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Tribology in Transportation: Lubricants Perspective

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Where opportunity creates success

Outline

- Changes in lubricants business over past 20-30 years
- Options for lubricant formulations
- Options for decarbonizing transport
- Trends affecting future lubricants
  - Electrification
  - Sustainability
  - New materials & economic considerations
  - Increasingly diverse range of fuels
  - Sensors/AI/ML
- Conclusions

Changes in Lubricants Business since 1990

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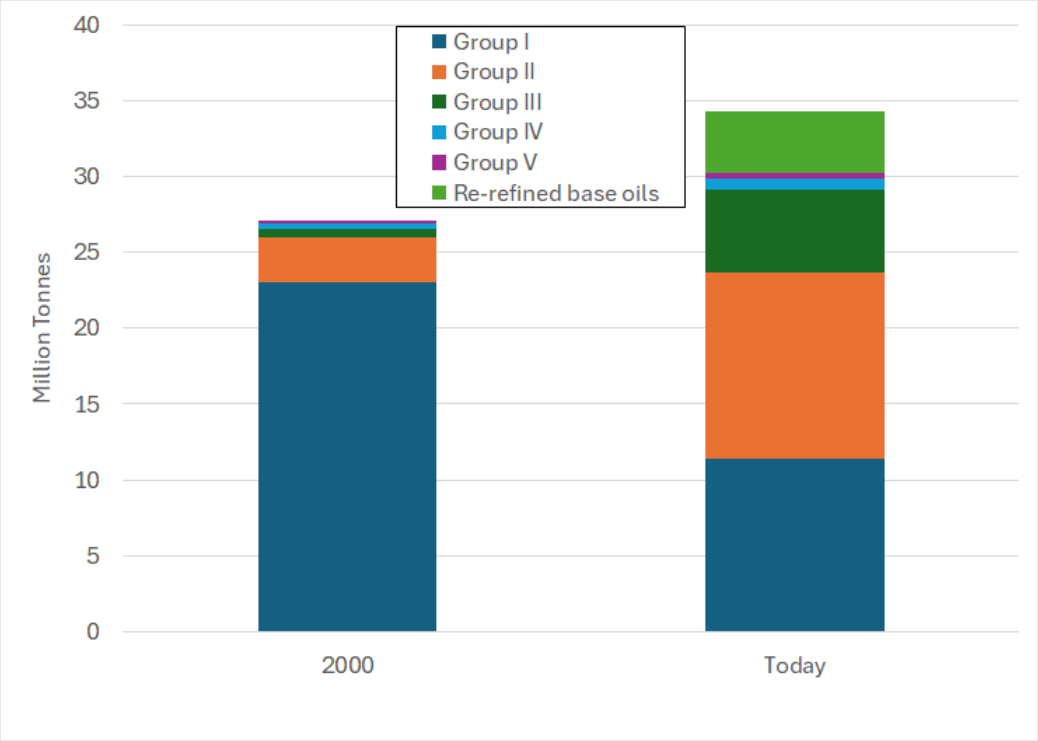
- Big shift away from Group I base oils
- Decreases in passenger car engine oil viscosities + wider use of friction modifiers
- Compositional constraints on lubricants (such as sulphur and phosphorus limits on engine oils in vehicles fitted with aftertreatment devices)
- Largest market demand is now in Asia (accounts for about 45% of worldwide demand)
- Overall market size has stayed roughly constant at approximately 37-40 million tonnes (apart from “blips” due to the 2008 financial crisis and the COVID pandemic)
- Currently about half of all lubricants are used in transportation

Changes in Base Oil use

- Big shift away from Group I base oils – to Group II, III, IV and V – estimated numbers below



Group IV = PAO
Group V = natural/synthetic esters + PAGs

Changes in Passenger Car Viscosity Grades

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- Large reductions in passenger car engine oil viscosity, more modest changes for heavy-duty engine oils
  - From 2016, API FA-4 heavy-duty diesel engine oils with HTHS viscosity between 2.9 to 3.2 mPa.s can be specified for use. Standard API CK-4 oils have HTHS viscosity $\geq$ 3.5 mPa.s.
  - Friction modifiers widely used in today's passenger car engine oils, but are not usually used in heavy-duty diesel engine oils

SAE grade	V_k40 (cSt)	V_k100 (cSt)	HTHS (mPa.s)	Approx year
15W-40	114.3	14.9	3.5	1990
5W-30	57.4	9.9	2.9	2000
0W-20	44.4	8.3	2.6	2015
0W-8	26.4	5.5	1.9	Future

Options for Lubricant Formulations

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- Many choices for the automotive lubricant formulator – choices will affect the cost of the lubricant and its performance

