A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory

Innovation for Our Energy Future

Technology Brief: Analysis of Current-Day Commercial Electrolyzers

A major goal of the U.S. Department of Energy's (DOE's) Hydrogen, Fuel Cells & Infrastructure Technologies Program is to develop low-cost, efficient hydrogen production technologies such as hydrogen production via water electrolysis. To evaluate the potential viability of electrolytic hydrogen production systems, the National Renewable Energy Laboratory (NREL), in partnership with industry, completed a technical and economic overview of commercially available electrolyzers. Developing a better understanding of the current state of electrolysis technologies will help to direct research efforts toward areas in which improvements will result in the largest cost reductions and to determine the potential for near-, mid- and long-term success. This Technology Brief summarizes the results presented in "Summary of Electrolytic Hydrogen Production," by Johanna Ivy (Report Number NREL/MP-560-36734, available at http://www.nrel.gov/publications/).

Key Findings

- Electricity costs are a major contributor to the cost of electrolytic hydrogen production, regardless of system size.
- Reductions in capital costs, especially for smaller scale electrolysis systems, are also needed to decrease the cost of electrolytic hydrogen production.
- Today's largest electrolysis systems may be too small to take advantage of the potential low cost, high volume electricity production methods such as wind and nuclear power.

Commercial Electrolysis Systems

The technical analysis focused on five companies' electrolysis units, commercially available as of December 2003: Stuart IMET; Teledyne HM and EC; Proton HOGEN; Norsk Hydro HPE and Atmospheric; and Avalence Hydrofiller. The operating ranges for these systems are summarized in Table 1.

For these systems, the water-to-hydrogen conversion efficiencies range from 80% – 95% and hydrogen purities range from 99.8% – 99.9998%. The system energy efficiency, defined as the higher heating value (HHV) of hydrogen divided by the energy consumed by the electrolysis system ("system" includes electrolyzer, rectifier, and auxiliaries) per kilogram of hydrogen produced, ranges from 56% for Proton's proton exchange membrane (PEM) process to 73% for Stuart's and Norsk Hydro's bipolar alkaline systems. Representative system efficiencies for Avalence and Teledyne units are 64% and 63%, respectively. Manufacturers are working to increase overall system efficiencies, which include compressing the hydrogen gas to 6,000 psig, to 78%. Currently, only the Avalence electrolyzers are designed to produce hydrogen at this pressure. The system energy efficiencies reported for the other systems would decrease if additional compression up to 6,000 psig were included.

All of these electrolysis units are sized to meet the demands of current hydrogen markets. In a future hydrogen economy, electrolyzers 10 to 100 times the size of today's largest units could be used to effectively utilize the large amounts of electricity generated by low-cost, high-volume generation methods like wind and nuclear power.

Table 1. Commercially Available Electrolysis Units

Manufacturer	Technology	← Operating Range Available Today → System Energy Requirement (kWh/kg)	H_2 Production Rate (kg/yr)	Power Required for Max. H_2 Production Rate (kW)	H_2 Product Pressure (psig)
Avalence	Unipolar Alkaline	56.4 – 60.5	320 – 3,600	2-25	Up to 10,000
Proton	PEM	62.3 – 70.1	400 - 7,900	3-63	~200
Teledyne	Bipolar Alkaline	59.0 – 67.9	2,200 - 33,000	17-240	60-115
Stuart	Bipolar Alkaline	53.4 – 54.5	2,400 - 71,000	15-360	360
Norsk Hydro	Bipolar Alkaline (high pressure)	53.4	7,900 - 47,000	48-290	~230
	Bipolar Alkaline (atmospheric)	53.4	39,000 - 380,000	240-2,300	0.3

Cost of Electrolytic Hydrogen Production

An initial cost boundary analysis was completed to determine the effects of electricity price on hydrogen costs (see Figure 1). For each electrolyzer, the specific system energy requirement was used to determine how much electricity is needed to produce hydrogen; no capital, operating or maintenance costs are included in the calculation. At current electrolyzer efficiencies, to produce hydrogen at less than $3.00/kg, electricity costs must be lower than 4 ¢ to 5.5 ¢ per kWh. For an ideal system operating at 100% efficiency, electricity costs must be below 7.5 ¢ per kWh. This analysis demonstrates that regardless of any additional cost elements, electricity costs will be a major contributor to the price of hydrogen.

