



Heavy-duty diesel engine oils specification evolution and engine tests

Overview



Formulations & Additives

Engine Tests

Drivers & Evolution of Specifications

Formulations and additives

Typical properties of HDD oils

Parameters	HDDEO	PCEO
*Additive Package, % mass	10 to 20	7 to 12
SAE Viscosity Grades	SAE 15W-40 , 10W-30, 10W-40, 5W-40, 5W-30, (5W-20, 0W-20 coming)	SAE 0W-16, 0W-20, 0W-30, 5W-20, 5W-30, and 10W-30 (0W-8, 0W-12 available)
HTHS Viscosity, mPa•s	2.9 to 4.2 (2.6 – 2.9 coming)	2.3 to 3.1 (1.7 – 2.3 available)
TBN, mg KOH/g	8 to 12	7 to 9
Sulfated ash, % mass	0.9 to 1.3	0.8 to 0.9
Shear Stability Index of VM	25 to 35	25 to 50
Oil Drain Intervals, miles	Up to 75,000	Up to 10,000
Standard Engine Sump Sizes	~ 8-10 Gallons	~ 1 Gallon

*Current quality levels

Function of HDD oil additive components

Component	Typical Type	Property/Function	Engine Test Stressing Property
Dispersant	Pre-EGR Engines (lower soot control need) EGR Engines (2002+) (higher soot control need)	+ Diesel Cleanliness + Soot & varnish control, soot dispersancy + Filter plugging + Valve train wear	+ 1K, 1N, 1P, 1R, C13 + VH, IIH, VIII, T-8, T-11, ISB Viscosity + ISM + RFWT, ISM, ISB
Meta Deterge			
Antioxid			
Anti-wear agents	ZDDP, metal based	+ Valve train and cyl./ ring wear control	+ VH, RFWT, T-12, ISM, ISB, DD13
Viscosity Modifier	OCP, Styrene Isoprene	+ High temp. viscosity + Dispersancy	+ T-12 + T-8, T-11, ISM, ISB, ISB Viscosity

What do Formulators consider the most important component in their tool-box?

- All components are critical as formulating is a very careful balance to optimize performance in HDD engines across all engine tests. More is not always better!!

Heavy-duty engine oil tests

- **Goal is to stress our formulations!**
- **Accelerate formation of conditions we are trying to protect against.**
 - Deposit Formation
 - Aeration
 - Soot-induced Wear
 - Sludge build-up
 - Oxidation
 - Scuffing
 - Soot-induced viscosity growth



Caterpillar C13 piston deposit & OC test



- **Evaluates Piston Deposits & Oil Consumption**
- 13L, electronically controlled, turbocharged, after-cooled, 6-cylinder engine designed for on-highway use
- Heavy-duty operating conditions selected to accelerate deposit formation
 - 500-hour steady-state test procedure
 - OC compared from 100-150hrs to 450-500hrs
 - Ratings: Top Groove Carbon, Top Land Carbon, Second Ring Top Carbon



Caterpillar C13 oil aeration test (COAT)

- **Evaluates and engine oil's resistance to aeration**

- Aeration is measured in real time via a micromotion meter which measures oil density

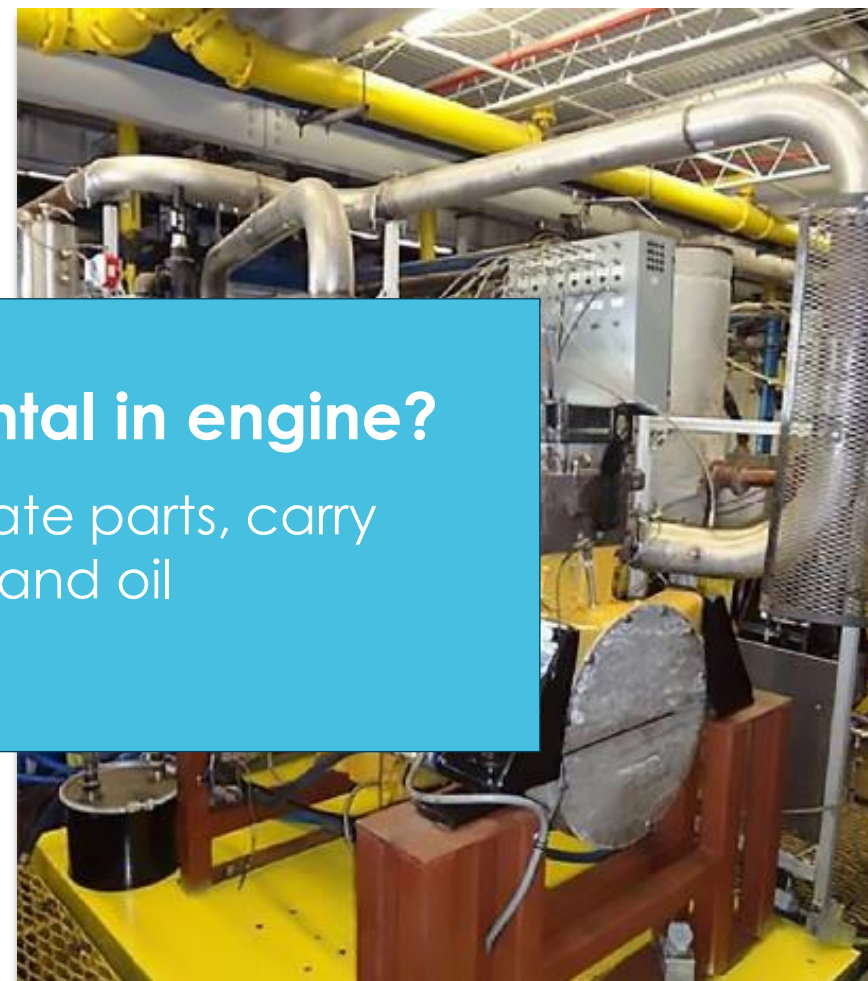
- 13L engine (same engine as C13 test)

- Test Parameters

- 50-hour
- High Speed
- Ratings limit: 11.8% max)

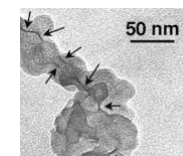
Why is high levels of aeration detrimental in engine?

