Hydrogen

Introduction

The hydrogen used for the production of energy is gas molecule hydrogen, identified with the formula H2. It is a molecule that has been known for over 200 years, and when it burns it frees energy, producing only water. However on the Earth there are no molecule hydrogen deposits, as in the case of fossil fuels. It is a molecule that is found in great quantities in nature, but only in combination with other atoms to form, for example, water or methane. Due to the simple fact that on the Earth there are none, hydrogen is not a primary source of energy, in order to use it, it must be produced, using energy. In any case, only when it will be produced in a sufficiently economic manner will it be used as an energy vector, and only after having solved the problems tied to the fact that it is a gas that is difficult to transport, store and use.

Hydrogen knowledge

What it is

Natural hydrogen is a colourless, odourless and non-toxic gas. It is very light, 14.4 times lighter than the air. Consequently, natural hydrogen alone cannot be found on the Earth since it disperses into the outer space. Researchers say that hydrogen only represents 0.9% of the Earth's crust components. It can be found in elementary state in volcanic emissions, fumaroles, and oil springs. However it is present combined with other elements in many compounds such as water, mineral substances, hydrocarbons such as oil and methane, coal, animal and vegetal organisms, and organic substances. Therefore, if natural hydrogen is to be found, it will be necessary to consume much energy to extract it from the substances that contain it. This is why hydrogen is not a primary energy source, but an "energy carrier", i.e. a form of energy that is not naturally available (as the case is with natural gas, oil or coal).
In the gaseous state it is a good fuel, albeit less dense than natural gas.
When it is burnt, it produces a quantity of heat expressed in Joules per kilogram 2.6 times greater than the energy produced by burning natural gas. Another feature is that it tends to form hydrides, i.e. solid compounds, when it gets in contact with most of elementary metals, thus making them more fragile.
If it is cooled at a temperature of –253°C, hydrogen becomes liquid and in that state it does not react chemically with metals. This is the reason why it is difficult, in the gaseous state, to use pipelines to transport it, whereas it is easier to transport it when it is liquid.

Production from fossil sources

The technologies for the production of hydrogen from fossil fuels are mature and widely used, even though they should be improved from an economic, energetic and environmental point of view.
These processes are bases on the production of hydrogen through different refining stages and fractioning of hydrocarbon molecules until the complete elimination of carbon is obtained.
In this way a huge quantity of hydrogen is currently produced, for example all the hydrogen consumed by the chemical sector to produce synthesis fertilizers and by the metallurgic sector, for steel production.
From oil and methane
To extract hydrogen from oil or methane water steam is used at a temperature of 800°C along with a material that speeds up the process (catalyst): carbon oxidizes, hydrogen is freed from the molecule and carbon dioxide (CO_2) is released. Through this operation, called reforming, impure hydrogen is obtained, i.e. it is mixed with another gas, carbon monoxide. To obtain pure hydrogen also this gas needs to be eliminated. This procedure is technically well experimented and is carried out at industrial level with large reactors, with a capacity of 100,000 cubic metres per hour.
Another system to produce hydrogen is cracking, which consists of breaking the methane molecule through thermal systems. This system does not produce carbon monoxide but coal and it is not among the most efficient systems.

From coal

To obtain hydrogen from coal a procedure called gasification is carried out: coal is made to react with water steam at 900°C, and then at 500°C with another catalysing compound. The resulting gas, formed of hydrogen and carbon monoxide, was once used as city gas. In the United States, over the last few years efforts have been made to carry out this operation directly in the mines, where waste could be confined, thus preventing the pollution of other areas.

