Evolution of Engine Lubricant Technologies Enabling Improved System Efficiency and Extended Durability

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PLENARY LECTURE

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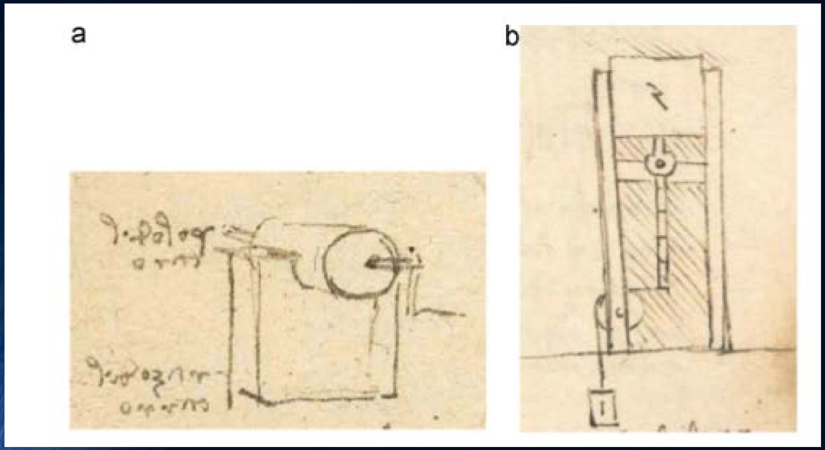
Outline

- Historical Perspective on Innovations in Transportation
- Current Engine Lubricants: Status Quo & Examples of Key Performance Characteristics
- Ways to Move Forward: Convergence of Technical Efforts in Combustion, Materials, and Fluids

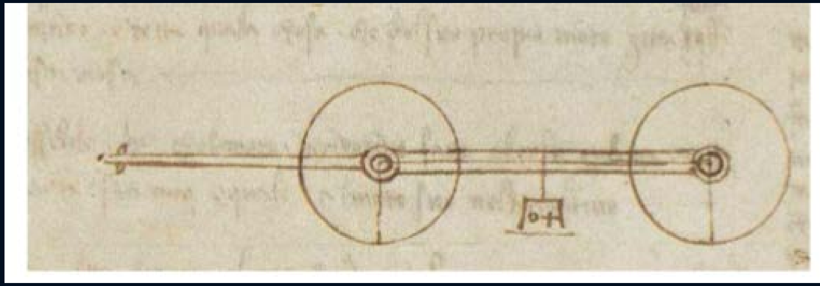
Tribute to Leonardo Da Vinci: World's First Tribologist

Tribology:

The study of friction, wear, lubrication, and the design of moving parts; the science of interacting surfaces in relative motion.



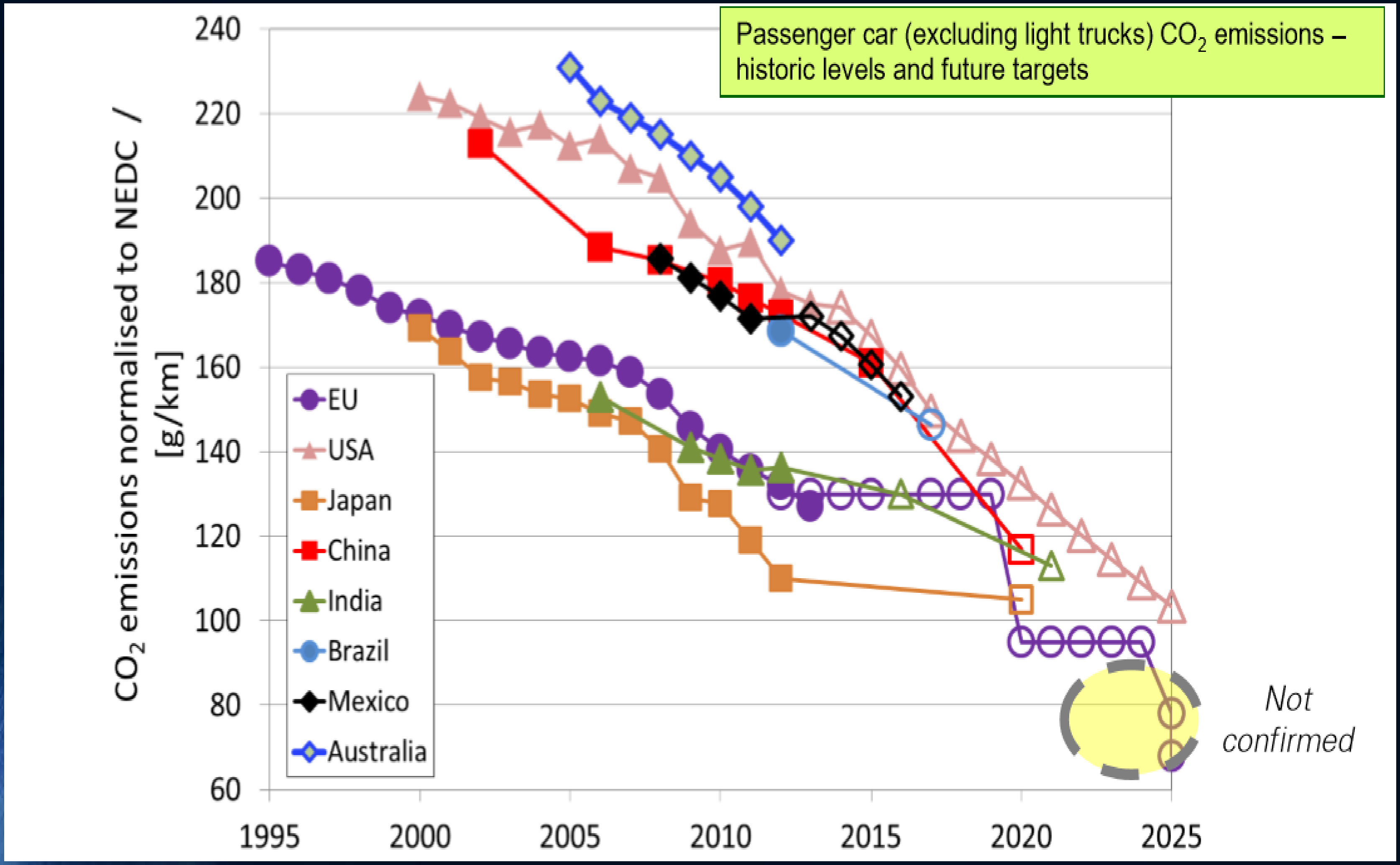
Sketches suggesting methods to measure the torque on rotating axles:
(a) c. 1487–90
(b) c. 1497.



Sketch showing a cart Leonardo analyzed regarding the effect of friction on the axles:c. 1493–7

Source: Wear (2016)

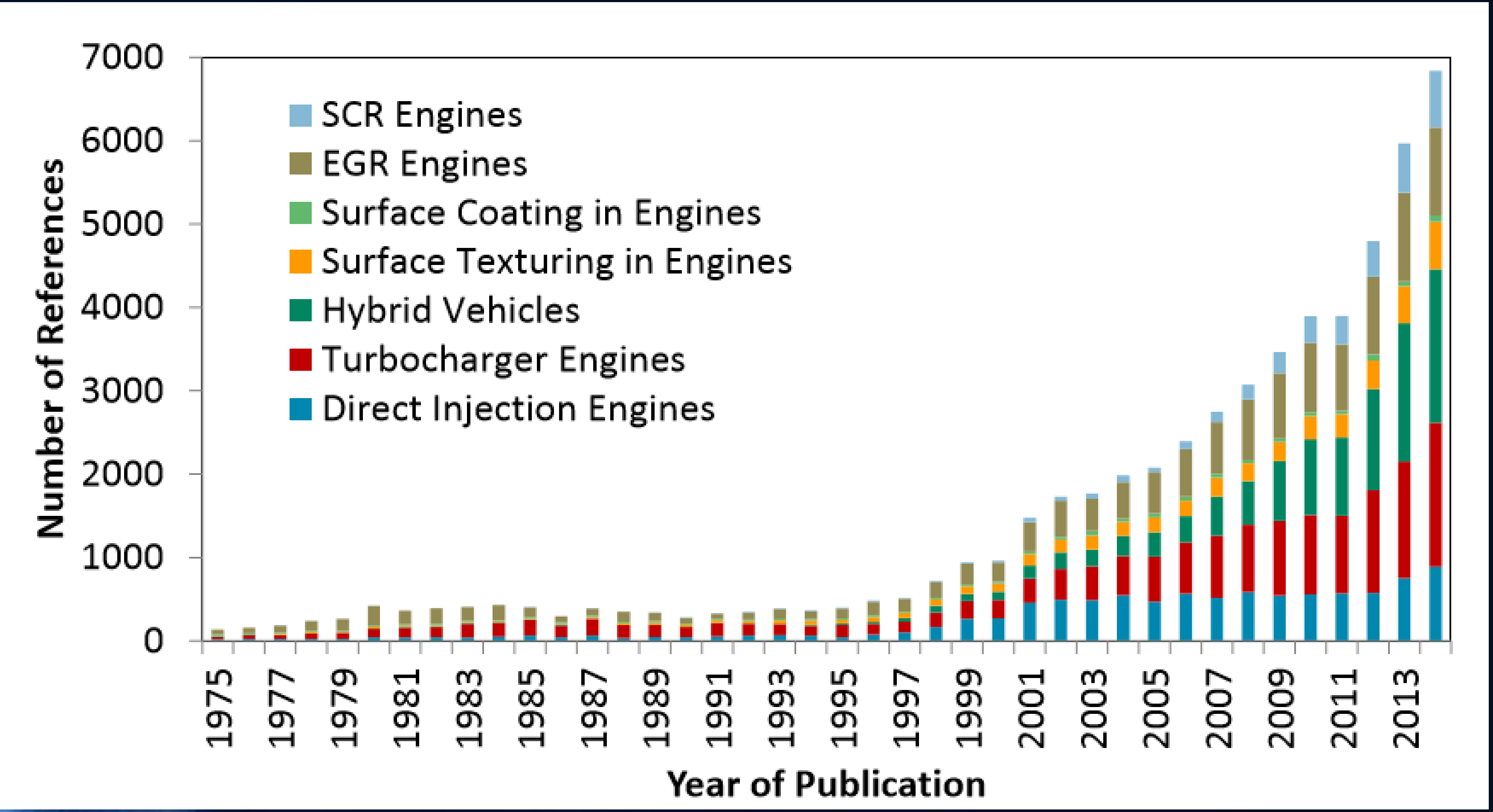
CO_2 and Fuel Economy Global Legislation



