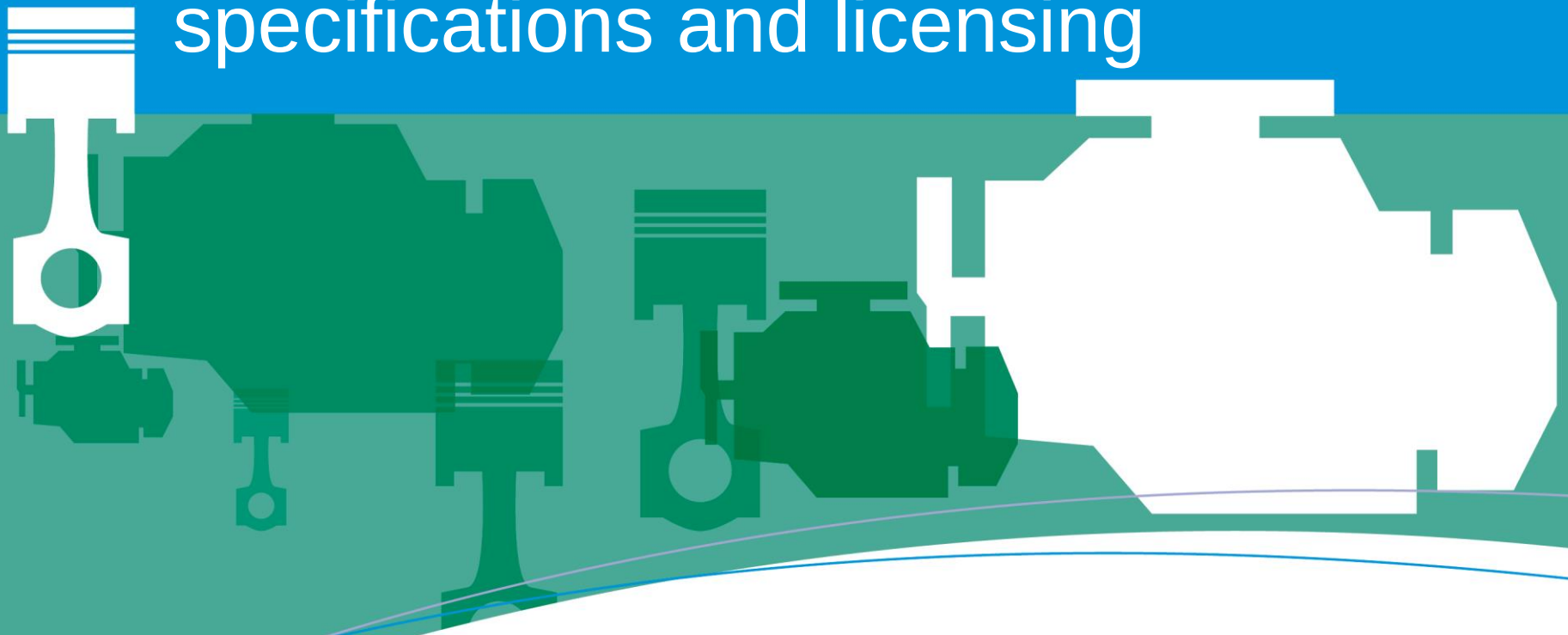
Performance you can rely on.

Engine oils – classifications, specifications and licensing



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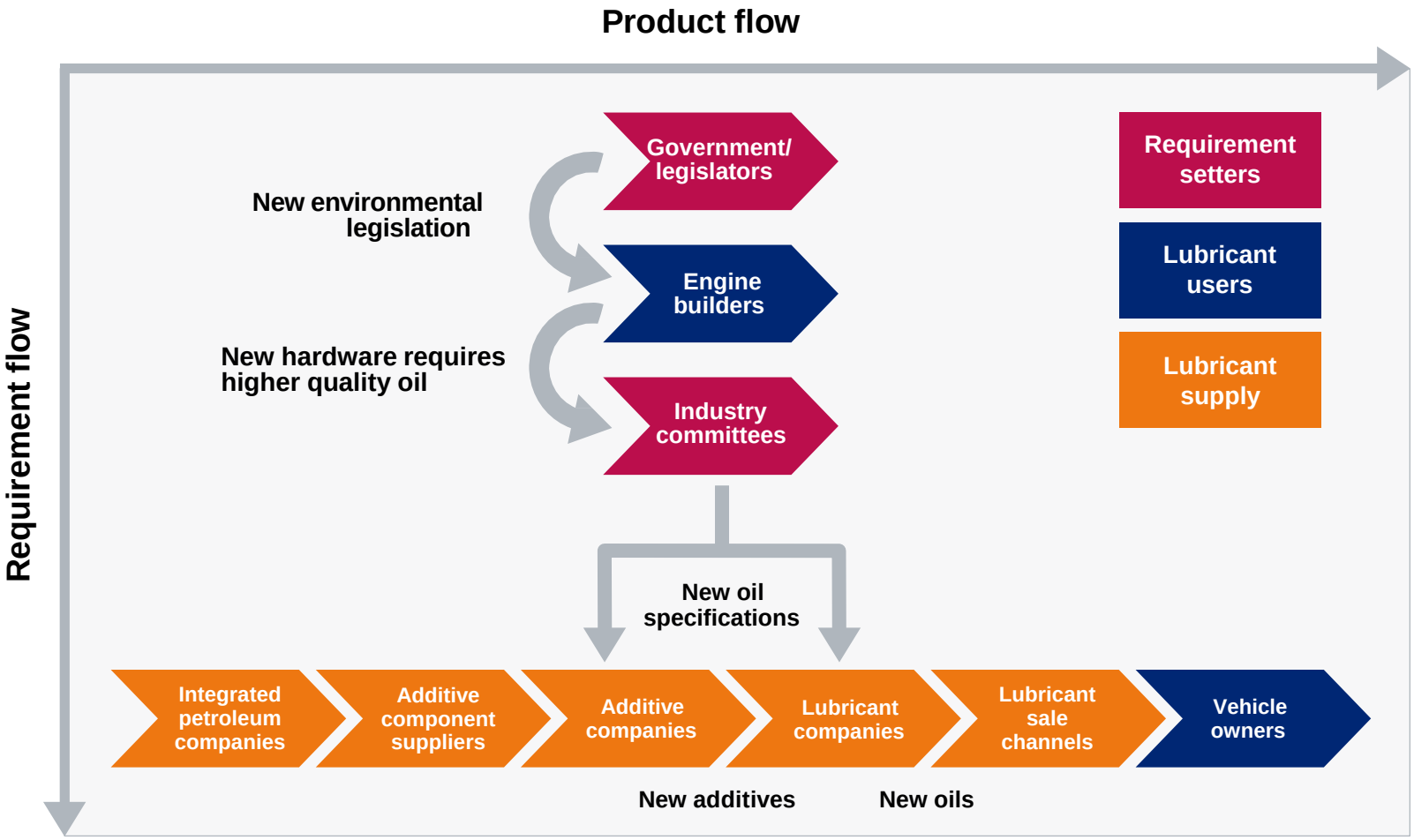
Outline

