HEAVY DUTY DIESEL ENGINE OIL FUEL ECONOMY: TODAY, TOMORROW AND BEYOND

David Brass

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Outline

Topics

- What is PC-11
- Enabling fuel economy
- Maintaining durability while enabling fuel economy
- Advancing fuel economy for the future

PC-11 Category

- EMA requested new API category be introduced in 2016 to help meet latest government regulations requiring improved FE performance
  - Driven by EPA and NHTSA requirements to reduce GHG emissions and fuel consumption, mandatory by 2018
  - Engine Manufacturers targeting use of new oils starting with 2017 model year engines

New Tests

New Viscosity Grades & Limits

Oxidation Control	Aeration Control	Shear Stability	Fuel Economy	Volatility

Volvo T-13

Caterpillar Engine Oil Aeration Test

API CK-4

Fully backward compatible

SAE XW-30 and Heavier
HTHSV > 3.5 mPa·s
PC-11, ACEA

API FA-4

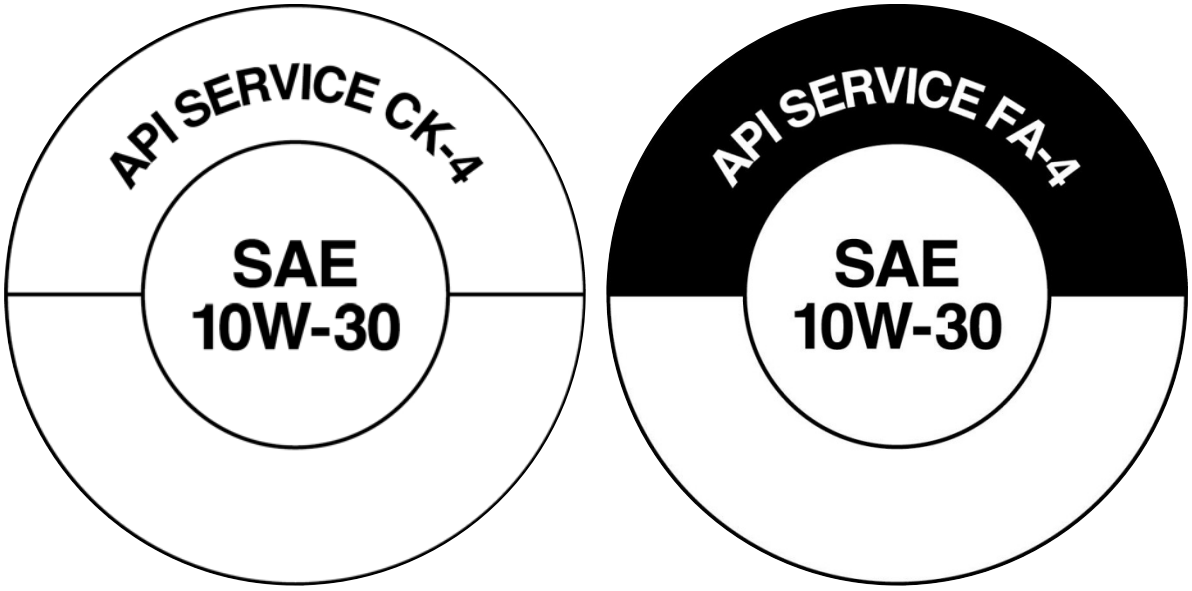
Backward serviceability uncertain

SAE XW-30
HTHSV: 2.9 – 3.2 mPa·s
PC-11, ACEA

PC-11 and Fuel Economy

PC-11 is introducing new, lower HTHS viscosity Heavy Duty engine oils to capture fuel economy.

