

BACKGROUND

Introduction

The drivers for change in engine oil quality are the EPA regulations dealing with Diesel Engine exhaust gas emissions. The next change in emission limits will require the use of exhaust aftertreatment devices on virtually all on-highway diesel engines. In addition, a significant number of OEMs have indicated that they will be using even higher levels of EGR to meet the 2007 NO_x limits than they are currently using. The use of exhaust aftertreatment devices will require limits on the SAPS of finished lubricants, while higher levels of EGR will simultaneously increase the stress on the lubricant. In addition, Caterpillar is proposing the use of a new C-13 engine test equipped with the proprietary ACERT (R-TM) emission control system to represent its current field configurations.

The new PC-10 category will vary significantly from the current CI-4 oil quality due to a number of factors:

- ❑ The use of exhaust aftertreatment devices will impose limits on the SAPS content of finished lubricants. Perhaps the most significant difference from CI-4 will be a reduction in TBN to meet the limit on sulfated ash (SASH). SASH is perhaps the best documented chemical limit as it represents that portion of PM emissions that will not regenerate in service. It will build up and eventually plug the PM trap and require manual cleaning to restore trap functionality.
- ❑ Early experience with EGR-equipped engines in field service revealed that the soot generated is significantly more difficult to disperse than that of non-EGR engines. The Mack T-11 test and the API CI-4 Plus supplement were developed specifically to address this issue. The T-11 is planned to replace the T-8E as the soot/viscosity test for PC-10.
- ❑ There are currently no tests for valve train wear with sooted oil in a sliding flat tappet valve train design. Cummins has supplied over 1 million "B" series engines in Dodge pick-up trucks using this design. Although there have not been any particular issues with these engines, they have not yet been subjected to service with lower SAPS lubricants. Cummins and the EMA want to ensure that any changes to reduce lubricant SAPS from the current CI-4 levels do not result in valve train wear problems.

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- ❑ Increased levels of EGR will result in greater recirculation of potentially harmful acidic by-products of combustion into the combustion chamber. Although the acidity of these gases should be reduced by the use of ULSD fuel, a test is required to ensure adequate protection of the engine power assembly.
- ❑ The Caterpillar ACERT (R-TM) emission control system is significantly different from the cooled EGR approach used by most other engine manufacturers. It has shown sensitivity to piston deposits that contribute to the loss of oil consumption control.

The following section provides additional background on this new category, as well as the many drivers initiating this change.

BACKGROUND

History of U.S. Air Quality Regulations

- 1970** First Federal Clean Air Act approved.
- 1974** Gasoline engines must meet emissions standards for CO, HC, and NO_x. Smoke opacity standards established.
- 1979** Emissions for HC and CO lowered for gasoline engines.
- 1983** EPA classifies diesel particulates as a known carcinogen.
- 1985** Southern California limits diesel fuel sulfur to 0.05% (80% lower than #2 diesel). Air quality regulations for diesel engines are established.
- 1988** EPA issues the first diesel particulate emissions standard at 0.6 g/bhp-hr. NO_x standards are lowered.
- 1990** Clean Air Act Amendments signed into law. Goals include reduction in dependence on foreign oil and removal of 56 billion lbs. of air pollution per year.
- 1991** Clean Air Act rules are established. Program calls for cutting particulate emissions 90% from pre-regulated 1987 levels.
- 1993** All highway diesel must meet 0.05 wt.% sulfur maximum by October 1993. Cetane index must be at least 40 (or aromatics must be less than 35%).
- 1994** Diesel particulate emissions are limited to 0.1 g/bhp-hr.
- 1998** Heavy duty diesel truck NO_x standard drops to 4 g/bhp-hr from 5 g/bhp-hr.
- 1998** Diesel engine manufacturers individually sign consent decrees with the U.S. EPA that, among other things, result in bringing forward a 50% NO_x reduction (4g/bhp-hr. to 2 g/bhp-hr.) from 2004 to October 2002.

BACKGROUND

History of U.S. Air Quality Regulations

- 2000** U.S. EPA signed emission standards for model year 2007 and later on-highway HD diesel engines. The rule includes two components: (1) emissions standards and (2) diesel fuel sulfur regulation.
- 2002** Diesel engine manufacturers implement 50% NO_x reduction starting in October. Most OEMs use cooled EGR as their primary NO_x reduction technology, but Caterpillar chooses its own proprietary emission control system known as ACERT (R-TM). Caterpillar cannot meet full compliance timing on October 1, 2002 and chooses to pay fines until its engines reach full compliance.
- 2006** U.S. EPA requires diesel fuel suppliers to make 15 ppm maximum sulfur diesel (ULSD) available for on-highway applications starting in June. However, ULSD availability is a phased-in requirement for 80% ULSD minimum and 20% 500 ppm sulfur fuel maximum for the years 2007-2009. Current EPA surveys indicate that actual ULSD availability will be on the order of 95%.
- 2007** Both NO_x and Diesel Particulate Emissions (PM) are reduced by an order of magnitude from 2002/2004 levels. Like the ULSD availability, the reduction in NO_x is phased-in between 2007-2009, with a requirement for a production average reduction of 50%. Rather than targeting half of production at 2 g/bhp-hr and half of production at 0.2 g/bhp-hr, most OEMs are targeting their overall production average to meet 1.1 g/bhp-hr. The full PM reduction from 0.1 g/bhp-hr to 0.01 g/bhp-hr takes effect in 2007. Meeting this level of PM reduction will require the use of diesel particulate traps on all engines.
- 2010** All on-highway diesel fuel must meet ULSD limit of 15 ppm maximum sulfur. All on-highway diesel engines must meet limits of 0.01 g/bhp-hr maximum PM emissions and 0.2 g/bhp-hr maximum NO_x emissions.