- Main drivers for engine oil classification and specifications
- Relevant industry groups and bodies
- Specification overview – focus on Europe and North America
- Engine oil quality management and licensing

Oil and additive industry value chain



Organisations classifying engine performance

Industry associations

- ACEA → European Automobile Manufacturers Association
- API → American Petroleum Institute
- ILSAC → International Lubricant Standardization & Advisory Committee
- JASO → Japanese Automobile Standards Organization

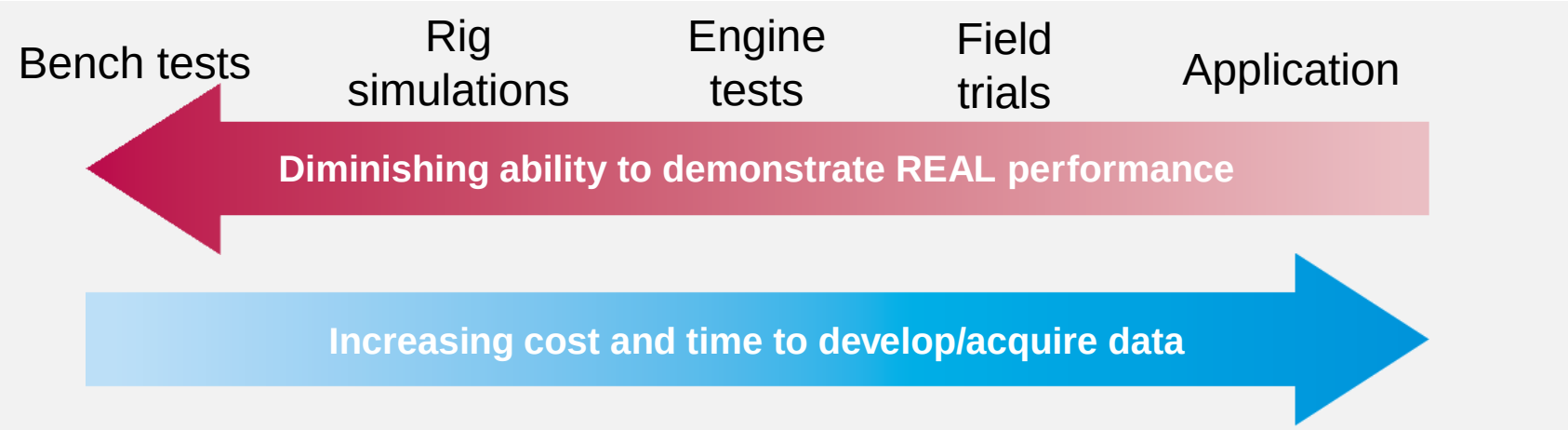
Vehicle or Original Engine Manufacturers (OEMs), such as:

- General Motors (GM)
- Volkswagen (VW)
- Daimler
- Volvo
- Ford
- MAN
- Scania
- Toyota

Industry trade organization responsibilities

Description	Europe	North America	Japan
Engine builders (passenger car)	ACEA	AAM, JAMA	JAMA
Engine builders (commercial)	ACEA	EMA	JAMA
Oil marketers base oil suppliers	ATIEL	API	JASO
Additive companies	ATC	API, ACC	
Specifications	ACEA	API, ILSAC	JASO
Test procedures	CEC	ASTM	JASO
Approvals		API	

Engine tests are the basis of specifications



- Developed by individual OEMs or industry groups to target specific performance parameters of concern
- Assessed relative to reference oil of known field performance
- Developments consider:
  - parts availability and quality
  - test conditions and duration
  - parameters of interest and pass/fail limits
  - qualification of test facilities
- Monitored continually by industry
- Specifications derived from compilation of engine tests and limits

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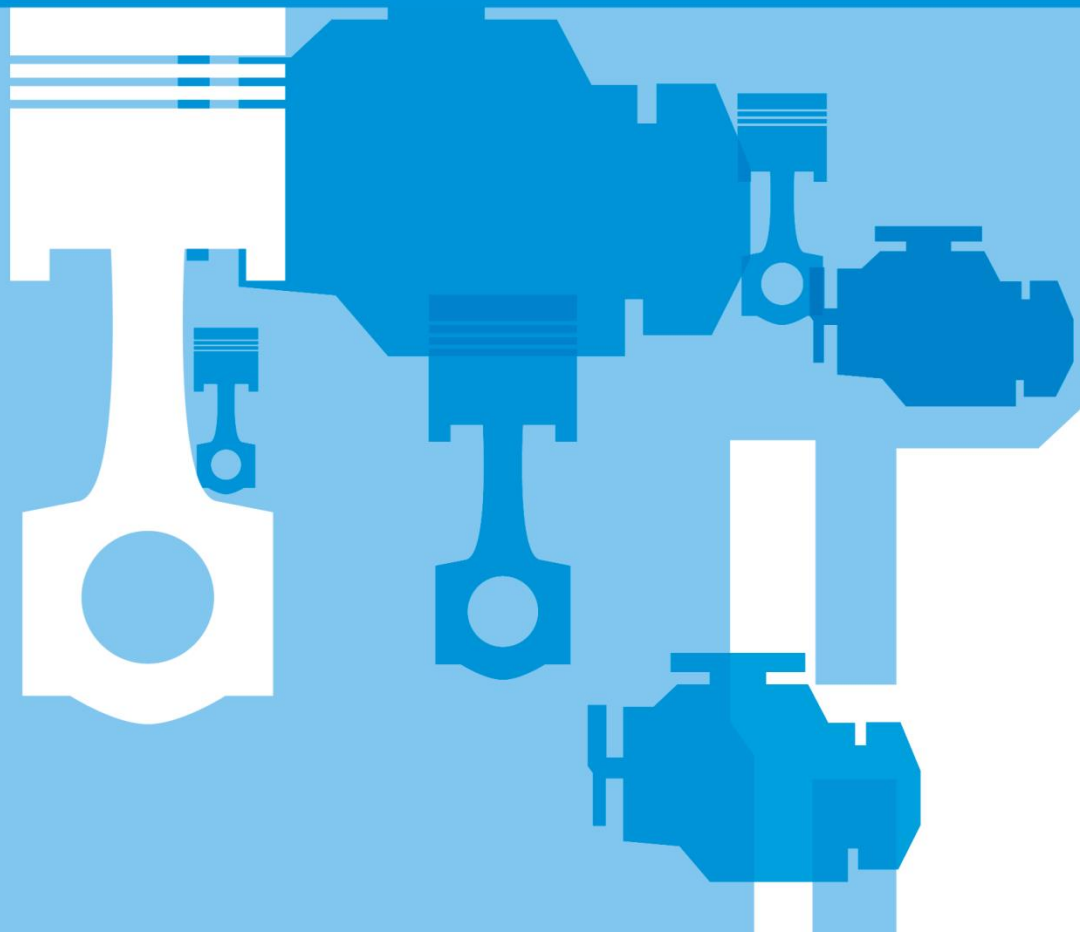
Performance you can rely on.