Detailed economic analyses were performed for three distinct systems for which cost and economic data were available: small neighborhood (~20 kg H_2/day), small forecourt, i.e., refueling station, (~100 kg H_2/day), and forecourt (~1000 kg H_2/day) size. The standardized analysis model developed by the DOE Hydrogen Analysis Team (H2A Model, August 2004 version) was used to calculate the discounted cash flow for the electrolysis process. In this analysis, the hydrogen selling prices were $19.01/kg H_2 for the small neighborhood size, $8.09/kg H_2 for the small forecourt size, and $4.15/kg H_2 for the forecourt size. For all three cases, the other raw material cost contribution and variable operating and maintenance cost contribution are negligible. In the forecourt case, electricity is the major cost factor at 58%. In the small forecourt and neighborhood cases, the electricity costs are still significant at 35% and 17% respectively, but the capital costs become the major cost factor at 55% and 73%. This analysis demonstrated that for all systems electricity price is a contributor to hydrogen price, but for small-sized electrolyzers, capital costs are more significant (see Figure 2).

The cost of producing hydrogen via current electrolytic processes is largely dependent on the cost of electricity, the efficiencies of the systems, and the capital costs of the systems. Because the amount the system efficiency can be increased is limited (current target is 78%), increased efficiency will not reduce the cost as much as a significant reduction in electricity price. For example, if forecourt systems can use industrial priced electricity as opposed to commercial priced electricity (7.89 ¢ vs. 4.83 ¢ per kWh), hydrogen prices can be reduced by 31%. All electrolysis systems will benefit from a reduction in capital cost as the hydrogen economy grows and these systems are mass produced, but the smaller systems will benefit the most, as the largest percentage of their hydrogen cost contribution comes from capital costs.

Next Steps

The results of this study will help to guide DOE's electrolytic hydrogen production research and analysis activities. Additional analysis efforts could investigate: future costs of electrolytic hydrogen production via electrolysis; scenarios to provide low cost electricity for distributed electrolysis; the practicality of using off peak electricity to produce hydrogen; the validity of using oxygen by-product credits to make electrolytic hydrogen more economical; the effects on the current power infrastructure when providing 2.3 MW of power to numerous forecourt stations; and scenarios based on hydrogen production for the home and neighborhood market. This work would help to determine what factors can make hydrogen production via electrolysis a reality in the future hydrogen economy.

Figure 1. Hydrogen costs via electrolysis with electricity costs only

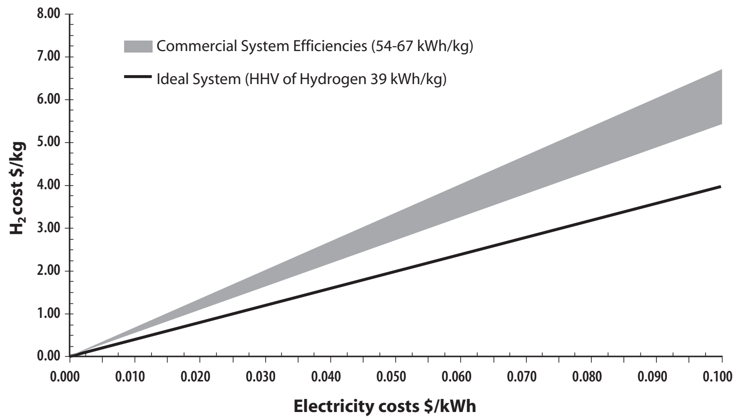
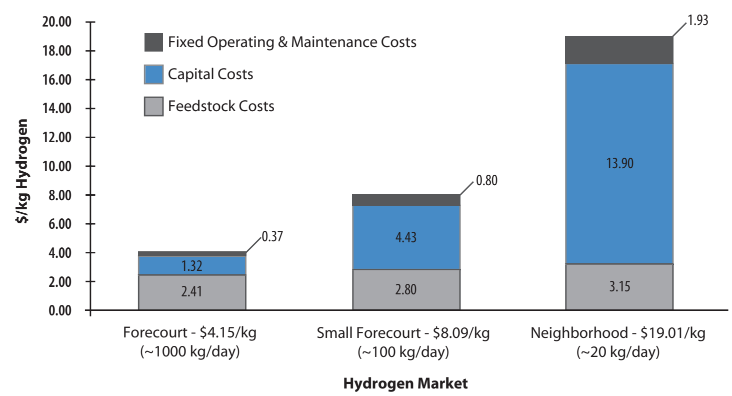


Figure 2. Hydrogen selling price (year 2000 dollars) industrial electricity*



* Decommissioning costs, other raw material costs, and other variable costs (including utilities) are negligible.

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