DAIMLER

ACEEE / ICCT Workshop on Emerging Technologies for Heavy-Duty Fuel Efficiency

- Downspeeding and Downsizing

WESTERN STAR

FREIGHTLINER

DETROIT

Thomas BUILT BUSES

FUSO

Detroit Diesel ad c.1961

July 22, 2014

Don Keski-Hynnila

Major drivers in 2020 from global HD powertrain perspective differ across markets

	Competition	Legislation	Cost Reduction	Size/Weight
TE	Fuel Economy Leadership	CO_2		Weight
TN	Fuel Economy Leadership	GHG 2020		Weight
TA	Fuel Economy Leadership	pJP15 FES (2023?) tbd		Weight

Fuel Economy Leadership is a, if not the, major driver in all marketplaces!

Vehicle and Drivetrain

Vehicle Improvements

- Aerodynamic improvements
  - Tractor
  - Trailer
- Tire rolling resistance
- Accessory management
- Weight
- Other

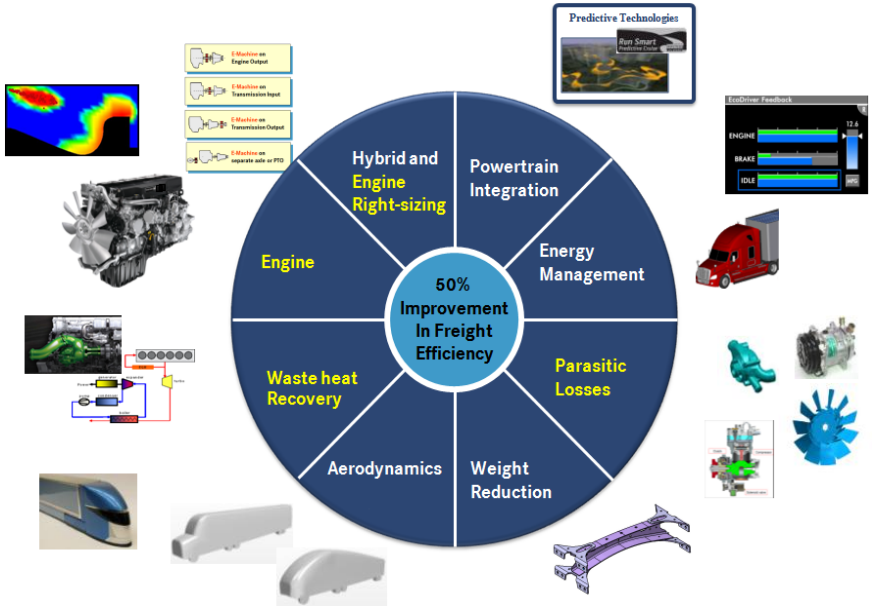
with

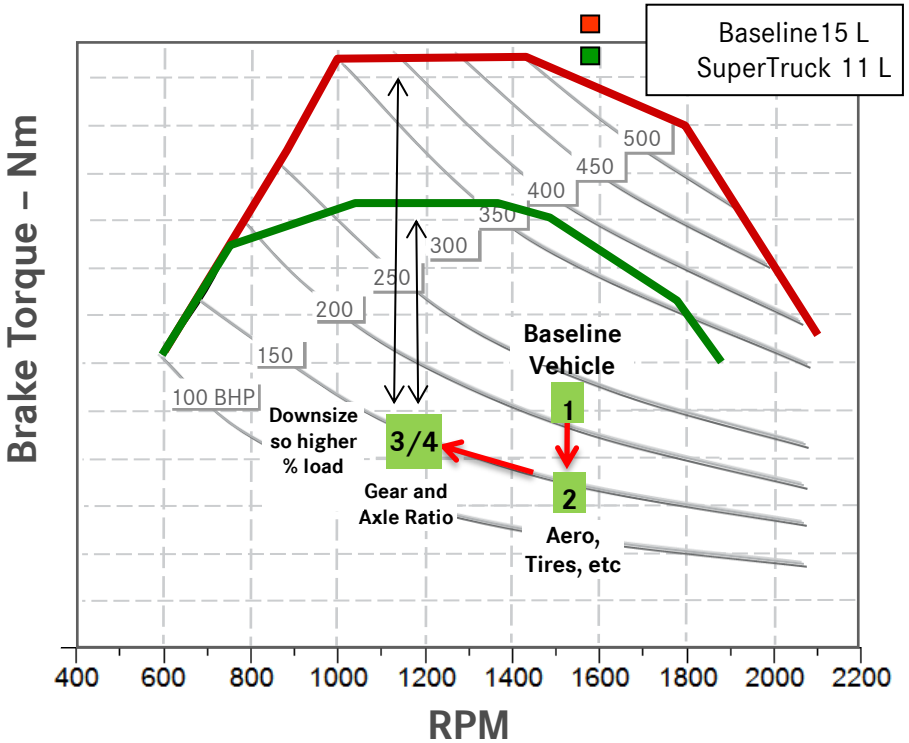
Optimization for fuel efficiency requires integrated vehicle, engine, transmission, axle and controls development approach.

