

A Hybrid Wind-Electrolysis Hydrogen and Electricity Generation System

The potential calamitous effects of climate change - more severe storms, regional droughts, higher sea levels, ocean acidification to name a few – are starting to become prominent worries throughout the world. According to a March 2007 Angus Reid Strategies survey, 77 percent of Canadians are convinced global warming is occurring... [and] 47 percent believe climate change will significantly affect their lives and those of future generations. In an August 2006 poll by Zogby International, about 75 percent of Americans stated global warming to be a very or somewhat serious threat. To confront these worries, and mitigate the risks caused by global warming, scientists, politicians, and businessmen are looking at ways to reduce greenhouse gas emissions. The transportation sector, comprising 29% of the United States energy use, is often stated as an area to take aggressive action (Tester *et al.* 2005). Currently, the vast majority of transportation fuels are extracted from around the world, transported to refineries, and then transported again to fueling stations for vehicular use. For diesel, this process means that for every gallon usable in cars, 1.2 gallons was consumed in the production processes. A potential piece of the solution, highly encouraged by the Bush Administration is the move towards a hydrogen economy. With this paper, we will look into the feasibility of producing hydrogen for the transportation sector using wind power, a renewable, emission free, energy source. Vehicles, by using pure hydrogen, would only emit water, and thus reduce the nation's carbon footprint.

Current wind-electrolysis technology involves an integrated system coupling a wind turbine to a high-pressure electrolyser, as shown below in Figure 1. This core system can then be optionally coupled to a fuel cell, a combustion engine, a steam reformer, or any other energy-producing technology. Gupta and Leishman note that wind turbines are particularly well suited as sites of hydrogen production, as excess hydrogen can be stored in the shaft of the turbine, assuming sufficiently strong building materials are provided (2005). In addition to providing a source of hydrogen for future use in automobiles or other fuel cell applications, wind-electrolysis technology also provides a significant improvement over current wind electricity generating stations (Fingersh 2003).

Unlike fossil fuels, utilization of wind energy is strongly dependent on daily and seasonal variations in wind intensity, which can be difficult to predict. A temporary deficit in wind could reduce the electrical input to the electrolyser, thereby also slowing hydrogen production and reducing overall power generation. Researchers have therefore designed control systems,

attempting to regulate levels of hydrogen production and electricity supply based on input of wind-generated electricity. Miland *et al.* have designed a fuzzy logic control system such that the hydrogen generator, as shown above, “can then function as energy storage on long-term basis and an active load controller on short-term basis” (2006).

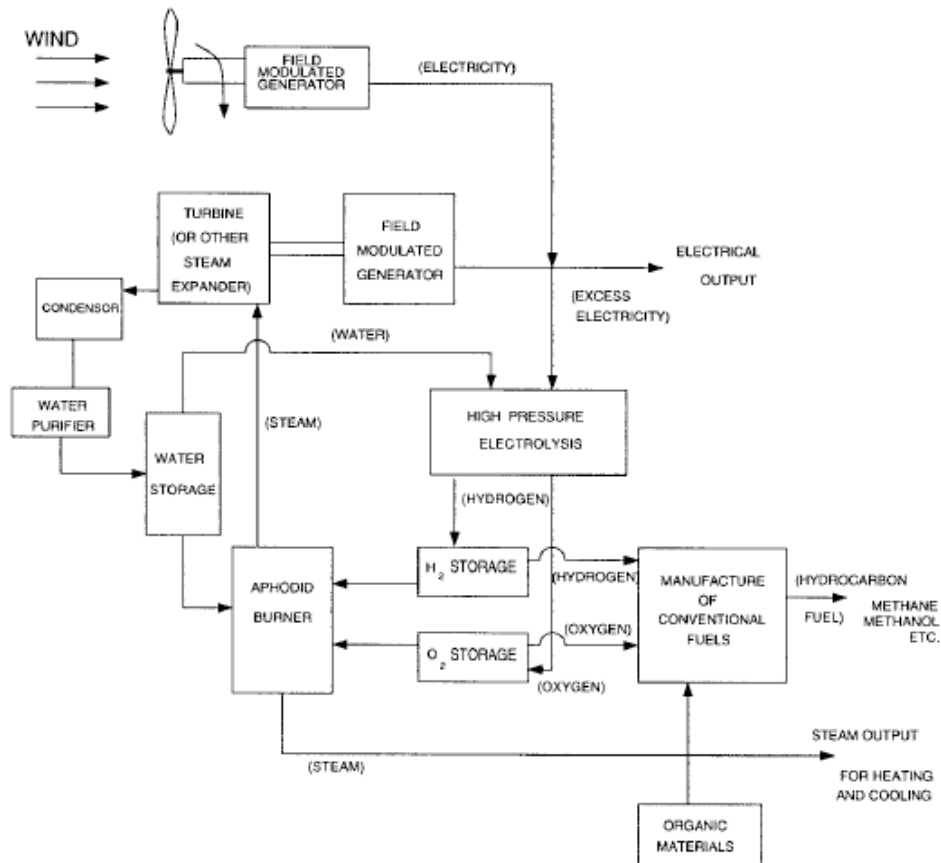


Figure 1. Flow diagram illustrating wind-electrolysis hydrogen generation and storage system (Yang and Aydin, 2001).