- Air bubbles hinders the oil's ability to lubricate parts, carry heat away from parts, increases oxidation and oil breakdown, and lowers oil pressure.

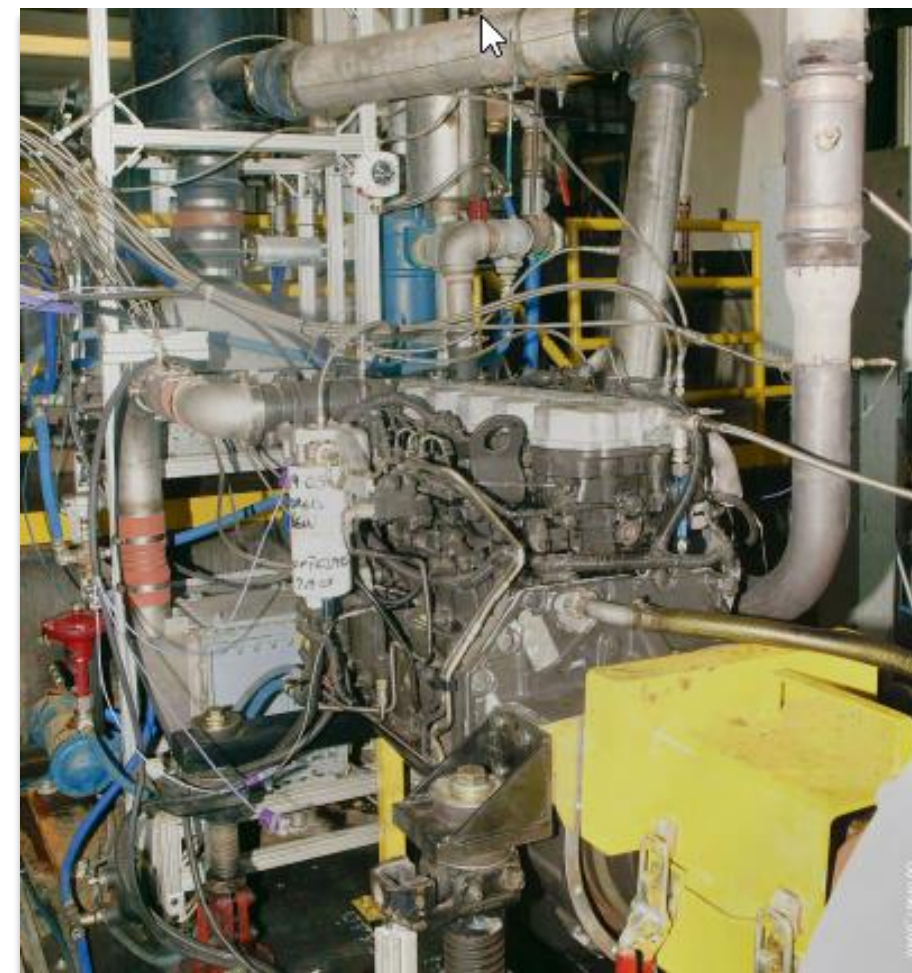


Cummins ISB valve-train wear test

- **Evaluates Soot induced Valve-Train Wear**
- Medium-Duty Engine
 - 5.9L 6-cylinder with Exhaust Gas Recirculation
- Test Parameters: 2-Stage Test
 - 100 hr **soot building** steady-state operation
 - 250 hr **“Wear” stage** with transient cycle operation (10s @ full-throttle, 800 nm, drop to idle in 1s... x 32,000 cycles!) – intense!
 - Ratings: Average Tappet Mass Loss, Average Camshaft Lobe Wear, Average Crosshead Mass Loss



Soot Particles



Cummins ISM test

- **Evaluates soot-induced Valve-Train Wear; Filter Plugging; & Sludge build-up** (wear and cleanliness)
- Heavy-Duty 11L 6-Cylinder Turbocharged diesel engine
- Test Parameters: 4-Stage 200 hr Test
 - Stage A & C: Soot Building – 50hrs Each
 - Stage B & D: High Torque Wear Stage- 50hrs Each
 - Results: Crosshead Mass Loss, Injector Adjusting Screw Mass Loss, Sludge Ratings, Oil Filter Plugging



Volvo T-13 oxidation test

- **Evaluates Oxidation performance**
- Heavy-Duty 13L 6-Cylinder MP8 Turbocharged Diesel Engine with EGR
- Test Parameters: 360 hr Steady-State
 - High Oil Temperature (130°C / 266°F)
 - High Torque
 - Results: IR Oxidation (Area and Peak), Viscosity Increase at 40C
- Oxidation performance is critical!
 - Leads to thickening of oil, deposits, acid formation, eventually loss of oil performance.



