FA-4 Discussion

Speaker Bio

Tony Negri
Director – Product Management

- Oversee Product Management, Technical Service and Packaging teams
- 31st year in Lubricants
- Notable career stops prior to Product Management include Sales, Technical Service and Brand Management

Webinar Agenda

API CK-4 & FA-4 categories

- What are they?
- What were the drivers of change?
- What is their impact / benefit?

FA-4 questions that may be on your mind

- What engines can take advantage of the FA-4 benefits?
- If I switch to FA-4, will I need more than one engine oil to service my diesel fleet?
- Will my drain intervals be affected?
- Will my equipment longevity be impacted?

Current API Categories

API CK-4

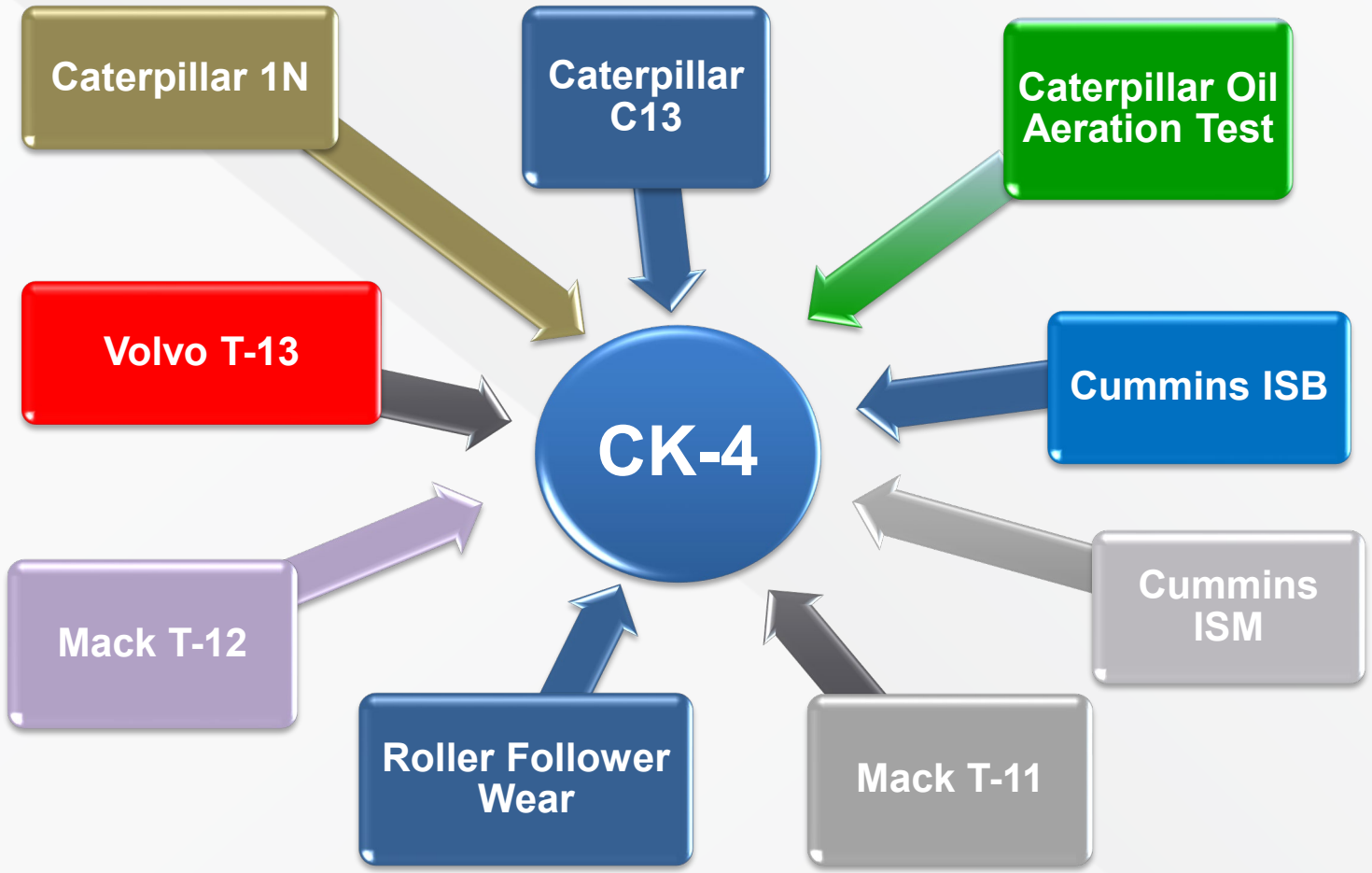
- A change with no downside
- Aligned with features of API CJ-4
- Higher performance standards
  - Improved aeration control
  - Better oxidation control
  - Lower volatility

API FA-4

- New category created exclusively for fuel efficiency
  - Includes SAE 10W-30 & 5W-30 grades only

- Must pass same durability performance testing as CK-4, but at lower High Temperature / High Shear (HTHS) viscosity

