2016 EPA-NHTSA Modeling Workshop

MODELING METHODOLOGY FOR EPA GHG ANALYSIS

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Topics

1) **Modeling Overview and the Role of Technology Effectiveness**

2) **ALPHA Effectiveness Modeling –** Current and Future LD Vehicle and Powertrain Technologies

   a) **Background**

   b) **Engine/Vehicle Benchmarking & ALPHA Model Validation**
      - Component Data
      - Vehicle Operational Rules

   c) **Looking Forward**
      - Putting it all together into technology packages
      - Validation of a sample technology package

3) **OMEGA –** Use of effectiveness estimates in fleet compliance modeling

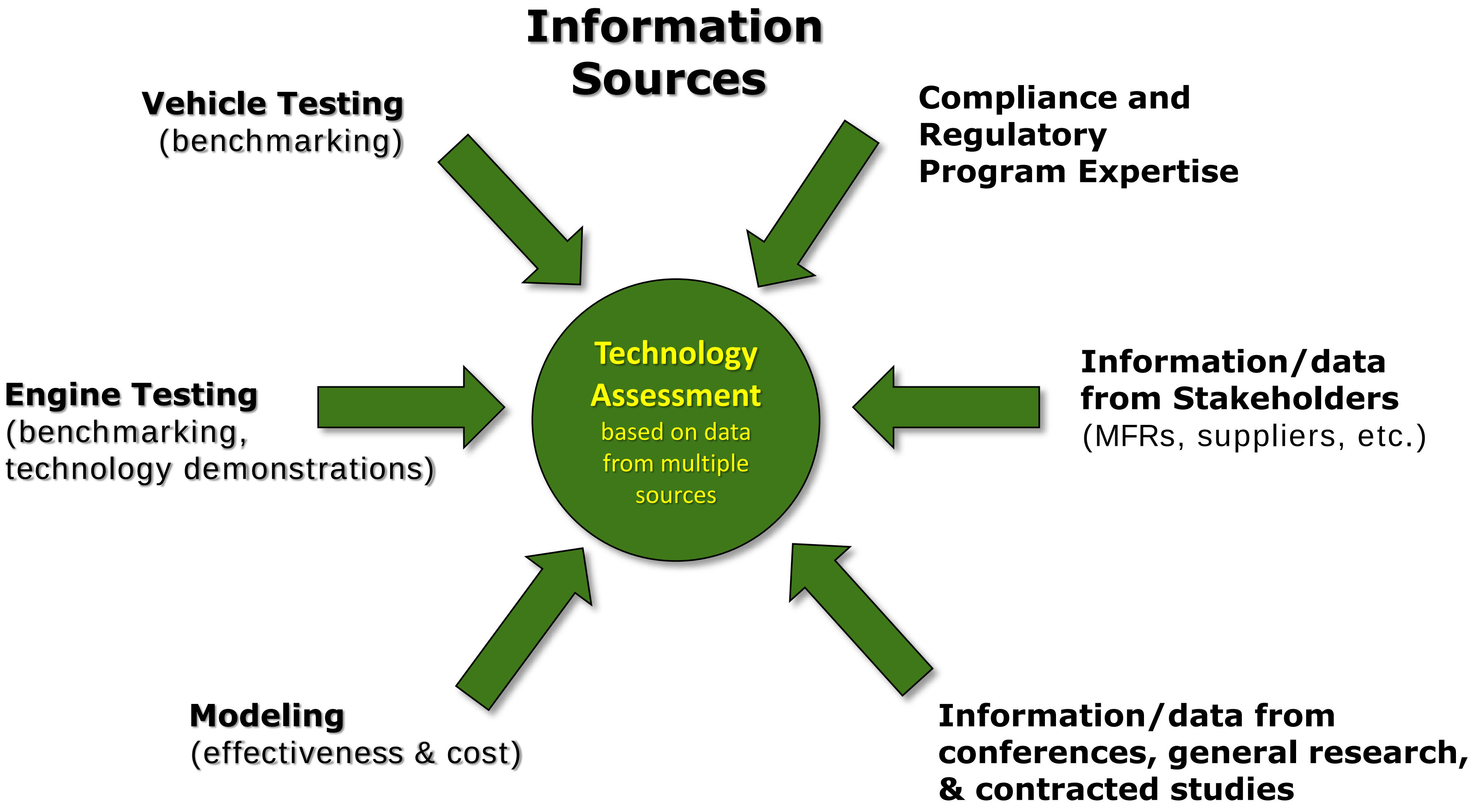
Background

- The 2017-2025 Light-Duty Greenhouse Gas rule requires EPA to conduct a Midterm Evaluation (MTE), in coordination with NHTSA and CARB, to assess the appropriateness of the MY 2022-2025 standards
- As part of this assessment, EPA will review the costs and effectiveness of technologies available to automobile manufacturers to meet the emission standards in MY 2022-2025

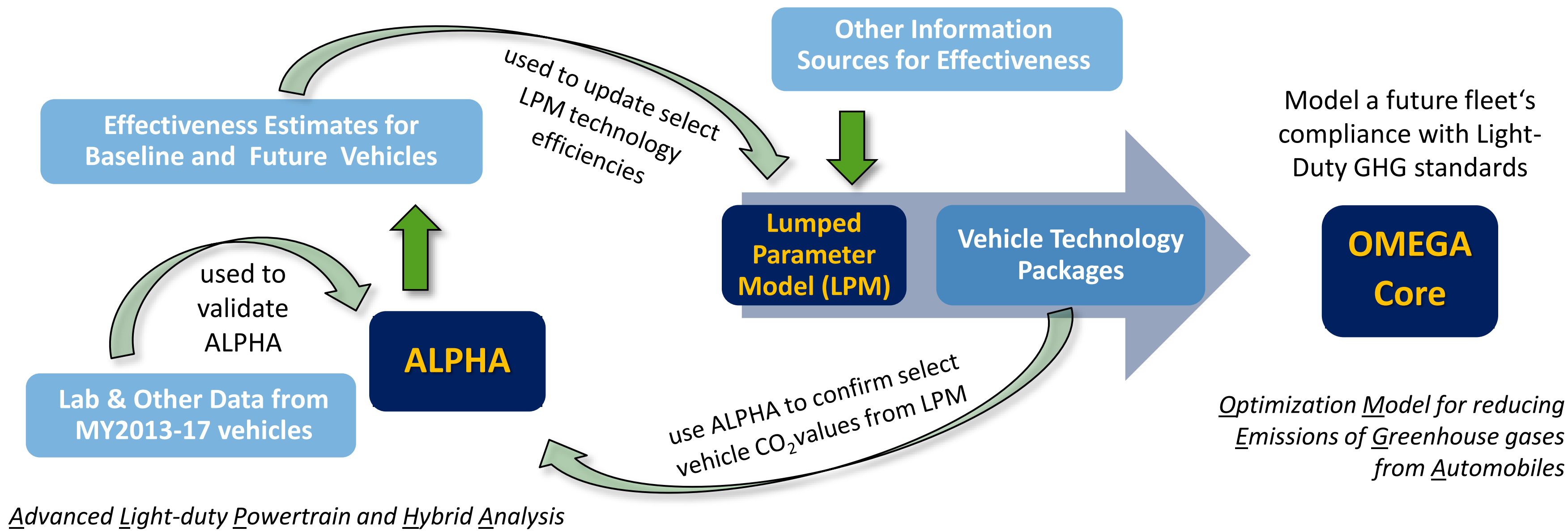
NOTE: This presentation focuses on the scientific <u>development</u> behind EPA's vehicle simulation and modeling, which is one tool we plan to use during the MTE.

****Data presented in this briefing are NOT MTE RESULTS.**

Technology Assessment Based on Multiple Sources of Information



Overall Modeling of Potential Compliance Pathways



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EPA's Advanced Technology Testing and Demonstration

EPA's National Vehicle and Fuel Emissions Laboratory – Part of EPA's Office of Transportation and Air Quality in Ann Arbor, MI

NVFEL is proud to be an ISO certified and ISO accredited lab
ISO 14001:2004 and ISO 17025:2005

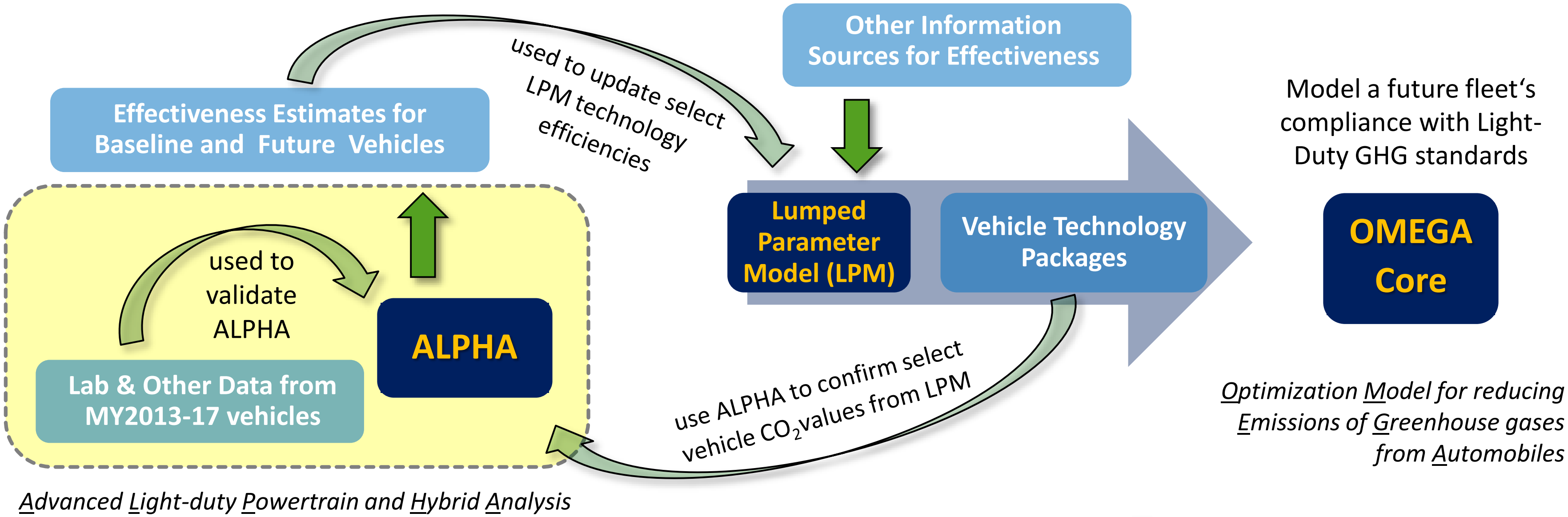
- NVFEL is a state of the art test facility that provides a wide array of dynamometer and analytical testing and engineering services for EPA's motor vehicle, heavy-duty engine, and nonroad engine programs which:
- Certify that vehicles and engines meet federal emissions and fuel economy standards
- Test in-use vehicles and engines to assure continued compliance and process enforcement
- Analyze fuels, fuel additives, and exhaust compounds
- Develop future emission and fuel economy regulations
- Develop laboratory test procedures
- **Research future advanced engine and drivetrain technologies (involving 20+ engineers – modeling, advanced technology testing and demonstrations)**

National Center for Advanced Technology (NCAT)

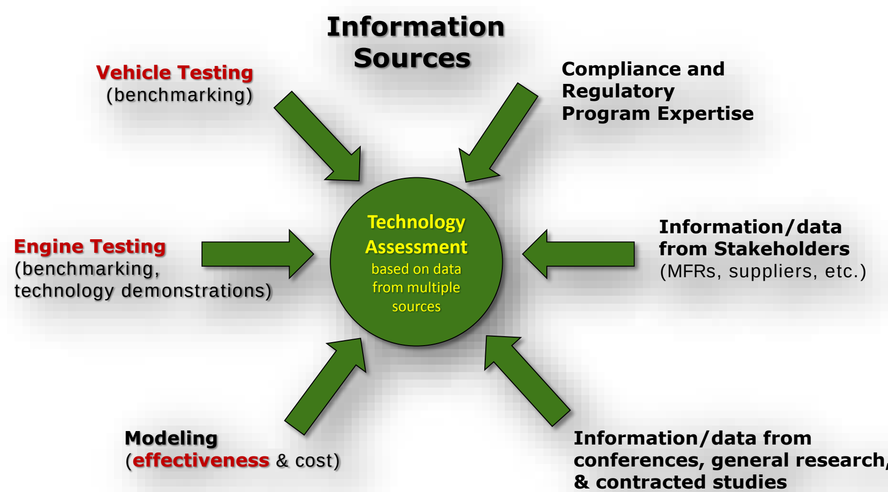
What is ALPHA?