Base oil & detergents

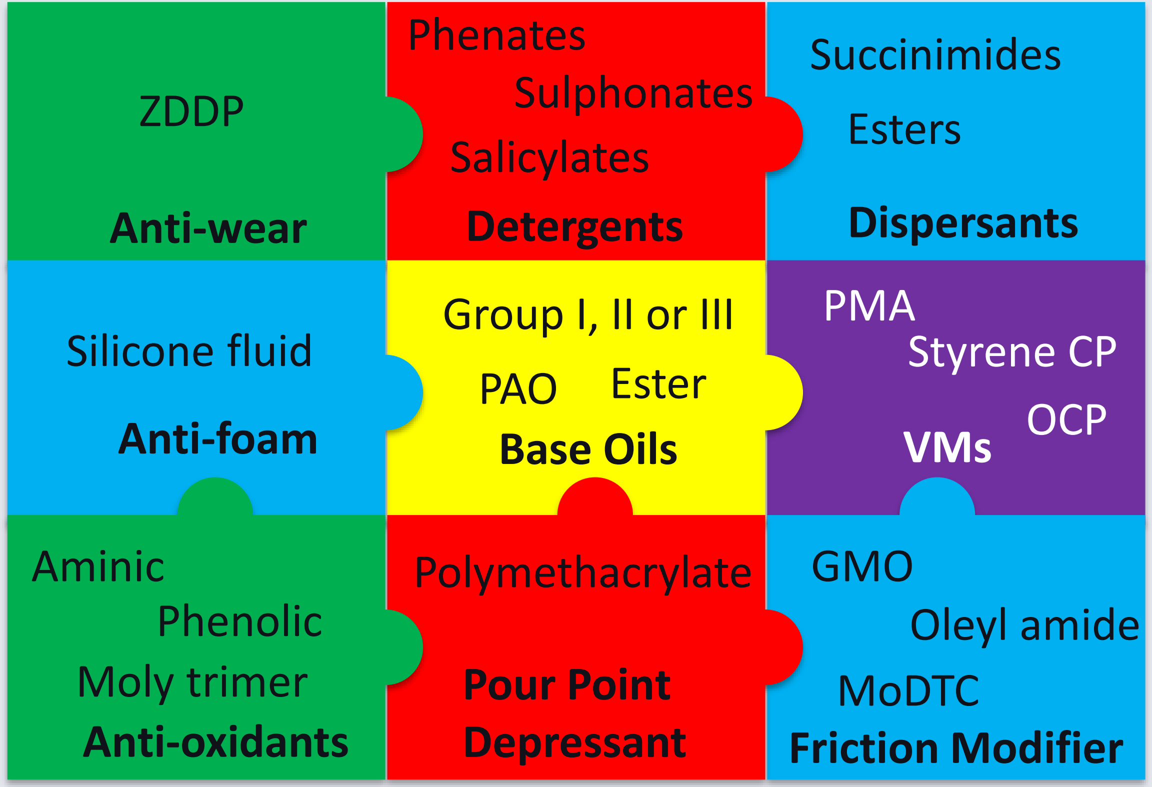
Protect the engine

VMs, PPDs, Anti-foam & Anti-Oxidants

Protect the lubricant

Dispersants & Anti-Wear

Protect the engine and the lubricant



Options for Decarbonizing Transport

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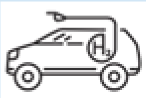
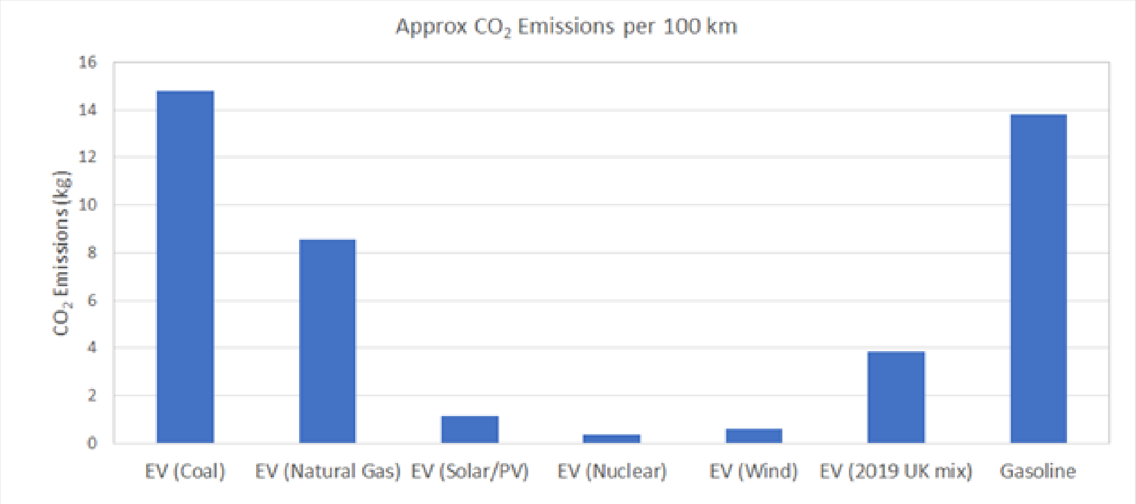
	 Electric	 Conventional	 Hydrogen	 Cycling
Energy to travel 100 km	15-25 kWh	6 litres gasoline ≈ 205 MJ ≈ 57 kWh	1 kg H_2 (≈ 50 kWh to make 1 kg H_2 by electrolysis)	2.2 kWh (David MacKay book)
CO_2 Emissions	≈ 4 kg (UK electricity mix)	≈ 14 kg	≈ 9 kg**	≈ 2.1 kg (eating extra food)
Approx cost*	£5.10 - £8.50	£8.40	£10 - £15 (per kg)	£5 (food)
Refuelling time	20 mins to few hours (depends on charger)	3-5 mins	5 mins	A few hours!
Other emissions	No tailpipe emissions	NO_x & PM (impacts local air quality)	Water	None