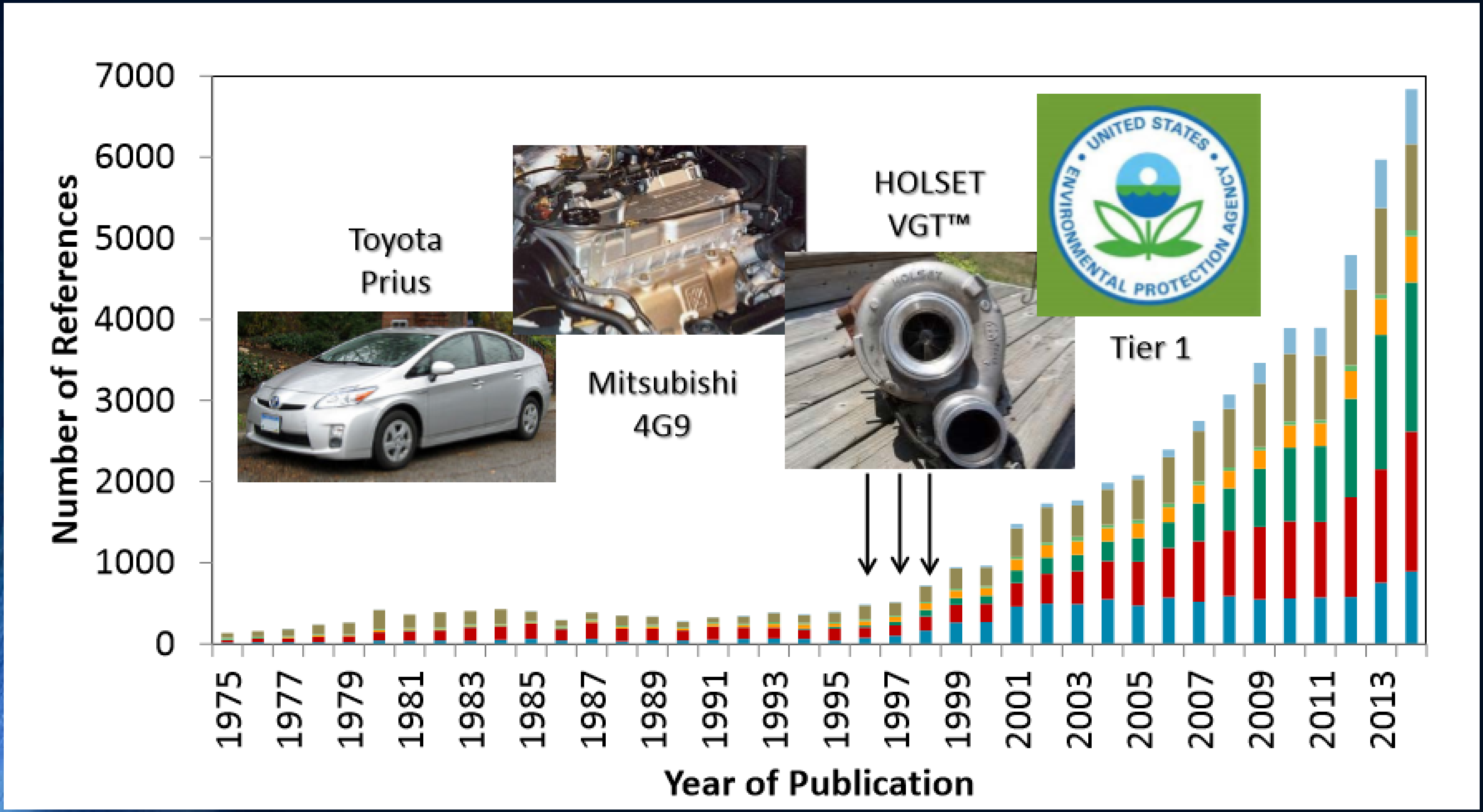
Source: BP

- HDV: Japan targeted a CO2 reduction of 15% in 2015 relative to 2002 levels.
- US have HDV FE legislation
- EU has LDV CO2 limits and proposes to monitor HDV CO2 with a view to setting targets

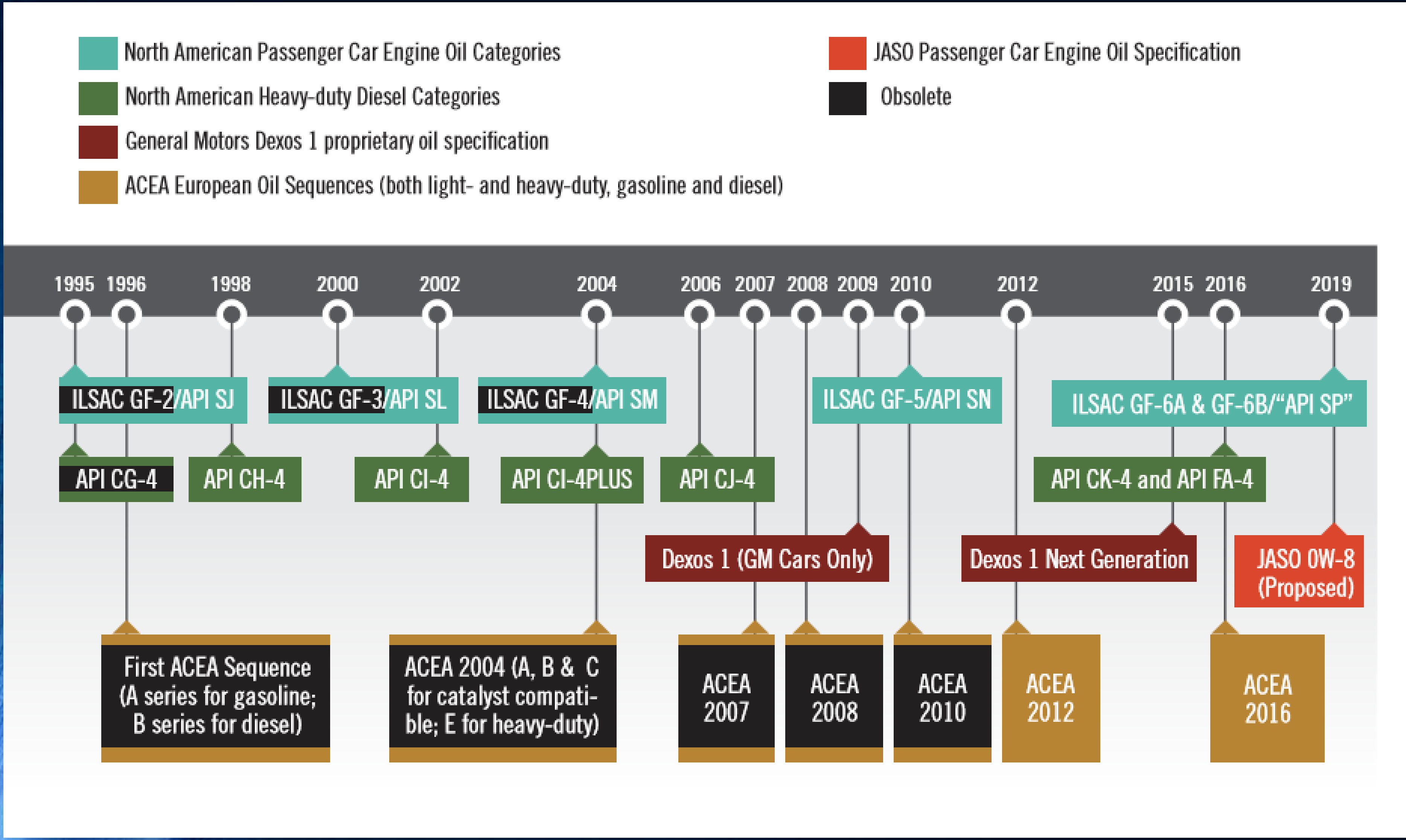
Timeline - Historical Trends in Innovation of New Engines/Vehicle Technologies (Patents Snap)



Examples of Introduction of Engine Technologies



Timeline: Evolution of Lubes Global Specifications



Fundamental Compositions of Engine Oils

Base Oils (~ 75 wt.%)

Performance Additives (up to 25 wt. %))

