VII.7 Hydrogen and Water: Engineering, Economics and Environment

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Project End Date: Project continuation and direction determined annually by DOE

Objectives

- Quantify the impact of water (cost, quality, scarcity) on a future hydrogen economy.
- Quantify the impact of a future hydrogen economy on national and regional water resources.
- Document best practices for hydrogen stakeholders in system design and feedstock management with respect to water.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior
(D) Feedstock Issues
(E) Unplanned Analyses

Contribution to Achievement of DOE Systems Analysis Milestones

This project will contribute to achievement of the following DOE milestones from the Systems Analysis section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 1:** Complete evaluation of the factors (geographic, resource availability, existing infrastructure) that most impact hydrogen fuel and vehicles. (3Q, 2005)
- **Milestone 5:** Complete analysis and studies of resource/feedstock, production/delivery and existing infrastructure for various hydrogen scenarios. (4Q, 2009)
- **Milestone 11:** Complete environmental analysis of the technology environmental impacts for the hydrogen scenarios and technology readiness. (2Q 2015)
- **Milestone 27:** Complete the 2nd version of the Macro-System Model to include the analytical capabilities to evaluate the electrical infrastructure. (2Q, 2011)

Accomplishments

- Concluded that under foreseeable price regimes, water management is unlikely to add more than $0.05 to the cost of a kilogram of hydrogen via analysis of water withdrawal and consumption for hydrogen process and cooling water.
- Determined most economic cooling and water treatment technologies under variable water purchase and disposal price regimes.
- Created a national map of water stress by watershed through collaborations with the National Energy Technology Laboratory (NETL) and Sandia National Laboratories.
- Identified potential hydrogen markets with high risk factors (beyond water price) for water impacts.

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Introduction

Water is a critical feedstock in the production of hydrogen. Major changes in the energy infrastructure (as envisioned in a transformation to a hydrogen economy) will necessarily result in changes to the water infrastructure.

Water is used as a chemical feedstock for hydrogen production and as a coolant for the production process. There are multiple options for water treatment and cooling systems, each of which has a different profile of equipment cost and operational requirements. The engineering decisions that are made when building out the hydrogen infrastructure will play an important role in the cost of producing hydrogen, and those decisions will be influenced by the regional and national policies that help to manage water resources.

Approach

This project takes a narrowly-scoped lifecycle analysis approach. We begin with a process model of hydrogen production and calculate the process water, cooling, electricity and energy feedstock demands. We expand beyond the production process itself by analyzing the details of the cooling system and water treatment system.

The narrow scope of the lifecycle analysis enables economic optimization at the plant level with respect to cooling and water treatment technologies. As water withdrawal and disposal costs increase, more expensive, but more water-efficient technologies become more attractive. Some of the benefits of these technologies are offset by their increased energy usage. We use the H2A hydrogen production model to determine the overall cost of hydrogen under a range of water cost and technology scenarios.

At the regional level, we follow the hydrogen roll-out scenarios envisioned by Greene and Leiby [1] to determine the impact of hydrogen market penetration on various watersheds. In collaboration with Sandia National Laboratories and NETL, we determine the level of water stress in each of the potential hydrogen markets, as well as the competing industrial water demand. We also analyze water purchase and discharge prices at the regional level to identify economic impacts of water on hydrogen at the regional level.

Results

As of this progress report, the final report for the hydrogen/water analysis is undergoing final revisions. An economic optimization of technologies for water management related to hydrogen production has been completed, and a regional analysis of water stresses and impacts on hydrogen production has been conducted.

Table 1 conveys the results of the techno-economic analysis. Multiple water treatment and cooling were analyzed. The three that were generally resulted in the lowest cost of hydrogen are arrayed on the right hand side of the table. For various combinations of water purchase and discharge prices (and assuming that other costs, such as labor and electricity, in the H2A model remained constant) the resulting hydrogen prices are shown in the center. As purchase and discharge prices rise, the least-cost water-management technologies shift. Because water purchase and discharge prices may be uncorrelated (Figure 1), the least-cost water option may not simply be the lowest withdrawal option.

