Technology Potential of Commercial Vehicle Transmissions

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Heavy Duty Vehicle Efficiency Technical Workshop:
Aligning Standards Internationally, Integration of Engines and Powertrains

San Francisco, CA October 22nd , 2013

Outline

- Current state of transmission technology and market
- Approaches to fuel efficiency improvement
- Near term transmission opportunities 2014-2017
- New technology potential 2018 and beyond
- Certification options

* Note: This presentation describes Eaton's internal research and development activities, and does not imply any future product strategy, technology roadmap, or product release timing.

Current state of transmission technology and market in NA

- Transmission market structure
  - Linehaul
    - Manual 85%, AMT 15%, automation is growing: fuel economy & demographics
    - $5,000 - $15,000 unit price
    - High mechanical efficiency: >95%, up to 98% in cruise gear
  - Vocational
    - Torque Converter Automatic 90%, AMT 10%
    - $3000 - $15,000+ unit price (MD and HD specialty)
    - Mechanical efficiency: <85% -- 95%
  - Hybrids, few
    - $25,000 – $100,000
    - Long payback period >3 years
    - Narrow applications and subsidized cost

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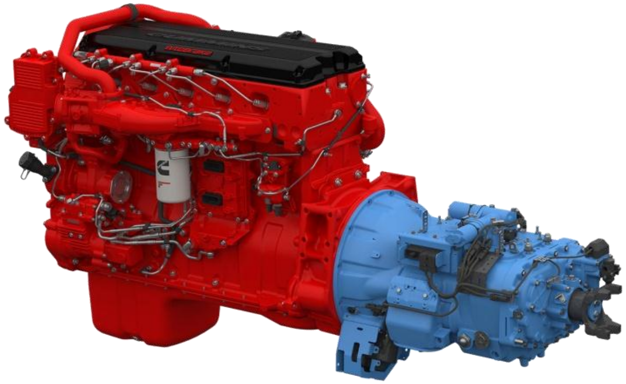
Eaton transmissions launching in 2014

Fuller Advantage: 2% fuel efficiency in linehaul

- Dry sump technology
- Reduced weight
- Optimized gearing
- Cooler and cooling lines removed
- Manual and AMT versions

Eaton-Cummins Alliance: 3-6% fuel efficiency in linehaul

- Deep AMT-ISX 15 integration
- Special ratios, improved shift logic, more time in DD
- Approx. 200 rpm engine downspeeding at cruise



Approaches to fuel efficiency improvement

Class 8 Truck, Linehaul drive cycle

Target 50% Freight Fuel Efficiency Improvement

Current Technology 170 kW (227 hp) cruise

Component	Fuel Energy loss	Thermal Power loss
Engine + accessory loads	60% (40% BTE)	255 kW
Transmission	2%	3.4 kW
Axle	2%	3.4 kW
Aerodynamic + RR losses	35%	162 kW
Braking	1%	1.7 kW

2020 Truck 112 kW (150 hp) cruise

Improvement Target
Engine increases to 50% BTE
From 98% to 99.5 %
From 98 % to 99 %
Decrease 20 - 30%
Somewhat increased due to less drag loss

- Pure transmission mechanical efficiency improvements can offer only minimal impact. Less than 2%

