# **III.12** Updated Well-to-Wheel Analysis of Energy and Emission Impacts of Fuel-Cell Vehicles

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Start Date: October 2001 End Date: Ongoing annual effort for DOE to update WTW results

## Objectives

- Develop and update the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model as part of the Model and Analysis Tool Development task under Systems Analysis in the Hydrogen, Fuel Cells and Infrastructure Technologies Multi-Year Research, Development and Demonstration (RD&D) Plan
- Conduct well-to-wheel (WTW) analyses for hydrogen (H<sub>2</sub>) fuel cell vehicles (FCVs) by using the GREET model
- Review and evaluate WTW studies conducted by others

# **Technical Barriers**

This project addresses the following technical barriers from the Systems Analysis section of the Hydrogen, Fuel Cells and Infrastructure Technologies 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

## Approach

The GREET model has been updated and applied to analyze the WTW energy and emission effects of  $H_2$  FCVs compared with conventional 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, 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 2,000 registered users have downloaded the GREET model to date.

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 (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O); and (3) emissions of five criteria pollutants (total and urban emissions, volatile organic compounds, CO, NO<sub>x</sub>, PM<sub>10</sub>, and SO<sub>x</sub>). 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-to-pump (WTP) stages, and the vehicle operation stage is called the pump to-wheel (PTW) stage. In GREET, WTW energy and emission results are presented separately for each of the three stages.

GREET includes a variety of vehicle propulsion technologies and transportation fuels, of which H<sub>2</sub> FCVs are a subset. Figure 2 lists various H<sub>2</sub> production pathways simulated in the GREET model. The model can simulate multiple options for a given pathway. For example, the most recent GREET version (version 1.7 — to be released in fall 2005) includes over 50 options for compressed H<sub>2</sub> and liquid H<sub>2</sub> pathways. Besides H<sub>2</sub>, many hydrocarbon fuels are being considered as intermediate fuel-cell fuels. For example, H<sub>2</sub> production from ethanol and methanol at refueling stations is included in GREET.

#### Accomplishments

Argonne applied the GREET model to estimate the WTW energy and emission impacts of FCVs powered with H<sub>2</sub> produced from several energy feedstocks. Many H<sub>2</sub> production pathways and intermediate fuel cell fuels have been added to the GREET model. A new GREET version will be released in fall 2005. A significant effort was made in the past year to address the uncertainties associated with key input parameters regarding H<sub>2</sub> production and FCV fuel economy. Figures 3 through 6 provide updated results for WTW total energy use, fossil energy use, petroleum use, and

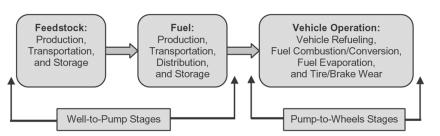
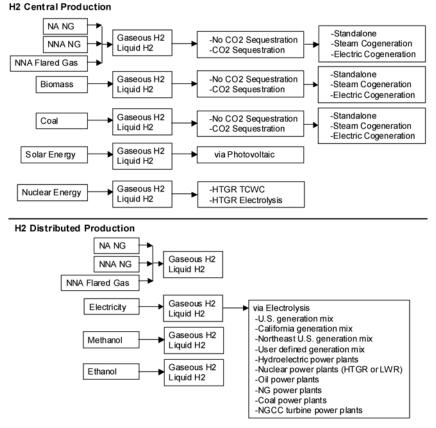
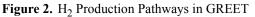


Figure 1. Stages Covered in GREET Well-to-Wheels Analysis





 $CO_2$ -equivalent greenhouse gas (GHG) emissions for the following selected H<sub>2</sub> production pathways: (1) distributed production of gaseous hydrogen (GH<sub>2</sub>) from North American natural gas; and (2) distributed production of GH<sub>2</sub> from renewable electricity via electrolysis; and (3) distributed production of GH<sub>2</sub> from cellulosic ethanol. To allow comparison of these H<sub>2</sub> FCV options with other vehicle technologies, we also present WTW results for conventional gasoline vehicles, diesel vehicles, gasoline hybrids, and diesel hybrids. Although the use of  $H_2$  produced from cellulosic ethanol may increase total energy use (Figure 3), the other two  $H_2$  pathways show significant reductions in total energy use. When one considers fossil energy use (petroleum, natural gas, and coal; Figure 4),  $H_2$  from both cellulosic ethanol and renewable electricity is far superior to any other fossil-fuel-based vehicle/fuel option. All of the three  $H_2$  FCV options almost eliminate petroleum use (Figure 5).

All three  $H_2$  FCV options achieve huge GHG emission reduction benefits compared to current gasoline vehicles (Figure 6). Reductions in GHG emissions by the FCV options are remarkable — even compared to those of gasoline and diesel hybrids.

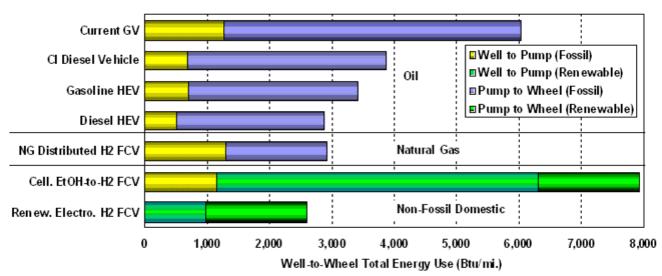


Figure 3. WTW Total Energy Use of Selected Vehicle/Fuel Systems

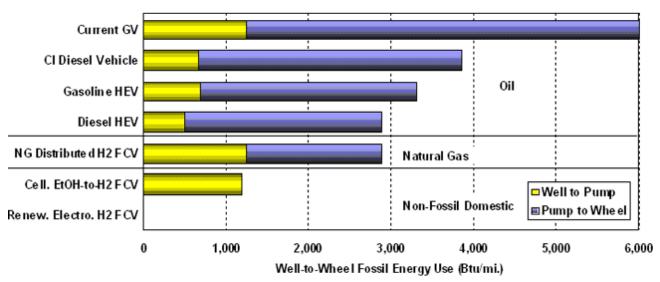


Figure 4. WTW Fossil Energy Use of Selected Vehicle/Fuel Systems

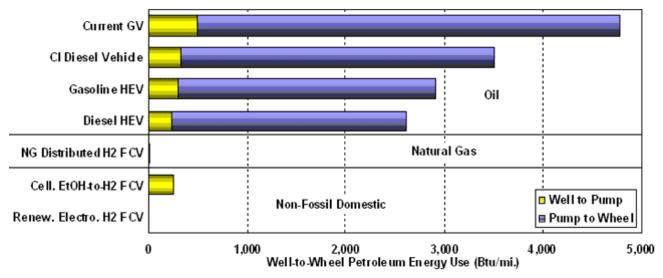


Figure 5. WTW Petroleum Use of Selected Vehicle/Fuel Systems

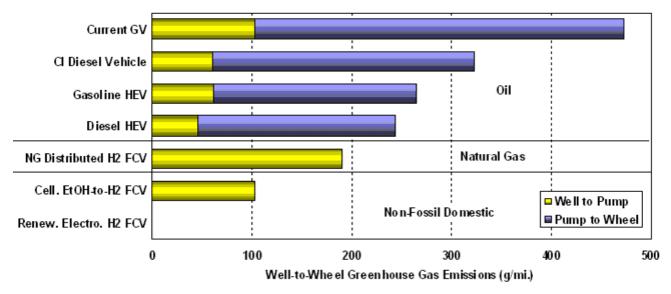


Figure 6. WTW Greenhouse Gas Emissions of Selected Vehicle/Fuel Systems