Daimler Truck SuperTruck Program Goals

Evaluate technologies capable of demonstrating potential for a 50% increase in vehicle freight efficiency:

- 30% increase via vehicle improvements.
- 20% increase via engine improvements; specifically 50% brake thermal efficiency.
  - Identify pathway to 55% brake thermal efficiency via modeling and analysis.

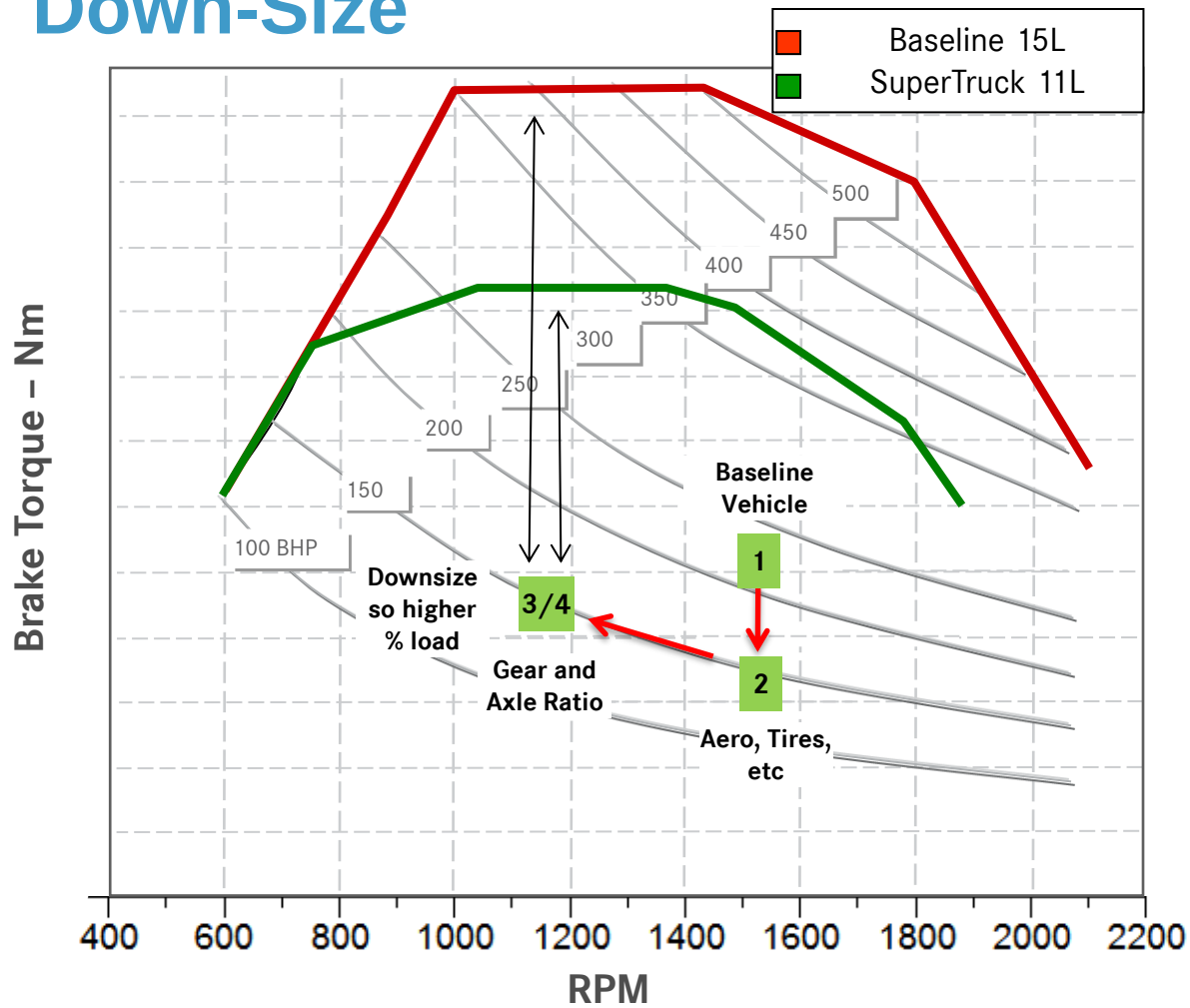




PARTNERS

