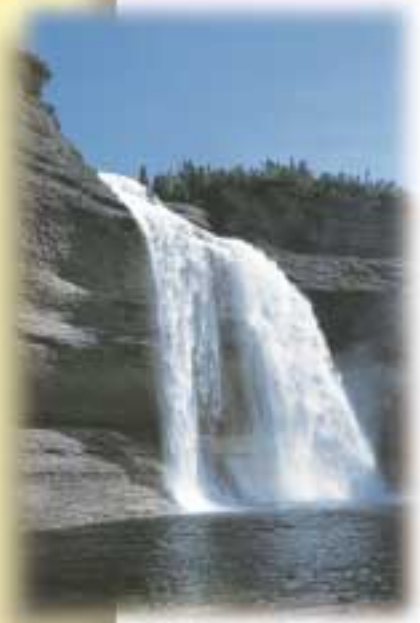
# Hydrogen

## a path for the future



Québec

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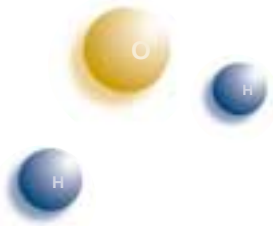



# Hydrogen, a path for the future

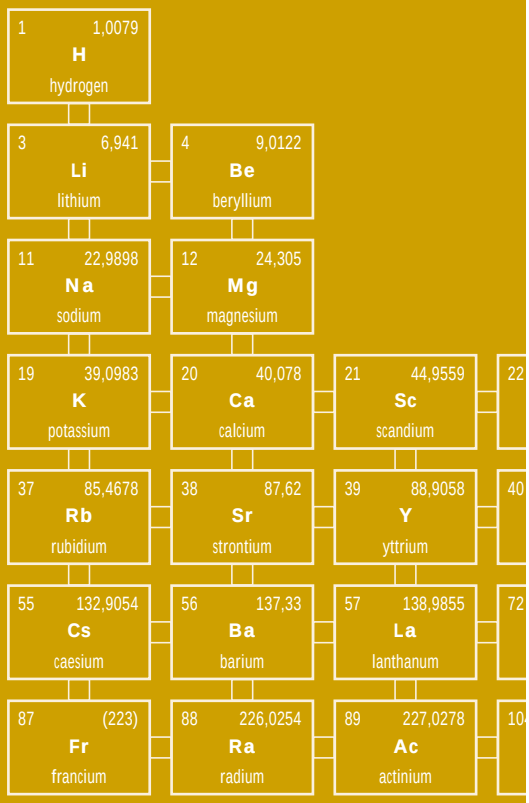
*Hydrogen is the most abundant element in the universe. It is found in very large quantities on Earth as well as in the Sun and stars.*

Used primarily to refine petroleum, produce compounds such as ammonia and peroxide, and process food products (hydrogenated oil), hydrogen is on the way to becoming a form of energy of the future, particularly with fuel cells.

Discovered in the 18th century by British chemist Henry Cavendish, hydrogen owes its name to Antoine Laurent de Lavoisier, a French chemist. Derived from the Greek words *hudôr* meaning "water" and *gennân*, "to beget", *hydrogen* means "that which produces water". Cavendish was the first to demonstrate that hydrogen and oxygen combine to form water.

# Properties

## of Hydrogen




- Hydrogen is a simple light, stable chemical which is not very reactive at room temperature.
- When mixed with oxygen to produce water, it releases a large amount of heat.
- Hydrogen is an energy vector, meaning it's a carrier as opposed to a source of energy.
- It can be produced in almost unlimited quantities from renewable sources such as hydro, solar or wind power, as well as from fossil fuels such as natural gas.
- Hydrogen is a highly volatile gas, being 14 times lighter than air; it is colorless, odorless and tasteless.

# Advantages

## of Hydrogen

- Stable, noncorrosive element.
- Efficient combustion.
- High specific energy (per unit of weight).
- Nonpolluting.

# Hydrogen Over the Years

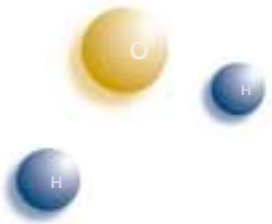
Just like natural gas, kerosene and propane, hydrogen is inflammable. It was first employed in small quantities mixed with water to fill balloons and in oxyhydrogen lamps for lighting. It was also used for heating by means of coal gas, which was made by mixing coal with 50% hydrogen and 25% methane.

