Performance you can rely on.

Passenger car engine oil

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Introduction and outline

- The components of a PCEO additive package
- API SN-PLUS and ILSAC GF-6 specifications
- The PCEO market and future trends

Overarching formulation considerations

- ACC Code of Practice, ATC Code of Practice, API EOLCS guidelines, and ATIEL guideline
- Desired performance level or specifications
- Viscosity grade coverage
- Customer / oil company requirements
- OEM requirements including factory fill or service fill applications
- Base stock availability and quality
- Component and viscosity modifier (VM) technology

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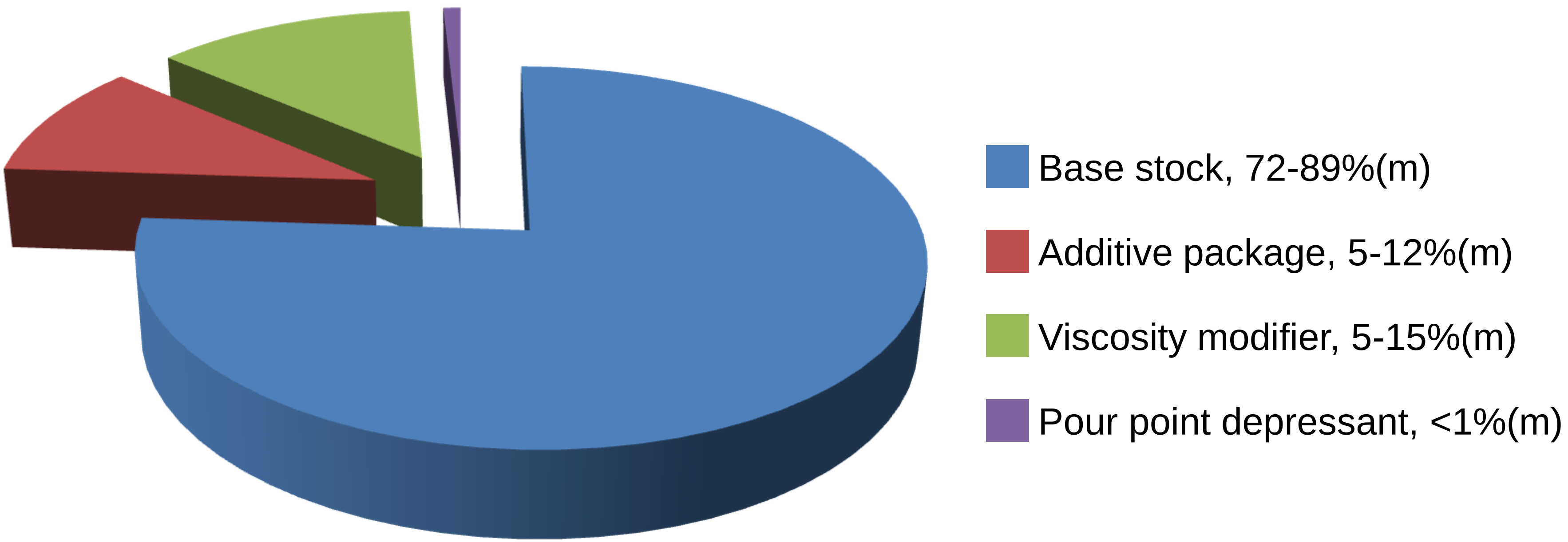
What goes into a finished PCEO?



What goes into a PCEO additive package?

Component	Function	Typical type
Dispersant	Suspension of soot, sludge, and deposit precursors	PIBSA/PAM
Detergents	Prevention of rust, corrosion, and deposit adhesion	calcium or magnesium based sulphonates, phenates, and salicylates
Antioxidants	Prevention of oxidation via radical traps and peroxide decomposition	ZDDP, diphenylamine, hindered phenols, metal and/or sulfur-based
Anti-wear agents	Prevention of surface microwelding and tearing	ZDDP
Friction modifiers	Reduction of boundary layer friction	short-chain organic acids, 'solid' lubricants
Anti-foamant	Reduction in foaming tendency and stability	polydimethylsiloxane

