Project ID # VAN023

Assessing the Energy and Cost Impact of Advanced Technologies through Model Based Design

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2018 DOE Vehicle Technologies Annual Merit Review

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Project Overview

Timeline	Barriers*
• Project start date : Oct FY17 • Project end date : Sep FY18 • Percent complete: 50%	• Risk aversion • Constant advances in technology • Cost • Computational models, design, and simulation methodologies *from 2011-2015 VTP MYPP

Budget	Partners
• FY17 Funding : $250K	Formal Collaborator • Energetics, USDrive, MD&HD OEMs Interactions • All USDrive Partners, outside companies (OEMs, suppliers…)

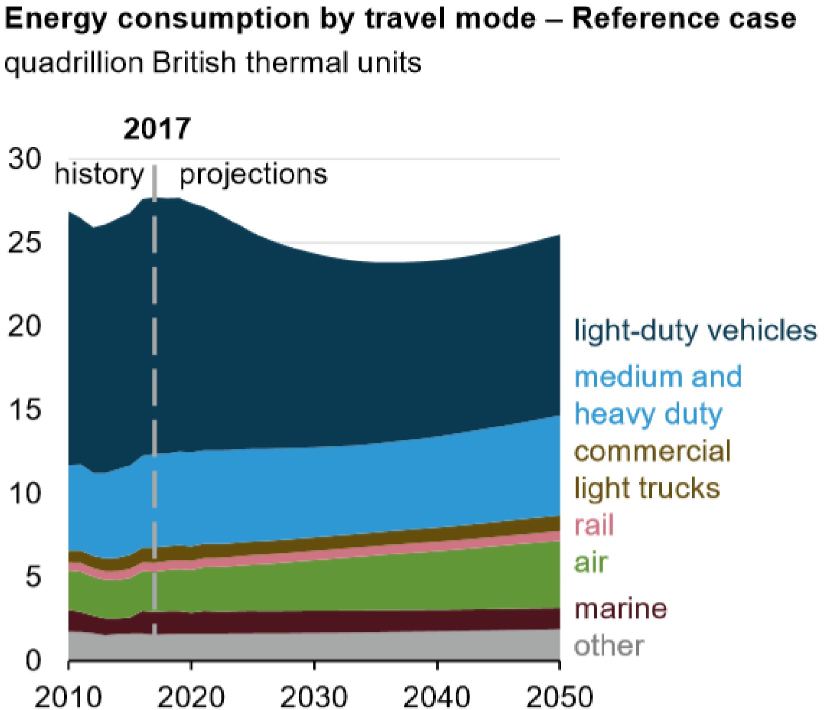
Project Relevance

Objective : Quantify energy and cost benefits of vehicle technologies improvements for light, medium & heavy duty vehicles

- Medium duty (MD) & Heavy duty (HD) vehicles consume more than a quarter of energy in transportation sector. Benefits of vehicle technology improvements for these vehicles are not well understood.

- A large scale analysis of multiple classes and vocations is needed to quantify the fuel saving potential of various vehicle technologies.

- Results will be combined with market penetration data to quantify the overall petroleum displacement potential of a technology.

