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# Market Segmentation Analysis of Medium- and Heavy-Duty Trucks with a Fuel Cell Emphasis

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Project Start Date: October 1, 2017  
Project End Date: September 30, 2019

## Overall Objectives

- Identify the most promising markets for medium-/heavy-duty vehicles using a systems analysis approach with established technology and cost targets.
- Assess technical barriers and opportunities for improvement in the medium-/heavy-duty fuel cell vehicle technology space to guide DOE investment in advanced technologies.

## Fiscal Year (FY) 2018 Objectives

- Develop total cost of ownership (TCO) systems analysis framework to assess medium-/heavy-duty vehicles with advanced powertrain technology.
- Leverage existing systems analysis models including the Scenario Evaluation and Regionalization Analysis (SERA) model and the Future Automotive Systems Technology Simulation (FASTSim) model in the TCO analysis framework.
- Apply TCO analysis framework to Class 8 tractors and Class 4 parcel delivery trucks and draft report detailing key insights, areas of opportunity for fuel cell powertrain applications, and areas to focus research efforts and investments.

## 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<sup>1</sup>:

- Future Market Behavior
- Inconsistent Data, Assumptions and Guidelines
- 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 1.16: Complete analysis of program performance, cost status, and potential use of fuel cells for a portfolio of commercial applications. (4Q, 2018)
- Milestone 1.17: Complete analysis of program technology performance and cost status, and potential to enable use of fuel cells for a portfolio of commercial applications. (4Q, 2018)

## FY 2018 Accomplishments

- Developed TCO systems analysis framework that includes both direct costs (purchase price, fuel, operating and maintenance) and indirect costs (dwell time costs due to refueling/recharging and payload opportunity costs from forgone revenue due to the truck being weight limited). By incorporating dwell time and payload opportunity costs, this analysis more accurately analyzes fuel cells for commercial applications (Milestones 1.16, 1.17) than previous studies.
- Completed comparative TCO evaluation of five different truck powertrain technologies (diesel,

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<sup>1</sup> <https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22>

diesel hybrid-electric, compressed natural gas, battery electric, and fuel cell electric) for three different truck applications (Class 8 long haul, Class 8 short haul, and Class 4 parcel delivery) and for different technology statuses (2018, 2020, 2040).

- Identified scenarios for fuel cell powertrain trucks to have the lowest TCO of all powertrains by 2020 if Fuel Cell Technologies Office program cost and performance targets are met. Analysis shows strong commercial application opportunities for fuel cell powertrains in Class 4 parcel delivery and Class 8 long haul trucking applications.

## INTRODUCTION

The medium- and heavy-duty transportation sector is experiencing rapid changes in technology innovation. Alternative powertrains including fuel cell electric and battery electric have been announced within the last few years for truck applications across the medium- and heavy-duty spectrum [1–5]. Because trucks are primarily used for business applications, the value proposition associated with a truck is a key metric that helps determine if the truck technology will be adopted. The total cost of ownership (TCO) is a critical metric that firms use to assess the value proposition of a truck purchase. Although not the only metric a business will consider, the TCO provides a simple benchmark that allows for direct comparison across different truck options.

This project aims to provide a transparent, system analysis approach to medium- and heavy-duty vehicle TCO analysis to identify commercial vehicle applications that fuel cell powertrains may or may not be well suited for. By doing so, this analysis aims to provide insights and recommendations for stakeholders on which commercial vehicle applications could be pursued in the near term and potential barriers to adoption.

## APPROACH

This project evaluates the TCO for three truck applications and five powertrains. The truck applications include Class 8 long haul (sleeper), Class 8 short haul (day cab), and Class 4 parcel delivery van. The powertrains analyzed are conventional (diesel), diesel hybrid-electric (HEV), compressed natural gas (CNG), fuel cell electric (FCEV), and battery electric (EV). The TCO includes all direct and indirect costs. Direct costs included in this analysis are the upfront purchase cost (segmented by powertrain component), taxes, regional fuel costs, and operating and maintenance costs. The indirect costs included in this analysis are dwell time costs due to refueling/recharging and payload opportunity costs (forgone revenue due to the truck being weight limited).

