HYDROGEN SYSTEMS

The Canadian opportunity for greenhouse gas reduction and economic growth through the deployment of hydrogen technologies and infrastructures

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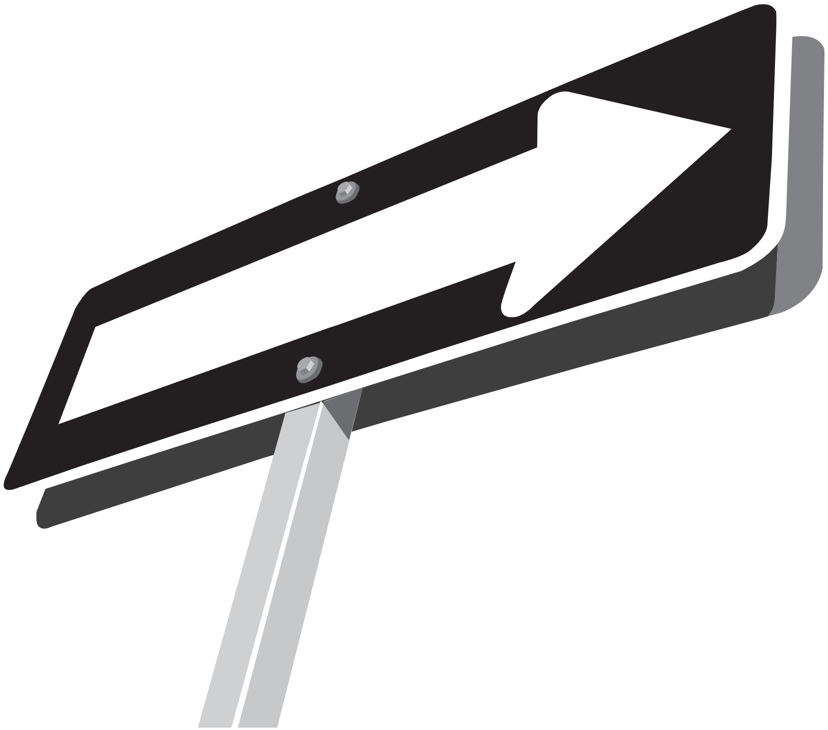

FOREWORD

The continuing prosperity of our global society depends on access to affordable energy services that are sustainable both with respect to the environment and to their future supply. By adopting hydrogen energy systems to supplement and eventually replace today's fossil-based energy systems, the global economy can make significant progress towards a sustainable energy system while continuing to grow and prosper at the same time.

There is an urgent need to do this. Reducing the future impacts of climate change requires major reductions in worldwide per-capita greenhouse gas (GHG) emissions within the next 50 years. To stabilize carbon dioxide concentration we need to re-engineer our energy systems to convert GHG-emitting systems to become effectively carbon neutral, and to rely more heavily on alternative, non-carbon energy systems. This paper proposes that hydrogen-based energy systems are a solution.

Canada is well positioned to be at the forefront of this change. First, we have a mix of fossil and non-fossil energy sources almost unmatched among developed nations, and these will play a vital role during the transition to hydrogen systems. Second, because of the creativity and initiative displayed by Canadian scientists, engineers, entrepreneurs and governments during the last 60 years, we are leaders in many hydrogen technologies. Finally, Canadians in general have a well-founded optimism about the future and a well-grounded concern for environmental issues. This is reflected in a political leadership that acts on these concerns and rises to the challenge of moving to a sustainable energy society.

Governments around the world have increased their support for the development of hydrogen systems. In April 2003 the United States, Canada and 13 other nations established the International Partnership for the Hydrogen Economy (IPHE) to coordinate hydrogen research, development and technology, and have committed to a roadmap that will put hydrogen vehicles in showrooms within the next 15 years. Almost all major auto manufacturers are now engaged in the development of hydrogen technologies.

Planning is required to provide early markets for promising Canadian hydrogen technologies to gain experience and to sustain and expand Canadian industrial capability for the major world hydrogen applications that lie ahead. Hydrogen products and systems that are ready today could have an impact on meeting emission targets in both the near and longer terms.

The paper that follows is based on two workshops held in Ottawa in the spring and summer of 2004, the aim of which was to prepare a plan to advance hydrogen systems in Canada. Over 60 experts from government, academia and the hydrogen and energy industries were involved in the workshops. The participants formed the Hydrogen Strategic Plan Working Group, and out of these workshops an in-depth discussion paper was prepared and posted on the Canadian Hydrogen Association Web site. Both the workshops and the discussion paper are the foundation for this paper.

This paper analyzes Canada's current hydrogen infrastructure and addresses the major challenges for further developing hydrogen systems in Canada, including the need to lower costs and develop effective hydrogen storage. The paper presents a four-step action plan that outlines the key steps that will help position Canada as a leader in the global shift to a sustainable, hydrogen-based economy.

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HYDROGEN AND NATIONAL STRENGTH

Canada is well positioned to lead the world to the Hydrogen Age and to benefit economically and technologically from the transition to a hydrogen economy. We are leaders in hydrogen system technologies and are also one of the world's largest per-capita producers of hydrogen, about half of which is produced by our oil and gas industries.[1] Applying our technical expertise in hydrogen production to achieve reductions in hydrogen-production emissions within the oil and gas industry could position Canada as a leader in the Hydrogen Age and could result in significant reductions in Canada's carbon dioxide (CO_2) emissions. Promoting early adoption of hydrogen systems will maintain Canada's lead in developing a viable hydrogen energy industry.

At the same time, maintaining our lead in the face of growing international competition demands that we focus on the mobilization of our resources and on partnerships among governments, industry, academia and research organizations. Our resources and technologies, as well as growing public support, are all key elements of the vision for Canada's entry into the Hydrogen Age.

CANADA'S ENERGY RESOURCES

Canada's greatest strength in the move towards the Hydrogen Age is its vast quantity and range of energy resources, all of which can be used to produce hydrogen. Although the country has only 0.5 percent of the global population, it holds about 5 percent of the planet's proven fossil fuel reserves. When coal is excluded, Canada's energy inventory actually doubles to 10 percent of the world's proven reserves.

Canada is the world's largest producer of hydroelectric power[2] and possesses an abundance of coal, natural gas and uranium. It has the second-largest proven oil reserves in the world after Saudi Arabia, with recoverable reserves exceeding 175 billion barrels.[3]

Non-conventional energy resources such as coal-bed methane could also add significantly to Canada's diverse energy stockpile. Renewable energy from wind, solar and biomass will play a growing and important role, although these resources are difficult to quantify fully at present.[4]

This wealth of resources and technology could serve as the foundation for the production of low-cost, clean hydrogen. Although producing hydrogen from fossil fuels generates greenhouse gases (GHGs), Canada also has substantial capacity for carbon sequestration and is developing capabilities in this area.[5]

CANADA'S HYDROGEN TECHNOLOGIES

Canada is also at the forefront of hydrogen technologies such as fuel cells and hydrogen storage, and has the means to maintain this role because of the creativity and initiative displayed by Canadian scientists, engineers, entrepreneurs and governments. As a result of vigorous research and investments, Canada has already achieved significant progress in hydrogen applications, particularly in hydrogen production, Proton Exchange Membrane (PEM) fuel cells and technologies associated with PEM-powered fuel cell vehicles (FCVs). Research is now broadening to embrace a wider range of hydrogen and fuel cell technologies.

CANADA'S GROWING PUBLIC SUPPORT

Canadians are beginning to understand that we can use energy much more wisely and that new energy technologies for improving efficiency and lowering CO_2 emissions are needed if we are to moderate the effects of climate change. This growing public support, coupled with our abundant energy resources and our technological expertise, makes Canada a natural leader for the transition into the Hydrogen Age.

A Short History of Hydrogen Energy in Canada

In 1800, about 50 years before the first commercial oil well began production in Oil Springs, Ontario, hydrogen was being used in Europe for lighting, heating and cooking in the form of “town gas” — a mixture of hydrogen, carbon monoxide and methane. The use of town gas grew rapidly during the first half of the 19th century, replacing the whale oil that had previously been used for lighting.[6] The first internal combustion engines (ICEs), invented in 1860 by France’s Etienne Lenoir, used town gas.[7] In a sense, these were the original hydrogen ICEs; gasoline-powered ICEs would not appear for another 40 years.

As early as 1905, the production of hydrogen by electricity was proposed by A. T. Stuart for the development of Niagara Falls. Fifty years later, he and his son, A. K. Stuart, would establish the Electrolyser Corporation, which later became Stuart Energy and now is part of Hydrogenics.[8]

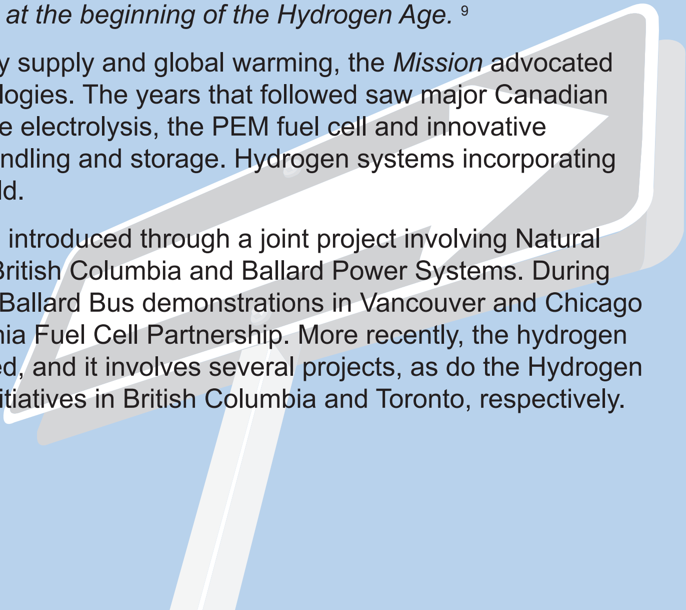
Coal gasifiers supplied Toronto with town gas until the end of the Second World War, when natural gas entered the market. Since then, hydrogen produced from natural gas has been used in the industrial gas sector for the hydro-treatment of fuels, fertilizer production, metal fabrication and glass making, as well as other applications.

