Medium- and Heavy-Duty Vehicle Choice Modeling and Applied Analysis

Alicia K. Birky and Aaron Brooker (Co-PIs)
National Renewable Energy Laboratory
June 2, 2020

DOE Vehicle Technologies Program
2020 Annual Merit Review and Peer Evaluation Meeting

Project ID # VAN034

Overview

Timeline

- Project start date: 10/01/2019
- Project end date: 9/30/2022
- Percent complete: 25%

Budget

- Total project funding: $900,000
  - DOE share: 100%
- Funding for FY 2020: $300,000

Barriers

- Indicators and methodology for evaluating benefits
- Complexity of freight transportation system
- Relating component-level technologies to national-level benefits
- Reliable and current medium- and heavy-duty (MDHD) market and operational data with sufficient detail/granularity

Partners/Collaborators

- NREL Lead: Alicia Birky and Aaron Brooker, co-PIs; Lauren Sittler, Chen Zhang, Jason Lustbader, Arthur Yip
- DOE cross office: Vehicle Technologies Office (VTO), Hydrogen and Fuel Cell Technologies Office (HFTO), Bioenergy Technologies Office (BETO)
- Argonne National Laboratory (ANL)
- 21st Century Truck Partnership (21CTP)

Relevance to VTO Analysis Program Goals

Provide critical information and analyses to ***inform VTO research portfolio planning*** through technology-, economic-, and interdisciplinary-based analysis, including ***target-setting*** and ***program benefit estimation***.

- Legacy and Automotive Deployment Options Projection Tool (ADOPT) MDHD modeling frameworks ***support program benefits estimation***.
- Integrated Future Automotive Systems Technology Simulator (FASTSim)-ADOPT framework enables ***simultaneous exploration of technical targets and program benefits***.

Vehicle ***modeling and simulation*** and applied analysis activities using unique ***capabilities, tools, and expertise*** resident in the National Laboratories.

- Creation, maintenance, and utilization of vehicle and system models to explore energy impacts.
- ***Integration of multiple models*** to yield ***useful findings***.

- Both legacy and ADOPT frameworks ***leverage FASTSim capabilities and MDHD models developed for various activities across VTO and HFTO***.
- Both frameworks integrate simulation results, market adoption, and stock modeling.
  - Legacy – manually
  - ADOPT – internally

Provide a holistic view of the transportation system and identify ***opportunities for advanced vehicle technologies to*** strengthen national security, increase reliability, and ***reduce costs***.

- Benefits analysis translates VTO targets into ***projections of in-use energy and emissions savings and expenditures*** on vehicles and fuel.
- Legacy payback methodology reflects adoption of ***cost-effective solutions that reduce lifetime transportation and truck freight movement costs***.

MDHD Scope: Weight Classes 4–8 (Gross Vehicle Weight Rating [GVWR] >14,000 lbs), potentially Class 3 (10,001–14,000 lbs).

Objectives

Provide critical tools, analysis, and information to prioritize and inform VTO research portfolio planning; explore energy-specific vehicle and transportation system advancements to inform VTO's early-stage research; and offer analytical direction for potential and future research investments.

- Provide continuity in benefits analysis support and develop cutting edge capabilities/approaches
- Develop ADOPT MDHD capabilities to **enable light-duty (LD) and MDHD analysis in a single, streamlined framework**
- Maintain and enhance legacy models (TRUCK + HDStock) and analysis approach during MDHD ADOPT development to maintain level of support

