VIII.10 Updated Well-to-Wheels Analysis of Energy and Emission Impacts of Fuel-Cell Vehicles

Michael Wang (Primary Contact) and Ye Wu
Argonne National Laboratory
ESD362/E337
9700 South Cass Avenue
Argonne, IL 60439
Phone: (630) 252-2819; Fax: (630) 252-3443
E-mail: mqwang@anl.gov

DOE Technology Development Manager:
Fred Joseck
Phone: (202) 586-7932; Fax: (202) 586-9811
E-mail: Fred.Joseck@ee.doe.gov

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End Date: Project continuation and direction determined annually by DOE

Objectives

- Develop and update the *G*reenhouse gases, *R*egulated *E*missions, and *E*nergy use in *T*ransportation (GREET) model as part of the Model and Analysis Tool Development task under Systems Analysis in the Hydrogen, Fuel Cells and Infrastructure Multi-Year Research, Development and Demonstration (RD&D) Plan.
- Conduct well-to-wheels (WTW) analyses for hydrogen (H_2) fuel-cell vehicles (FCVs) by using the GREET model for the Office of Hydrogen, Fuel Cells, and Infrastructure Technologies' Multi-Year Program Plan (MYPP), Posture Plan, and other requests.
- Review and evaluate WTW studies conducted by others.

Technical Barriers

This project addresses the following technical barriers from the Systems Analysis section (4.5) of the Hydrogen, Fuel Cells and Infrastructure Multi-Year RD&D Plan:

(A) Lack of Prioritized List of Analyses for Appropriate and Timely Recommendations

(B) Lack of Consistent Data, Assumptions, and Guidelines

(D) Stove-Piped/Siloed Analytical Capabilities

Accomplishments

- Added 16 new H_2 production pathways and intermediate fuel-cell fuels into the most recent version of the GREET model (Version 1.7, released in November 2005).
- Addressed the uncertainties associated with key input parameters regarding H_2 production and FCV fuel economy.
- Provided WTW results for H_2 production pathways and vehicle technologies for DOE sponsor and the National Renewable Energy Laboratory (NREL).

Introduction

The GREET model has been updated and applied to analyze the WTW energy and emission effects of H_2 FCVs compared with conventional technologies and other advanced vehicle technologies. The GREET model provides a consistent modeling methodology to allow comparison of the WTW energy and emission effects associated with various vehicle/fuel options. In developing key assumptions for the model, Argonne conducts extensive research – investigating open literature; contacting industry representatives and stakeholders; and collaborating with industry partners, other national laboratories, and members of other DOE programs. More than 3,000 registered users have downloaded the GREET model to date. In November 2005, Argonne released the latest version of the model: GREET1.7 (beta version).

Approach

For a given vehicle/fuel option, the GREET model separately calculates the following (on a WTW basis): (1) energy consumption for three energy categories (total energy, fossil fuels, and petroleum); (2) emissions of three greenhouse gases (GHGs) (carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O]); and (3) emissions of five criteria pollutants (total and urban emissions, volatile organic compounds [VOCs], carbon monoxide [CO], nitrogen oxides [NO_x], particulate matter with diameters of 10 micrometers or less [PM_{10}], and sulfur oxides [SO_x]). Figure 1 shows the stages covered in GREET simulations. A WTW analysis includes the feedstock, fuel, and vehicle operation stages. The feedstock and fuel stages together are called well-

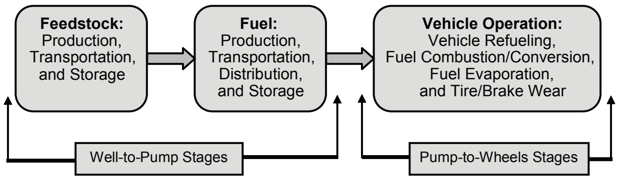

FIGURE 1. Stages Covered in GREET WTW Analysis

to-pump (WTP) stages, and the vehicle operation stage is called the pump-to-wheels (PTW) stage. In GREET, WTW energy and emission results are presented separately for each of the two stages.

