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Executive Summary

Early successes in research and development activities by Canadian hydrogen and fuel cell companies have demonstrated the viability of hydrogen and fuel cells as enablers of clean and efficient energy, and have established a global reputation for Canada as a leader within the emerging industry. However, despite sustaining years of substantial research cost, Canadian companies, and the industry at large, have yet to reap the benefits of significant innovation through the commercialization of intellectual property.

After more than a decade of primarily industry-driven development, many Canadian fuel cell producers and supporting technology providers are preparing for wide-spread commercialization in stationary, portable and transportation markets. Yet, significant competitive, technological, infrastructure and regulatory hurdles remain. Overcoming these barriers will require increased commitment and cooperation between public and private sector stakeholders at a national and international level.

For Canada, successful innovation in the fuel cell industry will largely depend on how our research-focused companies leverage their current leadership position to address such issues as production, integration, manufacturing and marketing. To meet this challenge, the Canadian federal government has established a number of programs to support demonstration projects within Canada, and is increasing the fuel cell research capabilities of several Canadian universities. In the private sector, Canadian companies are partnering with multinational automakers and energy companies to gain access to capital and showcase Canadian technology in demonstration projects around the world. Canada is also playing a major role in the development of international safety and performance standards which will be integral to the transition to a worldwide hydrogen economy.

Introduction

The following review of Canada's fuel cell industry is part of a cross-country, cross-industry comparison of innovation systems and research and development (R&D) productivity in the energy sector being conducted by the Organization for Economic Cooperation and Development (OECD). Its objective is to provide a foundation from which to make sound policy decisions on public/private partnerships, intellectual property rights and R&D Funding.

For the purposes of this review, innovation is defined as the process of successful development and commercialization of new or improved products or services resulting from the creation and diffusion of knowledge. The innovation system describes the interaction between a network of stakeholders and the influences that drive those interactions.

This review identifies the major global, national and local drivers of innovation within the Canadian fuel cell industry. It describes the evolving relationship between the principle public and private sector stakeholders, particularly with respect to funding and the management of intellectual property. It also looks at the influence of trends such as globalization, advances in information and communication technology, and increasing environmental concern. Finally, an evaluation of the effectiveness of the innovation system is presented. Available quantitative information on employment and revenue is reviewed. Qualitative measures such as international reputation and cluster development are discussed and an OECD-supplied benefit matrix is presented.

Material used to compile this review was gathered from published documents and interviews with industry experts in both the public and private sector.

The Drivers of Innovation

The key drivers influencing the Canadian fuel cell innovation system continue to evolve. Initially, the demand for new technologies to meet the rigorous performance requirements of the defence and aerospace industries was the principal driver of innovation. In the early eighties, Ballard Power Systems of Vancouver, while working on contract to the Department of National Defence, pioneered much of the early research which became the foundation of the fuel cell industry. Other government departments with strategic interests in technological innovation, particularly Natural Resources Canada (NRCan) and the National Research Council (NRC), also played a pivotal role in establishing the nascent industry.

With support from these public agencies, basic research became more established, fuel cell performance increased and manufacturing costs decreased. By the mid 1980's, Ballard was established as an "Anchor" firm around which a cluster of other technology firms and suppliers soon gathered. At this time, multinational automakers, energy companies and public equity markets became important partners and sources of R&D funding. Consumer applications were explored and the potential profit from huge consumer markets became the primary driver of innovation. Throughout the 1990's, investment by these private sector stakeholders led to a period of rapid growth in the industry. Companies rushed to develop and test technologies focused on automotive and residential power applications. Today, only a limited number of applications have entered consumer markets, but many more are ready for pre-commercial testing in end-use applications.

Fuel cells are emerging as a versatile alternative energy solution with applications in a wide range of markets. However, significant barriers hinder their integration into the lucrative transportation and stationary power markets. In these applications, fuel cell and related technologies must be refined and tested in real-world situations, a supportive infrastructure must be created, international standards must be established and consumer acceptance must be promoted. For the small technology companies that dominate the Canadian fuel cell industry, this means sustaining further operating losses—with R&D costs continue to exceed sales over the near term. For the industry as a whole, this means a return to increased reliance on public sector support, and an increased level of international cooperation and collaboration. Most significantly, social interests—as represented by government priorities—are now becoming the key driver of innovation in the industry.

Global Markets

Today, concerns over the environmental and health consequences of the world's ever-increasing rate of energy consumption are creating a global market demand for cleaner, more efficient sources of power. These concerns are driving fuel cell development and commercialization programs around the world. In Canada, industry, government and academia are aggressively leveraging their current dominance in fuel cell R&D to secure a share of these rapidly developing international markets, and to meet domestic societal priorities.

Global demand for fuel cells is estimated to exceed \$45 billion by 2011. The stationary market is expected to be the largest at this time, followed by the portable market and, finally by the automotive market. However, beyond 2011, automotive applications are expected to lead continuous growth in all fuel cell markets. At a conservative annual growth rate of 50 percent, global markets for fuel cells could exceed \$2.6 trillion by 2021.¹

Reducing Automotive Emissions

Increasingly stringent automotive emission legislation—particularly California's Zero Emission Law—is creating the demand for fuel cells in the consumer transportation markets. Today, every major automaker is aggressively pursuing the development and integration of fuel cell technology. Many Canadian firms are making valuable contributions towards developing and demonstrating the viability of fuel cell technology in these applications through strategic partnerships with many of the world's leading automakers and participation in such organizations as the California Fuel Cell Partnership.

Consumer markets for fuel cell powered vehicles are not expected to emerge until well into the next decade, at the earliest. Considerable cost, performance and infrastructure challenges need to be overcome before wide spread commercialization becomes possible in transportation markets. It is important to note that automakers are also exploring the potential of other technologies such as advanced internal combustion engines, alternative fuels, and electric/hybrid vehicles, to reduce greenhouse gas (GHG) emissions. The success of these competing technologies may have a profound impact on the scope and timing of fuel cell integration in the automotive industry.

Although the use of fuel cells in automotive applications will provide the largest reduction in GHG emissions, it is the portable and stationary applications that are expected to be on the market earlier. To generate much needed revenue and promote consumer acceptance, some Canadian fuel cell companies, originally pursuing automotive applications, are now also focusing on the development of these more immediately marketable applications. The success of these applications will critically influence market acceptance of fuel cell technology in later transportation markets.

Deregulation in Energy Markets

A trend toward deregulation and fewer technical barriers to commercialization is creating opportunities for many new players in energy markets. Grid-based and distributed electric power generation hold the most near-term potential for the integration of fuel cell technology as a power solution. These technologies will be introduced in niche markets such as remote and industrial locations, back-up power for the telecommunications industry and as a source of uninterrupted power supply. Later, distributed stationary fuel cells used in residential applications could provide a mechanism for consumers to feed power back into the grid.

Table 1 Estimated Global Fuel Cell Systems Demand (\$ Millions)²

Market Segment	2003	2005	2007	2009	2011
Stationary	\$886	\$1,747	\$2,734	\$ 7,974	\$17,940
Portable	3	94	1,875	10,875	1,7625
Transportation	79	123	311	1,746	10,257
Total	\$968	\$1,963	\$4,920	\$20,595	\$45,822



1. PricewaterhouseCoopers and Fuel Cells Canada. 2002. *Fuel Cells: The Opportunity for Canada*

2. Ibid

Over the next ten years, fuel cells are expected to be more widely integrated into new residential developments.

Developing and Emerging Markets

Globalization is accelerating the pace of industrialization and creating further market demand for alternative energy sources. In developed countries, new technologies such as the Internet have added to the pressures on existing electrical resources. In many developing countries, purchases of energy-intensive devices such as air conditioners, computers and washing machines by a new and affluent middle-class are rapidly increasing demands for energy. In less developed countries, rapid population growth is adding to the pressures induced by globalization and further intensifying energy demand. These issues are also contributing to the global demand for the adoption of cleaner and more efficient power technologies and further driving innovation in the Canadian fuel cell industry.

National Policy

Innovation in the Canadian fuel cell industry has also been driven by a national public agenda that recognizes the impact and supports the development of technical innovation, and places a high value on environmental stewardship and sustainability.

The Governor General's Speech from the Throne in February, 2004, reiterated a national desire for leadership in "green technologies." It identified improved access to capital and increased capacity for innovation and research as priorities for Canada's federal government. The Speech from the Throne traditionally anticipates programs to be announced in subsequent federal budgets.

Meeting Climate Change Commitments

In November 2002, the Government of Canada released *The Climate Change Plan for Canada*. This Plan is the result of intensive consultation with the provinces and territories, as well as with stakeholders and individual Canadians. It reflects the Government's commitment to action on climate change while maintaining economic competitiveness. The Plan specifies measures to reduce GHG emissions from the transportation sector, which includes working with automotive manufacturers towards a 25 percent improvement in new vehicle fuel efficiency by 2010.

Additionally, the Plan recognizes and highlights the important role that innovation will play in future emission reductions. It states: "Through innovation we will be able to maintain our strong economic growth, create additional export opportunities and reduce greenhouse gas emissions." The Plan further states that we must accelerate the development and adoption of new low-emission technologies.

Health and the environment continue to be very strong drivers for Canadian policy makers. Through the ratification of the Kyoto Agreement in December 2002, Canada has committed to reducing GHG emissions to 6 percent below the levels emitted in 1990, by the period between 2008 and 2012. This goal could require an aggressive regulatory approach or an increased focus on the development of alternative energy technologies, including fuel cells. In 1997, Canada's GHG emissions were 13 percent above 1990 levels. If emissions continue at the current rate, levels in Canada are estimated to be 26 percent above 1990 levels by 2010.

As an integral part of the 2003 Federal Budget, *The Climate Change Plan for Canada* outlined a five year, \$1.1 billion investment towards meeting Canada's climate change commitments. The Plan will support measures to reduce GHG emissions by 23.7 mega tonnes by 2010.³ Fuel cell technology is seen as a viable 'clean air' alternative to all applications of the internal combustion engine (ICE) and other conventional power supply technologies. The virtual elimination of urban pollutants and emissions possible through use of this technology will lower health care costs and improve quality of life in all of Canada's major cities. The Plan calls for \$80 million to be allocated to the development, testing and commercialization of fuel cells and other technologies for the emerging hydrogen economy.

Supporting Technical Innovation and the 21st Century Economy

With exports generating approximately 40 percent of Canadian economic activity, increasing productivity through increased innovation is seen as one way to decrease Canada's vulnerability to fluctuating global markets. Yet, Canada has traditionally under-invested in R&D and, when compared to other leading industrialized countries, has received limited benefit from the commercialization of knowledge. Canada currently ranks 14th in the OECD measurement of gross expenditure on R&D relative GDP, and Canada's overall level of innovation is near the bottom of the G7. However, this record is improving. Levels of public and private

3. Government of Canada. 2001. *Government of Canada Targets Key Sources of Greenhouse Gas Emissions*.

sector investment in R&D are growing. In Canada gross expenditures on R&D reached \$21 billion in 2001—up 9 percent from 2000, which in turn was up 11 percent from 1999. The Canadian government investment in the fuel cell industry has also been modest relative to recent public sector investment in other jurisdictions. However, public investment in the early years was integral to establishing Canada's current industry leadership position.

A national innovation strategy has been developed to facilitate the creation and application of knowledge and to establish, for Canada, an international reputation for innovation. In *Achieving Excellence*, Canada has committed to several targets for 2010, including:

- Ranking among the top 5 countries in the world in terms of R&D,
- Doubling the Canadian Government's investment in R&D,
- Ranking among world leaders in the share of private sector sales attributable to R&D,
- Raising venture capital investments per capita to US levels,
- Doubling R&D and tripling commercialization performance of universities and colleges.

