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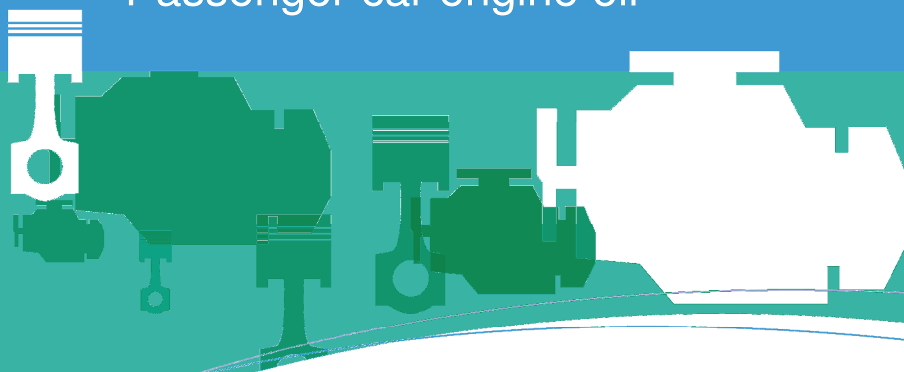
Passenger car engine oil



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Introduction and outline

- The components of a PCEO additive package
- API SN, SN-RC and ILSAC GF-5 specifications
- The PCEO market and future trends

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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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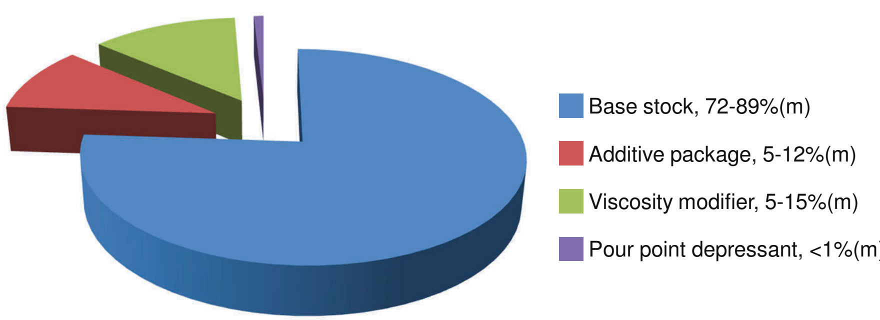
What goes into a finished PCEO?



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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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API SN, SN-RC and ILSAC GF-5 engine tests

Test	Parameter	Engine description
Sequence IIIG <u>OR</u> Sequence IIIH	Oxidation and deposits control	1996 GM 3.8L 2012 FCA 3.6L
Sequence IIIGA <u>OR</u> ROBO	Aged oil viscosity	1996 GM 3.8L Bench
Sequence IIIGB* <u>OR</u> Sequence IIIHB*	Phosphorous retention	1996 GM 3.8L 2012 FCA 3.6L
Sequence IVA	Wear control	1994 Nissan 2.4L
Sequence VG	Sludge and varnish control	2000 Ford 4.6L
Sequence VIII	Bearing corrosion resistance and shear stability	Coordinated Lubricants Research (CLR) 0.7 single cylinder
Sequence VID*	Fuel economy	2009 GM 3.6L

*Sequence VID and Sequence IIIGB/IIIHB required only for API SN-RC/ILSAC GF-5
ROBO Test (Romaszewski Oil Bench Oxidation test).

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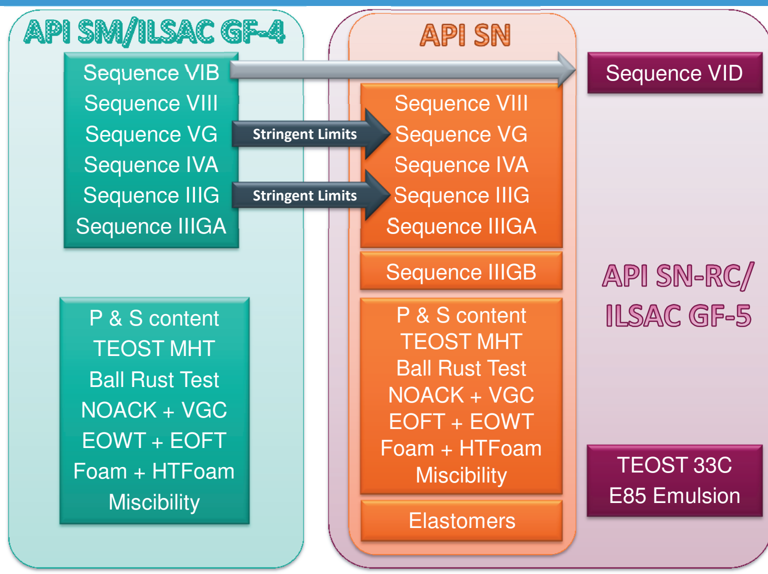
API and ILSAC gasoline specifications

