IX.2 Life-Cycle Analysis of Water Consumption for Hydrogen Production

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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 associated with hydrogen as a transportation fuel for use in fuel cell electric vehicles (FCEVs).
- Compare water consumption of hydrogen for use in FCEVs with other fuel or vehicle systems on a life cycle basis.
- Identify major contributors in upstream supply chain to water consumption.

Fiscal Year (FY) 2016 Objectives

- Review and update water consumption for baseline petroleum fuels and hydrogen production technologies, such as natural gas steam methane reforming (SMR), electrolysis and biomass gasification.
- Examine the impact of various cooling technologies (e.g., single loop vs. recirculating and tower vs. pond) and cooling water source (e.g., freshwater, saline, brackish water and wastewater) in thermoelectricity generation.
- Address outstanding water consumption issues for hydrogen production
  - System boundary
  - Fate of discharged water from a process

Technical Barriers

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

(B) Stove-piped/Siloed Analytical Capability
(C) Inconsistent Data, Assumptions and Guidelines
(D) Insufficient Suite of Models and Tools

Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes to achievement of the following DOE milestone from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration 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 2016 Accomplishments

- Updated water consumption for petroleum products.
- Evaluated impact of various cooling technologies and cooling water source in thermoelectricity generation.
- Examined wastewater treatment plants (WWTPs) to evaluate impact of discharged water in water consumption factor (WCF) calculations.
- Revised WCFs for hydrogen production via biomass gasification, SMR and electrolysis.
- Expanded the GREET model to include updated and new WCFs.
- Compared water consumption on per mile basis for various fuel and vehicle combinations and showed that FCEVs fueled by H_2 from SMR and biomass gasification consume 37% and 24% less water compared to baseline gasoline internal combustion engine vehicles (ICEVs), respectively.

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INTRODUCTION

Providing a consistent accounting of energy use and emissions associated with the production of transportation fuels, lifecycle analysis has played an important role in decision-making at various places. Recently, Argonne have expanded the lifecycle analysis boundary into water consumption in order to estimate water consumption along the supply chain of different transportation fuels since water consumption is an important sustainability metric. The focus of this study is on hydrogen production pathways since hydrogen is a zero-carbon energy carrier with potential for significant reduction in greenhouse gas and air pollutant emissions. Moreover, hydrogen is essential for processing and upgrading of crude oil and the production of biofuels, such as the processing of heavy crude in refineries and the hydroprocessing of bio-oils.

APPROACH

Water withdrawal is the water uptake from a source by any given process, while water consumption is the net of the withdrawal amount minus the amount returned to the same withdrawal source. Argonne developed WCFs by identifying major contributors in the supply chain to fuel production and developing WCFs for fuel production stages from various data sources. For example, Argonne updated WCFs for petroleum products using a detailed refinery water analysis model developed by Jacobs Consultancy. The WCFs for thermoelectric generation by cooling technology and by cooling water source were developed from Energy Information Administration's database. Also, WCFs for hydrogen production via biomass gasification, SMR and electrolysis were revised from open literature data as well as data provided by industrial sources. Moreover, Argonne examined WWTPs to evaluate impact of discharged water in WCF calculation using open literature data and Environmental Protection Agency's database.

