2021 U.S. Department of Energy
Vehicle Technologies Office
Annual Merit Review

COMPREHENSIVE VEHICLE TOTAL COST OF OWNERSHIP (TCO) FRAMEWORK

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PROJECT ID: VAN038

VTO Annual Merit Review
June 22, 2021

Overview

Timeline	Barriers addressed
• Project start: October 1, 2019 • Project end: March 31, 2021 • 100% complete (1.5 years)	• "Fill gaps or deficiencies in the analysis toolset based on the best publicly available, up to date techno-economic assessments." (ISATT roadmap, 2018)

Budget	Partners

• Total project funding: $510,000 (100% DOE share)
• All funding from FY 2020 or forward-funded from FY 2019
• No FY 2021 funding
	• Collaboration across several DOE labs:
	  • Lawrence Berkeley National Laboratory
	  • National Renewable Energy Laboratory
	  • Oak Ridge National Laboratory
	  • Sandia National Laboratories

Relevance

- **DOE VTO is interested in being able to compare economics of vehicle operation across multiple technologies in a balanced manner**
- In order to accurately compare the costs of two vehicles, the total cost of ownership (TCO) should consist of all costs related to both purchasing and operating the vehicle.
- This TCO analysis builds on previous work to provide a comprehensive, internally consistent perspective of all relevant vehicle costs of ownership for light-duty vehicles (LDV) and medium/heavy duty vehicles (MHDV).
- Data from this project is made public so that future researchers can build upon our framework.

Approach – General

Develop framework for calculating total cost of ownership based on discounted cash flow

Identify and fill gaps in knowledge for major cost components of vehicle ownership and operation

Quantify the Total Cost of Ownership (TCO) and Levelized Cost of Driving (LCOD) for scenarios of interest

Approach – Milestones

- Multiple tasks spread across multiple labs. Key tasks presented here
- No FY2021 milestones or go/no-go decision points remaining

Tasks	Subtasks	FY2020				FY2021		
		Q1	Q2	Q3	Q4	Q1	Q2	Q3
Cost factors	Identify R&D gaps							
	Gather data							
	Quantify each factor							
Synthesis	Framework							
	Cross-factor linkage							
Collaboration	Workshops							
Online data	Web tool							
Publication	Draft report							
	Final report							

Approach – Scope

- Modeled vehicles from Autonomie with varying sizes, vocations, powertrains, and technological advancement

Sizes and Vocations		Powertrains and Fuels	Timeframe
Light Duty	Medium & Heavy Duty		
Compact Sedan	Class 4 Delivery	Spark-Ignition (gasoline) Internal Combustion Engine	2020
Midsize Sedan	Class 6 Delivery	Compression-Ignition (diesel) Internal Combustion Engine	2025
Small Sport Utility Vehicle	Class 8 Bus	Gasoline Hybrid Electric Vehicle	2030
Large Sport Utility Vehicle	Class 8 Refuse	Plug-in Hybrid Electric Vehicle	2035
Pickup Truck	Class 8 Vocational	Hydrogen Fuel Cell Electric Vehicle	2050
	Class 8 Tractor – Day Cab	Battery Electric Vehicle	
	Class 8 Tractor – Sleeper Cab		

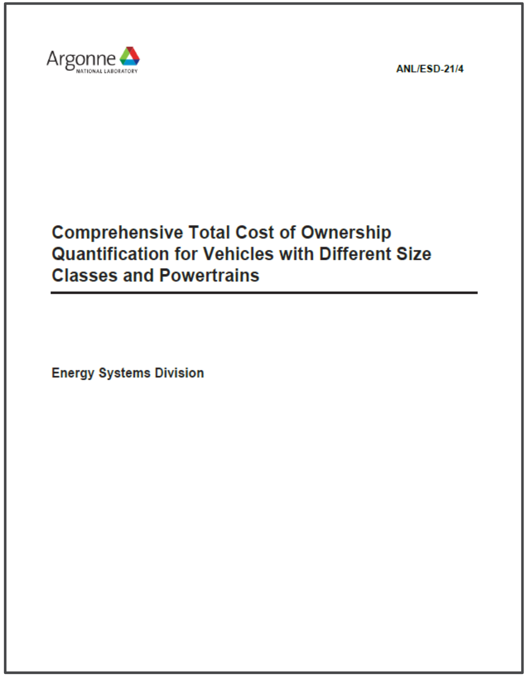
Approach – Cost Components

- We identified 8 key factors as most important cost components for quantifying TCO

