X.4 Life-Cycle Analysis of Water Use for Hydrogen Production Pathways

Amgad Elgowainy (Primary Contact),
David Lampert, Hao Cai, May Wu, Jennifer Dunn,
Jeongwoo Han and Michael Wang
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439
Phone: (630) 252-3074
Email: aelgowainy@anl.gov

DOE Manager
Fred Joseck
Phone: (202) 586-7932
Email: Fred.Joseck@ee.doe.gov

Project Start Date: April 2013
Project End Date: September 2015

Overall Objectives

Incorporate water consumption as a new sustainability metric for evaluating hydrogen as a transportation fuel for use in fuel cell electric vehicles (FCEVs) and other fuel/vehicle systems on a life-cycle basis.

Fiscal Year (FY) 2014 Objectives

- Provide a platform for evaluating and comparing hydrogen production pathways and other transportation fuels on a life-cycle basis.
- Develop water consumption factors for various processes along the fuel cycles of hydrogen, gasoline, natural gas, ethanol, and electricity production.
- Incorporate the water consumption factors into the Greenhouse gases and Regulated Emissions, and Energy use in Transportation (GREET) model to evaluate life-cycle water consumption for hydrogen production from steam methane reforming (SMR) and water electrolysis, and compare them to those for gasoline and other major transportation fuels.

Technical Barriers

This project directly addresses Technical Barriers C, D and E in the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan. These barriers are:

(C) Inconsistent Data, Assumptions and Guidelines

(D) Insufficient Suite of Models and Tools

(E) Unplanned Studies and Analysis

Technical Targets

This project expands the GREET model to include water consumption factors for the various life-cycle stages of hydrogen and other fuels, and to compare the life-cycle water consumption of the various fuel/vehicle systems on a consistent basis.

Contribution to Achievement of DOE System Analysis Milestones

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

- Milestone 1.13: Complete environmental analysis of the technology, environmental impacts for hydrogen and fuel cell scenarios and technology readiness. (4Q, 2015)
- Milestone 2.2: Annual model update and validation. (4Q, 2011 through 4Q, 2020)

FY 2014 Accomplishments

- Developed water consumption factors for hydrogen production processes via SMR and water electrolysis.
- Developed water consumption factors for petroleum fuels, natural gas, corn ethanol, and various electricity generation technologies.
- Incorporated water consumption as a new sustainability metric in the GREET model.
- Evaluated and compared the life-cycle water consumption for various fuel/vehicle systems, including hydrogen use in FCEVs.

✧ ✧ ✧ ✧ ✧

INTRODUCTION

One emerging sustainability metric of interest to the life-cycle analysis of alternative fuel/vehicle systems is water consumption. The production of most energy feedstocks and fuels require significant water use. Fossil feedstock sources such as natural gas, crude oil and oil sands require the use of water and steam for extraction, processing, refining and upgrading. Similarly, biofeedstocks such as corn, need water for growth. Converting these feedstocks to fuels requires additional water consumption. Producing electricity at thermal power plants requires a substantial amount of water to cool the equipment and complete the power cycle. A large amount of water evaporation is reported from water reservoirs used for hydropower generation.

Water withdrawal is the water uptake from a source by any given process, while water consumption is the withdrawal amount minus the amount returned to the same withdrawal source. Argonne developed water consumption factors for petroleum fuels (e.g., gasoline and diesel), conventional natural gas and shale gas, corn ethanol, hydrogen production via SMR and water electrolysis, and various electric power generation technologies. Water consumption factors for hydrogen production were developed from data provided by industrial sources. Water consumption factors for hydrogen production included water rejection during the preproduction treatment processes, steam use in the SMR process, water use as a feedstock for the electrolysis process, and water consumption with the various cooling technologies.

RESULTS

Table 1 shows the water consumption factors for hydrogen production via SMR and electrolysis in central production and distributed locations. The water rejection rate of reverse osmosis water treatment is assumed to be lower with production scale. The cooling technology is assumed to be cooling tower for large-scale central production and closed-loop dry cooling for small-scale distributed production. The cooling tower water circulation rate is approximately 0.1 gpm per each kg/h hydrogen production. We assumed that 3% of the circulating water is required as makeup water to compensate for blow down, evaporation, and drifting losses.

TABLE 1. Water Consumption Factors for Central and Distributed Hydrogen Production (gal/kg hydrogen)

Production Technology	SMR		Electrolysis	
Production Scale	**Central**	**Distributed**	**Central**	**Distributed**
Reverse Osmosis Treatment	1.3*	4**	1.3*	4**
Production Process	4 (3.9–4.2)	4 (3.9–4.2)	4 (3.6–5.4)	4 (3.6–5.4)
Cooling	0.2‡	0‡‡	0.2‡	0‡‡
Total	5.7	8	5.7	8

* 25% water rejection rate
** 50% water rejection rate
‡ Cooling tower with 3% of circulating water as makeup water and 0.1 gpm of circulating water per kg hydrogen/h production
‡‡ Closed-loop dry cooling

Table 2 shows the water consumption factors for various fuels and power generation technologies. It is noted that the water consumption factor for hydropower generation is large, mainly due to the evaporation from the large surface area of the water reservoir. The water consumption rate by the U.S. average generation mix is significantly impacted by the large water factor for hydropower even though the share of hydropower generation in the U.S. average generation mix is only 6.5%.

Table 3 shows the life-cycle water consumption per gallon of gasoline equivalent (gge) for petroleum gasoline, natural gas and corn ethanol. The table shows a wide range of water consumption for corn ethanol with the low end representing states that rely on rain fall (green water) for corn growth, while the high end represents states that depend on irrigation. The reported average water consumption in Tables 1–3 represents the production weighted average for each of the fuel production pathways.

