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F+L WEEK

JUNE 14-16, 2023, KUALA LUMPUR, MALAYSIA

New basestock technology for automotive lubricants and greases

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Agenda

- **Automotive Industry trends**
- **Novel Basestock Technology**
- **Performance illustrated in-Application:**
  - PCMO
  - EV driveline
  - Grease
- **Conclusions**

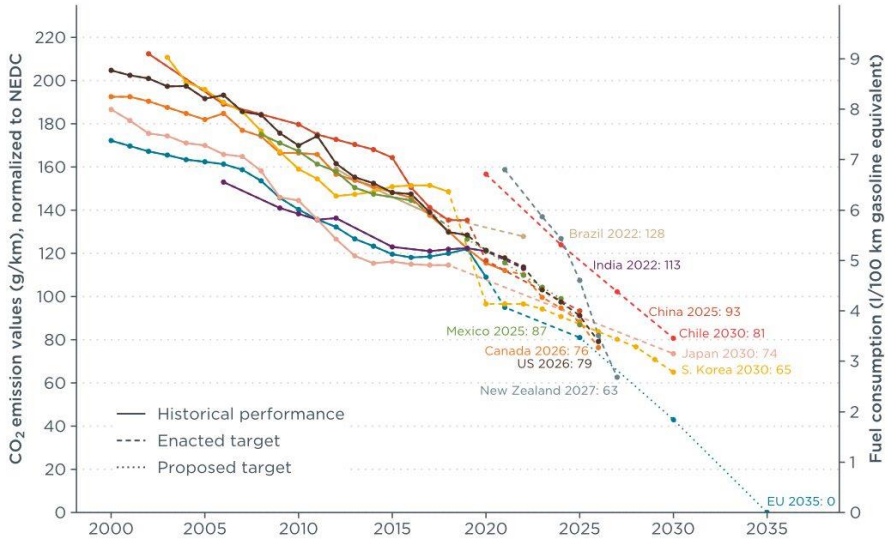
Automotive industry trends

Overarching trend: Energy efficiency to reduce CO_2

ICE market trends dominated by fuel economy

Global regulations continue to be aggressive;
EU imposed emission penalties on OEMs in 2021

Passenger car CO_2 emission and fuel consumption values, normalized to NEDC

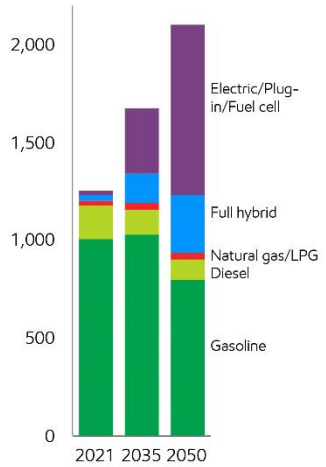


Source: The International Council on Clean Transportation (ICCT)
https://theicct.org/pv-fuel-economy/

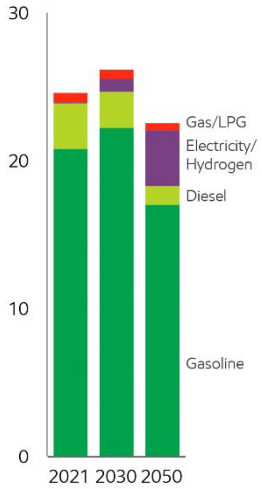
EV market trend focused on extending range

New energy efficient fluids required for e-mobility

Light-duty fleet by type
Million vehicles



Light-duty demand drops
Million oil-equivalent barrels per day



Source: ExxonMobil Energy Outlook 2022

Low viscosity fluids enable improved energy efficiency to reduce emissions and enhance e-mobility

Novel basestock technology

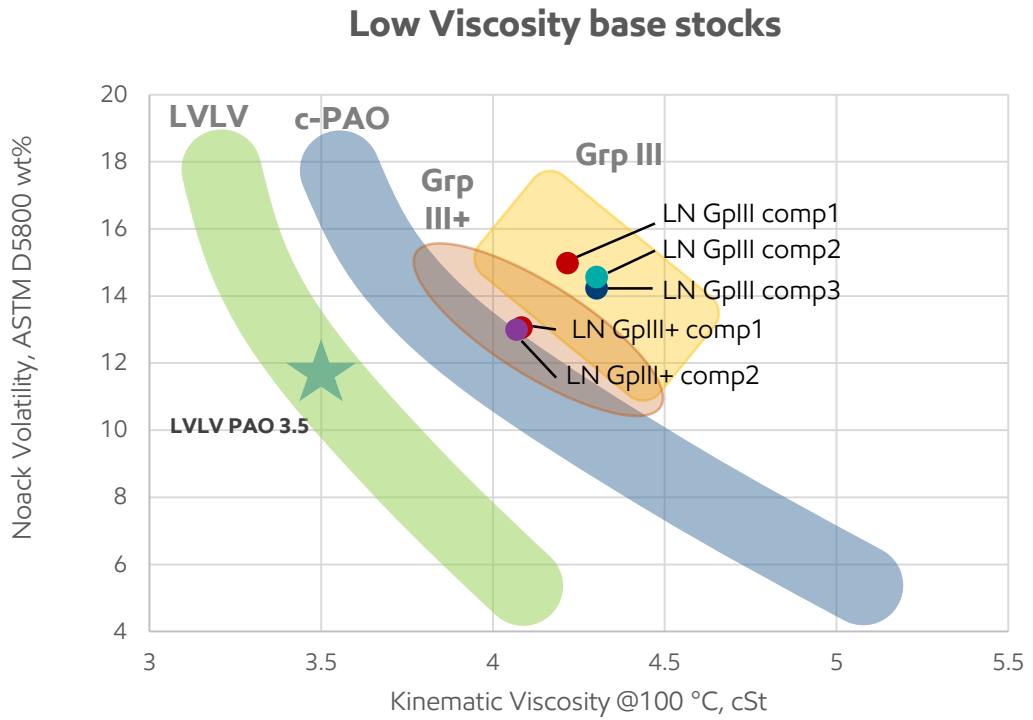
Low viscosity/low volatility (LVLV) PAO technology