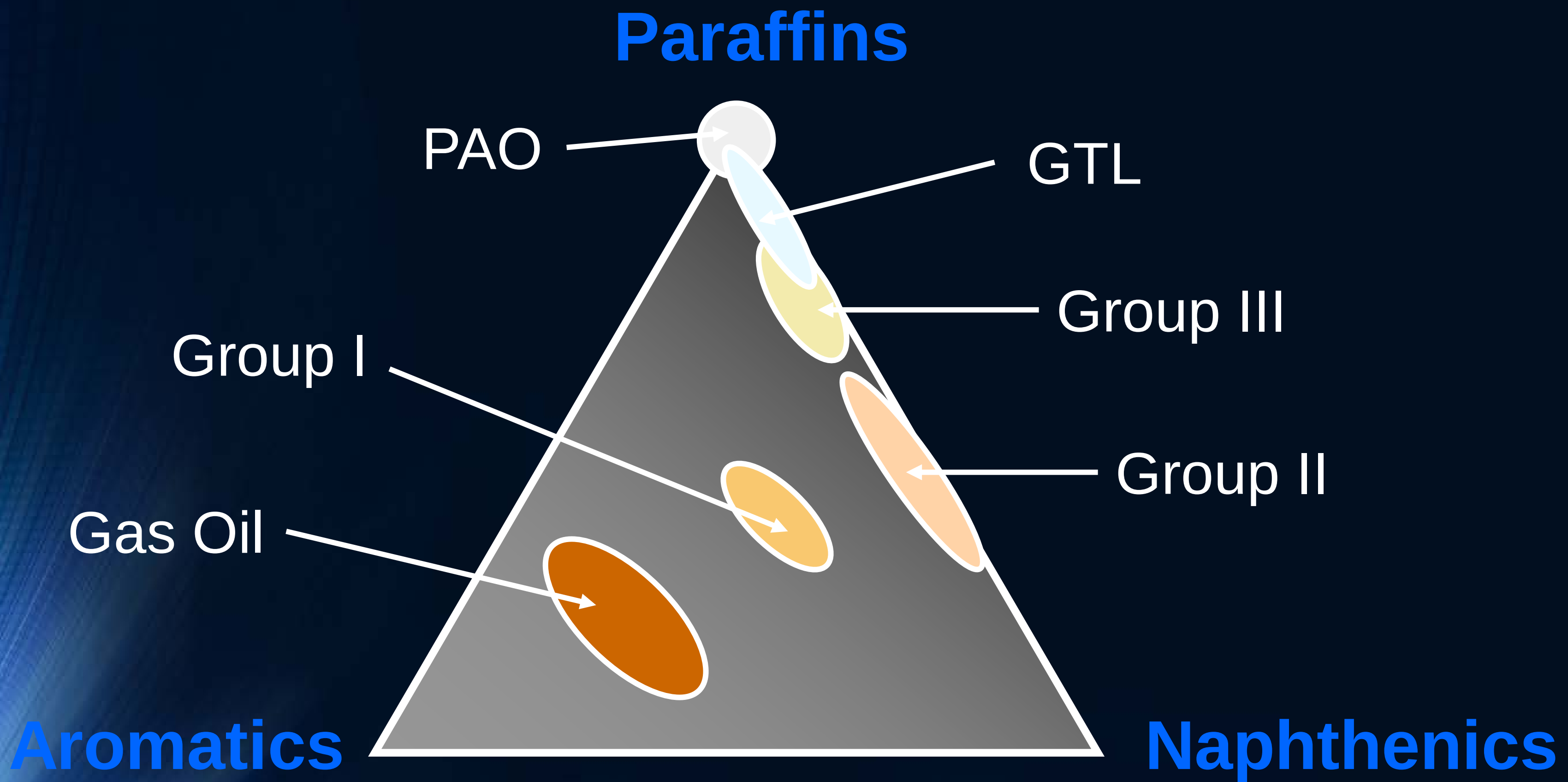
- Antifoams
- Pour Point Depressants
- Corrosion Inhibitors
- Friction Modifiers
- Antioxidants
- Anti-wear Agents
- Detergents
- Viscosity Modifiers (VM)
- Dispersants
- Dispersant Viscosity Modifiers (DVM)
- Others

Thousands of unique formulations customized for applications, performance levels, OEMs, oil marketers, etc.

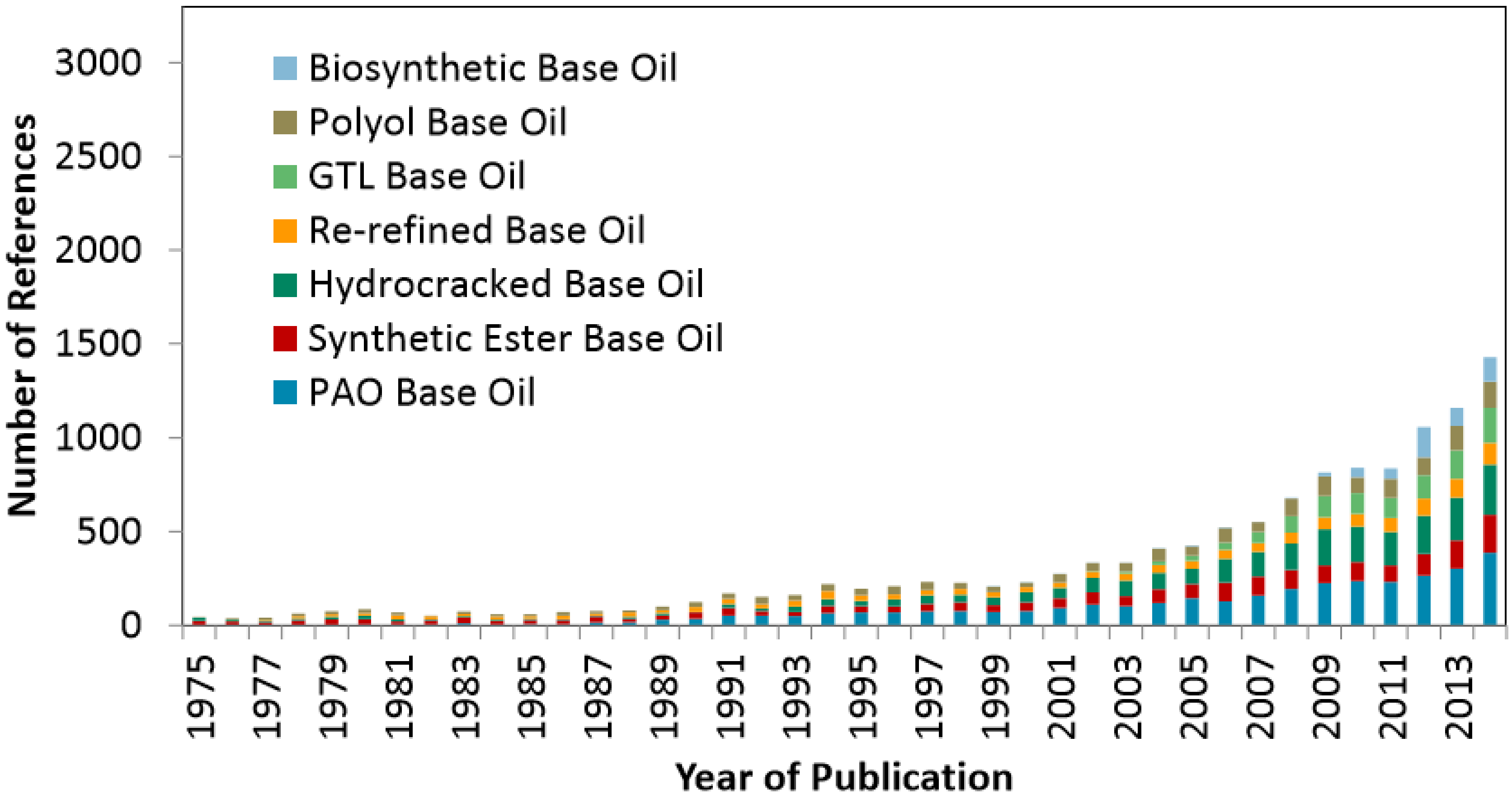
API Base Oils Categories

API GROUP	SULFUR % WT.		SATURATES %	VISCOSITY INDEX
Group I	> 0.03	And/or	< 90	80-119
Group II	≤ 0.03	And	≥ 90	80-119
Group III	≤ 0.03	And	≥ 90	≥ 120
Group IV	All Polyalphaolefins (PAOs)			
Group V	All base stocks not in Groups I-IV (naphthenics, non-PAO synthetics)			

Chemical Composition of Base Oils



Timeline: Innovations of Base Oils (Patents Snap)