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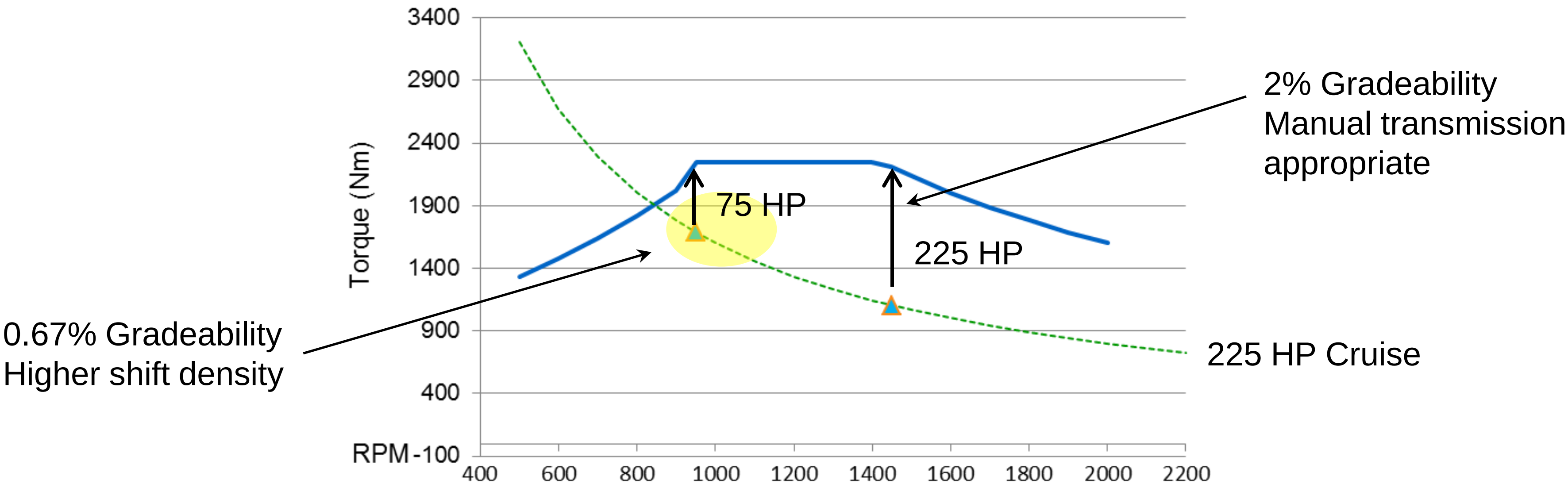
Approaches to fuel efficiency improvement

- Transmission can enable new engine technologies. Improved engine transmission integration is the major avenue for future powertrain improvement:
  - Downspeeding
  - Reduce engine operation in low efficiency areas by:
    - Minimizing shift transients
    - Making more intelligent shift decisions



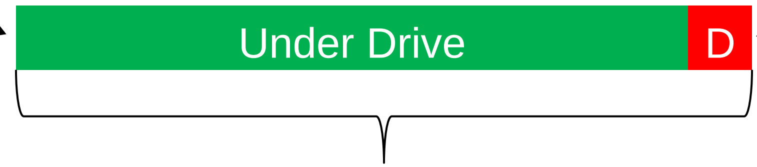
Downspeeding Increases Ratio Spread

Design Trade-offs in size, mass and efficiency

Launch gear set by creep speed and startability

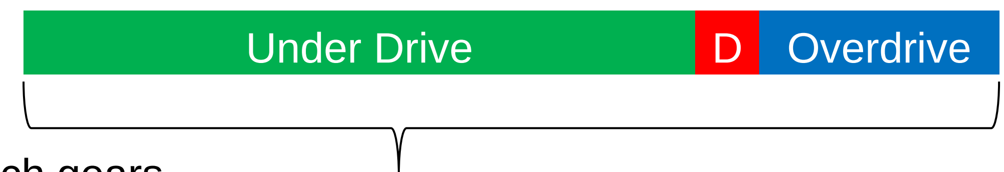
Current Linehaul Product

Axle Ratio and Tire Size Set Engine RPM at cruise speed with direct-drive



16:1 ratio spread

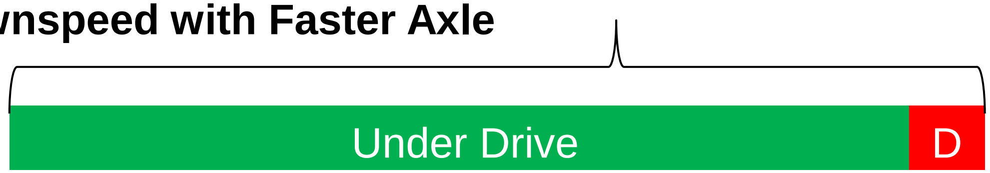
Option 1: Downspeed with Overdrive: reduces engine RPM at cruise



+ No change in launch gears

20:1 ratio spread

Option 2: Downspeed with Faster Axle



+ Maintains efficiency of direct drive
- Higher launch torque increases driveline mass
- Requires axles in the range of 2.0:1