LVLV PAO 3.5 unique PAO attributes

- Exceptional low viscosity, low volatility balance
- Excellent low-temperature properties
- Improved oxidative stability
- Enhanced lubricity and traction
- Improved flashpoint versus conventional PAO (c-PAO)

May deliver step-out performance vs. alternatives

- Fuel economy improvements for EO and driveline
- Energy efficiency for EV driveline
- Enhanced durability for extended oil drain intervals



Source: ExxonMobil Data and Publicly available data

LVLV products outperform existing Gr III, III+ and conventional PAO base stocks, enabling next-gen performance

LVLV PAO 3.5 – Key properties

Test	Unit	Test method	LVLV PAO 3.5	PAO 3.6	PAO 4	Gr III+ 4
Kinematic Viscosity @ 100°C	cSt	D445	3.51	3.60	4.10	4.16*
Noack Volatility	wt %	D5800	11.6	17.0	12.4	13.0*
Pour Point	°C	D5950**	-78	-65	-66	-18*
CCS @ -35°C	cP	D5293	790	1050	1430	2045
RPVOT (oxidation test)	min	D2272B	102	47	41	40
Flash Point COC	°C	D92	234	224	220	224

Source
ExxonMobil Data unless noted otherwise
*Publicly available data
**ASTM method D5950 only covers up to -66 °C

LVLV PAO 3.5 achieves low viscosity, while improving or maintaining other key properties

Performance illustrated in-application

LVLV PAO 3.5 – Expanding formulation window

Components	20% cPAO	80% cPAO	10% LVLV PAO 3.5	16% LVLV PAO 3.5	20% LVLV PAO 3.5	38% LVLV PAO 3.5
Group III+	60	-	48	43	34	-
Group III	-	-	22	20	26	-
AdPack/VM	~20	~20	~20	~21	~20	~22
cPAO	20	80	-	-	-	-
LVLV PAO 3.5	**-**	**-**	**10**	**16**	**20**	**38**
Gr II+	-	-	-	-	-	40
Formulated Fluid Properties						
KV100 (6.9-9.3 cSt)	8.1	8.4	8.0	7.8	8.1	7.9
HTHS (≥ 2.6 cP)	2.6	2.7	2.7	2.7	2.6	2.6
CCS –35 °C (<6200 cP)	5290	5014	6038	5242	5500	5439

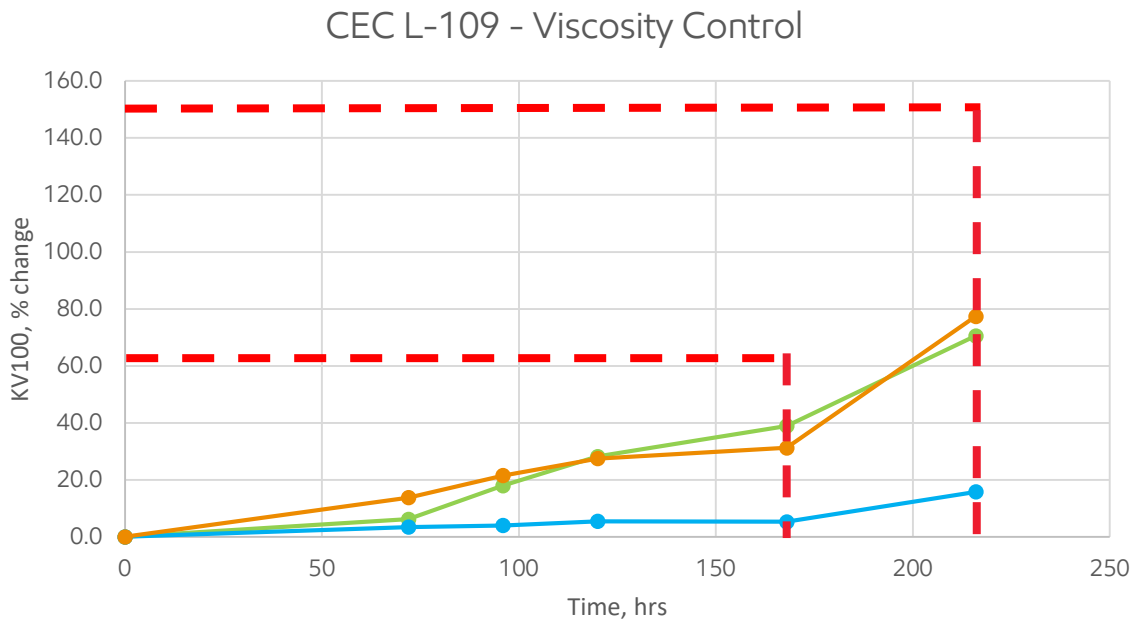
- Benchmark
- Reduce PAO treat with LVLV PAO 3.5 and enable use of Grp III
- Unlock max Grp II+ with LVLV PAO 3.5

