2016 SAE Government-Industry Meeting

ALPHA EFFECTIVENESS MODELING

CURRENT AND FUTURE LIGHT-DUTY VEHICLE & POWERTRAIN TECHNOLOGIES

January 20, 2016

Daniel Barba, Director
National Center for Advanced Technology

Office of Transportation and Air Quality
Office of Air and Radiation
U.S. Environmental Protection Agency

SAE INTERNATIONAL

UNITED STATES • ENVIRONMENTAL PROTECTION AGENCY

Topics

1) **ALPHA Model Background**

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

3) **Technology Packages** – Putting it all Together

4) **Looking Forward -** Sample Technology Package

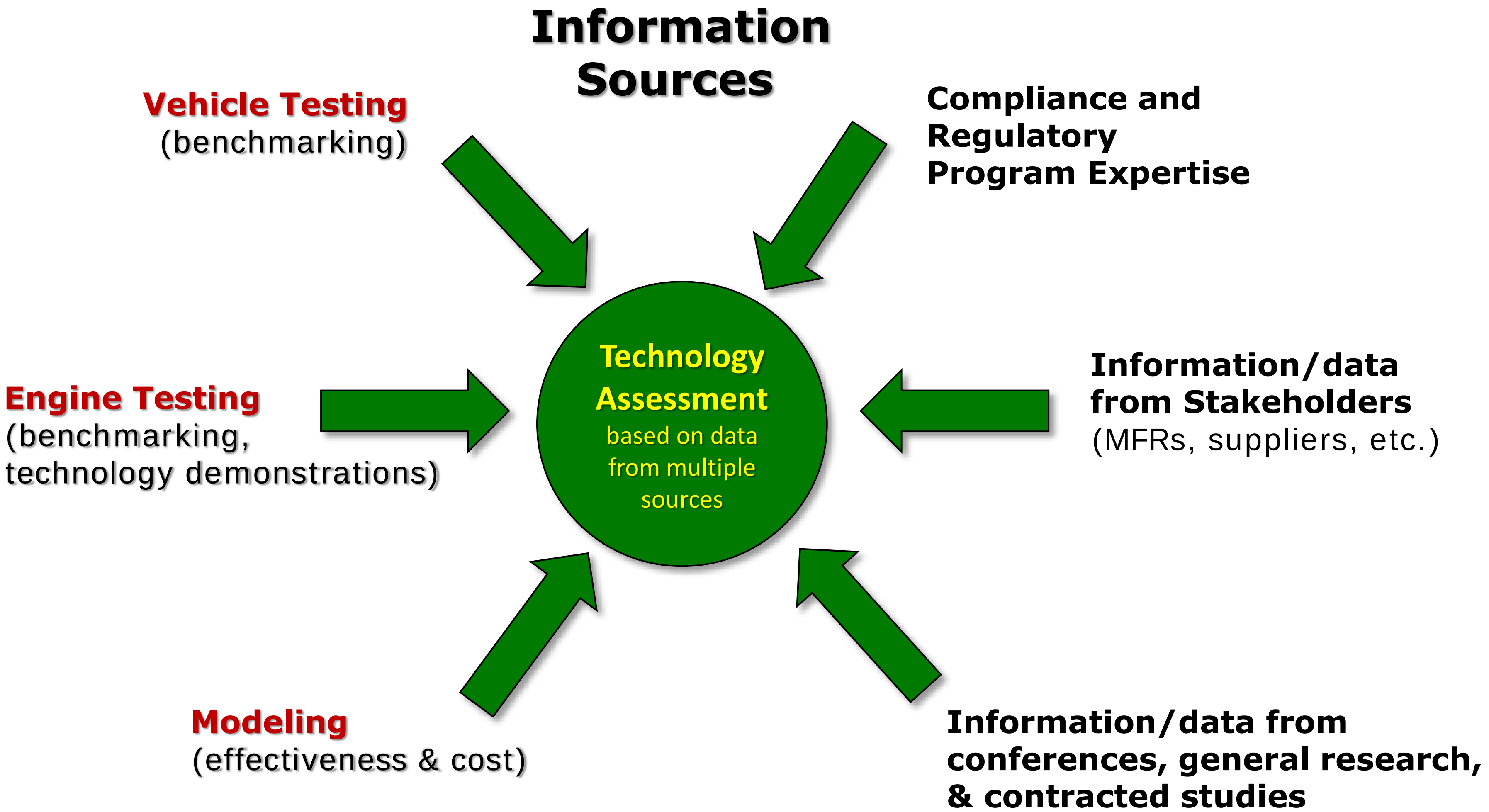
Background

- 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
- 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

NOTE: This presentation focuses on the scientific development 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



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 not a commercial product (e.g. there are no user manuals, tech support hotlines, graphical user interfaces, or full libraries of components).

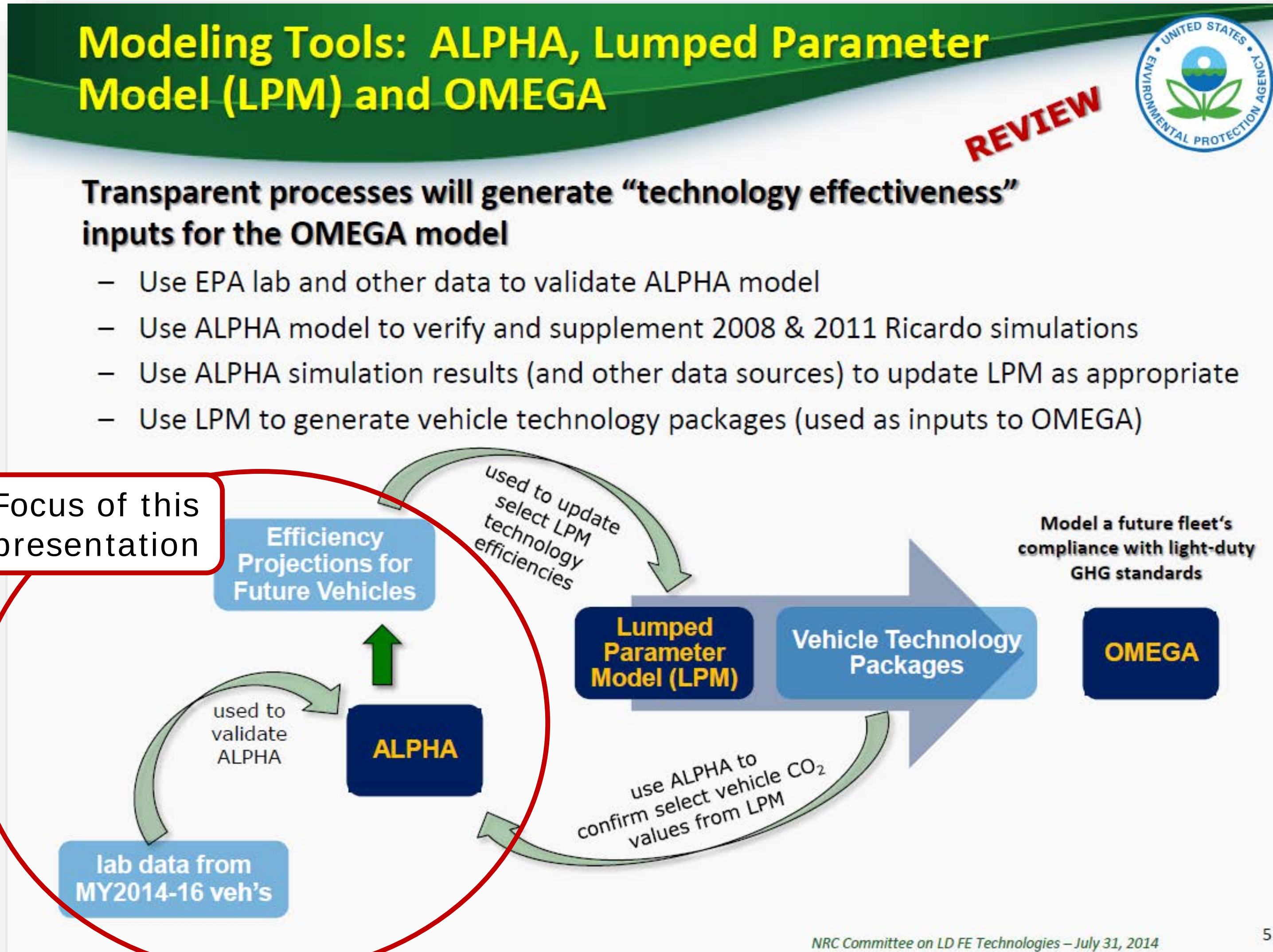
Why was ALPHA developed?