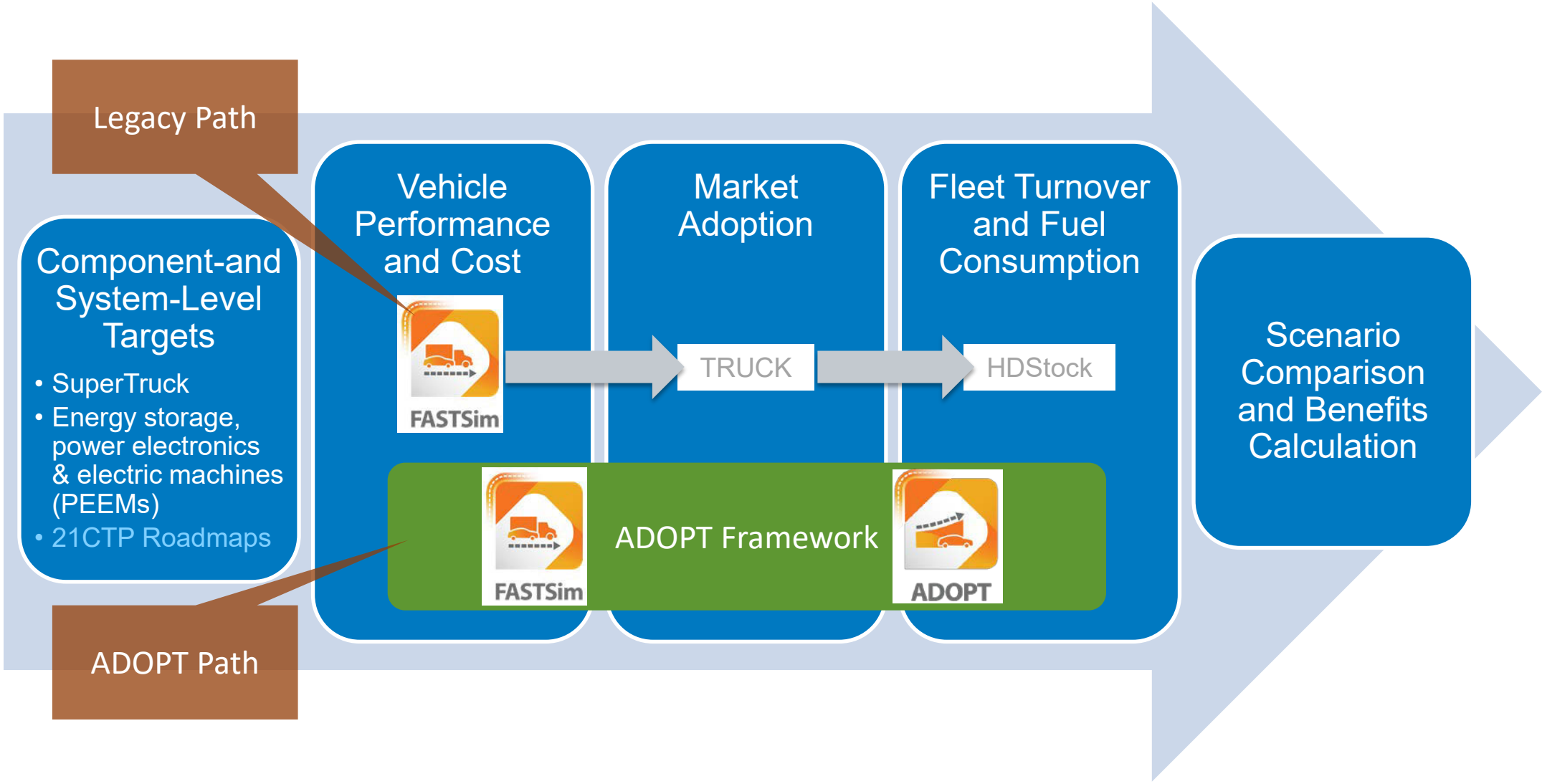
Year 1 Objectives

- ADOPT
  - Develop and demonstrate capabilities for Class 7 and 8 tractors
  - Develop plan for expansion to other classes/segments
- Legacy TRUCK choice model
  - Enhance recent model additions to enable modeling wider range of technologies for evolving VTO MDHD portfolio
  - Enable future enhancement through migration to more flexible platform
- Complete MDHD benefits analysis
  - Incorporate recent activities in target-setting
  - Use ADOPT and TRUCK in parallel

Milestones

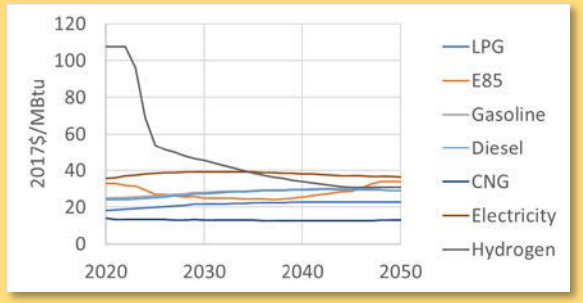
Date Due	Description	Status
June 2020	Report on updated ADOPT MDHD capabilities—provide a presentation and/or draft technical paper describing ADOPT MDHD updates and enhancements (such as fuel availability, preference heterogeneity, and vocation addition).	On Track
June 2020	Share preliminary MDHD benefits analysis run outputs with DOE for review and feedback.	
September 2020	Complete TRUCK model documentation updates—reporting on updates and enhancements made during the year (such as fuel availability and technology set expansion).	On Track
September 2020	Deliver completed MDHD Benefits Analysis Report for final DOE review.	On Track
September 2020	Go/No-Go: Based on progress with ADOPT MDHD development, determine whether to phase out use of TRUCK in FY 2021, continue with a parallel MDHD choice model approach, or redouble efforts for further needed TRUCK revisions and enhancements.	

MDHD Benefits Analysis Approach Overview: Translating Component and System-Level Targets into In-Use Energy Savings Benefits

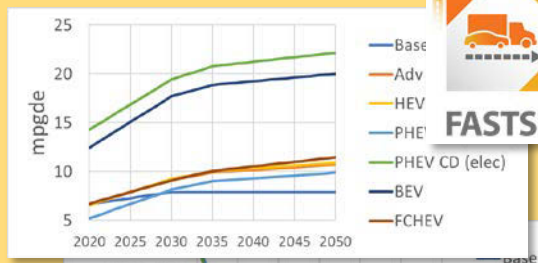


Approach: TRUCK Market Adoption Model Overview and Goals

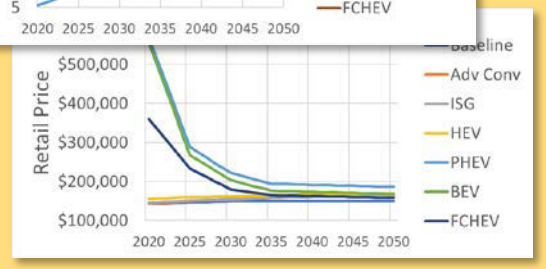
Annual Energy Outlook (AEO) Fuel Prices



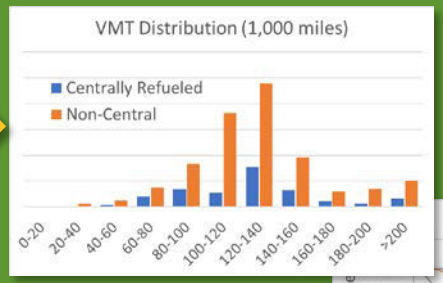
Vehicle Performance

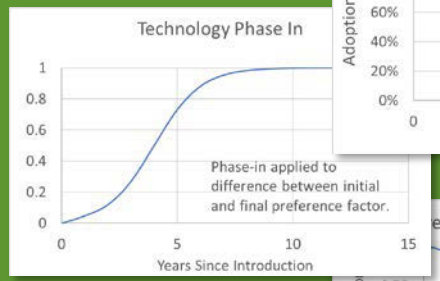


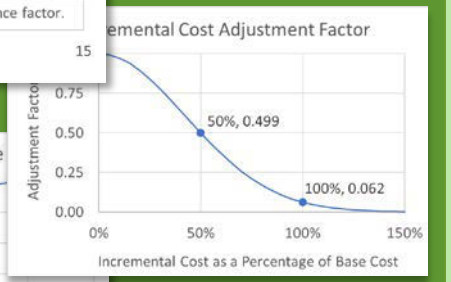
FASTSim

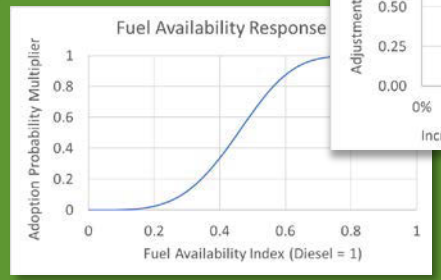


TRUCK

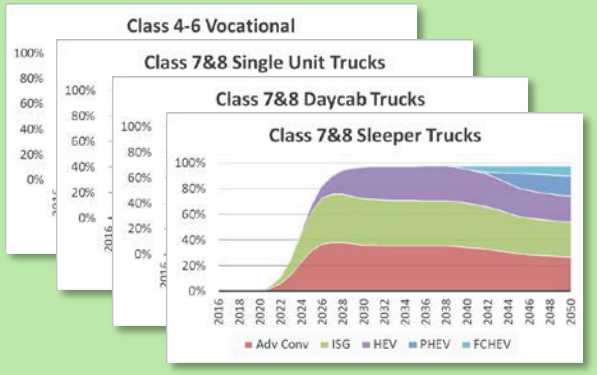








- Separate model for each market segment
- Base + 5 alternative vehicles using any fuel; baseline must be cheapest
- Adoption based on payback
  - 20,000-mile cohorts
  - Central, non-central distributions
  - Survey on acceptable payback
- Adjustments
  - Technology phase-in
  - Incremental cost as % of base cost
  - Fuel availability response
- Outputs
  - Sales shares as fraction of new vehicle miles traveled (VMT)
  - Sales fleet mpg, VMT, utility factor



