ALPHA EFFECTIVENESS MODELING
CURRENT AND FUTURE LIGHT-DUTY VEHICLE & POWERTRAIN TECHNOLOGIES

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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
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

Information Sources

- **Vehicle Testing** (benchmarking)
- **Engine Testing** (benchmarking, technology demonstrations)
- **Modeling** (effectiveness & cost)
- Compliance and Regulatory Program Expertise
- Information/data from Stakeholders (MFRs, suppliers, etc.)
- Information/data from conferences, general research, & contracted studies

Technology Assessment based on data from multiple sources
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

Modeling Tools: ALPHA, Lumped Parameter Model (LPM) and OMEGA

Transparent processes will generate “technology effectiveness” inputs for the OMEGA model
- Use EPA lab and other data to validate ALPHA model
- Use ALPHA model to verify and supplement 2008 & 2011 Ricardo simulations
- Use ALPHA simulation results (and other data sources) to update LPM as appropriate
- Use LPM to generate vehicle technology packages (used as inputs to OMEGA)

Focus of this presentation

Presented to NAS-NRC
June & July, 2014

OMEGA
Lumped Parameter Model (LPM)
Vehicle Technology Packages

Efficiency Projections for Future Vehicles
used to validate ALPHA
lab data from MY2014-16 veh’s

used to update select LPM technology efficiencies
use ALPHA to confirm select vehicle CO₂ values from LPM

Model a future fleet’s compliance with light-duty GHG standards

NRC Committee on LD FE Technologies – July 31, 2014
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
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
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

### Fuel Economy 3625 lbs ETW

<table>
<thead>
<tr>
<th>Test</th>
<th>Average Test MPG</th>
<th>Average Model MPG</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDDS Phase 1</td>
<td>30.40</td>
<td>30.69</td>
<td>0.95</td>
</tr>
<tr>
<td>UDDS Phase 2</td>
<td>26.66</td>
<td>26.39</td>
<td>-0.99</td>
</tr>
<tr>
<td>HWFET</td>
<td>45.96</td>
<td>45.92</td>
<td>-0.10</td>
</tr>
<tr>
<td>US06 Phase 1</td>
<td>17.88</td>
<td>17.84</td>
<td>-0.22</td>
</tr>
<tr>
<td>US06 Phase 2</td>
<td>33.70</td>
<td>33.86</td>
<td>0.49</td>
</tr>
</tbody>
</table>

### Fuel Economy 4000 lbs ETW

<table>
<thead>
<tr>
<th>Test</th>
<th>Average Test MPG</th>
<th>Average Model MPG</th>
<th>Error %</th>
</tr>
</thead>
<tbody>
<tr>
<td>UDDS Phase 1</td>
<td>29.87</td>
<td>29.55</td>
<td>-1.10</td>
</tr>
<tr>
<td>UDDS Phase 2</td>
<td>26.01</td>
<td>25.55</td>
<td>-1.75</td>
</tr>
<tr>
<td>HWFET</td>
<td>42.03</td>
<td>41.91</td>
<td>-0.28</td>
</tr>
<tr>
<td>US06 Phase 1</td>
<td>16.84</td>
<td>16.54</td>
<td>-1.78</td>
</tr>
<tr>
<td>US06 Phase 2</td>
<td>29.96</td>
<td>30.60</td>
<td>2.15</td>
</tr>
<tr>
<td>LA92 Phase 1</td>
<td>18.40</td>
<td>17.92</td>
<td>-2.61</td>
</tr>
<tr>
<td>LA92 Phase 2</td>
<td>26.84</td>
<td>26.57</td>
<td>-1.02</td>
</tr>
</tbody>
</table>
## Vehicle Component Benchmarking

### Conventional Vehicle Engine Transmission Primary Reasons for Benchmarking ALPHA Validation

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

<table>
<thead>
<tr>
<th>Engines</th>
<th>Transmissions</th>
<th>Reductions of Mass</th>
<th>Reductions of Aerodynamic Resistance (Cd)</th>
<th>Reductions of Rolling Resistance (Crr)</th>
<th>Modes of 12 volt Start-Stop Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline - Camry 2.4L I4 engine from the 2010 Ricardo analysis for LD GHG Federal Rulemaking (FRM)</td>
<td>2008 AT5 – parameters from vehicle testing</td>
<td>Base (0% reduction)</td>
<td>Base (0% Cd)</td>
<td>Base (0% start-stop)</td>
<td></td>
</tr>
<tr>
<td>2014 NA - Mazda SkyActiv 2.0L I4 13:1 compression-ratio engine</td>
<td>2013 AT6 – GM6T40, parameters from vehicle testing</td>
<td>5% reduction</td>
<td>10% reduction</td>
<td>100% start-stop</td>
<td></td>
</tr>
<tr>
<td>Future TDS – 24 bar down-sized turbo with cooled EGR from the 2010 Ricardo analysis for LD GHG Federal Rulemaking (FRM)</td>
<td>2014 AT8 – FCA845RE, parameters from EPA trans stand testing</td>
<td>10% reduction</td>
<td>20% reduction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

StdCAR Matrix: 1080 Vehicle Packages

Preliminary data for illustrative purposes only to explain the analysis methodology

Case study on next slide
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)

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

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Total Fuel (g)</th>
<th>Idle Fuel (g)</th>
<th>Adjusted Fuel (g)</th>
<th>FE (mpg)</th>
<th>g/mi CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIL L1</strong></td>
<td>FTP (total)</td>
<td>257.9</td>
<td>12.8</td>
<td>245.1</td>
<td>43.0</td>
</tr>
<tr>
<td></td>
<td>HWFE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HIL L2</strong></td>
<td>FTP (total)</td>
<td>247.6</td>
<td>12.2</td>
<td>235.4</td>
<td>44.3</td>
</tr>
<tr>
<td></td>
<td>HWFE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

Focus of this presentation

Efficiency Projections for Future Vehicles

Lab & other data from MY2013-16 veh’s

ALPHA

data used to validate ALPHA

used to update select LPM technology efficiencies

Other information sources

Lumped Parameter Model (LPM)

Vehicle Technology Packages

OMEGA

Model a future fleet’s compliance with light-duty GHG standards
Questions?