

# Canadian Fuel Cell Commercialization Roadmap Update

— Progress of Canada's Hydrogen and Fuel Cell Industry



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of Canada

Gouvernement  
du Canada

Canada

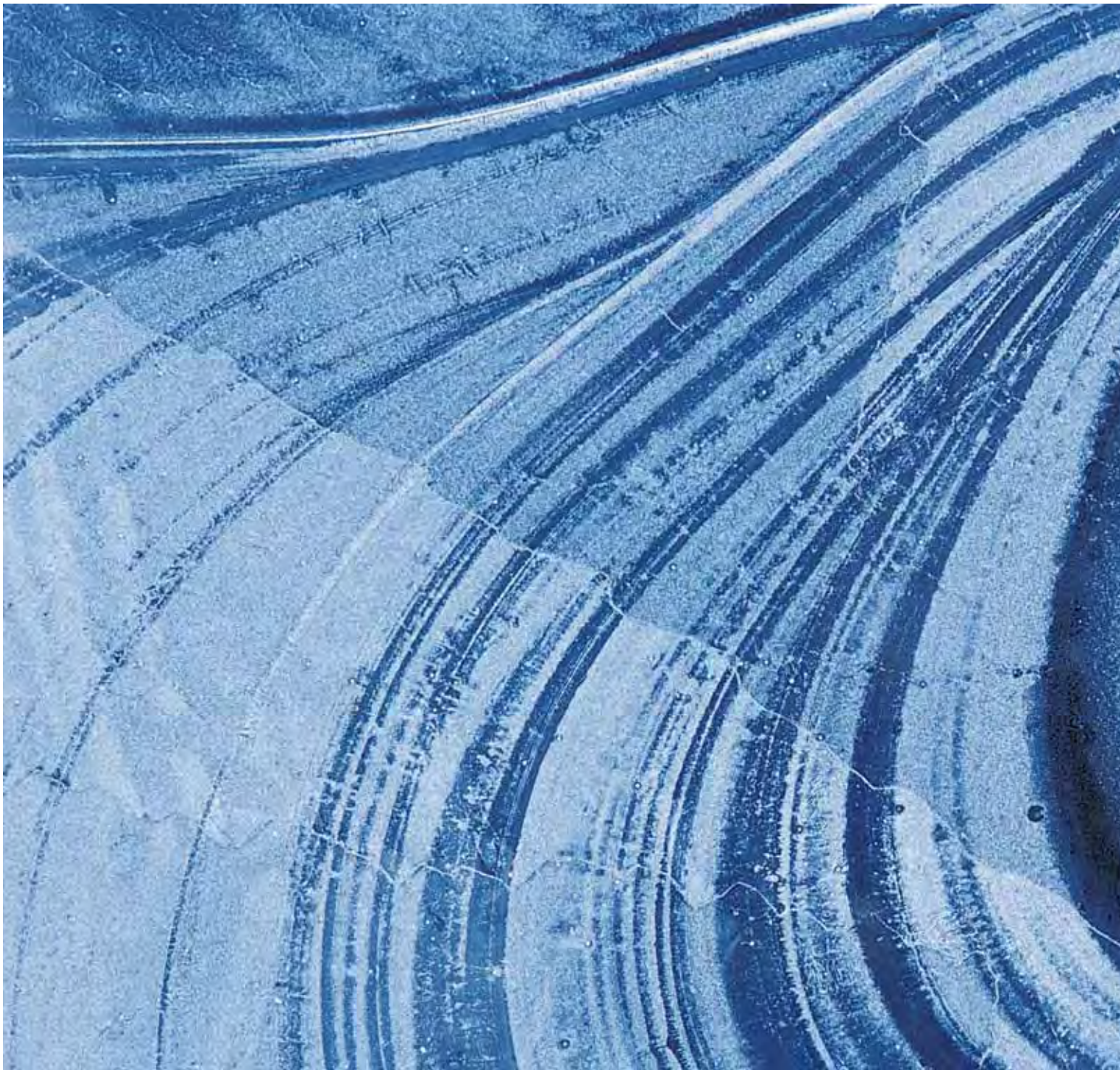
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December 2008



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## Interviews

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Angstrom Power Inc.  
Automotive Fuel Cell Cooperation  
Ballard Power Systems Inc.  
BC Transit  
Bell Canada Enterprises  
Exxon Mobil Corporation  
Hydrogenics Corporation  
Hyteon Inc.  
Interlink Connectivity Inc.  
The Linde Group  
Motorola Canada Ltd.  
Plug Power Inc.  
Powertech Labs Inc.  
Purolator Courier Ltd.  
QuestAir Technologies Inc.  
Sacré-Davey Group  
Tekion Inc.  
The Raymond Corporation  
TransLink

## Workshop

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# Executive Summary

Since 2003, the concept of the Hydrogen Economy has evolved. Over the past five years, technology advances have provided many viable alternative energy and transportation options. Today, a more inclusive vision recognizes a significant contribution of hydrogen and fuel cells towards a cleaner, more diversified energy and transportation mix.

The mass market potential of hydrogen and fuel cell solutions retains its lure for government and others seeking enhanced security, diversity of energy supply and the reduction of pollution and greenhouse gas emissions. National governments around the world, including the US, Germany and Japan, are taking an active role in developing technology of benefit to society and the environment. In their policy context, a technology push approach to achieve mass market deployment in the longer term is justified by these “common good” benefits. While they remain committed to developing hydrogen and fuel cell solutions, governments are hedging their investments across a mix of technologies.

This wider vision has moved beyond the long-term commercialization of fuel cell automobiles to encompass commercialization in near-term markets where products can be deployed using current technology and which require a much simpler fuelling infrastructure. The automotive original equipment manufacturers (OEMs) have demonstrated their commitment to the development of fuel cell vehicles through their collective investment of billions of dollars in research and development. They do however, remain dependant on the roll-out of the hydrogen fuelling infrastructure which to date has not received the same level of investment from energy companies. The most promising near-term market applications include materials handling, backup power, transit buses, and portable electronics.

These near-term markets play an important role in paving the way for the commercial fuel cell automobile by providing an early build-out of hydrogen infrastructure while addressing factors such as cost, durability and reliability. They will also provide early gains in the reduction of greenhouse gas (GHG) emissions. The total reduction in GHG emissions anticipated from these near-term markets is estimated to be equivalent to removing up to one million gasoline passenger vehicles from the road over the next ten years. The 20 hybrid fuel cell buses to be deployed in British Columbia alone will provide a 62% reduction in greenhouse gas emissions relative to their diesel equivalents based on a fuelling solution with liquid hydrogen supplied from Quebec.

For the past 20 years, Canada has led the way in the global hydrogen and fuel cell sector. Today, the Canadian industry is comprised of 80 relatively small, knowledge-based enterprises. Over the past five years, these companies have made average annual R&D investments of approximately \$200 million — a level of investment equivalent to one third of the total energy industry R&D expenditure in Canada. While the industry continues to make significant technical and commercial progress, competition in both investment and end-user markets is becoming increasingly fierce. Large, well financed

multinationals operating in the energy, automotive and electronics sectors are active across all fuel cell markets. Canadian public funding of fuel cell programs falls far below many other countries, including the United States, the European Union and Japan.

In light of these considerations, many Canadian companies have restructured their operations and refocused their research and development investments away from the fuel cell passenger car towards product sales in near-term markets. These products include fuel cell forklifts, backup power systems, portable electronics and urban transit fuel cell buses. This strategy has enabled firms to concentrate on refining and marketing applications that will generate early revenue streams, cultivate investor confidence and provide a platform to build consumer awareness and acceptance.

Refocusing their efforts on near-term markets has allowed Canadian fuel cell and hydrogen companies to make significant progress towards cost, performance and reliability targets and infrastructure development. The cost and performance of fuel cells, for example, have improved seven fold over the past five years. The industry is also working with government to create the world's first large scale, integrated demonstration projects – the Hydrogen Highway and the Hydrogen Village.

The Canadian industry continues to maintain its enviable international position. Fuel cells produced by Canadian companies are being rigorously tested and commercially deployed in residential cogeneration (co-gen), backup power, portable electronics, materials handling, and transit bus applications. Canada is a key contributor to the global industry's annual growth rate of 59% in fuel cell units. Ballard alone accounted for almost 10% of the total 2007 North American production of fuel cells and 22% of the residential co-gen and backup power units shipped globally in 2007.

## A Near-term Market Approach

### Materials Handling

Canada has been a pioneer in the fuel cell materials handling sector and today, Plug Power and Hydrogenics together, are deploying hundreds of fuel cell lift trucks to Wal-Mart's 24 hour, three-shift warehouses and to GM's assembly plant operations. As sales volumes increase, significant reductions in cost are expected. The market is expected to evolve from battery replacement to purpose built lift trucks as demonstrated by The Raymond Corporation's partnership with Ballard Power Systems to co-develop a new generation of fuel cell lift trucks.

### Backup Power

In the domain of backup power, the battery costs required to comply with new government regulations anticipated in many jurisdictions mandating eight hours of backup operation time for emergency communication services are making fuel cell technology

more competitive. With existing international partnerships with companies including Dantherm, India based ACME Tele Power Ltd. and American Power Conversion, Canadian fuel cell companies are well positioned for the backup power expected to support demand for 75,000 units by 2010.

### Residential Cogeneration

In Japan, a competitive and well coordinated government-assisted program is underway to validate the viability of a one kilowatt (kW) residential cogeneration fuel cell system powered by natural gas, LPG and kerosene. This program includes many multinational companies such as Sanyo, Toyota and Matsushita (Panasonic), as well as the huge Japanese energy companies like Tokyo Gas, Osaka Gas and Nippon Oil. Canadian-based Hyteon and Ballard Power Systems have gained a foothold in this highly competitive near-term market through strategic partnerships with large Japanese utilities. Products from these Canadian companies account for close to one quarter of the total number of units installed.

### Portable Electronics

Canadian companies like Angstrom and Tekion are working on alternatives to direct methanol micro fuel cells for handheld and laptop electronic devices. They are addressing the escalating demand for energy density and extended run times that are challenging traditional batteries. Canadian players were instrumental in the International Civil Aviation Organization (ICAO) Dangerous Goods Panel approval of regulatory proposals for aircraft passenger cabin exception for fuel cell cartridges containing formic acid as a direct fuel, and hydrogen in metal hydride storage solutions.

### Buses

BC Transit, with funding assistance from the Province and the Public Transit Capital Trust, is leading a project to deploy 20 hybrid fuel cell buses into commercial operation. These buses will be showcased in Whistler during the 2010 Olympic Games. Many Canadian transit authorities are supportive of a broader deployment of fuel cell technology into the community shuttle bus network that exists in many urban areas. Canadian bus manufacturer, New Flyer, recently signed an exclusive agreement with Ballard Power to develop fuel cell shuttle buses for the North American market. Internationally, interest in using Canadian expertise is high, including a new project with London (UK) to purchase five hybrid fuel cell buses powered by Ballard fuel cells. Through the formation of numerous consortia and the support of government and transport authorities, there are a growing number of fuel cell bus deployment programs in the pipeline.

## Infrastructure

Over the short to medium term, it is expected that the existing industrial hydrogen infrastructure is sufficient to service niche fuel cell markets. Gaseous compressed, cryogenic hydrogen, and waste streams will be sufficient to meet the fuelling needs for materials handling, backup power and buses. With a diverse energy base, Canada has multiple hydrogen production pathways, including renewables, hydro-electricity, and natural gas and coal with carbon capture and sequestration. While Canada produces most of its hydrogen in the chemical and refining industry, it also produces roughly 200,000 tons of waste hydrogen every year. This amount of hydrogen is equivalent to approximately 800 million litres of gasoline. Air Liquide is slated to build the world's largest hydrogen refuelling station in Whistler, BC, dispensing 1,000 kg of renewable and waste hydrogen daily. With key players like Air Liquide, Hydrogenics, Sacré-Davey, Dynetek, QuestAir, and in its partnerships with Linde, Canada is a leader in electrolytic production of hydrogen from renewable energy sources, natural gas, compressed gas storage solutions, as well as in the capture of waste hydrogen sources and production and distribution of cryogenic hydrogen. Over the longer term, renewable energy, biomass and nuclear power are expected to be key sources of hydrogen production. Hydrogen produced for the oil and gas industry, which could be potentially redirected to meet the needs of mass fuel cell markets, is also expected to be a source of fuel.

## The Path Forward

While the opportunity for commercial growth has improved significantly since 2003, there are still end-user concerns around cost and reliability. Adopting a new technology into an existing, highly efficient operating system such as a warehouse, telecommunications network or public transportation system, is accompanied with risks for the end-user. There are infrastructure challenges with new fuel systems, different types of safety issues and staff training requirements, among other things. In virtually all applications, fuel cell technology is required to replace well-established, mature, well-supported and cost effective incumbents such as Internal Combustion Engine (ICE) and battery technology. While many end-users see value in the “clean” aspect of fuel cell technology, they do not tend to assign a significant economic value to this attribute, and focus more on the standard value propositions of price, performance and reliability. For mass market applications like the passenger vehicle, traditional cost assessments that examine the economic costs and not the full societal and environmental costs of a product, prevent hydrogen and fuel cell technologies from being competitive with current commercial offerings. However, even in light of these barriers, the market growth for fuel cell technology into near-term markets has never looked so promising.

It is important to highlight that the fuel cell development driven by the automotive sector is a critical part of the overall development of fuel cells for commercialization. There is

significant synergy between automotive and non-automotive fuel cell developments, especially in the areas of fundamental understanding and development of fuel cell components in the supply base. While there are some differences in the requirements from each application, for example only the automotive application requires fast and robust freeze-start capability, there are many areas that are synergistic, such as lower cost materials, lower catalyst loadings, and designs that are capable of high volume manufacturing. Ford and Daimler now have their fuel cells developed by Automotive Fuel Cell Cooperation (AFCC), the Vancouver, Canada based successor of the automotive division of Ballard Power Systems. AFCC is one of the world leaders in automotive fuel cell development, and is one of the largest fuel cell development centres in the world.

Fuel cell technology and, perhaps even more importantly, the demonstration and validation of the technology in near-term commercial applications has advanced considerably over the last five years. Canadian stakeholders estimate (2010) global near-term markets demand at 1.1 million units. Further, they expect to achieve durability measures of between 10,000 and 40,000 operating hours, depending on the application, and reliability measures of between 95% and 99%. Effective commercialization of near-term markets will achieve significant value for longer-term mass markets including keeping existing companies in business, generating profits and renewed investor confidence and interest; continued expansion of employment and training of key skills for future mass markets; building business for component suppliers to develop better materials; and developing a total systems understanding of hybridization technologies, controls strategies and software that could be of direct use in mass market applications. Sustained success in these near-term markets will be critical to building the capacity for Canadian companies required to participate in the longer term mass markets. Key aspects of this capacity building will be the further expansion of the base of skilled technical and manufacturing personnel, increased production capacity and associated university and government research activities. Streamlined and focused R&D programs for commercialization, support to expand global value chains, the efficient local adoption of codes and standards, as well as cost effective product deployments will also help Canada maintain its position as a key player in the global hydrogen and fuel cell industry.

As the hydrogen and fuel cell mass markets in portable electronics, residential cogeneration, and electric mobility open up, this Canadian capability proven in the near-term markets will be sought out by automotive OEMs and other strategic partners needing access to competitive hydrogen and fuel cell technology and know-how. Canada has an opportunity to bolster the commercialization of these home grown technologies to help reduce greenhouse gas emissions and air pollution to mitigate the effects of climate change, and benefit many sectors, including transportation, manufacturing and telecommunications.





# Preface

## Background on the 2003 Fuel Cell Commercialization Roadmap

Industry Canada facilitated a Roadmap process with the Canadian fuel cell sector in 2002/03. The Roadmap process was funded by Industry Canada and the Climate Change Technology Development and Innovation Program. The Roadmap was aimed at accelerating full-scale commercialization of Canadian hydrogen and fuel cell technologies to capture benefits from substantial industrial investments in research and development and to develop long-term solutions to meet Canada's climate change goals. The process was facilitated by Industry Canada and developed by senior representatives from 45 industry, governmental and research organizations. The Roadmap identified key recommendations to be undertaken by industry, research and government to realize potential economic, environmental and social benefits from the deployment of fuel cell technology and to help maintain global leadership of Canadian companies in the sector.

The Roadmap reinforced the need for collaboration among government, industry and academia to realize commercialization goals. It also strengthened international relationships and provided the Canadian pathway in global roadmaps, including a world roadmap developed by the International Partnerships for the Hydrogen Economy. It also served as a benchmark for roadmaps conducted by a number of foreign nations, including UK, Australia, APEC economies, Mexico and South Africa.

In October 2003, the Government of Canada announced a five-year \$215 million investment in the transition to the Hydrogen Economy. The Hydrogen Economy Initiative was directed by three strategic priorities that were identified in the Roadmap: early adoption of hydrogen solutions through integrated demonstration projects undertaken in partnership; initiatives aimed at establishing hydrogen infrastructure and improved performance and reduced costs of hydrogen technologies; and, the extension of Canadian leadership through research and development of innovative new applications in strategic areas of the hydrogen and fuel cell value-chain. Over the five-year term, significant technological progress was made on cost, performance, reliability and infrastructure development. Cost and performance of fuel cells improved seven fold and the industry worked with government to create the world's first large-scale, integrated demonstration projects — the Hydrogen Highway and the Hydrogen Village. The Hydrogen Economy Initiative, as scheduled, sun-set at the end of March 2008.

Industry Canada has an opportunity to continue a strong partnership with Canada's hydrogen and fuel cell sector and, together with stakeholders, determine priorities for supporting the deployment of near market products and supporting hydrogen infrastructure. This update to the 2003 Fuel Cell Commercialization Roadmap complements current work in progress and provides concrete updates on technology progress, and analysis of linkages with the longer term mass markets.

The work contributes to Industry Canada and Government of Canada objectives, including the environment, climate change, competitiveness and the science and technology agenda.



# Methodology

Industry Canada has worked in partnership with public and private stakeholders to provide an update to the 2003 Canadian Fuel Cell Commercialization Roadmap. The Commercialization Update used both primary and secondary sources of information. An industry-led process was completed to provide an update on the industry, technology development (cost and performance), and market deployment, and to examine infrastructure requirements for near-term markets focused on deployment of fuel cell buses, forklifts, backup power, and portable electronics applications.

## Literature Review

An initial literature scan was conducted to gather data on fuel cell deployments and the state of the industry globally.

## Interviews with Industry and End-users

In order to focus on the commercialization and market deployment of hydrogen and fuel cell related products in Canada by Canadian companies, it was imperative to gain perspective from end-users as well as from developers and manufacturers.

During March 2008, PricewaterhouseCoopers conducted one-on-one interviews with CEOs and key technical contacts from fuel cell technology developers, integrators and infrastructure companies, as well as fuel cell sector end-users from the five user groups:

- Buses
- Backup Power
- Residential Cogeneration
- Materials Handling
- Portable Electronics

In total, 28 interviews were conducted. The summary findings from the interviews were shared with the Update team and incorporated into this report.

## Target Setting

In addition to the interviews, five survey questionnaires were created to develop key technology, product and market targets for each of the five sectors.

These targets were discussed and validated at a workshop held in April 2008 attended by representatives from industry, government and academia. The output of the workshop appears in this document.

## Reporting

The findings from the literature review, interviews and target validation workshop were distilled and analysed to identify common trends and key information points for inclusion in this final report.

This final report sets the stage for initial discussions on R&D priorities related to commercialization of near-term hydrogen and fuel cell products.