- ALPHA is an Advanced Light-duty Powertrain and Hybrid Analysis tool created by EPA to estimate greenhouse gas (GHG) emissions from current and future light-duty vehicles.
- ALPHA is a physics-based, forward-looking, full vehicle computer simulation capable of analyzing various vehicle types combined with different powertrain technologies.
- ALPHA is used to assess the synergistic effects of vehicle technologies
- EPA has enhanced its ALPHA model with more detailed and recent vehicle and component level benchmarking data to better simulate operation of current and future vehicles
- ALPHA is EPA's tool for understanding vehicle behavior, effectiveness of various powertrain technologies and their greenhouse gas emissions
- ALPHA is not a commercial product
(e.g. there are no user manuals, tech support hotlines, graphical user interfaces, or full libraries of components)

ALPHA's Role in the Overall Modeling of Potential Compliance Pathways



- Data is obtained from multiple sources, including benchmarking lab data
- Data from <u>2013-2016 MY</u> vehicles has been used to calibrate and validate ALPHA
- ALPHA can look at multiple packages and multiple case studies simultaneously
- Combinations of the best available technologies can be used to make efficiency projections for future vehicles
- Going forward, test data and modeling results will be used to update LPM



ALPHA Development

- ALPHA is EPA's engineering tool to explore the impacts of current & emerging low-GHG technologies.
- EPA needed a model for HD Compliance anyway (GEM), so adding a LD model (ALPHA) could be done cost-effectively.
- EPA's objective in its rulemaking processes is to achieve the highest level of transparency and openness possible.
- Peer review of GEM/ALPHA has already begun:
  - GEM been peer reviewed by outside experts and by industry
  - A formal peer review of ALPHA will be completed before the draft TAR is released

Planned Vehicle and Engine Benchmarking

- Currently, there are ~20 conventional vehicle and engine test projects at various stages of completion. The items on the list were chosen based on our need to evaluate key technologies like:
  - Advanced naturally aspirated, down-sized boosted and diesel engines
  - Advanced automatic, dual-clutch and continuously variable transmissions
- The vehicle list shown is constantly evolving and subject to change. It is provided here to give a sense of the scope of technology currently being evaluated in our testing program. We reassess the vehicle list every 3-6 months.
- NCAT has tested enough new engine and vehicle technologies to begin using ALPHA to generate effectiveness data for future vehicles to compare with other sources of effectiveness data for the June 2016 Draft Technical Assessment Report (TAR).
- We are building an ALPHA vehicle simulation to combine the best-in-class technologies for conventional standard car and large truck classes – to estimate how far the industry has come so far, and to predict how far they should be able to go in the future.
- We plan to continue testing even more 2016 and 2017 vehicles and engines after the draft TAR is released, in order to strengthen EPA's analysis for the MTE.

Vehicle Component Benchmarking and Validations

			Conventional Vehicle	Engine	Transmission	Primary Reasons for Benchmarking
1	Turbo engine	car	2013 Focus (Euro)	1.6L I4 EcoBoost (Euro)	6MT	large volume turbo, VVT, EURO-cal efficiency map
2			2013 PSA	PSA 1.6L turbo	---	efficiency map
3			2015 Volvo S60 T5	2.0L I4 turbo	8AT	I4 with 8AT, start-stop
4			2016 Honda Civic	1.5L turbo	CVT	1.5L turbo, CVT
5			2016 Acura ILX	2.4L I4 turbo	DCT8 w/TC	DCT8 with torque converter
6		truck/SUV	2013 Escape	1.6L I4 EcoBoost	6AT	large volume turbo, VVT, US-cal efficiency map
7			2014 RAM 1500 EcoDiesel	3.0L V6 diesel (VM Matori)	8AT (845RE)	8AT
8			2015 Ford F-150	2.7L EcoBoost V6	6AT (same as GM 6L80)	next generation EcoBoost with VVT, integrated exhause manifold, twin-scroll turbo, start-stop, US-cal efficiency map
9	Naturally Aspirated engine	car	2013 Malibu Base	2.5L I4 GDI engine	6AT (6T40)	shift algorithm, transient fueling
10			2013 Chevrolet Malibu Eco	2.4L I4	6AT (6T40)	BAS operation, start-stop
11			2013 Jetta hybrid	1.4L I4	P2, DCT7	DCT operation, P2 hybrid operation
12			2013 Mercedes E350	ETEC diesel	7AT	diesel operation, 7AT
13			2013 Altima SV	2.5L I4	Jatco CVT8	CVT operation
14			2014 US Mazda 6	SkyActiv 2.5L I4	6MT	
15			2014 US Mazda 3	SkyActiv 2.0L I4, 13:1CR	6AT	advanced NA engine operation
16			2014 Dodge Charger 5-spd	3.6L V6	5AT (NAG1)	5-speed operation
17			2014 Dodge Charger 8-spd	3.6L V6	8AT (8HP45)	8AT to compare with 5AT with same engine
18		truck/SUV	2014 RAM 1500 HFE	3.6L V6	8AT (845RE)	8-speed operation
19			2014 Chevy Silverado 1500 2WD	4.3L EcoTec3 V6/V3	6AT (6L80 MYC)	cylinder deactivation, limited 6AT benchmarking
20			2015 BMW X5 xDrive 35d	3.0L I6 Diesel	8AT (845RE)	

OTAQ Publications Supporting ALPHA

2013 / 2014

1. SAE 2013-01-0808, "Development of Advanced Light-Duty Powertrain and Hybrid Analysis Tool", B. Lee, S. Lee, J. Cherry, A. Neam, J. Sanchez, E. Nam
2. SAE 2013-01-1470, "Modeling and Validation of Power-Split and P2 Parallel Hybrid Electric Vehicles", S. Lee, B. Lee, J. McDonald, J. Sanchez, E. Nam
3. SAE 2013-01-1539, "Modeling and Validation of Lithium-Ion Automotive Battery Packs", S. Lee, B. Lee, J. McDonald, E. Nam
4. SAE 2014-01-1863, "HIL Development and Validation of Lithium Ion Battery Packs," S. Lee, J. Cherry, B. Lee, J. McDonald, M. Safoutin

2015

1. SAE 2015-01-1266, "Downsized boosted engine benchmarking method and results," M. Stuhldreher, A. Moskalik, C. Schenk, J. Brakora, D. Hawkins, P. Dekraker
2. SAE 2015-01-0589, "Vehicle Component Benchmarking Using a Chassis Dynamometer," A. Moskalik, P. Dekraker, J. Kargul, D. Barba
3. SAE 15PFL-0373, "Effect of Current and SOC on Round-Trip Energy Efficiency of a Lithium-Iron Phosphate (LiFePO4) Battery Pack," M. Safoutin, J. Cherry, J. McDonald
4. SAE 2015-01-1140, "Benchmarking and Modeling of a Conventional Mid-Size Car Using ALPHA," K. Newman, J. Kargul, D. Barba
5. SAE 2015-01-1142, "Development and Testing of an Automatic Transmission Shift Schedule Algorithm for Vehicle Simulation," K. Newman, J. Kargul, D. Barba

2016

1. SAE 2016-01-0565, "Air Flow Optimization and Calibration in High-compression-ratio Naturally Aspirated SI engines with Cooled-EGR", S. Lee, C. Schenk, J. McDonald
2. SAE 2016-01-0662, "Fuel Efficiency Mapping of a 2014 6-Cylinder GM EcoTec 4.3L Engine with Cylinder Deactivation", M. Stuhldreher
3. SAE 2016-01-0910, "Estimating GHG Reduction of Combinations of Current Best-Available and Future Powertrain and Vehicle Technologies for a Midsized Car Using EPA's ALPHA Model", J. Kargul, K. Newman, P. DeKraker, A. Moskalik, D. Barba
4. SAE 2016-01-1007, "Benchmarking and Hardware-in-the-Loop Operation of a 2014 MAZDA SkyActiv 2.0L 13:1 Compression Ratio Engine", B. Ellies, C. Schenk, Paul DeKraker
5. SAE 2016-01-1141, "EPA ALPHA Modeling of a Conventional Mid-Size Car with CVT and Comparable Powertrain Technologies", K. Newman
6. SAE 2016-01-1142, "Investigating the Effect of Advanced Automatic Transmissions on Fuel Consumption Using Vehicle Testing and Modeling", A. Moskalik
7. SAE 2016-01-1143, "Modeling the Effects of Transmission Type, Gear Count and Ratio Spread on Fuel Economy and Performance Using ALPHA", K. Newman

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ALPHA Model Inputs and Data Processing

ALPHA inputs fall into one of four categories:

1. **Test Cycle**
   - Drive cycle speed (e.g., FTP, HWFET, US06)
2. **Vehicle Parameters**
   - Weight / inertia, road load, driveline type or vehicle class
3. **Component Data**
   - Engine fuel consumption map, torque curves
   - Transmission gear ratios, spin losses, efficiencies, torque converter specs
   - Accessory loads
4. **Vehicle Behavior**
   - Shift strategy, torque converter strategy, driver behavior, idle speed management, pedal map, other dynamic effects

Sample Model Validation – 2013 Malibu

Vehicle Information

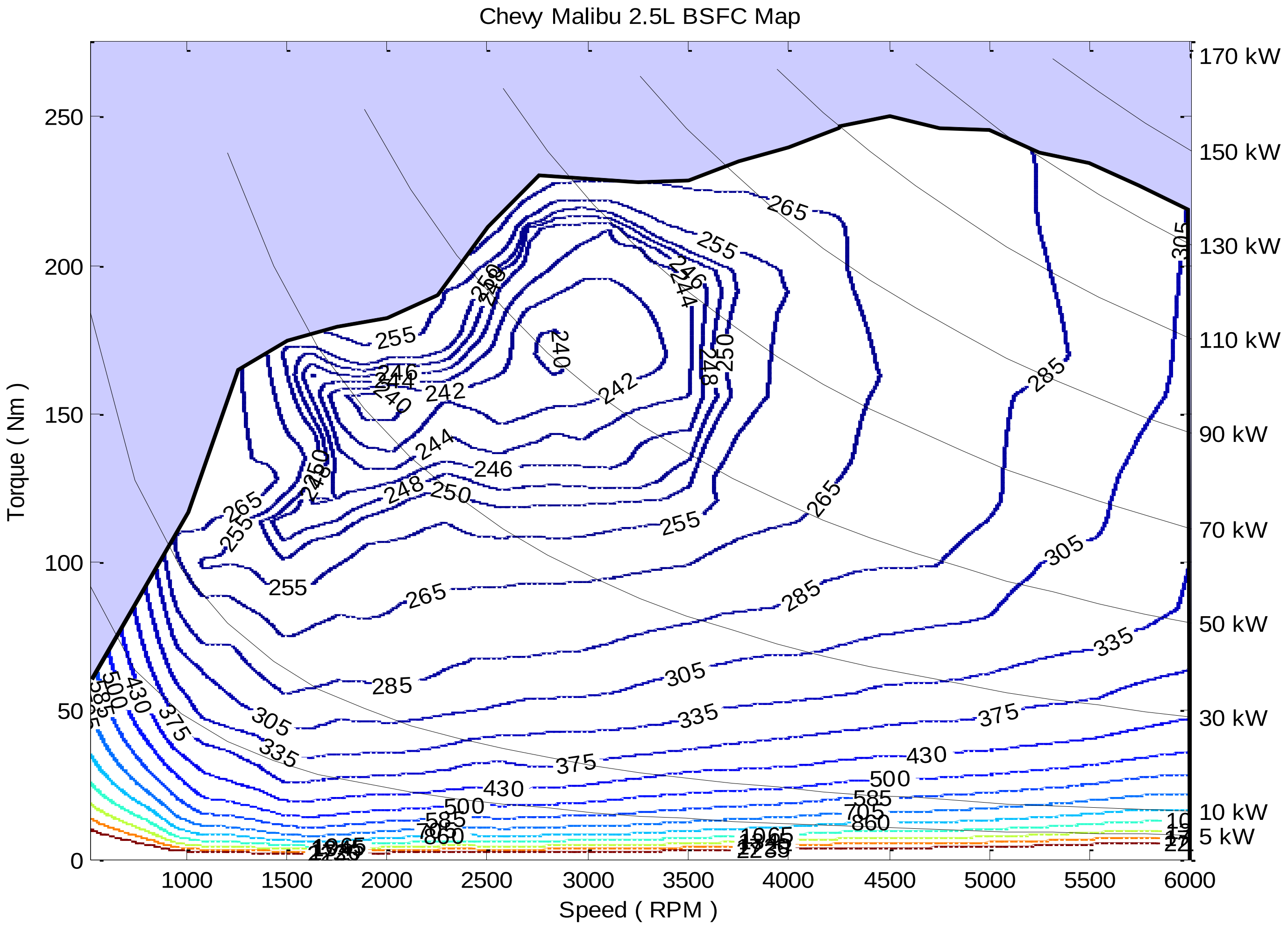
2013 Chevy Malibu 1LS

- 2.5L I4 GDI engine
- 6-speed automatic transmission
- *Non-Hybrid*
- 22 City / 34 Highway / 26 Comb

Chosen as representative of an average midsize car

SAE 2015-01-1140

Sample Model Validation
2.5L Engine BSFC Map

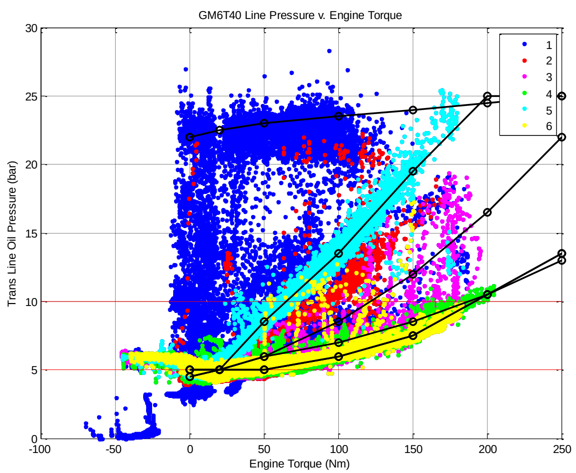


SAE Figure 10. Chevy Malibu 2.5L BSFC map (87 AKI E10 gasoline)