Engine Oil Specifications: Europe



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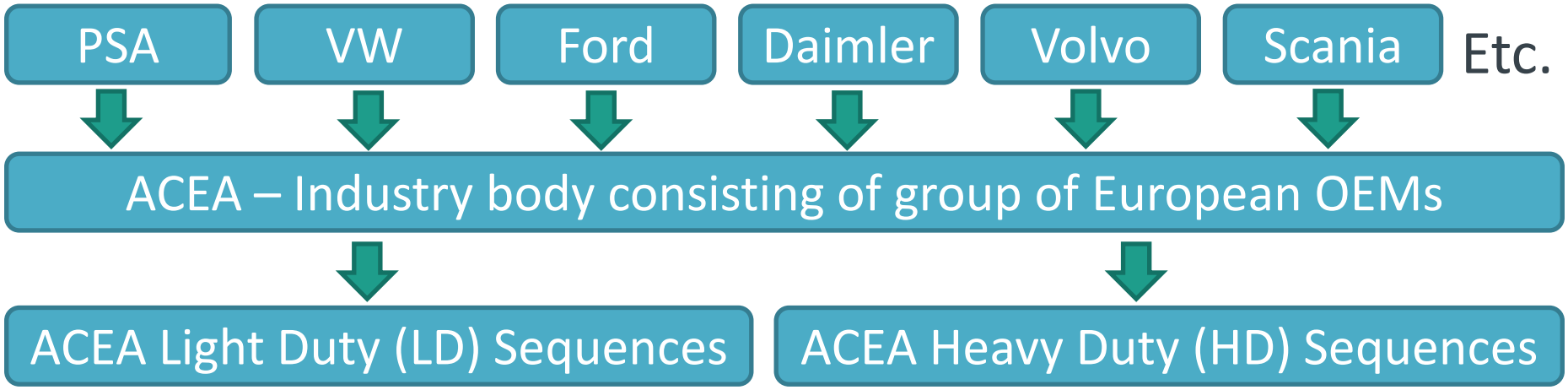
ACEA Sequences



- Covers lubricants for passenger car diesel and gasoline vehicles
- Covers lubricants for heavy duty trucks and buses

- Define a minimum "baseline" quality level for lubricants to be used in ACEA members' engines
- Are self-certified – there is no formal approval body.
  - But oils must conform to a specified quality system (EELQMS)
  - This includes compliance with ATC and ATIEL codes

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ACEA 2016

- **Latest ACEA Sequences – ACEA 2016**
  - **Objectives**
    - Keeping pace with advancement in engine technology and the trend to lower viscosity grades
    - Replace tests coming to the end of life
    - Introduce tests for biodiesel compatibility

ACEA 2016 Sequences

ACEA LD Sequences

Gasoline & Light Duty Diesel Engine Oils **A/B Categories**	A3/B3-16, A3/B4-16, A5/B5-16
Catalyst & GPF compatible Engine Oils for Gasoline & Light Duty Diesel Engines C-Categories	C1-16, C2-16, C3-16, C4-16, C5-16

ACEA HD Sequences

Heavy Duty Diesel Engine Oils E-Categories	E4-16, E6-16, E7-16, E9-16

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Important Bench and Analytical Tests for ACEA A/B and C Categories

Lubricant property	Test	A3/B3	A3/B4	A5/B5	C1	C2	C3	C4	C5
"SAPS" Levels	**S**ulphated **A**sh (ASTM D874)	H	H	H	L	M	M	L	M
	Phosphorus (ASTM D5185)	report			L	M	M	M	M
	Sulphur (ASTM D5185)	report			L	M	M	L	M
Total Base Number	TBN (ASTM D2896)	M	H	M	L				
High Temperature Viscosity	HTHS (CEC L-036-90)	H	H	M	M	M	H	H	L
Oxidation with Biodiesel	"L-109" (CEC L-109)	X	X	X	X	X	X	X	X
Elastomer Compatibility	Seals Tests (CEC L-112-16)	X	X	X	X	X	X	X	X

Catalyst-compatible oils

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Important Bench and Analytical Tests for ACEA A/B and C Categories

Lubricant property	Test	A3/B3	A3/B4	A5/B5	C1	C2	C3	C4	C5
"SAPS" Levels	**S**ulphated **A**sh (ASTM D874)	≥ 0.9 ≤ 1.5	≥ 1.0 ≤ 1.6	≤ 1.6	≤ 0.5	≤ 0.8	≤ 0.8	≤ 0.5	≤ 0.8
	Phosphorus (ASTM D5185)	report			≤ 0.05	≥ 0.07 ≤ 0.09	≥ 0.07 ≤ 0.09	≤ 0.05	≥ 0.07 ≤ 0.09
	Sulphur (ASTM D5185)	report			≤ 0.2	≤ 0.3	≤ 0.3	≤ 0.2	≤ 0.3
Total Base Number	TBN (ASTM D2896)	≥ 8.0	≥ 10.0	≥ 8.0	L				
High Temperature Viscosity	HTHS (CEC L-036-90)	≥ 3.5	≥ 3.5	≥ 2.9 ≤ 3.5	M	M	H	H	L
Oxidation with Biodiesel	"L-109" (CEC L-109)	X	X	X	X	X	X	X	X
Elastomer Compatibility	Seals Tests (CEC L-112-16)	X	X	X	X	X	X	X	X

Catalyst-compatible oils

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Engine tests for ACEA A/B and C categories

Lubricant property	Test	Engine supplier	A3/B3	A3/B4	A5/B5	C1	C2	C3	C4	C5
Gasoline DI engine cleanliness	CEC L-111-16 (**EP6**CDT)	Peugeot	X	X	X	X	X	X	X	X
Low temperature sludge	ASTM D6593-00 (**Sequence VG**)	Ford	X	X	X	X	X	X	X	X
Black sludge	Currently using non-CEC test (**M271**)	Daimler	X	X	X	X	X	X	X	X
Fuel economy	CEC L-054-96 (**M111**)	Daimler			X	X	X	x	x	X
Medium temperature oil dispersion	CEC L-106-16 (**DV6C**)	Peugeot	X	X	X	X	X	X	X	X
Wear	CEC L–099-08 (**OM646LA**)	Daimler	X	X	X	X	X	X	X	X
DI diesel Piston cleanliness & Ring sticking	CEC L-078-99 (**VW TDI**)	VW	X	X	X	X	X	X	X	X
Effects of biodiesel	CEC L-104-16 (**OM646LA Bio**)	Daimler		X	X	X	X	X	X	X

Catalyst-compatible oils

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ACEA 2016 Sequences

ACEA LD Sequences

Gasoline & Light Duty Diesel Engine Oils A/B Categories

- A3/B3-16
- A3/B4-16
- A5/B5-16

Catalyst & GPF compatible Engine Oils for Gasoline & Light Duty Diesel Engines C-Categories