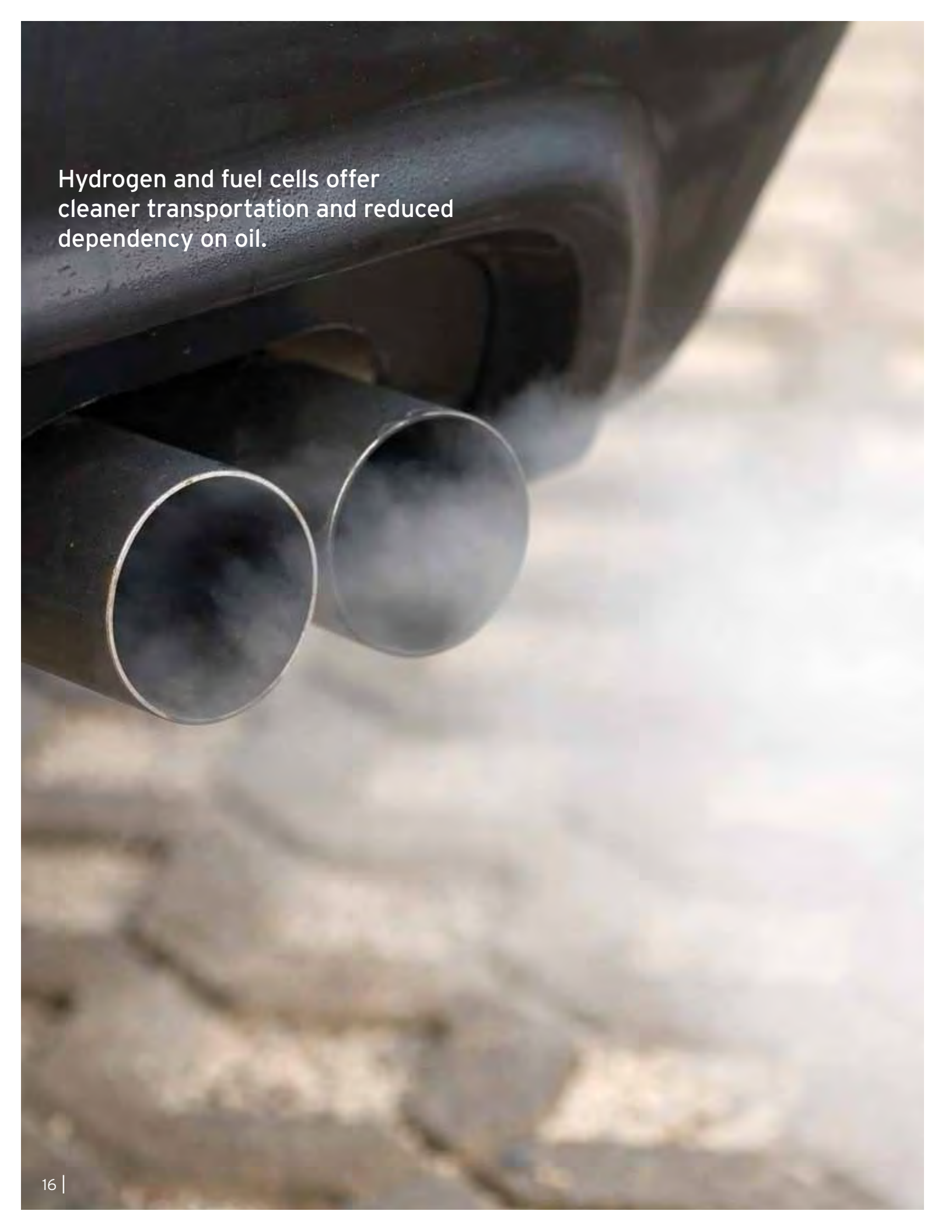


# Introduction

This Canadian Fuel Cell Commercialization Roadmap Update begins by outlining why hydrogen and fuel cells are considered an essential part of the future low carbon energy system for transportation and stationary power, and an energy innovation in portable electronics. It continues by providing an overview of global hydrogen and fuel cell markets as background and context for the activities of the Canadian industry.

Approaches toward commercial viability and mass market success are then presented. These approaches have been probed in interviews with CEOs and CTOs of leading Canadian companies and senior managers of international companies who are active Canadian partners as suppliers and early adopters. These executives provided their perspectives on the market and technology challenges that must be overcome to achieve success in the near-term markets and to position their companies for further mass market participation.

A possible scenario and process by which these mass markets could develop is then discussed, including a perspective on the build-out of the hydrogen infrastructure. The Report concludes with a discussion of hydrogen and fuel cell industry priorities and recommendations for action.

A close-up photograph of a vehicle's exhaust system. Two black, cylindrical exhaust pipes are visible, with a thick plume of white smoke or steam emerging from the right-hand pipe. The background is a blurred, light-colored surface, possibly a road or pavement. The text "Hydrogen and fuel cells offer cleaner transportation and reduced dependency on oil." is overlaid in the upper left corner.

Hydrogen and fuel cells offer cleaner transportation and reduced dependency on oil.

# The Rationale for Hydrogen and Fuel Cells

Hydrogen has a number of properties that make it an attractive energy carrier: it is carbon free, exceptionally clean as a fuel, lighter than air, odourless, non-toxic, and has a more favourable energy-to-weight and energy-to-volume ratios than any battery technology. When mixed with air, it also has a high rate of diffusion and dispersion, thus providing important safety advantages over conventional liquid fuels.

Hydrogen can be produced from primary energy sources such as natural gas, biomass, coal and oil, and from nuclear and renewable energy sources. Two of the most common processes used to make hydrogen today are electrolysis (splitting water into hydrogen and oxygen) and steam methane reforming (using high temperatures to extract hydrogen from fossil fuels, most commonly natural gas). Currently, the latter is being used for 95% of total hydrogen production for the chemical and refining industries.

Hydrogen's adaptability as an energy carrier means it can play an important role in extending our current energy supplies. It can be used as a vehicle fuel in both internal combustion engines (ICEs) and fuel cells. It can also be used to store energy produced by wind, solar, hydroelectric and nuclear power so that it is available when needed.

Hydrogen is increasingly being used in alternative energy systems, including hydrogen-fuelled ICEs. This document, however, will concentrate on the use of hydrogen in Proton Exchange Membrane (PEM) fuel cells, which operate much like batteries and can be designed to power everything from two-way radios and cellphones to automobiles to entire buildings. Unlike batteries, however, these devices do not discharge electrode material and can be refueled quickly, rather than via time-consuming recharging.

Hydrogen fuel cells work by electrochemically combining hydrogen and oxygen to generate electricity, heat and pure water. Relative to combustion, they are inherently more efficient in converting carbon-based energy sources to electricity and have none of the nitric oxides (NOx) or particulate emissions inherent to combustion.

Fuel cells are the key to using hydrogen efficiently while offering grid-free mobility. Without them, hydrogen is not an optimal alternative to most current energy conversion technologies. Used together, however, fuel cells and hydrogen have the potential to contribute significantly to the global energy paradigm in very positive ways.

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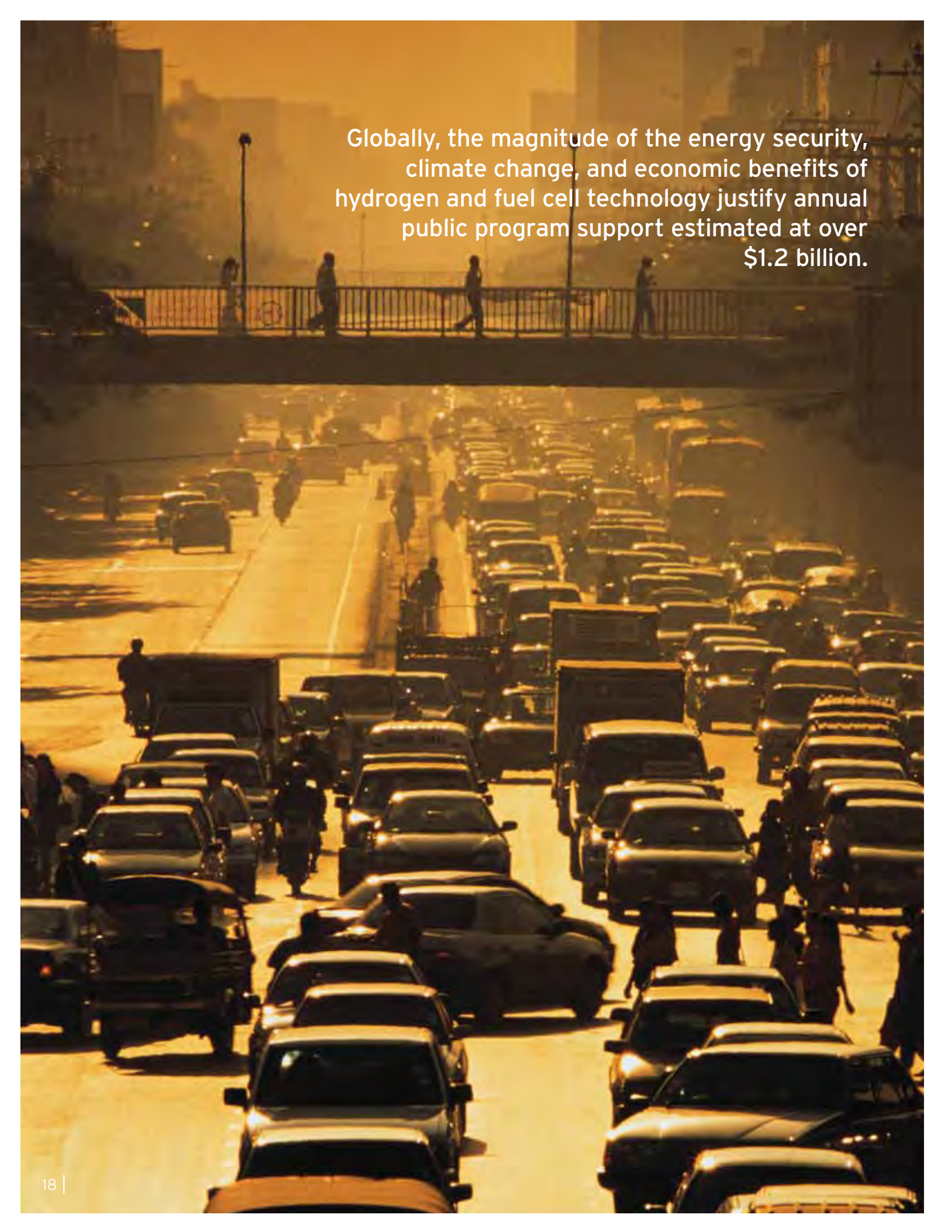
## Important facts that influence the success of hydrogen and fuel cell technologies:

- The electrochemical efficiencies of fuel cells are inherently greater than the thermodynamic efficiencies of combustion engines.
- Increasing energy prices, rising energy security and environmental concerns are driving the desire to diversify and de-carbonize sources of energy.
- Hydrogen is a storable energy carrier that can be produced from many sources, including fossil fuels.
- Hydrogen offers the potential to diversify the transportation energy mix, and hence reduce our dependence on oil.
- Fuel cells, in combination with materials containing hydrogen, can store more energy by weight or volume than any known battery technology.
- Hydrogen is key to the operation of PEM fuel cells for transportation, which is the largest sector drawing on oil imports in OECD countries.

## Developments mitigating against the early deployment of automotive fuel cell technologies:

- Incumbent combustion technologies have inherently lower initial costs.
  - Incumbent battery technologies can make use of the pervasive electrical grid for re-charging.
  - Plug-in hybrid electric vehicles can be a more efficient and sustainable transportation technology for vehicles travelling less than 70 km between recharge cycles.
  - Adoption of other fuels for combustion technology, such as E85 and ethanol, as well as flexfuel vehicles all add up to a deceleration and dilution in the adoption of fuel cell vehicles.
-



A photograph of a busy city street with heavy traffic and a pedestrian bridge in the foreground, all bathed in a warm, golden light. The scene is hazy, suggesting either early morning or late afternoon. The text is overlaid on the upper right portion of the image.

Globally, the magnitude of the energy security,  
climate change, and economic benefits of  
hydrogen and fuel cell technology justify annual  
public program support estimated at over  
\$1.2 billion.

# The Global Commercialization Context


Competition for private and public funding has played a significant role in the evolution of the sector. Recognizing that the long time-lines to commercialization in mass markets such as the commercial automobile have reduced the investment interest of the financial community, many hydrogen and fuel cell companies are building viable businesses in near-term markets where immediate revenue can be generated from technologies in their present state of development. In these markets, customers are experiencing less than satisfactory performance from incumbent energy technologies and are willing and able to transition to alternate energy solutions.

But the mass market potential retains its lure. In the global context, mass markets are still the primary driver for the continuing and indeed growing government interest. The potential for these technologies to help address issues of climate change, urban pollution and energy security remains a large motivator for governments in the United States, the European Union and Japan. Here, these “common good” benefits justify programs and policies reflecting a technology push approach towards longer-term deployment of fuel cell technology.



## The Government Drivers for Commercialization: Climate Change, Urban Pollution and Energy Security

With the notable exception of nuclear power and hydroelectricity, most of our energy needs have been met with technologies based on the combustion of fossil fuels. Over the past ten years however, governments have been supporting the development and deployment of alternative energy technologies to improve energy security, mitigate climate change, and reduce urban pollution. This support has taken various forms depending on, and appropriate to, the development stage of the technology and the benefits being sought. In the United States, the Department of Energy awards research and development contracts to advance basic science and early technology development. The Canadian government is integral to the BC Hydrogen Highway demonstration project. In Germany, feed-in tariffs support the large-scale deployment of several alternative energy technologies. In Japan, government programs are helping to subsidize the medium-scale domestic deployment of fuel cell-based units for residential cogeneration of heat and power (residential co-gen).



The further development of hydrogen storage devices, deployment of hydrogen infrastructure, hydrogen safety education and hydrogen purity standards will positively impact the onset of mass market applications.

Vancouver Downtown  
Photographer: Wendy Strandt

## Addressing Climate Change with Fuel Cell Technology

Globally, the magnitude of the energy security, climate change and economic benefits of hydrogen and fuel cell technology justifies annual global public program support estimated at over \$1.2 billion.<sup>1</sup>

### United States – \$512 million/year

The US Department of Energy has two major programs. The first is the Hydrogen, Fuel Cells and Infrastructure Program funded at \$300 million annually and focused on hydrogen and PEM fuel cells for vehicles. The second is the Solid State Energy Conversion Alliance which is focused on the use of carbon based fuels and hydrogen in solid oxide fuel cells for stationary power. This program is funded at \$60 million annually.

The US Department of Defense supports various hydrogen and fuel cell programs with funding of \$152 million. Various state governments, such as New York, Connecticut, Ohio, Texas and California, also have well funded programs, most of which focus on subsidies for early commercial deployment of hydrogen and fuel cell systems.

### Japan – \$310 million/year

In 2007, hydrogen and fuel cell related funding totaled \$310 million. As in previous years, this funding was spread across fundamental research on PEM and solid oxide fuel cells, hydrogen production and purification technologies, and the substantial residential co-gen demonstration program. Japan is also focused on developing the codes and standards on which to base a receptive regulatory regime.

### European Commission – \$236 million/year

The Hydrogen and Fuel Cell Joint Technology Initiative identified \$110 million in targeted average annual funding over six years. In addition, hydrogen and fuel cell proposals can compete with other energy research initiatives for energy research funding of \$3.3 billion.

Individually, member states also have targeted programs. Germany has a ten year program with average annual funding of \$70 million. Programs in the UK total \$26 million, and in Denmark, annual funding is slated to grow from \$24 to \$48 million over the next ten years.

### **Korea – \$98 million/year**

The Korean government has budgeted \$688 million from 2004 to 2011, an average annual expenditure of \$98 million, to support hydrogen and fuel cell research, development, demonstration and deployment. The funding is focused on the development of fuel cell vehicles and residential cogeneration applications.

### **China – \$60 million/year**

It is estimated that China provides funding at a level of about \$60 million per annum, and that to date, China has invested approximately \$2.8 billion in fuel cell and infrastructure research and development.<sup>2</sup>

### **Canada – \$30 million/year**

Canadian government funding for hydrogen and fuel cells has historically been spread across a number of ministries with total average annual funding of \$30 million. About one-third of this funding supports programs at universities and government labs, with the other two-thirds split between companies and end-users to support product development and demonstrations.

## Environmental Concerns: The Near-term Market Driver for Urban Transit

Hydrogen fuel cell buses are zero emitters of GHG and criteria air contaminants, while hydrogen fuelled internal combustion engine buses are near-zero emitters.

Transit buses are one of the best applications for demonstrating alternative fuels and advanced technology systems. They provide an immediate contribution to pollution reduction in the highly urbanized areas where they typically operate, Infrastructure logistics are more straightforward due to the centralization of fueling facilities, and the buses provide the high visibility necessary for communications and outreach purposes.

Since urban transit operations are already government subsidized, this application provides a platform for governments to show ongoing support of new technologies and leadership in GHG reductions. Government engagement in the sector also provides manufacturers with the much needed assurance of market demand for clean vehicle technologies. Demonstrations and early deployments also spur the development of hydrogen refuelling infrastructure and generate a cluster of activity that enhances the visibility of hydrogen and fuel cell related activities.

Hydrogen fuel cell buses have been demonstrated in many cities since the early 1990s. Today, there are over 60 fuel cell buses running in 40 separate initiatives worldwide. Within the next two years over 200 more buses are planned to be ordered or deployed across five continents. The Clean Urban Transit for Europe (CUTE), the most extensive fuel cell demonstration project, was started in 2003 and continues to this day with fuel cell buses operating in cities across Europe.

Over the operating life cycle of a bus in the EU, the cost of health and GHG impacts associated with diesel bus emissions have been estimated at 130,000 euros. The European Union is proposing to mandate that public agencies include these costs at the time of procurement. The effect of this mandate would be to almost double the present 150,000 euros cost of a diesel bus.<sup>3</sup>

Internationally, large urban centres are developing collaborative approaches towards the deployment of fuel cell transit and shuttle buses and the development of the necessary infrastructure. The Hydrogen Bus Alliance is a good example of the work currently underway to accelerate the commercialization of this near-term market.

Through the formation of numerous consortia and the support of government and transport authorities, there are a growing number of fuel cell bus demonstration programs in the pipeline. Advances in stack hardware, system design and hybridized operation offer a new generation of fuel cell engines where 10,000 hours of durability is not only claimed but, in some instances, warranted by the supplier.

### The Hydrogen Bus Alliance



## Hydrogen Bus Alliance

Created to further the aim of zero emission public transport, the Alliance includes public transit agencies from Amsterdam, Barcelona, Berlin, British Columbia (BC Transit), Cologne, Hamburg, London, and South Tyrol. They have formed a unified end-user base for hydrogen buses, which will work to accelerate the commercialization of hydrogen buses to the benefit of their citizens. The Alliance has three main aims:

- To share information on existing hydrogen bus procurement activities (each city will deploy at least five hydrogen buses in the short term).
- To promote the use of hydrogen buses in other regions and cities, by expanding Alliance membership and sharing of information.
- To develop a strategy for joint Alliance activities (including possibly common purchasing) to bring hydrogen fuelled buses closer to commercialization.

At present, the Alliance represents a cumulative fleet of over 12,000 buses and an average yearly purchase of over 1,200 city buses. The cities and regions all intend to move towards procuring hydrogen buses on a continuous basis as hydrogen buses move towards commercial viability in the 2010-2015 time frame.<sup>4</sup>

## The Impact of Near-Term Markets on Greenhouse Gas Reduction

To varying degrees, near-term market applications are expected to reduce GHG emissions. By the year 2025, estimates of total GHG emission reductions attributable to fuel cell applications in near-term markets range from 31,000 to 116,000 tons – equivalent to removing 1.4 to 5.6 million passenger vehicles from the world’s roads (Figure 1).