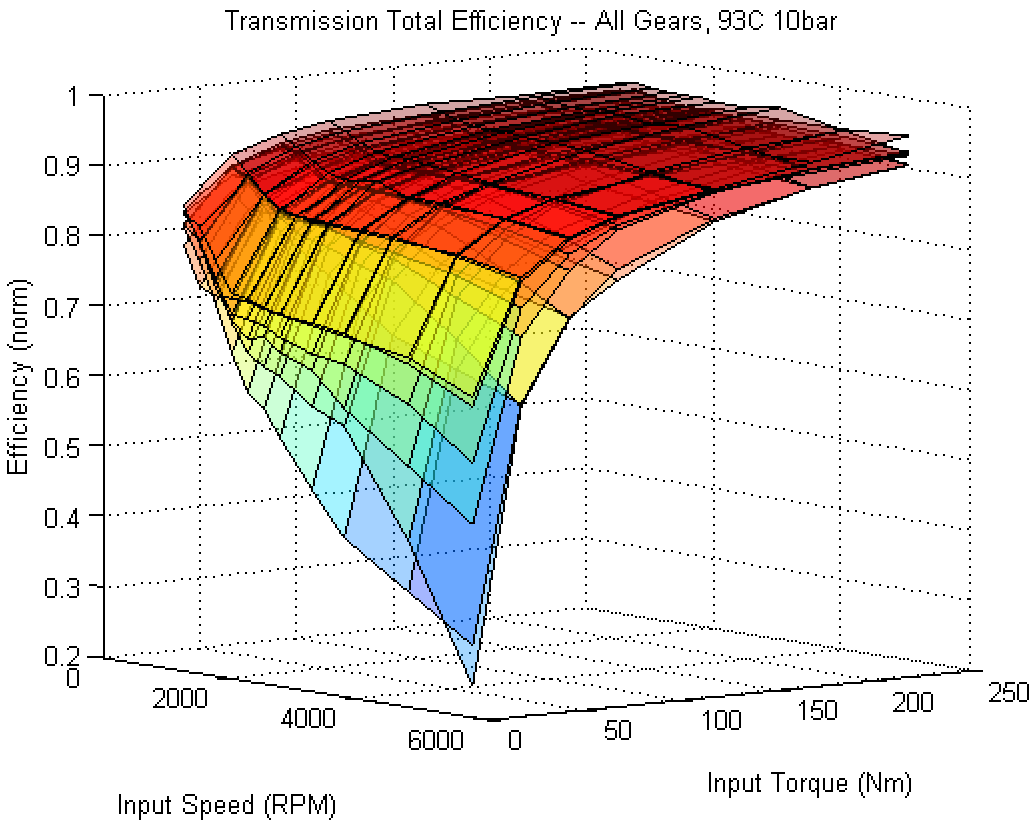
SAE 2015-01-1140

Sample Model Validation
Transmission Efficiency

Line pressure varies significantly during operation and exceeds the tested limits



SAE Figure 16. Transmission line pressure during vehicle operation



SAE Figure 6. Transmission efficiency data at 93 C and 10 bar line pressure

SAE 2015-01-1140

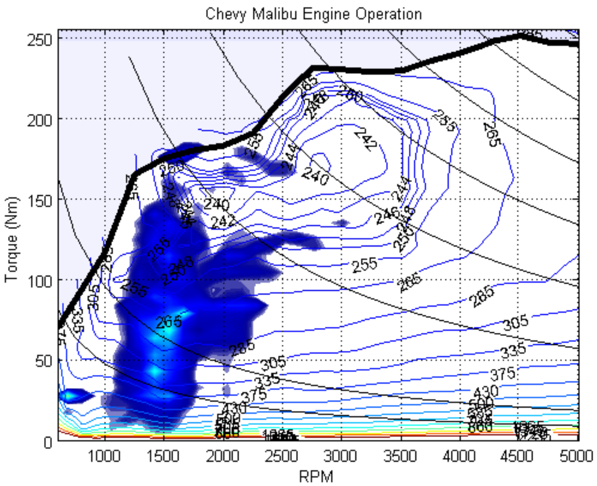
Sample Model Validation
Transmission Shift Strategy - ALPHAshift

- Automatic transmission technology has been advancing rapidly, both in terms of the number of gears available and the transmission’s overall efficiency
- Automatic transmission changes affect the greenhouse gas emissions of a vehicle as well as its drivability
- To support the midterm evaluation, EPA is modeling a wide variety of transmissions mated with a potentially wide variety of engines
- EPA has developed a transmission shift algorithm that dynamically calculates shift points during vehicle simulation based on user-defined parameters, driver demand and a cost map

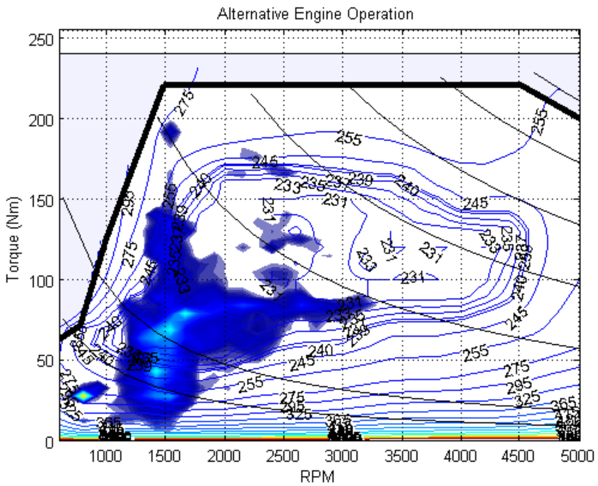
SAE 2015-01-1142

Sample Model Validation
ALPHAshift Results for Alternate Engine & Shift Strategy

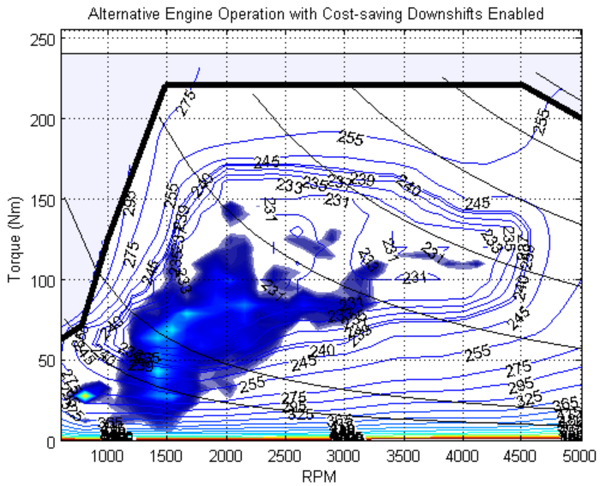
- Since the ALPHAshift algorithm calculates shift points dynamically it's possible to run different engines without being required to alter any shift parameters.



Baseline engine operation



An alternative engine with the same shift parameters



An alternative engine with cost saving downshifts enabled

SAE 2015-01-1142

Bridging the Gap Between a Simulation and a Real Vehicle – Accounting for All the Fuel Consumed

- The concern is often raised that vehicle simulation models will under-predict fuel consumption (over-predict fuel economy) if they overlook the fuel used to manage a vehicle's "overhead" functions, including extra fuel required for:
  - heavy transient operation
  - accessory loads (power steering, A/C, electronics, etc.)
  - torque transitions related to performance and drivability
  - special controls for emissions
  - NVH considerations
- One of the primary goals of EPA's extensive engine and vehicle benchmarking program is to identify appropriate modeling "rules" that can account for these vehicle operating requirements.
- We have imbedded these rules within ALPHA to account for some of the most significant extra use of fuel.

SAE 2015-01-1140

Bridging the Model Validation Gap
Operational Rules Applied to Malibu Validation

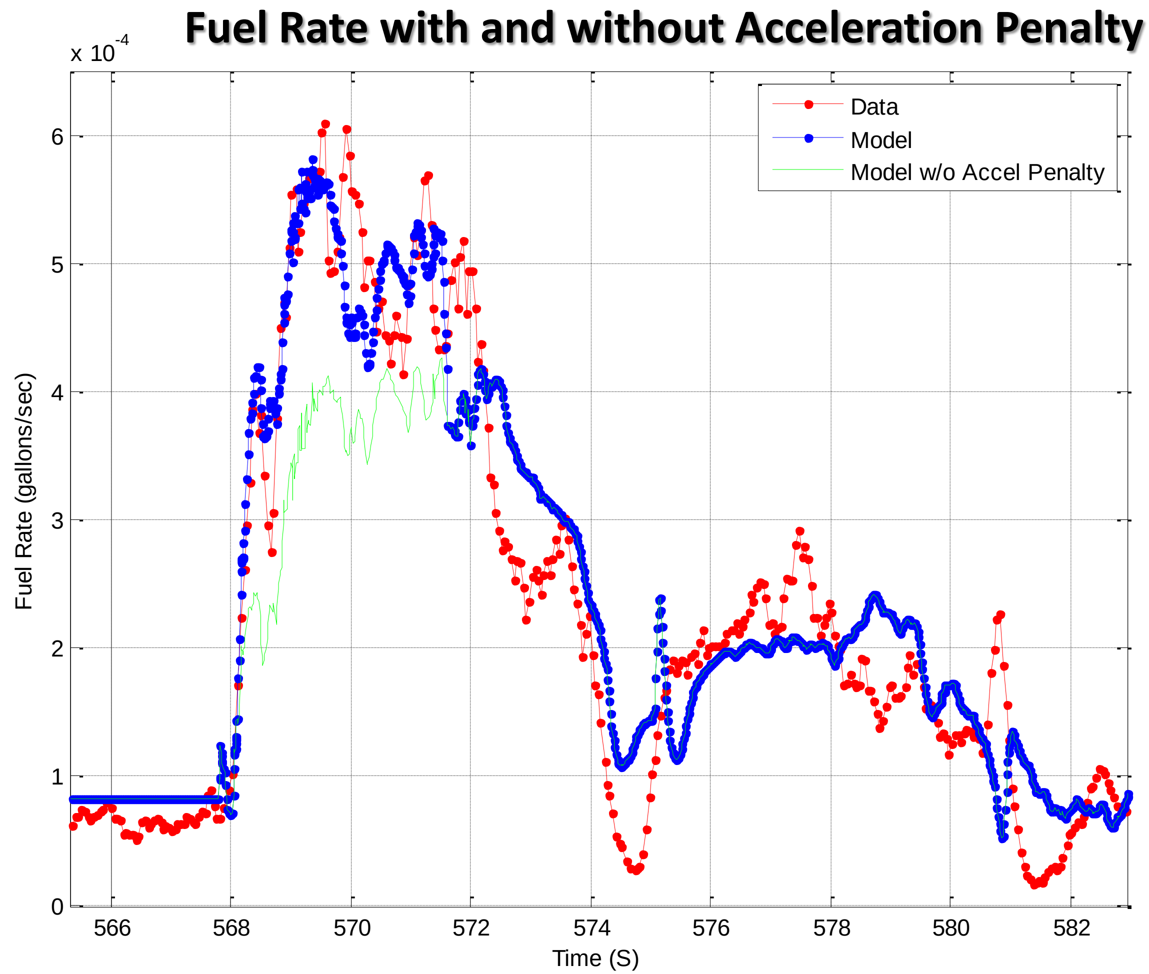
Determining Malibu's Operational Rules
1. Dynamic Fuel Effects – acceleration
2. Dynamic Fuel Effects – tip-in
3. Decel-Fuel-Cutoff – transitions during deceleration
4. Idle Speed Control
5. Torque Converter Slip
6. Variable Accessory Loads

Note: EPA plans to describe ALPHA's vehicle control rules further in upcoming SAE publications and the draft TAR

SAE 2015-01-1140

Bridging the Model Validation Gap
Dynamic Fuel Effects - Acceleration

- This figure shows the difference between the expected (green) and the measured (red) fuel rate
- The blue shows the model result including the acceleration-based fuel penalty
- This penalty is most obvious on the US06 or during transient torque converter slip