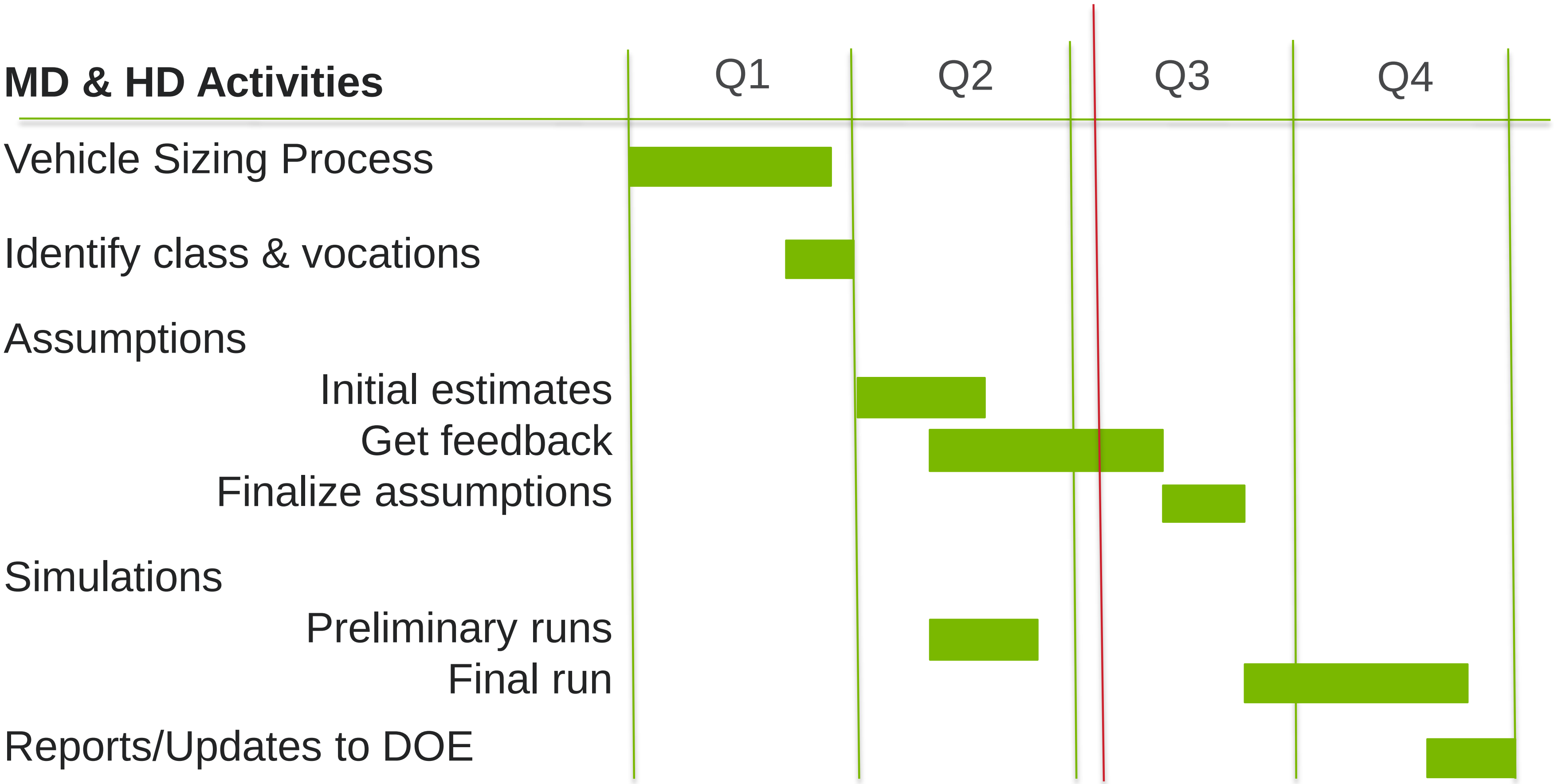


Ref: EIA, Annual Energy Outlook 2018

Project Milestones

Light Duty Activities

- Baseline Scenario (BaSce) report is complete and under final review



Approach

Build on existing work from various agencies

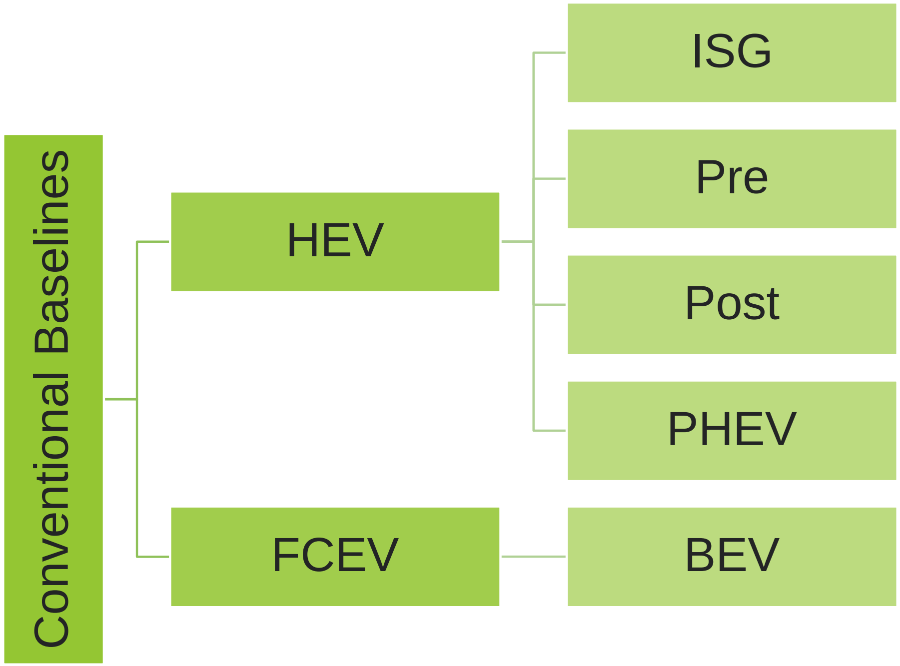
Component Specs
- EPA, GEM, SmartWay
- LLNL, SWRI, DOT, DOE

Classes & Vocations
- EPA regulation
- VIUS Database
- DOE & Industry feedback

Test Procedure
- EPA Regulatory Cycles

Sizing Parameters
- 6% grade speed
- Acceleration time
  - 0-30mph, 0-60mph
- Cruising speed
- Range

Technology Forecast
- National Labs
- Supertruck
- VTO, 21st Century Truck



Model building & simulation approach

Approach

Validate Autonomie MD HD Models & Develop Additional Powertrain Options

- **FY 16**
  - Sensitivity to key parameters was verified against NHTSA Report *
  - Engine data taken from SWRI reports and EPA GEM model
- **FY 17**
  - Implemented new MDHD regulatory test procedures from EPA
  - Developed reference models for all powertrain options
  - Initiated powertrain sizing algorithm development
- **FY 18**
  - Technology forecast from FY17 updated for 21CTP roadmap, new engine targets from DOE, Supertruck 2 goals & regulatory requirements
  - Sized vehicles were evaluated for technology forecast assumptions
  - After obtaining feedback on technology forecast assumptions, final simulations will be carried out

* **DOT HS 812 146: Commercial Medium- and Heavy-Duty Truck Fuel Efficiency Technology Study – Report #1**

Approach

Expand Process Developed for Light Duty BaSce Analysis

Vehicles
class 2 Van
class 3 EnclosedVan
class 3 SchoolBus
class 3 Service
class 4 WalkIn
class 5 Utility
class 6 Construction
class 7 SchoolBus
class 8 TransitBus
class 8 Construction
class 8 Linehaul
class 8 Refuse
class 8 Tractor
....