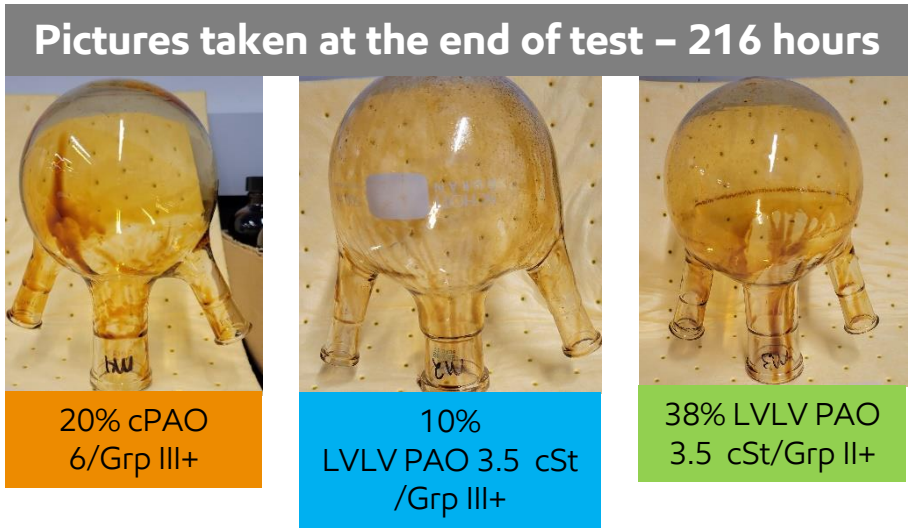
SpectraSyn™ MaX 3.5 Data Source: ExxonMobil Testing Data; cPAO Data Source: Third Party Supplied Data

LVLV PAO 3.5 containing formulations could enable the development of formulations containing Group III or Group II+

LVLV PAO 3.5 – Oxidative stability benefits

- Assessed oxidative stability of finished lubricants in presence of Biodiesel (CEC L-109)
- ACEA standard test run for 168 and 216 hours, with oxidation change ≤ 60% and ≤ 150% respectively
- Pictures were taken at the end of test after 216 hours



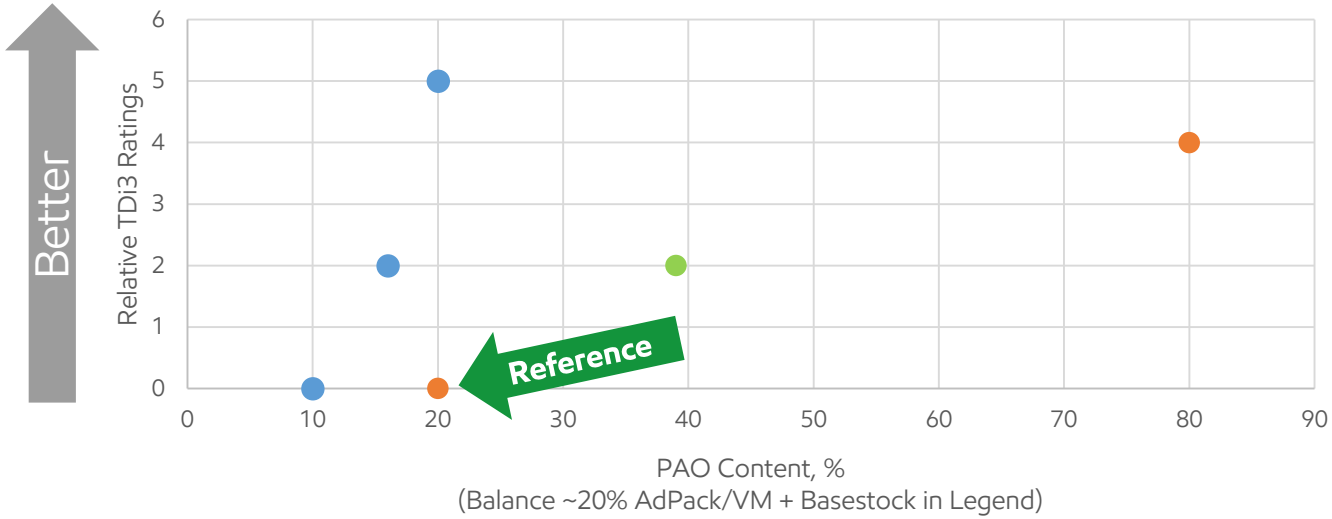


Source: ExxonMobil Internal Testing Data

All formulations meet ACEA requirements, but formulations with LVLV PAO 3.5 substantially outperforms benchmark

VW TDi3 proof of concept: Doing MORE with less

PAO impact & relative TDi3 rating in 0W-20 candidates



Conventional PAO w/ Grp III+

LVLV PAO 3.5 w/ Grp III/III+

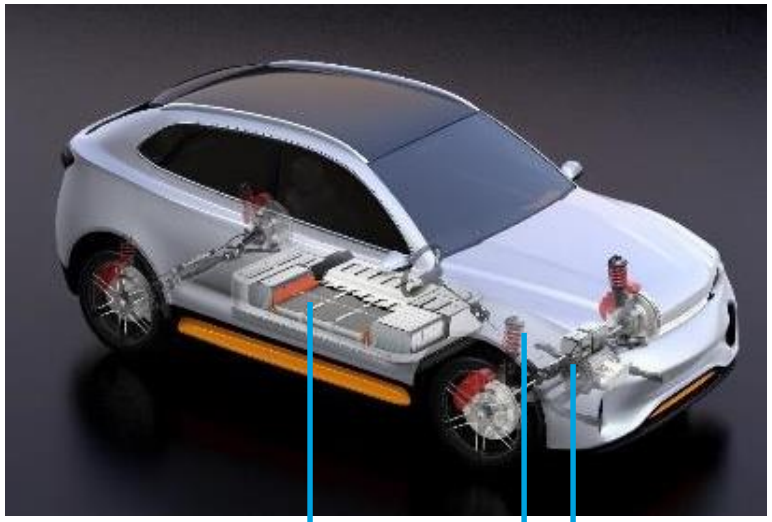
LVLV PAO 3.5 w/Grp II+

LVLV PAO 3.5 Data Source: ExxonMobil Testing Data; cPAO Data Source: Third Party Supplied Data