- EPA's objective in its rulemaking processes is to achieve the highest level of transparency and openness possible.
- 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.

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

Presented to NAS-NRC
June & July, 2014

Focus of this presentation



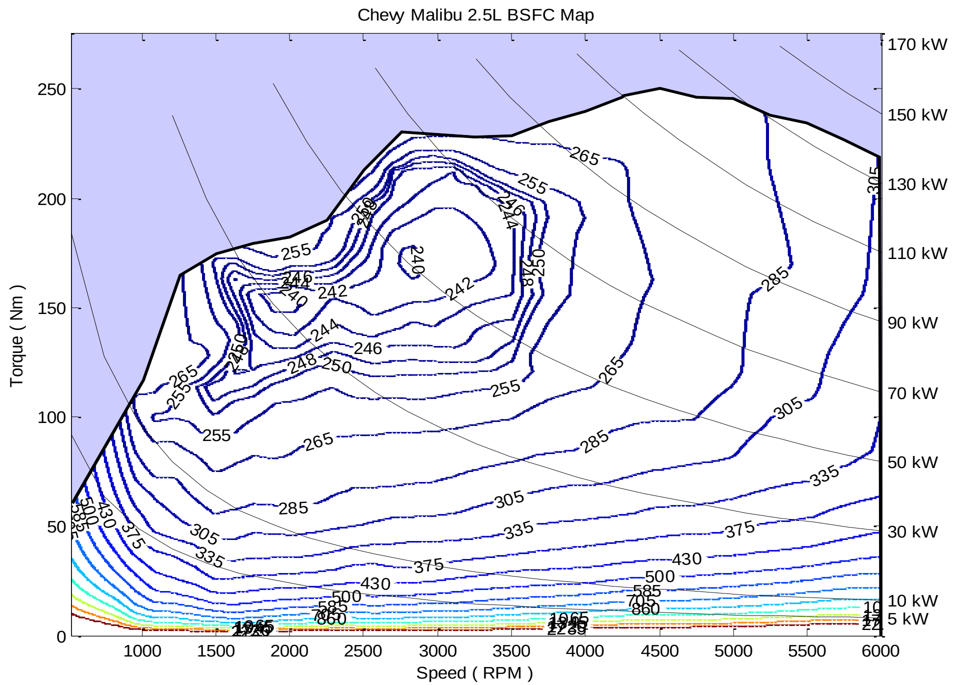
ALPHA Model Inputs and Data Processing

ALPHA inputs fall into one of four categories:

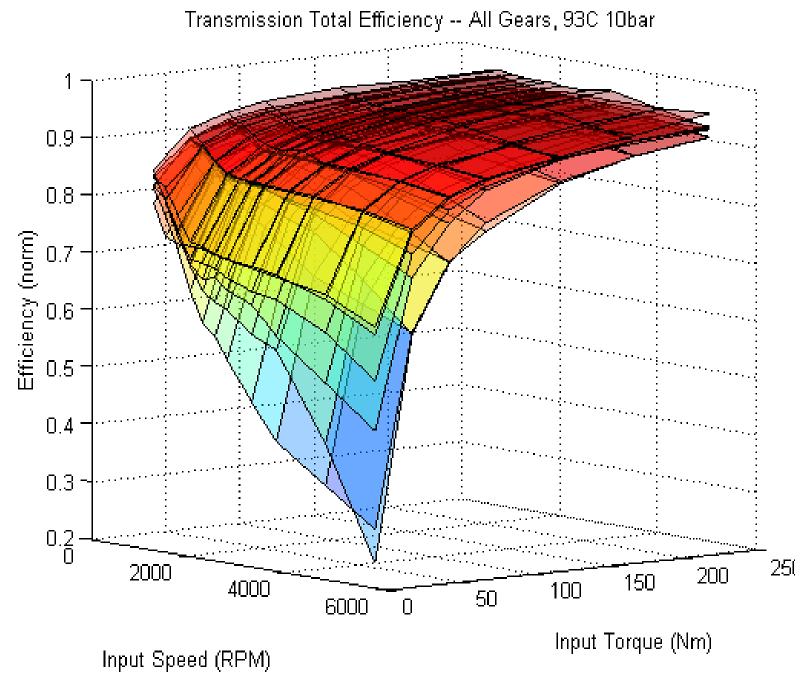
1. **Test Cycle**
   - Drive cycle speed (e.g., FTP, HWFET, US06)
2. **Vehicle Parameters**
   - Weight / inertia, road load, driveline type or vehicle class
3. **Component Data**
   - Engine fuel consumption map, torque curves
   - Transmission gear ratios, spin losses, efficiencies, torque converter 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 Chevy Malibu 1LS
Vehicle and Component Information

2.5L I4 GDI, *Non-Hybrid*
22 City / 34 Highway / 26 Comb
Chosen as representative of an average midsize car



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



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

SAE 2015-01-1140

Bridging the Gap Between a Simulation and a Real Vehicle

Accounting for All the Fuel Consumed

- Vehicle simulation models tend to under-predict fuel consumption (over-predict fuel economy) because they often overlook 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.

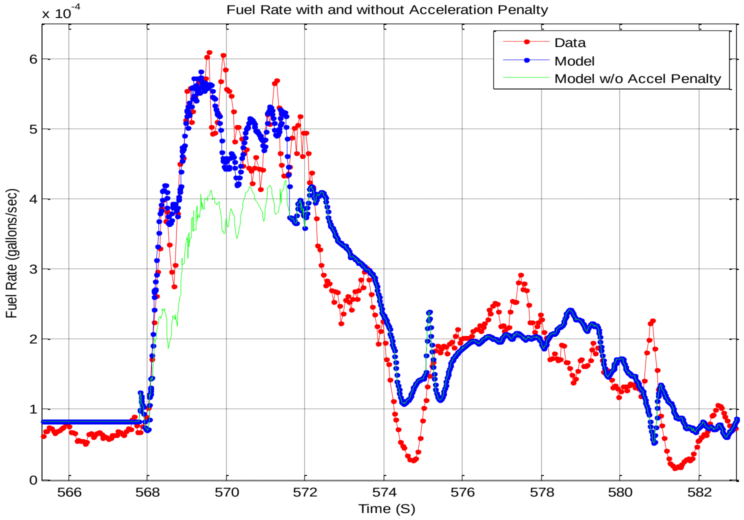
- We have embedded these rules within ALPHA to account for some of the most significant factors requiring extra use of fuel.

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

Bridging the Model Validation Gap
Dynamic Fuel Effects – Acceleration and Torque Converter Slip