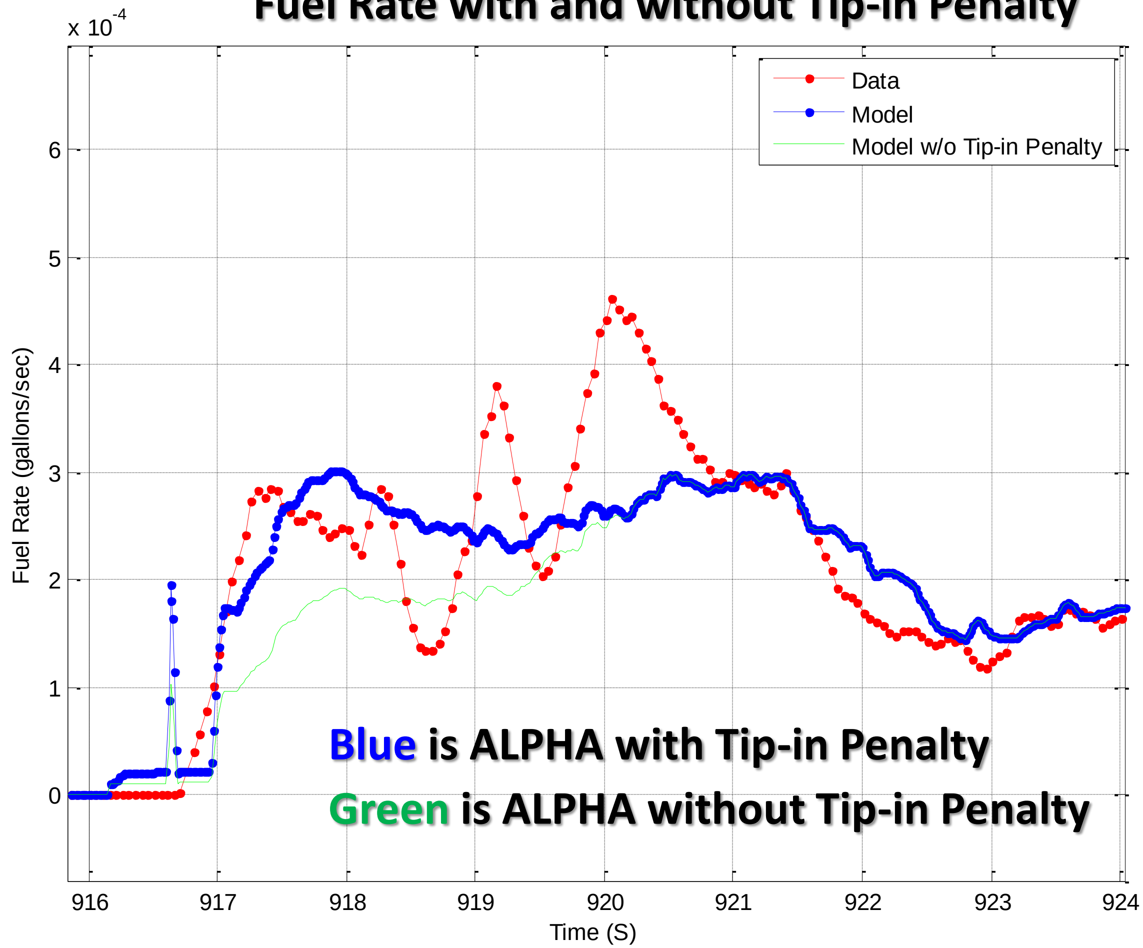
Blue is ALPHA with Acceleration Penalty
Green is ALPHA without Acceleration Penalty

SAE 2015-01-1140

Bridging the Model Validation Gap
Dynamic Fuel Effects - Tip-in

- This figure shows the difference between the expected (green) and the measured (red) fuel rate
- The blue shows the model result including the tip-in based fuel penalty
- This penalty occurs after operating in decel-fuel-cutoff for a minimum time

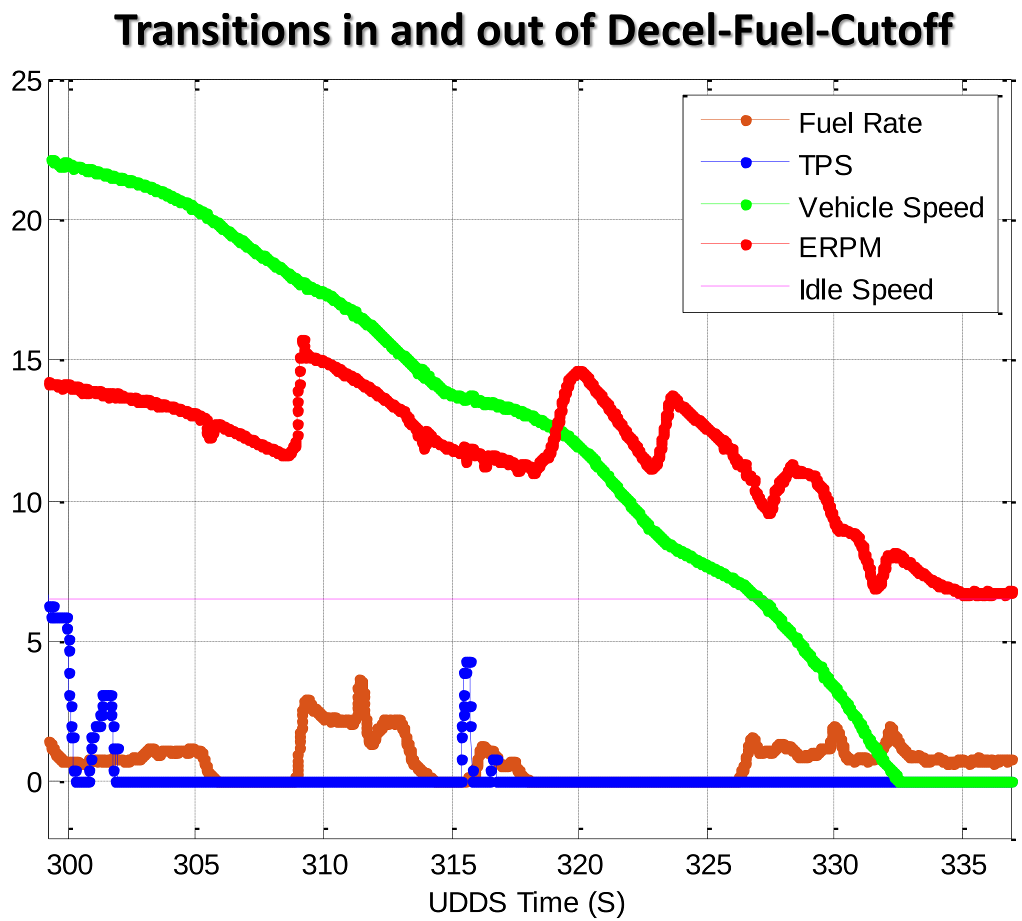
Fuel Rate with and without Tip-in Penalty



SAE 2015-01-1140

Bridging the Model Validation Gap
Decel-fuel-cutoff Transitions during Deceleration

- During deceleration events, the engine appears to transition in and out of decel-fuel-cutoff (DCFCO) even though the throttle position sensor (TPS) is at zero

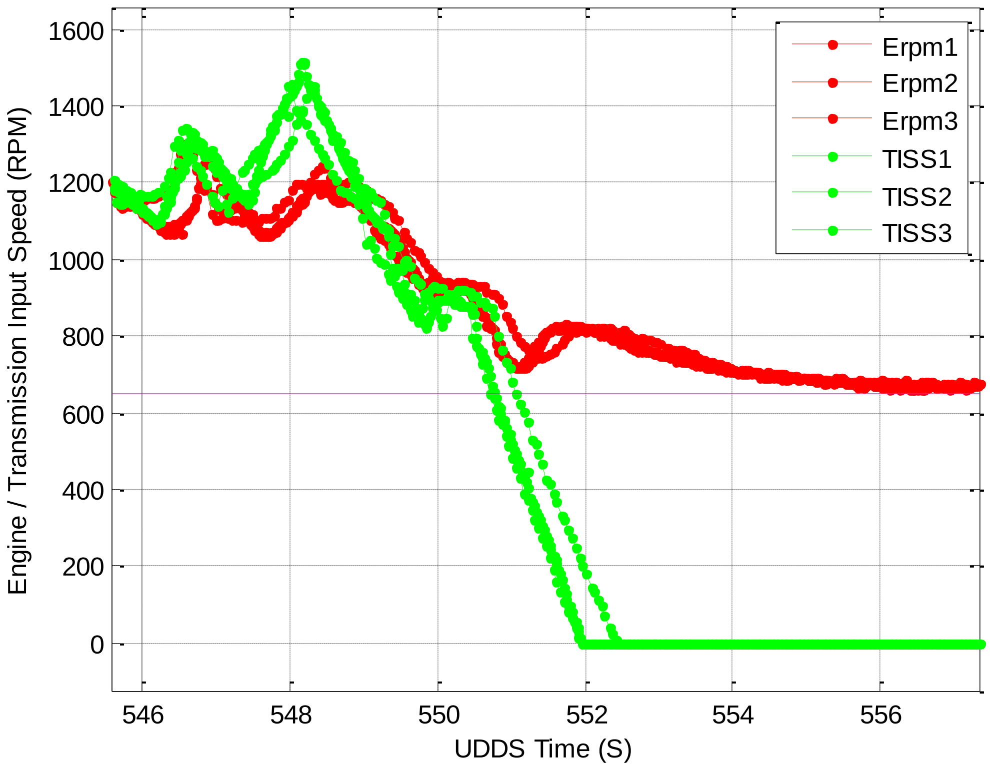


SAE 2015-01-1140

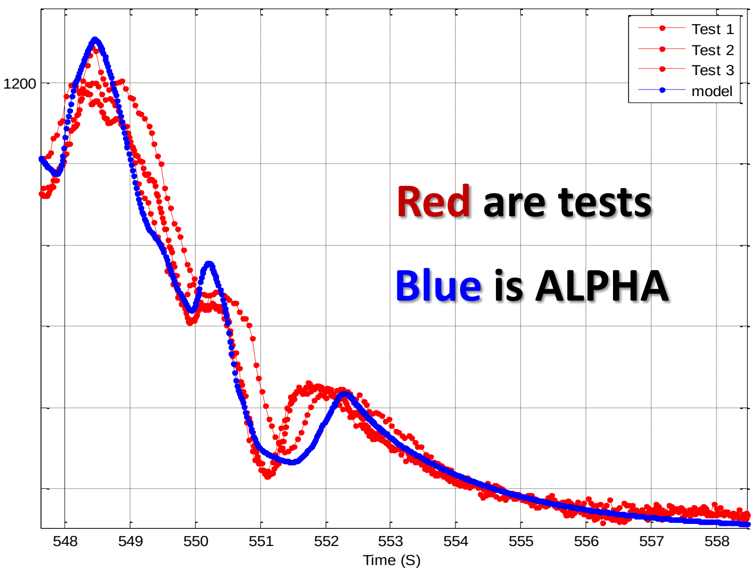
Bridging the Model Validation Gap
Idle Speed Control

- The idle speed control shows some interesting behaviors at low vehicle speed

Engine Idle Flare at Low Vehicle Speed



Engine Idle Flare at Low Vehicle Speed



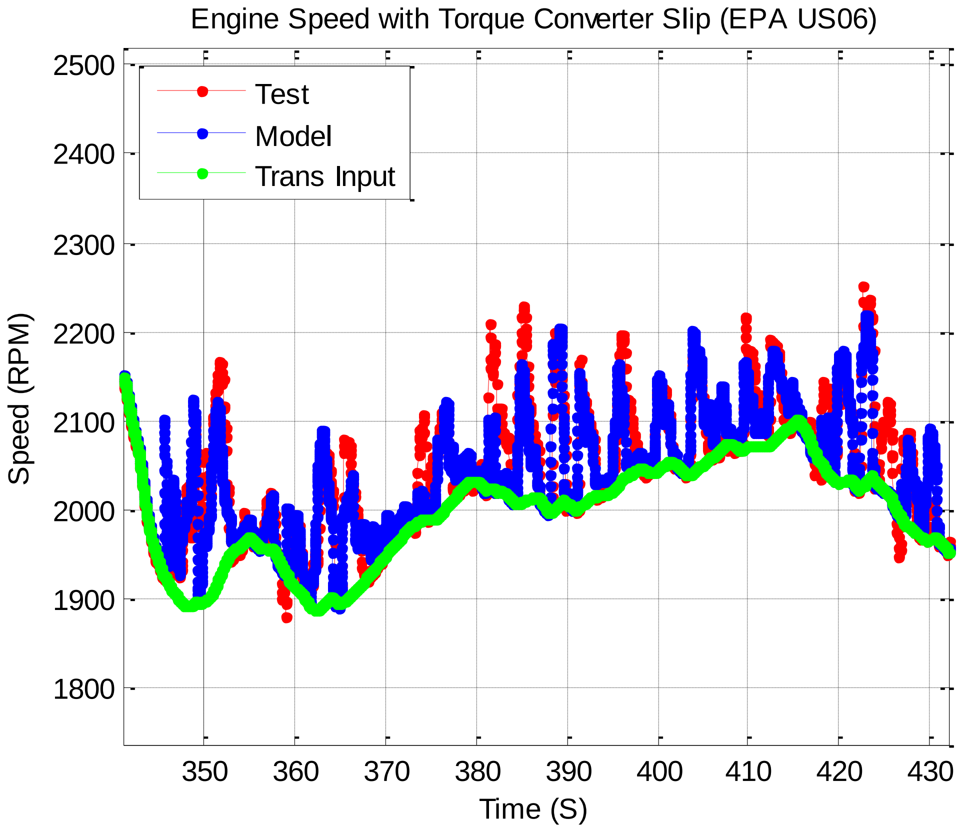
Engine idle flare at low vehicle speed, the vehicle decelerates through 3 MPH at about 551.4 seconds

SAE 2015-01-1140

Bridging the Model Validation Gap
Torque Converter Slip

Engine Speed with Torque Converter Slip (EPA US06)