- Address modeling limitations through migration to more flexible modeling platform
- Build out capabilities for expanded technology portfolio, beginning with fuel availability calculation and response (added in FY 2018)
- Document methodology and capabilities

Approach: TRUCK Enhancements

- Legacy model from 1990s with continuous updates through 2019
- Implemented in MS Excel with VBA
  - Open accessibility but possible Excel version compatibility issues
  - Inflexible—adding more powertrains requires major editing/rebuilding
  - Algorithm changes require restructuring

Implementation Upgrade

- Flexible programming platform (R)
- Open access and compatible with other legacy modeling components
  - Web-based or executable
  - Similar user interface to existing model
  - Input and output spreadsheets compatible with processing tools for simulation output and stock model input
- Enable expansion and updates
  - Easily add vehicle classes
  - Flexibly specify powertrains and number of options
  - Easily change algorithms in code

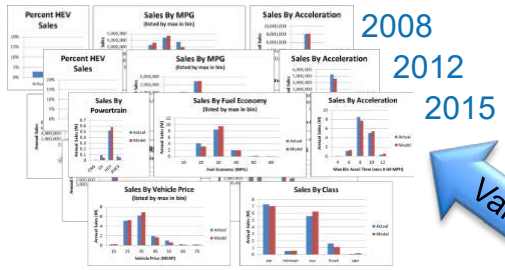
- Fuel availability added in FY 2018 based on light duty
  - Gasoline station counts serve as baseline for index
  - Number of stations has been decreasing (fewer, larger, farther apart)

Methodology Improvements

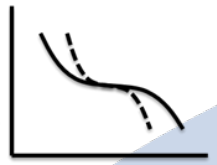
- Light duty appropriate for Class 4–6, some class single-unit trucks
- Stations versus capacity (pumps or throughput)
- Re-baseline tractors to truck stop data
  - Diesel lanes?
- Consider geographic distribution or spacing

Efforts include continuous methodology and data improvements building on prior years' work, as well as a major implementation upgrade to provide flexibility for future expansion and advances.

Approach: ADOPT



Validation



Consumer Preferences
- Nonlinear
- Income dependent

Regulations
- CAFE
- GHG Rule
- Incentives

Benefits

All Existing Makes/Models [1]

Market Driven Future Options

FASTSim

Technical Targets

[2]

Images credits
1. D. Schroeder, NREL
2. Jim Snyder, NREL

Adapt ADOPT methodology to account for differences in MDHD market dynamics compared to LD

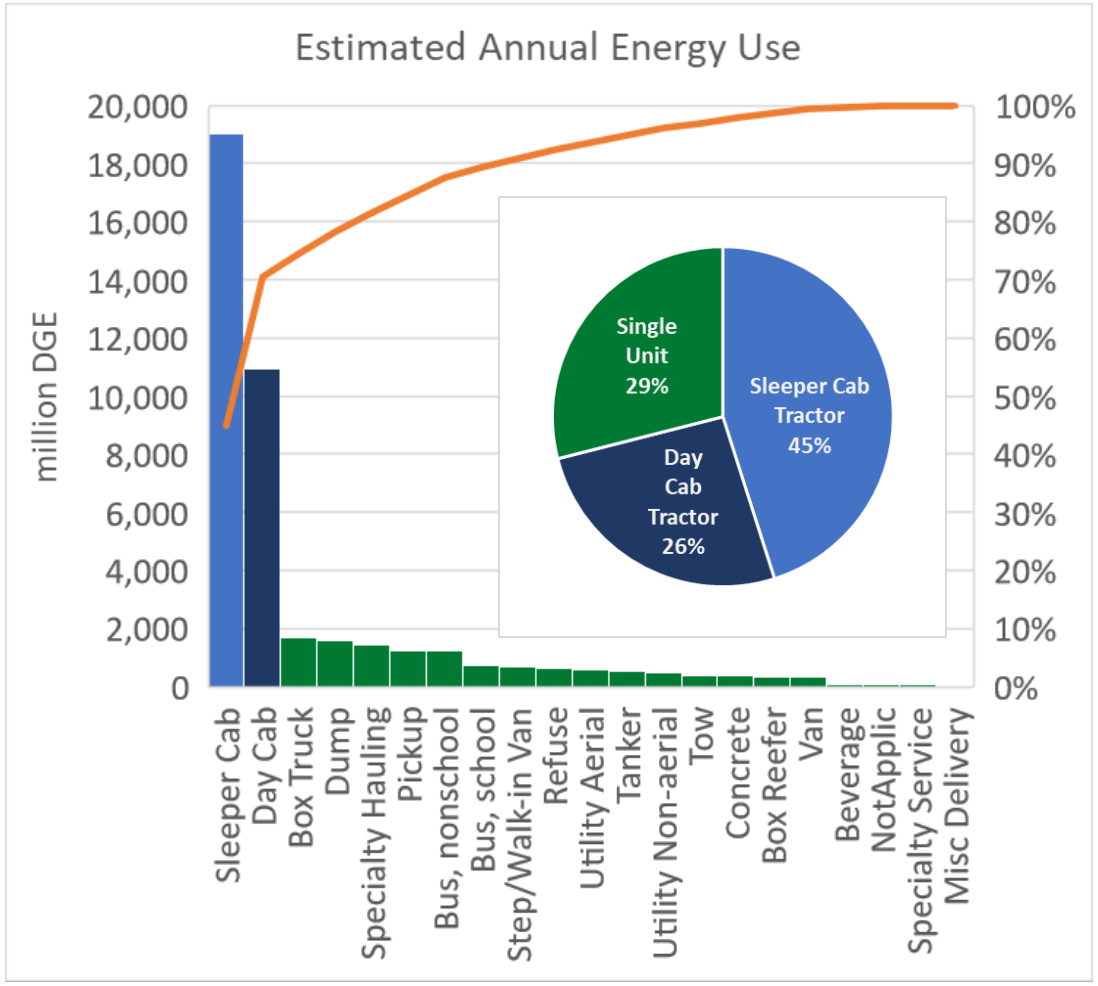
Approach: ADOPT MDHD Plan

Update ADOPT for Class 8 tractors

- Highest fuel user – biggest impact
- Framework updates
  - Change from income-based preferences to VMT-based preferences
  - Acceleration (increase max time from 10 s to 60 s)
  - Add missing potential powertrains
  - Add HD drive cycle leveraging NREL target-setting efforts
- Update with HD inputs
- Review and revise

Go/No-Go

Complete updates for other MDHD classes



Source: Analysis by NREL (2020) of 2013 IHS Polk registrations, 2017 National Transit Data Base, 2002 Vehicle Inventory and Use Survey, and various other data sources.