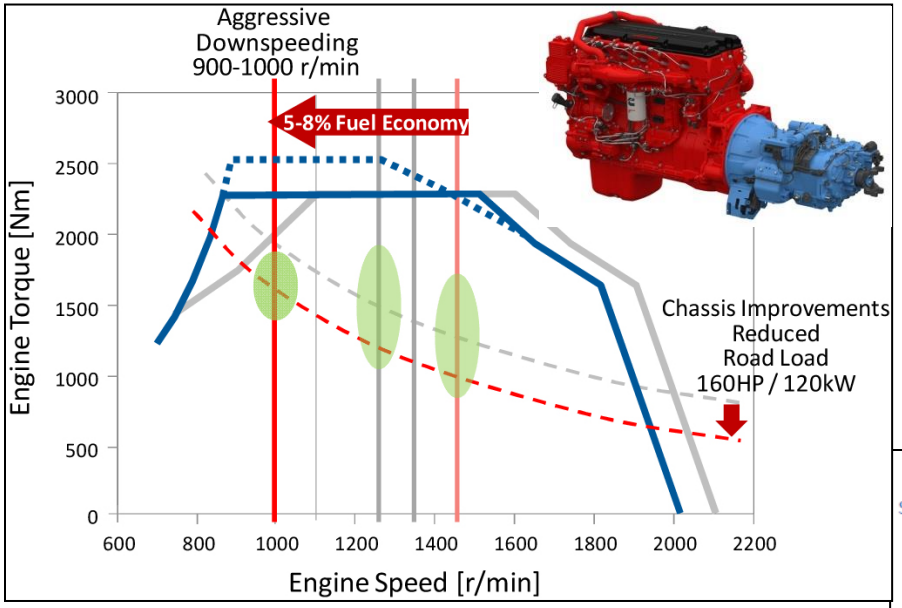
- Department of Energy
- Oak Ridge National Laboratory
- Massachusetts Institute of Technology
- Atkinson LLC

SuperTruck Concept: Engine Down-Speed and Down-Size



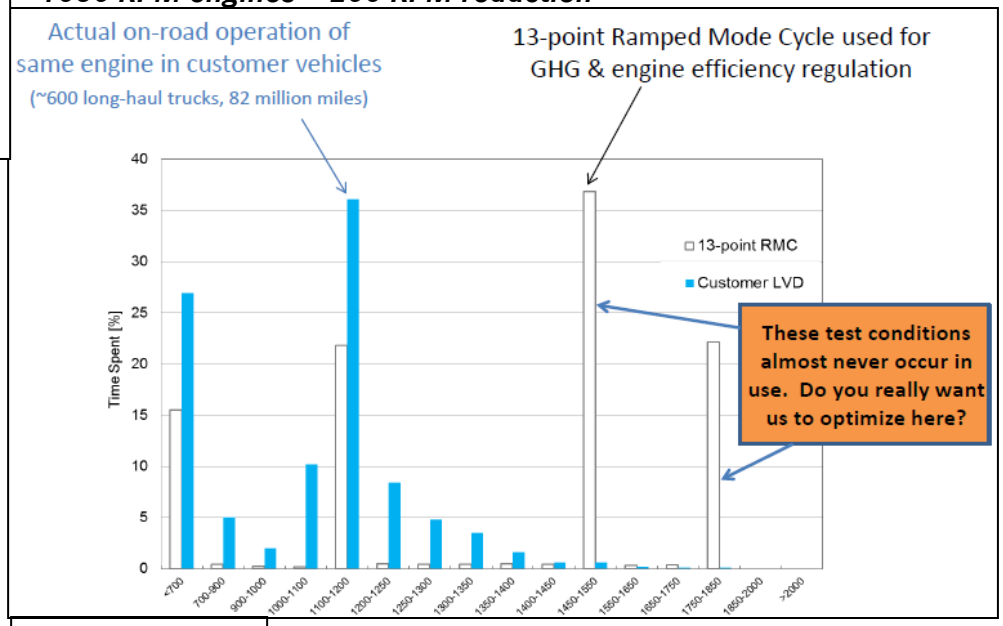
- 1 → 2
  - Efficient vehicle – better aerodynamics, reduced rolling resistance, etc.
- 2 → 3
  - Downspeeding
- 3 → 4
  - Downsize from 15L to 11L to increase road load BMEP