Production from biomass

With regard to the production of hydrogen from biomass, no process has yet reached a mature level from an industrial point of view.
One of the most used techniques to obtain hydrogen from biomass is pyrolysis, that is a process based on thermal decomposition, which breaks complex molecules of organic substances into simple and separate elements. Pyrolysis consists of heating the substance at 900-1000°C, in the absence of air, with adequate equipment, in order to obtain volatile substances and a solid residue.
Very small organisms, called photosynthetic micro-organisms, produce hydrogen with the aid of solar energy. Many researchers are now trying to understand how it is possible to obtain quite large quantities of hydrogen by using these micro-organisms. This is called photo-biological technique, and it is based on the use of solar energy combined with biological systems like algae, micro-organisms, organic waste. In particular, the studies are involving genetic engineering in order to optimise hydrogen production with the use of photosynthetic micro-organisms.
Some researchers are testing the production of hydrogen from “wet waste”, or waste water of food-processes through anaerobic bioreactors, which exploit fermentation phenomena: these techniques are called biochemical techniques. This is a promising technology and, even thought it is still at an experimental stage, researchers think they will be able to obtain commercial systems in the medium-short term.
All the above-mentioned alternatives require a significant commitment to research, development and demonstration, even if at different levels. However, they are all promising alternatives, also considering the different materials that need to be used.

Production from water

Hydrogen can be produced from water by splitting the molecule into its components (hydrogen and oxygen) through different processes, among which the most consolidated is electrolysis.
Electrolysis is the scission of water through the use of electric energy according to the following reaction: water plus electric energy equal hydrogen plus oxygen.
Electric energy could be produced in plants that exploit renewable sources. In order to obtain a cubic metre of hydrogen in the gaseous state 4-5 kW/h of electric energy are needed.
The main problem is still the cost. It is true that water electrolysis produce pure hydrogen, but the price will be acceptable only when technological innovations allow to produced electric energy from renewable sources at extremely low costs.
An experimental system to separate water is thermo-electrolysis: by applying the electrolysis on high temperature vapour (900/100°C) the result is hydrogen with 2.4 kW per cubic metre. However electrolysis efficiency is directly proportional to temperature: at 15-20°C, in order to separate water, 83% of the reaction energy must be electric energy, while at 1000 °C the percentage is reduced to 65%. High temperature vapour could be obtained from geothermal fumaroles or concentration thermo-solar power plants.
Other experimental processes are:

- photo-conversion that separates water by using biological organisms or synthetic materials;
- photo-electrochemical techniques that generate electric power;

- by using catalysing systems or semi-conductors that, associated to the sunlight, are be able to separate water molecules;
- thermolysis that separates water molecules by using heat. It requires very high temperatures, i.e. around 3000°C (with many problems deriving from such temperatures).

A bit of history

The use of hydrogen as fuel was already known around the 1950s. At that time in big Italian cities, and still today in some European cities, the so-called “city-gas” was distributed for household heating purposes. That gas was a mixture of hydrogen (approximately 50%) and carbon oxide, achieved through the reaction of carbon and water steam.
Many people still associate hydrogen to the memory of the first German airships, the mythical Zeppelins, “filled” with hydrogen (lighter than the air) and very famous thanks to their transatlantic routes. Unfortunately, tragic memories emerge too.
To highlight the dangers of hydrogen, the tragedy of the Hindenburg airship is often mentioned, which exploded and fell on the ground in 1937. A more accurate analysis actually showed that the presence of hydrogen was not the main cause of the tragedy. Recent studies tend to give the responsibility for the accident to the very flammable airship cover.
Over the years, the sector stimulating most research projects has been the transport sector. For decades, for example, the use of hydrogen has been proposed to replace the fuel currently used in airborne transport, mainly because hydrogen is much lighter. The first experiments in this field date back to 1957, when the United States built a hydrogen-propelled B-57 bomber (a military plane).
In the road transport sector, at the beginning of the 1970s an engineer from Turin, Massimiliano Longo, developed a system to use hydrogen in cars. This possibility became strategic with the development of fuel cells over the last decades. Actually, in 1939 the British physic William R. Grove had already shown that the electrochemical combination of hydrogen and oxygen generates electricity. During an experiment, he managed to generate electric energy in a cell that contained sulphuric acid. Inside the cell, two electrodes, made up of two thin platinum layers, respectively attracted hydrogen and oxygen.
Nevertheless, fuel cells based on this principle remained a lab prop for over 50 years, i.e. until the ‘60s, when NASA started implementing light (and very costly) versions thereof as energy source for spaceships. At the beginning of the 1950s, the U.S. financed research on a new type of bomb characterised by greater destructive potential than the atomic bomb. The project was entrusted upon a group of scientists headed by Edward Teller and led to the implementation of a new generation of bombs, called “H” bombs or “hydrogen bombs”, the destructive power of which was astonishing, as shown by the first experimental explosion on the 1st November 1952 on the small island of Eniwetok, one of the Marshall Islands (South Pacific). The 65-tonne bomb dug a 3 km wide and 800 m deep hole, virtually annihilating the whole island. Such bombs were never used during a war, but many experimental tests were carried out with undesired effects. In particular, the radioactive fall-out can contaminate food and cause serious diseases such as cancer. Partly to reduce such dangers in August 1963 the United States, the Soviet Union and Great Britain signed a treaty to ban any experiment with any kind of nuclear weapon in the atmosphere (including the hydrogen bomb), in the space or underwater. Since then, many nations signed the treaty. However, some countries have not signed it yet and still carry out experiments in the atmosphere.