- LVLV PAO 3.5 seems to provide directional cleanliness benefits compared to conventional PAO at lower treat rates
- LVLV PAO 3.5 with Grp II+ can perform comparably to PAOs and Group III/III+

LVLV PAO 3.5 enables formulation flexibility / performance balance

Evolving requirements, new opportunities



Lubrication challenges:

- High speed
- High temperature
- Long life (improved oxidative stability)
- Electrical properties
- Material compatibility

Base oil directly impacts:

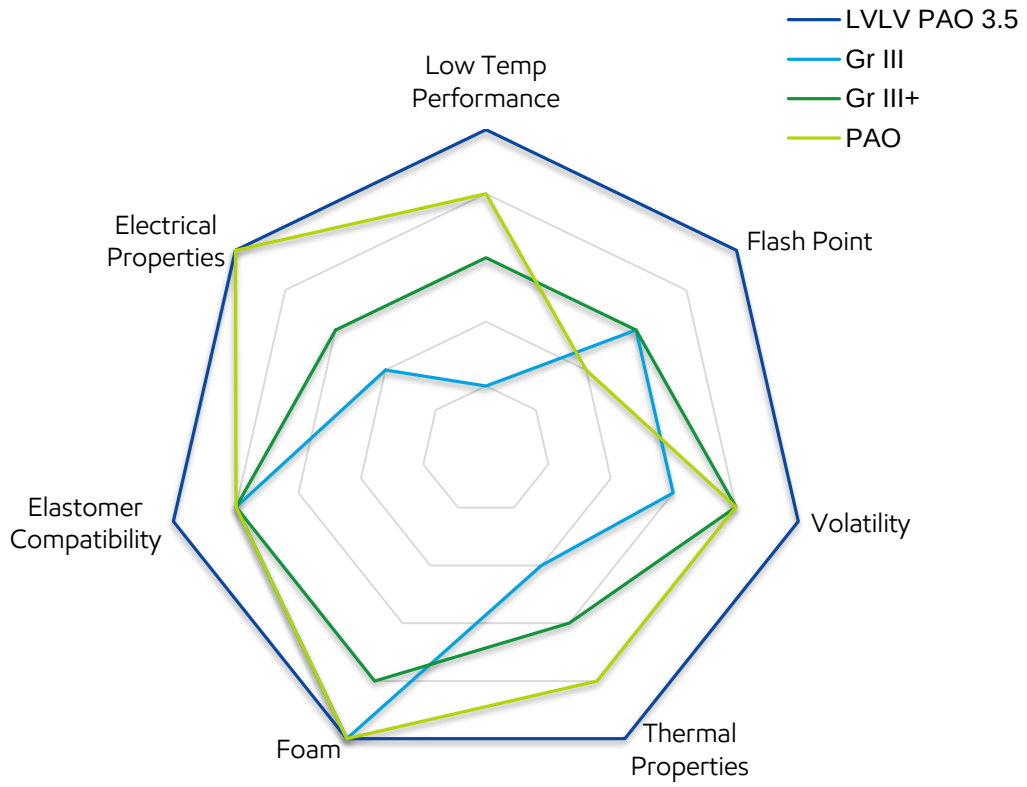
- Energy efficiency (driving range)
- Heat transfer and thermal management
- High-/low-temperature properties, oxidation stability

	Lubrication needs	Thermal needs	Electrical needs
Electric motor	• Energy efficiency • Wear protection	• Heat transfer / cooling • Thermal stability	• Optimized conductivity • Material compatibility
Gearbox	• Energy efficiency • Wear protection	• Oxidative stability	
Battery/ electronics		• Thermal management • Safety	• Insulation • Material compatibility

LVLV PAO 3.5 vs. alternatives

The performance of LVLV PAO 3.5 was compared to other base stocks blended to the same viscosity