Approach: ADOPT MDHD

ADOPT goes beyond cost/payback framework to capture performance advantages advertised by manufacturers

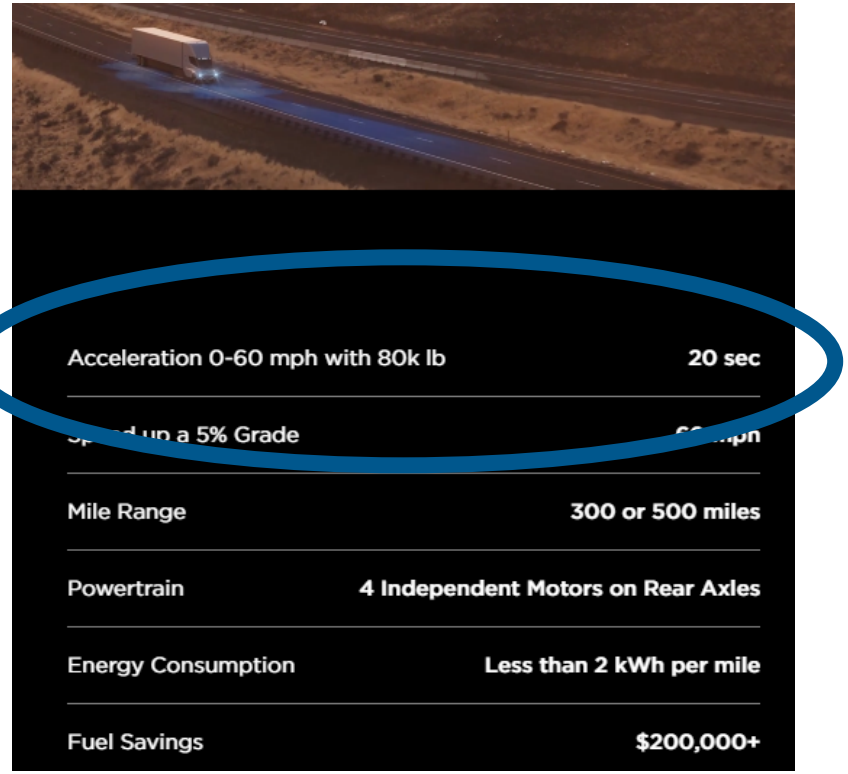
Vehicle attributes include acceleration time (usually neglected in MDHD choice models).

- Toyota
  - Advertising ~2x acceleration time diesel vs. fuel cell

Source: https://www.youtube.com/watch?v=JIksYnH4uEc

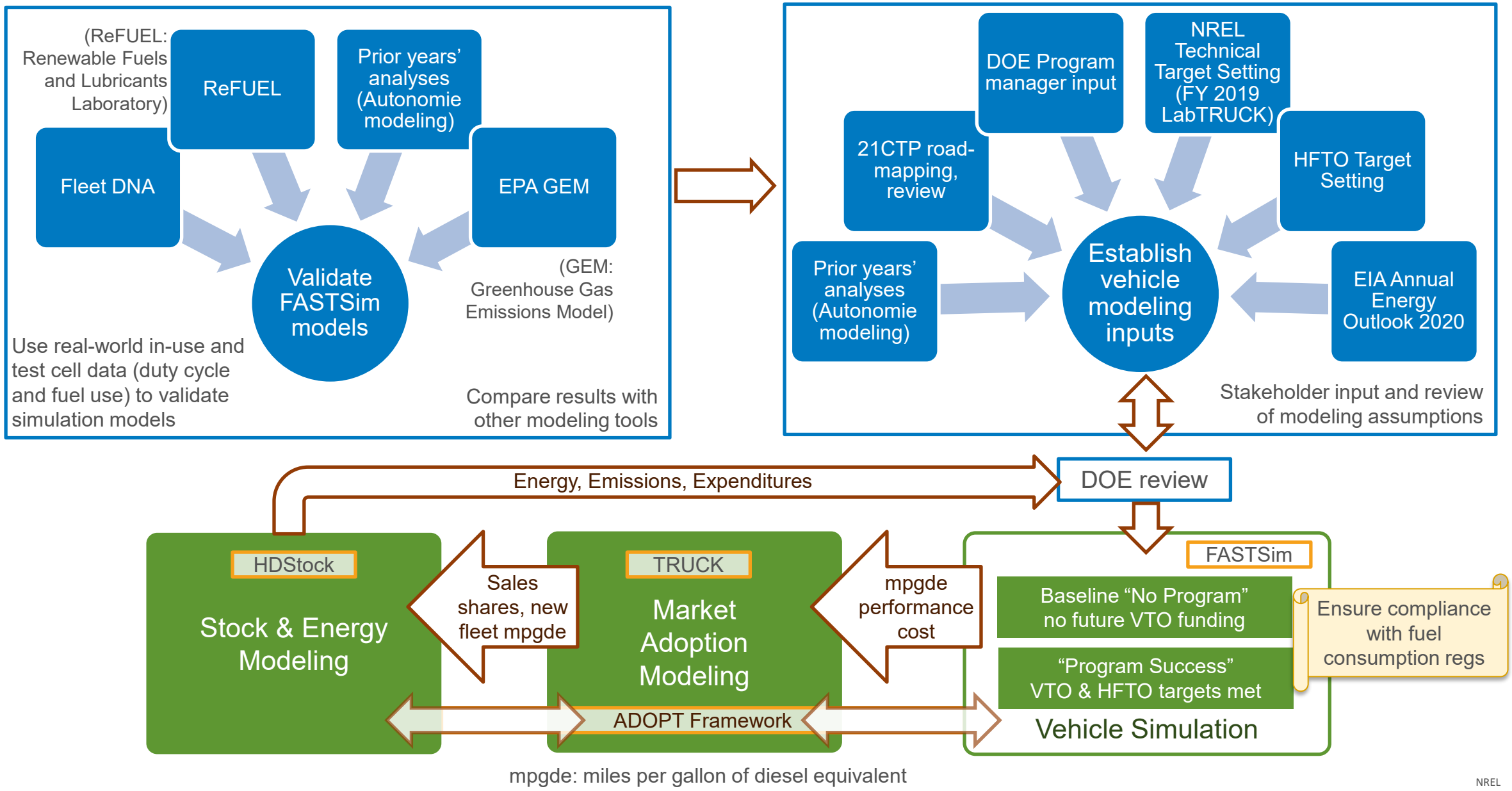
Faster acceleration of battery electric tractor-trailers would provide safety benefits at traffic lights and highway on-ramps.