Storage and transport

How it's transported

Hydrogen not only needs to be produced, but it also needs to be transported and stored in the place of consumption. Such activities are particularly difficult due to the characteristics of hydrogen. It is flammable, has a low density and is easily dispersed into the air. Preservation and transport still make a widespread use of hydrogen quite difficult. In the last few years different storage systems have become more and more efficient and suitable for many applications.

Hydrogen can be built-up and transported in gaseous, liquid state or absorbed by special materials. Each way has some pros and cons. Anyhow it is necessary to make significant progress in terms of R&D in order to make hydrogen more reliable and economically competitive (i.e. to build a suitable network for car supply).

Storage of compressed hydrogen

The easiest and most economical way to accumulate hydrogen, and use it, is in the form of compressed gas at a pressure of 200-250 bar (and over). Tanks containing compressed gas are the simplest mode of transportation, however this method is limited by the fact that hydrogen needs very large containers, up to three times the size of the tanks used for methane and ten times the size of those used for petrol. Therefore this technology is not so suited for use on traditional cars, due to the weight and volume of the tanks that are currently used, which can provide a limited range besides a limited loading capacity of the vehicle. Recently, remarkable progress has been made with the introduction of metal structure tanks, or thermoplastic structure tanks reinforced with carbon fibre, glass fibre and other materials, whose weight is 3 to 4 times less than the common tanks, so that it has been possible to overcome most of the inconveniences of using the traditional tanks. These tanks can reach pressures up to 350 bar (potentially up to 700 bar) and therefore it is possible to obtain a hydrogen accumulation density that is suitable for vehicles. The safety specifications are usually very high due to the robust nature of the tanks and due to the introduction of explosion-proof devices in case of fire, and circuit breaker valves in case of impact.

Storage of liquid hydrogen

In order not to use big containers, it is possible to make use of liquid hydrogen, which occupies less volume than methane. But also this method causes some difficulties: hydrogen becomes liquid at –253°C and in order to keep it in this state special tanks and lots of energy are needed. Moreover, there are many problems related to safety (losses during refuelling or in case of accident). For this reason the most modern tanks for cars are made up of two very resistant steel layers with an empty space in between. Storage in liquid state is probably the best technology as it satisfies car requirements. However, it also has some cons, for example: the system is much more complex, not only on board of the vehicle but also on earth, when dealing with the distribution and refuelling, as well as higher costs connected to it. Also the energy cost for liquefaction is high, as it amounts to 30% of the energy content of the fuel, while cost for compressed hydrogen is between 4% and 7%.