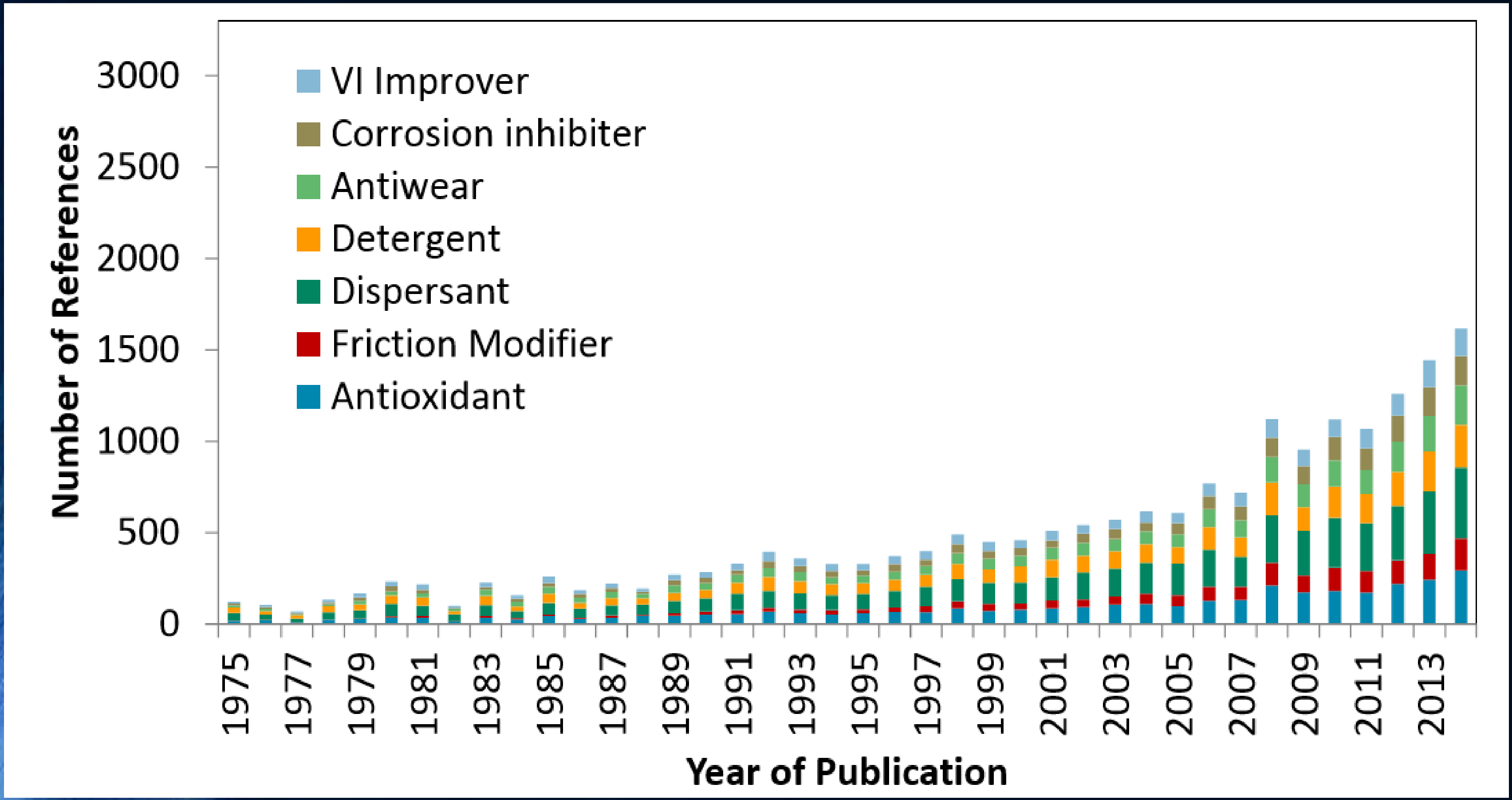
Typical Lubricants Additive Performance Package

	Formulation Component	Possible Elements
Base Oil Type		
Fluidity	Mineral or synthetic oil	H, C, O
Performance Components		
Multigrade	Viscosity modifier (VM)	
Low temperature flow	Pour point depressant	
Suspend contaminants	Polymeric dispersant	H, C, N, B, O
Rust protection **Cleanliness** **Acid neutralization**	Metalic detergents	Ca, Mg, Na
Wear control **Oxidation protection**	Dithiophosphates, esters Ashless, S antioxidants	Zn, P, S, B N, O, S
Friction reduction	Friction modifiers	Mo, S
Foam control	Antifoam	Si

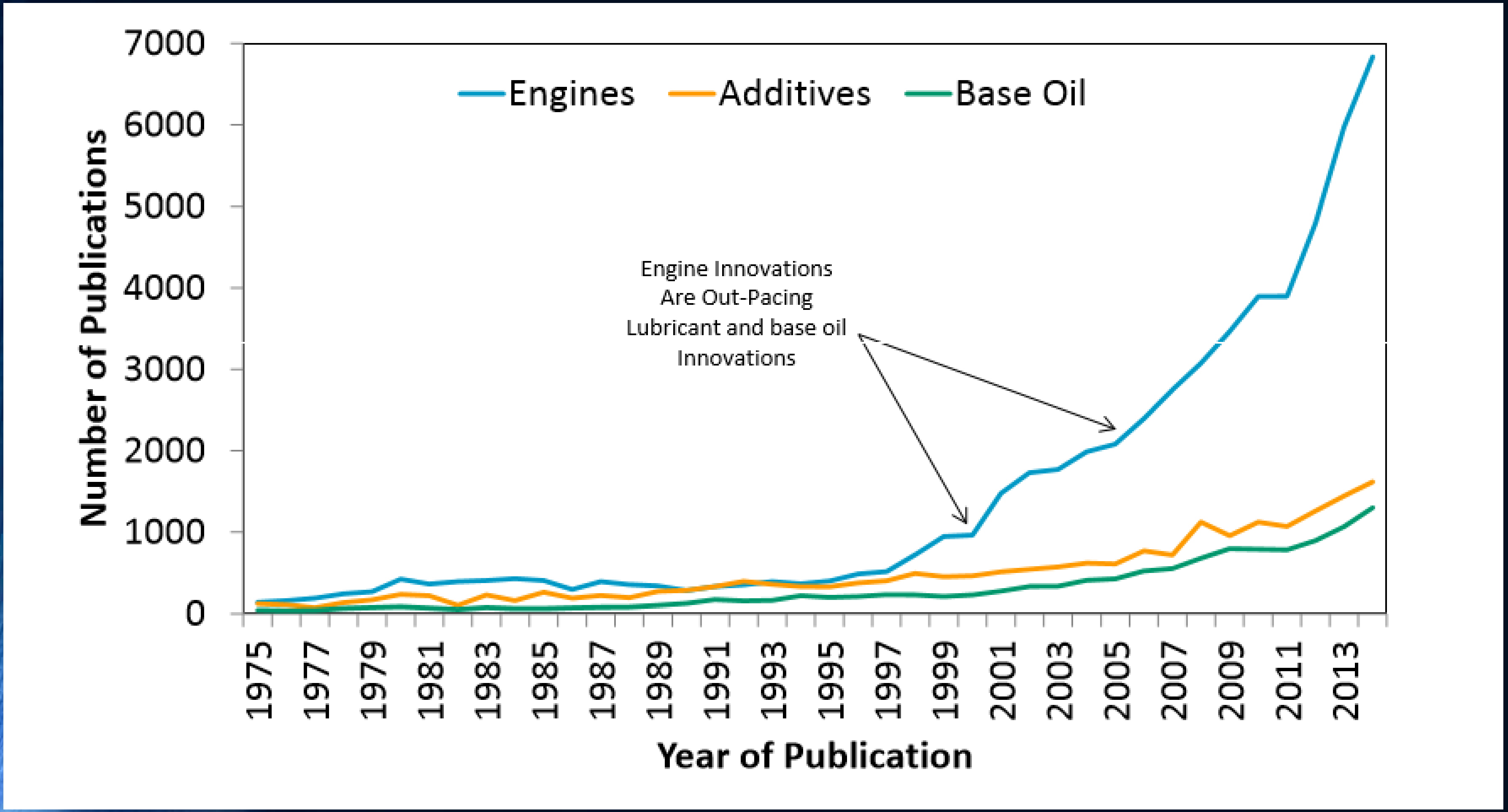
Lubricants: The Lifeblood of Efficient Engine Combustion and Emissions Control Systems

Challenges	Oil Additive Solution
High temperature	Antioxidant, Detergent, Dispersant, VM
Oxidation & nitration	Antioxidant, Detergent, Dispersant, VM
Piston deposits	Dispersant, Detergent, Antioxidant, VM
Soot	Dispersant, VM, Antiwear Agent
Acids	Antioxidant, Detergent, Corrosion Inhibitor
Engine wear	Antiwear Agent, Dispersant, Friction Modifier
Fuel dilution	Detergent, Antioxidant, VM
Low quality fuel	Dispersant, Detergent, Antioxidant
Sludge	Dispersant, Detergent, Antioxidant

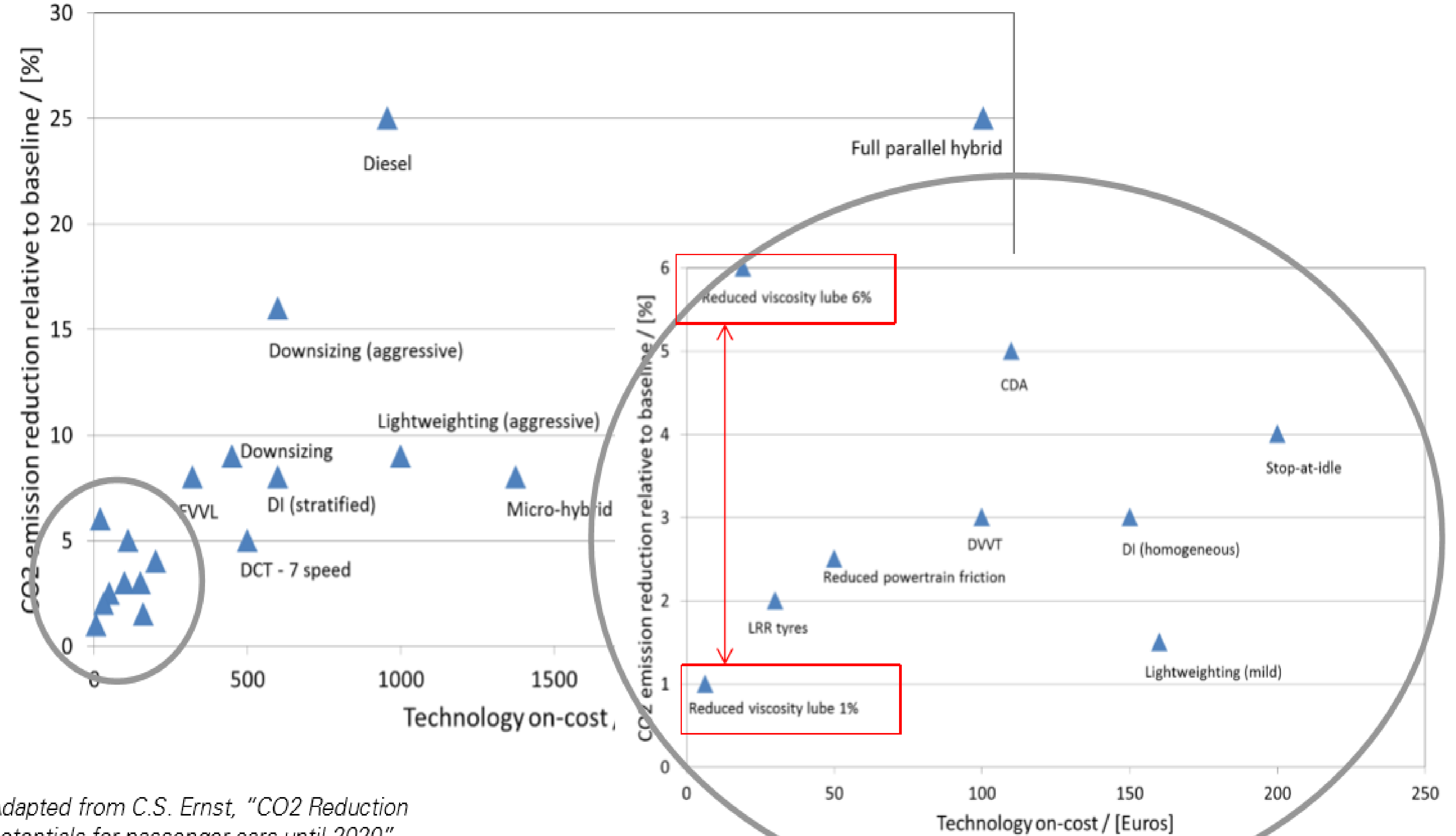
Timeline: Innovations of Engine Oil Additives (Patents Snap)