Figure 2 shows the results of the water stress analysis that was performed for the entire nation at the watershed level. The blue "pinpoints" represent metropolitan areas highlighted in previous analyses as likely to have significant hydrogen vehicle penetration within the next 15 years. Table 2 lists these areas and provides quantitative metrics of risk to hydrogen rollout. Water stress, in this analysis, is defined as the total water

TABLE 1. The price of central steam methane reformed hydrogen, in \$/kg-H_2, as calculated by H2A spreadsheets modified to account for water purchase and discharge prices and the varying capital and operating costs of different cooling and water treatment systems. The cells colored red indicate the lowest hydrogen price from among the three water-technology options.

Water Discharge Price ($/gal)	Water Purchase Price ($/gal): $0.0001	$0.001	$0.01	$0.10	$1.00	Technology
$0.0001	1.357	1.362	1.415	1.942	7.211	Cooling Tower, Reverse Osmosis
$0.001	1.358	1.363	1.416	1.943	7.212	Cooling Tower, Reverse Osmosis
$0.01	1.370	1.375	1.428	1.955	7.224	Cooling Tower, Reverse Osmosis
$0.10	1.485	1.491	1.543	2.070	7.339	Cooling Tower, Reverse Osmosis
$1.00	2.642	2.647	2.670	3.227	8.496	Cooling Tower, Reverse Osmosis
$0.0001	1.955	1.957	1.973	2.131	3.715	Dry Cooling, Deionization Zero Discharge
$0.001	1.955	1.957	1.973	2.131	3.715	Dry Cooling, Deionization Zero Discharge
$0.01	1.955	1.957	1.973	2.131	3.715	Dry Cooling, Deionization Zero Discharge
$0.10	1.955	1.957	1.973	2.131	3.715	Dry Cooling, Deionization Zero Discharge
$1.00	1.955	1.957	1.973	2.131	3.715	Dry Cooling, Deionization Zero Discharge
$0.0001	1.385	1.387	1.412	1.666	4.202	Dry Cooling, Reverse Osmosis Treatment
$0.001	1.385	1.388	1.413	1.667	4.203	Dry Cooling, Reverse Osmosis Treatment
$0.01	1.395	1.398	1.423	1.677	4.212	Dry Cooling, Reverse Osmosis Treatment
$0.10	1.490	1.493	1.518	1.772	4.307	Dry Cooling, Reverse Osmosis Treatment
$1.00	2.442	2.445	2.470	2.724	5.259	Dry Cooling, Reverse Osmosis Treatment

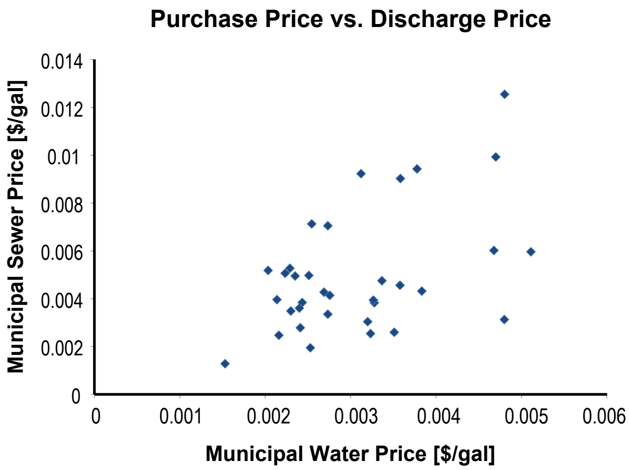

FIGURE 1. Water discharge (sewer) prices plotted against water purchase prices for 34 different municipalities. There is wide variability in water prices and little correlation between purchase and discharge prices.

withdrawal within a watershed divided by the total annual flow into that watershed (including precipitation, groundwater influx and runoff from other watersheds). A water stress greater than unity does not necessarily indicate unsustainable water usage because a significant fraction of all withdrawn water is discharged within the watershed from which it was withdrawn. However, the most highly stressed areas are, without a doubt, using water beyond their local means, either from "fossil" water resources (aquifers that are being depleted) or from water imports. High water-stress areas likely to be impacted by more severe water policies in the near-term.

