Lubricants - Pathway to Improving Fuel Efficiency of Legacy Fleet Vehicles

George Fenske, Layo Ajayi, Robert Erck, and Nicholaos Demas

Argonne National Laboratory

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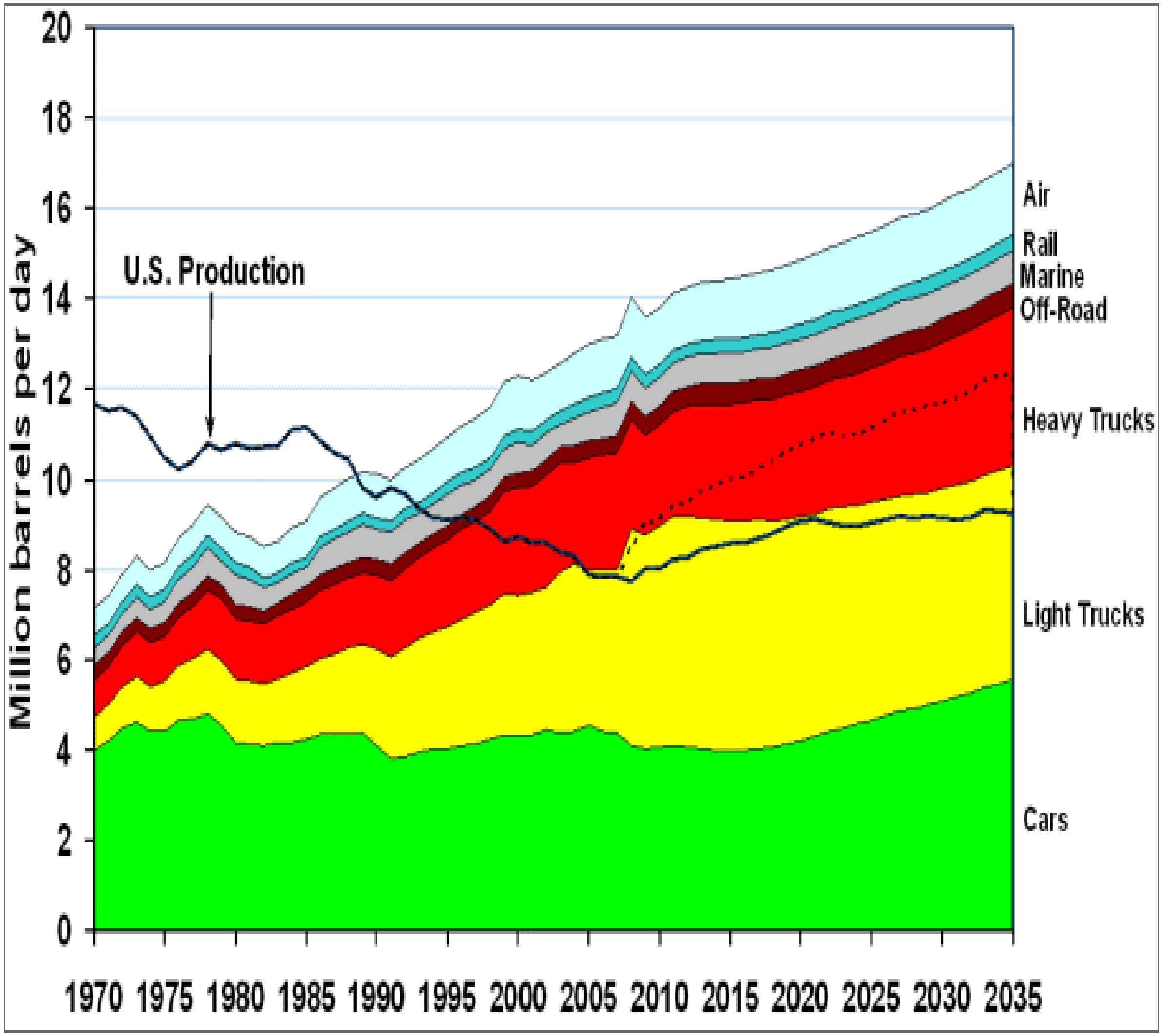
Outline

- Drivers for Fuel Efficient Lubricants
- Critical Parameters the Impact Fuel Efficiency – Boundary Friction, Mixed Lubrication, Hydrodynamic Lubrication
- Potential Size of Improvements
- Examples
- Cautionary Notes and Concerns

Historical Use of Petroleum – Continued Growth in Petroleum Consumption – Multiple Approaches to Improve Fuel Efficiency

- Multiple approaches being pursued to reduce dependence on petroleum
  - HEV, PHEV, non-petroleum based fuels, advanced combustion concepts, lightweight materials, regeneration, waste heat recovery, …
- Many approaches involve introduction of advanced technologies for NEW vehicles and do not address legacy fleet vehicles
- **Fuel efficient lubricants offer a pathway to improve fuel economy of LEGACY FLEET**



Historical Use of Petroleum for Transportation in the US (Fact #609: February 8, 2010 – The Petroleum Gap - http://www1.eere.energy.gov/vehiclesandfuels/facts/2010_fotw609.html