- Tesla:
  - Acceleration tops list of specs:



Source: https://www.tesla.com/semi

Approach: MDHD Benefits Analysis



mpgde: miles per gallon of diesel equivalent

ADOPT MDHD Technical Accomplishments and Progress

Identified required revisions and incorporated MDHD data sources. Quality testing and validation is progressing.

Framework Revisions for Class 8 Tractor

ADOPT LD was modified for HD to capture differences in consumer price sensitivity, technical constraints for HD vehicles, and the HD market evolution.

Change from income-based preferences to VMT-based preferences

Acceleration test (increase max time from 10 s to 60 s)

Add missing potential powertrains

Added HD drive cycle leveraging NREL target-setting efforts

Data Set Updates

Completed

The following data categories were updated to reflect the most recent data applicable to HD vehicle sales.

Max Penetration Rate

Fuel Prices

VMT by Age

Tech Targets
- Electric Vehicles (EVs)
- Fuel Cells

Survival

Vehicle Data

Total Sales Forecast

VMT Distribution

Incentives

Regulations

Consumer Preference Adjustments

Preference settings specify the importance of each vehicle attribute. Updates were made to reflect HD consumer preferences.

Adjusted the fuel cost discount rates for high and low VMT consumers. (For LD these are income-based.)

Changed acceleration settings to match HD performance and reflect lower value to HD consumers.

Adjusted the volume coefficient parameters (ongoing)

Adjusted the penalties for battery electric vehicle (BEV) battery range (ongoing)

Quality Testing

In Progress

As framework updates were completed and preferences adjusted, coding errors were identified and corrected:

Plotting of results in the user interface

Seeding new powertrains

Preference validation

Engine efficiency improvements

Work to identify and correct coding issues is ongoing.

Results Validation

Once all coding updates, data inputs, and quality tests are complete, sales by powertrain will be compared to historical data.

Total cost of ownership calculated by ADOPT (fuel costs and MSRP) will be compared to cost of ownership calculated from traditional analysis.

TRUCK Technical Accomplishments and Progress

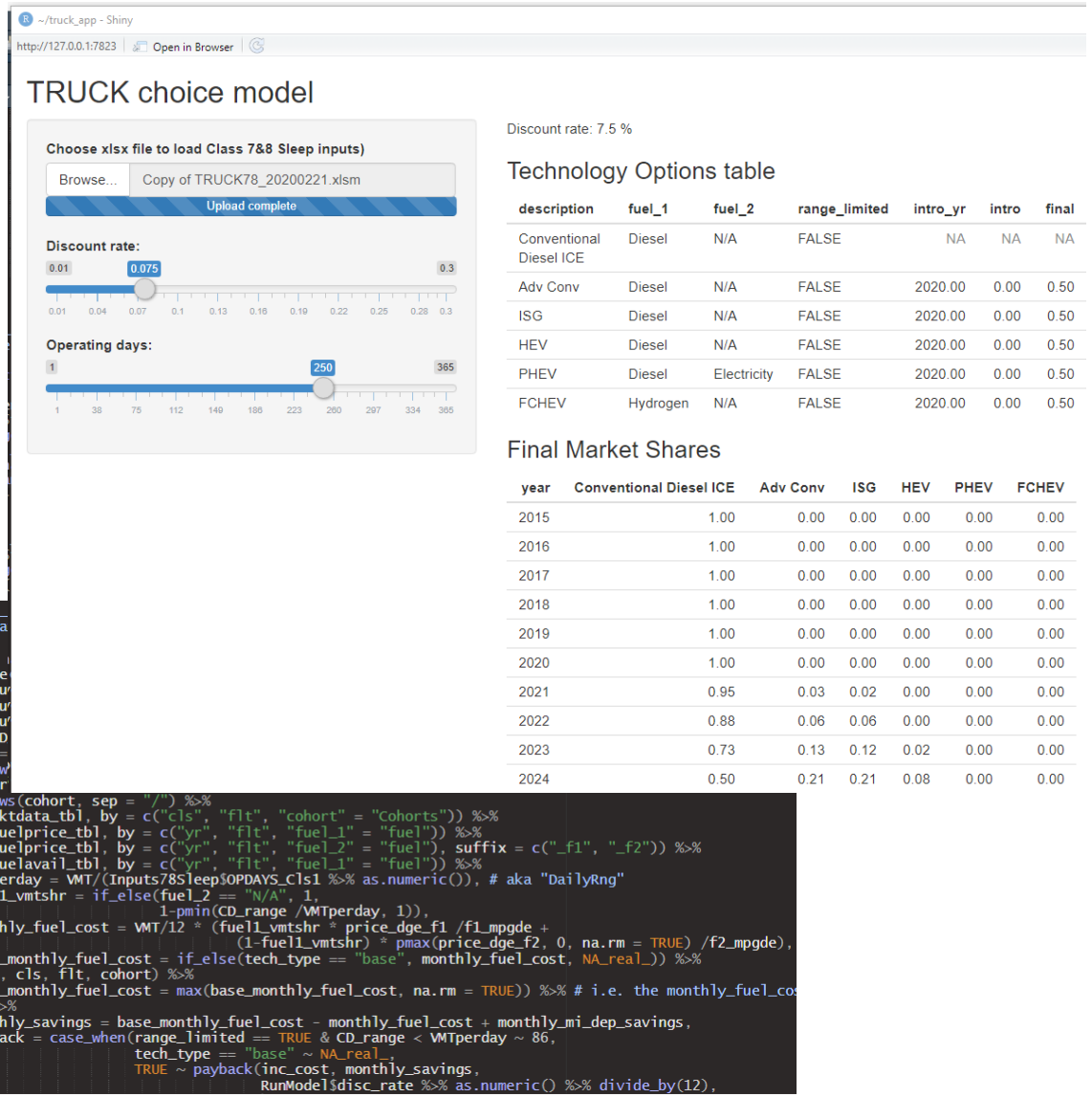
Model refactoring

- R interface
- Input reorganization
- Existing algorithms implemented, with improvements
- Output tables consistent with Excel model for easy integration with HDStock