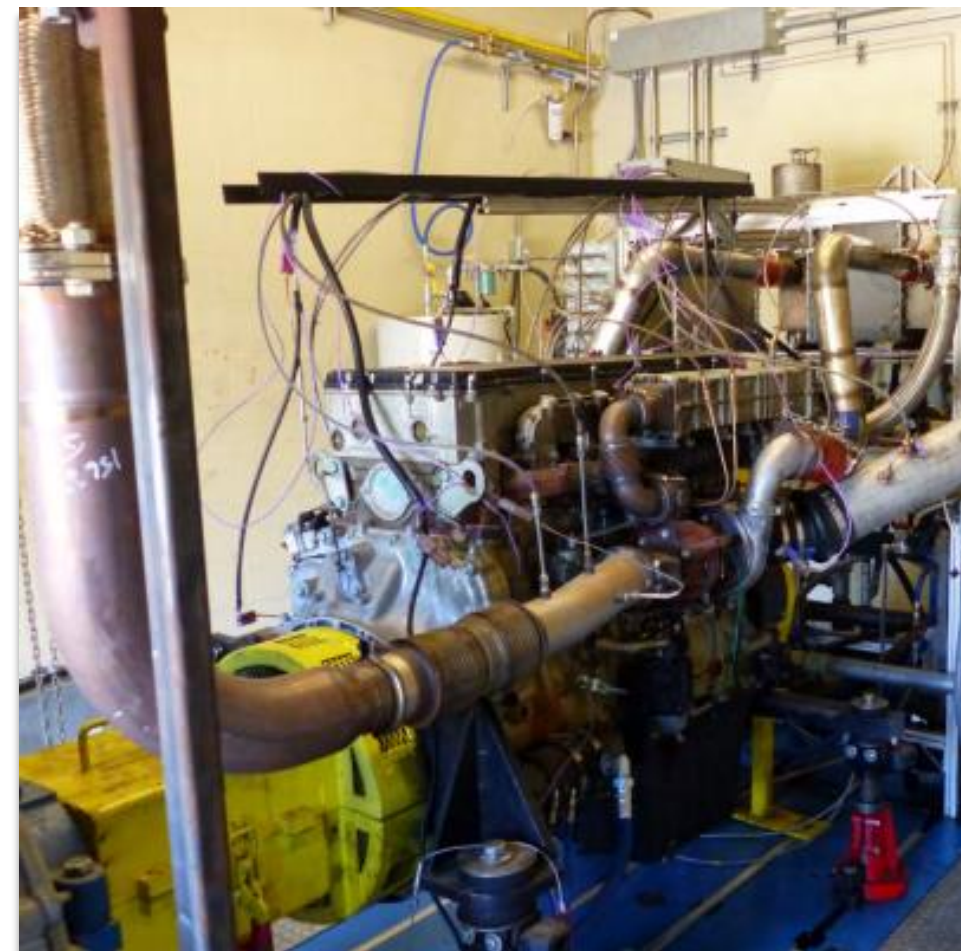
Tightened Limits for PC-12



Detroit DD13 scuffing test

Existing Test added to PC-12

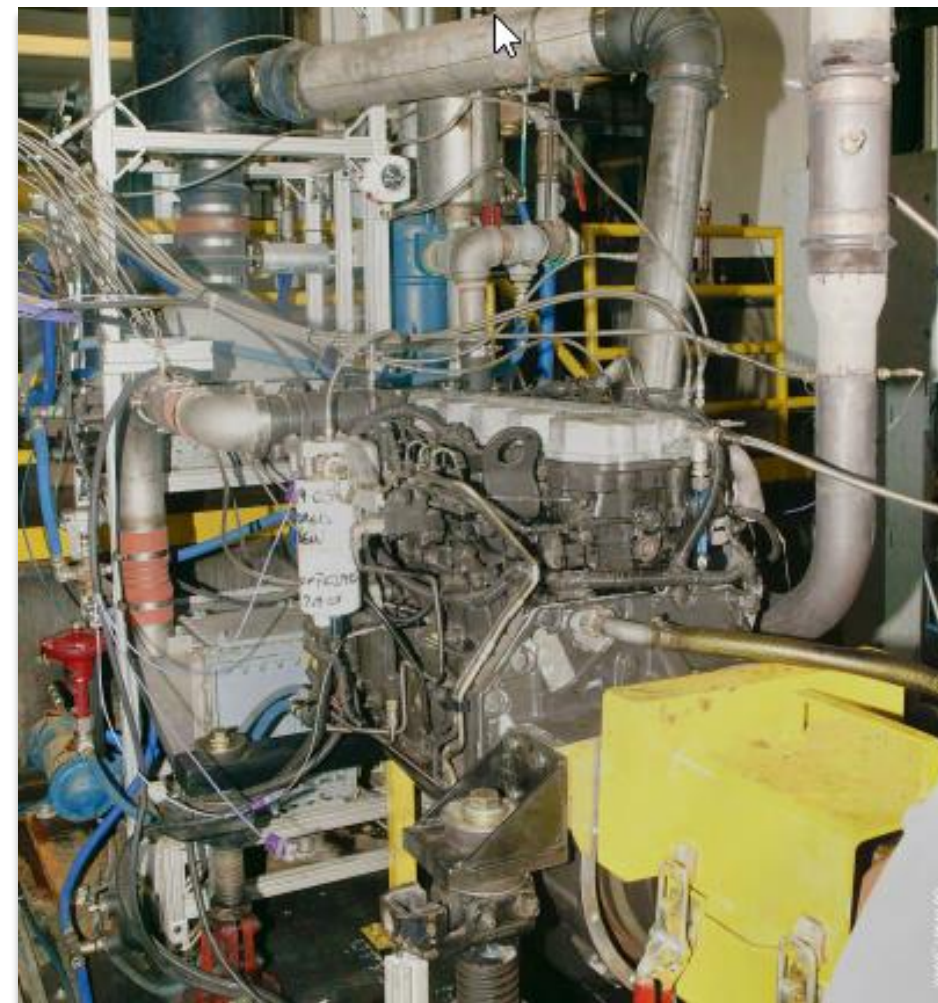
- **Evaluates Piston/Liner Scuffing Wear (Adhesive)**
- Heavy-Duty 12.8L 6-Cylinder Turbocharged Diesel Engine with EGR
 - Uncoated Top Rings to simulate high mileage engine
- Test Parameters: 2-Stage Test
 - Stage 1: Lower Torque Steady-State (30hrs)
 - Stage 2: High Torque Steady-State (170hrs)
 - Slow transition period at 30 hrs to stage 2
 - Engine “soaks” every 20hrs of runtime (Shutdown for 4 hrs)
 - Results: Hours to Scuff (Run to failure or 200 hrs)