Today we prefer other forms of energy and electricity is the most common source of lighting. Interest in hydrogen has revived, however, particularly in the field of transportation, because of its capacity to generate electricity in fuel cells. Furthermore, space vehicles are generally fueled by liquid hydrogen.

The chemical industry makes use of hydrogen in petroleum refineries (hydrogenation of heavy oils), and the element is still widely used on an industrial scale to produce ammonia, methanol and hydrogen peroxide, as well as in metallurgy, pharmacology, electronics, glassmaking and food processing.

*Experimental magnetic refrigeration unit*

*Diane Barry, MRN Source : IRH-UQTR*



## Did you know that

when hydrogen is made by electrolysis, about 80% of the energy used to produce it can be recovered? This percentage, however, drops to 65% if the hydrogen is liquefied?

Used in internal combustion engines, hydrogen is 25% more fuel-efficient than gasoline or diesel oil?

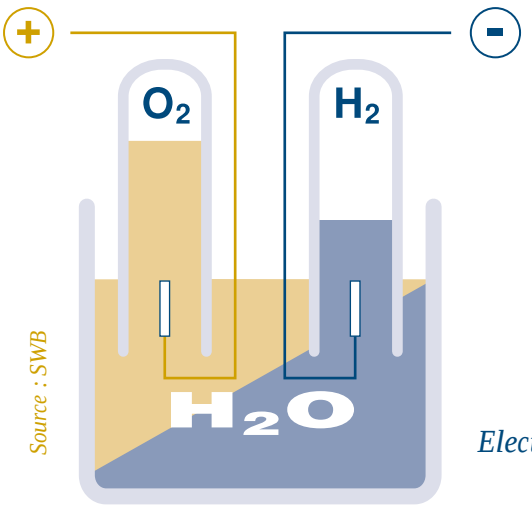
Burning hydrogen instead of gasoline is far more efficient because hydrogen burns away better amid surplus air (0.9 ratio for gasoline/air, 0.4 for hydrogen/air), and allows for higher compression rates?

# Some hydrogen, Please

Hydrogen production requires electricity or heat. This means that different sources of energy, including natural gas and any kind of fossil fuel, can be used to produce hydrogen. The most environment-friendly approach, however, is the use of clean, renewable energy. Hydrogen can be produce by hydroelectricity, wind, biomass and solar energy — renewable resources which abound in Québec.

### Hydrogen Production Methods

- **Natural gas reforming.**
  This process involves exposing natural gas to very hot steam. The result is hydrogen, carbon monoxide and carbon dioxide.
- **Electrolysis.**
  Electrical energy can break water molecules ($H_2O$) into their two components, hydrogen ($H_2$) and oxygen ($O_2$). The use of clean, renewable resources such as water, wind and sunlight to produce electricity is better for the environment.




*Source : SWB*

*Electrolyzer*

## Did you know that

Electrolysis is a better means of producing hydrogen than reforming natural gas because it's about 15% more efficient?

- **Biomass gasification.**
  Hydrogen can be made from biomass primarily through thermal gasification, a process by which organic compounds such as wood, agricultural waste and urban waste decompose mainly into hydrogen and carbon monoxide.
- **Photobiology.**
  What are known as photosynthetic microorganism or bacteria produce energy by capturing the energy of light.

*Most hydrogen is actually made from natural gas. Yet the trend is towards using clean, renewable energy to produce hydrogen through electrolysis.*

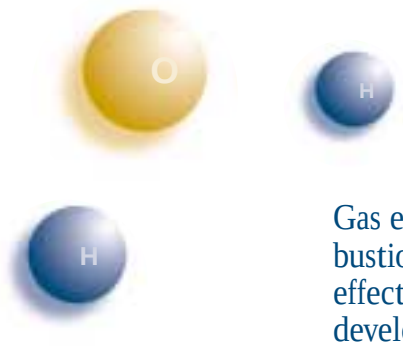
*Gaz métropolitain*

# Hydrogen and the Environment

*The growing concern for the environment and climatic change, especially in view of the commitments made following the Kyoto Conference, call for the development of clean, renewable energy sources. Hydroelectricity meets these environmental criteria in that its use helps reduce greenhouse gases.*

*The commitments made at Kyoto also favor the development of new energy technologies. Hydrogen technology ranks among the most interesting and will become increasingly important in the coming decades.*