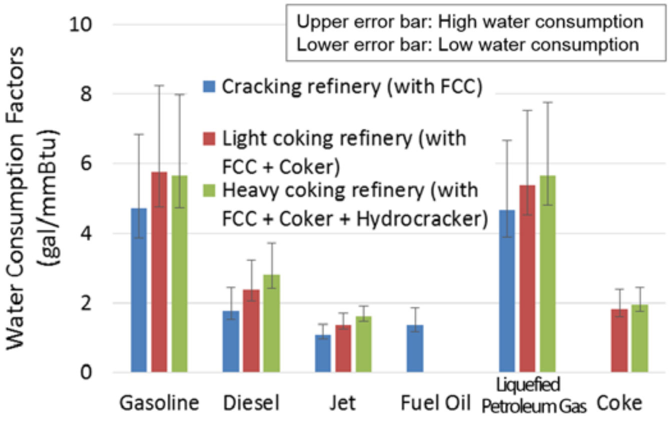
RESULTS

Figure 1 shows the updated WCFs for petroleum products. Since WCFs vary by refinery configuration and refinery cooling technology, three refinery configuration models, each with three water consumption scenarios were examined. The three refinery configuration models included cracking, light coking, and heavy coking refineries. The three water consumption scenarios included base water consumption case as well as low and high water consumption cases, denoted by lower and upper error bars in Figure 1, respectively. As shown in Figure 1, gasoline and liquefied petroleum gas consume more water than the other products because their production involves water-intensive processes, such as alkylation and reformation. Also, more complex refineries (i.e., the heavy coking refinery) are more water-intensive in general than less complex refineries (i.e., the cracking refinery). Note that water consumption in refineries correlates well with energy consumption since cooling is a major water consumption source.

Figure 2 shows the overall and fresh WCFs of thermoelectric generation by North American Electric Reliability Corporation region. The overall WCFs include the consumption of fresh, saline, brackish water or treated wastewater. The national average of overall and fresh WCFs for thermoelectric generation are 0.36 gal/kWh and 0.29 gal/kWh, respectively. Thermoelectric power plants in the Southwest Power Pool are the most water-intensive at 0.47 gal/kWh while those in Northeast Power Coordinating Council (NPCC) are the least water intensive at 0.08 gal/kWh. The map in Figure 2 shows the location and generation of thermoelectric power plants using non-freshwater for cooling, most of which are located near the coastal areas. As a result, the fresh WCFs in Florida Reliability Coordinating Council (FRCC), Western Electricity Coordinating Council (WECC) and NPCC are significantly lower than the overall WCFs in each of these regions (0.07 gal/kWh vs. 0.24 gal/kWh in FRCC, 0.25 gal/kWh vs. 0.39 gal/kWh in WECC, and 0.03 gal/kWh vs. 0.08 gal/kWh in NPCC).

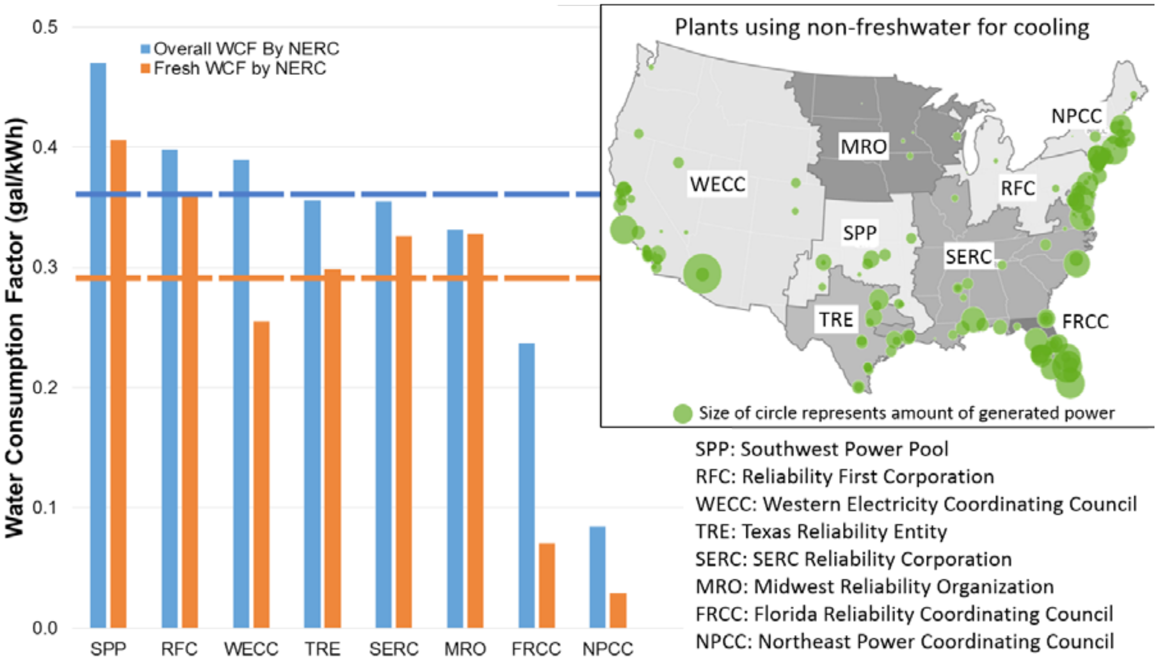
Figure 3 presents the updated WCF for hydrogen production via biomass gasification using two data sources: Spath et al. (2005) and Choi et al. (2009) [1,2]. The resulting WCFs of hydrogen from biomass gasification from these two independent sources are quite similar (3.3 gal/kg H_2 and 3.7 gal/kg H_2) when excluding the discharged water that goes into WWTPs. The process water consumption is in the range of 1.4–1.7 gal/kg H_2, while the cooling water consumption is 1.9–2 gal/kg H_2.

