IX.6 Life Cycle Analysis of Water Use for Hydrogen Production Pathways

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Project Start Date: April 2013
Project End Date: Project continuation and direction determined annually by DOE

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) 2015 Objectives

- Review and update water consumption for baseline petroleum fuels and current hydrogen production technologies, including natural gas steam methane reforming (SMR) and electrolysis
- Incorporate water consumption for low-carbon hydrogen production pathways of biomass gasification and biogas purification and reforming
- Address outstanding water consumption issues for hydrogen production such as impact of water treatment for SMR and electrolysis, and indirect water consumption associated with hydropower electricity generation (for electrolysis pathway)
- Examine impact of various cooling technologies (wet cooling vs. dry cooling)

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 (MYRDD) Plan.

(C) Inconsistent Data, Assumptions, and Guidelines

(D) Insufficient Suite of Models and Tools

(E) Unplanned Studies and Analysis

Technical Targets

This project expands the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (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 milestone from the Systems Analysis section of the Fuel Cell Technologies Office MYRDD Plan:

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

FY 2015 Accomplishments

- Developed water consumption factors for hydrogen production from biogas reforming, and from coal and biomass gasification
- Updated water consumption factors for hydrogen production via SMR and electrolysis
- Updated water consumption for petroleum pathways
- Developed methodology for allocating water consumption to hydropower generation
- Examined tradeoff between water saving and energy use of dry cooling vs. wet cooling
- Expanded the GREET model to include updated and new water consumption factors
- Compared water consumption per mile for various fuel/vehicle combinations
- Documented approach, data, methodology, and analysis in a report

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INTRODUCTION

One emerging sustainability metric of interest to the lifecycle 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 consumes additional water. Producing electricity at thermal power plants requires a substantial amount of water to cool the equipment and complete the power cycle. Large amounts of water evaporation are 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, various electric power generation technologies, and hydrogen production via SMR, water electrolysis, biogas reforming, and biomass gasification. Water consumption factors for hydrogen production were developed from open literature data as well as 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 updated water consumption factors for hydrogen production via SMR and electrolysis in central production and distributed locations based on information acquired from industry. The stoichiometric steam-to-carbon ratio (S/C) on a molar basis is 2, which translates to 1.2 gallon of water per kilogram of hydrogen. However, an S/C ratio of 2.5–3 is used in large industrial production to maximize methane conversion. For small scale distributed SMR production, the S/C is higher to increase the hydrogen yield at the expense of small efficiency reduction. Cooling can be performed with either wet cooling or dry cooling.

TABLE 1. Water Consumption Factors for Central and Distributed SMR Hydrogen Production [gal/kg$_{_H2}$]

Production technology	SMR	
Production scale	Central	Distributed
S/C ratio	2.5–3	4–5
Production process	1.6 (1.5–1.8)	2.5 (2.4–3.0)

Argonne also investigated the water consumption associated with biogas upgrading since the CH_4 content in raw biogas is typically 60–70% while the rest of the raw biogas is largely CO_2 along with other impurities, such as H_2S and NH_3. For biogas upgrading, six processes are used: chemical scrubber, water scrubber, organic physical scrubber, pressure swing adsorption, membrane separation, and cryogenic separation. Among them, chemical scrubber, water scrubber and organic physical scrubber use an absorption technique with a different absorbent. Water scrubbers utilize the higher water solubility of CO_2 relative to CH_4 for separation and thus consume more water than the other upgrading technologies. Water scrubbers are the most commonly used technology in the world but are less common in the United States, thus most information collected on water scrubbers is based on European plants. Depending on the water recovery employed by different plants, the range of make-up water consumption for scrubbers covers a wide range (4 to 192 gal/mmBtu), with a production weighted average of 59 gal/mmBtu. We assume that the water consumption of water scrubbers in the United States is consistent with that in Europe. Water consumption by the other biogas upgrading technologies is assumed to be small since no water-intensive process is used. Thus, their water consumption is assumed to be similar to that of fossil natural gas processing at 1.7 gal/mmBtu. Taking account for the biogas upgrading capacity by each technology in the United States, a production weighted average water consumption for total biogas upgrading in the U.S. is estimated at 9.3 gal/mmBtu, with a range from 2 to 27 gal/mmBtu.

