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THE UTILIZATION OF HYDROGEN AS AN ENERGY SOURCE

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Annotation

This article provides a detailed analysis of hydrogen utilization as an energy source. The main theme focuses on improving in hydrogen utilization from the reformate flow. Presented types of fuel cells, along with the most essential characteristics, show their alternatives in practical use. The procedure describes a current development utilization of hydrogen as an energy source. After evaluation of available solutions, preferred cell types are proposed to be used in these systems. In respect to it, types of hydrogen energy present chosen results, their characteristics, selection criteria and development.

Keywords: hydrogen energy, hydrogen storage, hydrogen anode, hydrogen production, hydrogen utilization.

I. Introduction

The idea of hydrogen utilization for power generation goes back to early 1970 in the context of the energy crisis that was caused by petroleum shortages. Hydrogen is scarcely available in its free form on earth, and hence its use as a fuel implies a hydrogen production step in which hydrogen is extracted from other materials. The sources of hydrogen are abundant: water, biomass, hydrogen sulfide, and even hydrogen-rich petroleum resources. Methods of hydrogen extraction from these kinds of sources were developed well before the 1970s (e.g., water electrolysis, coal gasification, natural gas reforming, etc.). The main issue that arises with applying these methods is related to several parameters, including environmental impact, cost effectiveness, commercial availability, reliability, etc.

In a hydrogen economy, environmentally sustainable hydrogen production methods must be implemented on a large scale. In this manner hydrogen in sufficient quantity can be generated and temporarily stored. Then, hydrogen is used on demand for power generation and any other uses. Of course, for generation of power hydrogen can be directly fed to fuel cells. The only exhaust is steam that is absorbed by nature with no or very limited environmental impact. Other major uses of hydrogen are for methanol and ammonia production. These two chemicals are crucial for the world economy because they are the feedstock for many other major products: formaldehyde, plywood, paints, textiles, fertilizers, and pharmaceutical substances. Besides these uses, ammonia and methanol can be directly used as fuels in fuel cells or engines. Nevertheless, the key element of a hydrogen economy is the development of sustainable hydrogen production on the one hand and effective fuel cell systems on the other.

From another perspective one notes that electrical power cannot be stored in large quantities because there are not any suitable devices to store electrons under fixed differences of potential. Supercapacitors cannot be applied on the scale of regional or national grids to satisfy all storage demand; at most they can dump partially the incidental demand peaks of very short duration. Other energy storage options for electricity grids have their disadvantage: batteries are heavy, costly and have a short lifetime, pumped hydro requires sites where dams can be built which are relatively expensive, compressed-air systems can be applied on an intermediate scale but not region wide; flywheels are applicable on a small scale only.

Power generation through hydrogen and fuel cells requires the development of a specific chain of technologies spanning from sustainable conversion of energy resources to hydrogen, to hydrogen storage, and finally to effective power generation with fuel cells.

The most emphasis is given to fuel cell systems which are introduced in some detail, with their classification and their modeling equations presented thoroughly. Several important fuel cell systems, including integrated fuel cell and gas turbine systems, are introduced, and their efficiencies are defined through energy and exergy analysis methods with some examples and case studies.