Cost Components	Major Gaps Addressed	
Vehicle	Depreciation; Retail markup	Slide 9
Financing	Loan terms	
Fuel	Charging infrastructure	
Insurance	Annual & per-mile costs	Slide 10
Maintenance & repair	Annual & per-mile costs	Slides 11-12
Tax & fees	Registration; taxes	
Payload changes	Estimation of payload loss	Slide 13
Labor	Cost of EV charging	

Technical Accomplishments and Progress

- Publication of major technical report: “Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains” https://www.osti.gov/biblio/1780970
- Development of software tool for third parties to make their own TCO calculations: https://anl.app.box.com/s/pzc4dh2qgstomlrol9u66ncdi8fanvh5
- Publication of literature review summarizing findings from nearly 200 other studies: https://escholarship.org/uc/item/8dq1b82q
- Organization of two-part industry workshop on TCO from manufacturer and fleet perspectives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ANL/ESD-21/4

Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains

Energy Systems Division

A. Burnham et al., 2021

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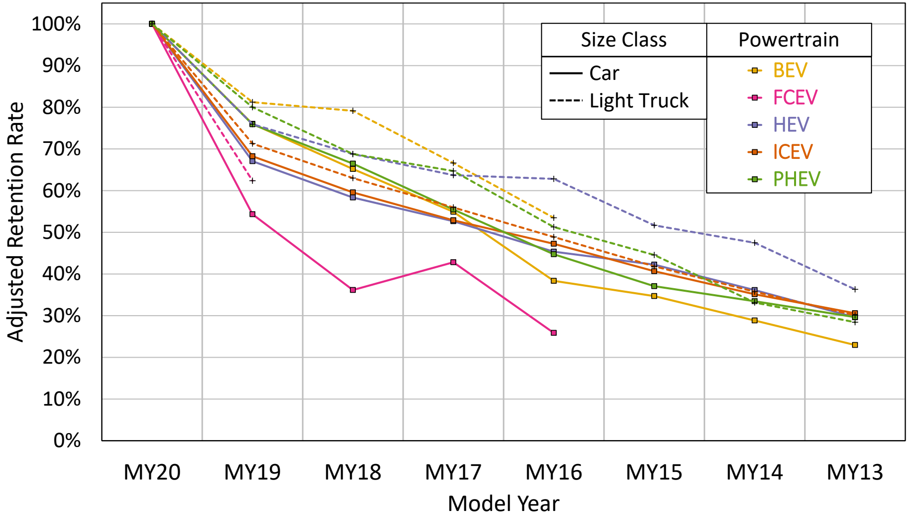
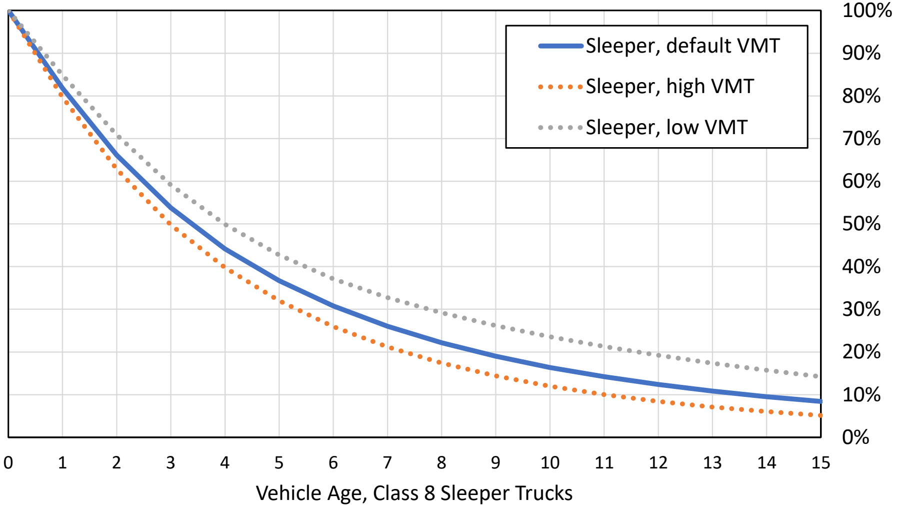
Technical Accomplishments – Vehicle Costs