Interest in hydrogen energy revived with the oil shocks of the 1970s, and Canada took a lead role in developing hydrogen-energy technologies. In 1987, the *Hydrogen National Mission for Canada* outlined a national vision for hydrogen as follows:

> *Civilization will converge to a future profoundly shaped by electricity and hydrogen, using technologies which employ them best…. A unique mix of hydrogen needs, supply options and key technologies gives Canada an important competitive advantage at the beginning of the Hydrogen Age.* [9]

In view of the looming problems of energy supply and global warming, the *Mission* advocated the development of key hydrogen technologies. The years that followed saw major Canadian progress in these areas, including alkaline electrolysis, the PEM fuel cell and innovative technologies for hydrogen production, handling and storage. Hydrogen systems incorporating Canadian technologies now lead the world.

In 1993, the world’s first fuel cell bus was introduced through a joint project involving Natural Resources Canada, the Government of British Columbia and Ballard Power Systems. During 1998–2000, progress continued with the Ballard Bus demonstrations in Vancouver and Chicago and Canadian participation in the California Fuel Cell Partnership. More recently, the hydrogen energy initiative in Manitoba was launched, and it involves several projects, as do the Hydrogen Highway™ and the Hydrogen Village™ initiatives in British Columbia and Toronto, respectively.



CANADA'S CURRENT HYDROGEN INFRASTRUCTURE

Hydrogen is a major chemical feedstock in Canada, supporting a host of economically essential processes for materials refining and production. Yet other than its use in the refining and upgrading of fossil fuels, hydrogen plays almost no role as an energy carrier in Canada's energy services. Many of the technologies that will usher in the Hydrogen Age are not commercially ready, and those that have been developed cannot yet compete with the lower costs of established, non-hydrogen technologies.

HYDROGEN AS AN ENERGY CARRIER

What is important to society is not energy in itself, but the services that energy provides, such as heating, transportation and manufacturing. Consequently, it is useful to see hydrogen not just as a fuel, but also as an energy carrier within an energy system chain. As an energy carrier, it forms the central link between energy sources and the services that society needs (see Figure 1).

Energy carriers (such as hydrogen and electricity) enable energy transactions, but they are not, in themselves, sources of energy. Hydrogen is independent of the source used to produce it, and *any* energy source can be used to manufacture it.

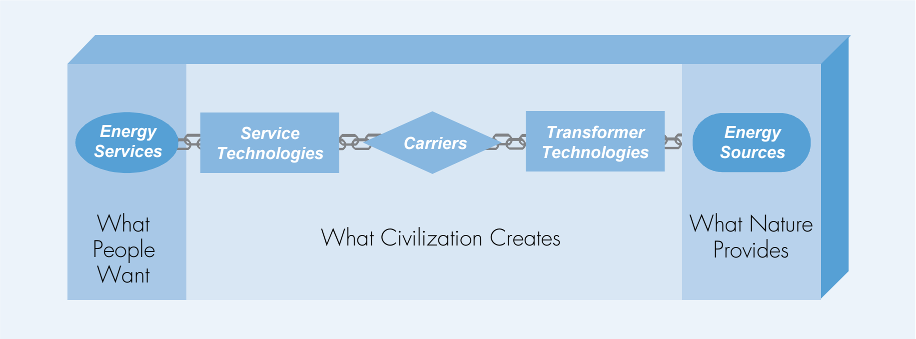


Figure 1 The energy system chain

HYDROGEN PRODUCTION

Canada produces more than 3 mega-tonnes (Mt) of hydrogen per year.[10] This is about one-third of the U.S. hydrogen production rate and makes Canada the largest per-capita hydrogen producer in the Organisation for Economic Co-operation and Development (OECD).[11]

Hydrogen for Canada's chemical and petroleum industry

The majority of the hydrogen Canada produces is generated and used on-site in the chemical and petroleum industry (see Figure 2). Producers and users trade a portion of this captive hydrogen, but a mere 0.6 percent is produced and sold as "merchant hydrogen" (gas that is sold in small quantities and delivered to a customer's site).[12]

Most of the hydrogen used in the chemical industry is produced from natural gas by steam methane reforming (SMR), while the refining industry produces hydrogen by reforming more complex hydrocarbons available within the refining processes. Electrolytic hydrogen production makes up an estimated 5 percent of Canada's supply.[13]

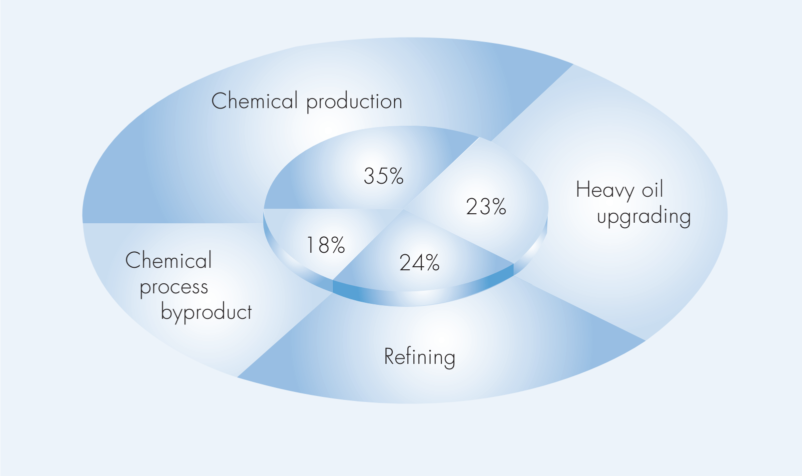


Figure 2 Hydrogen use in Canada's chemical industry[14]

Hydrogen production in Western Canada

Because of its large fossil fuel resources, Western Canada dominates Canadian hydrogen production, and Canada's largest hydrogen plants are located in the oil-upgrading facilities of this region. Three plants in Alberta and one in Saskatchewan together produce nearly 790,000 tonnes (t) of hydrogen annually.[15] The upgrading of heavy oil from the Alberta oil sands is Canada's fastest-growing hydrogen demand sector, with annual production expected to rise to 2.8 Mt per year by 2020.[16]

Capturing hydrogen surplus

Certain chemical processes generate hydrogen that is not directly useful to the generating facility. In some regions, particularly in Alberta, Ontario, Québec and New Brunswick, complementary chemical industries have been constructed near such facilities to take advantage of this surplus. Nonetheless, the amount of surplus hydrogen produced in Western and Eastern Canada is estimated at 200,000 t per year.[17] From an energy perspective, this amount of hydrogen is equivalent to 760 million litres of gasoline — enough to fuel a million light-duty FCVs for a year.

Canada's hydrogen surplus is a valuable asset for developing low-cost hydrogen supply systems for hydrogen vehicles and power-generating facilities. Unfortunately, many of the locations that produce a surplus are located far from the areas of projected demand, and, unless the quantities involved are large, delivering hydrogen over long distances rapidly increases the cost.

Hydrogen production costs

Hydrogen produced by large natural gas reformers can compete with gasoline on an energy-cost basis, provided that production facilities are located close to main natural gas supply lines. Under these conditions, if natural gas costs are approximately US$3.00 per gigajoule (GJ), hydrogen production costs can be in the range of about US$0.60 per kg or, on an energy basis, about US$0.15 per litre of gasoline equivalent.[18] However, the depletion of conventional natural gas supplies in the Western Sedimentary Basin, coupled with the expansion of Canada's oil sands, is already leading to steep increases in the costs of natural gas and of the hydrogen produced from it. With future contracts for natural gas in the range of US$7.00 per GJ, hydrogen production costs would increase to around US$1.35 per kg.[19]

HYDROGEN DELIVERY AND STORAGE

Canada's current infrastructure is capable of supporting the technology development of hydrogen energy services, but commercialization will demand new infrastructures to reduce costs and life-cycle emissions. New infrastructures based on distributed electrolysis and distributed SMR (i.e., hydrogen production occurs at the fueling station) are being demonstrated and are working towards meeting the necessary cost and/or emission targets.

Methods of delivery and storage

Over short distances, merchant hydrogen is distributed by tube trailer or, for smaller quantities, in individual, high-pressure steel cylinders. Over long distances, it is transported as a liquid in cryogenic tanks. To provide it in liquid form, Canada has hydrogen liquefaction facilities in Sarnia, Ontario; Magog, Québec; and Bécancour, Québec. Pipeline transport is possible as well, as in the case of the 52-km hydrogen pipeline that connects hydrogen producers and users in Northern Alberta.

