Greenhouse gas Emission Model (GEM)

A Compliance Vehicle Model for Certification

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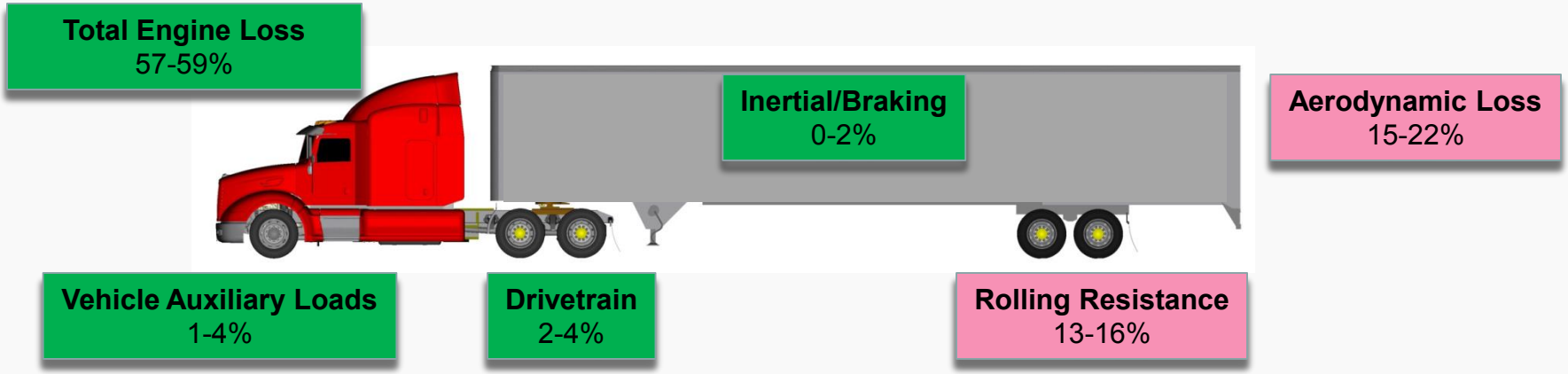
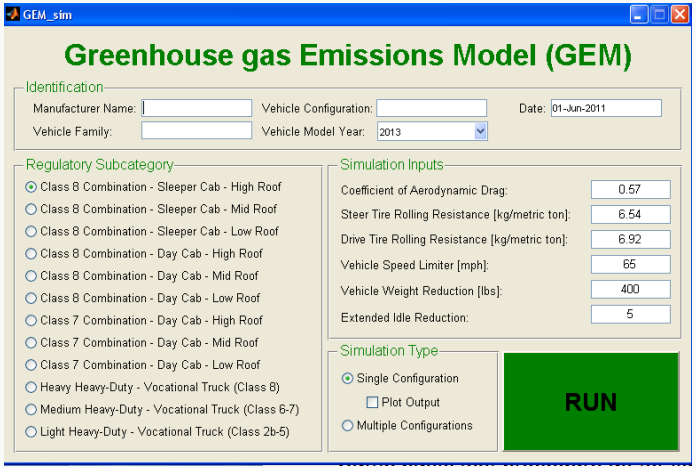
Outline

