

Innovation Snapshot

Hydrogen and fuel cells

"Ontario is uniquely positioned to commercialize fuel cell research and development. We have some of the world's best researchers in the area of alternative fuels and advanced materials and manufacturing. We also have a collaborative approach to research that helps accelerate solutions and a strong history of working with the private sector."¹

Dr. Brant A. Peppley, Canada Research Chair in Fuel Cells, Queen's University, Director of Queen's-Royal Military College Fuel Cell Research Centre

Introduction

Although the hydrogen and fuel cell sector is still considered an 'emerging' industry, the concept of hydrogen as an energy source has been around for more than 100 years. The principles that underlie fuel cells – generating electricity from hydrogen and oxygen gas – were first realized in 1838 by Christian Friedrich Schönbein. It was in 1842 that the first fuel cell prototype was created by Sir William Robert Grove.²

Hydrogen fuel cells have been successfully implemented in niche power applications. Top segments currently include power generation, stationary power for industry, portable electronics, and motor vehicles. NASA (the US National Aeronautics and Space Administration) has been using hydrogen as rocket fuel since the late 1950s. Current research in hydrogen energy revolves around

hydrogen production, storage, and optimization to make such systems more efficient, more cost-effective and easier to manufacture.^{3,4} The most common method of producing hydrogen is through steam methane reforming (the separation of hydrogen from natural gas through heating). Many other innovative approaches have been cited in scientific literature over the years. One approach is based on algae which produce hydrogen gas as a by-product of photosynthetic reactions.^{5,6}

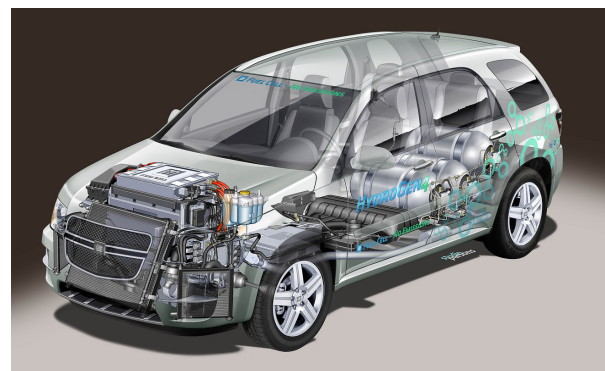
Canadian Market at a Glance

Total hydrogen fuel cell spending was estimated globally at \$5.6 billion in 2008, taking into account commercial sales, prototyping, demonstration activities and research and development (R&D) spending. An estimated \$570 million was derived from sales of 17,800 fuel cells.⁷

Canada is a leading force in hydrogen technologies. It is one of the largest global producers of industrial hydrogen and is, in fact, the largest producer of hydrogen per capita among OECD (Organization for Economic Development and Co-operation) countries. The primary use for hydrogen in Canada is for upgrading fossil fuels used in transportation such as gasoline, jet fuel and diesel.⁸ The agriculture, chemical, electronic, metal and glass industries are also major consumers of hydrogen.

Did you know...

- The 19th World Hydrogen Energy Conference will be held in Toronto, Canada in 2012.⁹
- For the 2010 Winter Olympics in British Columbia, BC Transit featured the world's largest hydrogen hybrid fuel cell bus fleet for urban mass transit.¹⁰
- The world's first hybrid fuel cell power plant designed for gas utility pressure reduction stations was built in Toronto in 2008 by Enbridge.¹¹



Source: GM HydroGen4 Equinox Hydrogen Fuel Cell Vehicle Cutaway ©2008 David Parsons Illustration

Canadian Strengths

The Canadian industry is internationally recognized for its leading role in the development of proton exchange membrane (PEM) fuel cells with applications in mobile, small stationary and portable power markets.¹² Canada is home to industry-leading companies that have excelled in the development and integration of hydrogen fuelling infrastructure and systems including Hydrogenics, Ballard Power Systems, DMA Technical Consultants, Air Liquide, Air Products, Dantherm, and Dynetek Industries.