BACKGROUND

U.S. EPA Engine Emissions Standards

Environmental compliance dates for emissions create needs for engine builders to redesign engines. Increased stress placed on lubricants from redesigns generates a natural trigger point for the introduction of new API heavy duty diesel lubricant categories.

The chart that follows outlines the U.S. EPA Engine Emissions Standards through the 2010 model year.

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U.S. EPA Engine Emissions Standards:

A Main driver for Oil Quality Changes

Heavy Duty Diesel Truck Engines (Emissions in g/bhp-hr)				
Year	HC	CO	NO_x	PM
1990	1.3	15.5	6.0	0.6
1991	1.3	15.5	5.0	0.25
1994	1.3	15.5	5.0	0.10
1998	1.3	15.5	4.0	0.10
2002	1.3	15.5	2.0	0.10

EPA Emission Standards for MY 2004 And Later HD Diesel Engines (Emissions in g/bhp-hr)		
Option	NMHC + NO_x*	NMHC*
1	2.4	N/A
2	2.5	0.5

* Limits effective October 1, 2002 for those manufacturers signing the October 1998 consent decree. Note: NMHC = Non-Methane Hydrocarbons. PM limit remains at 1998 level.

EPA Emission Standards for MY 2007 And Later HD Diesel Engines (Emissions in g/bhp-hr)		
PM*	NO_x*	NMHC*
0.01	0.20	0.14

* PM maximum limit takes full effect in 2007 model year engines. NO_x and NMHC limits are phased-in between 2007 and 2010, with a requirement for 50% compliance on a sales-weighted basis for MY 2007-2009 and 100% compliance for MY 2010.

Urban Bus Engines (Emissions in g/bhp-hr)				
Year	HC	CO	NO_x	PM
1991	1.3	15.5	5.0	0.25
1993	1.3	15.5	5.0	0.10
1994	1.3	15.5	5.0	0.07
1996	1.3	15.5	5.0	0.05*
1998	1.3	15.5	4.0	0.05*

* In-use standard is 0.07

BACKGROUND

U.S. EPA Engine Emissions Standards:

A Main driver for Oil Quality Changes

Federal Smoke Opacity Standards			
Year	Acceleration	Lugging	Peak
All	20 Percent	15 Percent	50 Percent

EPA Off-Road Standards					
Output (HP)	HC	CO	NOX	PM	Date
>175 to <750	1.0	8.5	6.9	0.4	1996
>100 to <175	--	--	6.9	--	1997
>50 to <100	--	--	6.9	--	1998
>750	1.0	8.5	6.9	0.40	2000

Note: *The emission limits shown here are condensed and summarized for easier presentation. A significantly more detailed description of HD Diesel emission limits can be found at:*

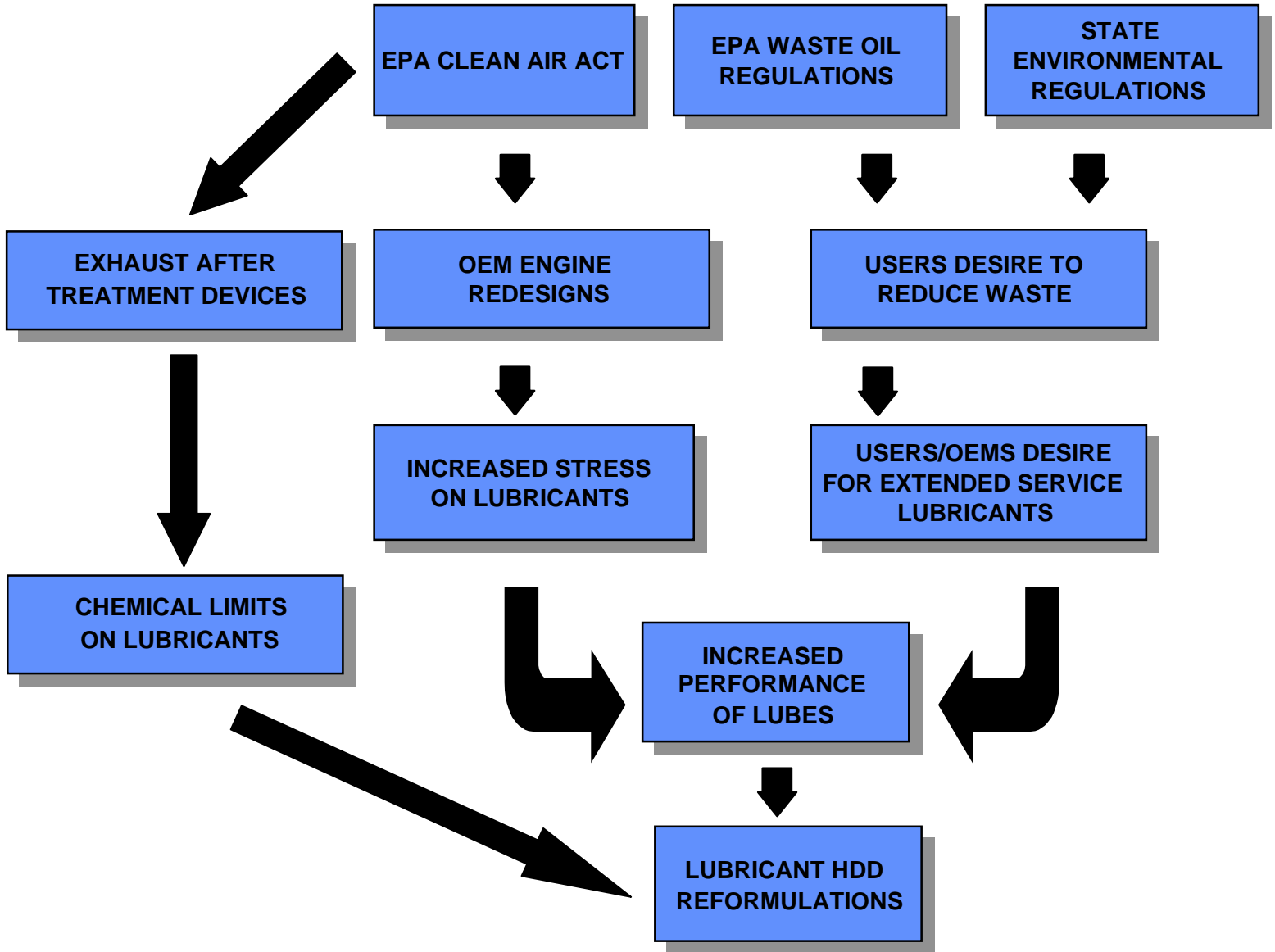
<http://www.dieselnet.com/standards/us/hd.html>

