ground water
Readers' Forum/

The Hydrogen Effluent

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Decontaminated ground water from environmental remediation sites may provide a critical hydrogen resource for a hydrogen economy that will require a tremendous volume of deionized water. Recent breakthroughs stemming from more than 20 years of research in hydrogen handling and fuel-cell technologies, together with popular accounts of hydrogen economy milestones (Rifkin 2002), foretell an age where hydrogen fuel cells will produce electricity for both transportation and distributed generation power production.

The hydrogen economy is predicated on the assumption that hydrogen is freely available in exploitable form. Currently, the most economically exploitable resource for hydrogen is fossil fuels, specifically natural gas, which produces hydrogen through a steam-reforming process. However, many geologists hold that the peak in global oil production will occur before 2020 (Campbell and Laherrere 1998; Hatfield 2001), with natural gas production peaking soon thereafter (Rifkin 2002, p. 125). EPRI predicts that use of natural gas to generate electricity in new gas-fired electric power plants will increase 15% to 60% over the next 20 years, a rate that cannot be maintained past 2025 (Rifkin 2002, p. 186). This dire forecast does not include increased demand for natural gas due to increased hydrogen demand brought on by a hydrogen-based economy. Furthermore, hydrogen production from fossil fuels produces CO_2, which can accelerate global warming if the CO_2 is not sequestered. In the long term, hydrogen will have to come primarily from the electrolysis of water. Ideally, the electricity needed for the electrolysis process will be provided by renewable energy sources: wind, solar, geothermal, tidal, and hydroelectric.

Energy experts who are considering the long-term production of hydrogen have proposed the electrolysis of seawater for coastal areas, and fresh water sources for inland areas. Electrolysis requires a specific KOH solution be made with the water, and thus even the electrolysis of seawater requires initial desalinization, which is energy intensive. Japanese scientists are considering desalinization and electrolysis of seawater for the offshore production and storage of hydrogen in a seafloor tower (Eliasson and Bossel 2003). Currently in the United States, wind energy markets are being created nearshore and offshore that could similarly be used for the electrolysis of seawater to hydrogen. Nearshore, a joint Clean Air Now/Xerox Corp. project used solar energy to produce hydrogen with an electrolyzer (Rifkin 2002, p. 188). However, the water was deionized municipal water from El Segundo, California (Fairlie, personal communication) and with potable water in relatively short supply, it should not be used in the production of hydrogen. Therefore, the only viable inland sources of water for hydrogen are wastewater and other contaminated water.

The only byproduct of fuel cell energy production is pure water, but with water as a source of the hydrogen, the pure water leaving a fuel cell is derived from the purified water entering an electrolyzer. Care must be taken in the future mass handling of hydrogen: one molecule of water is lost from the hydrologic cycle for every molecule of unreacted hydrogen released to the atmosphere. Reacted in a fuel cell or in combustion, hydrogen becomes part of the hydrologic cycle, and traditional concepts of source water consumption hold. Hydrogen fuel economy expressed in terms of this water consumption is elucidating. The ideal gas law shows that 1 L of water produces 1.2 M^3 of hydrogen at STP, with a density of 90 g/M^3. Fuel efficiencies for hydrogen fuel-cell cars are expressed in kilometers per kilogram hydrogen, with 109 km/kg hydrogen estimated for a small vehicle (Atkins and Koch 2003). This fuel efficiency is equivalent to 9.8 km/M^3 of STP hydrogen, or 12 km/L of water: 28 mpg water. In 1999, 130 million passenger cars traveled an average 51 km (32 miles) per day (U.S. Department of Transportation 2001). The fuel efficiency translates this driving into 4.3 L (1.2 gallons) of water consumed per vehicle per day; a total of 560 million liters, or 160 million gallons, of processed water would have to be produced daily just for passenger car fuel. It thus will be essential to recycle the highly processed fuel-cell water.