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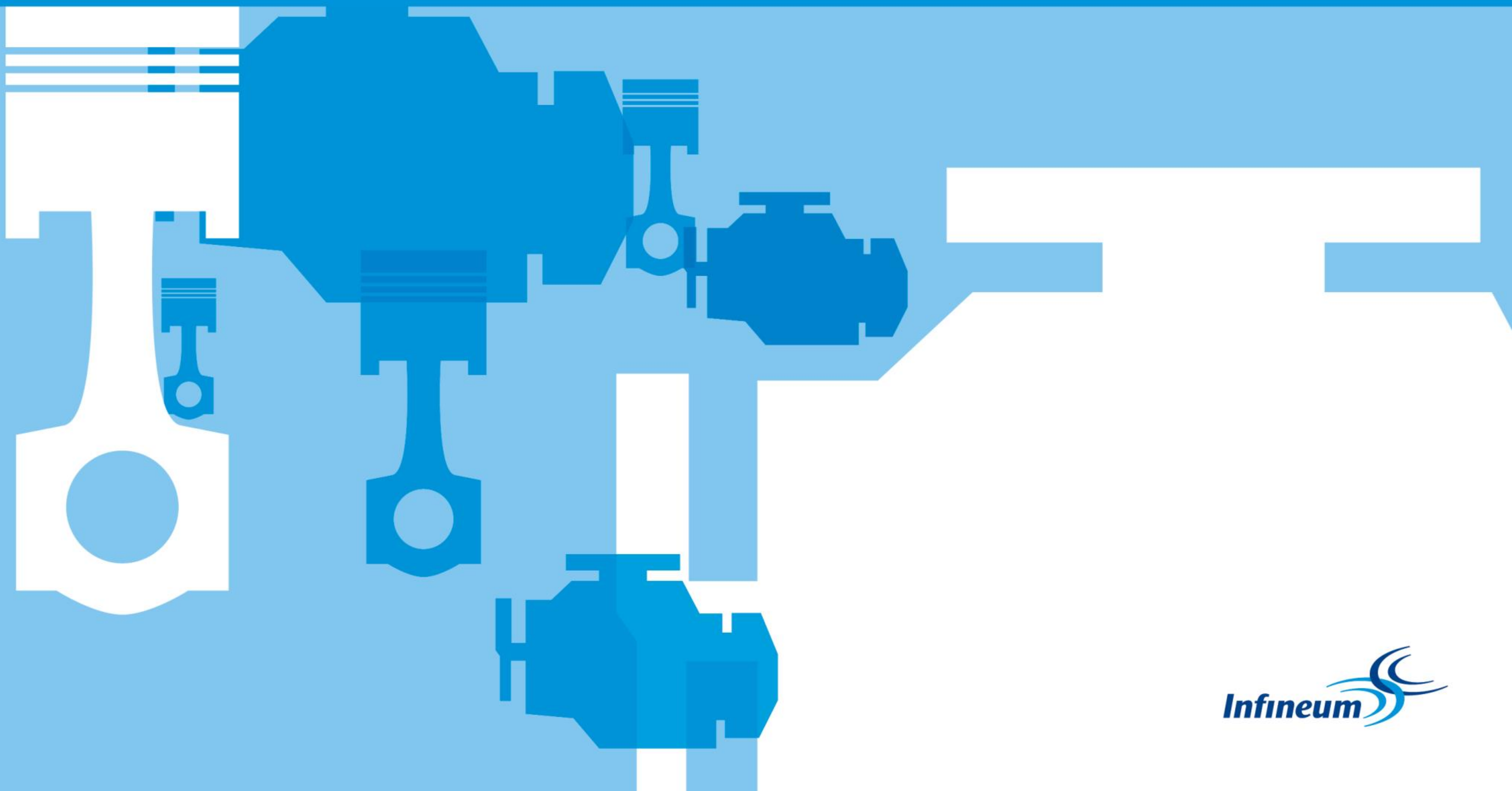
PCEO categories: past, present, future



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ILSAC GF-6

ILSAC GF-6 is driven by a combination of **regulatory** and/or **performance** needs

- **Fuel economy improvement**
- **Low Speed Pre-Ignition (LSPI) protection**
- **Improved deposits protection**
- **Improved cam chain wear performance**
- **Replacement of old tests**

API and ILSAC gasoline specifications

API SN/ILSAC GF-5

- Sequence VID
- Sequence VIII
- Sequence VG
- Sequence IVA
- Sequence IIIG
- Sequence IIIGA

- P & S content
- TEOST MHT
- Ball Rust Test
- NOACK + VGC
- EOWT + EOFT
- Foam + HTFoam
- Miscibility

API SN Plus

- Sequence IX

- TEOST 33C
- E85 Emulsion

ILSAC GF-6A/B

- Sequence VIE/F
- Sequence VIII
- Sequence VH
- Sequence IVB
- Sequence IIIH
- Sequence IIIHA
- Sequence X

- P & S content
- Ball Rust Test
- NOACK + VGC
- EOFT + EOWT
- Foam + HTFoam
- E85 Emulsion
- Miscibility

