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

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Overall Objectives

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

Fiscal Year (FY) 2019 Objectives

- Review the total cost of ownership (TCO) systems analysis framework developed in FY 2018 to assess medium- and heavy-duty vehicles with advanced powertrain technology with stakeholders (industry, state and federal agency, and national laboratory) and update assumptions based on stakeholder feedback.
- Finalize the Class 8 short-haul, Class 8 long-haul, and Class 4 parcel delivery truck TCO analyses and update the draft report detailing key insights, areas of opportunity for fuel cell powertrain applications, and areas to focus research efforts and investments.
- Develop validated vehicle powertrain models in the Future Automotive Systems Technology Simulator (FASTSim) for the remaining trucks to be assessed in this project including Class 8 drayage, Class 8 transit bus, Class 8 refuse, Class 6 parcel delivery, Class 6 box truck, and Class 5 van.
- Begin TCO modeling of the additional truck segments (Class 8 drayage, Class 8 transit bus, Class 8 refuse, Class 6 parcel delivery, Class 6 box truck, and Class 5 van) and draft preliminary National Renewable Energy Laboratory (NREL) report by the end of the fiscal year.

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[1]:

- Future market behavior
- Inconsistent data, assumptions, and guidelines
- Insufficient suite of models and tools.

Contribution to Achievement of DOE 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)
- Milestone 1.18: Complete life cycle analysis of vehicle costs for fuel cell electric vehicles compared to other vehicle platforms. (4Q, 2019)

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

- Milestone 1.20: Complete review of fuel cell and hydrogen markets. (4Q, 2011 through 4Q, 2020)

FY 2019 Accomplishments

- Completed two rounds of peer review that included 15 stakeholders across major industry partners, state agencies, non-profit organizations, national laboratories, and DOE. Peer reviewers' comments were used to update the FASTSim (vehicle powertrain modeling) and Scenario Evaluation and Regionalization Analysis (SERA) (TCO modeling) modeling assumptions and results communications (visualizations in the report and presentation).
- Completed an updated, comparative TCO evaluation of five different truck powertrain technologies (diesel, 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, 2025, Ultimate).
- Revised the NREL report that summarizes modeling methodologies and results for the FASTSim powertrain modeling and SERA TCO modeling for the Class 8 long haul, Class 8 short haul, and Class 4 parcel delivery truck segments.
- Identified operating scenarios for fuel cell powertrain trucks to have the lowest TCO of all powertrains by 2025 if FCTO 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, particularly when the dwell time and payload costs are incurred to the vehicle owner/operator.
- Completed preliminary FASTSim powertrain modeling for additional truck segments including Class 8 drayage, Class 8 transit bus, Class 8 refuse, Class 6 parcel delivery, Class 6 box truck, and Class 5 van.

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 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 multiple truck applications with five powertrain technologies. The initial analysis framework was applied to Class 8 long haul (sleeper [750-mile range]), Class 8 short haul (day cab [300-mile range]), and Class 4 parcel delivery van. For the remainder of this project, the TCO framework is being applied to the Class 8 drayage, Class 8 transit bus, Class 8 refuse, Class 6 parcel delivery, Class 6 box truck, and Class 5 van. The powertrains analyzed are conventional (diesel or gasoline), 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 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 powertrains for other powertrain technologies based on vehicle specifications (acceleration and grade requirements). 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

Four scenarios are evaluated to understand TCO under different commercial vehicle applications: (1) Single-Shift, Volume-Limited,[2] (2) Single-Shift, Weight-Limited,[3] (3) Multi-Shift, Volume-Limited,[4] and (4) Multi-Shift, Weight-Limited.[5] Single-shift operation implies no dwell time costs, while volume-limited correlates with no payload opportunity costs.

The vehicle powertrain modeling component cost and performance metric assumptions for each technology and model year are summarized in Table 1. These inputs are used within FASTSim for vehicle powertrain modeling.

Class 8 long haul truck TCO in the Single-Shift, Volume-Limited scenario and the Multi-Shift, Weight-Limited scenario is shown in Figure 1. These two scenarios are shown as they reflect the edge cases analyzed in this analysis. Error bars represent uncertainty in fuel prices and operations and maintenance (O&M) costs. As seen in Figure 1, the TCO of each powertrain in the Single-Shift, Volume-Limited scenario is typically within the range of uncertainty except for FCEV, which is higher than CNG under current technology cost scenarios. In the Multi-Shift, Weight-Limited scenario, the payload opportunity costs are substantial for battery EV, FCEV, and CNG. FCEVs become competitive with diesel technology if the DOE 2025 targets are achieved and diesel is at ~$4/gal.

