Hydrogen and fuel cells

Hydrogen technology

Toward a sustainable energy system

Fossil fuels have made a vital contribution to economic development, and will continue to do so for many years to come. However, allowing more people to gain the benefits of mobility while minimizing emissions of greenhouse gases will require a more diversified range of motor fuel options. Hydrogen is one of the options being considered to resolve this equation. Using it in conjunction with fuel-cell technology would constitute a clean and sustainable source of energy, but many technological and economic hurdles still remain.

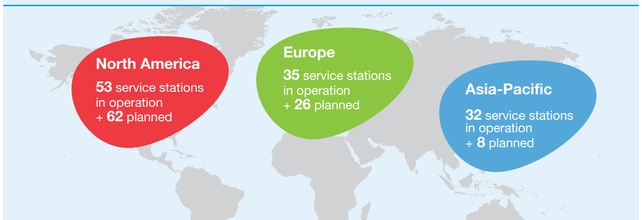
Hydrogen has applications both as a fuel to produce heat and/or electricity, and as a motor fuel. In the latter case, it can be combusted onboard the vehicle, or it can supply a fuel cell. There are currently about 600 hydrogen-fueled vehicles and 120 service stations equipped to refuel them around the world.

What is the point of using hydrogen in conjunction with fuel cells? By transforming a combustion-powered vehicle into an electric vehicle, fuel cells offer two major advantages:

1. significantly better overall energy efficiency

2. lower emissions – not only of CO_2, but also of all other tailpipe pollutants (e.g., NO_x, CO, HC) because they supply electricity and release only water.

Geographical distribution of hydrogen service stations



The hydrogen chain

Because hydrogen is not itself a primary energy source, it must first be manufactured and stored before being distributed and used. Today, each link in that chain continues to pose technical, social (in terms of acceptability) and above all, economic challenges.

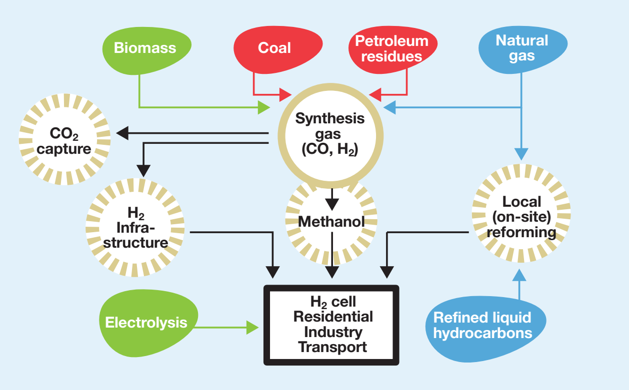
Hydrogen can be produced through two broad process technologies:

1. By reforming or gasification of fossil fuels (e.g., natural gas, petroleum, coal) or products derived from the biomass (e.g., ethanol);

2. Alternatively, by electrolysis (using electricity generated by nuclear, wind, solar or other power).

Today, hydrogen is produced at centralized plants, to be used on site or transported by pipeline or road tanker. Efforts must now be directed at establishing decentralized infrastructure for hydrogen production (by reforming or electrolysis) so it can be used as a motor fuel for vehicle fleets.

Hydrogen supply chain



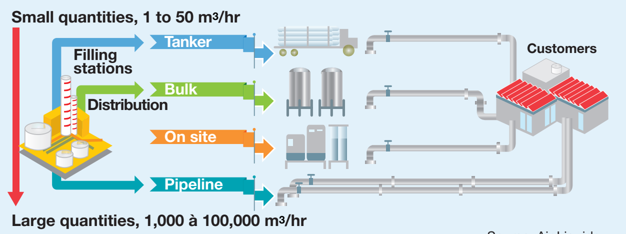
Hydrogen distribution and storage

Today, hydrogen is used mainly as a raw material in the chemicals industry and for crude oil refining.

A highly volatile gas, hydrogen can be transported by various means: pipeline, compressed in cylinders or tube trailers, or in liquefied form (cryogenic transport).

For storage, hydrogen can be compressed or liquefied. Although its energy density per unit of volume is highest in the liquid form (at -253°C), liquefaction utilizes about 35% of its own energy and costs four times more than storing compressed hydrogen.

Hydrogen transport and distribution options



Source: Air Liquide

Hydrogen as motor fuel

Today, producing one metric ton of oil equivalent (tOE) of hydrogen, free of greenhouse gas emissions, costs between €370 and €1,225, depending on the process used. The cost of gasoline on the worldwide market is on the order of €350/tOE, and can reach up to €1,000/tOE at the pump in some countries, due to taxation. Fossil fuels thus still hold somewhat of an economic advantage, but it is not inconceivable that competitive niches will emerge for hydrogen from about 2010.

The automotive industry is exploring the feasibility of launching hydrogen as the motor fuel of the future. However, although some technologies look promising, numerous hurdles have yet to be overcome before hydrogen can achieve widespread development as a motor fuel. These include distribution infrastructure, onboard storage, and the lack of regulations or standards relevant to this technology.