- Elastomers

API SP and ILSAC GF-6 engine tests and some have replacements

Test	Parameter	Engine description
Sequence IIIH	Oxidation and deposits control	2012 FCA 3.6L PFI
Sequence IIIHA	Aged oil viscosity	2012 FCA 3.6L PFI Bench
Sequence IIIHB*	Phosphorous retention	2012 FCA 3.6L PFI
Sequence IVB	Wear control	2010 Toyota 1.5L PFI
Sequence VH	Sludge and varnish control	2013 Ford 4.6L PFI
Sequence VIII	Bearing corrosion resistance and shear stability	CLR Test 0.7L
Sequence VIE OR Sequence VIF*	Fuel economy	2012 GM 3.6L PFI
Sequence IX	Low Speed Pre-Ignition protection	2016 Ford 2.0L GDI
Sequence X	Cam chain wear protection	2016 Ford 2.0L GDI

*Sequence VIF only required for GF-6B (0W-16)

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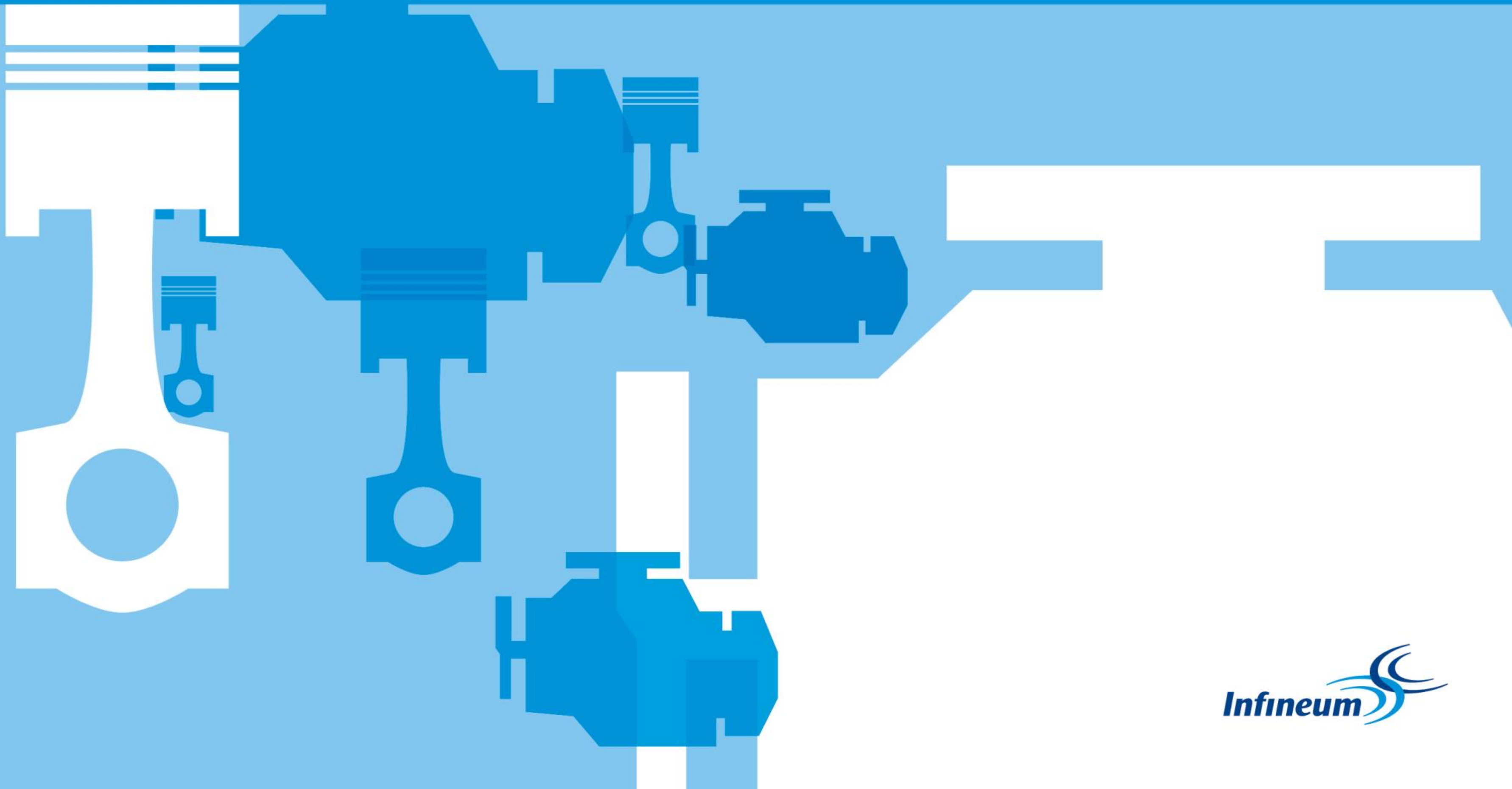
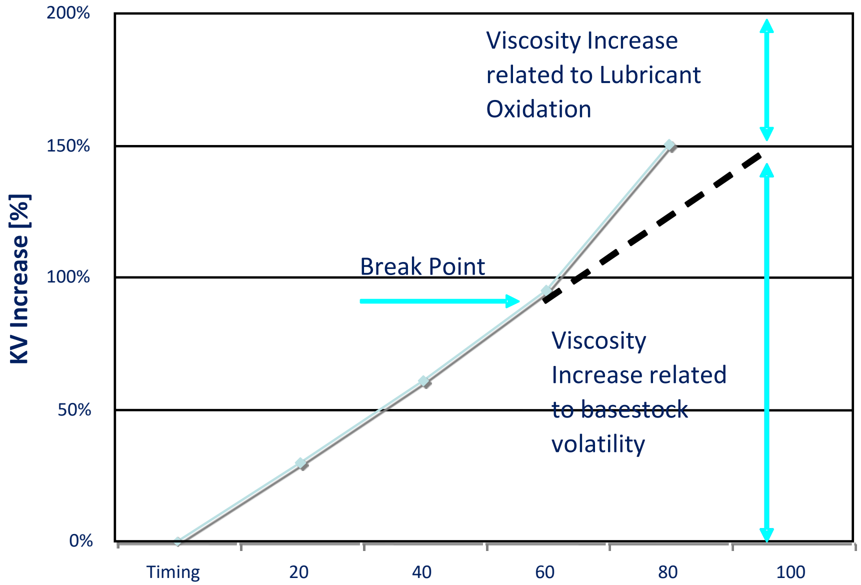
Engine Tests