Chemical storage

Other technologies exploit the ability of hydrogen to bind to chemical compounds or metals in order to facilitate its storage and transport. Hydrogen can chemically bind to different metals and metal alloys by forming hydrides, i.e. compounds that are able to trap the hydrogen at relatively low pressures (the gas penetrates inside the crystal lattice of the metal) and release it at high temperatures. This technology allows to reach energy densities that are potentially higher than compressed hydrogen and can be compared with liquid hydrogen. Storage volume could be reduced by 3-4 times, making its use in cars possible, while specific energy depends on the specific gravity of the basic metal. The percentage of hydrogen weight as compared to the total metal weight varies from 1% to 12.7% (lithium hydride), while for ordinary bottles that percentage is slightly higher than 1%. Despite all these positive characteristics, there are still many problems to be solved in order to have a competitive storage. For example, it is necessary to work better to improve the structural and thermal stability of the material, to make pressure and temperature compatible with the expected applications, etc. Anyhow, at present, the available materials provoke a very heavy storage: with the same weight, the vehicle has three time less autonomy than what would be obtained with liquid or compressed hydrogen and advanced tanks. Instead, there are clear advantages in terms of convenience, compact shape, and safety. As an alternative, it is possible to transport molecules rich in hydrogen from which the gas can be extracted only where and when it is needed by means of a device called reformer (but in this way a certain quantity of waste will be obtained, too). There are different molecules that could be used in order to reach this objective, like methane (CH_4) and methanol (CH_3OH). These chemical procedures are advantageous as they allow to use already-existing transport and storage facilities. Although they are very promising, these technologies have many negative characteristics: methanol, for example, is toxic. At the moment a chemical compound, sodium boronhydride, is being tested, as it is able to bind with plenty of hydrogen. A aqueous solution, composed of half of sodium boronhydride and half of water, supplies hydrogen with an energy ratio that is similar to petrol, in terms of volume. Sodium boronhydride without hydrogen converts into borax, a substance that is present in ordinary detergents and that can be used again.

Storage in carbon nanostructures

An extremely recent experimental technology for hydrogen accumulation consists of using carbon nanostructures (carbon nanotubes and nanofibres), i.e. microscopic structures made of carbon fibres inside which it is possible to store a certain quantity of hydrogen. Discovered at the beginning of the '90s, they are showing a good capacity to absorb hydrogen, with sometimes impressive results. Several research groups are working on these materials, but the results obtained so far are still contrasting and difficult to compare, since the tests were made on samples of different materials, at very different pressure and temperature conditions.

Storage in crystal micro-spheres

A new promising technology to store hydrogen is based on the use of crystal micro-spheres with 25-500 micron diameter (a micron corresponds to a thousandth of a millimetre) and with walls that are a micron thick. When heated up to 400°C, the crystal wall of the micro-spheres becomes permeable to hydrogen. In this way it is possible to "trap" the gas inside them and transport it as fine dust in low-pressure micro-spheres. The extraction of hydrogen is obtained by heating the micro-spheres that, after being emptied, can be filled again. Hydrogen can be released also by breaking the spheres, although in this case they could not be recycled.

The distribution

According to the quantities, hydrogen can be transported through tankers and hydrogen pipelines. The two possibilities significantly differ in costs and therefore only technical-economic assessments can determine the best solution for each case. The long experience in the gas sector can be directly used to create hydrogen distribution networks, which are quite similar to natural gas existing networks. The main differences include the materials used (some types of steel are more compatible with hydrogen) and the design criteria for pumping stations. In fact, hydrogen requires three times as much pumping pressure as methane due to its lower density. Moreover, if the ideal diameter of a gas pipelines is 1.4 metres, the ideal diameter for hydrogen pipelines is 2 metres. However, although it has a lower energy density than natural gas, hydrogen is less viscous than natural gas. As a consequence, the energy needed for its pumping is similar to the energy required for the same quantity of natural gas. Large hydrogen pipelines are present in several countries. In northern France there is a network of around 170 km, while in Europe the total length amounts to more than 1500 km. North America has more than 700 km of pipes for the hydrogen transport. The distribution networks for liquid hydrogen result to be particularly expensive and difficult to manage. They were created only for highly specialized applications, like the refuelling of space ships.