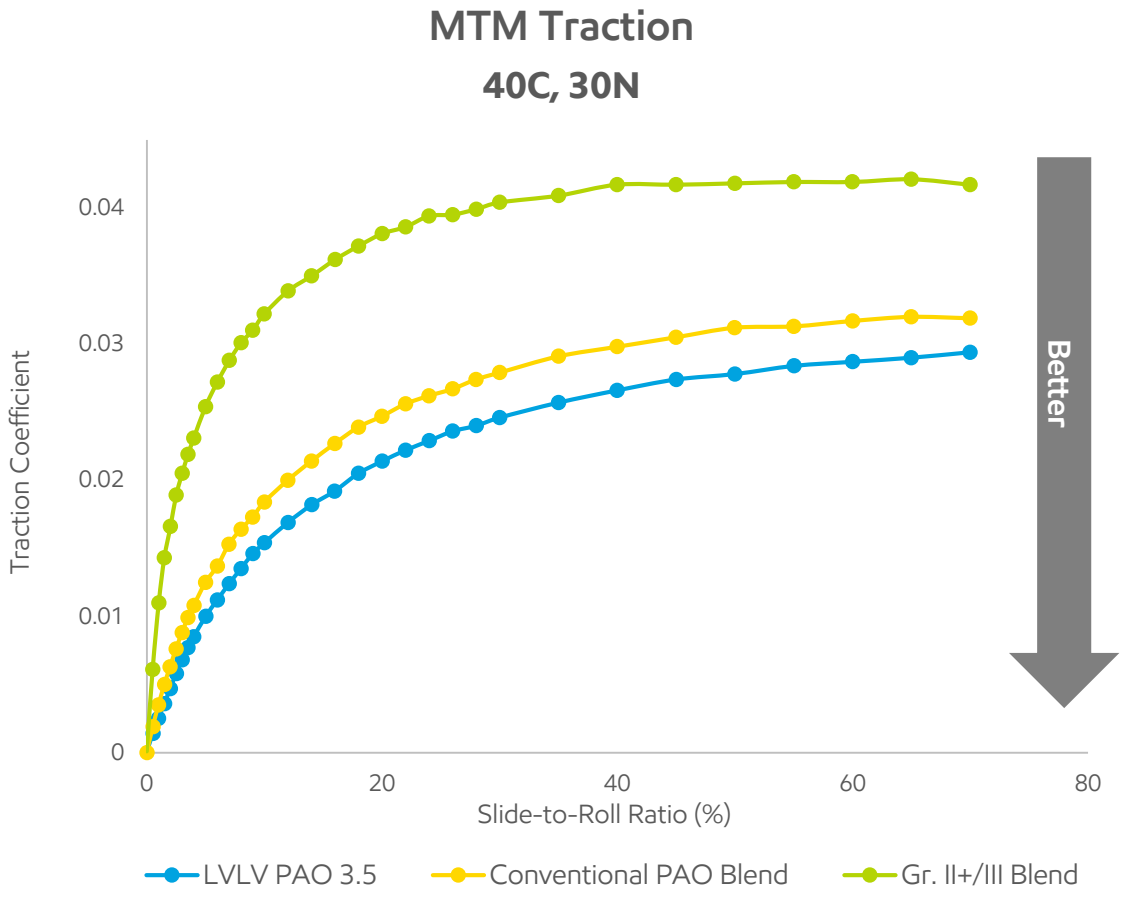
	LVLV PAO 3.5	Gr III	Gr III+	PAO
KV100, cSt (ASTM D445)	3.51	3.43	3.49	3.48
KV40, cSt (ASTM D445)	14.2	14.4	14.4	14.4
VI	**128**	114	122	120
Pourpoint, °C (ASTM D97)	**-78**	-24	-51	-60
Noack at 250 °C, 1 hour (ASTM D5800)	**12.5**	33.4	26.4	28.0
Flash point (CoC), °C (ASTM D92)	**225**	201	210	203



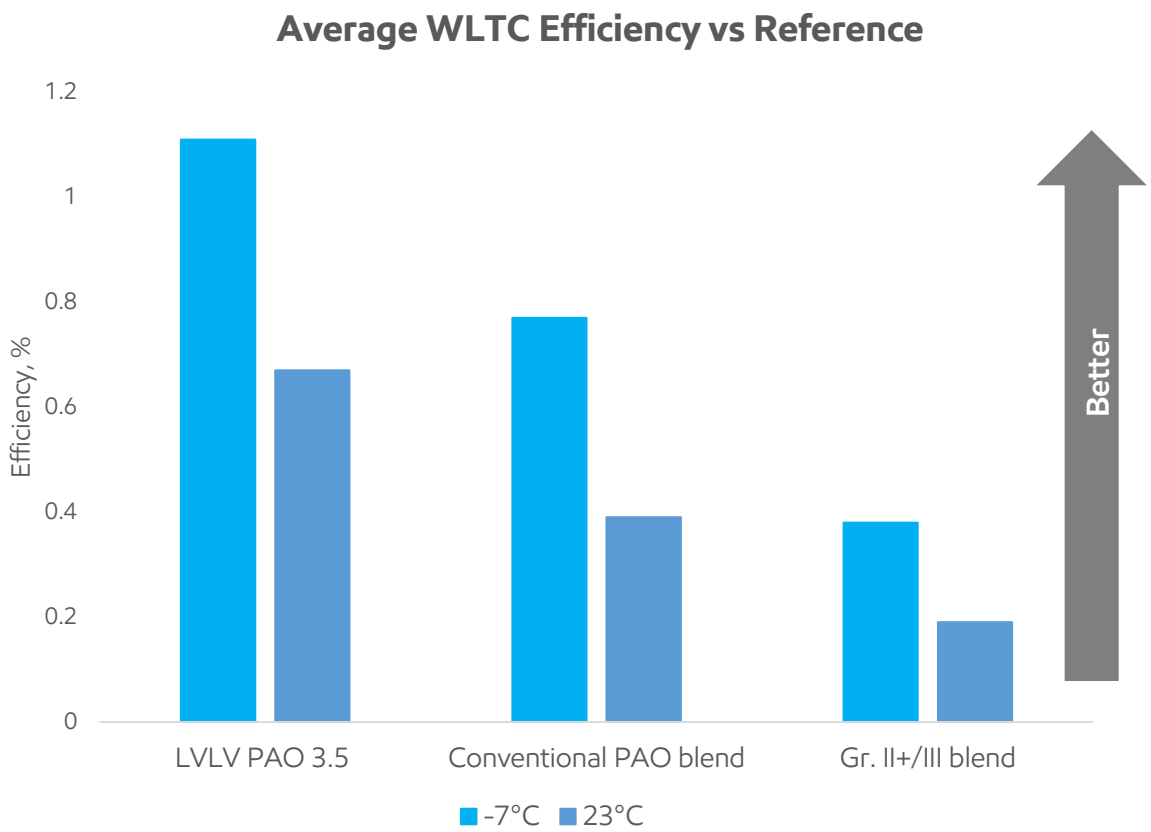
Source: ExxonMobil Data & Analysis of publicly available data