Sequence IIIH

Evaluates viscosity increase, piston deposits, and valve train wear during high temperature conditions



PASS

FAIL

Parameter	Units	Seq. IIIH
KV40 increase	[%]	≤ 150
Avg. weighted piston deposits	[merits]	≥ 3.7
Avg. cam + lifter wear	[µm]	-
Hot stuck rings	[#]	= 0

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Sequence IIIHA (and ROBO)

- Evaluates the low temperature performance of used oil
- Seq. IIIHA utilizes used oil previously evaluated in the Seq. IIIH
- ROBO (Romaszewski Oil Bench Oxidation) intended to simulate oxidation of fresh oil in the Seq. IIIH on the bench scale to improve efficiency in oil qualification
  - Oil oxidized with NO_2 and air for 40h at 170°C in the presence of iron catalyst
- Both Seq. IIIHA and ROBO evaluated against the same criteria:

Parameter	Units	GF-6 Limit
MRV apparent viscosity at EOT	[cP]	≤ 60,000 (at original or next highest viscosity grade)
MRV yield stress at EOT	[Pa]	< 35

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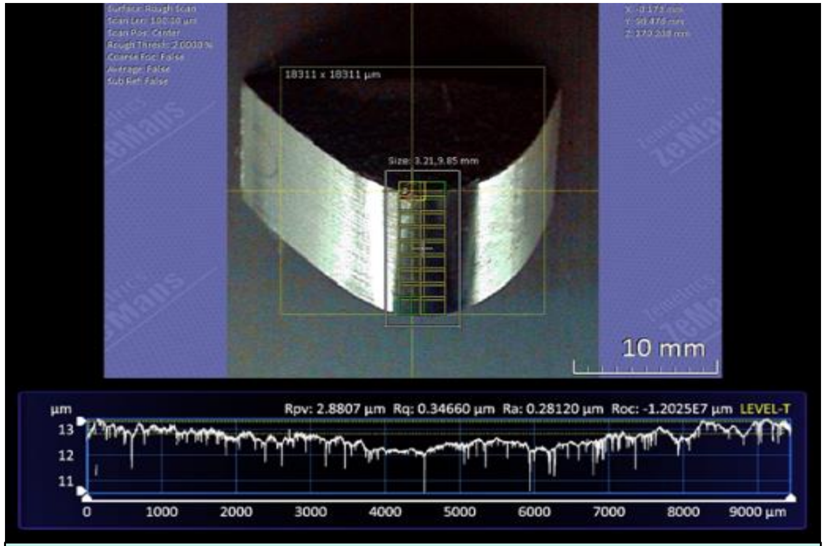
Sequence IVB

- Evaluates a lubricant's performance in resisting valve train wear and control of iron concentration

Parameter	Units	GF-6 Limit
Average Intake Lifter Volume Loss	[µm]	≤ 2.5
Fe Content at EOT	Ppm	≤ 400



Camshaft Lobe from Toyota 2NR-FE Engine Imaged using 3D Profilometry

Sequence VIII

- Evaluates a lubricant's performance in resisting copper-, lead-, or tin-bearing corrosion and measures shear stability

Parameter	Units	GF-6 limit
Bearing weight loss	[mg]	≤ 26
Shear stability		= stay in grade