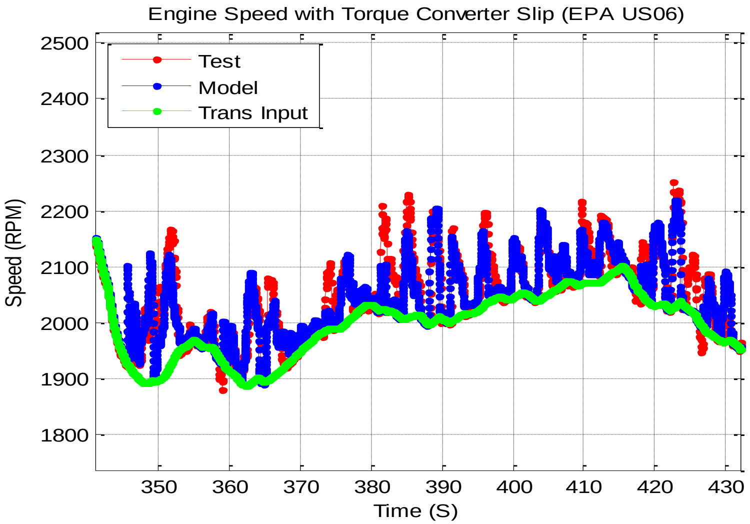
Sample 1: Transient Fuel Use

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



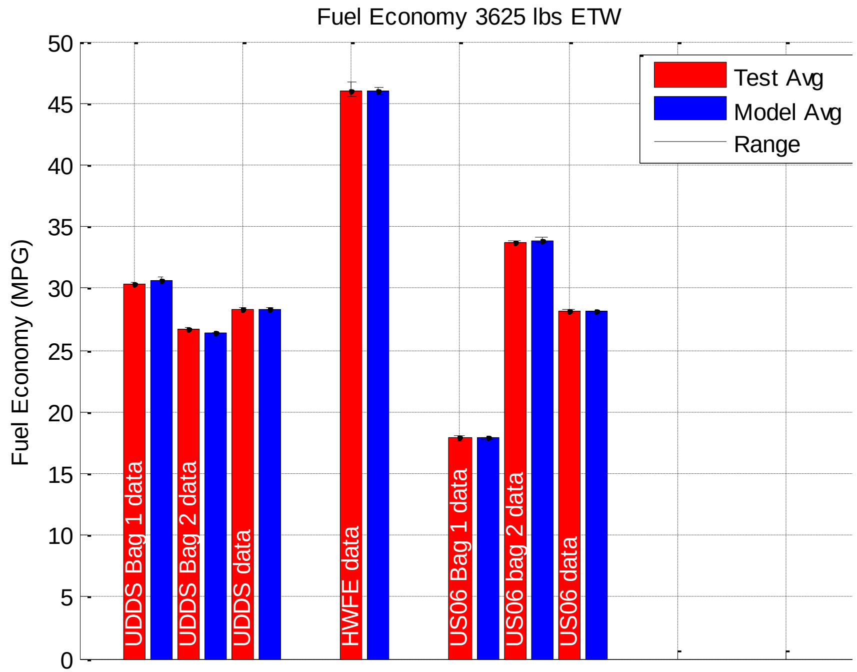
Sample 2: Torque Converter Slip

- Earlier versions of ALPHA had a simple “lockup” strategy, which was then updated to account for limited-slip operation