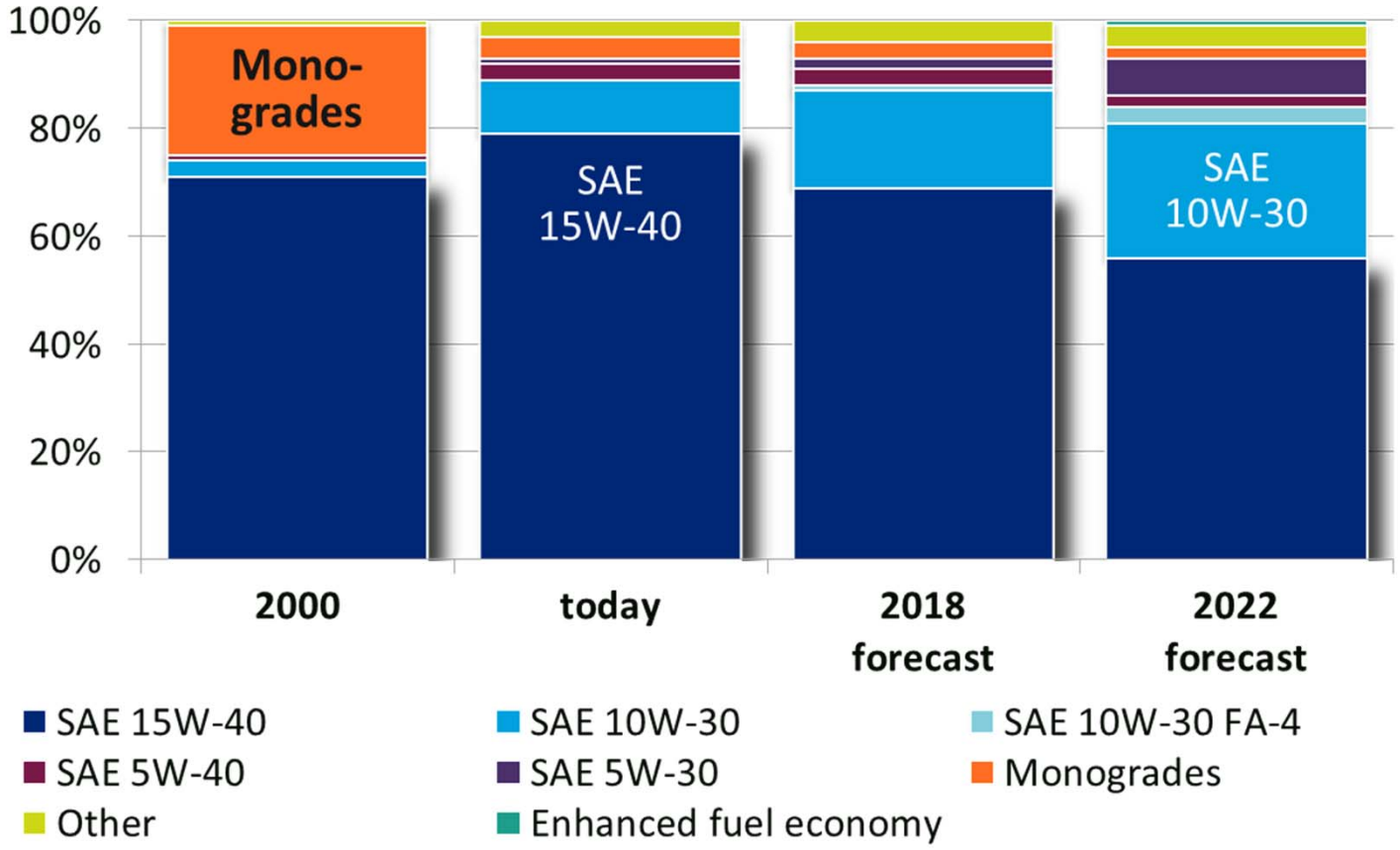
- PC-11 will further promote the growing trend to SAE 10W-30s.
- Market penetration of SAE 10W-30 API FA-4's will take time without broad back serviceability by all OEMs and limited applications at PC-11 launch



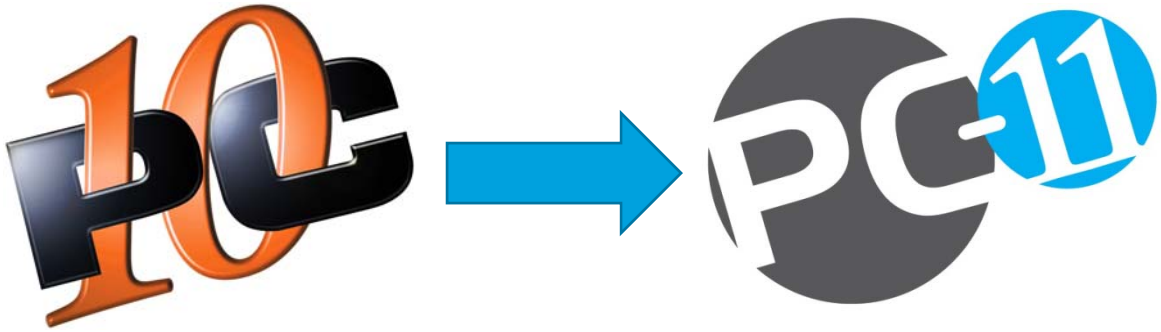
*Proposed API CK-4 and API FA-4 donuts under consideration by API

Evolution of Viscosity Grades for the Future

- Today = SAE 15W-40
- Tomorrow = SAE 10W-30
- Beyond = SAE 5W-30, 5W-20, 0W-XX oils