### Heavy Duty Transit Buses

GHG emissions from a conventional urban diesel bus range from 3,000 to 7,000g CO<sub>2</sub>e/mi/year. Combined with an annual trip range of 20,000 to 50,000 mi., diesel buses emit between 140 to 150 tons CO<sub>2</sub>e/year. A bus powered by fuel cells using renewable hydrogen would displace all of these GHG emissions. Hybridizing diesel buses would yield a 20 to 40% reduction in GHG emissions. Analysis conducted for the State of California indicates that a fuel cell bus running on hydrogen either reformed at a central station and pipelined, or reformed on-site, would reduce GHGs by 23% when compared with a diesel bus running on California low sulphur diesel. On this basis a hydrogen fuel cell bus run completely on hydrogen from renewable resources would displace 65 to 163 tons/CO<sub>2</sub>e/year of diesel bus emissions.

### Backup Power Systems

2.5kW, 5kW and 10kW backup power units using hydrogen derived from natural gas reduce emissions proportional to the duration of equipment operation, approximately 0.3 tons per 1,000 hours of operation. If the 2.5kW, 5kW and 10kW backup power units were similarly run on renewable hydrogen, they could displace roughly two, four and eight tons of emissions, respectively.

### Residential Co-gen Units & Distributed Generation

In Japan, over 2,200 fuel cell units from 15 utilities and fuel suppliers currently provide hot water and additional energy for homes. Ranging in power from 0.7kW to 1kW, the units run for nine hours a day and provide GHG emission reductions on average of 1.021 tons/year. Looking at distributed generation applications in which electric generation occurs at or near the point of end use, these systems could provide GHG reductions of

one tonne CO<sub>2</sub>/year for each kilowatt of power. Based on this, if the same 5kW units were similarly run on renewable hydrogen, they could displace roughly 30 to 40 tons CO<sub>2</sub>/year.

### Materials Handling

Independent analysis determined that lift trucks using fuel cells and hydrogen reformed from natural gas demonstrate a 25 to 50% reduction in emissions relative to lift trucks run on propane and diesel. This would reduce GHG emissions by 4.3 tons/year on only a 6hr/260day work schedule.

Figure 1: Key Fuel Cell Estimates of Environmental Impacts

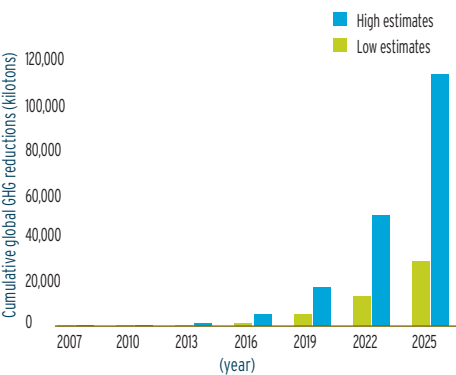
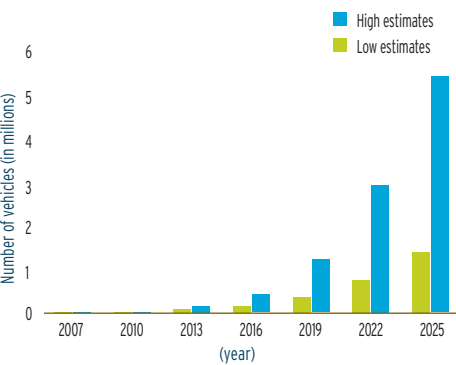


Figure 2: Estimated GHG Reductions on Vehicle Equivalent



Source: CEERT, GHG reductions from fuel cell products, October, 2007  
Ballard Power Systems, Inc.

## British Columbia Fuel Cell Bus Program



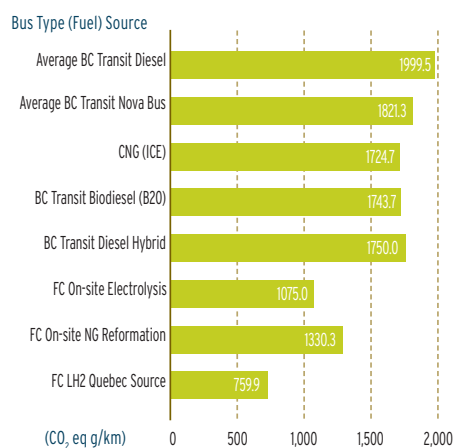
Photo: First delivered BC Transit Fuel Cell Bus

BC Transit, with funding assistance from the province and the Public Transit Capital Trust, is leading a project to deploy 20 hybrid fuel cell buses into commercial operation. These buses will be showcased during the 2010 Olympic Games.

These buses will provide a 62% reduction in GHG emissions relative to their diesel equivalents, based on a fuelling solution with liquid hydrogen supplied from Quebec. This reduction is based on the expected fuel economy of the fuel cell bus at 10 kg of hydrogen per 100 km versus a base diesel bus at 55 litres of fuel per 100 km.

To fuel the fleet, the province has partnered with Air Liquide Canada to supply hydrogen. To start the process, BC transit, with help from federal and provincial governments, will invest in a new hydrogen fuelling station in Whistler, which will be yet another stop on the BC Hydrogen Highway.

Figure 3: GHG Emissions Summary



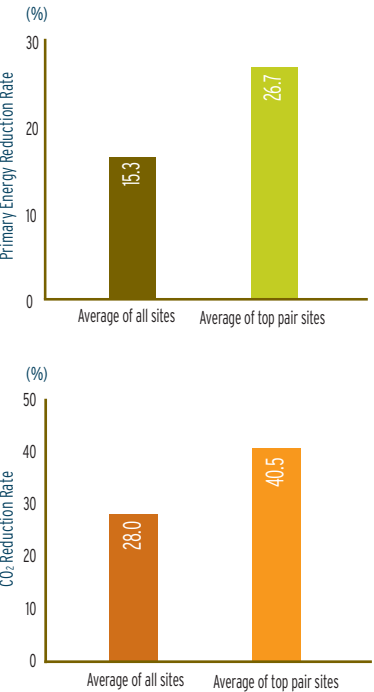
Source: Life Cycle Assessment of Diesel and Fuel Cell Buses, Jeremy Wise, January 2008, NRCan – GHGenius Analysis



Japanese Residential Co-gen Program

In Japan, a competitive and well coordinated government assisted program is underway to validate the viability of a one kilowatt (kW) residential co-gen fuel cell system testing multiple primary fuels and powered by natural gas, LPG and kerosene. This program includes many multinational companies such as Sanyo, Toyota and Matsushita (Panasonic), as well as huge Japanese energy companies like Tokyo Gas, Osaka Gas and Nippon Oil. In 2006, Ballard Power Systems, in conjunction with its co-development partner Ebara Corporation, claimed that 40,000 hours of operation is achievable for their latest product design.

Figure 4: Per Home Average Energy and GHG Reductions with Residential Co-gen



Source: [http://www.nedo.go.jp/kankobutsu/pamphlets/kouhou/2007gaiyo\\_e/79\\_86.pdf](http://www.nedo.go.jp/kankobutsu/pamphlets/kouhou/2007gaiyo_e/79_86.pdf)

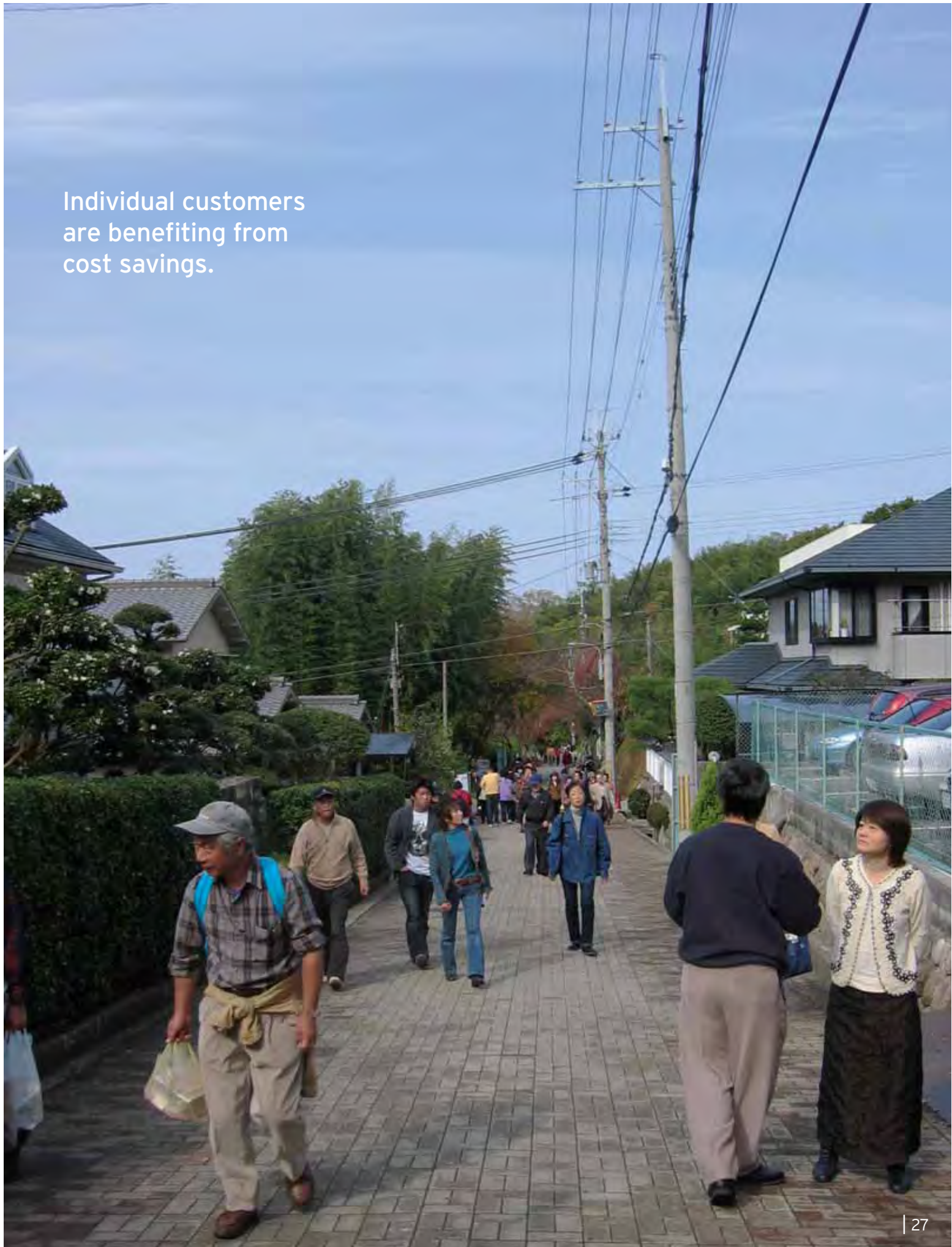
Energy Security & GHG Concerns: The Near-term Market Drivers for Residential Cogeneration

Energy security and GHG concerns are driving government support for the adoption of fuel cell powered cogeneration of heat and power in residential markets in South Korea and Japan. Both these countries use expensive imported natural gas or propane for domestic heating and hot water.

With the rise in the cost of these imports, plus the increasing political instability in some of the supplier countries, New Energy Development Organization (NEDO), a crown agency of the Japanese government, in Japan has fostered the development and early deployment of more energy efficient residential co-gen systems employing reformers and PEM fuel cells. By generating the first kilowatt of power and the heating of hot water for the home, these co-gen units provide increased energy efficiency and reduced GHG emissions.

In residential co-gen markets, major Japanese gas companies are working together to develop component supply chains and working with fuel cell developers to reduce system costs.

Individual customers  
are benefiting from  
cost savings.



# Industry & Customer Dialogue

To ensure that this update to the 2003 Canadian Fuel Cell Commercialization Roadmap had the required input from key industry leaders and their customers, PricewaterhouseCoopers conducted sequential one-on-one interviews with CEOs and key technical contacts from fuel cell technology developers. They also interviewed executives from integrators and infrastructure companies, as well as fuel cell sector end-users from five user groups – Buses, Materials Handling, Backup Power, Portable Electronics and Residential Co-gen.

## Key Findings

Both fuel cell developers and end-users are in agreement that cost, especially life cycle cost, is the most significant consideration when making a decision to buy a fuel cell product.

Canada's ability to maintain its position as a key player in the fuel cell industry, will be enhanced if governments can provide additional help in the form of subsidies, regulations, demonstrations, education of end-users and legislation.

Canadian companies in the hydrogen and fuel cell business are confident of their continued role in the commercial growth of products for near and mid-term markets.

## Markets and customers

In addition to cost, other barriers to commercial growth in near-term markets include: product reliability, product awareness and availability of hydrogen infrastructure.

Large warehousing facilities operating on two, or preferably three shifts, offer the best business case for early adoption of materials handling fuel cell products.

Bus applications will continue to require subsidies to encourage end-users and fuel cell developers to build products.

Fuel cell companies do not believe that warranty costs and technology adoption issues are barriers to commercial growth of near-term markets; however, these are concerns for end-users.

Fuel cell companies believe that near-term markets can provide them with positive gross margin.

Rapid establishment of stable codes and standards for hydrogen infrastructure, storage and fuel cell products use is important to commercial growth.

## Actions

Encourage crown corporations (e.g., Canada Post) and government departments to be important first purchasers of fuel cell products.

Use taxation on fossil fuels as subsidies for transport authorities to adopt fuel cell buses.

Invest in R&D directed at cost reduction of key components and design simplification.

Introduce flow-through shares for the hydrogen and fuel cell industry to help attract consumer investors in public markets.

Focus more on the development and local adoption of global codes and standards to accelerate proliferation of hydrogen infrastructure and fuel cell products.

## Building Global Value Chains



John Sheridan, President & Chief Executive Officer, Ballard Power Systems Inc.



Steve Medwin, Manager of Advanced Research, The Raymond Corporation



Michael McGowan, Head, Hydrogen Solutions, North America, The Linde Group

### Technology and materials

Focus should be on engineering design optimization, as opposed to fundamental R&D, to drive commercial growth in near term markets.

Intellectual property concerns are not a barrier to commercial growth in most near-term markets.

For the portable electronics sector, the government framework for intellectual property poses significant challenges for companies to undertake long-term fundamental research collaborations with universities and research institutes.

Most companies believe that manufacturing processes and engineering design optimization are key to driving cost reduction and quality enhancements.

Given the ever-increasing price of platinum, loading reduction, effective recycling and creative pricing strategies will facilitate profitable commercial growth.

#### Actions

Enable national research establishments with expertise in engineering design, materials and continuous manufacturing processes to execute programs that benefit many near-term fuel cell commercialization objectives.

Providing low interest loans to fuel cell companies for the purchase of manufacturing equipment can help meet volume growth opportunities.

Develop financial strategies to “prime the pipe” for platinum recycling by funding or hedging initial purchases of platinum for near-term markets.

### Manufacturing, post sales service and recycling

R&D, product development, process development and early stage prototype manufacturing have a longer term value for Canadian companies as compared to true volume manufacturing.

Component development and manufacturing will be done offshore, most likely in Asia.

Supply chain consolidation and integration will accelerate development and reduce costs.

Post sales service is immature in many markets and must be developed ahead of significant volume growth.

Recycling is key in many applications for environmental reasons and to recover expensive reusable components.

OEMs will be the key interface to end-users.

#### Actions

Rationalize existing Canadian R&D efforts to focus on three or four centres of excellence.

Enhance coordination and leverage activities in other global research centres.

Actively seek strategic relationships with offshore, low-cost manufacturers with the core competencies to produce fuel cell components.

Promote formation of servicing and recycling spin-offs for fuel cell products.

### Other challenges to commercial growth in near-term markets

Talent pool constraints will likely be an issue as companies expand to meet growth in product sales.

Different levels of maturity within the supply chain could decelerate growth.

Commercial growth will be accelerated when fuel cell products offer a superior overall value proposition to incumbent technologies.

Component cost reduction and overall system design simplification will facilitate commercial growth.

#### Actions

Establish cross-functional science and engineering programs in academia to build the expertise required to staff and support hydrogen and fuel cell companies.

Encourage technical colleges to set up training programs to create service-based competencies for fuel cell products.

Facilitate the formation of strategic supplier relationships, with open communication of end-user requirements, volume projections and shared risk/reward is necessary to facilitate a robust supply chain for near-term markets.



## The User Need Drivers for Near-term Markets: Battery Deficiencies



Photo: Plug Power

British Columbia based **Plug Power** (formerly Cellex Power and General Hydrogen) and Hydrogenics all carried out demonstration trials of hydrogen and fuel cell power packs as direct replacements for lead acid battery packs in forklifts used inside distribution centres.

Ballard supplies stacks in volume to backup power system suppliers and Hydrogenics provides fuel cell power modules to the backup power market.

Fuel cell commercialization is occurring today in existing markets that are not being served well by battery technology. These include forklifts, backup power, and portable electronics for civilian and military applications. Fuel cell attributes that exceed present battery technology include constant levels of continuous power as long as fuel is available, and increased energy density. The combination of fuel cells and batteries in battery fuel cell hybrid applications is becoming more common and can offer superior performance to incumbent technology.

### Materials Handling

Fuel cells offer end-users in the materials handling market improved productivity. Unlike traditional batteries that deliver declining power as charge levels diminish, fuel cells deliver constant power output throughout the standard eight hour shift. Moreover, because hydrogen refueling is fast, there is no need for the supplementary power packs normally needed to compensate for the multi-hour charge times associated with traditional batteries.

The trend towards the development of fuel cell solutions as battery replacements in materials handling has been further demonstrated by a focus on this market by large players including Toyota, General Motors and others in Scandinavia and Germany.

Numerous product demonstration programs are now underway with multinational corporations such as Wal-Mart, Verizon, GM, and Bridgestone. These efforts are increasing end-user confidence and demonstrating that fuel cells can be durable, reliable, safe, and cost effective.

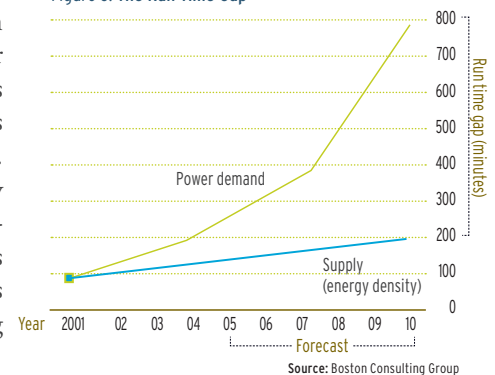
## Backup Power

Power outages lasting for many hours or days due to weather related events such as Hurricane Katrina have caused US communications regulators to mandate much longer power backup for critical communications services like cellphone towers. Due to their low energy density, an increased number of batteries are needed to meet these new backup requirements. However, fuel cells running on stored hydrogen are proving to be a cost effective solution.

## Portable Electronics

Lithium ion battery technology is not keeping pace with the growing power demands in mobile phones and laptops. The users of these devices require run times of five hours or more, but when using the power-hungry features of the latest generations of devices, users will be facing run times of 30 minutes or less. For conventional (long) charging cycles the energy density of lithium ion batteries is increasing at around five percent per year. However, the fast-charge cycle technology now being developed is sacrificing the energy density and battery lifetime. To meet the resulting run time gap, many consumer electronics companies, battery manufacturers, and fuel cell companies have intensive programs to develop high-energy-density fuel cell systems. A number of recent announcements indicate systems with twice the energy-density of lithium ion batteries and fast refuelling will be coming to market in the next couple of years.