EPA REGULATIONS – ULSD DIESEL TIMETABLE FOR 2006

Introduction to pipeline at <15 ppm	June 1
Typical levels fall to <30 ppm	3Q
ULSD appears at terminals	September 1
ULSD mandatory at pump	October 15

BACKGROUND

Reformulations in HDD Lubricants



BACKGROUND

The Next Heavy Duty Diesel ASTM Lubricant Specification

The current performance category for emission-controlled, four-stroke cycle heavy duty diesel engines is API CI-4, which was available for licensing in September 2002. While the tests for this category were under development by the ASTM Heavy Duty Engine Oil Classification Panel, it was known as PC-9, or proposed "C" category, 9th change. These oils were intended for use in on-highway heavy duty trucks using advanced emission-control systems such as exhaust gas recirculation (EGR) or the proprietary Caterpillar ACERT (R-TM) system.

The Engine Manufacturers Association (EMA) has advised the DEOAP that a new performance category will be required by the third quarter of 2006 to match the availability of ULSD arriving in June 2006. The desire is to have licensing and market availability of these new oils in the third quarter, even though the new emission limits do not take effect until January 2007. This timing is driven by the OEMs desire to begin introducing their new engines as soon as the ULSD fuel is readily available. In order to meet this timing and still allow time for a major reformulation of all HD oils, the ASTM new test development work **was targeted to complete by the third quarter of 2005. Although that timing was missed, all of the proposed new tests had completed their precision and/or BOI Matrix testing by the start of the fourth quarter. Following several months of intense work by all of the new test development Task Forces and the HDEOCP, all of the tests and limits to define this new category (currently being referred to within ASTM as PC-10) were finalized in January 2006.**

The primary focus of PC-10 is to develop a category to define oils for use in heavy duty diesel engines that are equipped with exhaust aftertreatment devices to control emissions to 2007 limits. Ideally, all parties involved in PC-10 development would prefer to have a performance test to measure the impact of lubricant formulations on exhaust aftertreatment devices. However, the short time available, the costs involved in test development and the demonstrated difficulty in developing such tests have led to the use of chemical limits on PC-10 formulations in lieu of an available test.

Based on the final category requirements and the read-across rules developed for the new engine tests, the DEOAP has agreed to recommend October 15, 2006 as the first license date for a new API Category to be called CJ-4, which is based on the PC-10 tests and limits.

BACKGROUND

Timetable for PC-10 Project Development

Recognizing that PC-10 will be the first new HD category that requires oil formulators to remove components to meet chemical limits, a special six month “new test understanding period” was added to the PC-10 development schedule. **Following the completion of Matrix testing and the development of test limits and read-across guidelines, this six month period was formally shortened to four months to help meet the desired licensing date of October 15. In addition, the desired one year reformulation period was shortened to nine months.**

CATEGORY DEFINITION

Introduction

The development of a **new** ASTM **performance** category is an evolving process that is balanced by the needs of OEMs, the ASTM and users. The work of all parties culminates in a specification that is licensable by the American Petroleum Institute, which represents the next standard in lubricant performance.

CATEGORY DEFINITION

EMA PC-10 Performance Requirements

Characteristic	Test	Notes
Piston Deposits and Oil Consumption, Fe	Caterpillar C-13*	Multi-Cylinder Diesel with Full ACERT System
Piston Deposits and Oil Consumption, Al	Caterpillar 1N	CG-4 Limits
Ring and Liner Wear, Bearing Wear, Oxidation	Mack T-12*	T-10/T-11 Hardware with Heavy EGR
Soot Valve Train Wear (Abrasive/Rolling)	RFWT	CH-4 Limits
Soot, Filter Plugging, Valvetrain Wear and Sludge	Cummins ISM*	Replaces M11-EGR with Current Hardware
Soot Valve Train Wear (Sliding)	Cummins ISB*	Cyclic Test with Flat Tappet Cam Follower
Thermal Stability	Sequence IIIF or IIIG	Oxidation Only
Oil Aeration	EOAT	CH-4 Limits
Elastomer Compatibility	Bench Test	CI-4 Seals Plus Vamac
Soot/Viscosity	Mack T-11	CI-4 Plus Test
Used Oil Low Temp Viscometrics	J300 Bench Tests	T-11 Used Oil
Shear Stability	90 Pass Kurt Orbhan	CI-4 Plus Test
Volatility	NOACK	13% (Except SAE 10W-30)
Hi Temp Corrosion Bench Test	Current HTCBT	CH-4 Limits
Chemical Limits	D874/D4951/D2622	SASH, P, and S
Foaming	D892	CH-4 Limits

