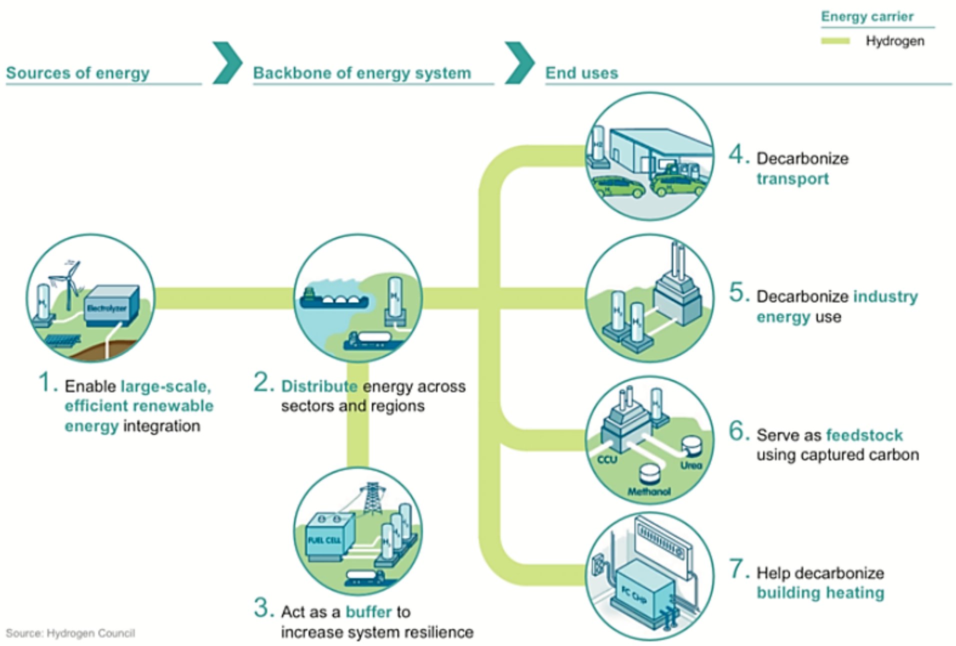
HYDROGEN EUROPE – TECH [Overview]

Hydrogen Applications

Hydrogen is versatile and can be utilized in various ways. These multiple uses can be grouped into two large categories:

1. Hydrogen as a feedstock. A role whose importance is being recognized for decades and will continue to grow and evolve.
2. Hydrogen as an energy vector enabling the energy transition. The usage of hydrogen in this context has started already and is gradually increasing. In the coming this field will grow dramatically. The versatility of hydrogen and its multiple utilization is why hydrogen can contribute to decarbonize existing economies. Hydrogen's role in the decarbonization process can be summarized as shown in the graph below:

Figure 2: Hydrogen has seven roles in decarbonizing major sectors of the economy



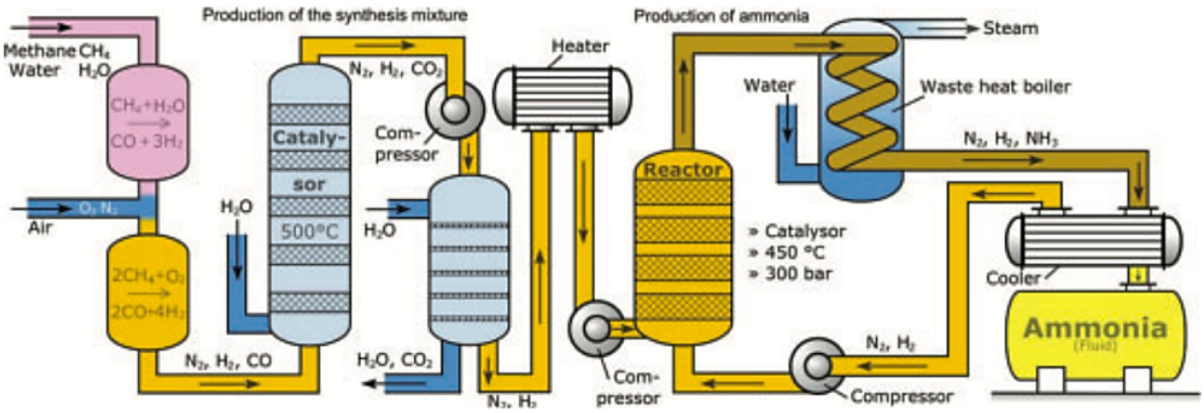
Long established uses – Hydrogen as a feedstock (material based uses)