Other obstacles to the full-scale deployment of hydrogen include the physical, technological and regulatory constraints relating to the production, storage, distribution and use of hydrogen under completely safe conditions, as well as the public perception of the risks associated with hydrogen.

A BMW 7 Series hydrogen-fueled car filling up at a Total hydrogen service station in Berlin

Operating principle of fuel cells

A fuel cell is a generator that uses electrochemical reactions to achieve the direct and continuous conversion of a fuel's energy content into electricity. In its simplest form, the system can be used to supply water and electricity from hydrogen and oxygen.

Fuel cells can be divided into two main categories:

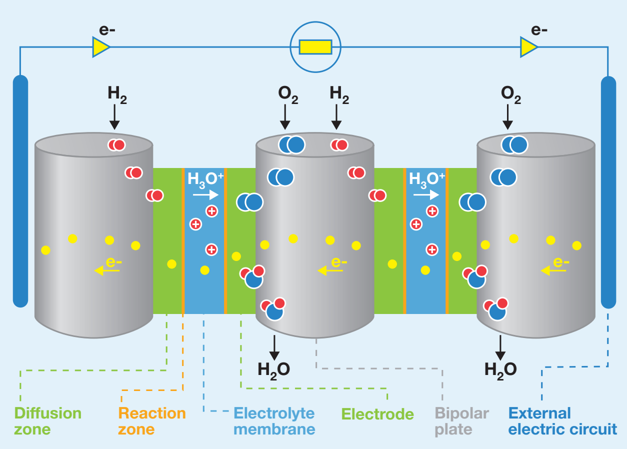
• **Liquid** fuel cells: due to drawbacks relating to volume and seals, this category is more suitable for stationary applications. More than 200 Phosphoric Acid Fuel Cells (PAFC) are currently in operation worldwide for the production of heat and/or electricity.

• **Solid** fuel cells: this category has the advantage of being more compact and thus more appropriate for vehicle applications. Proton Exchange Membrane Fuel Cells (PEMFC), which have a working temperature of about 80°C, and Solid Oxide Fuel Cells (SOFC), which have a working temperature of more than 700°C, are the main technologies.

Types of fuel cells

	Type	Electrolyte	T (°C)	Efficiency (%)
AFC	Liquid	KOH solution	80 - 90	55 - 60
PAFC	Liquid	Phosphoric acid	180 - 210	36 - 45
MCFC	Liquid	Molten carbonate	600 - 700	50 - 60
DMFC	Liquid	Polymer membrane	80 - 90	~ 34
PEMFC	Solid	Polymer membrane	80 - 90	30 - 50
SOFC	Solid	Solid oxide	800 - 1,000	50 - 70

Operating principle of a PEMFC



The key advantages of fuel cells are:

• high energy efficiency

• reliability

• no emissions

• low noise.

Challenges

Key challenges for vehicle applications

In the years ahead, vehicle fuel cell applications will be faced with five major challenges:

1. Reduction in production costs: to be competitive, the cost of a fuel cell system will have to be brought in line with that of a combustion engine, or about $30/kWh.

2. Platinum availability and price: platinum plays a vital role as a catalyst in fuel cell membranes. Today, global platinum output is estimated at about 200 metric tons per year, which would barely suffice to meet the needs of the French market alone at the current state of the art. A major challenge is therefore to achieve a five-fold reduction in the quantity of platinum required per vehicle.

3. Vehicle range: today's prototypes have a range of between 200 and 400 kilometers, depending on the characteristics of onboard hydrogen storage. The aim is to achieve a range comparable to that of conventional vehicles, i.e., about 600 km.

4. Cold starts: because a fuel cell produces water, its start-up behavior must be improved for temperatures below 0°C.

5. Fuel cell service life: to date, the manufacturers of the most advanced fuel cells have announced a service life of about 2,100 hours (or 100,000 kilometers). A fuel cell life of at least 4,000 hours must be attained.

The main obstacle is cost

The infrastructure costs related to fuel cells would come to billions of dollars, and the cost of a refueling station currently lies between $1.2 and $3 million.

For example, the following hydrogen highways are planned:

• in California (50 to 100 refueling stations by 2010 at a cost of $50 million in taxpayer money);

• in Canada (7 refueling stations by 2010 at a cost of $9 million in taxpayer money);

• in Norway (7 refueling stations in 2008 at a cost of $3.5 million in taxpayer money).

Hydrogen highway

All the hydrogen/fuel cell vehicles in operation in 2007 are prototypes, or "demonstrators." As is the case for fueling stations, their cost runs into million(s) of dollars. This is the main reason that commercial development of the technology is not foreseeable until 2015-2020.

The two main cost items in hydrogen/fuel cell-powered vehicles are the fuel cell itself and the onboard hydrogen storage system.