GREET includes a variety of vehicle propulsion technologies and transportation fuels, of which H_2 FCVs are a subset. Figure 2 lists various H_2 production pathways simulated in the GREET model. The model can simulate multiple options for a given pathway. For example, the most recent GREET version (GREET1.7) includes approximately 50 options for compressed H_2 and liquid H_2 pathways. Besides H_2, GREET includes many hydrocarbon fuels that are being considered as intermediate fuel-cell fuels: for example, H_2 production from ethanol and methanol at refueling stations.

Results

Argonne applied the GREET model to estimate the WTW energy and emission impacts of FCVs powered by H_2 produced from various energy feedstocks. We added 16 new H_2 production pathways and intermediate fuel-cell fuels to the GREET model. A significant effort was made in the past year to address the uncertainties associated with key input parameters regarding H_2 production and FCV fuel economy.

With co-funding from the Office of HFCIT and other DOE sponsors, Argonne completed a detailed WTW analysis of energy use, GHG emissions, and criteria air pollutant emissions associated with selected vehicle/fuel systems (e.g., conventional gasoline vehicle [GV], GV hybrid, diesel vehicle [DV] hybrid, and FCV hybrid) using GREET1.7. For this analysis, we applied stochastic simulation features in GREET1.7. The findings of the analysis were documented in a Society of Automotive Engineers (SAE) paper (#2006-01-0377)