* **New test *that required* precision and/or BOI/VGRA testing.**

CATEGORY DEFINITION

PC-10 Category: Status of Tests

Primary Test	Status
Caterpillar C-13	New Test, Precision and BOI Matrix testing completed and merit system to define pass/fail limits adopted.
Caterpillar 1N	Established Industry Test
Mack T-12	New Test, Precision only Matrix completed with BOI and VGRA from T-10 accepted. Merit system to define pass/fail limits adopted.
Roller Follower Wear Test	Established Industry Test
Cummins ISM	Replacement for M11-EGR, Limited "mini-Matrix" run to develop correlation to M11-EGR. Merit system to define pass/fail limits adopted.
Cummins ISB	New Test, Precision only Matrix completed with BOI and VGRA from M11-EGR accepted. Tiered pass/fail limits adopted.
Sequence IIIF or IIIG	Established Industry Tests
EOAT	Established Industry Test
CI-4 Seals	Procedure Set, Vamac Material added.
Mack T-11	Established Industry Test
90 Pass K.O.	Established Industry Test
Noack	Established Industry Test
HTCBT	Established Industry Test
D874 / D4951 / D2622 / D892	Established Industry Tests

CATEGORY DEFINITION

Status / Timing of Category Development

Development activities in support of PC-10 have been progressing for **about four** years. Following an EMA request to the Diesel Engine Oil Advisory Panel (DEOAP), a New Category Evaluation Team (NCET) was formed in March 2002, and the first NCET meeting was held the following July. The NCET concluded its work with the recommendations that a PC-10 category was both feasible and needed to protect the engines and emission control systems capable of meeting the 2007 exhaust emission limits.

Following these conclusions, the NCET was reformed into a New Category Development Team (NCDT) to manage the PC-10 development process. However, in June 2003, the EMA approached the DEOAP with a request to upgrade the quality of API CI-4 lubricants to provide more robust protection of engines in the field meeting the October 2002 emission limits. This request caused a significant dilution of the PC-10 development activities, but it did eventually result in a new supplemental category, identified as API CI-4 **PLUS**, which became licensable on September 1, 2004.

Once the CI-4 **PLUS** supplement was settled, industry resumed its concentration on PC-10 development. The EMA has confirmed **the need for** three brand new tests: Caterpillar C-13, Cummins ISB, and Mack T-12; along with one of the CI-4 **PLUS** tests, the Mack T-11, and a replacement for the Cummins M11-EGR, the ISM. These tests **required** varying levels of development to meet the timing for PC-10 inclusion. In addition to these new diesel tests, the EMA has also requested use of the Sequence IIIG test to measure oxidation in PC-10. **Following an analysis of the Mack T-12 oxidation requirements, the HDEOCP voted to keep the IIIF as the category oxidation test. However, a passing IIIG oxidation result may be substituted for those customers wishing to license an API SM performance claim. The addition of SM will have dramatic impacts on both formulation cost and base stock usage. The Sequence IIIG, at GF-4 pass/fail performance, shows a strong preference for more highly saturated base stocks, as well as a need for significantly more antioxidant in the oil formulation versus the needs of HD diesel engines. Infineum fully supports the use of the Sequence IIIF as the HD oxidation test and provided engine test data to support this decision.**

CATEGORY DEFINITION

Status / Timing of Category Development

The Mack T-11 **had** already been developed for use in both Mack EO-N Premium Plus 03 and API CI-4 **PLUS**. **It was recently accepted into the ACC Code of Practice, and somewhat more restrictive pass/fail limits have been endorsed for PC-10.** The T-11 uses PC-9 test fuel with 500 ppm maximum sulfur.

The Cummins ISM, also uses PC-9 fuel. This test is a replacement for the M11-EGR test that has run out of hardware. The ISM is the current production configuration of the Cummins 11 liter diesel engine. It has a significantly more robust valve train design than the M11, and testing in a mini-matrix has shown much less separation between very good and very bad M11 oils on valve train wear protection. However, although the differences were smaller, they were still statistically significant. **Correlation limits to replace the M11-EGR in API CI-4 have been established, and more restrictive limits have been endorsed for PC-10.**

The Cummins ISB, a new valve train wear test, uses a version of the 5.9 liter diesel engine that Cummins supplies to the Dodge Ram pick-up truck. Since this test uses flat tappet cam followers rather than roller followers, Cummins believes that it is protecting against a different kind of wear than either the RFWT or the ISM. **Limited data comparing the high and low performing reference oils from the M11-EGR test in both the ISM and ISB show that the ISB is a more restrictive test than the ISM. However, the EMA would not support the removal of any valve train wear tests, so PC-10 contains three.** The ISB uses ULSD fuel with 15 ppm maximum sulfur as defined by the PC-10 fuel specification. **Both the ISM and ISB tests have been accepted into the ACC Code of Practice.**

The Caterpillar C-13 engine is a new test using a 13 liter Caterpillar engine with a full ACERT (R-TM) emission control system. Early versions of the C-13 experienced field problems with piston deposits and oil consumption, and this test is designed to predict those field issues.