*Vauréal Falls, Anticosti Island*



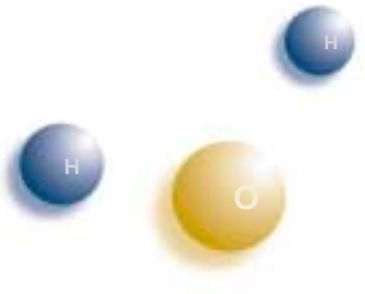

Gas emissions resulting mainly from the combustion of fossil fuels intensify the greenhouse effect. It is therefore in our best interests to develop, as soon as possible, energy systems based on clean, renewable resources, that do not pollute the atmosphere. The use of hydrogen could help us attain our environmental protection objectives because hydrogen can be made from water and burning hydrogen produces water.

The most environment-friendly means of producing hydrogen is electrolysis if the electricity comes from a renewable source (water, wind, sunlight). Hydrogen production from natural gas also has substantial environmental benefits. Hydrogen made in this way can be used in fuel cells, which are cleaner and more efficient than internal combustion engines powered by fossil fuels.

*Like electricity, hydrogen is an energy carrier. The fact that burning it essentially does not produce any pollution makes it an attractive fuel, even though hydrogen production requires an input of energy.*

## Québec Expertise

Some 15 Québec companies, research centers and organizations working with hydrogen have gained skills, developed new technologies and acquired a unique know-how. Québec achievements in this area include the design and development of electrolysis equipment, new methods of storing hydrogen, as well as responsibility for developing international safety standards through the Bureau de normalisation du Québec.




## The Euro-Québec Hydro-Hydrogen Project

The work done through a Québec-Europe cooperation project, namely the Euro-Québec Hydro-Hydrogen project, has focused mainly on the applications and uses of hydrogen. This includes:

- Demonstration of an urban bus running on hythane;
- Development and testing of an aircraft jet engine adapted to hydrogen;
- Design and development of liquid hydrogen storage tanks;
- Studies of the comparative socioenvironmental costs of using hydrogen instead of conventional fuels.

These efforts have led to the development of concepts and equipment such as:

- Hydrogen gas, hythane, and liquid hydrogen tanks for vehicles;
- Tanks for storing and transporting liquid hydrogen;
- Systems for adapting urban buses to hythane;
- Injectors for hydrogen-adapted turbine engines.

While these inventions has not yet been deployed on a commercial or industrial scale, their development is being pursued through projects at Québec companies and research centers.

*The research done by the Euro-Québec Hydro-Hydrogen project has proven that hydrogen produced by means of water electrolysis has substantial benefits as a clean fuel, and that there are no major technical obstacles preventing the creation of a hydrogen-based energy system. Nonetheless, a great deal of work remains to be done in the areas of developing storage techniques and reducing production costs.*

## Hythane Buses

Today's motor vehicles are main source of air pollution. They account for 50% of the nitrogen oxide ($NO_x$), 70% of the carbon oxide (CO and $CO_2$) and 50% of the volatile organic compounds (VOC).

Tests conducted by the Société des transports de la communauté urbaine de Montréal have proven that using hythane, a fuel made of 20% hydrogen and 80% methane, reduces emissions of carbon gas (CO and $CO_2$) by 20% and nitrogen oxide ($NO_x$) by over 40%. Hythane therefore has a good potential as a means of reducing polluting emissions and air pollution in cities.