- 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



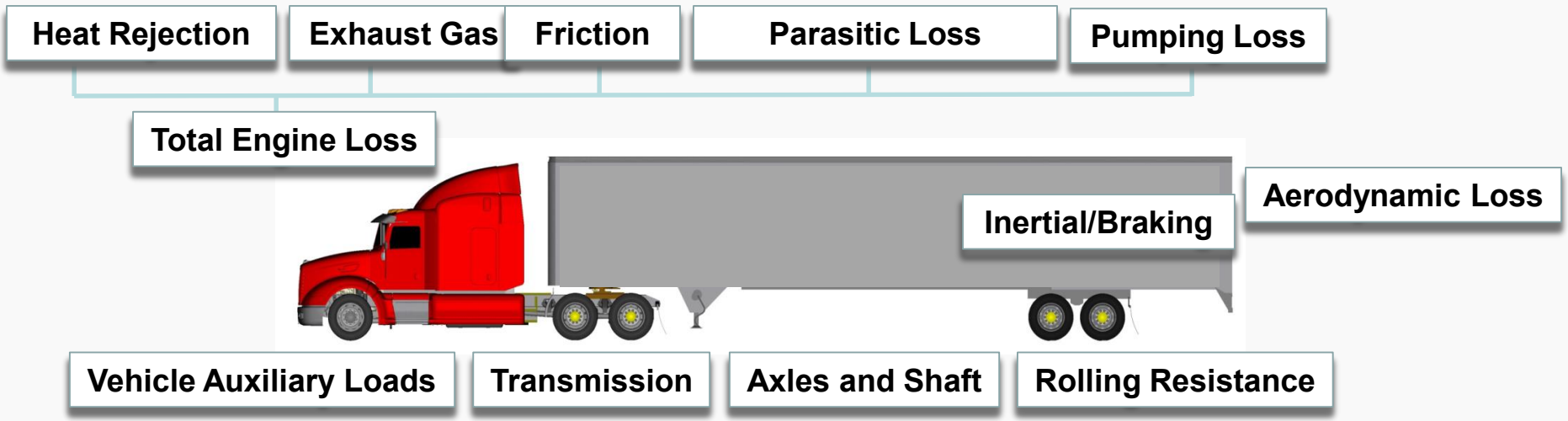


EPA pre-specified

Allowed user inputs

http://www.epa.gov/otaq/climate/gem.htm

Phase 2 GEM



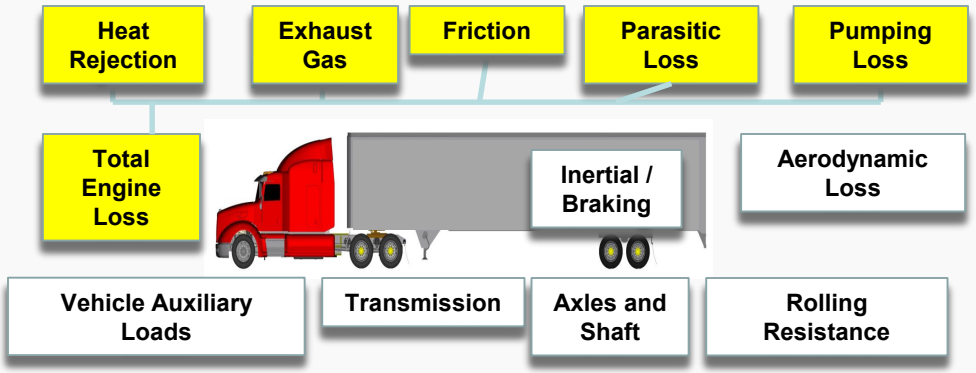
- Phase 2 will consider all possible technologies that can be evaluated in a chassis dyno cell in order to improve engine and vehicle efficiency
- A significantly upgraded version of GEM is being developed and validated to account for all possible technologies mentioned above
- GEM is intended for demonstrating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