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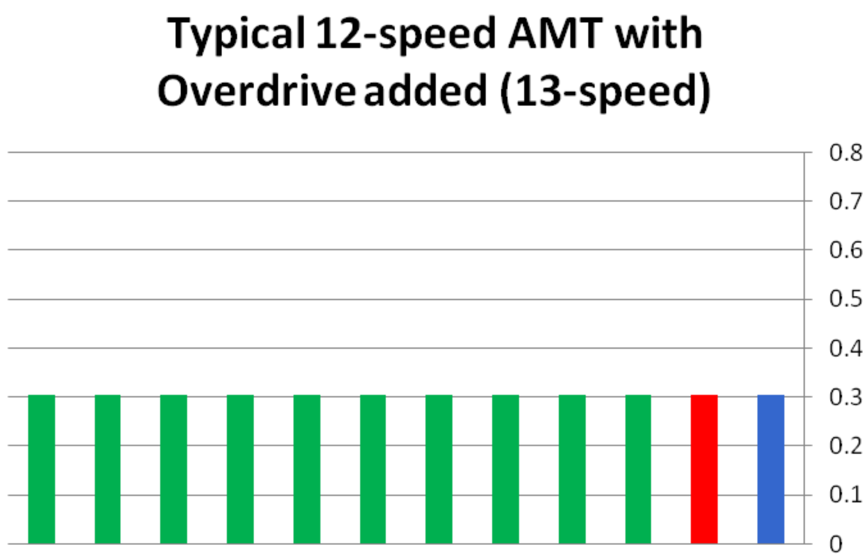
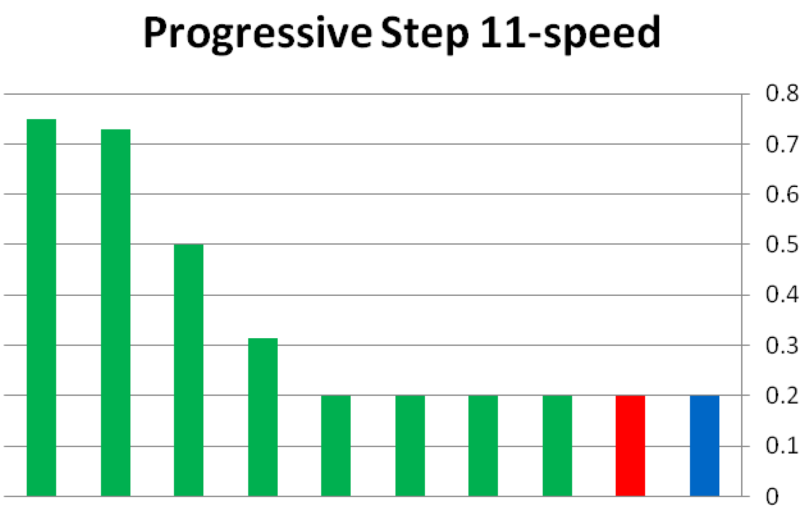
Progressive Gear Ratios

Smarter Gearing: More Ratio Spread without adding speeds





Same Overall Ratio Spread!

+ Progressive ratio steps allow smaller steps in the cruise gears without adding speeds

+ Eliminate skip-shifting during fast launches (light load / down hill)

- Wider engine speed range during launch

Increasing Ratio Spread with smaller steps sizes at cruise do NOT require more gears

Not All 12-speeds are created equal!

Eaton Hybrid Electric Power Systems





Total Miles Accumulated: over 400 million
Fuel Savings: 11 million gallons
Emissions Reduction: 110,000 metric tons
Units in Operation: approaching 6,500