The fuel cell sector has been identified as a key contributor to innovation in Canada. The Government of Canada and the industry association Fuel Cells Canada (FCC) are developing a Sector Innovation Action Plan. This plan identifies strategies to address key innovation challenges in the fuel cell and hydrogen sector and outlines measures to facilitate the adoption of these new technologies in Canada.

Sustainable Energy

The Canadian fuel cell industry is impacted by a national energy policy focused on sustainable development, deregulation and energy security. As a clean and efficient source of power, hydrogen and fuel cells represent an important sustainable source and efficient use of energy—reducing both GHG emissions and fossil fuel consumption.

The continued security and integrity of energy resources and supply are priorities for Canada, as they are for most nations. Canada was reminded of the economic significance of power reliability in August 2003 when a blackout on North America's eastern seaboard cost \$550 million in Ontario alone. Innovative applications of stationary fuel cell technology and the progressive deregulation of Canadian energy markets could lead to a distributed

power model—effectively limiting issues of efficiency and demand that currently challenge the existing grid system. The Canadian federal government and leading stationary fuel cell developers and integrators, such as Ontario Power Technologies and Hydrogenics Corporation, are working together to address technical barriers to distributed power generation.

Local Influence

Canadian culture, standard of living and immigration policies are contributing to the attraction and development of a highly educated and entrepreneurial workforce. As a result, there are a large number of small and medium size private, knowledge-based businesses in Canada. These businesses can focus on specific areas of expertise and react quickly to market opportunities, and have proved to be ideal research partners for larger more diversified companies.

Within these companies, the vision and skill of several key individuals are a major driving force behind innovation in the Canadian fuel cell industry. Their knowledge, contacts and management skills are integral to the competitive ability of the Canadian industry. Some key individuals, including Geoffrey Ballard and Paul Howard, were instrumental in creating some of the early breakthroughs in fuel cell technology. Their foresight and dedication helped establish Canada's current leadership position in the industry. Such industry champions have also helped the Canadian government recognize the benefits of developing the sector. Their effort contributed to the creation of public programs to conduct R&D and generate market awareness.

Technology clusters

Clusters are significant catalysts for knowledge creation and diffusion within the industry. The proximity of core firms, academic institutions, suppliers, customers and supporting organizations within the cluster provides the structural support that facilitates the spread of knowledge and resources. In so doing, clusters accelerate the pace of innovation, attract investment, create jobs and generate wealth.

In Canada, public agencies and institutions, economic development corporations and private firms are working together to foster local networking and cluster development. Many stakeholders within a specific cluster may also have

relationships with industry players in other Canadian clusters as well as partners and suppliers in other parts of the world. As international competition for fuel cell producers and suppliers continues, clusters are becoming even more important in uniting the Canadian industry.

Strong industry clusters are also helping Canadian companies attract and retain key individuals. Senior level specialists are essential as fuel cell companies continue to develop technical expertise or transition to manufacturing and integration. These industry experts, with the knowledge and experience required to achieve innovation, are often attracted by the career opportunities within a dynamic, localized concentration of industry expertise.

Provincial Support

The provincial governments of BC, Ontario and Québec have also demonstrated their support of fuel cell companies in their respective jurisdictions and have contributed to national government efforts to grow the Canadian industry. The Governments of BC and Ontario contributed a regional perspective to the Canadian Fuel Cell Commercialization Roadmap. Their support has been critical to the growth of clusters that are developing in Vancouver, Calgary, Toronto, Kingston and Montréal.



Knowledge Creation and Flow

Issues concerning the high cost of sustained R&D and the ownership of intellectual property (IP) are integral to the creation and flow of knowledge within the Canadian fuel cell industry.

For the past twenty years, small private firms—engaged predominantly in product R&D activities—have leveraged support from Canadian federal government programs or large multinational automotive and energy partners to amass a portfolio of privately owned IP. As the industry moves towards full-scale commercialization, IP is becoming a key strategic asset influencing a global trend towards mergers, acquisition and consolidation.

Today, public investment in fuel cell research, which has lagged behind that of the private sector, is rapidly increasing. The federal government has invested over \$200 million in the fuel cell industry since the 1970's, and in October of 2003, announced a further \$215 million of support over the next five years. Through specific funding programs and private sector partnerships, Canadian universities and public research organizations are now becoming more active in basic and applied fuel cell research. Knowledge created at these institutions could lead to increased public ownership of fuel cell related IP and a greater return on public investment through IP commercialization.

While the depressed technology investment climate is improving, the recent market downturn contributed to the creation and flow of knowledge within the industry by fostering a sense of urgency. Canadian fuel cell vendors became focused on getting products to market more quickly and reducing burn rates for R&D. It also resulted in more realistic assessments of the business prospects for fuel cell technology over the medium term.

Canadian companies are enjoying success with several early-market and demonstration stage products in stationary, portable and transportation fuel cell markets. Yet significant challenges to wide spread commercialization remain. How small Canadian technology developers secure and incorporate the manufacturing and marketing knowledge required to achieve full-scale commercialization will be integral to completing the innovation cycle within the industry.

Through focused research, fuel cell costs and performance are improving but have yet to become competitive with conventional incumbent technologies. Canadian companies are now looking beyond the lab to find the people and partners with the knowledge and capabilities required to achieve commercial success. Continued innovation from R&D success will take business leadership and cooperation with public and private partners within local clusters, and at the national and international level.

The Private Sector

Canadian companies were instrumental in performing the basic research to develop fuel cell technology and are today recognized as world leaders in the industry. While public funding sources played an important role in supporting the basic science that initially established the industry, capital for applied research activities has been funded largely through internal resources and alliance partners. In 2001, for instance, private sector fuel cell-related R&D expenditures reached \$179 million, representing almost \$100,000 per employee. The result of this level of private investment is that much of the industry knowledge now resides within the private sector. Today, Ballard and other Canadian companies own, or share with their international partners, many of the industry's patents.

Over the past ten years, the 40 percent growth in overall R&D within Canada has been attributed to the strong growth of private sector investment—of which the fuel cell sector is a prime example.⁴ However, generally speaking, private sector R&D investment in Canada still lags behind that of most other OECD countries. This may be partly due to a predominance of small Canadian technology firms with limited resources to invest and the number of large foreign companies in Canada that prefer to conduct research in their home country.

The Creation of Private Knowledge

Fuel cells have been used in the defence and aerospace sectors for decades. However, their footprint was large and the technology was expensive. Then in 1987, while working on a contract for the Canadian Department of National Defence, Dr. Geoffrey Ballard developed a technology which dramatically increased the power density of the fuel cell stack. This breakthrough was quickly recognized by Daimler-Benz and General Motors—auto makers with strong ties to the aerospace industry—as a technology that could help them meet increasingly stringent US emission regulations. Lacking the internal expertise and uncertain about the viability of the technology, these auto makers looked to Ballard and other Canadian companies to continue fuel cell-related R&D. Today, all of the world's leading automotive companies have launched fuel cell programs. While some auto makers are rapidly developing internal capabilities, many have formed alliances with fuel cell and hydrogen firms. Canadian companies are an integral part of the highly defined and well established international automotive supply chain. Over half the world's automakers use Canadian fuel cell technology.⁵

Large private industry is also playing a key role in the development of non-automotive fuel cell applications. Original equipment manufacturers (OEM's), natural gas companies, electrical power utilities, chemical companies and methanol producers are aligning themselves with Canadian fuel cell companies to develop stationary and portable fuel cell applications. It is expected that these non-automotive applications will face fewer commercialization challenges. The early acceptance of the technology in stationary and portable markets is needed to build capacity, improve product performance, reliability and cost, and to create public awareness of the safety and effectiveness of fuel cells.

Industry Overview

Canada's entrepreneurial research firms have benefited from the outsourced, portfolio, approach to technology investing adopted by multinational OEM's and energy companies. As basic research began to prove the viability of fuel cells, research and knowledge creation became focused on specific components, applications and markets. New companies were formed to explore new technologies, specialize and refine specific applications or provide support to existing companies. In Canada, the private sector industry comprises 17 companies whose primary focus or goal is fuel cell production or systems integration and many other companies focused on providing services and developing a fueling infrastructure.

Most of these companies are small to medium sized enterprises (SMEs) specializing in the development and commercialization of specific fuel cell technologies. Balance of plant and systems integration activities account for the majority of activity within the industry. Some suppliers and providers of fueling infrastructure and services are closely aligned with one or two Canadian producers, but most are involved with many industry players—providing parts, systems and services to foreign as well as domestic stakeholders. An overview of Canadian fuel cell companies is presented in Appendix 2.

In Canada, total industry revenues reached \$96.9 million in 2001.⁶ With revenues exceeding \$90 million in 2002, Vancouver's Ballard Power Systems is globally recognized as the industry leader. However, it is expected that Ballard's market share will decrease as smaller firms consolidate to pool resources and broaden product lines. In 2001, these SMEs made up approximately 82 percent of the Canadian industry and produced 53 percent of its revenue. Due to a trend towards consolidation, SME's revenue share has been projected to increase to 64 percent in 2002.

4 Runci, Energy R&D in Canada, 2000

5 Veljkovic, Supporting Canada's Fuel Cell Industry, NRC Institute for Fuel Cell Innovation, 2003

Industry clusters are defined as a critical mass of companies in one location with unusual competitive success in specific fields. They include characteristics such as the presence of an anchor company, strong linkage among firms, close proximity to educational institutions, access to government resources and self sufficiency in terms of employees and financial resources. Clusters of fuel cell companies, suppliers, infrastructure developers and service suppliers exist in the Vancouver area, and are growing in the Calgary, Toronto, Kingston and Montréal areas. All have localized fuel cell and infrastructure developments with considerable growth potential. By concentrating resources and expertise in localized areas, these clusters act as catalysts for the creation and diffusion of industry-specific knowledge.

A number of Canadian fuel cell products are in the demonstration and early market stages of commercialization, with many more expected to move from development and testing to early-markets stages within the next two to five years. For many Canadian fuel cell companies and across the industry in general, this means a continued focus on R&D. It is expected that most fuel cell companies in Canada, and in other jurisdictions, are still several years from profitability.

Knowledge Transfer

Although knowledge may be created in specialized boutique firms, it is often owned by larger multinational OEMs and Energy investors or shared across a number of partner firms. These partnerships are key channels for the diffusion of knowledge within the industry—the technology company leverages the OEMs resources and market share while the OEM leverages the technology developer's R&D expertise. The result is a strong relationship that benefits

Table 2 Major Activities within the Canadian Fuel Cell Industry*⁷

Engineering services	36%
Hydrogen production equipment	29%
Testing equipment	25%
Fuel cell stacks	25%
Electrical components	21%

* Some companies are involved with more than one activity.

both partners, and the industry as a whole.

Technology transfers are proceeding apace as the industry becomes more vertically integrated. But, the mergers, acquisitions and strategic alliances that promote the diffusion of knowledge, are also helping to create knowledge. Larger firms can afford to spend more resources and capital on R&D. As a percentage of total revenue in 2001, SME's spent 42 percent on R&D, whereas larger firms spent 343 percent.^{Reference}

Pooling of resources, expertise and risk is particularly important for smaller firms in reducing research costs and improving market access. Canadian firms have a strong track record in forming strategic alliances to access markets and increase sales—within local clusters, nationally or with partners and suppliers in other parts of the world. They are adopting a number of growth strategies to acquire the competencies required to achieve innovation. Companies with a broad range of IP ownership and core competencies may choose to grow organically, where as those with specific competencies and limited IP ownership may be more suitable for mergers, acquisitions, joint ventures or partnerships. Companies with neither core competencies nor IP ownership may enter the market through straight equity investments.