Captive hydrogen generated on-site in an integrated chemical plant (sometimes referred to as "inside" or "over-the-fence" hydrogen) is delivered as a low-pressure gas, which is in a relatively difficult form to store and transport long distances. The low volumetric energy density of hydrogen — less than one-third that of natural gas[20] — poses a challenge to its use as an energy carrier. To deliver it as a "packaged gas" to customers in merchant markets, its energy density must be increased by compression or liquefaction. This process incurs considerable economic and energy costs. The cost of delivered hydrogen gas today can be as high as CAN$50 per kg, based on its purity, quantity and the distance from the hydrogen source. This cost is more than 50 times the production cost of the largest hydrogen-producing plants.

HYDROGEN ENERGY TECHNOLOGIES

Canada is a world leader in PEM fuel cells, electrolysis technology and hydrogen storage. Companies such as Ballard Power Systems, Hydrogenics and Dynetek are generating global interest in their hydrogen technologies.

Canada's hydrogen energy and fuel cell sector (2003)[21]

Number of people directly employed:	2,671
Revenues of sector:	CAN$188 million
Research and development expenditures:	CAN$290 million

Government support for technology research

The Government of Canada, through Natural Resources Canada, has been long aware of the potential of hydrogen energy and the need to retain the country's leadership in developing it, and has supported research and development for core hydrogen technologies since the early 1980s.

With potential economic opportunities in mind, the Governments of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Québec and Prince Edward Island have also made hydrogen a part of their energy and industrial development strategy and have invested in hydrogen research and technology.

Hydrogen energy technologies are still in the early stages

Despite substantial progress, the current state of hydrogen energy technology requires considerable development. In 1999, for example, it was predicted that commercial PEM FCVs would be available by 2004. However, the challenges of reliability and cost have proven to be more difficult than originally thought, and industry leaders now believe that the commercialization of hydrogen FCVs will occur between 2010 and 2020.[22] However, as technology companies focus on markets other than FCVs, new revenue opportunities are appearing, including hydrogen internal combustion engine (ICE) vehicles and "off-road" applications. Different fuel cell designs are being explored and new research efforts are finding solutions to previously intractable problems.

HYDROGEN ENERGY MARKETS AND COMMERCIALIZATION

A key element of a hydrogen strategy addresses the creation of a market that reflects hydrogen's full "value proposition". The single greatest barrier to this is the design of the existing energy market, which places no value on environmental or strategic factors, especially the value of avoiding CO_2 emissions.

Concerns about the timing of FCVs and hydrogen systems have resulted in a decrease in investments in the technology. Investments in companies devoted to hydrogen and fuel cell technologies have dropped to 10-20 percent of their peak values, and the inability to raise capital in the sector has led to the demise of several hydrogen and fuel cell start-up companies.

Key stakeholders

The most committed champions in the hydrogen constituency are the technology developers, some electrical utilities and certain power equipment suppliers who use primarily non-fossil energy sources. These groups have special expertise and knowledge of hydrogen and a financial stake in its success. In the narrow sense of the meaning of "stakeholder," it is these groups who will determine the success or failure of hydrogen as a fuel.

Other stakeholders are companies and institutions in the general supply chain such as financial institutions. These stakeholders see hydrogen both as a solution to environmental issues and as a potential business opportunity. They wield political and financial power, which can play an enabling and supportive role.

The federal government has also been in the "help make it happen" group; it has not committed to a hydrogen future, but has viewed it as one of a number of alternatives to achieve its policy objectives. Environmental advocacy groups may also fall into this category, although not all are convinced that hydrogen has a role as a long-term component of a comprehensive, sustainable energy strategy and that hydrogen technologies can provide major environmental benefits.

Because oil companies control access to the existing retail fuel infrastructure, they hold a key position in the energy supply chain. Only some oil companies have made investments in hydrogen technology and participate in the general development of the sector. However, the development of hydrogen supply infrastructure, such as the implementation of CO_2 capture from existing hydrogen production, will create long-term prospects for hydrogen energy systems, and could provide a "win-win" strategy for gaining the broad support of the fossil fuel industry.

Public awareness

The lack of public support for hydrogen systems, and skepticism about them, results partly from limited public knowledge about energy systems and hydrogen, including hydrogen safety issues. Demonstrations such as the 1998–2000 Ballard-British Columbia transit bus project have helped allay this concern, and more ambitious projects such as the Hydrogen Village™ and the Hydrogen Highway™ will generate greater confidence and engage a broader stakeholder base. Canada is also playing a major role in the development of codes and standards through its leadership of ISO TC 197,[23] which will help manage risks and build on precedent-setting demonstrations.

International Standards Organization TC 197

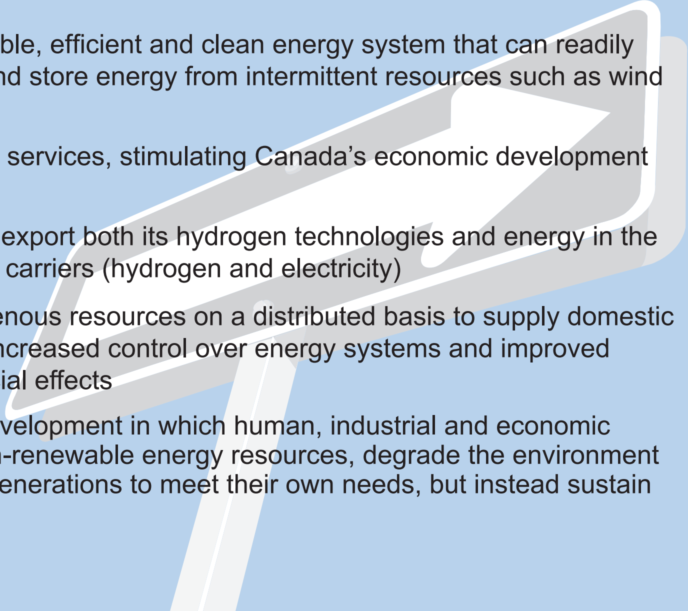
ISO TC 197 governs standardization in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen. Canada's Bureau de Normalisation du Québec (BNQ) provides the Secretariat for this standard, and Canada holds the Chair. The BNQ is one of four Canadian standards organizations reporting to the Standards Council of Canada.

MOVING TOWARD CANADA’S HYDROGEN FUTURE

The mission proposed by the Hydrogen Strategic Plan Working Group sets a national goal that is:

> *“To deploy sustainable hydrogen energy systems such that, by 2025[24], Canada will no longer need to expand its use of fossil fuels for Canadian energy services. Building on its energy resource base and its leading expertise in hydrogen technologies, Canada will become one of the world leaders in hydrogen technology development, deployment and the export of hydrogen service technologies.”*

In setting this goal it is recognized that Canada will continue to develop and expand the use of fossil fuel energy sources beyond 2025; however, the delivery of energy services will increasingly use energy carriers such as hydrogen and electricity rather than gasoline and natural gas.



Benefits of moving into the Hydrogen Age

The vision of Canada’s future in the Hydrogen Age includes many benefits:

- mitigation of climate change, reducing environmental instabilities
- reduction of air pollutants that affect human health and reduce agricultural yields, such as particulate matter, NO_x, SO_x and CO.
- increase in the use of indigenous energy worldwide and diminished global dependence on oil, reducing the political, economic and social instabilities produced by this dependence
- establishment of a dependable, efficient and clean energy system that can readily use renewable resources and store energy from intermittent resources such as wind and solar
- development of new energy services, stimulating Canada’s economic development and technological progress
- opportunities for Canada to export both its hydrogen technologies and energy in the form of value-added energy carriers (hydrogen and electricity)
- increase in the use of indigenous resources on a distributed basis to supply domestic energy needs, resulting in increased control over energy systems and improved efficiency, reliability and social effects
- promotion of sustainable development in which human, industrial and economic activities do not deplete non-renewable energy resources, degrade the environment or limit the ability of future generations to meet their own needs, but instead sustain a high quality of life

SETTING A TARGET FOR REDUCTIONS IN GREENHOUSE GAS EMISSIONS

An attainable global target for a stabilized atmospheric CO_2 concentration has been proposed to be approximately 550 ppm (parts per million) in air, or about twice pre-industrial levels.[25] The mitigation strategy depicted in the Wigley, Richels and Edmonds (WRE) 550 scenario of the Intergovernmental Panel on Climate Change proposes a challenging but realistic course of action that would result in a global mean temperature rise of 2.5–3.5°C.[26] Under this scenario, global emissions would peak at around 40 giga-tonnes (Gt) of CO_2 per year in 2030, drop below 1990 levels by 2075 and eventually stabilize by 2200 at less than 7.3 giga-tonnes (Gt) of CO_2 per year, which is roughly 20 percent of today’s global emissions.

Comparing the WRE 550 scenario with global emission projections according to the “business as usual” scenario, and based on historical rates of emission increase, achieving the 2050 emission target of 36 Gt per year of CO_2 in 2050 would require a 50 percent reduction in global emissions.[27] If world equal-per-capita emission allocations were applied to achieve these emission targets, Canadians would have to lower their annual emissions from today’s level of 24 t of CO_2 per capita to 4 t per capita, or by approximately 80 percent.[28] By 2150, our annual emissions would need to drop to 1 t per capita — a reduction of over 95 percent from current levels.