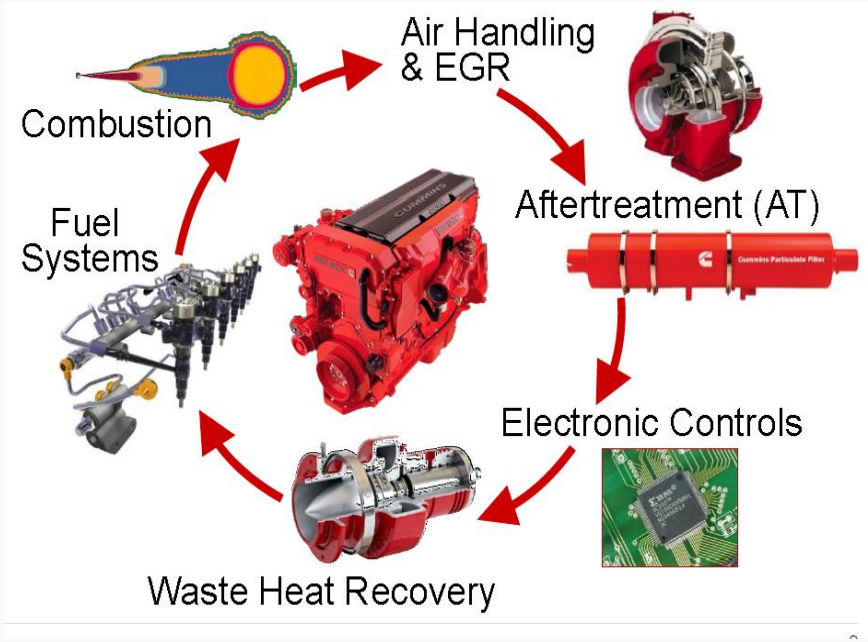
GEM between Phase 1 vs Phase 2

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

Engine Technology

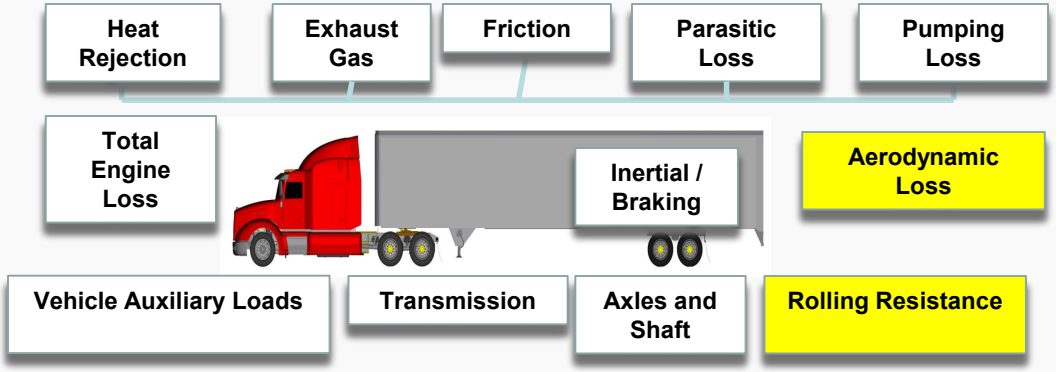
- Phase 2 GEM is developed to account for all engine technologies that are tested in an engine dyno
- Engine fuel map will be used as the user input





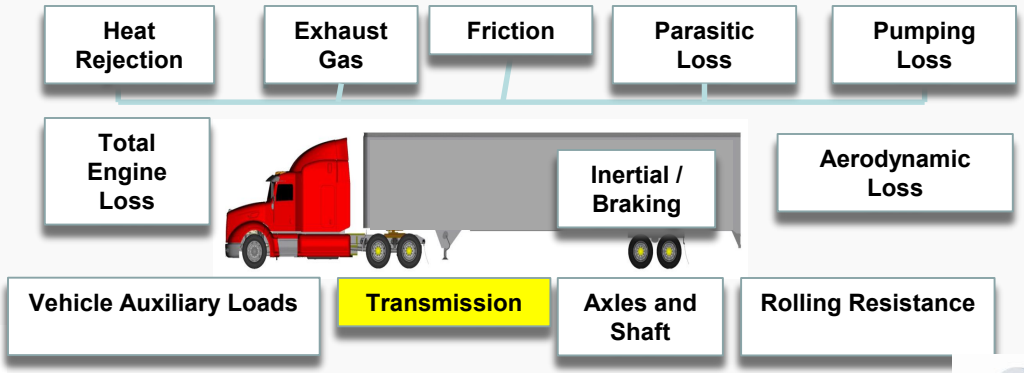
Vehicle Technology

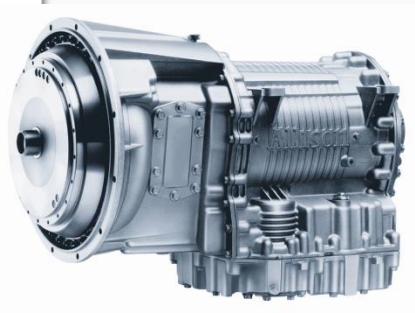
- OEM supplied aero drag and rolling resistance coefficients could be used to model the associated losses and
  - Promote advanced aerodynamic technologies
  - Encourage low rolling resistance tires