CATEGORY DEFINITION

Status / Timing of Category Development

Since the C-13 is the first Caterpillar multi-cylinder engine test ever developed for an industry category, it experienced a fair number of operational and precision issues. However, the development Task Force worked through these issues, and the test has been endorsed for PC-10. Acceptance into the ACC Code of Practice is still pending. The C-13 uses ULSD fuel with 15 ppm maximum sulfur.

The Mack T-12 uses composite hardware from the T-10 and T-11 tests with a new EGR system. The T-12 operating conditions are very similar to the T-10, but with significantly higher EGR flow in both Stage 1 and Stage 2. **Although similar to the T-10, the higher temperatures and EGR flow rates make the T-12 a more severe test, and the limits endorsed for PC-10 represent a performance upgrade from CI-4.** The T-12 uses the ULSD PC-10 fuel.

CATEGORY DEFINITION

Status / Timing of Category Development

Since the introduction of this notebook **in 2004**, industry has made significant progress on the definition of **this** new category and on development of new tests that will be included. However, this does not mean that progress has been either as smooth or as timely as originally planned.

The original timeline called for all new tests and category definition to be “frozen” at the December 2004 meeting of the HDEOCP and for PC-10 Matrix testing to start in January 2005. In fact, none of the proposed new tests met that suggested timing, and the Memorandum of Agreement (MOA) on PC-10 Matrix funding was not finalized until late April 2005.

The MOA describes the detailed test matrices for each of the new tests included and allocates funding of these tests according to an overall funding budget. This budget allows up to one-half the cost of Matrix testing to be funded by the participating laboratories, while the remaining costs – up to a maximum of \$3,000,000 – is split among the Engine Manufacturers Association, the American Petroleum Institute and the American Chemistry Council. Both the API and the ACC have each pledged up to \$1,000,000 in cash, while the EMA has pledged up to \$350,000 in cash and \$650,000 in “kind” (test parts and hardware to support Matrix testing).

Matrix testing started in early May 2005 **and completed in September. Preliminary test targets were discussed at the December 2005 ASTM meetings. The HDEOCP unanimously agreed to all of the PC-10 tests and limits on January 26, 2006.**

In the same timeframe, the DEOAP agreed to recommend a new category name of API CJ-4 to the API Lubricants Committee with a first license date of October 15, 2006. A written ballot of the Lubricants Committee closes in mid-March with an expected positive result.

PERFORMANCE TESTS

EMA PC-10 Performance Requirements

Test	Measures
Mack T-11*	Soot related viscosity control in EGR environment
Mack T-12*	Ring and liner wear, bearing corrosion and oxidation with latest production style pistons, heads and injectors
Cummins ISB*	Valve train wear with mushroom flat tappet cam followers using version of Dodge Ram pickup truck engine
Caterpillar C-13*	Piston deposits and oil consumption using a full ACERT emission-controlled C-13 engine
Cummins ISM**	Valve train wear, sludge and filter plugging using current production ISM engine as replacement for Cummins M11-EGR, which is out of production

* = New Test

** = Replacement Test

PERFORMANCE TESTS

Mack T-11

Scope

PC-10 will be the first full API category using the Mack T-11. However, the test is fully developed and has been in use for roughly two years in support of either Mack proprietary approvals or the API CI-4 PLUS supplement. **The pass/fail limits for PC-10 are significantly more restrictive than for CI-4 PLUS.**

PERFORMANCE TESTS

Mack T-11

Test Conditions

The test runs at steady state speed with variable timing and EGR to hit specified soot target windows.

Test Conditions	Limits
Parameters	Test
Time, h	252
Injection Timing, °BTDC	Variable ^(A)
Controlled Parameters ^(B)	
Speed, r/min	1800
Fuel Flow, kg/h (lb/h)	53.5 (118.0)
Intake CO ₂ Level, %	1.5+/-0.05
Inlet Manifold Temp., °C (°F)	70 (158)
Coolant Out Temp., °C (°F)	66 (150)
Fuel In Temp., °C (°F)	40 (104)
Oil Gallery Temp., °C (°F)	88 (190)
Intake Air Temp., °C (°F)	25 (77)
Ranged Parameters ^(C)	
Inlet Air Restriction, kPa (in. H ₂ O)	3.5 – 4.0 (14 – 16)
Inlet Manifold Pressure, kPa (in. Hg)	141 Minimum
Exhaust Back Pressure, kPa (in. H ₂ O)	2.7 – 3.5 (11 – 14)
Crankcase Pressure, kPa (in. H ₂ O)	0.25 – 0.75 (1 – 3)
Uncontrolled Parameters	
Power, kW (bhp)	~257 (~345)
Torque, N•m (lb•ft) ^(D)	Record ^(D)
Exhaust Temp., °C(°F)	
Pre-turbine	Record
Tailpipe	Record
Oil Sump Temp., °C(°F)	Record
Coolant In Temp., °C(°F)	Record
EGR Cooler Inlet Temp. Front, °C(°F)	Record
EGR Cooler Outlet Temp. Rear °C(°F)	Record
EGR Pre-Venturi Temp., °C(°F)	Record
Inlet Air Dew Point, °C(°F)	Record
Blowby, L/min (ft ³ /min)	Record
Pre-turbine Exhaust Pressure, kPa (in. Hg)	Record
Main Gallery Oil Pressure, kPa (psi)	Record
Fuel Pressure	Record
Oil Filter ΔP, kPa (psi)	Not to exceed 207 (30) ^(E)

(A) = For pretest and post-test oil flushes, injection timing is not specified.

(B) = All control parameters shall be targeted at the mean indicated.

(C) = All ranged parameters shall fall within the specified ranges.