Figure 5: The Run Time Gap



"The Energy from batteries won't meet the portable device demand"<sup>15</sup>



## Global Commercialization Indicators

Figure 6: Cumulative Shipments to 2007

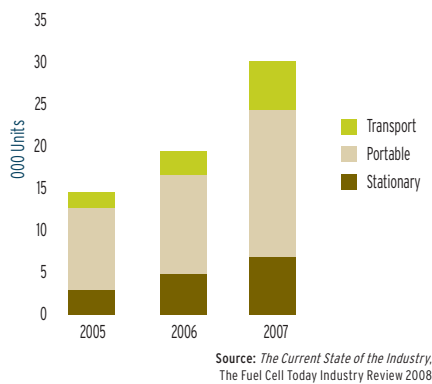
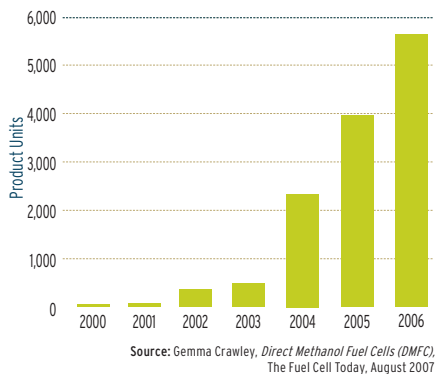


Figure 7: Cumulative DMFC units installed globally in portable applications



### Shipments, Revenues and Relationships

It has been estimated that a total of 12,000 fuel cell units, across all markets, were shipped in 2007. This represents an average annual growth rate of 59% in shipments over the past three years.<sup>6</sup>

Although the portable market saw the largest number of delivered units, total revenues from this market were likely the lowest of the three segments, with Smart Fuel Cells (Germany) and Horizon (Singapore) being the dominant suppliers.

The transportation sector is growing rapidly due to sales in niche applications, including auxiliary power units for recreational vehicles and power systems for materials handling. In addition, some 250 light duty vehicles were manufactured in 2007 by automotive OEMs. Excluding the largely in-house sales of light duty vehicles, revenues for this segment were likely between those of the portable and those of the stationary segment, with Hydrogenics and Smart Fuel Cells being the largest suppliers.

In 2007, about 3,000 co-gen units were sold into the residential markets, backup power and distributed power plants. The unit sizes in this market range from low kilowatts up to megawatts, with the per unit revenues ranging from tens of thousands to millions of dollars. Ballard reports sales of 445 residential co-gen units and 200 backup power units, while Fuel Cell Energy reports orders for 13 molten carbonate fuel cell stationary plants of megawatt sizes. The total revenue for 2007 in the stationary power segment was likely the largest of the three segments.

Total revenues reported by public fuel cell companies in 2006 were \$415 million, nearly double that of 2005.<sup>7</sup> Among the largest companies, Ballard reported fuel cell product revenues of \$15.3 million, Fuel Cell Energy \$33 million, Smart Fuel Cells \$16 million, and Hydrogenics \$6.1 million.

Canadian companies have a strong record in developing collaborative relationships with other organizations, both within and outside the country. In 2006, Canadian organizations reported 124 strategic alliances with a wide variety of organizations, including energy providers, automotive and other OEMs, and hydrogen and fuel cell developers. Canadian companies were also involved in many public-private partnerships. Companies such as Boeing, Linde AG (BOC Gases), Cummins, Daimler, Ford, General Motors, Mitsubishi, Shell Hydrogen, have made strategic investments with BC technology partners. The recent purchases of Cellex and General Hydrogen by Plug Power, and of Ballard's automotive assets by Daimler/Ford, represent significant investments in Canadian fuel cell technology.







Internationally, interest in using Canadian expertise is high for new projects, with London purchasing five fuel cell buses powered by Ballard fuel cells and a large purchase order from US-based Wal-Mart for Plug Power Canada's fuel cell forklifts.



# Canada in the Global Context

Canada is considered a world leader in hydrogen and fuel cell technologies. Nationally, the industry is comprised of over 80 companies collectively employing approximately 2,000 highly skilled personnel. In 2006, these relatively small knowledge-based enterprises realized revenues of over \$130 million and invested \$200 million in R&D.

However, Canadian SMEs face a challenging investment climate and their leadership role is threatened by increasing competition from well financed multinationals operating in the energy, automotive and electronics sectors, in jurisdictions such as the United States and the European Union, where substantial government support is available.

In response, many Canadian hydrogen and fuel cell companies have been restructuring their operations and refocusing their R&D investments away from the long-term commercialization of automotive applications towards more near-term market opportunities. These companies are now looking to pre-commercial markets in materials handling, backup power, and urban transit to provide the revenue streams required to fund operations and enhance investor confidence. In addition, some Canadian companies have specifically targeted near-term markets from the start, notably in the areas of portable electronics and materials handling. Strategically, developing expertise in these markets will also position Canadian companies to play an important role in paving the way for the commercial fuel cell automobile and provide opportunities for early investment in the hydrogen infrastructure for mass consumer markets.

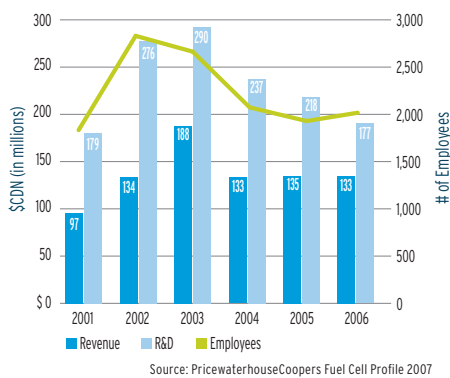
However, even with these early deployments, barriers to commercialization still exist. Product quality must be increased, costs must be reduced, fuelling sources must be made affordable and reliable, and capital must be secured.

## Status of Canadian Industry

### Growth of Canadian Industry

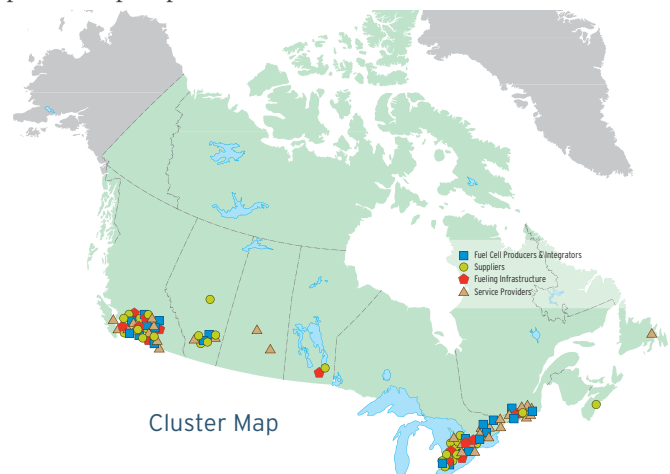
- Revenue has grown 37% – from \$97 million in 2001 to \$133 million in 2006.
- R&D expenditures have decreased 1% from \$179 million in 2001 to \$177 million in 2006.
- Employment in the industry has seen an increase of 15% from 1,772 in 2001 to 2,043 in 2006.

Figure 8: Canadian Industry Profile



The hydrogen and fuel cell sector in Canada remains stable as it concentrates on building commercial product sales.<sup>8</sup> While R&D is still very important, the consistency of the largest revenue stream — product sales — demonstrates the sector is moving towards early commercialization.

- Revenue was reported at \$133 million in 2006, similar to \$135 million in 2005, with product sales being the largest category of revenue.
- Product sales remain consistent at \$89 million in 2006; a decrease of 8% from \$97 million in 2005.
- Industry research, development and demonstration expenditure decreased 11% to \$193 million in 2006 versus \$218 million in 2005. This is the second consecutive year of decrease.
- The total government budget for hydrogen and fuel cell related activities in 2006, excluding employee salaries and benefits, was \$30 million.
- Universities and non-profits indicated that their total 2006 budget for hydrogen and fuel cell related activities, excluding employee salaries and benefits, was \$6 million.
- Overall employment increased to 2,043 in 2006 from 1,902 in 2005, with western Canada once again accounting for the largest employment cluster.
- Total capital requirements for the period 2008 to 2013 were estimated at \$864 million with operations (37%), private equity (23%) and public capital markets (18%) identified as the leading expected sources of this funding.
- The number of demonstration projects declined 12% to 125 in 2006 from 142 in 2005.
- The number of strategic alliances reported in 2006 was 124.
- There were 221 research partnerships reported in 2006.





British Columbia is home to one of the largest fuel cell industry clusters in the world.





### Integrated Waste Hydrogen Utilization Project

Currently, the Northlands station provides hydrogen to refuel nine hydrogen-powered pick-up trucks as well as two Ford hydrogen-ICE shuttle buses.

In 2005, the Integrated Waste Hydrogen Utilization Project, a three year project led by Sacré-Davey Innovations, was launched to take advantage of untapped sources of hydrogen emitted as a waste stream from a sodium chlorate plant in North Vancouver. The plant has the capacity to produce sufficient hydrogen to continually fuel a fleet of 20,000 fuel cell vehicles. This source of hydrogen will be a stop on the British Columbia Hydrogen Highway.



Photo: Sacré-Davey

## Hydrogen Infrastructure for Industry and Energy

Canadian companies are involved in the entire spectrum of hydrogen infrastructure, including production, storage, distribution, and delivery. They participate in almost all of the approximately 60 hydrogen fuelling demonstrations around the world, and have established eight fuelling stations across Canada. These projects have required Canadian companies to develop expertise in hydrogen safety, certification procedures, and testing methods and protocols, as well as in experimental analysis for developing appropriate codes and standards. From their involvement in these projects, Canada's relatively small companies are gaining the global market experience needed to take quick advantage of foreign opportunities as they arise.

Canada was one of the first jurisdictions in the world to publish a National Hydrogen Installation Code, facilitating deployment of hydrogen products across the country.

### Production

The Canadian hydrogen industry has a technological edge in electrolytic hydrogen production and steam methane reformation, as well as in the integration of renewable energy sources into the production process.

With a diverse energy resource base, Canada has multiple hydrogen-production pathways from sources including coal, oil, natural gas and hydroelectricity. Hydrogenics is a world leader in hydrogen infrastructure technology and products supported by over 55 years of world-leadership in the development, manufacturing and installation of on-site hydrogen generation systems for industrial and energy markets. Its modular HySTAT™ hydrogen generation systems, based on water electrolysis, provide on-site hydrogen in multiple configurations to meet varied industrial and energy needs. Hydrogenics is also developing hydrogen on-site solutions based on natural gas reformation.

Canada is one of the world's largest producers of industrial hydrogen. In BC, Alberta and Saskatchewan alone, approximately 1.5 megatons of hydrogen are produced and consumed annually — enough to support 7.5 million hydrogen fuel cell vehicles.

Most Canadian hydrogen is produced in the chemical and refining industries where it is used as a feedstock in a host of processes. As hydrogen production in the oil and gas industry grows, so do the opportunities for Canada. Over the next 20 years the hydrogen production for the oil sands alone is expected to grow to three megatons per year. With adequate investment in refuelling infrastructure, this would be enough hydrogen to fuel up to eighteen million hydrogen vehicles.

Canada also produces roughly 200,000 tons of waste hydrogen every year, which in energy terms is equivalent to approximately 800 million litres of gasoline. The Integrated Waste Hydrogen Utilization Project in North Vancouver, British Columbia, captures such hydrogen for use as a low cost source of supply for various applications.

This breadth of expertise, coupled with access to vast quantities of hydrogen, can be leveraged to create a competitive position for Canada within world hydrogen markets. While in the short to medium term it is expected that the existing hydrogen infrastructure should be sufficient, over the longer-term hydrogen produced for the oil and gas industry could be potentially redirected to meet the needs of mass fuel cell markets.

In addition to, or in place of, current means of production, Canada can potentially produce hydrogen through economical and environmentally friendly methods including:

- The gasification of fossil fuels coupled with sequestration of the resulting carbon dioxide;
- The production of hydrogen from water using Canada's abundant sources of clean electricity; and
- The production of hydrogen from water using sunlight, and biological processes that decompose organic materials into hydrogen and other by-products.

## Storage, Distribution and Delivery

Canada leads in the development, manufacturing and testing of both on-board, high-pressure gaseous hydrogen storage cylinders and solid-state hydrogen storage materials.

For short distances and for demonstration purposes, hydrogen is distributed in specially designed tube trailers or, for smaller quantities, in individual, high-pressure steel cylinders. Over longer distances, most is trucked as a liquid in cryogenic tanks. Pipeline transport is possible as well, as in the case of the 52-km hydrogen pipeline connecting hydrogen producers and users in northern Alberta. Pre-commercial infrastructure, based on distributed electrolysis and steam methane reforming, is presently being demonstrated.

Fuelling stations in Canadian demonstration projects are using a number of renewable and fossil fuel energy sources for on-site hydrogen production, which reduces the need for long distance distribution. These sources include electrolysis-based fuelling stations and hydrogen generation through renewable energy.

## Codes and Standards

In July 2007, the Canadian Hydrogen Installation Code was published by the Bureau de normalisation du Québec as a National Standard of Canada to provide Canadian industry and regulatory authorities guidance to approve the use of hydrogen as an energy carrier and facilitate the approval of hydrogen installations across Canada.

The code will help the commercialization of hydrogen and fuel cell technologies, build consumer confidence in the use of hydrogen as a clean, safe source of energy.

Air Liquide recently published a guide entitled "Permitting Hydrogen and Fuel Cell Installation in Canada" which provides background on relevant authorities, codes, standards and regulation, and on the procedures for obtaining approval for designs, facilities and installations from the appropriate authorities having jurisdiction in the area of hydrogen.

### Key International Relationships

Leading Canadian fuel cell developers, Ballard and Hydrogenics, are successfully partnering for export markets. They have strategic relationship and supply arrangements across their targeted markets.

**Ballard** has relationships with Plug Power, The Raymond Corporation, H<sub>2</sub>Logic in the materials handling sector, New Flyer for shuttle buses, and Dantherm, ACME and IdaTech in the backup power market.



Photo: Ballard Power Systems Inc.

**Hydrogenics** has key supply relationships with American Power Conversion for backup power, General Motors for materials handling, and Air Liquide for on-site generation.



Photo: Hydrogenics Corporation

## Research, Development and Demonstration

Canadian industry has been the leader in R&D activities for the last decade. To put things in perspective, the industry's average annual R&D investment of \$200 million is on par with the R&D investment of the Canadian automotive industry. Industry accounts for approximately 85% of total public/private investment in hydrogen and fuel cell research, and in 2003 accounted for almost 30% of total industry investment in energy R&D in Canada.

Considering the high levels of government investment supporting the hydrogen and fuel cell industry in other countries, Canadian industry has made significant achievements with comparatively modest public investments.

As the industry evolves from a focus on R&D for mass automotive markets to meeting end-user needs in near-term markets, an increasing emphasis is needed on demonstrations and deployment of technologies and products. These demonstration projects help refine technologies, establish codes and standards, and inform end-users and investors of the benefits of hydrogen and fuel cells.

Major Canadian demonstrations include the Hydrogen Highway and Vancouver Fuel Cell Vehicle projects, which are focused on infrastructure and on-road transportation, and the Hydrogen Village project, which examines both stationary power and off-road applications. These projects are globally recognized as ground-breaking initiatives, unique in both their holistic approach to successfully integrating the expertise of individual companies, and the cost-sharing arrangements between industry and governments.

### Participation in International Demonstration Projects

Because of Canada's relatively small domestic market for hydrogen and fuel cells, our companies must be export-oriented. Fortunately, many opportunities exist in the global market and this, combined with a program of international demonstrations, can help position Canadian companies as first-choice suppliers of products and technologies. Accordingly, the Canadian sector has placed a high priority on developing collaborative international relationships. Since 2004, Canadian companies have continued to be major participants in at least 100 international projects, including the following:

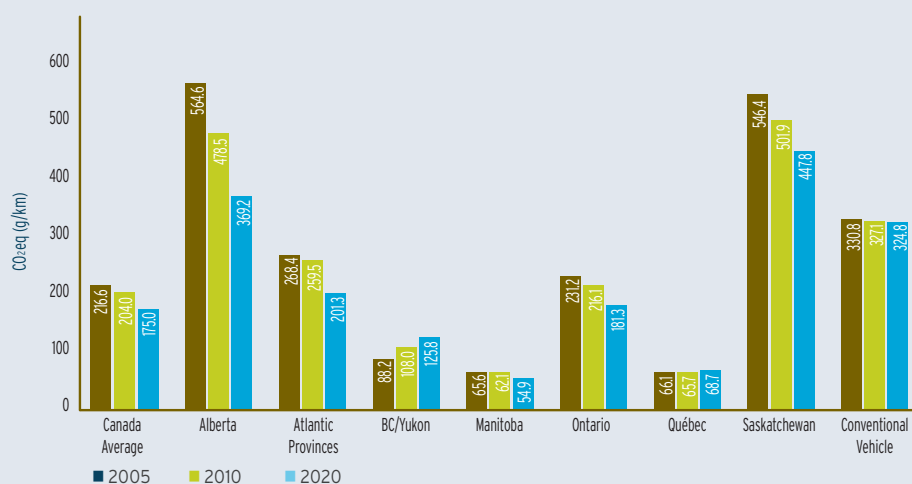
- Ballard tested five generations of heavy-duty fuel cell bus engines in almost 50 buses. Currently, Ballard's fuel cell stacks are being used in 30 buses operating in nine European cities as part of the CUTE program. Ballard-powered transit buses are also operating in the US, Australia, and China.
- Hydrogenics' hydrogen production technologies are being used in refuelling stations worldwide. Its products can be found in such diverse locations as Hong Kong, Stockholm, Amsterdam, Barcelona, and Oakland, California.

- Dynetek's fuel storage and refuelling systems are being used in cities such as Beijing, Sydney and Orlando.
- QuestAir's purification systems are included in 17 refuelling stations worldwide, including California, Japan, Korea and Toronto.

### Industry Canada

Industry Canada's goal is to enhance the competitiveness of the Canadian industry. It is responsible for maintaining channels of communication with key sectors to facilitate informed advocacy of industry interests in government decision making and to convey the government perspective back to industry; analyzing the challenges and opportunities that face key sectors in the economy, developing policy options for possible government response to extraordinary challenges and opportunities, and delivering the subsequent programs and services.

Figure 9: Hydrogen Production from the Electrolysis Pathway



Source: GHGenius

### Natural Resources Canada

Over the last two decades, Natural Resources Canada (NRCan) has been key in the development and demonstration of hydrogen and fuel cell technologies. Its unique role in sharing risk with industry has led to numerous world-firsts taking place with Canadian-developed technology. These include the application of fuel cells in transit buses in cities around the globe, world class technology in the high pressure storage of gaseous hydrogen, efficient electrolytic production of hydrogen, residential co-gen fuel cells being deployed in Japan, and the development of Canada's Hydrogen Highway and Hydrogen Village.

### GH Genius

Modelling conducted by NRCan and others has shown that hydrogen and fuel cells will play an important role in the long-term plan to meet Canada's emission reduction goals. This is especially true for the transportation sector, where forecasts show the demand for transportation services will only increase. Given consumers' demonstrated buying preferences, many experts believe developing advanced low and zero-emission technology is the only way to reduce emissions from this sector. Hydrogen produced from electrolysis pathways can eliminate significant greenhouse gases.

# Canada's Hydrogen and Fuel Cell Community

As a pioneer of hydrogen and fuel cell technologies and products, the Canadian sector has enjoyed solid growth over the last ten years. In 1997, less than 20 companies maintained hydrogen and fuel cell activities. Today, the Canadian hydrogen and fuel cell sector features over 100 stakeholders, including a number of core technology developers. Canadian capabilities include fuel cell technology development, hydrogen production, components, system supply and integration, fuelling and fuel storage, and engineering and financial services.

## A Strong Research Base:

Canadian universities and colleges conduct a significant amount of R&D in fuel cells and hydrogen, much of it in collaboration with industry and government organizations.

British Columbia has a world-class regional fuel cell research hub of 180 researchers. Fuel cell research and testing facilities have been developed, including National Research Council Institute for Fuel Cell Innovation, the UBC Clean Energy Research Centre, SFU 4D Labs, and an expanded IESVic at the University of Victoria.

**Alberta Research Council** delivers innovative science and technology solutions to meet the priorities of Albertans. Focus is on solid oxide fuel cells through developing the design and manufacturing process for high power density solid oxide tubular fuel cells.