TRANSFORMING CANADA’S ENERGY SYSTEMS

A breakdown of CO_2 emissions according to the sectors in the Canadian economy is shown in Figure 3. To make significant reductions, we must reduce the burning of fossil fuels.

To do so, a radical redesign of our energy systems is required to convert current GHG-emitting energy sources to alternative sources that are effectively carbon-neutral. The Hydrogen Strategic Plan Working Group (see page 27) proposes that energy systems using electricity and hydrogen as energy carriers offer an answer to this challenge, and that Canada is well positioned to develop hydrogen systems as a strategic initiative to reduce GHG emissions.

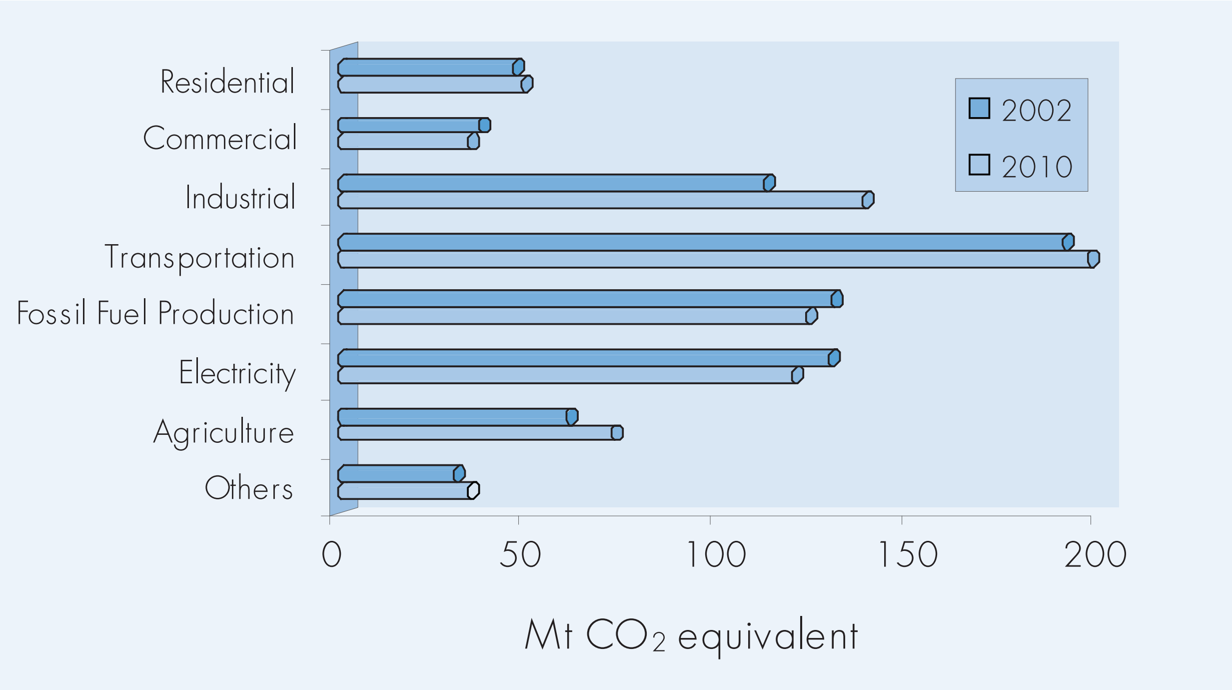


Figure 3 CO_2 emissions in Canada by sector[29]

Advantages of hydrogen systems

The development of hydrogen systems provides a solution that meets three of the key challenges for the future sustainability of our energy systems:

1. Hydrogen has a diverse resource base

Hydrogen can be produced from a wide range of energy resources, including fossil fuels, nuclear power, solar power, tidal power, wind power, hydro power and biomass. Adopting hydrogen will diversify our energy resource base and reduce our demand on oil resources, especially for transportation applications.

2. Hydrogen significantly reduces harmful emissions

Using hydrogen as an energy carrier can significantly reduce the amount of CO_2 and other GHGs that our energy systems release into the environment. The emissions produced from hydrogen in the energy system chain depend on how the hydrogen is produced and delivered, and on how efficiently it functions at the point of use. With hydrogen, the emissions at the point-of-use stage are zero (when used in fuel cells) or near zero (when used in combustion systems with appropriate emission controls).[30] The total life-cycle (well to wheels) emissions of a hydrogen energy system therefore depend primarily on the energy source used to produce the hydrogen.

For example, producing hydrogen via water electrolysis using electricity from renewable energy sources achieves a 90 percent or greater reduction in CO_2 emissions compared to fuel cycle emissions from conventional energy carriers. Producing hydrogen from fossil fuels and natural gas generates CO_2, but the CO_2 can be captured and sequestered before it is released into the environment, which can result in emissions reductions of up to 90 percent.[31]

3. Hydrogen is interchangeable with electricity

From a practical standpoint, one of the chief advantages of hydrogen is that it can be readily converted into electricity, and vice versa. This means that an energy system based on both hydrogen and electricity can be extremely adaptable. For example, while electricity cannot be stored in widely useful ways or in substantial amounts, the energy it contains can be converted into hydrogen, which *is* storable. Reversing the process, stored hydrogen can be changed into electricity as and where it is needed. Although round-trip efficiencies are lower than conventional electricity storage systems in stationary applications, hydrogen is both a clean energy carrier suitable for fueling automobiles, and a competitive alternative to the electric storage battery in portable power applications.

DEVELOPING HYDROGEN PRODUCTION

The basis for a successful hydrogen strategy is a comprehensive infrastructure plan that addresses energy source issues. In the short to medium term, we need energy sources that use fossil fuels in conjunction with efficient CO_2 sequestration, or sources that are carbon-free.

In the long term, the development of hydrogen-electricity utilities will likely integrate hydrogen production and electricity generation to achieve emission reductions. While there is risk involved in building infrastructure before achieving widespread commercialization of hydrogen energy technologies, this risk can be reduced by building the infrastructure around existing industrial applications or by using small, on-site production systems.

Developing hydrogen production around Canadian energy resources

The challenge for hydrogen in an energy service market is to produce and make available small quantities of hydrogen (relative to industrial standards) to many customers across a large geographical area. One approach is to evolve a production/distribution strategy by mapping the distribution of energy sources across Canada (see Figures 4 and 5).

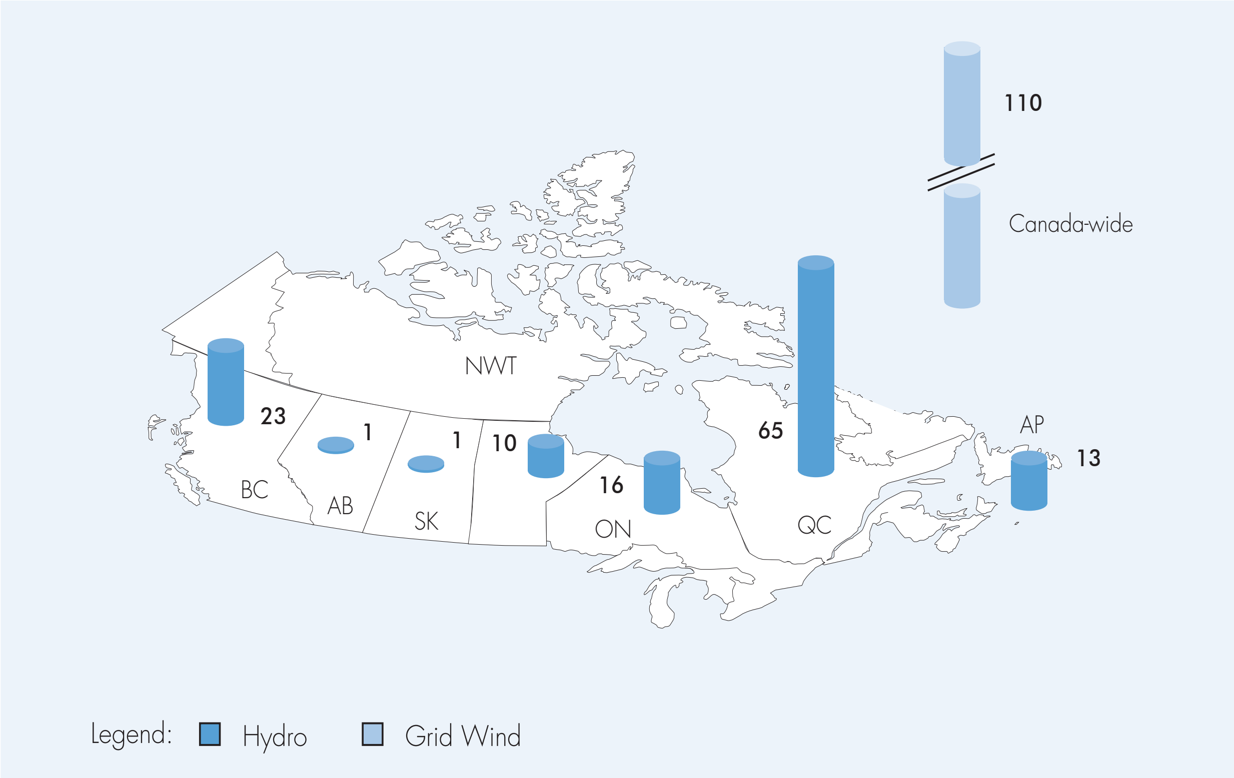


Figure 4 Canadian renewable energy resources in exa-joules (integrated over 100 years to provide a comparison with non-renewable energy resources)[32]