Downspeeding – industry snapshot



Cummins – SAE 2013-24-0094

Volvo "XE" powertrain packages optimized to max torque @ 1050 RPM engines – 200 RPM reduction

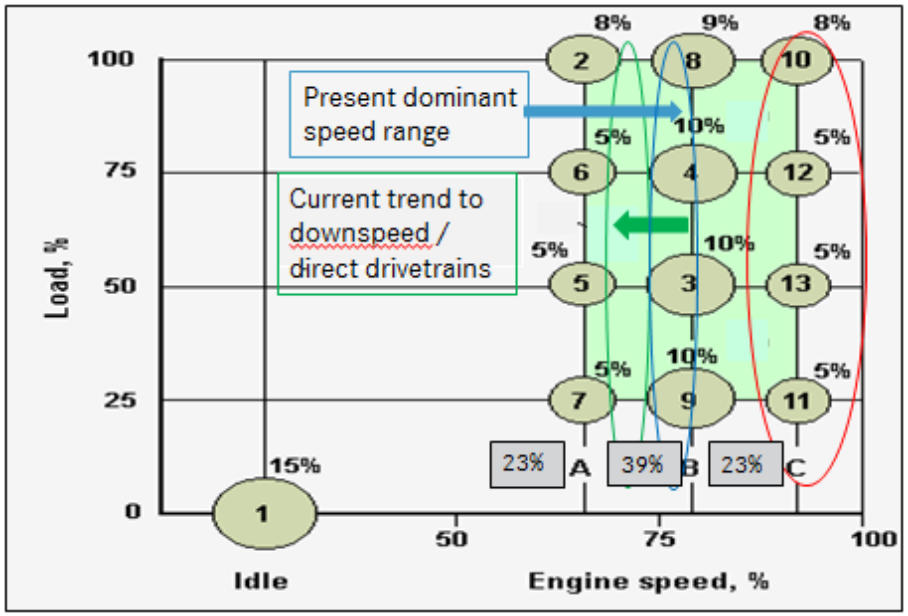


Courtesy of Volvo

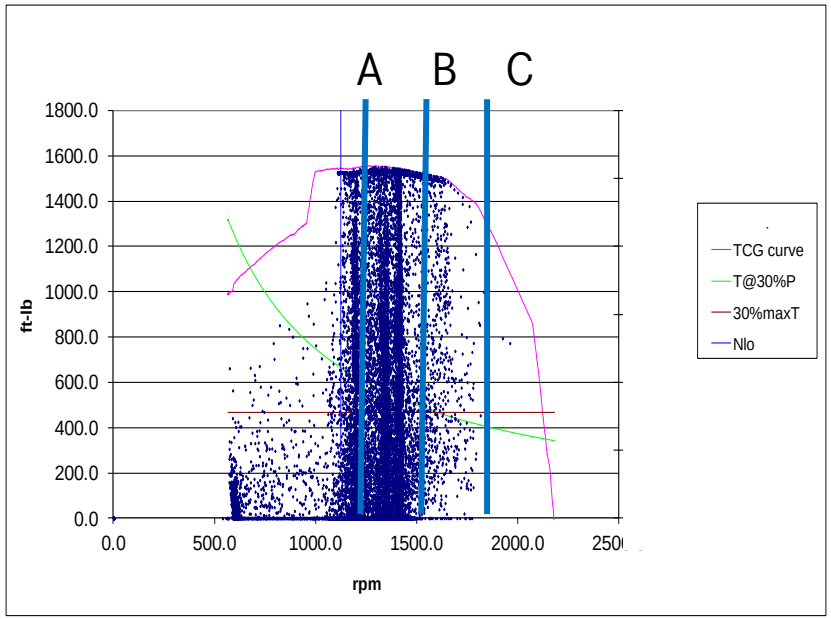
- **Push to optimized drivetrains having lower operating speeds is consistent across the HD Class 8 truck industry.**

Downspeeding – comparison to emissions test cycle

- Development towards lower operating speeds for fuel efficiency improvement
  - Shifts operation to lowest speeds of existing Supplemental Emissions Test cycle (SET) test speeds