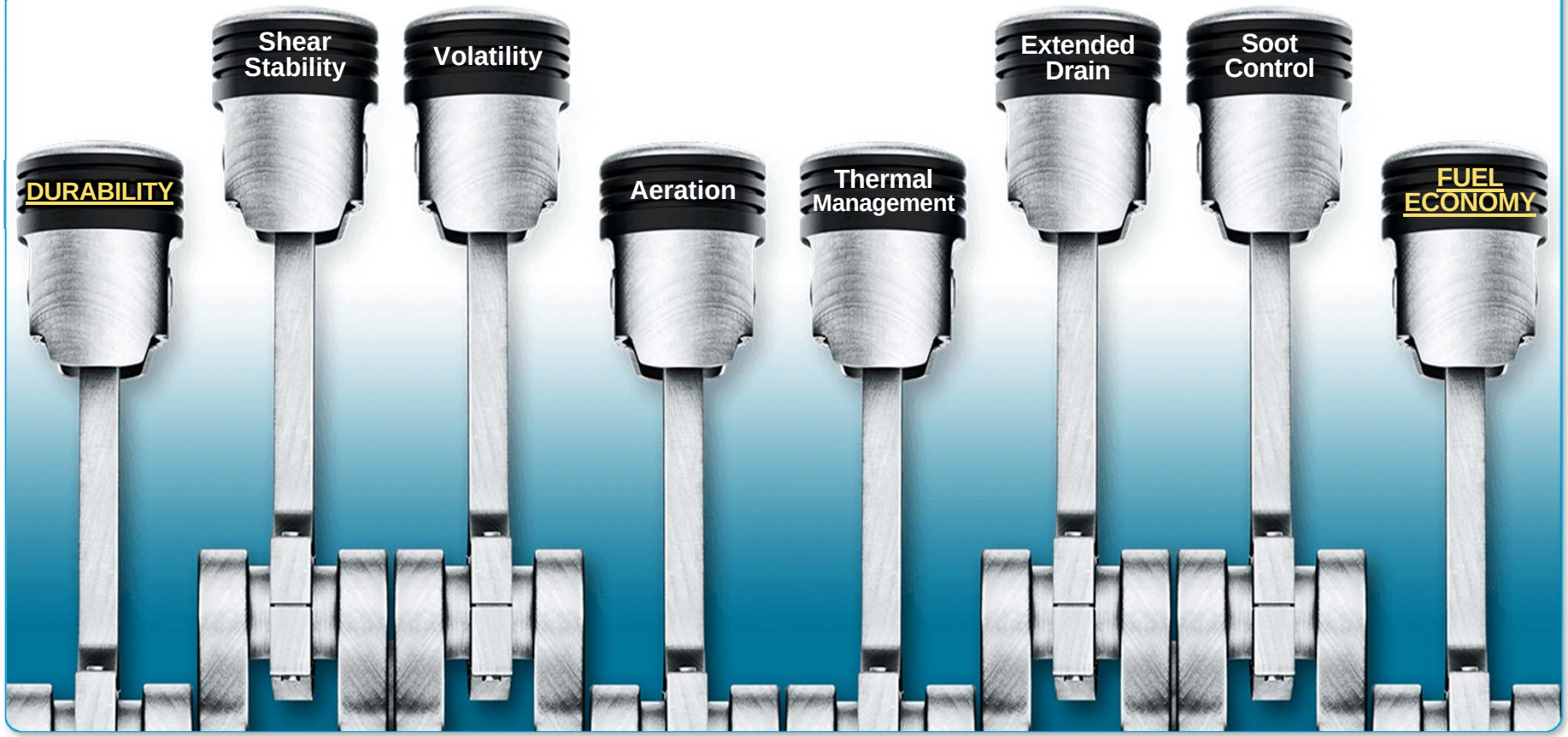
Changes in Demands on Oil from PC-10 to PC-11



Changes	Effect on Oil	Effect on Fuel Economy
Moderate EGR w/ SCR replacing Heavy EGR	Reduced soot level at drain from 3-4% to 1-2%	↑
Shear Stability Tightening	Less 35 SSI type polymers will be used	↓
Thermal management of engines leads to higher oil operating temperature in engines	Operating oil viscosities will be lower in the engine	↑
	Increased oxidation of the oil due to longer time spent at high temperatures	↓
Larger sump size and larger available oil supply	Reduced oxidation of oil	↑

Greater Demands on Oil

Robust durability is a must and needs to come together with fuel economy along with many critical factors that are integrated into PC-11



Enabling Fuel Economy

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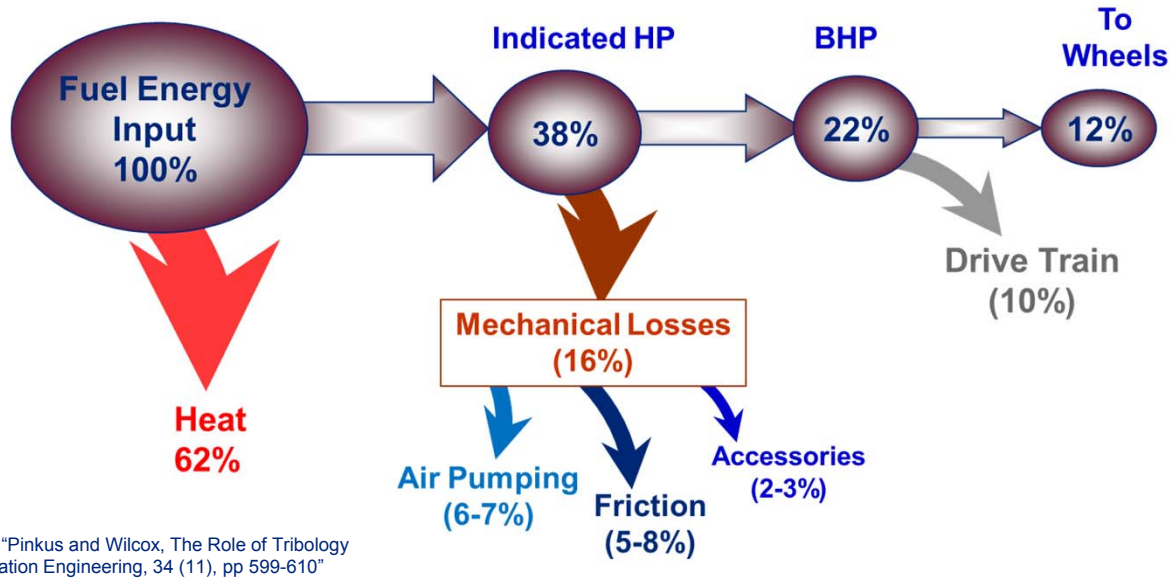
What Drives Fuel Economy

- Engine oil lubricants systems consume energy while pumping and engine oil films play a role determining frictional losses in engine operation
- Efficiency could be increased with a engine oil lubricant tailored to minimize friction and pumping losses
- **Durability** remains a paramount concern and should never be compromised or sacrificed for fuel economy benefits
- This requires a carefully balanced lubricant formulation with an optimized combination of additive components, viscosity modifiers and base oils.