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Timeframes

Current

2017
...
...
...
...
...
...
....
2050

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Powertrain Configurations

Conventional

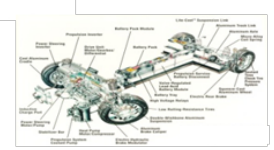


ICE HEV

PHEV



Fuel Cell

Electric


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Fuels

Gasoline



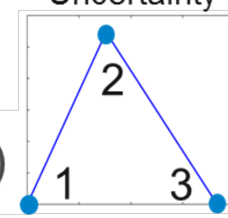
Diesel

Ethanol


H_2

⊗

Triangular Uncertainty



1 = 10%
2 = 50%
3 = 90%

~ 4000 Vehicles

Technical Accomplishments

Additional Class/Vocation Combinations Have Been Added Based on Feedback from Project Partners

Properties		Classes & Vocations														
		2	3			4	5	6		7		8				
		Van	Closed Van	Service/Utility	School bus	Walk In	Utility	Pickup & Delivery	Construction	School bus	Flat Bed	Transit Bus	Construction	Refuse	Tractor	Linehaul
Summary	Daily driving range (mi)	153	163	150	150	200	150	150	200	150	150	150	200	150	400	400
	Power (kW)	187	140	298	187	149	224	225	149	169	169	243	160	242	261	336
Performance	Cargo Mass (lb)	1388	5898	5720	5500	5280	10340	10326	14227	17600	17600	4000	19934	27280	31900	43890
	Cruising Spd (mph)	70	70	70	70	70	65	70	65	60	60	60	60	60	60	60
	6% Grade Spd (mph)	66	49	70	68	41	65	33	30	38	38	27	21	28	27	31
	0-30mph accel (s)	7.6	7.6	6.3	7.1	8	9.3	12.6	12.5	14.8	14.8	15	20.8	15	16.7	17.1
	0-60mph accel (s)	22	24.8	14.3	20.5	34.2	23.6	48	47.2	54.4	54.4	62	100	56.5	63.3	61.1
Transmission	Auto / Manual	A	A	A	A	A	A	AMT	AMT	AMT	AMT	A	AMT	AMT	AMT	AMT
	Number of gears	6	5	5	6	5	5	6	6	6	6	5	6	8	10	10
	Number of driven axles	1 / 2	1 / 2	1 / 2	1 / 2	1 / 2	1 / 2	1/2	1 / 2	1 / 2	1 / 2	1 / 2	1 / 2	1 / 2	2 / 5	2 / 5

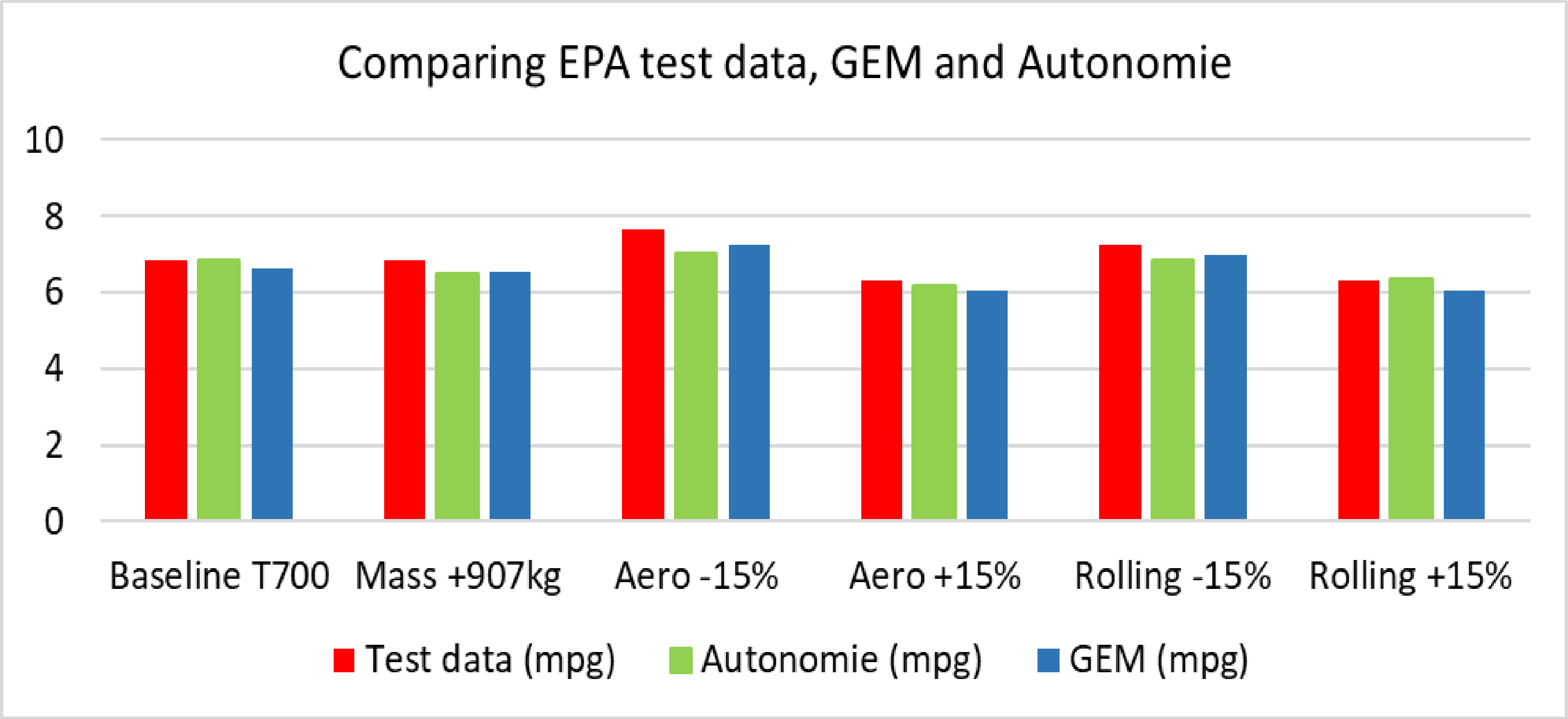
These reference vehicles are available as part of the 2017 fleet mix. New ones are continuously added (Eg. Class 6 Delivery, Class7 Flatbed).

The highlighted ones will be used for the ‘preliminary runs’

Technical Accomplishments

Class 8 Linehaul Model was Validated against Test Data from EPA & GEM.