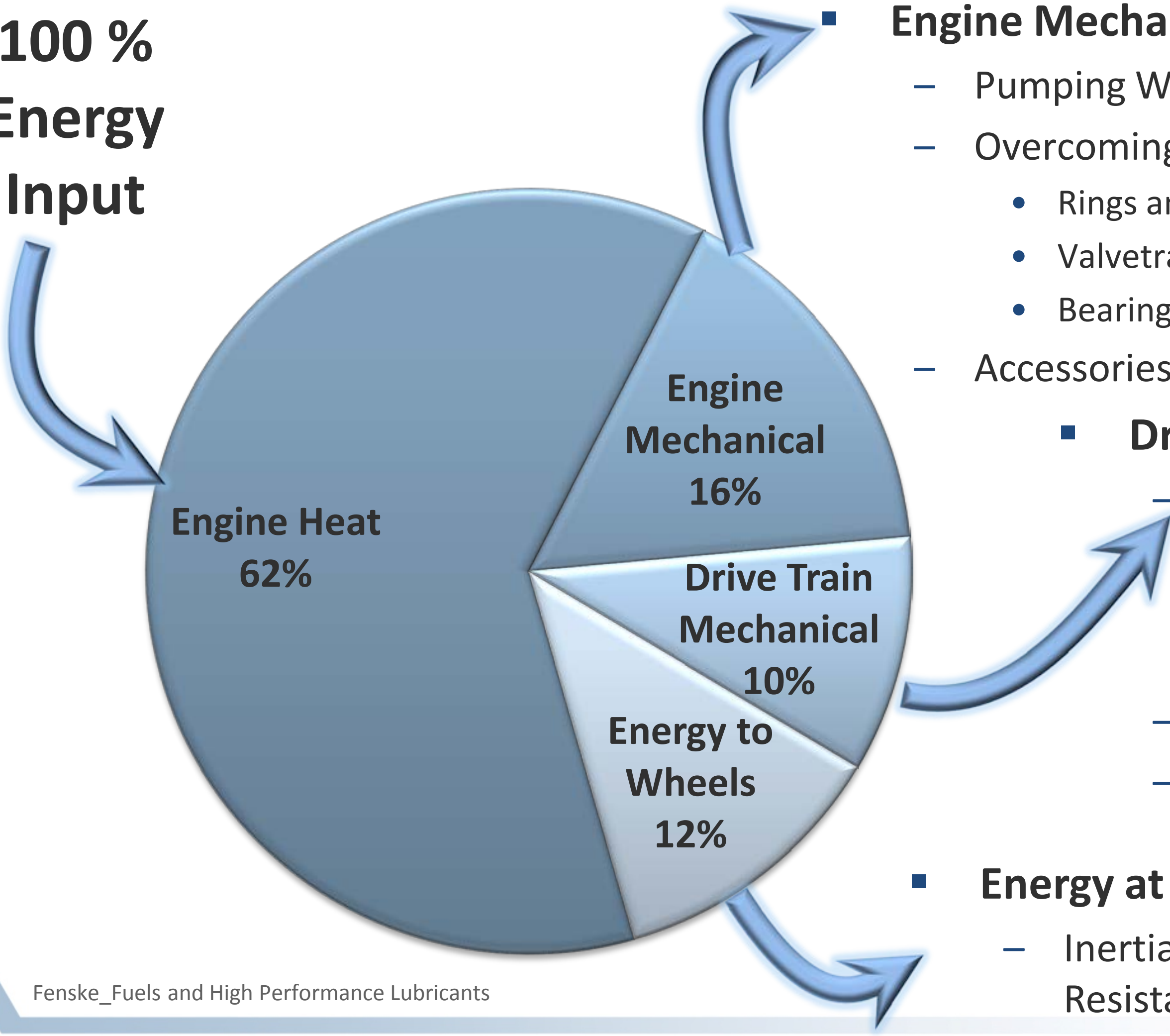
Vehicle Lubricant Facts

- **250^{+} million** – number of automobiles and trucks on the road as of 2008 (Transportation Energy Data Book – 29 – Table 3.1)
- **3 million-million** (3 x 10^{12}) – number of vehicle-miles driven by 250^{+} million vehicles in 2008 (Transportation Energy Data Book – 29 – Table 3.6)
- **13.4 MBB/day** – amount of petroleum consumed per day for transportation in 2008 (Transportation Energy Data Book – 29 – Table 1.13)
- **11.5 MBB/day** - amount of petroleum consumed per day for **highway transportation** in 2008 (Transportation Energy Data Book – 29 – Table 1.16)

- **10-15 %** - percent of fuel consumed that is lost to parasitic friction in engines (10%) and transmissions/axles (5%)
- **1.1–1.7 MBBL/day – amount of petroleum consumed by friction per day for transportation**
- **1.2 billion** – number of gallons of **automotive** lubricants sold in the US marketplace in 2008 (engine and transmission) (2010 Lubricants Industry Factbook)
- **1.8 billion** – number of gallons of fuel saved per year by reducing engine friction by 10%

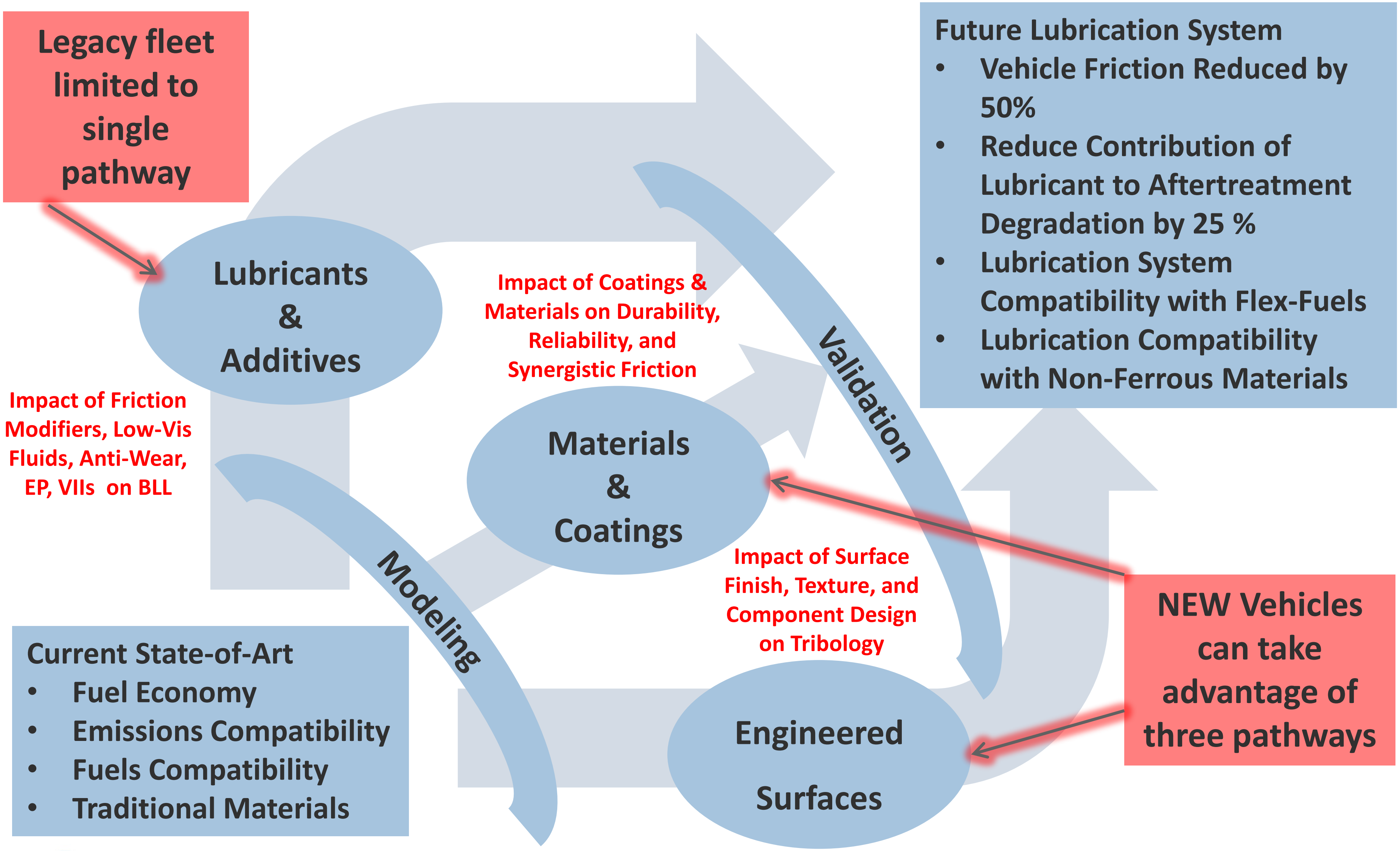
How Much is Lost to Friction ? - More Energy is lost to Friction than is Delivered to the Wheels - Approximately 10% in Engine and 5% in the Drivetrain (1.1-1.7 MBBL/day)