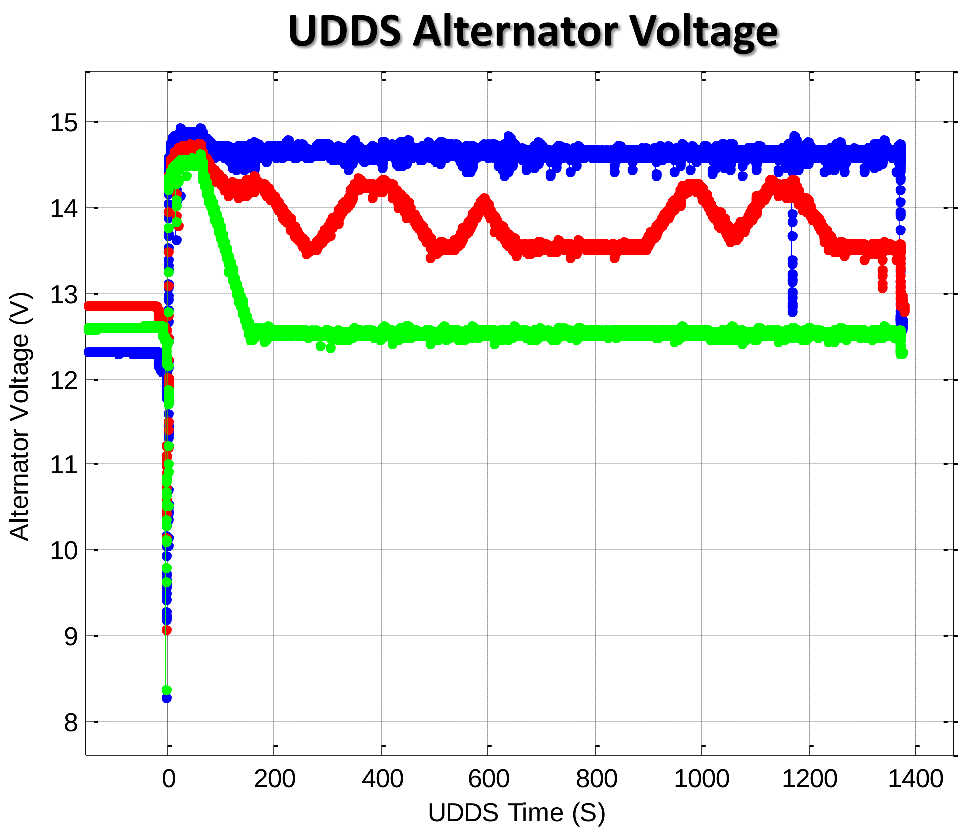
- Our original model only implemented a very simple “lockup” strategy
- It was updated to allow for limited-slip operation

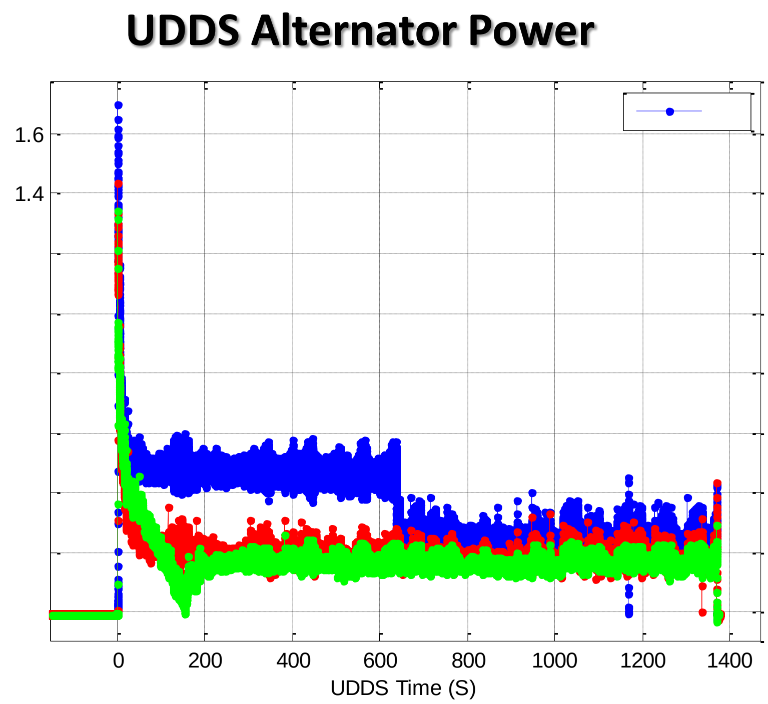


SAE 2015-01-1140

Bridging the Model Validation Gap
Accessory Loads Vary

- Charts show variability of alternator voltage and power over 3 different “hot” UDDS tests

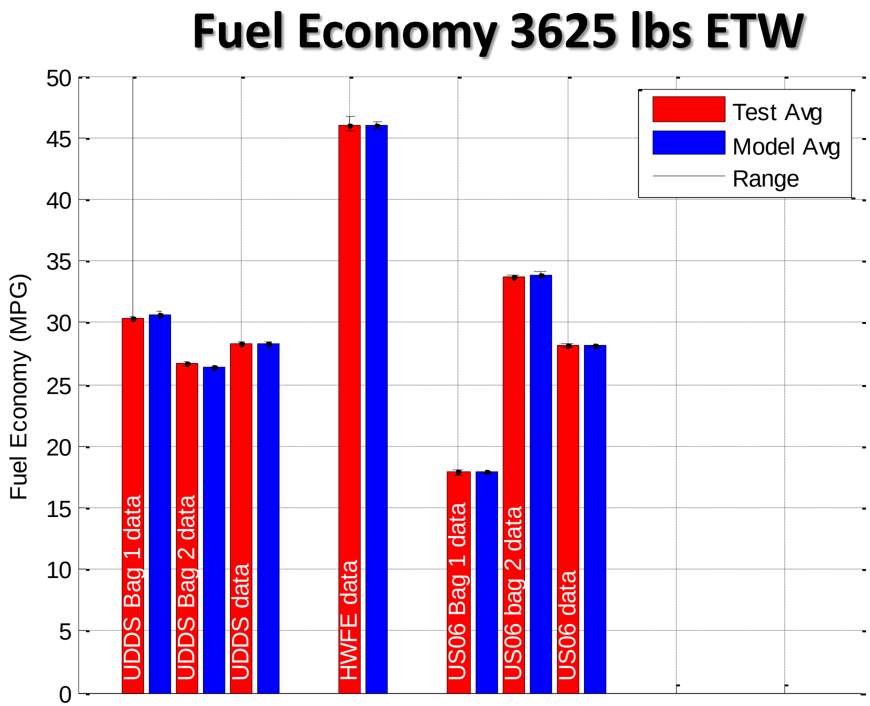


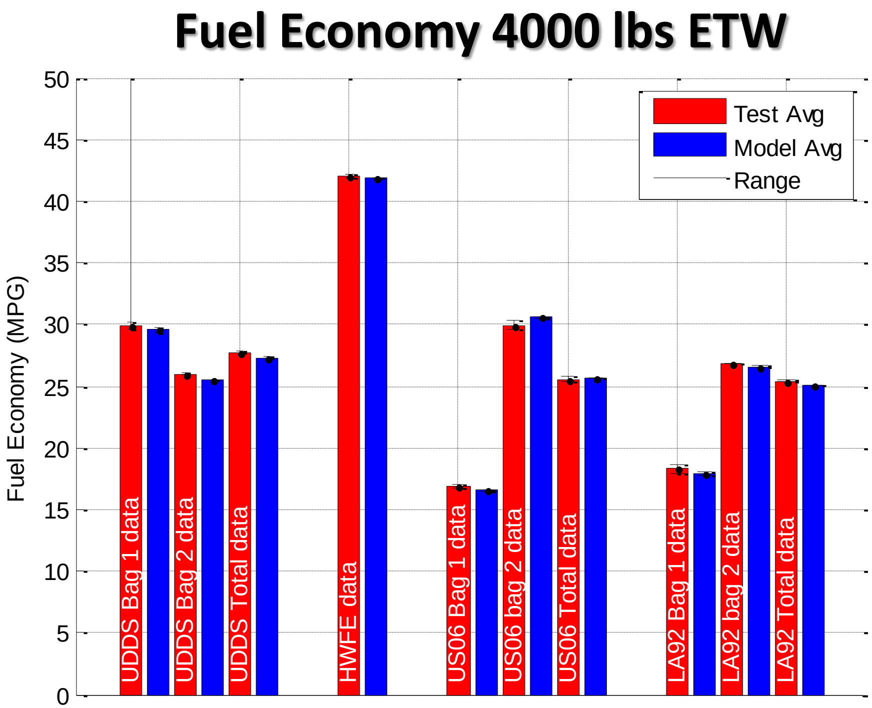


Within ALPHA, accessory loads are modeled as a constant average load

SAE 2015-01-1140

Sample Model Validation
Fuel Economy Results





Test	Average Test MPG	Average Model MPG	Error %
UDDS Phase 1	30.40	30.69	0.95
UDDS Phase 2	26.66	26.39	-0.99
HWFET	45.96	45.92	-0.10
US06 Phase 1	17.88	17.84	-0.22
US06 Phase 2	33.70	33.86	0.49

Test	Average Test MPG	Average Model MPG	Error %
UDDS Phase 1	29.87	29.55	-1.10
UDDS Phase 2	26.01	25.55	-1.75
HWFET	42.03	41.91	-0.28
US06 Phase 1	16.84	16.54	-1.78
US06 Phase 2	29.96	30.60	2.15
LA92 Phase 1	18.40	17.92	-2.61
LA92 Phase 2	26.84	26.57	-1.02

SAE 2015-01-1140

2013 Malibu Validation Conclusion

- A 2013 Chevy Malibu was benchmarked at a vehicle and component level and the test data was imported into the ALPHA model
- The results of the ALPHA model simulation compared well with the results of vehicle testing at two different test weights and road loads conducted at different laboratories with different drivers (within +/- 3%)
- Many valuable lessons were learned and will be applied to current and future validation exercises

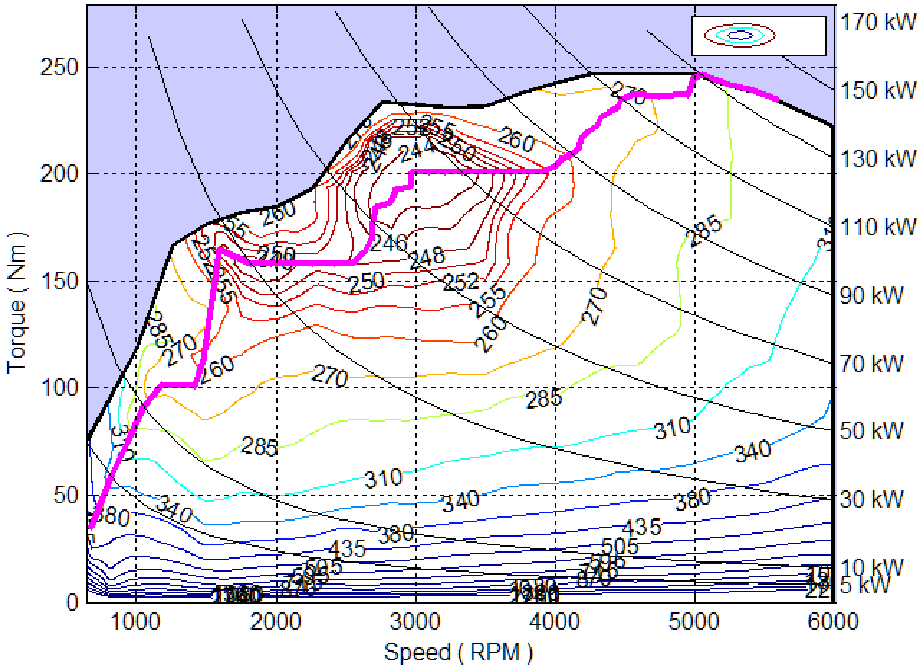
Sample Model Validation – 2013 Altima/CVT

- EPA benchmarked a 2013 Nissan Altima with a continuously variable transmission (CVT) to help us build a new version of ALPHAshift called "ALPHAshift-CVT".
- Because EPA did not have data for the Altima's Jatco CVT8 transmission, we used CBI data from another manufacturer's CVT which allowed us to build the ALPHAshift-CVT module.
- The validation work uses "comparable" powertrains as modeling inputs.

ALPHAshift-CVT

- Since we did not have a fuel map for the Altima's 2.5L engine, for this validation exercise it was necessary to use a BSFC map from a suitable "proxy engine".
- We generated target CVT ratios during model simulation, similar to ALPHAshift for step-gear transmissions but with fewer parameters.
- We tried to stay on the optimal BSFC line with a minimum RPM constraint.