Table 3. Overview of the Canadian Fuel Cell Industry⁸

Components and Subsystems	Supply, store and transport hydrogen or methanol	Complete fuel	Test equipment cell solutions	Service providers
Dynetek Industries	BC Hydro Powertech Labs	Angstrom Power	Transformix Engineering	Hydro-Québec CapiTech
HERA Hydrogen Storage Systems	Enbridge Gas Distribution	Ballard Power Systems	Greenlight Power (div. Hydrogenics)	PricewaterhouseCoopers
Pivotal Power Corporation	General Hydrogen Products	Cellex Power Measurement Systems	Advanced Partnership	Chrysalix Energy Limited
QuestAir	Methanex Corporation	Global Thermoelectric		Fuel Cells Canada
Xantrex Technology	Stuart Energy Systems	Hydrogenics (including refueling)		
DuPont Canada	Kraus Group	Palcan Fuel Cell Technologies		

⁶ Fuel Cells Canada, Government of Canada, PricewaterhouseCoopers, Canadian Fuel Cell Commercialization Roadmap, 2003

⁷ Ibid

⁸ Ibid



Figure 1 Canada's Fuel Cell Clusters⁹

Financial markets

Financial markets have played a large role in supporting innovative activity within the Canadian industry. Many fuel cell technology developers and systems integrators successfully raised capital from public markets in order to facilitate start-up and ongoing operations. Their ability to raise capital during the bull market of the late 1990's was advantageous for many fuel cell companies—with \$1.5 billion raised in 2000 alone. This available funding was essential to the creation of knowledge through R&D.

As the market took a significant down-turn in early 2001, fuel cell companies were faced with a much more challenging fund raising environment. R&D expenditures continued to increase while company capitalization decreased. In 2002, average market capitalization of North American public fuel cell companies was reduced by approximately 70 percent—almost double the rate of reduction of the standard indexes¹². However, government support to the sector continued through this period, largely through targeted programs and contributions to university-based R&D. The soft market resulted in restricted access to capital from public markets, and caused many firms to

Table 4 Early Market Products¹⁰

Market	Company	Product
Stationary	Ballard	Nexa PEMFC (1.2 kW) and scalable Nexa (1–60 kW)
	Hydrogenics	HyPM (10–60 kW); HyUPS (10–20 kW)
Portable	Ballard	Nexa PEMFC (1.2 kW)
	Hydrogenics	HyPM (10 kW); HyPORT Series (500 W–5 kW)
Mobile	Ballard	Mark 902 PEMFC power module HY 75 fuel cell engine
	Hydrogenics	HyPM (10–60 kW)
Products	DuPont	Nafion membrane
	General Hydrogen	Hydricity fueling system
	Greenlight (Hydrogenics)	Fuel cell test station
	Hydrogenics	Hydrogen refuelers
	Methanex	MCELL fuel service package
	QuestAir	H-6100 hydrogen purification unit
	QuestAir	C-9100 hydrogen purification unit
	QuestAir	C-7100 gas management system
Stuart Energy	Hydrogen fuelers	
Xantrex	Inverters and controls	

9 Ibid

10 Ibid

seek alternative funding sources. This led to an increased number of strategic alliances and increased reliance on public-private partnerships. Specialized venture capital firms such as Chrysalix and Conduit Ventures have played an important role as sector promoters as the industry pursued alternate sources of investment.

Overall venture capital investment in the North American energy companies is on the rise. According to Nth Power Technologies, venture capital investment in energy-related companies rose, from an average of \$US 15 million between 1990 and 1995, to almost \$US 1 billion in 2000.^{Source}

Regulatory burdens and slow return on investment limits the amount of venture capital available for new technology development. Through the Canada Community Investment Plan (CCIP), the Canadian federal government is helping improve access to risk capital for growth oriented SME's.

The Role of the Public Sector

Over the past 25 years, the Canadian federal government has been integral to the creation and transfer of knowledge within the fuel cell industry. National policies and programs have been established to provide financial and collaborative R&D support to the private sector and to provide leadership in coordinating an international push towards commercialization.

Table 5 Profitability of Public Canadian Fuel Cell Companies (US\$, '000)¹¹

	2002		2001	
	REV	R&D	REV	R&D
Ballard Power Systems	90,937	113,736	36,204	77,197
Hydrogenics	15,840	3,761	7,418	2,337
Global Thermoelectric	14,207	14,850	9,918	9,744
Dynetek Industries	8,174	2,676	6,128	1,449
Stuart Energy	5,052	11,019	6,255	8,864
Fuel Cell Technologies	709	1,592	443	2,505
Astris Energi	94	—	17	—
Energy Visions	50	678	141	856
Palcan Fuel Cells	—	315	—	240
Snow Leopard	—	115	—	134
Total	135,063	148,742	66,524	103,326

The Government of Canada is committed to supporting the transition to a hydrogen economy and securing for Canadians the benefits of clean and efficient energy production. These benefits, as outlined in *The Climate Change Plan for Canada*, include a sustainable solution to climate change, reduced pollution, new growth and investment opportunities for Canadian industry, the creation of high-quality jobs and a higher quality of life for all Canadians.

Investing in the Future

Since 1979, the public sector has invested over \$200 million to support basic and applied research in the hydrogen and fuel cell sector, and since 1997, has invested a further \$1.7 billion to address a broad range of issues relating to

Table 6. Selected Canadian Companies and their International Alliances/ Partnerships/ Collaborations

Ballard Power Systems	DaimlerChrysler, Ford, Ebara, Alstom, First Energy Subsidiaries in US (Mass. Michigan)
Hydrogenics Corporation	General Motors, John Deere alliance, Hydrogenics Japan, Hydrogenics GmbH (Germany), Greenlight Power Technologies is wholly owned subsidiary in Burnaby B.C.
General Hydrogen Inc.	General Motors, Air Products, BhPhilliton, British Energy, Cameco,
Stuart Energy	Toyota USA, Hamilton Sundstrand Space Systems International, Cheung Kong Infrastructure Holdings, Ford Power Products
Palcan	Morgan Fuel Cells, Johnson Matthey, Shanghai Ow Bowl Company; Shanghai Giant, Ltd.; Shanghai Shin-Fu Wheelchair Company; and the China Shipbuilding Industry Corporation's number 711 research institute (Shanghai 711 CSIC Institute)
Fuel Cells Technologies Inc.	Siemens Westinghouse Power Corp., Kinectrics Inc., ECN/InDec (Holland), Bluefin Corp. NKK, Border States Electric Supply (BSE)
Global Thermoelectric	Enbridge Corp., Dana Corp., Bonneville Power Administration, Superior Propane Inc.,
Dynetek Industries	Paul Scherrer Institute, ETH Zuerich, Kokan Drum (Japan), Mitsubishi Corp., Ford Motor CompanySubsidiary New Valve Business Unit, wholly owned European subsidiary Dynetek Europe GmbH
QuestAir Technologies Inc.	Shell Hydrogen, Ballard Power Systems, BOC Corp. Chrysalix Energy Limited Partnership, Fuel Cell Energy
Chrysalix Energy Limited Partnership	BASF, BOC Corp., Duke EnergyMitsubishi Corp. Shell Hydrogen

¹¹ PricewaterhouseCoopers, 2003 Fuel Cell Industry Survey, 2003

¹² Ibid

Table 7 Market Capitalization of Canadian Public Fuel Cell Companies (\$ US ,000)¹³

	2002	2001	% Change
Ballard Power Systems	1,282,226	3,103,360	-59
Hydrogenics	173,211	353,492	-51
Global Thermoelectric	44,009	132,023	-67
Dynetek Industries	16,580	31,580	-47
Stuart Energy Systems	87,168	90,130	-3
Fuel Cell Technologies	13,034	14,468	-10
Astris Energi	10,719	3,068	+249
Energy Visions	2,814	6,031	-53
Palcan Fuel Cells	2,838	38,875	-93
Snow Leopard	4,597	7,036	-35
Total	1,637,196	3,780,063	

climate change. The 2003 Federal Budget committed an additional \$2 billion over the next five years to support environmental and climate change initiatives and facilitate partnerships in areas such as renewable energy, energy efficiency, sustainable transportation and alternative fuels. Of this funding, \$250 million has been allocated to Sustainable Development Technology Canada (SDTC) to develop and demonstrate technologies with the potential to reduce GHG emissions. The Budget also proposed tax measures to encourage the production and use of specific renewable fuels, such as bio-diesel, and provide accelerated tax depreciation for certain investments in renewable and alternative energy technologies, such as stationary fuel cell systems.^{Source}

On October 9th, 2003 the Ministers of Natural Resources and Industry announced an investment of \$215 million targeted to the hydrogen economy. Of this funding, \$60 million will go towards early adoption projects and initiatives, \$20 million to existing R&D activities and \$85 million will be reallocated internally to fund existing federal initiatives. This commitment to industry and innovation will bring Canadian companies one step closer to providing the hydrogen and fuel cell technologies necessary for a hydrogen economy. A further \$50 million of SDTC funding has been specifically dedicated to developing hydrogen and fuel cell technologies.

Providing A Leadership Role

The Canadian government acknowledges the benefits of fuel cell technology and their potential contribution towards meeting public priorities relating to climate change, health, energy security and economic prosperity. The government also recognizes that the introduction of transformative

technologies such as fuel cells could fundamentally change the nature of established industries and will, therefore, require “top down” leadership and coordination at the national and international level. Canada understands the international issues impacting the industry and is continuing to work with international stakeholders to ensure that national policy is harmonized with that of other jurisdictions.

Federal policies and programs have been established to increase support for basic and applied research and testing of fuel technologies, demonstration activities to build public awareness and the provision of the coordinated leadership required to facilitate commercialization. In addition, government officials will continue to build Canada’s reputation for technical leadership by showcasing Canadian industry and innovation through trade missions and an extensive network of international contacts.

National Coordination

The Hydrogen and Fuel Cell Coordination Committee’s (H2FCC) role is to coordinate the development and implementation of a national strategy for the creation of the hydrogen economy. Chaired by Industry Canada and Natural Resources Canada, this committee advises program managers, provides policy analysis, and generally serves as the focal point of a coordinated national emphasis on fuel cell and hydrogen technologies.

To advance the development of the hydrogen economy, the Hydrogen and Fuel Cell Committee focuses its activities on the following areas:

- advocacy and advice;
- supportive infrastructure;
- international partnerships;
- coordination, communications and outreach; and
- social, environmental, economic analysis.

The H2FCC provides advice and strategies in partnership with other governments, industry and non-governmental organizations. The committee plays an important advisory role in national planning and R&D work related to hydrogen and fuel cells. It provides direction for research and analysis to generate the knowledge and understanding needed to establish the hydrogen economy. The H2FCC assists in the development of future policies, measures, and strategies, and engages in efforts to build public and business confidence, decrease technology and marketplace hurdles and build international cooperation.

H2FCC is developing a Vision Document and National Strategy for the sector which will build on the work of

the Commercialization Roadmap. It will help guide the development and commercialization of fuel cells and other hydrogen technologies, the installation of necessary infrastructure for the use of these technologies in all sectors of the economy and help build consumer and business confidence.

Developing Safety, Codes and Standards

For several years Canada has supported the activities of the International Standards Organization (ISO) Technical Committee for Hydrogen Technologies. In addition, through the Canadian Hydrogen Association, Canada has recently become a founding member of the Partnership for the Advancement of the Transition to Hydrogen (PATH)—an organization that promotes the importance of international standards in creating the hydrogen economy. Canada is currently pursuing policy objectives that will:

- recognize and accelerate current domestic and international activities to reduce tariff barriers amongst partner countries;
- develop codes and standards for the installation and use of fuel cell systems;
- define specifications and methodologies for testing and evaluation protocols; and
- advocate international standards for hydrogen production, distribution and storage.

Increasing Public Education and Confidence

A greater understanding of the safety of hydrogen and the environmental benefits associated with the widespread use of hydrogen-based technologies is essential for commercialization. The Canadian government is increasing public confidence in the safety of fuel cell technology by establishing policies to regulate the use and production of Hydrogen fuel – similar to those that currently exist for other fuels such as gasoline and natural gas. Through its support of high profile demonstration and installation projects and public education activities, the public sector shows commitment to building consumer awareness and confidence in this technology.

