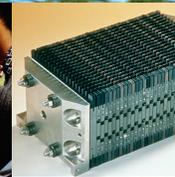


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- 2 → Radioactivity
- 3 → Radiation and man
- 4 → Energy
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- 6 → How a nuclear reactor works
- 7 → The nuclear fuel cycle
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FROM RESEARCH
TO INDUSTRY

12 → Hydrogen



CHARACTERISTICS OF HYDROGEN
THE CHALLENGES OF A HYDROGEN ECONOMY

METHODS OF PRODUCTION OF HYDROGEN
DISTRIBUTION AND STORAGE OF HYDROGEN

THE FUEL CELL

TOMORROW'S WORLD: HYDROGEN IN DAILY
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A small molecule full of energy 6

Present everywhere... but available nowhere 6

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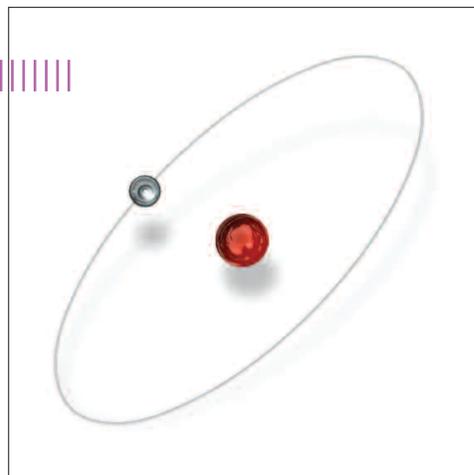
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New materials, tests and the development of technologies: hydrogen/fuel cell systems will soon supply power to much of our equipment.

“Hydrogen as an energy system is now a major challenge, both scientifically and from an environmental and economic point of view.”

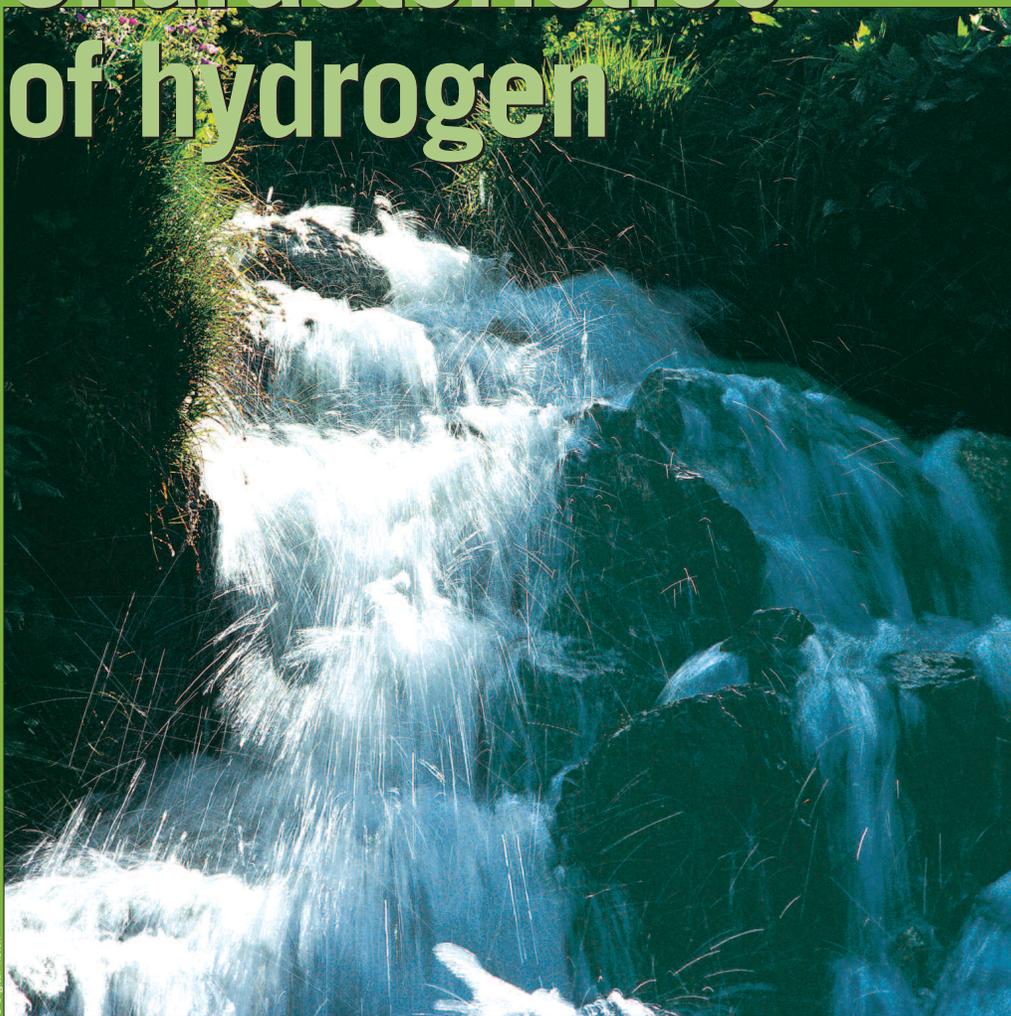
introduction

More than a century ago, Jules Verne wrote in “The Mysterious Island” that water would one day be employed as fuel: “Hydrogen and oxygen, which constitute it, used singly or together, will furnish an inexhaustible source of heat and light.” Today, the “water motor” is not entirely the dream of a writer. Fiction is about to become fact thanks to hydrogen, which can be produced from water and when burned in air itself produces water. Hydrogen is now at the heart of international research. So why do we have such great expectations of hydrogen?

Dominated as it is by fossil fuels (oil, gas and coal), our current energy system has left a dual threat hovering over our environment, exposing the planet to the exhaustion of its natural reserves and contributing to the greenhouse effect. If we want sustainable development for future generations, it is becoming necessary to diversify our methods of producing energy. Hydrogen is not, of course, a source of energy, because first it has to be produced. But it has the twofold advantage of being both inexhaustible and non-polluting. So in the future, it should have a very important role to play.

LIGHT, ABUNDANT AND FULL OF ENERGY...
 IN THE FACE OF WORLDWIDE DEMAND FOR ENERGY,
 IT WILL BE THE KEY PLAYER OF THE 21ST CENTURY.

Characteristics of hydrogen



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1766

The British chemist Henry Cavendish managed to isolate a strange gas that produces water when burned in air. It is hydrogen.

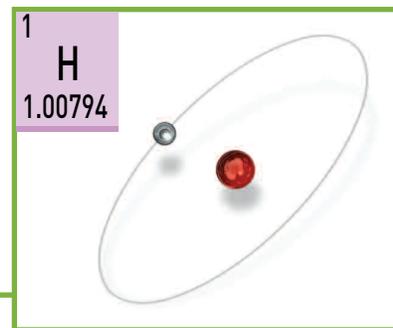
1781

Known until then simply as the "flammable gas", hydrogen owes its name to the French chemist Antoine-Laurent de Lavoisier, who performed the synthesis of water.