Conclusions and Future Directions

- Water is an important issue for hydrogen stakeholders to monitor because the areas anticipated to have the earliest hydrogen rollout (particularly the Los Angeles area) are some of the most highly water-stressed. Hydrogen producers in these areas may be faced with limited ability to procure a water permit.
- Although permitting may be an issue, water is inexpensive and abundant on a national scale. Under all reasonable water-price scenarios, the total cost of water to hydrogen producers (including the capital cost of treatment and cooling systems) is unlikely to exceed \$0.05/kg-H_2
- Hydrogen will not be adopted "in a vacuum." Hydrogen will displace other fuels, each of which has its own water footprint. Therefore, the net impact of hydrogen on water resources will be somewhat lower than this engineering/economic analysis shows.

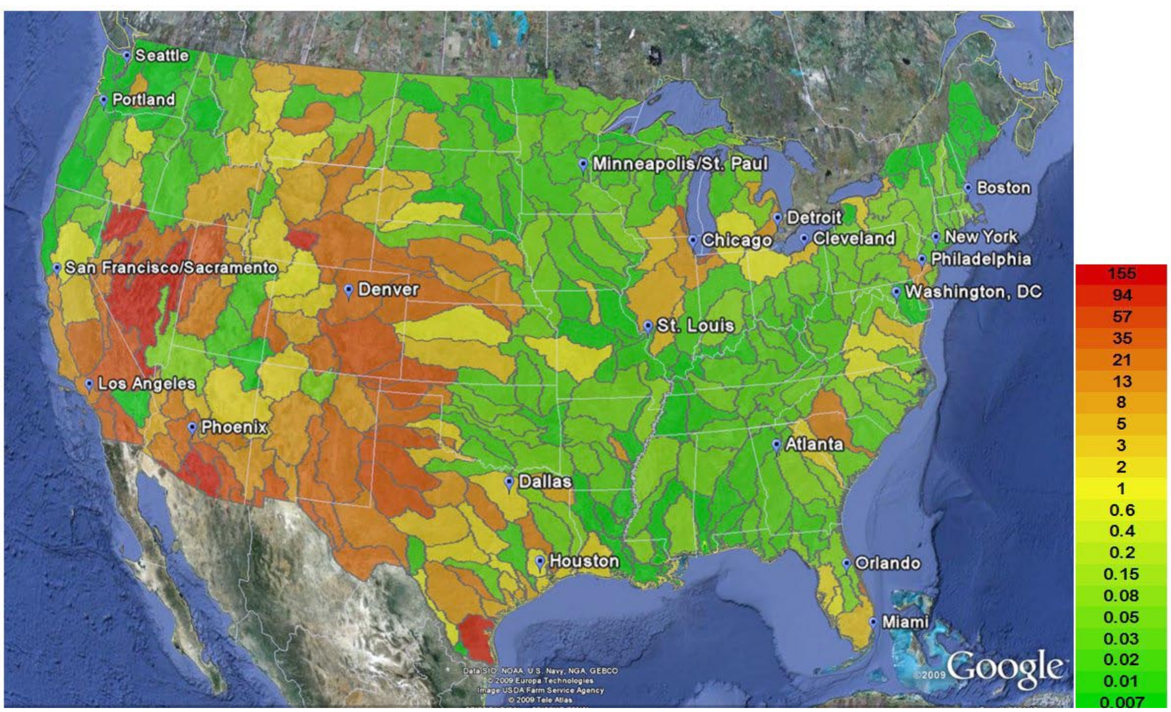

FIGURE 2. A Google Earth[TM] map of the United States showing 329 watersheds. The watersheds are color-coded by the levater withdrawals (ground plus surface water) divided by the total water influx (precipitation plus stream inflow). Red regions are more highly stressed. The metropolitan areas expected to see early hydrogen rollout are labeled.