* Assumes UK electricity price of 34p per kWh, petrol price of £1.40 per litre & current UK H_2 costs

https://www.forbes.com/sites/rrapier/2020/06/06/estimating-the-carbon-footprint-of-hydrogen-production/

Future Trends

- Electrification – most countries that are decarbonizing their electricity grids have concluded that the best way to reduce CO_2 emissions from passenger cars is to move from internal combustion engines to batteries
- Figure below shows estimated CO_2 emissions (kg) for a car driving 100 km. CO_2 emissions for electric vehicles will be at the power plant rather than the tail pipe.



https://www.mdpi.com/2075-4442/9/7/66

Future Trends

- Electrification – most countries that are decarbonizing their electricity grids have concluded that the best way to reduce CO_2 emissions from passenger cars is to move from internal combustion engines to batteries
- It will take 10-20 years (at least) to fully electrify the passenger car fleet. At present roughly 43% of new cars are electrified, but only about 20% are fully electric (BEVs) – the others are various types of hybrids
- Hybrid cars – with both engine and battery may need a different lubricant – due to higher fuel dilution and water levels in oil, with lower oil temperatures and many more stop-starts during operation

Future Trends

- Sustainability – currently there is great focus on lubricant sustainability at present
- Lubricant product carbon footprint guidelines are available from the API and ATIEL
- However, the lubricant contribution to CO_2 emissions is almost negligible compared to the CO_2 emissions arising from the energy needed to move the car – see table below (which assumes cars with annual mileage of 10,000 miles) – table below show CO_2 emissions in kg

	CO_2 emissions (energy)	CO_2 emissions Engine oil	CO_2 emissions Transmission oil
Gasoline car	3568	14.2	2.8
BEV	1408	-	2.8

- The easiest way to make lubricants more sustainable is to formulate them from re-refined base oils (made from recycled used oil) and extend the oil drain interval

https://www.jstage.jst.go.jp/article/trol/18/6/18_268/_pdf

Future Trends

- New materials & economic considerations
- Much research ongoing into novel nanoparticle lubricant additives and all sorts of bio-based base oils
- In addition, today's lubricants do not just have to lubricate steel-on-steel, but also steel/DLC, steel/coatings, aluminium etc.

Future Trends

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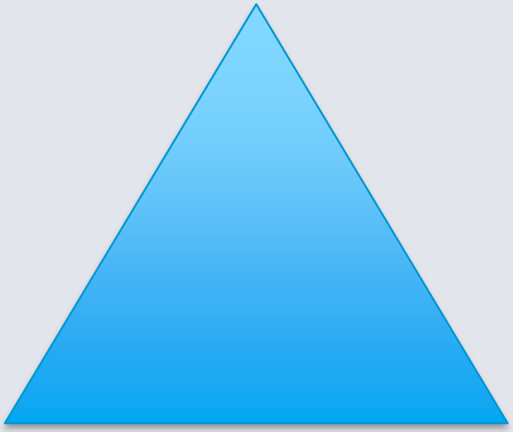
- Novel lubricant additives – it is important to realize that the choice of what additives to use in a lubricant is **NOT** just a technology decision

Technology – what additives can be used
to reach required performance specification



Commercial – Price/performance
calculation for the various options

Supply Chain – Number of manufacturing
plants, financial stability of supplier,
additive package options

Future Trends

- Novel lubricant additives – choice of what additives to use in a lubricant is **NOT** just a technology decision
- Using publicly available data, a "ball-park" estimate of the average additive package cost is \$5,700 per tonne, ZDTP is about \$3,300 per tonne and MoDTC is about \$10,000 per tonne
- If we take graphene as a typical potential lubricant nanoparticle additive, this is likely to be around \$50,000 per tonne! ***It is not surprising that nanoparticle additives are not currently used in high-volume, mainstream, commercial lubricants.***
- In addition, novel lubricant additives will not be used if they are not registered with regulatory chemistry authorities.
- Manufacturers of such additives may be better advised to target lower volume, high profit niche areas such as high-performance greases, motorsports applications, space etc.

