



Original Research Article

Fusion of Power and Storage: Leveraging Nuclear Energy for Hydrogen Production and Advanced Energy Storage

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ABSTRACT

Hydrogen is significant and may be viewed as an alternative for main fossil fuels, coal, crude oil, and natural gas, as well as its derivatives when utilized as fuel. It has the potential to be a clean, efficient, and inexpensive energy source. Being an environmentally friendly energy source, hydrogen is a good alternative to the current fossil fuels. Researchers' interest in the topic of green energy has been sparked by current developments in the hydrogen economy. Hydrogen is stored through a variety of techniques. Our review first focuses on different categories of renewable and non-renewable energy sources, after which we go into great detail regarding the hydrogen economy. One strong contender for a sustainable energy source is hydrogen. The benefits of hydrogen and its uses in various industries are discussed. Before moving on to hydrogen storage techniques, we first explore various hydrogen synthesis techniques. The ideal method for storing hydrogen is electrochemical since it produces hydrogen on-site and stores it at normal pressure and temperature conditions. As a result, energy resources should be combined with energy storage devices in order to offer continuous power. This paper examines the various storage systems and concentrates on energy storage systems based on hydrogen.

Keywords: Hydrogen Energy, Nuclear Energy, Nuclear Reactor, Sustainable Energy

Introduction

The current mainstream energy source is fossil fuels that have enormous effects on the environment and climate change. Trace gas which contributes considerably to rising temperatures, oxides of sulphur and oxides of nitrogen causing acid rain and chemical contamination, do not simply produce carbon dioxide. Furthermore, during the next few years, fossil fuels will disappear. As a consequence of their sustainability and cost-effectiveness, much Intensively exploring renewable energy (RE) resources [1-6]. A few of the primary limitations of Renewable resources is that they provide us with discontinuous energy, most of them not available on a continuous basis. For example, the night and rainy days do not have solar energy. From time to time, the wind speed varies. Therefore, the need of constructing energy storage systems is increasing as power output from RE resources increases [7-9].

Hydrogen as an energy transporter

Since it may be manufactured from a variety of sources and is used in so many diverse ways, hydrogen has been employed as a chemical for many years. It might act as a universal energy carrier in the future global energy economy, competing with electricity and fossil fuels. These three energy sources will persist, but their relative proportions will undoubtedly change. Synthetic hydrocarbon fuel production will undoubtedly continue to dominate during the era of transition to a hydrogen-based economy. This transitional period will be characterised by increased synthetic fuel production from the conversion of fossil fuels. The CO₂ balance is improved by incorporating hydrogen into the transformation process. In the future, both electricity and hydrogen will be significant energy carriers. Both are effective and simple to operate, and when used with non-fossil fuels, they emit almost nothing. Protons and electrons in electricity and hydrogen work in synergy to transport and store energy for a variety of purposes. They can be exchanged in a particular sense, albeit conversion losses do happen. Both work best when combined since they each have strengths that the other lacks, giving us considerably greater flexibility when it comes to macro-scale energy structure optimisation (such as when hydrogen replaces natural gas in peaking power plants). Reusing CO₂ that is readily available and mixed with hydrogen to create liquid synthetic fuels could also help cut down on CO₂ emissions. Fuel cells can be used to turn hydrogen or a hydrogen-rich liquid fuel (like methanol) into electricity for use in vehicles. If inexpensive (CO₂ free) electricity is available (for example, off-peak nuclear power), decentralised electrolysis hydrogen

production systems can be constructed. A new hydrogen market might be prepared and introduced first through the energy industry [10-12].

Nuclear Energy

Six countries — the United States of America (USA), France, Japan, Germany, the Russian Federation and the Republic of Korea — produce about 70% of the nuclear electricity in the world. In 16 countries, nuclear power provides more than 25% of the electricity. Nuclear is a proven technology that provides clean electricity at predictable and competitive prices with approximately 14 000 reactor-years (as of 2010) of accumulated operating experience, generating a total of some 6000 TWh. Nuclear expanded steadily until the mid-1980s, when it began levelling out or even declining [13-14]. As an example, in October 2007, 15 of the 27 countries of the European Union (EU27) operated 146 reactors, down from 151 units in 2003 and 177 reactors in 1989. The major reasons were:

- Energy efficiency improvements in power plant operation;
- Economic restructuring;
- A significant drop in electricity demand;
- Excess generating capacity;
- Oil price collapse;
- Highly efficient gas turbine technology;
- Liberalization and privatization of electricity market;

Methods of Hydrogen Production

Modern industrial hydrogen production relies heavily on the extraction of hydrogen from fossil fuels, particularly the reforming of natural gas (48% of global production), but also on procedures like the partial oxidation (POX) of oil, off-gas from chemical industry refineries (30%), and gasification of coal (18%). 3.9% of the process is contributed by electrolysis, with around 2% of it coming from chlorine-alkaline electrolysis as a byproduct[15].

