IX.2 Regional Water Stress Analysis with Hydrogen Production at Scale

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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 the upstream supply chain to water consumption.
- Analyze the technology environmental impacts on regional water stress for hydrogen and fuel cell deployment scenarios.

Fiscal Year (FY) 2017 Objectives

- Estimate regional hydrogen demand and associated water consumption for large scale deployment of hydrogen FCEVs.
- Evaluate the fresh water supply and demand at a county level and generate a water index representing relative water scarcity for the conterminous United States.
- Perform regional water consumption impact analyses for hydrogen production at scale.

Technical Barriers

This project directly addresses Technical Barriers B, C, and D in the Systems 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 will contribute 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 2017 Accomplishments

- Developed hydrogen production scenarios based on H2@Scale and National Renewable Energy Laboratory's resource analysis.
- Estimated regional hydrogen demand and associated water consumption for FCEVs by 2040.
- Evaluated county-level water index for regional water stress impact analysis.
- Performed water consumption impact analysis for the large-scale deployment scenarios of hydrogen FCEVs.

INTRODUCTION

Hydrogen is a zero-carbon energy carrier that can be produced from various domestic feedstock sources. Hydrogen is also important for FCEVs and the processing and upgrading of other fuels. Fresh water is essential for various energy systems, including transportation fuel production, since those systems typically consume a significant amount of water. However, available fresh water resources vary greatly by region. Large scale deployment of energy production in water-stressed regions has the potential to deprive water required to sustain human activities and the environment, which may lead to negative environmental and social impacts. Thus, water stress analysis at a regional level is critical for a sustainable future of energy systems. Life-cycle impact analysis is a method that provides a consistent accounting of fresh water consumption for the production of fuels along their supply chain.

The objective of this study is performing regional water consumption impact analysis for hydrogen production at scale using life-cycle water consumption of various hydrogen production pathways. In this study, the regional impact of hydrogen production at scale for FCEVs on water stress is evaluated based on the estimated water consumption for hydrogen demand and a newly developed regional water stress index at the county level. This study contributes information that can be used to guide sustainable water management decisions.

APPROACH

The project mainly consists of two parts; one is estimating regional hydrogen and water demand for hydrogen FCEVs by 2040, and the other is evaluating fresh water supply and demand at a county level to generate a water index that represents relative water scarcity locally across the United States. These together can be used to perform water stress impact analyses using life-cycle water consumption data. First, using Argonne's VISION model, a scenario for the number of hydrogen FCEVs that can be deployed by 2040 was developed, and the required hydrogen production to satisfy the FCEV stock was calculated at a county level. Regional hydrogen production pathways were generated based on resource availability (National Renewable Energy Laboratory's resource analysis). This provides an estimation of water consumption for hydrogen production at a county level by integrating the life cycle water consumption factors of various hydrogen production pathways [1] and the hydrogen demand at each county.

For water consumption impact analyses, fresh water supply and demand should be evaluated by region since water availability shows significant spatial variation, which leads to significantly different impacts on regional water stress, even for the same amount of water consumption across regions [2]. Thus, we evaluated fresh water supply and demand using measured runoff and human water use data provided by United States Geological Survey; then the water index representing water scarcity was calculated at a county level. This index was named AWARE-US, which quantitatively indicates available water remaining that can be used for other activities. Argonne evaluated the regional impact caused by the water consumption to meet the hydrogen demand for FCEVs by combining estimated water consumption for hydrogen production and the AWARE-US index. This study also evaluated the possibility of groundwater depletion by comparing groundwater recharge and human groundwater consumption. Where a human consumes more groundwater than recharge, it can be assumed that the region depletes stored groundwater, which is not a sustainable practice.

RESULTS

Figure 1 represents county-level water consumption for hydrogen production to support a deployment scenario of FCEVs by 2030, and shows significant regional water demand variation. There are many factors that influence the water consumption such as the number of deployed fuel cell vehicles, the employed hydrogen production technologies (e.g., electrolysis or steam methane reforming), and the upstream water consumption along hydrogen production supply chain. The most influential driver for the regional variation is the difference in the number of deployed FCEVs. The employed technologies for hydrogen production and the FCEVs' fuel economy do not notably change the regional variation trend. The results shows that western and eastern United States, where FCEVs may be more actively deployed, would require a significant amount of fresh water for hydrogen production that meets number of deployed vehicles.