100 % Energy Input



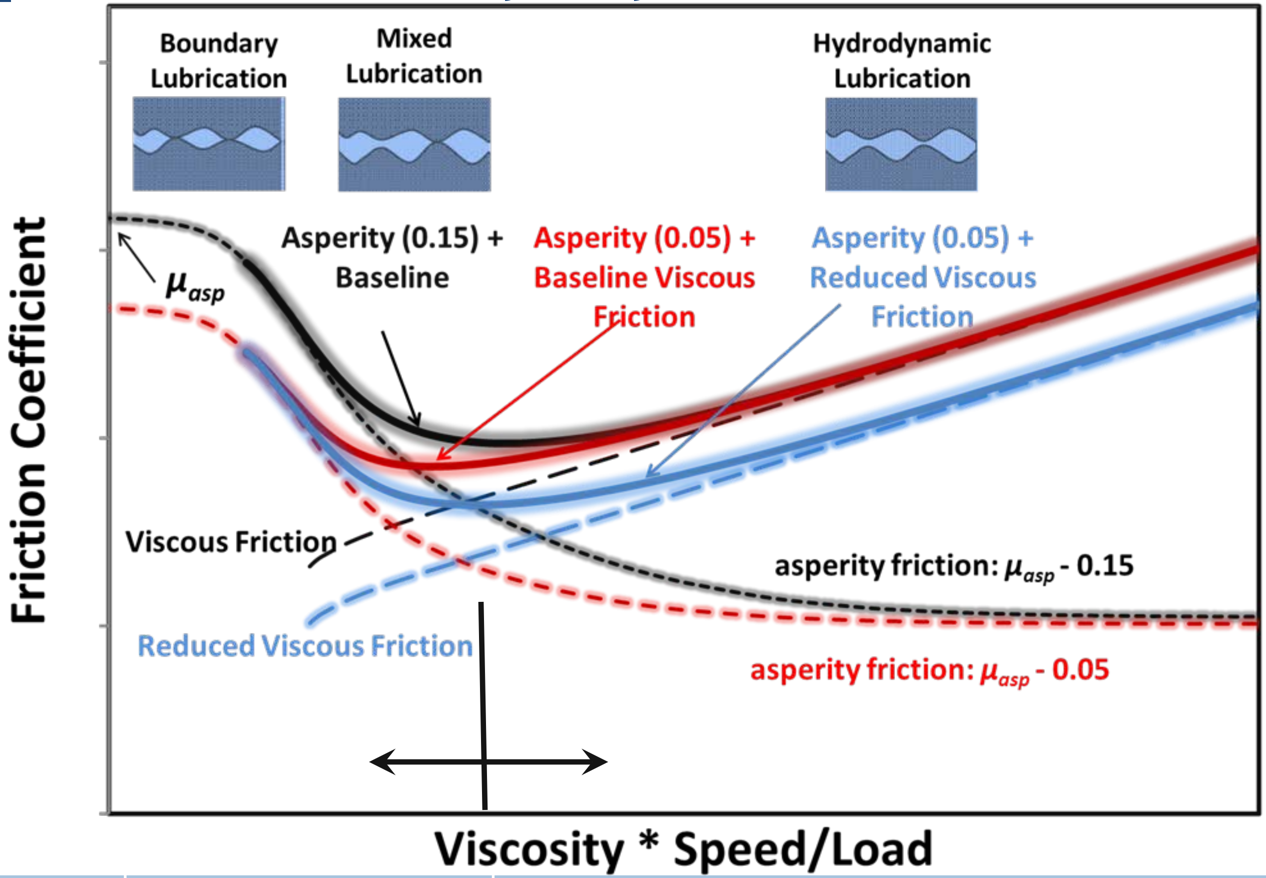
- **Engine Mechanical Losses**
  - Pumping Work
  - Overcoming Friction
    - Rings and piston skirt
    - Valvetrain
    - Bearings & Seals
  - Accessories
- **Drive Train Mechanical Losses**
  - Overcoming friction
    - Transmission
    - Differential
    - Bearings & Seals
  - Coasting and Idle Work
  - Braking Work
- **Energy at Wheels**
  - Inertia, Rolling Resistance, Air Resistance, Gravity (grades)

Multiple Pathways to Improve Fuel Efficiency with Improved Tribological Systems



- Reducing the <u>Boundary Friction</u> Reduces Asperity and Mixed Lubrication Losses,
- Reducing <u>Viscosity</u> Reduces Mixed and Hydrodynamic Losses

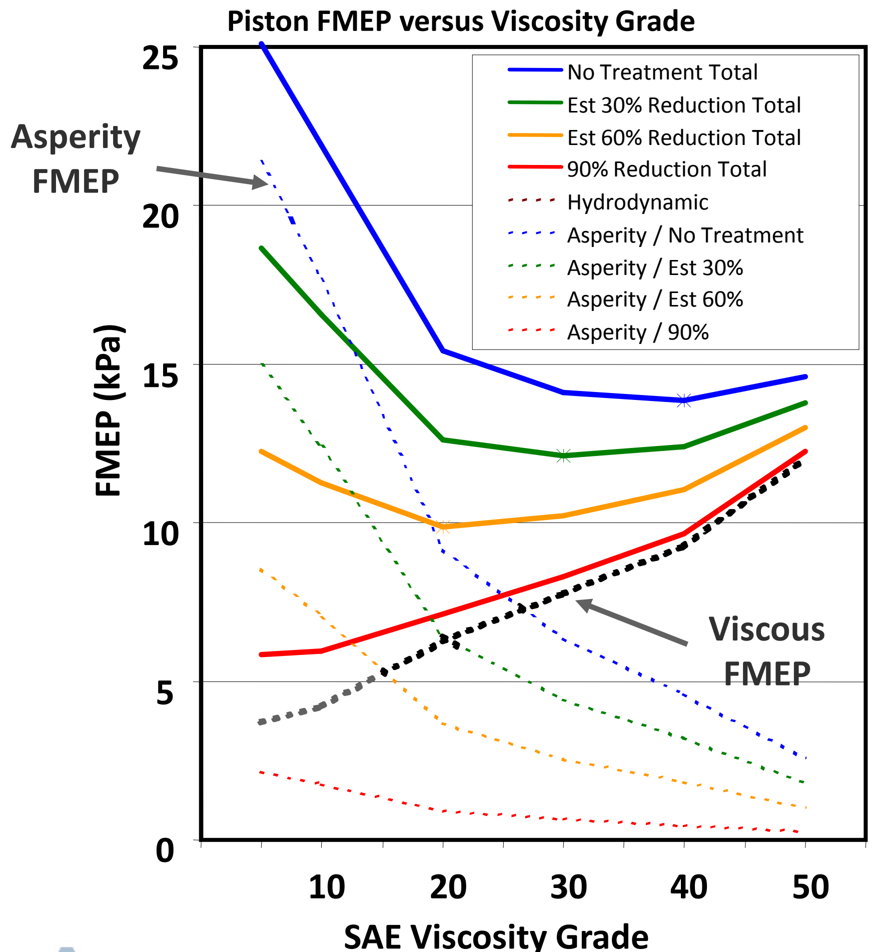
- Impact of increasing or decreasing viscosity, speed, and load depends on which side of the curve your on - which in turn depends on component