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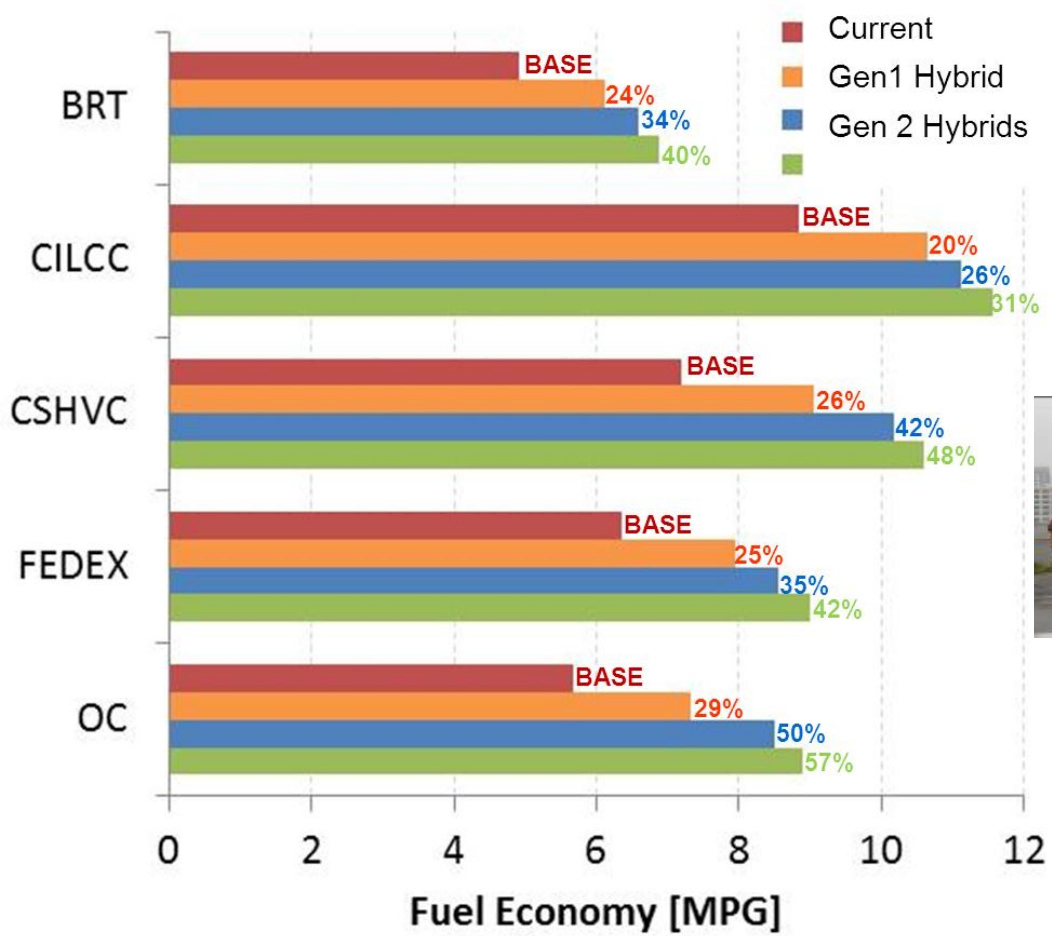
MD Hybrid concept architectures

The challenge: 2-3 year payback based on value of saved fuel

- Improve fuel efficiency – hybrid architecture
- Lower cost components – hybrid architecture
- Lower battery cost: leasing model, downsize through intelligence



32000 miles/yr @ 8mpg
25% → 35%
$4k/yr →$5.6k/yr

12000 miles/yr @ 6mpg
2400 gal export power
$1.6k (driving) + $6.8k power,

10000 miles/yr @ 4 mpg
30%→45%
$3k→$4.5k

Case for the Heavy Duty Hybrid

2009

Decreasing Cd & RR vs. time means more regen energy available

2020

Next Gen Architecture

Turbo-compounding

Electrification

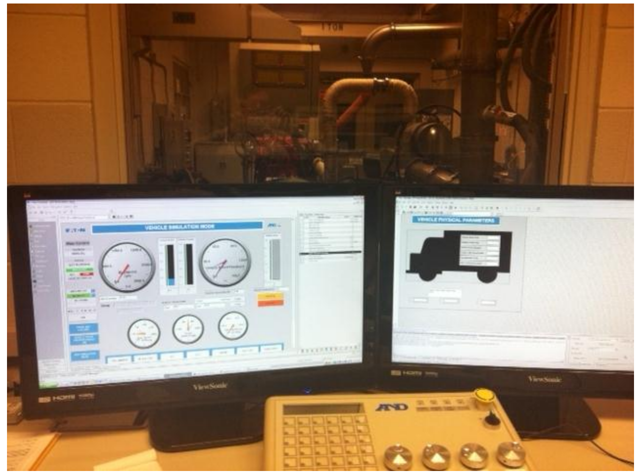
- 44kW motor
- 8kWh battery
- 5-10% time coasting/braking
- 4% average fuel economy (**6 mpg**)
- 660 gal/ year = $2640/ year
- $45,000 / system

- 90kW motor
- 23kWh battery
- 15-30% time coasting/braking
- 15% average fuel economy (**9 mpg**)
- 1660 gal/ year = $6640/ year
- $20,000 / system (500/kWh)