Canadian companies have been traditionally export-oriented with the US, Japan, Germany, Korea and India as major markets for their products. The Canadian hydrogen industry employed 1,556 in 2008 and generated revenues of \$195 million. An estimated \$142 million was spent on R&D and demonstration projects.¹³

Canadian Hydrogen and Fuel Cell Association

The Canadian hydrogen and fuel cell sector is represented nationally by the **Canadian Hydrogen and Fuel Cell Association (CHFCA)** – a non-profit association that brings together major stakeholders (companies, government, universities) and simultaneously serves to raise the profile of the industry, promote the widespread implementation of hydrogen technologies, and facilitate networking and demonstration projects.¹⁴

National Hydrogen Networks

The National Sciences and Engineering Research Council of Canada (NSERC), one of Canada's main granting agencies, supports two national strategic networks for fuel cell technologies. The **H2CAN Network** involves 28 researchers from 7 provinces and over 20 industrial partners. R&D activities are carried out across key themes: production, purification, storage, infrastructure, and safety.¹⁵

The Solid Oxide Fuel Cell (SOFC) Network brings together 21 research groups from 7 universities and numerous industrial partners such as Vale Inco, Shell Canada Energy and Nova Chemicals. The objective is to remove barriers to SOFC deployment through improvements in cell lifetime, performance, and manufacturability.¹⁶

Industry Overview

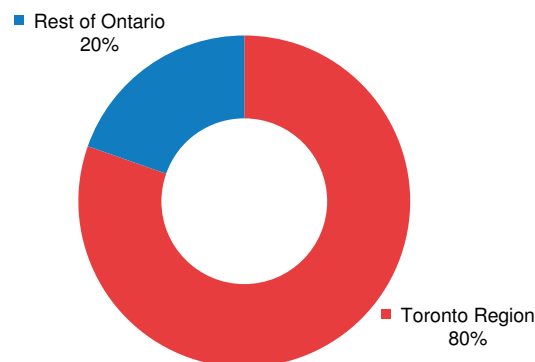
Canada brings a number of industrial strengths: (1) existing domestic hydrogen production is one of the highest in the world; (2) internationally-respected expertise in all aspects of hydrogen production, storage, distribution and delivery; (3) strong legal and regulatory framework.

The Ontario hydrogen fuel cell landscape is made up of stakeholders along the entire hydrogen supply chain: system integrators (e.g. Ford and General Motors), parts, components and materials (e.g. Dana Canada Corp., Schneider Electric, Air Liquide), and supporting public and private infrastructure (government, universities, research institutes, trade associations, financing). In fact, 34% of Canada's and 80% of Ontario's hydrogen companies are located in the Toronto Region (Figure 1).^{17,18} These are some of the key companies in the region:

Hydrogenics (Mississauga, Ontario) is an internationally-leading company in the development of PEM fuel cell systems for electric vehicles and power applications. Hydrogenics is also a world leader in electrolyser systems. The company develops fuel cell installations for electrical power plants, and hydrogen storage and power systems as a complement to other renewable energy systems.¹⁹ Products such as HyPX™ Power Packs and HyPM™ HD Fuel Cell Power Modules have successfully powered demonstration vehicles around the world.²⁰

Figure 1: Distribution of Hydrogen-related Companies in Ontario

51 companies in the province



Source: TRRA analysis based on Industry Canada and the Canadian Hydrogen and Fuel Cell Association, 2010

With over 60 years of pioneering work, Hydrogenics has become a global leader in the hydrogen and fuel cell sector. It has been involved in the building of an estimated 40 of 220 hydrogen fuel stations that exist around the world, and has participated in contracts in Turkey, Germany, and countries in Africa and Asia.²¹

Enbridge (Toronto, Ontario) was the recipient of the Toronto Green Award in 2009 for its hybrid fuel cell project.²² The world's first Direct Fuel Cell-Energy Recovery Generation™ plant was a joint effort between Enbridge and FuelCell Energy. With near-zero air emissions, the hybrid fuel cell power plant, which opened officially in 2008, has the capacity to produce 2.2 MW of electricity. It could initially supply 1,700 Ontario homes with clean electricity.¹¹

Dantherm Power (Oakville, Ontario) is owned by the world-leading fuel cell company Ballard Power Systems based in Burnaby, British Columbia. Dantherm develops and produces clean-energy backup power systems for industry and government.²³ By 2012, the company plans to launch a micro combined heat and power unit run by hydrogen fuel cells for use in homes, apartments, and small-scale industries.²⁴

Dana Corporation (Oakville, Ontario) is a multinational automotive parts supplier whose Oakville fuel cell development centre is one of Dana's four technical hydrogen-related centres worldwide. The Ontario location focuses on thermal and water management subsystems, high-temperature fuel processor and SOFC components. Dana's expertise was instrumental in the development of a unique cooling system for one of the first hydrogen fuel cell plug-in hybrid electric vehicles (FC-PHEV). Vehicle design and development was headed by the University of Waterloo Alternative Fuels Team – a team of students participating in the North American EcoCAR competition.²⁵