- As part of the rulemaking activities, EPA tested T700 on dyno and modelled the same vehicle in GEM. Autonomie simulation match closely with the vehicle test results



In addition, class 6 and class 8 vehicle models have been verified against OEMs proprietary data

Performance Assumptions for BaSce Vehicles

Vehicle Level Requirements for Cargo, Performance & Range Unchanged Across Powertrain Options

- Target performance values based on conventional vehicles simulation results

Class	Purpose	Acceleration		6% grade speed (mph)	Max Speed (mph)	daily driving (miles)
		0-30mph (s)	0-60mph (s)			
3	PnD	9.2	28.5	50	70	150
6	PnD	12.6	48	33	70	150
7	Vocational	18	70	30	65	100
8	Linehaul	18	66	30	65	300

- Vehicles are closely aligned with EPA's regulatory frame work (e.g., High Roof, Mid Roof, Low Roof variants will also be modelled for Class 8 line haul trucks)

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Technical Accomplishments

Performance Based Sizing Logic

- Component power requirements vary with powertrain architecture
- Powertrain sizing objectives
  - Find minimum component sizes needed to meet performance targets
  - Reduce energy consumption (not optimization).
  - Fully utilize the components available in architecture

<table>
<tr><th>Powertrain</th><th>Engine</th><th>Electric Machine</th><th>Energy Storage</th></tr>
<tr><td>Conventional</td><td rowspan="3">Acceleration Grade & Cruise</td><td></td><td></td></tr>
<tr><td>ISG</td><td>Size based on Starter & Alternator</td><td>Energy: Sustain electric loads for at least 1 minute[2]</td></tr>
<tr><td>HEV</td><td>Maximize regen in ARB Transient[1]</td><td>Power: to sustain peak motor output</td></tr>
<tr><td>PHEV</td><td>Grade & Cruise</td><td rowspan="2">Acceleration Grade & Cruise</td><td rowspan="2">Energy: Electric Range Driving Range in EPA 65.
Power: Sufficient power to support motor & aux loads</td></tr>
<tr><td>BEV</td><td></td></tr>
</table>

[1] Among the cycles used by EPA for regulation, this is the cycle with frequent braking events
[2] Based on EPA off-cycle credit system in LDV. Stop time needs to be calibrated based on real world data.

Technology Forecast Assumptions

Inputs from SuperTruck (ST), EPA, Smartway, 21CTP Roadmap & DOE Targets

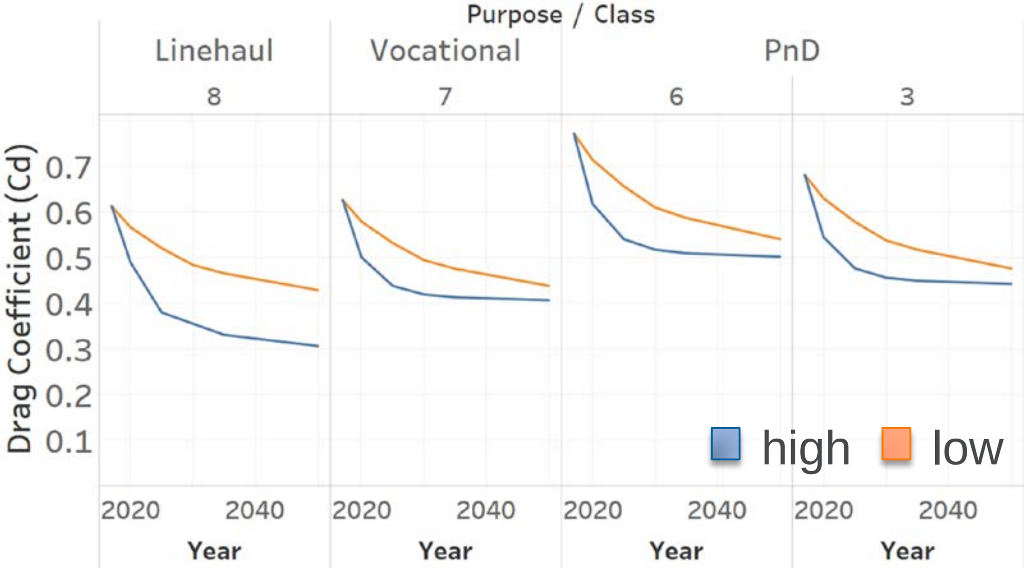
- Technology adoption in class 8 fleets from NACFE 2016 fleet study used to identify technologies in current trucks
- Similar data for other classes of vehicles will be valuable.

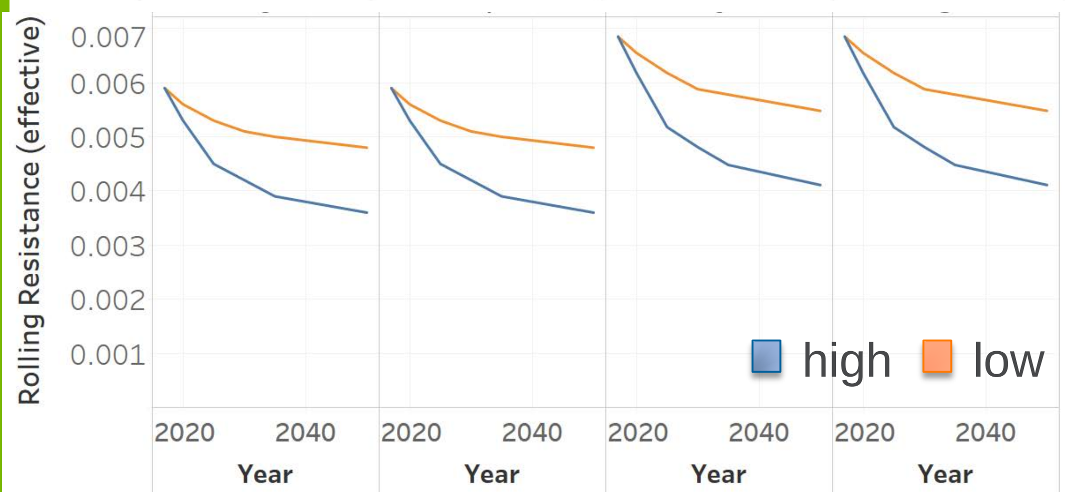
Parameter	Current Reference	Future References
Cd, Frontal Area	EPA[1]	ST1[2] results
Rolling resistance	SmartWay	ST1 results
Auxiliary loads	EPA[1]	ST1 results
Light Weighting	Reports from DOE Tech Teams[3]	
Engine efficiency	EPA test data, GEM	ACEC, ST1 results, ST2 target, 21CTP road map
Electric machines & Battery	Light Duty BaSce Assumptions	