PASS

FAIL

Sequence VH

- Evaluates a lubricant's ability to prevent sludge and varnish formation

Parameter	Units	GF-6 limit Seq. VH
Engine sludge, average	[merits]	≥ 7.6
Rocker cover sludge, average	[merits]	≥ 7.7
Engine varnish, average	[merits]	≥ 8.6
Piston skirt varnish	[merits]	≥ 7.6
Oil screen sludge	[%]	Report
Hot stuck compression rings	[#]	= 0
Cold stuck rings	[#]	Report
Oil screen clogging	[%]	Report
Oil screen debris	[%]	Report

PASS FAIL

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Sequence VIE/VIF

- Evaluates the effect of engine oil on the fuel economy of passenger cars and light-duty trucks
- Seq VIF run only for 0W-16 viscosity grade with different procedure for Seq VIE

SAE Grade	FEI_2 Limit [%] Seq. VIE	FEI_{SUM} Limit [%] Seq. VIE	FEI_2 Limit [%] Seq. VIE	FEI_{SUM} Limit [%] Seq. VIE
xW-20	≥ 1.5	≥ 3.2		
xW-30	≥ 1.2	≥ 2.5		
10W-30	≥ 1.0	≥ 2.2		
0W-16			≥ 1.9	≥ 4.1

Sequence IX

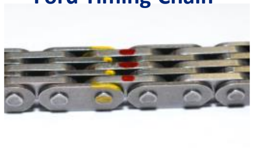
- Fired engine dynamometer lubricant test which evaluates the ability of a test lubricant to reduce pre-ignition events
- Test sequence (each 175000 cycles) repeated for 4 test iterations
- LSPI events are defined as outliers of peak pressure (PP) and crank angle location of 2% mass fraction burned (MBF02) data.
- Limit on total number of LSPI events across all 4 cylinders averaged over 4 iterations

Parameter	Units	GF-6 Limit
Average total number of LSPI events	#	≤ 5

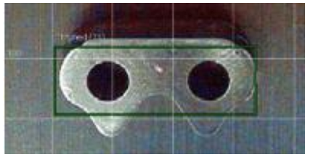
Sequence X

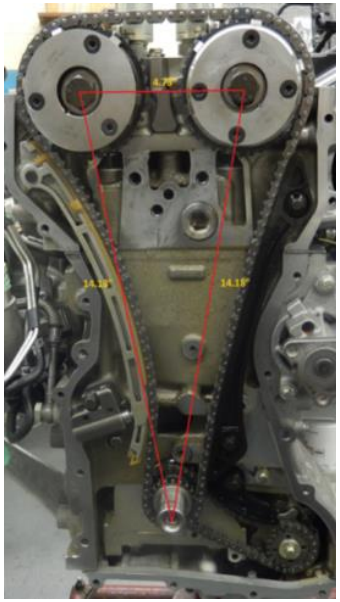
- Sequence X Ford Chain Wear test designed to induce wear on timing chain
- Elongation occurs over time, which can lead to potential misfires and loss of power

Ford Timing Chain



Inner Guide Link Plates





Parameter	Units	SN PLUS Limit
Chain stretch	%	≤ 0.085

The PCEO market and future trends

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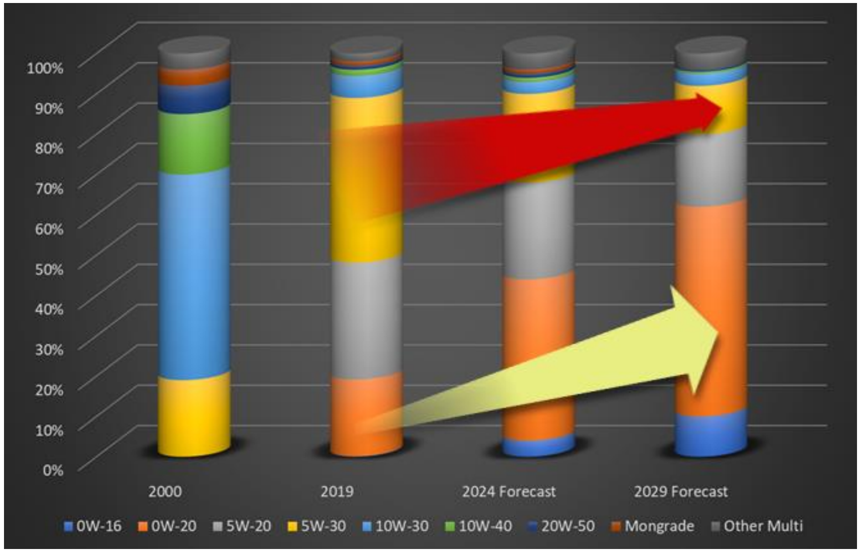
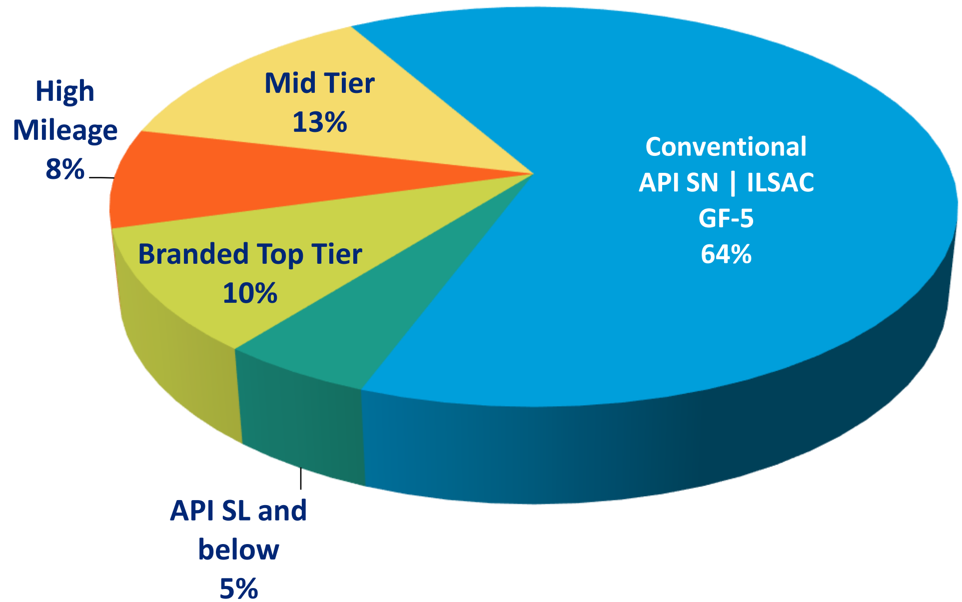
NA viscosity grade trends