Historical Innovation Trends: Novel Engines Technologies vs. Novel Lubricants

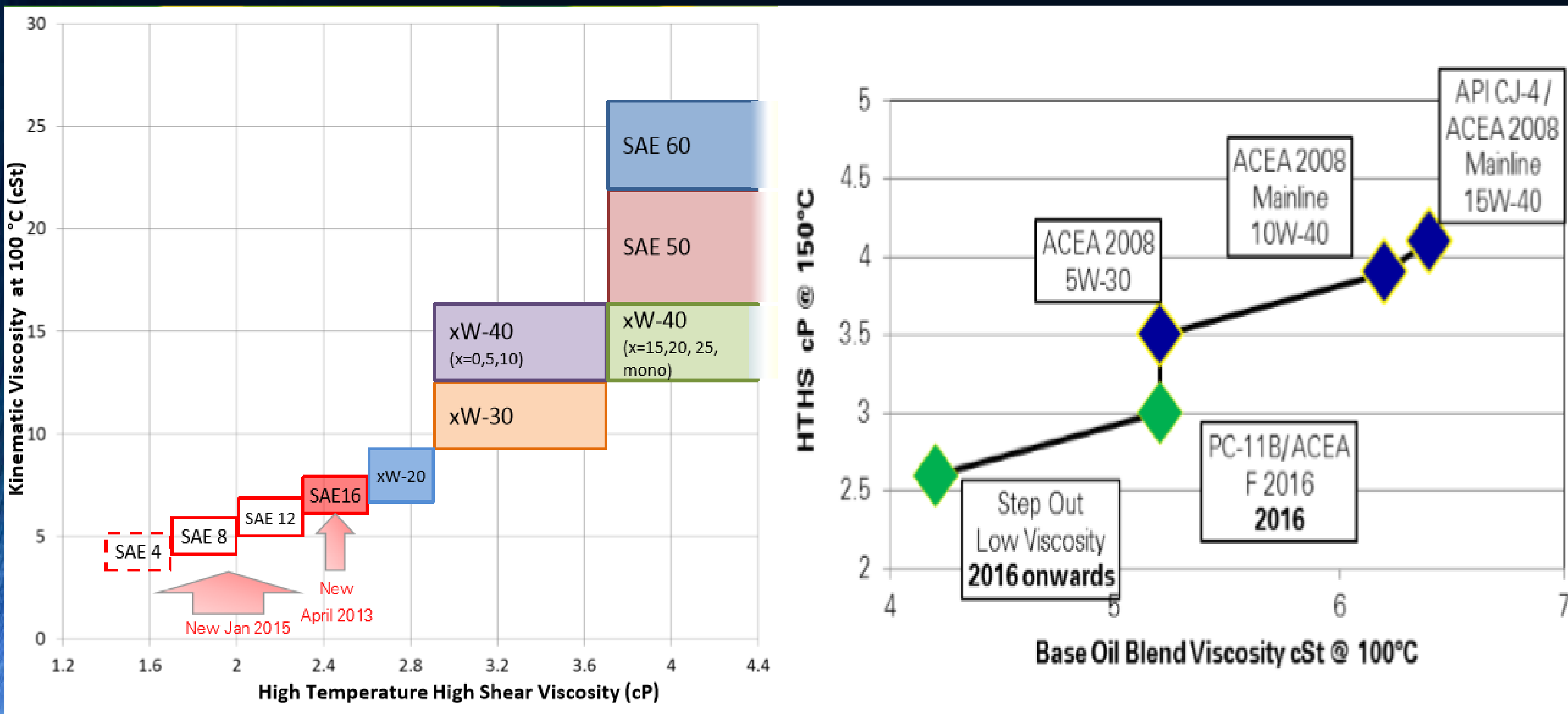


Value of Low Viscosity Lubricants vs. Other Engine Developments Targeting CO_2 Reduction



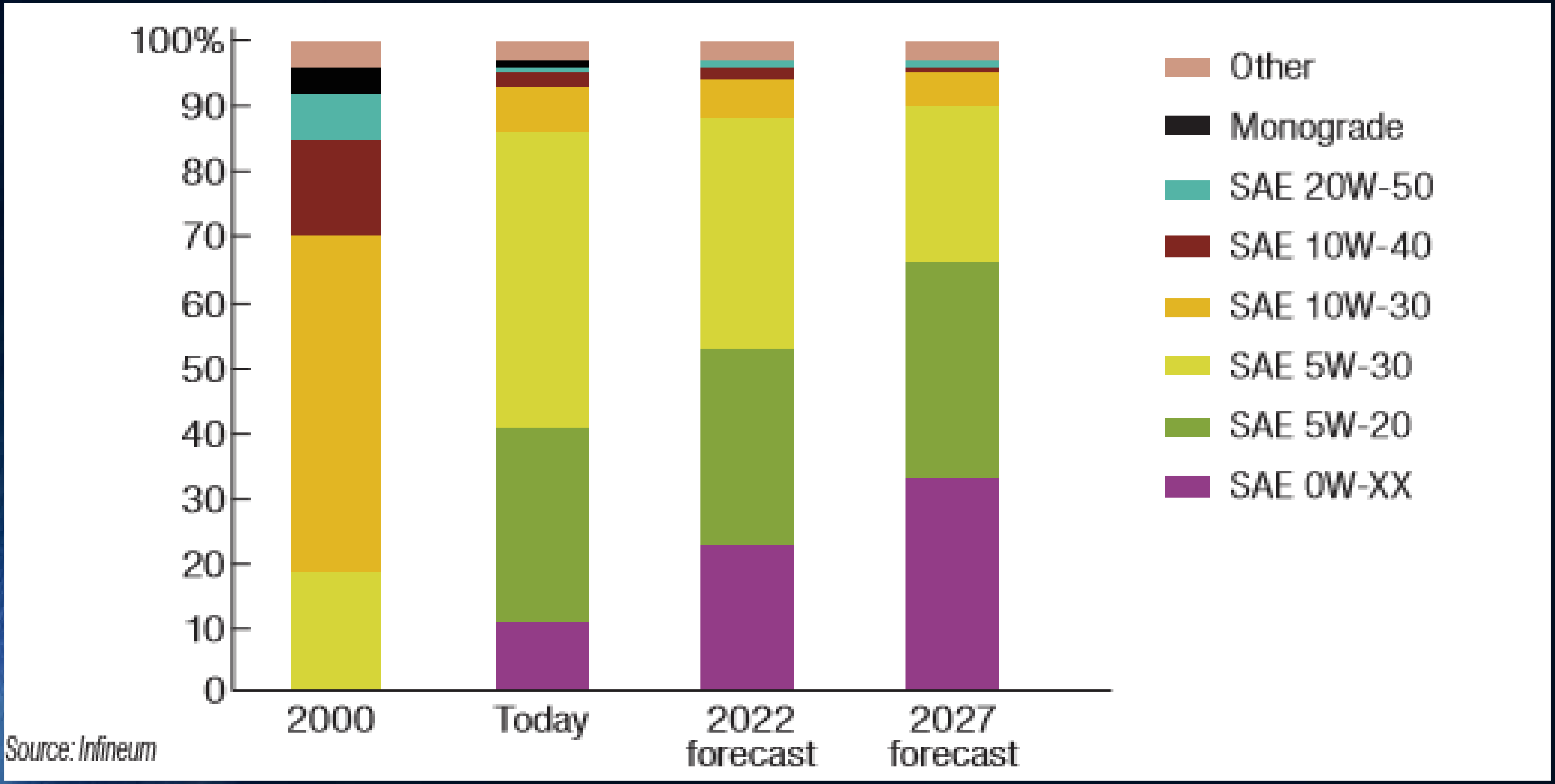
Adapted from C.S. Ernst, "CO2 Reduction potentials for passenger cars until 2020" Management Summary 113510, Institute fur Kraftfahrzeuge, Aachen December 2012.