1804

The Frenchman Louis-Joseph Gay-Lussac and the German Alexander von Humboldt demonstrated together that water is made up of one part oxygen for two parts hydrogen.

history of hydrogen and the fuel cell: key dates. history of hydrogen



HYDROGEN: TOP OF THE CLASS

Hydrogen is the lightest of all the chemical elements because it has the simplest atomic structure: its nucleus consists of a single proton and a hydrogen atom has only one electron. So it takes first place in Mendeleev's periodic table. Chronologically, hydrogen is also the ancestor of all the other elements. Present from the first

Mendeleev's periodic table

1																	2	
1	H 1.00794																	He 4.00206
2	3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.9984	10 Ne 20.1797
3	11 Na 22.9898	12 Mg 24.3050											13 Al 26.9815	14 Si 28.0855	15 P 30.9736	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
4	19 K 39.0983	20 Ca 40.078	21 Sc 44.956	22 Ti 47.88	23 V 50.942	24 Cr 51.996	25 Mn 54.9309	26 Fe 55.847	27 Co 58.9332	28 Ni 58.69	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.82	50 Sn 118.710	51 Sb 121.75	52 Te 127.60	53 I 126.905	54 Xe 131.29
6	57 La 58 Ce 59 Pr 60 Nd 61 Pm 62 Sm 63 Eu 64 Gd 65 Tb 66 Dy 67 Ho 68 Er 69 Tm 70 Yb 71 Lu 138.906 140.115 140.908 144.24 145 150.36 151.965 157.25 158.925 162.50 164.930 167.26 168.934 173.04 174.967																	
7	55 Cs 132.905	56 Ba 137.327	57 La 138.906	72 Hf 178.49	73 Ta 180.948	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.08	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
	87 Fr (223)	88 Ra 226.025	89 Ac 227.028	104 Rf (261.11)	105 Db 262.11	106 Sg 263.12	107 Bh 264.12	108 Hs 265.13	109 Mt 268	110 Uun* 269	111 Uuu* 272	112 Uub* 277	89 Th 90 Pa 91 U 92 Np 93 Pu 94 Am 95 Cm 96 Bk 97 Cf 98 Es 99 Fm 100 Md 101 No 102 Lr 227.028 227.036 231.036 238.029 237.048 244 243 247 247 251 252 257 258 259 260					

* Names and symbols of these elements are temporary.

KEY
 Atomic number = number of protons → 1
 = number of electrons → H
 Symbol → H
 Atomic mass = number of protons + neutrons → 1.00794
 + neutrons = number of nucleons in the nucleus
 The figures between brackets indicate the mass number of the most stable isotope.
 According to Handbook of Chemistry and Physics, 74th Ed. 1993, CRC Press and Pure and Applied Chemistry, 1997, 69, 2471

1839

The Englishman William R. Grove discovered the principle of the fuel cell: it involved a chemical reaction between hydrogen and oxygen producing electricity, heat and water simultaneously.

1939-1953

The Englishman Francis T. Bacon made progress with chemical electricity generators, which enabled the first powerful industrial prototype to be produced.

1960

After that, NASA used fuel cells to supply electricity for its spacecraft (Apollo and Gemini capsules).

hydrogen and the fuel cell: key dates. history of hydrogen and the fuel cell: key dates



© Digital Vision

Hydrogen is the most abundant element on the planet, but it hardly ever exists naturally in its elementary state.

moments of the Universe, hydrogen nuclei fused to create heavier and more complex nuclei.

A SMALL MOLECULE FULL OF ENERGY

The hydrogen molecule, which is what we mostly use, consists of two hydrogen atoms (H_2). Colorless, odorless and non-corrosive, this molecule has the benefit of being particularly full of energy: 1 kg of hydrogen releases three times as much energy as 1 kg of gasoline (i.e. 120 MJ/kg compared with 45 MJ/kg for gasoline).

On the other hand, because hydrogen is

Millions of joules (Megajoules). The joule is the unit used to measure energy.

the lightest of the elements, for an equal weight it occupies a much greater volume than any other gas. So to produce as much energy as

1 liter of gasoline, we would need 4.6 liters of hydrogen compressed to 700 bars. These high volumes make the transportation and storage of hydrogen gas a problem. Like many fuels, hydrogen can catch fire or explode on contact with the air. It must therefore be handled with care. But because its molecules are very small, they disperse very rapidly in the air (four times more quickly than natural gas), a positive safety factor.

PRESENT EVERYWHERE... BUT AVAILABLE NOWHERE

Hydrogen is extremely abundant on our planet. Every molecule of water (H_2O) results from the combination of one oxygen atom and two hydrogen atoms. Water covers 70% of the Earth's surface. Hydrogen is also found in hydrocarbons, which as their name suggests,

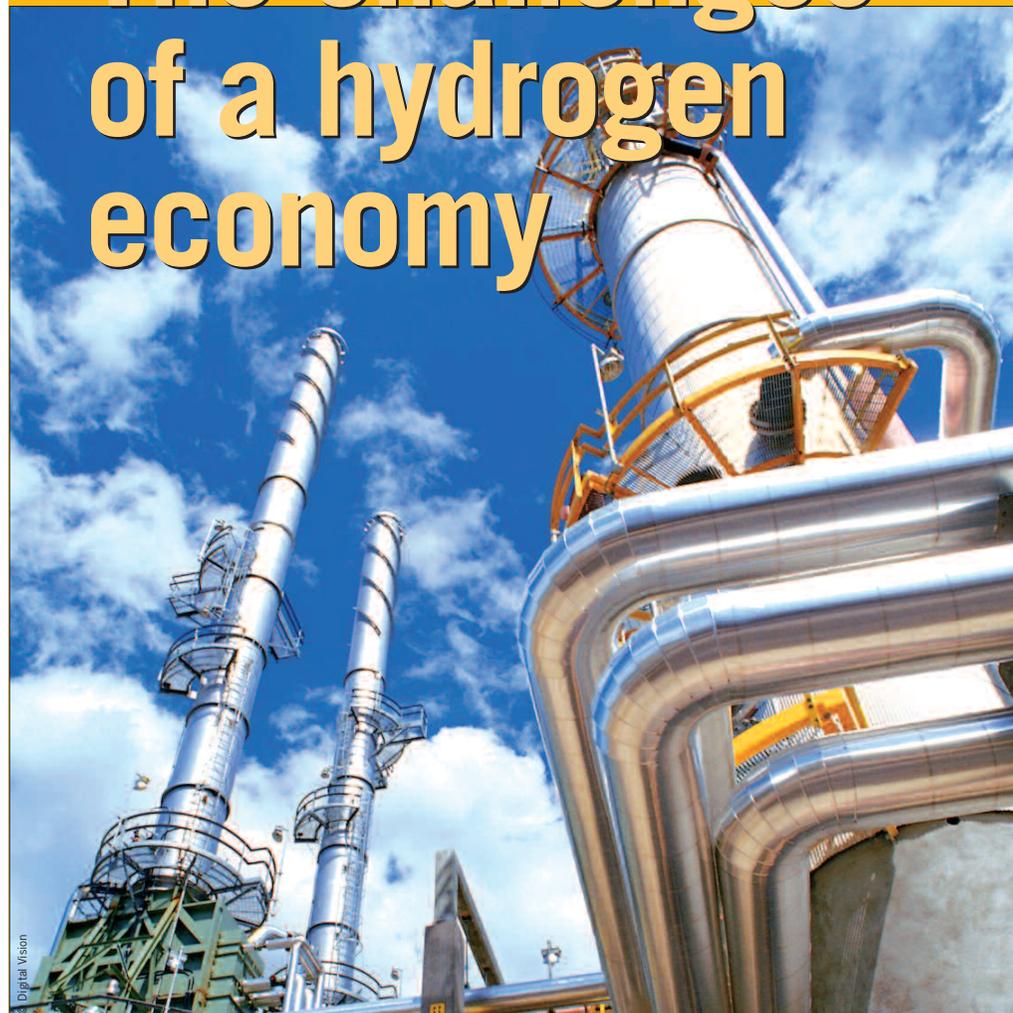
Oil, natural gas, etc.

are the result of the bonding of carbon and hydrogen atoms. All living things, whether animal or vegetable, contain hydrogen, so biomass is another potential source of hydrogen.