Data collection

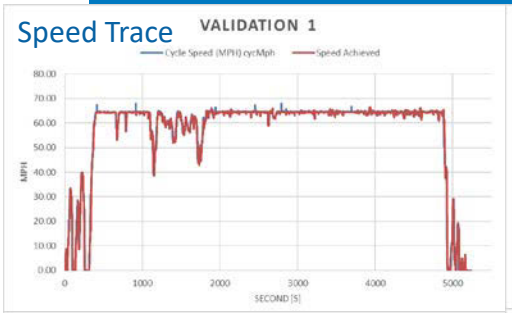
- Truck stops: locations and capacity (not complete)
- Literature review of MDHD response to fuel availability

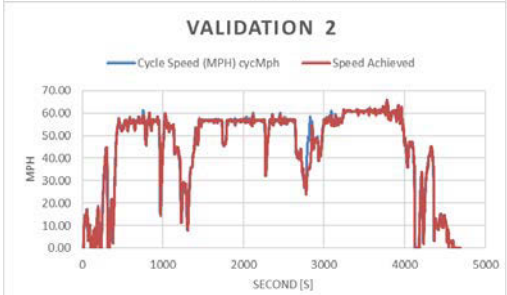
Successfully replicated model in R and enabled analysis of greater number of powertrains while improving usability and preserving compatibility with input generation and legacy stock model.

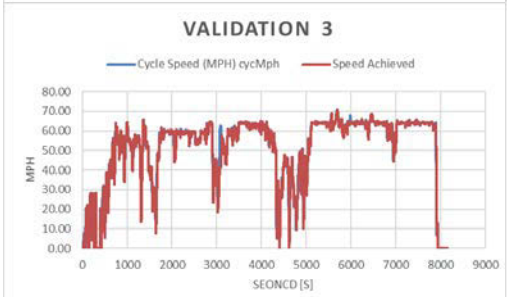


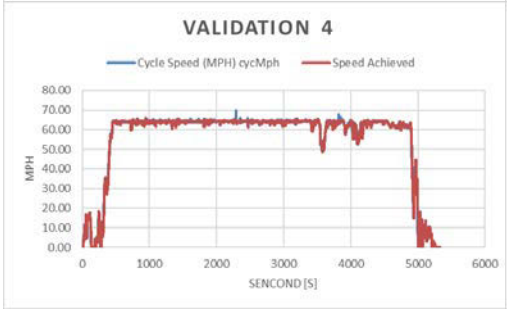
Benefits Analysis Technical Accomplishments and Progress: Vehicle Model – Sleeper Cab Truck Model Validation

Speed Trace

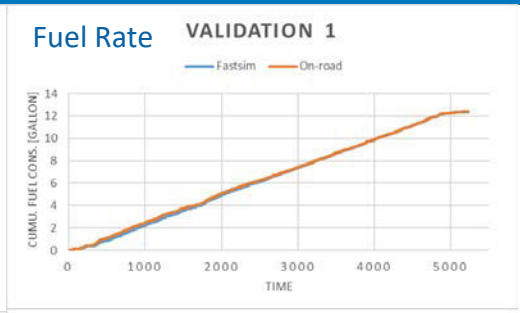


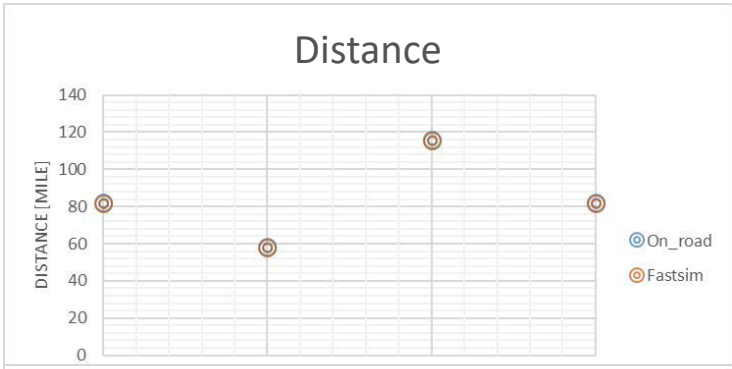


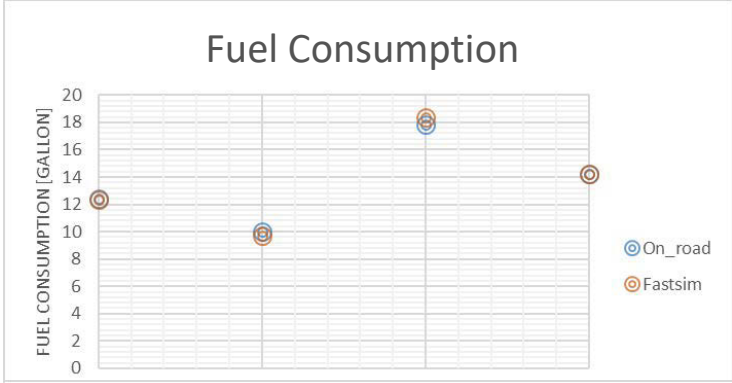


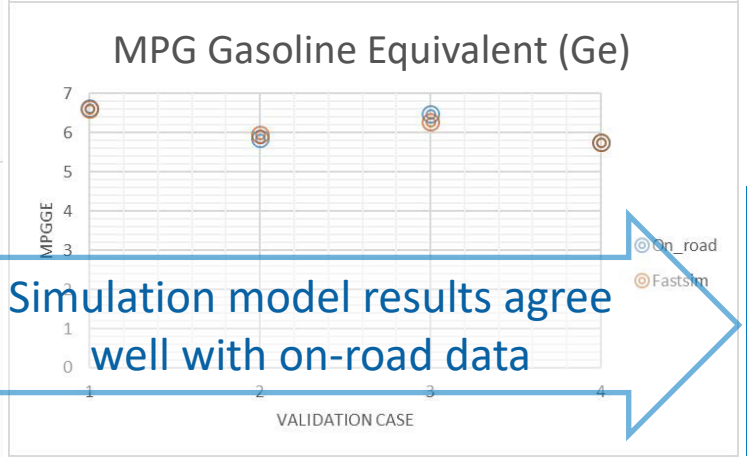


Fuel Rate









Simulation model results agree well with on-road data

Distance	On-road	FASTsim	Error
Case 1	82.04	81.85	0.22%
Case 2	58.42	58.01	0.70%
Case 3	115.76	115.20	0.48%
Case 4	82.04	81.77	0.36%

Fuel Con.	On-road	FASTsim	Error
Case 1	12.39	12.54	−1.21%
Case 2	9.99	9.85	1.41%
Case 3	17.85	18.30	−2.53%
Case 4	14.24	14.42	−1.19%