- US PCMO lubricant demand for 2018 was estimated around 545 MM gal.
  - Up ~1% from 2017, modest increase due to increased disposable income
  - Significant sales from collective independent brands
- Viscosity grades are changing…
  - SAE 5W-30 remains the dominant grade (40%)
  - Lower viscosities continue to grow
  - Significant growth for 0W-20 seen. Only 10% of the market in 2016, expected closer to 20% by YE 2018
  - SAE 0W-16 continues to be a very niche grade but generates interest
  - More Grp III players in the market in 2018, creating significant qualification work



NA market segmentation

- Conventional ILSAC GF-5 oil is the majority of the market
  - Roll to GF-6 expected to be relatively swift
- Conventional API SN/ILSAC GF-5 included synthetic blend volumes
- Mid Tier includes mainline synthetics, dexos 1, 0W-20 's
  - dexos1 increasingly being commoditized
- Top Tier Includes EU PCMO needs



*Infineum estimate

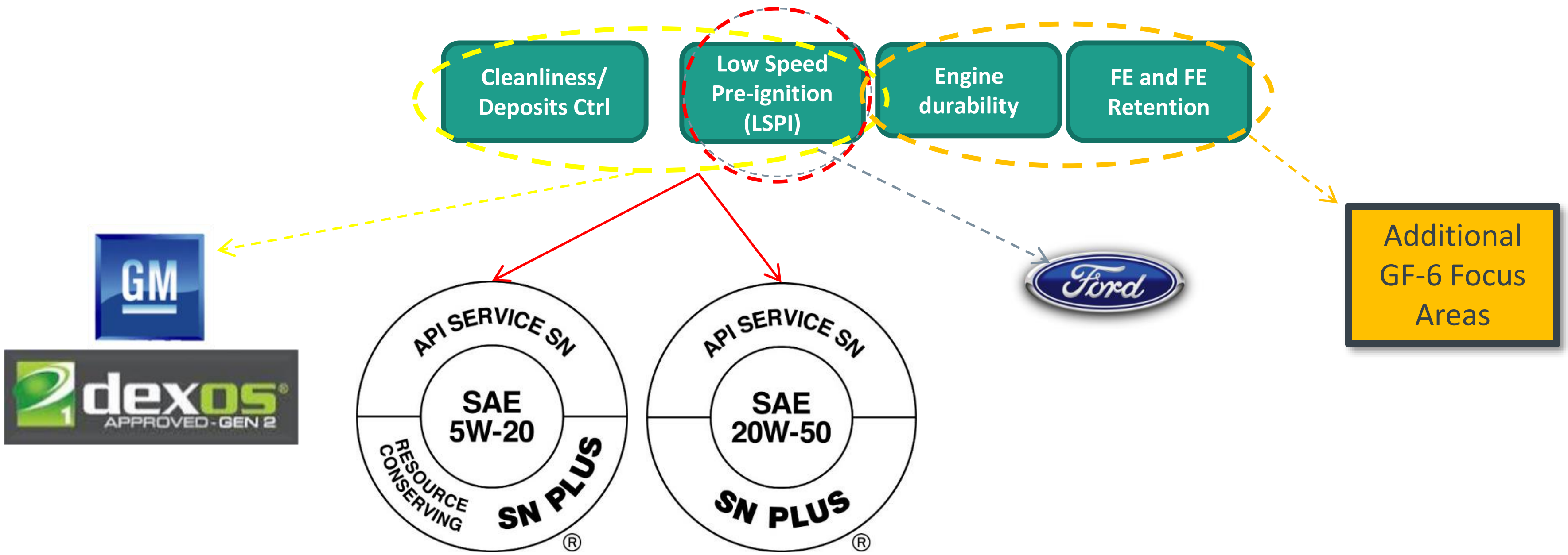
Market action/reaction concentrated in Mid Tier and Branded Top Tier

