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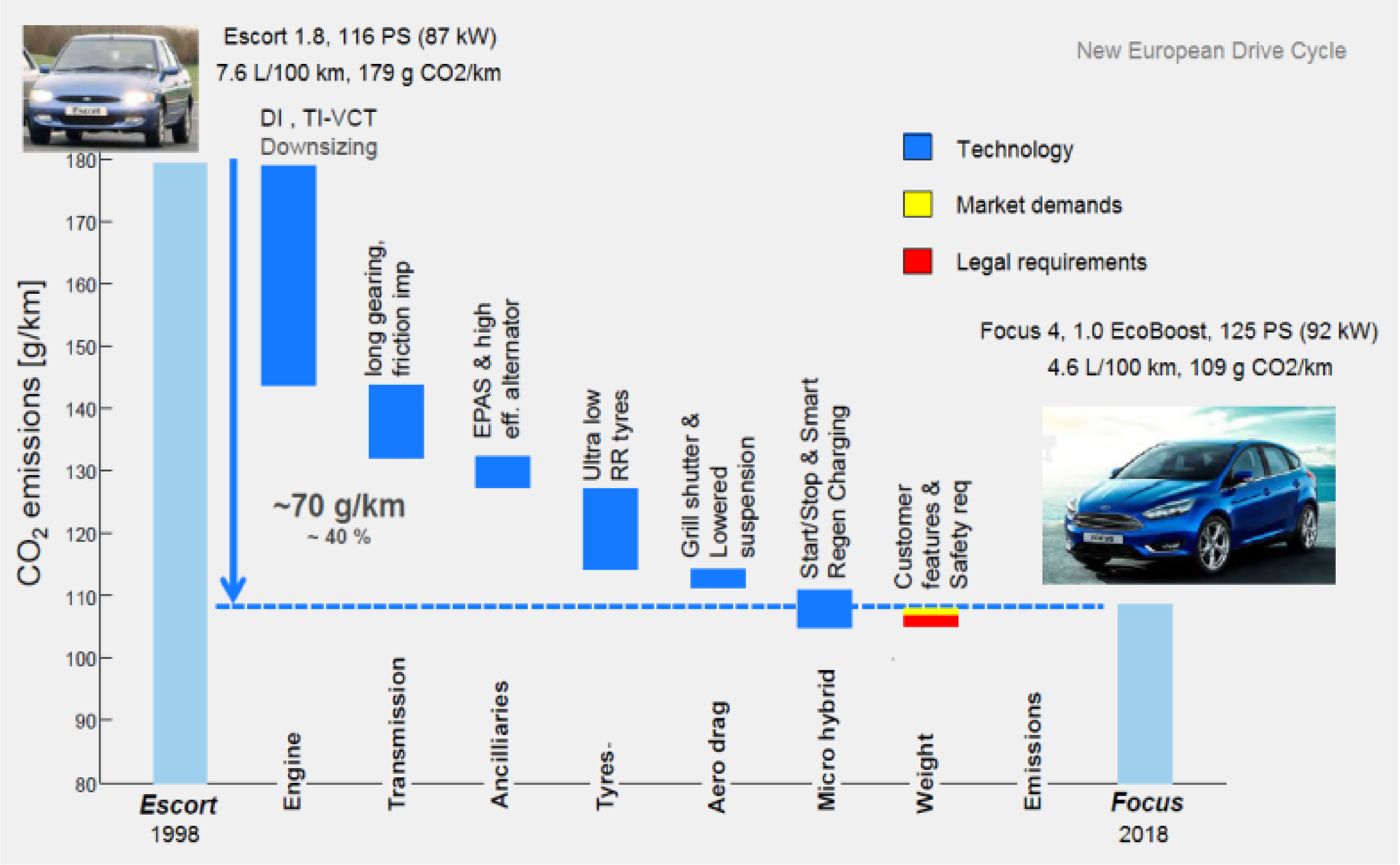
Fuel Economy Engine Oils:

Scientific Rationale and Controversies

Boris Zhmud,[1] Arthur Coen,[2] Karima Zitouni[2]
[1]BIZOL Germany GmbH
[2]OLEON France SARL

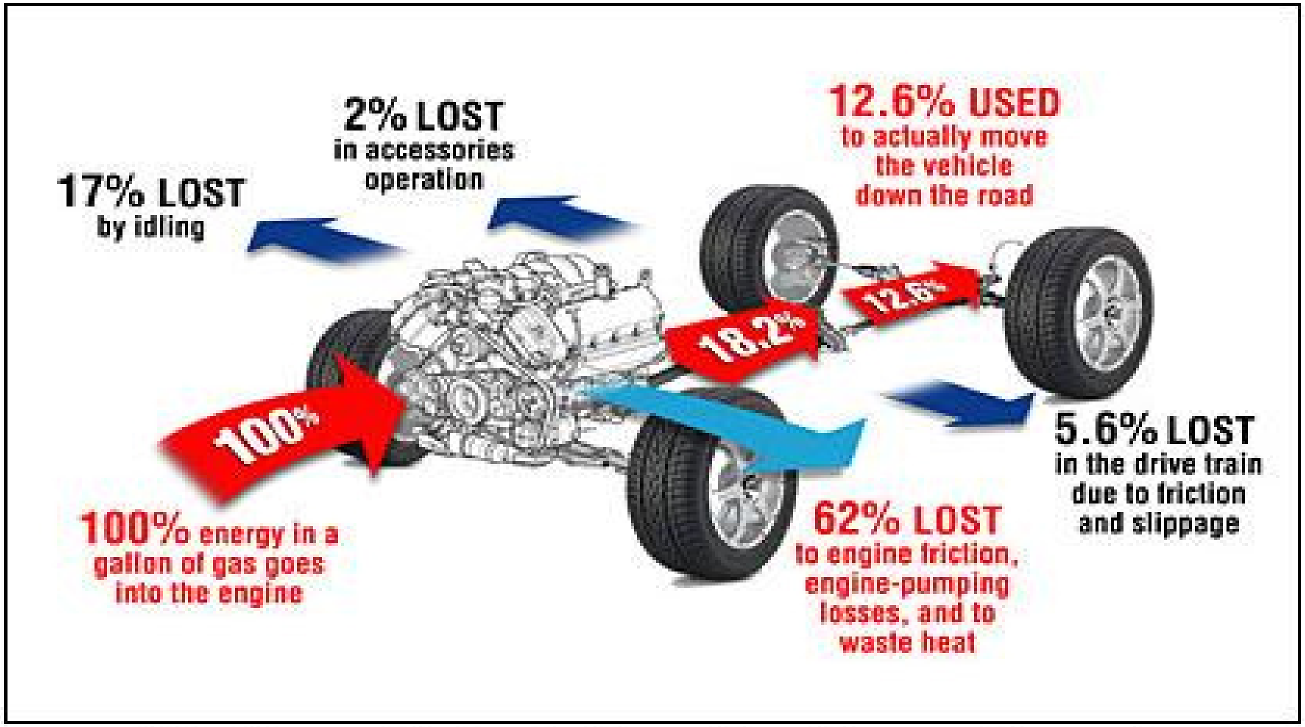
BIZOL oleon a natural chemistry

Reduction in CO2 emissions for 1990-2020



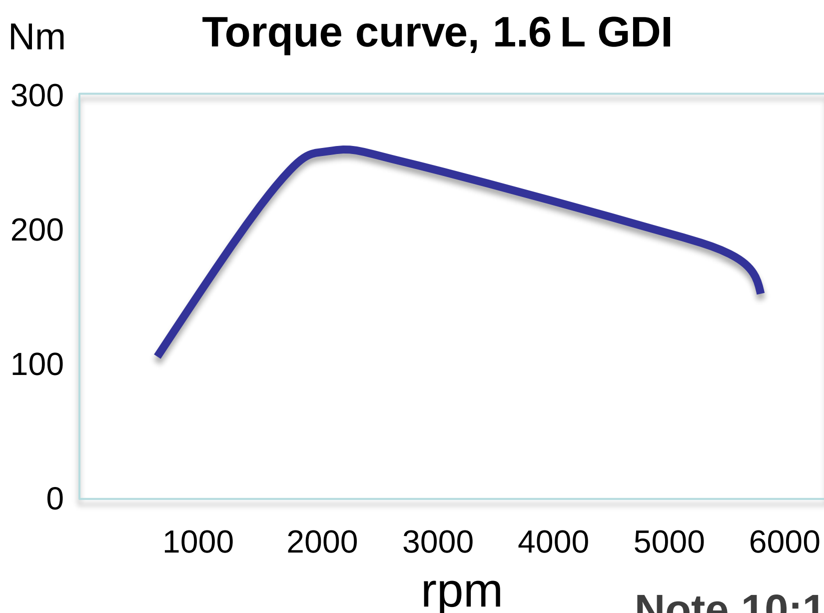
Kramer, et. al. “Options for the Complete Defossilization of the Transport Sector”, VDI Fachtagung: Ventiltried und Zylinderkopf, June 25, 2019.