Cummins ISB viscosity test

- **Evaluates soot-induced viscosity growth**
- Replacing the legacy Mack T-11 test for PC-12
- Test Performance
 - Soot induced viscosity increase in EGR engines
 - MRV
- Test Parameters: Steady-State
 - ISBV108 – 108-hour test procedure for “F” category performance level
 - ISBV156 – 156-hour test procedure for “C” category performance level
 - Results: Soot % at 4cSt, 12cSt, and 15cSt Viscosity Increase, MRV

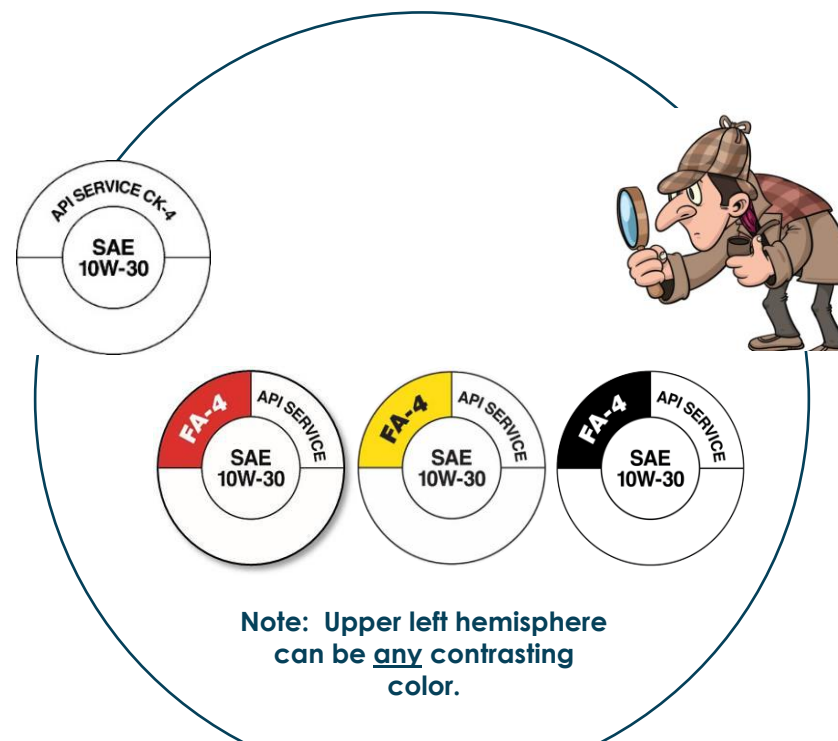
Newly Developed for PC-12



HDD oil specification drivers and evolution

Heavy-duty diesel engine oil specifications

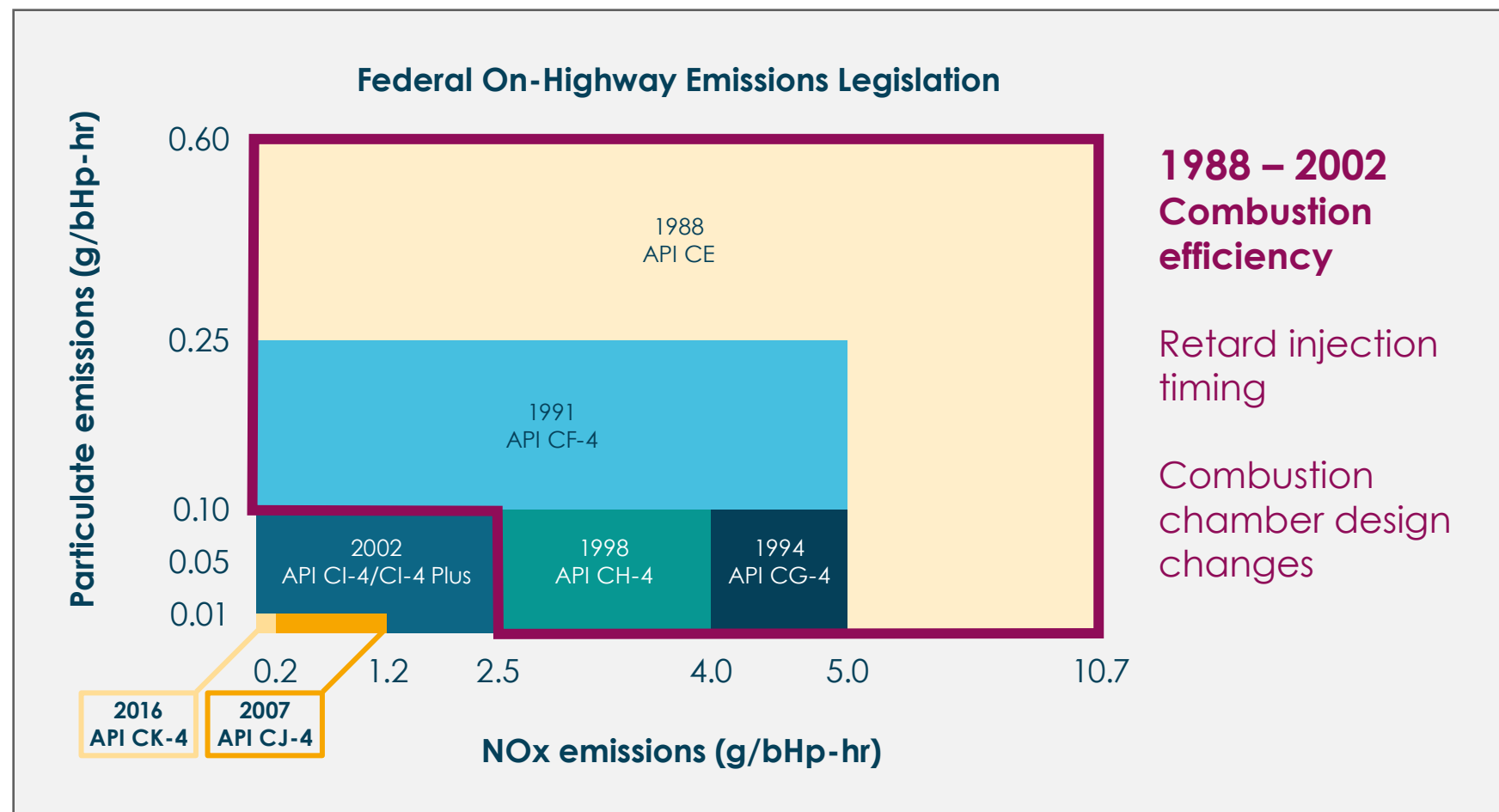
- API sets the engine oil performance categories
- Meets API 'C' (Commercial/Compression)
- Category requirements (API CH-4, CI-4, CI-4 PLUS, CJ-4 or CK-4)
- Now includes API "F" category (low viscosity / FE improving grades)
- Additive companies formulate and test their oils to meet the standards defined by API.
- OEMs often require oils to meet API categories and/or their own specs.



- "C" categories for use in on-road and off-road equipment and heavy-duty truck applications.
- "F" categories typically used on on-road applications only.