- **Niche vis grade coverage**
- **Non-standard claim sets**
- **Extended drain claims**

US OEMs Continue to Drive Oil Performance Forward

- API SN Plus has brought LSPI prevention to the general market
- Some interim OEM specifications have also advanced oil quality ahead of GF-6
- The ILSAC GF-6 specification development targets these performance improvements valued by API and OEMs

ILSAC GF-6 Targeted Performance Areas



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General Motors and dexos™

- GM created harmonized specifications to improve efficiency and cost while ensuring consistent quality among suppliers
  - dexos1™ for gasoline engines
  - dexos2™ for diesel engines
- Current dexos1™ includes elements of ILSAC GF-5 (more stringent) and ACEA A in addition to GM/OPEL engine tests
- New dexos1TM generation 3 specification (released in May 2020) will include elements of ILSAC GF-6, as well as two new GM engine tests for transient SPI and Fuel Economy
- GM licenses use of dexos™ trademark separately from the API Service Symbol ('donut') and Certification Mark ('starburst'), and the marketer incurs an annual licensing and royalty fee based on their market share
- dexos1™ program costs about 3-4x an ILSAC GF-5 approval
- Mandatory use of dexos1™:2015 was August 31, 2017
  - To include Low Speed Pre-Ignition (LSPI) protection
  - New dexos1™ Gen 2 trademark

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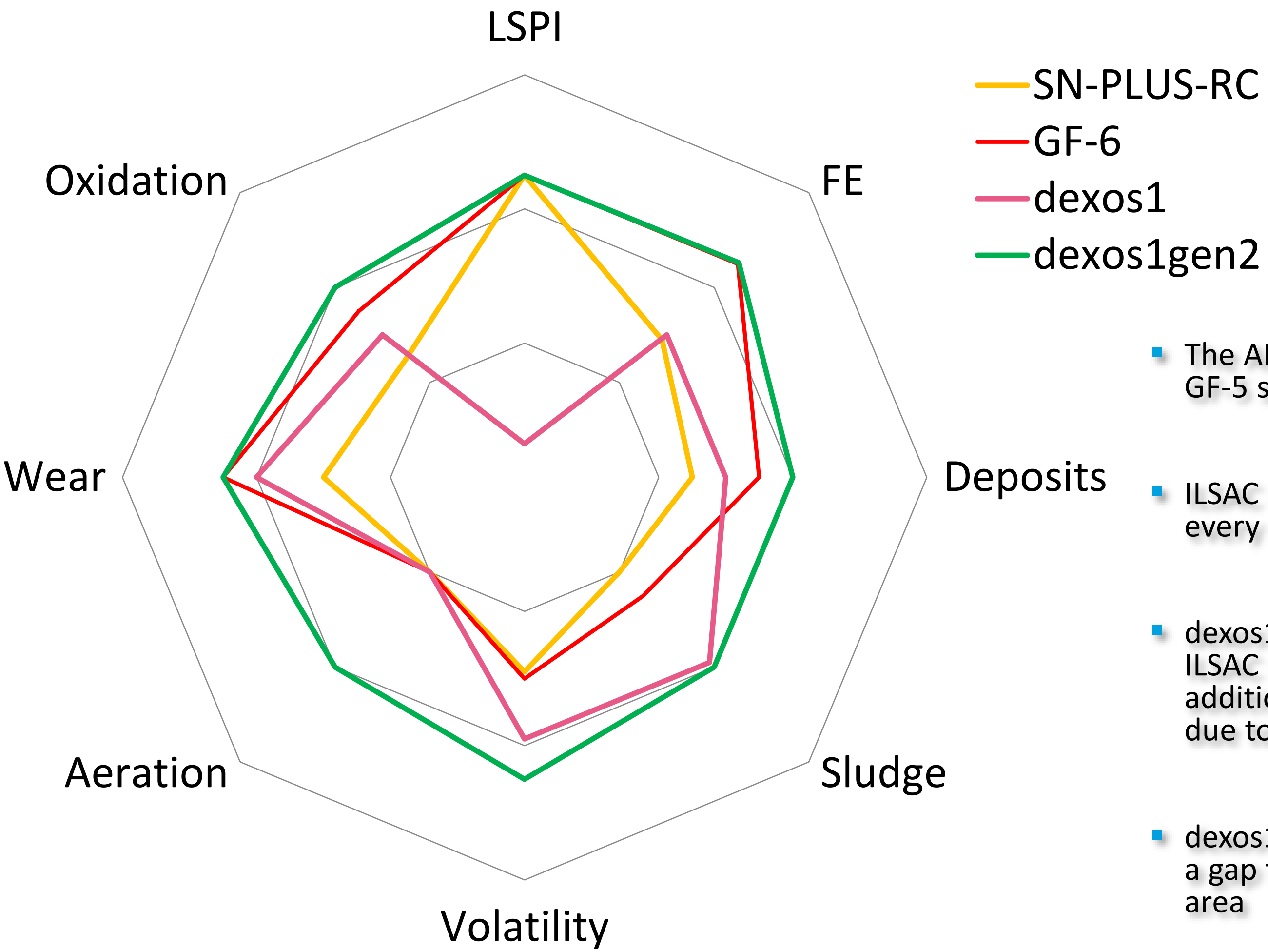
Relative PCMO Spec Performance Comparison