Nowadays, hydrogen is used in several industrial processes. Among other applications, it is important to point its use as raw material in the chemical industry, and also as a reductor agent in the metallurgic industry. Hydrogen is a fundamental building block for the manufacture of ammonia, and hence fertilizers, and of methanol, used in the manufacture of many polymers. Refineries, where hydrogen is used for the processing of intermediate oil products, are another area of use. Thus, about 55 % of the hydrogen produced around the world is used for ammonia synthesis, 25 % in refineries and about 10 % for methanol production. The other applications worldwide account for only about 10 % of global hydrogen production.

Ammonia - Fertilizers

The most important hydrogen-nitrogen compound is ammonia (NH_3), also known as azane. Technically, ammonia is obtained on a large scale by the Haber-Bosch process. This process combines hydrogen and nitrogen together directly by synthesis. To this end, the starting materials nitrogen and hydrogen must first be obtained. In the case of nitrogen this is achieved by low-temperature separation of air, while hydrogen originates today from natural gas steam reforming.

Almost 90 % of ammonia goes into fertilizer production. For this purpose, a large part of the ammonia is converted into solid fertilizer salts or, after catalytic oxidation, into nitric acid (HNO3) and its salts (nitrates). Owing to its high energy of evaporation, ammonia is also used in refrigeration plants as an environmentally friendly and inexpensively produced refrigerant; its technical name is R-717.



Industrial Fields

Hydrogen is used in various in industrial applications; these include metalworking (primarily in metal alloying), flat glass production (hydrogen used as an inerting or protective gas), the electronics industry (used as a protective and carrier gas, in deposition processes, for cleaning, in etching, in reduction processes, etc.), and applications in electricity generation, for example for generator cooling or for corrosion prevention in power plant pipelines.

The direct reduction of iron ore – i.e., the separation of oxygen from the iron ore using hydrogen and synthesis gas – could develop into an important industrial process in steel manufacturing, because in the traditional blast furnace method large amounts of carbon are released. While direct reduction with natural gas is now well-established in steel production (World Steel Association 2015), corresponding production methods based on hydrogen so far exist only on a pilot scale.

Fuel Production

Hydrogen is used to process crude oil into refined fuels, such as gasoline and diesel, and also for removing contaminants, such as sulphur, from these fuels.

Hydrogen use in refineries has increased in recent years for different reasons:

I. The strict regulations that require low sulphur in diesel;
II. The increased consumption of low quality 'heavy' crude oil, which requires more hydrogen to refine and;
III. The increased oil consumption in developing economies such as China and India.

Approximately 75% of the hydrogen currently consumed worldwide by oil refineries is supplied by large hydrogen plants that generate hydrogen from natural gas or other hydrocarbon fuels.

Hydrogen is also an important basic substance for producing methanol (CH 3 OH). The production of methanol (methanol synthesis) takes place by means of the catalytic hydrogenation of carbon monoxide.

Methanol can be used directly as a fuel in internal combustion engines. It is also used in direct methanol fuel cells or, after reforming, in PEM fuel cells. Fuel additives are produced from methanol, and it is used to transesterify vegetable oils to form methyl esters (biodiesel).

Commencing uses - energy based uses

In the energy field, most hydrogen is used through Fuel Cells (FCs). A fuel cell is an electrochemical device that combines hydrogen and oxygen to produce electricity, with water and heat as by-products. In its simplest form, a single fuel cell consists of two electrodes - an anode and a cathode - with an electrolyte between them. At the anode, hydrogen reacts with a catalyst, creating a positively charged ion and a negatively charged electron. The proton then passes through the electrolyte, while the electron travels through a circuit, creating a current. At the cathode, oxygen reacts with the ion and electron, forming water and useful heat.