- C1-16
- C2-16
- C3-16
- C4-16
- C5-16

ACEA HD Sequences

Heavy Duty Diesel Engine Oils E-Categories

- E4-16
- E6-16
- E7-16
- E9-16

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ACEA E categories: heavy-duty diesel engine oils

ACEA E4

- **Excellent** control of piston cleanliness, wear, soot handling and lubricant stability
- It is recommended for highly rated diesel engines meeting Euro I, Euro II, Euro III, Euro IV and Euro V emission requirements and running under **very** severe conditions
- It is suitable for engines **without** particulate filters, and for **some** EGR engines and **some** engines fitted with SCR NOx reduction systems

ACEA E6

- **Excellent** control of piston cleanliness, wear, soot handling and lubricant stability
- It is recommended for highly rated diesel engines meeting Euro I, Euro II, Euro III, Euro IV, Euro V **and Euro VI** emission requirements and running under **very** severe conditions
- It is suitable for EGR engines, with or without particulate filters, and for engines fitted with SCR NOx reduction systems

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ACEA E categories: heavy-duty diesel engine oils

ACEA E7

- **Effective** control with respect to piston cleanliness and bore polishing. It further provides **excellent** wear control, soot handling and lubricant stability
- It is recommended for highly rated diesel engines meeting Euro I, Euro II, Euro III, Euro IV and Euro V emission requirements and running under severe conditions
- It is suitable for engines **without** particulate filters, and for **most** EGR engines, and **most** engines fitted with SCR NOx reduction systems

ACEA E9

- **Effective** control with respect to piston cleanliness and bore polishing. It further provides **excellent** wear control, soot handling and lubricant stability
- Recommended for highly rated diesel engines meeting Euro I, Euro II, Euro III, Euro IV Euro V and **Euro VI** emission requirements and running under severe conditions
- It is suitable for engines with or without particulate filters, and for most EGR engines and for most engines fitted with SCR NOx reduction systems

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Important Bench and Analytical tests for ACEA E Categories

Lubricant property	Test	E4	E6	E7	E9
"SAPS" Levels	**S**ulphated **A**sh (ASTM D874)	H	M	H	M
	Phosphorus (ASTM D5185)	-	L	-	M
	Sulphur (ASTM D5185)	-	L	-	M
Total Base Number	TBN (ASTM D2896)	H	L	M	L
High Temperature Viscosity	HTHS (CEC L-036-90)	H	H	H	H
Oxidation with Biodiesel	"L-109" (CEC L-109)	X	X	X	X

Important Bench and Analytical tests for ACEA E Categories

Lubricant property	Test	E4	E6	E7	E9
"SAPS" Levels	**S**ulphated **A**sh (ASTM D874)	≤ 2.0	≤ 1.0	≤ 2.0	≤ 1.0
	Phosphorus (ASTM D5185)	-	≤ 0.08	-	≤ 0.12
	Sulphur (ASTM D5185)	-	≤ 0.3	-	≤ 0.4
Total Base Number	TBN (ASTM D2896)	≥ 12	≥ 7	≥ 9	≥ 7
High Temperature Viscosity	HTHS (CEC L-036-90)	≥ 3.5	≥ 3.5	≥ 3.5	≥ 3.5
Oxidation with Biodiesel	"L-109" (CEC L-109)	X	X	X	X

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Engine tests for ACEA E Categories

Lubricant property	Test	Engine supplier	E4	E6	E7	E9
Wear	CEC L–099-08 (**OM646LA**)	Daimler	X	X	x	x
Soot in oil	ASTM D 5967 (**Mack T-8E**)[1]	Volvo North America	X	X	X	X
Bore polishing Piston Cleanliness	CEC L-101-08 (**OM501LA**)	Daimler	**X**	**X**	X	X
Soot induced wear	ASTM D7468 (**Cummins ISM**)	Cummins			X	**X**
Wear (liner-ring-bearings)	ASTM D7422 (**Mack T-12**)	Volvo North America		X	X	**X**
Effects of biodiesel	CEC L-104-16 (**OM646LA Bio**)	Daimler		X		X

[1] E4, E6, E7 and E9 all now use Mack T-8E. However Mack T11 (ASTM D7156) results obtained as part of API CI-4, CI-4 Plus, CJ-4, CK-4 or FA-4 approval program can be used in place of Mack T8E.

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ACEA 2016 – what's changed?

- **Light Duty Sequences**
  - A1/B1 removed – Requirements covered by A5/B5 (HTHS 2.9-3.5) and C5 (HTHS 2.6)
  - C5 introduced – New Mid SAPS category with improved FE benefits (HTHS 2.6 vs 2.9-3.5)
- **New Lab Bench Test**
  - HTHS at 100°C report requirement introduced – all LD/HD categories
  - Harmonisation of PDSC requirements – HD only
  - CEC L-109 oxidation test replaces GFC oxidation test in LD categories
    - Introduced as new test for HD
  - CEC L-39 elastomer test replaced by new CEC L-112 elastomer compatibility test – all LD/HD categories

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ACEA 2016 – what's changed?

- **New Engine Tests**
  - EP6 (CEC L-111) introduced – LD only
    - GDI TC engine – piston cleanliness (main parameter) and TC deposit (safety parameter)
  - DV4 (CEC L-93) replaced by new DV6 (CEC L-106) – LD only
  - OM646Bio (CEC L-104) with performance limits (LD + HD (E6/E9 only))
- **End of life Engine Tests**
  - TU3 and TU5 have been withdrawn from the ACEA Sequences
- **"State of flux" Engine Tests**
  - Seq VG is predicted to become unavailable during 2017
    - Seq VH to be introduced once ready (as per ACEA 2016 footnote)
  - The new M271EVO sludge test is still under development by CEC
    - Currently a Daimler version is in use (no CEC number)
  - Mack T8E replaces T11 for HD E9 – T11 still allowable alternative

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ACEA 2016

Timetable for ACEA Product Claims:

Sequence issue	First allowable use	Mandatory for new claims	Oils with this claim may be marketed until
2004	1st November 2004	1st November 2005	31st December 2009
2007	1st February 2007	1st February 2008	23rd December 2010
2008	22nd December 2008	22nd December 2009	22nd December 2012
2010	22nd December 2010	22nd December 2011	22nd December 2014
2012	14th December 2012	14th December 2013	1st December 2018
2016	1st December 2016	1st December 2017	–

- Products may still claim ACEA 2012 and 2016 as indicated by dates above
- Next planned sequence is ACEA 2018 – still under discussion

