priorities and growth objectives, whether through venture capital, mergers, acquisitions, strategic alliances, or IPOs.

Marsh Canada Ltd. is the world's leading risk and insurance services firm. Its mission is to create and deliver risk solutions and services that make its clients more successful.

McCarthy Tétrault LLP is Canada's largest law firm, with offices in every major Canadian financial and business centre.

National Bank Financial is a full-service investment dealer, with offices in Canada, the US, Britain and Switzerland. NBF's services include private placements of equity, initial public offerings, follow-on offerings, credit and debt products, and mergers and acquisitions advisory services.

National Defence's mission is to defend Canada, its interests and its values, while contributing to international peace and security. Under Canadian defence policy, the Canadian Forces fill three major roles: protect Canada, defend North America in cooperation with the US, and contribute to peace and international security

National Research Council's Institute for Fuel Cell Innovation through its Innovation Centre in Vancouver, acts as a hub for research programs, laboratories, scientific and technical expertise, networking and financial assistance for the fuel cell industry in Canada. It showcases the country's fuel cell technologies and is a champion for linking fuel cell regional clusters into a Pan-Canadian fuel cell cluster.

Natural Resources Canada (Technology Early Action Measures) funds projects supporting the demonstration and deployment of innovative technologies that reduce greenhouse gas emissions. **CANMET Energy Technology Centre** partners with industry and other federal and provincial agencies to develop and deploy new transportation technologies, such as alternative fuels and advanced propulsion systems, advanced energy storage systems, emissions control technologies, vehicle transportation system efficiency, and fueling infrastructure technologies. Natural Resources Canada recently initiated the Canadian Transportation Fuel Cell Alliance (CFTCA), a $23-million initiative that will advance the fueling infrastructure required for fuel cell vehicles.

Ontario Ministry of Enterprise, Opportunity & Innovation promotes economic growth. Faced with an increasingly competitive global marketplace, the ministry aims to accomplish this by creating a culture of innovation, promoting investment and expanding exports to world markets.

PricewaterhouseCoopers LLP understands and supports the fuel cell industry in Canada and around the world. Its Alternative Energy network of professional staff, drawn from 125,000 people in 142 countries, has a firm grasp of the issues facing companies as the industry evolves toward commercialization.

Public Works & Government Services Canada is the common service provider to the Government of Canada. Employing nearly 12,000 people, the department delivers services and programs through offices across Canada, as well as in the United States and Europe. The department deals with approximately 50,000 contracts totaling $8 billion, making it Canada's largest purchasing organization, buying for approximately 100 federal departments and agencies.

TD Securities Inc. provides financial advisory services in equity and debt financing, mergers & acquisitions, divestitures and risk management. It has been involved in raising over $435 million in private and public equity for energy technology companies over the last 18 months.

Technology Partnerships Canada is an investment fund that contributes to the achievement of Canada's objectives of increasing economic growth, creating jobs and wealth, and supporting sustainable development in many areas of technology. The program is a key element of the Government of Canada's strategy to build a more innovative Canada. By sharing the risks of private sector investment in innovation, Technology Partnerships Canada spurs growth in the technology base and technological capabilities of Canadian industry.

TISEC Inc. has produced a number of products, including a sourcebook for hydrogen applications, safety and reliability studies, and code compliance. The sourcebook provides information to facilitate designing, building and operating hydrogen systems for new transportation applications, including fuel cells.

Transport Canada's mission is to develop and administer policies, regulations and services for the best transportation system for Canada and Canadians – one that is safe and secure, efficient, affordable, integrated and environmentally friendly.

University College of the Fraser Valley is a comprehensive educational institution, offering bachelor's and associate degree programs, academic and applied diplomas and certificates, trades training and continuing education. Fuel cell technology is an important focus for its applied research in alternative energy solutions.

Ventures West Management funds some of Canada's leading technology companies. It was a lead investor in Ballard Power, QuestAir, Cellex, Statpower (sold to Xantrex), Inverpower (sold to Satcon), Astropower, Greenlight Power, NxtPhase and Serveron.

Western Economic Diversification Canada has provided support to the fuel cell sector since 1990, and continues to partner closely with Fuel Cells Canada, Industry Canada, the National Research Council, the Provinces of BC and Alberta, and other industry stakeholders to identify and collaborate on initiatives that support and accelerate the growth of the fuel cell sector.

Fueling Infrastructure

A number of corporations across Canada are involved in the development of the fuel infrastructure necessary for the success of fuel cell applications.

BC Hydro uses renewable electricity and has an extensive distribution network to produce hydrogen for industrial, transportation and portable power markets. Hydrogen is part of its diversification strategy to move the company into the sustainable energy market. BC Hydro and its research subsidiary, **Powertech Labs**, are positioning to be major contributors to the emerging hydrogen economy through the sale of hydrogen and commercialization of hydrogen technologies.

Duke Energy (formerly Westcoast Energy) is one of the largest North American players in the natural gas industry. The company operates a $15-billion network of natural gas gathering, processing, transmission, storage and distribution assets, as well as electric power generation, international, financial, information technology and energy services businesses.

Enbridge Gas Distribution is Canada's largest natural gas distributor and one of the fastest growing natural gas companies in North America, serving 1.5 million residential, commercial and industrial customers.

ENRG designs, installs and services natural gas stations throughout California, Arizona, Ontario and British Columbia.

General Hydrogen Corporation develops technologies and invests in companies involved in the development and introduction of hydrogen infrastructure. The company has a 25-year strategic alliance with General Motors Corporation, with a focus on advancing fuel cell related technologies.

Kraus Group is a designer and manufacturer of transportation refueling systems. It manufactures and packages complete refueling stations for compressed natural gas, propane and compressed hydrogen.

Methanex Corporation is the world leader in methanol production and marketing. The company is working with some of the world's leading companies to advance the commercialization of fuel cell technology and introduce methanol as a cost-competitive and environmentally-friendly fuel alternative.

Ontario Power Generation is one of the largest generators of electricity in North America. It is participating with Siemen's Westinghouse, the Government of Canada and the US Department of Energy in the development of the 250 kW Solid Oxide Fuel Cell (SOFC) design. A pre-commercial unit is currently in the commissioning stages in Ontario.

Stuart Energy Systems Corp. is a leading developer and supplier of hydrogen generation and supply systems. These systems incorporate proprietary water electrolysis technology designed to service the industrial hydrogen market and the emerging hydrogen fuel market for transportation and regenerative electric power applications.

Stuart Energy and Powertech hydrogen refueling station, and the Ford Focus FCV.

PARTICIPATING COMPANIES AND ORGANIZATIONS