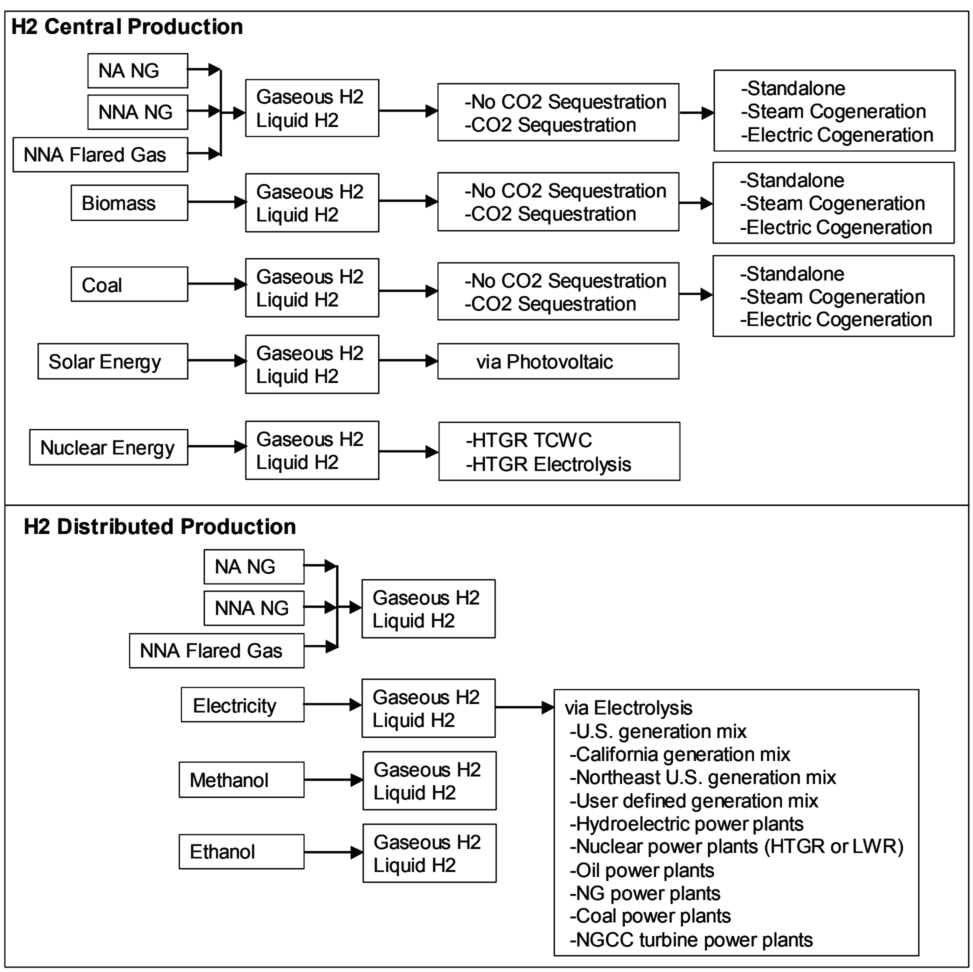

FIGURE 2. H_2 Production Pathways in GREET

and presented at the 2006 SAE World Congress. The study showed that a gaseous hydrogen (GH_2) FCV hybrid system could achieve significant reductions in energy use and GHG emissions compared with the baseline GV. Specifically, we found that the FCV hybrid with H_2 production from renewable sources (e.g., central wind electricity in this study) could reduce fossil energy use, petroleum energy use, and GHG emissions by more than 90%. We also found that H_2 FCV hybrid options may reduce VOC and NO_X emissions significantly, but may have varied results for PM_{10} emissions, depending on the selection of H_2 production feedstocks.

During the last year, Argonne continued to interact with the DOE sponsor and NREL to provide WTW results for certain H_2 production pathways and vehicle technologies. Figures 3 through 6 present WTW results for total energy use, fossil energy use, petroleum energy use and CO_2-equivalent GHG emissions for the following selected H_2 production pathways. These results were produced for DOE's Posture Plan:

1. Distributed production of GH_2 from North American natural gas (NA NG) via steam methane reforming (SMR) (2005 and 2015);
2. Central production of GH_2 from cellulosic biomass via gasification (2005 and 2015);
3. Central production of GH_2 from coal via gasification with CO_2 sequestration (2005 and 2015);
4. Distributed production of GH_2 from wind/grid electricity via electrolysis (2005 and 2015);
5. Central production of GH_2 from wind/grid electricity via electrolysis (2005 and 2015);
6. Central production of GH_2 from nuclear via thermo-chemical water cracking (2030).

To allow comparison of these H_2 FCV options with other vehicle technologies, we also presented WTW results for conventional GVs, GV hybrids, and DV hybrids.

Almost all H_2 pathways showed slight to significant reductions in total energy use compared with conventional GVs (Figures 3 [a] and [b]). The two exceptions are distributed and central electricity pathways for 2005, which increase total energy use. These two pathways were assumed to use 60% of electricity from the U.S. grid and the remaining 40% from wind electricity. When one considers fossil energy use (petroleum, natural gas, and coal; Figures 4 [a] and [b]), all H_2 pathways achieve significant reductions compared with conventional GVs. Specifically, H_2 from biomass, nuclear, and 100% wind electricity is far superior to any other fossil-fuel-based vehicle/fuel option. All of the H_2 FCV options almost eliminate petroleum use (Figures 5 [a] and [b]).

Except two H_2 options (distributed and central electricity pathways for 2005), all other H_2 FCV

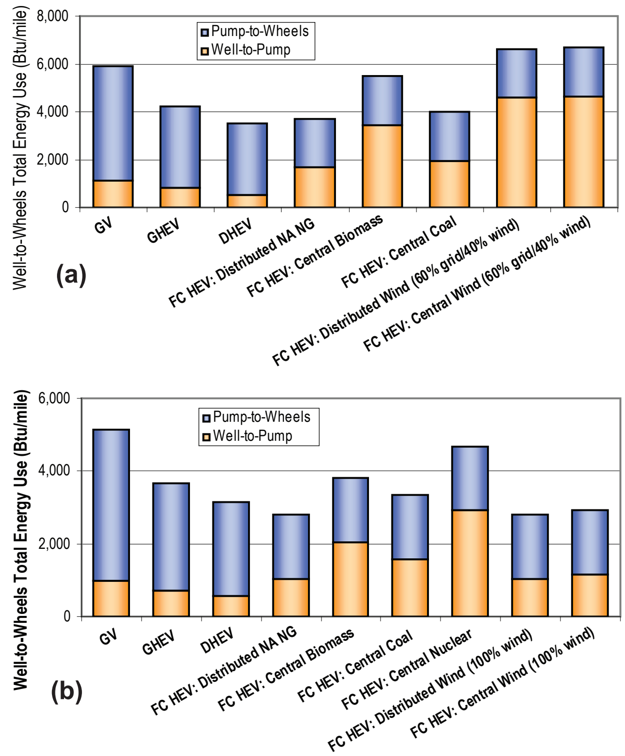

FIGURE 3. WTW Total Energy Use of Selected Vehicle/Fuel Systems (a) 2005 and (b) 2015 (2030 for central nuclear option)