Providing Early Adoption

Early adopters are usually characterized as sophisticated buyers willing to pay a premium price for new products or technologies that meet very specific performance and reliability requirements. Federal leadership in early-market adoption can help assure the successful commercial launch of new technologies by providing a bridge between relatively expensive pilot programs and cost-competitive

consumer offerings. Early public sector applications of fuel cell technology could include public buses, motor vehicle fleets, military applications, industrial uses, government buildings and power generation in Canada's remote communities.

Through the Climate Change Action Fund, federal programs such as Hydrogen Early Adopters (H2EA) and Technology Early Action Measures (TEAM) and the Canadian Transportation Fuel Cell Alliance (CTFCA) have been funded to accelerate market adoption of technologies for climate change and economic benefit. These programs will support demonstrations projects including the proposed Hydrogen Highway™ and Hydrogen Village.

Coordinating R&D

Advances in a broad range of technologies and industries are required to overcome the many barriers to commercialization. To reduce duplication of effort, Canada is working in partnership with domestic industry and academic institutions, and with other jurisdictions, to develop a coordinated R&D vision with set technology performance and commercialization targets.

Government of Canada support is not limited to fuel cell technologies in the transportation markets. Federal programs also support research, development and pre-commercial activity in stationary and portable markets. These applications are expected to make an early contribution to reducing GHG emissions, create consumer acceptance and spur the development of more efficient fuel cells and related technologies such as; advanced materials, power-electronics, hydrogen production technologies, storage systems and transportation balance of plant. These advances will in turn broaden the markets for fuel cells, accelerate the commercialization of the transportation applications, and further reduce GHG emissions.

Hydrogen can be produced through reformed fuels (natural gas, methanol, ethanol, gasoline, coal or diesel) or through electrolysis using various sources of electricity (hydro, wind, photovoltaic, geothermal or nuclear), or through bio-mass. Since the choice of hydrogen supply depends on regional strengths, cost and resource availability, public policy supports the development and testing of all methods of hydrogen production, storage and distribution. The federal government will be developing a comprehensive report addressing hydrogen production challenges and strategies. This Hydrogen Roadmap, planned for publication in the spring of 2005, will provide critical reference to support policy in this area.

Encouraging Multilateral Cooperation

It is becoming increasingly evident that the systems supporting and encouraging the creation and diffusion of knowledge in the Canadian fuel cell industry do not function in isolation. Cross-boarder collaboration and cooperation is needed to reach full-scale commercialization and enable the transition to a hydrogen economy. In an effort to leverage resources and expertise from the international fuel cell community, Canada has joined with other nations to create a synergistic approach to R&D and pre-commercialization activity. The US-led International Partnership for the Hydrogen Economy (IPHE)—a partnership of over 14 countries—will create a mechanism to organize and implement effective, efficient and focused research, and to develop and deploy activities that advance hydrogen and fuel cell programs. This sharing of knowledge and resources will be key to overcoming the barriers to fuel cell commercialization.

Canada's participation in the IPHE will foster multilateral partnerships among other member countries and encourage stronger bilateral relationships with the US that could help Canada plan appropriately for a hydrogen economy within a North American context. Large scale demonstration projects spanning the Canada-US border, and involving a strong contingency of Canadian and American companies across the hydrogen and fuel cell value chain, will be a critical component of building a hydrogen economy. In addition to technology validation, integration and refinement, such demonstration initiatives will allow for the development of codes, standards and training, and help promote public and consumer awareness and confidence.

Creating Tax Incentives

Canada has implemented progressive corporate and personal tax incentives to encourage R&D and early adoption of fuel cell technologies.

Canada's SR&ED tax incentive program to promote spending on product or process R&D is the largest single source of federal government support for industrial R&D. It provides over \$1.5 billion of investment tax credits (ITCs) annually to about 11,000 businesses operating in all parts of the country.¹⁵ Qualifying current and capital expenditures on SR&ED, such as wages, equipment and materials in Canada, are fully deductible. The general rate of credit is 20 percent. A rate of 35 percent is available to smaller Canadian-controlled private corporations on their first \$2 million of SR&ED expenditures, with unused credits being wholly or partially refundable.¹⁶ Most Canadian fuel cell companies are banking ITCs against future, taxable, earnings.

The Canadian government is reviewing the impact of future policy options on the commercialization of fuel cells. A recent study on the economics of hydrogen fueling pathways prepared for Natural Resources Canada underscored the importance of tax policy on the commercialization of transformative technologies such as fuel cells. Initial findings suggest that a decrease in the provincial sales tax on fuel cell vehicles in conjunction with excise tax exemptions for hydrogen producers could make the use of hydrogen fuels competitive with gasoline and diesel. It also suggests that an emissions tax on the production of fuel would be an effective instrument in achieving the national policy goal of reducing GHG emissions.¹⁷

Conducting Research

There are about 200 Government of Canada labs with research budgets totalling \$1.7 billion. These labs employ approximately 6,000 research scientists and engineers focused on specific areas impacting regulatory policy, including health and safety, natural resources, the environment and stewardship. In fiscal year 2000–2001, the federal government was granted approximately 110 new patents, held 1,341 active licenses and collected over \$16 million in royalties¹⁸. Of the 1,466 total patents that the federal government holds, 8 are related to fuel cell technology.¹⁹

Canada's gross expenditure on R&D (GERD) declined slightly from \$20.8 billion in 2001 to \$20.7 billion in 2002, resulting in a ratio of GERD/GDP of 1.85—significantly below the OECD average of 2.24. While the federal government's overall expenditure on R&D has increased by approximately 21 percent since 1997, relative to the private sector and academia, the proportion of research funded or performed by Canadian government is now less than 11 percent.²⁰

Federal Departments

A recent study by the US Office of Technology Policy on international fuel cell vehicle development has stated that: “Canada’s small but very focused programs have had a major impact in helping Ballard get a head start as a world leader and in getting other companies up to speed. Canada is, however, being chased”.²¹

The Canadian fuel cell industry was initiated, in part, by efforts of the Department of National Defence to explore the feasibility of fuel cells in military applications. Today, NRCan, through their CANMET labs, and the NRC, primarily through their Institute for Fuel Cell Innovation, perform the majority of federal government R&D focused on fuel cell and hydrogen technologies. Such research is conducted across the country, and is increasingly performed in partnership with industry and the academic community.

Through the CANMET Energy Technology Centre, NRCan has provided collaborative R&D support to fuel cell companies and universities across Canada since 1985. Presently, NRCan spends about \$4 million per year on research toward the production and use of fuel cells and hydrogen as a transportation fuel.

The NRC Fuel Cell Program at the NRC Institute for Fuel Cell Innovation in Vancouver provides a critical mass of expertise in a broad range of areas supported by state-of-the-art equipment and facilities. The Program addresses the efficient, low-cost operation of different types of fuel cells as well as the hydrogen fuel requirements and the infrastructure needed to deliver it. Over 70 scientists and technicians are focused on advancing technologies such as proton exchange and solid oxide fuel cells, fuels and oxidant systems, and fuel cell testing and evaluation. This infrastructure is also available to industry to test, evaluate and demonstrate new products and applications. Ten Canadian companies work on-site in fuels-safe laboratories. The NRC is currently building specialized testing facilities and will soon add an all weather, fuels-safe testing facility. The National Fuel Cell Research and Innovation Initiative receives annual funding of \$30 million over five years, while the NRC Institute for Fuel Cell Innovation is allocated \$40 million over 5 years.

Appendix 1 summarizes the contribution of key federal departments towards advancing fuel cell innovation in Canada.

Table 8 Government Departments and Programs Targeted at the Fuel Cell and Hydrogen Sector

Federal Department	Programs
Natural Resources Canada (NRCan)	Hydrogen and Fuel Cell R&D Program CANMET Energy Technology Centre Canadian Transportation Fuel Cell Alliance Technology Early Actions Measures* Alternative and Future Transportation Fuels Program Buildings Energy Technology Advancement Plan Processing and Energy Catalyst Program Industry Energy Research and Development
Natural Sciences and Engineering Council of Canada (NSERC)	Industrial Research Chairs NRC/NSERC Research Partnership Program Strategic Projects Program Collaborative Research and Development Program Ideas to Innovation Program
Technology Partnerships Canada (TPC)	R&D Program Hydrogen Early Adopters Program
National Research Council of Canada (NRC)	NRC/NSERC Research Partnership Program Industrial Research Assistance Program NRC Fuel Cell Program
Canada Customs and Revenue Agency (CCRA)	Science Research and Experimental Development Program
Sustainable Technology Development Canada (SDTC)	Research, Development and Demonstration Program
Western Economic Diversification Canada	Western Economic Partnership Agreements, Grants
Other agencies providing program support:	Export Development Canada; Investment Partnerships Canada; Trade Team Canada
Department of National Defense	Defense Industrial Research Program Technology Demonstration Program DND/NSERC Research Partnership Program

* The TEAM Program is funded by Natural Resources Canada, Industry Canada and Environment Canada.

15 www.cra.gc.ca

16 Ibid

17 Ernst and Young, An Economic Analysis of Various Hydrogen Fuelling Pathways from a Canadian Perspective, 2003

18 Government of Canada, Science and Technology Advice: A Framework to Build On, 2002

19 Source needed

Provincial Departments

The provincial governments of BC, Ontario and Québec are playing a role in the development of the industry within their respective provinces. The majority of their contributions have been collaborative partnership with federal government organizations. Provincial governments have also played a role in growing and promoting their respective clusters.

In BC, for example, Fuel Cells Canada, industry stakeholders and members of the B.C. Premier's Technology Council have developed a Hydrogen and Fuel Cell Industry Strategy and Implementation Plan. The strategy focuses on building a Hydrogen Highway™ between Vancouver and Whistler in time for the 2010 Olympics, and on developing an urban cluster of knowledge-based energy technology companies in South Western B.C. by 2020. The strategy also aims to revitalize the province's communities by providing efficient, sustainable energy technologies to help the energy, forest and tourism industries thrive. The Province has indicated a willingness to support the hydrogen and fuel cell sector, particularly as it relates to the 2010 Olympic Games. However, implementation of the recommendations included in the document is largely dependent on the accessibility of federal and provincial funding.

Since 1989, support to the Fuel Cell Industry by the province of British Columbia is estimated to have totaled approximately \$33M. Under the last Federal–Provincial Western Economic Partnership Agreement (WEPA), the province contributed \$6.5M towards demonstration projects with Fuel Cells Canada, BC Transit, Ballard Power Systems, BC Hydro and others. In addition, recent contributions to clean energy and fuel cell research at BC Universities through the BC Knowledge Development Fund have totaled \$4.4M.

In the summer of 2003, the province, in association with Fuel Cells Canada, Ford Motor Company and the federal government, contributed \$300,000 to the Vancouver fuel cell vehicle demonstration program.

The fuel cell component of the WEPA was completed in 2003. However, a renewed WEPA was signed by the Federal government and the Province in December 2003 to jointly fund up to \$50M in projects and initiatives (\$25M each) between 2004 and 2010. Fuel cells were identified as a strategic priority under the agreed schedule of activities for this new WEPA.

Universities and Public Research Organizations

Universities contribute towards the creation and flow of knowledge within Canada's innovation system by conducting research, creating an educated work-force and providing direct links to communities across the country. Over the past ten years, Canadian universities have become more active partners with private industry—generating innovation from basic and applied research through IP licensing and spin-offs. In 1997, Canadian universities held over \$22.5 million in equity in 366 spin-off companies and produced 21 percent of Canada's R&D.²² Of these spin-offs, a modest number have been related to hydrogen and fuel cells. From the University of Victoria came Angstrom Power and CyroFuels, and from the University of British Columbia came Westport Innovations.

