IX.8 Greenhouse Gas (GHG) Emissions and Petroleum Use Reduction of Medium- and Heavy-Duty Trucks

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Project End Date: Project continuation and direction are determined annually by DOE

Overall Objectives

- Evaluate the potential benefits and trade-offs of hydrogen fuel cell electric vehicle (HFCEV) technology in comparison with conventional diesel internal combustion engine (ICE) for medium- and heavy-duty vehicle (MHDV) applications in terms of air emissions and petroleum use.
- Develop representative and up-to-date estimates of well-to-wheels (WTW) petroleum consumption and air emissions.
- Collaborate with vehicle manufacturers, modelers/analysts (national laboratories, universities, and consulting firms), and fleet operators and managers in the MHDV sector to acquire/review data and results.
- Inform DOE program managers and other stakeholders of the environmental benefits of medium- and heavy-duty hydrogen fuel cell vehicle applications to guide research, development, and demonstration decisions.

Fiscal Year (FY) 2017 Objectives

- Quantify WTW petroleum use and air emissions for medium- and heavy-duty HFCEVs.
- Reflect the diversity of MHDV sector by incorporating different vehicle types, weight classes, and vocations.
- Compare HFCEV technology to conventional diesel and other alternatives in terms of energy use and air emissions (GHGs and criteria air pollutants).
- Incorporate different hydrogen fuel production pathways into the WTW comparison.
- Accurately represent real-world vehicle operation characteristics and its impact on energy consumption and air emissions.
- Actively involve experts from industry (manufacturers and fleet managers) and academia/national laboratories (researchers and analysts) to ensure accuracy of data and results.

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) Insufficient Suite of Models and Tools

Contribution to Achievement of DOE Systems Analysis Milestones

This project contributes 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 2.2: Annual model update and validation. (4Q, 2011 through 4Q, 2020)
- Milestone 3.1: Annual update of Analysis Portfolio. (4Q, 2011 through 4Q, 2020)

FY 2017 Accomplishments

- Developed representative fuel economy values for a variety of medium- and heavy-duty hydrogen fuel cell electric and diesel vehicle classes, based on the most recent heavy-duty vehicle fuel efficiency standards, and employing a high-fidelity advanced vehicle dynamic simulation software (Autonomie), supplemented with real-world idle fuel rates.
- Compared different fuel economy simulation models with different approaches and data sources.
- Expanded the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET®) model by adding HFCEV to the existing MHDV technology portfolio.

- Incorporated up-to-date air emissions factors for refineries and steam methane reforming (SMR) operations.
- Evaluated regional fuel economy variations for various types, weight classes, and vocations of medium- and heavy-duty hydrogen fuel cell electric and diesel vehicles.
- Assessed WTW petroleum use and air emissions reduction benefits by switching from conventional diesel ICE vehicles to HFCEVs, more than 90% for petroleum use, 20–50% for GHG emissions, and 25–70% for criteria air pollutants emissions can be reduced.
- Examined the impacts of different hydrogen production pathways (e.g., conventional central SMR, central solar electrolysis, and central biomass gasification) for the comparison of WTW petroleum consumption and air emissions of hydrogen fuel cell electric and baseline diesel vehicles.
- Analyzed the differences between gaseous and liquid hydrogen fuels for MHDVs in terms of WTW petroleum use and GHG emissions.

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INTRODUCTION

MHDVs, particularly trucks, are the second largest and fastest-growing petroleum consumers and GHG emitters in the U.S. transportation sector. The significance of MHDVs becomes even more important for local air quality management in some areas. For instance, in the South Coast of California (Los Angeles and Long Beach), MHDVs account for 40% of the total summer NO_x (a ground-level ozone precursor) emissions. Whether it's national or local, MHDVs can make a considerable contribution to reducing petroleum consumption, lowering GHG emissions, and improving air quality. To this end, HFCEVs can play an important role, as they create zero tail-pipe emissions and don't consume petroleum fuels. However, information is scarce as to how exactly hydrogen fuel cell MHDVs compare to other vehicle technologies and what the potential benefits are on a holistic life-cycle basis. The main goal of this project is to quantify and examine the WTW petroleum energy use and air emissions of hydrogen fuel cell MHDVs in comparison with conventional diesel ICE vehicles.