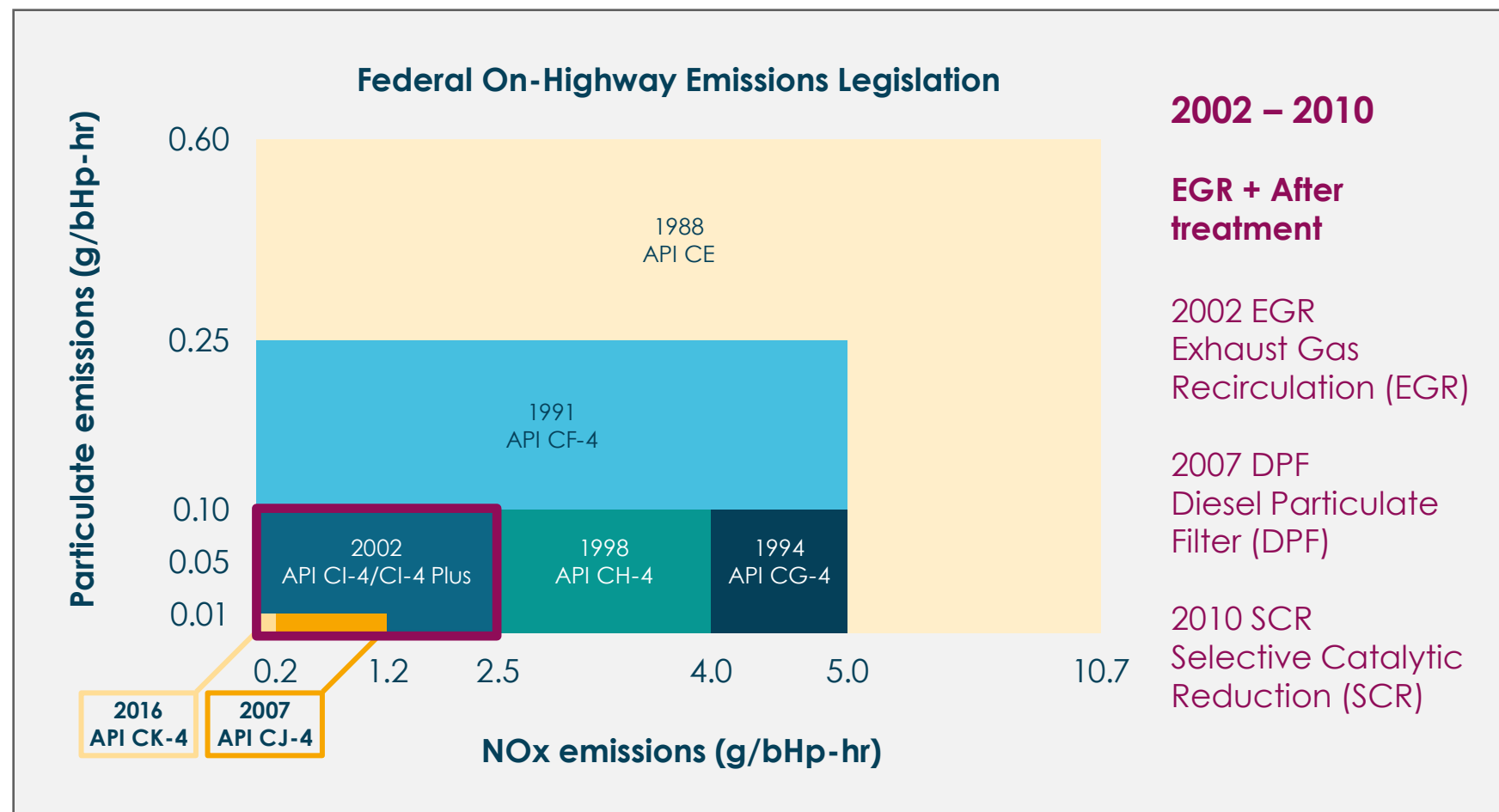
Changes in diesel engine hardware

- **Ever tightening emissions regulations** drives evolution of engine hardware
- **Have achieved near zero exhaust emissions** for Class 8 On-Highway vehicles



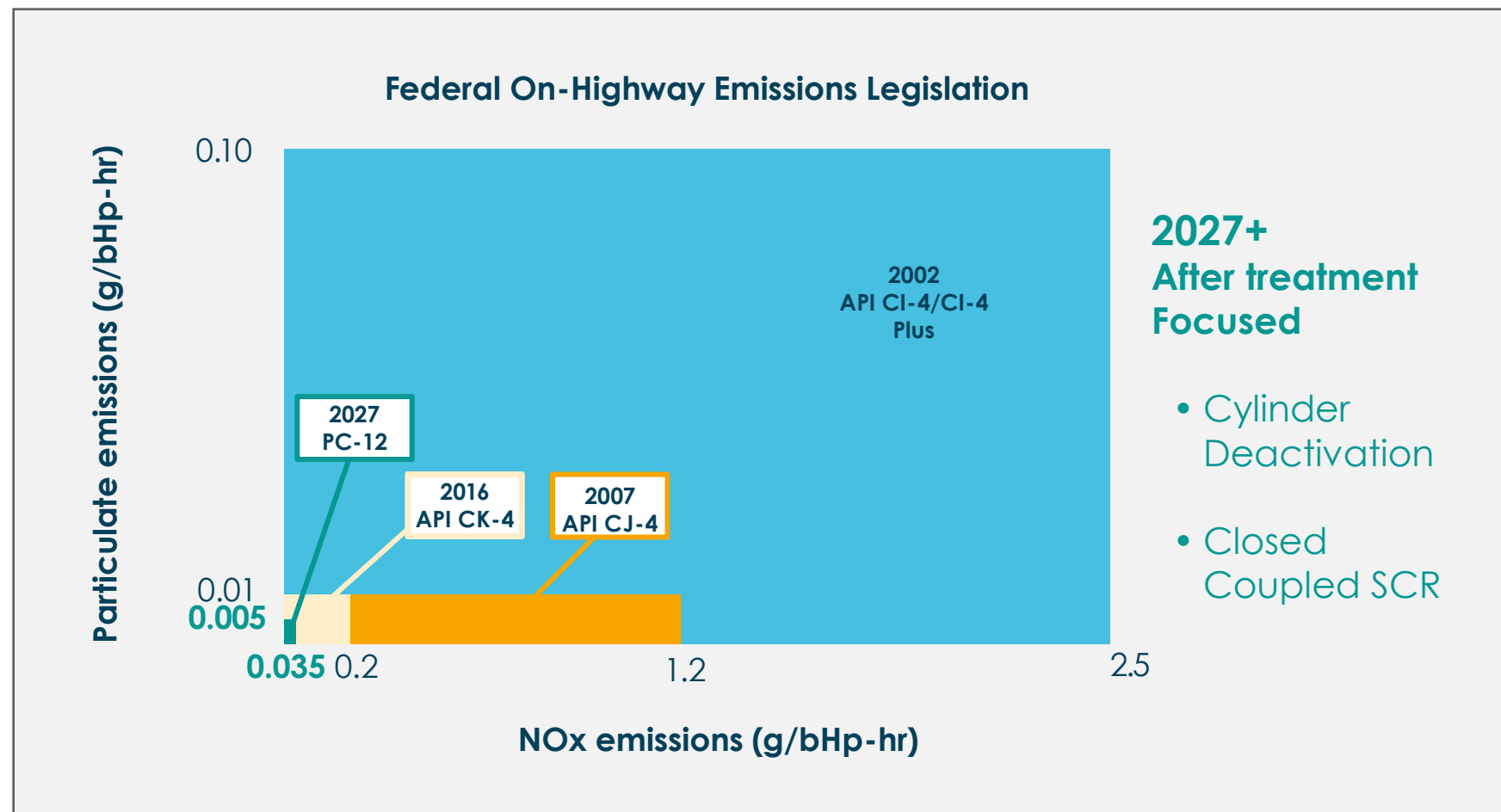
Changes in diesel engine / after-treatment hardware

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Changes in diesel engine / after treatment hardware

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Off-highway legislation trails on-highway by a few years