[1] EPA – assumptions used by EPA & NHTSA in the medium & heavy duty rule making
[2] Average values achieved by participants in Super Truck 1 program
[3] WORKSHOP REPORT: Trucks and Heavy-Duty Vehicles Technical Requirements and Gaps for Lightweight and Propulsion Materials, February 2013

Aero & Rolling Resistance Assumptions

Technology Forecast & Cost Assumptions are Class and Vocation Specific for Most Parameters



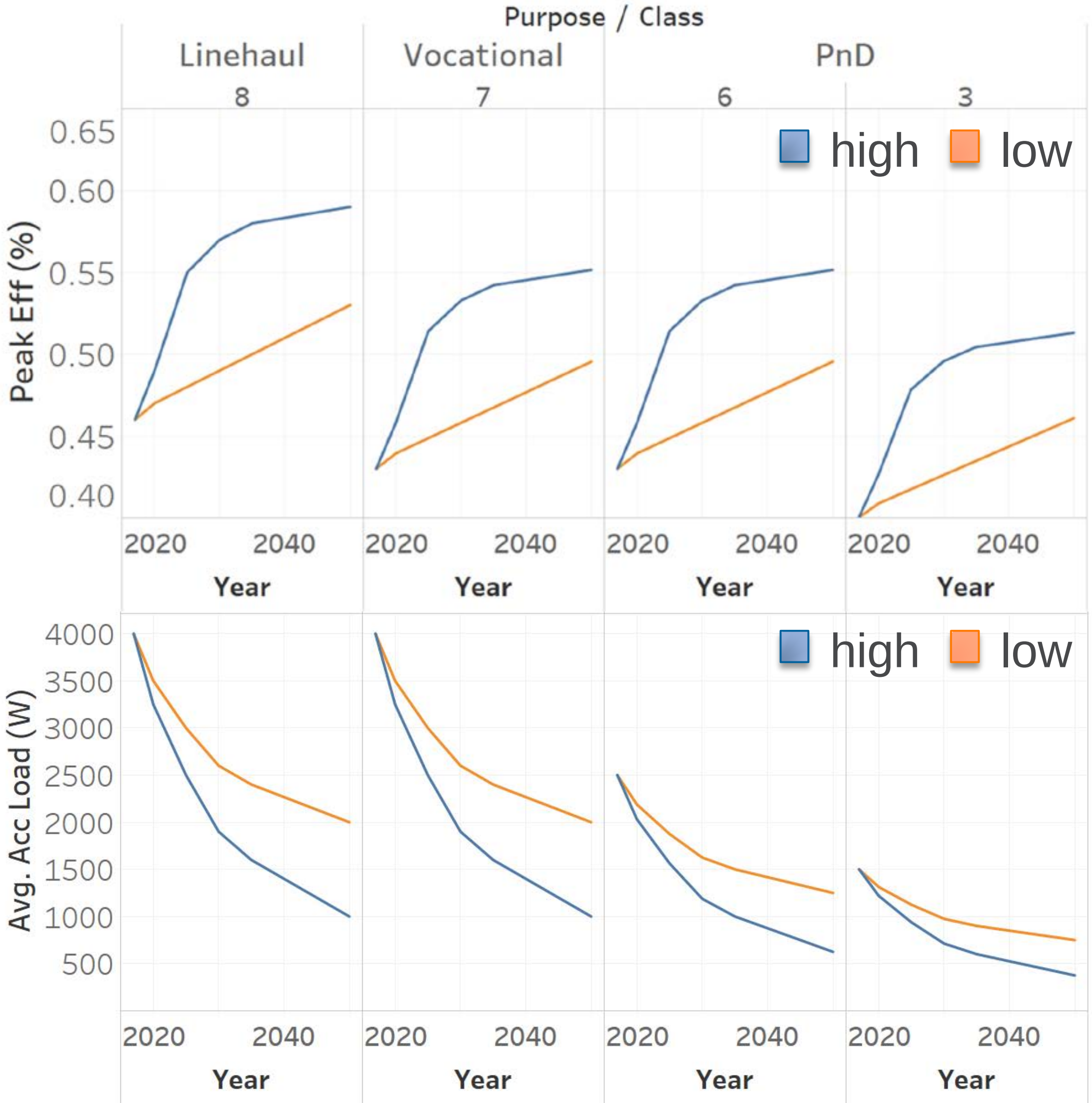


- Cd & Crr reductions achieved in ST1 is expected to be in class8 trucks by 2025
- Class 3 and 6 PnD : Delivery trucks may not see a big reduction in Cd. As many of the HD Aero improvement features are not applicable for this type of a body.
- Cd improvements are expected to increase the price of vehicles by \$1050 in HD, and by \$250 for class 3 vehicles
- Low Rolling Resistance tires have an incremental cost of \$14 per tire for Class3 vehicles, \$26 for class6 and \$37 for class 8 trucks

Ref: NHTSA, “Commercial Medium- And Heavy-Duty Truck Fuel Efficiency Technology Cost Study”, June 2015

Engine & Auxiliary Load Assumptions

5 to 10 Year Gaps are Expected between Lab Demonstrations and Production Readiness for Engine Technologies.