Majority of the data taken from "Pinkus and Wilcox, The Role of Tribology in Energy Conservation, Lubrication Engineering, 34 (11), pp 599-610"

Benefits to Fuel Economy Improvement in Heavy Duty Diesel Engines

	Single Truck / Month
Miles Driven	10,000 Miles
Current MPG	7 MPG
Fuel used	1428.6 Gallons
Fuel Savings for 1% FEI	14.1 Gallons
	Single Truck / Year
Fuel Savings for 1% FEI	169.1 Gallons
Cost Savings ($2.50 / Gallon)	$422.8

- A fleet of 50 trucks can save ~$20k per year even with low diesel gas prices.
- 300k Class 8 trucks sold in NA in 2015, which would save 50.7M gallons of fuel/year and $127M/year at 1% FEI

Types of Fuel Economy Testing

J1321
Line Haul
Class 8 Trucks

Detroit Diesel Series 60
Detroit Diesel DD15

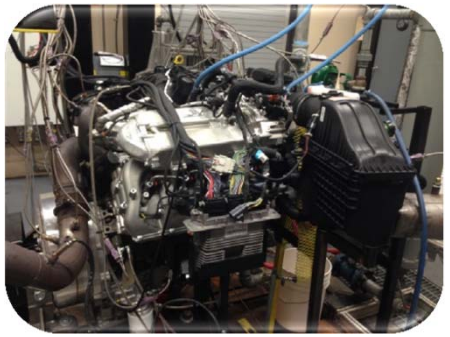
J1321
Stop & Go
Class 5/6 Trucks

IHDT466E
Ford 6.7L Power Stroke

Class 4-7 trucks make up just under 50% of commercial trucks

Engine
Dynamometer
Class 5 Engines

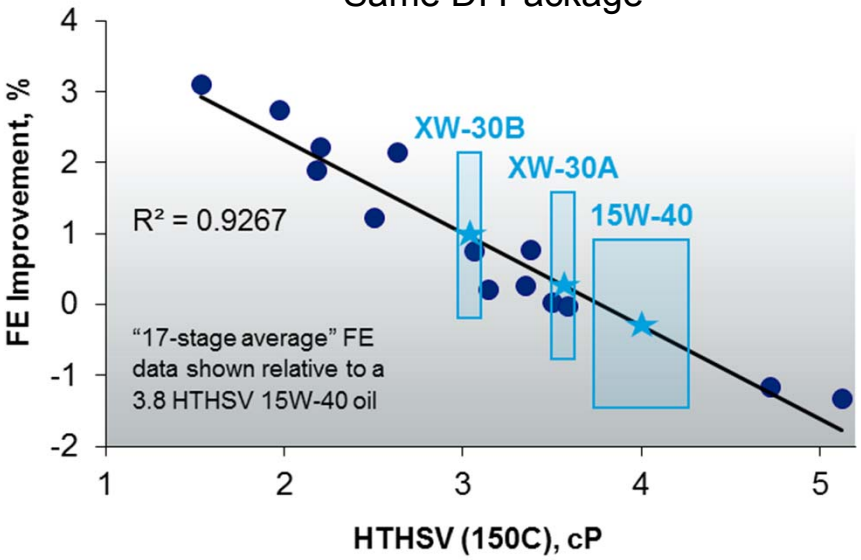
GM 6.5L
Ford 6.7L Power Stroke



Lower HTHS Viscosity Enables Improved Fuel Economy

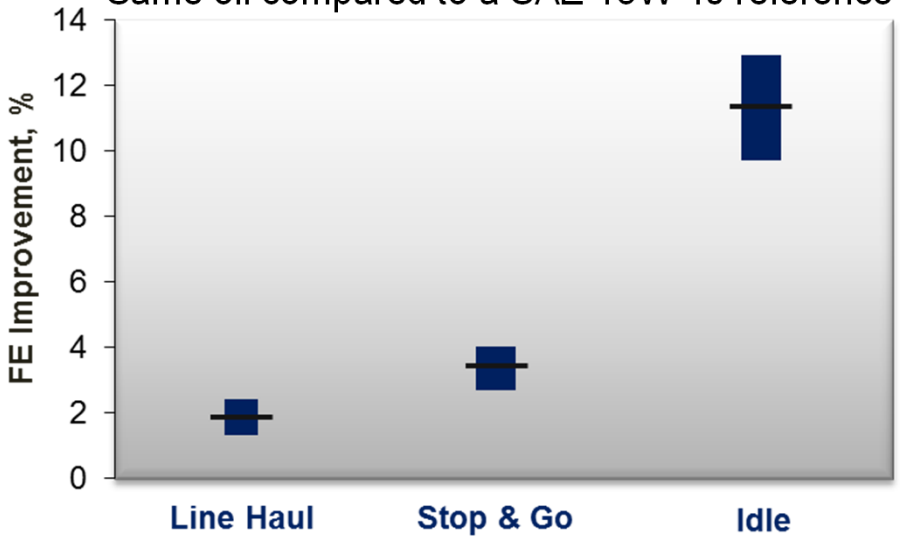
Lower HTHS Improves FE

Same DI Package



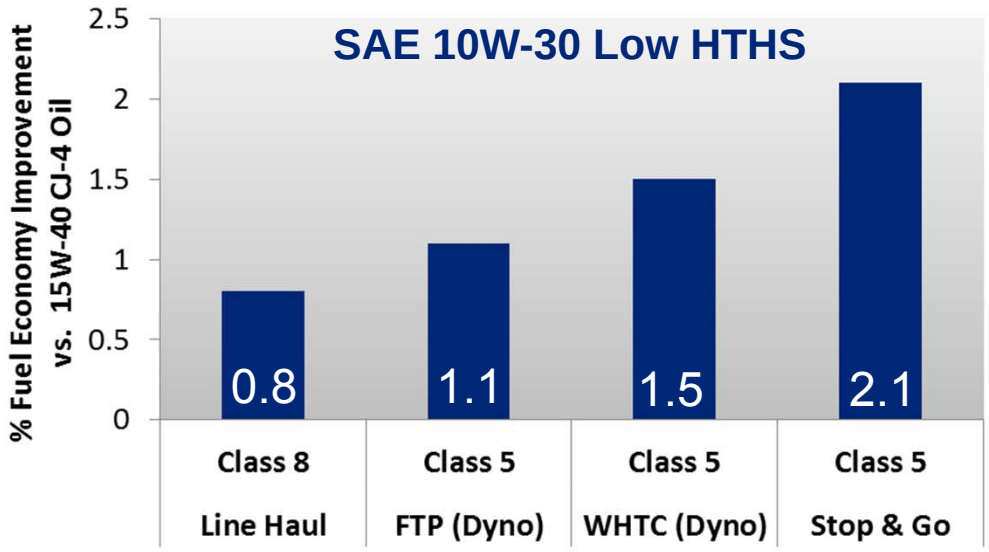
Drive Cycle Impacts FE Improvements

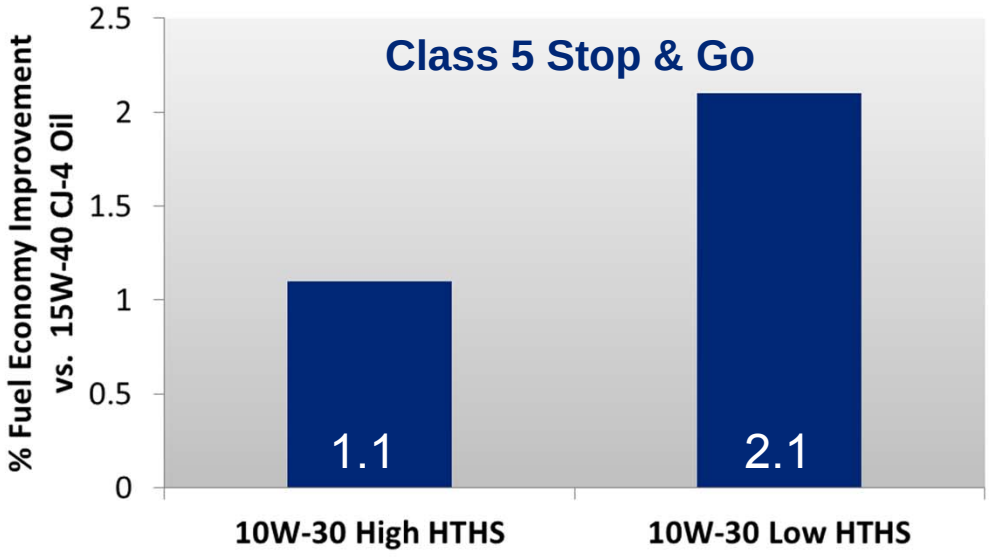
Same oil compared to a SAE 15W-40 reference



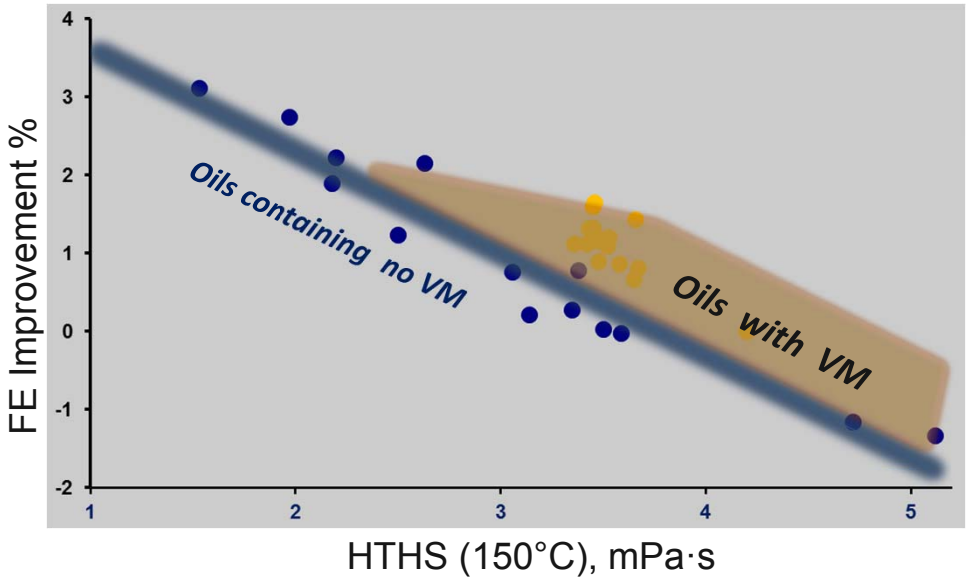
The reduction in viscosity grade from SAE 15W-40 to SAE 10W-30 (2.9-3.2 HTHS) will provide a boost in fuel economy.