But although it is the most abundant element on the planet, hydrogen practically never exists naturally in its pure state. So hydrogen could be converted into an inexhaustible energy supply... if only we could produce it in sufficient quantity.

COMBINED WITH ELECTRICITY, HYDROGEN SHOULD FULFILL OUR PRINCIPAL ENERGY NEEDS.

The challenges of a hydrogen economy



© Digital Vision

HYDROGEN AND FOSSIL FUELS

At the end of the 19th century, hydrogen was an important fuel. It was used in lamps to provide lighting and also in “town gas”, in a mixture with carbon monoxide. During the 20th century, when natural gas and especially oil appeared, hydrogen largely fell out of use for supplying energy, except in the field of rocket propulsion. Oil and natural gas can be used direct because they naturally occur in that form, so using them is easier.

But the gradual exhaustion of reserves is unavoidable, hence the resurgence of interest in hydrogen. But it is not just a question of having to opt for second best, for unlike fossil fuels, the combustion of hydrogen does not give off greenhouse gases.

The way we use hydrogen in the future will be different from the way we used it in the past. In the future, it will be used to produce heat, but also electricity, from fuel cells (see p. 21).

HYDROGEN OR ELECTRICITY WITH NO STRINGS ATTACHED

But why use hydrogen to produce electricity? Why not produce electricity direct? Because hydrogen gives electricity the flexibility of use it currently lacks. Although we can produce electricity in many different ways, we do not know how to store it efficiently. Batteries are expensive and offer only very limited independence. Hydrogen, meanwhile, can be stored. With a reserve of hydrogen and a fuel cell, we can produce electricity anywhere and at any

“The production of electricity is possible anywhere, at any time, using the combination of a fuel cell and a hydrogen reserve.”

time, without being connected to the mains network. With hydrogen and the fuel cell, electricity and mobility are becoming more compatible.



Hydrogen in its liquid state: the fuel of space propulsion.

POSSIBLE APPLICATIONS

In the transport sector, electric vehicles powered by a fuel cell working on hydrogen could replace our current vehicles to advantage: the only exhaust from our cars would be water. This is a huge challenge for an automotive sector currently dependent entirely on fossil fuels. Finding an alternative is therefore essential. On a smaller scale, the fuel cell can be adapted to portable devices (telephones, computers, etc.). Compared with the current system, it will provide five times the battery life and will be instantly rechargeable, anywhere.



Today, annual hydrogen production covers barely 10% of the annual energy requirements of transport alone.

There are also interesting stationary applications of the fuel cell. In homes, hydrogen will be both a source of heat and of electricity. It will also enable the provision of electricity to isolated outposts that cannot be connected to the mains network (mountainous areas, at sea, etc.).

In these areas, it could be the perfect complement to renewable energies. Solar and wind energy have the disadvantage of being intermittent. With hydrogen, this unreliability

Alternation of day and night with the sun, irregular levels of wind.

can be managed: when there is overproduction, the excess electricity



Well suited to portable devices, the fuel cell would give them five times more reserve time and would be rechargeable in an instant.

can be used to produce hydrogen; when there is underproduction, hydrogen can in turn be converted into electricity.

Hydrogen's potential is not limited only to producing electricity. It can also provide energy by combustion. This is already the case in space applications, where it is used to propel rockets. It could equally be used to make synthetic gas, which might permit more efficient fuels than those currently in existence.

Inexhaustible, environmentally friendly, flexible to use – hydrogen has many advantages. Combined with electricity, it should fulfill our principal energy requirements. In the face of the developing fossil fuel crisis, there is no doubt about the value of using hydrogen. But before hydrogen can become part of our everyday lives, further progress is needed at every stage, from production, transportation and storage to its actual use.

“Hydrogen is the perfect complement to intermittent renewable energies.”

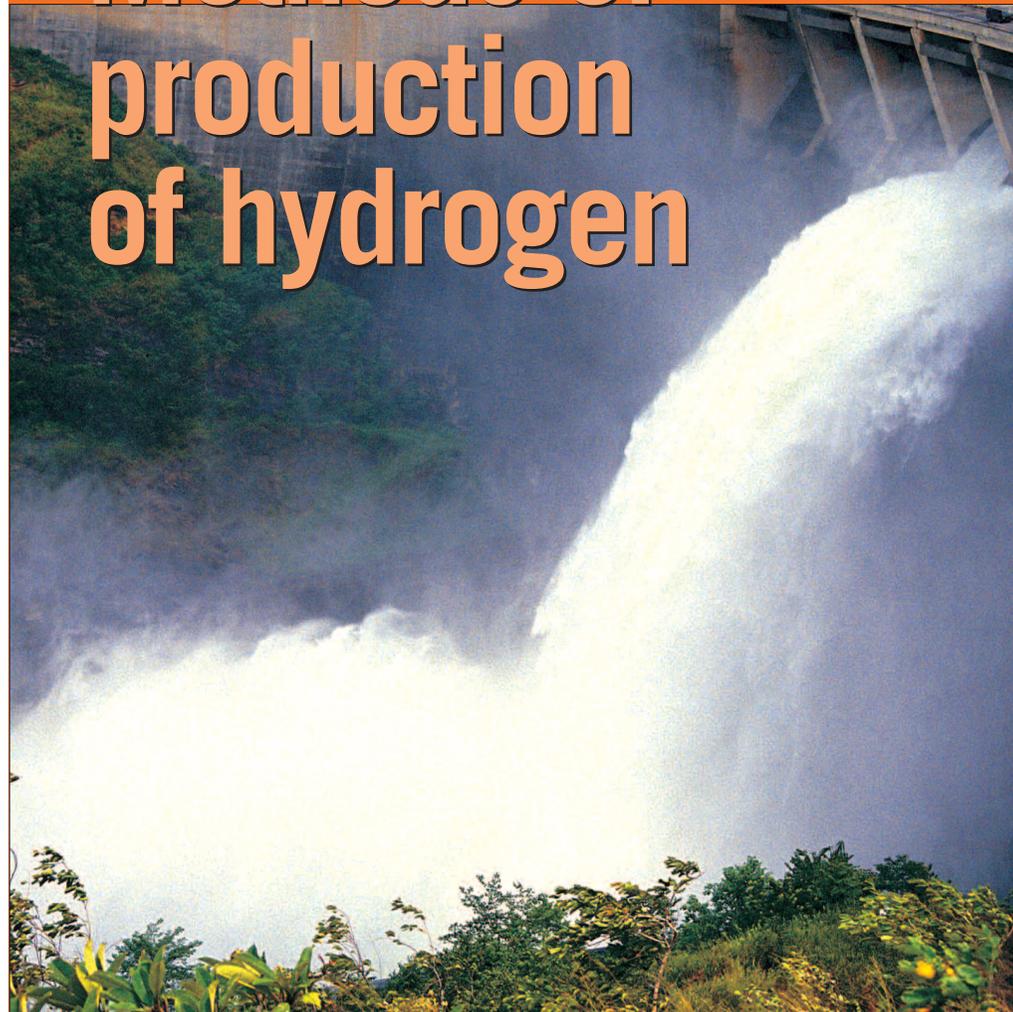


© PhotoDisc

Hydrogen would enable the supply of electricity to isolated outposts that cannot be connected to the mains network.