Uses

Using hydrogen

The annual production of hydrogen amounts to 500 billion cubic metres, corresponding to 44 million tons, that are obtained as follows: 90% is obtained from the reforming chemical process of light hydrocarbons (mainly methane) or from the cracking of heaviest hydrocarbons (oil) and 7% from coal gasification. Only 3% comes from electrolysis. Hydrogen can be used to produce other compounds or as a fuel to produce energy. In particular, the hydrogen produced is used in the chemical industry, to produce ammonia, methyl alcohol (methanol), fertilizers for agriculture and oil products, as well as being used in the metallurgic industry for metal treatment.

Hydrogen is also an excellent fuel. It can be used to produce energy in two ways. The first method is by burning hydrogen alone, or added to other fuels. The second method is based on a chemical reaction between hydrogen and oxygen (without burning it), obtaining electric energy directly through a device called fuel cell.

Directly as a fuel

The combustion of hydrogen does not provoke particular problems and produces emissions that are much less polluting than other fuels. Combustion in the air produces water, un-burnt hydrogen and traces of ammonia. Thus, using this gas to supply a household boiler or a car engine, energy would be produced avoiding the emission of toxic substances. For a few years now, hydrogen vehicles have been circulating experimentally. Moreover, any other fuel mixed with hydrogen improves its combustion and efficiency. Therefore, in the United States the use of methane to which hydrogen is added in the tune of 15% of the weight – commercially known as Hythane – is being assessed.

Fuel cells

Hydrogen can be used to supply cars operated with fuels cells. Liquid hydrogen is also used as a fuel for the cells that supply electricity to activate the equipment on board of space ships. The water obtained as a by-product from fuel cells can be drunk by the crew. As well as in transports, fuel cells could be usefully applied in buildings.

Finally, hydrogen could soon supply many popular electronic devices, such as mobile phones, laptop computers, toys, that today require heavy and expensive batteries. A miniature fuel cell is light, cheap and lasts longer than an ordinary battery. Mobile phones, for example, could work constantly for months, and it would be sufficient to periodically buy a small tube of fuel rich in hydrogen (such as methane or methanol) to be inserted into the device, in order to supply the small fuel cell.

Fuel cells

The devices that use hydrogen to directly produce electric energy are called “fuels cells”. Hydrogen fuel cells are electrochemical generators where electric energy is produced from threaction between a fuel (hydrogen) and a gaseous oxidizing compound (oxygen and air). Together with electricity, heat and water are produced.

A fuel cell is made up of two electrodes of porous material, namely the cathode (negative pole) and anode (positive pole). Electrodes act as catalytic sites for the cell reactions that mainly consume hydrogen and oxygen, with water being produced and electric power running in the external circuit. Between the two poles there is an electrolyte, that has the task to drive the ions produced by a reaction (the one occurring in the anode) and consumed by the other reaction (the one occurring in the cathode), closing the electric circuit inside the cell (see image).

The electrochemical transformation is accompanied by the production of heat, which has to be extracted in order to keep the cell functioning temperature constant. This structure is completely similar to the structure of ordinary electric batteries but, differently from them, hydrogen fuel cells consume substances that come from outside and therefore can work without interruptions as long as they are supplied with fuel and oxidant.

The cell has a flat three-layer structure: the central layer, between the cathode and the anode, is made up of or contains the electrolyte. Individual cells overlap and are connected in such a way to obtain the desired voltage. A pile of cells is called stack.

Usually a fuel cell plant includes, as well as the electro-chemical part, a power converter and a transformer that convert continuous power generated by the stack into alternated power.

Fuel cells are different according to the chemical nature of the electrolyte and their functioning temperature. Those cells that release temperatures between 60 and 200°C are called low-medium temperature cells, while high temperature cells release a temperature up to 1000 °C. The latter are often used for applications that require both electricity and heat. Low-medium temperature cells cause fewer technological problems than high temperature ones, but have a worse performance.