Horsepower	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020 +
< 11					(7.8) [0.75]					(5.6) [0.60]								(5.6) [0.3]							
11 ≤ X < 25					(7.1) [0.60]					(5.6) [0.60]								(5.6) [0.3]							
25 ≤ X < 50					(7.1) [0.60]					(5.6) [0.45]							(5.6) [0.22]				(3.5) [0.022]				
50 ≤ X < 75					6.9 / -- [--]					(5.6) [0.3]							(3.5) [0.3]				(3.5) [0.022]				
75 ≤ X < 101					6.9 / -- [--]					(5.6) [0.3]							(3.5) [0.3]	(3.5) [0.015]			0.30 / 0.14 [0.015]				
101 ≤ X < 174					6.9 / -- [--]					(4.9) [0.22]							(3.0) [0.22]	(3.0) [0.015]			0.30 / 0.14 [0.015]				
174 ≤ X < 302					6.9 / 0.97* [0.40]					(4.9) [0.15]							(3.0) [0.15]	(3.0) [0.015]			0.30 / 0.14 [0.015]				
302 ≤ X < 603					6.9 / 0.97* [0.40]					(4.8) [0.15]							(3.0) [0.15]	(3.0) [0.015]			0.30 / 0.14 [0.015]				
603 ≤ X < 751					6.9 / 0.97* [0.40]					(4.8) [0.15]							(3.0) [0.15]	(3.0) [0.015]			0.30 / 0.14 [0.015]				
751 ≤ X < 1207 {Generator Sets}					6.9 / 0.97* [0.40]					(4.8) [0.15]							2.6 / 0.3 [0.075]				2.6 / 0.14 [0.03]			{0.50 / 0.14 [0.022]}	
> 1207 {Generator Sets}					6.9 / 0.97* [0.40]					(4.8) [0.15]							2.6 / 0.3 [0.075]				2.6 / 0.14 [0.03]			{0.50 / 0.14 [0.022]}	

Tier 1
Tier 2
Tier 3
Tier 4 Interim
Tier 4 Final

Tier 5 is coming. Off-Road typically trails on-road by 4-5 years

On-Road Emissions Standards

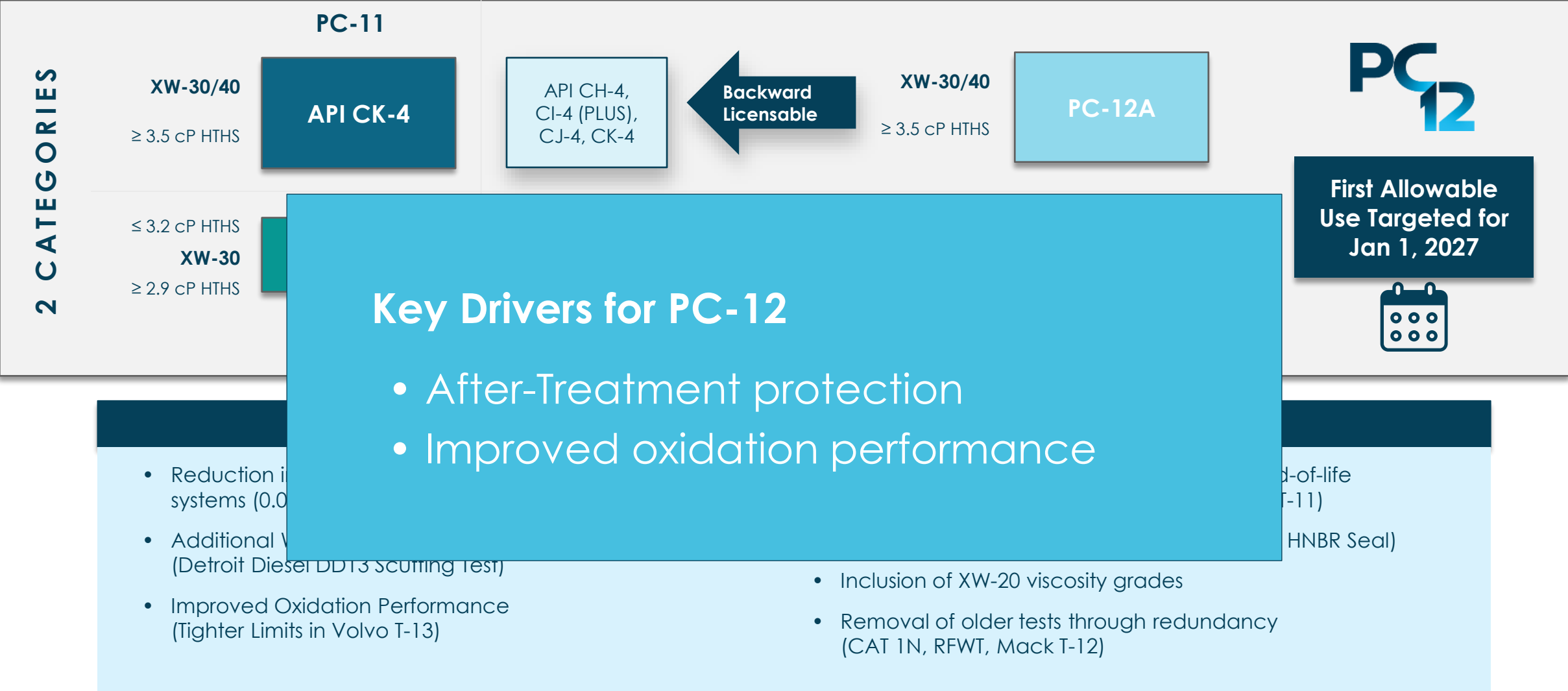
Emission	Current	2027
NO _x	0.20 g/HP-hr	0.035 g/HP-hr
PM	0.01 g/HP-hr	0.005 g/HP-hr

NO_x / NMHC [PM], g/HP-hr
 NO_x / HC* / [PM], g/HP-hr
 (NO_x + NMHC) [PM], g/HP-hr

NO_x – Nitrogen Oxides
 NMHC – Non-Methane Hydrocarbons
 HC - Hydrocarbons
 PM – Particulate Matter