HYDROGEN CAN BE PRODUCED FROM DIFFERENT SOURCES OF ENERGY.

Methods of production of hydrogen



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As we have seen, hydrogen is not directly available in nature. However, it has the advantage that it can be produced from three major sources: fossil, nuclear and renewable energies.

To be economically and environmentally viable, hydrogen production must fulfill three criteria. It must be:

- competitive: production costs must not be too high,
- efficient: hydrogen production should not require too much energy,
- clean: the manufacturing process must not pollute, otherwise this would cancel out one of hydrogen's principal assets.



A share of global hydrogen production is used in oil refining.

“Competitiveness, efficiency and cleanliness: these are three criteria to be taken into account in the production of hydrogen.”

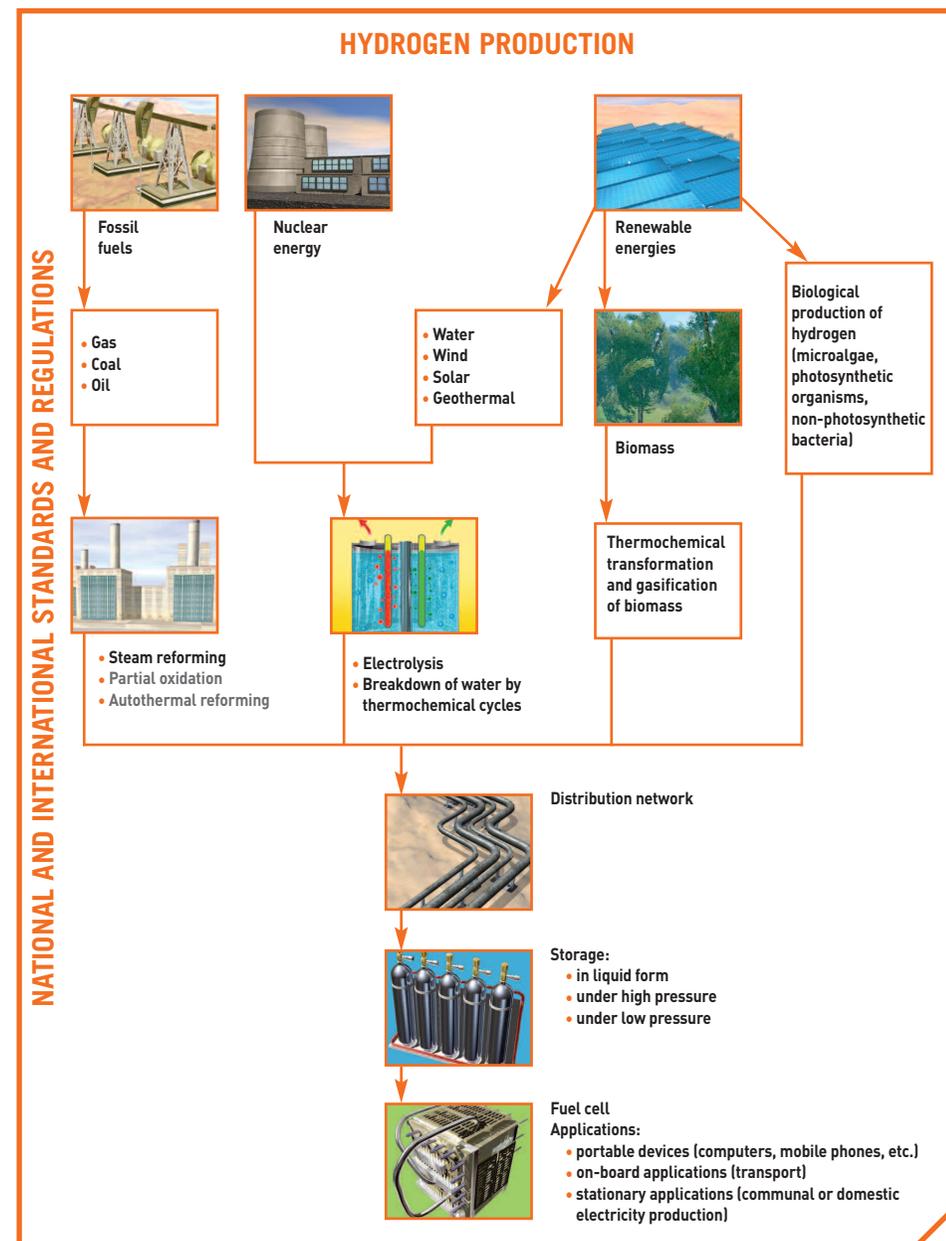
Several methods are in use today, but none of them currently fulfill all of these criteria completely. In particular, production costs remain very high, which is one hurdle to widespread use. Some promising new methods are currently being developed.

CURRENT HYDROGEN PRODUCTION

Although hydrogen is hardly used at all for energy, it is one of the basic materials of the chemical and petrochemical industries. In particular, it is used for the production of ammonia and methanol and in oil refining; it is also used in metallurgy and electronics, pharmacology and the processing of foodstuffs. To cover these requirements, 50 million metric tons of hydrogen are already produced each year. But if these 50 million metric tons were to be used for energy production, they would only meet 1.5% of global primary energy demand. If hydrogen were to be used as an energy vector, its production

An energy vector is not the same as an energy source; it is a carrier of energy.

would have to be dramatically increased.



© Air Liquide
Steam reforming plant.

PRODUCTION OF HYDROGEN FROM FOSSIL FUELS

Today, 95% of hydrogen is produced from fossil fuels by reforming; this is a chemical reaction in which hydrocarbon molecules are cracked under the action of heat to release hydrogen. The steam reforming of natural gas is the most common process: natural gas is exposed to very hot steam and releases the hydrogen it contains. But the production of hydrogen by reforming has the disadvantage that it gives off carbon dioxide gas (CO₂) into the atmosphere, which is the principal gas responsible for the greenhouse effect. To avoid this, the production of hydrogen from fossil fuels would involve imprisoning the car-

bon dioxide using techniques yet to be developed (for example, the possibility of re-injecting the carbon dioxide into exhausted oil wells is being considered).