Transmission Technology

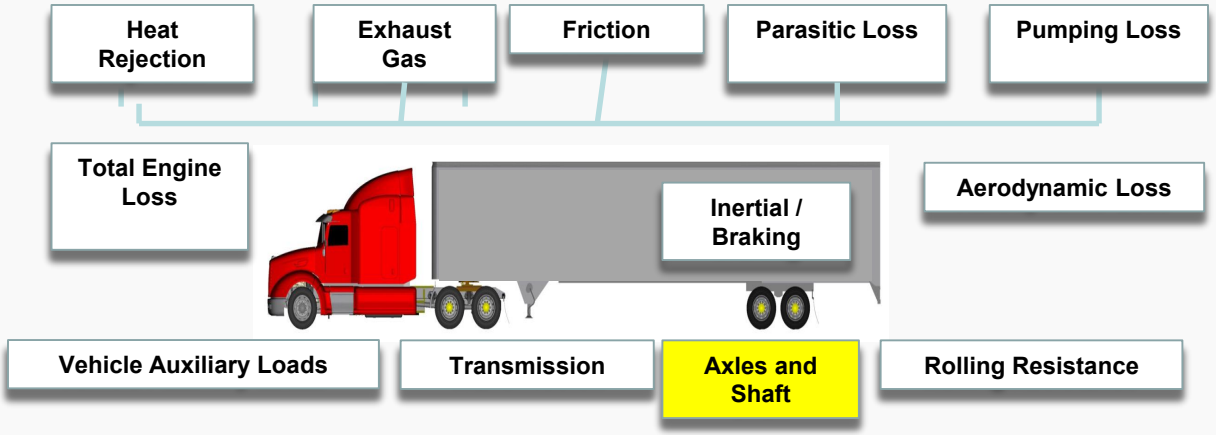
- Transmissions, such as manual (MT), automated manual (AMT) and automatic (AT), can be modeled within GEM
- GEM will allow OEM to enter transmission information, such as gear ratio vs. gear number
- GEM includes a shift strategy for each type of transmission



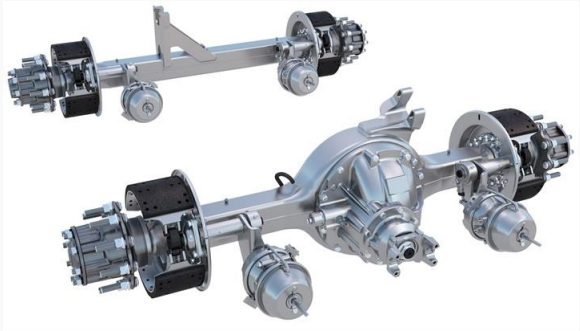


Driveline Technology

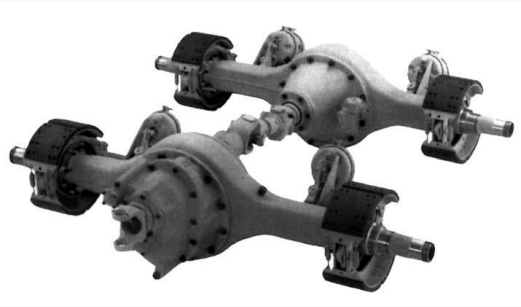
- Axle modeling parameters, such as axle ratio, can be input by OEM
- GEM is able to recognize other axle technologies, such as 6x2 axle configurations