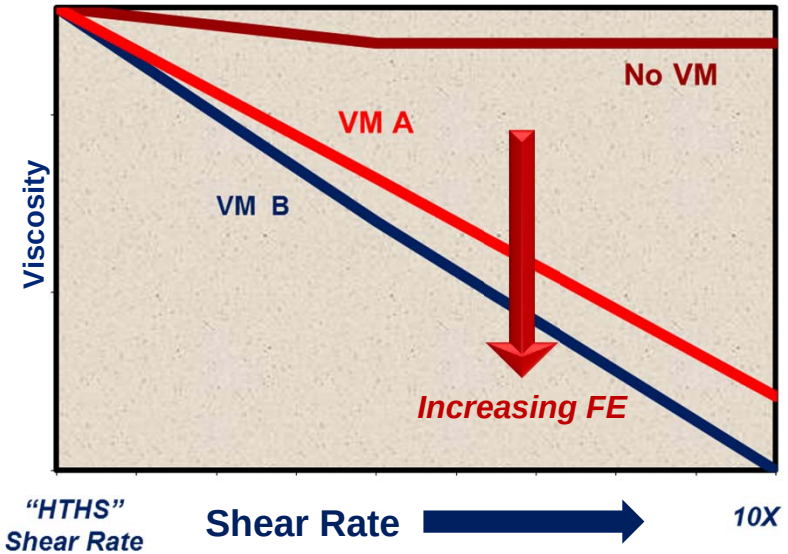
Fuel Economy Improvement for PC-11 Prototypes





Effect of Viscosity Modifiers on Fuel Economy

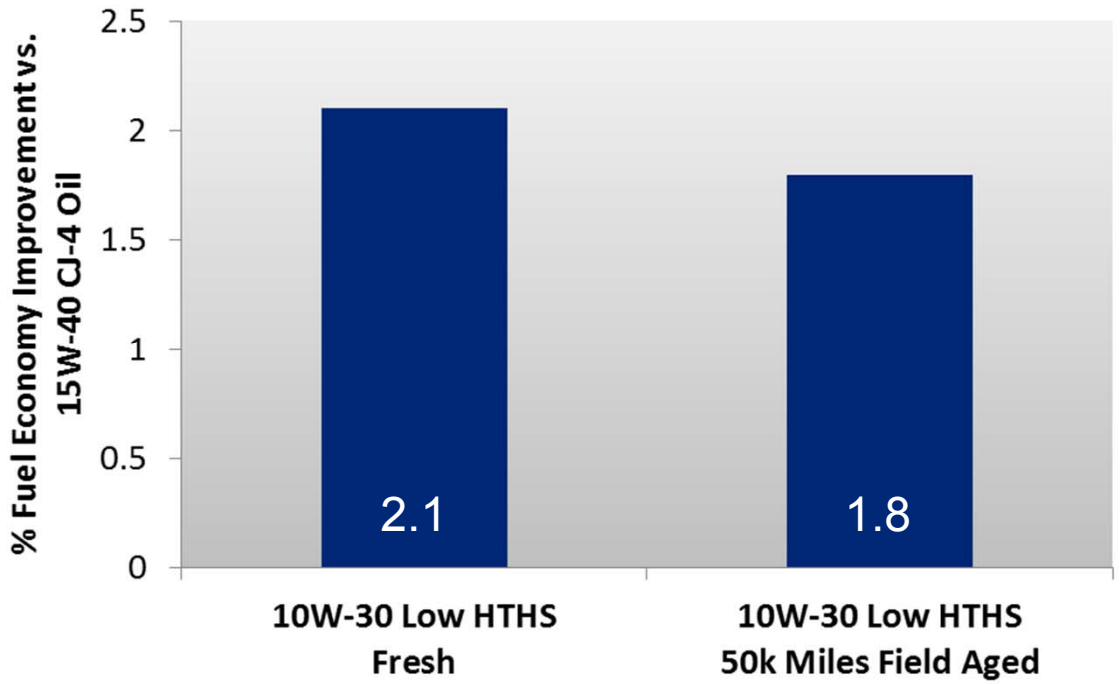




- The addition of viscosity modifiers to an oil improves fuel economy over a pure Newtonian oil
- Higher shear thinning polymers help more with fuel economy
- Limits on shear stability for PC-11 will restrict use of 35 SSI polymers
- Lower viscosity grades will use less viscosity modifiers

Retained Fuel Economy of PC-11 Prototype

- Increased oxidation strength will help to retain fuel economy for longer as viscosities will be held lower for longer



- PC-11 Prototype was able to maintain fuel economy improvement at 50k Miles field aging in DD15 engines which is the recommended oil drain interval for that service

Maintaining Durability While Enabling Fuel Economy

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Durability at New, Lower Viscosities

- For PC-11, durability must be maintained at lower viscosities
  - The performance in all legacy wear tests from API CJ-4 must be met at the lower viscosities