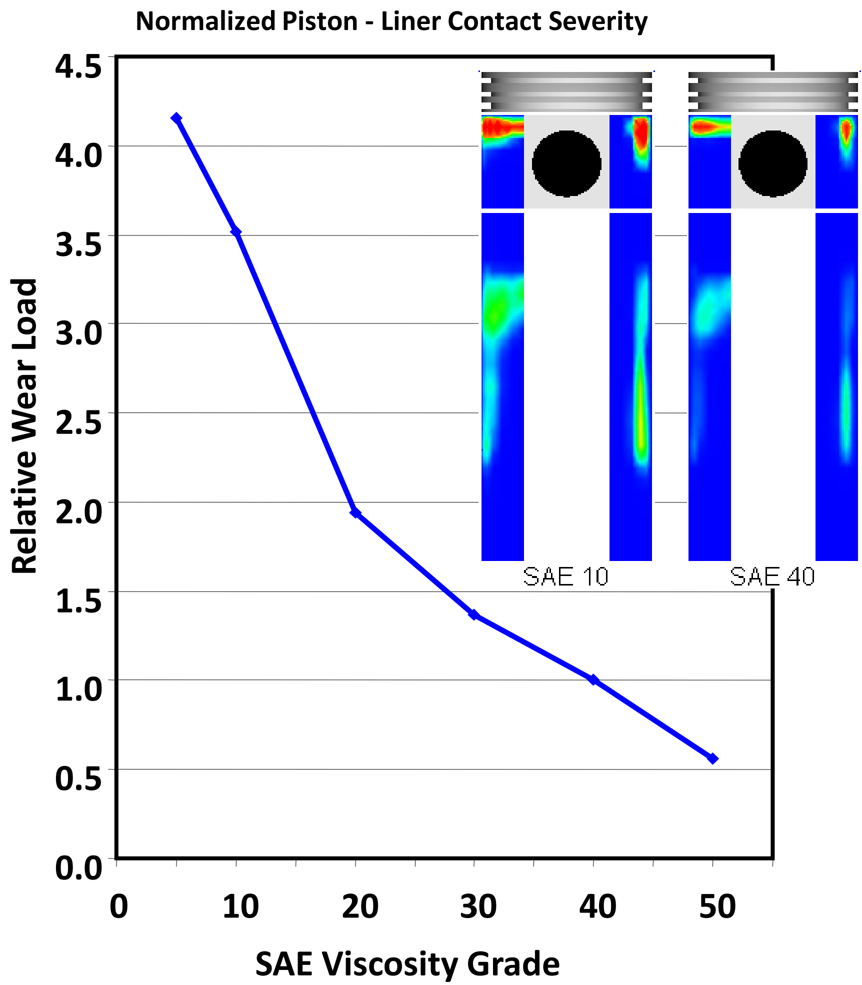


As Viscosity increases	Friction Decreases	Friction Increases
As Speed Increases	Friction Decreases	Friction Increases
As Load increases	Friction Increases	Friction Decreases

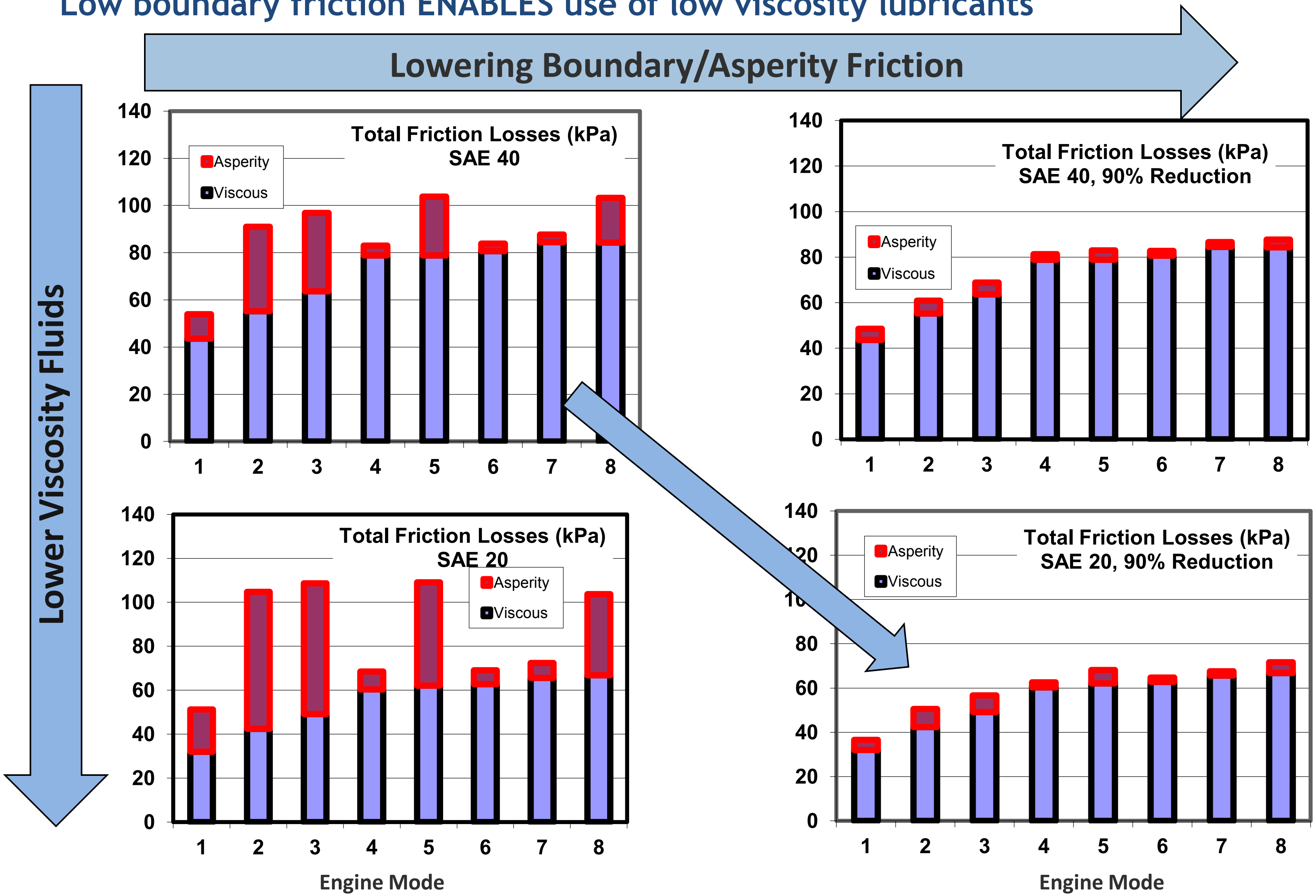
Boundary and Hydrodynamic Friction: Model Impact on FMEP and Wear Severity