Future Trends

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- Increasingly diverse range of fuels used in future transport
- There will undoubtedly be tribological challenges along the way
- Fuels such as ammonia are being considered for ships. Natural gas is also an option, and is also currently used for heavy-duty trucks

E10
B7

Conventional fuels

Electricity

H_2

Hydrogen

E100
E85
E20

Biofuels

LNG
CNG

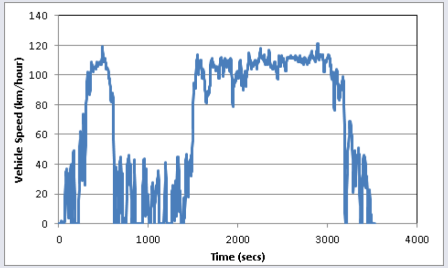
Natural Gas

NH_3

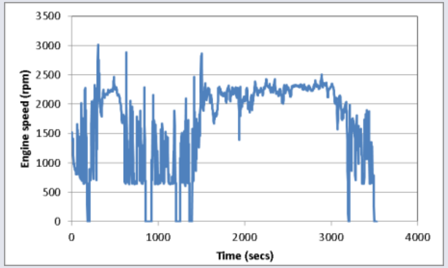
Ammonia

Future Trends

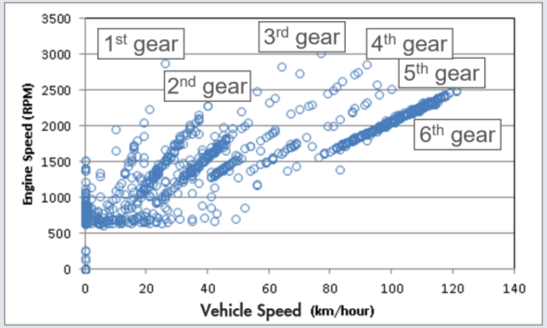
- The impact of sensors, AI and ML on tribology will be potentially massive
- Useful data can already be obtained just by analyzing data from a car’s ECU – data below taken from datalogger fitted to my personal car in 2016



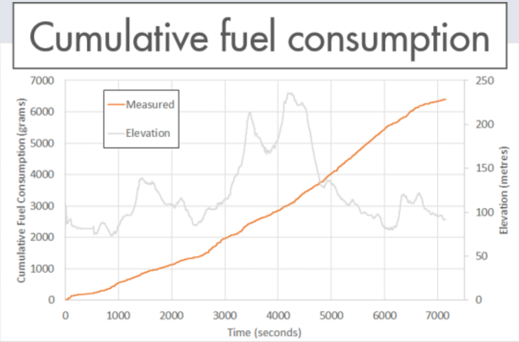
Vehicle speed versus time



Engine speed versus time



Engine speed versus vehicle speed



Future Trends

- The impact of sensors, AI and ML on tribology will be potentially massive
- For lubricant sensors, the following economics are worth considering
  - Budget for condition monitoring for high Capex equipment (e.g. wind turbine, 400 tonne mining vehicle) – about $10,000 per year
  - Budget for vehicle condition monitoring for single heavy-duty truck probably only about $100-$200 per year – main option here is ECU datalogging
  - Vehicle condition monitoring for passenger cars – zero
- Any sensor that is intended to be used for lubricant condition monitoring will need to be **CHEAP**

Conclusions

- It is anticipated there will be many future challenges for lubricants used in transport
- However, it must be recognized that the lubricants business is used to change
- There is likely to be an increasingly diversified range of fuels used in future vehicles
- The impact of electrification – it's pace, and take-up – will greatly impact the lubricants business (because of the potential drop in demand for engine lubricants and the impact on the lubricants specification systems)
- Although there is much academic tribology research on bio-based lubricants and novel nanoparticle additives, there are many hurdles for these to overcome before they will become more widely used – most lubricant companies are likely to use re-refined base oils to make their lubricants more sustainable
- There will be many opportunities arising in tribology from the use of smart sensors coupled with appropriate AI and ML algorithms

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Many thanks for attending the talk

Any questions?

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