APPROACH

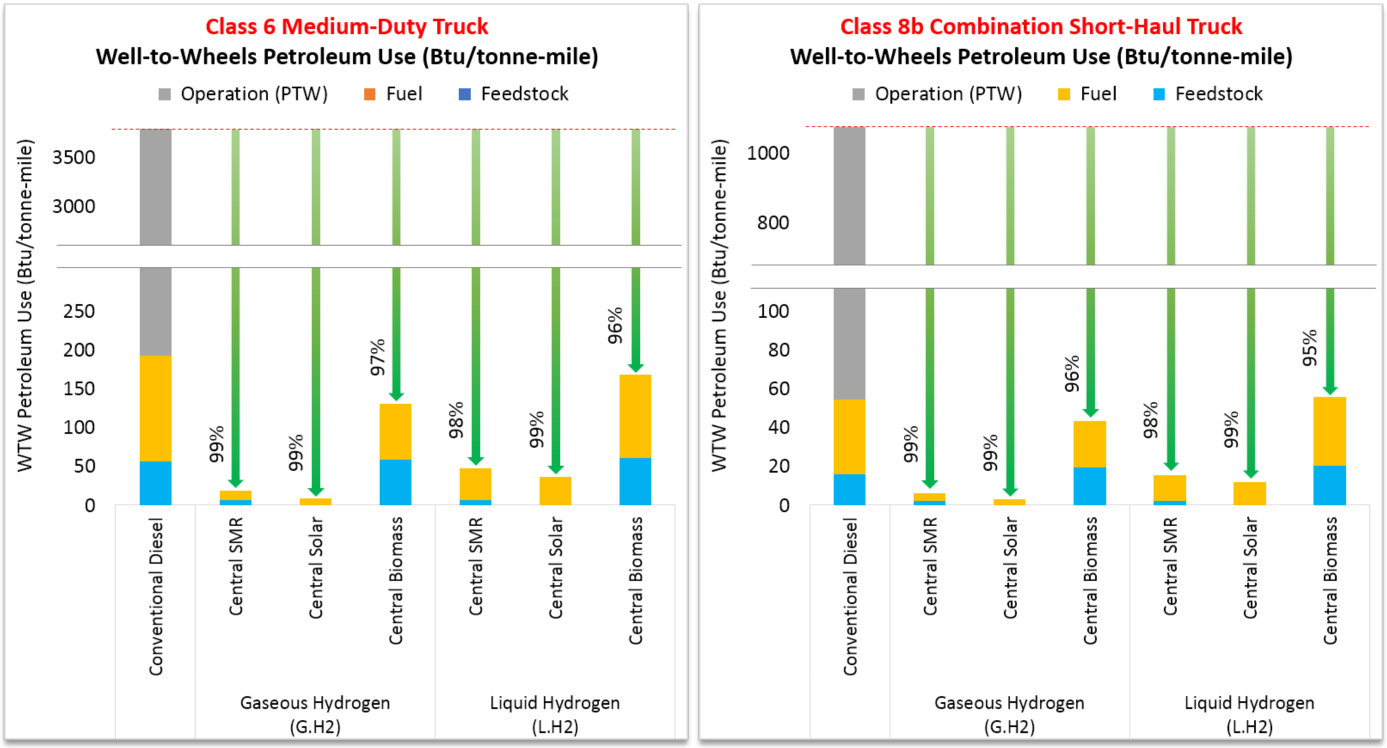
For a holistic and subjective analysis, a WTW analysis framework is adopted to quantify and examine life cycle petroleum use and air emissions of medium- and heavy-duty hydrogen fuel cell electric vehicles. More specifically, GREET MHDVs module was expanded to include HFCEV technology. GREET accounts for both direct (i.e., tail-pipe) and indirect (e.g., fuel production) lifecycle stages, providing well-to-wheels energy use and emissions results for different vehicle technologies and fuel pathways.

Real-world data for vehicle operation characteristics and fuel consumption were collected from several sources in industry and academia. When combined with real-world data, fuel economy estimates were developed from a high-fidelity vehicle dynamic simulation too (Autonomie). The fuel economy results were incorporated into GREET. Fuel economy (or fuel consumption) of HFCEVs is estimated based on the most recent heavy-duty vehicle fuel efficiency standards. The same method is used for conventional diesel for an apples-to-apples comparison. Based on real-world duty cycles for MHDVs and the high-resolution spatial and temporal data for meteorology and vehicle activity, variations in the life-cycle results were evaluated under different vehicle operating conditions, and in different locations and times. This detailed analysis helps develop representative regional and national average fuel economy values for incorporation into GREET.