II. Methods and Results

Centralized and distributed hydrogen production and utilization are currently used. In both cases, storage is required although with different capacity requirements. Several hydrogen storage issues must be addressed. First, safety is important given the high volatility and high energy of hydrogen gas. Second, storage cost is currently too high with durability issues. Third, the weight and volume are presently too high. Fourth, the overall energy efficiency should be improved. Fifth, the refueling time is too long. Numerous hydrogen-absorbing materials and concepts have been considered to address these issues, although most are not considered economical in the near term. Tank volume and safety issues have been addressed with low-pressure liquefied hydrogen, although more than 30% of stored energy is wasted during liquefaction. A compressed hydrogen tank of 700 bars with hydrogen content in weight of about 11% has been demonstrated. These two storage solutions are below the industry gravimetric and volumetric capacity goals. Indeed, it is suggested that a storage capacity of 6.5 wt% and 62 kg H_2/m^3 are required for the automotive and other applications. For example, hydrogen storage in steel and composite material cylinders allows a maximum of about 1 wt% and 3%, respectively. Nanomaterials in general and NPs in particular may provide viable alternatives [455]. Very high surface area with controlled surface chemistry will allow not only high hydrogen adsorption but also controlled H_2 binding strength with adsorbing sites. Numerous nanostructured materials with large surface area based on carbon structures, metals, and metal alloys have been considered. Up to 2.8- wt% hydrogen absorption – desorption capacity has been achieved under a moderate temperature and pressure conditions. Nickel-catalyzed hydrogen dissociation has been suggested as an effective reversible hydrogen storage method. Stoichiometric Mg_2Ni intermetallic NPs are produced by arc-melting Mg and Ni. These NPs showed excellent hydrogen absorption behavior at low temperature. Hydrogen storage contents of 2.77, 2.93, and 3.03 wt% at 523, 573, and 623 °C, respectively, have been reported within minutes. This suggests very low activation energy. $NaAlH_4$ microparticles doped with 2% mol of TiN NP catalysts have been shown to provide 4.5 wt/% hydrogen storage capacity.

There are a number of hydrogen production and utilization demonstration units in trial around the world, based on a variety of different fuel cell technologies. One such system, which has attracted a lot of attention within the United Kingdom, is the ITM Power HOST (Hydrogen On-Site Trial) unit, which demonstrates on-site hydrogen production via PEM electrolyser technology, compression and high pressure storage of hydrogen gas, and finally dispensing of this fuel gas to on-vehicle storage for use within a hydrogen internal combustion engine (HICE) on a van. Some of the technology used within the HOST unit is illustrated in the following series of images. For example, Picture 1 shows the water processing plant requiring to clean up a typical potable water supply for use within high purity PEM electrolysers.

Picture 1. Water treatment. Courtesy of Dr. A. Cruden.

Picture 2 shows a palladium dryer unit that is used to help purify the hydrogen gas produced from the PEM electrolysers prior to gas compression and storage. This stage helps prevent corrosion issues within the compressor and storage vessels.

Picture 2. Dryer/heater/separator. Courtesy of Dr. A. Cruden.

Hydrogen and fuel cell technologies have been identified as priorities for direct investment by many governments such as those of the UK and other EU countries. These technologies will contribute to tackling the UK/EU climate change targets (80% reduction in CO2/GHGs by 2050) and energy security, whilst providing significant market opportunities to a strong UK/ EU capability base. Many governments have set targets for fuel cell and hydrogen technologies, e.g. increasing durability and performance levels up to 8,000 hours for transport applications and 40,000- hours for stationary applications with target costs of longer term sustainable hydrogen below €5/kg ($6.80/kg).

There are a few challenges related to hydrogen generation, storage and utilization and governments, together with academic and industry researchers, are currently looking to tackle them. These include:

- The design and development of low-cost and efficient hydrogen production systems using novel technologies, with a particular emphasis on the production of ‘green’ hydrogen from renewable sources (biomass, biowaste, electrolysers powered by photovoltaic and wind energy systems, etc.)
- Novel technologies associated with low carbon emission hydrogen production and utilisation from fossil fuels (including hydrogen separation technologies) and distributed hydrogen technologies (in terms of transport, this would include innovative on-site vehicle refuelling systems) and
- The development of novel systems, materials and solutions for hydrogen storage and transportation, with low costs and high energy efficiency (with a focus on systems offering storage solutions suitable for integration with HFC vehicles).

III. Discussion

At any partial pressure of hydrogen, when hydrogen utilization increases, the maximum cathode potential exceeds 0.9 V versus RHE, and there is a high possibility of carbon corrosion. The maximum cathode potential was observed at the fuel outlet area.