Meritor ECSA Smar 6x2



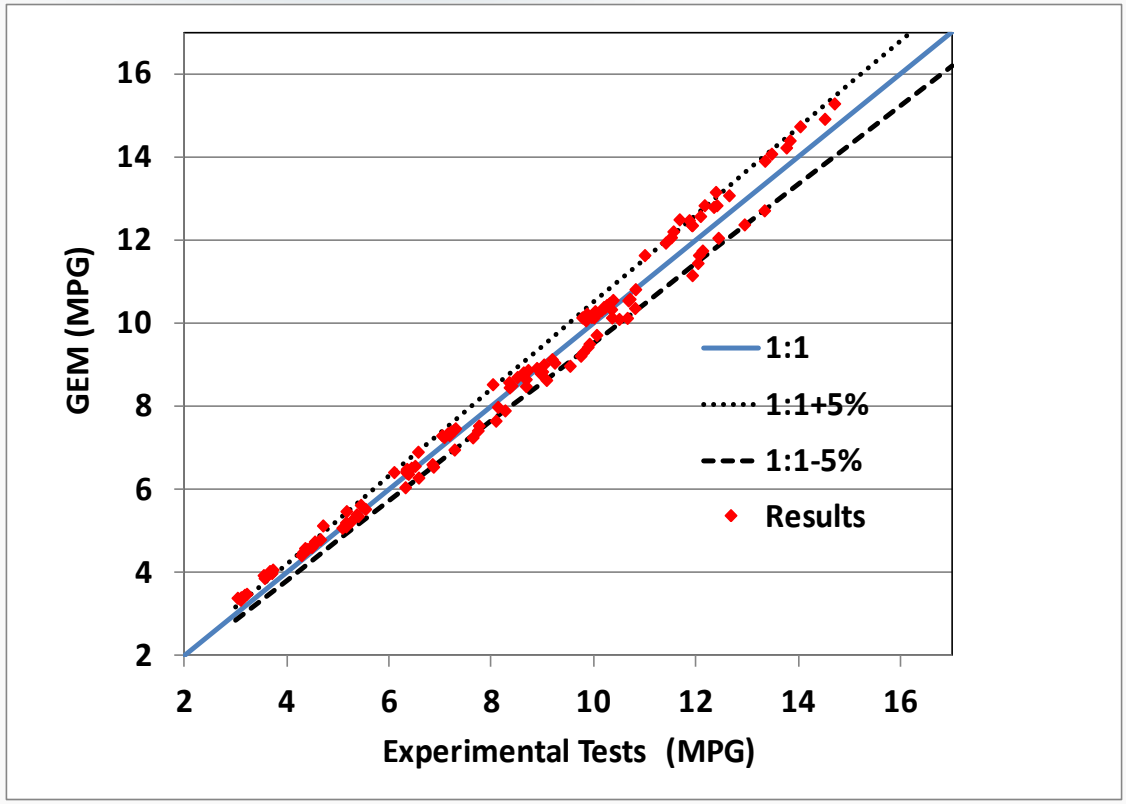
Dana's dual range axle



Technology Improvement Input

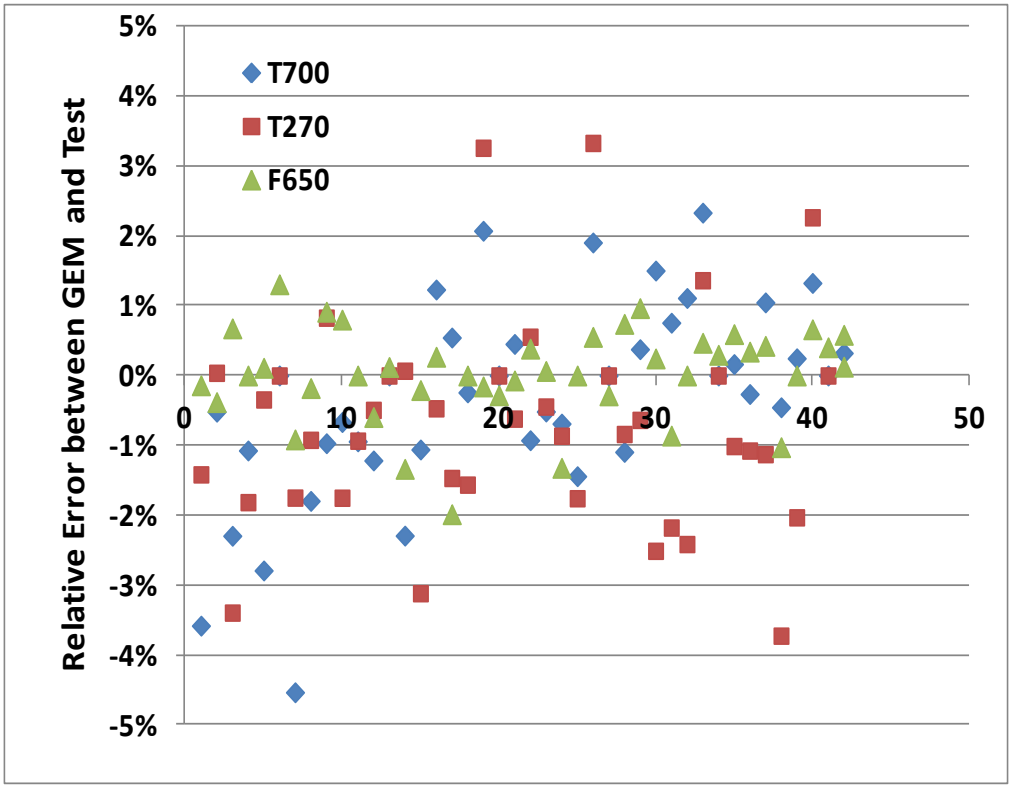
- Technology improvement input approach can be specifically designed to account for those technologies that are deemed inappropriate to model
  - Lightweight material, such as high strength steel, aluminum, thermoplastic
  - Predictive cruise control (look ahead/smart coast …)
  - Accessory loads
  - 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.