(D) = At 98.2 kPa (29 in. Hg) and 29.5 °C (85°F) dry air.

(E) = If oil filter ΔP exceeds 207 kPa (30 psi), change the two full flow filters. If the filters are changed, attempt to recover as much oil as possible by draining the filters. No new oil is to be added. The test report shall indicate if the filters are changed.

PERFORMANCE TESTS

Mack T-11

Status

The T-11 has been brought into the ACC Code of Practice and allowed pre-registration of T-11 results back to February 17, 2004, which is the date the HDEOCP endorsed the test. The Mack T-11 test procedure has been issued as ASTM standard D7156.

PERFORMANCE TESTS

Mack T-12

Scope

The Mack T-12 uses the same production style pistons, heads and fuel injectors as the T-11 but runs a test cycle similar to the T-10 test with increased levels of EGR.

PERFORMANCE TESTS

Mack T-12

Test Conditions

Phase One in the Mack T-12 runs for 100 hours with 35% EGR versus 75 hours and 15% EGR in the T-10. Phase Two runs 200 hours with higher sump temperature and 15% EGR versus 225 hours and essentially zero EGR for the T-10.

Parameters	Limits	
	Phase I	Phase II
Time, h	100	200
Injection Timing, °BTDC	Variable	21
Controlled Parameters^(A)		
Speed, r/min	1800	1200
Fuel Flow, kg/h (lb/h)	59.2 (130.5)	63.5 (140.0)
Intake CO ₂ Level, %	3.09+/-0.05	1.42+/-0.05
Exhaust CO ₂ Level, %	9.25+/-0.15	9.93+/-0.15
Inlet Manifold Temp., °C (°F)	90 (175)	80 (175)
Coolant Out Temp., °C (°F)	66 (150)	108 (226)
Fuel In Temp., °C (°F)	40 (104)	40 (104)
Oil Gallery Temp., °C (°F)	88 (190)	116 (240)
Intake Air Temp., °C (°F)	25 (77)	25 (77)
Ranged Parameters^(B)		
Inlet Air Restriction, kPa (in. H ₂ O)	3.5 – 4.0 (14 – 16)	3.5 – 4.0 (14 – 16)
Inlet Manifold Pressure, kPa (in. Hg)	Tbd	Tbd
Exhaust Back Pressure, kPa (in. H ₂ O)	2.7 – 3.5 (11 – 14)	2.7 – 3.5 (11 – 14)
Crankcase Pressure, kPa (in. H ₂ O)	0.25 – 0.75 (1 – 3)	0.25 – 0.75 (1 – 3)
Uncontrolled Parameters		
Torque, N•m (lbf•ft) ^(C)	Record	Record
Exhaust Temp., °C(°F)		
Pre-turbine	Record	Record
Tailpipe	Record	Record
Oil Sump Temp., °C(°F)	Record	Record
Coolant In Temp., °C(°F)	Record	Record
EGR Pre-Venturi Temp., °C(°F)	Minimum 104 (220)	Minimum 104 (220)
Intercooler Out Temp., °C(°F)	Minimum 30 (86)	Minimum 30 (86)
Inlet Air Dew Point, °C(°F)	Record	Record
Inlet Air Humidity, g/kg (gr/lb)	Record	Record
Blowby, L/min (ft ³ /min)	Record	Record
EGR Pre-Venturi Pressure, kPa (in. Hg)	Record	Record
Pre-turbine Exhaust Pressure, kPa (in. Hg)	Record	Record
Main Gallery Oil Pressure, kPa (psi)	Record	Record
Oil Filter ΔP, kPa (psi)	Not to exceed 138 (20) ^(D)	Not to exceed 138 (20) ^(D)

(A) = All control parameters shall be targeted at the mean indicated.

(B) = All ranged parameters shall fall within the specified ranges.

(C) = At 98.2 kPa (29 in. Hg) and 29.5 °C (85°F) dry air.

(D) = If oil filter ΔP exceeds 138 kPa (20 psi), change the two full flow filters. If the filters are changed, attempt to recover as much oil as possible by draining the filters. No new oil is to be added. The test report shall indicate if the filters are changed.

PERFORMANCE TESTS

Mack T-12

Status

The Mack T-12 is significantly more severe on oxidation and bearing corrosion than the T-10 and slightly less severe on ring and liner wear. However, the pass/fail limits have been set so that a passing T-12 represents a measurable performance upgrade. Infineum data suggest that there is about a 300 Merit offset between the T-10 and T-12, i.e., a 1000 Merit passing result in the T-12 correlates to about a 1300 Merit result in the T-10. The Mack T-12 has been brought into the ACC Code of Practice and tests are fully registrable.

PERFORMANCE TESTS

Cummins ISB

Scope

The ISB test uses an industrial version of the 5.9 liter engine that Cummins supplies to the Dodge Ram pickup truck. Unlike most class 8 heavy duty engines that use roller cam followers, the ISB uses a mushroom style (base of the tappet is larger diameter than the body) flat tappet cam follower. Although this engine is very robust in on-highway service, Cummins claims to have seen cam and tappet wear issues in certain applications such as front-end loaders, and the ISB test cycle is designed to mimic this service.

Test Conditions

The test consists of a 100 hour pre-sooting phase of steady-state operation followed by a 250 hour cyclic phase to generate wear.