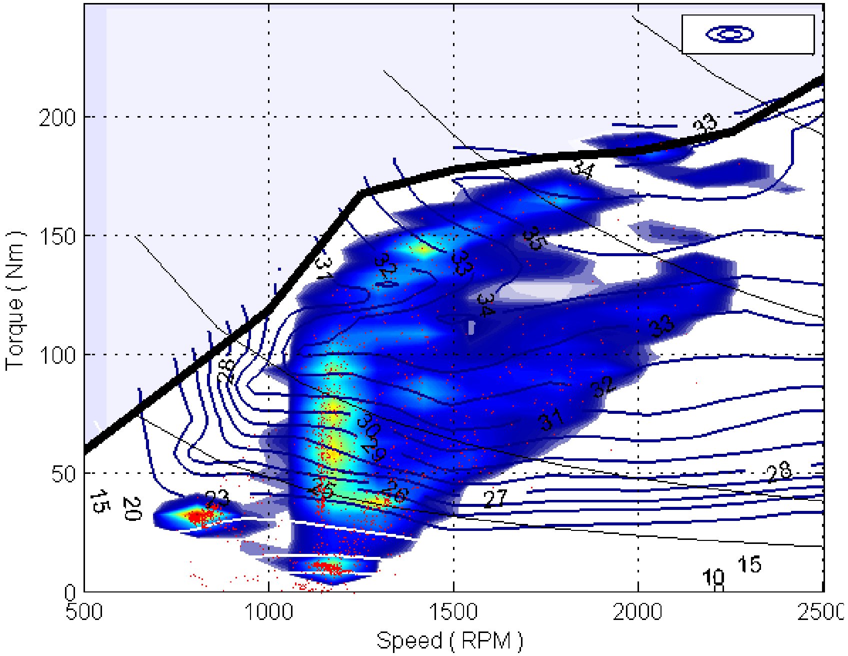
Proxy Engine BSFC (g/kW*hr)



Comparison with Altima data

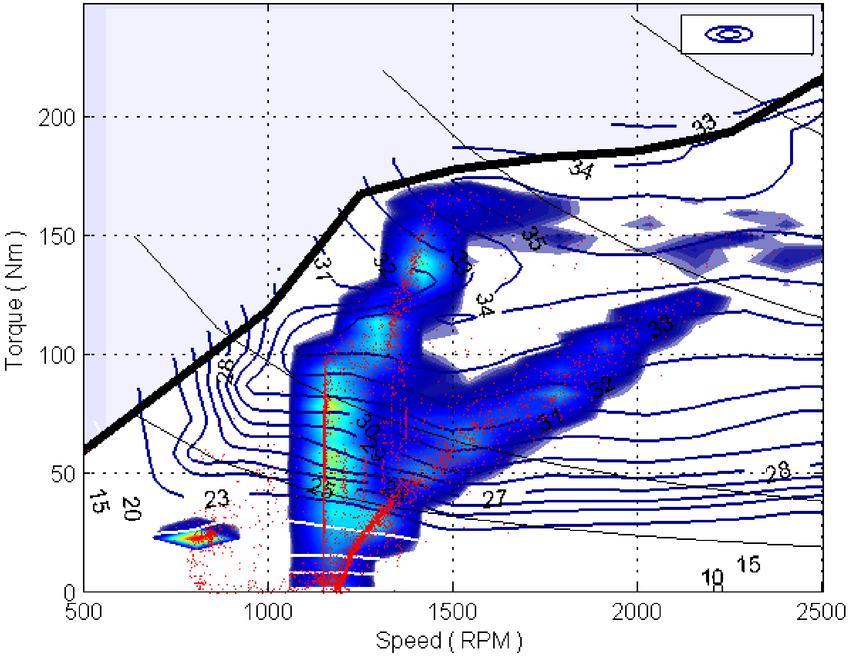
- Overall comparable on UDDS cycle

Vehicle Test Engine Operation on UDDS



Altima data

Model Engine Operation on UDDS

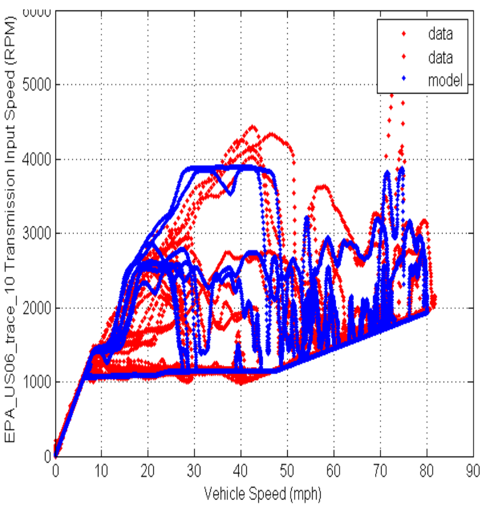


ALPHA data

Comparison with Altima data

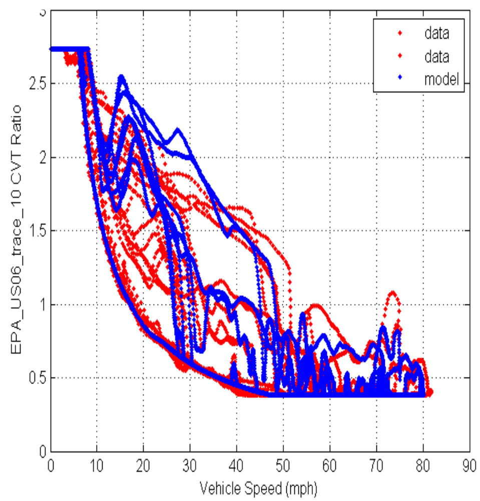
- Overall comparable on US06 cycle

US06 Transmission Input Speed v. Vehicle Speed



Transmission Input Speed

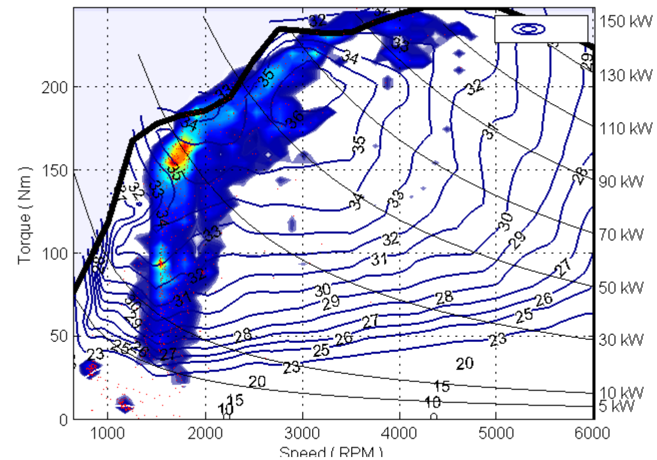
US06 CVT Ratio v. Vehicle Speed



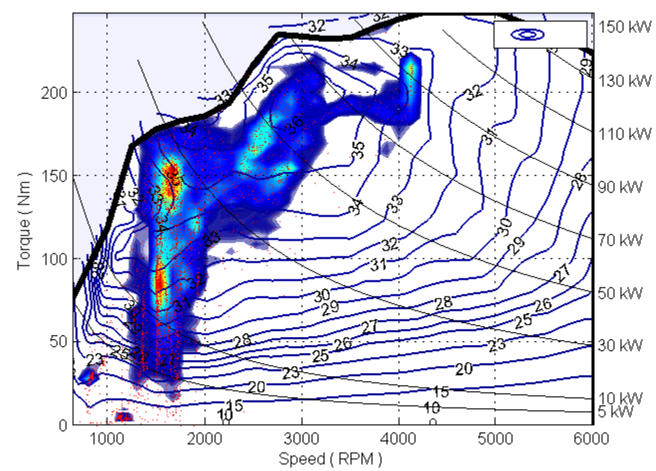
CVT Ratio

Red are tests
Blue is ALPHA

Altima Engine Operation on US06



ALPHA Engine Operation on US06

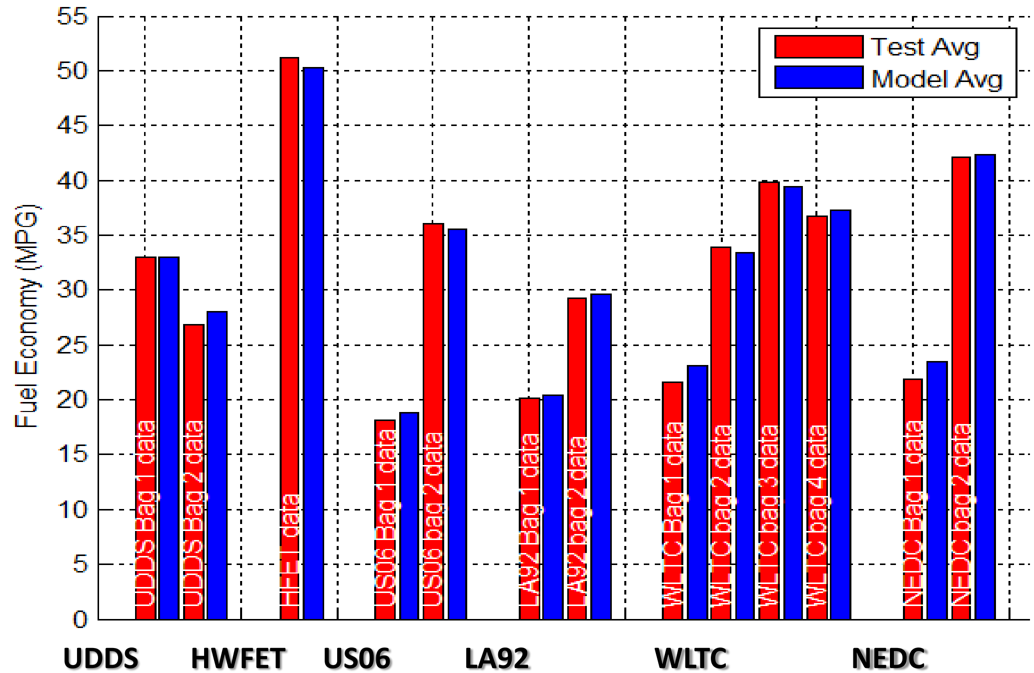


Fuel Economy

Fuel economy results were good across a wide range of drive cycles

Drive Cycle	Average Test MPG	Average Model MPG	Error %
UDDS Phase 1	33.0	33.0	0.1%
UDDS Phase 2	26.8	28.1	4.6%
HWFET	51.1	50.3	-1.6%
US06 Phase 1	18.1	18.8	3.8%
US06 Phase 2	36.1	35.5	-1.6%
LA92 Phase 1	20.1	20.4	1.6%
LA92 Phase 2	29.3	29.6	1.0%
WLTC_c3 Phase 1	21.7	23.0	6.3%
WLTC_c3 Phase 2	34.0	33.4	-1.9%
WLTC_c3 Phase 3	39.8	39.5	-0.9%
WLTC_c3 Phase 4	36.8	37.2	1.2%
NEDC Phase 1	21.9	23.4	7.2%
NEDC Phase 2	42.1	42.5	0.9%

Fuel Economy of Altima Tests and ALPHA Modeling



ALPHA MPG modeling results using modified engine map and transmission with ALPHAshift-CVT and observed lockup strategy

Red are Altima tests **Blue is ALPHA modeling**

Altima/CVT Validation Conclusions

- Comparable “proxy” powertrain approach yielded reasonable results
- ALPHAshift-CVT provides a reasonable strategy at least for this vehicle
  - More parameters may be required for future vehicles, depending on behavior (e.g. step-gear emulation)
- As part of our normal quality control process, we met with the company who provided CVT data to discuss the results and confirm we correctly applied the data within ALPHA.
- This will be the subject of a paper to be presented at the 2016 SAE World Congress (SAE 2016-01-1141).

Topics

1) **Modeling Overview and the Role of Technology Effectiveness**

2) **ALPHA Effectiveness Modeling –** Current and Future LD Vehicle and Powertrain Technologies
   a) **Engine/Vehicle Benchmarking & ALPHA Model Validation**
      - Component Data
      - Vehicle Operational Rules
   b) **Looking Forward**
      - Putting it all together into technology packages
      - Validation of a sample technology package

3) **OMEGA –** Use of effectiveness estimates in fleet compliance modeling

Technology Packaging Matrix
"Putting It All Together"

This matrix run is for illustrative purposes only to explain the matrix methodology, and does NOT feed directly into future MTE analyses.

StdCAR Matrix → 1080 Vehicle Packages

3 Engines:

- **Baseline** - Camry 2.4L I4 engine from the 2010 Ricardo analysis for LD GHG Federal Rulemaking (FRM)
- **2014 NA -** Mazda SkyActiv 2.0L I4 engine with 13:1 compression-ratio
- **Future TDS –** 24 bar down-sized turbo engine with cooled EGR from the 2010 Ricardo analysis for LD GHG Federal Rulemaking (FRM)

5 Transmissions:

- **2008 AT5 –** parameters from vehicle testing
- **2013 AT6 –** GM6T40, parameters from vehicle testing
- **2014 AT8 –** FCA845RE, parameters from EPA trans stand testing
- **Future AT8 gen3 –** constructed using data from paper published by ZF
- **Future damp DCT8 –** constructed using DCT7 data provided by a supplier

4 reductions of Mass:

- **Base (0% reduction)**
- **5% reduction**
- **10% reduction**
- **15% reduction**

3 reductions of Aerodynamic resistance (Cd):

- **Base (0% reduction)**
- **10% reduction**
- **20% reduction**

3 reductions of Rolling Resistance (Crr):

- **Base (0% reduction)**
- **10% reduction**
- **20% reduction**

2 reductions from 12-volt Start-Stop:

- **Base (0% start-stop)**
- **100% start-stop**

Be Cautious When Comparing Technology Effectiveness Values from Different Sources

Benchmarking and modeling results are only one source of data measuring technology effectiveness, and should be compared to data from other sources.