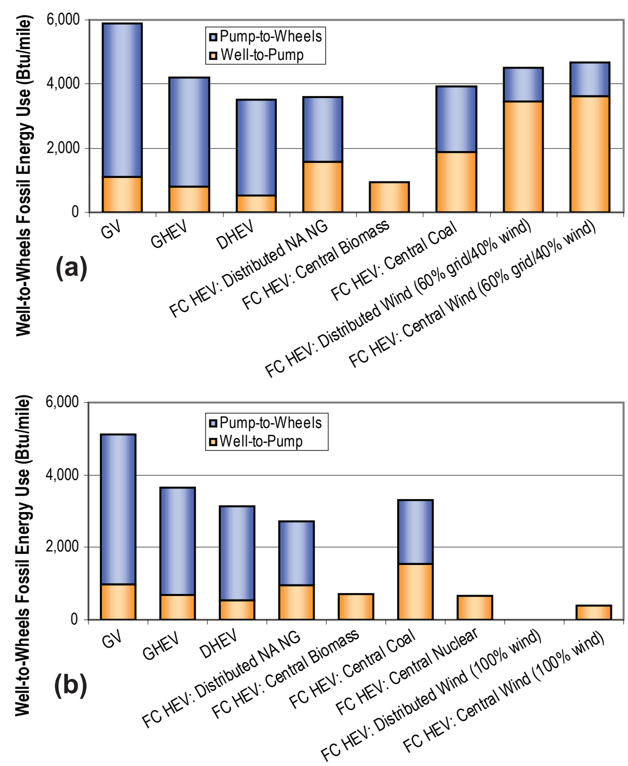

FIGURE 4. WTW Fossil Energy Use of Selected Vehicle/Fuel Systems (a) 2005 and (b) 2015 (2030 for central nuclear option)

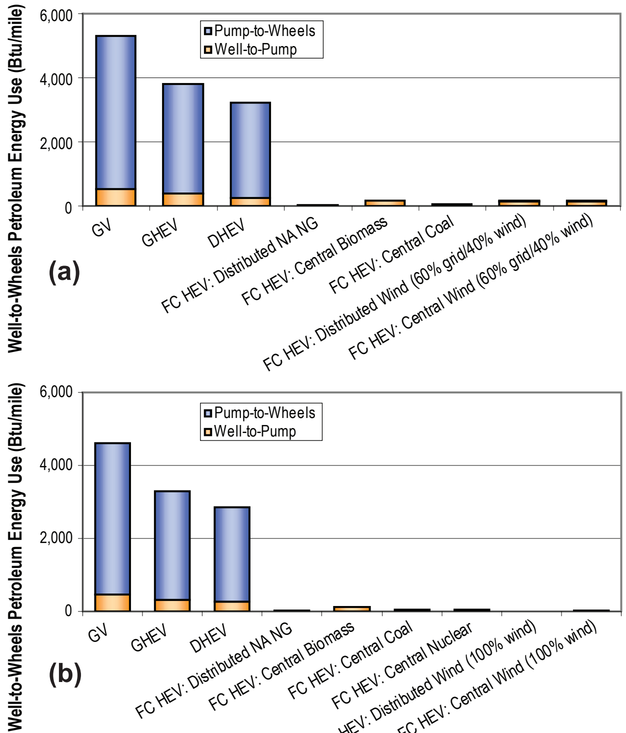

FIGURE 5. WTW Petroleum Use of Selected Vehicle/Fuel Systems (a) 2005 and (b) 2015 (2030 for central nuclear option)