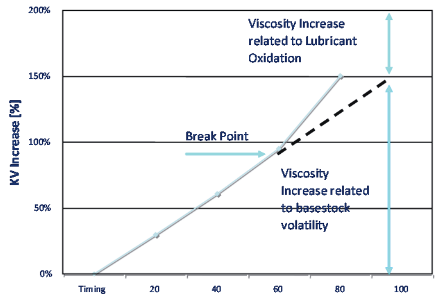


Specification evolution – ILSAC GF-4 to GF-5

Parameter	Units	GF-4	GF-5
Fuel Economy			
Fuel economy	[%]	Seq. VIB	Seq. VID
Deposits			
Seq. IIIG piston deposits **OR** Seq. IIIH piston deposits	[merits]	≥ 3.5	≥ 4.0 ≥ 3.7
TEOST 33C	[mg]		≤ 30 (ex. 0W-20)
Emissions System Compatibility			
Seq. IIIGB phosphorus retention **OR** Seq. IIIHB phosphorus retention	[%]		≥ 79 ≥ 81
Sludge			
Seq. VG Engine Sludge	[merits]	≥7.8	≥8.0
Seq. VG Rocker Sludge	[merits]	≥8.0	≥8.3
Seq. VG Oil Screen Clogging	[%]	≤20	≤15
Other			
Used oil low temperature pumpability	[cP]	Seq. IIIGA	Seq. IIIGA or ROBO
E85 emulsion retention	[%]		=100%
Elastomer compatibility			5 materials

Sequence IIIG/IIIH

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



Parameter	Units	Seq. IIIG	Seq. IIIH
KV40 increase	[%]	≤ 150	≤ 150
Avg. weighted piston deposits	[merits]	≥ 4.0	≥ 3.7
Avg. cam + lifter wear	[µm]	≤ 60	-
Hot stuck rings	[#]	= 0	= 0

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Sequence IIIGA (and ROBO)

- Evaluates the low temperature performance of used oil
- Seq. IIIGA utilizes used oil previously evaluated in the Seq. IIIG
- ROBO (Romaszewski Oil Bench Oxidation) intended to simulate oxidation of fresh oil in the Seq. IIIG 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. IIIGA and ROBO evaluated against the same criteria:

Parameter	Units	GF-5 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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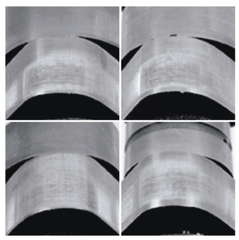
Sequence IVA

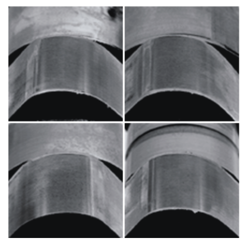
- Evaluates a lubricant's performance in resisting camshaft lobe wear in an overhead camshaft engine
- Engine speed alternates between 800 RPM and 1500 RPM for 1h, for 100 cycles

Parameter	Units	GF-5 Limit
Cam wear, average	[µm]	≤ 90

PASS



FAIL



Sequence VIII

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

Parameter	Units	GF-5 limit
Bearing weight loss	[mg]	≤ 26
Shear stability		= stay in grade

PASS

FAIL

Sequence VG

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

Parameter	Units	GF-5 limit
Engine sludge, average	[merits]	≥ 8.0
Rocker cover sludge, average	[merits]	≥ 8.3
Engine varnish, average	[merits]	≥ 8.9
Piston skirt varnish	[merits]	≥ 7.5
Oil screen sludge	[%]	≤ 15
Hot stuck compression rings	[#]	= 0
Cold stuck rings	[#]	report
Oil screen clogging	[%]	report
Oil screen debris	[%]	report

PASS FAIL

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Sequence VID

- Evaluates the effect of engine oil on the fuel economy of passenger cars and light-duty trucks
- Procedure:
  - Fuel consumption is measured twice at each of 6 speed/load/temperature test conditions for SAE 20W-30 baseline oil (BL)
  - The candidate oil is introduced and aged for 16 hours at aging conditions. Fuel consumption is measured for each of the 6 test conditions
  - The candidate oil is aged for an additional 84 hours. Fuel consumption is measured for each of the 6 test conditions and followed by a repeat of the BL oil at the 6 test conditions. Candidate fuel economy results reported relative to the BL