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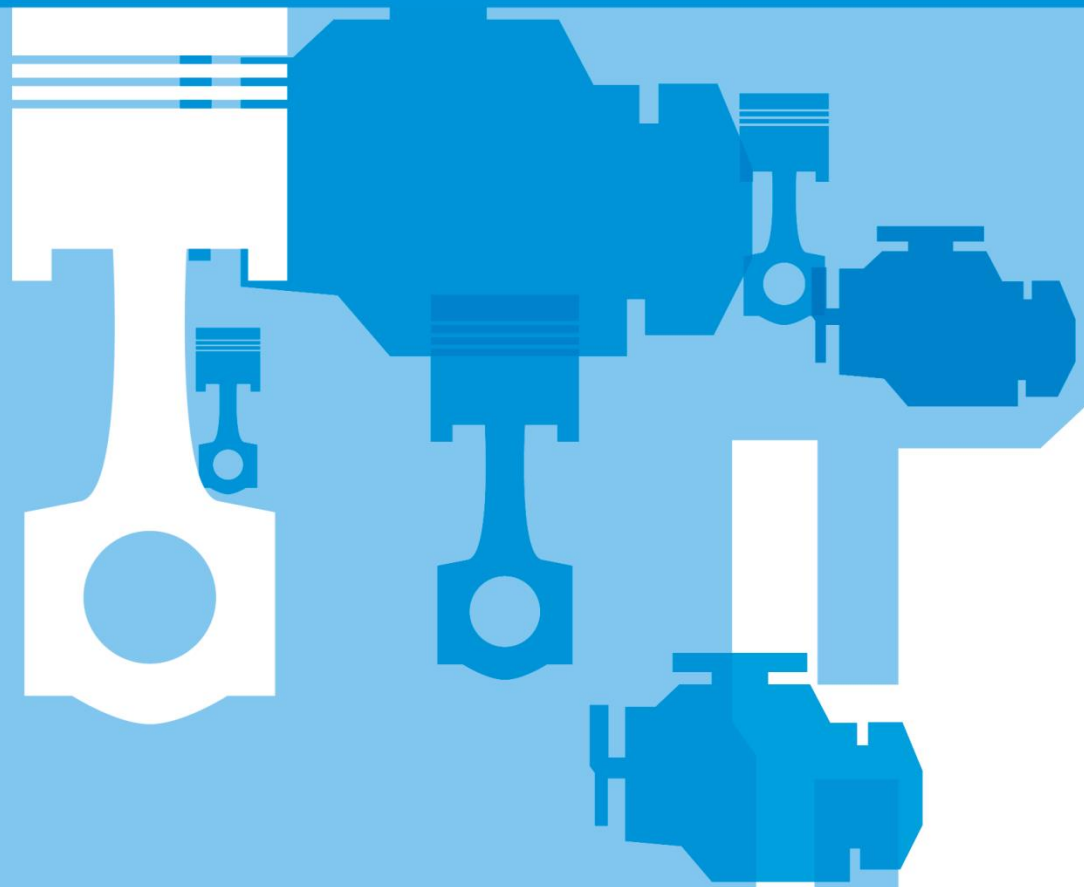
North American specification system



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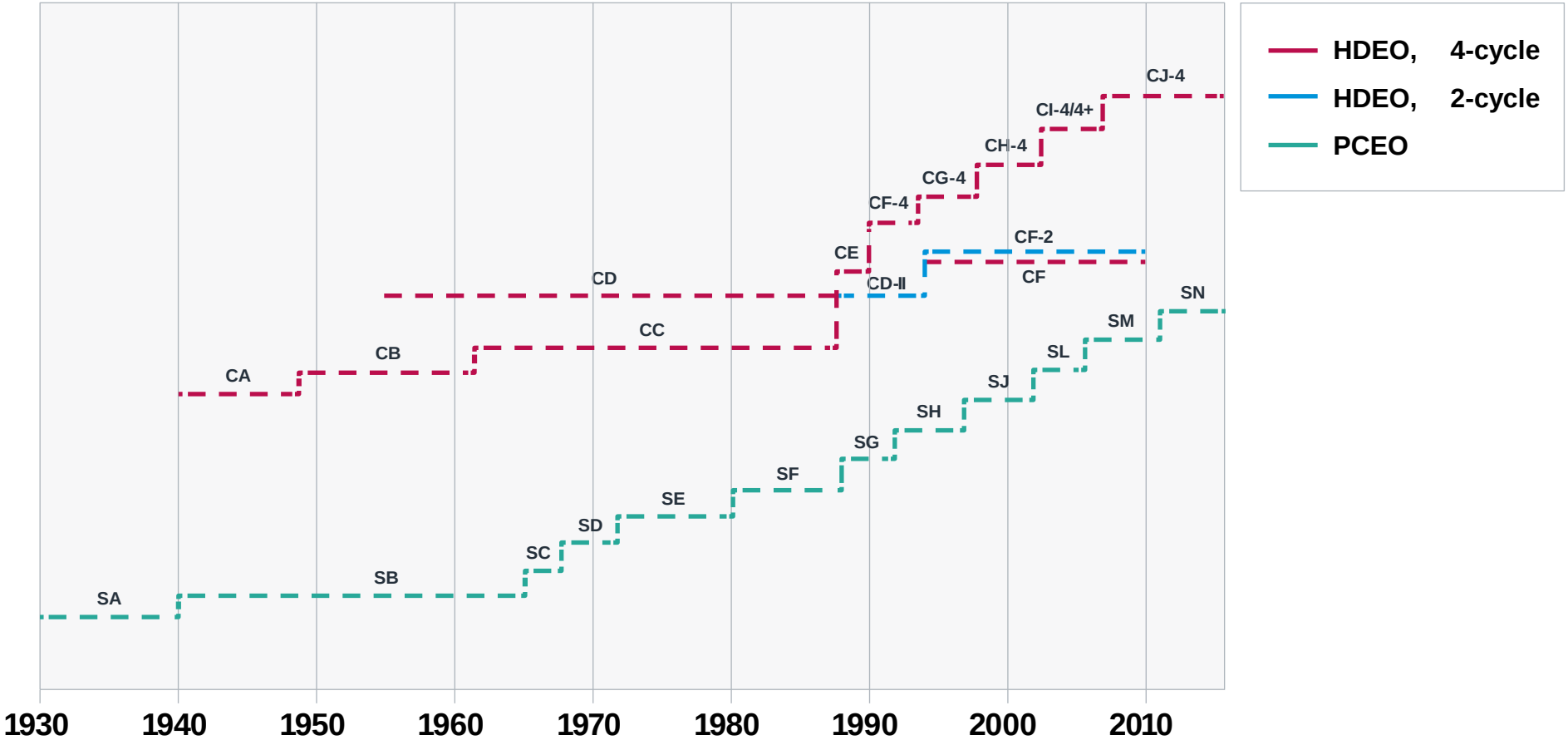
Evolution of API engine oil specifications



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API diesel specifications

API Category	Status	API recommendations
CK-4	**Current**	Introduced in 2016 To meet 2017 model year on-highway exhaust emission standards Sulfur content up to 500 ppm (0.05% by weight) > 15 ppm (0.0015% by weight) may impact exhaust aftertreatment system durability and/or drain interval (Consult engine manufacturer) Effective at sustaining durability of emission control system (particulate filters and other advanced aftertreatment systems) Can be used in CH-4, CI-4, CI-4+, CJ-4 applications
CJ-4	**Current**	Introduced in 2006 To meet 2010 model year on-highway exhaust emission standards Sulfur content up to 500 ppm (0.05% by weight) > 15 ppm (0.0015% by weight) may impact exhaust aftertreatment system durability and/or drain interval (Consult engine manufacturer) Can be used in CF-4, CG-4, CH-4, CI-4, CI-4+ applications

