X.7 Water Needs and Constraints for Hydrogen Pathways

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Objectives

The objective is to evaluate the water footprint of a hydrogen economy – similar to a well-to-wheels assessment of the total water required to support a hydrogen economy.

- Define water accounting methods.
- Identify the major technologies and processes that use water in a hydrogen economy.
- Quantify the water requirements for each technology and process.
- Develop regional cost curves for water.
- Assess the well-to-wheels water requirement for possible hydrogen pathways.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.5) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Future Market Behavior
(C) Inconsistent Data, Assumptions and Guidelines
(E) Unplanned Studies and Analysis

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 Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 5:** Resource evaluation – Estimate the total water requirement within a region for hydrogen production including the cost to acquire, treat, and dispose of water. (4Q, 2009)
- **Milestone 8:** Technological readiness – Develop methods and a database system to evaluate regional water sources for suitability as a feedstock for various hydrogen production technologies. Develop methods to estimate how a regional water economy will respond to a change in water use (e.g. what additional water infrastructure might be required) due to an increase in hydrogen production. (4Q, 2014)
- **Milestone 23:** MSM integration: Adding cost, quality and availability of water resource as input to other models via MSM. (4Q, 2008)

Accomplishments

LLNL has accomplished the following milestones:

- Developed a model of water use for a well-to-wheels hydrogen pathway – i.e. the set of production technologies, supporting processes, and feedstocks required for hydrogen production.
- Estimated water use for a range of candidate pathways (2.0 to 40 gallons per kg of hydrogen – depending on the choice of production method and the source of the electricity "feedstock" used in hydrogen production).
- Estimated cost of water for various processes in the hydrogen production pathway ($0.2 to $8 per 1,000 gallons).
- Developed and demonstrated methodology for estimating substitution costs for improved water efficiency for a candidate pathways.

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Introduction

Like most industrial products, hydrogen requires water for its production. Water is required as a direct input in the hydrogen production process itself, both as process water (e.g. the steam in steam methane reforming, SMR) and as cooling water for those processes. Hydrogen production also utilizes water indirectly, when feedstocks (e.g. electricity and natural gas) containing "embedded water", that is the water required to produce and thus embedded in those feedstocks, are consumed.

This project is tasked with determining the full well-to-wheels water requirement for a hydrogen economy;

both the direct and indirect water requirement. Understanding this "water footprint" of hydrogen fuels will improve the chances for a successful and efficient transition to a hydrogen economy.

Approach

To understand the dynamics and economics of water in hydrogen production, we take a two-pronged approach to defining and estimating the footprint. Firstly, from the perspective of the producers of hydrogen we will assess the role water in the producer's production choices (e.g. which production process are chosen - SMR or electrolysis) and how those choices impact water use. This is a bottom-up approach of identifying and classifying the costs and efficiencies, both water and energy, of the individual technologies that utilize water within the hydrogen production chain. Secondly from the perspective of the "regional" planners we will assess how the aggregate hydrogen production in a region impacts the water resource of that region and how regional planners might respond to an increased water demand from the production of hydrogen. Based on this regional evaluation we will construct cost curves for water that reflect the localized water conditions.

Results

The water use for several subset pathways has been estimated and is shown in the Figure 1. This pathway subset only includes the hydrogen production process, the embedded water in the electricity feedstock, and the source water treatment requirements. These sectors of the pathway are the main contributors to the total water use. The figure includes both water withdrawal [*W*] (the amount withdrawn from a water source) and water consumption [*C*] (the amount of water consumed by the process and so unavailable for reuse). Electrolysis and SMR production is shown along with gasoline and corn based ethanol for comparison.

The cost of water also depends on a number of factors including the quality of the raw "source" water and the *quality requirements* for each process. Figure 2 shows the cost for various raw sources and the additional treatment costs to raise the quality to meet the quality requirements for each process.

Conclusions and Future Directions

The total water required for the hydrogen economy depends strongly on the choice of technologies utilized in the hydrogen pathway. In our pathway subset, we have shown that there is a range of water use from 2 to 40 gallons water per kg of hydrogen produced. The development of pathway technologies based solely on water use is not likely since the main objective is to produce hydrogen not minimize water use. So the well-to-wheels analysis should first evaluate how regional conditions influence the choice of water efficient technologies, then assess the water use for that region given the water constraints. A national assessment based on either an average water use (21 gallons/kg of hydrogen for our subset), or a best-case water use (2 gallons/kg of hydrogen) would be inadequate in both cases. In the average water use case, water would be significantly under valued in regions where water