SAE Grade	FEI_2 Limit [%]	FEI_{SUM} Limit [%]
xW-20	≥ 1.2	≥ 2.6
xW-30	≥ 0.9	≥ 1.9
10W-30	≥ 0.6	≥ 1.5

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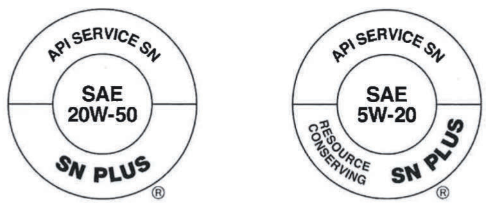
API SN PLUS, SN PLUS - RC

- Request from 10 automakers to come up with a supplemental standard to the current API SN gasoline engine oil spec to address low-speed pre-ignition (LSPI) problem in turbocharged direct injection gasoline engines.
- On November 9, 2017, API Lubricants Standards Group approved the adoption of SN PLUS.
- Addition of Sequence IX (Ford LSPI) test to API SN and modified API Donuts are the only direct changes.
- Oils satisfying API SN PLUS, SN PLUS - RC can also effectively lubricate engines calling for API SN, SN-RC or ILSAC GF-5



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API SN PLUS, SN PLUS - RC and ILSAC GF-5 engine tests

Test	Parameter	Engine description
Sequence IIIG **OR Sequence IIIH**	Oxidation and deposits control	1996 GM 3.8L 2012 FCA 3.6L
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Sequence VG	Sludge and varnish control	2000 Ford 4.6L
Sequence VIII	Bearing corrosion resistance and shear stability	Coordinated Lubricants Research (CLR) 0.7 single cylinder
Sequence VID*	Fuel economy	2009 GM 3.6L
Sequence IX	Low speed pre-ignition	2016 Ford 2.0L

*Sequence VID and Sequence IIIGB/IIIHB required only for API SN PLUS - RC/ILSAC GF-5

ROBO Test (Romaszewski Oil Bench Oxidation test).

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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	SN PLUS Limit
Average total number of LSPI events	#	≤ 5

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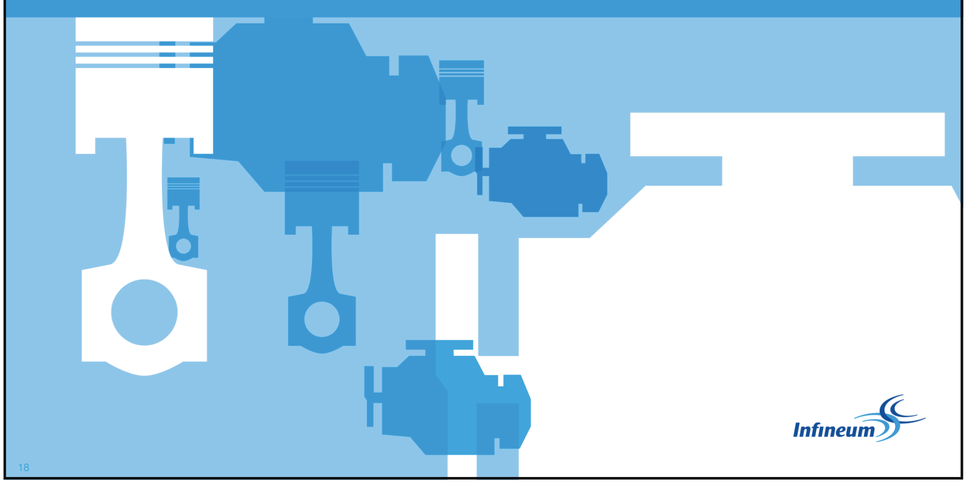
The PCEO market and future trends



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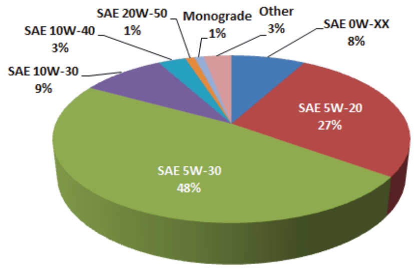
NA viscosity grade trends



*Infineum estimate

- SAE 5W-30
  - Is currently the highest proportion viscosity grade
  - Has begun to decline in favor of other 'lighter' viscosity grades such as SAE 0W and 5W-20, which are growing about 10-20%/y
- SAE 0W-20
  - Several OEMs now recommend SAE 0W-20 engine oils in most engines including Toyota, Honda and now General Motors
  - Requires a minimum of all Group III basestock, increases cost
  - Generally marketed as a mid-tier or premium product at retail outlets and quick lubes