Hydrogen produced from natural gas is the cheapest, but its production cost is still triple that of natural gas. As this method of production creates pollution and as fossil energy resources are set to decrease, the diversification of production methods is essential.

PRODUCTION OF HYDROGEN BY DECOMPOSITION OF WATER

One possible method is to separate the oxygen and hydrogen atoms bound together in water molecules (according to the reaction $H_2O \rightarrow H_2 + 1/2 O_2$). This solution looks the most promising in terms of greenhouse gas emissions... provided that this breakdown can be performed using energy sources that do not themselves release CO₂. Among the possible

Renewable energies or nuclear energy.

processes, two are currently being studied: electrolysis and the breakdown of water molecules by thermochemical cycles.

With electrolysis, water is decomposed chemically into oxygen and hydrogen using the action of an electrical current. Hydrogen could be produced by electrolysis in small units all over the country. To be viable, this process requires the provision of electrical current at a very low cost. Currently, the production of hydrogen by electrolysis costs 3 to 4 times more than production by the reforming of

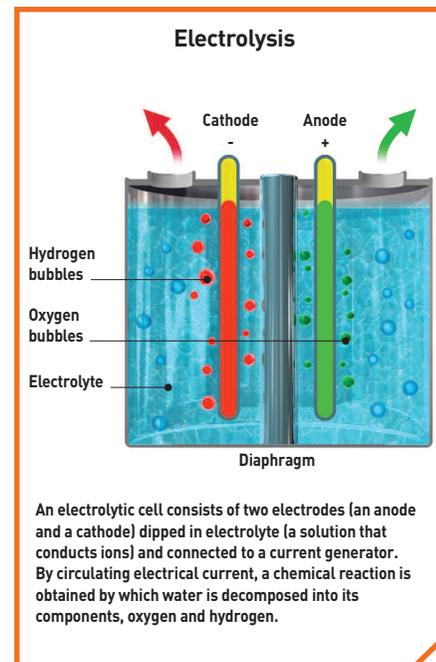
“If hydrogen were to be used as an energy vector, its production would have to be dramatically increased.”

high-temperature nuclear reactors currently being designed, or in solar power stations.

DIRECT PRODUCTION FROM BIOMASS

Biomass is a potentially very important source of hydrogen production. It consists of all plants (wood, straw, etc.) that re-grow from the Earth's surface. Hydrogen is produced by gasification, which produces a synthetic gas (CO + H₂). After purification, this gives hydrogen. This is an attractive solution because the quantity of CO₂ emitted during the conversion of biomass into hydrogen is more or less equivalent to the amount absorbed by the plants when they were growing; the environmental balance sheet is therefore zero.

One day, it may be possible to produce hydrogen from bacteria and micro-algae. It has recently been discovered that a feature of some of these organisms is that they produce hydrogen under the action of light. But this process is still only at the laboratory stage.



natural gas. It also gives a poor overall yield. High temperature electrolysis, an improvement on traditional electrolysis, would give a better yield.

The other process of decomposing water molecules using thermochemical cycles requires temperatures of 800°C to 1,000°C to break down the molecules. These temperatures could be obtained in the new generation



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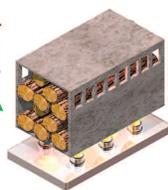
The conversion of plants – wood, straw, etc. – is one source for the production of hydrogen.



Damp forest biomass

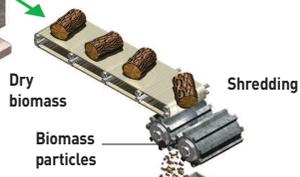


Drying: the wood is kept for six months under a shelter...



...then heated to 120°C

Wood gasification process



Dry biomass
Biomass particles

Synthetic gas
(CO*, hydrogen,
methane...)



1 The particles are mixed with steam then drawn through.

2 Solid carbon residues, the result of the biomass gasification, are drawn through by sand circulating in the circuit.

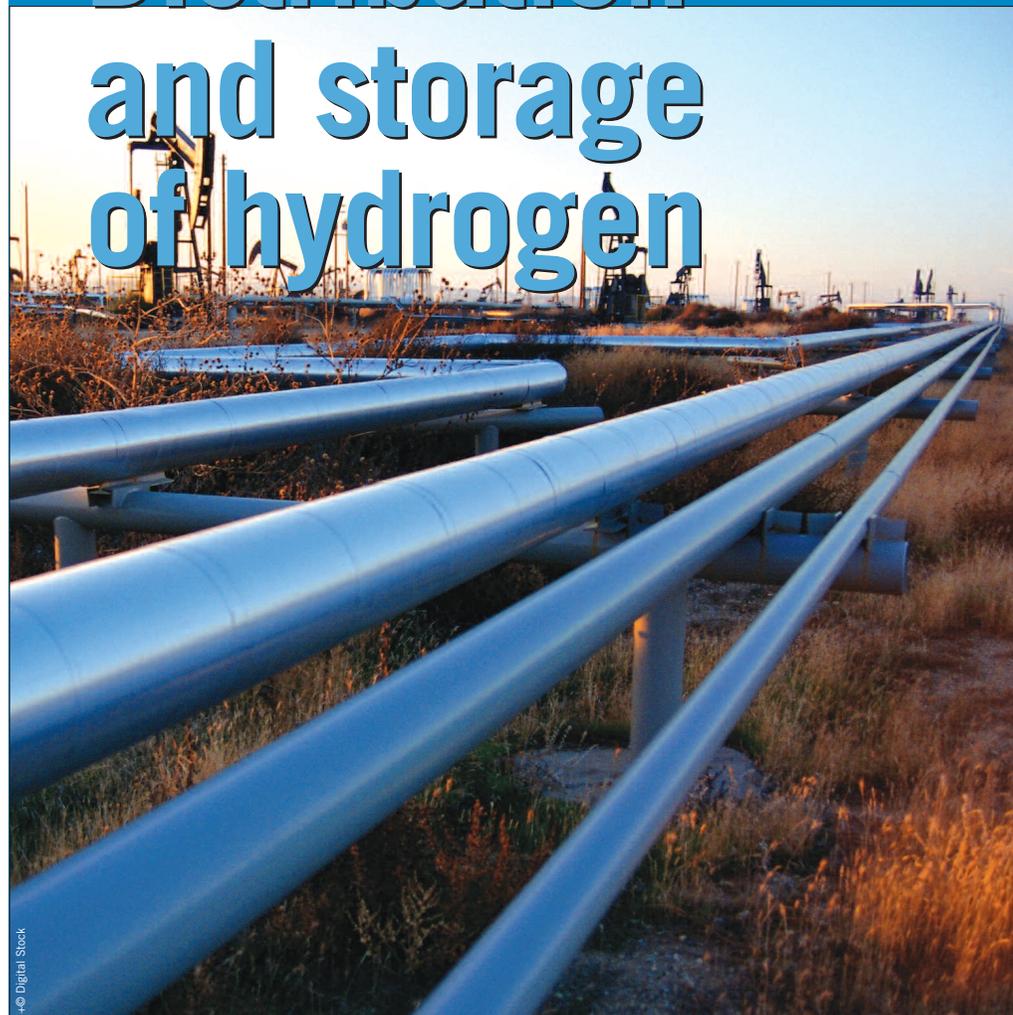
3 The solid carbon residues are burned to heat the sand.