- Depreciation for LDV as a function of MSRP, vehicle age, powertrain, size class, and market segment



$$\text{Retained Value} = \text{MSRP} \times ARR_{i,l,p}$$
$$= \text{MSRP} \times b_{l,p} \times exp\left(k_{l,p} \cdot i\right)$$

- Depreciation for MHDV as a function of MSRP, vehicle age, and vehicle miles traveled



$$\text{Retained Value} = \text{Retail Price} \times \exp(A \cdot a + M \cdot s)$$

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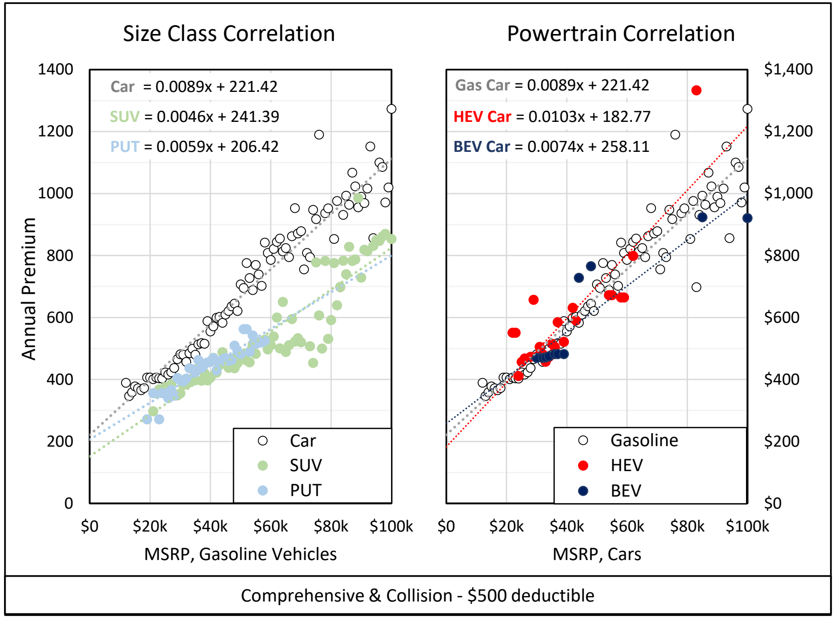
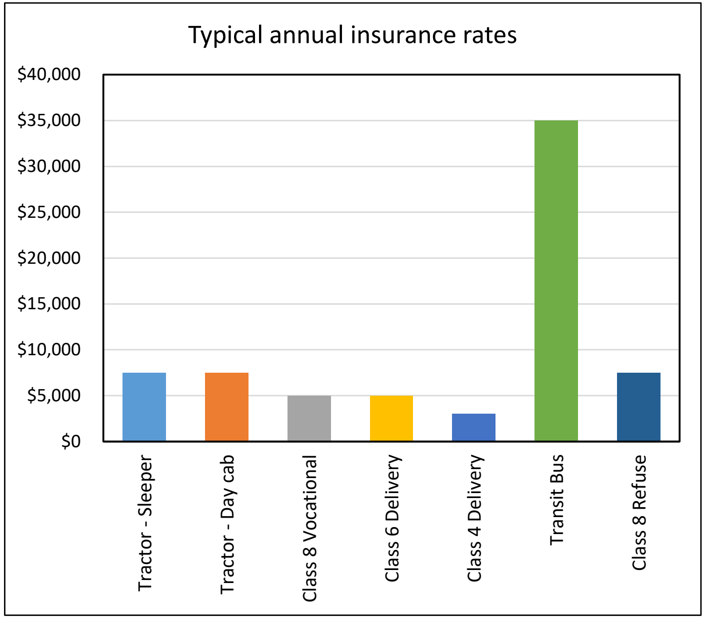
Technical Accomplishments – Insurance