- The API SN PLUS improves upon ILSAC GF-5 solely by LSPI
- ILSAC GF-6 raises the bar in most every dimension over API SN PLUS
- dexos1 gen2 is well aligned with ILSAC GF-6 today but does provide additional performance in some areas due to additional tests and limits
- dexos1 gen3 may help create more of a gap from GF-6 in yet undetermined area

Summary

- PCEO formulation requires careful component and base stock selection to achieve balanced performance in combination engine and bench tests defined by a specification
- The NA market continues to experience segmentation due to diverging OEM needs, engine platforms, and consumer preferences
- ILSAC GF-6 will deliver improved fuel economy and more robust engine protection, similar to its predecessors → still a very competitive market segment

Appendix

Detergents

Background	Many configurations available including: • Salicylates, phenates, and sulphonates • Neutral and highly overbased • Magnesium and/or calcium
Formulation considerations	1. Mixture of detergents generally used to provide an balance of attributes 2. Neutral provide detergency for piston cleanliness while overbased provide a source of alkalinity reserve 3. Sulfonates more effective at lower temperature (piston skirt) while phenates more effective at higher temperature (piston crown) 4. Salicylates provide detergency and antioxidant protection, and their low sulfur content enables greater flexibility in restricted formulations 5. Metal variety can affect wear performance 6. Source of ash, a restricted parameter in some applications

Dispersants

Background	Many configurations available including: • High and low molecular weight • Chloro or thermal • Borated or non-borated
Formulation considerations	1. Concentration and type chosen to provide: • Sludge and filter plugging control • Piston and engine cleanliness • Control of soot-induced oil thickening 2. Contributes significantly to additive package and finished oil viscosity, so high treat rates can be detrimental to fuel economy performance 3. Detrimental to CCS viscosity 4. Chloro-dispersant contains residual chlorine, a restricted parameter in some applications 5. May be detrimental to compatibility with certain elastomers 6. Borated dispersants are beneficial in wear and elastomer compatibility, at the expense of sludge control efficiency

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ZDDP

Background	Many configurations available including: • High or low molecular weight • Primary or secondary
Formulation considerations	1. Provide dual-functionality as both an antioxidant and antiwear component 2. Lower molecular weight provides better wear protection while higher molecular weight provides better thermal stability 3. Secondary provides better wear protection while primary provides better thermal stability 4. Source of ash, a restricted parameter in some applications 5. Contribute phosphorous, a controlled parameter for emissions system protection 6. Highly efficient and cost-effective

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Antioxidants and Friction Modifiers

Antioxidants	
Background	Several options available beyond ZDDP including: • Aminic and phenolic • Metal – and/or sulfur-based
Formulation considerations	1. Response of oil to oxidation varies significantly by engine test, so a combination of antioxidants typically used to achieve performance

Friction Modifiers	
Background	Several options available including: • Organic • Inorganic
Formulation considerations	1. Some are highly surface active and can detrimentally impact wear performance 2. Organic FMs may cause stability issues in the additive package or finished oil

Viscosity Modifiers

Background	Many options available including: • OCP, PMA, styrene/isoprene copolymer • Functionalized (dispersant) or non-functionalized
Formulation considerations	1. Exhibit different degrees of temporary and permanent viscosity loss in high-shear operating conditions 2. Exhibit different contributions to low temperature performance 3. Typically detrimental to engine cleanliness 4. Selection of VM may benefit fuel economy 5. VM diluent contributes to finished oil volatility

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