4 Gasification of the wood biomass + water.
CO*, hydrogen, methane...
(the energy needed for the reaction is provided by the hot sand).

* Carbon monoxide

ESTABLISHING A HYDROGEN ECONOMY MEANS THAT HYDROGEN MUST BE AVAILABLE AT ALL TIMES EVERYWHERE IN THE COUNTRY.

Distribution and storage of hydrogen



© Digital Stock

For hydrogen really to become the energy vector of tomorrow, it needs to be available at all times everywhere in the country. Setting up effective transportation, storage and distribution methods is therefore a crucial challenge.

DISTRIBUTION NETWORK

Currently, industrial distribution generally works in the following way: hydrogen is produced in centralized units and used on site or transported in pipelines. Transporting gas in pipelines enables the main sources of production to be connected to the main points of use. Hydrogen pipeline distribution networks already exist in a number of countries for supplying

the chemical and petrochemical industries (approximately 1,050 km in France, Germany and Benelux are operated by Air Liquide). The fact that this industrial infrastructure exists demonstrates that we already have a good grasp of the generation and transportation of hydrogen. To put this into perspective though, the transportation cost is approximately 50% higher than the cost of transporting natural gas, and one unit volume of hydrogen carries three times less energy than one unit volume of natural gas.

A supply station infrastructure would need to be developed for the distribution of hydrogen. Creating service stations does not seem to pose

AIR LIQUIDE PIPELINE NETWORK



“Developing suitable storage technologies involves taking account of hydrogen’s physical and chemical characteristics.”



Pilot hydrogen service stations are being developed. Shown here is a Total hydrogen station in Germany.

STORING HYDROGEN

Designing tanks that are compact, light, safe and cheap is of critical importance because it is hydrogen’s capacity for storage that makes it particularly attractive compared with electricity.

Storage in liquid form

Storing hydrogen in liquid form is one solution that looks, on the face of it, quite attractive. Hydrogen is used in liquid form in space applications. But, after helium, hydrogen is the most difficult gas to liquefy. It takes a large amount of energy at a high cost, making it more difficult to apply to the general public.

Hydrogen condenses at -253°C.

Storage as a gas under high pressure

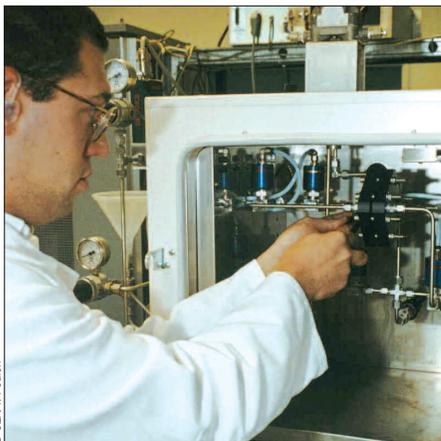
any particular technical problems. About 40 pilot stations already exist throughout the world, particularly in the United States, Japan, Germany and Iceland.

However, it will be some time before these service stations cover whole countries, and this may slow down the development of hydrogen use in transport. To overcome this, some car manufacturers are considering the use of fuels containing hydrogen rather than hydrogen itself. In this case, the reforming stage takes place on board the vehicle. The benefit of the process is then reduced, because reforming produces carbon dioxide, the gas mainly responsible for the greenhouse effect.

Storing hydrogen as a gas is one promising option. But there are many problems with this. A light, bulky gas, hydrogen must be highly compressed to reduce the size of storage tanks. There has been some progress in this direction: the pressure of industrial bottles of hydrogen has now been increased from 200 to 350 bars, and tanks are now being developed that can resist a pressure of 700 bars. But this compression is costly, and even at 700 bars, 4.6 liters of hydrogen are still needed to produce as much energy as 1 liter of petrol. The risk of hydrogen leaks must also be taken into account, because of the flammable, explosive nature of the gas under certain conditions.



Bottles have evolved: lighter and smaller, they contain a greater mass of hydrogen.



Storage materials are tested: in particular they have to be impermeable and must not be made brittle by hydrogen.

Because it is such a small molecule, hydrogen can pass through many materials, including certain metals. Some it weakens, making them brittle. So research into high-pressure storage mainly consists in testing the resistance of materials to hydrogen under pressure. These materials must be resistant, but relatively light (for reasons of portability).

The metal tanks used at present are still expensive and heavy for the quantity of gas they can supply. Tanks made from polymers rather than metals are currently being developed to eliminate these problems.

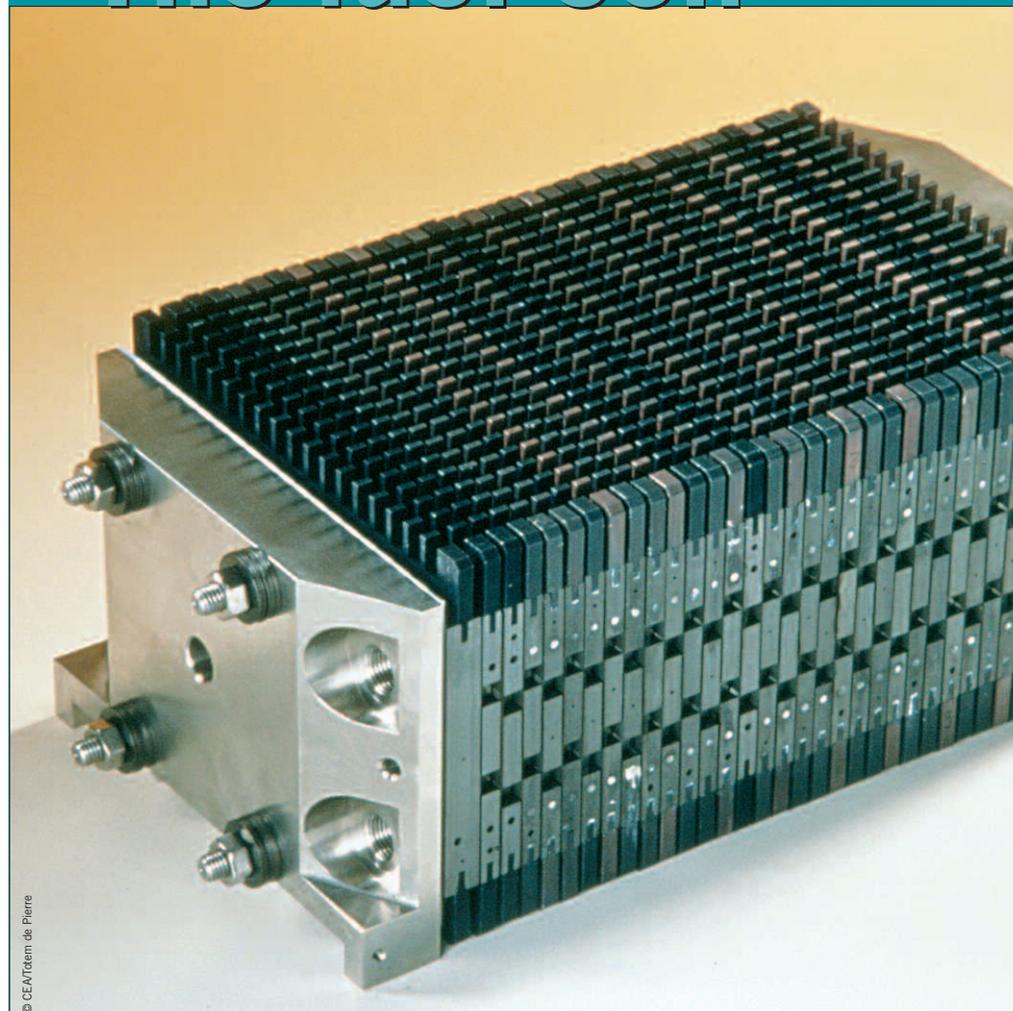
Members of the plastics family.