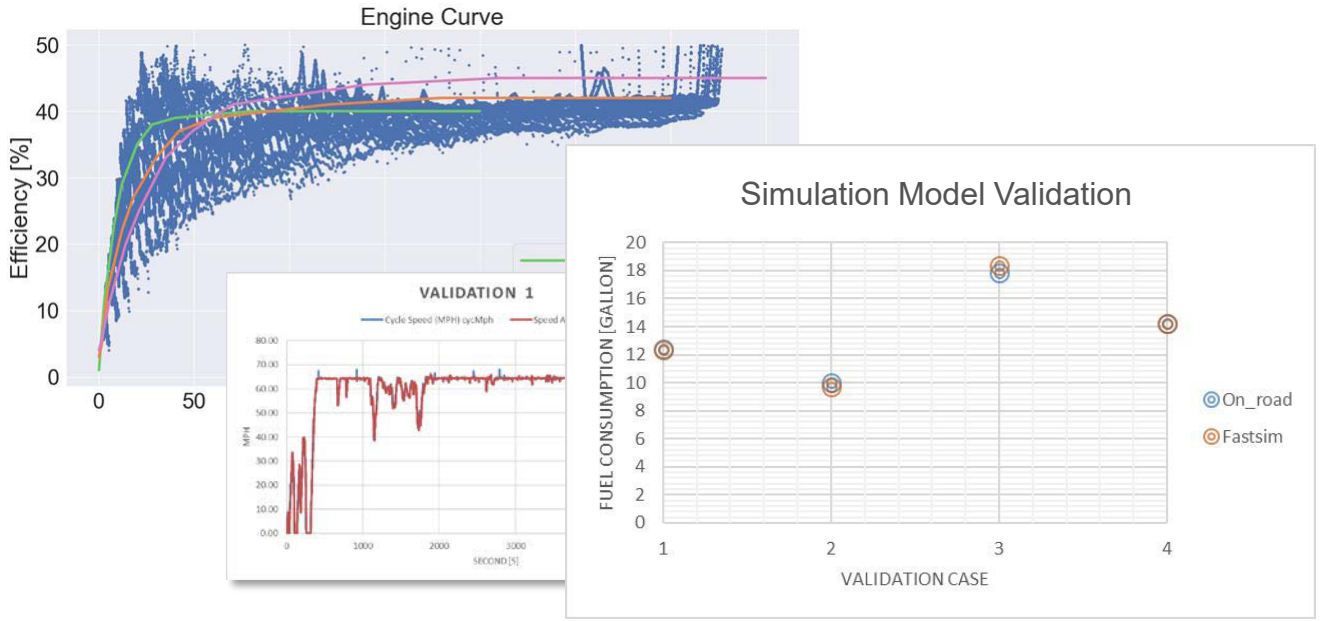
MPG Ge	On-road	FASTsim	Error
Case 1	6.62	6.53	1.38%
Case 2	5.84	5.89	−0.71%
Case 3	6.48	6.29	2.94%
Case 4	5.76	5.67	1.50%

Fuel consumption error over four tests with on-road data within ±3%

Benefits Analysis Technical Accomplishments and Progress

FASTSim Model Validation

- Leveraging ReFUEL and Fleet DNA data
- Class 8 sleeper and day cab models validated in LabTRUCK tech target efforts
- Identified appropriate data for Class 8 and Class 6 box trucks
- Comparison with in-use, test, and EPA GEM (EPA regulatory cycles) fuel consumption



Input Specification

- Comparison of parameters from prior year's inputs, HFTO market segmentation study, LabTRUCK target-setting.
- Reassessment of costs including data from LabTRUCK target-setting and VTO Analysis Program total cost of ownership efforts.

- Successfully developed validated models for representative vehicles in each class required in the legacy approach.
- Updated inputs using latest analyses and information; continued use of some parameters, as appropriate.
- Review of inputs by DOE program managers and 21CTP underway.

Responses to Previous Year Reviewers' Comments

- This project is new this fiscal year and was not reviewed in the previous year.

Collaboration and Coordination

- Establishing appropriate modeling inputs requires coordination across DOE:
  - VTO program managers with MDHD portfolio activities
    - SuperTruck
    - PEEMs
    - Energy Storage
  - HFTO program managers with MDHD portfolio activities
  - Initiated coordination discussions with BETO
- Leveraging NREL efforts across VTO, HFTO, and work for others (where possible)
  - Expertise, knowledge, and model development
- Information exchange with ANL on Autonomie simulation inputs for prior benefits analysis and other projects
- Project benefits from collaboration with industry through 21st Century Truck Partnership
  - NREL team members participate in monthly tech team and working group meetings
  - Presentation of inputs, methodology, and results for review and feedback

Remaining Challenges and Barriers

- Data availability for fuel availability response validation
- Data availability for non-tractor vehicle classes
- Evolving 21CTP roadmaps and technical targets

Future Work

Remainder of FY 2020

- Reach out to industry stakeholders for expert input on fuel availability response methodology and parameterization (American Trucking Association, North American Council for Freight Efficiency, fleet contacts, etc.)
- Complete benefits analysis input and preliminary results review
  - DOE, 21CTP
- Revise and finalize ADOPT and legacy benefits analysis.
  - Document methodology and results (September 2020 milestone)
  - Present results to 21CTP for consideration in roadmapping and development of technical targets
- Complete documentation of TRUCK model (September 2020 milestone)
- Present ADOPT capabilities and expansion plan to VTO for Go/No-Go decision (December 2020 milestone)

FY 2021

- Depending on Go/No-Go decision
  - Complete expansion of ADOPT to more market segments/vehicle types
  - Investigate enhancements and alternative methodologies for TRUCK, including stock model integration and endogenous fuel availability calculation
- Work with DOE and 21CTP to update assumptions and inputs for next benefits analysis, incorporating new 21CTP Roadmaps and technical targets when available

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

Summary

Relevance	❑ MDHD benefits analysis provides critical information to inform VTO research portfolio planning. This is crucial as VTO expands R&D activities for commercial vehicles.
Milestones	❑ Efforts are on track to meet project milestones for ADOPT and TRUCK modeling as well as benefits analysis.
Approach	❑ NREL has a sound approach that maintains continuity of benefits analysis support while developing enhanced and new capabilities.
Accomplishments	❑ ADOPT MDHD model quality testing is progressing well ❑ TRUCK model has been ported to new platform and fuel availability for truck stops data has been incorporated ❑ FASTSim vehicle models have been developed and validated ❑ Benefits analysis inputs are in review process
Coordination	❑ The project team is coordinating with VTO, HFTO, BETO, and 21 CTP and is leveraging work within NREL that cuts across DOE-funded projects.
Remaining Challenges	❑ The MDHD sector suffers from serious data availability issues. NREL is working with DOE and external partners to mitigate these issues.
Future Work	❑ The team has a research plan to achieve remaining objectives for this fiscal year, address challenges, and meet VTO goals in future years.