Supplemental emissions test points

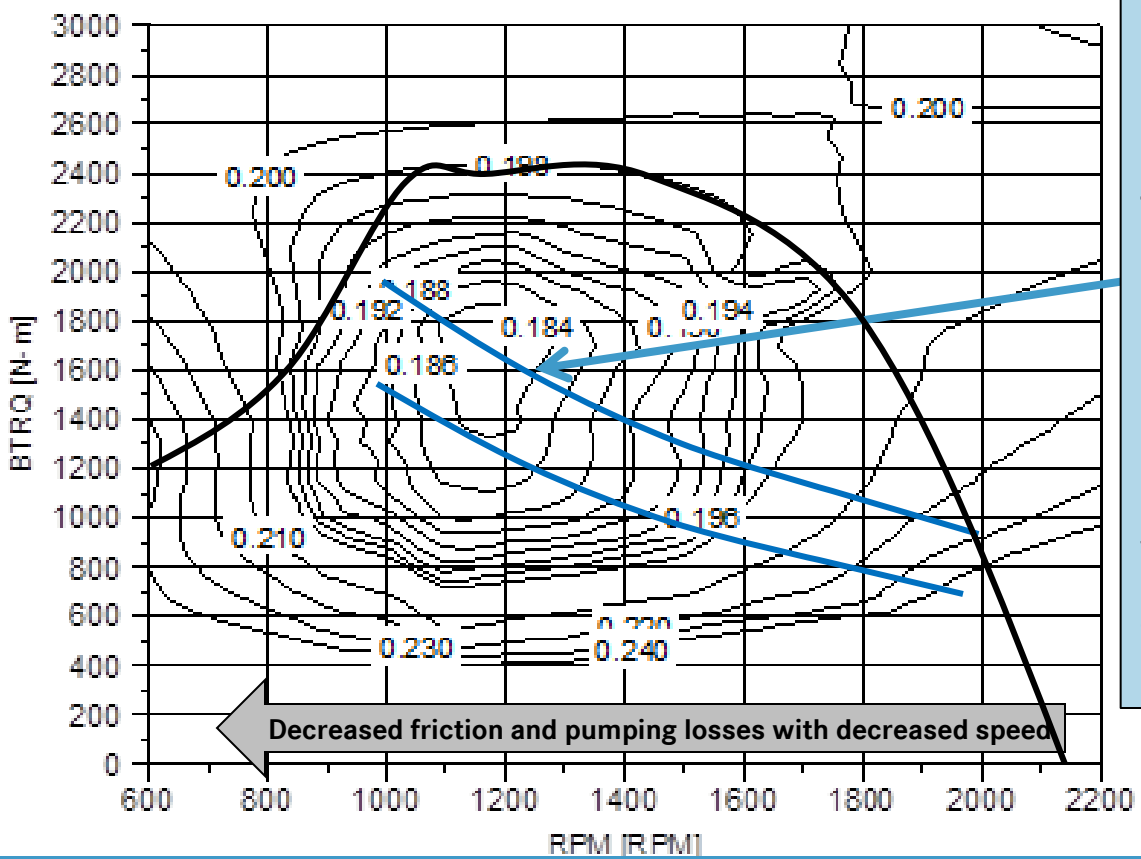


Typical in-use test result

Inclusion of actual engine fuel map within drive cycle simulation tool will link actual engine operation with evolving drivetrains and changing operation speeds.

Downspeeding – Efficiency Improvement

EPA Phase 1 Generic GEM fuel map



Efficiency improvement potential: Dependent on multiple factors including map characteristics, axle ratio, transmission ratios, tire size, vehicle aero, weight, tire rolling resistance, vehicle drive cycle, governed vehicle speed.