RESULTS

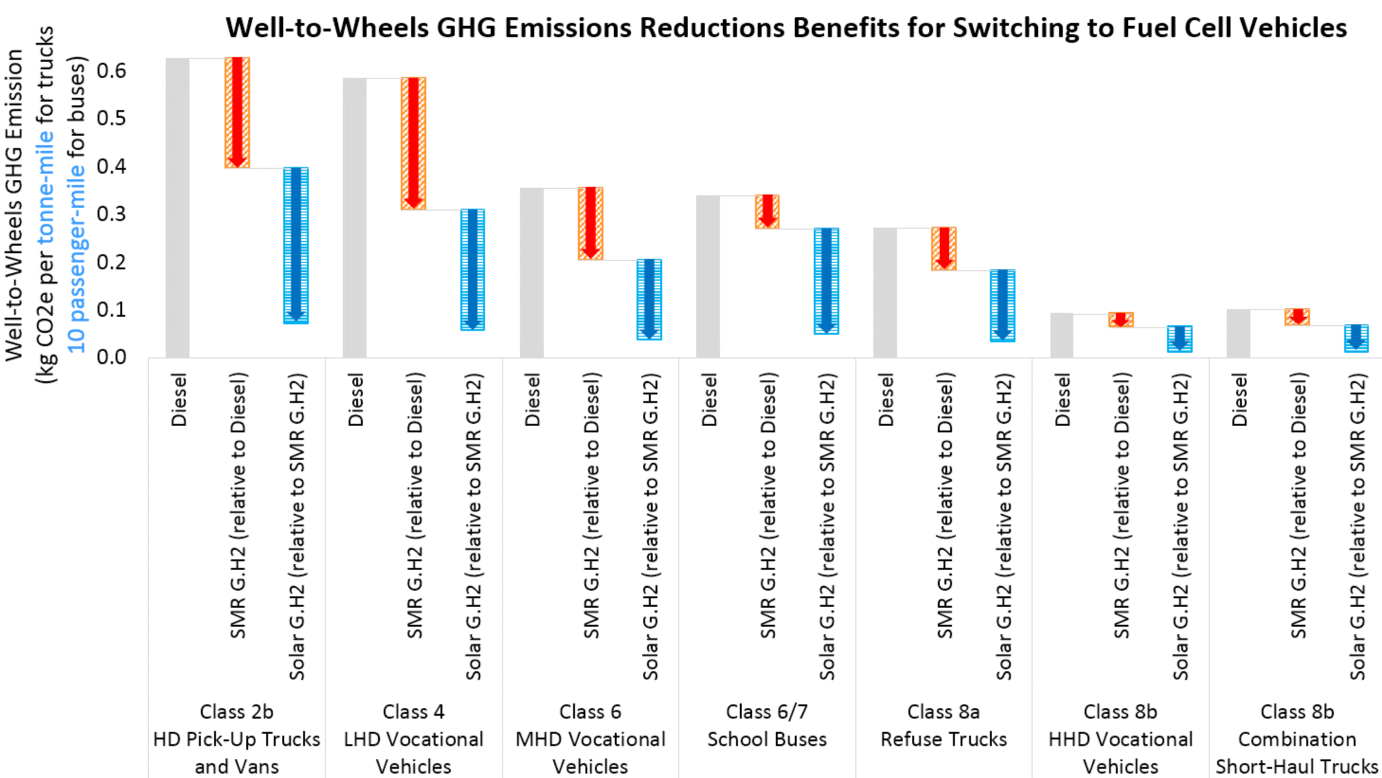
Simulation results show that medium- and heavy-duty HFCEVs generally achieve 1.7 times better fuel economy (miles per diesel gallon equivalent) compared to conventional diesel vehicles. The fuel economy comparison varies by vehicle type and weight class, which have different duty cycles. For instance, the fuel economy benefit of HFCEVs over diesel ICE vehicle is larger for classes with high share of urban driving compared to classes that serve regional operation, which has a larger share of highway driving. For the early market medium- and heavy-duty HFCEVs, urban driving is a more appropriate reference operating condition. Also, fuel economy of HFCEVs tends to be more sensitive to climate conditions, compared to diesel vehicles. For example, waste heat from the internal combustion engine available is for miscellaneous thermal energy demand in diesel vehicles (e.g., cabin heating). Fuel economy estimates also vary by employed vehicle simulation model, but the comparison of different models reveals that Autonomie (the primary model used for this study) provides more accurate and consistent results that are comparable to surveyed fuel economy values obtained from actual operation. Developing representative fuel economy values and evaluating their sensitivity to various factors and parameters are crucial for fair and realistic comparison between HFCEVs and diesel vehicles.

The WTW results from the GREET model show that HFCEVs provide significant reduction in petroleum consumption (95–99%) compared to conventional diesel vehicles for all hydrogen production pathways (Figure 1). Additional reduction benefits can be found in terms of WTW GHG emissions (Figure 2). Compared to conventional diesel



G.H2 – gaseous hydrogen; LH2 – liquid hydrogen; PTW – pump to wheels

FIGURE 1. WTW load-specific petroleum consumption: conventional diesel vs. HFCEVs (gaseous and liquid hydrogen fuel)–examples for medium-duty (left) and heavy-duty (right) trucks



HD – heavy duty; LHD – light and heavy duty; MHD – medium and heavy duty; HHD - heavy and heavy duty

FIGURE 2. WTW load-specific GHG emissions for MHDVs–conventional diesel vs. hydrogen fuel cell