NREL's Future Automotive Systems Technology Simulator (FASTSim) model was used to build conventional vehicle models that match real-world performance and cost data including fuel economy, acceleration, and manufacturer's suggested retail price. FASTSim was then used to build cost-optimized powertrains for other powertrain technologies based on current costs and DOE future component performance and cost targets. Fuel costs were based on the 2018 Annual Energy Outlook and approximate hydrogen cost levels, operating and maintenance costs were based on an extensive literature survey, dwell time costs were based on stated carrier detention rates, and payload opportunity costs were based on typical less-than-truckload carrier rates observed today. All the cost data was input into the SERA model to compute the regional TCO for each truck application, powertrain, and model year.

## RESULTS

Multiple scenarios were evaluated within this project. Under a scenario in which diesel and compressed natural gas prices are high while electricity and hydrogen prices are low (\$0.07/kWh and \$4/kg, respectively), the TCO for battery electric and fuel cell powertrains shows an advantage over diesel, HEV, and CNG by 2020. In this scenario, Class 8 long haul trucks (range requirement of 1,200 miles) with fuel cell powertrains could have a lower TCO than diesel by 2020 and may have the lowest TCO depending on the regional fuel prices that are considered. Figure 1 illustrates the TCO breakdown by powertrain technology for each model year analyzed across two U.S. census division regions. As seen in Figure 1, the Pacific region typically has higher fuel costs leading to higher TCO for diesel, diesel hybrid-electric, and CNG powertrains while electricity and hydrogen costs are assumed to be constant. This regional difference allows fuel cell powertrains to have the lowest TCO in the Pacific region while being slightly higher than CNG in the Middle Atlantic region.



**Figure 1. Present value cost (\$/mile) for Class 8 long haul tractors traveling 100,000 mile/yr in the (top) Middle Atlantic and (bottom) Pacific region under the Low Electricity and Hydrogen Prices scenario**

In the low electricity and hydrogen prices scenario, Class 8 short haul (range requirement of 500 miles) truck TCO follows a similar story as Class 8 long haul. By 2020, fuel cell electric powertrains are estimated to have the lowest TCO in certain high-fuel-cost regions such as the Pacific region. Figure 2 summarizes the Class 8 tractor TCO on a per-mile and per-ton-mile basis (where ton refers to the maximum tonnage of payload the truck can haul while remaining within the 80,000 lb gross vehicle weight rating) for the Pacific region as a function of vehicle range required.

As seen in Figure 2, by 2020 fuel cell and battery electric Class 8 tractors become very economically competitive with diesel powertrain technology. Additionally, under these conditions, fuel cell and battery powertrains dominate all Class 8 tractor ranges in 2040 with fuel cells being economically advantageous in the longer range requirement (>500 mile) regime and battery electric trucks being economically advantageous in the shorter range requirement (<500 mile) regime.

