XI.10 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 Objective

Quantify water consumption associated with various hydrogen production pathways

Fiscal Year (FY) 2013 Objectives

- Evaluate water consumption for various hydrogen production processes
- Identify approaches to efficient water use
- Assess impacts of feedstock source on life-cycle water consumption for hydrogen production
- Identify major contributors to water consumption in the upstream supply chain of hydrogen

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(C) Inconsistent Data, Assumptions and Guidelines

(D) Suite of Models and Tools

(E) Unplanned Studies and Analysis

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)

FY 2013 Accomplishments

- Quantified the water consumption associated with central and distributed production of hydrogen via steam methane reformation (SMR).
- Quantified the water consumption associated with central and distributed production of hydrogen via electrolysis of water.

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INTRODUCTION

One emerging category of interest to the life-cycle analysis (LCA) of alternative fuels is water consumption. The production of most energy feedstocks and fuels require significant water use. Competing fuel production pathways strain available water resources and raise the potential of water supply and demand imbalance at a regional level. Addressing the potential regional imbalance requires the examination of the growing needs for water use in different energy production systems. Fossil feedstock sources such as natural gas and crude oil require significant volumes of water for extraction. Similarly, biofeedstocks such as corn and cellulosic biomass need water for growth, Figure 1. Converting conventional and biofeedstocks to fuels require additional water consumption. Producing hydrogen from electricity (via electrolysis), natural gas (via SMR), or biomass (via gasification) requires the use of water for the conversion process as well as for cooling.

The stages included in the life cycle of any product include its raw material acquisition, transportation and processing, as well as its manufacturing, distribution, use and disposal or recycling. LCA of a fuel is known as fuel-cycle analysis or well-to-wheels (WTW) analysis. With support from DOE Energy Efficiency and Renewable Energy offices, including the Fuel Cell Technologies Office Argonne National Laboratory developed the Greenhouse gases, Regulated Emissions, and Energy in Transportation (GREET) model to evaluate the environmental impacts of various fuel-vehicle systems on a life-cycle basis. The life cycle stages in the GREET model are shown in Figure 2. This phase of the project will focus only on the fuel cycle water consumption. LCA metrics in GREET include energy use by type (e.g., fossil, petroleum, natural gas, coal, nuclear, renewable), greenhouse gases emissions (e.g., CO_2, N_2O, CH_4), and criteria air pollutants emissions (e.g., CO, VOC,