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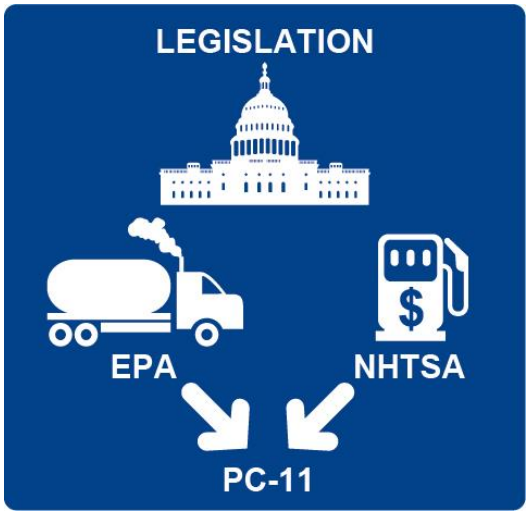
API diesel specifications

API Category	Status	API recommendations
CI-4	**Current**	Introduced in 2002 To meet 2004 exhaust emission standards (implemented in 2002) For engines with EGR using up to 0.5% sulfur in fuel Can be used in CD, CE, CF-4, CG-4 and CH-4 applications Some may qualify for CI-4+ designation
CH-4	**Current**	Introduced in 1998 To meet 1998 exhaust emission standards Up to 0.5% sulfur in fuel Can be used in CD, CE, CF-4 and CG-4 applications
CA, CB, CC, CD, CD-II*, CE, CF, CF-2*, CF-4, CG-4	**Obsolete**	Not recommended for modern diesel engines

* Specifications for two-stroke diesel engines

API CK-4 & FA-4: Oxidation & Fuel Economy

- New fuel economy and greenhouse gas rules began phased implementation in 2014 with full effect in 2018
  - Reduce CO2 by 270 million tons and save 530 million barrels of oil
- At the June 2011 ASTM meeting, the EMA issued a formal request for a new API performance category to help meet these new regulations
- Areas requested for improvement versus API CJ-4
  - Shear stability
  - Oxidation
  - Aeration
  - Bio-diesel compatibility (eventually dropped)
  - New lower viscosity oils to help deliver fuel economy performance
- API first license date was December 1, 2016



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API CK-4 & FA-4: Why 2 API oil categories?

API CK-4

More Robust API CJ-4
Recommended by all OEMs
Full backward compatibility

SAE xW-30 and xW-40
HTHSV > 3.5 mPa•s
API CK-4, ACEA E

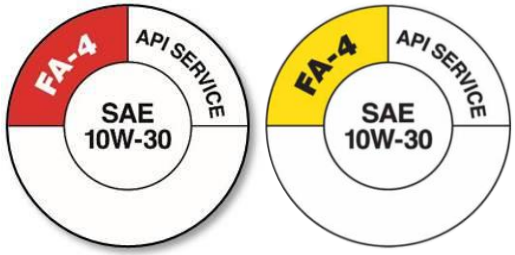
API FA-4

Robust CJ-4 at lower viscosity
Some OEM's opted out
Not backward serviceable

SAE xW-30
HTHSV: 2.9 – 3.2 mPa•s
API FA-4, New ACEA F

API CK-4 has the same durability requirements as API FA-4 to minimize risks associated with the new lower viscosity fuel economy grades

Note: Upper left hemisphere can be any contrasting color.



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API CK-4 & FA-4: Test requirements

- Combination of new and carry forward tests from API CJ-4

	Test	Performance Parameters	Fuel Sulphur
Legacy Tests	Caterpillar C13	Piston Deposits, Oil Consumption	15 ppm
	Caterpillar 1N	Aluminum Piston Deposits, Oil Consumption	500 ppm
	Cummins ISB	Valve Train Wear	15 ppm
	Cummins ISM	Valve Train Wear, Filter Plugging, Sludge	500 ppm
	Roller Follower Wear Test	Roller Follower Pin Wear	500 ppm
	Mack T-11	Soot Induced Viscosity Increase	500 ppm
	Mack T-11A	Sooted Oil Low Temperature Pumpability	500 ppm
	Mack T-12	Ring/Liner Wear parameters only	15 ppm
	Kurt Orbhan 90 cycle	Shear Stability Bench Test	No Fuel Used
New	Volvo T-13	Oxidation	15 ppm
	Caterpillar C13 Oil Aeration Test (COAT)	Oil Aeration	15 ppm

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API and ILSAC gasoline specifications

ILSAC Category	Status	ILSAC Service Recommendations
GF-6	**Pending**	Legislation to reduce emissions and improve fuel economy is driving changes in passenger car hardware system design and engine operation, which places increased demands on the engine oil. These factors, combined with the demise of some of the engine tests used in ILSAC GF-5, were the key drivers behind the ILSAC GF-6 Needs Statement, which was first published in 2011.
GF-5	**Current**	Introduced in October 2010 for 2011 and older vehicles, designed to provide improved high temperature deposit protection for pistons and turbochargers, more stringent sludge control, improved fuel economy, enhanced emission control system compatibility, seal compatibility and protection of engines operating on ethanol containing fuels up to E85.
GF-4, GF-3, GF-2, GF-1	Obsolete	Use GF-5 where GF-4, GF-3, GF-2 or GF-1 is recommended.

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API and ILSAC gasoline specifications

API Category	Status	API Recommendations
SN, SN with Resource Conserving	**Current**	For 2011 and older vehicles, designed to provide improved high temperature deposit protection for pistons, more stringent sludge control and seal compatibility. API SN with Resource Conserving matches ILSAC GF-5 by combining API SN performance with improved fuel economy, turbocharger protection, emission control system compatibility and protection of engines operating on ethanol containing fuels up to E85.
SM	**Current**	For 2010 and older automotive engines.
SL	**Current**	For 2004 and older automotive engines.
SJ	**Current**	For 2001 and older automotive engines.
SH, SG, SF, SE, SD, SC, SB, SA	Obsolete	Not recommended for modern gasoline engines.

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ILSAC

What is ILSAC?

- International Lubricant Standardization and Advisory Committee
- A committee consisting of major US vehicle manufacturers and JAMA formed in 1992
- Chrysler, General Motors (GM), and Ford
- Honda, Isuzu, Mazda, Mitsubishi, Nissan, Subaru, and Toyota

What does ILSAC do?