Approximately, 0.7–1 gal of WCF shown in Figure 3 represents discharged water that goes to WWTPs. Thus, the fate of wastewater and the energy, and the water consumption



FCC – Fluid catalytic cracking

FIGURE 1. Water consumption factors for petroleum products



SPP: Southwest Power Pool
RFC: Reliability First Corporation
WECC: Western Electricity Coordinating Council
TRE: Texas Reliability Entity
SERC: SERC Reliability Corporation
MRO: Midwest Reliability Organization
FRCC: Florida Reliability Coordinating Council
NPCC: Northeast Power Coordinating Council

FIGURE 2. Overall and fresh water consumption factors of thermoelectric generation by region

associated with WWTPs were also investigated. In a WWTP, there are two sources of water consumption: the water consumed in the upstream of electricity generation, and the water consumption by solid disposal. The water consumption associated with wastewater treatment use of electricity were estimated at 0.0028 gal/gal of treated water (or 0.28%) without internal generation of electricity from biogas. With internal generation of electricity, the WCF for WWTP decreases to 0.03–0.15%. On the other hand, digestate is a key water outlet by solid disposal. From the digestate's typical solid content (17–33%), the water consumption by solid disposal is estimated at only 0.1–0.2%. Moreover, water consumption via evaporation is negligible since water in WWTPs continuously flows. Conclusively, WCF of wastewater treatment is very small and is considered negligible.

Table 1 shows the updated WCFs for hydrogen production via SMR and electrolysis in central production

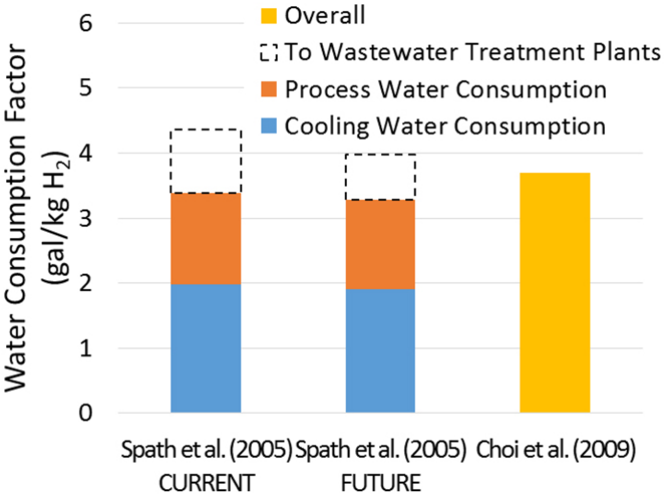


FIGURE 3. Water consumption factors for hydrogen production via biomass gasification

TABLE 1. WCFs for Central and Distributed SMR and Electrolysis Hydrogen Production (gal/kg H_2)

	SMR			Electrolysis	
Process	**Central w/o Carbon Capture**	**Central w/ Carbon Capture**	**Distributed**	**Central**	**Distributed**
Production Process	1.7	1.7	2.5	2.9	2.9
Cooling Loss	0.65	1.15	0	1.2	0
Total	2.4	2.9	2.5	4.1	2.9

w/o – Without; w/ – With

and distributed locations based on information acquired from industry data. One key revision made to these WCFs compared to previous estimates is that the water discharge amount (0.7–3.9 gal/kg H_2) is excluded from the WCF calculations, assuming negligible water consumption by WWTPs. Thus, the updated WCFs for SMR and electrolysis are lower from our previous estimates by 0.7–3.9 gal/kg H_2.