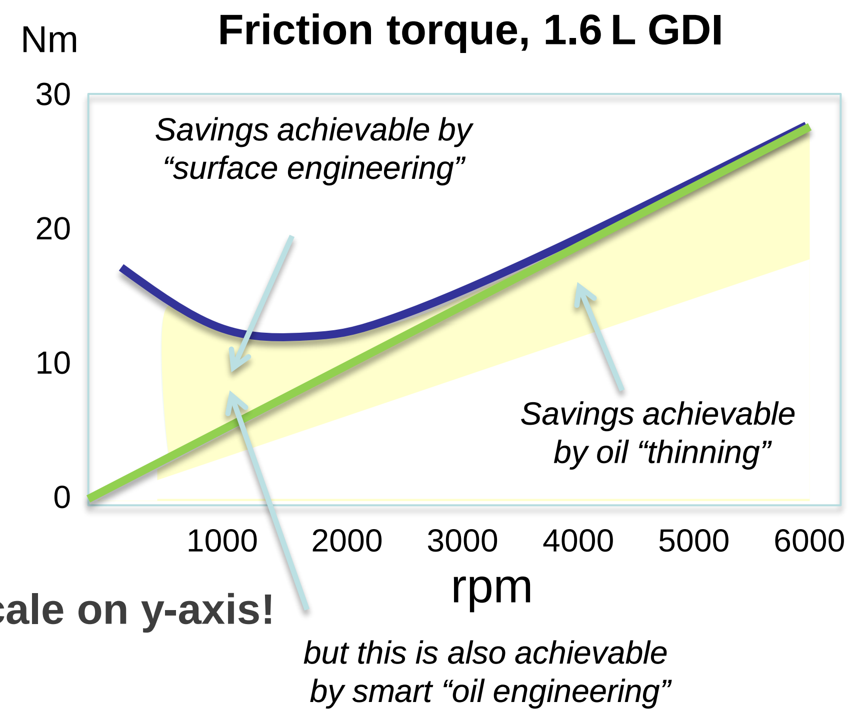
Lowering powertrain friction remains actual



This diagram illustrates the paths of energy through a typical gas-powered vehicle in city driving.

Fuel saving by tribology optimization

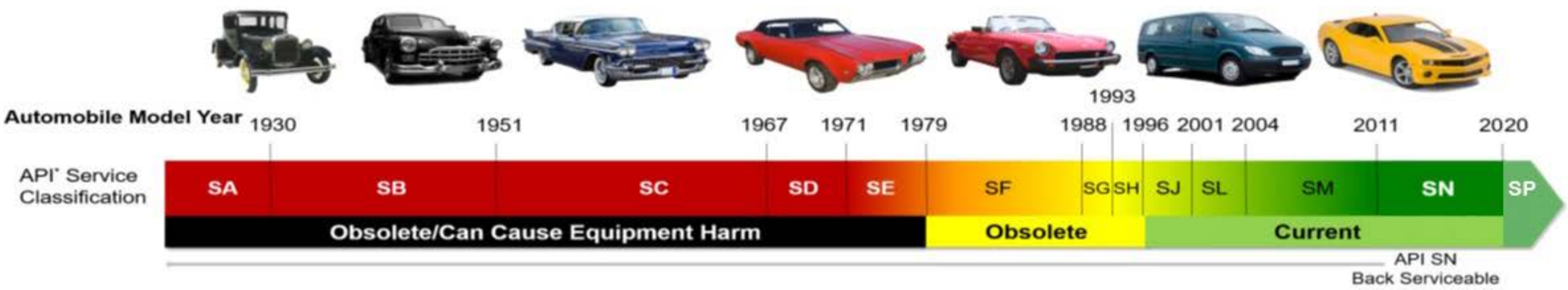




Note 10:1 scale on y-axis!

$$FE \sim \frac{\Delta FMEP}{IMEP} \leq 10\%$$

Evolution of fuel-economy motor oil



Sequence VIB
ASTM D 6837

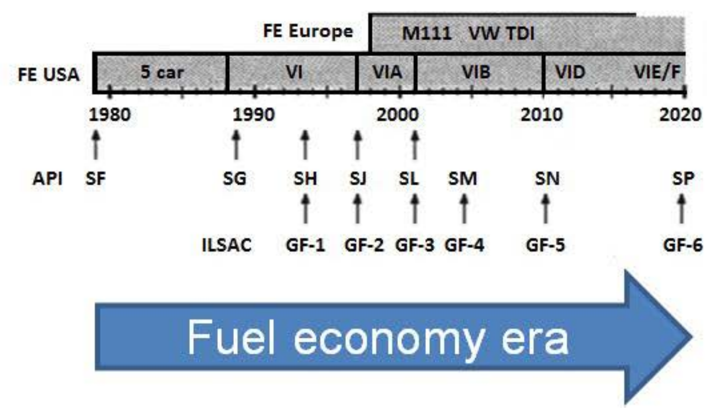
Uses 1993 4.6 L Ford V8 and 5W30 "baseline" oil to measure the effects of automotive engine oils on the fuel economy of passenger cars and light-duty trucks equipped with a "low-friction" engine.

Sequence VID
ASTM D 7589

Uses 2009 3.6 L GM V6 and 20W30 "baseline" oil to measure the effects of automotive engine oils on the fuel economy of passenger cars and light-duty trucks equipped with a "low-friction" engine.

Sequence VIE
ASTM D 8114

Uses 2012 3.6 L GM V6 and 20W30 "baseline" oil to measure the effects of automotive engine oils on the fuel economy of passenger cars and light-duty trucks equipped with a "low-friction" engine.