Universities are still relatively new in the fuel cell field and the number of spin offs is expected to increase as academic institutions build expertise and capabilities. Aside from spin off companies, universities are making a direct and very significant contribution to established firms in the industry in the form of highly educated employees

Federal agencies including the NRC and NSERC are helping forge R&D alliances between universities and the private sector at a rate unparalleled among the G7. Canadian firms rely more on universities as source of R&D than any other G-7 country—contracting over 6 percent of total R&D.²³

In 1999, the Association of University Technology Managers estimated that the commercialization of academic research in Canada resulted in more than \$1.6 billion in sales and supported more than 7,300 jobs.²⁴ Canada's innovation strategy calls for this level of commercialization to triple by 2010. To achieve this goal, the Canadian government has committed \$11 billion to research and innovation from 1997 to 2005—raising Canada to 13th in the OECD rankings and up one place to fifth among the G7 nations. To ensure the Canadian people reap the benefit of public investment, much of these funds will be used to strengthen the R&D capability of universities and public research organizations (PRO).

The Government of Canada's Research Chairs program is part of this commitment. It has a \$ 900 million budget and the mandate to fill 2,000 positions by 2005. These grants provide funding for infrastructure, equipment, general expenses and the salary of a distinguished senior researcher. So far, 926 Research Chairs have been created. As part of

20 Gowlings, 2004

21 Office of Technology Policy, US Department of Commerce, Fuel Cell Vehicles: Race to a New Automotive Future, 2003

this program, the NSERC is establishing several Industrial Research Chair grants to create the strength required to conduct major fuel cell related research. Three Industrial Research chairs have been funded to date, and two more chairs are expected to be established in the near future:

- Hydrogen Storage – Université du Québec a Trois-Rivières
- Solid Oxide Fuel Cell Systems – McMaster University
- Fuel Processing for Fuel Cells – Royal Military College

Of the few Canadian universities having contributed to the creation of knowledge in the fuel cell sector, the most notable are the Université du Québec a Trois-Rivière, the University of Victoria's Institute for Integrated Energy Systems (IESVic), Queens University and Royal Military College. Fuel cell and hydrogen related research activity at these universities is expected to increase moderately over the next few years as these institutions move up the learning curve and continue to build partnerships with industry and government on collaborative projects.

Universities and PROs are partnering with private industry on collaborative research projects. For example, IESVic has relationships with several leading Canadian fuel cell companies (Angstrom, Ballard, Greenlight, QuestAir Technologies, Palcan and AECL). Other public organizations (NRC's Institute for Fuel Cell Innovation, NRCan, and BC's Ministry of Energy and Mines) as well as other members of

the academic community (University of British Columbia, Simon Fraser University and Université du Québec à Trois-Rivières) are also collaborating with private industry towards developing knowledge in the industry.

However, the academic community still lags behind the private sector in fuel cell related R&D performance as measured by patent activity.

Canadian universities are developing long term strategies towards managing intellectual property rights, pursuing technology transfers and attracting top people. Assuming a ten year lead time between the registry of a patent and the commercialization of a resulting product, Canada may soon realize a significant return from this strategy.

Other institutions have limited research expertise on fuel cells and related technologies. The following universities currently make nominal contributions to the sector currently, but are expected to increase participation over the next 5 years:

- McMaster University
- University of British Columbia – Centre for Clean Air
- University of Calgary
- University of Alberta
- University of Toronto

Table 9 Canadian Universities and Public Research Organizations and Their Technology Focus

Alberta Research Council	Innovative science and technology solutions for the current and emerging needs of their customers Develops and commercializes technologies to give clients a competitive advantage.
AUTO 21, The University of Windsor	Improving and enhancing the global competitiveness of the Canadian automotive industry
Hydrogen Research Institute, Université du Québec à Trois-Rivières	Fundamental properties and technological applications Storage, safety, transport and uses of hydrogen
Institute for Integrated Energy Systems, University of Victoria	Modelling fuel cell systems Systems integration Microscale fuel cells Fuel cell diagnostics
Centre for Automotive Materials Manufacturing (CAMM), Queens University	Fuel cell applications, transportation, portable and stationary Testing and evaluation of materials, components and systems Computational fluid dynamics Reactions kinetics, finite element, and failure modelling Product cost modelling and dynamic simulation of fuel cell component and system manufacturing alternatives.
Royal Military College	Fuel processing Catalyst development, kinetic studies, mechanisms and reactor design Reliability studies of FC components, basic work on DMFC's and modeling of all the components that make up fuel cell systems

Public Private Partnerships

Public–Private Partnerships (P3s) are co–operative ventures for the provision of infrastructure or services. They build on the expertise of each partner to meet clearly defined public needs, through the appropriate allocation of resources, risks, and rewards. In most P3s, the public sector maintains an oversight and quality assessment role while the private sector is more closely involved in actually delivery of the service or project.

P3s are categorized according the extent of public and private sector involvement and the degree of risk allocation between the two. Traditional P3 categories include: contract operation and management, design-build-operate, concession-lease, finance-design-build-operate, own and operate, and asset sale or transfer.²⁵

The Canadian fuel cell industry has applied a less traditional approach to P3s. The public sector has traditionally assumed the roles of early facilitator of R&D and early adopter of new technology and products. Indeed, Canada's National Defence and NRC research contracts directed Ballard toward the early performance and cost breakthroughs that demonstrated the viability of fuel cells as an alternative energy source. While federal and provincial government support has always been crucial to fuel cell innovation, for the past decade, public funding has been overshadowed by private sector investment. After a decade of technological research driven mainly by multinational automakers and energy companies, some Canadian fuel cell companies have market-ready products with many others ready to commence pre-commercial testing and demonstration.

Pre-commercial testing of new and transformative technologies such as fuel cells require large-scale demonstration projects. These projects involve several participants from across the value chain—from component suppliers to hydrogen production and distribution organizations and end users. These projects will enable firms to test and showcase their technologies in integrated, micro-models of a hydrogen economy. They will also help increase investor and consumer awareness of the many benefits and uses of hydrogen-powered applications.

Knowledge flow in P3s

In the fuel cell industry, P3s facilitate the diffusion of knowledge by bringing industry, government and the public together in a collaborative initiative to integrate, test and refine technologies. This in turn can stimulate the creation of a value chain and generate data for further analysis, validation and feedback. P3s also provide critical information to help policy makers benchmark safety and performance standards and establish regulatory guidelines.

These projects also increase the transfer of knowledge between the industry and the consumer. Demonstration projects will be critical in generating the level of consumer awareness and market acceptance needed to establish the hydrogen economy. Demonstrating fuel cell technology in real word applications will mitigate public misconceptions and uncertainties and reinforce the understanding that these technologies represent a sustainable energy solution. These projects will also allow the public and other end users to provide usability and performance feedback to the industry.

Information gathered through demonstration projects is of great value in comparing the progress of the Canadian industry against other jurisdictions. Canada is considered to be proactive in gathering information and statistics on the fuel cell industry. The information volunteered by private industry is the basis upon which the value and potential of the Canadian industry is gauged.

²⁵ http://strategis.ic.gc.ca/epic/Internet/inupr-bdpr.nsf/vwGeneratedInterE/h_qz01546e.html

Demonstration Projects

The Canadian Transportation Fuel Cell Alliance (CTFCA) and the Hydrogen Early Adopters (H2EA) programs have been established to fund and coordinate the infrastructure and end-user demonstration projects required to test and validate hydrogen technologies for transportation and electrical generation under real-world operating conditions. These projects will require the input and expertise of fuel cell developers, systems integrators, component suppliers, researchers, hydrogen production and distribution companies, end-users, energy companies and industry experts from across the country. Although the specifics of these projects have yet to be finalized, two proposals from Canadian industry are well into the planning and feasibility stages, and both are considered to be ideal candidates for such federal programs.

The Hydrogen Village Partnership is a multi-million project that will bring together 35 members from three key stakeholder groups; early adopters, technology providers and technology integrators. The early adopters slated to participate in this project include municipal government groups, learning institutions, automotive and utility vehicle OEMs, utilities and other energy corporations. The technology providers will develop fuel cells, fuel cell systems, hydrogen generation and conversion technologies, components, storage and fueling technologies. Technology integrators will work as a bridge between the technology providers and the early-adopting end-users.

The Hydrogen Highway™ is a proposed network of hydrogen refueling facilities and related technologies in hydrogen “nodes” from Vancouver to Whistler, and in Victoria. This large-scale demonstration project will connect communities that use hydrogen and fuel cells transportation and stationary applications with the goal of accelerating the transition to a hydrogen economy. In this hydrogen economy microcosm technology developers and users will help demonstrate not only the technical merits of specific applications, but also the social, environmental, and economic impacts of the technology. The Hydrogen Highway™ will be a centerpiece of the Vancouver 2010 Olympic Games and the legacy of sustainability the games seeks to establish.

Apart from large-scale demonstrations of the hydrogen economy, government, industry and academia have participated in several successful, more focused demonstration initiatives. These include:

- Western Economic Partnership Agreement

(WEPA) provided funding for BC Transit’s purchase of three fuel cell bus engines from XCELLSIS Fuel Cell Engines. BC Hydro supplied off-peak electricity to produce fuel for the fuel cell powered buses.

- Five Ford Focus fuel cell vehicles will be operated and evaluated over a period of three years in the Vancouver Fuel Cell Vehicle Project. This partnership between FCC, Ford, NRCan, NRC and the Government of BC—in part funded by the federal TEAM program—will assess the usability of automotive fuel cell technology and hydrogen fueling infrastructure.
- NRCan entered into partnership with Fuel Cell Technologies Ltd. to install the first residential fuel cell in Canada. Performance and integration information will be gathered in a simulation that has a virtual family making routine domestic power demands.

The Expanding Role of the Public Sector

Fuel cells represent a “transformative” technology that could fundamentally change the way established industries function. The scope of the technical challenges and infrastructure requirements required to implement this sort of technology is changing the nature of P3s operating within the industry—demanding an increased level of collaboration and coordination both domestically and internationally. Canadian governments, as well as governments in other jurisdictions, are being identified as leaders in establishing and implementing national and international infrastructure projects. As a result, innovation in the sector, while still led by a market driven private sector, is being more significantly influenced by the societal agendas of the public sector in Canada and abroad.

The development and commercialization of fuel cell technology is recognized as strategically important to meeting Canada’s climate change objectives, establishing a knowledge-based economy, and achieving energy sustainability and integrity. The Canadian government is increasing its participation in the sector to meet these broad agendas. It is working with industry to build an infrastructure to support transportation, stationary and portable fuel cell demonstration projects. The ability of a project to affect social drivers, such as the reduction of

GHG emissions, is integral to project selection and program objectives.

Increased Participation of Universities and PROs

Funding has been committed to strengthen the innovative capabilities of Canadian universities and PROs. These institutions have gone beyond their traditional role in basic research and are now actively pursuing applied R&D and the commercialization of IP through an increased level of collaboration with private industry partners. Universities and PROs are also becoming key participants of large scale P3 demonstration projects—illustrating their growing technical capabilities, their value as a collaborative partner, and their capacity for producing highly skilled employees for the industry,

Supporting Early Adoption

Through successful TEAM demonstration projects in the 1990's and new initiatives like the CTFCA and the H2EA programs, the Canadian government is responding to the industry's need for early adopters. As an early adopter the Government is performing the pivotal role of testing new products and technology under real-world conditions, while at the same time increasing the profile of the industry. The extent of government participation as early adopters will also impact the level of public sector understanding of the potential of the technology and the issues facing the industry, and the level public sector influence within the industry.

Uniting the Industry

The federal government has contributed significant resources to establish and help operate FCC, the national industry association. FCC membership represents over 90 percent of the private sector industry, including 66 companies from across the fuel cell value chain as well as several academic institutions and PROs. The mandate of FCC includes developing and coordinating industry development through cluster building, acting as a liaison between industry, government and non-government organizations, building markets for Canadian companies and enhancing consumer awareness.