Hydrogen in transport

Hydrogen fuel is considered a good candidate to contribute to the decarbonisation of the road transport sector if it is produced renewable energy sources through the process of electrolysis. In this case, the main advantages of fuel cell electric vehicles are the zero emission of CO 2 and pollutants (the emission at the tailpipe is only water), and the higher efficiency of fuel cells compared with internal combustion engines. Passenger cars and urban buses, among other vehicles, as material handling equipment, etc., are good examples of the new technology ready for mass commercialization in the coming years.

The application options for hydrogen as a fuel for mobility can be differentiated firstly by the chemical form or bonding of hydrogen and secondly by the energy converter by means of which the energy stored in the hydrogen is made available.

- In direct use, (pure) molecular hydrogen (H2) is used by the transportation means directly, i.e., without further conversion, as an energy source. In this case hydrogen can be used both in internal combustion engines and in fuel cells (fuel cell systems).
- In indirect use, hydrogen is used to produce final energy sources or is converted by means of additional conversion steps into gaseous or liquid hydrogen-containing fuels. Such PtG (Power-to-Gas) and PtL (Power-to-Liquids) fuels can then in turn be used in heat engines. Use in fuel cells would also be possible (in some cases), using a reformer, but it is not economically viable.

Aviation

In civil aviation, hydrogen-powered fuel cells are regarded as potential energy providers for aircraft as they have been in space travel for some time now. Thus, fuel cell modules can supply electricity to the aircraft electrical system as emergency generator sets or as an auxiliary power unit. More advanced concepts include starting of the main engine and the nose wheel drive for airfield movements by commercial aircraft.

Maritime Applications

As in aviation, fuel cells are currently being tested as energy providers for the on-board power supply. The use of hydrogen-powered fuel cells for ship propulsion, by contrast, is still at an early design or trial phase – with applications in smaller passenger ships, ferries or recreational craft. The low- and high-temperature fuel cell (PEMFC) and the solid oxide fuel cell (SOFC) are seen as the most promising fuel cell types for nautical applications (EMSA 2017). As yet, however, no fuel cells have been scaled for and used on large merchant vessels.

Trains

In electric locomotives, motive power is supplied via stationary current conductors (overhead lines, conductor rails) and current collectors on the vehicles. However, for technical, economic or other reasons, not every railway line can be electrified. Especially on lines with a low transport volume, the high up-front investment that is needed for electrification of the lines cannot always be justified. Moreover, overhead lines cannot be used for shunting if cranes are also in use for moving transport goods. In subsurface mining, by contrast, traction vehicles have to operate without air pollutants.

Rail vehicles that use hydrogen as an energy store and energy source can offer an additional alternative. Fuel cell-powered rail vehicles combine the advantage of pollutant-free operation with the advantage of low infrastructure costs, comparable with those for diesel operation.

Material Handling Vehicles

Fuel cell industrial trucks, like forklifts or towing trucks (airports) are especially suitable for indoor operation, because they produce no local pollutant emissions and only low noise emissions. Fuel cell vehicles have advantages over battery-operated industrial trucks in terms of refueling. Instead of having to replace the battery, the trucks can be refueled within two to three minutes.

They take up less space and are cheaper to maintain and repair. Fuel cell industrial trucks allow for uninterrupted use and are therefore particularly suitable for multi-shift fleet operation in material handling (FCTO 2014b). In the case of larger industrial truck fleets in multi-shift operation, (moderate) cost reductions can be achieved in comparison to battery technology, and productivity in material handling can also be increased.

Buses

In terms of road transport, buses in the public transport network are the most thoroughly tested area of application for hydrogen and fuel cells. Since the early 1990s, several hundred buses have been and are being operated with hydrogen worldwide – predominantly in North America, Europe and increasingly also in Asia.

Although hydrogen was initially still used in buses with internal combustion engines, bus developers are now concentrating almost entirely on fuel cell electric buses (FCEB). The use of small FCEB fleets is being promoted in urban areas as a way of contributing to technological development and to clean air policy.

Fuel cell buses have now reached a high level of technical maturity, although they are not yet in series production. Owing to the small numbers, until now they have still been much more expensive, at around 1 million EUR, than standard diesel buses, which cost in the region of 250,000 EUR. The maintenance costs have also been significantly reduced and the reliable operating times increased (Hua et al. 2013).