Engine Trends: Downsize and Charge

Volvo XC90 2005 V8
4.4 L V8, 315 hp, 440 Nm

<u>BMEP = 12.6 bar</u>

- **Fewer cylinders**
- **Smaller displacement**
- **Same power**

Volvo XC90 2016 T6
i4, 2.0 L, 316 hp, 400 Nm

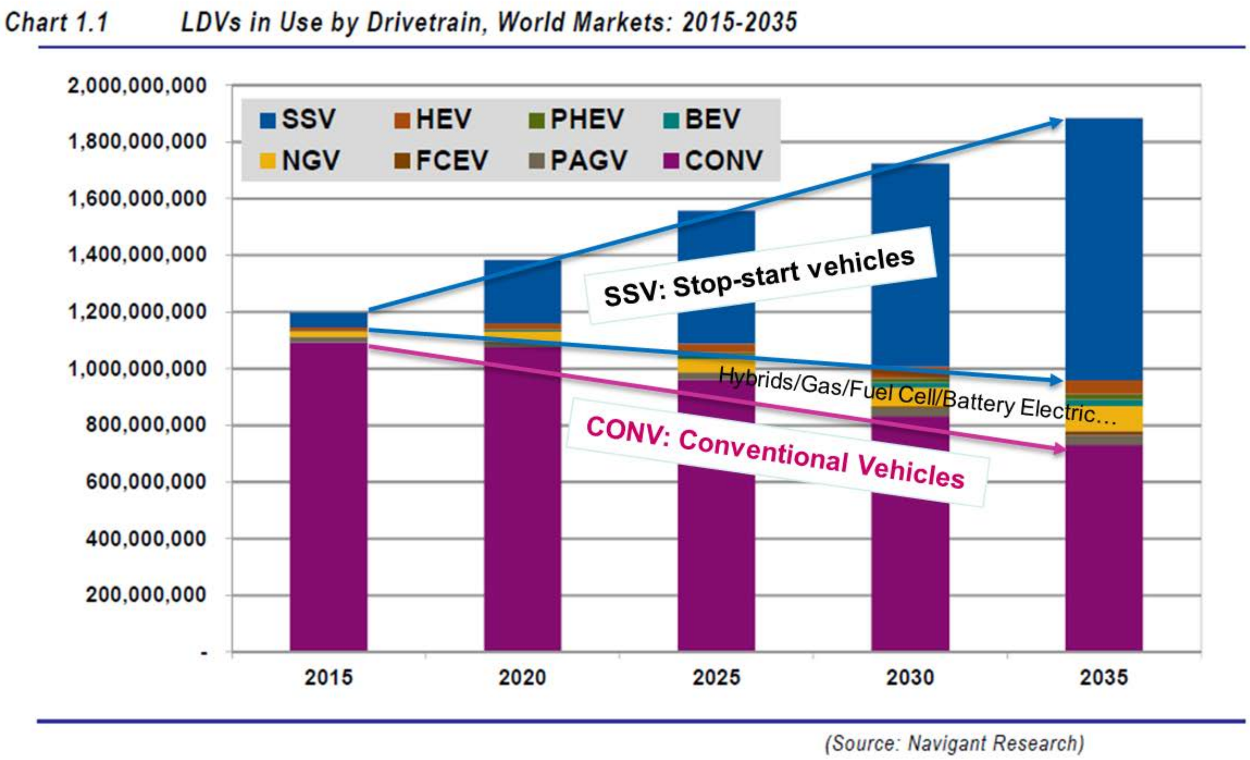
<u>BMEP = 25.5 bar</u>

Consumer vehicles closing the gap with racing cars

Koenigsegg Agera 5.0 L bi-turbo, 1000 hp, 1100 Nm
<u>BMEP = 28 bar</u>

Engine Trends: Automatic stop-start

Good deeds, bad consequences



Stop-**S**tart **V**ehicles
Hybrid **E**lectric **V**ehicles
Plug-in **H**ybr. **E**lectric **V**eh.
Battery **E**lectric **V**ehicles
Natural **G**as **V**ehicles
Fuel **CE**ll **V**ehicles
Propane **A**uto**G**as **V**ehicles
CONVentional **V**ehicles

New problems:

- Suboptimal temperature
- Water contamination
- Fuel dilution

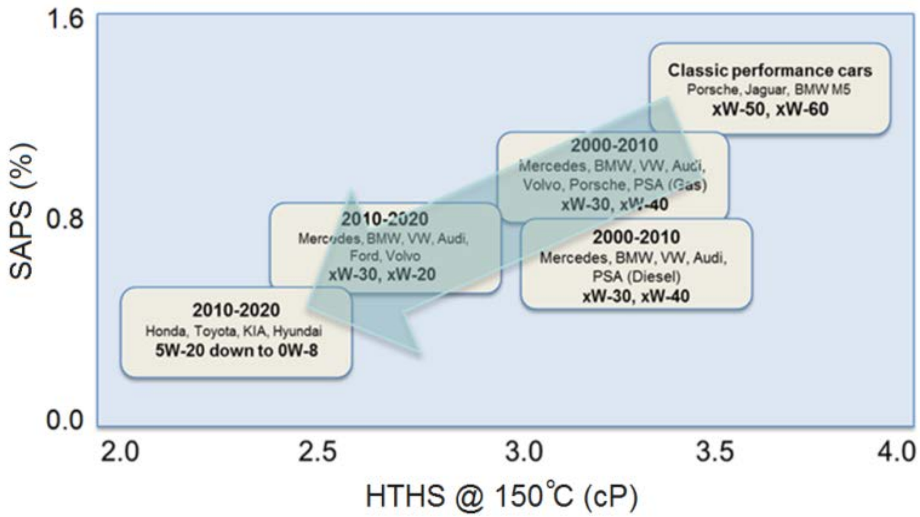
Bearings must withstand 300,000 instead of 30,000 start-stops

Lower viscosity, lower SAPS lubricants

SAE J300 - Revised January 2015

SAE Viscosity Grade	Low Temp. Cranking (cP)	Low Temp. Pumping (cP)	Minimum Kinematic (cSt)	Maximum Kinematic (cSt)	Hi-Temp. Hi-Shear (cP)
0W	6,200 @ -35°C	60,000 @ -40°C	3.8	-	-
5W	6,600 @ -30°C	60,000 @ -35°C	3.8	-	-
10W	7,000 @ -25°C	60,000 @ -30°C	4.1	-	-
15W	7,000 @ -20°C	60,000 @ -25°C	5.6	-	-
20W	9,500 @ -15°C	60,000 @ -20°C	5.6	-	-
25W	13,000 @ -10°C	60,000 @ -15°C	9.3	-	-
8	-	-	4	<6.1	1.7
12	-	-	5	<7.1	2.0
16	-	-	6.1	<8.2	2.3
20	-	-	6.9	<9.3	2.6
30	-	-	9.3	<12.5	2.9
40	-	-	12.5	<16.3	3.5 (0W-40, 5W-40, 10W-40)
40	-	-	12.5	<16.3	3.7 (15W-40, 20W-40, 25W-40, 40 monogrado)
50	-	-	16.3	<21.9	3.7
60	-	-	21.9	<26.1	3.7

A trend towards low visc and low SAPS oils:



MB 229.71 ~ ACEA C5 — 0W-20, HTHS 2.6
MB 229.61 ~ ACEA C2 — 0W-30, HTHS 2.9
MB229.51 ~ ACEA C3 — 5W-30, 0W-40, 5W-40, HTHS 3.5

Downsides of oil thinning

Wear

Twofold reduction in HTHS viscosity => twice thinner oil film

Jon Vilardo, PCMO Product Manager, Lubrizol:

"*Lower can have a negative impact on durability; the protective oil film is less robust, or under the most extreme loading conditions, non-existent*."

Simon Tung, Global OEM Technology Manager, Vanderbilt:

"*Lower viscosity grade oil might not be able to have enough oil film thickness to protect engine wear as higher viscosity grade oils*."

Infineum:

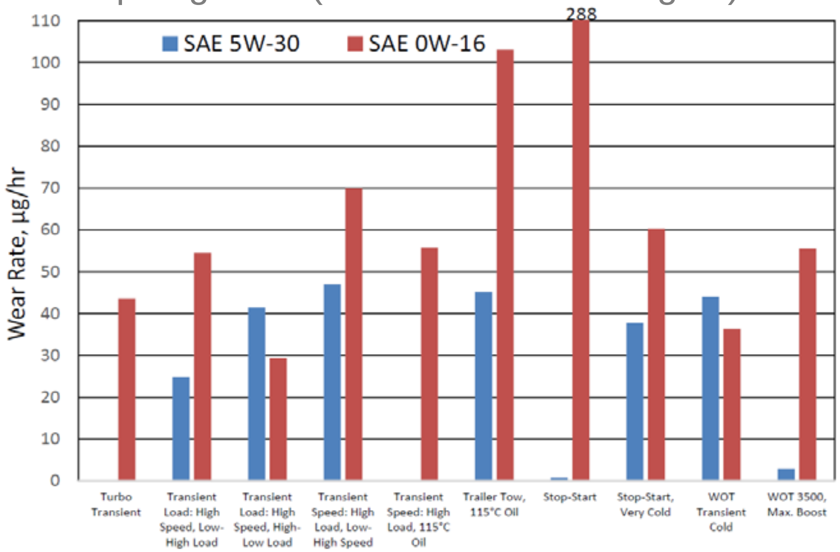
"*Misapplication will be a concern for OEMs, particularly the potential for new lower viscosity grades to find their way into engines not designed to take advantage of the fuel economy improvements*."

… and hence risking to be screwed up!