De Battista *et al.* are optimistic about the future of wind-electrolysis technology, noting that “due to the comparatively low cost of wind technology, along with the persistent growth in installed wind power capacity over the world, wind-electrolysis is the favorite candidate to become the first economically viable renewable hydrogen production system” (2006). Indeed, sustainable stand-alone systems have already been implemented at the pilot scale. One such project, implemented by Unst Technologies, Ltd in Scotland, utilizes two 15 kW wind turbines, a hydrogen electrolyser, and a hydrogen fuel cell, to provide energy and heating for five business properties on a remote island in the North Sea. This project has not only proven the feasibility of

implementing wind-electrolysis technology on a community scale, but also motivated refinement of the alkaline electrolysis technology used in this system (Gazey *et al.* 2006).

Due to the present difficulty of designing and implementing a large-scale infrastructure for hydrogen storage, transport, and utilization, many researchers are exploring the implementation of combined wind-electrolysis-fuel cell technologies on the scale of small, autonomous power stations requiring only water input. In a paper exploring the implementation of wind-electrolysis technology for roadside emergency phone systems, Bitterlin concludes that wind power is technically viable for this option, noting that windmills have the added advantage of possible integration with existing radio antennas (2005).

The community-scale work of Unst Technologies, Ltd, summarized by Gazey *et al.* (2006), is particularly useful, as it describes numerous, previously-unforeseen operating conditions. For example, in a preliminary description of wind-electrolysis technology written in 2001, Yang and Aydin optimistically explain, “Since the efficiency of most electrolyzers is nearly 100 per cent, the overall efficiency of hydrogen production relies heavily on the voltage.” However, as shown in Figure 2, Gazey *et al.* list a different result from empirical data, with efficiency (defined as the ratio of stored hydrogen energy produced to the energy input into the electrolyser) varying from approximately 60% to 90%, with the highest efficiencies achievable only at low hydrogen production levels.

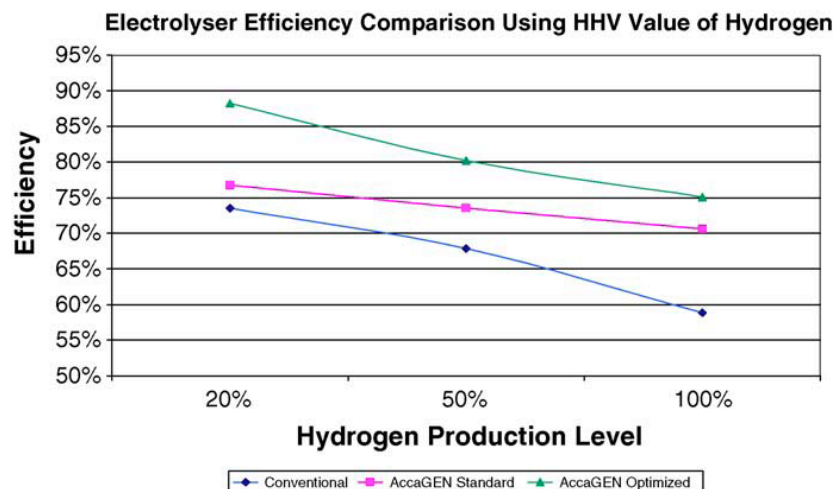


Figure 2. Electrolyser efficiency at various levels of hydrogen production, as measured at Unst. Scotland wind-electrolysis site (Gazey *et al.* 2006)

Gazey *et al.* also describe difficulties encountered when attempting to find a suitable electrolyser for long-term operation of a wind-electrolysis system. They note that current “market ready [photo-electric membrane] technology” is not feasible for use on this scale due to premature stack failures, with many retailers offering “only small 6–12 month warranties with expected stack lifetime ranging from 3000 [hours] up to a maximum of 5 years at lower efficiency and current densities” (2006). Unst Technologies, Ltd eventually found a manufacturer offering a “patented alkaline electrolyser” with a 20-year warranty, removing the need for frequent replacement or for periodic cleaning (2006).