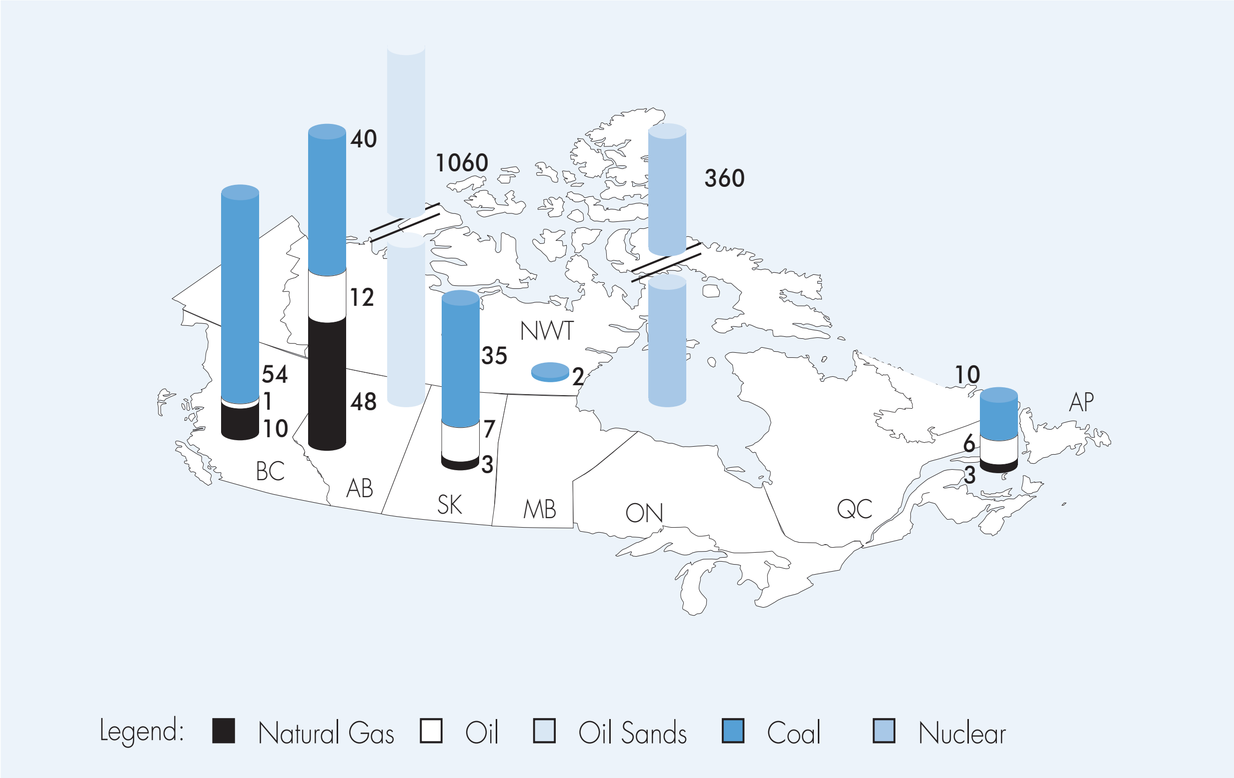


Figure 5 Canadian fossil and nuclear energy resources in exa-joules[33]

For example, hydrogen production from fossil resources could be developed in Western Canada and the Atlantic provinces. Using nuclear energy for water electrolysis is most suitable where there is operating experience with nuclear plants, as in Ontario and New Brunswick. Hydroelectric power, along with other renewable energy resources, could be exploited in Québec, Manitoba and on both coasts. Wind energy would favour grids with hydro storage and control capabilities, as in Québec and Manitoba. The use of biomass could play a role in all provinces. Such a hydrogen infrastructure may eventually evolve to handle volumes of hydrogen so large that bulk transmission by pipeline between regions would become economically feasible.

Hydrogen from surplus production

A preliminary analysis indicates that 200,000 t of hydrogen are burned or vented in Canada every year.[34] This surplus hydrogen could provide a low-cost supply suitable for component and system testing, or it could be used to generate electricity for either the hydrogen producer or the grid.

1-Mt analysis for surplus hydrogen

One Mt of CO_2 could be avoided annually by using surplus hydrogen to displace 83,200 t of SMR hydrogen production (based on an SMR emission rate of 12 t of CO_2 per t of hydrogen produced). Using the same amount of hydrogen as a fuel would provide an approximate reduction of 0.86 Mt of CO_2 based on the equivalent energy of hydrogen and gasoline (see “How much energy is there in 1 kg of hydrogen?” on page 22). This emission reduction could possibly double to 1.7 Mt based on the higher efficiency of hydrogen FCVs.

Hydrogen from clean electricity grids

In the near term and continuing into the long term, provinces that currently derive most of their power from hydroelectric sources could produce clean hydrogen through grid-connected electrolysis. Manitoba, Québec, Newfoundland and British Columbia fall into this category. Hydrogen produced by electrolysis could be used as a chemical feedstock and as a fuel for vehicles and portable power applications.

Hydrogen production for use as a transportation fuel would represent a major new load on the electricity system, which could help finance the expansion of clean electricity generating capacity. Because of the energy storage capability of hydrogen systems, hydrogen production could provide energy management services in the form of load levelling for grids to allow high penetration of intermittent or base-loaded generators.

Hydrogen produced and consumed through reversible electro-chemical devices could play a useful role in backup power applications and in ancillary services that would help balance the system. These hydrogen subsystems could also be integrated with fuel production for vehicles.

1-Mt analysis for clean electricity grids

Based on an average grid emission intensity of 0.05 t of CO_2 per MWh[35] and an electricity-to-hydrogen conversion rate of 55 kWh per kg of hydrogen, the emission rate for grid electrolysis is approximately 2.75 kg of CO_2 per kg of hydrogen. A reduction of 1 Mt of CO_2 could be achieved through the production of 131,000 t of electrolytic hydrogen, replacing 520,000,000 litres of gasoline on an energy basis.

Hydrogen FCVs could potentially double this reduction to 2 Mt. At an electrolysis conversion rate of 55 kWh per kg, producing this amount of hydrogen would require 7,200 GWh of electricity. The amount of hydrogen produced would be sufficient to fuel approximately 655,000 vehicles, based on an annual fuel consumption of 200 kg of hydrogen per vehicle. The amount of electricity required is about 1 percent of Canada’s total power generation during 2004, which was approximately 568 billion kWh.[36]

Hydrogen from nuclear energy

In the medium and long term, nuclear energy could play a major role in developing Canada's hydrogen infrastructure. Because of the AECL Advanced CANDU Reactor (ACR), Canada holds a strong position if a near-term expansion of nuclear power in North America occurs. Preliminary cost analyses of hydrogen production based on nuclear power with distributed electrolysis show that this method could be competitive with centralized SMR.[37] Off-peak nuclear energy could be dedicated to producing hydrogen at the reactor for use as a chemical feedstock or for large transportation systems such as railways. Liquefaction might be needed to deliver hydrogen to such markets.

1-Mt analysis for nuclear electrolysis

Based on an average CO_2 emission intensity of 0.015 t per MWh[38] and an electricity-to-hydrogen conversion rate of 55 kWh per kg, the emission rate for nuclear electrolysis would be 0.83 kg of CO_2 per kg of hydrogen. A 1-Mt CO_2 reduction could be achieved through the production of 104,000 t of electrolytic hydrogen, replacing 424,000,000 litres of gasoline on an energy basis.

This CO_2 reduction could potentially double to 2 Mt with the use of hydrogen FCVs, as compared to today's gasoline ICE vehicles. At an electrolysis conversion rate of 55 kWh per kg, producing this amount of hydrogen would require 5,700 GWh of off-peak electricity.

Hydrogen from renewable electric power

In the near term, renewable forms of electric power generation will be coming on stream; these can be used to generate hydrogen with almost zero GHG emissions. Other than large-scale hydroelectric facilities, wind offers the lowest-cost renewable energy and is particularly attractive because it has the shortest lead-time for construction and the least environmental impact. This abundant resource could play a major role in developing a hydrogen infrastructure. Water electrolysis from off-peak, wind-energy production is the ideal "dump load" that would allow more predictable dispatching of the generated energy.[39]

In the medium and long term, Canada's renewable energy resources will play a much larger role in the country's energy supply, and this will require major infrastructure developments. In the case of intermittent resources, such as wind and tidal energy, power must be gathered when it is available. Frequently, though, supply is out of phase with demand, so supply and demand management is required to balance the two. Large-scale energy storage can help in this regard; however, optimizing the power grid to cope with such issues requires real-time measurement and control of complex systems, and the capability to do this needs to be developed.

Hydrogen production from fossil fuels

In the near and medium term, the oil- and gas-producing regions of Alberta, British Columbia and Saskatchewan offer the opportunity of increasing demand for hydrogen production. On a per-capita basis, the oil and gas industries in these provinces are among the largest hydrogen producers in the world, generating 1.5 Mt annually. This is enough hydrogen to support 7,500,000 vehicles, based on an annual average fuel consumption of 200 kg per vehicle. Moreover, depending on whether oil upgrading is done by hydrogen addition or carbon rejection,[40] the existing hydrogen infrastructure could easily triple in size to meet the demands of the oil sands during the next two decades.