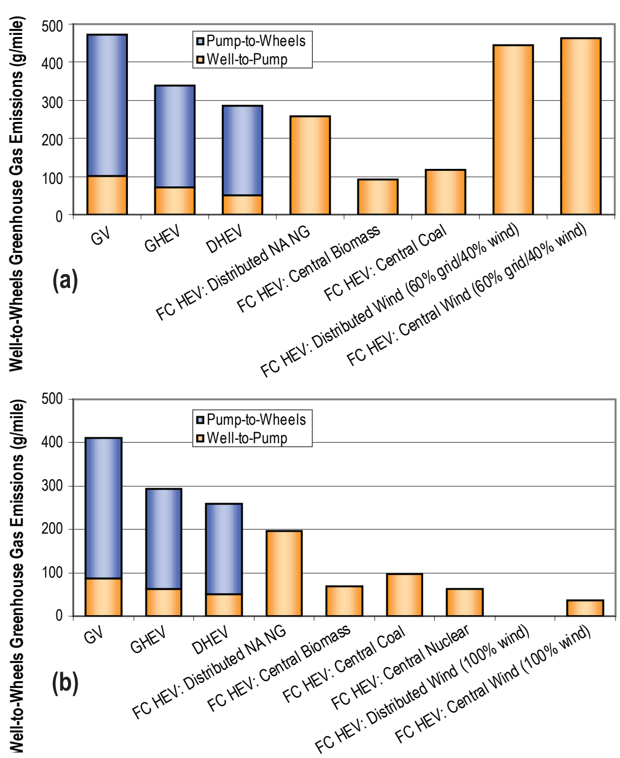

FIGURE 6. WTW Greenhouse Gas Emissions of Selected Vehicle/Fuel Systems (a) 2005 and (b) 2015 (2030 for central nuclear option)

systems achieve huge GHG emission reduction benefits compared with conventional GVs (Figures 6 [a] and [b]). Reductions in GHG emissions by the FCV options are remarkable even compared with those of gasoline and diesel hybrids.

Conclusions and Future Directions

- All H_2 pathways in these studies achieve significant reductions in fossil energy use and almost eliminate petroleum energy use.
- Almost all H_2 pathways achieve huge GHG emission reduction benefits compared with conventional GVs.
- Argonne will continue to add new H_2 pathways and new vehicle technologies into the GREET model and update current available H_2/FCV systems when new data are available.
- Argonne will continue to interact with DOE and other national laboratories to provide WTW results for H_2 production pathways and vehicle technologies.
- Argonne will examine potential H2 supplies from other sources such as coke oven gas from steel mills.

Special Recognitions & Awards/Patents Issued

1. 05/2006. Honorable Mention: Awards for Excellence in Technology Transfer: GREET Model for Evaluating Energy/Emission Impacts of Advanced Vehicle/Fuels, Federal Laboratory Consortium for Technology Transfer.

2. 05/2006. Runner-Up for Category of New Methods and Tools, 2005 SAE Environmental Excellence in Transportation Award: The GREET Model for Transportation Life-Cycle Analysis.

3. 05/2005. 2005 DOE Hydrogen Program R&D Award in Recognition of Outstanding Achievement in Developing a Hydrogen Production Cost Model Known as H2A.

FY 2006 Publications/Presentations

1. Wu, Y., Wang, M., Sharer, P., and Rousseau, A., 2006, "Well-to-Wheels Results of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions of Selected Vehicle/Fuel Systems," SAE paper 2006-01-0377, SAE Congress, Detroit, MI, April 3–6.

2. Sverdrup, G.M., Mann, M.K., Levene, J.I., and Wang, M., 2006, "Status of Hydrogen Production Pathways – Comparison of Energy Efficiencies, Fossil Fuel Use, Greenhouse Gas Emissions, and Costs," presented at the 16th World Hydrogen Energy Conference, Lyon France, June 13–16.

3. Wang, M., Wu, Y., and Elgowainy, A., 2005, *Operation Manual: GREET Version 1.7*, Center for Transportation

Research, Argonne National Laboratory, ANL/ESD/05-03, Argonne, IL, Nov.

Presentations

1. "Well-to-Wheels Analysis of Vehicle/Fuel Systems with the GREET Model," the Joint FPITT/HPITT Tech Team Meeting, DOE, Washington, DC, April 28, 2006.

2. "Well-to-Wheels Analysis of Advanced Vehicle Systems with New Transportation Fuels," Workshop on WTW Efficiency Analysis, Tokyo, Japan, March 7–8, 2006.

3. "Life-Cycle Analysis of Advanced Vehicle Technologies and New Fuels," Sustainable Systems Symposium, Ohio State University, Columbus, OH, March 2–3, 2006.

4. "Well-to-Wheels Results of Advanced Vehicle Technologies Fueled with Different Transportation Fuels", Advanced Transportation Workshop, Global Climate Change Project of Stanford University, Palo Alto, CA, October 10–11, 2005.