Figure 2 shows the AWARE-US index calculated from measured fresh water supply and demand. AWARE-US ranges from 0.1 to 100, representing regional water scarcity relative to the U.S. consumption-weighted average (AWARE-US = 1). For example, when the index is 0.1, the regionally available remaining water is 10 times higher than the U.S. average, which means the region has abundant fresh water resources leading to less water stress. On the other hand, if the index value is 10, the region has only 10% of available water resource when compared to the U.S. average, and there would be significant competition over fresh water among various purposes in that region. The results shows that western U.S. counties have high index values, while most counties in the eastern United States have indices lower than the average. The west central U.S. counties have the highest index values mainly because they have low runoff (due to low precipitation with high evapotranspiration) and high water consumption (mostly for irrigation). This means any marginal increase in water demand in these regions magnifies its impact on water stress and may result in depletion of stored groundwater.

Since available fresh water resources vary by region significantly (Figure 2), water consumption for FCEVs in Figure 1 should be considered along with the balance of fresh water supply and demand, i.e., available water. For the regional water consumption impact analysis, water footprint for FCEVs in each county can be expressed in terms of equivalent water consumption at a reference flow by multiplying the volume of water consumption and the AWARE-US in the region where it is consumed. Figure 3 represents the impact of water consumption for FCEVs at a county level. The results showed that the western United States has much higher water consumption impact compared to the eastern United States. For example, using the FCEV deployment scenario generated by VISION, California consumes only 1.3 times the volume of fresh water consumed in New York in order to meet the hydrogen demand in their

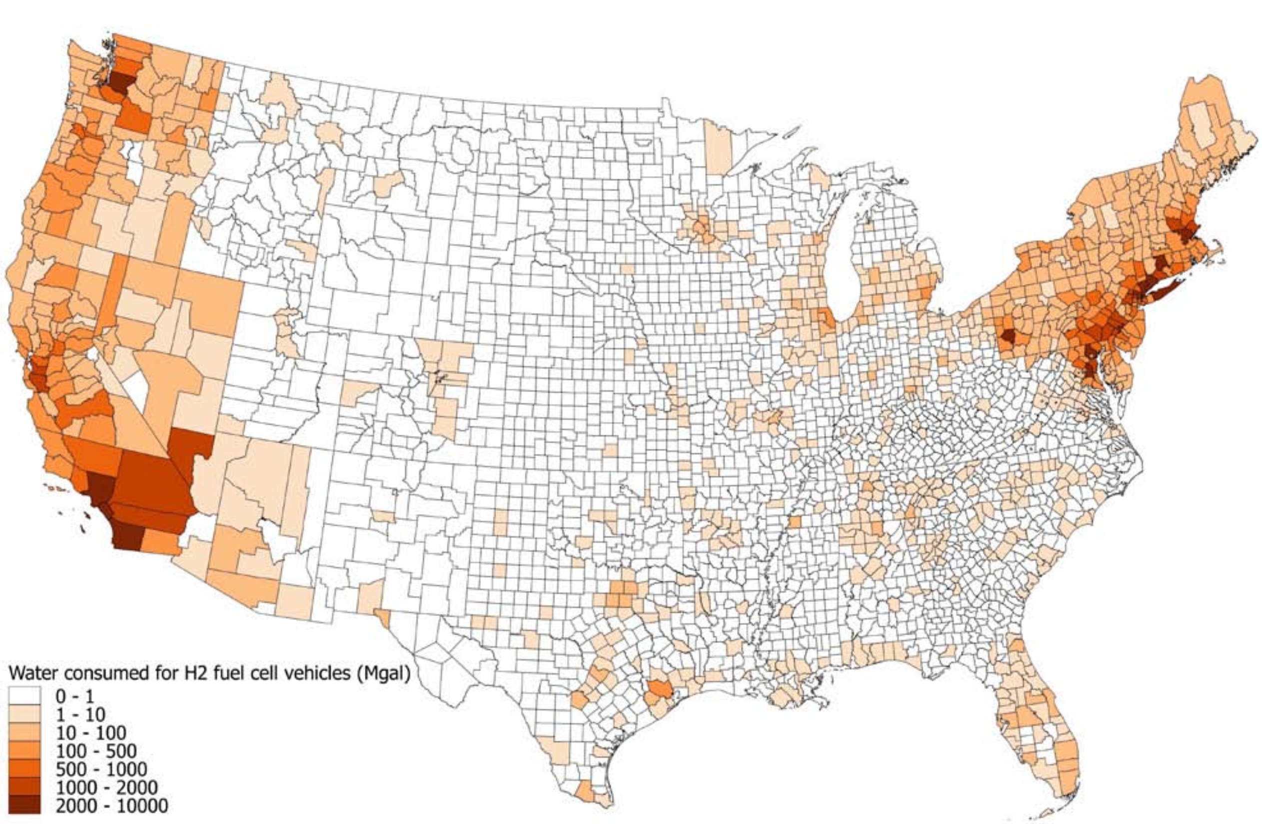

FIGURE 1. County-level water consumption to support hydrogen production for FCEVs by 2040