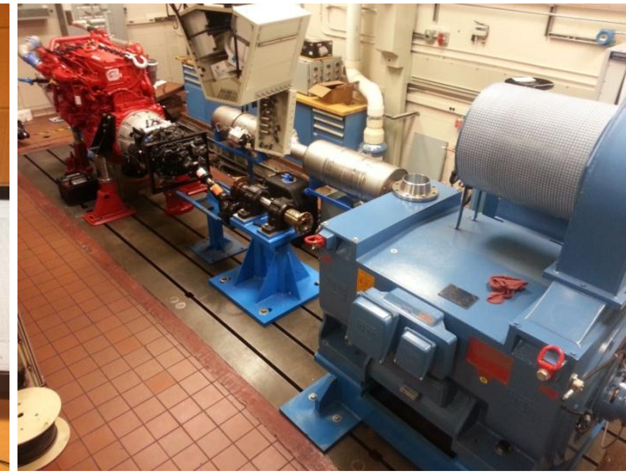
Powertrain testing

MD and HD Powertrain Dynamometers

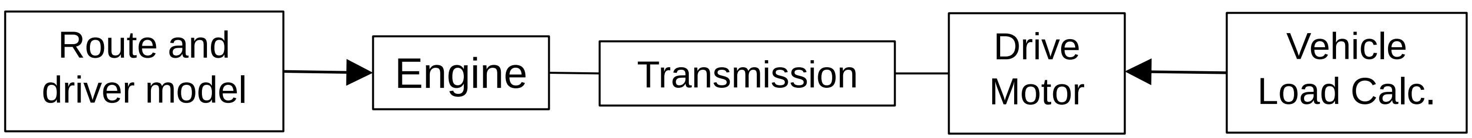
Medium duty cell: HV trans + ISB



Simulation: vehicle, road, driver



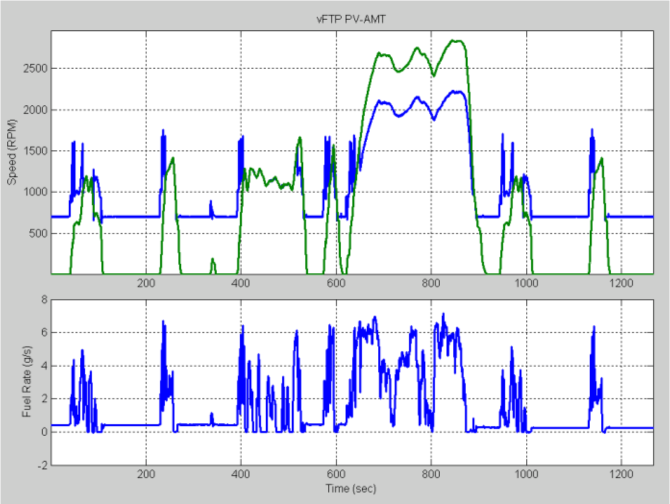
Heavy Duty: Fuller Advantage + 15L ISX



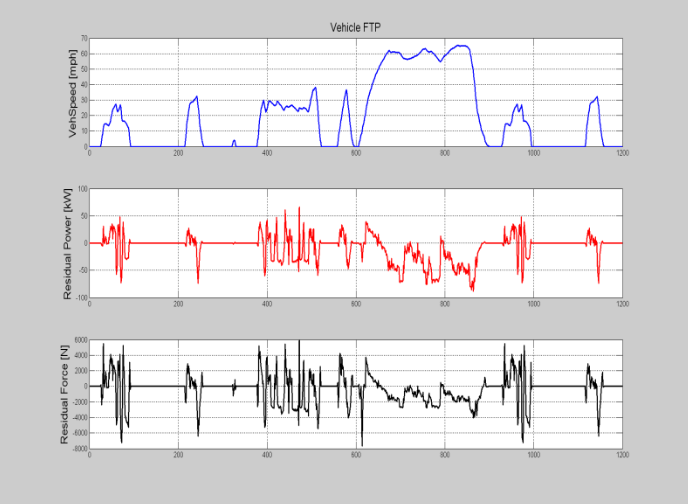
- Simulated vehicle with real engine & transmission
- Fully exercises real engine and transmission controls
- Quantifies engine-transmission deep integration optimization
- Vehicle simulations: multiple drive cycles and vehicle configurations
- MD and HD cells build with similar configuration to: SwRI, EPA, ORNL
- Eaton engine test cell update costs: $600k capital, $300k labor