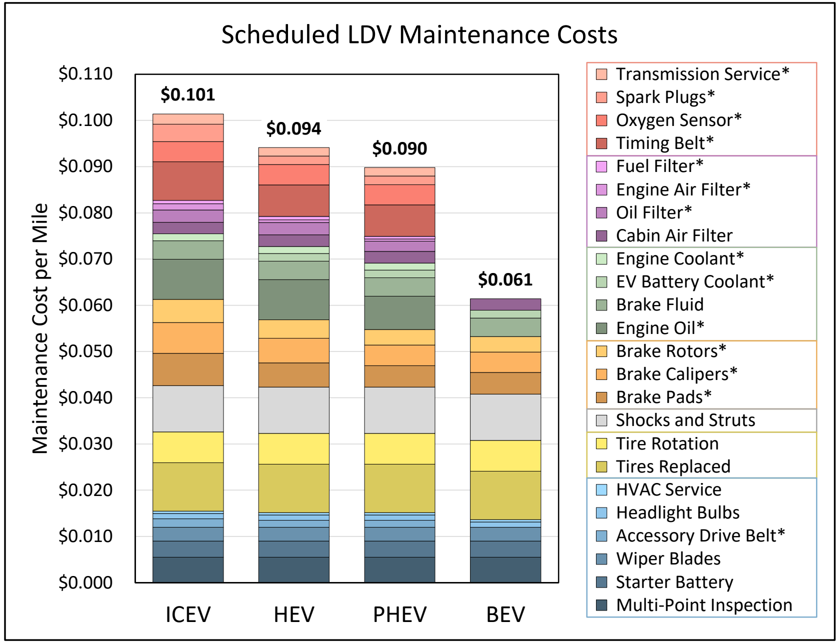
- Quantified typical insurance rates for LDV, including liability, comprehensive, and collision as a function of MSRP, vehicle size, powertrain, and residual value
- Identified insurance rates for MHDV as a function of vocation, and for tractors as a function of MSRP and annual vehicle miles traveled





Technical Accomplishments – Maintenance and Repair

- Compiled scheduled LDV maintenance for ICEV, HEV, PHEV, and BEV



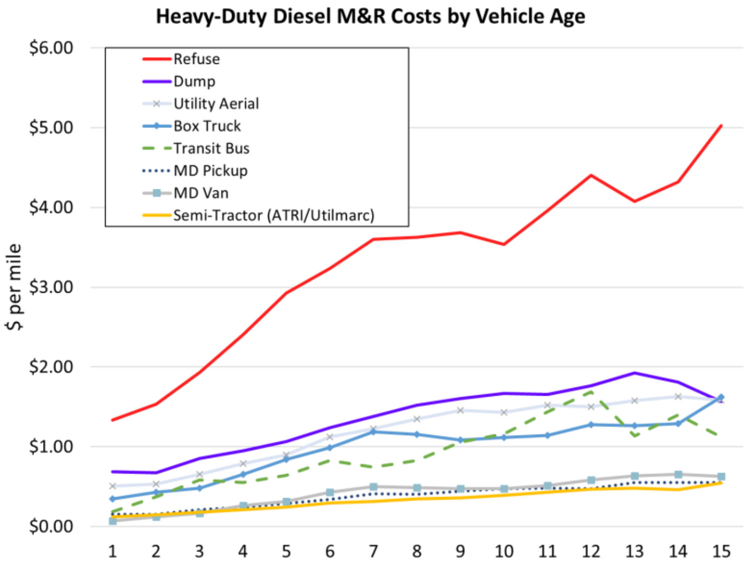
- Quantified LDV repair costs as a function of vehicle MSRP, vehicle size, and powertrain throughout vehicle lifetime

	Powertrain	ICEV	HEV	PHEV	BEV	FCEV
Vehicle Type	Multipliers	1.00	0.91	0.86	0.67	0.67
Car	1.00	1.00	0.91	0.86	0.67	0.67
SUV	0.91	0.91	0.81	0.78	0.61	0.61
Pickup	0.70	0.70	0.62	0.60	0.47	0.47

$$\text{Repair} = (\text{Powertrain \& type multipliers}) \times (\text{age factor}) \times (\text{MSRP factor})$$

Technical Accomplishments – Maintenance and Repair

- Compiled data on MHDV maintenance and repair (M&R) costs by vocation for diesel trucks