Biomass gasification, which creates a fuel gas rich in hydrogen and/or methane, is still taking place on a small scale and is still in the demonstration phase. Figure 25 depicts the multiple process routes from primary energy to the final product and secondary energy carrier, hydrogen, including both the CO₂-emitting hydrocarbon extraction procedures and the CO₂-free water splitting processes[16].

Hydrogen From Fossil Fuel Processing

The principal conversion product of hydrocarbons is synthesis gas, a mixture of hydrogen and carbon monoxide, mainly resulting from the processes of steam reforming, POX or autothermal reforming[17]. The process is,

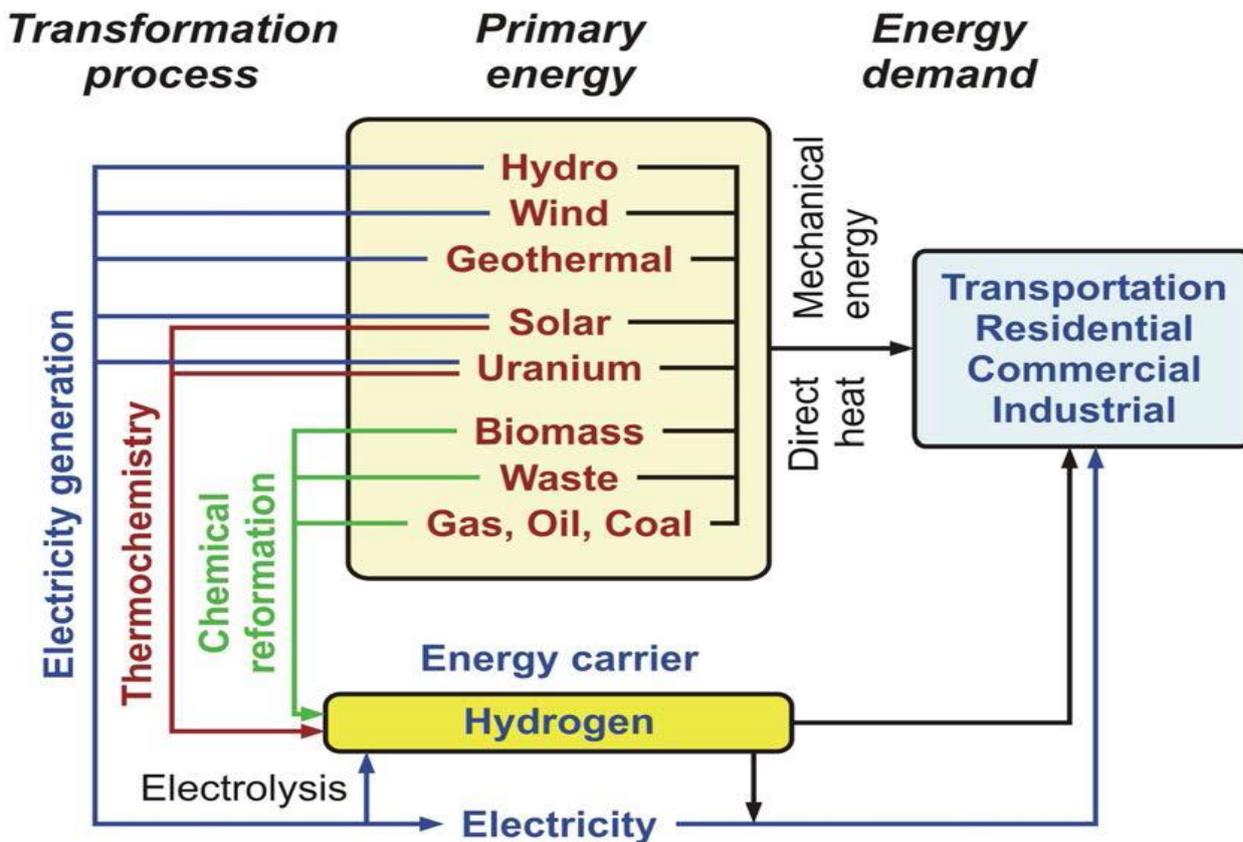


Fig. 1. Routes of hydrogen production[18].