**Fuel Cell Research Centre, (FCRC)**, Kingston is Canada's leading university-based research and development organization dedicated to advancing the knowledge base needed to address the key technology challenges facing the adoption of fuel cell applications.

Co-hosted by Queen's University and the Royal Military College, FCRC researchers collaborate with colleagues at the University of Waterloo, McMaster University, the University of Windsor and industry partners, including E.I. du Pont Canada Company, Fuel Cell Technologies Ltd., QuestAir Industries, Daimler, Kingston Process Metallurgy and Long-Dana.

**The Hydrogen Research Institute** of the Université du Québec à Trois-Rivières focuses on material science, system

development and technology demonstration. It addresses technical gaps needed for commercially competitive hydrogen energy systems and hydrogen storage materials, performs fluid dynamics simulations of hydrogen releases and conducts safety and lifetime analysis of new materials and hydrogen energy systems.

**Institute for Integrated Energy Systems (IESVic) University of Victoria:** IESVic promotes feasible paths to sustainable energy systems by developing new technologies and perspectives for widespread adoption of sustainable energy. As a multidisciplinary centre, it conducts original research in fuel cells design and diagnostics, hydrogen systems, and energy system modelling.

**National Research Council Canada** conducts research in the area of fuel cells and hydrogen with over 100 researchers from various



disciplines working in research institutes located across Canada, including the NRC Institute for Industrial Materials in Boucherville, QC. Its flagship, the NRC Institute for Fuel Cell Innovation located in Vancouver, British Columbia has helped prime the Vancouver cluster into the world's fastest growing group of companies and organizations working on fuel cell and hydrogen-energy technologies. Key NRC capacities include:

- Membranes and separation technologies used both for H<sub>2</sub> purification and fuel cells
- H<sub>2</sub> storage using gas hydrates and metal hydrides
- Materials development and characterization

- Small scale hydrogen production – on demand
- Modelling and simulation
- System testing

NRC works closely with Canadian universities, government agencies and companies on projects focused on the research, development, demonstration and testing of hydrogen and fuel cell systems in three strategic areas of critical importance to Canada's fuel cell industry: Polymer Electrolyte Membrane Fuel Cells (PFMFC), Solid Oxide Fuel Cells (SOFC), Hydrogen and Alternative Fuels.

**Natural Sciences and Engineering Research Council** is one of Canada's main granting agencies, funding research at universities and colleges. In 2005-06, NSERC awarded approximately \$7 million in hydrogen and fuel cell related research grants. In addition to funding curiosity driven research and providing scholarships and fellowships for students, NSERC also funds collaborative research with the private and public sectors. Approximately 50% of the current funding is being provided through NSERC's Research Partnerships Programs to support collaborative R&D projects, industrial research chairs and strategic projects and research networks. These collaborative initiatives involve over 25 private and/or public sector partners and have levered an additional \$1.8 million in research support.

**Queen's University** conducts extensive research in fuel cells and is home to the Centre for Manufacturing of Advanced Ceramics and Nano materials.

**Royal Military College** hosts both the Research Chair and the Associate Chair in Fuel Processing for Fuel Cells, funded by the Natural Sciences and Engineering Research Council (NSERC).





**University of British Columbia:** current fuel cell research includes engineered materials and new approaches for fuel cell function; integration / elimination of components and function in fuel cell systems; new catalysis approaches for fuel cells and fuel processing and fuel cell failure modes, durability, and accelerated testing methods.

**Saskatchewan Research Council** develops enabling technologies to facilitate the use of alternative fuels. Technologies include electronic fuel injection systems to convert gasoline and diesel engines to hydrogen and other gases, as well as electronic pressure regulators for fuel cells. The Council designed and ran the world's first dual-fuelled hydrogen gasoline and hydrogen-diesel trucks.

**University of Calgary** includes the Fuel Cell Research Group and Western Canada Fuel Cell Initiative, which study electrochemistry and surface-material science and do contract research for Canadian fuel cell companies. The U of C founded the Western Canada Fuel Cell Initiative. Researchers are engaged in fuel cell research programs that include high-temperature fuel cells, proton-conducting electrolyte fuel cells, hydrogen storage and corrosion issues, and fuel cell stack development.

**University of Waterloo:** the 20/20 Laboratory for Fuel Cells and Green Energy aims to develop and promote green energy systems through conducting original research to develop technologies for diversified and localized energy systems. Fuel Cell activities include modelling and simulation, the development of key component materials and innovation design and manufacturing.

## Collaboration and Demonstration:

### British Columbia's Hydrogen Highway



is a practical demonstration and deployment of hydrogen fuel cell vehicles, infrastructure and hydrogen technology in southwestern British Columbia. The fuelling infrastructure will take many forms and serve a wide variety of transportation, stationary, portable and micro power applications. The centrepiece of the program will be the demonstration of a fleet of 20 fuel cell transit buses operating in Whistler during the 2010 Winter Olympics and beyond. This will provide a one-of-a-kind opportunity to showcase Canadian hydrogen and fuel cell products to the world.

The Hydrogen Highway's longer-term vision is to be part of a west coast Hydrogen Highway extending south to California and east to Alberta. More than a demonstration project, this will establish an early-stage infrastructure from which consumer-based usage can more easily develop. It also ties Canada more intimately to the progress of US developers and ensures that Canada will remain a major partner in the development of a North American hydrogen infrastructure.

### Vancouver Fuel Cell Vehicle Program



initiated in 2003, assesses the performance of five Ford Focus fuel cell cars operating in everyday conditions. The cars use a Ballard fuel cell stack and a Dynetek Industries hydrogen storage system. This five-year initiative

provided valuable information on vehicle durability, reliability and performance. The project has been so successful that Ford has agreed to extend it by another two years, until 2010.

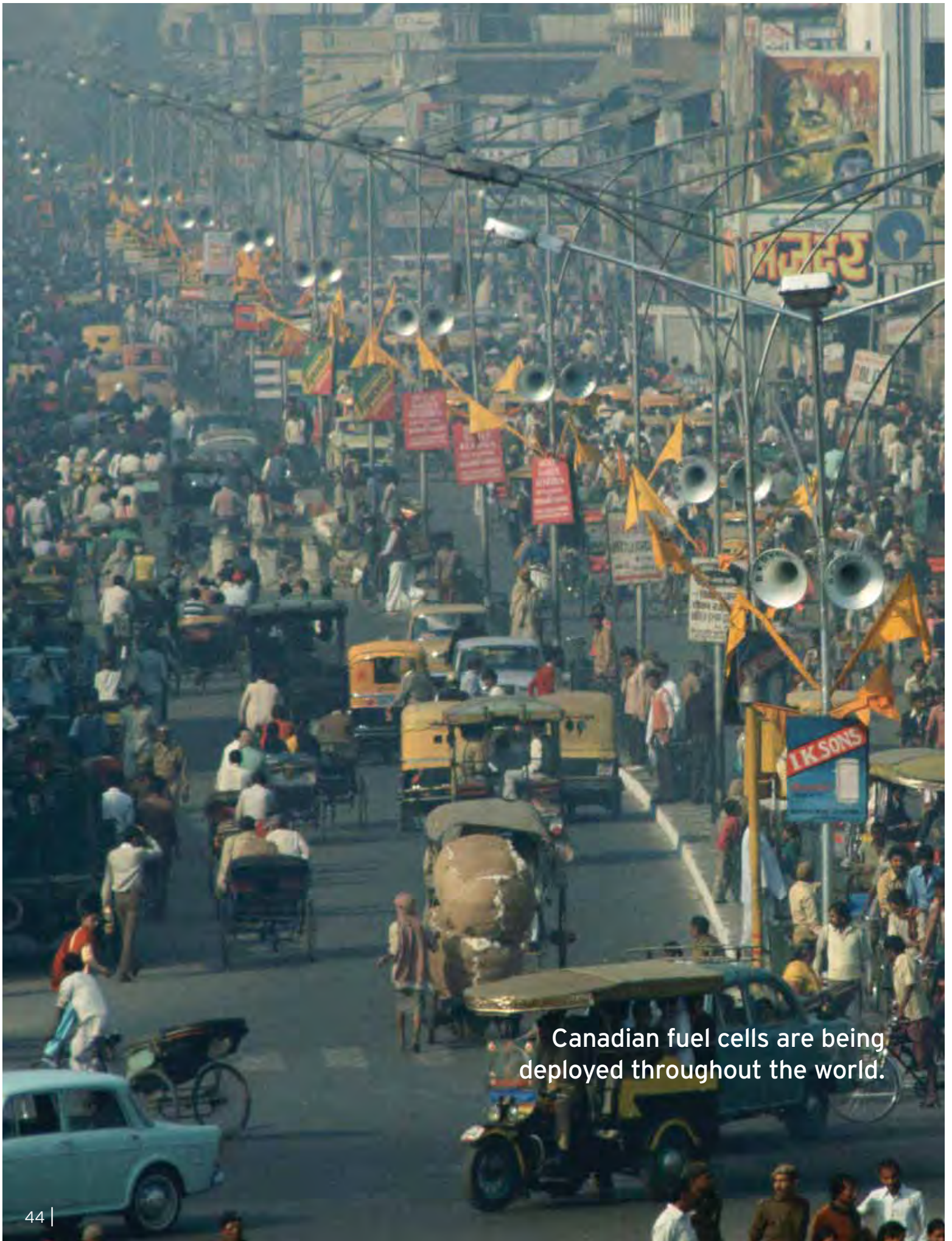
Program partners include Ford, Hydrogen & Fuel Cells Canada, the Province of British Columbia, the City of Vancouver, BC Transit, BC Hydro, Natural Resources Canada, and the National Research Council's Institute for Fuel Cell Innovation.

**The Hydrogen Village** consists of several demonstration projects in the Greater Toronto Area. It is designed to lead toward a green and sustainable energy future by raising awareness and breaking down barriers to markets for hydrogen, fuel cells, and other relevant technologies. These projects, started in 2004, involve 41 companies and organizations such as John Deere and Purolator. Currently installed projects include refuelling stations, utility and delivery vehicles, forklift trucks, and residential power.

## International Collaboration

Because of Canada's relatively small domestic market for hydrogen and fuel cells, our companies must be export-oriented. Fortunately, many opportunities exist in the global market and this, combined with a program of international demonstrations, can help position Canadian companies as first-choice suppliers of products and technologies. Accordingly, the Canadian sector has placed a high priority on developing collaborative international relationships. In 2004, Canadian companies were major participants in at least 100 international projects.





Canadian fuel cells are being  
deployed throughout the world.

# Hydrogen and Fuel Cells: Transformative Technologies

Driven by the much publicized issues surrounding climate change, governments, NGOs and various key industry leaders are creating a critical mass of opinions and actions that will accelerate the development and adoption of technologies to reduce GHG emissions. These efforts will not rely on any one technology and the commercial adoption of these technologies will likely be more evolutionary than revolutionary.

As the cleanest of fuels and most efficient of technologies, hydrogen and fuel cells will certainly be part of the mix. To achieve their full potential as an energy carrier of the future, efficient, sustainable and cost effective methods of producing, storing and transporting hydrogen will need to be developed and applied to the specific needs of each fuel cell application.

While low-cost options are available in the capture and purification of waste hydrogen, today most hydrogen is produced by steam reforming of natural gas — a process which also produces carbon dioxide. The near future however, offers many methods to produce hydrogen in a truly renewable manner. But, at up to US \$7 per kilogram, the cost of electrolytic production of hydrogen via wind is still double that of conventional fuel.

The ever-increasing price of crude oil continues to erode the gap between conventional fuels and hydrogen. In the interim, the fact that hydrogen production from wind and other renewable energy is carbon-free from beginning to end is very attractive. Further, the ability to produce energy sources closer to point of use, reduces cost, and risks of loss of service in extreme weather conditions.

When considering mass markets for fuel cells, the application that everyone thinks of is, of course, automotive. The opportunity to drive low noise, zero emission vehicles without loss in functionality is truly an aspiration worthy of fulfillment. According to the major automotive OEMs the transition from conventional internal combustion engines (ICEs) to fuel cell vehicles will be an evolutionary process whereby conventional ICEs are optimized and fuels are improved as regards to pollution and overall efficiency. Later efficiency is further enhanced by hybrid vehicle technology and then, finally, we have fuel cell vehicles.

The concept of hybridization, where the energy sources that provide either direct propulsion or extended range, is a common feature in the transition from conventional ICEs to Fuel Cell Vehicles (FCVs). Development of the Hybrid Electric Vehicle (HEV) began in earnest in the early 1990s. The first commercial HEVs, the Honda Insight and the Toyota Prius were launched later that decade. Today, all major OEMs have launched HEVs or are in the process of doing so.

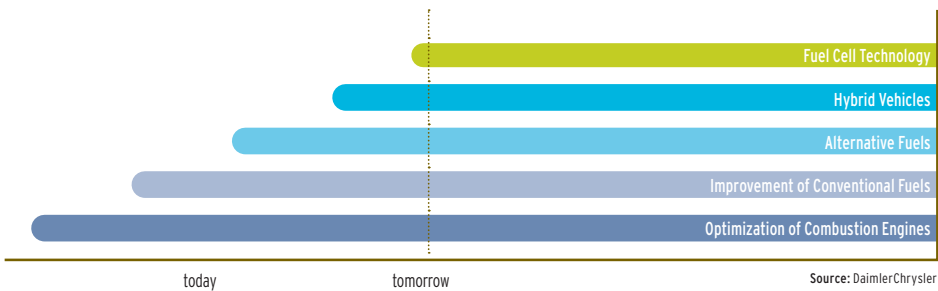
In these vehicles, where the ICE and battery act together to provide power, gas consumption is reduced and regenerative braking recharges the battery. These are complex systems that some industry experts feel may limit cost reduction, reliability and operational performance and flexibility, but the advantages of enhanced efficiency and advanced battery systems mean that hybridization will be part of the technology mix for a long time to come.

While offering maximum choice for customers, the anticipated evolution of fuelling options will most likely pose challenges to energy companies regarding the need to provide a fuelling infrastructure to support numerous technologies. However, it certainly does meet the political vision of fuel diversification for transportation, which today accounts for two-thirds of crude oil consumption in the United States.<sup>9</sup>

The classic “chicken-and-egg” scenario between the development of a hydrogen infrastructure and the commercial maturity of fuel cell technology for automotive transportation applications has played a role in the extending timelines for FCV deployment. Nevertheless, there are two key obstacles remaining to the adoption of hydrogen as a fuel of the future:

- The cost of manufacture, storage and transportation relative to conventional fuels, a barrier that is further exacerbated when other methods of hydrogen production (e.g., electrolysis using energy from renewables) are considered.
- Infrastructure: today we have a tried and true global distribution system of pipelines for conventional liquid and gaseous fuels. No such system exists for hydrogen.

Figure 10: The Evolutionary Development of Fuel Cell Vehicles



*In the “tomorrow” scenario, all automotive technology options will coexist.*

Collectively, these challenges are more relevant to the rate of adoption of automotive applications, but the cost issues will likely have some impact to the overall economic decision to adopt fuel cell technology in the near-term markets such as backup power, buses and materials handling.



The technology transition from ICE to HEV is less challenging than from HEV to FCV due to such factors as maturity of supply chain, manufacturing development and build-up. It may be reasonable to assume that we could see millions of FCV units in production by mid-2020s. Of course, there are numerous additional tangible and intangible factors that will influence this commercialization timeline.

Figure 11: World Production of Light Vehicles by Powerplant Type (000s units)

Item	1994	1999	2004	2009	2014
Total Light Vehicle Production	49,375	54,375	60,510	69,500	77,950
Spark Ignition ICE	46,520	4,8135	47,715	49,100	48,540
Diesel ICE	2,855	6,240	12,600	19,000	24,400
Hybrid-Electric	--	neg	195	1,400	5,000
Fuel Cell	--	--	neg	neg	10

Source: <http://www.freedomiagroup.com/Hybrid-Electric-Vehicles-And-Competing-Automotive-Powerplants.html>

*New generations of advanced technology vehicles are introduced to markets in an evolutionary way.*

Some major automotive OEMs have recently announced the deployment of their next generation fuel cell vehicle fleets. For example, Daimler has announced its B-Class F-Cell, Honda its FCX Clarity, and GM has announced its Fuel Cell Equinox. Ford has also announced that it is in the final development stages of its next generation vehicle platform, and has also been demonstrating some novel concept vehicles, such as their HySeries Edge plug-in Fuel Cell Hydrogen Hybrid and the land speed record-breaking Ford Fusion 999. Toyota recently announced the development of its prototype vehicle FCHV-adv, which demonstrated 830km range on a single tank of H<sub>2</sub>. These vehicles are demonstrating freeze start capability, extended range, and improved performance over the previous fleets, and either meet or beat the performance of similar ICE powered vehicles. While fuel cell vehicles still have years of development remaining, especially in cost reduction, all the major OEMs are demonstrating that they are very serious about the development of these vehicles.

The fuel cell development driven by the automotive sector is a critical part of the overall development of fuel cells for commercialization. There is significant synergy between automotive and non-automotive fuel cell developments, especially in the areas of fundamental understanding and developing fuel cell components in the supply base. While there are some differences in the requirements from each application, for example only the automotive application requires fast and robust freeze-start capability, there are many areas that are synergistic, such as lower cost materials, lower catalyst loadings, and designs that are capable of high volume manufacturing.

### Automotive Fuel Cell Cooperation

Ford and Daimler now have their fuel cells developed by Automotive Fuel Cell Cooperation (AFCC), the Vancouver, Canada-based successor of the automotive division of Ballard Power Systems. AFCC is one of the world leaders in automotive fuel cell development, and is one of the largest fuel cell development centres in the world. As the main owners of AFCC, Ford and Daimler bring unique capabilities to the company. Daimler has the largest fuel cell fleet of any manufacturer, with over four million emission-free kilometres, in their concept vehicles, passenger cars, vans, and Citaro city buses; Ford has a large fleet as well, including five Fuel Cell Focus vehicles in Vancouver, and has demonstrated many novel concept fuel cell vehicles. Both Ford and Daimler have deep experience and expertise to apply to the development of the transportation fuel cell.



Daimler B class F-Cell, powered by a Ballard fuel cell running in freezing conditions.



Ford Fusion 999 concept vehicle, powered by a Ballard fuel cell, recently broke the fuel cell vehicle land speed record at 335kms/hr.

## Commercialization of Transformative Technologies

In virtually all applications, fuel cell technology is required to replace well-established, mature, well-supported and cost effective incumbent technology. This presents a high bar to adoption, especially considering that each member of the dispersed and immature value chain needs to achieve a profitable return. In addition, while many end-users see value in the “clean” aspect of fuel cell technology, they are often unwilling to assign a significant economic value to this attribute, and choose instead to focus on the more standard value propositions of price, performance and reliability. These value propositions are however, effectively addressed in many of the near-term fuel cell applications in portable electronics, backup power, materials handling, residential co-gen and transit/shuttle bus markets.

While fuel cell developers have refocused their operations to take advantage of these market opportunities, there are still end-user concerns around cost and reliability. Adopting a new technology into an existing, highly efficient operating system such as a warehouse, telecommunications network or public transportation system is accompanied with risks for the end-user. There are infrastructure challenges with new fuel systems including different types of safety issues and staff training requirements. However, even in light of these barriers, growth in these near-term markets has never looked more promising.



In large warehouses, fuel cell powered forklifts provide increased productivity, lower operational costs, and zero emissions.



At 1,000 kg/day capacity, Whistler's new hydrogen refuelling station will be the world's largest for transportation applications.



# A Near-term Market Approach: The Canadian Industry Since 2003

Despite the many positive changes that have occurred in the Canadian hydrogen and fuel cell industry over the past five years, today our international leadership role is being out-paced by activities and investments in the United States, Europe and Asia. At home, access to funding from both public and private stakeholders is diminishing, and increasing sales and reduced operating costs have yet to lead to profitability. In Canada, investor interest remains weak and the funding required to increase Canadian manufacturing capacity to the levels needed for commercialization in near-term markets has not been forthcoming.