Offsets to CO_2 emissions in this sector can be achieved by the following actions:

- improving the recovery and efficiency of existing hydrogen production systems;
- capturing and sequestering the CO_2 emitted by hydrogen production from fossil fuels; and
- migrating towards new hydrogen production processes that incorporate carbon sequestration or avoid net GHG emissions, such as water electrolysis using clean electricity sources.

In the medium and long term, because of the rising cost of natural gas due to depletion of North American natural gas reserves, hydrogen production processes may move away from SMR to oxygen-assisted or other gasification of coal, heavy oil or bitumen. This produces even more CO_2 per unit of hydrogen; however, like SMR, the CO_2 is fairly pure.

CO_2 sequestration

There is good evidence that most of the CO_2 from fossil fuel-based, large-scale hydrogen production can be captured and separated for sequestering.

There are three basic options for sequestering CO_2:

- underground storage in gas-tight natural reservoirs;
- deep-sea injection; and
- chemical reduction to solid carbon and carbon compounds.

Depleted oil and gas reservoirs and coal beds have the highest near-term potential for storing CO_2. They also offer a potential economic return through enhanced production of oil, natural gas and coal-bed methane. Deep-sea injection and chemical reduction are currently unavailable pending field testing to ensure minimal venting to the atmosphere and assessment of CO_2 injection on deep-sea chemistry.

Potential CO_2 sequestration sites in Canada generally lie near oil and gas deposits. Fossil fuels processed near the point of extraction present an opportunity for low-cost sequestration. Deep saline aquifers are also potential CO_2 sinks and can be found in many locations.

Preliminary analysis estimates the sequestration storage capacity of the Western Sedimentary Basin to be 36,000 Mt of CO_2.[41] At a sequestration rate of 100 Mt per year (appropriate for near-complete substitution of hydrogen for gasoline in the transport sector), this storage capacity is sufficient for 360 years. SMR hydrogen plants in Western Canada are good candidates for CO_2 sequestration because they are located near these sequestration sites, and because of the purity of the CO_2 they emit.

The cost of CO_2 sequestration depends on many factors, including the purity of the CO_2 and the quality of the site. For the oil sands, this cost has been estimated at CAN$75 per t of CO_2 (adding about CAN$0.90 per kg to hydrogen production costs).[42] The cost may be less where sequestration can be used in enhanced oil recovery or in coal-bed methane extraction.

The development of more efficient gas separation processes, which optimize hydrogen recovery as well as hydrogen quality and CO_2 concentration, will be a key to making CO_2 sequestration practical.

1-Mt analysis for hydrogen production for heavy oil upgrading

Production of hydrogen for heavy oil upgrading in Alberta is expected to increase from 0.92 to 2.92 Mt per year[43] during the near to medium term, creating an opportunity to build an infrastructure that would reduce emissions and supply hydrogen for local vehicles. Assuming that 2 Mt per year of new hydrogen production is supplied by SMR, and assuming an emission rate of 12 t of CO_2 per t of hydrogen produced, 1 Mt of CO_2 emissions could be avoided by:

- achieving a 4.1 percent improvement in hydrogen recovery or in the energy efficiency of the hydrogen production process;
- capturing and sequestering 4.1 percent of CO_2 emissions; and
- shifting 4.3 percent of the current hydrogen production through SMR (89,000 t per year) to production via electrolysis from a captive clean-electricity generator, such as nuclear power (assuming an emission rate of 0.015 t per MWh).

Hydrogen production from biomass and waste streams

Biomass, in the form of agricultural and wood wastes or purpose-grown crops, could be a feedstock for many hydrogen production processes, including gasification, pyrolysis, bio-oil reforming, iron-steam hydrogen production and biological processes such as fermentation.

The amount of potential biomass in Canada has been estimated to be equivalent to 18–27 percent of oil production,[44] including 92 Mt of wood waste. Even today, biomass is estimated to fuel about 1,900 MW of electricity generation.[45]

The underlying issue in a biomass hydrogen strategy is whether a compelling case can be made for producing hydrogen from this resource, versus using the resource directly. The potential CO_2 reductions from producing hydrogen and sequestering CO_2, combined with the potential higher efficiency of hydrogen systems, need to be weighed against the increased cost of hydrogen production, purification and gas handling, and the collateral CO_2 emissions associated with the energy needed to transport feedstock and to dispose of CO_2.

DEVELOPING HYDROGEN DELIVERY AND STORAGE

Developing a secure delivery and storage infrastructure in Canada is crucial as we move towards the hydrogen future. Several options exist for hydrogen delivery and storage methods. However, near-term actions to develop these systems will be determined by opportunities in the existing infrastructure, where hydrogen can be obtained cheaply from common processes and where there are production surpluses.

Delivery options

Hydrogen could be delivered to the market through several channels. In addition to fleet fuelling, for which a dedicated fuelling station could be built at the vehicle terminal, hydrogen could be sold through retail outlets. Because real estate is a major cost in fuel distribution, existing fuel outlets are an obvious choice for this approach. However, since hydrogen can be produced on-site, thereby avoiding the hazards and complications of large-scale fuel storage, other retail channels might be used.

Storage options

Perhaps the biggest challenge to be faced in hydrogen transportation applications is on-board hydrogen storage. To achieve the range of current gasoline ICE vehicles — about 480 km on a full tank — hydrogen vehicles demand storage capabilities that exceed the available technologies.[46] In the near term, current vehicle range expectations could only be met in platforms such as buses and delivery vehicles that can accommodate gaseous hydrogen storage. Discovery of new storage media would be valuable, although much effort has so far produced no real breakthrough.

Alternatively, passenger vehicle platforms could be redesigned to accommodate compressed hydrogen storage or liquid hydrogen systems. Greater fuel efficiency, fuel cell hybrids, new fuelling methods and even different vehicle expectations (“city cars”, for example) may reduce the need for large amounts of on-board hydrogen storage.

Among the storage options is compressed gas at up to 700 bar (10,000 psi). Improvements in hydrides and engineered nanostructures may be possible, which would provide competitive, low-pressure, on-board storage at ambient temperatures. Large-scale static storage, though, will continue to use liquid or high-pressure gas and, in the future, possibly metal and chemical hydrides.

In the medium to long term, depending on distance and economics, hydrogen will be “moved” by wire (as electricity) or by pipeline. Other future storage and distribution possibilities are:

- improved liquefaction processes and cryogenic containment systems to allow on-board, liquid hydrogen storage and thermal energy recovery; and
- new adsorbent media that can compete with compressed gas and/or liquid storage, capable of about 6 percent hydrogen storage by weight or better.

DEVELOPING HYDROGEN TECHNOLOGIES

Because the sector with the largest potential impact for reducing GHG emissions is transportation, most effort to date has concentrated on the development of transportation systems. Other end-use applications include stationary power, chemical feedstocks and niche applications such as forklifts and portable micro fuel cells. The applications that will lead the commercialization process will need to deliver a high value proposition and thus support a higher cost to end-users.

Transportation

Hydrogen could be the key to reducing both global CO_2 emissions and criteria pollutants in transportation systems. Only hydrogen and electric storage batteries are able to power vehicles and other transportation systems with zero tailpipe emissions. Widespread adoption of hydrogen vehicles will encourage the growth of Canada's hydrogen infrastructure and create opportunities for product innovation, for further industrial uses of hydrogen and for an increasing range of energy services.

The transition to hydrogen vehicles

The duration of the transition period to hydrogen vehicles will be affected by improvements in incumbent technologies. Examples are improving fuel economy with battery-hybrid technologies or using other fuel solutions such as bio-fuels, which will raise the bar for market entry of hydrogen technologies. If hydrogen vehicles are to realize significant CO_2 reductions by the time they are commercialized, then new, lower-emission hydrogen supply systems will be required.

In the medium term, the global penetration of hydrogen vehicles is expected to grow rapidly, pulling the hydrogen supply infrastructure along with it. The U.S. Department of Energy Posture Plan, for example, projects that the market share of hydrogen-powered new cars will grow from 4 percent in 2018 to 78 percent in 2030.[47] As the availability of hydrogen grows, other applications such as rail links, jet aircraft and marine power systems will convert as well. This rapidly expanding hydrogen infrastructure will bring new hydrogen producers and new distribution channels to the market.

In the long term, some experts believe that transportation will converge with stationary power generation, allowing FCVs to become electric power sources contributing to the electricity grid when not in use for transportation.[48]

Hydrogen ICE vehicles

Hydrogen ICEs, hydrogen ICE hybrids and the use of blended fuels, such as hydrogen with natural gas and hydrogen with diesel,[49] could be demonstrated and commercialized in the near term. These technologies can offer near-term GHG reductions, improve efficiency and provide load for existing hydrogen infrastructure, making them good transition technologies. Hydrogen ICEs will face challenges, however, from technologies such as diesel hybrids, gasoline hybrids and bio-fuels, and will need to compete on the basis of energy efficiency, emission levels, cost, refuelling availability and vehicle range.