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Even with recycling, a tremendous volume of pure water will be required to usher in the hydrogen economy. One possible source of water is contaminated ground water. Most ground water at environmental remediation sites is relatively dilute and thus could be viewed as a viable resource for the hydrogen economy. Ground water cleanup procedures are energy intensive, but most of these technologies are less energy intensive than the desalinization of seawater. Rifkin (2002, p. 46) argues that in accordance with the second law of thermodynamics, "society is organized around the continuous effort to convert available energy from the environment into used energy to sustain human existence." Waste streams are part of what Rifkin calls the entropy bill in that it takes tremendous energy (with associated costs) to overcome entropy and completely separate two components in a solution. Indeed, the energy costs of the entropy bill are arguably the reason for recent lessening of the environmental cleanup standards at brownfield sites. But viewed as part of the hydrogen economy, cleanup efforts may be renewed as contaminated ground water is viewed as a hydrogen resource. Freeze (2001) alludes to the thermodynamic limitations of site cleanups, discussing the expense of pump-and-treat systems owing to the treatment and discharge of tremendous volumes of effluent, but he also states that this expense is why cleanup efforts should focus on contaminant containment. Current pumping and trenching containment systems also produce a sizable volume of effluent to be treated and discharged. An environmental remediation system could contain the spread of a contaminant plume if it were coupled with electrolysis, consuming the effluent to produce oxygen, fed back for bioremediation, and hydrogen for fuel. Contaminated ground water may be used as a hydrogen fuel resource, spurring environmental cleanup efforts while contributing to the hydrogen economy.

References

Atkins, M.J., and C.R. Koch. 2003. A well-to-wheel comparison of several powertrain technologies. 2003 SAE World Congress, 2003–01–0081.

Campbell, C.J., and J.H. Laherrere. 1998. The end of cheap oil. *Scientific American* 278, no. 3: 78–83.

Eliasson, B., and U. Bossel. 2003. The future of the hydrogen economy, Part 2. *EV World*, January 5, 2003. www.evworld.com/databases/storybuilder.cfm?storyid=475.

Fairlie, M. Stuart Energy, personal communication.

Freeze, R.A. 2001. *The Environmental Pendulum: A Quest for the Truth About Toxic Chemicals, Human Health, and Environmental Protection*. Berkeley, California: University of California Press.

Hatfield, C. 2001. How long can oil supply grow? *Hubbert Center Newsletter* 97, no. 4.

Rifkin, J. 2002. *The Hydrogen Economy*. New York: Tarcher/Putnam.

U.S. Department of Transportation. 2001. *National Transportation Statistics, 2001*. Bureau of Transportation Statistics. www.bts.gov/publications/nts/index.html.

Corrections

"MAROS: A Decision Support System for Optimizing Monitoring Plans," by J.J. Aziz, M. Ling, H.S. Rifai, C.J. Newell, and J.R. Gonzales, May–June 2003, v. 41, no. 3: 355–367.

Two equations in this paper contained errors. Following are the correct equations:

$$\begin{cases} sgn(x_j - x_k) = 1 & if\, x_j - x_k > 0 \\ sgn(x_j - x_k) = 0 & if\, x_j - x_k = 0 \\ sgn(x_j - x_k) = -1 & if\, x_j - x_k < 0 \end{cases} \qquad (2)$$

$$S_b = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{(n-2)\sum_{i=1}^{n} (x_i - x)^2}} \qquad (6)$$

Ground Water regrets any inconvenience these errors may have caused.

The issue paper titled "A Fresh Water Odyssey: Some Observations on the Global Resource" by Warren W. Wood, which was published in the May–June issue of the journal, should have carried the following editor's note:

Editor's Note: We invited Dr. Wood to contribute an issue paper on a topic of his choice to mark our 40th anniversary celebration this year of the publication of the first issue of *Ground Water*. Dr. Wood is a former editor-in-chief of the journal.