FCC has acted as a catalyst in developing strong P3s within the Canadian fuel cell industry. The association's proactive approach to industrial and business development is forging the necessary relationships among key domestic and international stakeholders. The influence of FCC's advocacy efforts, both federally and provincially, have also

contributed to the increased support from government stakeholders.

International Coordination and Cooperation

While 17 demonstration projects are taking place in Canada, 78 percent of projects involving Canadian companies are in foreign jurisdictions.²⁶ Over the past two years, Canadian companies have been involved in 82 demonstration projects in foreign jurisdictions, translating into a product export rate of 85 percent.²⁷ This figure underscores the prominence of Canadian firms in international markets, the importance of international partnership and alliances as well as the commitment of foreign governments to achieving full-scale commercialization of fuel cell technology.

A priority of the federal government is to coordinate with international organizations. For example, the CTFCA has an agreement with the California Fuel Cell Partnership to ensure that research efforts are not duplicated. There are mutual advantages in cooperating internationally on the development and demonstration of hydrogen supply infrastructure and fuel cell development, particularly with respect to the sharing of pre-competitive information and data. The proposed Hydrogen Highway™ in British Columbia will benefit from the experiences of fuelling stations currently in operation or being installed in Southern California, Europe and Japan. Conversely, the Hydrogen Highway™ experience will benefit those who will be developing and installing hydrogen stations elsewhere in the future.

The evolving nature of P3s within the Canadian fuel cell industry is also exemplified in the collaborative participation of the private and public sector with the ISO, PATH, and IPHE. The broad regulatory parameters being established by these collaborations will become the foundations of a future hydrogen-based economy.

Protecting Intellectual Property Rights

Patents are a means of protecting intellectual property rights and patent data is one of the most available, objective, and quantitative measures of innovation. A country's patenting activity is also an indicator of its research capability, technological strengths, and pre-commercialization activities.

In the Canadian fuel cell industry the majority of knowledge—as measured by patents for fuel cells and related technologies such as fuel processing and hydrogen storage—is owned by private industry. This knowledge is a key asset and a critical measure of corporate value. Issues relating to the development, ownership, protection and transfer of this knowledge are central to the current and evolving structure of the industry.

Product Patents

The remarkable pace of fuel cell development is reflected in the 227 percent increase in the number of patent applications worldwide—from 286 in 1999 to 652 in 2001. Leading nations for patent publication are the US, Germany, Japan and Canada. Major players include: UTC Fuel Cells, USA; Siemens AG, Germany; and Ballard Power Systems, Canada.²⁸

A recent study showed that despite a \$180 million annual expenditure on R&D, for most companies within the Canadian fuel cell industry, IP ownership is substantially lagging. Ballard Power Systems, by far the most dominant player in the fuel cell market in terms of both revenue and IP ownership, is the marked exception—with a total of 80 US patents for the period of 1976 to present. Overall, patent activity by Canadian firms was much stronger in the US than at home, suggesting a strategic emphasis on protecting IP within the primary, projected, market for their products and services.³¹ It also suggests that IP protection is either a low priority or beyond the means of the small research firms that

make up the majority of the Canadian fuel cell industry.

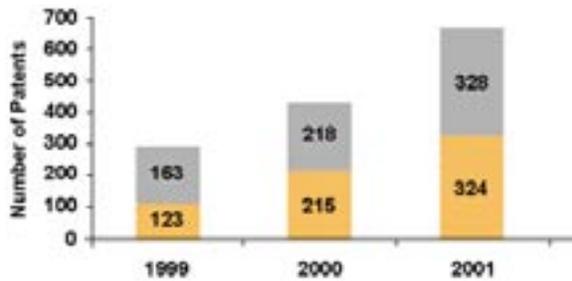
A low priority on IP protection may reflect an assumption that the results of early research tend to become generic and that the value of IP protection may be better realized on later, more applied developments. It may also suggest a contractually mandated transfer of IP ownership between the Canadian research firm and its multinational OEM or energy partner.

Furthermore, it must be noted that a vertically integrated company could potentially have a greater number of patents because they are developing components internally. Horizontally integrated companies, on the other hand, work with key suppliers of specialized components who would take on the burden of IP development and protection, which could be argued as a more cost-effective corporate strategy.

28 Government of Canada, Innovation Sector Action Plan – Hydrogen and Fuel Cells, 2003

31 Ibid

FIGURE 3. Patents for Fuel Cells and Related Technologies for 1999



Public Sector IP Involvement

Technology transfer is primarily achieved through licensing and through collaborative R&D. Federal government labs at NRCan, NRC and the Department of Defence, work with industrial and university collaborators to adapt and create new technologies and improve existing products and services. Original discoveries, know-how, software and new technologies – protected by patent or copyright – are the foundations for new products, process innovations and commercialization in the world's marketplaces. Federal labs have developed a collection of proven IP management tools and practices that guide the evaluation, protection, exploitation and licensing of technologies to receptor firms.

Collaborative agreements pool resources such as funding, in-kind contributions, background IP, equipment, and knowledge, and share management of medium-to-long-term research. Private collaborators are engaged early to ensure that projects align with their needs, the needs of the marketplace and government needs. The public sector works side-by-side with researchers, increasing the technical expertise and ensuring that the government is plugged into marketplace realities, and improving the odds for commercial success.

Collaborations range from projects with single companies to multi-partner arrangements with small and larger firms, as well as university partners and all three levels of government.

Public IP Ownership

As the level of collaboration with private industry increases, innovation through the commercialization of intellectual property, is becoming more of a priority for Canadian universities and PROs. Technology transfer officers have been established in universities to work with the public and private sector to identify IP licensing opportunities arising from public-private collaborations.

Protecting IP developed through publicly funded organizations is essential to ensure the Canadian public receive a return on their investment. Issues arising from the sharing of IP ownership between researchers – that have in the past hindered commercialization of university-based IP – are currently being addressed. One study recommends that the IP developed through federal funding at universities and PROs remain the property of those institutions.³³

Moving towards Commercialization

Pioneering Canadian technology developers should benefit from an increased pace of commercialization resulting from a world-wide focus on demonstration and infrastructure projects, and rising consumer awareness. The true measure of Canadian innovation in the fuel cell industry will become more evident as markets for the technology mature and the licensing of manufacturing, marketing, distribution rights increase.

As the industry approaches commercialization fuel cell-related patent activity may become a more significant part of the IP strategy of large OEM and energy firms. The ability of Canadian firms to maintain their leadership role will, to a considerable extent, depend on their IP strategy and their ability to access or develop capabilities areas of manufacturing and integration.

29 Ibid

30 Cowlings 2004. This data is based upon fuel cell patents in the HO 1M 8 category. Please note that the US does not publish data on fuel cell applications, therefore this data was not used for comparison.

A Comparison between the Canadian Fuel Cell and Biotechnology Industries

A comparison between the R&D models for biotechnology and fuel cells highlights the relationship between public sector funding and the ownership of intellectual property.

Total R&D investment is extensive in both industries—roughly \$131,578 per employee in the biotechnology sector and \$115,000 per employee in the fuel cell and hydrogen sector. Yet there is a very significant difference in the level of public funding provide to these industries. In 2000, every dollar the private sector invested in biotechnology R&D was matched by a public investment of \$1.40. At the same time, every dollar the private sector invested in fuel cell R&D was matched by a public sector investment of \$ 0.03. Despite this disparity in government funding, the Canadian fuel cell and hydrogen industry achieved revenues of \$96.9 million in 2001³².

By far, the bulk of research in the publicly-funded biotechnology industry is conducted in university laboratories, with any resulting IP remaining publicly owned. In contrast, the fuel cell industry conducts the majority of research within the private sector, with resulting IP being privately owned. In this comparative example, it is evident that issues of IP ownership join other factors—such as social agenda, public interest and national priorities—in influencing the level of public sector support enjoyed by specific industry sectors. Developing fuel cell-specific capabilities within Canadian universities and PROs and encouraging increased collaboration with private sector is one way of enhancing public sector participation in the industry and achieving major breakthroughs in technology development.

Table 10 Total Canadian and US Patents Held by FCC Members³⁰

Company	Canadian fuel cell applications	Canadian fuel cell patents	US fuel cell patents	Total US patents (including non fuel cell patents)
Ballard Power Systems	105	23	99	181
Hydrogenics Corp.	10	1	4	6
QuestAir Technologies	7	0	0	7
Global Thermoelectric	11	0	0	2
Fuel Cell Technologies	2	0	4	6
Stuart Energy Systems	1	0	0	8
HERA, H2 Storage Systems	1	0	0	0
Inco Special Products	1	0	0	0
General Hydrogen	1	0	1	1
Cellex Power Products	0	0	1	5
Dynetek Industries	0	0	0	11

32 Sypher:Muller International, Economic Impact of Industrial Hydrogen Activity in Canada, 2001

33 Advisory Council on Science and Technology, Government of Canada, Public Investments in University Research: Reaping the Benefits, 2003

34 Government of Canada, Innovation Sector Action Plan – Hydrogen and Fuel Cells, 2003

Global Market Position

The drivers encouraging innovation and the barriers to commercialization of fuel cell technology are not national phenomena. Resolving global issues of climate change and increasing energy consumption will require international cooperation. Venues such as the International Partnership for the Hydrogen Economy (IPHE) will be critical in fostering the multilateral and bilateral sharing of knowledge, markets and resources needed to achieve commercialization. As an integral part of this global network, the Canadian industry is working in partnerships with foreign firms, organizations and governments, to create the foundations of a hydrogen economy.

Export Market for R&D

In 2001, revenues from domestic fuel cell-related R&D totalled approximately \$8.2 million, whereas export R&D totalled \$12.6 million.³⁵ This net export of fuel cell related R&D illustrates the importance of global markets to the Canadian industry.

R&D is heavily influenced by the strategic objectives of multinational automakers and energy companies, which operate in extremely competitive environments and maintain established infrastructures to support continuous innovation. At facilities around the world, expertise is brought together to develop application and integration solutions. Canadian fuel cell companies

have been successfully integrated into these existing systems for product development through an extensive network of strategic partnerships and alliances.

Opportunities for Canadian fuel cell companies in international markets also arise from targeted support for the introduction and early purchase of new technologies by governments in foreign jurisdictions. In recent years, the same degree of support has not been available within Canada. Recent initiatives, however, reflect an increasing level of federal support.

³⁵ Sypher/Muller International, Economic Impact of Industrial Hydrogen Activity in Canada, 2001

Branding Canada

The Canadian hydrogen and fuel cell industry and the federal government have undertaken several domestic and international branding initiatives. Today, the Canadian industry is recognized for its technical expertise and the high level of public-private cooperation. This 20 year relationship is one of the strongest features of Canada's innovation system, and it has been a critical success factor of buying and selling the Canadian brand.

Industry and government are continuing to work together to increase the competitive position of Canadian fuel cell companies by strengthening this existing brand. Strategies to expand this brand to include recognition of process, manufacturing and infrastructure expertise are also being explored.

One strategy to strengthen Canada's current position within the industry is to build on our current involvement in the development of international codes and standards related to hydrogen and fuel cells. These standards will ensure various components of the technology are compatible and interchangeable regardless of their point of origin. Canada is a founding member of PATH and is actively involved with the ISO in developing industry wide standards. Specifically, Canada is:

- Focusing on the development of codes and standards necessary for the installation and use of fuel cell systems
- Defining specifications and methodologies for testing and evaluation protocols, and
- Advocating international standards for hydrogen production, distribution and hydrogen fuel

storage pressure vessels.

The media and private interest groups have been very successful in identifying and advocating the environmental concerns surrounding global warming. While climate change concerns are a global issue, Canada's commitment to the Kyoto Accord, our current strengths in R&D and leadership in developing global standards, are the foundations of the Canadian brand in the international industry.