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

Thank You

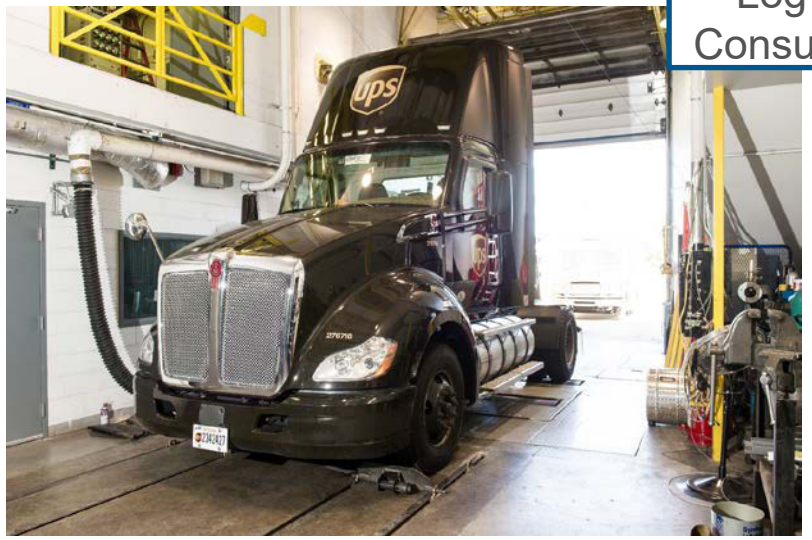
www.nrel.gov

NREL/PR-5400-76740

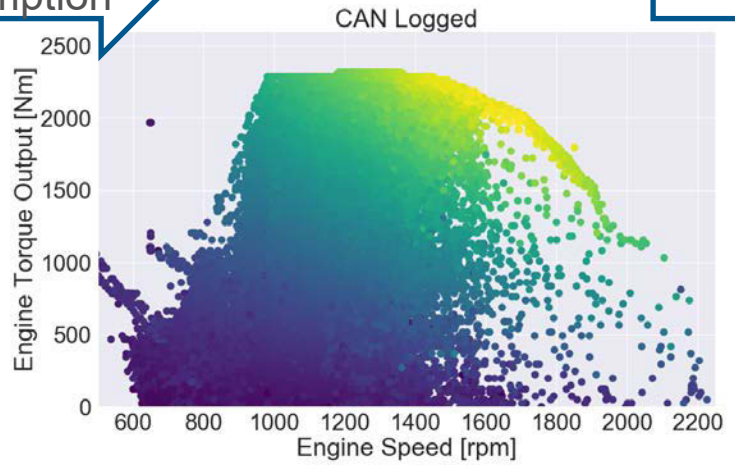
This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Vehicle Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Technical Back-Up Slides

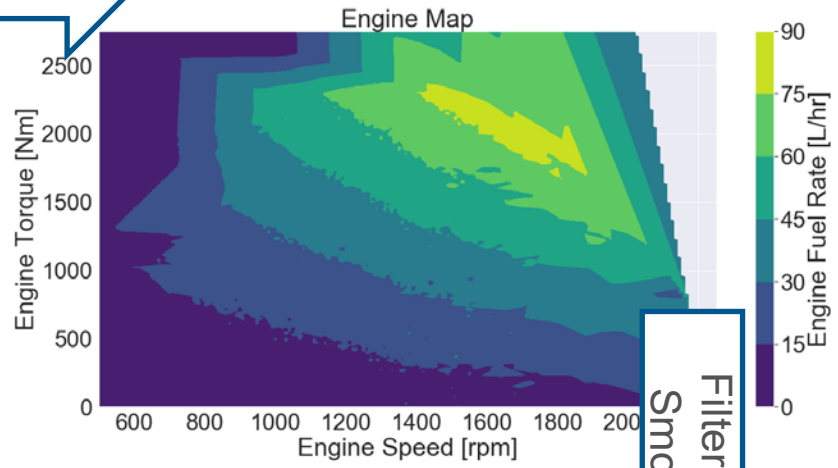
Generating Engine Curves From Dynamometer Data



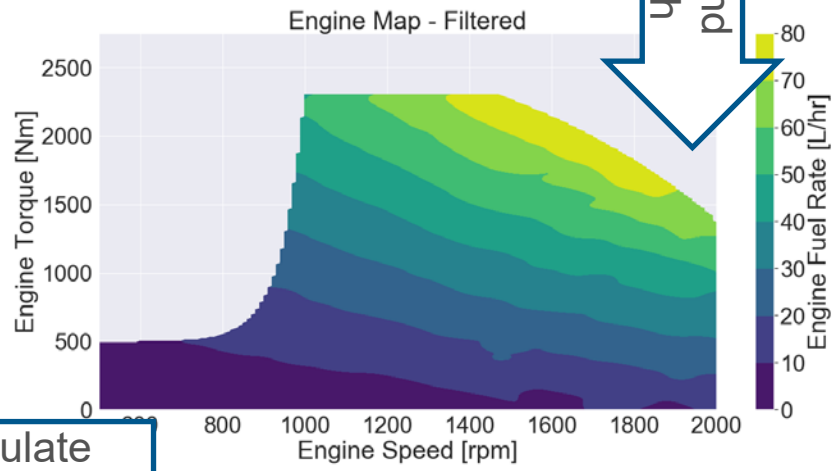
Log Fuel Consumption



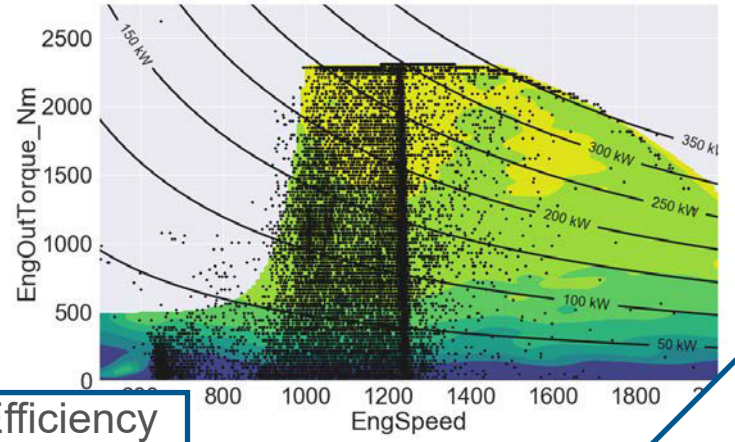
Fit to Grid



Filter and Smooth



Calculate Efficiency



Fit Efficiency Curve