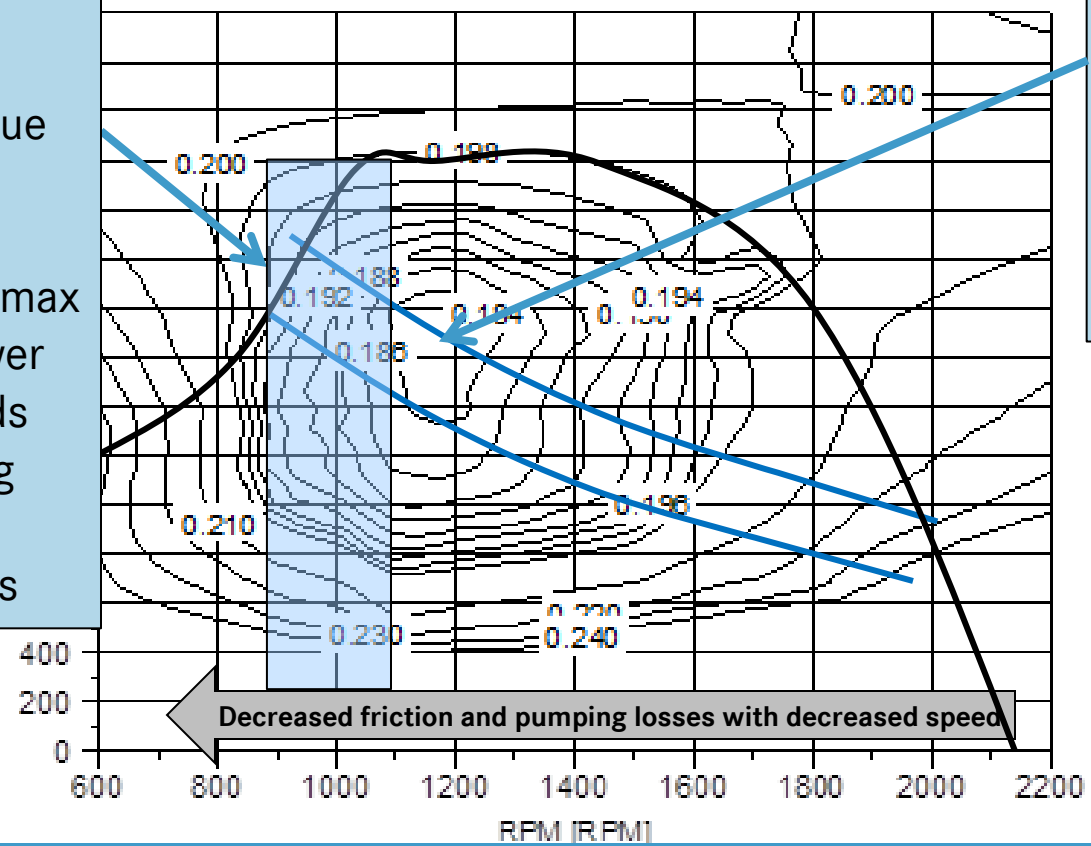
Efficiency improvements are realized as operating speeds decrease and losses due to friction and pumping are reduced, actual fuel map in GEM is essential.

Downspeeding – Drivability

Drivability:
Shrinkage of operating range with usable torque creates new demands

- Extension of max torque to lower engine speeds
- Rapid shifting automated transmissions

EPA Phase 1 Generic GEM fuel map



Constant power:
Driveline optimization for reduced operating speed necessitates higher operating torque to meet road load requirements.

Downsped operation requires development of higher torque capacity at lower engine speeds. Actual torque curve in simulation tools is needed.

Downspeeding – Areas of Development

- To maintain required road load horsepower at reduced engine speeds, higher drivetrain torque capacity is required since HP = [(Engine speed) * (Torque) / Constant]
  - Driveline robustness to handle higher operating torques
    - Size and weight tradeoff
  - Engine redesign for higher torque output at lower engine speeds
    - Limited by thermodynamics and
    - Mechanical limits of core engine
- As engine speed at highway cruise conditions decreases, the usable engine speed range diminishes (since minimum engine speeds are unchanged)
  - Automated manual transmissions for faster shift capability
  - Possible need for dual clutch technology