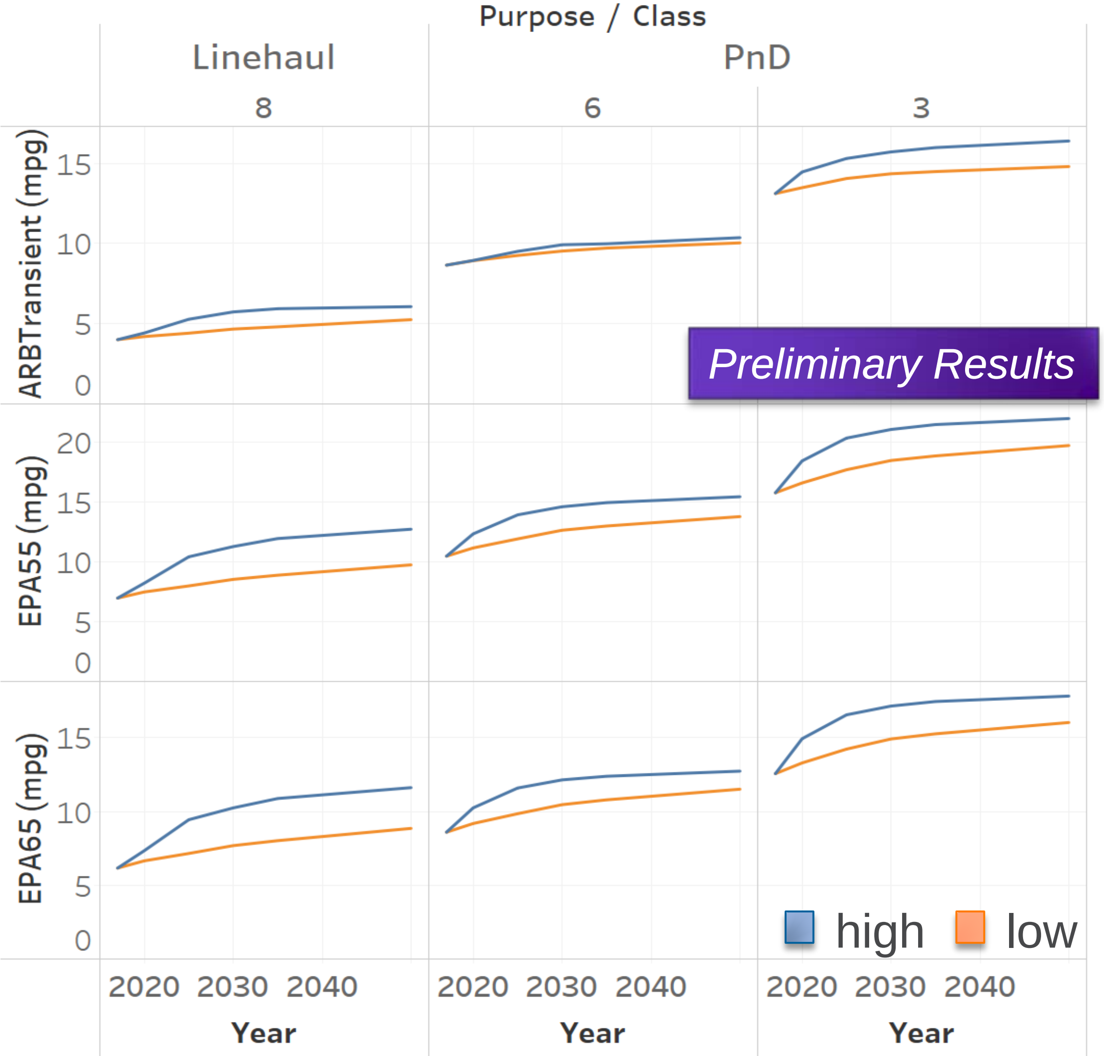
- Engines with technologies shown in ST1 & ST2 are expected in class8 trucks by 2020 and 2025 respectively.
- Engines developed based on 21CTP roadmap (57% demonstration in 2025) is expected in vehicles by 2030.

- Class 8 auxiliary loads too are based on the average values reported by ST1 teams.
- Class 3 and 6 values were taken from the EPA NHTSA assumptions for MDHD rulemaking process

Technical Accomplishments:

Process to Read Large Number of Assumptions, Define and Size Vehicles, as well as Run Simulations Developed and Tested.

- Preliminary runs show potential improvements for Class 3, 6 and 8 vehicles
- Data analysis process using Tableau is being developed.
- Class 8 results are consistent with improvements observed in ST1 program.



Response to Previous Year Reviewers' Comments

Comments Related to Vehicle Modelling Efforts from FY16 Review

- The reviewer suggested that the presenter consider the addition of electrification; for example, plug-in hybrid electric vehicles (PHEV) or fuel cell vehicles (FCV), for medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs).
  - *Medium & Heavy Duty Electrification has been the main focus in FY17-FY18*
- The reviewer said that Autonomie should continue to collaborate with industry and others to continue to seek good empirical input and review.
  - *Argonne's development team has regular interactions with multiple OEMs. Models and processes are improved based on feedback from them.*
  - *DOE funded projects where vehicles have been validated are*
    - *Supertruck, FOAs involving Class 2, Class 4 and Class6 delivery trucks*
  - *As part of non DOE funded projects*
    - *Autonomie team collaborated with 3 major OEMs to develop and validate vehicle models*
    - *Lessons learnt from these projects are imbued in Autonomie*
  - *21CTP, SmartWay & Supertruck programs also contribute to this effort*