The technology that exploits hydrogen as an energy source is now rapidly developing both for stationary applications (which do not move, like industries, households) and moving systems (transport).

Fuel cells are extremely interesting as far as electric energy production is concerned, as they have advantageous energy and environmental characteristics:

- high electricity performance, with values between 40-48% (referring to the minimum calorific value of the fuel) for low-temperature cell plants, up to 60% for high temperature cell plants
- extremely low environmental impact, both with regard to gaseous emissions and acoustic emissions. Therefore plants can be located in residential areas, making the system particularly suitable for the production of the electric energy to be distributed
- cogeneration possibility (associated production of electric energy and vapour): co-generated heat can be available at different temperatures, as vapour or hot water, and used for sanitary aims, air conditioning, etc.

One of the biggest “fuel cell” electric power plants is located in Bicocca, Milan (1.3 MW power).

Hydrogen vehicles

In this sector both internal combustion engines and fuel cell engines are being developed. The latter are essentially important in order to obtain a transport system with a minimum environmental impact.
In the first case, the engine has cylinders and pistons, it burns hydrogen instead of petrol or gas oil and does not force to review the internal combustion engine technology. In the second case, fuel cells produce power and supply electric engines.
One of the advantages in the use of fuel cells for vehicle propulsion is their energy performance. In fact, 50% of the energy produced by the fuel can be used to move the vehicle, while with petrol engines the maximum percentage amounts to 40%. Moreover, in urban traffic, energy performance of hydrogen vehicles is twice as much as traditional cars. Finally, exhaust materials only consist of aqueous vapour, therefore with no environmental impact.
Hydrogen is supplied to the vehicle cells from a tank where it is kept in liquid or gaseous state. As an alternative, it can be extracted from hydrocarbons, such as methane or methanol, directly on board, through a reformer. At present the possibility to use sodium boronhydride and sunflower oil is being evaluated.
The characteristics of fuel cells allow to build vehicles of different dimensions (from bicycles to cars, buses, locomotives) by using the same technology and with a similar performance, consumption and environmental impact.
At the moment many car manufacturers are making experimental models of hydrogen cars and buses (see image). Some prototypes are already circulating in several Italian and foreign cities.
The problem related to the development of hydrogen vehicles, as well as the production of this fuel, is that there is no distribution network and there is a lack of refuelling stations for this gas. Today hydrogen refuelling stations are very rare. The only two are in Berlin and Munich, and a third one is being built in Milan, close to Bicocca “fuel cell” plant.
Among technological problems, one of the most critical difficulties is the storage of hydrogen on board, as it heavily affects the autonomy of the vehicle due to the excessive weight and tank volume.

Sustainable transport

In particular hydrogen can offer a solution to the problem of emissions (including greenhouse gas emissions) generated from the transport sector. Estimates say that the global emissions of carbon dioxide associated to energy will increase by 1.8% between 2000 and 2030, increasing by 70% as compared to today’s levels. Electricity production and transports will represent almost ¾ of the new emissions and estimates say that the global emissions in the transport sector will increase by more than 85% between 2000 and 2030, and at that time transports will represent almost ¼ of the global emissions associated to energy. Hybrid vehicles with internal combustion engine working with fossil fuels or fuel cells, could reduce CO2 emissions by approximately 25% as compared to the most advanced internal combustion engines. However, significant emission reductions can be obtained only with the introduction of totally renewable fuels.
Several fuels deriving from biomass offer interesting alternatives in the short-medium term: the biodiesel obtained fro

oleaginous seeds, bioethanol obtained from plants rich in sugar and starch, ethanol, etc. It seems, however, that hydrogen has the highest potential in the long term as a renewable transport fuel, thanks to the wide range of resources it can be obtained from, its efficiency in fuel cell vehicles and the absence of emissions.