LVLV PAO 3.5 may provide superior performance compared to other basestocks

Improved energy efficiency & extended drive range



(All blends are formulated to similar KV100°C viscosity, Load 30N, speed 2 m/s, SRR 0-70%)



(All blends are formulated to similar KV100°C viscosity)

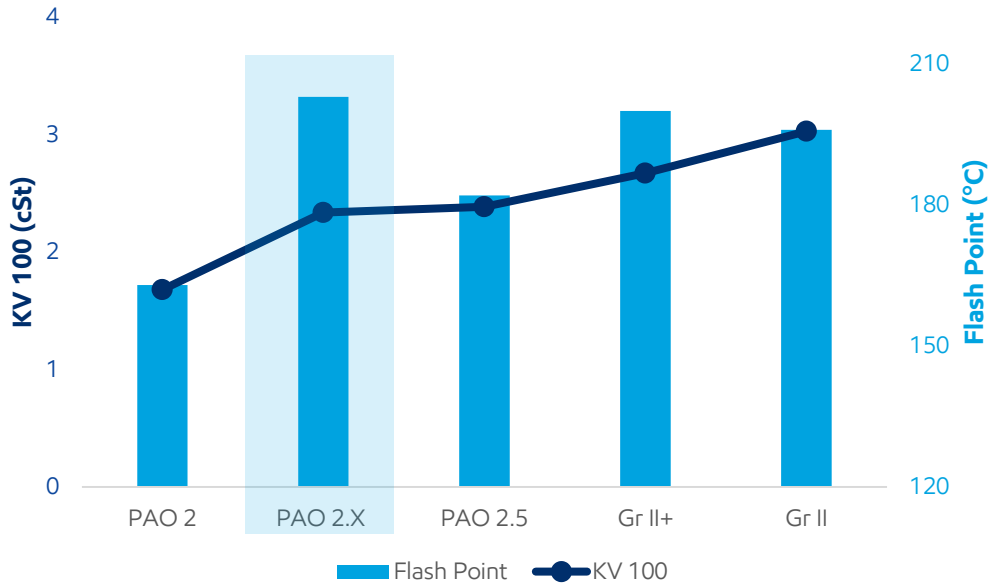
Source: ExxonMobil Internal Testing & Analysis of publicly available data

LVLV PAO lowers friction & torque losses, resulting in improved energy efficiency in mechanical systems.

LVLV PAOs deliver differentiated volatility/flash point

Property	Based on method	LVLV 3.5	PAO 2.X *
KV @ 100°C, cSt	ASTM D445	3.5	2.3
KV @ 40°C, cSt	ASTM D445	14.2	8.2
Flash Point , °C	ASTM D92	234	203

* PAO 2.X is an experimental next-gen PAO



Source: ExxonMobil Data & Publicly available data

Next-gen PAOs achieve low viscosity, while improving or maintaining other key properties

Grease test candidates do not contain any additives

	Gr III	PAO 6	LVLV PAO 3.5 I (mPAO 300)	LVLV PAO 3.5 II (AN12)
Thickener LiX	16.4%	16.4%	16.4%	16.4%
Base Oil Blend				
LVLV PAO 3.5			81%	55%
PAO 6		95%		
Gr III	100%			
mPAO 300			14%	
AN 5		5%	5%	
AN 12				45%
BOV, ASTM D7042, cSt	29.2	29.8	28.5	29.5
Penetration after 60 strokes, 1/10 mm	277	276	271	281

	Gr III	PAO 6	LVLV PAO 3.5 I (mPAO 300)	LVLV PAO 3.5 II (AN12)
Thickener PU	16.5%	14.1%	15.3%	16.3%
Base Oil Blend				
LVLV PAO 3.5			81%	55%
PAO 6		95%		
Gr III	100%			
mPAO 300			14%	
AN 5		5%	5%	
AN 12				45%
BOV, ASTM D7042, cSt	29.2	29.8	28.5	29.5
Penetration after 60 strokes, 1/10 mm	272	276	268	280

SpectraSyn™ MaX 3.5 = low-viscosity/low-volatility PAO 3.5 cSt @100°C
mPAO 300 = metallocene PAO 300 cSt @100°C
AN 5 = alkylated naphthalene 5 cSt @100°C
AN12 = alkylated naphthalene 12 cSt @100°C

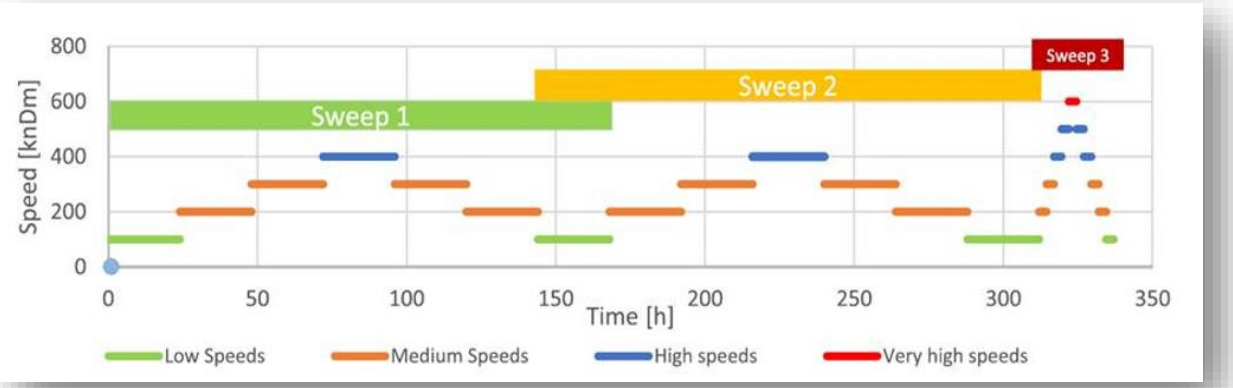
Tests conducted on novel high-speed test rig, KTH Stockholm