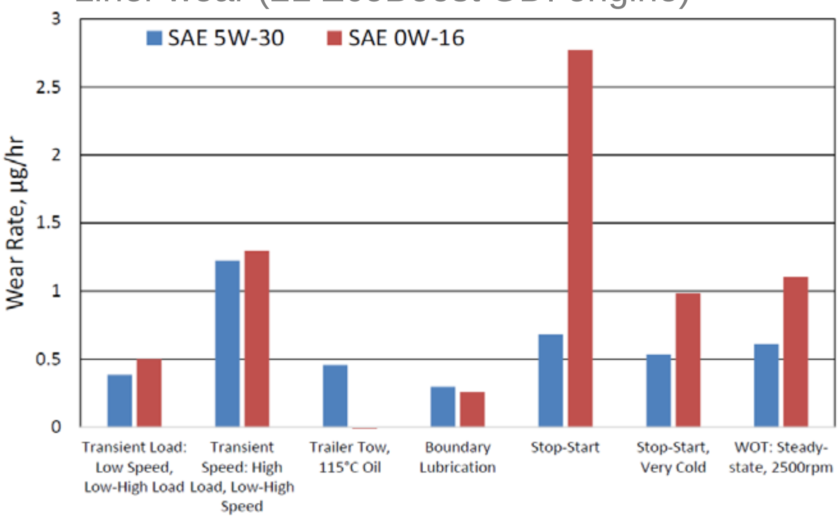
See also: Lee & Zhmud, Lubricants 2021, 9(8), 74

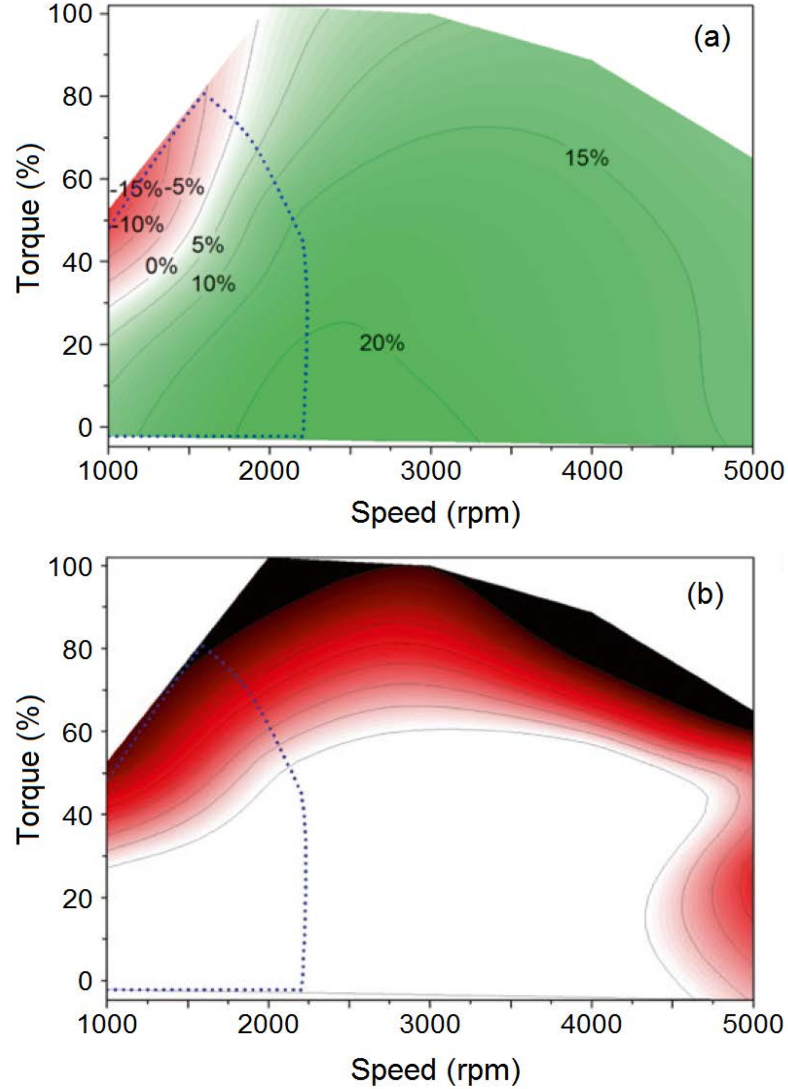
When low viscosity sounds a problem

Top ring wear (2L Ecoboost GDI engine)



Liner wear (2L EcoBoost GDI engine)

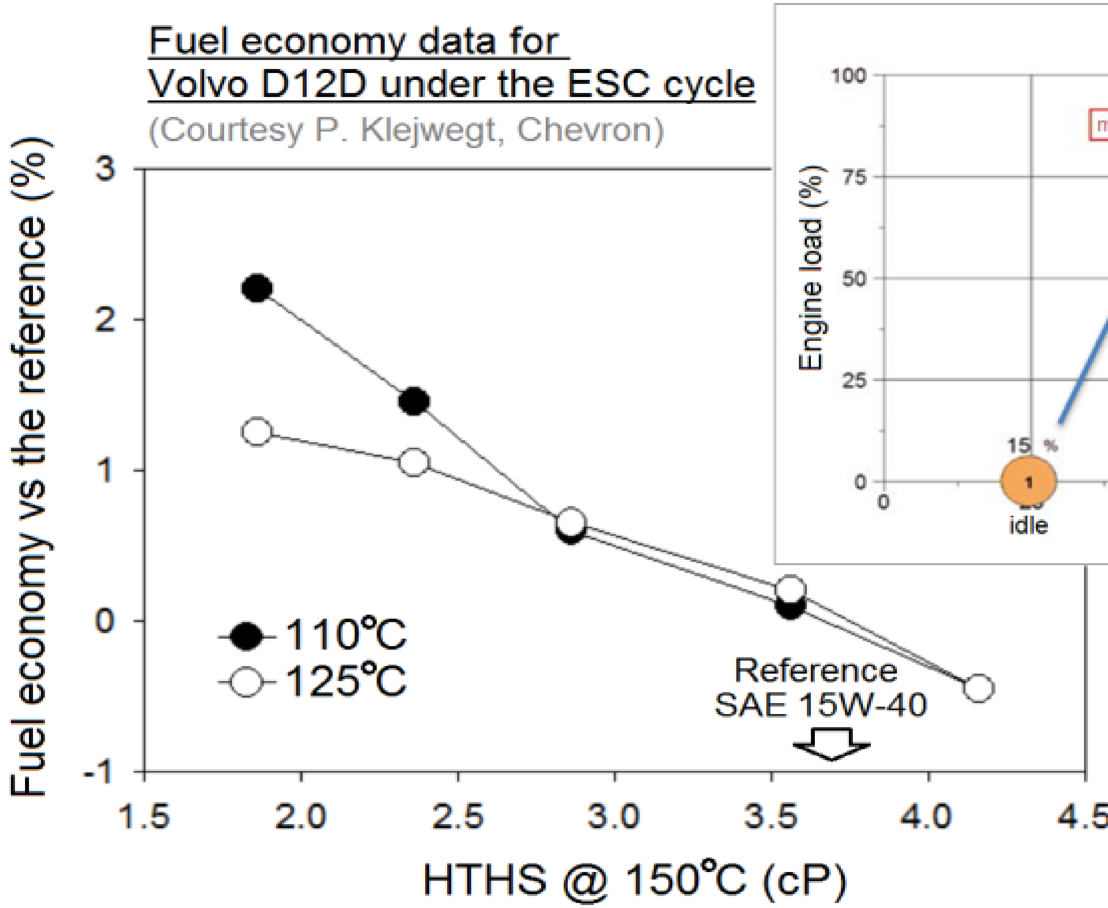


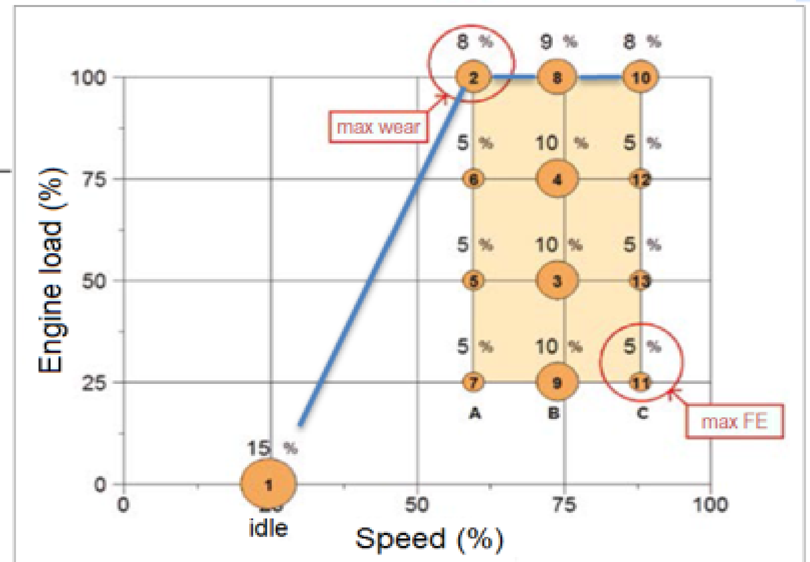


Lee & Lochte, Gasoline direct injection (GDI) engine wear test development, CRC Project No. AVFL-28, SwRI, San Antonio, Texas, October 9, 2017

Sander, et al. Potentials and risks of reducing friction with future ultra-low-viscosity engine oils. MTZ Worldwide 79 (2018) 21.