Storage under low pressure

One alternative to the use of pressurized tanks is to store hydrogen in certain carbonaceous materials or metal alloys that will absorb hydrogen and return it when needed. Much research is currently being carried out into these methods of storage.

A POTENTIAL AREA FOR ELECTRICITY PRODUCTION, FOR ANYTHING FROM JUST A FEW WATTS TO MEGAWATTS.

The fuel cell



A TECHNOLOGY OF THE FUTURE WITH A LONG PAST

The development of interest in hydrogen has largely been in response to fuel cell technology. It is not a new principle, for it was discovered in 1839 by William R. Grove. At that time, this English lawyer and amateur electrochemist, noted that by re-combining hydrogen and oxygen, it was possible to create water, heat and electricity simultaneously. The fuel cell was born. It was the engineer Francis T. Bacon who, in 1953, made the first powerful industrial prototype (several kW).

But it was only NASA that would use the technology, in the 1960s, to supply electricity to some of its Gemini and Apollo spacecraft. Although the fuel cell was simple in principle,



Example of fuel cell use: "Roller Pac", a 2 kW generator unit, in an emergency situation.

in practice it was complex and costly, preventing it from becoming widely used by the general public. Today, much progress has meant that many applications can be envisaged. From the micro fuel cell that produces the few watts needed to run a mobile phone, or the fuel cell

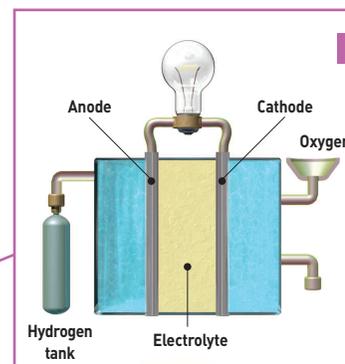
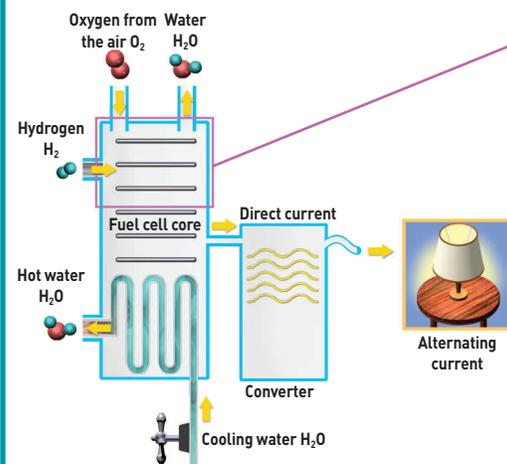
for on-board applications in the transport sector, to the battery capable of producing 1 MW to supply electricity to an apartment block, a whole range of fuel cells now exist. The operating principle is still the same, though different technologies are in development.



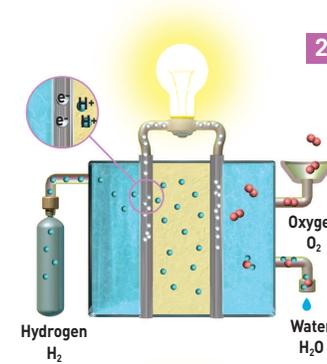
The micro fuel cell produces the few watts required to power a mobile phone.

HOW A FUEL CELL WORKS

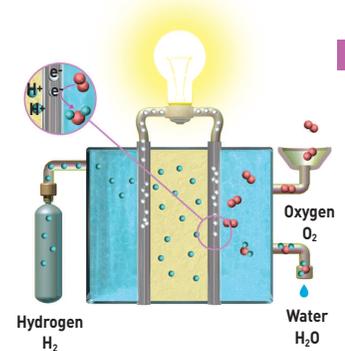
A fuel cell works the opposite way round to the electrolysis of water. While electrolysis breaks water down into hydrogen and oxygen using an electrical current, a fuel cell recombines the hydrogen and oxygen to create an electric current.



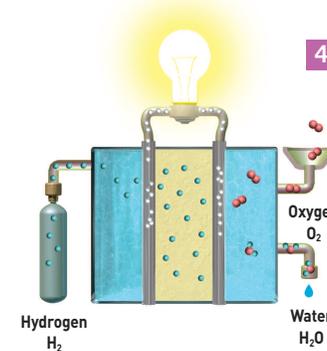
1 The fuel cell consists of many individual electrochemical cells made up of two electrodes (an anode, negatively charged) separated by an electrolyte (liquid that conducts electricity).



2 The anode in the cell is charged with hydrogen, and the cathode with oxygen. The hydrogen molecules in the anode dissociate. The H+ ions disperse into the electrolyte.



3 The electrolyte in the fuel cell is structured to block the passage of electrons. So while the ions can pass through the electrolyte, the electrons have to circulate through an external circuit, thereby creating an electrical current.



4 In the cathode, the H+ ions and the oxygen combine to form water. The reaction also produces heat, which can be recovered.

THE DIFFERENT TYPES OF FUEL CELL			
NAME	OPERATING TEMPERATURE	DEVELOPMENT	COMMENTS
PEMFC (Proton Exchange Membrane Fuel Cell)	80-120°C	The most suitable for the mass market. Many prototypes. Transport applications.	Sensitive to impurities, so the air or oxygen must be purified or catalysts resistant to pollutants must be developed.
DMFC (Direct Methanol Fuel Cell) DEFC (Direct Ethanol Fuel Cell)	100-130°C	In development. Much progress has been made.	Much lower efficiency than with pure hydrogen.
SOFC (Solid Oxide Fuel Cell)	750-1,000°C	Promising technology requiring further development. Overall efficiency (electrical and thermal) above 80%. Stationary applications.	Operating temperature still very high.

THE DIFFERENT TECHNOLOGICAL PATHS

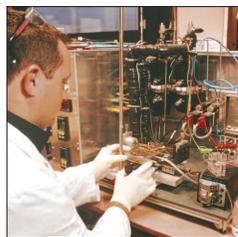
There are a number of different types of fuel cell, distinguished from each other by their **electrolyte**. The electrolyte determines the operating temperature of the cell, and therefore its application. Two major obstacles remain to the development of commercial applications for fuel cells: technological difficulties (they are not compact enough, the materials wear out too quickly, their energy efficiency could be improved) and manufacturing costs.

Current research is aiming to reduce costs while improving performance. It is revolving principally around two families of solid electrolyte cells.