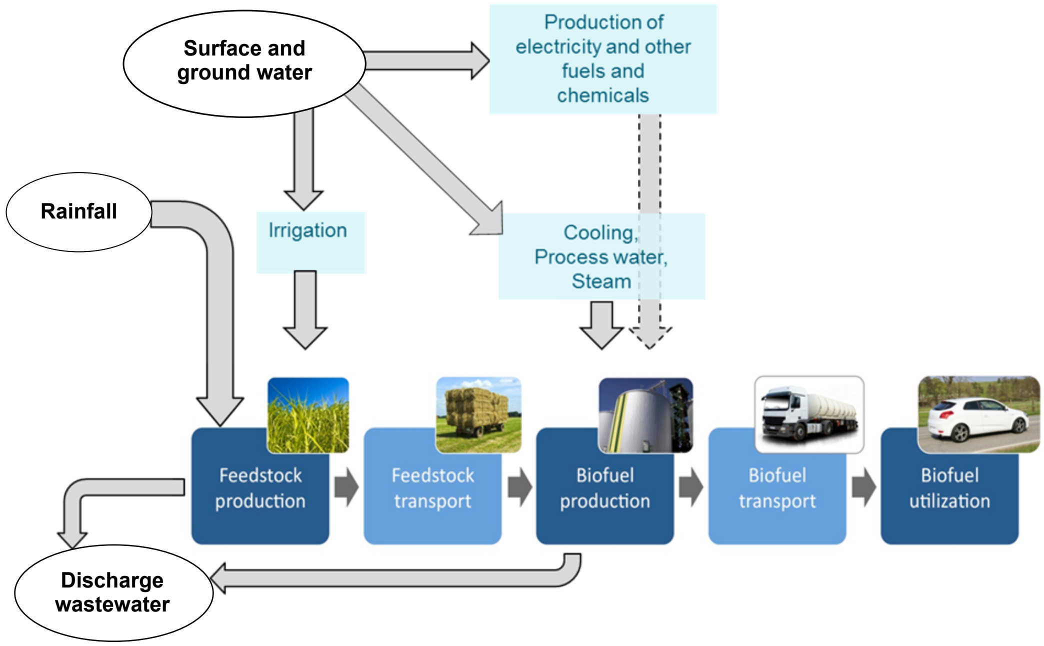

FIGURE 1. Example of Water Accounting in the Biofuel Production Pathway

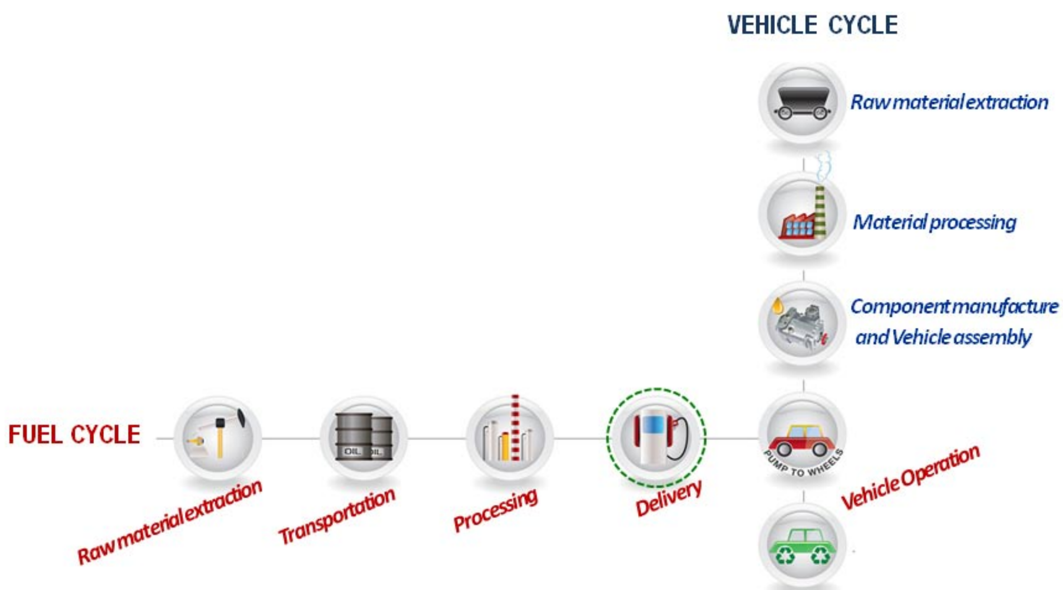

FIGURE 2. Life-Cycle Stages in the GREET Model

NOx, SOx, particulate matter. With the help of this effort, water consumption will be added as a new metric to the GREET model. Water consumption will account only for fresh surface and ground water (also known as “blue” water). Water consumption is defined as fresh water withdrawal from a given surface or ground source minus the fresh water returned to the same withdrawal source.

APPROACH

The water consumption during hydrogen production processes can be attributed to three main factors: (1) water rejection at water treatment plant, (2) water consumption needed for the energy conversion process, and (3) water consumption during cooling process. Data sources for this project include open literature, Fuel Cell Technologies Office H2A models, industrial sources, and engineering process calculations. Once water consumption is estimated for the hydrogen production processes, the indirect water use in the upstream supply chain will be evaluated and incorporated in the life-cycle water consumption assessment.

RESULTS

The rejection rate at the water treatment plant depends on the quality of supply water and on the employed purification technology. While municipal water's total dissolved solids are typically below 500 ppm, total dissolved solids in surface and ground waters typically exceed 1,000 ppm. Deionization systems use ion selective membranes that allow the positive ions to separate from the water toward the negative electrode and the negative ions toward the positive electrode, and achieve nearly 100% water recovery rate. Reverse osmosis systems remove nonionic organic contaminants by forcing water under pressure through a semi-permeable membrane while excluding most contaminants. The water recovery rate in such systems depends on the quality of supplied water and can achieve water recovery rate up to 75-80%. The water required for the conversion process to H_2 fuel depends on the feedstock source and the employed technology, and is typically higher than the water consumption calculated from stoichiometric chemistry (1.2 and 2.4 gallon of water per kg of H_2 for SMR and electrolysis, respectively) due to the frequent blow down operations to remove the accumulated impurities which negatively impacts the system performance. Cooling towers require water circulation rate of approximately 10 gal/min for each 100 kg/day hydrogen production [1]. The water consumption rate in cooling towers is typically less than 2% of the water circulation rate. However, dry cooling technologies do not consume any water but are more expensive. The water consumption for hydrogen production via SMR and electrolysis is typically in the range of 9-12 gallon of water per kg of H_2. Rejection at water treatment plants and water loss in cooling towers represent more than 50% of the total water consumption. Future water conservation technologies can practically reduce the water consumption rate to 5-7 gallon of water per kg of H_2 with the lower end for production via SMR and the higher end for production via electrolysis.

CONCLUSIONS AND FUTURE DIRECTIONS

Water consumption during industrial hydrogen production via SMR is in the range of 9-12 gallon of water per kg of H_2. Further analysis is required to evaluate water consumption in other hydrogen production pathways (e.g., biomass and coal gasification). In the next project step, indirect water consumption in the upstream supply chain (e.g., natural gas recovery, electricity generation, biomass growth, transportation and distribution, etc.) will be evaluated. Finally, the water consumption by process will be incorporated in the GREET model to estimate life-cycle water consumption for each production pathway.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. Amgad Elgowainy and Michael Wang received the DOE Joint Vehicle Technologies and Fuel Cell Technologies R&D Award in recognition for their outstanding contributions to life-cycle assessment of alternative fuel vehicles pathways, including fuel cell and battery electric vehicles (2013).

REFERENCES

1. Simon, A., Daily, W., White, R. 2010, Hydrogen and Water: An Engineering, Economic, and Environmental Analysis, Lawrence Livermore National Laboratory, Report# LLNL-TR-422193.