In the near term, while the development and demonstration of FCVs continues, hydrogen ICEs could be commercialized for applications such as transit buses. The efficiency and cost of an optimized, high-compression hydrogen ICE could approach that of a diesel vehicle if current U.S. Department of Energy targets of 45 percent peak efficiency at a cost of US$30 per peak kW are met.[50] Powering a hybrid platform, the fuel efficiency of the high-compression hydrogen ICE hybrid could approach that of the diesel hybrid. Emissions from a hydrogen ICE, although not zero, are very low, with a greater than 99 percent reduction in CO_2 compared to fossil fuels.

If the hydrogen ICE is brought to market in the near term, the number of hydrogen vehicles in operation could soon reach the tens of thousands.[51] Penetration will likely be led by fleet vehicles such as transit buses, courier, delivery and light-duty utility vehicles that refuel at a home base.

Fuel cell vehicles

Although hydrogen ICE and hybrid technologies may play a commercial role in the near term, most automotive manufacturers believe that hydrogen FCVs are the long-term solution. If world development targets are met, FCVs are expected to be commercially ready in the time frame of 2015–2020. Some manufacturers, notably in the Japanese market, have projected a rollout of tens of thousands of vehicles by 2010.[52]

In the near term, fuel cells could be used in off-road vehicles and "light mobility products." These products could be brought into the marketplace as leading-edge FCVs.[53]

Comparison of fuel and power system emissions and fuel consumption

The following table shows the GHG emissions and fuel consumption for several pathways/vehicles over a standard driving cycle.[54] The emissions are calculated on a life-cycle basis and can be compared in the context of fuel consumption and the energy content in fuel as shown below. FCVs are projected to be twice as efficient as gasoline ICEs, based on the higher heating value of the fuel. When hydrogen ICE hybrids are compared to gasoline hybrids, the efficiency is almost the same, and with the development of high-compression hydrogen ICEs, the gap in efficiency between hydrogen ICE hybrids and FCVs would be significantly reduced.

Fuel and power system	**GHG emissions** (g CO_2eq/km)	**Fuel consumption** (L or kg of H_2/100 km)
H_2 FCV *	51.1	1.15 kg
H_2 ICE-electric hybrid *	52.8	1.69 kg
SMR H_2 FCV **	177.3	1.15 kg
Diesel-electric hybrid	187.0	4.79 L
Gasoline ICE-electric hybrid ***	227.1	6.72 L
Gasoline ICE ***	327.1	10.30 L

* Hydrogen produced by water electrolysis with 50% nuclear and 50% hydropower

** Hydrogen produced locally at gas station by SMR of natural gas

*** Using reformulated gasoline with sulphur content 30 ppm

How much energy is there in 1 kg of hydrogen?

Comparing the energy content of hydrogen with conventional fuels, on a higher heating-value basis:[55]

- 1 kg of hydrogen ≈ 4.08 L of gasoline ≈ 3.74 Nm^3 (normal cubic metres) of natural gas

The emissions produced by the combustion of conventional fuels, including emissions from production, are:[56]

- 4.08 L of gasoline produces ≈ 10.4 kg of CO_2
- 3.74 Nm^3 of natural gas produces ≈ 8.1 kg of CO_2

Stationary power

Applications for direct, stationary hydrogen power could include “energy stations” that combine distributed electricity generation and fuelling. In the near term, these stations could use hydrogen ICEs or fuel cells to serve in backup power applications.[57] Another potentially large application for such stationary power systems could be the conversion of surplus hydrogen that is currently vented or flared, into electricity, provided the cost of the conversion systems becomes affordable.

In the medium term, when fuel cells achieve utility standards for operating life, the energy stations could serve as primary power generators using natural gas and carbon management, along with added hydrogen production for fuelling vehicles and other applications. Remote, off-grid population centres could integrate renewable electrical energy generation and hydrogen storage to convert an intermittent, primary-power source to a continuous supply of energy.

Chemical feedstocks

Low-emission, hydrogen-based infrastructures using SMR with carbon sequestration, or electrolysis from low-emission and low-cost power, could supply hydrogen to established industrial applications such as ammonia and hydrogen peroxide manufacture. Ammonia production, for example, absorbs approximately 30 percent of Canada's hydrogen output, or about 900,000 t per year of SMR hydrogen production.[58] Such infrastructures could also support new hydrogen applications, such as methanol synthesis from CO_2 streams[59] and the direct reduction of metals.[60]

Niche applications

By encouraging the early commercialization of technologies, niche applications could play a strategic role in developing hydrogen infrastructures and energy systems. Examples of niche applications are forklifts and off-road vehicles. Although these will not significantly reduce global CO_2 emissions, they can help create a market for products and assist in prototyping new technologies in controlled environments. Niche applications could also encourage a volume of fuel cell manufacturing that would reduce product costs.

Portable micro fuel cells and hydrogen-based backup power systems will also promote the use of hydrogen and help create new stakeholders in the hydrogen economy.

DEVELOPING HYDROGEN MARKETS AND COMMERCIALIZATION

Recognizing the value of hydrogen systems by giving tangible credit to low-GHG energy systems will create an economic model that will accelerate adoption of these systems. But creating market demand depends on the availability of proven, reliable, hydrogen-based products. Environmental imperatives may ultimately demand a switch to hydrogen and low-carbon or carbon-neutral alternatives, but the emergence of hydrogen systems will occur sooner and more easily if its capabilities — measured in economics, convenience and performance — equal or exceed those of competing technologies. Fiscal incentives, a solid energy market design, international collaboration and a healthy public image are all central to a strong commercialization strategy.

Incentives for adopting hydrogen technologies

In the near term, the value proposition for hydrogen could also be reinforced by fiscal policies that provide incentives for adopting new technologies. Building clean-hydrogen infrastructures could be seen as a strategic policy objective by the government, and industrial hydrogen systems could be targeted to reduce CO_2 emissions.

In the medium term, incentives and energy taxes should consider the cost of CO_2 reduction in other parts of the economy. There could also be a move towards the full-cost accounting based on CO_2 capture and sequestration for particular applications, which will encourage conversion to cleaner alternatives such as hydrogen.

In the long term, regulations restricting or attaching a price on CO_2 emissions could be used to guide the market to the desired low-emission outcome.[61]

Energy market design

Because hydrogen is a new energy carrier, the market will need time to adjust to its characteristics and maximize market efficiency. In the long term, hydrogen-electricity utilities are likely to evolve to convert primary energy into both hydrogen and electricity, and will use the storage capability of hydrogen to complement the transient nature of electricity. A hydrogen infrastructure will encourage independent producers, new distribution channels and new ways of providing power to the grid.

Market challenges for hydrogen

Hydrogen is an established industrial commodity. However, the market for hydrogen and hydrogen systems faces substantial cost, technology and image barriers that it must overcome before hydrogen can be used as a common energy carrier.

- Hydrogen will have to compete with the relatively low cost of fossil fuels and their easy availability through an established, familiar infrastructure. Studies estimate that hydrogen delivered to the vehicle could cost CAN$3 to CAN$5 per kg, which is about two to three times the historical wholesale cost of gasoline on an energy-equivalent basis (CAN$0.40 per litre).[62] GHG emission benefits will help hydrogen compete, but at present these benefits are not given sufficient monetary value to allow economics to drive wide-scale adoption of hydrogen as an energy carrier. In the long term, more efficient hydrogen systems and increased fuel prices are expected to close this gap.
- Hydrogen energy service technologies are still in the early stages of development. Canada needs low-cost, emission-free hydrogen production and delivery systems. We are depleting our domestic fossil fuel reserves, and we urgently need to look beyond SMR and other conventional production methods.
- Hydrogen is viewed as an industrial commodity and there is little demand for it in non-industrial sectors. Consequently, no infrastructure has been built to make it easily available on a broad scale. Both this infrastructure and a market will have to be developed if hydrogen use is to become widespread.

Export potential and international collaboration

Hydrogen and fuel cell technologies will be commercialized in markets where they have the strongest business case. Because of Canada's relatively low consumer energy prices and well-entrenched fuelling infrastructure, the commercialization of applications is likely to occur in foreign markets first. In some of these foreign markets, government tax policies place a high surcharge on oil-based products and provide incentives to promote alternatives to oil, which will help create an export market for Canadian hydrogen technologies.

Hydrogen fuel cells could have a huge impact in developing economies, such as those of China and India, by improving efficiency, cutting energy consumption, reducing oil imports and improving air quality. The Asian region, which is experiencing a phenomenal growth in energy services, provides a possible opportunity to leapfrog conventional technologies, much as the cell phone did to telecommunications in these markets.

In the near term, Canadian hydrogen technologies could build on the existing infrastructure for natural gas vehicles to produce blended fuels such as Hythane®. Regions such as Latin America and Asia, where there is a growing market for natural gas vehicles, present opportunities in this respect.[63]

Improving public awareness

The Canadian public needs to be made more aware and informed about current levels of CO_2 emissions and the future implications. Doing so will require more and better education about energy and the costs of adaptation to climate change. Education will also help alleviate the public's misunderstandings about hydrogen safety and the risks of hydrogen commercialization. Wider public recognition of the issues will promote energy efficiency and encourage the development of environmentally unobtrusive energy sources.