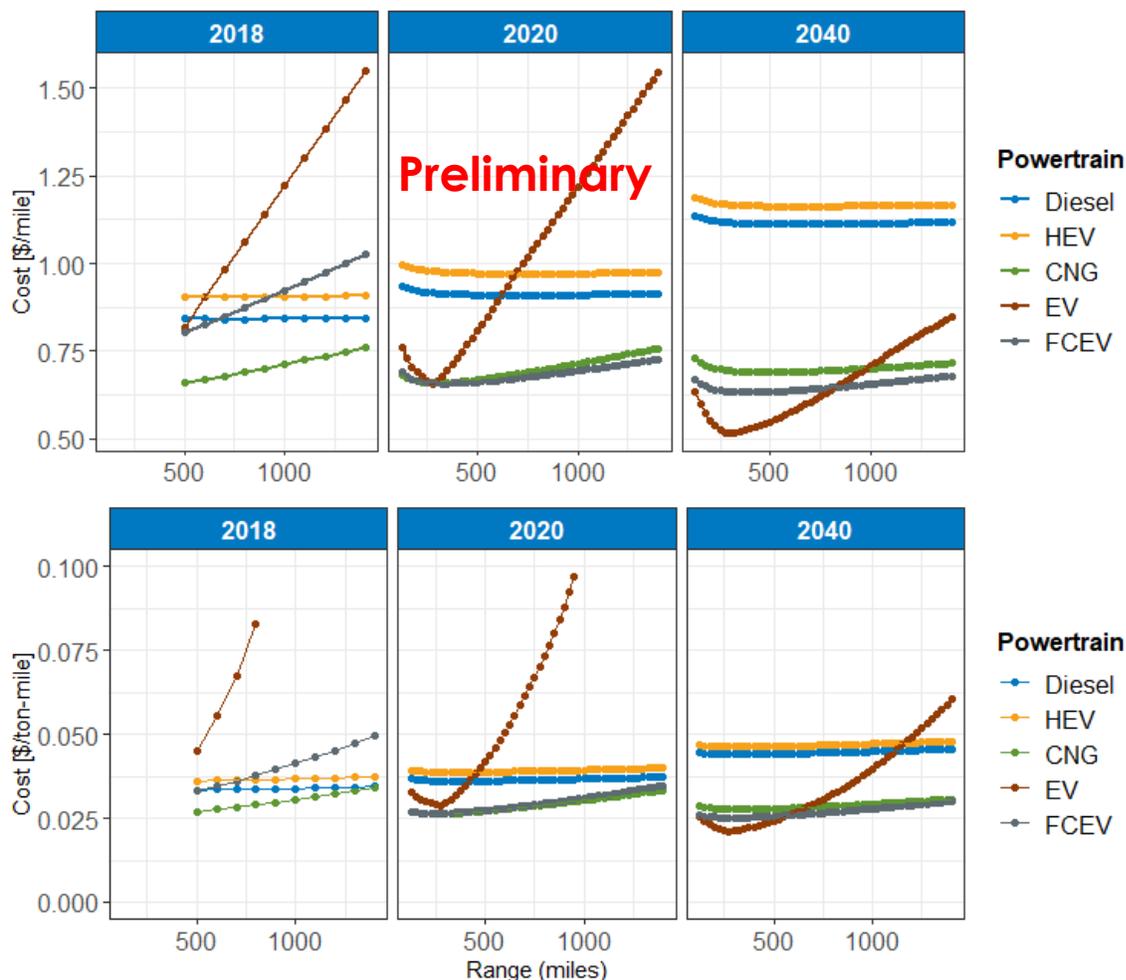


Figure 2. Present value cost (\$/mile and \$/ton-mile) for Class 8 tractors traveling 100,000 mile/yr in the Pacific region under the Low Electricity and Hydrogen Prices scenario

Class 4 parcel delivery (range requirement of 120 miles) TCO is more sensitive to upfront costs because the total miles driven is lower than the Class 8 trucks. Additionally, dwell time costs become significant because the vehicle range is low requiring more refueling events. In the scenario with low electricity and hydrogen fuel prices, the fuel cell electric powertrains show higher TCO with current technology (2018), but lower TCO by 2020 primarily by achieving reduction in fuel cell stack costs as seen in Figure 2. Battery electric powertrains do not have the lowest TCO primarily due to high battery costs in 2020 and relatively high dwell time costs from electric charging in 2040. In this scenario, battery electric charging occurred over 30 minutes but in other scenarios when trucks could be charged overnight, battery electric powertrains could have the lowest TCO by 2040.