Test Conditions – Cummins ISB				
Test Parameter	Units	Stage A	Stage B	Limits
Time	h	100	250 ^(A)	
Engine Speed	RPM	1600	Varies	±10
Torque	Nm	Resultant	Varies	
Fuel Rate	Kg/hr	20.0	Varies	±0.3
Coolant Out Temp.	Deg. C	99	99 ^(B)	±3
Coolant Reservoir Pressure	kPa	99-107	99-107 at idle step	
Intake Manifold Pressure	kPa	Resultant	Varies	
Intake Manifold Temp., Pre-EGR	Deg. C	68	68 ^(B)	±2
Inlet Air Temp.	Deg. C	25-35	25-35 ^(B)	
Turbine Inlet Temp.	Deg. C	Resultant	Varies	
Oil Pan Temp.	Deg. C	110	110 ^(B)	±2
Oil Pressure	kPa	Resultant	Varies	
Intake Air Restriction	kPa abs	94-98	Varies	
Exhaust Back Pressure	kPa abs	107	Wide Open	±1
Fuel Temp.	Deg. C	40	40	±2
Fuel Inlet Restriction	kPa	(C)	(C)	
Fuel Return Restriction	kPa	(C)	(C)	

(A) = Stage B length is determined by test time. A minimum of 32,000 cycles shall be completed for the test to be valid.

(B) = May vary due to cyclic conditions

(C) = Maintain to avoid cavitations at high pressure fuel pump.

PERFORMANCE TESTS

Cummins ISB

Status

The Cummins ISB test is one of three different valve train wear tests included in PC-10. Although the wear mechanism for all three tests is nominally different, both Industry Reference Oil data and Infineum data show that it is the most restrictive of the three tests, and oils that pass the ISB easily pass both the ISM and the RFWT. These data were shared with the PC-10 Valve Train Wear Task Force in an attempt to remove one or more of the redundant tests from the category. However, none of the sponsoring OEMs would allow their test to be dropped, and PC-10 was finalized containing all three tests.

The pass/fail limits set for the ISB are so restrictive that they fail several of the Matrix test results in spite of the fact that all Matrix test results were rated as passes by Cummins' visual ratings from expert raters at Cummins.

The ISB has been brought into the ACC Code of Practice and tests are fully registerable.

PERFORMANCE TESTS

Caterpillar C-13

Scope

The C-13 is the first multi-cylinder test Caterpillar has ever offered for use in defining a new API performance category. It uses the proprietary Caterpillar ACERT (Advanced Combustion Emission Reduction Technology) emission control system as opposed to the cooled EGR used in other new tests.

Test Conditions

The C-13 is a 500 hour steady state test used to measure piston deposits and oil consumption in a high output, emissions compliant class 8 engine.

Parameters	Units	Limits
Test Length	h	500
Speed	r/min	1800 ±5
Power	kW	Record
Torque (Typical)	N•m ^(A)	1760
Fuel Flow	g/m	1200 ±6
Intake Manifold Temp.	°C	40 ±2
Blowby Flow	L/min	Record
Coolant Out Temp.	°C	88 ±2
Coolant In Temp.	°C	Record
Coolant Delta Temp.	°C	Record
Fuel In Temp.	°C	40 ±2
Oil Gallery Temp.	°C	98 ±2
Turbo Inlet Temp.	°C	Record
Intake Manifold Pressure	kPa g	275-285
Exhaust Temp.	°C	Record
Fuel Pressure	kPa	Record
Oil Gallery Pressure	kPa	Record
Oil Filter Delta Pressure	kPa	Record
Coolant System Pressure	kPa ^(B)	99-107
Exhaust Restriction	kPa	6 ±1
Crankcase Pressure	kPa	Record
Inlet Air Pressure	kPa abs.	92 – 98
Intercooler Delta Pressure	kPa	Tbd
Humidity	g/kg	Record

(A) = *At standard atmospheric temperature and pressure.*

(B) = *Measure coolant pressure on the top of the expansion tank.*

PERFORMANCE TESTS

Caterpillar C-13

Status

The Caterpillar C-13 marks the first time a multi-cylinder Caterpillar engine had been used to measure oil consumption and piston deposits in an API category. Despite the lack of known good and poor performing field oils, the C-13 was able to demonstrate acceptable discrimination and precision to allow its inclusion into PC-10.

The late addition of a second ring top carbon deposit rating to the pass/fail parameters caused significant concern over finalizing this test, but an acceptable compromise was worked out in the HDEOCP.

The pass/fail limits in the C-13 are more restrictive than in any of the single cylinder Caterpillar tests, and a passing C-13 covers both the 1P and 1R requirements of previous categories. However, several of the engine manufacturers still using one-piece aluminum pistons have insisted on keeping the 1N test in PC-10.

The Caterpillar C-13 test has been brought into the ACC Code of Practice and tests are fully registerable effective April 1, 2006.

PERFORMANCE TESTS

Cummins ISM

Scope

Although the ISM is truly a new engine test, it is being treated as simply a replacement for the M11-EGR engine that is no longer in production. It is not being subjected to even precision Matrix testing as part of PC-10.

Test Conditions

The test procedure is exactly the same as the M11-EGR, but the test length is shortened from six 50 hour segments and 300 total hours to four 50 hour segments and 200 total hours. End of test soot levels **drop** from around 9% to around 6%, and overall valve train wear is reduced significantly due to both lower soot and more robust hardware design.