Argonne investigated the water consumption associated with gasification of biomass to hydrogen. Gasification processes require water both to drive the process and for cooling. The cooling required in a gasification facility can be wet, dry, or some combination of the two. Additionally, the process efficiency can be improved using heat recovery that impacts the overall process water consumption rate. A water consumption rate of 38.1 gal/mmBtu was developed using the material balance from a detailed process of a woodchip gasification facility.

Argonne developed an allocation method to update the water consumption factor for hydropower generation. The approach included merging the eGRID and National Inventory of Dams databases. The gross reservoir evaporation was estimated based on pan evaporation data, while the background evapotranspiration was deducted from the gross evaporation. The reservoirs were divided into two categories: multipurpose and dedicated to hydropower generation. An allocation methodology was developed to allocate the water consumption burden in multipurpose reservoirs. Figure 1 shows a schematic of the allocation approach that resulted in a weighted average net water consumption factor for hydropower generation of 9.85 gal/kWh.

Figure 2 shows the life cycle water consumption for hydrogen production via natural gas and renewable natural gas (biogas) SMR, water electrolysis, and gasification of coal and woody biomass. The hydrogen production stage dominates the life cycle water consumption for all pathways

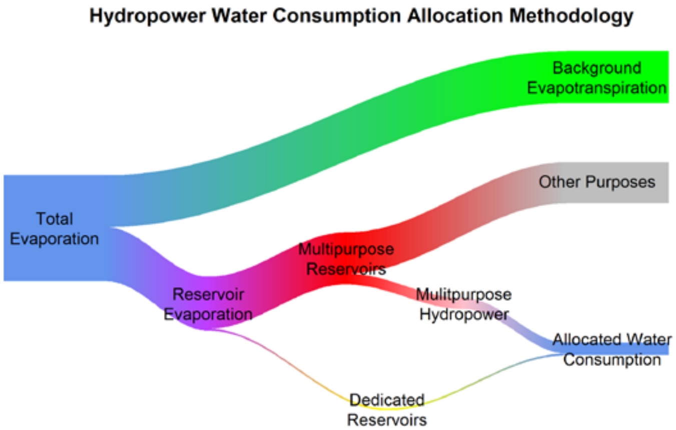


FIGURE 1. Hydropower water consumption allocation methodology

with the exception of electrolysis using United States electricity grid mix due to its high water consumption factor and the significant use of electricity. The water embedded in the electricity used for hydrogen compression at the station is also significant contributor to the life cycle water consumption for all pathways.

Figure 3 shows a chart of the life cycle water consumption per 100 mile for various fuel/vehicle systems of the midsize vehicle class with the fuel economy of various fuel/vehicle systems shown in the upper chart of the figure.

Figure 3 shows the significant impact of the large water consumption factors of corn ethanol on the E85. The figure also shows the significant impact of water embedded in the United States electricity grid mix on the electrolysis and battery electric vehicle (BEV) pathways, even after revising the hydropower water consumption factor from 18 to 9.85 gal/kWh based on the allocation methodology discussed above.

CONCLUSIONS AND FUTURE DIRECTIONS

Argonne developed water consumption factors for hydrogen production from biogas and from coal and biomass gasification and updated the water consumption factors for hydrogen production via SMR and electrolysis. A methodology for allocating water consumption to hydropower generation was developed. Argonne expanded the GREET model to include the water consumption factors for the new and updated hydrogen production pathways. The water consumption per 100 miles for various fuel/vehicle combinations was compared to identify the stages with major contribution to life cycle water consumption. The outstanding issues include the use of different water consumption evaluation methods with respect to system boundary and allocation. Also the variability of water consumption by region and the water consumption during purification need to be assessed.