Engine Oils Viscosity Grades: Status Quo and Move Onwards

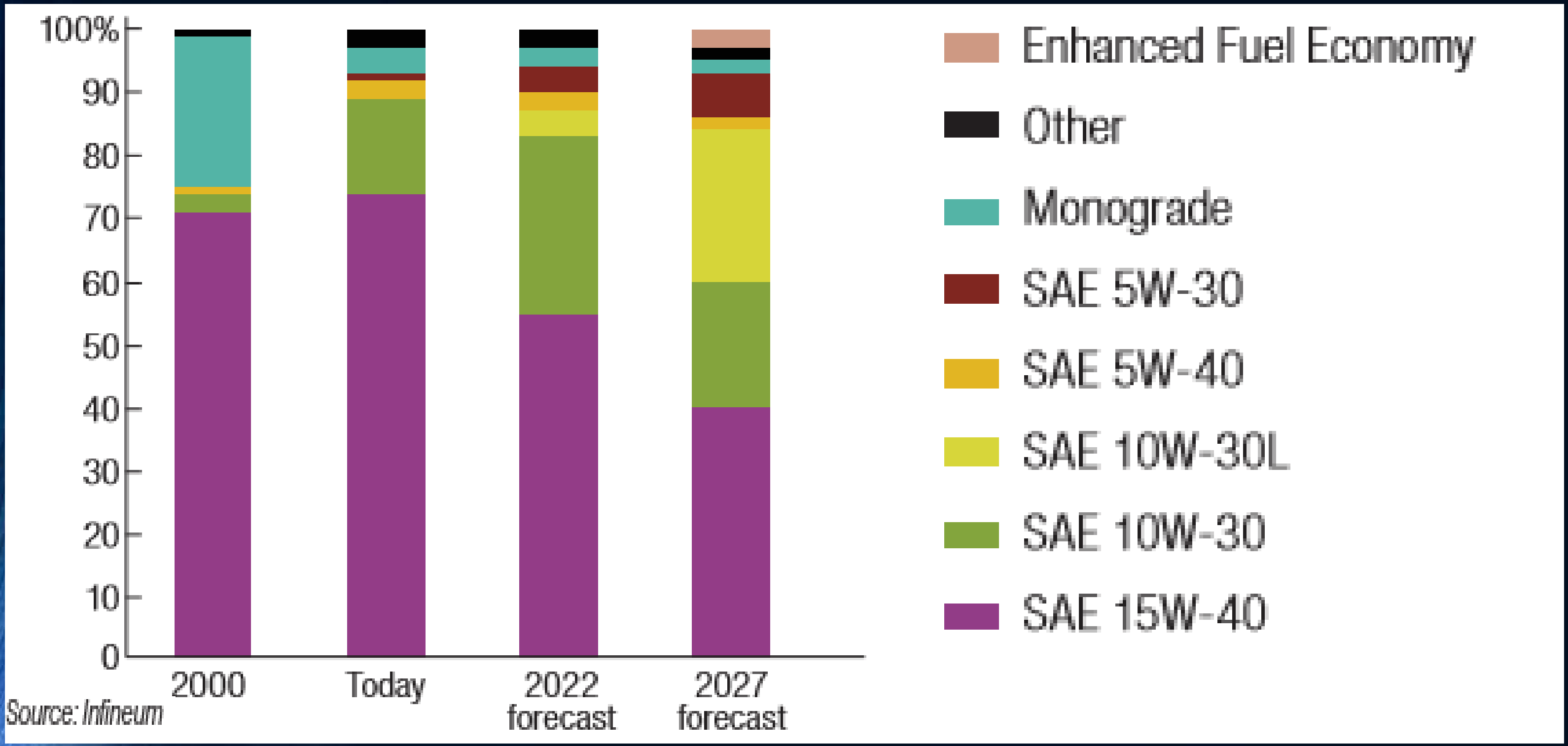


Source: BP

Trends in N. American PCMO Viscosity Grades

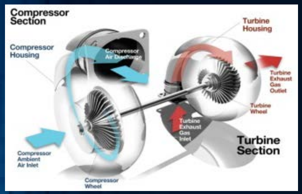


Trends in North American HDMO Viscosity Grades

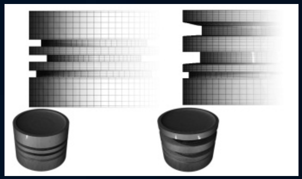


Diesel Engines and After-treatment Approaches to Emissions Control vs. Evolution of Engine Lubricants

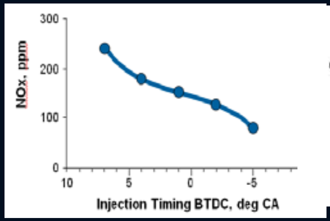
US 1998 ➡ Euro II ➡ Euro III ➡ US 2004 ➡ Euro IV ➡ Euro V ➡ US 2010



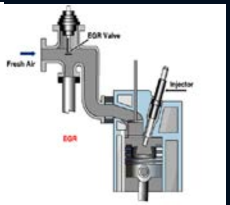
Turbo-Charging



Raised Top Rings



Retarded Injection Timing



Exhaust Gas Recirculation

Selective Catalytic Reduction

Diesel Particulate Filters

Higher temperatures and pressures

⬇

Improved thermal and oxidative stability

Higher soot and acid levels

⬇

Improved soot handling & acid and corrosion control

Susceptible to poisoning and blockage

⬇

Restrictions on *Sulfur, Sulphated Ash & Phosphorus,*

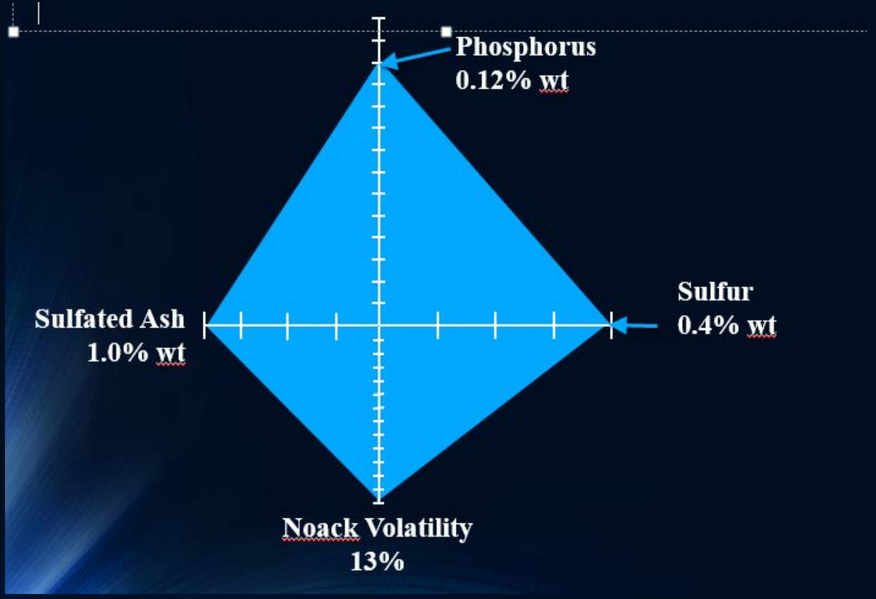
Newest HDMO API Specifications (2016)

New category is split by HTHS at 100 C:

High HTHS (**API CK-4**), 3.5 cSt **H**igh **T**emperature **H**igh **S**hear viscosity – Backwards compatible to all previous API categories.

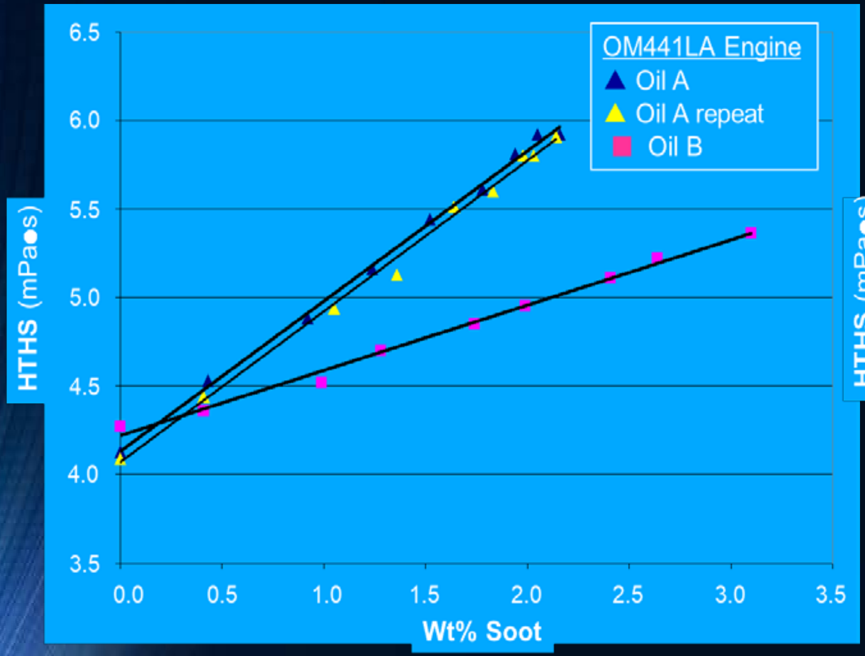
Low HTHS (**API FA-4**) – Fuel Economy grade engines designed to run on low viscosity oils, 2.9-3.2 cSt.

Chemical limits stay the same.
Lubricants remain low SAPS.