Canada has been very successful in branding itself through partnership opportunities, networking events, technology missions, and other international venues such as conferences and trade shows. However, another critical component of branding Canada will involve educating and creating awareness among Canadians. National performance and safety standards are required to establish an effective brand for fuel cell technologies within Canada and to generate the level of consumer trust required to successfully compete with incumbent technologies. Many members of the Canadian industry, including the Government and FCC are already developing material to support public education. To be fully effective, public education programs will need to focus on the real customers of the future hydrogen economy—children currently in Grade Four.³⁷

Figure 4. Canadian Involvement in Demonstration Projects³⁶

Country	Installations	Country	Installations
UK	1	China	5
Canada	17	Australia	1
USA	47	Sweden	3
Germany	4	Belgium	2
Switzerland	2	Europe	5
Japan	7	Italy	1
Netherlands	3	Spain	1

³⁶ Government of Canada, Innovation Sector Action Plan – Hydrogen and Fuel Cells, 2003

³⁷ US Department of Energy, Hydrogen, Fuel Cells and Infrastructure Technologies Program: Education Plan Workshop Proceedings, 2002

The Influence of Recent Trends

Increasing public concern for environmental sustainability and increasing public power consumption are two broad trends influencing the fuel cell industry. The creation of a hydrogen economy using “clean air” fuel cell technology is seen as one way of addressing both these concerns. In Canada, as in other jurisdictions, there is an increasing recognition that public sector involvement is crucial to reaching this goal. Private industry cannot achieve wide spread commercialization of fuel cell technology without a significant level of government partnership. The role of the public sector could include legislating the deregulation of existing power markets, providing financial support and facilitation for large scale demonstration projects, developing international safety and performance standards and promoting public acceptance. The level of government participation will also greatly influence the competitiveness of the Canadian industry in rapidly evolving international markets.

Deregulation of Energy Markets

The global trend towards privatization of electricity and power markets, initiated by deregulation, is promoting competition and driving industry-wide restructuring. Increasingly, domestic and business consumers are free to choose their supplier of gas or electricity. These suppliers, in-turn, are diversifying as consolidation brings foreign and multinational vendors into domestic markets—creating a more international industry.

Ontario, Canada’s most industrialized province, completed deregulation of its electricity market in 2002. Other Canadian provinces have also completed, or are in the process of, deregulation. This continued evolution towards open energy markets in Canada is creating domestic opportunities for Canadian stationary fuel cell technology companies. In a collaborative effort, Electro-Federation Canada, Natural Resources Canada and Industry Canada have committed

to support the manufacturers of alternate energy, including fuel cells, with the objective of establishing a renewable and distributed power generation industry. The project is centred on the development and implementation of a Canadian guideline for the interconnection of small, distributed power sources. This collaborative effort functions through MicroPower Connect, an organization dedicated to facilitating the interconnection of alternative energy technology to the grid.

The US market represents about one quarter of the world’s power generating capacity. Following deregulation in 1978, this market was opened to Canadian energy companies. Canada is now the largest energy supplier to the US.³⁸ Canadian companies are actively pursuing opportunities for stationary fuel cell applications in US energy markets.

The Development of Industry Standards

An international industry accepted code of performance and safety standards is critical to innovation in the Canadian fuel cell industry. Not only will it allow for the development and integration of components along a production-based value chain, it will also build consumer confidence in fuel cell technology.

Canada is focused on the development of codes and standards necessary for the installation and use of fuel cell systems and the definition of testing methodologies. Many Canadian companies and public sector representatives are actively working with the ISO and the International Electrotechnical Commission (IEC) to develop international standards governing hydrogen production, distribution and storage. In addition, through the Canadian Hydrogen Association, Canada is a founding member of the PATH and the IPHE—organizations promoting the importance of international standards in development of the hydrogen economy. Canada's leadership role in developing regulatory guidelines will support innovation in the fuel cell industry at home and foster a stronger, more competitive international marketplace.

Adoption of Information and Communication Technologies (ICT)

The widespread adoption of Information and Communication Technologies (ICT) over the past decades forever changed the way businesses operate—facilitating globalization and impacting every sector of the economy.

Internal operations in areas including inventory management and procurement have become more streamlined and critical information is being shared in real time. Small research-focused fuel cell firms with limited resources are joining global giants to form international value chains. Canadian products and expertise are becoming increasingly more accessible to foreign markets and international partnerships became more effective. Efficiency, productivity and, therefore, the pace of innovation are increasing due to advances in ICT.

Business to business workflows among multinational OEM's

are accelerating. Collaborative approaches to purchasing, procurement and product design now involve many individual companies along the value chain. The pace of innovation in the Canadian fuel cell industry is expected to increase as more fuel cell products and companies join these networks.

In consumer markets, advances in the processor and display technologies of mobile electronic devices such as cameras and cell phones are outpacing advances in battery technology. Manufacturers are looking to fuel cells to meet their increasing demand for electrical power. While Canadians have limited expertise specific to these micro-fuel cells applications, the increasing consumer demand for information and communication technology is expected to drive rapid commercialization of portable fuel cell technology, facilitating further acceptance of Canadian technology in stationary and transportation markets.

Environmental Concerns

Public awareness of the environmental and health consequences of global warming is building momentum. Social responsibility, sustainability and triple bottom line reporting are now mainstream strategies for the creation of corporate value.

The fuel cell industry is constantly promoting the benefits of widespread adoption of their clean and efficient power technologies. Producers of stationary and portable applications are looking to government to become early adopters and spur development of performance efficiencies, power-electronics, hydrogen production technologies, storage systems and transportation balance of plant.

Since ratification of the Kyoto Accord in December 2002, the Canadian government has launched several initiatives, including *The Climate Change Action Plan*, that have become principal drivers for fuel cell innovation. Together with industry, programs under the Action Plan will help demonstrate fuel cell technology, contribute to commercialization, broaden the market acceptance and reduce GHG emissions.

The Effectiveness of Canada's Innovation

Canada's innovation system has produced measurable national economic benefits despite the lack of wide-spread commercialization. The effectiveness of the innovation system within the Canadian fuel cell industry can be expressed in growing sales, employment and knowledge. Other, more qualitative measures, such as a global reputation for technical excellence and the quality of international alliances, also attest to the success of the Canadian innovation system.

Employment

As of October 2001, an estimated 1,800 people were directly employed by the Canadian companies whose core business is focused on fuel cell and hydrogen activities, with additional jobs supported in sectors that supply and service the industry.³⁹

The Canadian workforce in the fuel cell and hydrogen sector is well educated: 78 percent of the 2001 workforce had a post-secondary education. Of that total, 55 percent held a university degree and 22 percent had a community college education.⁴⁰

Revenues

Revenues reached \$96.9 million in 2001. Of these revenues, 82 percent were based on exports, with sales of equipment (77 percent) being the mainstay of the growing industry. R&D revenue accounted for another 21 percent, with 2 percent generated from other services. Total revenues for the Canadian industry are projected to increase by almost 70 percent to \$165.2 million by 2003.⁴²

Table 11. Direct Fuel Cell Industry Employment⁴¹

EMPLOYMENT	2001	PROJECTED 2003	GROWTH
Domestic	1,701	2,523	48%
Out-of-Canada	71	115	62%
Total	1,772	2,638	49%

Measuring Global Success

Canada's reputation as a leader within the global fuel cell industry is difficult to prove using traditional methods dependent on comparative economic and business data. There is limited statistical information available on the Canadian fuel cell and hydrogen sector, or for that matter, on the industry in other jurisdictions.

However, a qualitative assessment of international success supports Canada's leadership position. Indicators used to compare the industry in Canada to that in other leading countries such as US, Europe and Japan, include:

- Assessment by respected international commentators,
- Product demonstration and international sales,
- International visitorship,
- US and World patents,
- Partnerships and alliances,
- Successful cluster development.

An International Model for Fuel Cell R&D

Canadian industry leadership has been recognized in a variety of international industry studies and assessments. A report on a recent UK fuel cell sector mission to Canada clearly asserted this leadership position: "The key aim of the DTI International Technology Service sponsored Mission to Canada was to foster the development of the UK fuel cell industry through exposure to what is probably the most successful example of a fuel cell industry to date, albeit

39 Sypher/Muller International, Economic Impact of Industrial Hydrogen Activity in Canada, 2001

40 Ibid

41 Ibid

42 Ibid

Table 12 . Canadian Fuel Cell Industry Revenue (\$m CDN)⁴³

Revenue	2001	Projected 2003	Increase
Domestic Total	17.1	31.4	84 %
Export Total	79.8	133.7	68 %
Total Revenue	96.9	165.1	70 %
Domestic Sales	8.5	20.4	140 %
Export Sales	65.6	104.4	59 %
Total Sales	74.1	124.8	68%

still in a nascent state".⁴⁴

The same report further recommended that the UK government adapt many of the activities undertaken by Canada and take additional steps to encourage closer and stronger relationships between Canadian and British developers of the technology.

International Sales

International sales are a measure of competitive position. Especially when most sales are for publicly subsidized demonstration projects where indigenously developed technologies would have a preferred advantage.

It is estimated that within the past two years, Canadian companies have been involved in over 99 demonstration projects. While 17 of these projects are taking place in Canada, 78 percent are in foreign jurisdictions. This 85 percent export rate attests to the competitiveness of Canadian technology. Similar world surveys produced by Fuel Cells 2000 indicate that Canadian companies are involved in:

- 9 of 29 fuel cell bus projects (Ballard, Hydrogenics),
- 33 of 61 fuel cell vehicles from auto manufacturers (Ballard, Hydrogenics),
- 12 out of 68 hydrogen fueling stations (Stuart, BC Hydro).⁴⁵

This information does not indicate the role of secondary suppliers such as Dynetek, which provides high-pressure hydrogen cylinders to many of the bus, auto, and fueling systems projects around the world.

International Visitorship

In Canada and around the world, Canadian government officials continue to showcase the Canadian fuel cells and hydrogen sector as a model of innovation and technology development.

In 2003, members of the Canadian fuel cell industry hosted delegations of scientist and businessmen from France, the US, the UK, China and Japan. These visitors are coming to Canada to developing alliances and joint ventures, assess Canadian strengths and weaknesses, and learn from the Canadian experience.

International Partnerships, Alliances and Overseas Subsidiaries

The success of Canadian fuel cell companies in establishing strategic relations with leading international companies is a testament to their reputation for expertise. These alliances will further strengthen Canadian industry by providing greater financial security and complementing their core capabilities in areas of manufacturing, integration and marketing.

Cluster Development

The depth and strength of industry clusters is a measure of sector success and competitiveness. For the nascent fuel cell and hydrogen industry, like many other measures, cluster development is only a rough indicator – the industry is too new to make definitive judgments about cluster success. However, it seems fairly clear that the most developed fuel cell and hydrogen cluster in the world exists in the Vancouver area.

The following assessment chart evaluates the R&D efforts of the Canadian fuel cell industry as a whole, taking into account the efforts of government, industry and academia. It follows the format set out by the OECD—listing the achieved and projected economic, environmental and security benefits of the Canadian fuel cell innovation system. Knowledge benefits are also addressed.