Figure 4 shows the life cycle water consumption per 100 miles for various fuel and vehicle systems of the midsize vehicle class with the fuel economies shown at the bottom of the figure. Figure 4 shows the significant impact of irrigation for corn ethanol on the baseline gasoline ICEV pathway (due to the 10% ethanol blending). The figure also shows the significant impact of water embedded in the U.S. electricity grid mix on the electrolysis and battery electric vehicle pathways. Except for the FCEVs fueled by H_2 from electrolysis, the FCEV pathways consume less water than baseline gasoline ICEV on a life cycle basis. For example, FCEVs fueled by H_2 from SMR and biomass gasification consume 37% and 24% less water compared to baseline gasoline ICEVs, respectively.

CONCLUSIONS AND FUTURE DIRECTIONS

The water consumption factors for hydrogen production via biomass gasification, SMR and electrolysis vary by feedstock source and conversion processes. While hydrogen production from SMR, wind electrolysis and biomass gasification consume less water on a well-to-wheels basis compared to gasoline (E10) ICEV and BEV (using U.S. average generation mix), water consumption for hydrogen production via electrolysis using U.S. average generation mix is higher compared to other hydrogen pathways, BEV and gasoline ICEV. The fate of discharged water in WWTPs shows negligible loss of water during water treatment for its reuse, thus the discharged water is now excluded from our calculations of WCF associated with all fuel production processes. Our future modeling and analysis will address emerging hydrogen production pathways and the variability of water consumption by region for various fuel production pathways.

FY 2016 PUBLICATIONS/PRESENTATIONS

1. Lampert, David J., Hao Cai, and Amgad Elgowainy. 2016. “Well to Wheels: Water Consumption for Transportation Fuels in the United States.” *Energy & Environmental Science* 9 (3): 787–802.

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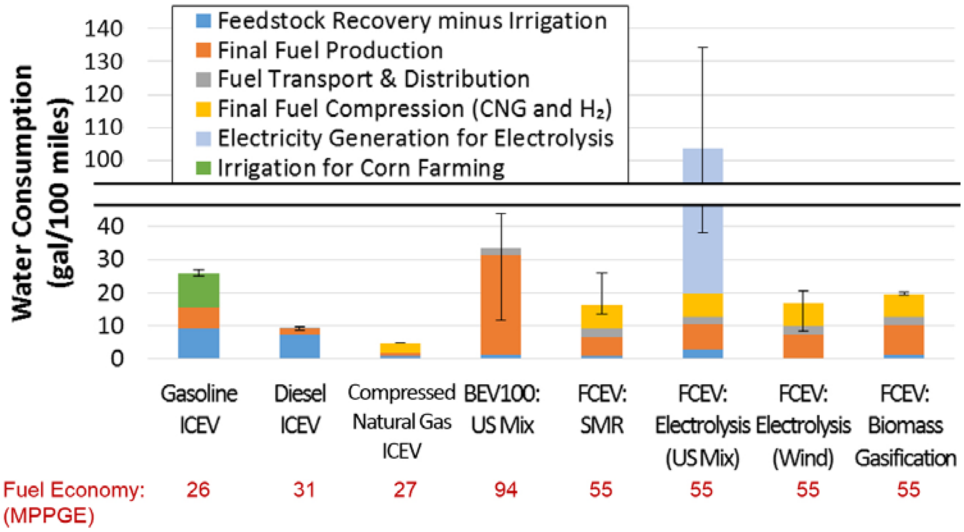
2. Choi, DongWon, David C. Chipman, Scott C. Bents, and Robert C. Brown. 2009. “A Techno-Economic Analysis of Polyhydroxyalkanoate and Hydrogen Production from Syngas Fermentation of Gasified Biomass.” *Applied Biochemistry and Biotechnology* 160 (4): 1032–46.



CNG – Compressed natural gas; BEV – Battery electric vehicle

FIGURE 4. Life cycle water consumption for alternative fuel/vehicle systems