Table 1. Technology Metrics and Assumptions by Year Used in the FASTSim Powertrain Modeling

Target year	Today	2025	Ultimate
Batteries			
Battery cell mass [kg/kWh]	4.80	3.48	2.50
Battery cell price HEV ($/kW)	20	16	13
HEV battery cell cost [$/kWh]	145	105	80
PHEV battery cell cost [$/kWh]	145	105	80
PEV battery cell cost [$/kWh]	145	105	80
Power Electronics			
Power electronics and motor (no boost) [$/kW]	22	8.0	4.0
Boost converter [$/kW]	8.5	3.0	2.0
DC/DC buck converter [$/kW]	95	50	18
Plug cost (on board charger) [$]	175	50	18
FCEV			
Fuel Cell			
Fuel cell specific power (kW/kg)	1.12	1.12	1.12
Fuel cell cost ($/kW)	220	80	60
Fuel peak efficiency (%)	60.0%	62.5%	69.0%
Fuel storage			
Hydrogen storage (kWh/kg)	1.48	1.52	2.11
Hydrogen tank cost ($/kWh)	36.7	9.0	8.0
CNG			

[2] Single-Shift, Volume-Limited: business operation with no time or cargo weight limitation such as if a truck refuels/charges overnight and the truck is cubed out.
[3] Single-Shift, Weight-Limited: business operation with no time limitation but with a cargo weight limitation such as if a truck refuels/charges overnight and the truck weighs out before cubing out.
[4] Multi-Shift, Volume-Limited: business operation with a time limitation but no cargo weight limitation such as if a truck is used for team driving or three-shift operation and the truck is cubed out.
[5] Multi-Shift, Weight-Limited: business operation with both time and cargo weight limitation such as if a truck is used for team driving or three-shift operation and the truck weighs out before cubing out.

Engine			
CNG storage [$/usable kWh NG]	10.1	7.88	3
CNG fuel storage mass (kWh/kg)	4.21	4.83	5.83
Fuel storage			
Engine efficiency improvement (absolute)	0	0	0
Engine cost ($/kW)	55	55	55
Conventional			
Engine			
Engine specific power (kW/kg)	0.23	0.23	0.23
Engine fixed cost ($)	5000	5000	5000
Engine cost ($/kW)	50	50	50
Fuel storage			
Fuel and storage specific mass (kWh/kg)	9.88	9.88	9.88
Fuel storage cost ($/kWh)	0.07	0.07	0.07