Partnerships and Collaborations

- **Government Agencies**
  – DOE : VTO, FCTO
- **Industry**
  – Discussions with OEMs, suppliers
- **National Labs**
  – Market penetration tools (TRUCK, HTEMS)
  – Life cycle analysis tool (GREET)
- **Other agencies/organizations**
  – 21CTP, Energetics, IEA, AVERE, multiple universities…

Remaining Challenges and Barrier

Need a Formal Mechanism To Capture Industry Inputs On MD&HD Activities

- Current assumptions are based on
  - Lessons learnt from working with OEMs on various projects
  - Informal discussions with various OEMs & suppliers
  - Reports & roadmaps from DOE, 21CTP, EPA, NHTSA etc.
  - Field test reports from various agencies
- Developing a vehicle technology database for multiple vehicle classes to better understand current component technologies
- Considering purchasing databases and reports for technology overview and prediction

Next Steps & Proposed Future Research

Expand Powertrains Considered

- Medium & Heavy Duty
  - Develop cost estimation in Autonomie for technologies based on EPA & NHTSA’s regulatory impact analysis documents
  - Add additional hybrid powertrains
  - Evaluate vehicle technology benefits as per the “Technology Forecast”
  - Identify potential class/vocations for specific vehicle technologies (eg: Economic viability of hybrid powertrains on delivery trucks)
  - Refine class/vocation mix based on feedback
  - Add gasoline variants to class3 trucks
- Many MD&HD conventional models are already integrated to Autonomie.
  - More example vehicles will be added, as we define vehicles in this project.
- Integrate the sizing process to AMBER.

Summary

LD Study Complete, MD & HD Study on Track.

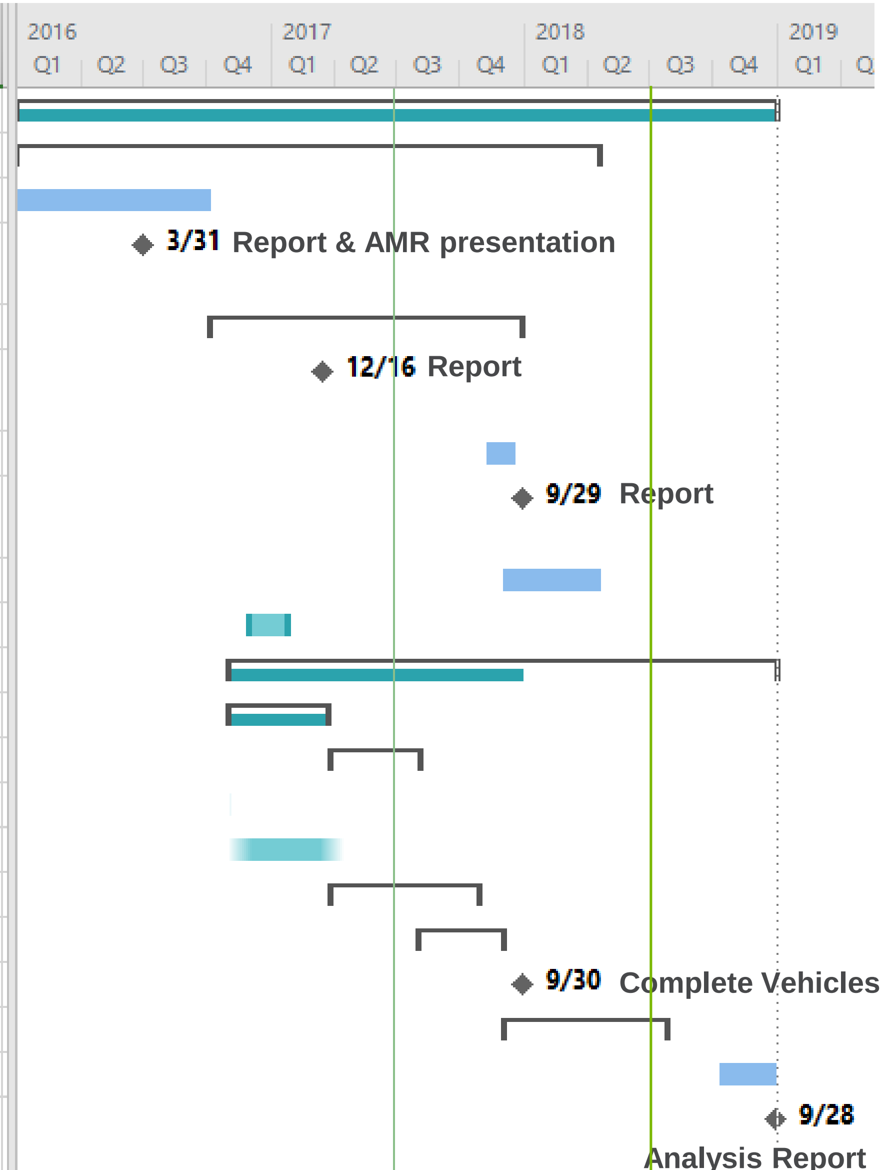
- Light Duty Activities
  - Final report is complete.

- Medium & Heavy Duty Activities
  - Baseline vehicles have been defined for 15 Medium & Heavy duty class & vocations
  - Automated powertrain sizing
  - EPA test procedure implemented for all vehicles.
  - Model accuracy validated against OEM and EPA data.
  - Technology sensitivity was verified against NHTSA reports.
  - Full technology forecast & preliminary results available.