API CJ-4

Wear performance demonstrated at HTHS Viscosity of ≥ 3.5 cP

RFWT
Cummins ISB
Cummins ISM
Mack T-12

Maintain Protection

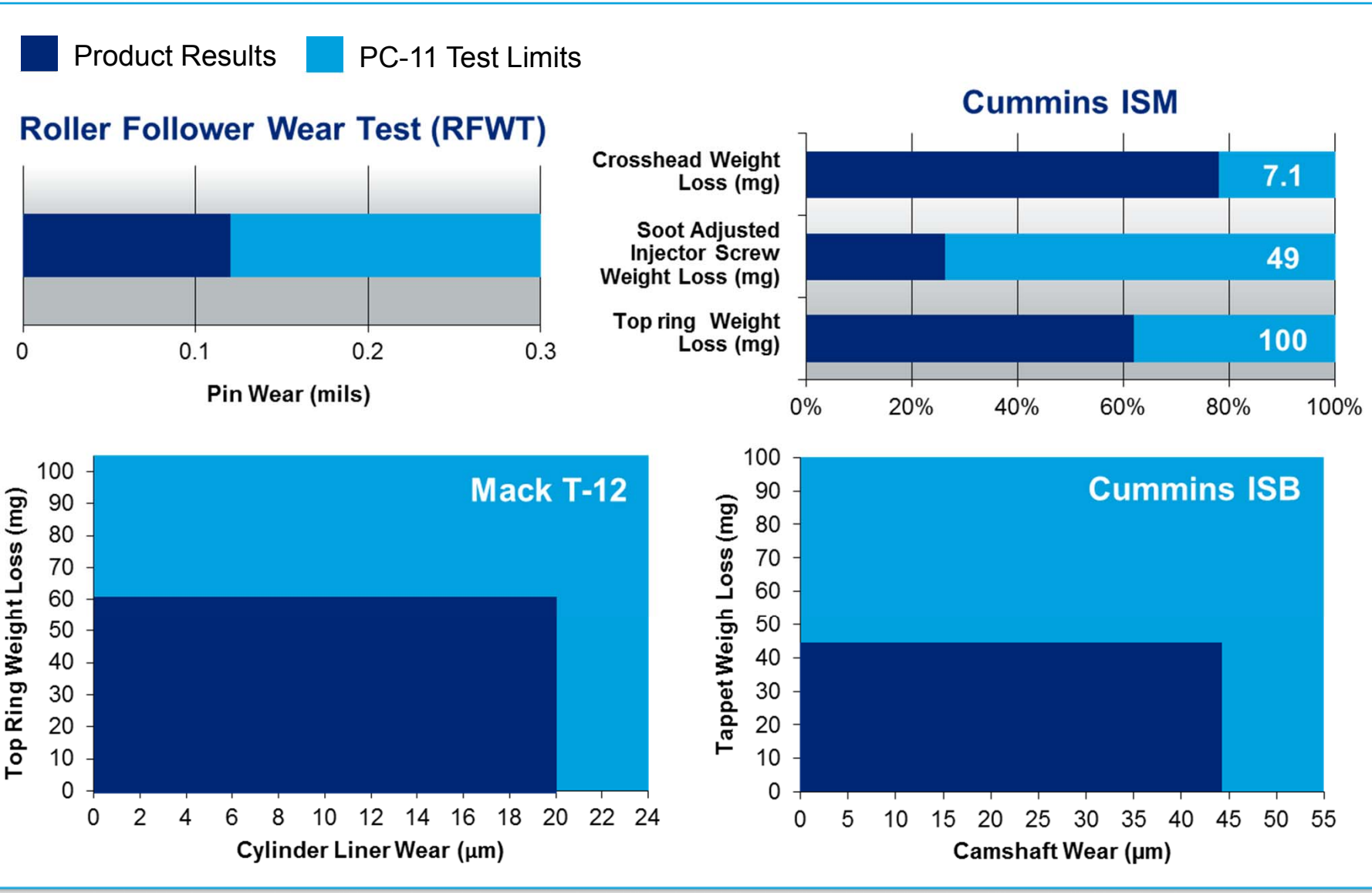
API FA-4

Wear performance demonstrated at HTHS Viscosity of 2.9 - 3.2 cP

RFWT
Cummins ISB
Cummins ISM
Mack T-12

Strong Wear Performance Achievable at Low Viscosity

All testing completed at 5.0 cSt BOV100 and 3.0 cP HTHSV150

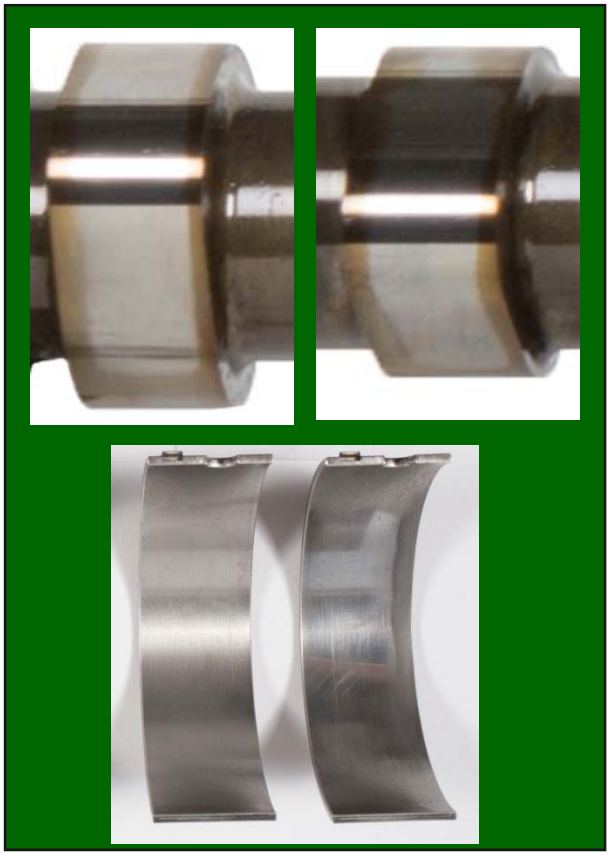


Formulation Balance is Critical for Durability and Fuel Economy

After 500k miles in the field unbalanced formulations can lead to durability concerns