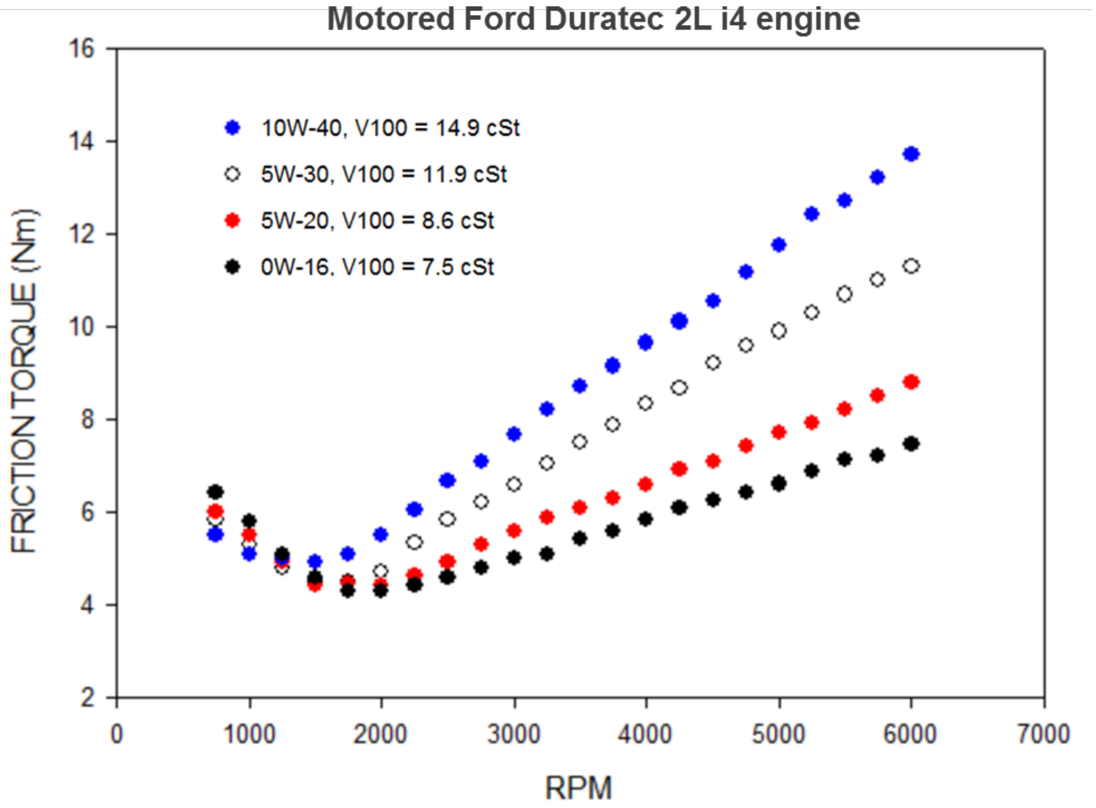
Wear is heavy duty diesel engines



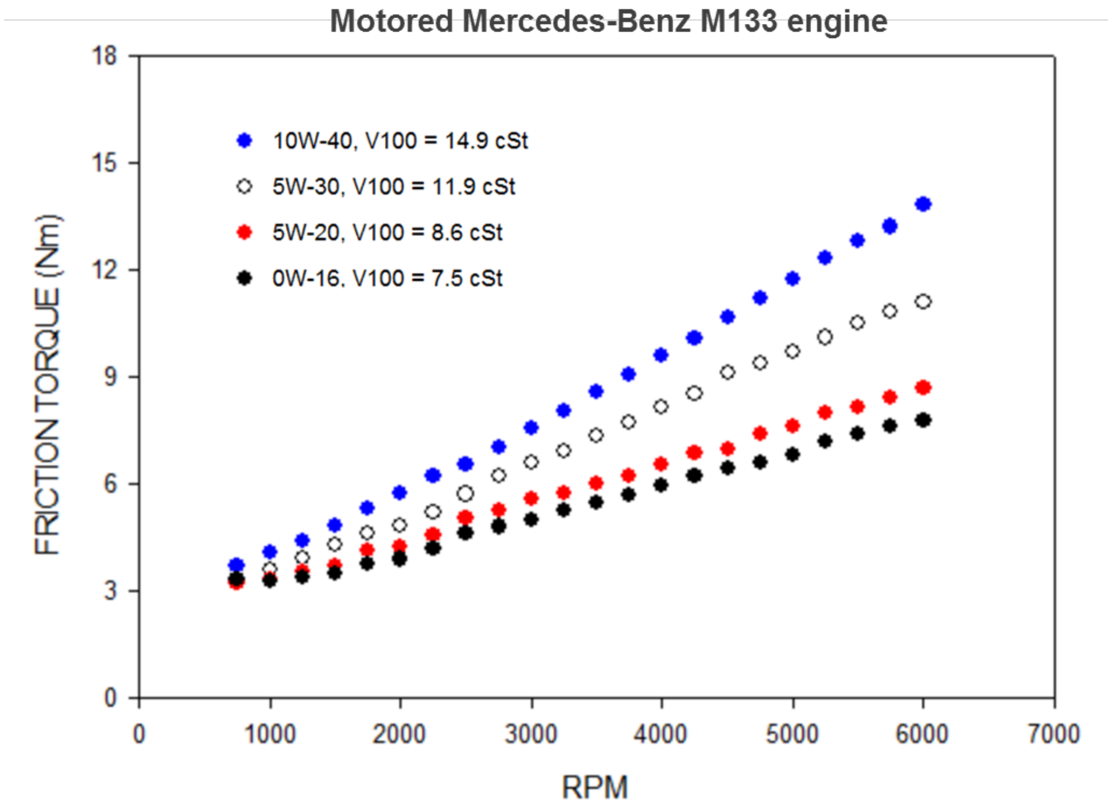


Benefits of lowering viscosity for HDEO are overrated:
- Most of the fuel economy effect is limited to high-speed / low load conditions
- Risk of piston ring and liner scuffing, rocker pad wear, roller follower wear, crosshead wear, bearing wear, and cam lobe wear

