Renewable Hydrogen Production Around the Globe

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ABSTRACT

Renewable hydrogen production technologies offer a promising way to reduce greenhouse gases and other emissions. Many countries have launched projects to demonstrate the feasibility of these technologies in complete systems, collect data, and educate the public. In association with the International Partnership for the Hydrogen Economy (IPHE), Sentech, Inc. is conducting a survey of international renewable hydrogen production demonstration projects. The research will result in the publication of an educational report that is intended to be a valuable information source to policy makers, researchers, and the general public. This paper provides an overview of the project's vision as well as preliminary findings.

Keywords: hydrogen, transportation, renewable, international, demonstration projects

1 PROJECT VISION

Many countries around the world are currently engaged in projects aimed at demonstrating the use of renewably-produced hydrogen in transportation and other applications. Sentech, Inc. is conducting a survey of these projects which will culminate in the publication of a report intended to both educate policy makers and the general public on the promise and achievability of renewable hydrogen, as well as to share information among researchers to facilitate networking and future collaboration. The report will include a series of two-page highlights covering demonstration projects that involve production of hydrogen from renewable sources including wind, solar, geothermal, hydropower and biomass. It will also cover the importance of renewable hydrogen production, provide a status of renewable production technologies, and emphasize projects that involve collaboration among multiple countries in order to highlight the importance of international cooperation.

This project is being conducted in cooperation with the IPHE, which serves as a mechanism through which member countries can collaborate on hydrogen and fuel cell-related projects. Members of IPHE currently include a total of 16 countries and the European Commission.

2 SIGNIFICANCE OF RENEWABLY-PRODUCED HYDROGEN

Achieving environmental quality, especially the reduction of greenhouse gas emissions, is one of the primary goals of hydrogen energy technology programs in countries throughout the world. However, hydrogen's environmental benefits can only be fully realized if it is produced through renewable energy sources.

As indicated in Figure 1, 96 percent of the hydrogen produced today is generated from fossil fuels. Using renewable energy sources to produce hydrogen will produce fewer, often near-zero greenhouse gas emissions and reduce dependence on fossil fuels.

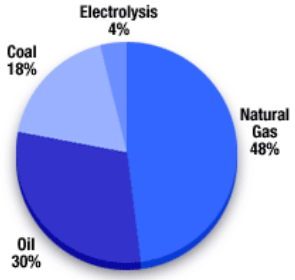

Figure 1: International Hydrogen Production Feedstocks [1]

As seen in Figure 2, fuel cell vehicles that run on renewably produced hydrogen are projected to emit less than one sixth the greenhouse gases of cars running on gasoline, and less than one third the greenhouse gases of cars running on hydrogen produced from natural gas.

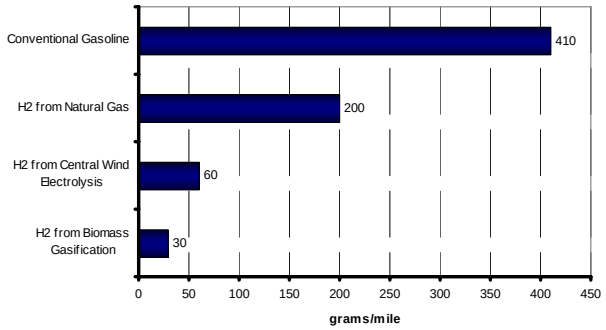

Figure 2: Projections of fuel cell and conventional vehicle well-to-wheels greenhouse gas emissions in 2015 [2]

3 RENEWABLE HYDROGEN PRODUCTION METHODS

Hydrogen can be renewably produced in a number of ways, although the most common method is electrolysis of water using a renewable electricity source. Other renewable methods include hydrogen production from biomass gasification, photoelectrochemical water splitting, and hydrogen producing algae.