Parameter	Units	Stage A	Stage B	Stage C	Stage D
Stage Length	H	50	50	50	50
Speed	r/min	1800 ±5	1600 ±5	1800 ±5	1600 ±5
Power	kW	Record	Record	Record	Record
Torque (Typical) ^(A)	N•m	1300 1220	1930 1830	1300 1220	1930 1830
Fuel Flow	kg/h	58 ±1	64.4 ±1	58 ±1	64.4 ±1
Intake Manifold Temp.	°C	80	65.5	80	65.5
Blowby Flow	L/min	Record	Record	Record	Record
Coolant Out Temp.	°C	65.5 ±2	65.5 ±2	65.5 ±2	65.5 ±2
Coolant In Temp.	°C	Record	Record	Record	Record
Coolant Delta Temp.	°C	Record	Record	Record	Record
Fuel In Temp.	°C	40 ±2	40 ±2	40 ±2	40 ±2
Oil Gallery Temp.	°C	115 ±2	115 ±2	115 ±2	115 ±2
Turbo Inlet Temp.	°C	Record	Record	Record	Record
Intake Manifold Press.	kPa abs.	≥300	≥320	≥300	≥300
Exhaust Temp.	°C	Record	Record	Record	Record
Fuel Pressure	kPa	Record	Record	Record	Record
Oil Gallery Pressure	kPa	Record	Record	Record	Record
Oil Filter Delta Press.	kPa	Record	Record	Record	Record
Coolant System Press. ^(B)	kPa	99-107	99-107	99-107	99-107
Exhaust Pressure	kPa abs.	107 ±1	107 ±1	107 ±1	107 ±1
Crankcase Pressure	kPa	Record	Record	Record	Record
Inlet Air Pressure	kPa abs.	Record	Record	Record	Record
Intake CO ₂	%	0.97-1.09	0.97-1.09	0.97-1.09	0.97-1.09

(A) = At standard atmospheric temperature and pressure.

(B) = Measure the coolant pressure on the top of the expansion tank.

PERFORMANCE TESTS

Cummins ISM

Status

The Cummins ISM pass/fail limits for PC-10 are significantly more restrictive than the limits set for backward compatibility for API CI-4. In addition to tightening the Crosshead Weight Loss and Filter Delta Pressure limits, an additional limit on Injector Adjusting Screw Weight Loss has been added.

The ISM test has been brought into the ACC Code of Practice and tests are fully registerable.

PERFORMANCE TESTS

Other Tests of Interest

Along with the ISM and ISB tests looking at valve train wear, the EMA has also requested that the Roller Follower Wear Test (RFWT) be carried forward from CI-4. This would make three separate tests addressing valve train wear in PC-10. This observation drew several negative ballots on inclusion of the ISM test into PC-10. The HDEOCP has established a PC-10 Valve Train Wear Task Force to look at data from all three tests to see if one or more can be declared redundant.

Infineum's position regarding valve train wear tests for PC-10 is that no more than one test is needed; based on current data, that test should be the Cummins ISB. The RFWT was introduced in the CG-4 category where it was the only valve train wear test. In CH-4 the Cummins M11-HST was added to measure valve train wear, and the pass/fail limits for the RFWT were tightened slightly. In CI-4, the M11-HST was replaced by the M11-EGR, and the RWFT was carried forward without change.

Discrimination testing was done in both **Cummins** tests using the good (TMC 830) and poor (TMC 1004) reference oils from the M11 tests. Both the ISM and the ISB ranked the oils in the same order as the M11, and the performance separation was more clearly defined in the ISB test. Given the above performance data combined with the fact that the ISB costs significantly less than the ISM, Infineum believes that the ISB should **have been** selected as the only valve train wear test in PC-10. (There may be some who consider the loss of filter delta P measurement in the ISM as a concern. Infineum would note that filter plugging was a concern with oils designed to pass the Mack T-8E test, and the T-11 has replaced the T-8E in PC-10. In our experience, an oil with sufficient dispersancy to pass a T-11 has shown virtually no filter delta P in either the M11 or the ISM tests.)

Data supporting these beliefs were presented to the PC-10 Valve Train Wear Task Force, and despite a passing ballot stating that PC-10 does NOT require three valve train wear tests, the Task Force could not agree on which test(s) to drop.

PERFORMANCE TESTS

Other Tests of Interest

The EMA requested inclusion of either the **Sequence** IIIF or IIIG in PC-10 to measure oxidation stability. Industry experience in CI-4 formulations clearly showed that bearing corrosion protection in the Mack T-10 test required more antioxidancy than the Sequence IIIF.

Analysis of the data from the Mack T-12 showed that passing lead in that test requires more antioxidant than a sequence IIIF, while a passing IIIG requires both more antioxidant and the use of special (more costly) base stocks. In light of these data, the HDEOCP agreed to use a passing viscosity increase in either the sequence IIIF or the IIIG as a requirement in PC-10. This allows the oil marketer to decide whether to license API SL or SM as the light duty category for universal oils.

PERFORMANCE TESTS

Summary

Although PC-10 category development **completed** behind the original plan, **progress on both category development and BOI/VGRA rules has allowed the DEOAP to recommend October 15, 2006 as the first license date for API CJ-4. This timing has been unanimously supported by the HDEOCP, and it is expected to be endorsed by the API lubricants committee.**

Regardless of the **timing of first licensing**, OEM specifications identifying PC-10 quality products will issue **by mid-year** 2006. One engine manufacturer has **announced** April 2006 as the timing of its next specification upgrade, **while the others are expected to issue between June and September.**

PC-10 will once again be a very expensive category. The cost of a one test pass for just the PC-10 tests is well over \$550,000, and the cost of either an API SL or SM approval will add to the final cost of deployment. **Detailed** cost impacts of the formulation changes for PC-10 **will vary**, but the new tests continue to show a preference for more expensive, higher saturates base stocks, and additive treat rates will be equal to or higher than CI-4.