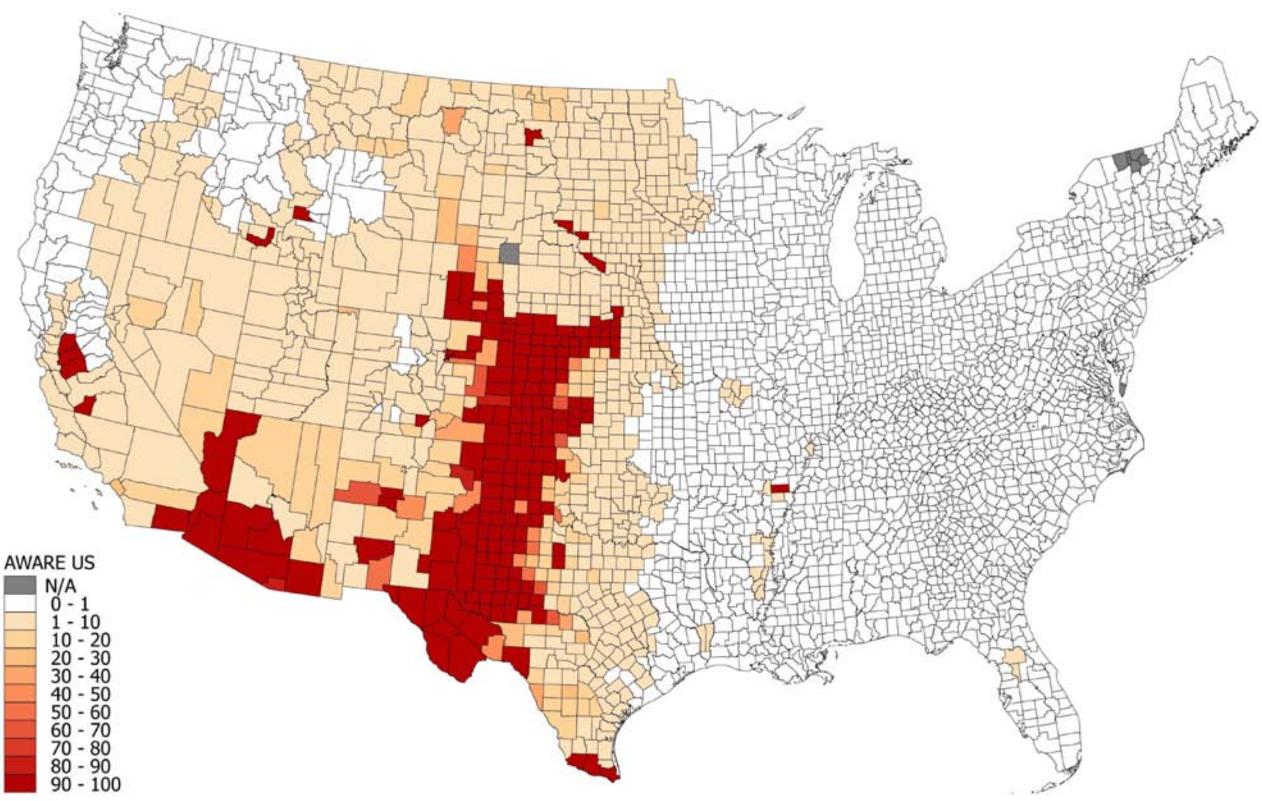

FIGURE 2. AWARE-US index range from 0.1 (water-abundant) to 100 (water-stressed)