PHEV – plug-in hybrid electric vehicle
PEV – plug-in electric vehicle

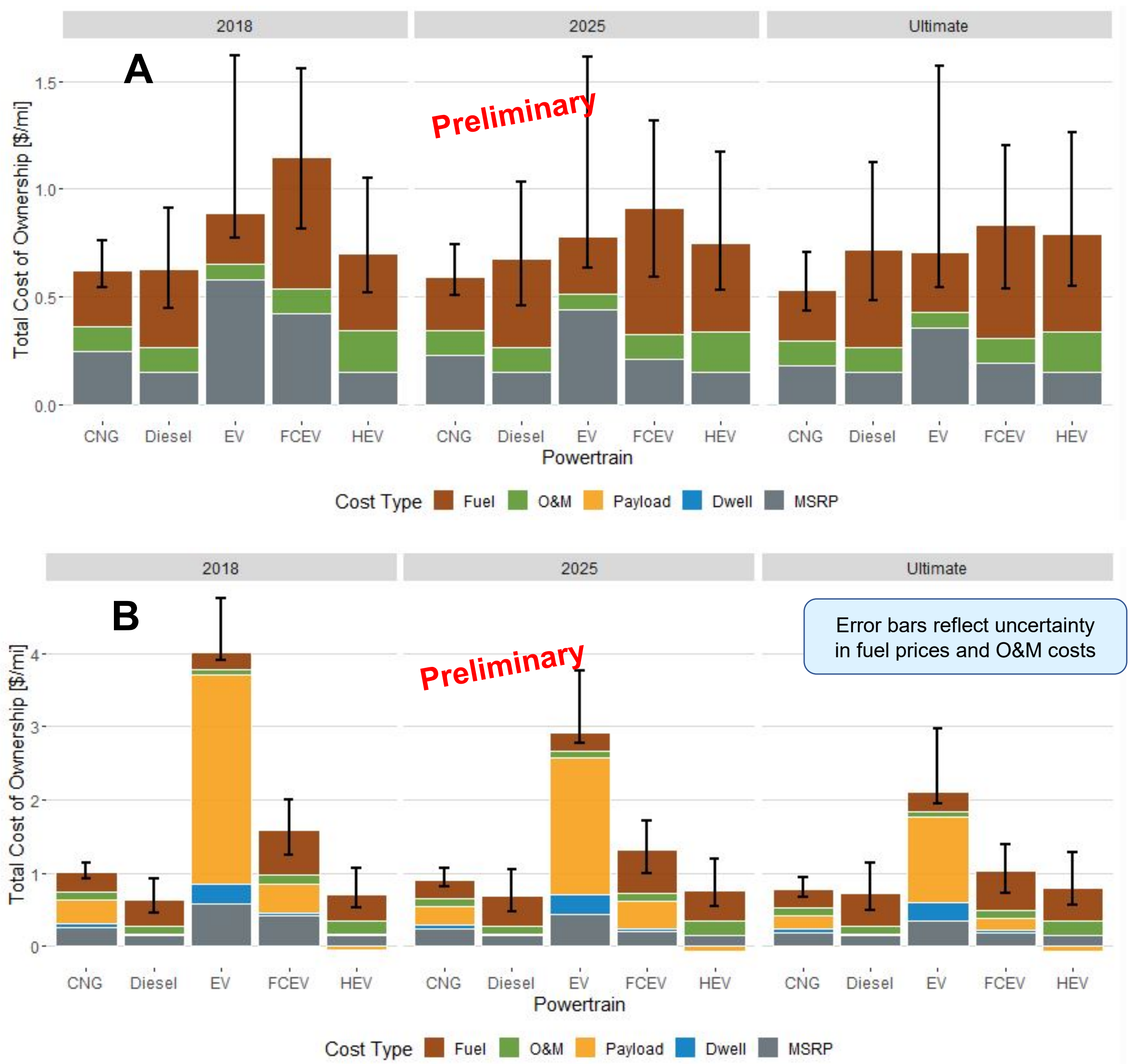

Figure 1. TCO ($/mile) for Class 8 long haul tractors in the Middle Atlantic region in (A) Single-Shift, Volume-Limited scenario and (B) Multi-Shift, Weight-Limited scenario

For Class 8 short haul trucks, the TCO in the Single-Shift, Volume-Limited scenario and the Multi-Shift, Weight-Limited scenario are shown in Figure 2. As with the Class 8 long haul trucks, the TCO of each powertrain is typically within the range of uncertainty (fuel price and O&M) in the Single-Shift, Volume-Limited scenario. When payload opportunity costs and dwell time costs are included in the Multi-Shift, Weight-Limited scenario, the TCO landscape shifts.

For the Multi-Shift, Weight-Limited scenario, CNG and HEV are competitive with diesel with current technology. If the 2025 targets are achieved, the FCEV TCO is within the range of uncertainty and could be economically competitive on a TCO basis. Additionally, the FCEV dwell time costs are minimal indicating that hydrogen refueling at rates of ~5 kg/min or higher allows FCEVs to be cost competitive with diesel. If payload opportunity costs are incurred, the battery EV TCO could be competitive with diesel if the Ultimate targets are achieved.