- Total FMEP is the sum of the Asperity friction and the hydrodynamic friction
  - Boundary FMEP decreases with increasing lubricant viscosity – shifting from BL to ML regime
  - Hydrodynamic FMEP increases with increasing viscosity

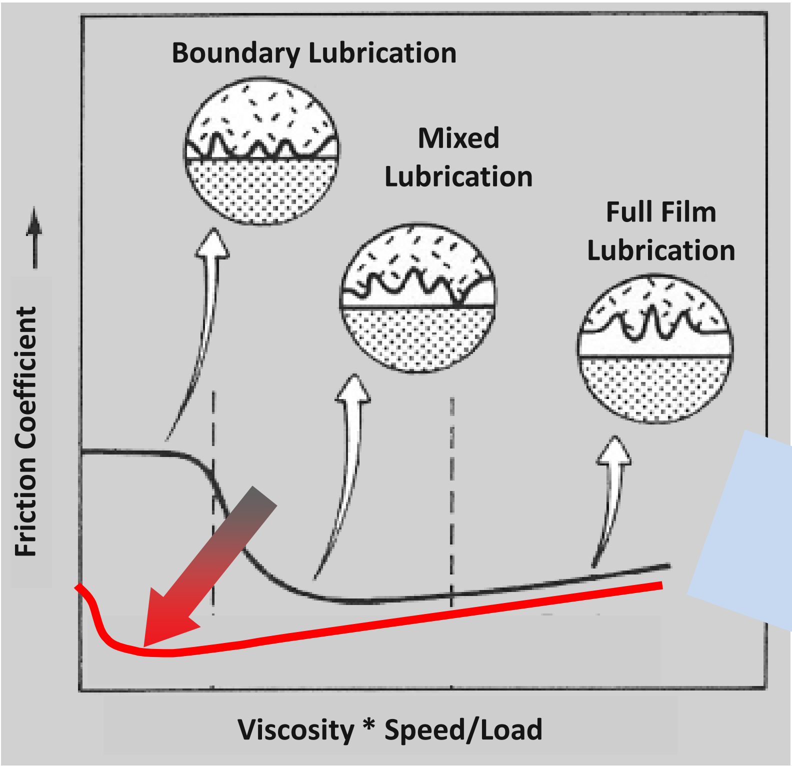




Lowering boundary friction while keeping viscosity the same reduces total friction; Lowering viscosity while keeping boundary friction constant does little at high loads Low boundary friction ENABLES use of low viscosity lubricants

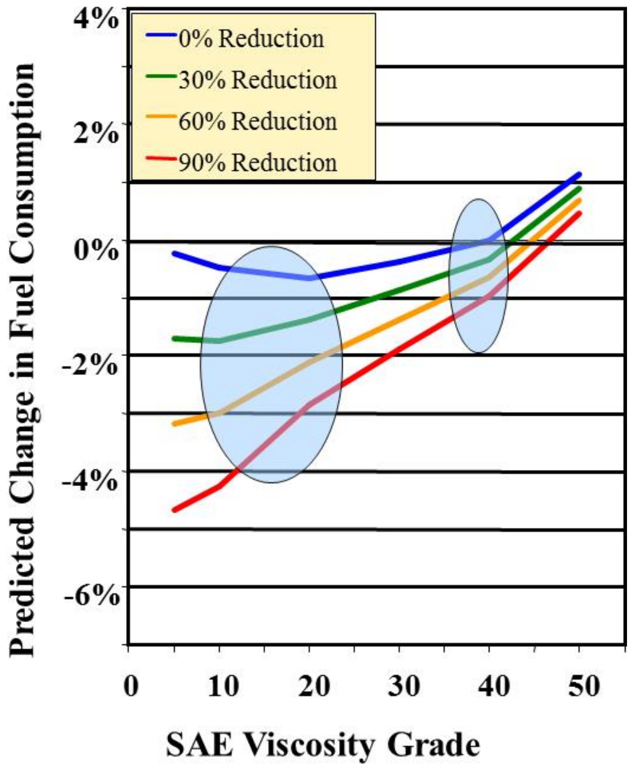


Models of Fundamental Friction Phenomena (Boundary and Fluid Film Lubrication) Predict Significant Reduction in Fuel Consumption