To grow, fuel cell companies need to build and sell products that meet customers' needs at a price that affords them a profit sufficient to invest in the development of new and improved products. Investor confidence in the industry will be restored when companies start to demonstrate some momentum in profitable revenue growth. Without significant cash injection and the return of market confidence, it will be challenging for Canadian fuel cell companies to grow ahead of the anticipated growth in product sales.

It is becoming apparent that high-volume manufacturing plants will ultimately be located in other countries, closer to major customer bases. While Canadian companies can and should continue to participate in efforts related to improved and scaled-up manufacturing, our long-term competitive position in global markets will more likely to be associated with the development and demonstration of technology and in the production and storage of hydrogen.

Since 2003, many Canadian companies have been developing and refining technologies needed to realize commercialization in a range of near-term markets. In the area of materials handling, numerous successful demonstrations indicate that today's technology is sufficient to drive profitable growth. In the portable electronics market, micro hybrid batteries and formic acid fuel cell systems can fit inside two-way radios, and direct hydrogen technology can now fit in cellular devices and provide twice the talk time. In residential co-gen markets, fuel cell power systems are moving continually closer to cost and durability targets. In backup power applications, overall system simplicity is providing opportunities for cost reduction and increased reliability. Across the globe, public reaction to zero emission fuel cell powered buses has been overwhelmingly positive and technological and design improvements are continually decreasing costs and increasing durability.

To capture value from commercialization in these near-term markets, Canadian companies will need to limit their focus to a specific range of technology and design options. This platform consolidation will help avoid divergence that would otherwise complicate the development of a much needed supply chain and manufacturing infrastructure, increase overall costs and make post sales service much more difficult. While competition within a supplier base is always healthy, near-term commercial growth in this nascent industry will depend on strategic supplier relationships where the risks and rewards are broadly shared.

The industry will also need to address areas of investment beyond the funding needed to support capital costs. A human capital and service infrastructure will be required well ahead of growth in product sales to avoid issues of customer satisfaction. End-user education in the safe and effective installation and operation of fuel cell products and the related hydrogen infrastructure will also be a huge incentive to increased sales.

Costs need to be reduced through further improvements in technology, simpler product designs and an improved fuelling infrastructure. Finally, the industry will need to create marketing and sales strategies that position hydrogen and fuel cell technology as integral to the broader interests of key corporate clients.

Figure 12: Global Fuel Cell Shipments 2005 to 2007

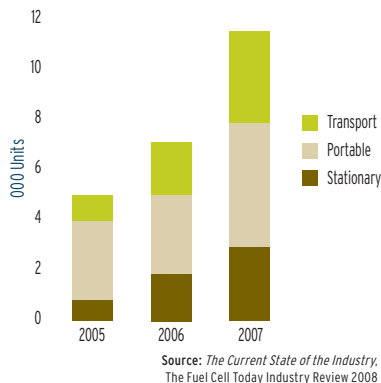
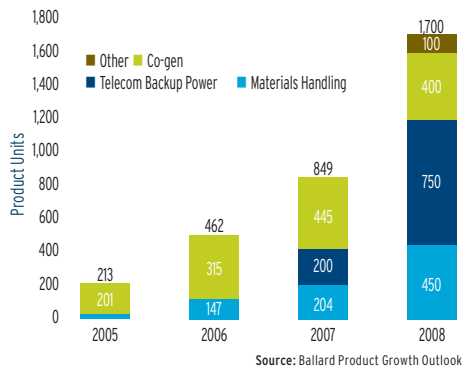


Figure 13: Ballard Product Shipments between 2005 to 2008



Canadian participation in global product shipments is significant, as demonstrated by Ballard Product Shipments over the last three years.

## Hydrogen Infrastructure Suppliers

While the purity and cost of hydrogen will factor into the economic analysis of the transition from incumbent technologies, the existing hydrogen infrastructure will support fuel cell commercialization in near-term markets. Compressed hydrogen and cryogenic hydrogen will meet the needs of backup, materials handling and bus markets. Hydrogen for the Japanese residential co-gen market will be produced through the reformation of conventional fuels. Substantial progress has been made in the use of metal hydrides for the storage of hydrogen in micro fuel cell applications.

The challenges around costs that do arise are related to both the fuel itself and the supporting infrastructure. These can be dealt with through effective strategic relationships with fuel providers. However, fuel cell companies will need to take a very hands-on approach when it comes to the employee training needed to meet general safety guidelines, and to the education of the general public concerning any real or perceived barriers associated with the use of hydrogen as a fuel source.

## Fuel Cell Stack Suppliers

Fuel cell stack suppliers have refocused their efforts on their core competencies and near-term market opportunities. They have rationalized their businesses to reduce cash burn, focusing on understanding end-users' requirements, and refining their existing technology capabilities to meet these requirements. Where appropriate, they have formed strategic relationships with key component suppliers and system integrators to ensure all required competencies and resources are focused to meet end-user needs. Manufacturing efficiencies remain a challenge as higher levels of automation are needed to reduce costs, enhance quality and increase throughput.

The activities and products of Canadian companies like QuestAir Technologies will contribute to providing solution to hydrogen purity requirements.



Photo: QuestAir



Photo: Air Liquide Truck

At 1,000 kg/day capacity, Whistler's new hydrogen refuelling station will be the world's largest for transportation applications. This project involves Air Liquide, Sacré-Davey Group, Hydrogenics, and others.



#### Canadian directions

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**Hydrogenics** continues to integrate systems development with stack development.

**Hyteon** has taken the same approach in the residential co-gen market application.

**Ballard**, on the other hand, has decided to focus on its core competence of stack and key component development, while partnering with entities that have systems expertise and sufficient resources to drive excellence in this area.

**SatCon Power Systems** and **Sustainable Energy Technologies** are developing and selling power electronics such as state-of-the-art inverters for stand-alone and grid connected fuel cell products. Some of these products have received grid approval in key jurisdictions that are targeted for near-term growth in stationary fuel cell products.

**Energix Research** and **Electric Hydrogen** have developed innovative solutions to the challenging issues around on-site hydrogen production and refuelling. **Dynetek**, in Alberta, is already a world recognized manufacturer of lightweight, high pressure compressed hydrogen storage tanks.

**Atlantic Hydrogen** is developing pre-treatment system for fuel using CarbonSaver™. The technology is unique in that it processes natural gas on-site creating a hydrogen-enriched feedstock.

**Contor Terminals** engineers and manufactures specialized containment system for the utility and telecom markets. Their system are being incorporated into large stationary fuel cell systems as a way of streamlining balance of plant systems that support the emerging large stationary fuel cells.

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## Component and System Suppliers

Fuel cell component suppliers have proliferated since 2003. Hydrocarbon membrane development continues to challenge incumbent Nafion-like perfluorinated materials, offering reduced costs and higher temperature operation as well as lower relative humidities. Yet today, most products continue to use Nafion-like membranes with a conventional carbon supported platinum catalyst applied either to the gas diffusion layers or to the membrane. Fuel cell companies looking to capture greater value for their customers will need to create strategic relationships with component suppliers offering lower cost and higher performance materials.

The jury is still out as to whether it is better to develop a key component and secure a position within a supply chain or take a broader approach to system development. Each strategy has its advantages and disadvantages, and it may be that success will be application dependent. It makes good sense to combine stack and systems development for micro fuel cells. With buses and residential co-gen, the overall complexity of each sub-system may be best served by having separate entities focus on their core competencies, while working to ensure that the key interfaces are addressed. Where the stack and system development and manufacture occur in separate entities, there are added complexities with regards to the end-user interface, product service and warranty; but these potential issues can be resolved through strong partnerships and equitable value distribution.



## Technology Performance Improvements Towards Mass Markets

In most of the near-term markets, the value proposition for hydrogen and fuel cells is generally accepted. While significant competition is expected, near-term market share will more likely go to companies with the products and partnerships that successfully address remaining customer concerns around costs, reliability and fuelling infrastructure. Significant technological progress has been made by Canadian organizations on cost, performance, reliability and infrastructure.

### Major accomplishments: Performance

With the feasibility of the technology established in many applications, the focus of R&D since 2000 has been to bring costs down while continually improving performance. This has been accomplished through a number of means, including reduced platinum requirements, component simplification, use of automotive assembly practices, and continued materials development. The state of fuel cell technology development is best assessed by looking at key performance indicators like cost, durability and power density.

#### Cost

Between 2000 and 2004, fuel cell stack costs have decreased from almost US\$10,000/kW to less than \$500. These improvements have been achieved by reducing platinum usage by 30% (while at the same time improving performance) and by employing advanced manufacturing techniques. Overall systems costs, including stack and auxiliary components, are being addressed by component simplification through improved design. With large scale manufacturing volumes the current cost is estimated at US\$100/kW, but by 2010 developers are striving to meet the US DOE target of US\$30/kW for automotive applications.

#### Durability

The required fuel cell durability, or lifetime, is dependent on the application. Stationary fuel cells require a much longer lifetime than mobile, but are operated over a significantly easier duty-cycle. For some off-road mobile and stationary applications (like materials handling and backup power) durability targets have already been met.

Typically, durability has improved from just a few hundred hours for early designs, to between 3,000 and 5,000 hours, depending on the duty-cycle. The target for automotive, the most difficult duty cycle, is 5,000 hours and current state-of-the-art is 2,200 hours (equivalent to 100,000 km of driving).

#### Power Density

Power density is a measure of how much power a fuel cell can deliver per given volume. It is especially important for mobile applications to provide the performance consumers demand. It is also closely linked with cost reduction targets. Getting more out of each individual cell reduces cost by allowing a smaller fuel cell to do the job.

Power density has increased by 50% and needs to be increased by a further 25% to reach automotive-targeted performance.

#### Freeze-Start

Fuel cells produce water as their main by-product. How that water is managed inside the fuel cell is very important when dealing with freezing temperatures. Fuel cells must be shut down in such a way that free water is not left where it could expand upon freezing and damage the cells. This is one area where significant progress has recently been made. Early demonstration vehicles had to be kept above zero degrees at all times. Automotive fuel cell engines are now able to not only freeze, but can be started from minus 30°C and can achieve 50% power in 90 seconds.

The challenge over the coming years will be to continue making progress on each performance indicator without adversely affecting any other.

Source: Natural Resources Canada

As markets grow, we may well see forklift OEMs offering their customers more integrated solutions that include system, and perhaps even stack development.



## Materials Handling

Zero emissions, increased productivity and lower operational costs over the life cycle of a lift truck combine to provide the materials handling market with one of the strongest business cases for fuel cell applications in the near-term. While estimates of the overall size of the market range from US\$1.5 to 3.5 billion, most industry players agree that fuel cell powered products are most appropriate for large warehouses or assembly plants with over 100 lift trucks running 24-hour multiple shifts. The hydrogen infrastructure required to fuel equipment at these larger facilities can be serviced by the existing cryogenic storage solutions offered by many hydrogen suppliers. Further, within this market, many end-users feel that fuel cells will provide particular value within cold storage facilities if freeze start and low temperature operating capabilities can be improved. In addition to these technology challenges, concerns regarding fuel cost and safety need to be addressed and, ultimately, competitive advantages may well depend on sales and marketing expertise.

Canadian companies playing an important role in the materials handling market believe that, given the current and projected order volumes and recent advances in stack and component design, the existing manufacturing capacity should be sufficient to achieve a significant reduction in cost. However, as with other battery replacement applications in mobile markets, the potential cost reductions and performance enhancements will remain limited until forklift manufacturers design their trucks to better match the particular capabilities of the fuel cell. As commercialization grows, forklift OEMs may offer their customers more integrated solutions that include systems and perhaps, even stack development. Until then, tax incentives such as those available in the United States (\$1,000/kW installed up to 30% of product value) will continue to be a significant part of the current return on investment for the end-users.

Figure 14: Market, Cost and Performance Targets – Materials Handling

Attribute	2010 Target	2015 Target
Projected Sales Volume	5,000	30,000
Durability (hours)	15,000	25,000
Reliability (%)	99	99.5
Total System Cost (US\$/kW)	3,000	2,000
Temperature Range	-30 to 45	-35 to 55

Source: PricewaterhouseCoopers: Canadian industry wide survey validated at Industry Canada/National Research Council April 2008 Workshop in Vancouver

The battery replacement market is forecasted to grow over the next five years and, subsequently, lift truck manufacturers are expected to develop new purpose-built fuel cell lift trucks.

For 2008, Ballard has forecasted that it will ship 450 stacks into the materials handling market. In May 2007, Ballard signed an initial two year supply agreement with Plug Power for materials handling products, subsequent to Plug Power's acquisition of both Cellex and General Hydrogen. Ballard is working with The Raymond Corporation, a North American leader in the design and manufacture of electric lift trucks, to design and develop a purpose built fuel cell lift truck as well as with Exide Technologies on the development of an on-board hybrid battery charging system for lift trucks.

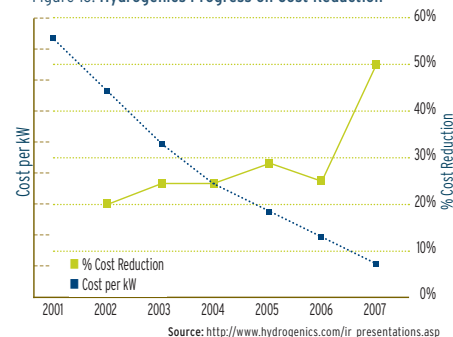
Hydrogenics estimates the materials handling market at \$3.5 billion.

Plug Power and Hydrogenics together, are deploying hundreds of fuel cell lift trucks in Wal-Mart's 24-hour three shift warehouses and at General Motor's assembly plants.



Photo: Plug Power

Figure 15: Hydrogenics Progress on Cost Reduction



Source: [http://www.hydrogenics.com/ir\\_presentations.asp](http://www.hydrogenics.com/ir_presentations.asp)



### India Calling

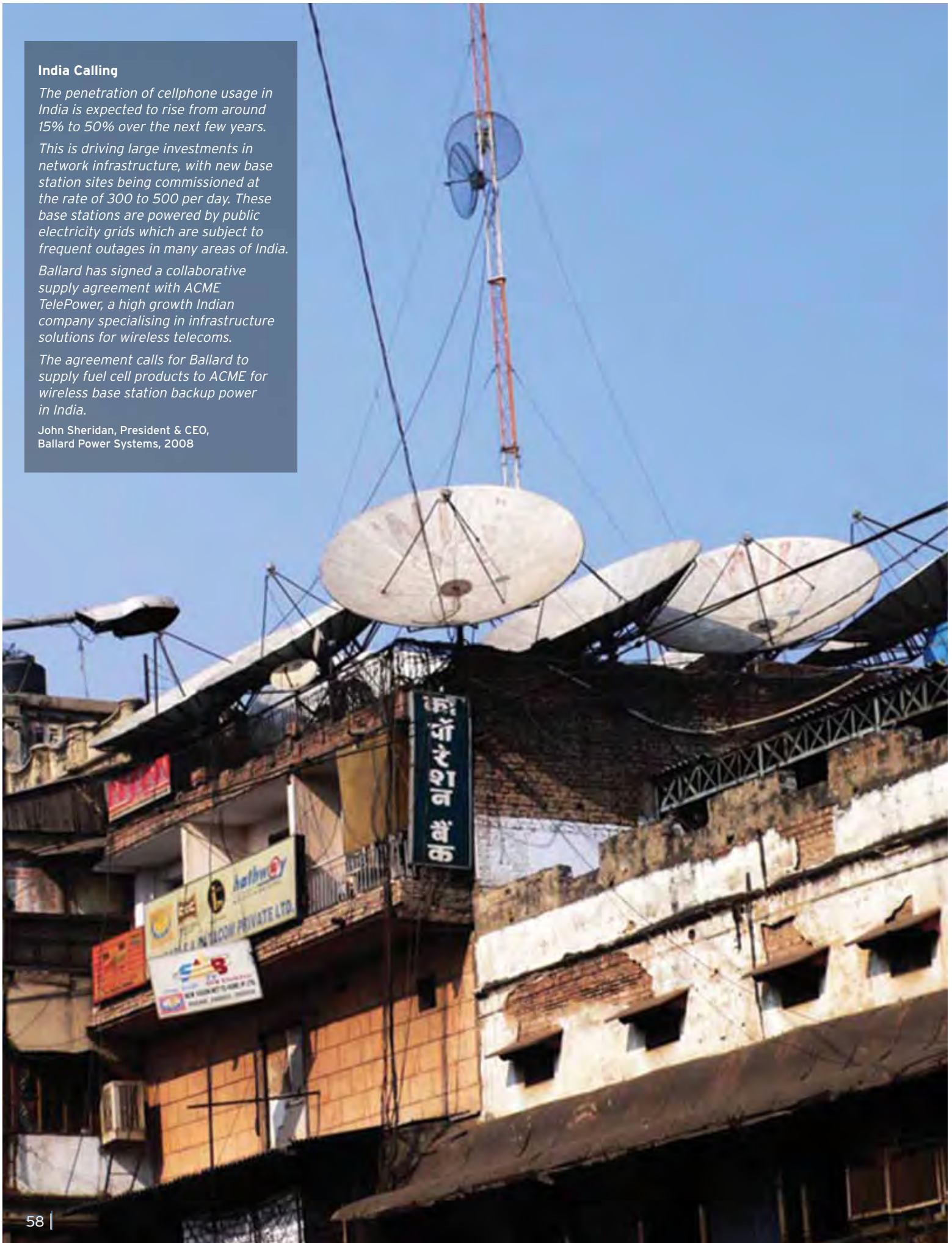
*The penetration of cellphone usage in India is expected to rise from around 15% to 50% over the next few years.*

*This is driving large investments in network infrastructure, with new base station sites being commissioned at the rate of 300 to 500 per day. These base stations are powered by public electricity grids which are subject to frequent outages in many areas of India.*

*Ballard has signed a collaborative supply agreement with ACME TelePower, a high growth Indian company specialising in infrastructure solutions for wireless telecoms.*

*The agreement calls for Ballard to supply fuel cell products to ACME for wireless base station backup power in India.*

John Sheridan, President & CEO,  
Ballard Power Systems, 2008



## Significant market opportunities for backup power expected in US, Europe and India.

### Backup Power

Significant market opportunities for backup power applications are expected in the telecommunications sector in the US, Europe and India. These markets are driven in the United States by legislation regulating the provision of eight hours of backup in the event of grid failure, in Europe by the Tetra Emergency Network, and in India by the growth of cellular service sites and an unreliable grid. Within this market, estimated at between \$2 to 3.2 billion, competition will be fierce. Not only will there be competition with incumbent providers who are continually improving their more traditional batteries and who will surely exploit their existing customer relations and financial strength to resist any erosion of market share, there will also be competition among fuel cell companies and between fuel cell technologies.

As in other markets, telecommunications and other potential end-users of backup power applications are looking for suppliers to provide complete solutions, which include fuelling and fuel infrastructure. For most developers of PEM fuel cell solutions, this usually means direct hydrogen. There are, however, companies outside of Canada offering reformer based products that take advantage of existing fuel infrastructure. Compressed hydrogen gas is an acceptable solution for many end-users. If pricing and infrastructure issues can be addressed, the opportunities for companies with the resources to expand beyond the US appear very promising, especially in areas where grid unreliability causes frequent and lengthy power outages. To understand the full growth potential of this application it will be important to see whether the fuel cell products are being deployed in niche applications or as more general displacements of incumbent technologies.

Figure 16: Market, Cost and Performance Targets – Backup Power

Attribute	2010 Target	2015 Target
Projected Global Sales Volume	75,000	300,000
Cold Start-up Time (sec)	10	3
Reliability (% availability)	99.9	99.9
Transient Power Response Time (sec) Running with load change	5	5
Total System Cost (US\$/kW)	2,000	1,500
Freeze Start (°C)	-10	-20

Source: PricewaterhouseCoopers: Canadian industry wide survey validated at Industry Canada/National Research Council April 2008 Workshop in Vancouver

With annual projected sales of 75,000 units by 2010, Canadian companies are well positioned to capture a large market share.