Industry Latest Updates: Changes for PC-12

PC-12 – proposed category



Key Drivers for PC-12

- After-Treatment protection
- Improved oxidation performance

API PC-12: test requirements

Combination of New and Carry forward tests from **API CK-4 and FA-4**

	Test	Performance Parameters
Legacy Tests	Caterpillar C13	Piston Deposits, Oil Consumption
	Caterpillar C13 Oil Aeration Test (COAT)	Oil Aeration
	Cummins ISB	Valve Train Wear
	Cummins ISM	Valve Train Wear, Filter Plugging, Sludge
	Volvo T-13	Oxidation
New	Cummins ISB Viscosity	Soot-induced Viscosity increase, MRV
	Detroit DD13	Piston/Liner Scuffing Wear (Adhesive)

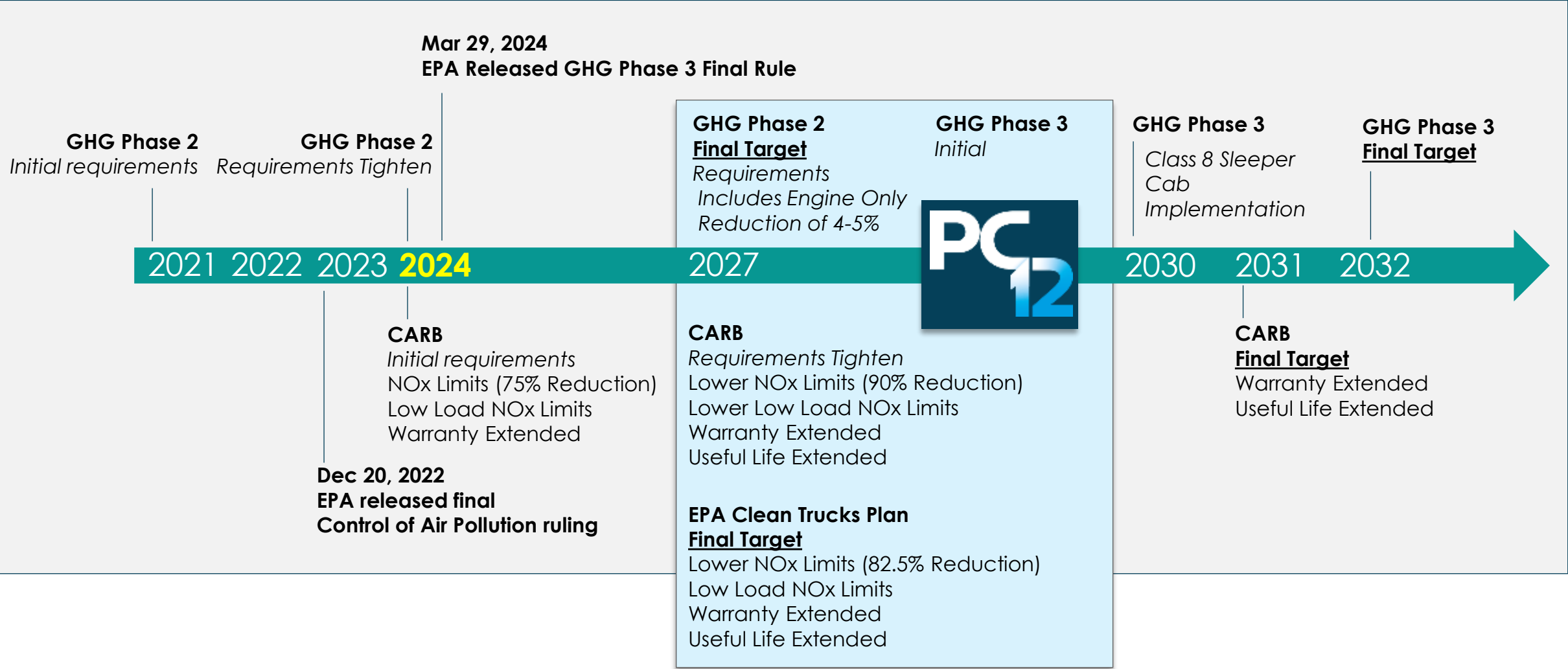
Current category OEM specifications and recommendations



OEM	API CK-4	API FA-4
Cummins	CES 20086	CES 20087
Detroit Diesel	DFS 93K222	DFS 93K223
Mack	Mack EOS-4.5	Mack EOS-5
Volvo	Volvo VDS-4.5	Volvo VDS-5
Caterpillar	API CK-4	
Navistar	API CK-4	API FA-4
PACCAR	API CK-4	
GM (Duramax 6.6L)	API CK-4	
Ford (Power Stroke 6.7L)	WSS M2C171-F1	
Ford (Power Stroke 3.0L)		WSS M2C214-B1

Industry Latest Updates: Changes for PC-12

Future us emissions timeline



Summary

1

HDD lubricants meet API 'C' or 'F' category requirements and are formulated to be extra robust for diesel engines that operate under "severe" conditions

2

Have higher levels of detergency, dispersancy, and anti-wear components and have been formulated to higher SAE viscosity grades than typical passenger car oils

3

Continued tightening of emission limits (NOx, Particulates, GHG) have a significant impact on diesel engine design and operation, fuels and lubricant formulation

- Drives evolution of heavy-duty diesel engine oil specifications
- Focus has been on improving soot handling and oxidation performance
- Addition of EGR significantly impacted HDD formulation
- Chemical limits with introduction of API CJ-4 limited use of some key components
- API CK-4 and FA-4 HDD oils were developed with significantly more oxidation performance, improved aeration and shear stability as well as a new subcategory of lower viscosity oils to meet fuel consumption and GHG Phase I regulations

Thank you



Formulating tomorrow together

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