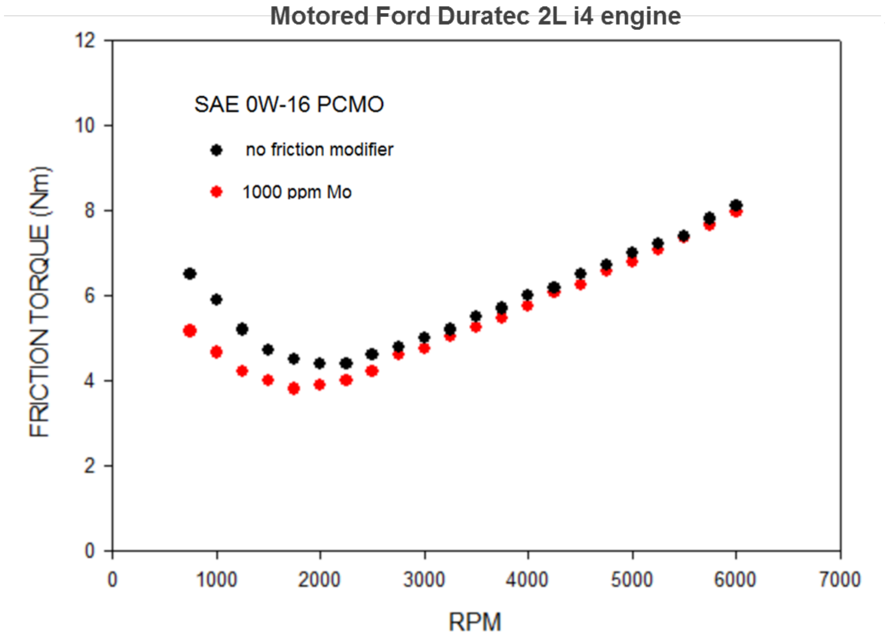
Effect of viscosity grade at 90ºC

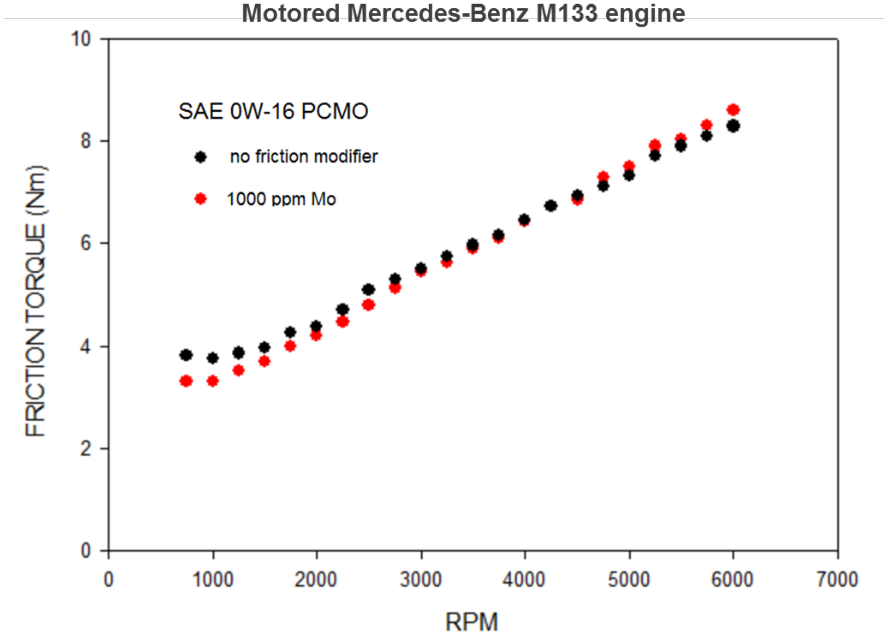


Effect of viscosity grade at 90ºC (cont'd)



Effect of friction modification





The properties of oils used in motored tests

Composition	0W-16	5W-20	5W-30	10W-40
Base oil 150N, wt.%	9.5	31.5	40.7	46.8
Base oil PAO5, wt.%	80	50	40	30
VI improver, wt.%	1	3.5	9.3	13.2
Add-pack, wt.%	10	10	10	10
Properties				
Kin.visc.@100°C, cSt	7.5	8.6	11.9	14.9
Kin.visc.@40°C, cSt	40.9	50.7	74.7	97.7
HTHS@150°C, cP	2.4	2.8	3.3	3.8

The oils were formulated using the same add-pack and base oils in order to separate the effect of viscosity from additive action

Different engines need different oils

Engine 1:

- Cast iron cylinder bores,
- Direct-acting mechanical bucket tappet (DAMB) valvetrain

Caution with using low viscosity oils is recommended
Significant benefit from EP/AW additives and friction modifiers.

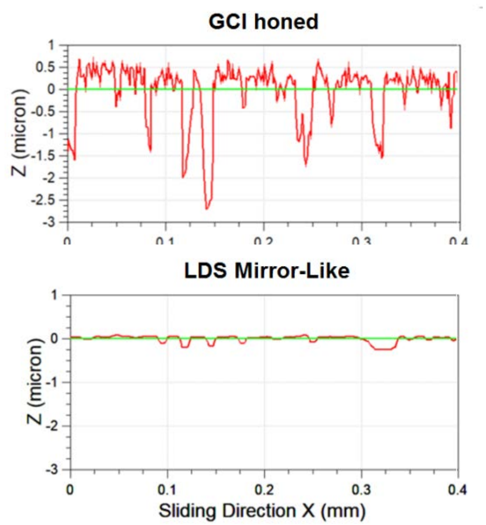
Engine 2:

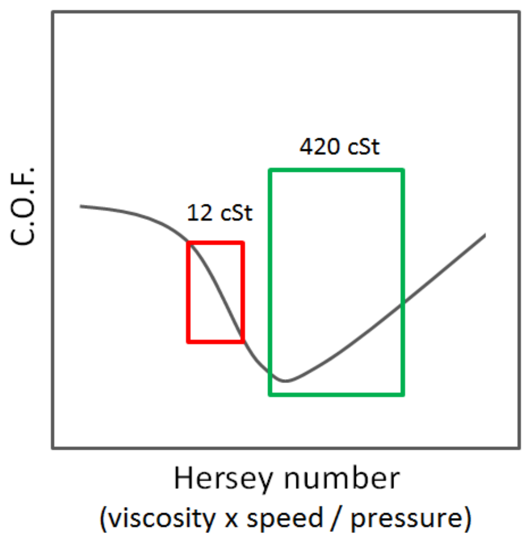
- PTWA/LDS/APS or Alusil cylinder bores,
- RFF, RRA, or EMV valvetrain

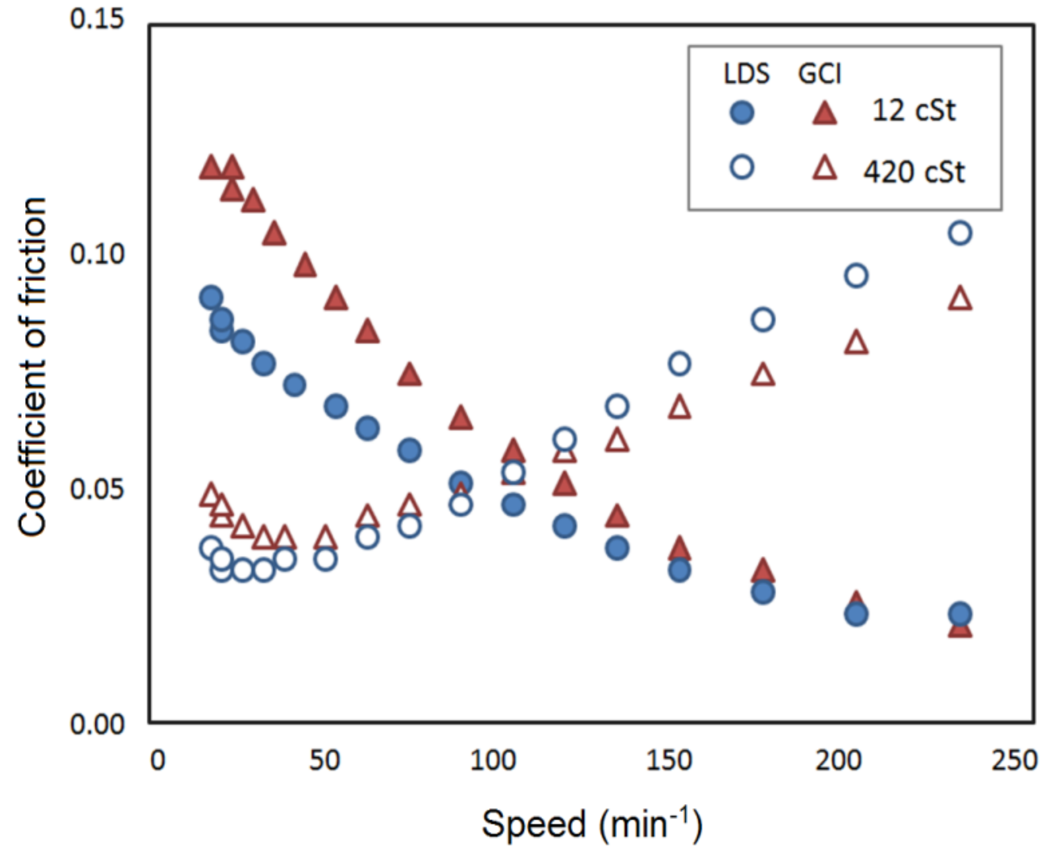
More benefits are likely to be seen for 0W-8 and 0W-12 grades

Safe to use low viscosity oils
Less benefit from EP/AW additives and friction modifiers.