Methods of Hydrogen-Based Energy Storage Currently in Use:

Hydrogen utilization was tested and analyzed in recent years in energy storage devices. Each section presents the latest work in this area.

- It presented an Integrated Wind Energy storage system and a Combined Cycle Power Plant (CCPP) hydrogen-oxygen with energy performance from 0.49 to 0.55. You decided that it can be used in any geological condition and that the proposed storage system looks to be a reasonable solution for intermittent renewable energies. There was a study conducted that carried out on a 100 MW wind turbine, which produces 225 GWh per year of electricity in Jiangsu Province, China. Economic studies and energy efficiency suggest the suggested system can achieve an overall

capacity of up to 0.50 per cent and can compensate for unpredictable electricity production [19].

- A wind-hydrogen micro-grid technology was implemented in Fife, Scotland, simulated, and evaluated at TRIF. The wind-hydrogen energy system has shown an average inaccuracy of under 0,02 for its dynamic behavior. The microgrid is connected to the grid with the power supply, comprising an electrical electrolyzer, a fuel cell and a hydrogen storage tank [20].
- It has theoretically and experimentally explored and compared hydrogen-based microgrid energy management strategies. This paper outlines the building of a microgrid system in a laboratory to mimic and analyze various energy management strategies in real life. The study contrasts simple strategies with complicated techniques of online optimization such as predictive control models. The output show how various control techniques may drastically affect performance of the system [21].
- A MATLAB technique for hydrogen resolution optimization in storage systems was developed. For the use of algorithms, they selected the Aegean Sea where various islands with diverse RE sources are accessible, including wind and sun energy. A temporary buffer storage unit, which stores hydrogen from water electrolysis and metal hydride tanks to store the hydrogen in the final form under low pressure, is modeled on an alkalized electrolyzer to analyze water into hydrogen and oxygen by means of electronic energy. The authors found that the methodology provided can give the hydrogen power storage system the optimum ability [22].
- Towards the Power to Gas (PtG) technology, it was examined electrical process requirements. PtG's energy generated from RE sources is utilized to analyze water to electrolyze hydrogen and oxygen. During the electrolysis, hydrogen is then produced as a synthetic natural gas in combination with Carbon Dioxide (CO₂) (SNG). For the operation of an oxy-combustion plant, the generated oxygen can be used. The evaluation was carried out on the basis of the size of the plant, the physiochemical characteristics of the fuel, and its end application. The authors indicated that district heating, industrial operations, and tiny CCPPs are the most suitable application of the PtG-Oxycombustion hybridization technique. The efficiency of the hybrid system has been successfully enhanced from 56% to 68% when the tiny CCPP is modeling and simulation and integration into the PtG process

thermally. The scientists concluded that the gas hybridization process of Oxy-combustion uses fewer electrolytic systems than other network power plants. It can achieve greater net electricity efficiency and generate more heat than coal-fired power plants [23].

Table 1: provides a summary of the above approaches.

Methods	Summary
[19]	Proposed an integrated wind and hydrogen-oxygen CCPP storage system.
[20]	The microgrid power wind-hydrogen system in Scotland was modelled, evaluated and assessed.
[21]	Energy management solutions in hydrogen micro-networks were theoretically and experimentally studied and compared.
[22]	A simulation tool has been developed for MATLAB to optimize hydrogen storage system sizing.
[23]	The electricity to gas process requirements for the production of methane as natural synthetic gas has been evaluated.

Nuclear Hydrogen Production Method

Given the current dominance of natural gas steam reforming in today's refineries, the addition of process heat by an HTGR to the refining process may be an ideal starting point for nuclear power to enter this market in the short and medium term, as well as a reasonable transition step towards fossil-free hydrogen production in the long term.

The Russian Federation's approach: Nuclear steam reforming

A 215 MW(th) nuclear plant (MHR-100SMR) feeds primary helium at 950°C to the thermal conversion unit under the Russian Federation's design for nuclear steam reforming of natural gas, as stated in Ref.[1]. It is made up of three separate high temperature steam reformer portions that transmit heat to the feed gas combination. On the secondary side, the heat exchangers are arranged in parallel with regard to the main helium and in series with regard to the process gas. The product gas exiting the third stage is highly enriched in hydrogen and still contains a steam fraction of 55%, and it then goes through the standard post-processing systems (separation,

purification), with the return fraction blended with natural gas and recycled to the thermal conversion unit.

Nuclear Reactor For Hydrogen Production

Nuclear reactors of the next generation

Nuclear reactors of the fourth generation (Generation IV) are planned to be introduced in the next 20-30 years. However, such reactor ideas are currently being developed based on needs that will lead to additional advancements in nuclear technology by addressing the areas of safety and reliability, proliferation resistance and physical protection, economics, and sustainability [1].