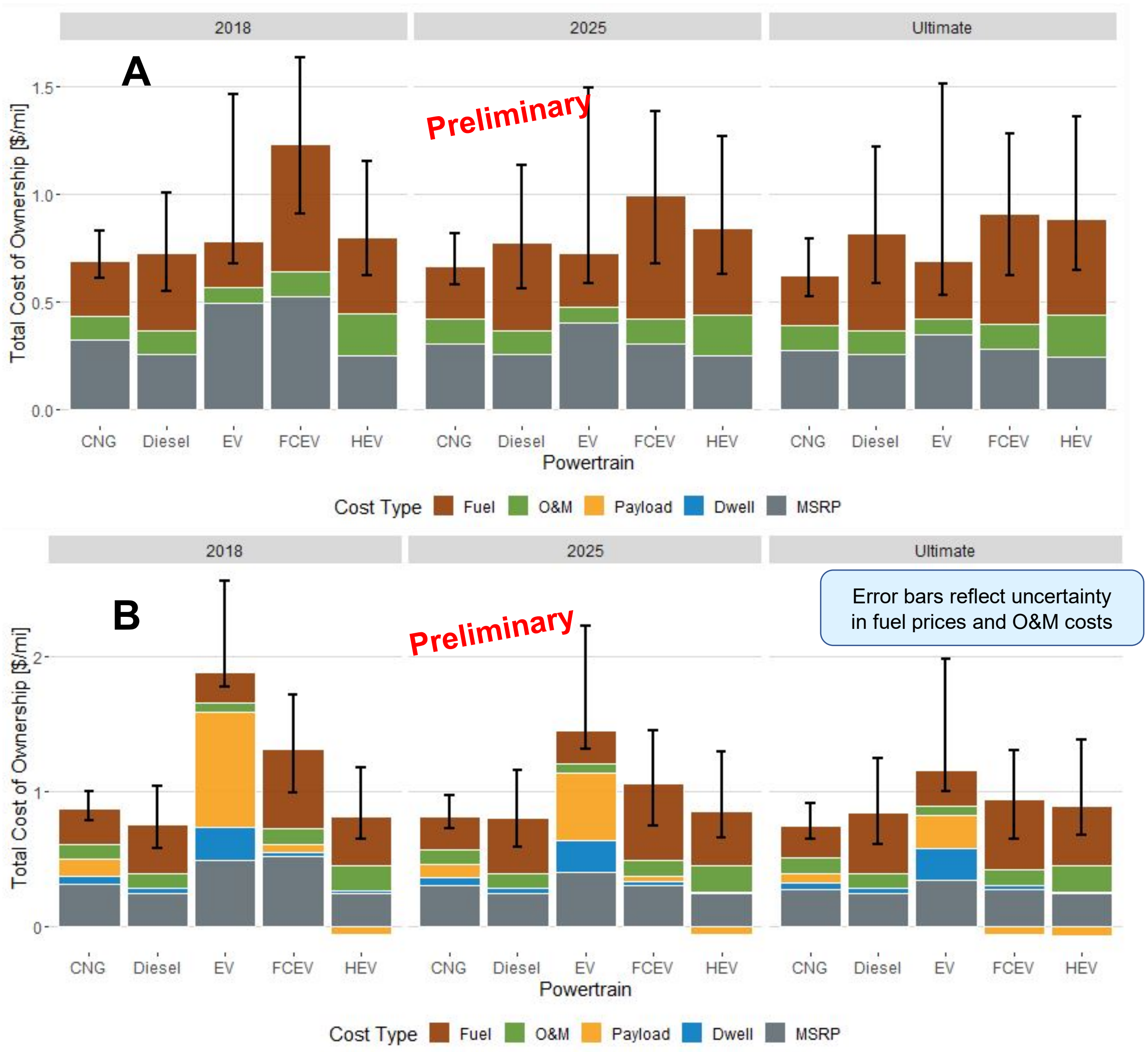

Figure 2. TCO ($/mile) for Class 8 short haul tractors in the Middle Atlantic region in (A) Single-Shift, Volume-Limited scenario and (B) Multi-Shift, Weight-Limited scenario

For Class 4 parcel delivery trucks the TCO in the Single-Shift, Volume-Limited scenario and the Multi-Shift, Weight-Limited scenario are shown in Figure 3. For the Single-Shift, Volume-Limited scenario, all powertrains have TCOs within the range of fuel and O&M cost uncertainty with current (2018) technology status, and battery EV TCO has the lowest potential limit. In the Multi-Shift, Weight-Limited operation, dwell time is a significant cost driver of TCO for battery EV and PHEV technology due to longer recharging times. The FCEV TCO has a dwell time impact similar to diesel since the amount of hydrogen required to fill a tank is relatively small (less than 7 kg). Under this scenario, the FCEV TCO is within the range of uncertainty of the diesel, CNG, and HEV TCOs with current technology costs, and it only becomes more competitive as 2025 and Ultimate technology targets are achieved.