These TCO results provide strong support that when accounting for all economic costs into a TCO analysis framework, fuel cell electric powertrains can result in a true cost advantage over conventional powertrains in these commercial applications if FCTO performance and cost targets are met (Milestone 1.16, 1.17).

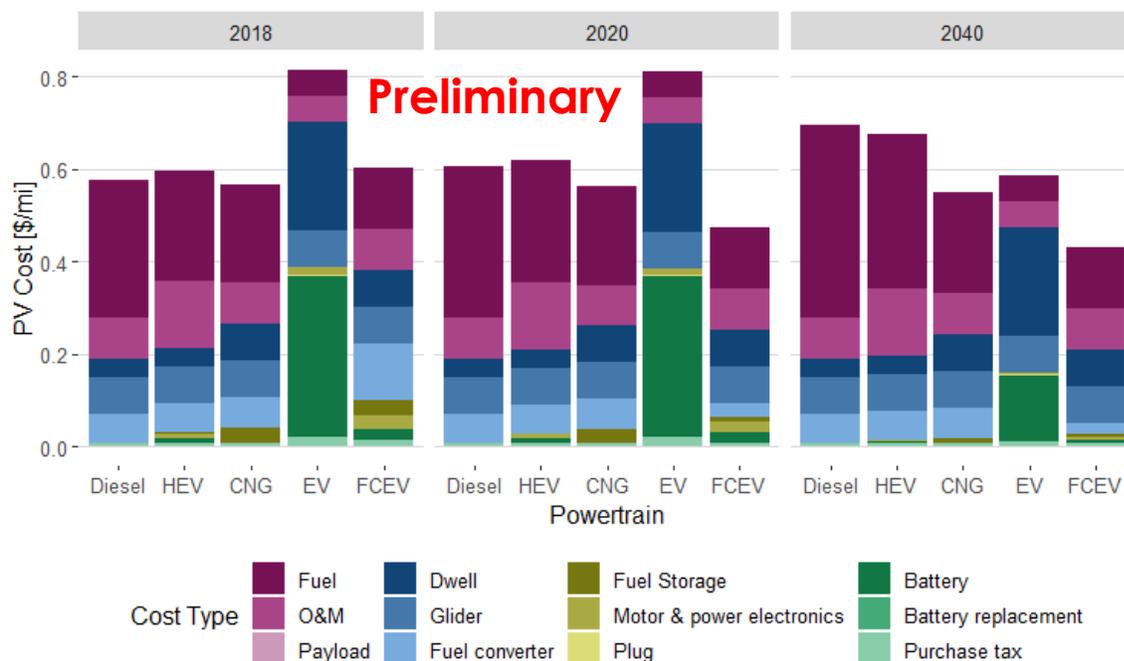


Figure 3. Present value cost (\$/mile) for 4 parcel delivery trucks traveling 30,000 mile/yr in the Middle Atlantic region

## CONCLUSIONS AND UPCOMING ACTIVITIES

Overall, this project presents a transparent and consistent TCO systems analysis that includes both direct and indirect costs that influence the TCO of three types of commercial vehicles, five powertrains, and three technology statuses. Depending on the specific scenario evaluated, fuel cell and battery electric powertrains could provide a lower TCO than trucks with diesel, diesel hybrid-electric, and CNG powertrain technologies.

The funding for FY19 is expected to be used to complete the peer review process for an NREL report as well as document findings and make the data accessible for others to download and use. Additionally, a follow-on report is expected to be completed analyzing additional vehicles/vocations in the commercial vehicle space.

## FY 2018 PUBLICATIONS/PRESENTATIONS

1. Chad A. Hunter. “Market Segmentation Analysis of Medium and Heavy Duty Trucks with a Fuel Cell Emphasis.” Presented at the DOE Hydrogen and Fuel Cells Program Annual Merit Review and Peer Evaluation Meeting, Washington, DC, June 13-15, 2018. NREL/PR-5400-71478.

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