Bearing test rig features include:

- Two heads with four Type 6208 Deep Groove ball bearings each
- Axial load ~210 N, radial load ~300 N
- Variable speeds up to 600.000 nDm
- Room temperature, uncontrolled
- **Grease test candidates do not contain any additives**

Bearing test profile:

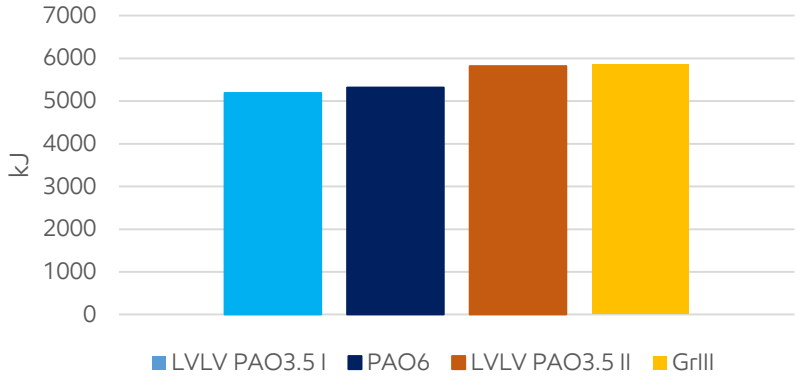
- Grease homogenized in the bearing for 50 hours at low, medium and high speeds
- Speed increments run for 24 hours in Sweep 1 and 2, every 2.5 hours in Sweep 3

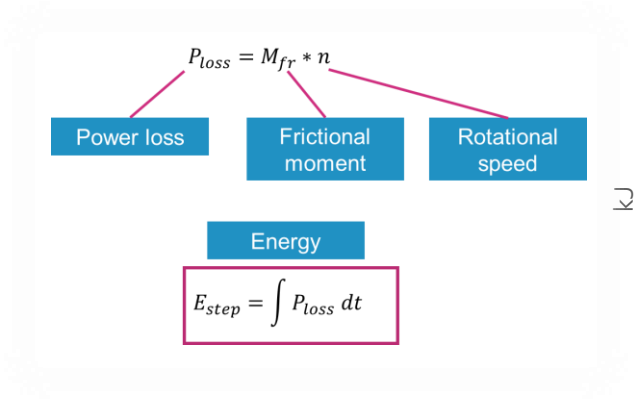


Source: ExxonMobil Data
Photos courtesy of KTH Stockholm

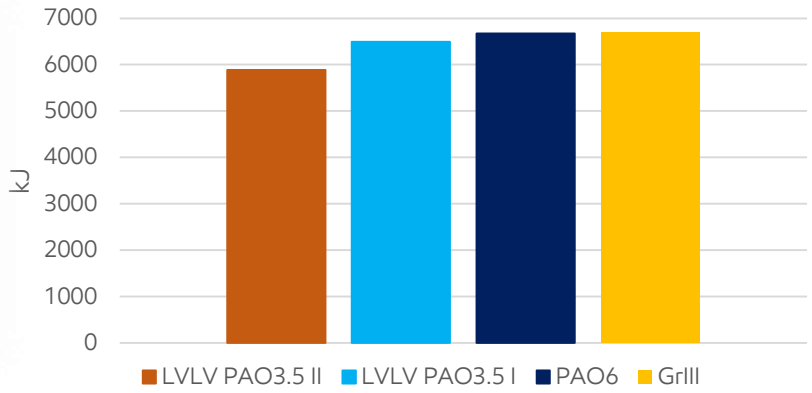
Energy consumption, high-/low-temperature properties