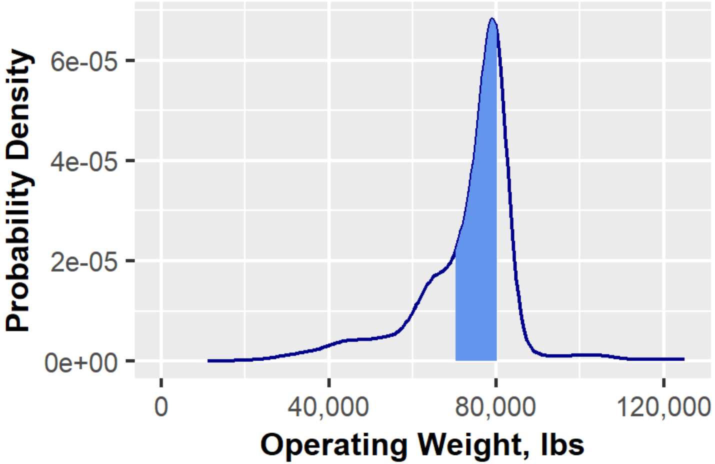


- Compiled variations in MHDV M&R costs from conventional diesel ICE trucks by powertrain based on data from alternative fuel buses

Case	Powertrain				
	CNGV	HEV	PHEV	BEV	FCEV
Low	111%	96%	94%	79%	79%
Mid	100%	87%	84%	60%	60%
High	88%	73%	69%	41%	41%

Technical Accomplishments – Payload

- Stakeholders identified potential loss in payload as a significant concern for BEVs, though anecdotal evidence suggests few truck trips are at gross vehicle weight rating (GVWR).
- Quantified fraction of tractor-trailer trips which are weight-limited in order to estimate loss in payload for a given increase in vehicle mass



Autonomie modeled vehicle weight (2025)		
ICEV	BEV (low-tech)	BEV (high-tech)
28,300 lb	35,400 lb	39,000 lb

- A MY2025 BEV sleeper cab loses an average of 2300 lbs of cargo capacity relative to the ICEV (after accounting for the one-ton weight allowance for BEV). This increases costs by 4.9%.
- However, in Autonomie low-tech case, batteries have lower energy density (kWh/kg). In this case, the expected payload loss is 4400 lbs, for a 10.3% increase in costs.

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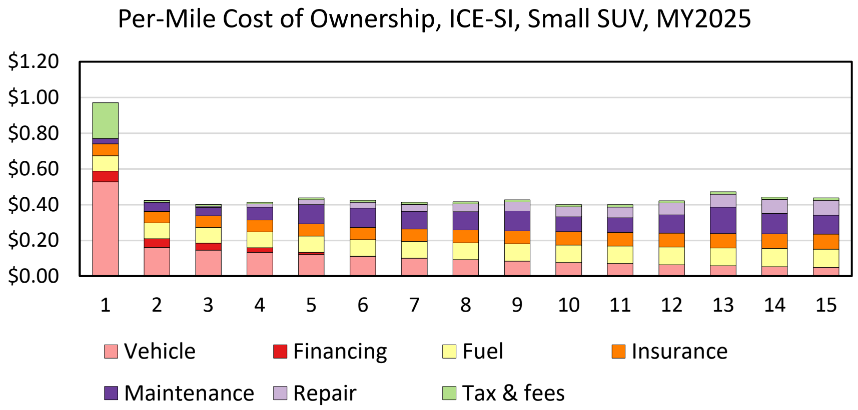
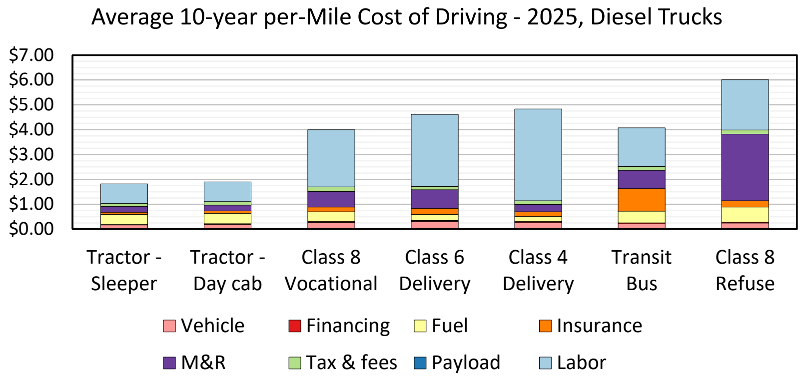
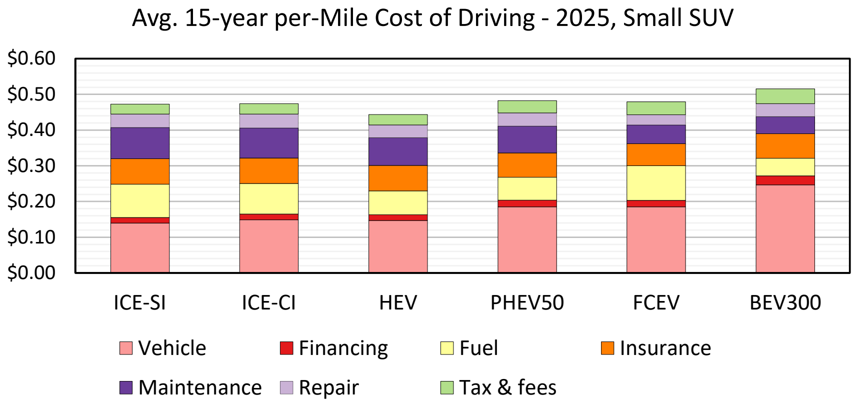
Technical Accomplishments – Levelized Costs