3.1 Electrolysis of Water

Hydrogen can be produced via electrolysis, in which an electric current is applied to water, splitting it into hydrogen and oxygen (eq. 1). The electricity can come from any power source, including renewable pathways such as solar power or wind power. The hydrogen essentially stores energy and can later be used in a fuel cell, undergoing the opposite reaction (eq. 2) and generating electricity, with water vapor as the only byproduct.

$$2H_2O_{(l)} + energy \rightarrow 2H_{2(g)} + O_{2(g)} \quad (1)$$

$$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)} + energy \quad (2)$$

3.2 Hydrogen from Biomass

Hydrogen can be produced from biomass feedstocks via several different methods. Thermochemical processes use feedstocks such as corn stover, straw, or wood. Biomass gasification is a popular thermochemical method, in which a feedstock is heated with minimal oxygen so combustion cannot take place. This produces syngas, a mixture of hydrogen and carbon monoxide. Thermochemical processes can operate at high temperatures and therefore obtain high reaction rates.

Hydrogen can also be produced by reforming of bio-liquids such as sugars, ethanol, or bio-oils, or through gasification or pyrolysis of biomass feedstocks. Pyrolysis is similar to biomass gasification, but it involves heating feedstocks in the complete absence of oxygen. Biomass pyrolysis produces a bio-oil that can be separated into certain chemicals and fuels, including hydrogen.

Biochemical processes include anaerobic digestion of organic wastes and fermentation; however, these production methods are limited to wet- and sugar-based feedstocks [3].

3.3 Other Methods

Most other renewable methods of hydrogen production are in the early stages of research and development.

Algae can produce hydrogen under certain conditions, such as in the absence of sulfur. Researchers are using genetic modification techniques to increase the hydrogen conversion efficiency of certain types of algae so that this hydrogen can be captured and stored.

In high-temperature water splitting, the high temperatures generated by solar collectors are used to separate water into hydrogen and oxygen at temperatures of up to 2,000°C. In photoelectrochemical water splitting, hydrogen is produced from water using sunlight and specialized semiconductors. In this process, the semiconductor uses light energy to directly dissociate water molecules into hydrogen and oxygen.

4 EXAMPLES OF RENEWABLE HYDROGEN DEMONSTRATION PROJECTS

The following is a sampling of the many international hydrogen demonstration projects involving renewably produced hydrogen that have been launched in recent years. These initiatives represent countries throughout the world, as well as multiple renewable energy technologies. These projects, among others, will be included in Sentech, Inc.'s report for IPHE on renewable hydrogen production.

4.1 HyNor

The objective of the HyNor project in Norway is to establish local hydrogen nodes along the 580 km long road between Stavanger and Oslo (see Figure 3), making it possible to drive hydrogen fueled vehicles across the corridor, the "Hydrogen Highway of Norway." The project began in 2005 and is scheduled to run through 2008.

Figure 3. Map of HyNor Corridor [4]

Of the seven nodes on the highway, three stations produce hydrogen from renewable resources: the Drammen node produces hydrogen from biomass and waste; the Oslo station produces hydrogen from hydropower electrolysis; and the Romerike station produces hydrogen from solar electrolysis and reforming of biogas or biodiesel [4].

As of 2007, fifteen Quantum H2 Priuses were being operated on the HyNor corridor and five plug-in hybrid H2 TH!NK cars were in the pipeline.

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4.2 The PURE Project

The PURE (Promoting Unst Renewable Energy) project is a demonstration project on the island of Unst, the most northerly island in the British Isles. This project involves production of hydrogen from wind electrolysis to provide the energy needs for a remote rural industrial estate.

Figure 4: PURE wind turbines on the island of Unst

Although wind electrolysis technology powers the PURE project system, it was designed such that any type of renewable resource could be connected to it. The installation includes two 15 kW wind turbines which both power the estate and produce hydrogen via electrolysis. The stored hydrogen is used to power one fuel cell vehicle as well as one 5 kW fuel cell used for the generation of 'on demand' back-up power for the estate [5, 6].