### Did you know that

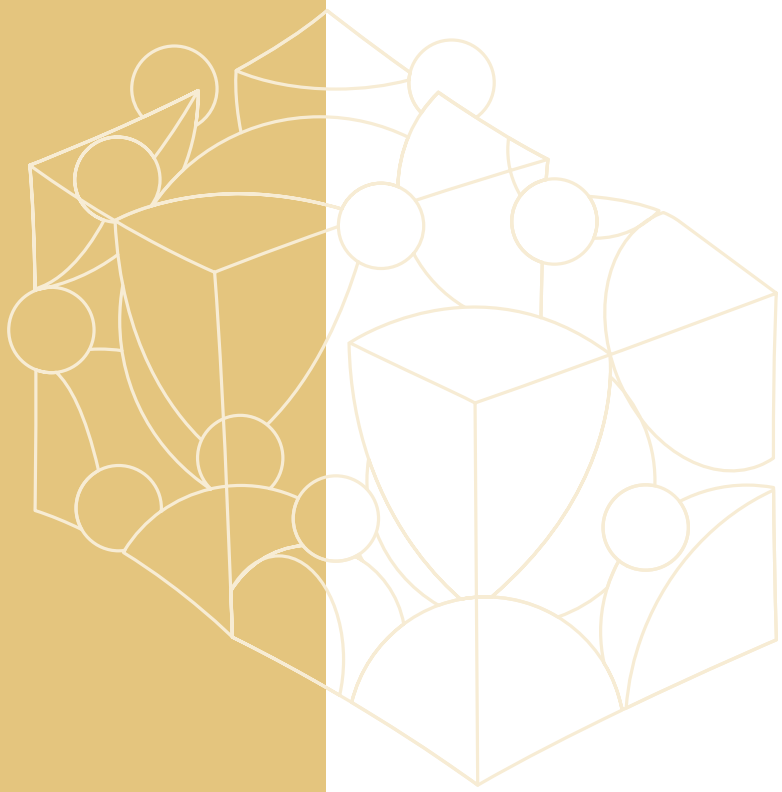
the performance of hythane buses is equal or superior to that of buses running on diesel fuel, that they're quieter, and that they're more powerful at low speeds?

*Source : IRH-UQTR*

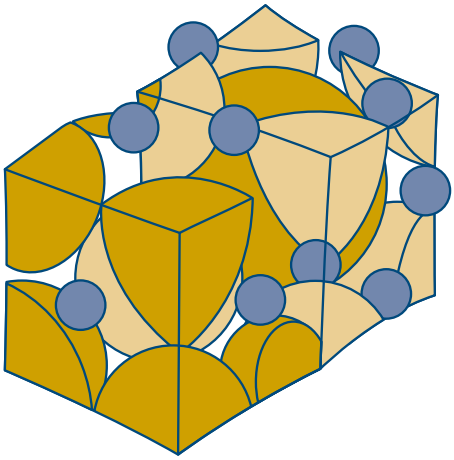
## Hydrogen Storage

The main obstacle to using hydrogen as a fuel is storage. Hydrogen's low density makes it especially difficult to store. The simplest solution has been to store hydrogen under heavy pressure. This method, however, requires heavy, bulky, expensive tanks. Another proposed solution is to keep hydrogen in its liquid state or in a semiliquid-semisolid state (slush). Although this substantially increases its density, it remains a costly, complex technology.

Québec scientists (at the Institut de recherche sur l'hydrogène de l'Université du Québec à Trois-Rivières, McGill University and the Institut de recherche d'Hydro-Québec) are trying to overcome these obstacles primarily by studying the possibility of storing hydrogen in absorbent substances. This would make hydrogen storage safer. From a technical standpoint, two storage solutions are being considered: metal hydrides and activated carbon.



*Metal hydride crystal lattice*



*Source : IRH-UQTR*

Hydrogen atom

Magnesium atom

Nickel atom

## Storage in Metal Hydrides

Metal hydrides (based on iron or magnesium, for example) are a potentially good means of storing hydrogen. While their storage capacity is relatively low (5% by weight), they are safe and can release pure hydrogen at a constant pressure. Storage in hydrides requires a tank filled with a metal alloy such as iron or magnesium. Pressurized hydrogen is injected into the tank and its atoms bond with those of the metal. At the right temperature and pressure, they absorb and retain hydrogen like a sponge.

## Storage in Activated Carbon

Hydrogen can also be stored in tanks filled with activated carbon, a highly porous substance. When pressurized hydrogen is injected, its molecules bond with the carbon's microporous surface.

The efficiency of this storage technique has already been proven for natural gas. Yet research (Institut de recherche sur l'hydrogène de l'Université du Québec à Trois-Rivières) is now being done on its use for hydrogen. The problem is that, at room temperature, the amount of hydrogen stored would be too small. For example, to store an amount comparable to 40% of the volume of liquid hydrogen, the hydrogen has to be injected at a high atmospheric pressure and subfreezing temperature (-196 ˚C).

## Storage in Nanotubes

Other absorbents such as carbon nanotubes also have the potential to store hydrogen. The inside of nanotubes consists of uniform-sized microscopic pores whose capillary action absorbs hydrogen. The hydrogen attaches to the surface of the carbon and fills the micropores, where it is then stored.