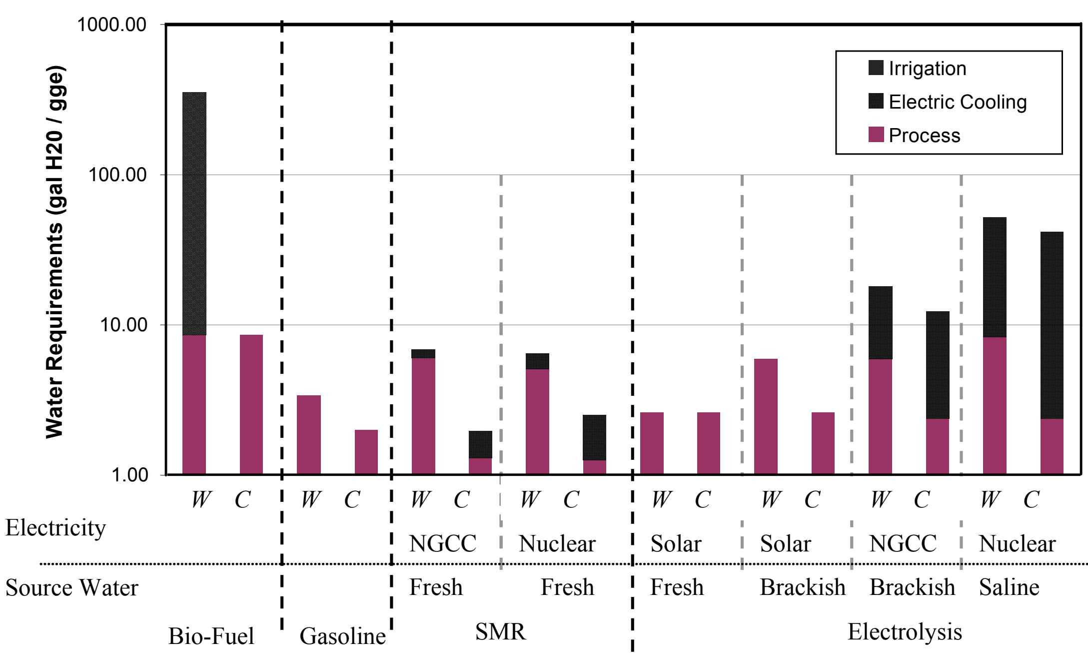

FIGURE 1. Water Intensities for a Subset of the Hydrogen Pathway

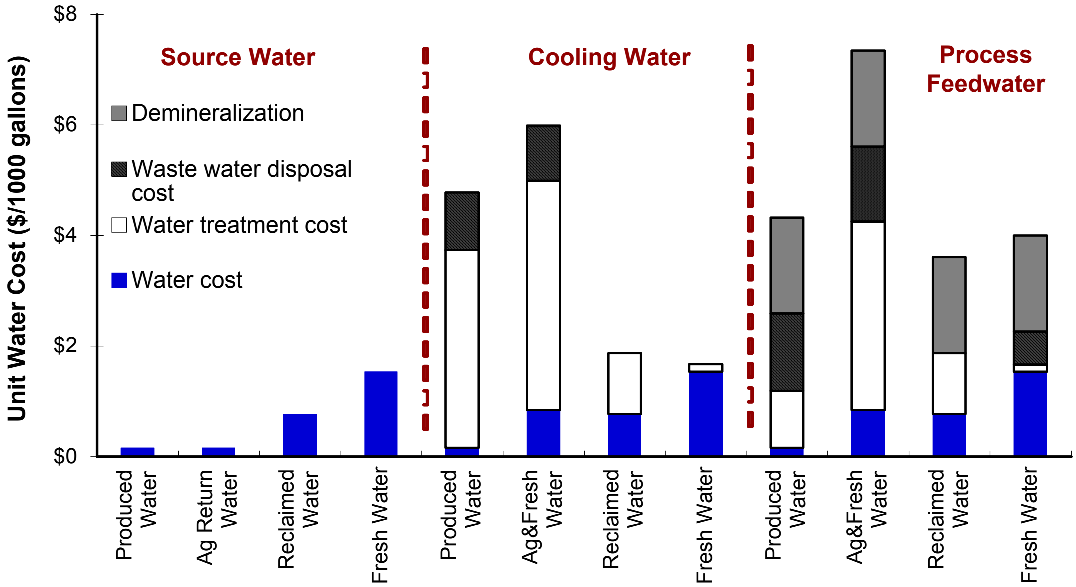

FIGURE 2. Cost of Water by Source and Production Use

is scarce. In the best water use case, production costs would be overestimated in regions where water is not likely to be scarce.

Based on lessons learned we are continuing with regional assessments:

- Assessing regional conditions that influence the adoption of water efficient technologies in the hydrogen pathway.
- Estimate cost curves for each region.
- Assess water source quality influence on total water costs.

FY 2008 Presentations

1. National Hydrogen Association Meeting Annual Conference, Sacramento, CA. March 31, 2008.

2. American Chemical Society 235th National Meeting in New Orleans. April 9, 2008 Session: Understanding the Water Footprint of Energy Production from Conventional and Alternative Sources.

3. United States Council for Automotive Research (USCAR) at Lawrence Livermore Lab, April 23, 2008.

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