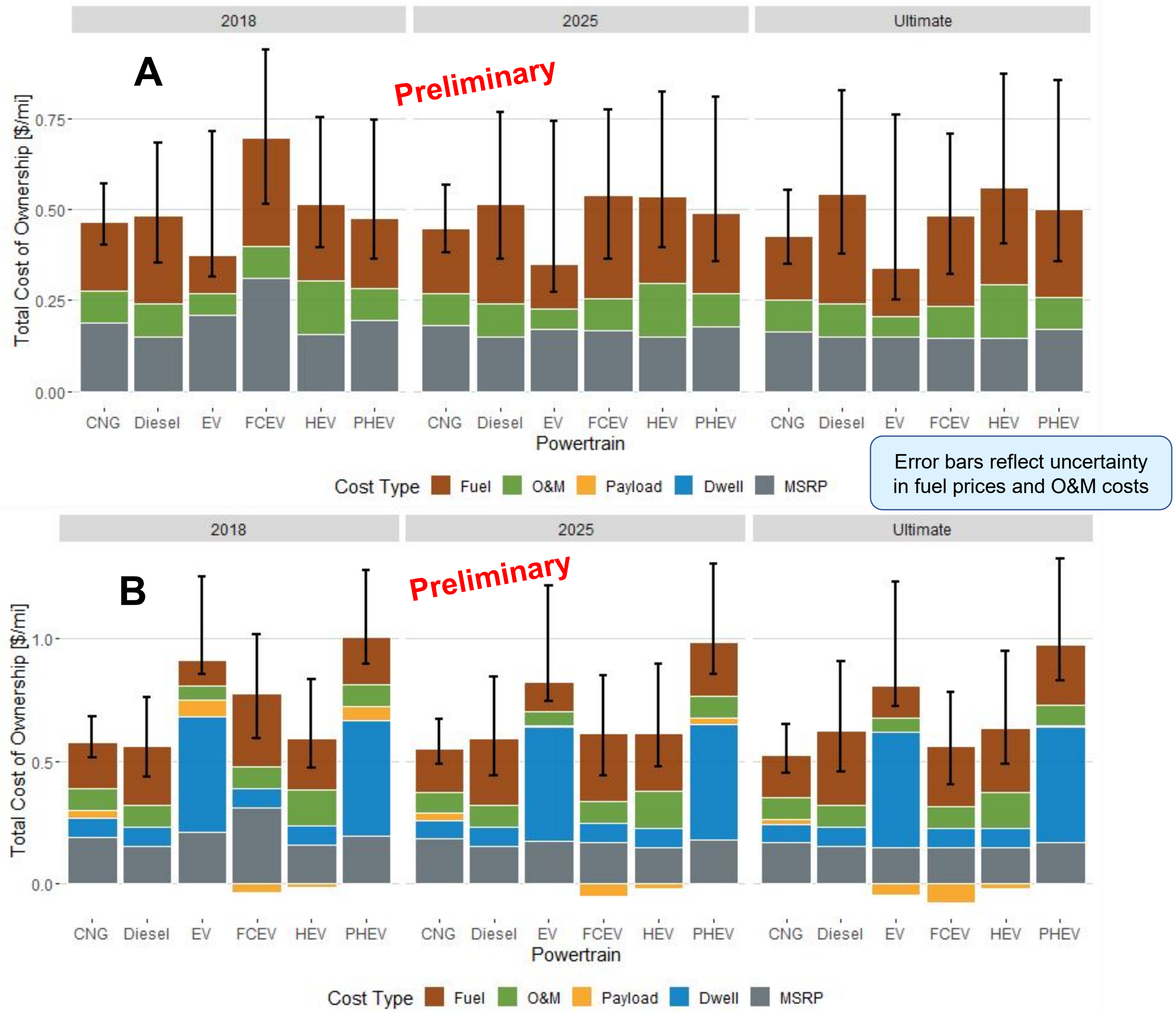

Figure 3. TCO ($/mile) for Class 4 parcel delivery trucks in the Middle Atlantic region in (A) Single-Shift, Volume-Limited scenario and (B) Multi-Shift, Weight-Limited scenario

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 compressed natural gas powertrain technologies.

The funding for FY 2020 is expected to be used to finalize the publication for the first NREL report covering the TCO for the Class 8 long haul (sleeper), Class 8 short haul (day cab), and Class 4 parcel delivery van. Additionally, FY 2020 funding will be used to complete the vehicle powertrain modeling and TCO modeling for the remaining truck segments including Class 8 drayage, Class 8 transit bus, Class 8 refuse, Class 6 parcel delivery, Class 6 box truck, and Class 5 van. A second NREL report is expected to be completed for these truck segments and published by the end of FY 2020.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. "Market Segmentation Analysis of Medium- and Heavy-Duty Trucks with a Fuel Cell Emphasis," DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting, Washington, DC, April 29–May 1, 2019, NREL/PR-5400-73491.

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