- Sets complementary specs to API passenger car specs to include fuel efficiency and catalyst protection
- Goes beyond ‘engine protection’ which is the basis for the API specs
  - Protects the catalyst system and adds a fuel efficiency measurement
- During update of ILSAC specifications the previous specification is only valid during a one year transition period
  - API specification become obsolete when no longer required or the tests are unavailable

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API SN and ILSAC GF-5 overview

- API SN designed to:
  - Improve deposits control
  - Improve sludge control
  - Ensure seal compatibility
- API SN-RC (resource conserving) and ILSAC GF-5 provide additional benefits, assisting OEMs in meeting regulatory requirements and providing additional benefits to the end-user:
  - Emissions system protection (reduced phosphorus and sulphur, and retained phosphorus requirement)
  - Improved fuel economy (Corporate Average Fuel Economy Requirements, CAFE)
  - Turbocharger protection
  - Engine protection for fuels containing up to 85%(m) ethanol (E85)
- ILSAC GF-5 mandatory use for API Certification Mark was October 1st 2011
- Same engine test requirements as for API SN
  - However in addition, ILSAC GF-5 must meet FUEL ECONOMY requirements as evaluated by the Sequence VID engine test
- In practice, ILSAC GF-5 finds application only to grades favourable to fuel economy:
  - e.g. 0W-20, 0W-30, 5W-20, 5W-30, 10W-30

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Engine tests for API SN/ILSAC GF-5

Lubricant property	Test	Engine description
Oxidation control	Sequence IIIG	Year 1996, GM 3.8L V-6
Viscosity of aged oil (only required for certain viscosity grades)	Sequence IIIGA (or ROBO)#	Year 1996, GM 3.8L V-6
Phosphorus Retention	Sequence IIIGB*	Year 1996, GM 3.8L V-6
Wear control	Sequence IIIG Sequence IVA	Year 1996, GM 3.8L V-6 Year 1994, Nissan 2.4L 4 Cylinder
Sludge and varnish control	Sequence VG	Year 2000, Ford 4.6L V-8
Bearing corrosion resistance	Sequence VIII	Coordinated Lubricants Research (CLR) 0.7L Single Cylinder
Fuel economy	Sequence VID*	Year 2009, GM 3.6L V6

*Sequence VID and Sequence IIIGB not required for API SN
(are only required for “API SN with Resource Conserving” or ILSAC GF-5)

ROBO Test (Romaszewski Oil **Bench** Oxidation test).

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Likely Engine tests for incoming ILSAC GF-6

Lubricant property	Test	Engine description
Oxidation control – replaces IIIG	Sequence IIIH	2012 FCA 3.6L
Wear control – replaces IVA	Sequence IVB	2010 Toyota 1.5L PFI
Sludge and varnish control – replaces VG	Sequence VH	20xx, Ford 4.6L PFI
Bearing corrosion resistance	Sequence VIII	Coordinated Lubricants Research (CLR) 0.7L Single Cylinder
Fuel economy – replaces VID	Sequence VIE	2012 GM 3.6L PFI
Fuel economy – new	Sequence VIF	2012 GM 3.6L PFI
Pre-ignition – new	LSPI	2016 Ford 2.0L GDI
Wear – new	Chain Stretch	2016 Ford 2.0L GDI

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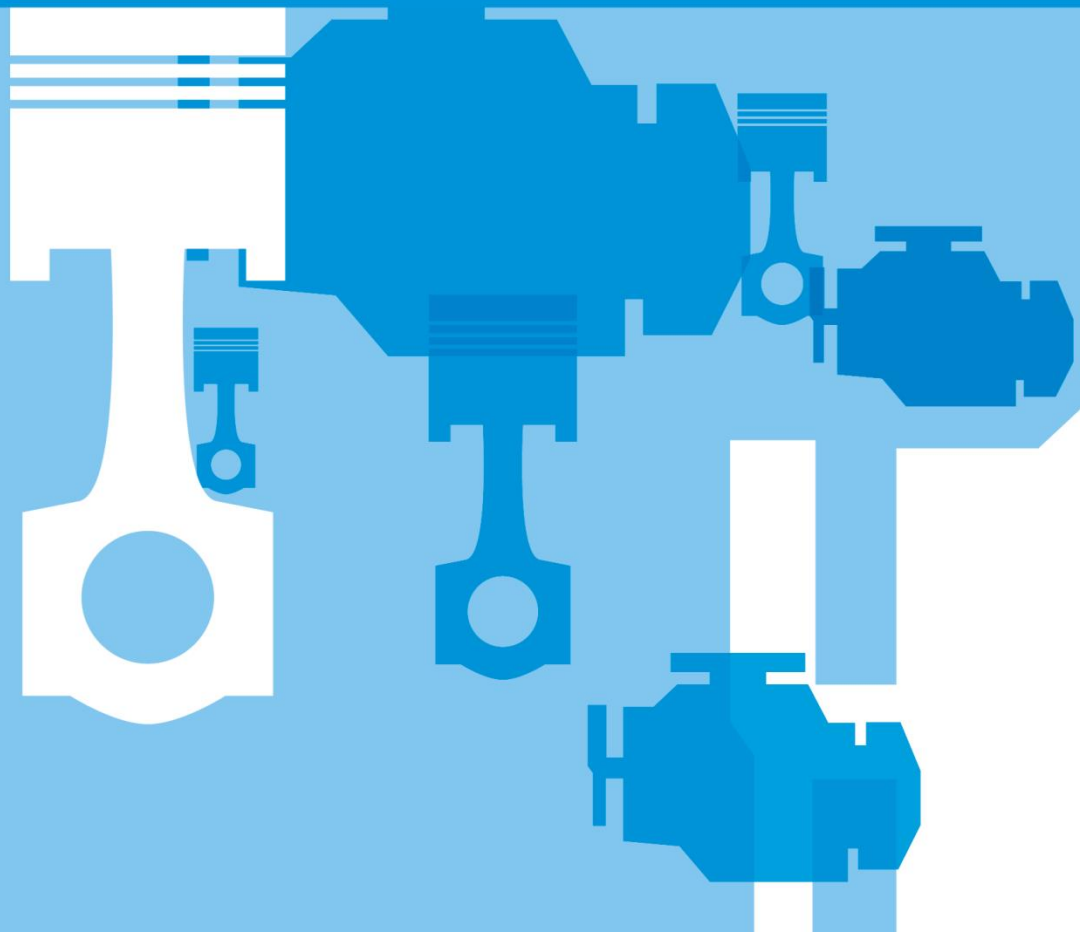
Performance you can rely on.