TABLE 2. Metropolitan areas likely to roll out hydrogen with their relevant watersheds. Water stress is calculated as the sum of total water supply (ground and surface) in all relevant watersheds divided by the sum of total water withdrawal in those same watersheds. Water used for hydrogen was calculated by using the number of predicted 1,500 kg/day stations [2] in each metro area and multiplying by a water intensive SMR-based hydrogen production technology (8.5 gallons withdrawal per kg hydrogen). The percent of supply used for hydrogen is calculated by dividing the water used for hydrogen by the total surface and groundwater supplies in the relevant watersheds. The percent increase in industrial water use is calculated by dividing the amount of water used for hydrogen by the watershed(s)-wide industrial use of water. Zero-discharge and dry cooling technologies are capable of reducing these figures by a factor of 4.

Metro Area	Watersheds	Water Stress	Water used for Hydrogen (MGal/day)	% of supply used for hydrogen	% increase in industrial water usage
New York	Lower Hudson	0.04	15.6	0.02%	16.1%
Los Angeles	Ventura-San Gabriel Coastal Santa Ana	2.01	12.3	1.14%	7.1%
Chicago	Upper Illinois	1.17	8.9	0.08%	0.8%
Washington	Potomac	0.09	7.5	0.02%	6.8%
San Francisco/ Sacramento	San Francisco Bay Lower Sacramento	0.18	5.1	0.01%	2.8%
Philadelphia	Lower Delaware	0.81	3.9	0.09%	1.6%
Boston	Massachusetts-Rhode Island Coastal	0.05	8.4	0.05%	20.6%
Detroit	St. Clair-Detroit	1.13	5.9	0.16%	0.8%
Dallas	Upper Trinity	0.34	5.7	0.08%	14.0%
Houston	San Jacinto Galveston Bay-Sabine Lake	0.27	5.4	0.08%	2.5%
Atlanta	Altamaha Apalachicola	0.09	4.9	0.01%	1.5%
Miami	Southern Flordia	0.44	1.4	0.02%	5.5%
Seattle	Puget Sound	0.00	1.8	0.00%	2.2%
Phoenix	Salt Lower Gila-Agua Fria Middle Gila	4.88	2.8	0.44%	44.0%
Minneapolis/ St. Paul	Upper Mississippi-Crow-Rum Minnesota	0.06	2.8	0.01%	6.4%
Cleveland	Southern Lake Erie	0.33	2.3	0.04%	1.5%
Denver	South Platte	8.75	2.5	0.66%	5.0%
St. Louis	Upper Mississippi-Meramec Lower Missouri	0.01	2.4	0.00%	6.2%
Portland	Willamette Lower Columbia	0.01	1.6	0.00%	0.3%
Orlando	Kissimmee St. Johns	0.15	1.0	0.01%	1.0%

FY 2010 Publications/Presentations

1. Simon, A.J., "Hydrogen and Water: Engineering, Economics and Environment", presentation to the DOE's Annual Merit Review, May 19, 2009. Alexandria, VA.

2. Simon, A.J., Daily, W.D., and White, R.G., "Hydrogen and Water, An Engineering, Economic and Environmental Analysis", LLNL TR-422193 (In Press).

References

1. Greene, D.L et. al. "Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements." Oak Ridge National Laboratory, March 2008.

2. Greene, D.L., Leiby, P.N., James, B., Perez, J., Melendez, M., Milbrandt, A., Unnasch, S., Rutherford, D., and Hooks, M., 2007, *Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements:* Oak Ridge National Laboratory, ORNL/TM-2008/30.