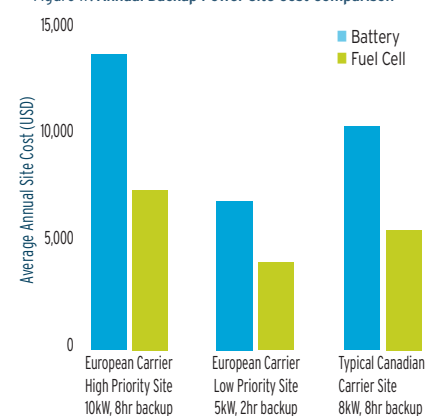
### Canadian Activities in Foreign Markets

Ballard has provided directional stack pricing of US\$800 to \$1,500 for 2010, and has announced that it expects to ship 750 backup stacks to markets in Europe and India in 2008, a 400 percent increase over the previous year's sales. Ballard has developed an air-cooled stack that supports a simplified system and has secured orders and partnerships with various system integrators, most prominently Dantherm.

Asteris, a Toronto-based developer of AFCs was recently purchased by the Indian telecom backup power provider, ACME Tele Power Ltd., providing deep pockets, as well as a direct path to end-users for this alternate fuel cell solution.

Hydrogenics is partnered with American Power Conversion and is well positioned to capture a significant market share in North America and Europe.

Figure 17: Annual Backup Power Site Cost Comparison



Source: [http://www.hydrogenics.com/ir\\_presentations.asp](http://www.hydrogenics.com/ir_presentations.asp)



Figure 18: Japanese Residential Co-gen Market

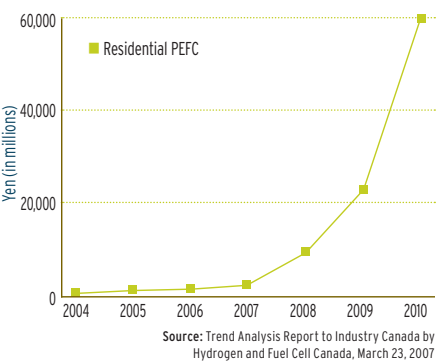


Photo: Ballard Systems

## Residential Co-gen

Today, the residential co-gen market is focused squarely on Japan, where over 2,000 fuel cell powered units have already been installed. This market is driven by the high cost of electricity and a federal mandate in that country to diversify energy supply, decentralize power and reduce smog and GHG emissions. While individual customers benefit from up to \$500 in annual savings, due in part to government installation credits and fuel subsidies, at a total cost of approximately \$5,000 for a complete co-gen unit, more work is needed to achieve significant commercial volumes. Major Japanese oil and gas companies, including Nippon Oil, Tokyo Gas, and Osaka Gas are working together to develop component supply chains and working with fuel cell developers to reduce system costs. These efforts may be helped by growing interest from the South Korean market for a similar product.

Proposed regulations related to standardization of codes may also help to smooth commercial growth in Japan and in other countries which adopt similar standards. While Japan offers a huge potential market opportunity in residential co-gen for Canadian companies, there is competition from the likes of Toyota, Toshiba, Matsushita and Sanyo. The opportunity to expand into other markets, including South Korea and Germany, with the same platform will certainly help brighten the mid-term picture.

Two Canadian companies, Ballard Power Systems and Hyteon, have used their expertise to gain a foothold in this highly competitive near-term market. Ballard has been in this market from the beginning, and through its joint-venture Ebara-Ballard, has provided close to a quarter of the total number of units installed. Hyteon, has been providing complete fuel cell systems for the Japanese residential market through a strategic partnership with a large Japanese utility since 2006.

Figure 19: Market, Cost and Performance Targets – Residential Co-gen (PEM)

Attribute	2010 Target	2015 Target
Projected Global Sales Volume (kW)	15,000	250,000
Total System Efficiency (%) (LHV; Natural Gas)		
Electrical/thermal	85	90
Electrical	35	37
Reduction in CO2 Emissions (%) Relative to Incumbent	35	40
Durability	40,000/10 years	60,000/10 years
Total System Cost (US\$/kW)	12,500	6,000
Failure Rate No. failures/system per year	0.2	0.05

Source: PricewaterhouseCoopers: Canadian industry wide survey validated at Industry Canada/National Research Council April 2008 Workshop in Vancouver

## Utility-scale Fuel Cells

The commercialization of large stationary fuel cells has evolved significantly over the last few years. While 200-400 kW units are still prevalent, a trend is emerging to advance multi-megawatt, utility-scale fuel cells. Technology cost reductions are being realized as fuel cells scale up into megawatt (1000 kW) and larger installations. At this size, today's technology costs are below \$3,500/kW for some manufacturers. The costs still reflect a price premium compared to incumbent technologies; however this premium is marketable in jurisdictions that assign monetary value the fuel cell's ability to reduce GHG emissions and the near-zero criteria air pollutants.

High temperature fuel cells are predominant in this market segment as a result of the technology's high fuel-to-power efficiencies and the high quality heat is ideal for cogeneration. Canadian expertise and R&D priorities are focused on the improving the balance of plant (BOP) systems such as the power conditioning systems (inverters) as well as pre-treatment system for water and fuel. To increase market penetration, the BOP systems are being refined to increase reliability, reduce footprint, and increase system efficiencies by reducing the parasitic loads that otherwise consume a portion of the fuel cell's electricity generation.

Within the utility-scale fuel cell markets Canadian expertise with fuel cell system integration is growing. Enbridge Inc. has partnered with FuelCell Energy Inc. to develop a hybrid fuel cell that focuses on natural gas distribution utilities as early adopters. Enbridge is integrating turboexpander technology into the fuel cell's operation to increase electrical efficiencies to an unmatched 60%. The turboexpander harvests waste pressure and enthalpy from pipeline pressure reducing stations for the useful production of electricity. The integration of the fuel cell more than doubles the electricity generation capabilities while ensuring the entire power plant operates without the combustion of fuel. The first 2,200 kW pilot-plant in Toronto, Ontario, will be in commercial operation by the late fall of 2008. It is estimated the near-term Canadian market potential is 60-100 megawatt (MW), and markets in the US Northeast, California, Korea, Japan and the United Kingdom are being evaluated.



Photo: Enbridge Gas Distribution and Fuel Cell Energy Direct Fuel Cell-Energy Recover Generation Power Plant in Toronto, Ontario

Figure 20: Market, Cost and Performance Targets – Utility Hybrid Fuel Cells

Attribute	2010 Target	2015 Target
Projected Global Sales Volume (kW)	35,000	300,000
Total System Efficiency (%) (LHV; Natural Gas)		
Electrical/thermal	80	90
Electrical	60	70
Reduction in CO <sub>2</sub> Emissions (%) Relative to Incumbent	50	55
Durability (stack life in hours)	50,000	80,000
Total System Cost (US\$/kW)	3,000	2,400
Technology Applications	Limited to baseload markets	Increase dispatch capabilities

Source: PricewaterhouseCoopers: Canadian industry wide survey validated at Industry Canada/National Research Council April 2008 Workshop in Vancouver

Angstrom Power



Angstrom's newly announced micro fuel cell and proprietary hydrogen storage and refilling technology, being tested by Motorola, fits into a standard mobile phone and provides twice the talk time of an equivalent battery operated device.<sup>10</sup> Angstrom hopes that its technology will be in commercial cellphone products by 2010.

Angstrom Power worked with Transport Canada to build the case to support significant Canadian regulatory proposals, including one for passenger cabin exception, for fuel cells cartridges containing hydrogen. This government-industry partnership illustrates Canada's leadership role in the hydrogen and fuel cell sector.

Tekion



In a joint Development program with Motorola, Tekion was the first to integrate a micro hybrid battery-formic acid fuel cell system inside the existing battery form factor of a two-way radio. Several prototypes have been delivered to Motorola for testing and evaluation.

From Tekion's work with Motorola, and other world class manufacturers, Tekion has been working on advanced fuel cell system design and intends to launch it's first commercial product in 2009.

Portable Electronics

Almost all global players in the portable electronics and battery markets are working on bridging the ever expanding gap between required run time and the power supply available using current battery technology. This is a market with strong customer pull. Here, the end-users are not concerned with how a device operates; all they want is mobility and freedom from the need to constantly recharge batteries. Hydrogen and fuel cell technology can offer that freedom.

These portable electronics applications have the potential to be the first mass market for fuel cell products — and Canada has been there, front and centre, from the very start. In partnership with OEMs, Canadian companies, including Angstrom and Tekion, have been working hard to overcome issues around system complexity, water management, cost and volumetric power density. While much of the early work by large multinationals in the consumer electronics sector in this area was focused on direct methanol fuel cells, today these companies are exploring alternatives. Tekion and Angstrom led the way with the international regulatory authorities to get the use of cartridges containing formic acid as a direct liquid fuel, and metal hydride solutions for the storage of hydrogen, approved by the International Civil Aviation Organization Dangerous Goods Panel for transport within airline passenger cabins. This official validation of the safety of these technologies will go a long way in facilitating the use of fuel cells in portable electronic devices. Going forward, strategic partnerships with end-users and throughout the supply chain will be essential to resolving the remaining challenges associated with system design and high-volume manufacturing. However, given the depth of our expertise and the strength of our existing relationships, Canada is well positioned to benefit from commercialization in this market with the right strategic partnership for manufacturing, distribution and marketing.

Figure 21: Market, Cost and Performance Targets – Portable Electronics

Attribute	2010 Target	2015 Target
Projected Global Sales Volume	1,000,000	5,000,000
Volumetric Energy Density (Wh/L)	350	500
Required Run Time (Laptop/Cellphone) [hours of device use]	15 Laptop 10 Phone (equivalent to 3 charges today)	20 Laptop 15 Phone
Charge/Recharge Cycles of Durability (number)	300	500
Total System Cost (Cellphone/Laptop) [US \$/Watt]	7.50/watt phone 1.50/watt laptop	5.00/watt phone 1.25/watt laptop
Max Device Operating Temp (°C)	45	40

Source: PricewaterhouseCoopers: Canadian industry wide survey validated at Industry Canada/National Research Council April 2008 Workshop in Vancouver

Canadian micro fuel cell technology can potentially meet escalating demand for energy density and extended run time in personal electronics.





As a public good, fuel cell transit buses provide a platform for government leadership in adopting clean transportation solutions.





## Buses

Thanks in large part to the staunch support of forward thinking governments and transit authorities, fuel cell powered buses continue to provide the general public with its most direct and accessible exposure to the benefits of fuel cell technology. Driven by the increasing cost of diesel, high levels of smog and GHG emissions in congested urban centres, and the California Zero-Emissions Vehicle policy, new transit demonstration programs are being announced almost every month. The number of these programs is a testament to the advancements made in fuel storage, infrastructure and fuel cell stack and system reliability. In the long run, the commercial viability of a fuel cell based powertrain may require the direct involvement of an existing bus engine OEM. The CUTE program, for instance, was an excellent example of what can be achieved when a key industry player like Daimler AG is able to leverage its strategic co-development partners to produce a product that surpassed almost all expectations. Data<sup>3</sup> now available from this and other programs suggest that, in terms of total life cycle cost, the value gap between fuel cell and more conventional technologies is narrowing. Indeed, one US developer is set to offer a 10,000 hour warranty on its next generation fuel cell bus. Still, at over \$2 million, fuel cell buses are very expensive, costing four times more than conventional diesel buses and over twice as much as diesel electric hybrid buses.

However, when compared with electric trolley buses which cost \$1.4 million each, the cost of a fuel cell bus is not too far out of reach. With the support of proactive transit authorities and the financial assistance from government, we are likely to see a growing number of fuel cell buses on roads. Given the advances in this market, the industry and transit operators expect that by 2012 the cost of fuel cell transit buses will be reduced to about \$850,000, roughly the cost of diesel hybrid electric buses.



Photo : Fuel Cell Bus from Ballard Power Systems Inc.

Canada has been a leader in fuel cell bus deployments all over the world through programs like HyFLEET, CUTE, ECTOS and STEP and the London project.

Canada is again at the forefront, deploying 20 hydrogen fuel cell buses in 2010.

Between 2000 and 2004, fuel cell stack costs decreased from almost \$10,000 \$US/kW to less than \$500.

Air Liquide

A leading global provider of industrial, medical and speciality gases, Air Liquide has more than 40 years of expertise in the hydrogen business. The company is actively developing the entire hydrogen energy supply chain, from H<sub>2</sub> research and fuel cell production to distribution and applications. Air Liquide's existing hydrogen infrastructure includes the world's longest pipeline network and the installation of hydrogen vehicle refuelling stations around the globe, including Canada. The company is involved in more than 20 projects in North America alone to demonstrate the safe use of hydrogen in over 30 industrial applications.

Across the country many transit authorities support a broader deployment of fuel cell technology into community shuttle buses. These smaller vehicles offer another near-term market opportunity. BC Transit is working with the Hydrogen Bus Alliance to maximize procurement opportunities with other regions. Canadian companies active in this market include Ballard and Hydrogenics, and they are continuing to develop advanced stack and system technologies and related cost reductions. Canadian bus manufacturer, New Flyer, recently signed an exclusive agreement with Ballard Power to develop fuel cell shuttle buses for the North American market.

Figure 22: Market, Cost and Performance Targets – Transit Buses

Attribute	2010 Target	2015 Target
Projected Global Sales Volume	200	1500+
Total Product Sales Price (US\$)	1,250,000	850,000
Durability (hours)	10,000	20,000
Operational Reliability (%)	95 (in service)	98 (in service)
Availability (%)	90	95

Source: PricewaterhouseCoopers: Canadian industry wide survey validated at Industry Canada/National Research Council April 2008 Workshop in Vancouver

Figure 23: Market, Cost and Performance Targets – Shuttle Buses

Attribute	2010 Target	2015 Target
Projected Global Sales Volume	50	100+
Total Product Sales Price (US\$)	750,000	500,000
Durability (hours)	10,000	20,000
Price of Hydrogen Fuel (US\$/kg)	\$10	\$2.50

Source: PricewaterhouseCoopers: Canadian industry wide survey validated at Industry Canada/National Research Council April 2008 Workshop in Vancouver

Fuel cell market and transit operators expect that the fuel cell bus will be cost competitive with diesel elective buses by 2012.

## Supporting Hydrogen Infrastructure

By and large, hydrogen infrastructure is not expected to be a major limitation in near-term commercial markets and demonstration projects. In Canada a wide range of hydrogen production, storage and distribution solutions are being developed.

BC Transit has finalized a six-year, \$20-million contract with Air Liquide Canada Inc. of Montreal to supply hydrogen for the fuelling of their 20 bus fleet that will be running in the Resort Municipality of Whistler, a key stop along British Columbia's Hydrogen Highway. The hydrogen supply for the fleet will be produced from clean and renewable sources, primarily electrolysis using hydro-electricity and from recovered waste gas. Air Liquide, together with Canadian companies Sacré-Davey Group, Hydrogen Technology and Energy Corporation and Hydrogenics Corporation, will design, supply, operate and maintain two hydrogen fuelling stations. The first fuelling station will be located in Victoria at BC Transit's Langford Transit Centre. The other station will be located in Whistler at a new BC Transit facility and, once complete, will be the world's largest hydrogen fuelling infrastructure.

The materials handling and backup power markets can be supported by an existing distribution and storage system for compressed hydrogen. For the mid to longer term, QuestAir is working with Exxon Mobile to develop on-board reforming technology for materials handling. Fuel cells for the portable electronics sector are benefiting from innovative approaches to hydrogen storage. As large renewable energy projects come on line, truly zero emission production of hydrogen via electrolysis becomes an increasingly viable option. Studies have recently indicated that hydrogen can be produced via electrolysis from wind electricity for approximately US\$7 per kilogram.<sup>11</sup> Overall, Canada is doing its fair share and more to position itself as a major supplier of hydrogen to the fuel cell industry.

### Powertech Labs

The Compressed Hydrogen Infrastructure Program (CH2IP) is a hydrogen fuelling station in Surrey, British Columbia, operated by Powertech Labs Inc. and opened in March 2002. In November 2002, the station was upgraded to deliver fuel to vehicles requiring higher pressure hydrogen gas, becoming the first in the world to fuel at 70 Mega Pascals (10,000 psi) of pressure. The higher pressure allows compatible fuel cell vehicles to carry more fuel and travel farther than the equivalent fuel cell vehicle with standard (35 Mega Pascal) pressure systems. The Lower Mainland's climate and geography, plus access to Powertech's 70 Mega Pascals hydrogen filling station, made the Vancouver area the place to test the viability and endurance of Nissan's fuel cell vehicle.



Photo: Powertech Labs

### The Linde Group

The Linde Group supports over 40 hydrogen filling stations all over the world and has a number of partnerships with Canadian Companies.



Photo: The Linde Group

## Common Linkages: From Near-term Market to Mass Market Requirements

**Technology advancements still required**

Advancement in the follow areas will smooth the path to profitable revenue growth for hydrogen and fuel cell companies:

- Platinum catalyst loading reduction, without sacrificing performance or durability
  - Composite membrane development using low-cost ionomers
  - Use of continuous gas diffusion media as an onset to continuous MEA manufacture
  - High volume sealing process technologies
  - Design simplification with reduced parts count
  - Rapid testing methods for finished products
  - Product recycling strategies
  - Strategic partnerships with component suppliers and system integrators
  - Strategic partnerships with hydrogen producers/suppliers
  - Enhanced marketing and sales expertise
  - Quality products and quality service
- .....

There are many clear and valuable linkages between near-term markets and more distant mass markets, like automotive. The growth and maturation of the supply chain, including after sales services, will ultimately benefit the light duty FCV market. Despite limited direct parallels in design and function, further development of stack and balance-of-plant technology to reduce cost and enhance performance will also be of benefit. Developments in hydrogen storage, purification, infrastructure deployment, and safety education will all have a positive impact to the onset of mass market applications. Continuous or highly-automated processes for the manufacture, assembly and testing of fuel cell stacks and systems will also foster development in mass market applications and ease the path to commercial growth.