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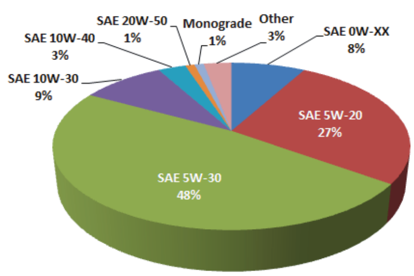
NA viscosity grade trends



*Infineum estimate

- For historical reference, SAE 10W-30 represented over 50% of all oil sold in 2000 to approximately 10% today. It takes a long time for new grades to integrate into the market
- Other viscosity grades are hard to find as retailers stock high value mid-and top-tier products
  - SAE xW-16 is the newest viscosity grade allowed. No significant demand is expected in NA for few years and likely won't be recommended until ILSAC GF-6 is implemented

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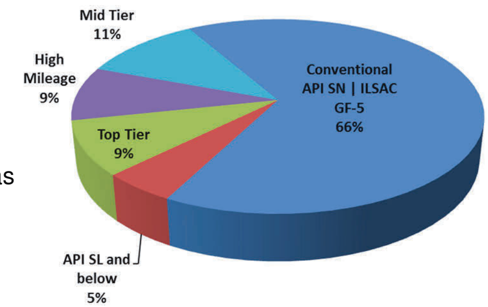
NA market segmentation

- ‘Conventional API SN | ILSAC GF-5’ includes synthetic blends sold in the conventional tier
- ‘Mid Tier’ includes mostly SAE 0W-20 and dexos1TM and premium brand synthetic blends only. It excludes estimate for some volume of SAE 0W-20 and dexos1TM volume sold as top tier. Infineum sees mid tier as the fast growing segment!
- ‘High Mileage’ quality varies from API SJ/SL to API SN | ILSAC GF-5
- ‘Top Tier’ includes only premium brands and European PCDO
- ‘API SL and below’ includes API SA – API SL, and primarily API SA/SF/SL



*Infineum estimate

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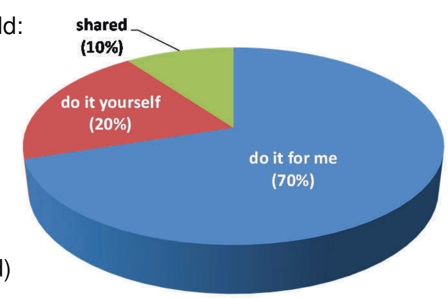
Market segmentation – conventional and mid tier

- Conventional
  - Very competitive segment.
    Bulk oil accounts for majority of oil sold:
  - Synthetic blend conventional oils do not guarantee premium performance
- Mid Tier
  - High mileage oils dominate, but their share is flat
  - Green oils (biostocks and re-refined) are still very small
  - Synthetic blends carry lower market premium to retailers than premium full synthetics



*Infineum estimate

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Market segmentation – mid tier and premium segment

- The premium market segment is:
  - Dominated by several major brands at over 90% of the segment
  - A profitable segment for marketers in which brand and premium approvals/performance claims provide value to the end consumer
  - Growth has slowed significantly as mainline products improve in quality and certain SAE 0W-20 and dexos1™ move into a growing mid tier segment that includes full or near full synthetic oils
  - This new mid tier will be the fastest growing market segment
  - Premium full synthetic oils will need to find innovative ways to differentiate against mid tier products
    - Longer drain intervals (such as value/convenience proposition)
    - New performance claims, such as cleaner engines
    - Additional performance claims including passenger car diesel performance

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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
- dexos1™ includes elements of ILSAC GF-5 (more stringent) and ACEA A in addition to GM/OPEL engine tests
- 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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ILSAC GF-6: A quick overview

Two categories proposed, based on viscosity grades

ILSAC GF-6A	ILSAC GF-6B
SAE XW-20 and XW-30	SAE 0W-16
HTHS Viscosity >= 2.6 mPa•s	HTHS Viscosity 2.3-2.6 mPa•s
Current ILSAC GF-5 grades	Fuel economy grade (Below SAE 20)

- ILSAC GF-6A and GF-6B will have same performance requirements except for the fuel efficiency test – Seq. VIE for GF-6A; Seq. VIF for GF-6B
  - Seq. VIF utilizes a lower temperature than the Seq. VIE in 4 of the 6 stages
- Need to differentiate ILSAC GF-6A oils from GF-6B oils to avoid misapplication
  - ILSAC GF-6A oils will contain current Starburst symbol; ILSAC wants a different symbol for GF-6B oils, but need marketers' consensus