Unbalanced Formulation

Balanced Formulation



Low viscosity oils can lead to fuel economy gains, but balanced formulations are needed to maintain durability

Advancing Fuel Economy For The Future

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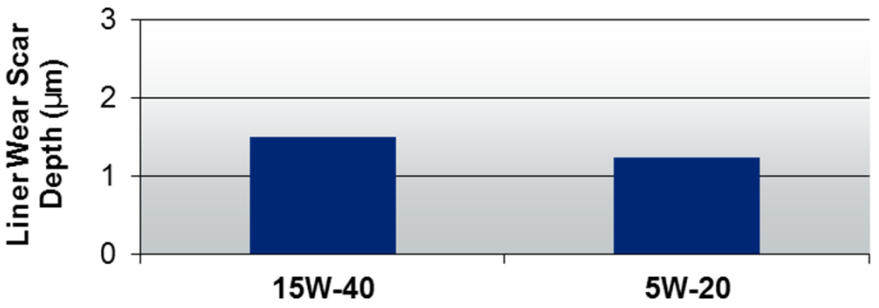
Enhanced Fuel Economy Lubricants Must Be Durability-Proven

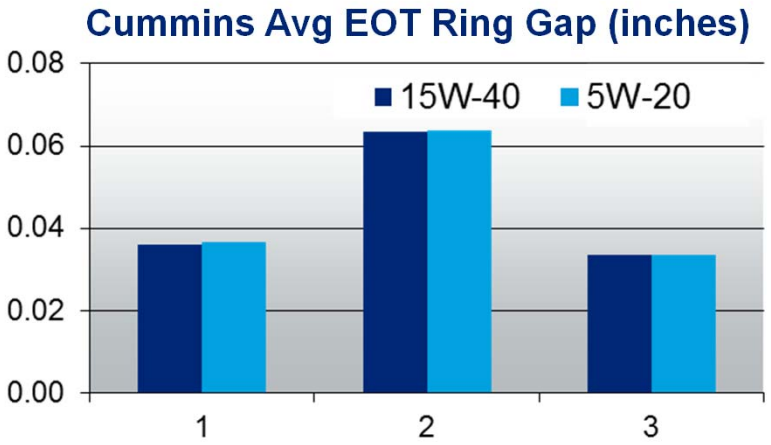
- SAE 5W-20 (2.6 HTHS) oils with Grp III/IV base stocks were engine/field tested and demonstrated “Fit for Purpose” performance in global API, ACEA and OEM specifications
- Was not qualified as API CJ-4 since formulation is below acceptable API HTHS minimum specification limit
- Demonstrates ability to meet PC-11 type qualifications with proper chemistry

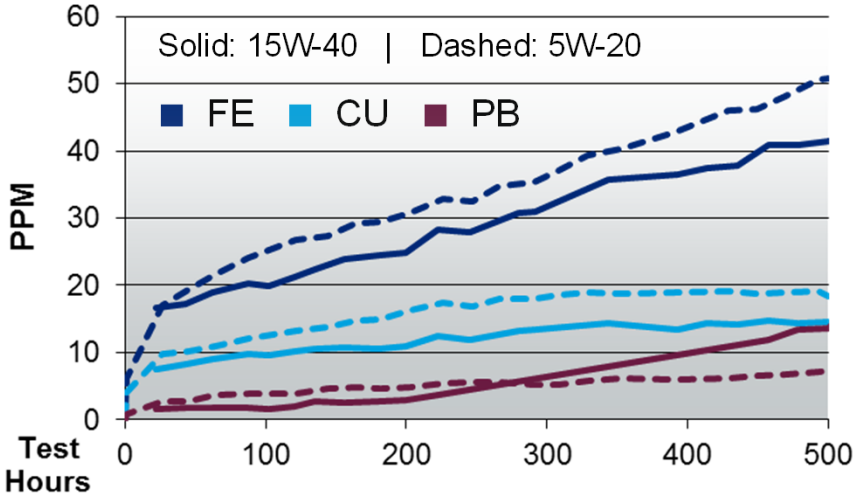
	Viscometric Results	SAE 5W-20 Limits
Kinematic Viscosity, 100°C, cSt	7.86	5.6 < x < 9.3
CCS, -30°C, cP	4560	6,600 max.
HTHS Viscosity,150°C, cP	2.6	2.6 min.

FE Demo Oil Project: Cummins ISX Durability Testing

- Two 500 hour tests at Cummins (2010 Engine, Cummins protocol):
  - 15W-40 (4.1 HTHS) Commercial CJ-4 oil
  - 5W-20 (2.5 HTHS) FE demo prototype oil with enhanced wear protection







- No appreciable wear difference between 15W-40 and 5W-20 in the Cummins cycle
- All wear metal parameters were below field condemning limits

Conclusion

- The PC-11 specification will introduce **two** new specifications: API CK-4 and FA-4
  - Introduces new, lower HTHS viscosity Heavy Duty engine oils to capture fuel economy
  - Requires increase in additive performance to provide significant benefits to end users especially in area of fuel economy and thermal degradation
- PC-11 will further promote the growing trend to SAE 10W-30s
  - Market penetration of SAE 10W-30 API FA-4's will take time due to lack of broad back serviceability by all OEMs and limited applications at launch
- Although Fuel Economy gains are dependent on drive cycle, the addition of the lower HTHS 10W-30 grade will boost fuel economy improvement by ~1%
- Further fuel economy improvements need to be balanced with formulation solutions that can ultimately maintain the durability of the engine