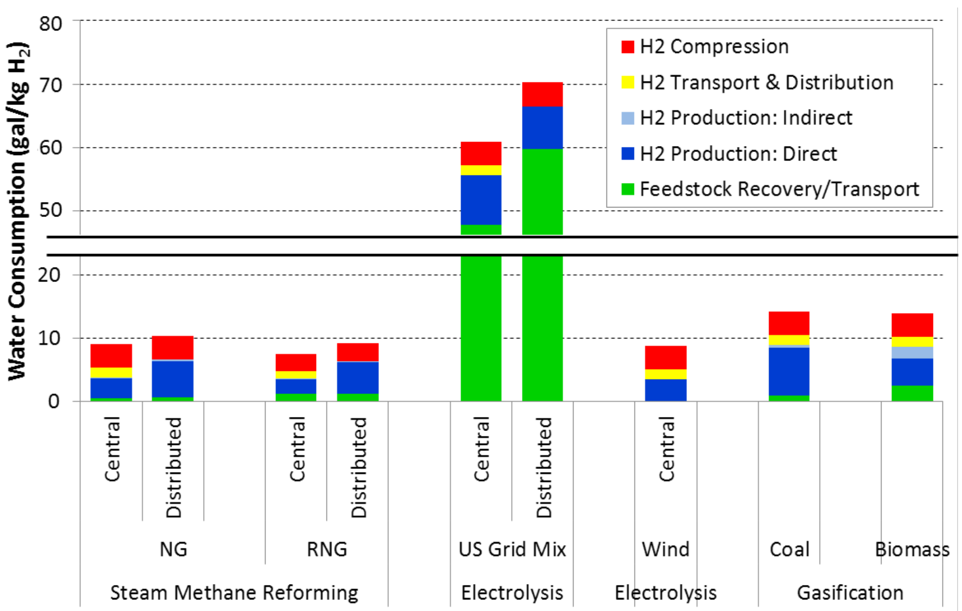
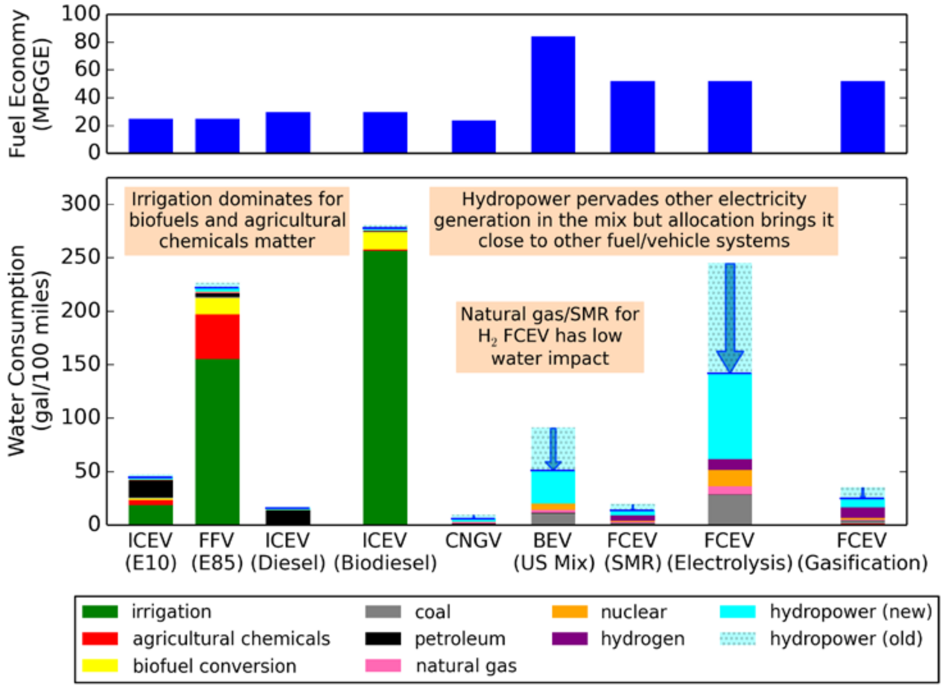


FIGURE 2. Life cycle water consumption for various hydrogen production pathways



BEV – battery electric vehicle; CNGV – compressed natural gas vehicle; FFV – flexible fuel vehicle; ICEV – internal combustion engine vehicle; mpgge – miles per gallon of gasoline equivalent; NG – natural gas; RNG – renewable natural gas

FIGURE 3. Life cycle water consumption for alternative fuel/vehicle systems