Energy Consumption – LiX Greases

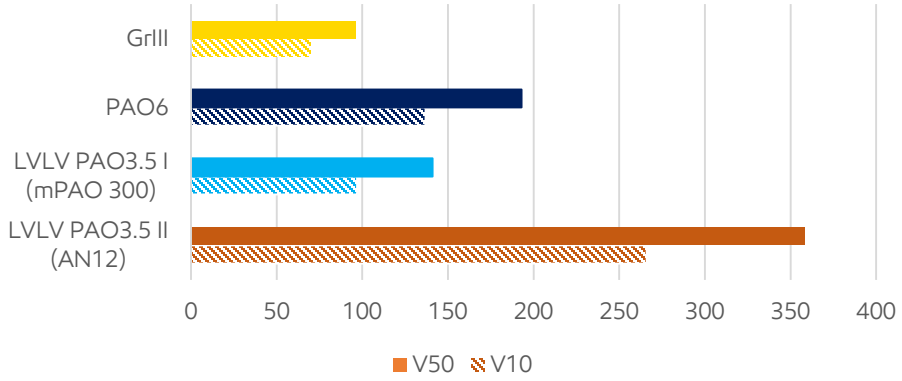




Energy Consumption – PU Greases

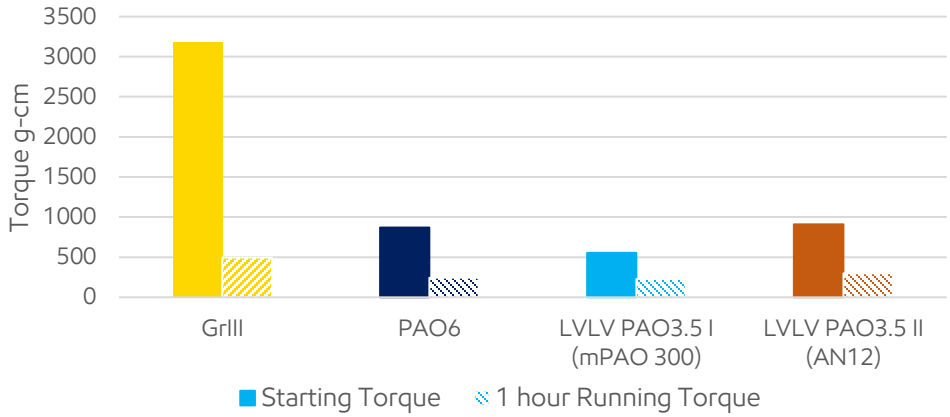


FE9 - DIN 51821; 6000 min-1, 120°C

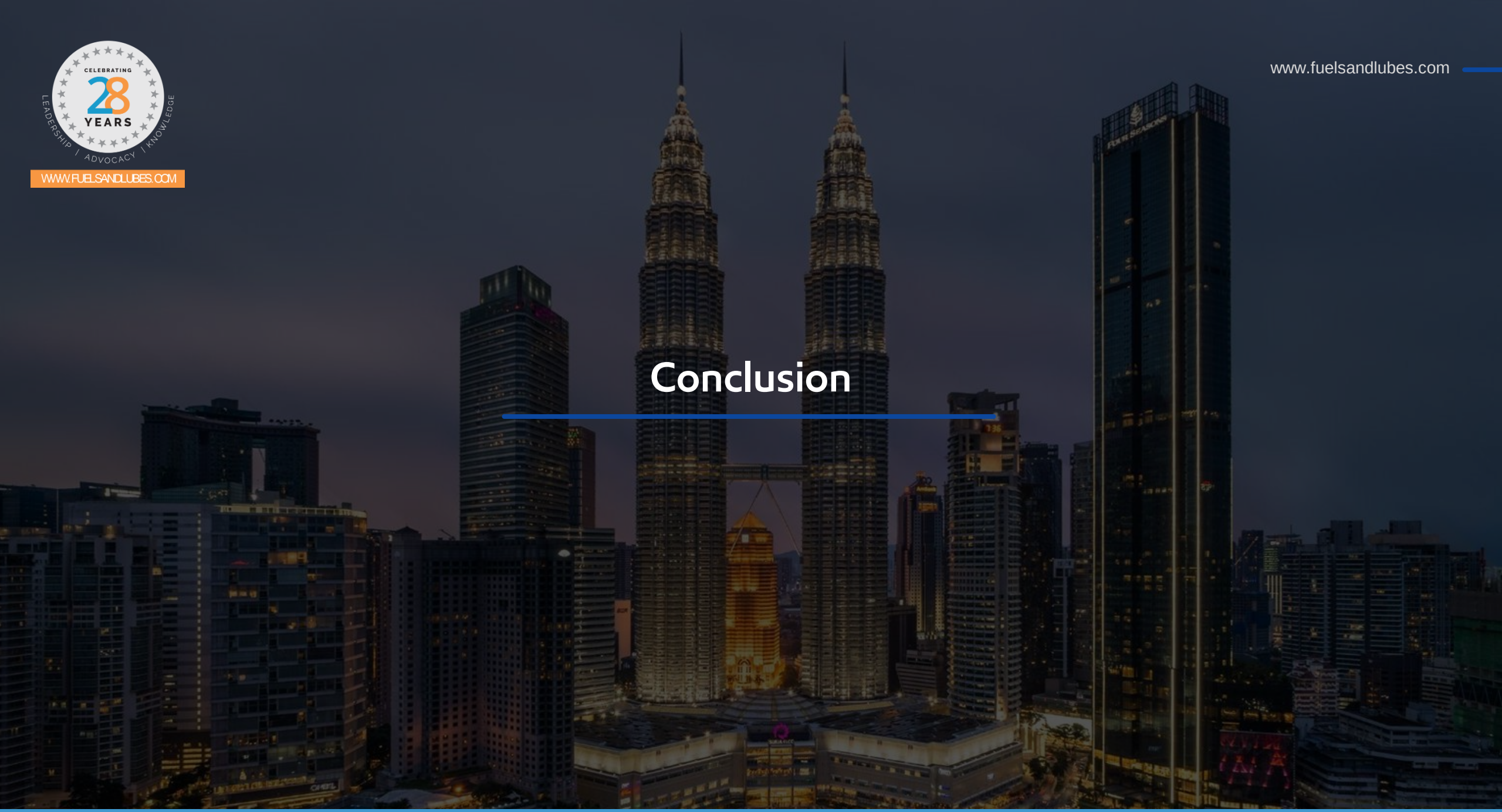


FE9 and low-temperature torque for LiX Greases

Low Temperature Torque @-40°C, ASTM D1478



LVLV PAO can improve energy efficiency as well as low-/high-temperature properties of bearing greases



Conclusion

Summary

- **Improved energy efficiency of ICE and EV driveline concepts remains a key driver of the automotive industry**

- **Low-viscosity/low-volatility basestock technology enables lubricant manufacturers to develop their next-generation lubricants and greases for automotive applications**

  - Significantly improved viscosity/volatility balance and low-temperature properties compared to conventional PAO and Gr III/III+
  - Increased formulation flexibility and performance benefits for the development of low-viscosity engine oils
  - Enhanced oxidation stability and lower traction can provide extended oil drain intervals and improved energy efficiency of transmission fluids
  - EV greases based on novel basestock technology can provide better durability and lower energy consumption

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Ask us about our new basestock technology for automotive lubricants and greases

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