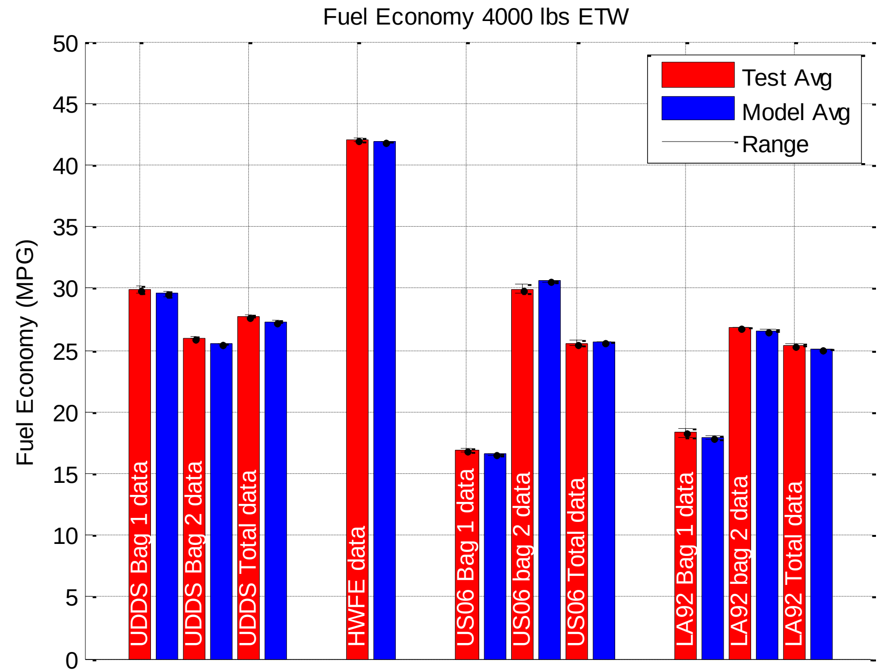


Note: EPA plans to describe ALPHA’s vehicle control rules further in upcoming SAE publications and the draft TAR

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

Vehicle Component Benchmarking

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

Technology Packaging Matrix
"Putting It All Together"

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 13:1 compression-ratio engine
- **Future TDS –** 24 bar down-sized turbo 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 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 modes of 12 volt Start-Stop technology:

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

Cautions When Comparing Technology Effectiveness Values from Different Sources

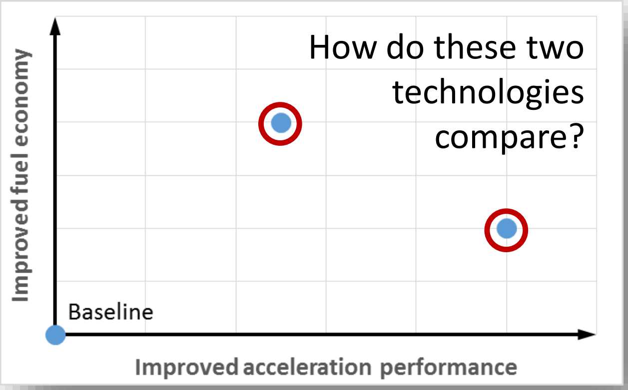
Benchmarking and modeling results are only one source of data measuring technology effectiveness, and should be compared to data from other sources. When comparing our data to an outside reference like, "*Our new engine provides a 10% improvement in fuel efficiency"…*

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. **The 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:

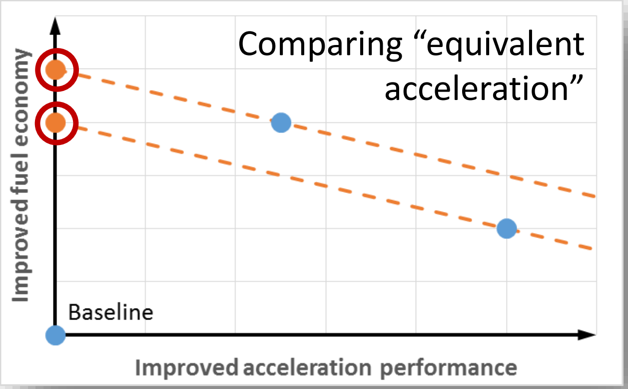
- Many fuel consumption reduction technologies decrease required wheel power, increase available engine power, or deliver power to wheels more efficiently
- If applied blindly, these technologies will reduce fuel consumption while also improving acceleration performance
- How do we "fairly compare" technologies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