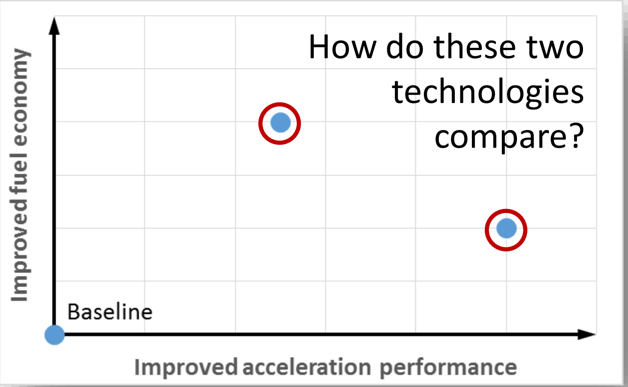
When comparing our data to a quoted outside reference like, "*Our new engine provides a 10% improvement in fuel efficiency***"…**

1. **Units Matter** – the percentage increase in fuel economy is not the same as percentage decrease in fuel consumption (25% increase in FE is a 20% reduction in fuel used)
2. **Vehicle Performance Matters** – do the vehicles being compared have equivalent performance (acceleration, towing, etc.), or not?
3. **Application Sequence Matters** – the order of applying technologies matters because different technologies may target the same losses (due to negative component synergy effects)
4. **Baseline Matters** – the percentage decrease in fuel consumption from a aerodynamic drag reduction of 2% will be different when applied to a 300 g/mi baseline vehicle than to a 200g/mi vehicle.
5. **Maturity Level Matters** – do components (e.g., engines/transmissions) being compared have the same generational or maturity level?
6. **Drive Cycles Matter** – technology has varying effects when measured on warm UDDS cycle vs. cold FTP vs. NEDC vs. US combined cycle

Technology Effectiveness:
Fuel Consumption and Performance

Problem Statement:

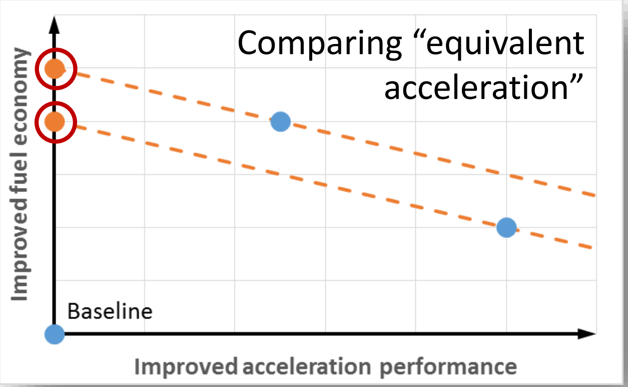
- Many fuel consumption reduction technologies decrease required wheel power, increase available engine power, or deliver power to wheels more efficiently
- If applied blindly, these technologies will reduce fuel consumption while also improving acceleration performance
- How do we "fairly compare" technologies that affect both fuel consumption and acceleration performance?



> **NAS 2011:** ***"Objective comparisons of the cost-effectiveness of different technologies for reducing FC can be made only when vehicle performance remains equivalent."***

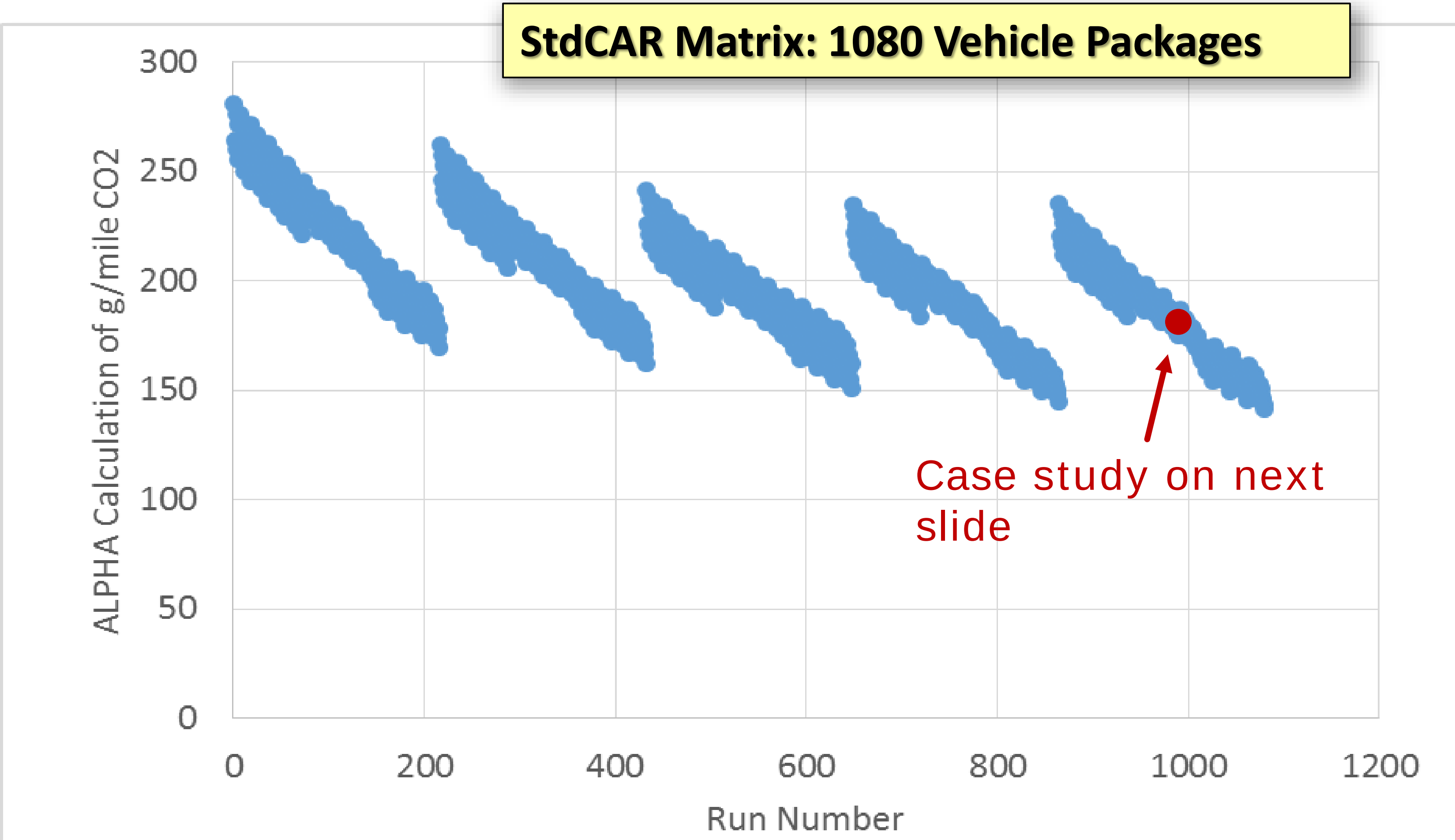
ALPHA's Current Approach:

- Reduce engine size to attain equivalent acceleration performance



Technology Packaging Matrix
Preliminary results

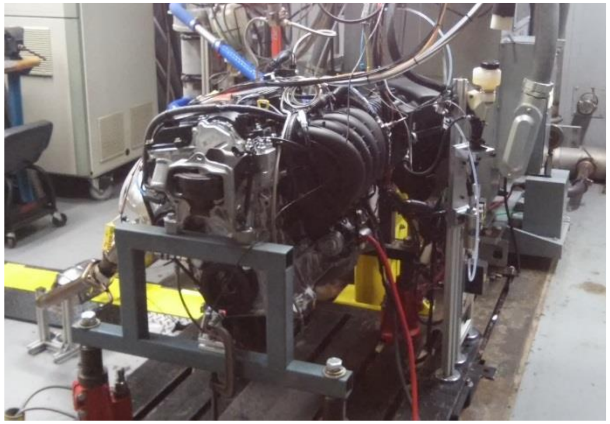
This matrix run is for illustrative purposes only to explain the matrix methodology and does NOT feed directly into future MTE analyses.



Validation of a Sample Technology Package
Replicate a modeling run in the test cell

Simulate a hypothetical mid-size vehicle with 2.0L Skyactiv-G in the test cell

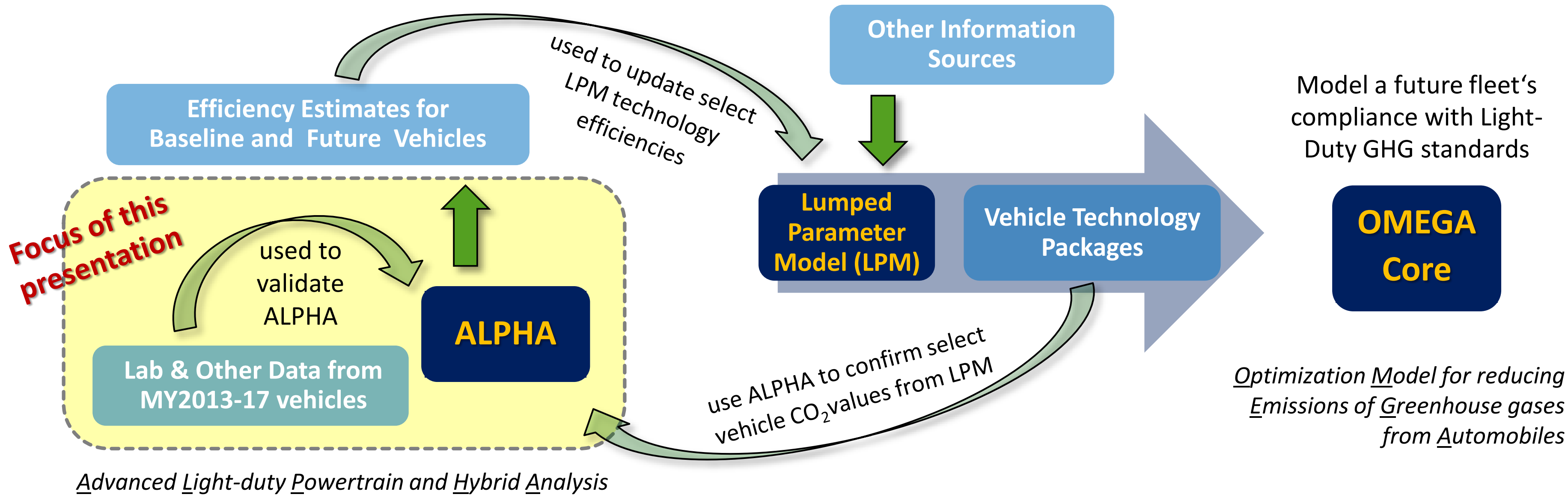
- Simulated chassis drive cycles using an engine dyno w/ Hardware-in-Loop (HIL) version of ALPHA
- Validated baseline test results with certification results and chassis test data from a 2014 Mazda3
- HIL w/ALPHA allows evaluation with different powertrains and/or road load conditions
- Applied advanced ZF 8HP50 8-sp AT and 12V start/stop
- Applied 2 levels of road load reduction
  - **L1:** 10% mass↓, 20% RR↓, 20% aero drag↓ (~2025 FRM analysis)
  - **L2:** 15% mass↓, 30% RR↓, 25% aero drag↓ (sensitivity analysis)



	Cycle	Total Fuel (g)	Idle Fuel (g)	Adjusted Fuel (g)	FE (mpg)	g/mi CO2
HIL L1	FTP (total)	257.9	12.8	245.1	43.0	206.7
	HWFE				64.5	137.7
	Combined				50.6	175.6
HIL L2	FTP (total)	247.6	12.2	235.4	44.3	200.8
	HWFE				67.1	132.4
	Combined				52.3	170.0

The HIL test results suggest that this *hypothetical* vehicle has potential to reach these levels with the existing 2.0L Skyactiv engine.