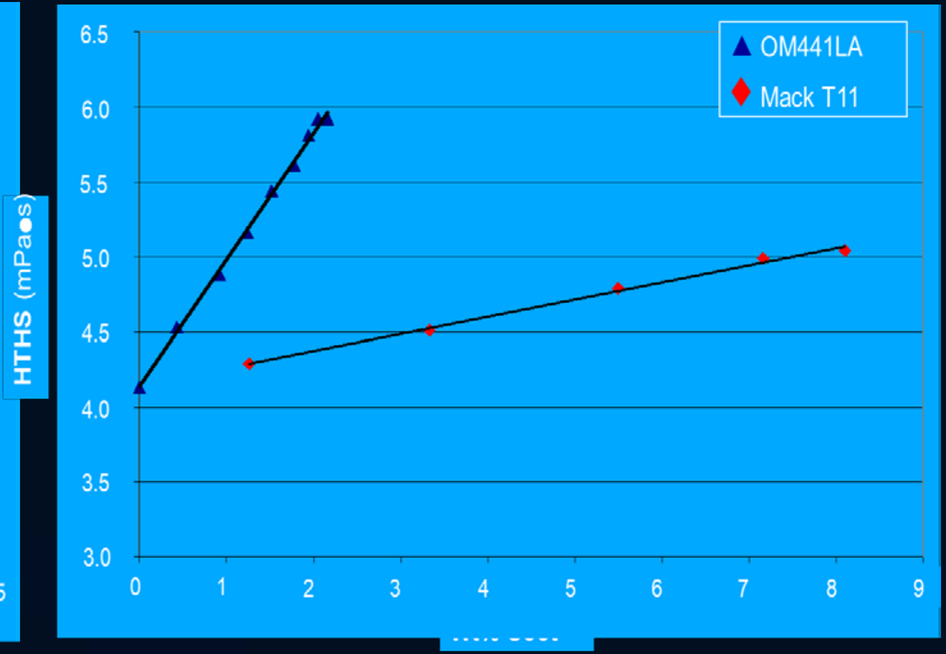
Oil Performance: Examples of Soot Handling

NOT ALL OILS HANDLE SOOT EQUALLY



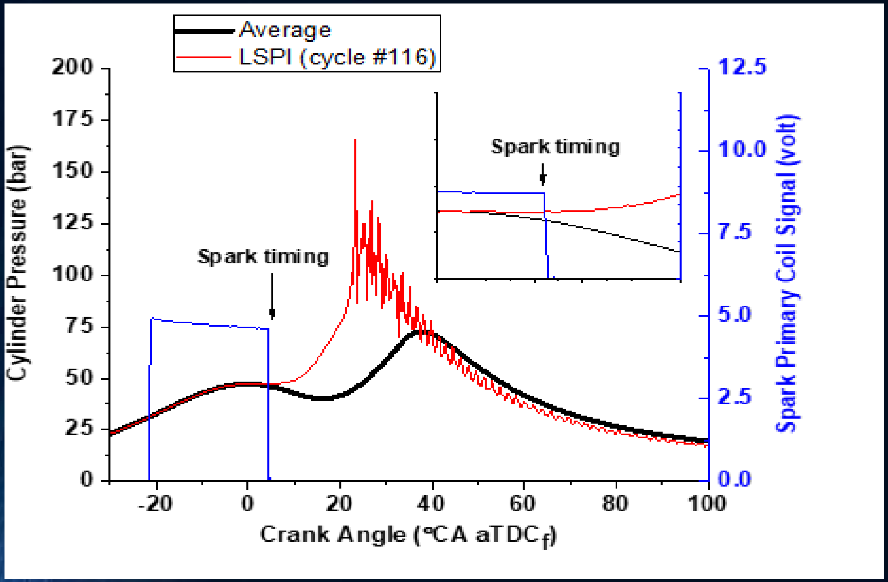
Same engine, same soot, different oils, different viscosity increases

NOT ALL SOOTS ARE EQUAL



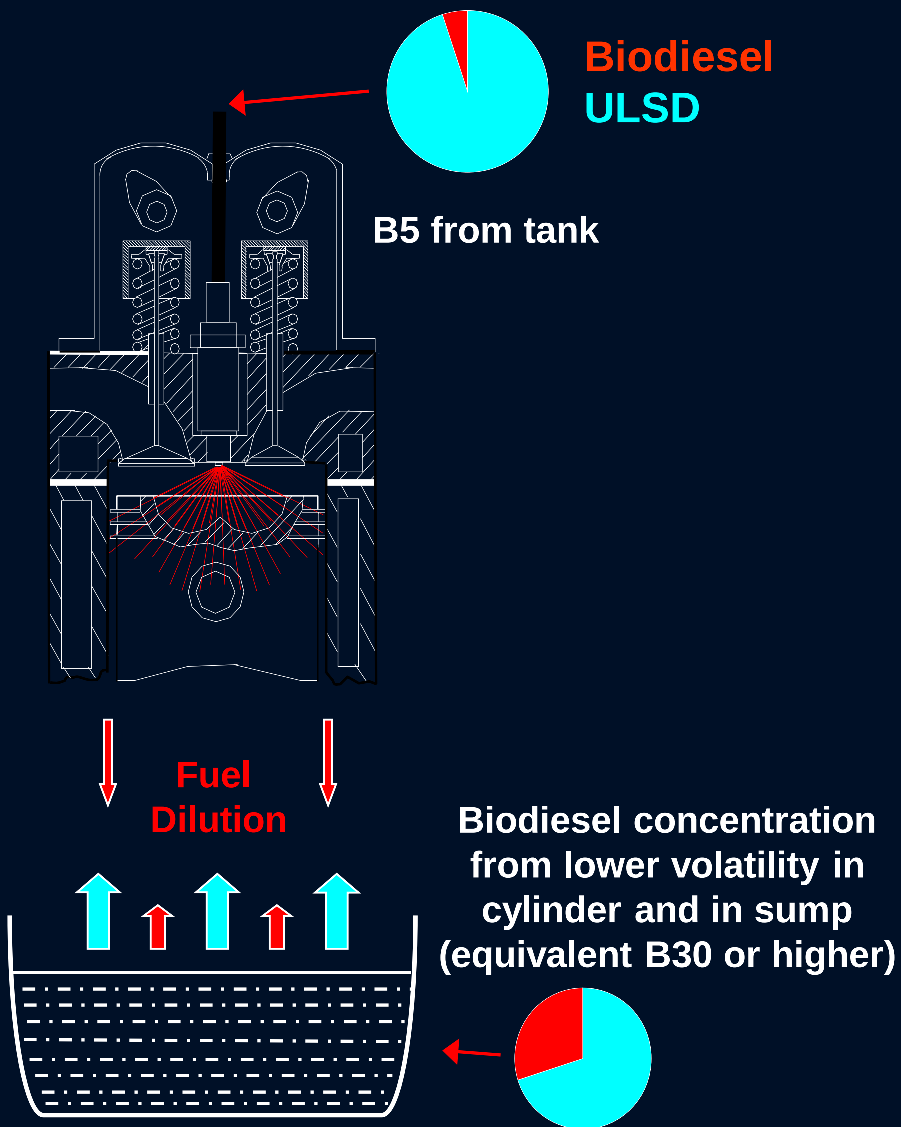
Same oil, different engines, different soots, different viscosity increases

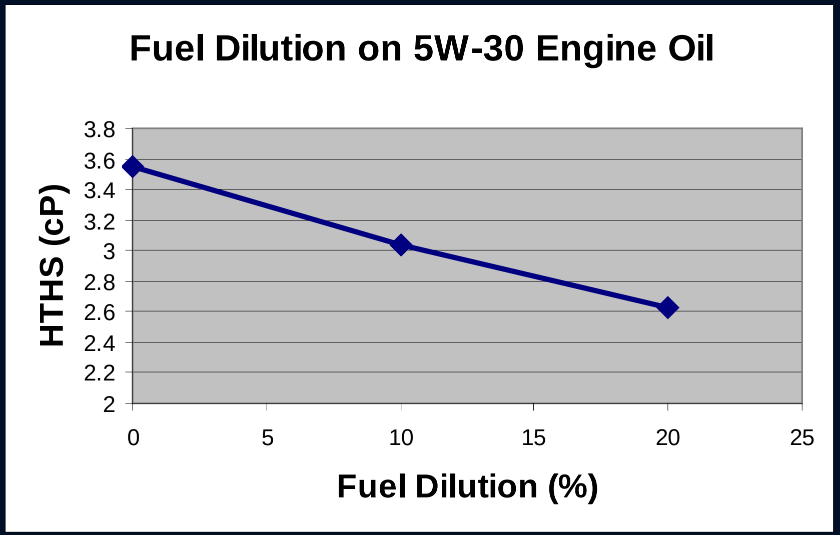
LSPI Challenge: Mitigation of Mega Knock

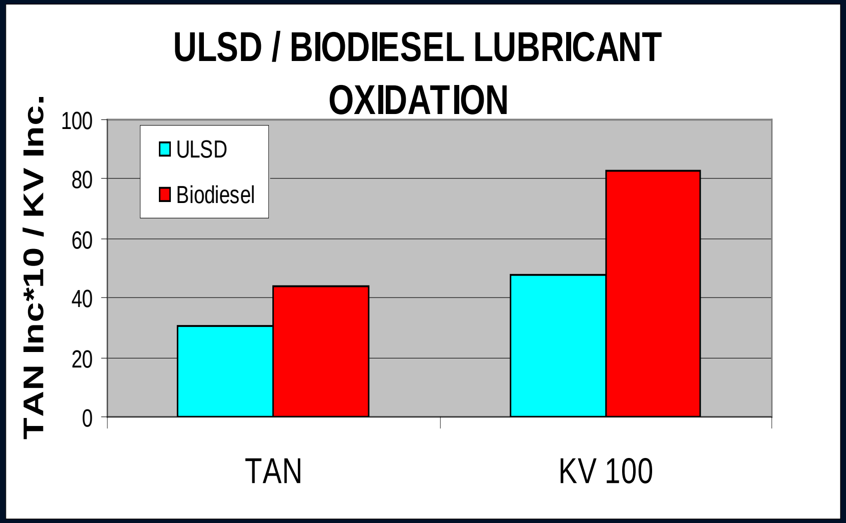


Recent research studies indicate that some metallic (Ca, Mg, Mo, Zn) oil constituents may impact occurrence of LSPI; impact is driven by choice of combustion strategies and engine design.