BACKUP SLIDES

Project Milestones

	Task Name
1	**Simulations to Inform BaSce Analysis**
2	**Light Duty**
3	Simulation & Analysis
4	**Report: Impact of individual VTO technologies on real world cycles**
5	**Individual Technology Benefits**
9	**Report: Impact of VTO targets on Battery requirements**
10	LD BaSce analysis
11	**Report: Impact of individual VTO technologies on LD vehicles on the standard cycles**
12	updating models & processes for future runs
13	Migration of Models to new Autonomie
14	**Medium & Heavy Duty**
15	**Understand exisiting work**
22	**Analyzing EPA MDHD rulemaking efforts**
26	Identify Classes & Vocations
27	MD & HD Technology Forecast
28	**Vehicle Model Development**
36	**Sizing process**
39	Vehicle sizing for MDHD
40	**Simulation Analysis**
46	Analysis & Report
47	Report: Impact of vehicle technology improvement on MDHD vehicles

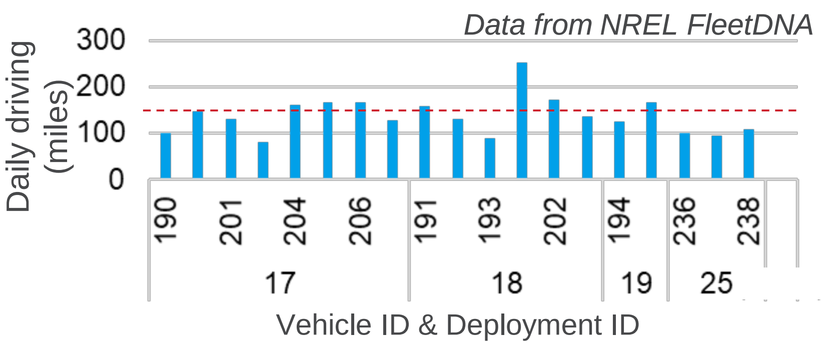


Process Verification:

Verifying Simulated Performance Tests Against Test Data

- Simulated performance estimates were verified against test data from ‘Altoona Bus Research and Testing Center’
- Acceleration and Grade performance matched with test data
- Cruise speed target is set at a minimum of 60mph for highway driving capability.

Performance Criteria for Transit Bus	Test	Simulation	Target
Cargo Mass (kg)	4000	4000	4000
Cruising Speed (mph)	50*	72	60
6% Grade Speed (mph)	30	29	29
0–30 mph Acceleration Time (s)	14.5	14.3	14.3
0–60 mph Acceleration Time (s)	NA*	66	66
Daily Driving Distance (miles)	NA	NA	150



- A new vehicle, with an electrified powertrain architecture, that matches this performance can be expected to perform the same functions as the baseline vehicle
- Driving Range is determined based on FleetDNA or VIUS data for each vocation

* The bus tested at Altoona was governed at 50mph. So test results involving higher speeds could not be verified.

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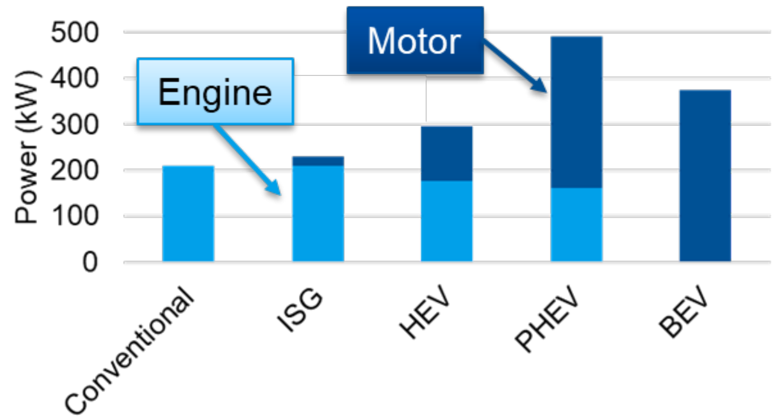
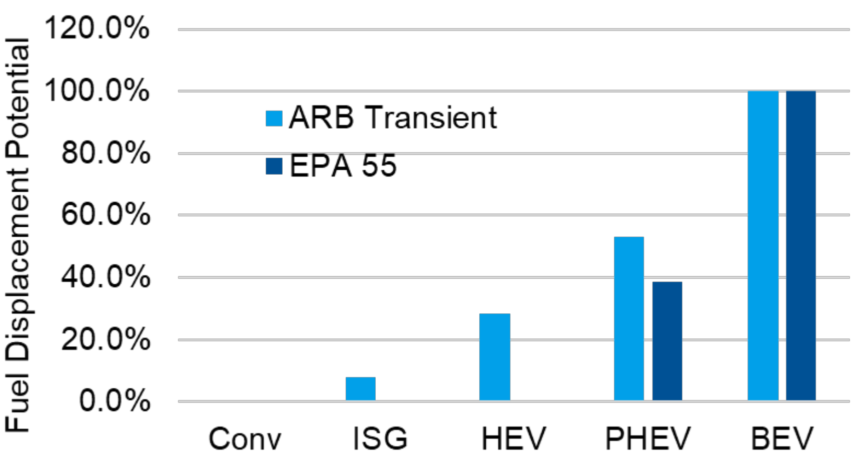
Sizing Results and Fuel saving potential of Hybrid Powertrains in Transit buses

- Electrified powertrains are heavier and needs more propulsion power. However, motor can help reduce the engine size.
- Mild and full hybrids obtain significant fuel savings in ARB Transient cycle. On highway driving, they have little impact.
- On highway driving, PHEVs and BEVs are needed to achieve any appreciable fuel savings





R.Vijayagopal, A.Vallet, A.Rousseau, "Fuel Consumption and Performance Benefits of Electrified Powertrains for Transit Buses", SAE WCX2018, Detroit 2018

Publications

- R.Vijayagopal, A.Vallet, A.Rousseau, “Fuel Consumption and Performance Benefits of Electrified Powertrains for Transit Buses”, SAE WCX2018, Detroit 2018