Talent and Labour Force

According to the Canadian Hydrogen and Fuel Cell Association (CHFCA), 1,556 people were directly employed in the sector in 2008. Most employees were located in British Columbia and Ontario.¹³ Toronto Region universities supply the industry with outstanding engineering and science talent. There were 13,201 undergraduate and 3,372 graduate students enrolled in related engineering and science programs such as chemistry, chemical engineering, and mechanical engineering in 2009 whose expertise and knowledge can be applied to hydrogen technologies.²⁶

Student teams from the University of Waterloo consistently score amongst the top teams in the annual Hydrogen Student Design Contest sponsored by the US Department of Energy and open to students across the world. Waterloo teams were recognized with the Grand Prize in the 2009 and 2011 competitions.

Research and Development in the Toronto Region

Research and development are at the core of the hydrogen and fuel cell industry. Major points of innovation include materials for catalysts, electrolytes, electrodes, as well as systems for hydrogen generation, fuel storage, distribution and refueling. Hydrogen-related research has been conducted in the Toronto Region since the early 1900s with Alexander Stuart's studies in electrolysis systems. Canadian fuel cell research began in the public sector with initial programs headed by the Royal Military College in Kingston and supported by Canada's National Defence. But R&D is being carried out increasingly by the private sector in collaboration with government. Toronto Region companies have a history of fuel cell innovation (Figure 2).³²

Figure 2: Fuel Cell Innovations in the Toronto Region

University of Toronto graduate Alexander Stuart developed a set of **electrolysis systems** that generated heavy water for the Manhattan Project in the 1920s.

Stuart Energy Systems (acquired by Hydrogenics in 2005) installed the **world's first photovoltaic and hydrogen-vehicle fueling station** in Toronto in 1990 for Mazda.

HYDROGENICS
Advanced Hydrogen Solutions

In 2002, Hydrogenics and Dow Corning began development of an innovative sealing technology for fuel cells and electrolyzers. **Fuel Cell "Seal-in-Place™" (FCSIP)** technology is an automated process using Dow Corning's proprietary silicone materials.

DOW CORNING



Vive Nano Inc. (Toronto, Ontario) is a nanotech company specializing in advanced materials. They have patented a platform technology to produce **improved "green" catalysts for fuel cell systems**. The company is winner of the 2009 Deloitte Technology Green 15™ Award and the Frost & Sullivan's 2010 North American Technology Innovation of the Year Award.



World's most advanced VOC conversion system "Fumes-to-Fuel" was installed at Ford's Oakville assembly plant in 2008. This is an air pollution control system that converts volatile organic compounds (VOCs), emitted during painting, into a hydrogen-rich mixture for use in downstream fuel cells.

Source: Canadian Hydrogen and Fuel Cell Association,²⁷ Vive Nano Inc.,^{28,29} Hydrogenics,³⁰ Ontario Ministry of Economic Development and Trade³¹

Toronto Region universities are a hub of research excellence recognized by Canada's major granting agencies. Experts in the region carry out studies in areas of importance to hydrogen technologies such as graded materials, membranes, electrochemical reactions, charge transport, and fuel cell system design.

Between 2000 and 2010, over \$42.8 million was invested in hydrogen-related projects across Canada by NSERC and CFI (Canada Foundation for Innovation) (Figure 3). Toronto Region universities received 19% (or \$8.1 million) of the national funding.^{33,34}

Scientific Publications and Patents

At the country level, Canada ranked 8th in the number of hydrogen energy-related publications worldwide with 1,240 scientific articles between 2000 and 2010. The Toronto Region generates more publications than any other region or province in the country. In fact, it contributed 27% of Canada's published articles in that time span (Figure 4).³⁵

The clean energy potential of hydrogen and fuel cells has led to an increase in the number of hydrogen and fuel cell patent filings worldwide. Major companies have sought protection for related technologies such as batteries, membrane and electrolyte materials, and hydrogen production systems. Canada placed 4th globally in the number of hydrogen and fuel cell-related PCT (Patent Cooperation Treaty) filings with 2,100 between 2000 and 2010. At the regional level, the Toronto Region was amongst the top five in the world with 523 patent applications (Figure 5).³⁶

Institutes

The Toronto Region is a centre of advanced R&D with 10 research institutes and groups involved in hydrogen-related activities including: Centre for Sustainable Energy (Toronto), Waterloo Centre for Automotive Research,

Green Energy Research Institute (Waterloo), McMaster Institute for Automotive Research and Technology (Hamilton), and the Advanced Materials Research Group (Oshawa).