The hydrogen supply chain is a concept in the life cycle perspective, consisting of several echelons, including selection of energy source, hydrogen production, hydrogen transportation, hydrogen refueling, and hydrogen utilization subsystems (see Fig. 1). Of course, there is not a unique hydrogen supply chain. Even if there is clear evidence for the use of renewable sources, as already highlighted from an environmental viewpoint, the switch to a 100% renewable scheme can only be gradual, in order to satisfy both economic and environmental concerns as well as to take into account the availability of the energy source. Hydrogen can thus be produced using different energy sources (renewables or fossil fuels) and with different technologies (mainly steam methane reforming (SMR), electrolysis, and gasification) and distributed via pipelines or tube trailers. Fig. 1 also embeds other options that may be encountered.

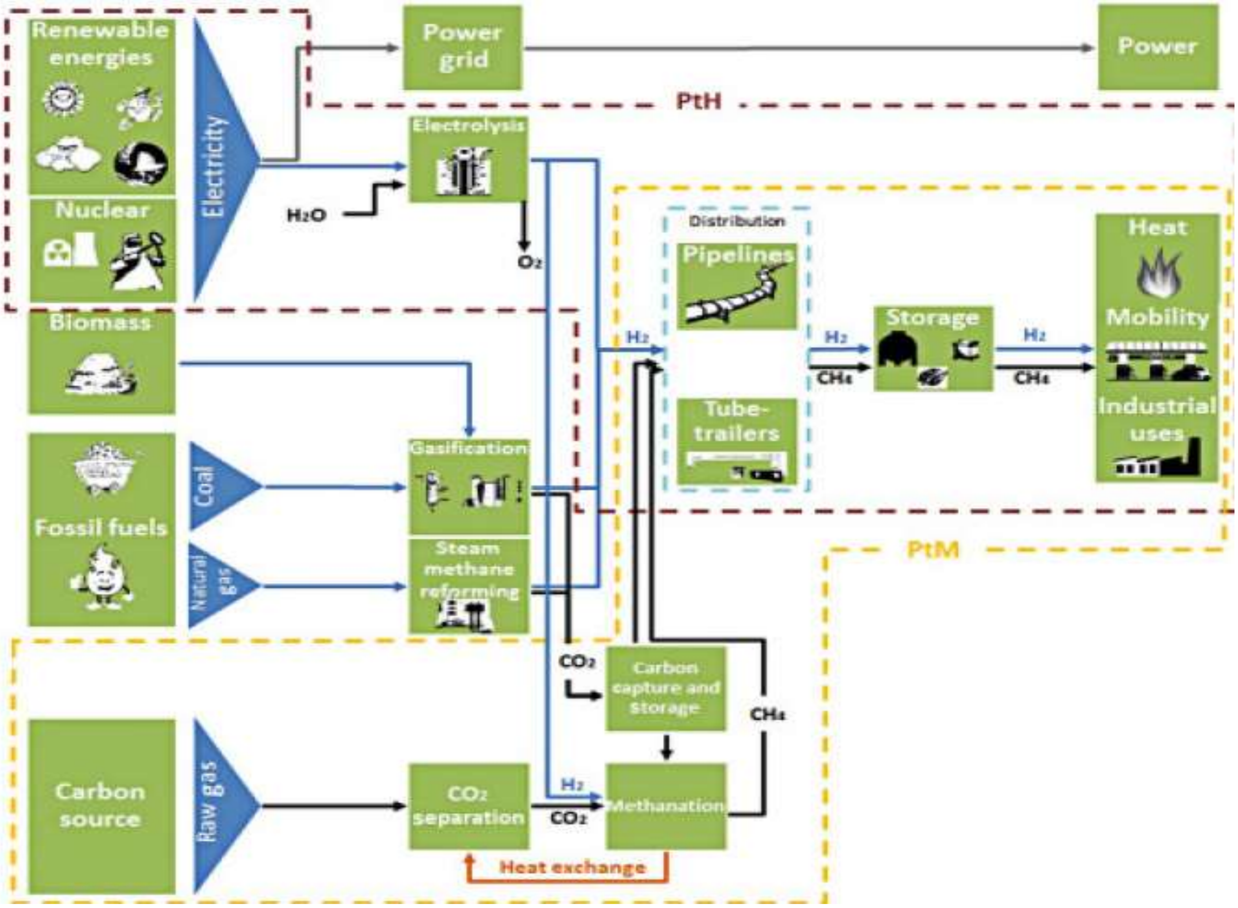

Figure 1. Power to gas supply chain

The key roles of hydrogen in the future energy system emphasize the PtG concept, in particular the PtH one (brown dotted line in Fig. 1). PtG refers to the process in which electrical energy is converted into chemical energy via gas production. The main purpose is to store surplus electricity from fluctuating renewable sources by generating hydrogen (H_2) via water electrolysis, with optional methane (CH_4) synthesis from carbon dioxide (CO_2) and H_2 (methanation process, yellow dotted line). This “green hydrogen” produced by renewable resources without pollution allows for the storage, transportation, and reuse of the energy when needed. The production of synthetic methane (synthetic natural gas, SNG) results in lower total efficiency but could be advantageous in terms of feeding the produced energy carrier into the gas distribution grid. In contrast to the case of pure H_2, the injection of SNG is not limited in amount. The SNG or H_2 can be used not only in electricity production, but also in other applications, such as mobility via fuel cells or natural gas vehicles (Fig. 1). A Power-to-Gas supply chain, as shown in Fig. 1, is ultimately a network of integrated facilities, or nodes, that are interconnected and work together in a specific way. The network begins with primary energy sources and terminates with end uses. A supply chain is not unique, and one typical feature of a PtG supply chain, as a segment of a hydrogen supply chain, is the large number of configurations that can be encountered from energy sources, production, distribution, and storage to final uses. The conversion to hydrogen and methane makes the transport of renewable energy outside the power grid possible, also allowing large-scale, long-term storage. The chemical energy carriers can also be converted to electricity and a multitude of other pathways are possible, resulting in different efficiencies of the total system.