Powertrain testing
Test procedure development for GHG Phase 2

6-Speed MD Transmission



18 Speed transmission



- MD cell operating for ~ 1 year
- HD cell is now in commissioning process
- We have been successful in running various vehicle cycles on MD-AMT, and MD-hybrid transmissions
- Results are repeatable
- We have been working to demonstrate the feasibility of powertrain based test procedures for GHG Phase 2

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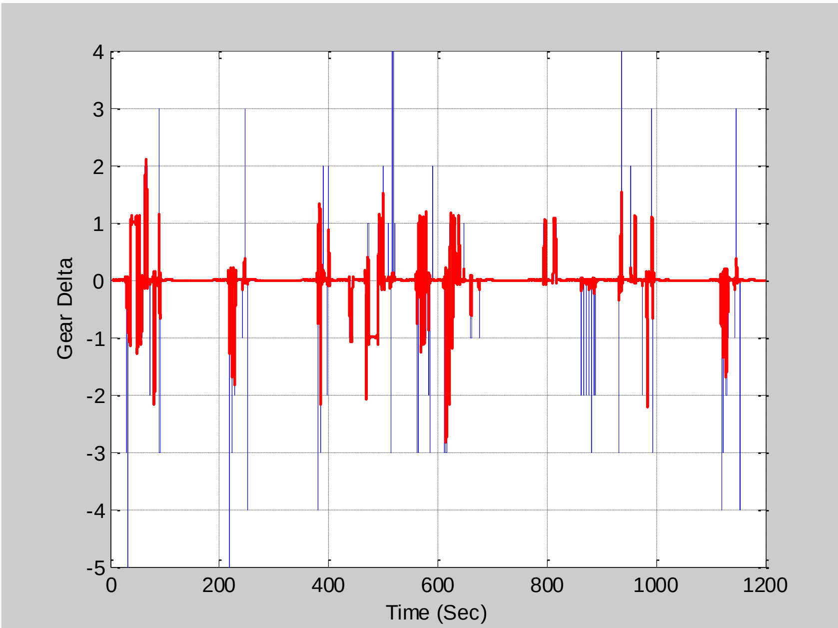
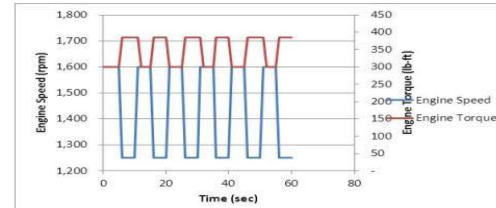
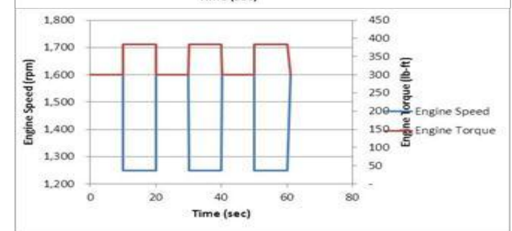
Motivation for powertrain testing



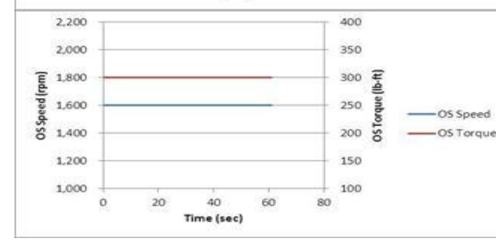
High transient



Med. transient



Steady state



- Gear Cmd delta between simple gear selection strategy, and actual control model on 18 speed AMT
- With more integrated engine and transmission it is difficult to accurately capture powertrain behavior without real control models

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Conclusions

1. Transmission technology is a key enabler to significant CO_2 reduction
   - 2014-2018: Deep transmission-engine integration driving moderate downspeeding, and increased automation in linehaul:
     - 3-6% improvement in linehaul; 8-12% improvement in vocational
   - 2020 and beyond: Significant penetration of power shifting, enabling engine downspeeding and optimization
2. Hybrid affordability realized through deep integration with the transmission
   - Vehicle load improvements present significant opportunity for HD hybrids
3. Powertrain certification drives CO_2 reductions
   - Recognizes and rewards deep integration and justifies controls investments
   - Objective and verifiable: drives compliance and enforcement
   - Low cost: $600k capital upgrade for both powertrain and vehicle HILS in same framework

