USES OF HYDROGEN

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Introduction

In 2018, hydrogen production stood at around 115 Mt, 97% of which is obtained through the chemical process of reforming light hydrocarbons (mainly methane) or from the cracking of heavier hydrocarbons (oil) and coal gasification. Only 1% is produced by electrolysis and the remaining 2% by other technologies. 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), agricultural fertilisers and petroleum products, and in the metallurgical industry for metal processing.

Using hydrogen

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 spaceships. 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. 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 CO_2 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 from 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.

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