Depending on annual production numbers, production costs for FCEBs should continue to fall, however, in future projects. The production costs for 12-metre buses are projected to fall to around 450,000 (purchase of 100 buses) EUR by 2020 and to approx. 350,000 EUR by 2030, bringing them within reach of diesel hybrid buses.

Modern fuel cell buses draw their energy from two fuel cell stacks, each with an output of approx. 100 kW. They also have a relatively small traction battery and are able to recover brake energy. In addition, they carry approximately 30 to 50 kg of compressed hydrogen on board, stored in pressure tanks at 350 bar. On the other hand, some battery electric bus models have large traction batteries and only small fuel cell stacks, which are used as range extenders.

Fuel cell buses now have a range of 300 to 450 km and so offer almost the same flexibility as diesel buses in day-to-day operation. While some older municipal buses still consume well over 20 kg of hydrogen (rather than 40 liters of diesel) per 100 km, newer fuel cell buses now use only 8 to 9 kg per 100 km, giving FCEBs an energy efficiency advantage of around 40 % as compared with diesel buses. In order to develop the market, demonstration projects with large fleets in long-term use are planned. The FCEB fleet in Europe is expected to expand from 90 to between 300 and 400 vehicles by 2020.

Read more about fuel cell buses here.

Passenger Cars

Along with battery electric vehicles, hydrogen-powered fuel cell passenger cars are the only zero-emission alternative drive option for motorized private transport. The first fuel cell passenger cars were tested back in the 1960s as demonstration projects. A new boost to fuel cell development came in the 1990s. In most cases the fuel cell test vehicles were converted cars that had originally been fitted with an internal combustion engine. At the time, however, the early test models were still not competitive, either technically or economically. In addition, up until about 10 years ago petrol engine prototypes were still being tested with hydrogen as an alternative energy and low-emission fuel. These were vehicles with modified bivalent engines, which could run on both petrol and hydrogen. Owing to the fuel, hydrogen-powered internal combustion engines not only achieve somewhat higher efficiencies than in petrol operation, they also emit much lower levels of pollutants.

Although hydrogen is a clean fuel with excellent physicochemical properties, it has been unable to gain acceptance as a fuel for motorized road transport. For passenger cars the focus is now almost entirely on hydrogen-powered fuel cells as a source of drive energy.

There is now a wealth of practical experience available with fuel cell prototype passenger cars. A number of major car manufacturers are starting to offer early series-production vehicles which are now just as good as conventional internal combustion engine cars in terms of functionality. The number of fuel cell cars manufactured over the coming years is projected to range from several hundred up to thousands of units. Virtually all fuel cell passenger cars today are equipped with PEM fuel cells, in both series and parallel configurations. The prices for medium-sized vehicles fitted with fuel cells are still well above those for passenger cars with internal combustion engines – at around 60,000 EUR/USD. With the launch of FCEV series production, vehicle cost and prices are expected to fall substantially.

The fuel cell stacks in the latest fuel cell models have an output of 100 kW or more. As compared with battery electric cars they have a greater range – of around 400 to 500 kilometers today – with a lower vehicle weight and much shorter refueling times of three to five minutes. They usually carry 4 to 7 kg of hydrogen on board, stored in pressure tanks at 700 bar.

Read more about refueling stations

Stationary Energy Applications

Electricity Generation

Stationary fuel cells can be used for decentralised power supply in off-grid areas. The market for backup power applications (BUP) is becoming increasingly important. Backup applications include firstly emergency power supply and secondly uninterruptible power supply (UPS).

Emergency generator sets are used for maintaining operation in the event of lengthy power outages. In such cases the switchover from the mains power supply is usually (briefly) interrupted.
Uninterruptible power supplies, on the other hand, are used to protect highly sensitive technical