University of Ontario Institute of Technology (UOIT) (Oshawa)

UOIT is leading an international collaborative effort that involves scientists from numerous Ontario and foreign universities, as well Atomic Energy of Canada, and the US Argonne National Lab. The work focuses on the development and scale-up of a new method of hydrogen production using a copper-chlorine cycle that generates hydrogen from water. The team is addressing novel coatings, safety, thermodynamic modeling and solution chemistry.

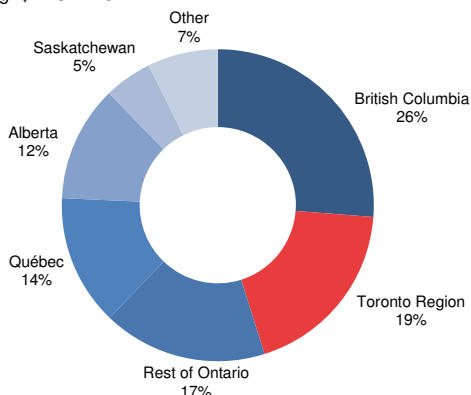
UOIT's Advanced Materials Research Group is a local effort that draws on the expertise of 11 faculty members from science as well as engineering and applied science. The group takes a collaborative approach to research projects in advanced materials and characterization techniques. The group has substantial expertise in fuel cell materials, cell performance modeling, membranes and related transport phenomena.³⁷

McMaster Institute for Energy Studies (Hamilton)

The McMaster Institute for Energy is a multidisciplinary institute that brings together 19 faculty members from the Department of Engineering Physics and the Faculty of Engineering. The institute covers multiple areas of study including fuel cells, photovoltaics, solar and wind energy, nuclear energy, conservation and energy modeling. The institute's main goals concerning fuel cells are characterizing cell performance and developing electrodes and materials for energy storage and generation.^{38,39,40}

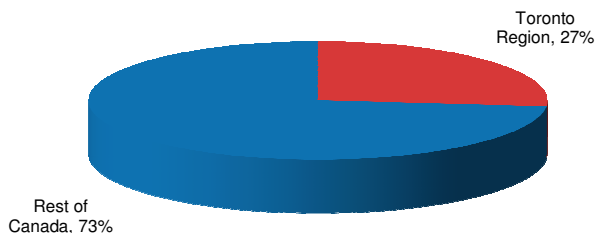
Figure 3: Combined NSERC and CFI Funding (2000-2010)

Total Funding: \$42.8 million



Source: TRRA analysis based on NSERC and CFI data, 2010

Figure 4: Total Number of Canadian Publications 1,240 (2000-2010)



Source: TRRA analysis based on ISI Web of Knowledge, 2010

Waterloo Institute for Sustainable Energy (Waterloo)

Created in 2008, the Waterloo Institute for Sustainable Energy (WISE) draws on the expertise of more than 70 professors from faculties of engineering, science, and environment. A major thrust area for the institute is PEM fuel cell research and development. This involves the design and analysis of PEM fuel cells, thermoset bipolar plates and establishment of laws for PEM fuel cell design.^{41,42}

Expertise

The Toronto Region is home to 20 science and engineering professors conducting cutting-edge research in fuel cell systems. The region is home to 4 related CRCs (Canada Research Chairs), including CRCs in Fuel Cell Materials and Manufacturing, Electrochemistry, Advanced Energy Systems, and Solid-State Materials. There is a critical mass in the development of advanced materials, including nanostructured materials for solid-state hydrogen storage, novel metal catalysts, amorphous and crystalline thin films, and nanocomposite membranes. The following are examples of some of the outstanding scientists in the region:



The principal investigator at the University of Toronto Fuel Cell Materials and Manufacturing Laboratory **Dr. Olivera Kesler** is also the Canada Research Chair in Fuel Cell Materials and Manufacturing. Her research areas include solid oxide fuel cells, cell manufacturing, graded and multi-layered materials, and plasma spray and sol-gel processing. Her research looks to develop durable fuel cells, which can also be mass produced using new materials and processing techniques.^{43,44}