- The proton exchange membrane fuel cell (PEMFC) operates at 80°C with a polymer electrolyte. This looks the most promising for transport. Current prototypes for vehicles stand at 7,600 euros/kW. The challenge for researchers is to bring the cost down to below 50 euros/kW. One variant, the direct methanol fuel cell (DMFC)

or direct ethanol fuel cell (DEFC) operates on the basis of direct consumption of the hydrogen contained in alcohol. This very compact fuel cell looks suitable for powering microelectronics and portable equipment.

- The solid oxide fuel cell (SOFC) looks appealing for stationary applications, because its very high operating temperature (in the region of 800°C) enables the direct use of natural gas without reforming. Any residual heat could be used in turn, either directly or to produce electricity using a gas turbine. This would give an overall efficiency of up to 80%.

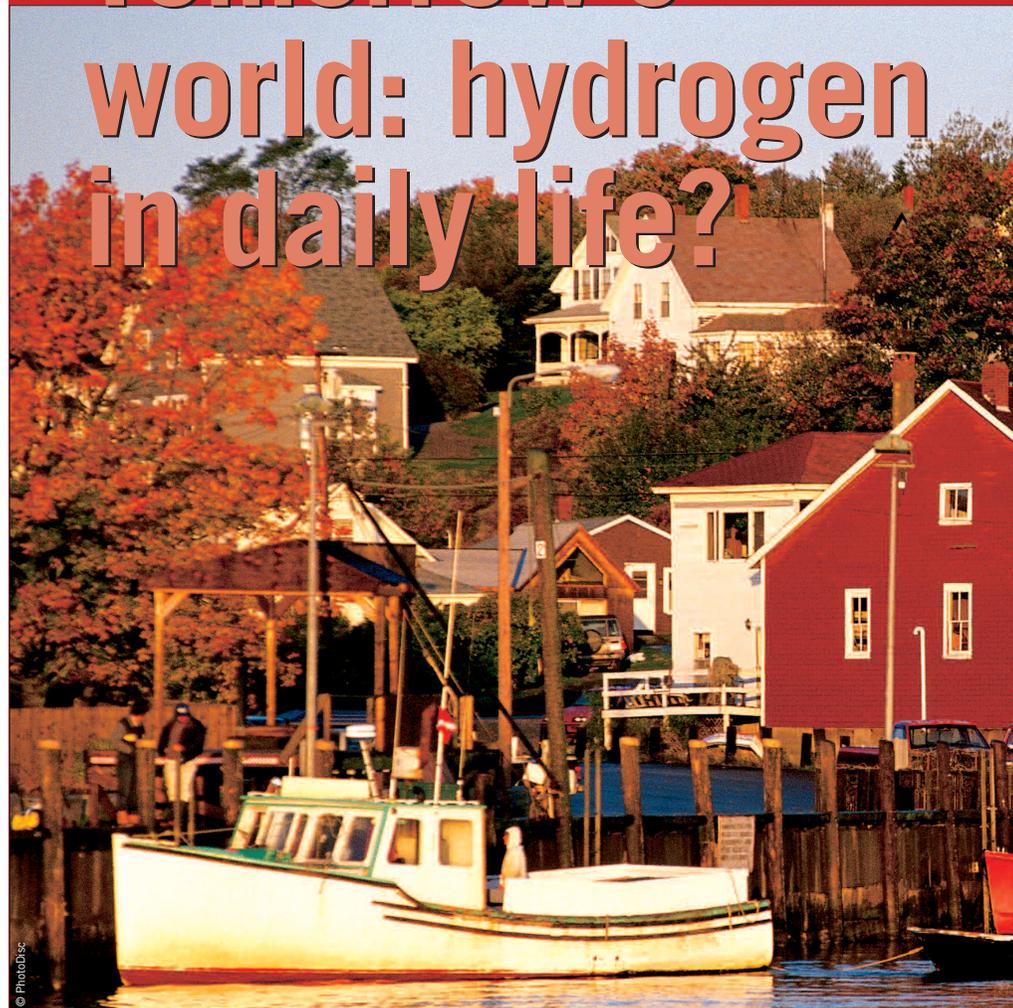


Hydrogen micro fuel cell and methanol micro fuel cell being tested.

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SAFETY STANDARDS FOR THE PRODUCTION, STORAGE, TRANSPORTATION AND USE OF HYDROGEN ARE CURRENTLY BEING PREPARED.

Tomorrow's world: hydrogen in daily life?



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PROGRESSIVE ADOPTION

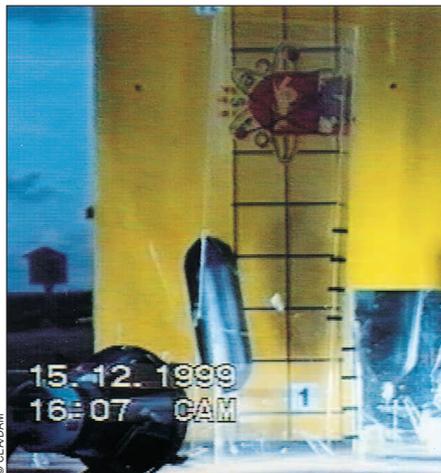
Many prototypes already exist for fuel cells, storage tanks, vehicles and service stations. Despite this, hydrogen will only enter our everyday lives very slowly.

By 2005, the first portable devices fitted with micro fuel cells should have been developed. In the transport field, car manufacturers are predicting the first applications of hydrogen by 2008 in "captive fleets": buses and service vehicles have mandatory passing and stopping points, making refueling easier. These vehicles also have fewer problems in terms of storage volumes. A few prototypes are already in circulation. The first private cars should begin to penetrate the market between 2010 and 2020.

Stationary applications (see p. 9) could start **supplying buildings with heat and electricity, etc.** to come onto the market by 2010.

HYDROGEN AND SAFETY

Although commonly used in industry, hydrogen is often thought to be a dangerous gas. This image is mainly linked to the Hindenburg airship disaster in 1937, even though we now know that the real cause of the fire was not hydrogen but the highly inflammable nature of the paint covering the jacket. At the start of the 20th century, hydrogen was widely used by the general public in town gas. This mix of hydrogen with carbon monoxide was dropped not because of the hydrogen, but because carbon monoxide is highly toxic. Hydrogen does have to be used with



14 m drop test on a high-pressure hydrogen tank.

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care, but it is no more dangerous than natural gas. There are just different risks.

To ensure the safe use of hydrogen, it is essential to avoid all risk of escape, because hydrogen is flammable and explosive and any **confined** situation could be dangerous. This

We talk about a confined situation when hydrogen is imprisoned with air in an enclosed environment.

requires the use of suitable safety devices (fans, detectors, etc.). Studies have been conducted at every stage of production and use to overcome these risks. For example, CEA is carrying out bursting, drop and perforation tests on the high-pressure tanks it is developing.

It is also important for common usage regulations to be defined. A hydrogen economy cannot be established without harmonization of standards and regulations at European and international level. In 1990, the International Standards Organization (ISO) set up a technical committee to prepare standards in the field of production, storage, transportation and the various applications of hydrogen. The European EIHP project (European Integrated Hydrogen Project), for example, issues proposals for legislation regarding hydrogen vehicles and distribution infrastructure.



The use of hydrogen to heat and supply electricity to homes could become a reality by 2010.

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