Engine Oil Licensing and Quality Management



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Industry Codes of Practice

ACC

ATC

- Members include Lubricant additive suppliers e.g. Infineum
- Covers oil development aspects from additive supplier perspective
  - Allowed changes to additive package and its components
  - Allowed changes to viscosity modifier
- Promotes quality of engine testing via specified protocols
- Specifies procedures to assist data reporting & traceability

API

ATIEL

- Members include major oil companies e.g. BP, Shell, Exxon Mobil
- Addresses oil development aspects from oil marketer perspective
  - Guidelines for base oil interchange (BOI)
  - Guidelines for viscosity grade read across (VGRA)
- Covers other aspects such as data reporting and (for API) licensing

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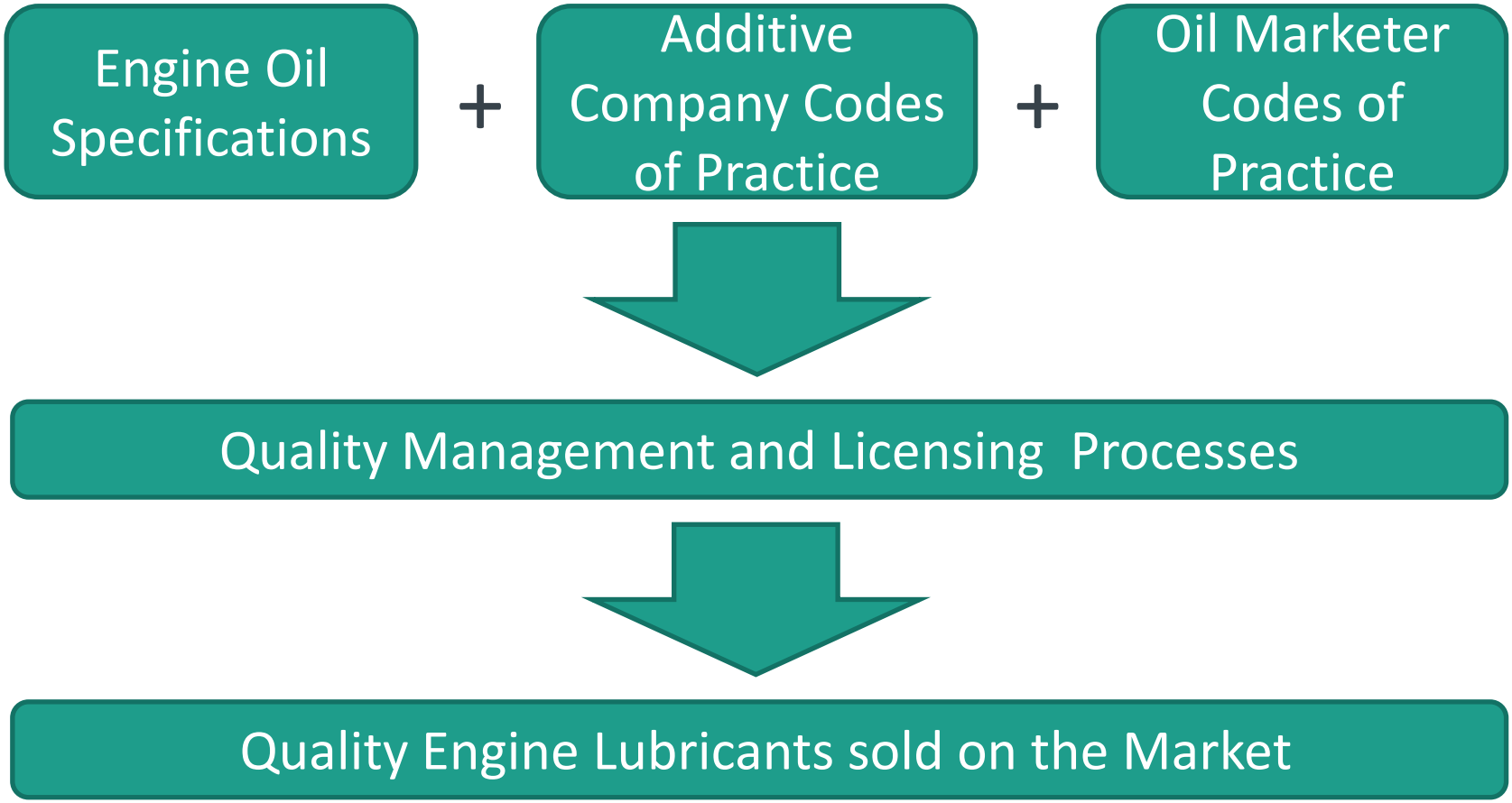
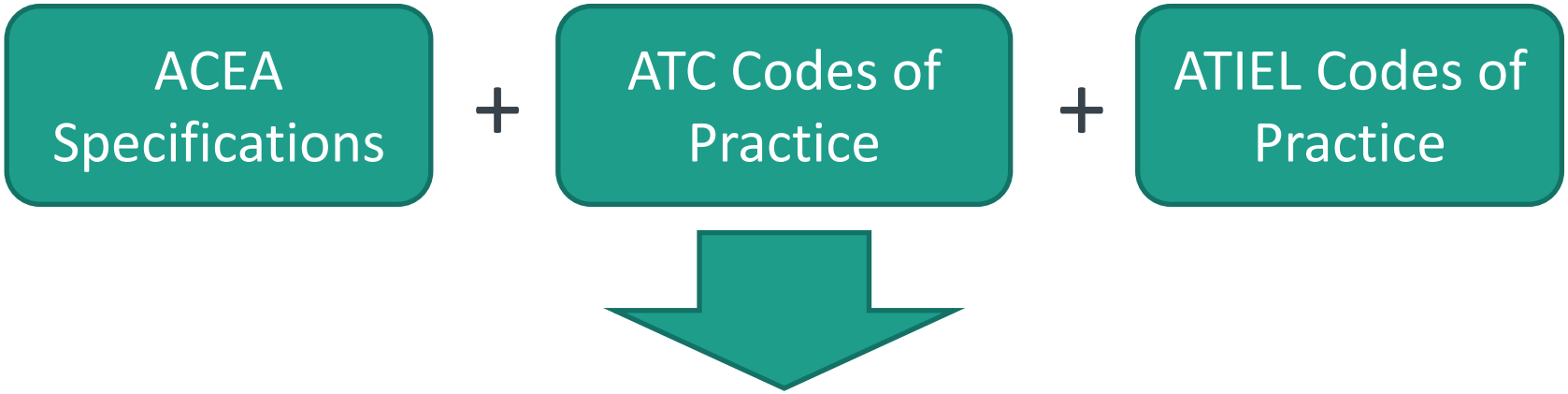
Overview



How this works in Europe



- **Joint** ACEA, ATIEL and ATC development
- **Voluntary** unless required by 3rd parties
- **Self-certification** system, no license issued
- The only system used to support ACEA claims - allows marketers to put claims on products
- Provide detailed process/structure to support product development, product validation/claims and lubricant production

How this works in North America

API Specifications + ACC Codes of Practice + API Codes of Practice

API Engine Oil Licensing and Certification System (EOLCS)

- A voluntary licensing and certification program Issued by API
- Defines, certifies and monitors engine oil performance in North America
- Issues licensing marks
- Ensures compliance by auditing
- Oil marketer is ultimately responsible

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Comparison of API licensing marks

API Service Symbol
'donut'

Used for API claims

API Certification Mark
'starburst'

As used for ILSAC claims

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Summary

- OEMs continue to challenge the oil and additive industries with increased quality level requirements – this drives the introduction of new specifications
- Marketers must offer oils that meet both industry and OEM specifications
- Category life challenges return on investment for the entire industry
- The number and complexity of industry and OEM specifications increase as OEMs introduce new hardware and emission system solutions
- Diversity in specification requirements cause increased fragmentation of products in the marketplace

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