Greenhouse gas Emission Model (GEM)
A Compliance Vehicle Model for Certification

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Outline

• GEM Background
  • Technology Assessment in GHG Phase 2
  • Vehicle Model (GEM) Validations

• Certification Process – Cycle Average Approach

• Additional Comments on GEM
Phase 1 GEM

- The Greenhouse Gas Emission Model (GEM) is a vehicle simulation tool being used by all vehicle OEMs for demonstrating compliance for the U.S. Greenhouse Gas Emission and Fuel Efficiency Standards
- GEM is run over three EPA drive cycles: 55mph, 65mph, and transient cycles
  - Only up to 5 inputs are supplied by OEM, depending on regulatory subcategory

**Total Engine Loss**
57-59%

**Inertial/Braking**
0-2%

**Aerodynamic Loss**
15-22%

**Vehicle Auxiliary Loads**
1-4%

**Drivetrain**
2-4%

**Rolling Resistance**
13-16%

EPA pre-specified
Allowed user inputs

http://www.epa.gov/otaq/climate/gem.htm
Phase 2 GEM

- Phase 2 will consider all possible technologies that can be evaluated in a chassis dyno cell in order to improve engine and vehicle efficiency.
- A significantly upgraded version of GEM is being developed and validated to account for all possible technologies mentioned above.
- GEM is intended for demonstrating compliance with the standards rather than for research and development or any other purpose.
### GEM between Phase 1 vs Phase 2

<table>
<thead>
<tr>
<th>Category</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certification Cycles</td>
<td>ARB Transient 55 mph cruise, 65 mph cruise</td>
<td>ARB Transient 55 mph cruise with road grade 65 mph cruise with road grade Idle cycle</td>
</tr>
<tr>
<td>Engine</td>
<td>EPA default steady-state fuel map</td>
<td>OEM provides steady-state fuel map for 55 and 65mph cycles, But use cycle average map for ARB cycle</td>
</tr>
<tr>
<td>Transmissions</td>
<td>EPA default gears and shift strategy Only default MT</td>
<td>OEM specified number of gears and gear ratios OEM has option to override EPA default power loss table EPA default shift strategy MT/AMT/AT</td>
</tr>
<tr>
<td>Axle</td>
<td>EPA default</td>
<td>OEM specified axle ratio and configuration (6x4, etc.) OEM has option to override power loss table</td>
</tr>
<tr>
<td>Aero</td>
<td>Cd bins based on measured Cd</td>
<td>CdA bins based on measured CdA</td>
</tr>
<tr>
<td>Tires</td>
<td>OEM specified Crr for Steer and Drive Tires</td>
<td>OEM specified Crr separately for each axle</td>
</tr>
</tbody>
</table>
Engine Technology

- Phase 2 GEM is developed to account for all engine technologies that are tested in an engine dyno.
- Engine fuel map will be used as the user input.
Vehicle Technology

- OEM supplied aero drag and rolling resistance coefficients could be used to model the associated losses and
  - Promote advanced aerodynamic technologies
  - Encourage low rolling resistance tires
Transmission Technology

- Transmissions, such as manual (MT), automated manual (AMT) and automatic (AT), can be modeled within GEM.
- GEM will allow OEM to enter transmission information, such as gear ratio vs. gear number.
- GEM includes a shift strategy for each type of transmission.
Driveline Technology

- Axle modeling parameters, such as axle ratio, can be input by OEM
- GEM is able to recognize other axle technologies, such as 6x2 axle configurations

Meritor ECSA Smar 6x2

Dana’s dual range axle
Technology Improvement Input

- Technology improvement input approach can be specifically designed to account for those technologies that are deemed inappropriate to model
  - Lightweight material, such as high strength steel, aluminum, thermoplastic
  - Predictive cruise control (look ahead/smart coast …)
  - Accessory loads
  - Idle reduction
  - Tire pressure systems
  - Start-Stop/Neutral idle
Phase 2 GEM Validations against 130 Vehicle Variants

- GEM has been extensively validated against chassis dyno tests covering 130 vehicle variants. Excellent agreements between GEM and tests have been obtained.

U.S. Environmental Protection Agency
GEM - Relative Comparisons

- Phase 2 GHG rule uses GEM to set up stringency standards
- To-be-certified vehicles will compare the simulation results with the baseline GEM results
- Only relative comparisons are important
- Most relative comparisons are under 2-3% difference except a few outliers
Many issues with steady state maps on transient cycle
- Early thinking was to apply a 1.05 adjustment factor to account for transient behaviors
- Rough approximation that may not be adequate for highly transient cases, such as thermal management, smoke control
- Only way to recognize improved transient response under the proposal would be powertrain testing

Cycle average essentially integrates engine, powertrain, and vehicle into a realistic platform to account for all kinds of transient behaviors

A new test procedure (§ 1036.540) is created
Comparisons between Steady State Map and Cycle Average Approach

- GEM with steady state map significantly under-predict fuel economy consumption because of failure of modeling thermal management
  - Data shown here is from ARB Cycle with ISB 300hp engine
Additional Comments on Phase 2 GEM

• An official Phase 2 GEM has been released to public in 2016
• Since then, EPA have received a large number of helpful comments
• There would be a good chance that more enhancements on GEM could be made during the period of GHG Phase 2 Tech Amendment
• It should be mentioned that GEM can’t model hybrid and electric vehicles. For those unconventional vehicles, powertrain tests would be recommended.
GEM Information

• Public version of Phase 2 GEM can be downloaded from EPA website at

• Other referenced technical papers are