Why hydrogen

Hydrogen is a gas that burns in the air according to a simple reaction: hydrogen plus oxygen equal water and heat, resulting in the production of pure water. It can be produced from fossil sources, renewable sources and nuclear sources; it can be distributed into the network quite easily according to its end use and the development of transport and storage technologies; it can be used for different applications (centralized or distributed electric energy production, heat generation, engine propulsion) with no or extremely reduced environmental impact.

Therefore we can say that hydrogen is the ideal component of a future sustainable energy system. It gives an incentive to the widespread use of renewable sources, but already in the short-medium term it will make fossil fuels compatible with environmental needs.

Its characteristics make hydrogen complementary to electricity (which is another energy carrier), although the former can be accumulated and transported. Hydrogen, then, can pave the way to renewable energy sources distributed all around the world, by providing Third World countries with the chance to export energy and be more independent from fossil fuel exporting countries.

Safety

There are still many doubts about the safety of this energy carrier, mainly because it is still scarcely known. Anyhow, a more careful analysis reduces the concept of hydrogen dangerousness.

This gas is less inflammable than petrol (it has a higher self-ignition temperature). Hydrogen is the lightest element and therefore can be rapidly diluted and dispersed into the open space.

It is almost impossible to make it explode, unless in a closed space (in order to find potentially dangerous concentrations, sensors are used to easily control suitable safety systems). Moreover, when it burns, hydrogen burns out very rapidly, always producing vertical flames.

Instead materials like petrol, gas oil, LPG or natural gas are heavier than the air and, as they do not disperse, they remain dangerous for much longer. It was calculated that a petrol vehicle on fire burns for 20-30 minutes, while a hydrogen vehicle does not burn for more than 1-2 minutes. Moreover, with hydrogen flames, the surrounding materials may also be set on fire. In this way the duration of the fire is reduced even more, and the danger of toxic emissions is also reduced.

Hydrogen, differently from fossil fuels, is not toxic, nor corrosive and any losses from the tanks do not provoke pollution on the soil or in aquifers.

Clean hydrogen

Hydrogen is an extremely environmentally friendly fuel. Its combustion produces water and small quantities of nitrogen oxides. Moreover, hydrogen can be extracted from a range of compounds and this is one of the aspects that make it considered as the fuel of the future. In order to produce hydrogen it is necessary to consume energy, and this operation has certain costs. When hydrogen is extracted from fossil fuels, a large quantity of carbon dioxide is produced. Carbon dioxide is one of the gases that provoke global warming (greenhouse effect). The idea is to create big plants to produce hydrogen from fossil fuels and collect the produced carbon dioxide, preventing if from dispersing into the atmosphere. When hydrogen is extracted from water through electrolysis, carbon dioxide is not produced. But electric energy has to be used in order to carry out the process. If this energy is produced from a thermoelectric power plant, as it normally happens, we have to take into account the pollution that the plant generates. The production of hydrogen from renewable sources is to be considered a better solution than the production of hydrogen from fossil fuels because it does not produce any polluting compounds, neither during production nor during consumption (in this way also the environmental damage associated to the extraction of fossil fuels from deposits is limited. In fact, oil drilling, transport, refining and waste significantly contribute to the pollution of the planet). In fact, with electrolysis the whole production and consumption of hydrogen is environmentally sustainable, as long as a corresponding quantity of clean electric energy is available, in order to supply the electrolysis process. The sun could be a source for this energy. The sun can be exploited through the use of photovoltaic conversion plants, whose technology can be considered as technically reliable and adequate, even though it is not fully competitive yet. In fact, through the use of photovoltaic solar energy, it is possible to produce electrolytic hydrogen and oxygen that can react inside fuel cells in order to produce the electric energy we need. Pure water is then produced as a final waste, whose amount is very similar to the beginning quantity. In this way the cycle closes without any polluting emission. Last, it is needless to say that oceans are huge reserves of hydrogen: each kg of pure water contains 111 grams of hydrogen that, after being burnt, could produce 3,200 kilocalories of thermal energy. Therefore it would be possible to extract from water all the hydrogen needed to satisfy all human needs in a clean way.