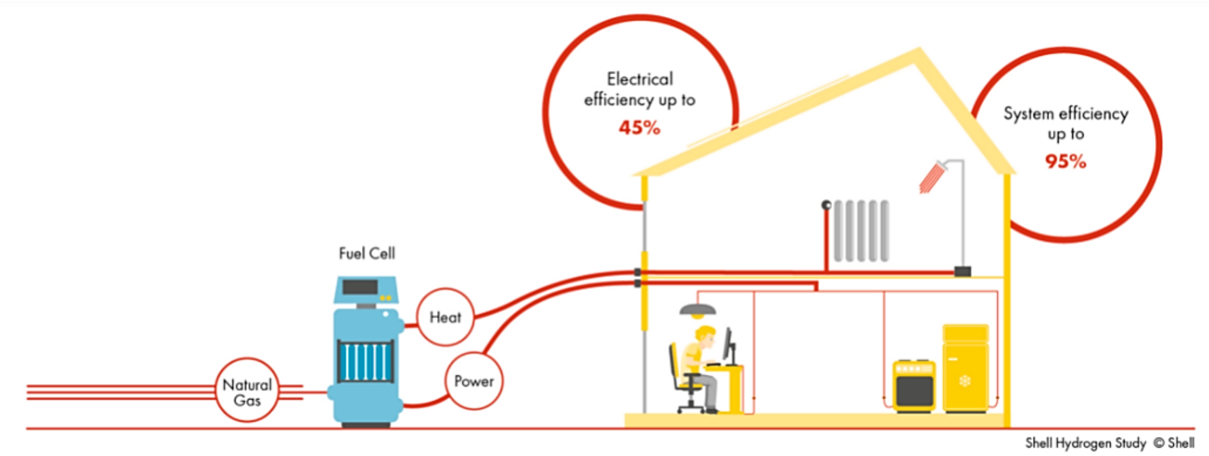
systems against mains supply fluctuations and short-term outages, so as to ensure continuous operation. Areas of use include in particular telecommunications and IT systems, such as radio towers or data processing centers.

In comparison to conventional thermal power plants, fuel cells have much higher electrical efficiencies of up to 60 %, even for small plants. This is advantageous from an exergetic perspective, since a lot of high-value electricity and little heat are produced.

In ongoing operation, fuel cell backups are characterized by the following advantages: long autonomous operation and service life, low maintenance costs due to the lack of moving parts, and quiet, (locally) emission-free electricity generation.

The backup capacity of stationary fuel cells varies from a few kW to over 1 GWe. Fuel cells with low-wattage electrical outputs are often portable fuel cells, which offer weight advantages over rechargeable batteries and generators. A variety of different fuel cell types are used in the stationary sector, in some cases also for cooling. In addition to hydrogen, methanol, natural gas and liquefied petroleum gas are used as fuels.

Domestic Energy



If, in addition to the generated electricity, the heat that is produced is also used, the process is referred to as combined heat and power (CHP). If such plants are used in the domestic heating sector, they are also described as micro-CHP or mini-CHP plants because of their smaller outputs.

CHP plants can be operated with two strategies: The plant covers either most of the electricity or of the heat demand. If electricity prices are high, an electricity-led mode of operation is appropriate. In this way, the purchase of electricity from the grid can be minimized, or the generated CHP electricity can be fed into the electricity grid and reimbursed.

The heat produced as a by-product of combined heat and power is used to cover part of the buildings heat demand. The mostly electricity-led mode of operation results in a low thermal output from fuel cell heating systems. The remaining heat requirement of the building is covered by an additional heating system, e.g. a condensing boiler. For that reason, fuel cells are particularly suitable for buildings with a low space heating requirement, such as low-energy or nearly zero-energy buildings. In buildings with a higher space heating requirement, hybrid fuel cell heating systems, comprising a fuel cell and a condensing boiler to cover peak heating requirements, are used.

Stationary fuel cells in the output range up to 10 kWe are usually PEM or SO fuel cells. The typical CHP output range for houses and apartment buildings is 0.7 to 5 kWe. If fuel cell systems are operated with natural gas as the fuel, an existing natural gas infrastructure can be used. However, the fuel must be reformed first. In the case of PEM fuel cells, reforming takes place externally. Owing to the higher temperatures, internal reforming is possible in SO fuel cells.

Probably the biggest advantage of fuel cells over thermal power processes is the direct electrochemical conversion during electricity and heat generation and the associated higher electrical efficiency. In combined mode, i.e. electrical and thermal, fuel cells can achieve efficiencies of up to 95 %. The electrical efficiency is up to 45 %. Furthermore, fuel cell systems are characterized by high efficiencies over all load points, they are quiet, have low maintenance costs and operate (locally) emission-free.