TABLE 2. Water Consumption Factors for Electric Power Generation (gal/kWh)

	Water factor (range)
Natural gas	0.21 (0.2–0.7)
Coal	0.52 (0.1–1.1)
Biomass	0.40 (0.1–1.0)
Nuclear	0.58 (0.4–0.7)
Hydropower	18 (14–100)
U.S. Mix	1.6

TABLE 3. Life-Cycle Water Consumption of Petroleum, Natural Gas and Corn Ethanol (gal/gge)

Fuel	Water consumption (range)
Gasoline	5.4 (1.3–9)
Natural gas	0.7 (0.3–1.2)
Corn ethanol	55 (2.2–300)

Figure 1 shows the life-cycle water consumption for hydrogen production via SMR and water electrolysis. The impact of the electricity generation technology employed in the electrolysis pathway is obvious in Figure 1, with the U.S. average generation mix resulting in water consumption of 75 gallons per kg of hydrogen, while wind electrolysis consumes only 5 gallons per kg of hydrogen. With the interest in low-carbon hydrogen for powering future FCEVs, the latter is the likely pathway for hydrogen production via electrolysis. Figure 2 shows the life-cycle water consumption per mile for various fuel/vehicle systems for the midsize vehicle class. Figure 2 reflects 25 miles per gge (mpgge) fuel economy for gasoline, compressed natural gas (CNG) vehicles, and E85 (i.e., 85% ethanol blend with gasoline by

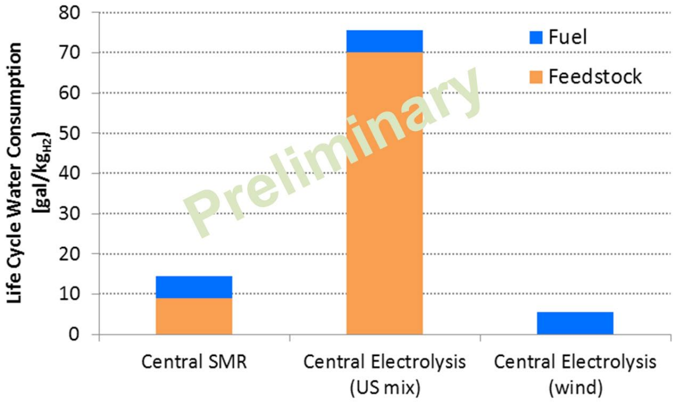
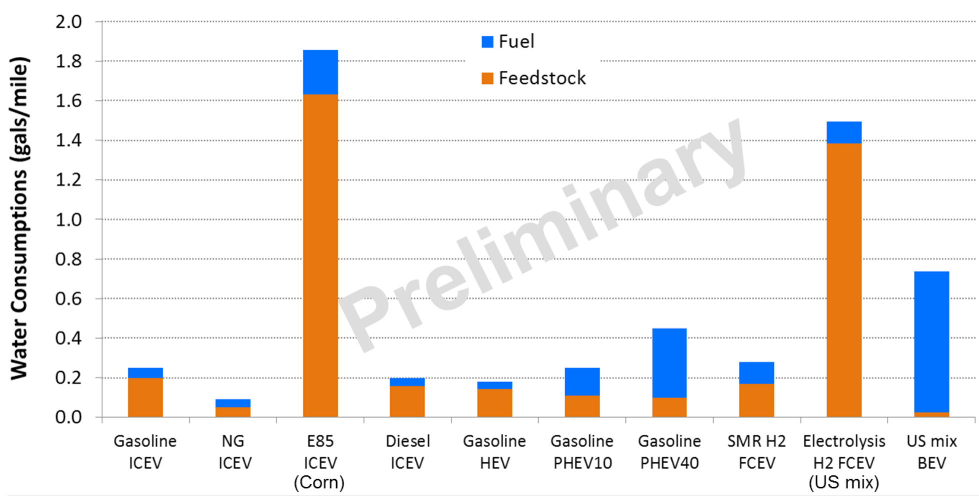


FIGURE 1. Life Cycle Water Consumption for Hydrogen Production via SMR and Electrolysis

volume), 29 mpgge for diesel vehicles, 35 mpg for gasoline hybrid electric vehicles (HEVs), 52 mpgge for hydrogen FCEVs, and 85 mpgge for battery electric vehicles (BEVs). Figure 2 shows the significant impact of the large water consumption factors of corn ethanol and U.S. electricity mix on the E85, hydrogen via electrolysis, and BEV pathways.

CONCLUSIONS AND FUTURE DIRECTIONS

Argonne expanded the GREET model to include water consumption factors for major transportation fuel pathways, including petroleum fuels, natural gas, electricity, corn ethanol and hydrogen, and completed the assessment of water consumption for hydrogen production from SMR and electrolysis. Irrigation water for farming, cooling water for electricity, and evaporation associated with hydropower generation have the greatest impact on life-cycle water consumption of E85 and electric vehicles. Water consumption factors are developed in GREET for the production of hydrogen, baseline petroleum fuels, and other fuels that are commonly used as feedstocks, blendstocks or process fuels (e.g., electricity, diesel, natural gas, corn ethanol, etc.) in the various pathways within the GREET model. The life-cycle water consumption analysis needs to be expanded to include additional hydrogen production pathways and alternative transportation fuel/vehicle systems.



ICEV - internal combustion engine vehicle; PHEV10 - plug-in hybrid electric vehicle, 10-mile all-electric range; PHEV40 - plug-in hybrid electric vehicle, 40-mile all-electric range

FIGURE 2. Life Cycle Water Consumption for Alternative Fuel/Vehicle Systems