The effect of cylinder bore technology



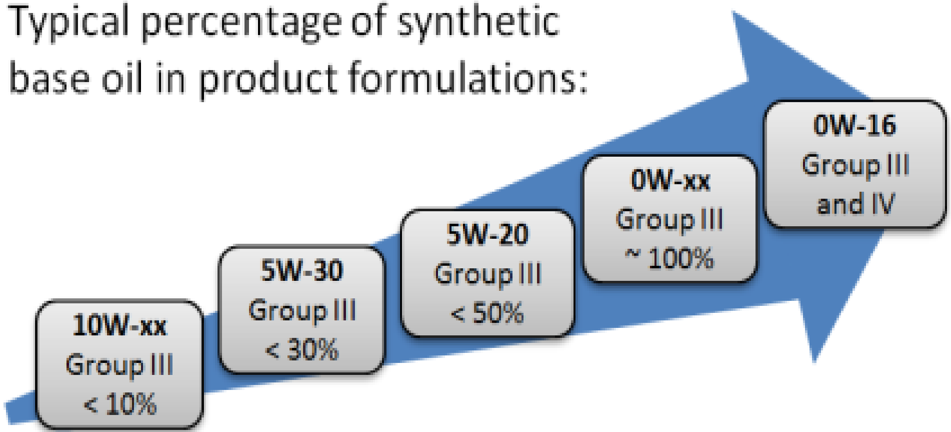


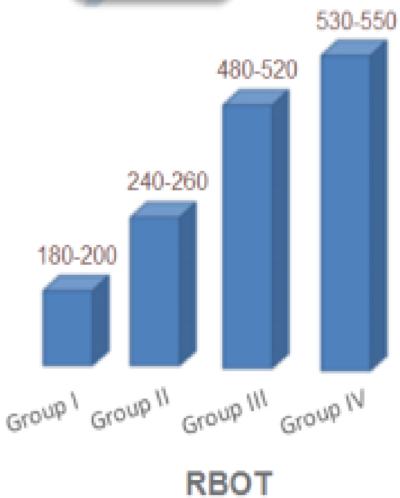


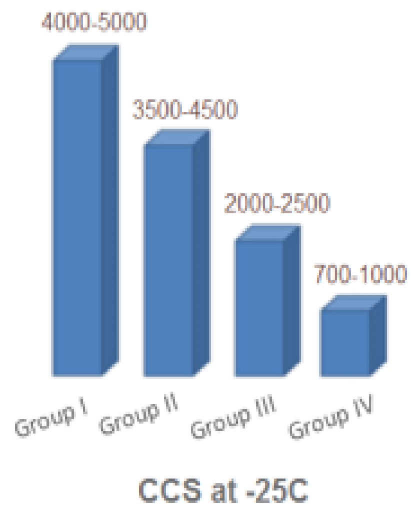
See also:
Tomanik et al. SAE Tech. Paper 2021-01-1214
Zhmud et al. SAE Tech. Paper 2021-01-1217

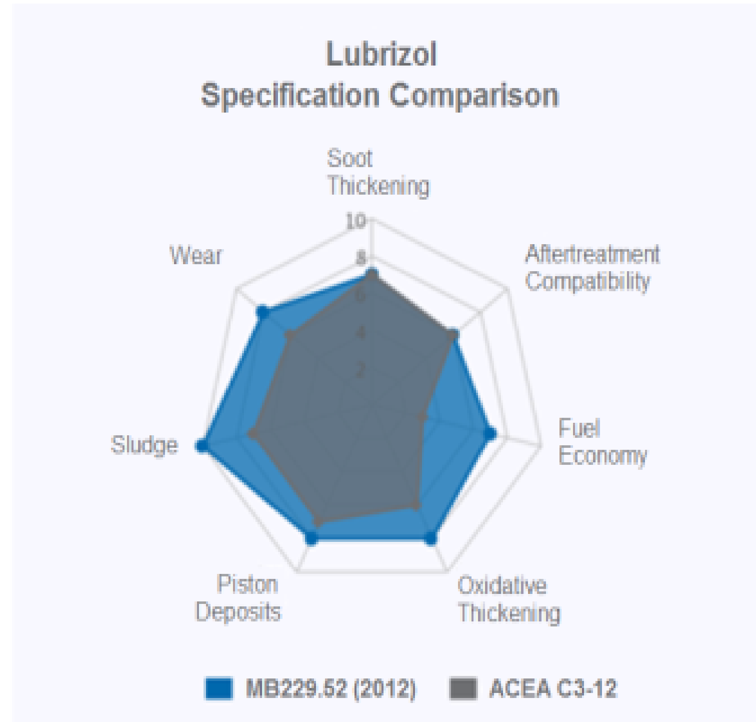
New performance requirements call for synthetics

Typical percentage of synthetic base oil in product formulations:



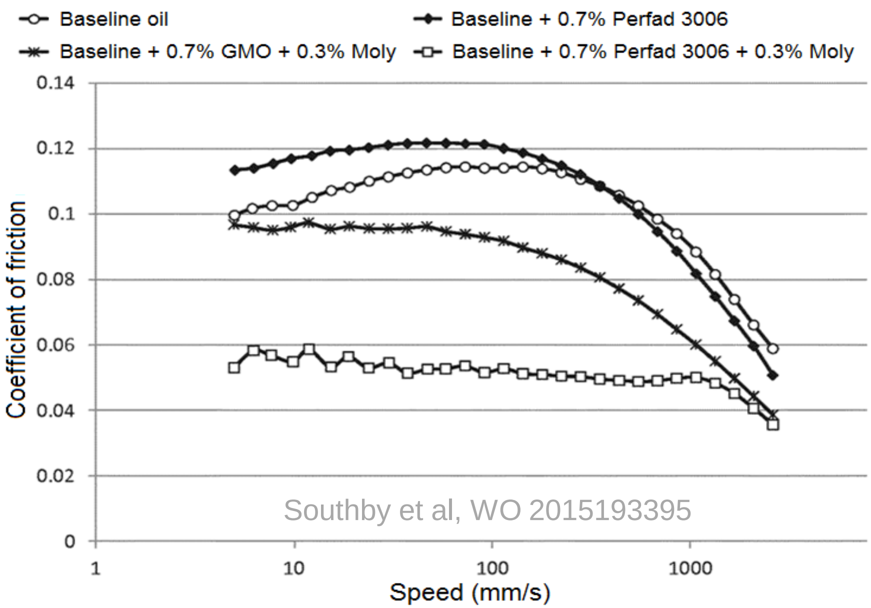


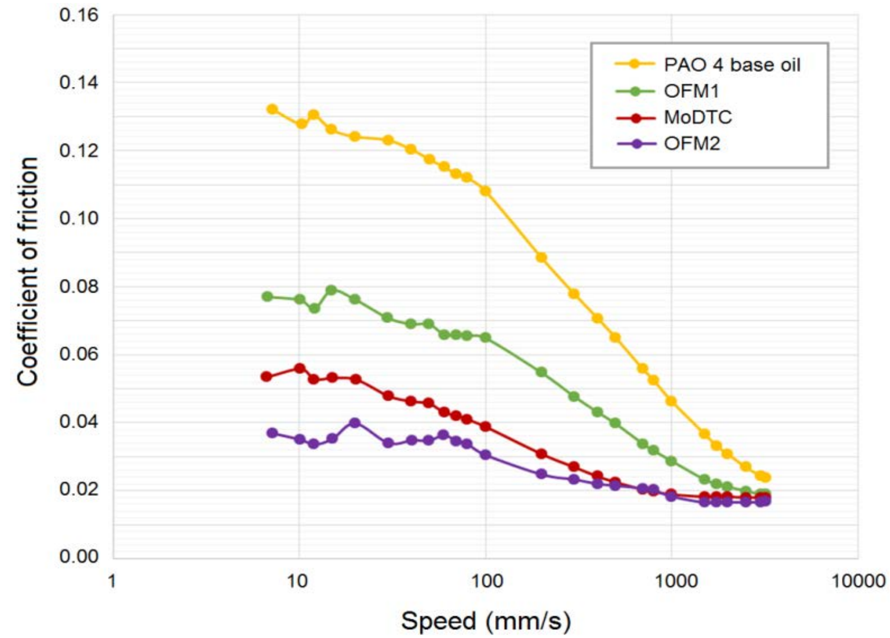


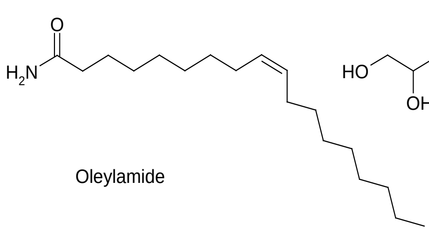


Specification	HTHS (cP)	SA (%)	P (ppm)	S (%)	TBN (mgKOH/g)
MB 229.52 (2012)	≥ 3.5	≤ 0.8	500-900	≤ 0.3	≥ 6.0
ACEA C3-12	≥ 3.5	≤ 0.8	700-900	≤ 0.3	≥ 6.0