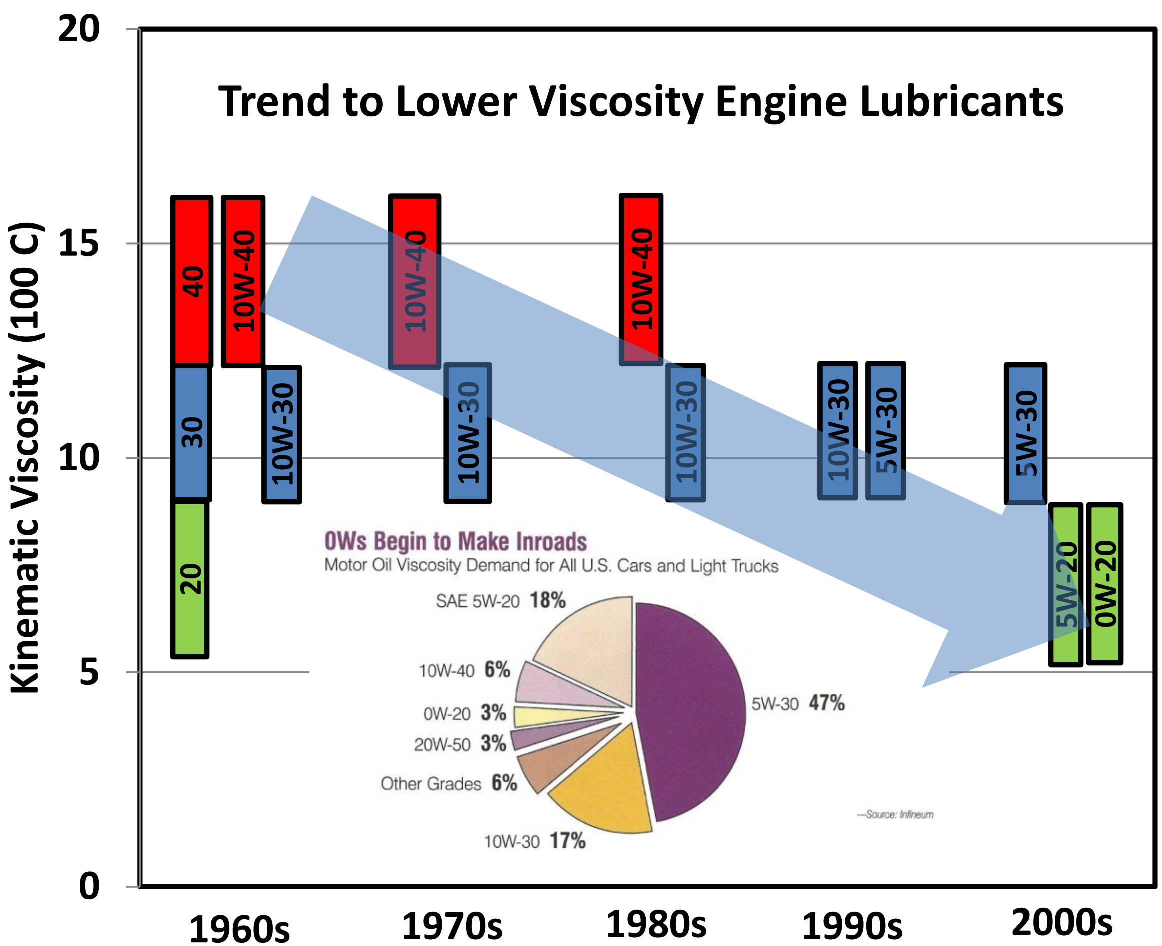
- Engine friction phenomena is modeled as **boundary, or, asperity friction** where metal-to-metal contact occurs, and **fluid film friction** where viscous losses are dominant

- While asperity friction accounts for approximately 10% of total engine friction, lowering **enables** the use of lower viscosity lubricants to achieve greater fuel economy gains

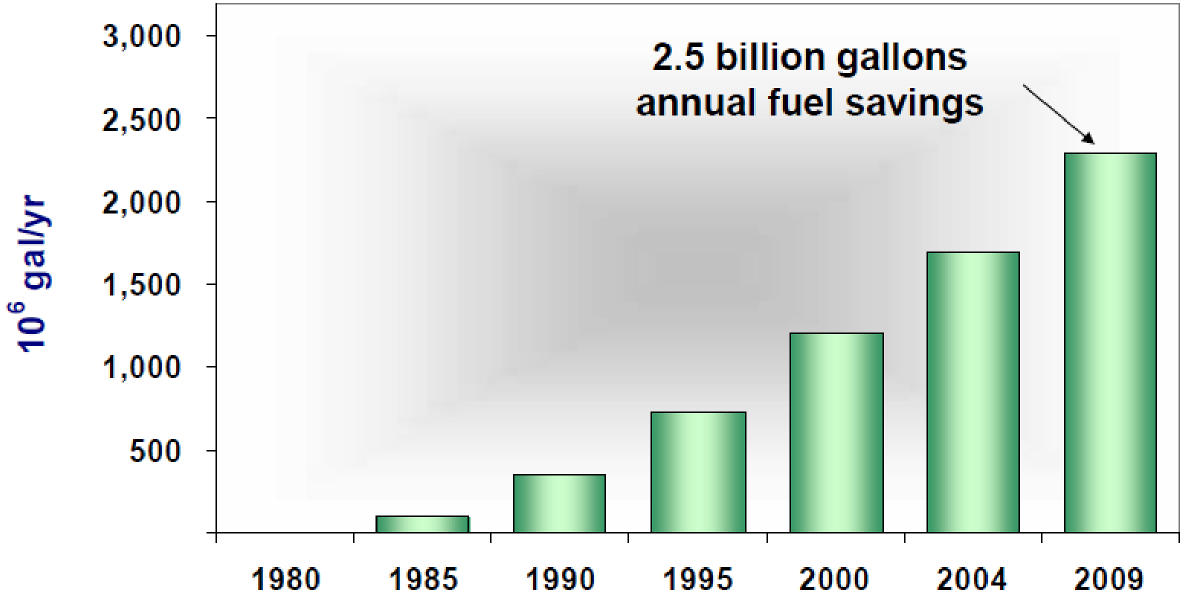


Lubricant Viscosity - Moving Toward Lower Viscosity Fluids

- **PCMO** – lower viscosity lubricants comprise greater share of market – 5W-30 giving way to 0/5W-20 lubricants
- **HDD** – Diesel lubricants dominated by 15W-40 with some 10W-30
- **PCMO** – significant friction loss in boundary or mixed regime, while hydrodynamic losses dominate HDD engines.
- **PCMO** – address rings and valvetrain friction
- **HDD** – address low viscosity fluids



Steady Increase in Fuel Economy Due to Shift to Lower Viscosity Lubricants .. With Improved Additives



- Steady increases in FEI for passenger cars from advanced additives and thinner lubricants result in sizeable fuel savings

Lubricant Contribution to Energy Efficiency : Are We There Yet?
SAE F&L Council Open Forum, Spring 2010
April 14, 2010, Cobo Center, Detroit
Jai G. Bansal, Global Crankcase Technology Advisor

- Improvement in FEI for HDD trucks with thinner lubricants

Volvo D12D FE	15W-40	10W-40	5W-40	15W-30 Base	10W-30	5W-30
On-Highway FEI %	-0.76	-0.51	-0.31	0.00	0.17	0.44
Hilly FEI %	-0.57	-0.38	-0.24	0.00	0.12	0.33