Downsizing Limitations for Commercial Trucking

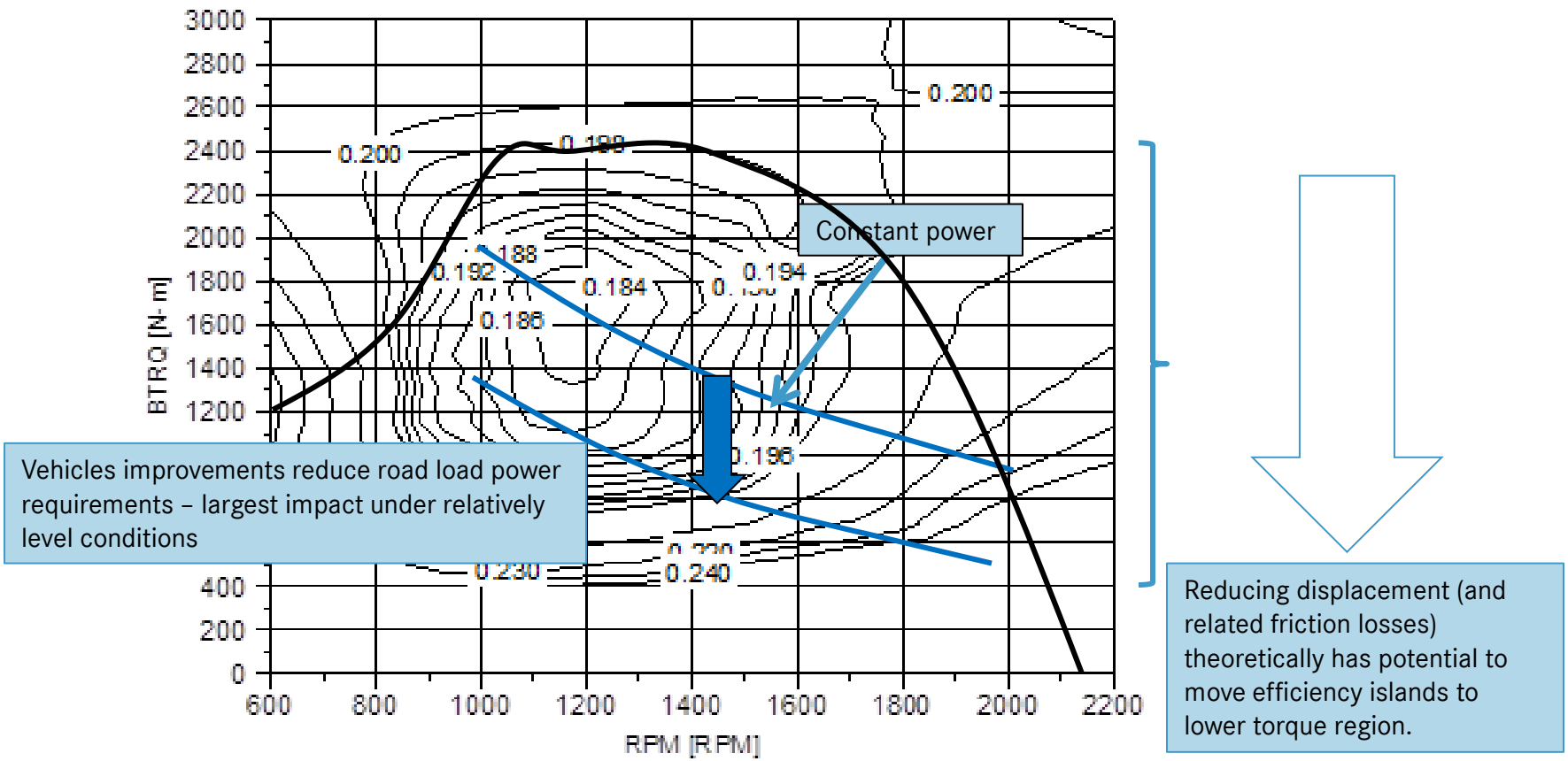
	2014 LDV	2014 Cascadia
Engine	2.0L I-4	12.8L DD13
Horsepower	160hp @ 6500rpm	350hp @ 1800rpm
Torque	146lb-ft @ 4450rpm	1350lb-ft @ 1100 rpm
Curb Weight/GVW (lbs)	2,948	60,000
Speed (mph)	62	62
Grade Resistance (hp)	15	298
Grade Power % of Total Power	9%	85%