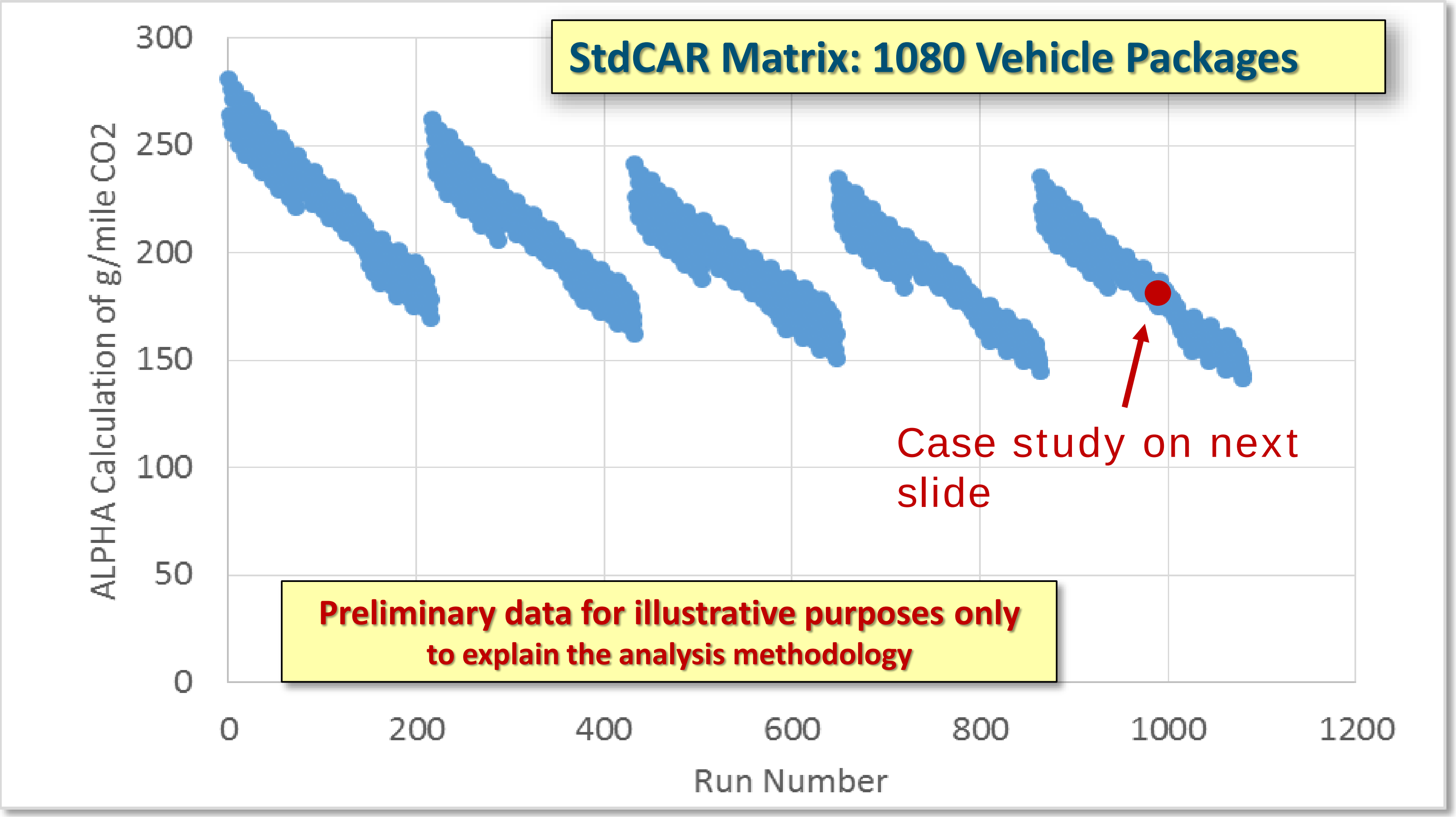
> **NAS 2011:** ***"Objective comparisons of the cost-effectiveness of different technologies for reducing FC can be made only when vehicle performance remains equivalent."***

ALPHA's Current Approach:

- Reduce engine size to attain equivalent acceleration performance



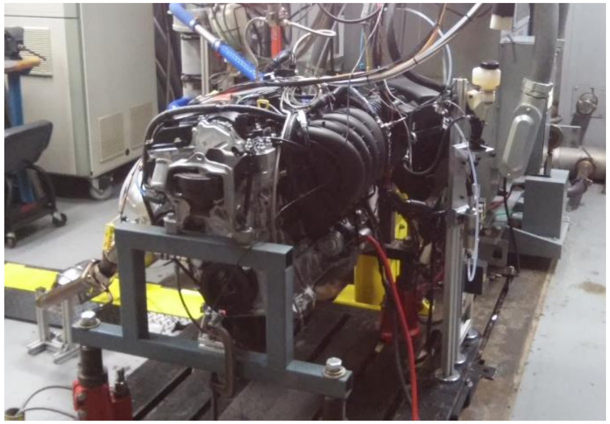
Technology Packaging Matrix
Preliminary results



What if…
We 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 & chassis test data for 2014 Mazda3

HIL w/ALPHA allows evaluation with different powertrains and/or road load conditions

- Applied Adv. 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)

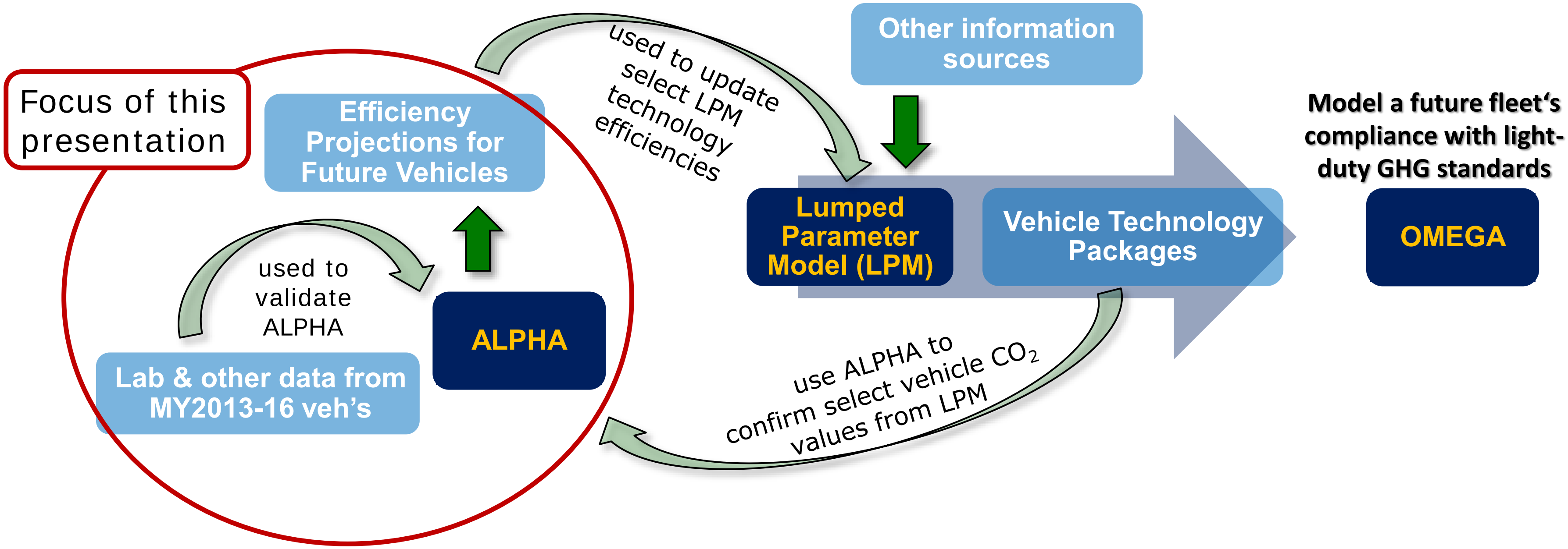
	Cycle	Total Fuel (g)	Idle Fuel (g)	Adjusted Fuel (g)	FE (mpg)	g/mi CO2
HIL L1	FTP (total)	257.9	12.8	245.1	43.0	206.7
	HWFE				64.5	137.7
	Combined				50.6	175.6
HIL L2	FTP (total)	247.6	12.2	235.4	44.3	200.8
	HWFE				67.1	132.4
	Combined				52.3	170.0

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



Questions?