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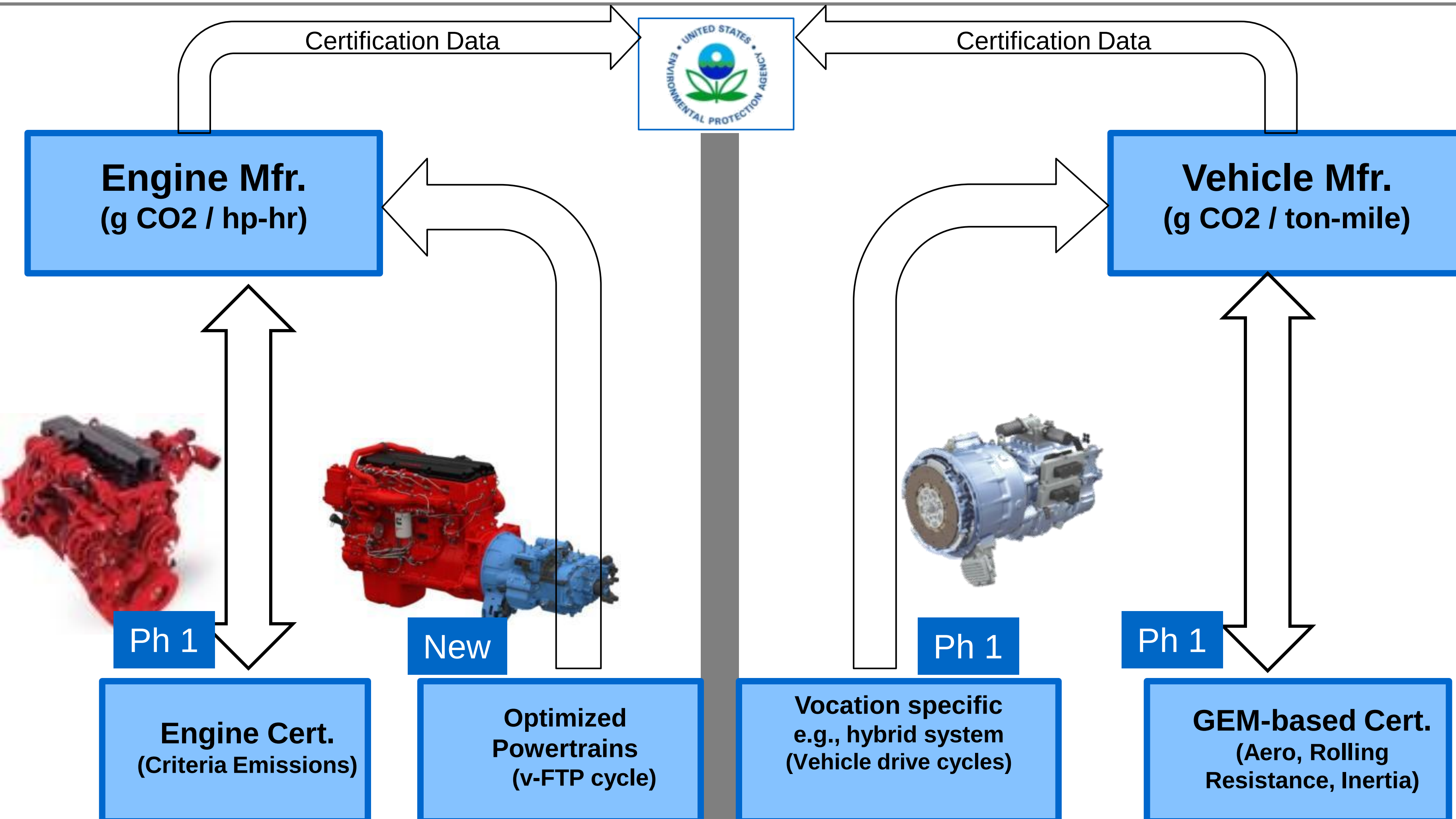
Regulatory structure

Achieve EPA objectives in maintaining the Phase 1 framework



Stricter standards drive technology, compliance and verifiable CO_2 reductions

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