Wrap Up – ALPHA Process Summary



- Data is obtained from multiple sources, including benchmarking lab data
- Data is used to calibrate and validate ALPHA modeling
- ALPHA can look at multiple packages and multiple case studies simultaneously
- Combinations of the best available technologies can be used to make efficiency projections for future vehicles
- Going forward, test data and modeling results will be used to update LPM

Topics

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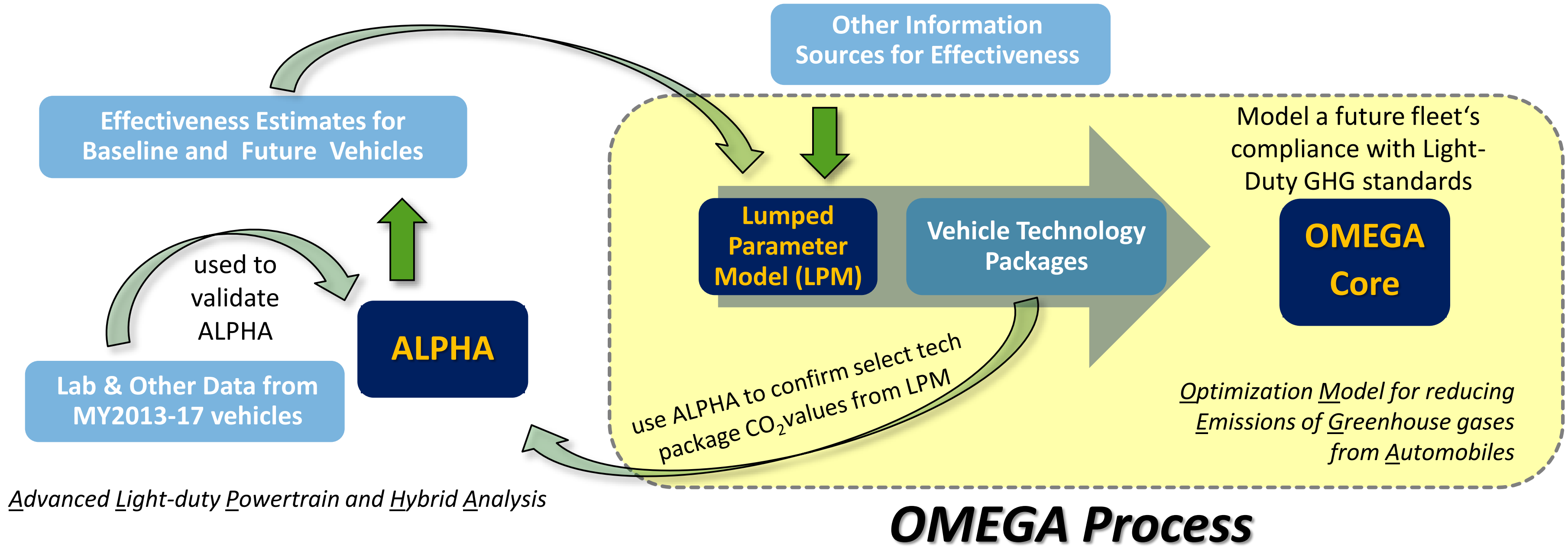
3) **OMEGA –** Use of effectiveness estimates in fleet compliance modeling

OMEGA's Role in the Overall Modeling of Potential Compliance Pathways



Purpose

- Determine the cost-minimizing pathway of adding technology to vehicles in order to achieve regulatory compliance with Greenhouse Gas standards.
- Technology costs and achieved emissions levels for the car and truck fleets of each manufacturer

OMEGA Process: Design and History

History

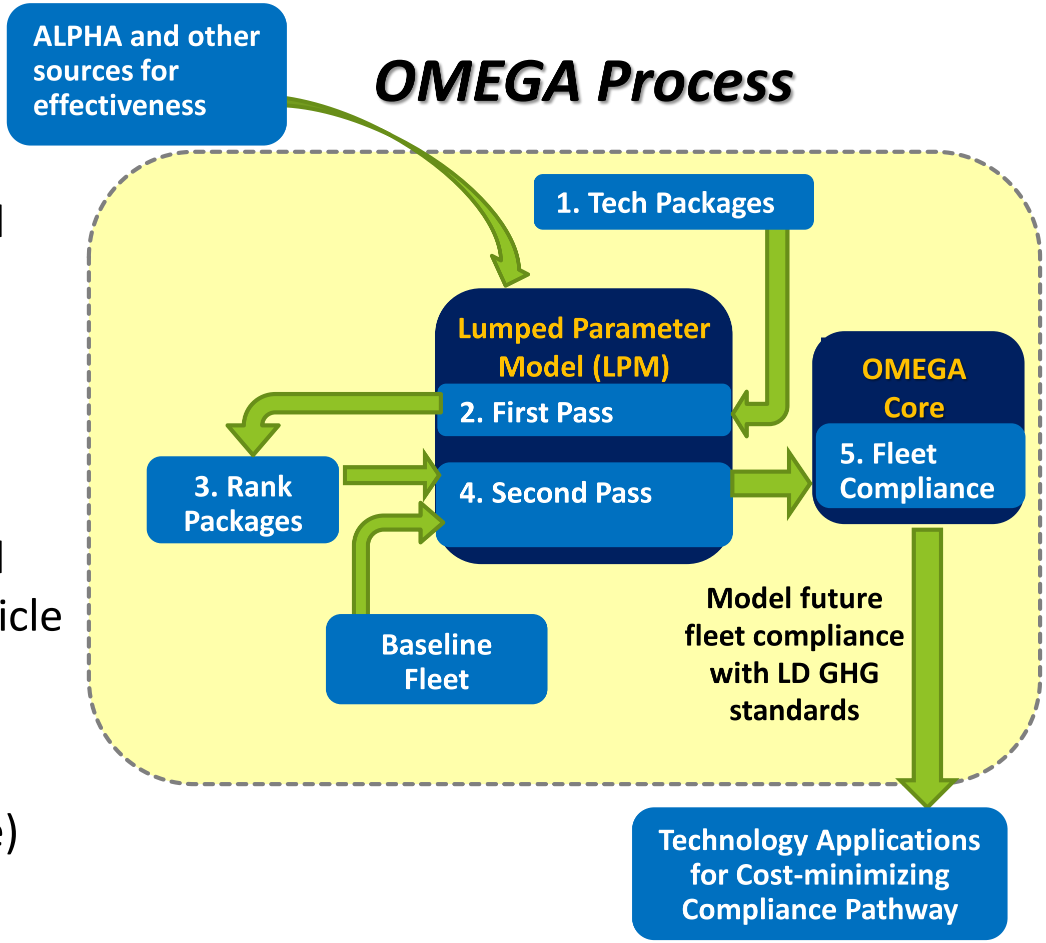
- OMEGA process was used in both the 2012-2016 and 2017-2025 rulemakings
- OMEGA core model is unchanged from the 2017-2025 GHG FRM
- Every input to the model is being re-examined for the MTE TAR

Design

- OMEGA is specifically designed for mid to long term regulatory analysis.
- OMEGA is based upon "redesign cycles,"
  - Allows sufficient time (approximately 5 years) to complete a vehicle redesign.
  - Incorporates manufacturers' multiyear planning.
  - Interpolation used for intermediate years.
- OMEGA is with grouped vehicles and grouped technologies
  - Vehicle Types
  - Packages
    - Upgrade several components simultaneously during a redesign cycle.
    - Includes consideration of (dis)synergies.

OMEGA Process Flow

- **Preparation of OMEGA core inputs**
  1. Generate technology packages
  2. Determine each package cost and effectiveness relative to NULL technology package
  3. Rank technology packages
  4. Create baseline
  5. Determine each package cost and effectiveness relative to each vehicle in the BASELINE fleet
- **Outputs**
  - Achieved compliance level (g/mile) and cost of compliance ($)
  - Fuel consumption and GHG emission impacts
  - Other Benefit-Cost Analysis impacts



1. Generate Technology Packages

- OMEGA adds new technologies in packages
- OMEGA does not add new technologies one-by-one
- OMEGA maps the fleet into one of 19 vehicle types driven by:
  - # of cylinders
  - Valvetrain configuration (DOHC, SOHC, OHV)
  - Pass car, MPV, Pickup
  - Towing/non-towing
- The packages built for each vehicle type depend on the vehicle type
  - E.g., Some techs are not applied to SOHC engines, or are not applied to towing vehicles (e.g., full EV)
- Roughly 10,000 technology packages are assembled for each of the 19 vehicle types

2. Determine Cost and Effectiveness for Each Package Relative to the NULL Technology Package (LPM 2nd Pass)

- **Assign effectiveness values by applying the Lumped Parameter (LP) model**
  - Effectiveness defined as percent CO2 reduction relative to the "NULL" technology package defined for each vehicle type
  - The NULL package is the "zero effectiveness technology floor"
  - The NULL package IS NOT the technology package on the baseline vehicle
  - Based on technology effectiveness estimates from ALPHA modeling and other sources
  - Accounts for synergies and dis-synergies among the technologies
- **LP model has been updated since the 2017-2025 FRM**
  - Improves fidelity of baseline attributes and technologies
  - Added flexibility in building technology packages

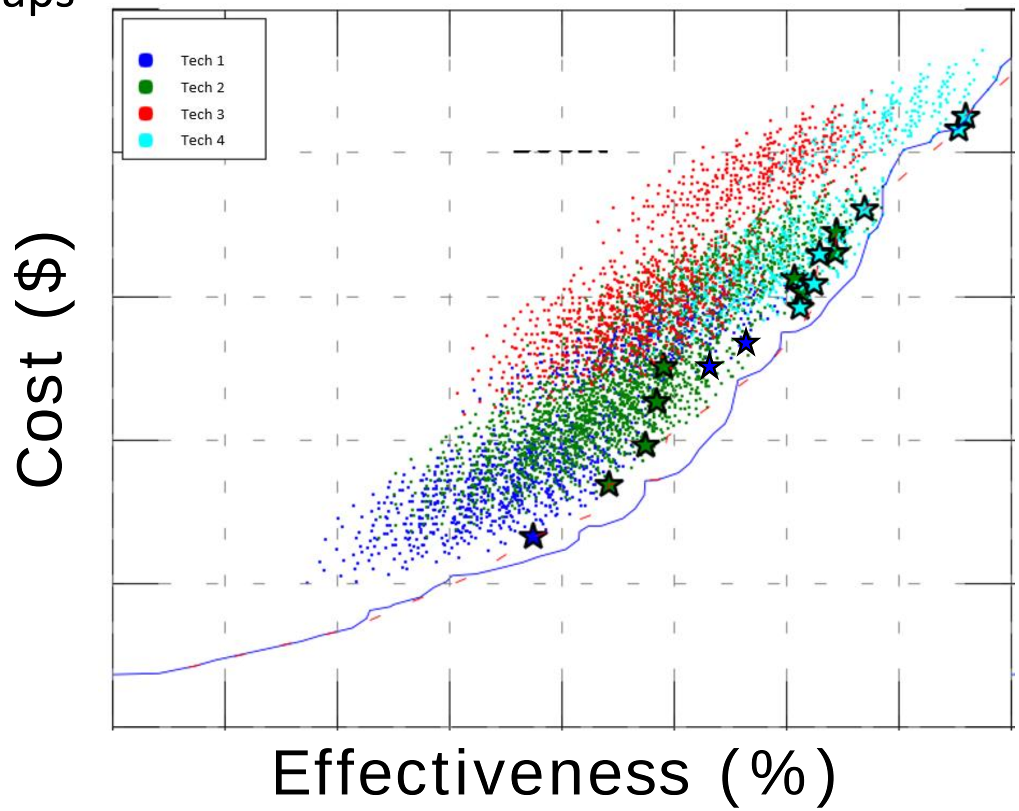
3. Rank Technology Packages

- **For the OMEGA core model to determine the cost-minimizing pathway packages are ordered from most to least cost effective**
  - (i.e., from the first package that “should” be applied to the last package that “should” be applied)
- **Cost effectiveness is determined by the “Technology Application Ranking Factor” or TARF**
  - There are multiple possible TARF definitions
  - The equation we use represents the relative cost effectiveness of each package to move the manufacturer closer to compliance

$$TARF = \frac{(Technology\ cost) - (Discounted\ fuel\ savings)}{Lifetime\ CO_2\ reduction}$$

3. Rank Technology Packages - Example

- Packages ranked based on TARF for each of the 19 vehicle types
- Approximately 50 packages are selected **(★)** to represent the cost-effective 'frontier'
- Some selected packages may lie above the absolute frontier due to phase-in caps



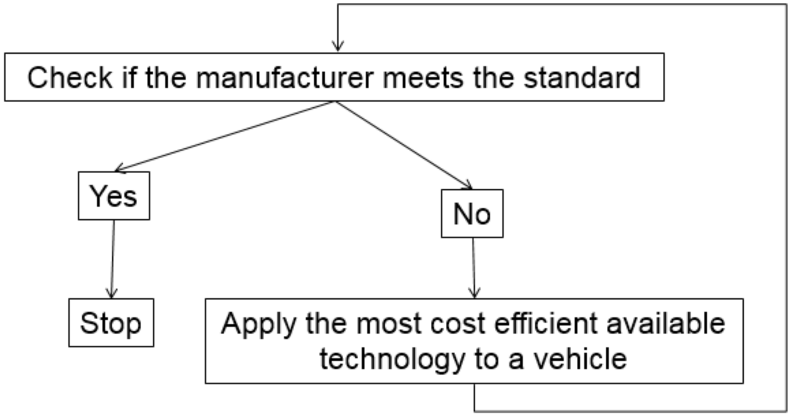
4. Determine Cost and Effectiveness for Each Package Relative to Each BASELINE Vehicle (LPM 2nd pass)

- **Create Baseline Fleet**
  - EPA will use the most recent certification data for which final sales data are available (for draft TAR this is MY 2014)
  - Adjustments for future fleets based on a purchased forecast
    - Includes scenarios for AEO high, low and reference fuel price
    - Market segment sales splits by manufacturer
    - Car and truck splits from AEO
- **Generate technology package effectiveness values by applying the Lumped Parameter (LP) model**
  - Each vehicle in the baseline has a current certified CO2 level
  - Each vehicle in the baseline fleet has a unique technology set
  - Addition of technology considers the current CO2 performance and the existing technology

5. Determine Cost Minimizing Tech Applications for Fleet Compliance

General OMEGA core model algorithm

1. Determine the GHG target for each manufacturer.
2. Determine the current GHG level for each manufacturer.
3. For each manufacturer that hasn't met its CO2 target (loop):
   - Find the technology package/vehicle type combination with the best TARF
   - Add the technology to that vehicle type up to its cap (user-defined)
   - Calculate the manufacturer's GHG improvement and technology costs
   - Determine whether the manufacturer has reached compliance.
   - If the manufacturer has over-complied and the technology cost is greater than the "threshold cost", back-calculate the cost at which the manufacturer exactly meets the standard



4. Generate Outputs
   - Technology penetrations
   - Technology costs and achieved emissions levels

Questions?