- Calculation & comparison of Levelized Cost of Driving (LCOD) across many perspectives
  - Changes in costs throughout vehicle lifetime
  - Comparison of lifetime costs for different powertrains
  - Comparison of lifetime costs for different vehicle use cases







Responses to previous years reviewer comments

- This is the first year that the project has been reviewed.

Remaining Challenges and Barriers

- Real-world data for alternative powertrains, particularly for MHDV, is very sparse
- Not all vehicles are operated in the same way – variations in VMT and ownership time
- Data-driven analysis using today's costs is not necessarily going to hold true in future

Any proposed future work is subject to change based on funding levels.

Proposed Future Research

- While this specific project is finished, there are several areas ripe for continued research outside the bounds of this project:
  - Applications of TCO analysis
  - Regional resolution of costs
  - Extension to other vehicle vocations & powertrains
- The groundwork we have set in this project can be used by other researchers to improve estimates of TCO / LCOD

Any proposed future work is subject to change based on funding levels.

Collaboration and Coordination with other Institutions

- Multi-lab research effort
  - Task leads from LBNL, NREL, ORNL, and Sandia, in addition to Argonne

by
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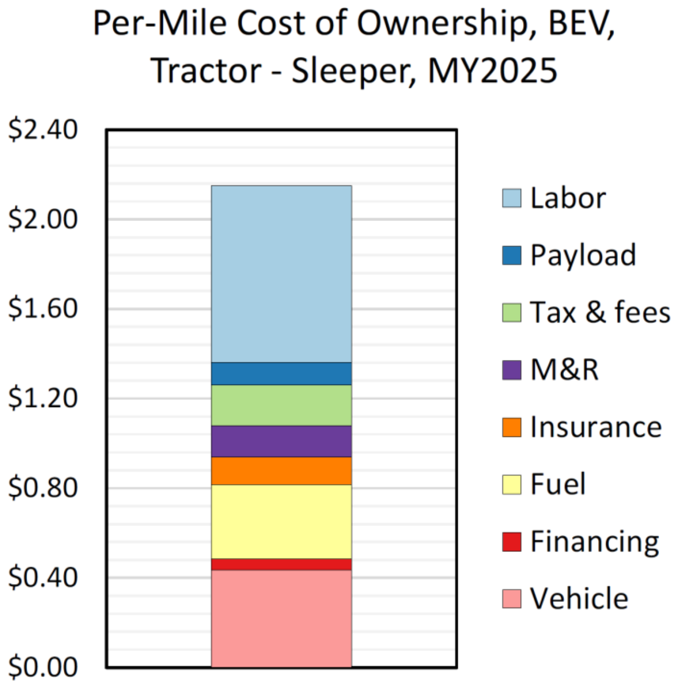
- TCO workshops for heavy-duty sector to vet methods and assumptions with industry
  - Vehicle manufacturer panel
  - Fleet panel
- One-on-one interviews with third parties to better understand main cost factors
- Feedback from US DRIVE Integrated Systems Analysis Tech Team (ISATT)

Summary

- Multi-lab research effort to identify and fill gaps for holistic calculations of vehicle costs for LDV and MHDV
  - Previous VTO analyses generally focused just on vehicle purchase cost and fuel expenditures
  - Potential variations in rank-order of the cost of technology from including maintenance, repair, insurance, financing, and taxes & fees
- Published major report documenting cost estimates for each important component for future analysis
  - Report also includes quantification of TCO for several scenarios and detailed sensitivity analyses exploring magnitude of different assumptions on TCO calculations



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