Assuming an initial output of 500,000 fuel cells/year, various sources put the overall cost of such vehicles between €2,000 and €10,000 higher than that of a conventional gasoline- or diesel- fueled vehicle.

Other applications

Given the expected power yield of fuel cells, along with their reliability, the quality of the electric current generated, the lack of emissions and the low noise level, the following applications are also on the agenda:

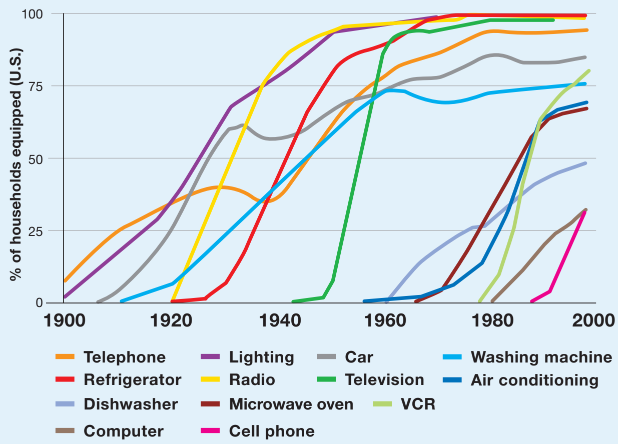
• as a replacement for conventional batteries in mobile telephones and laptop computers,

• in telecommunications, IT centers and data processing,

• for distributed electric power generation, cogeneration or tri-generation for residential and commercial applications,

• in automotive markets including onboard power auxiliaries.

Commercial-scale development is taking time



Source: Federal Reserve Bank, Dallas

Total's **commitment**

Key players

Alongside the primarily North American companies dedicated specifically to fuel cell development are the traditional players of the energy and chemical sectors:

• **the chemical industry** is developing materials for the core components of fuel cells, such as membranes and bipolar plates

• **automakers and their components suppliers** are working to optimize and miniaturize the fuel cell + auxiliaries system and lower its costs

• **the oil and gas industry** is developing and testing hydrogen fuel technologies (production, storage technology, infrastructure, safety aspects)

• **research institutes** are striving to develop technologies for future generations of fuel cells.

Role and aims of Total

• Join other players of the sector in guiding the transition to the hydrogen/fuel cell system.

• Participate actively in European studies and research conducted by the European Hydrogen and Fuel Cell Technology Platform (HFP), especially in partnership with the European Commission and the other key industrial players.

• Assess the potential of PEMFC and SOFC technologies for stationary and automotive applications.

• Broaden the Group's hydrogen fuel offering for stationary applications and ultimately for the automotive market and captive fleets.

• Play a role in the deployment of the distribution logistics needed for hydrogen motor fuel supply to specially-designed vehicles.

The Group's initiatives

Total is undertaking concerted initiatives and developing a comprehensive vision of the entire system, including the fuel and its value chain, as well as the materials and the various fuel cell technology systems.

In transportation, the Group is helping to set up the first components of a hydrogen fuel marketing infrastructure with two retail outlets in Germany and a third scheduled to open in another European country in early 2008.

The first, in Berlin, refuels the hydrogen demonstrator cars manufactured by automakers who belong to the Clean Energy Partnership (CEP[1]) as well as the MAN hydrogen bus fleet used for regular service by the Berlin transit authority, BVG, as part of the HyFLEET: CUTE project. The second service station opened in Munich in November 2006. It supplies liquid hydrogen fuel to the BMW 7 Series hydrogen car under a partnership agreement between BMW and Total.

A Total hydrogen service station in Munich

© Pierre Adenis / Total

For stationary applications, the Group is testing two fuel cells powered by hydrogen supplied by the liquefied petroleum gas (LPG) reformer installed at the commercial hydrogen service station in Berlin.

Total is also an active participant in several major European projects:

• HyWays, which is preparing a Roadmap for the development of commercial applications for hydrogen by 2030-2050

• HyLights, which is planning and will follow up future demonstration projects

• HyApproval, which is drawing up a European Handbook for the installation of hydrogen filling stations.

With the European Commission, industrial partners and research institutes, Total is also engaged in the Implementation Panel of the European Hydrogen and Fuel Cell Technology Platform, which is developing a European action plan and defining the framework for large-scale demonstration projects (Lighthouse Deployment Project).

In France, Total is involved in the National Hydrogen Action Plan (PAN-H) to define an R&D program ultimately aiming for economic and industrial developments, contributing to European efforts.

And in the United States, Total is a partner in two research programs coordinated by the UC Davis Institute of Transportation Studies:

• Hydrogen Pathways, which focuses on the potential transition to a hydrogen-based transportation system, and

• STEPS (Sustainable Transportation Energy Pathway), launched in early 2007 to compare the various options for alternative motor fuels, including hydrogen-based technologies.

[1] CEP is a research program sponsored by the German Ministry of Transportation. Participants include manufacturers, automakers and research institutes with an interest in hydrogen energy.

Read more: **www.total.com**

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