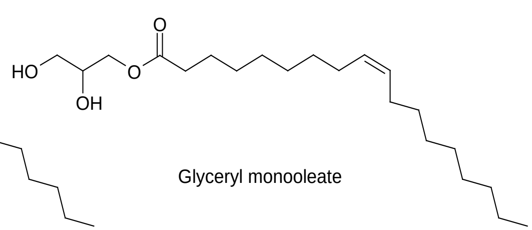
Use of organic friction modifiers for improved fuel economy



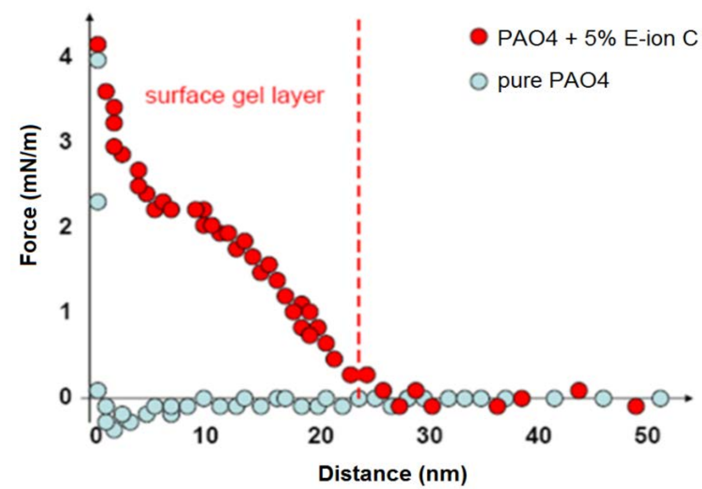




Oleylamide



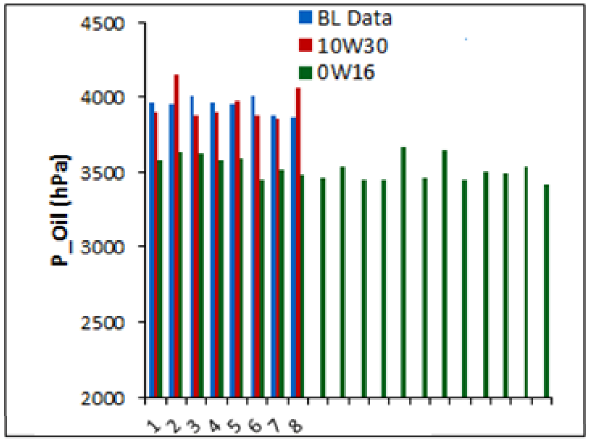
Glyceryl monooleate



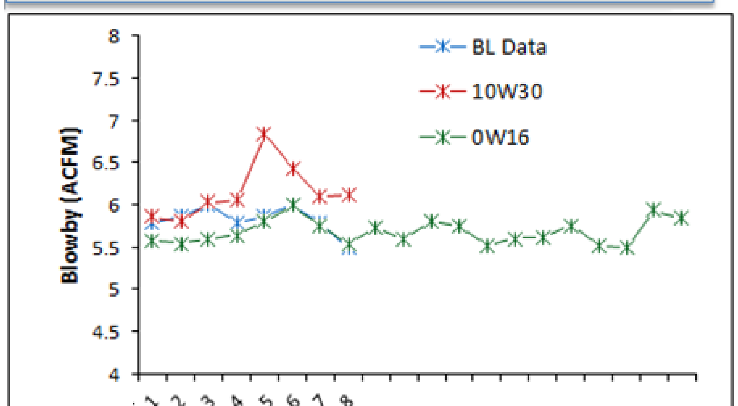
Early experience with ULV HDEO SAE 0W-16

TC25 Daily Check Point Real Engine Data

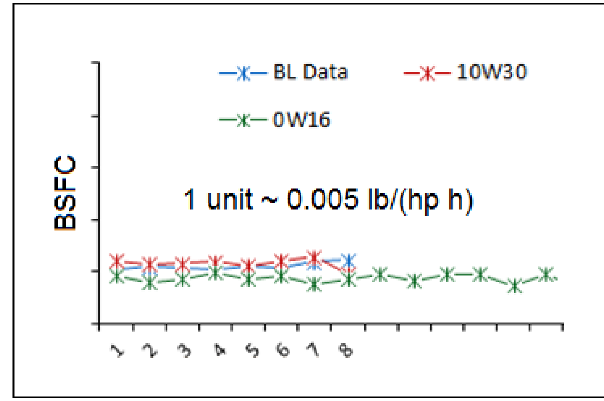
Consistently lower oil pressure with 0W-16

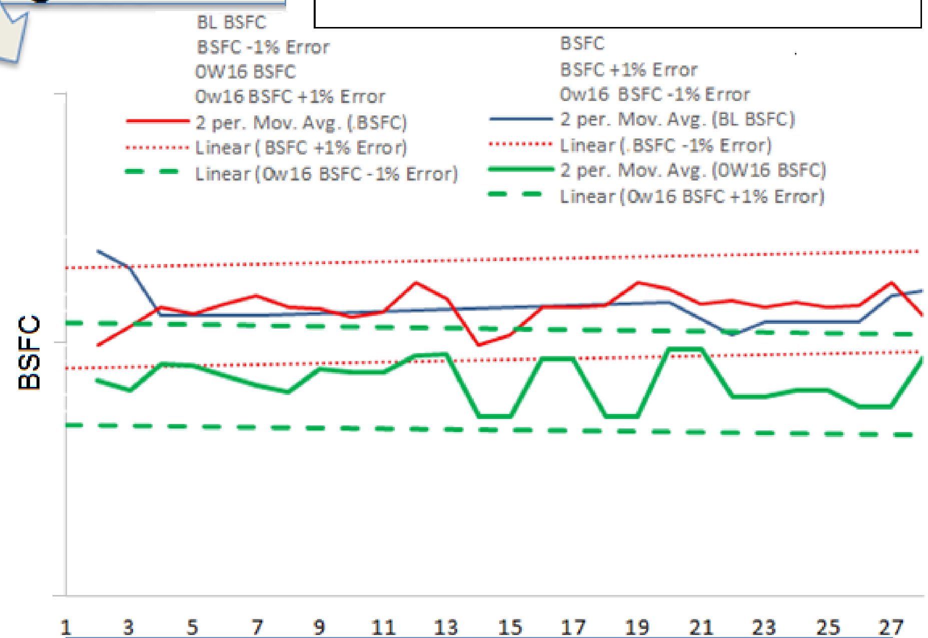


0W-16 has shown good stability in blowby



1% + or - margin with moving average comparisons for BSFC @ DCPs





Roughly 0.5% decrease in BSFC with 0W-16 compared to baseline API FA-4 SAE 10W-30

Data courtesy of NAVISTAR

Conclusions

Motor oil is an important element in the development of low friction powertrains. Switching to low viscosity motor oil is an efficient way to reduce friction losses in internal combustion engines. However, low viscosity oil tends to compromise wear protection necessitating deployment of friction modifiers and antiwear additives in crankcase lubricant formulations. Together with a broader adoption of synthetic base oils, friction modifiers are expected to play an increasingly important role in future.

See also: SAE Tech. Paper 2021-24-0067

THANK YOU!

Questions?

E-mail: zhmud@bizol.de