Dr. Greg Naterer is the Associate Dean and Professor in the Automotive, Manufacturing and Materials Department at UOIT. He is the Tier 1 Canada Research Chair in Advanced Energy Systems. His research areas include hydrogen production by thermochemical water splitting, design for improved energy utilization, multiphase flows with heat transfer and micro and nano-energy systems. Dr. Naterer's research into sustainable hydrogen production revolves around developing methods of producing hydrogen without fossil fuels for curbing greenhouse gas emissions.^{45,46,47}



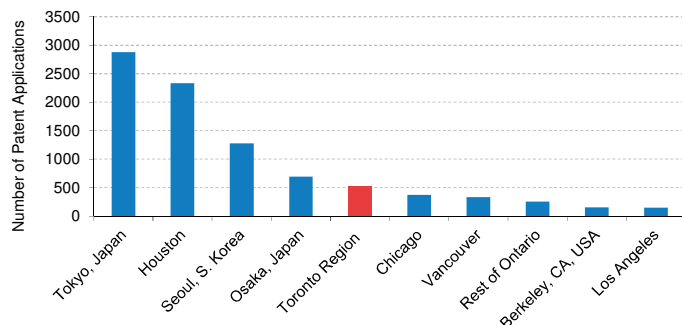
Dr. Jacek Lipkowski currently holds the Tier 1 Canada Research Chair in Electrochemistry and is working at the University of Guelph in the Department of Chemistry. His research areas include molecular analysis of electrochemical processes. A major area of interest is how ions and neutral molecules behave at an electrode surface. His research can lead to the development of electrodes that will maximize the energy conversion efficiency in fuel cells.^{48,49}



University of Waterloo's **Dr. Linda Nazar** is the Tier 1 Canada Research Chair in Solid State Materials. Her research investigates solid state chemistry to design materials for batteries, energy storage, fuel cell catalysts, and delivery applications. Because the performance and efficiency of hydrogen fuel cells are dependent on underlying materials, Dr. Nazar's team is discovering new materials to make the conduction of electrons and ions in solids more efficient. She has authored over 100 papers, review articles and patents in the field.^{50,51}

Figure 5: Number of International Patent Applications, Top 10 Regions (2000-2010)

Total number of applications: 55,918



Source: TRRA analysis based on WIPO, 2010

Did you know...

- A European study deployed 500 fuel cell electric vehicles which have successfully logged over 15 million km and have been safely refueled 90,000 times.⁵⁴
- Walmart Canada is using fuel cells in 90 forklifts at its Calgary distribution centre. This will save \$2 million over 7 years and curb greenhouse gas emissions by 530 tonnes of CO₂ per year.⁵⁵



Dr. Xianguo Li is a Professor in the Department of Mechanical and Mechatronics Engineering at the University of Waterloo. His research interests include modeling of transport phenomena in fuel cells, performance and optimization of PEM fuel cells and mechanism of liquid atomization and spray formation. He has over 130 conference publications and has written one book entitled “Principles of Fuel Cells”. Some of Dr. Li’s research publications rank amongst the top 1% in the field in terms of citation impact. He is widely recognized as a leading expert in clean technology systems.^{52,53}

Conclusion

Canada as a whole maintains a leadership position in the development and commercialization of hydrogen systems. Canadian products have been used in fuel cell demonstration projects around the world. The Toronto Region is home to internationally-respected companies with a history of fuel cell innovations. Based on the state and strengths of the provincial hydrogen industry, some business opportunities lie in:²⁷

- Control systems that integrate hydrogen systems into existing electricity grids,
- Hydrogen fuel cells for demand side management,
- Infrastructure development for hydrogen generation, distribution, and delivery,
- Serving the needs of the transportation industry in Southern Ontario – one of the largest automotive manufacturing regions in North America,
- Power supplies for niche applications (materials handling operations, backup power for industry, financial services and data centers).

Ontario and the Toronto Region are home to innovative companies, advanced research institutes and a skilled workforce that could contribute to the advancement of this sector. Hydrogen-based technologies offer environmental benefits and encourage companies to continue to employ highly-skilled personnel because of the sophisticated nature of such systems and materials. Southern Ontario is also Canada’s ‘manufacturing heartland’ with a strong industry base in advanced manufacturing and information and communications technology that can support a burgeoning hydrogen sector. This constitutes North America’s second-largest region for automotive assembly and presents business opportunities to supply the auto sector with efficient and clean fuel cell systems.

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