+298 hp due to 3% Grade

+15 hp due to 3% Grade

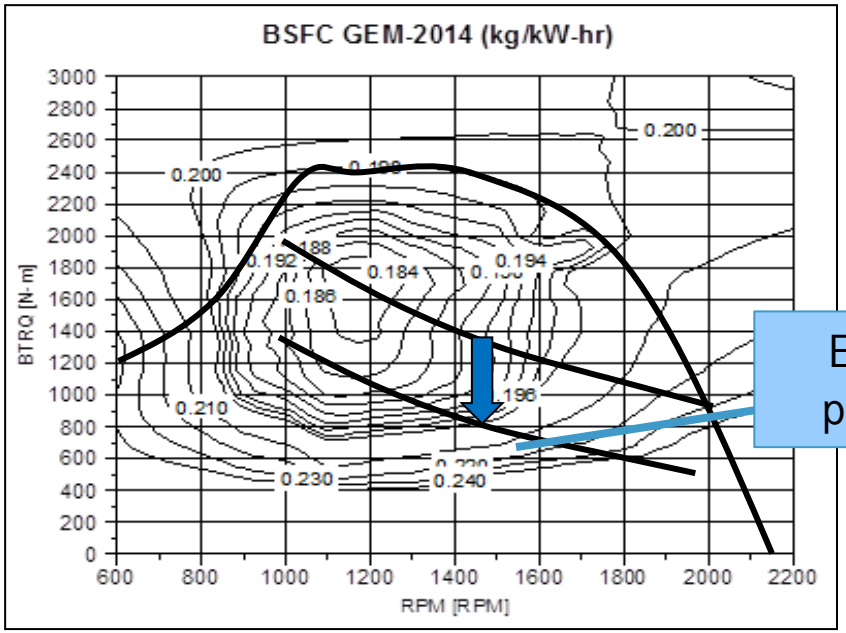
Engine Downsizing - Concept

EPA Phase 1 Generic GEM fuel map

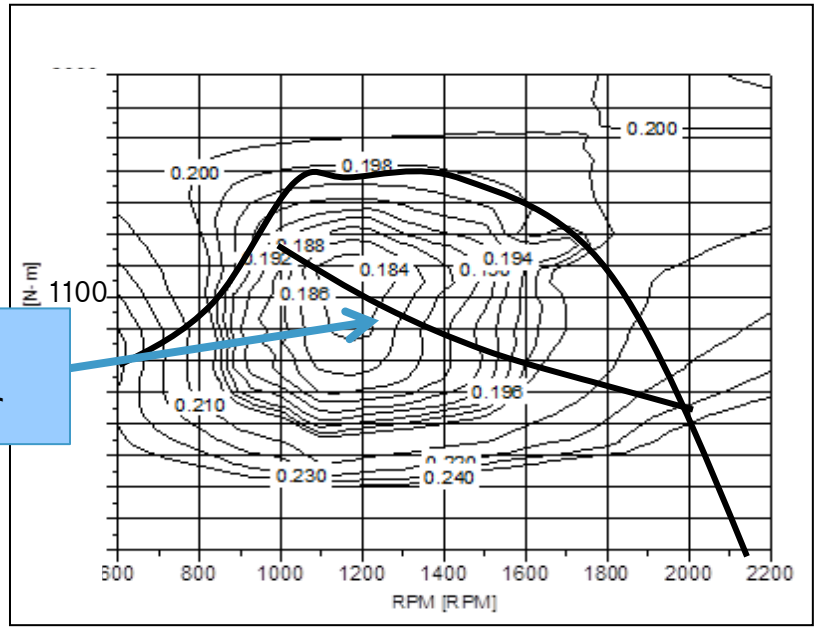


Engine Downsizing – Example Concept

Base engine



Downsized engine



Equal power

Base and downsized engines have same brake specific fuel consumption characteristics as measured on the RMC test cycle, however, the downsized engine theoretically produces lower CO2 under level road load conditions.

Benefits of downsizing for improved efficiency are not recognized by the RMC, but will be in simulations using the actual torque curve and map.

Engine Downsizing – tradeoffs

- Improved efficiencies at lower displacement have not been demonstrated
  - Increased thermal losses due to less favorable surface/volume ratio, exacerbated at lower operating speeds
- Torque capacity diminishes as displacement decreases, especially at low engine speeds, due to brake mean effective pressure constraints.
  - Compromises drivability
  - Increased operation at higher BMEP generally sacrifices B50 Life to wearout
- Residual value – The secondary market places a higher value on lager displacement engines which factors into the customer's TCO equation at the end of the trade cycle.

Engine downsizing trade-offs

Factor	Larger Displacement	Smaller Displacement
Weight	-	+
Gradability	+	-
Friction	-	+
Life Expectancy	+	-
Packaging	-	+
Heat Rejection	+	-
ATS Performance	-	+
NVH	+	-
Backpressure sensitivity	+	-

"+" = advantage
"-" = disadvantage

Summary

- Truck and engine manufacturers are focused, and can be expected to continue to focus, on powertrain optimization at lower operating speeds for efficiency improvement.
  - Trends show increasing customer adoption of downsped powertrains
  - Development of drivetrain components (transmissions, prop shafts, joints, differentials, axles, etc.) with increased robustness goes hand in hand with downspeeding.
  - Engine operating speed range, torque capacity, and associated tradeoffs must be considered.
- Engine downsizing must consider numerous trade-offs
  - No “one size fits all” solution.
  - A range of displacements is necessary to meet power and torque requirements across a broad range of applications.

Thank you for your time! Questions?