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ILSAC GF-6: An unprecedented challenge

- ILSAC GF-6 will contain 4 replacement engine tests and 3 new engine tests.
  - Most done previously was 4 replacement tests in ILSAC GF-3
- This has placed a lot of strain on test labs and the rest of the industry, resulting in significant delays in test development and completion of category

ILSAC GF-5	
Sequence IIIG	1996 GM 3.8L
Sequence IVA	1994 Nissan 2.4L
Sequence VG	2000 Ford 4.6L
Sequence VID	2009 GM 3.6L
Sequence VIII	CLR Test 0.7L

ILSAC GF-6A/B	
Sequence IIIH	2012 FCA 3.6L
Sequence IVB	2010 Toyota 1.5L
Sequence VH	2013 Ford 4.6L
Sequence VIE	2012 GM 3.6L
Sequence VIII	CLR Test 0.7L
Sequence VIF	2012 GM 3.6L
Sequence IX	2016 Ford 2.0L
Sequence X	2016 Ford 2.0L

First Allowable Use possibly in 2020

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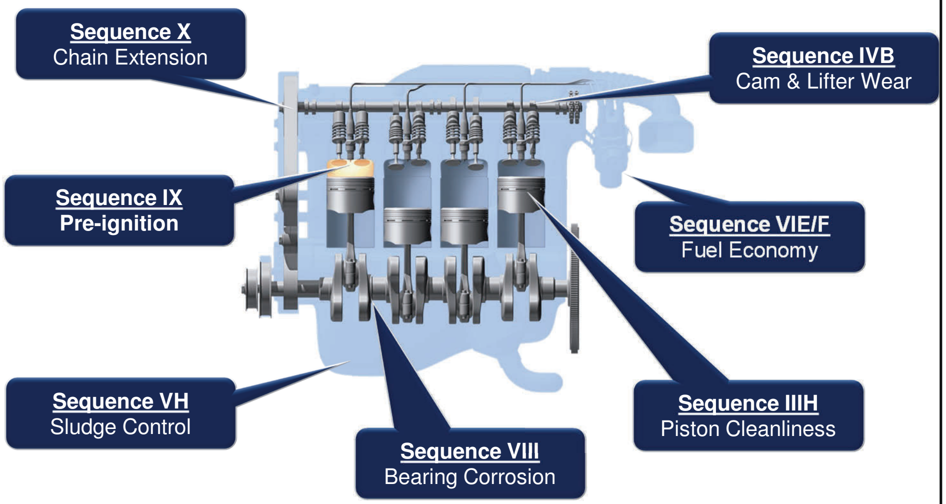
Engine map of ILSAC GF-6 tests



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Summary

- PCEO formulation requires careful component and base stock selection to achieve balanced performance in combination engine and bench tests defined by a specification
- API SN PLUS will address automakers' concerns about low speed pre-ignition problem in turbocharged direct injection gasoline engines
- 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

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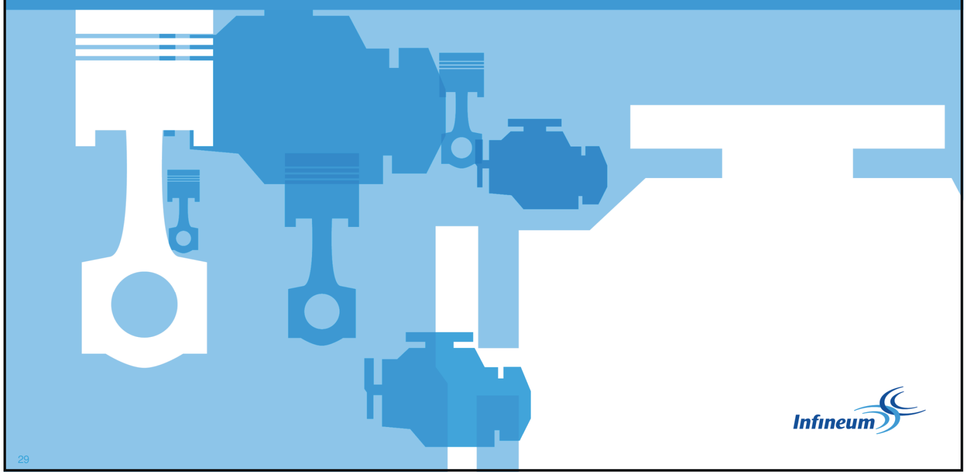
Appendix



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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

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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

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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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