GEM - Relative Comparisons

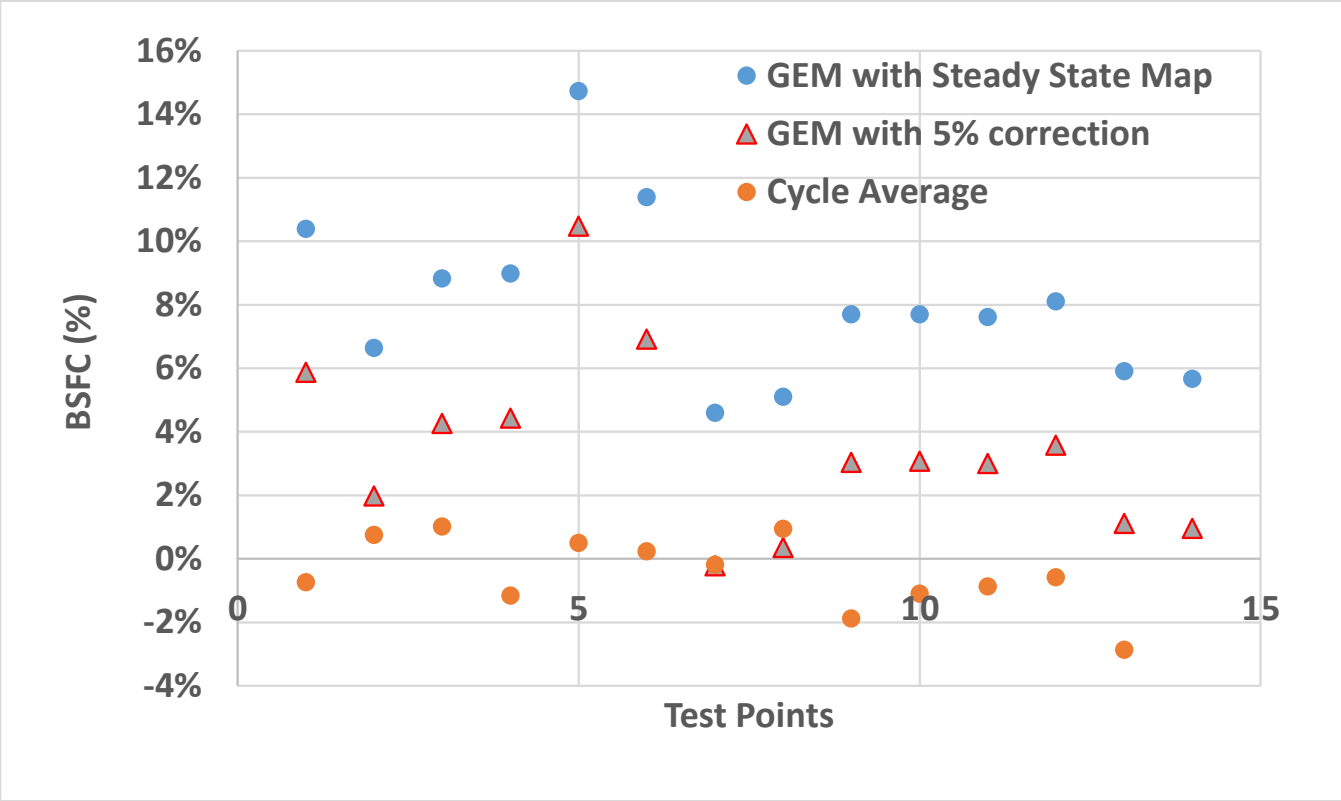


- Phase 2 GHG rule uses GEM to set up stringency standards
- To-be-certified vehicles will compare the simulation results with the baseline GEM results
- Only relative comparisons are important
- Most relative comparisons are under 2-3% difference except a few outliers

Cycle average map for Certification

- 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 down loaded from EPA website at
  - https://www.epa.gov/regulations-emissions-vehicles-and-engines/greenhouse-gas-emissions-model-gem-medium-and-heavy-duty

- Other referenced technical papers are
  - H. Zhang, J. Sanchez, M. Spears, J. Sarlashkar, D. Robertson, and M. Ross, "Cycle-Average Heavy-duty Engine Test Procedure for Full Vehicle Certification - Numerical Algorithms for interpreting cycle-average fuel maps," SAE *Int. J. Commer. Veh.* 9(2): 2016 doi:10.4271/2016-01-8018
  - H. Zhang, J, Sanchez, M, Spears, "Alternative Heavy-duty Engine Test Procedure for Full Vehicle Certification," SAE *Int. J. Commer. Veh.* 8(2): 2015, doi:10.4271/2015-01-2768.
  - K. Newman, P. Dekraker, H. Zhang, J. Sanchez, P. Guruajar, "Development of Greenhouse Gas Emissions Model (GEM) for Heavy- and Medium-Duty Vehicle Compliance," SAE *Int. J. Commer. Veh.* 8(3): 2015, doi:10.4271/2015-01-2771