The Generation IV International Forum initiative

The Generation IV International Forum (GIF) was established in 2000 as a joint initiative of nine countries (Argentina, Brazil, Canada, France, Japan, Republic of Korea, South Africa, United Kingdom, and United States of America), and was later joined by Switzerland (2002), Euratom (2003), China, and the Russian Federation (both in 2006). The primary goal is to develop the fourth generation of nuclear reactors between 2030 and 2040; aside from being safer, more reliable, more economically viable, and less susceptible to proliferation, these reactors are also expected to penetrate non-electrical markets on a large scale, such as the supply of process heat (for hydrogen production). After the evaluation of some 100 potential Generation IV designs that had been suggested, the GIF agreed in 2002 to continue studies on six selected nuclear reactor designs that were deemed to meet the above requirements and to be deployable in due time [2]:

- Gas cooled fast reactor (GFR) system;
- Lead cooled fast reactor (LFR) system;
- Molten salt cooled reactor (MSR) system;
- Sodium cooled fast reactor (SFR);
- Supercritical water cooled reactor (SCWR) system;
- Very high temperature reactor (VHTR).

Disadvantages:

The main drawback of hydrogen is the enormous losses resulting from the number of conversions. In the case of an energy-induced system, the following stages with related efficiencies typically have been undertaken when hydrogen is utilized for its final purpose:

1. The electrolysis is generating hydrogen - efficient by 85%;
2. storing of hydrogen - efficient by 65% to 70%;
3. and hydrogen utilization in fuel-cell automobiles, power plants, and CHP devices - performance ranges from 40% to 80%.

The whole output thus amounts to between 22% and 48%. This technique also requires only one storage stage during hydrogen life, when more than one storage step, i.e. when made and stored on the site of usage, is normally needed. The hydrogen economy is therefore very efficient and could lead to high energy expenditures and very inefficient use of finite resources like wind or biomass. The efficiency of the system is relatively low. In short, although the hydrogen energy storage technology offers enormous flexibility, it does not contribute to the overall efficiency of the energy system [24-26].

Future of Hydrogen Energy Storage System:

With electrolyzes, storage techniques and fuel cells becoming more economically available the usage of hydrogen in the transport and energy-producing industries should be expanded fast. Hydrogen programs, which show an expanding interest in hydrogen technology, are particularly ambitious in the EU, the United States, and Japan. By creating hydrogen from the excess renewable energy and transitioning its transport infrastructures from fossil fuels to hydrogen, Iceland is trying to become the first 'hydrogen country' in the world [27]. Statkraft wants to connect an electrolysis unit with a huge wind turbine in Norway, and Norsk Hydro is carrying out a wind system in Utsira Island. The wind hydrogen motor is being developed in Germany, Siemens, and P&T Technologies using an ICE. In Great Britain, Wind Hydrogen Limited plans to construct wind-hydrogen systems on a big scale. In California, Hy-Gen is also creating a network that produces and distributes multi-megawatt hydrogen. Automobile manufacturers are driving hydrogen development in the transportation and infrastructure sectors [28]. The automobile companies have developed a strategy for introducing hydrogen into transportation, which includes a number of solo prototype initiatives that will progress to fleet demonstration. Due to its adaptability, hydrogen is a serious supporter of future energy storage. Once hydrogen can be successfully produced, it can be used for virtually any desired

application. The most desirable goal today is therefore to produce sustainable hydrogen via electrolysis. "The transition toward a hydrogen economy is expected to be less than fifty years away," mainly because of the versatility and potential of hydrogen to replace conventional fuel [29-30].

Conclusion:

The hydrogen energy storage system has become more and more a major challenger in the transport industry for power production. We have described the many ways to energy storage including hydrogen power generation. The latest hydrogen storage methods were summarized and the technological problems in this area were addressed. Hydrogen-based storage is a potential technique for the storage of energy. It is used for the conversion of hydrogen back to electricity, hydrogen is therefore apparently necessary for future usage, for example for heating, transport, or other purposes. This is an area that has a lot of potentials, even if it may be an inefficient process. In this article, we described various approaches to energy storage in general and energy storage based on hydrogen in particular. Hydrogen-based storage is a promising energy storage technology which might be examined further in future research. Due to a rising global population, economies using higher quantities of energy and electricity, growing worries about climate change, and more trust deriving from improved nuclear power plant performance and safety records, a substantial change looks to be on the horizon.

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