4.3 ECTOS

The Ecological City Transport System (ECTOS) demonstration project in Reykjavik, Iceland was led by Icelandic New Energy and operated from 2004 to 2006. In this project, three hydrogen fuel cell buses were powered by hydrogen produced via electrolysis from the grid [7]. Since 72 percent of Iceland's electricity comes from renewable sources (mainly geothermal and hydropower), this can be considered renewably produced hydrogen [8].

The ECTOS project is affiliated with the IPHE-sponsored HyFLEET:CUTE initiative, which has plans to operate 33 hydrogen fuel cell buses in nine international cities.

Figure 5: The ECTOS refueling station in Reykjavik

4.4 Brazilian Hydrogen Fuel Cell Buses

In November 2006, Brazil's Ministry of Mines and Energy along with the Metropolitan Company of Urban Transport of São Paulo (EMTU) launched the project "Energetic-Environmental Strategy: Hydrogen Fuel Cell Powered Bus," a partnership with the United Nations Development Program, the Global Environment Facility and the Projects Funding Body [9].

In this project, up to five buses will be operated for four years beginning in late 2007. Similar to the ECTOS initiative in Iceland, this project took advantage of renewable energy available on the grid to produce hydrogen via electrolysis. In Brazil, hydroelectric plants account for more than 90 percent of the electricity produced, making grid electrolysis a good choice for renewable hydrogen [10].

4.5 Wind2H2 Project

Wind2H2 is a wind-to-hydrogen project launched by the U.S. National Renewable Energy Laboratory (NREL) and Xcel Energy. The project is located at NREL's National Wind Technology Center near Boulder, Colorado.

Figure 6: Schematic of the Wind2H2 project

The project uses electricity from two wind turbines (100 kW and 10 kW), as well as photovoltaic panels, to produce hydrogen. Up to 85 kg of hydrogen can be stored in tanks on site and converted to electricity, which is fed into the utility grid during peak demand hours [11].

4.6 Hydrogen from the Sun

The Hydrogen from the Sun project in Brescia, Italy was developed by the U.S. Sandia National Laboratory (SNL), in conjunction with the European Union, and involves producing power for a private residence.

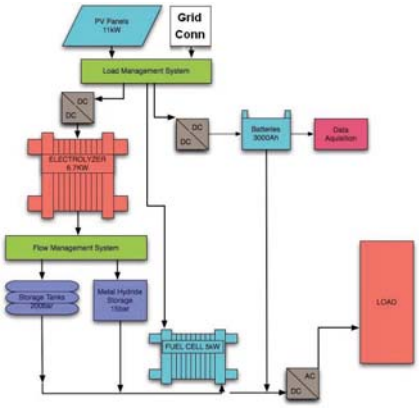

Figure 7. Schematic of the "Hydrogen from the Sun" Project [12]

The "hydrogen house" is intended to operate independently from the electrical grid during emergencies, and is powered by a 5 kW fuel cell, a battery, and by photovoltaic panels, which supply 11 kW at peak solar incidence. Hydrogen is produced using an electrolyzer powered by the solar panels, and is stored in conventional and metal hydride storage tanks. When needed, the hydrogen powers the fuel cell to produce electricity. A load management system controls the flow of power such that when the electrolyzer is not in operation, the solar panels can power the load directly [12].

4.7 HYDEPARK Project

The Turkish HYDEPARK "Hydrogen Demonstration Park" project began in June 2005 and will run through 2008. The project is intended to demonstrate a standalone system for the production and storage of hydrogen, and may be used to supply a hydrogen refueling station in the future. The hydrogen is produced by wind and solar electrolysis using 145 photovoltaic panels (~12 kW_p) and one wind turbine (5 kW_p) [13]. Currently, the wind- and solar-powered hydrogen production plant has been designed and constructed, and preliminary single component tests have been performed.

Figure 8: The HYDEPARK Photovoltaic field and wind turbines [13]

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