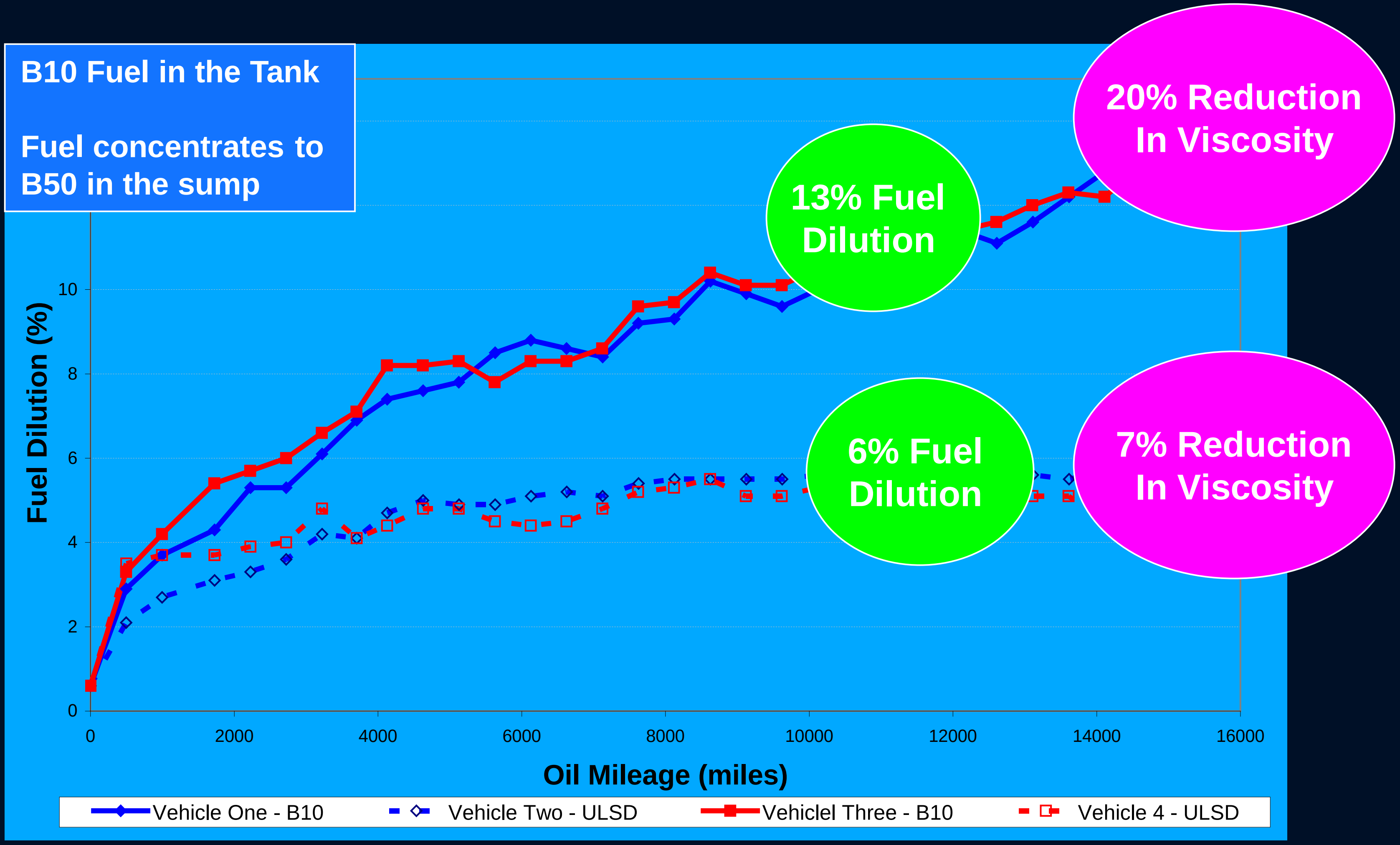
DPF Regeneration, Fuel Dilution, & Lubricant Performance



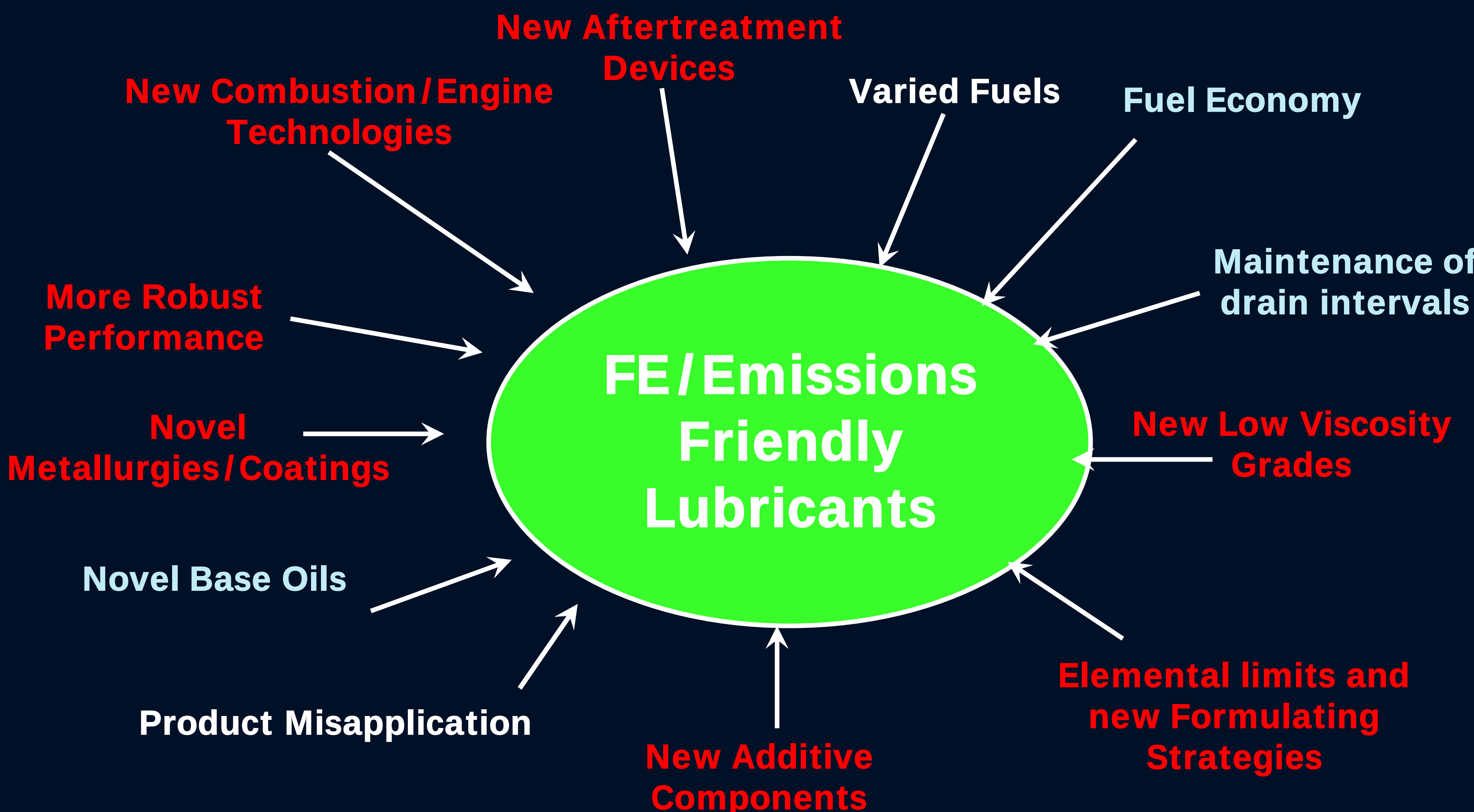




Interaction Between Biodiesel Fuel and Lubricants: Impact of Fuel Dilution



Challenges for Future Engine Lubricant Technologies



Key Building Blocks for Future Engine Oils

Technologies Controlling Mega Knock Optimizing detergents metal mix Selecting proper type of metallic additives (anti-wear, friction modifiers)	**Clean Base Oils** Delivering low volatility Good additive solvency Superior lubricity characteristics
Novel High Temperature Antioxidants Showing effectiveness over extended drains Sulfur free technologies	**New Friction Modifiers** Metal free Beneficial interactions with coated or nonferrous surfaces
Improved Polymer Additives (VM) Shear stable Contribute to creation of robust oil film Improve wear control	**Gasoline Particulate Filter Compatible** Reinforcement/selection of metallic content and phosphorous derived from oil

A Way Forward

- Internal combustion engines will continue as the key transportation systems in a forthcoming future ~ 2040.
- New combustion hardware approaches call for reformulated lubricants
- In order to reach challenging technical goals, we need to create a paradigm shift

Future *low viscosity* ***lubricants*** *cannot be developed* ***in dated hardware***

Future hardware *cannot be developed* ***with dated lubricants***

↓

THERE IS A CRITICAL NEED for CO- ENGINEERING EFFORTS:

Engineers and researchers need to discuss path forward for improving ICE systems efficiencies through collaborative approaches to selecting novel combustion systems, innovative hardware materials & unique lubricants.

Thank you for your attention

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