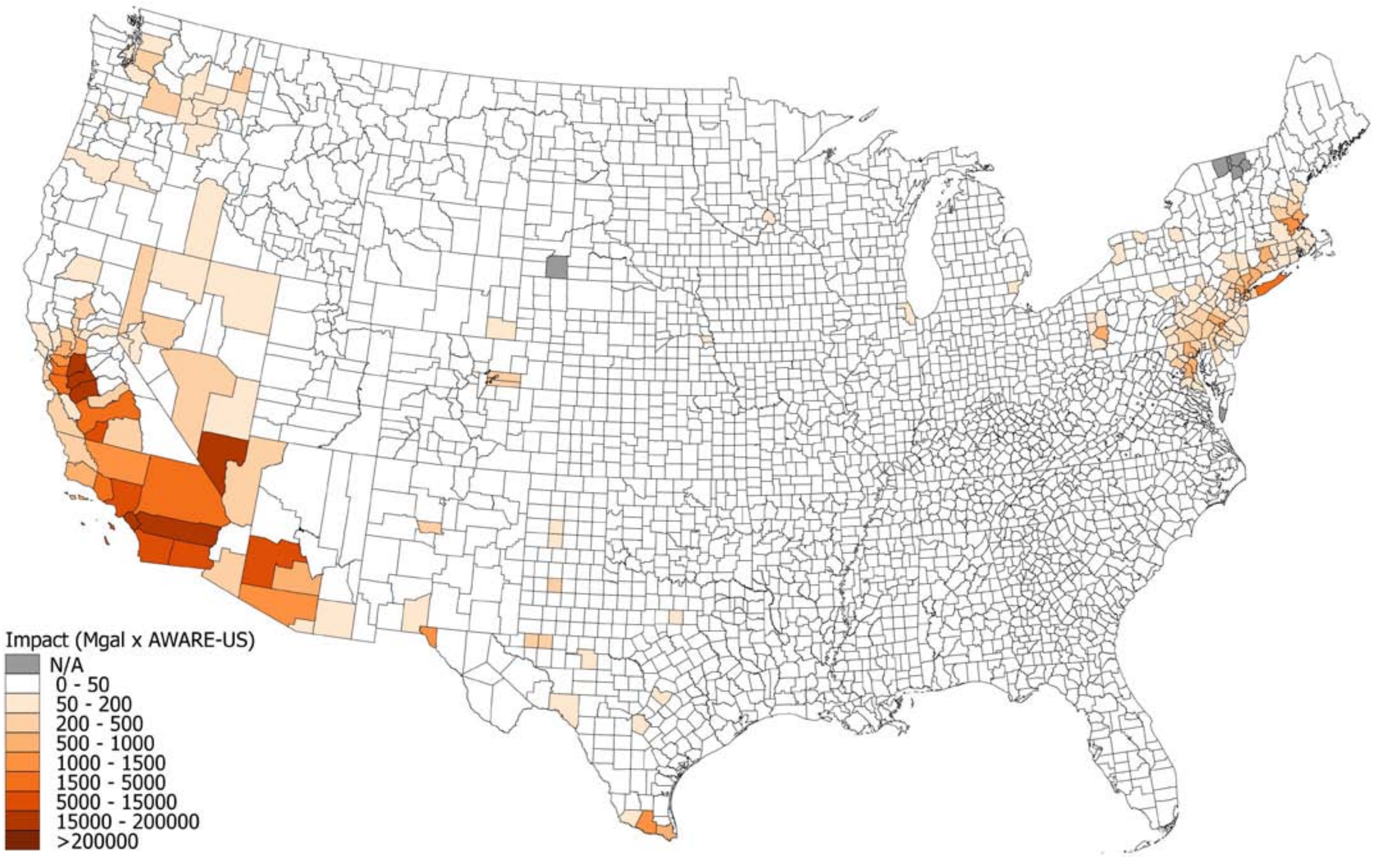

FIGURE 3. Regional water consumption impact analysis for hydrogen production for FCEVs by 2040 in the conterminous United States

respective states. However, the water consumption impact in California is 27 times higher compared to New York due to the higher AWARE-US (water stress index in California).

The red colored counties in Figure 4 indicate the regions where human groundwater consumption may exceed the groundwater recharge in the county. When compared with Figure 2, Figure 4 also shows that counties with AWARE-US of 100 deplete stored groundwater due to the insufficient surface water supply. Therefore, any additional fresh water demand for fuel production in these counties will likely incur further groundwater depletion. If groundwater is used to supply additional water demand in this region, it may lead to additional groundwater depletion problems.

CONCLUSIONS AND UPCOMING ACTIVITIES

This analysis focused on identifying the regional impact of water consumption for large scale deployment of hydrogen FCEVs. The results showed that significant regional variation exists for water consumption for FCEVs, and there is spatial variation in fresh water supply and demand between counties. Any marginal increase in water demand for fuel production in water-stressed regions will magnify the impact on water stress. This study provides a systematical approach to evaluating the sustainability of various energy systems in terms of water use and its impact on water stress in various regions in the United States. Further analysis is needed to address issues such as analyzing existing baseline fuels (non-marginal). Life-cycle water consumption inventory needs to be expanded further to include alternative hydrogen pathways with low water consumption.