IV. Conclusion

The emerging importance of hydrogen-based energy strategies has recently led to increased research on aspects of hydrogen generation, storage and utilisation. Problems of particular importance for transport applications are the safe storage of a maximum amount of hydrogen, its efficient retrieval from the storage medium and the possibility of re-hydrogenation of the spent material.

From these equations, the voltage change associated with a change in utilization equals that associated with the change in the partial pressure of the reaction gas. Under normal conditions, the coefficient between utilization and voltage remains the same. When some fault such as a problem in the gas diffusion occurs, the utilization property changes.

The change in the local electrochemical potential is also canceled if hydrogen or protons are supplied in abundance from the fuel inlet area to the fuel-starved area. However, since the cell area is quite large compared to the thickness of the matrix layer, protons cannot be supplied sufficiently through the matrix layer. When the fuel gas flow increases, hydrogen can be supplied to the fuel-starved area faster than protons, and the supplied hydrogen is quickly changed to protons. Actually, the flow rate of hydrogen is rather slow compared to that of electrons. Since the cell is mainly made of carbon, which is a good electrical conductor, electron movement from the fuel inlet area to the fuel outlet area is sufficiently fast.

Hydrogen is storable directly in large volumes of compressed gas, absorbed in heavy masses of metal hydride, stored as a cryogenic liquid or be stored seasonally in amounts of tens of kilotons through reversible chemical conversion of ammonia or methanol or other chemical forms. Thus, stored hydrogen can be helpful in overcoming the fluctuating issues with renewable energy sources, such as solar and wind. Furthermore, the possibility of seasonal storage allows for alternating between the more efficient production during winter and the increased demand in summer. Again, fuel cells must be part of the system because they generate hydrogen power on demand in the most convenient manner. Therefore, hydrogen has another major role besides that of being a fuel and a primary material for the worldwide economy. Namely, hydrogen is treated as a basic energy storage option that can moderate between the fluctuating and intermittent nature of the renewable energy availability (solar, wind, tidal, etc.) and the rather constant demand for electric power. Because of its roles as a synthetic fuel and energy storage capability, hydrogen is denoted as an energy carrier.

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