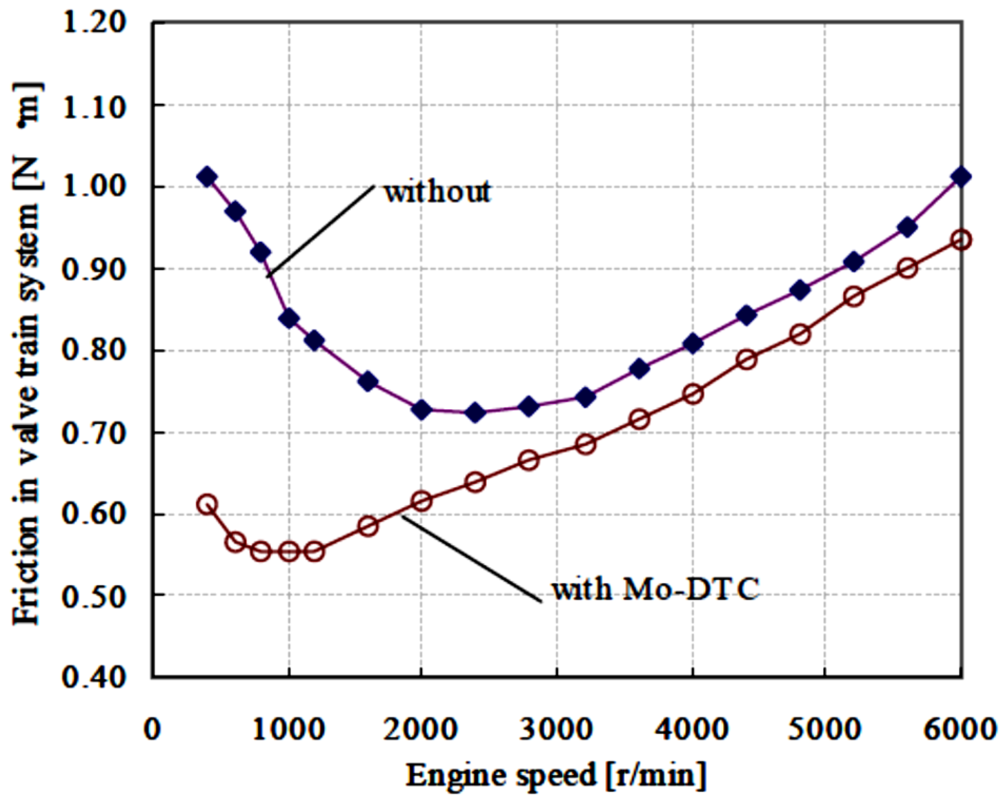
The Lubricant Contribution to Improved Fuel Economy in Heavy Duty Diesel Engines; Wim van Dam, Chevron Oronite, SAE 2009-01-2856

Role of Lubricant Additives on Fuel Efficiency

- Additives (friction modifiers) that reduce boundary/asperity friction are required to **ENABLE** the use of low viscosity fluids: Under typical driving cycles, asperity friction accounts for approximately 10% of total engine friction, yet lowering asperity friction by use of additives that form low friction boundary films mitigates mixed and boundary friction and ENABLE the use of low-viscosity fluids
- Asperity friction is a surface phenomenon and friction modifiers compete with other functional additives (e.g. viscosity index, pour-point, antiwear, extreme-pressure, detergents, dispersants, antioxidants, corrosion inhibitors, anti-foaming…) – consequently it is often necessary to re-formulate the total additive package to optimize lubricant performance
- **Friction modifiers** can be classified as:
  - **Solid lubricants** – in particulate form: e.g. graphite, teflon, molydisulphide, boron nitride, ..
  - **Organic FMs** – carboxylic acids, amides, imides, amines, phosphoric acids, organic polymers, ..
  - **Metallo-organic compounds**: e.g. Molybdenum or copper based.

Impact of Low-Friction Additives Often Dependent on Other Variables Including Aging

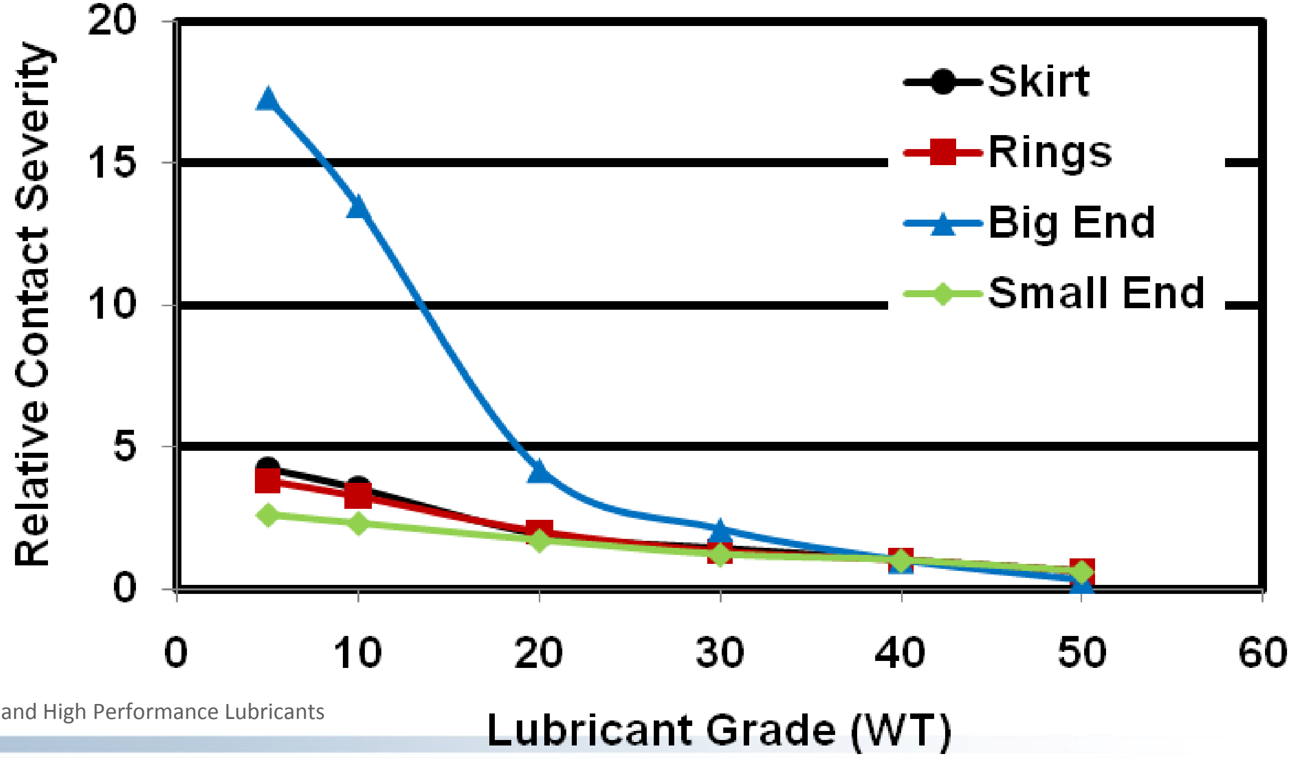
- Friction Modifiers such as Mo-DTC are effective in reducing boundary friction
- Significant improvements in FEI have been reported, however the magnitude of improvement is dependent on a number of variables including temperature, HTHS, and engine design
- **Reports on the fuel economy improvement durability suggest FEI may degrade as the oil ages – VI degradation, soot buildup, fuel dilution/oxidation, additive/FM depletion**