*Long used only in spacecraft, the chemical electricity-generators known as fuel cells today can power computers, buses, automobiles and buildings.*

*Diane Barry, MRN Source : IRH-UQTR*

# Fuel Cells

*In 1839 British physicist William Grove proved that electricity can be generated from the chemical reaction by which hydrogen and oxygen combine to form water. The fuel cell he invented remained on the shelf until about 1960, when NASA began using fuel cells to generate electricity for spacecraft.*

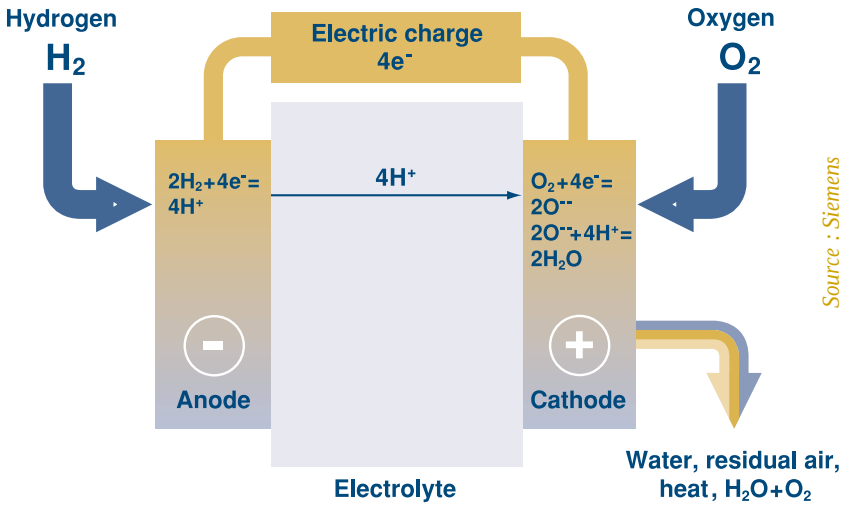
Unlike electrolysis which splits water molecules into hydrogen and oxygen, fuel cells combine the two elements to produce electricity. A fuel cell therefore converts chemical energy directly into electricity through this oxidation process whose only byproduct is water.

Almost 45% of the chemical energy contained in hydrogen is converted into electricity and the heat emanating from the cell can be used for heating, making fuel cells one of the most energy-efficient systems.

## How Fuel Cell Works

A fuel cell consists of two electrodes separated by an electrolyte, a substance that blocks the flow of electrons, but not of protons. Hydrogen and oxygen flow into the cell from plates on both sides (an anode and a cathode) connected by a wire and separated by an electrolyte. In the most powerful cells such as those developed for automobiles and buses, the electrolyte consists of a polymeric membrane.

A porous membrane separates the compartments containing hydrogen and oxygen (air). Upon contact with platinum (a catalyst), the hydrogen breaks up and its electrons flow into the electrical circuit between the two electrodes, thereby producing an electric current. The protons (hydrogen ions) pass through the permeable membrane and react with the oxygen in the air to produce water.




*Source : Siemens*

*Ultrasound inspection tank*

*Diane Barry, MRN Source : IRH-UQTR*

## Safety

Like many gases, hydrogen can be burnt. Its flames are colorless, almost invisible, and spread very quickly (2.7 meters per second). The safe use of hydrogen makes a clear understanding of its inflammable properties essential:

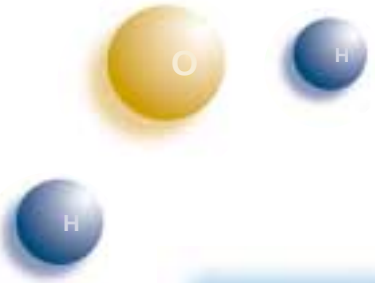
- It burns at hydrogen-air concentrations ranging from 4% to 75% (a very broad band compared to other fuels);
- It easily bursts into flame (a simple spark of static electricity is all it takes).

Because of its low density, however, hydrogen quickly scatters by rising in the atmosphere, unlike other fuels which cling to the ground. Moreover, hydrogen is relatively safe when used in properly ventilated areas.

## Québec Government Action

Over the past ten years, the Québec government has played an active role in hydrogen research and development through the Euro-Québec Hydro-Hydrogen project.

In addition, through its assistance program for the development of energy technologies (PADTE), the ministère des Ressources naturelles du Québec funds hydrogen research and development projects. At present, teams of scientists associated with three Québec universities (McGill, Université du Québec à Trois-Rivières and Université de Sherbrooke) and about a dozen private companies are engaged in hydrogen research with the assistance of government funding.

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Ministère des
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