43 Sypher Muller International, Economic Impact of Industrial Hydrogen Activity in Canada, 2001

44 Ibid

45 Fuel Cells 2000, Fuel Cell Buses, Fuel Cell Vehicles, And Worldwide Hydrogen Fueling Stations, 2002

Figure 5: Effectiveness of the Canadian Fuel Cell Innovation System

		Benefits	
	Realized	Projected	Knowledge
Economic	<p>Approximately 2,500 are employed in the fuel cell sector</p> <p>Cluster development; Vancouver, Calgary, Kingston, Toronto, Montréal; over 60 firms in total</p> <p>Export market development, 85% of sales are export sales of approximately \$80 million (2001)</p> <p>Pre-commercial products that have generated sales, \$96.9 million in 2001</p> <p>The stimulation of a supply chain; the addition of firms into the industry; product developers, systems integrators, parts and systems suppliers, service providers and infrastructure providers</p> <p>Foreign investment in Canadian companies; contributing wealth to the economy (possibly have spun off into other industries besides fuel cell and hydrogen firms)</p> <p>Employment, 24,450; payroll, \$544.5 million; operating expenses, \$1.9 billion⁴⁶</p>	<p>Increased domestic sales and sales from exports, \$165.2 million projected for 2003;</p> <p>Increasing goods and services in the economy, a global market upwards of \$4.6 billion⁴⁷ in 2011</p> <p>Greater efficiency of producing power/more efficient automobiles</p> <p>Reduction of costs associated with energy generation</p> <p>The sale of proprietary knowledge (patents and licensing) to fuel cell producers in other countries</p> <p>Offset existing demand on traditional energy sources leading to marketable energy surplus</p>	<p>The eventual creation of fuel cell discipline through post secondary institutions and trade schools</p> <p>The international collaboration and cooperation efforts of today will establish a strong network that can be used to pursue other related technologies</p>
Environmental	<p>Increased attention to improving environmental regulations and legislation</p> <p>Prioritizing climate change and sustainable development initiatives and policy work; the potential of this technology, as indicated by R&D, has encouraged departments and organizations to participate technologies initiatives</p>	<p>Once fully commercialized, fuel cell powered vehicles are expected to reduce emissions by 25%</p> <p>Creation of a sustainable energy source</p> <p>Health benefits improved air quality</p> <p>Reduced demands on non-renewable every resources as a result of greater fuel efficiency</p> <p>Reduced impacts on the land base caused by constructing corridors for new transmission lines</p> <p>Reduced costs associated with incumbent technologies (e.g. ground-water pollution)</p>	<p>Successful commercialization of fuel cell technology in initial markets will drive consumer awareness and adoption of technology in other markets.</p>
Security		<p>Reduced dependence on foreign oil reserves (although Canada is a net exporter of energy)</p> <p>Sustainable and reliable energy source (solution to black and brown outs)</p> <p>Distributed generation solution</p>	

46 PricewaterhouseCoopers, Fuel Cells: The Opportunity for Canada, 2002. Calculated assuming a 15 percent North American market share for the stationary market in 2011; 25 percent North American market share for the transportation market in 2011.

47 Ibid. Assuming that Canada capture 10 percent of market projection of \$46 billion in 2011.

Conclusion

Early success in R&D, pre-commercialization activities and strong partnerships have helped establish Canada as a global leader in the fuel cell industry. Today, public and private sector stakeholders are continuing to working together to build the Canadian industry—increasing innovation and strengthening our competitive position within growing international markets.

Industry, government and academia have developed the *Canadian Fuel Cell Commercialization Roadmap* to identify industry priorities and national policy needed to achieve wide-spread fuel cell commercialization. They are also becoming increasingly engaged in large-scale, collaborative demonstration projects and through participation in industry surveys and studies—such as this OECD Case Study—are helping to build an international hydrogen economy.

Appendix 1

Descriptions of Key Federal Departments

Department of National Defence (DND)

Through its Department of Chemistry and Chemical Engineering DND has long supported the development of Canadian hydrogen and fuel cell technologies. DND is involved in the International Energy Agency ANNEX VIII PEM Fuel Cells, the Panel on Energy Research and Development and has fuel cell development contracts with a number of leading Canadian firms in this arena.

www.dnd.ca

Department of Foreign Affairs and International Trade (DFAIT)

The Trade Commissioner Service, through its network of offices abroad, promotes Canadian capabilities in hydrogen and fuel cells and provides export development assistance to Fuel Cells Canada for participation in international events. The Enhanced Representation Initiative (ERI) Secretariat, in cooperation with The United States Business Development Division and ERI partner departments, will organize a hydrogen and fuel technology partnership mission to the US in March 2004 to encourage business and technology partnerships between Canadian and US companies. The Science and Technology Division promotes international R&D collaboration in hydrogen and fuel cells between Canadian researchers from universities/companies and their counterparts in other countries.

www.dfait.gc.ca

Environment Canada (EC)

EC, through its Environmental Technology Advancement Directorate, brokers projects that promote the development and demonstration of fuel cells and hydrogen infrastructure. EC's Environmental Technology Centre (ETC) evaluates various technologies related to fuel cells. Its Emissions Research and Measurement Division is involved in the emissions testing of fuel cell vehicles. EC's objective is to ensure hydrogen is produced in a cleaner and environmentally sustainable manner.

www2.climatechange.gc.ca/ccaf

Industry Canada (IC)

IC supports the development of new energy technologies including fuel cells and hydrogen. Its activities include demonstrating pilot and large-scale technology projects; increasing access to investment capital for emerging companies; and addressing technical barriers to distributed generation. IC facilitated the industry-led, Fuel Cell Commercialization Roadmap – a report that outlined the sector's key commercialization challenges, and presented recommendations to help Canadian industry capitalize on its leadership position. Its Energy and Marine Branch is developing policies and programs to enhance the industry's economic growth potential.

www.strategis.gc.ca/electrical

National Research Council Canada (NRC)

NRC operates world-class research facilities and innovation support networks from coast to coast. The NRC Institute for Fuel Cell Innovation, located in Vancouver, B.C., is the home of the NRC Fuel Cell Program, an international effort linking industry, government and academic partners worldwide.

Among its facilities, the Institute includes one of North America's few environmental test chambers, and nine fuels-safe laboratories—infrastructure that enables NRC researchers and Canadian companies to develop, test and evaluate fuel cell and hydrogen technologies.

www.ifici-iipac.nrc-cnrc.gc.ca

Natural Resources Canada's CANMET Energy Technology Centre (CETC)

CETC is Canada's leading federal S&T organization that is developing and deploying energy efficient, alternative energy and renewable energy technologies. CETC's Transportation Energy Technologies program partners with industry and other federal and provincial agencies to develop and deploy new transportation technologies, including hydrogen and fuel cells, alternative fuels and advanced propulsion systems; energy storage systems; emissions control technologies; vehicle transportation system efficiency; and hydrogen fuelling infrastructure technologies.

The program supports R&D through cost-shared agreements, standards development, and technology transfer, both domestically and internationally. NRCan is also involved in hydrogen separation technologies and utilization of hydrogen fuel cells in underground mines as well as stationary applications for fuel cells. NRCan also is responsible for Canada's energy policy.

www.nrcan.gc.ca/es/etb/cetc/cetchome.htm

Natural Sciences and Engineering Research Council (NSERC)

The NSERC invests in people, discovery, and innovation by supporting basic university research through discovery grants and project research through partnerships among universities, governments and the private sector, and also by helping provide for the advanced training of highly qualified people.

www.nserc.ca/programs/rpg_e.htm

Public Works and Government Services Canada (PWGSC)

PWGSC plays a leadership role in a Federal House-in-Order initiative to improve the energy efficiency and reduce greenhouse gas emissions of government operations and activities. The department is working with industry to explore alternative energy sources, including electricity production from fuel cells. PWGSC is also helping Indian and Northern Affairs evaluate fuel cell applications for remote Northern communities.

www.pwgsc.gc.ca

The Social Sciences and Humanities Research Council of Canada (SSHRC)

The SSHRC is Canada's foremost granting agency for research and training in the social sciences and humanities. SSHRC does not conduct research itself. It distributes funds to Canadian researchers, scholars, and universities through highly competitive granting programs. Technology Partnerships Canada and SSHRC have entered into an agreement to establish a joint initiative with the common objective of funding research-related activities in the area of social sciences and humanities related to ongoing working integrated models that will contribute to the development of a hydrogen economy

Technology Partnerships Canada (TPC)

TPC is an instrument of Industry Canada that invests

strategically in research, development and innovation initiatives to encourage private sector investment and technology commercialization. Over the past several years TPC has provided approximately \$60 million of financial support to Canadian fuel cell and hydrogen businesses to develop innovative products and processes.

www.tpc.gc.ca

Transport Canada (TC)

TC supports research into future fuels including hydrogen, and as an active member of the Canadian Transportation Fuel Cell Alliance is also interested in fuel cell vehicles.

Part of TC's Freight Efficiency and Technology Initiative, which is designed to reduce the growth of greenhouse gas emissions from freight transportation, is its commitment to demonstrating and encouraging the uptake of innovative technologies.

www.tc.gc.ca

Western Economic Diversification Canada (WD)

WD promotes economic diversification in Western Canada and has supported the growth of a hydrogen and fuel cell sector in Western Canada since 1990.

www.wd.gc.ca

Appendix 2

Canadian Fuel Cell Companies

Components and Subsystems:

- Dynetek Industries develops, produces and markets high performance lightweight fuel tanks for storing compressed natural gas and compressed hydrogen. Their products are sold worldwide.
- HERA Hydrogen Storage Systems develops hydrogen storage products based on metal hydrides for various hydrogen applications.
- Pivotal Power offers power electronics engineering solutions to the fuel cell industry with inverters and converters products.
- QuestAir designs and manufactures complete hydrogen purifying units.
- Xantrex Technology develops, manufactures, power electronic and control products.
- DuPont Canada has the specific business mandate within the global Fuel Cell business for the marketing, development and production of fuel cell conductive flowfield plates and value-added functionality that can be built from flowfield plates.
- Hydrogen Supply, Storage and Transportation
- BC Hydro uses renewable electricity and has an extensive distribution network to produce hydrogen. BCHydro works on the commercialization of hydrogen technologies with its research subsidiary, Powertech Labs.
- Enbridge Gas Distribution is Canada's largest natural gas distributor.
- General Hydrogen Corporation develops technologies and invests in companies involved in the development and introduction of hydrogen infrastructure.
- Methanex Corporation is the world leader in methanol production and marketing.
- Stuart Energy Systems develops and supplies hydrogen generation and supply systems using their proprietary water electrolysis technology
- Kraus Group is a designer and manufacturer of transportation refueling systems.
- General Hydrogen Corporation develops technologies and invests in companies involved

in the development and introduction of hydrogen infrastructure

Complete Fuel Cell Solutions:

- Angstrom Power is a developer of micro-structured fuel cells that could replace batteries for portable power.
- Ballard Power Systems is recognized as the world leader in developing, manufacturing and marketing proton exchange membrane (PEM) fuel cells.
- Cellex Power Products is a leading developer of products to be used as power sources for industrial vehicles.
- Global Thermoelectric is involved in the development of SOFC technology.
- Hydrogenics develops commercial PEM fuel cell systems for transportation, stationary and portable power applications.
- Palcan Fuel Cell Technologies has developed technologies for manufacturing PEMFC stacks and systems, targeted at small electric vehicles and portable power.

Test Equipment

- Transformix Engineering designs and builds testing, quality control, material handling and assembly equipment
- Greenlight Power Technologies (a division of Hydrogenics) is a leading global supplier of testing and diagnostic equipment to the fuel cell industry.
- Advanced Measurement Systems manufactures customized test systems measuring fuel cell characteristics such as voltages, current, humidity, temperature and gas flows into a fuel cell.

Service Providers

- Hydro-Québec CapiTech invests in companies offering energy related products and services that can increase the performance of Hydro-Québec's business units.
- PricewaterhouseCoopers LLP understands and supports the fuel cell industry in Canada and around the world through its Alternative Energy network of professional staff.
- Chrysalix Energy Limited Partnership is an early-stage private equity venture capital firm focusing on the fuel cell industry.
- Fuel Cells Canada, a non-profit national industry association providing services and support to Canadian corporations and educational institutions that promote fuel cell and related products and services.
- Hydrogen Research Institute is an R&D unit of the Université de Québec à Trois-Rivières, working on issues of storage, safety and use of hydrogen and fuel cells.