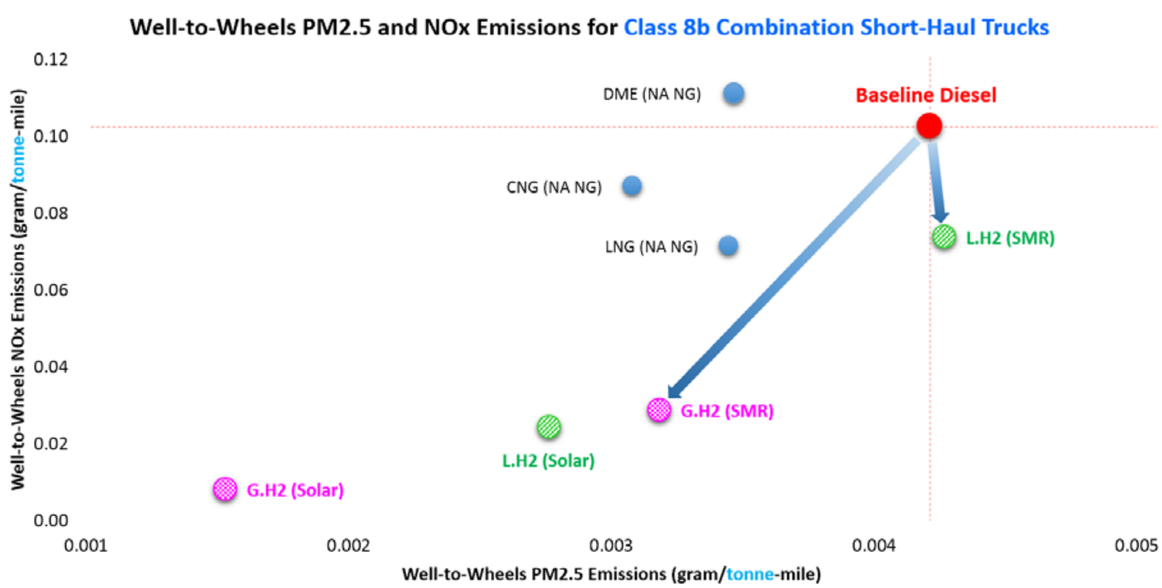
vehicles, HFCEVs using hydrogen fuel from central SMR generates 30% lower GHG emissions on a WTW basis, while the central solar electrolysis pathway provides about 90% emissions reduction. Regardless of vehicle types, weight classes, or vocations, HFCEVs provide significant reductions in WTW GHG emissions over conventional diesel counterparts (Figure 2). HFCEVs that use liquid hydrogen fuel along its supply chain achieve lower GHG emissions reduction benefits compared to gaseous hydrogen, mainly due to the high energy intensity of the hydrogen liquefaction process. HFCEVs also reduce criteria air pollutants emissions compared to conventional diesel trucks and buses. For example, relative to conventional diesel-powered heavy-duty combination short-haul trucks, HFCEVs can provide 70% lower NO_x and 25% lower PM2.5 emissions on a WTW basis (Figure 3). For other types of air pollutants (e.g., carbon monoxide, volatile organic compounds, etc.), 50–60% reductions are achieved. These WTW petroleum use and emissions information provide decision-makers and stakeholders a better understanding of the benefits and trade-offs of HFCEV technology for MHDV applications.

CONCLUSIONS AND UPCOMING ACTIVITIES

Medium- and heavy-duty HFCEVs provide large reductions of petroleum consumption and air emissions (GHG and criteria air pollutants). Although the exact magnitude may vary, the reductions benefits apply to all the MHDV types and vocations considered. For gaseous hydrogen fuel, the reductions of petroleum use and air emissions are robust across different pathways. Liquid hydrogen pathways tend to achieve lower reductions benefits compared to gaseous hydrogen pathways, mainly due to the energy intensity of the hydrogen liquefaction process. However, as the future of the electric grid relies on larger share of renewables, the benefits of liquid hydrogen pathways will also improve. Future work includes a detailed regional analysis, the inclusion of more diverse duty cycles, the harmonization of suite of models/approaches, and integrated sensitivity analysis. The methods and results will be published as a report, and the obtained HFCEV fuel economy values will be used to update the GREET model.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Lee, D.-Y., Elgowainy, A., and Wang, M. "Greenhouse Gas (GHG) Emissions and Petroleum Use Reduction of Medium-and Heavy-Duty Trucks." Presented at the DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., June 5–9, 2017.



PM2.5 – Particulate matter with diameters of 2.5 micrometers or less; CNG – compressed natural gas; LNG – liquid natural gas; DME – dimethyl ether

FIGURE 3. WTW criteria air pollutants emissions comparison between hydrogen fuel cell and other fuel-vehicle technologies for heavy-duty combination short-haul truck