Study of Future Engine Oil(first Report): Future Engine Oil Scenario: JSAE 20077045/SAE 2007-01-1977

Development of Fuel Efficient Lubricants for Legacy Vehicles Must Maintain Reliability/Durability

- Use of low-viscosity lubricants, while effective in reducing fuel consumption, will increase contact severity
  - Need for improved wear-resistant materials, coatings and anti-wear additives
  - For **legacy vehicles** – improvements in friction and anti-wear package need to be addressed



Issues Impacting Development of Future Lubricants

- **Fuel Economy** – Development of advanced lubricants that reduce fuel consumption – 'Resource Conserving' lubricants
  - Control lubricant viscosity and additive to reduce viscous losses and asperity losses in engines and transmissions/axles
- **Emissions** – Development of advanced lubricant formulations compatible with emission control strategies.
  - Degradation/poisoning of aftertreatment systems by sulphated ash, phosphorous, and sulphur (SAPS)
  - Degradation of lubrication performance due to enhanced use of EGR in diesel engines
- **Alternative Fuels** – Development of advanced lubricants compatible with alternative fuels (bio-based fuels, natural gas, synthetic fuels, hydrogen)
  - Lubricant and additive performance
  - Fuel dilution
- **Vehicle Lightweighting (alternative materials)** – development of advanced lubricants compatible advanced materials
  - Non-ferrous, lightweight materials – e.g. Mg, Al alloys, advanced coatings
  - High-power density – higher contact stresses associated with downsized components

Summary - Lubrication Potential

- 250+ million vehicles consume 11-12MBBL/day petroleum
- 10-15 % (1.1 to 1.7 MBBL/day) consumed by parasitic friction mechanisms in engine, transmissions, and axles.

- A 10% reduction in engine friction will save 0.1 to 0.2 MBBL/day in petroleum if adopted fleet-wide.
- Reducing boundary friction alone by 90% can reduce fuel consumption of HD fleet by 1%
- Reducing viscosity alone is limited to approximately ½ % reduction in fuel consumption in HD vehicles before consumption starts to increase at viscosities below 20 WT.
- Combining low viscosity lubes with low boundary friction technologies enables greater savings (3-4%) in fuel consumption

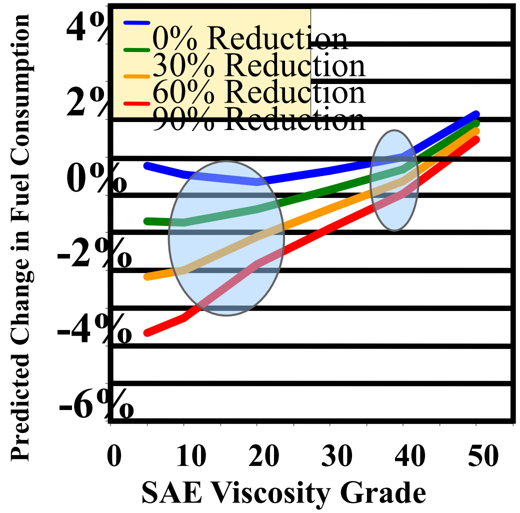
- NEW vehicles can take advantage of multiple paths to improve fuel economy
- LEGACY vehicles will require low-viscosity lubes, improved VI and FM additives to reduce fuel consumption
- Fuel efficient lubes for legacy vehicles need to address potential impact of increased boundary regime effects on durability/reliability
- Need to start now to reach consensus – is it possible to develop and market a new class of fuel efficient lubes for legacy vehicles that utilize reduced viscosity lubricants that are below OEM recommendations – can one develop a lube formulation that provides low viscosity, low boundary friction and maintains durability/reliability?

Thank-You

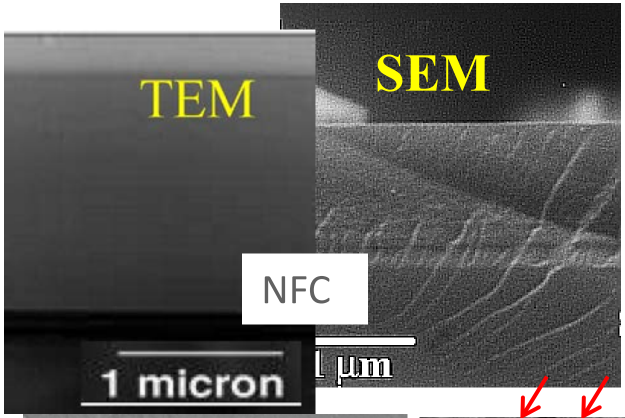
Questions ?

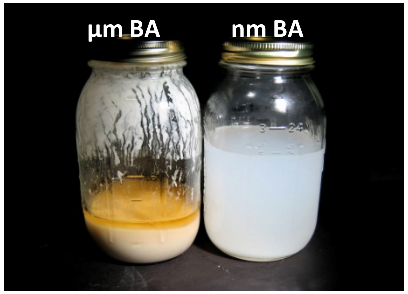
Argonne Activities – Advanced Lubrication

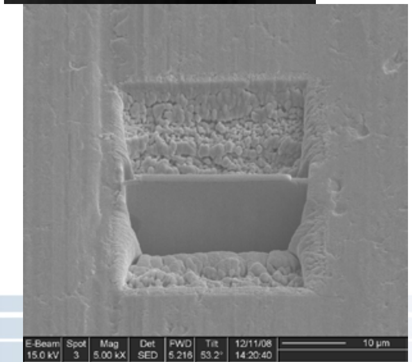
- Modeling impact of low-friction technologies on Fuel efficiency – ‘what-if’ studies

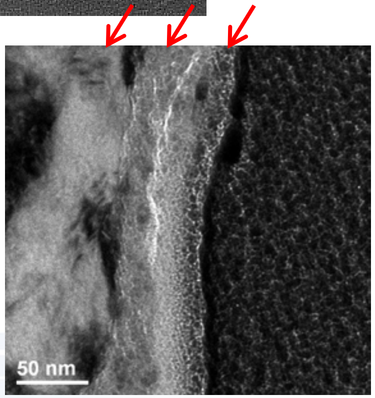


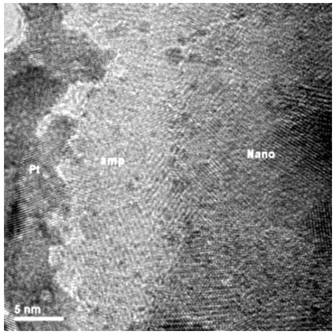
- Technology development/evaluation
- Phenomenological friction mechanism studies
  - Focused ion beam spectroscopy
  - X-ray spectroscopy of tribo-film
  - Nanomechanical propertiesof tribofilm formation











Chemical and Structural Analysis of TriboFilms

Chemical analysis of tribo film by EDAX of TEM sample shows complex composition