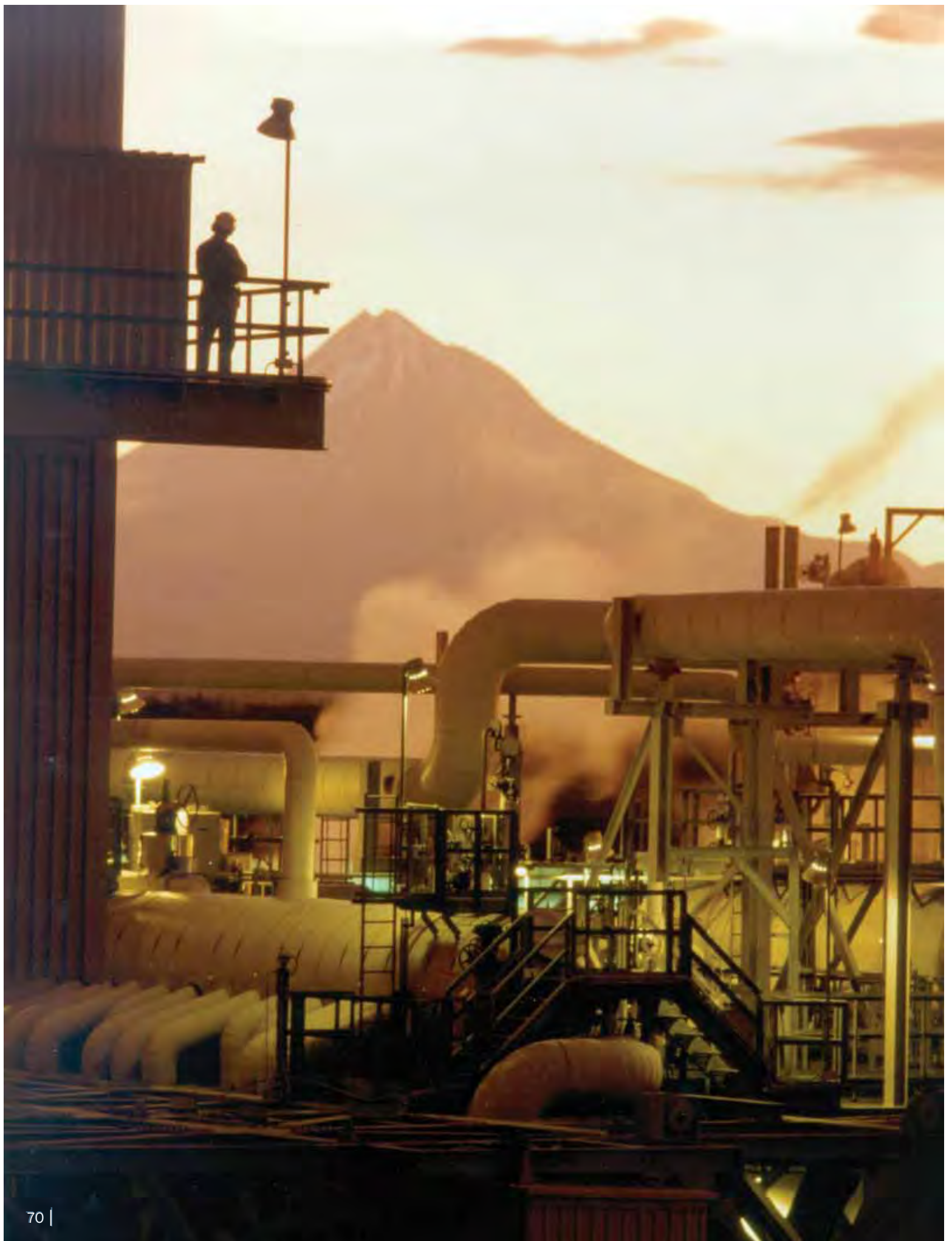
Applicability of near-term market driven technologies, components and processes will be, dependent on the technologies and design that trigger the commercial launch of FCVs. If, as many believe, these vehicles are to be heavily hybridized, there may be a high degree of applicability between markets. However, there will also be other areas related to the key elements of the stack system interface, control and monitoring processes, integration within the complete powertrain, and other subtleties where the overlap in learning will be more limited.

Lastly, the growth in near-term markets will result in a corresponding growth in employment and training. These resources will help position Canada as a source of skilled personnel who can develop, build, test and repair fuel cell products. Automotive manufacturers will recognize Canada as a location for both Tier 1 and Tier 2 suppliers and vehicle assembly plants.





Photo: Ballard Power Systems





# The Commercialization Path for the Canadian Hydrogen and Fuel Cell Industry

## How the Mass Markets May Unfold

The success of hydrogen and fuel cell technologies in the mass markets is dependent on their ability to provide substantially better solutions than the incumbent combustion or battery technologies. What makes for a “better” solution depends on a balance of technical and societal benefits.

### Fuel cells for portable electronics should be first (2009-13)

Power hungry handheld devices incorporating G3 wireless protocols and supporting broad multimedia capabilities, including streaming video, video-phone and GPS, are creating an energy gap. Today, high-end users are compelled to carry replacement batteries. With the power demand projected to quadruple over the next four years, micro fuel cells that provide higher energy density and can be refuelled in ten minutes or less will become a viable replacement for lithium ion batteries.

To participate in this potential mass market application, Canadian companies developing fuel cells for portable electronics will need to ally themselves with the battery companies that presently provide the micro-power solutions for mobile phones, laptop computers, and other portable electronic devices.

### Residential co-gen will emerge in certain countries (2012-17)

The residential co-gen market for fuel cell systems is being driven by government support in Japan and, more recently, South Korea. Participation by Canadian industry will be through partnerships with organizations based in those countries. The technology, manufacturing and supply chain knowledge they develop through those relationships should strengthen their competitiveness in other near-term markets, such as backup power, materials handling, and buses, and thus further position them to be suppliers when the mass market in cars begins to happen.

Although the residential co-gen system is unlikely to become common in North America because of the low cost of electricity, the very low cost reformer sub-system could be deployed in homes as hydrogen refuelling systems for cars, and fuel cell systems for portable electronics.

### Fuel cells in cars as the ZEV end-game for plug-in hybrids (2015-25)

Full-performance, zero-emission, sustainable mobility, is the end-game for automotive OEMs. GM, Toyota, Ford, Daimler and Honda are developing a portfolio of sustainable mobility solutions ranging from bio-fueled ICEs, through hybrids and plug-in hybrids, to hydrogen fuel cell vehicles. This scenario presents opportunities to leverage synergies between emerging plug-in hybrid vehicle technology and the “heavy-hybrid” fuel cell solutions being deployed in the materials handling and bus markets. Canadian companies participating in these near-term markets will have to develop the technologies and talent pool to be successful participants in automotive “end-game”.



## How will the Hydrogen Infrastructure for the Mass Markets Evolve? (2015-2025)

The first widespread use of hydrogen as a fuel will be in early fuel cell markets. Thus, the first elements of the hydrogen infrastructure for the mass automotive market will be the fleet deployments in the materials handling and bus markets. Residential co-gen markets may also provide the basis for home fuelling of fuel cell vehicles.

This deployment of a hydrogen fuelling infrastructure for fleets will solidify the framework of codes and standards. The regulations and safety rules will engender the social acceptance needed to support more widespread deployment. In addition, the fuel providers will develop the delivery logistics or on-site systems needed to provide quality fuel on a reliable basis. Since materials handling and bus fleets are concentrated in large urban environments, this near-term market infrastructure is well located to support the initial automotive hydrogen infrastructure deployment.<sup>12</sup>

Where the need to address energy security, urban pollution and climate change issues are a high priority, hydrogen infrastructure may involve centralized hydrogen and electricity production with carbon capture. Such facilities could augment renewable electricity sources for charging plug-in series hybrid fuel cell electric vehicles and provide the hydrogen by pipeline to refuelling stations or the home.

Canadian companies that are commercially successful in the near-term markets will be well positioned to exploit the mass markets as they unfold and have key intellectual property positions if any technology surprises do occur. For instance:

- if on-board reforming technology for the materials handling market is viable, it would also be suitable for plug-in hybrid fuel cell vehicles;
- if high temperature fuel cells become economic in residential co-gen applications, they could also be the basis for very economic hydrogen generation in off-peak periods; and,
- if fossil fuels become “sustainable” through carbon sequestration, then it is more likely for cars to use the hydrogen in a fuel cell than to convert it to electricity to charge a plug-in hybrid. This could drive a longer term trend toward a light-hybrid fuel cell vehicle being the most sustainable solution.

The Canadian hydrogen and fuel cell industry is focused on achieving commercial viability by exploiting opportunities in near-term markets. The expertise and capacity developed in markets for materials handling, backup power, residential co-gen, clean transit, and portable electronics applications will help position Canadian companies to play a key role in longer-term mass markets. Such proven capabilities will be sought out by OEMs and other strategic partners needing access to competitive hydrogen and fuel cell technology, and stimulate interest from investors eager to participate as these mass markets emerge.

Thus commercialization for this industry is on the same near-term to mass market path successfully followed by other technologies such as personal computing and global positioning systems.



## Success and Cross-Impacts in the Near-term Markets

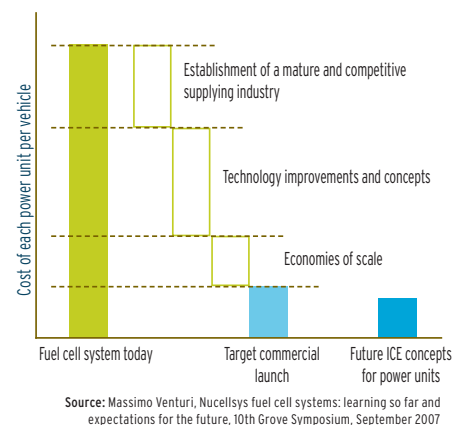
While issues of cost, reliability and durability have been successfully overcome for early adopters in certain near-term markets, they still present significant challenges for others.

Volume manufacturing could drive costs out of the residential co-gen market. Here, higher volumes will help create a mature and competitive supply chain and permit economies of scale through deployment of high volume manufacturing technologies and substantial learning curve effects. Residential co-gen products may, therefore, be a near-term mass market in jurisdictions where energy costs are very high. It could potentially create a competitive supplier industry, including stack and component suppliers which could benefit all near-term markets and help reduce costs in the mass automotive market.

Alone, the product volumes for the materials handling, backup power and bus markets are unlikely to be sufficient to provide the volume-driven cost reduction or economies of scale necessary for the development of a mature and competitive automotive vehicle supply chain. Costs in the bus market can only be addressed through R&D and the development of cost effective refitting and recycling strategies. However, some advances in the materials handling market may be transferable to the bus market. Similar requirements for heavy hybridization, durability and infrastructure suggest R&D efforts focused on one market could have direct benefit in the other. In addition, the greater number of forklifts per site should create a hydrogen demand comparable to the smaller number of buses likely to be deployed in initial trials.

A major benefit of the portable electronics market is that volume will drive economies of scale for manufacturing without the necessity of massive capital investments or materials consumption. If companies succeed in producing fuel cells for portable electronics in volumes in excess of one million units per year, the manufacturing technology will likely have been validated. Assuming the technology is scalable, they will have made significant progress towards achieving cost targets in mass markets.

Figure 24: Supply Chain, R&D, and Manufacturing Drivers for Cost Reduction



## How can Canada Maintain a World Leading Position?

While Canadian companies have begun to experience commercial success in near-term markets, a number of actions would help Canada maintain its position as a key player in the hydrogen and fuel cell industry. Despite Canada's many advantages, the global lead of Canada's hydrogen and fuel cell industry is at risk. Actions will be required to ensure that the industry is well positioned to invest adequately in its future, and joint industry and government efforts continue so that Canada reaps the economic, environmental and energy benefits that hydrogen combined with fuel cells can provide.

### R&D investments and knowledge expansion are still critical for early commercialization

- Rationalize Canadian R&D efforts for increased focused and enhanced coordination
- Focus on engineering design simplification and optimization to drive down costs and increase product quality
- Develop pathways for platinum loading reduction and recycling combined with creative pricing strategies
- Build continuous manufacturing processes
- Establish cross-function science/engineering programs in academia to build knowledge and expertise in the sector

### Build global value chains to help reduce costs

- Encourage formations of strategic supplier relations between international companies and Canadian hydrogen and fuel cell companies
- Access offshore low-cost, expert manufacturing for fuel cell components to build a robust supply chain for near-term markets
- Consolidate and integrate supply chain to reduce costs
- Promote formation of serving and recycling expertise

### Local adoption of codes and standards

- Accelerate the development and local adoption of global codes and standards for the proliferation of hydrogen infrastructure and fuel cell products

## Commercial product deployments for financial viability

- Ensure effective warranty and post sale service is available
- Encourage technical colleges to set up training programs to create service-based competencies for fuel cell products
- Develop recycling strategies for key components
- Support the need for public investments by crown corporations and all levels of government for early adoption in near market applications such as transit
- Make available low interest loans and accelerated depreciation of cost of capital for fuel cell manufacturing equipment purchases
- Examine the feasibility to launch public cost and risk sharing incentives for early industrial users

## Path forward

Effective commercialization in near-term markets will achieve significant value for mass markets including keeping existing companies in business, generating profits and renewed investor confidence and interest; continued expansion of employment and training of key skills for future mass markets; building business for component suppliers to develop better materials; and, developing a total systems understanding of hybridization technologies, controls strategies and software that could be of direct use in mass market applications.





# Conclusion

As a pioneer in the global sector, Canada remains a world leader in the development and commercialization of hydrogen and fuel cell technologies. Since 2003, many Canadian companies have restructured their operations and refocused research and development investments away from long-term automotive markets towards the development and deployment of products in near-term markets. Others have specifically targeted near-term markets from the start. This refocusing has enabled firms to concentrate on applications that will generate early revenue streams and cultivate investor confidence. Over the past five years, significant progress has been made — cost and performance of fuel cells have improved seven fold and the industry has worked with government to create the world's first large scale, integrated demonstrations — the Hydrogen Highway and the Hydrogen Village.

Today, fuel cells produced by Canadian companies are being rigorously tested and commercially deployed in five near-term markets: residential cogeneration, backup power, portable electronics, materials handling, and transit bus applications. Canada is a key contributor to the global industry annual growth rate of 59% in delivered fuel cell units.

Over the short to medium term, it is expected that the existing industrial hydrogen infrastructure is sufficient to service the niche fuel cell markets. Gaseous compressed, cryogenic hydrogen, and waste streams will meet the fuelling needs for materials handling, backup power and buses. With a diverse energy base, Canada has multiple hydrogen production pathways, including renewables, hydro-electricity, and natural gas and coal with carbon capture and sequestration, and can be an important global supplier of hydrogen.

Sustained success in near-term markets will be critical in building the capacity for Canadian companies to participate in the longer term mass markets. Key aspects of this capacity building will be the expansion of the base of skilled technical and manufacturing personnel, increased production capacity and associated university and government research activities. Streamlined and focused R&D programs for commercialization, support to expand global value chains, the efficient local adoption of codes and standards, as well as incentive for cost effective product deployments, will help Canada maintain its position as a key player in the global hydrogen and fuel cell industry.

As the hydrogen and fuel cell mass markets in portable electronics, residential cogeneration, and electric mobility open up, Canadian capability proven in near-term markets, will be sought out by automotive OEMs and other strategic partners needing access to competitive hydrogen and fuel cell technology and know-how. Canada has an opportunity to bolster the commercialization of these technologies to help reduce greenhouse gas emissions and air pollution in global markets to mitigate the effects of climate change, and benefit many sectors, including transportation, manufacturing and telecommunications.

# References/Bibliography

## References

1. Hydrogen and Fuel Cells Canada. *Trend Analysis Report to Industry Canada* (2007) pp. 26-57.
2. Government of Canada. *Towards a National Hydrogen & Fuel Cell Strategy: A Discussion Document for Canada* (2006).
3. *Sustainable economics with clean and energy efficient vehicles*. In *Press releases RAPID*, (2007) [Online]. Available: <http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/07/594> [2008, October 28].
4. Hydrogen Bus Alliance (Ed.). *Hydrogen Bus Alliance* [Homepage of Hydrogen Bus Alliance], [Online]. Available: <http://www.hydrogen-busalliance.org/> [2008, October 28].
5. *AIM Flotation Road Show Presentation in PolyFuel*, (2005)[PDF]. Available: <http://ir.polyfuel.com/pyf/highlights/presentations/> [2008, October 28]
6. Fuel Cell Today (Ed.). *The Fuel Cell Today Industry Review 2008, Fuel Cells: Commercialisation* (2008).
7. PricewaterhouseCoopers (Ed.). *PwC 2007 Survey of Public Fuel Cell Companies*, (2007).
8. PricewaterhouseCoopers (Ed.). *Canadian Hydrogen and Fuel Cell Sector Profile 2007*, (2008).
9. Jeff Wise. (2006). *The Truth About Hydrogen*. In *PopularMechanics* (copyright 2008), [Online]. Available: <http://www.popularmechanics.com/technology/industry/4199381.html> [2008, October 28]
10. Angstrom Power Inc. (Ed.). *Press Releases*. (2008). In *Angstrom Power Inc. :: Better than Batteries™* [Homepage of Angstrom Power Inc.], [Online]. Available: [http://www.angstrompower.com/press\\_release/news\\_2008\\_01\\_08.html](http://www.angstrompower.com/press_release/news_2008_01_08.html) [2008, October 28]
11. Dawn Levy. *Researchers envision a hydrogen economy, fueled by wind and new technology*. (2005). In *Stanford News Service* [Homepage of Stanford University], [Online]. Available: <http://news-service.stanford.edu/news/2005/july13/hydrogen-071305.html> [2008, October 28].
12. Sig Gronich, US DOE Hydrogen Technology Advisory Committee Meeting. *2010-2025 Scenario and Infrastructure Analysis*. (2007).

## Bibliography

- Angstrom Power Incorporated (Ed.). *Angstrom Power Inc. :: Better than Batteries™* [Homepage of Angstrom Power Inc.] (2008-copyright). [Online]. Available: <http://www.angstrompower.com/> [2008, October 29]
- Ballard Power Systems Inc. (Ed.). *Ballard Power Systems – Accelerating Fuel Cell Market Adoption*. (2008). [PDF]. Available: [http://media.corporate-ir.net/media\\_files/irol/76/76046/BallardCorpPresFINAL.pdf](http://media.corporate-ir.net/media_files/irol/76/76046/BallardCorpPresFINAL.pdf) [2008, October 29]
- Ballard Power Systems Inc. (Ed.). (2008-copyright). *Hydrogen Power in Buses / Ballard Power* [Homepage of Ballard Power Systems Inc.], [Online]. Available: <http://www.ballard.com> [2008, October 28]
- Ballard and Voller sign fuel cell supply agreement*. (2007). In *FuelCellToday* [Homepage of FuelCellToday] (2008-copyright). [Online]. Available: <http://www.fuelcelltoday.com/online/news/articles/2007-10/Ballard-and-Voller-sign-fuel-cel> [2008, October 29]
- Dr. Massimo Venturi. *Nucellsys fuel cell systems: learning so far and expectations for the future, 10th Grove Symposium*, (2007).
- Hydrogenics Corporation (Ed.). Hydrogenics [Homepage of Hydrogenics Corporation], [Online]. Available: <http://www.hydrogenics.com> [2008, October 28]
- New Energy and Industrial Technology Development Organization (Ed.). *Fuel Cell and Hydrogen Technologies 7*. (2007). [PDF]. Available: [http://www.nedo.go.jp/kankobutsu/pamphlets/kouhou/2007gaiyo\\_e/79\\_86.pdf](http://www.nedo.go.jp/kankobutsu/pamphlets/kouhou/2007gaiyo_e/79_86.pdf) [2008, October 28]
- New Scientist (Ed.). *How traffic pollution damages the heart*. In *New Scientist*. (2008)
- Patrick Tucker. *Futurists forecast rapidly growing competition in the hybrid marketplace*. In *PR Leap*. (2007-copyright), [Online]. Available: <http://www.prleap.com/pr/80105/> [2008, October 28]
- PricewaterhouseCoopers Advisory (Ed.). *Impact Assessment on a New Approach for The Cleaner and More Energy Efficient Vehicles Directive Proposal* (Final Report). (2007). [PDF]. Available: [http://ec.europa.eu/transport/clean/promotion/doc/2008\\_ia\\_dir\\_en.pdf](http://ec.europa.eu/transport/clean/promotion/doc/2008_ia_dir_en.pdf) [2008, October 28]
- Status and Prospects for Zero Emission Vehicle Technologies. Independent Expert Panel Report, Presentation to California Air Resources Board, (2007).
- Steve Medwin. *Application of Fuel Cells to Fork Lift Trucks*. (2005). [PDF]. Available: [http://www.raymondcorp.com/das/PDF\\_storage/TechnicalPapers/0130FuelCells.pdf](http://www.raymondcorp.com/das/PDF_storage/TechnicalPapers/0130FuelCells.pdf) [2008, October 29]
- The Freedonia Group (Ed.). *Hybrid Electric Vehicles & Competing Automotive Powerplants - Market Research, Market Share, Market Size, Sales, Demand Forecast, Market Leaders, Company Profiles, Industry Trends*. (2006). In *The Freedonia Group - Market Research* [Homepage of The Freedonia Group]. (2008-copyright). [Online]. Available: <http://www.freedoniagroup.com/Hybrid-Electric-Vehicles-And-Competing-Automotive-Powerplants.html> [2008, October 29]



Participating Companies and Organizations

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