Large-scale demonstration projects, such as those planned for the Hydrogen Highway™ and the Hydrogen Village™, will help bring hydrogen into public use, expand the base of stakeholders, dispel the myths about hydrogen and prepare consumers for the adoption of hydrogen technologies. In regions of high population density, these demonstrations can grow into economic market corridors such as the proposed corridor from Vancouver to California.

FOUR-STEP ACTION PLAN TO REALIZE THE CANADIAN HYDROGEN OPPORTUNITY

The timing of the transition to the Hydrogen Age will depend on market conditions, the rate of technological development and consumer acceptance. The transition will take decades, which means that if we expect hydrogen to play a significant role on a global scale by 2050, we must act now.

The following four steps will help position Canada as a leader of the Hydrogen Age and the global shift to sustainable energy systems.

1. SET A NATIONAL STRATEGY

Canada urgently needs an integrated national energy and climate change strategy, both because of the magnitude of the changes needed and because the increasing costs of adaptation to climate change may limit our ability to act in the future.

What the strategy would include

The national strategy would address the environment, energy supply and economy, and set the direction for Canada's future energy systems. In defining near- to medium-term goals, the Hydrogen Strategic Plan Working Group's mission to "no longer expand the use of fossil fuels for Canadian energy services after 2025" establishes a tangible objective and sets the time frame in which changes should occur.

The strategy would also include a framework for CO_2 emissions mitigation measures, including an economic framework for the cost of GHG emissions. To accelerate the market for new, clean-energy technologies, fiscal incentives based on the current cost of managing CO_2 in fossil-based energy systems would be established. These incentives should be in line with actions already being developed by groups such as the Large Final Emitters Group[64] and the National Round Table on the Environment and Economy.[65]

Creating the strategy

A task force, led at the federal government level and including representatives from provincial energy ministries, the energy industry, academia and NGOs, would develop the national strategy. Government action to create the national strategy would also reflect the commitment of an informed majority of Canadians.

Achieving the objectives of the strategy

To achieve the objectives of the strategy, governments, energy system stakeholders and energy users will all have to make commitments to move towards hydrogen systems. The governments responsible for our energy systems need to work with the energy industry to ensure that the transitions occur. Canadians need clear guidance on the implications of climate change, the future costs of adaptation and the need to change our energy future to meet long-term climate change objectives.

2. CREATE STAKEHOLDERS IN A HYDROGEN FUTURE

Industry needs to build up the stakeholder base for hydrogen systems before we can realize the hydrogen opportunity in Canada. In the near term, this should focus on bringing the energy industry as a whole to this conclusion.

Key stakeholders in a hydrogen future

The oil and gas industry is an important group of potential stakeholders because these companies are involved in the development of the oil sands. The creation of a hydrogen infrastructure for further expansion of the oil sands presents a tremendous near- and mid-term opportunity for reducing GHG emissions in the oil upgrading process, while positioning the oil sands as a future source of hydrogen.

The electrical utilities compose a second group of stakeholders, some of which are already developing hydrogen systems. To reduce emissions will require them to choose among power sources such as nuclear plants, renewable energy including biomass, and fossil sources with carbon sequestration. These choices will depend partly on available local resources, and will create regionally distinct energy systems that will be well developed before hydrogen infrastructures are widely established. Planning is therefore required for the long-term development of hydrogen infrastructure and production and its smooth integration into energy market design.

Gaining the support of stakeholders

A strong and convincing case for a hydrogen future needs to be made to stakeholders in the current energy system. This group needs to assess the critical need and the potential impact that hydrogen could have in lowering emissions across the entire energy system, including oil production in the near term and transportation and electricity generation in the long term.

Carrying out a competitive analysis of Canadian hydrogen deployment strategies would establish a starting point for future development priorities and establish targets and metrics for commercialization. This analysis should assess the competitive position of hydrogen versus other GHG-mitigation measures in the energy supply chain. Assessing hydrogen's position can also provide a benchmark for Canadian hydrogen systems relative to those of other countries and gauge the competitiveness of various strategies.

The energy industry should also develop pathway analyses that examine the transformation of the current energy system into a system that uses hydrogen as a primary energy carrier for transportation and portable applications. This information would feed into the analysis of Canadian hydrogen deployment strategies.

To ensure progress, the hydrogen and fuel cell industry, together with a broader group including stakeholders in the energy industry, should function as a single voice and take responsibility for the Action Plan. This voice should represent industry, government and academics, and work jointly with existing initiatives such as those led by the Energy Dialogue Group and the Council of Energy Ministers.[66]

3. ESTABLISH A HYDROGEN ENERGY SYSTEM AS A STRATEGIC LONG-TERM OBJECTIVE

The strategic role that hydrogen can play in Canada's energy future needs to be explored. The development and realization of the potential of hydrogen systems should become a high-priority, long-term strategic policy objective.

Increase funding of hydrogen systems technologies

Public and private funding of basic technology developments in industry and universities should be increased. The funding should target key areas such as PEM fuel cell materials and components, carbon sequestration, hydrogen storage and safety. This could be done through a national system of research centres in universities and through government and industry development projects, as well as through international efforts to ensure that Canadian academia, industry and stakeholders have access to the best available technology. A system of peer review should be established to ensure that the program is effective.

Create a technology plan

The government, together with the hydrogen and energy industries, should create a technology plan that establishes technical goals. These goals could be based on rationalized metrics and targets that are similar to the U.S. Department of Energy's hydrogen program[67] and the U.K.'s Energy White Paper.[68] Wherever possible, the Government of Canada should enter into bilateral and multilateral agreements that will leverage Canadian expertise and investments to overcome the remaining technology barriers. Both the International Partnership for the Hydrogen Economy and the International Energy Agency offer formal mechanisms by which nations can discuss and conclude such agreements.

Develop a national hydrogen research network

Models such as the Knowledge Networks proposed in the British Columbia Hydrogen and Fuel Cells Strategy[69] could provide a model for a national network on hydrogen research, which would build awareness and interest in the academic community. The Canadian Hydrogen Association, through its technical meetings, has already played a leading role in providing this forum and could provide a starting point for organizing such a network.

The current mode of industry/university/government collaborative research should also be reviewed to ensure that it is effective in transferring technology to Canadian industry and in benefiting the Canadian economy.

Develop educational and training programs

Shaping a cultural shift towards sustainable development also requires educational initiatives at every level of learning. Government and industry should work together to develop course materials, programs and curricula that will give Canadians the workforce skills and innovation that we will need to be a leader in the Hydrogen Age.

4. DEVELOP A PLAN FOR NEAR-TERM COMMERCIALIZATION OF HYDROGEN SYSTEMS

Commercializing hydrogen technologies in the near term requires a comprehensive plan and focused product development that will close technology gaps. Industry, supported by government agencies, should develop a plan that deals with core technology issues related to achieving cost and performance targets. Furthermore, work on national regulations and international codes and standards should continue, both to speed up their implementation and to encourage wide acceptance of new hydrogen technologies within the global marketplace.

What the plan would include

To increase the market pull for hydrogen systems and gain consumer support, the plan would position hydrogen in the mainstream of sustainable energy options, along with energy efficiency and renewable energy initiatives. The national mission to “no longer expand the use of fossil fuels for Canadian energy services after 2025” is a goal that could be shared among all three of these initiatives.

The plan would also analyze the benefits of early adoption of near-term hydrogen energy service technologies and the development of low-GHG hydrogen infrastructures in industrial markets — in the oil sands in particular — to determine how Canada could reduce GHG emissions by 1-Mt per year by 2012. The entry of new businesses and entrepreneurs into the sector should also be encouraged.

The plan would balance near-term commercialization with the development of long-term technologies and focus on overcoming the fundamental technical challenges we face today. Delivery systems that address consumer concerns regarding gaseous fuels also need to be addressed, and hydrogen storage targets must be reviewed to align vehicle requirements with the available storage options.

Near-term hydrogen technologies

Technologies that could be commercialized in the near term include hydrogen ICE and FCVs in fleet applications. Other possibilities are power applications, off-road vehicles and portable fuel cells in high-value niche applications.

Although fuel cells have the greatest potential to create demand for hydrogen systems and should receive the investment required for commercialization, other technologies can also play a role in developing infrastructure and energy services, and should be encouraged. These technologies include large-format, low-cost electrolysers (1 MW or larger), hydrogen production from biomass and from fossil fuels with CO_2 sequestration, gas separation and purification processes, fuelling station components, compressors, hydrogen ICEs and hydrogen storage systems.

The development and implementation of advanced hydrogen production technologies and the development of carbon capture and sequestration systems should be undertaken in the oil and gas sector. Doing so would prove these technologies for oil and gas production and create a low-emission, hydrogen production infrastructure that meets the plan’s emission target of a 1-Mt reduction in GHG emissions over the next few years.

Fleet procurement and demonstrations

In the early stages of market adoption, governments and energy companies could lead the market through fleet procurement. Such procurement would occur after a testing period, which would ensure that the technology meets the performance targets of the plan.

Demonstrations should be encouraged to promote the early adoption, testing and rapid prototyping of products in the development phase. The value of such demonstrations should be carefully weighed against the opportunity cost to core technology development and downstream commercialization. Demonstrations that have important scale and impact on high-priority markets, and that demonstrate the entire energy chain, should be undertaken and leveraged within the international frameworks of the International Partnership for the Hydrogen Economy and the International Energy Agency and through joint projects between the U.S. Department of Energy and Canada’s hydrogen programs.

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