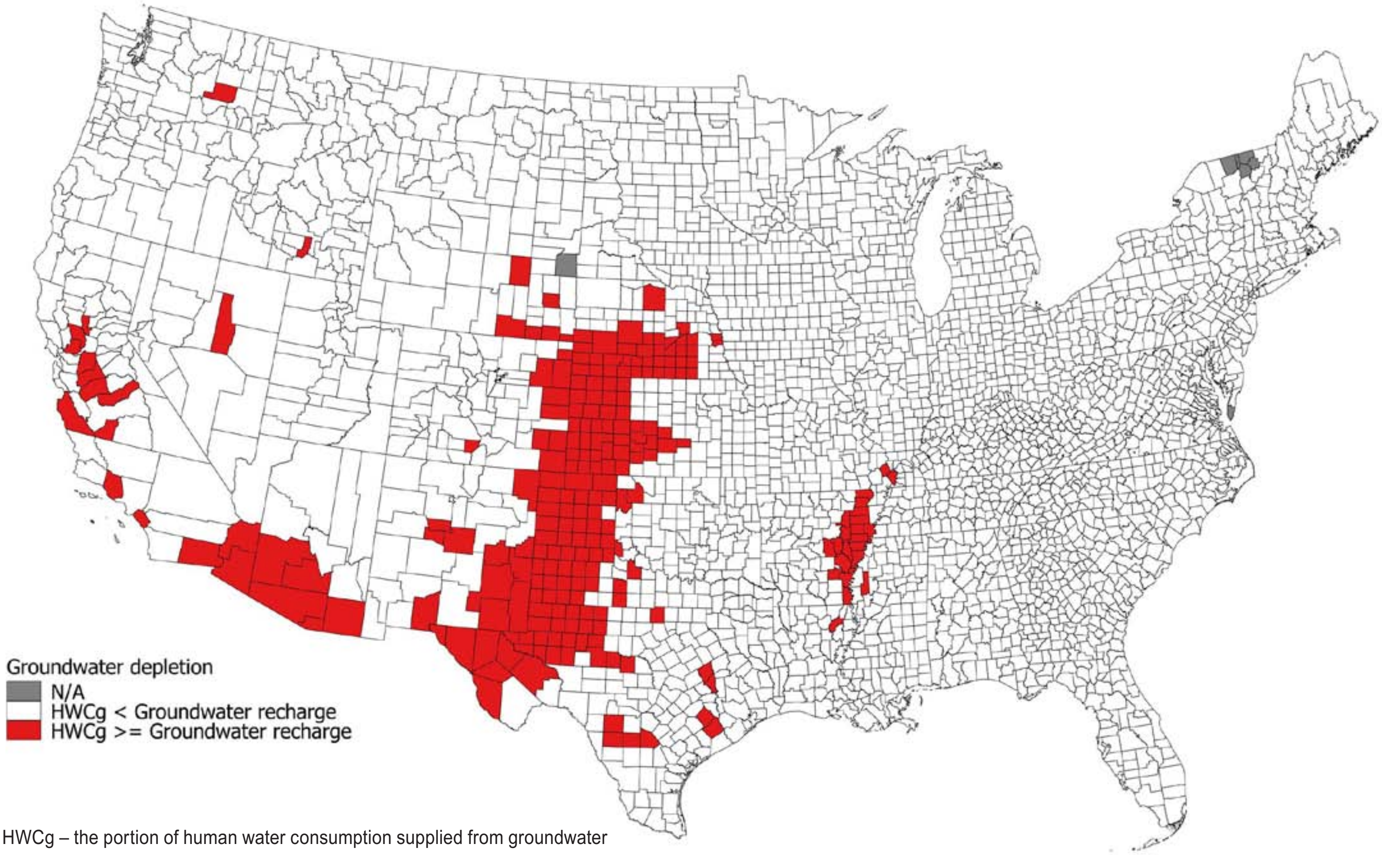

FIGURE 4. Groundwater depletion in the conterminous United States

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Lee, Uisung, Jeongwoo Han, Amgad Elgowainy, and Michael Wang. 2017. "Regional Water Consumption for Hydro and Thermal Electricity Generation in the United States." Applied Energy. doi:10.1016/j.apenergy.2017.05.025.

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1. U.S. Department of Energy. 2016 Annual Progress Report, DOE Hydrogen and Fuel Cell Program. No. DOE/GO-102017-4891. Washington, D.C., 2016.

2. Boulay, A-M., Jane Bare, Lorenzo Benini, Markus Berger, Michael J. Lathuillière, Alessandro Manzardo, Manuele Margni et al. "The WULCA consensus characterization model for water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE)." *The International Journal of Life Cycle Assessment* (2017): 1–11.