In addition to the Unst Technologies system, the National Renewable Energy Laboratory (NREL) has recently implemented wind-electrolysis technology in Colorado. A report on this subject is currently scheduled for release in summer 2007. Correspondence with NREL could facilitate this study by providing otherwise unavailable design and performance data for this “second-generation” technology currently being implemented in at the National Wind Technology Center.

As summarized above, wind turbines generate electricity that can create hydrogen by electrolysis. Hydrogen can be combusted or used in a fuel cell to power vehicles. This project will analyze the number of windmills, and space required, to displace 20%, 50%, and 100% of our light-duty transportation fuels with windpower-generated hydrogen, for both combustion engines and fuel cells. This will likely result in the creation of a correlation between number of windmills and percent displacement of light-duty vehicles. Our project will focus on current technology, including that which currently exists only at the laboratory scale or as a prototype. From this analysis, the number of windmills necessary to fulfill a wedge, as identified in Princeton’s Carbon Mitigation Initiative (Socolow and Pacala 2004), can also be determined. By looking at the space requirements and comparing the wedge against other previously analyzed options, the feasibility of combating climate change through hydrogen-via-wind in the transportation sector will be examined. However, this project will admittedly focus only on a single aspect of the implementation of hydrogen as a storage medium; other factors such as storage and transport must also be explored before final judgments are made on this process.

Sources

- Bilodeau A, Agbossou K (2005). Control analysis of renewable energy system with hydrogen storage for residential applications. *Journal of Power Sources*. 162: 767-754.
- Bitterlin IF (2006). Modelling a reliable wind/PV/storage power system for remote radio base station sites without utility power. *Journal of Power Sources*. 162: 906-912.
- De Battista H, Mantz RJ, Garelli F (2005). Power conditioning for a wind-hydrogen system. *Journal of Power Sources*. 175: 478-486.
- Granovskii M, Dincer I, Rosen MA (2007). Air pollution reduction via use of green energy sources for electricity and hydrogen production. *Atmospheric Environment*. 41: 1777-1783.
- El-Shatter TF, Eskander MN, El-Hagry MT (2006). Energy flow and management of a hybrid wind/PV/fuel cell generation system. *Energy Conversion and Management*. 47: 1264-1280.
- Fingersh LJ (2003). Optimized hydrogen and electricity generation from wind. National Renewable Energy Laboratory, Golden, Colorado.
- Gazey R, Salman SK, Aklil-D'Halluin DD (2006). A field application experience of integrating hydrogen technology with wind power in a remote island location. *Journal of Power Sources*. 157: 841-847.
- Gupta S, Leishman JG (2005). Comparison of momentum and vortex methods for the aerodynamic analysis of wind turbines. 43rd AIAA Aerospace Sciences Meeting and Exhibit. Reno, Nevada.
- Miland H, Gloeckner R, Taylor P, Aaber RJ, Hagen G (2006). Load control of a wind-hydrogen stand-alone power system. *International Journal of Hydrogen Energy*. 31: 1215-1235.
- Ogden JM (1999). Prospects for Building a Hydrogen Energy Infrastructure. *Annual Review of Energy and the Environment*. 24: 227-279.
- Onar OC, Uzunoglu M, Alam MS (2006). Dynamic modeling, design and simulation of a wind/fuel cell/ultra-capacitor-based hybrid power generation system. *Journal of Power Sources*. 161: 707-722.
- Santarelli M, Cali M, Macagno S (2004). Design and analysis of stand-alone hydrogen energy systems with different renewable sources. *International Journal of Hydrogen Energy*. 29: 1571-1586.
- Pacala S *et al.* (2004). Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. *Science*. 305: 968-972.
- Yang WJ, Aydin O (2001). Wind energy-hydrogen storage hybrid power generation. *International Journal of Energy Research*. 25: 449-463.

News Articles

- An overview of biodiesel and petroleum diesel life cycles. 23 March 2007. National Renewable Energy Laboratory. 1998. <<http://www.nrel.gov/docs/legosti/fy98/24089.pdf>>.
- Canada's largest survey on climate change. 26 March 2007. Angus Reid Strategies. 21 March 2007 <<http://www.angus-reid.com/admin/collateral/pdfs/polls/2007.03.21%20Enviro%20Press%20Release.pdf>>
- Experimental "wind to hydrogen" system up and running. 1 April 2007. <<http://www.physorg.com/news87494382.html>>
- Wind power to generate hydrogen in new research project. 1 April 2007. <<http://www.renewableenergyaccess.com/rea/news/story?id=44875>>
- Zogby International/National Wildlife Survey. 15 August. 2006. Zogby, 29 Sept. 2006 <<http://www.zogby.com/wildlife/NWFfinalreport8-17-06.htm>>