API Test Requirements

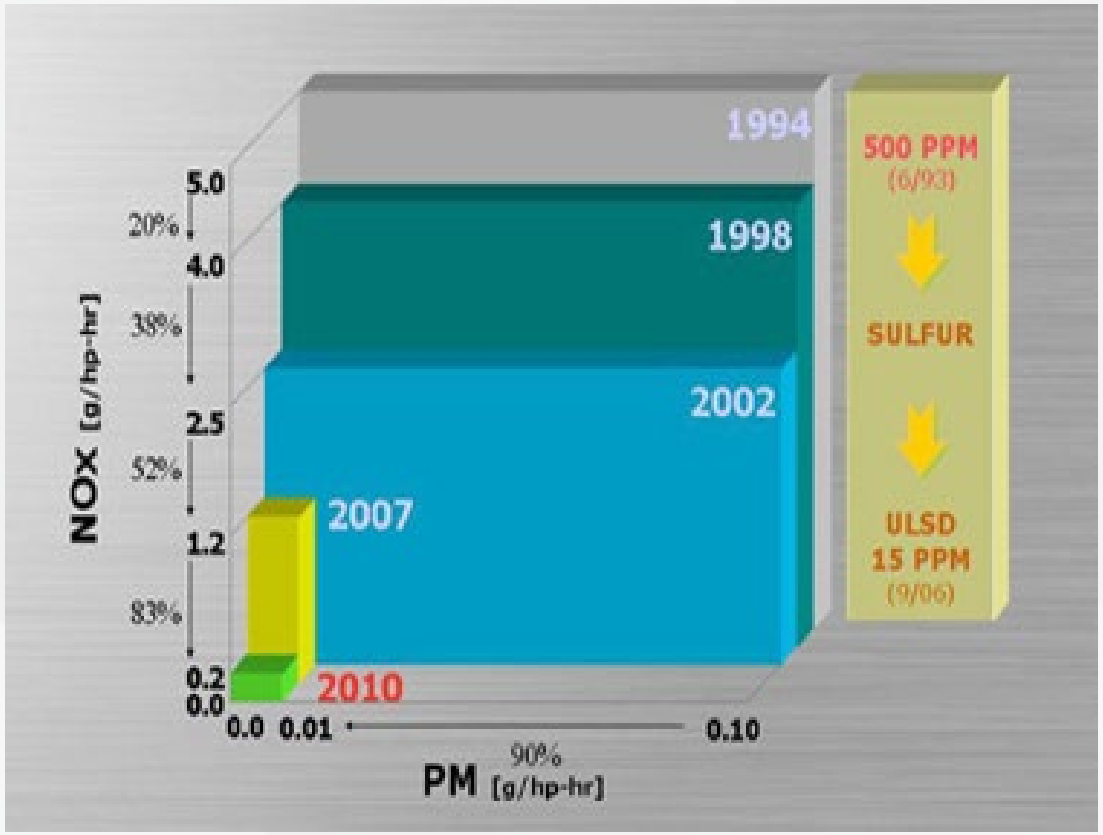


API FA-4 products must pass the same tests at the same limits!

EMISSIONS REGULATIONS

Where we've been (on-highway)

- 1994 – 2007: Phased NOx reduction
- 2007 – 2010: Reduced diesel particulates
- 2010 – 2013: Full deployment and onboard diagnostics (OBD)



Resulted in >90% reduction in NOx and particulates since 1994!

CK-4 / FA-4 Oil Design Drivers

Regulations

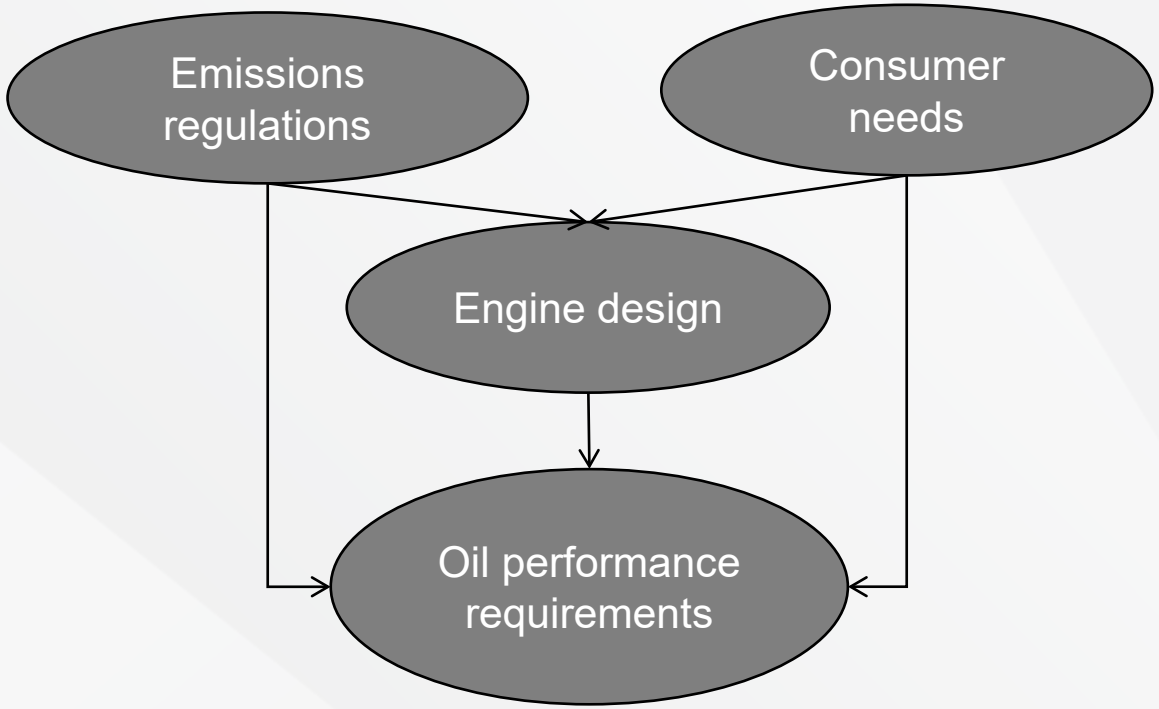
- EPA, CARB
- NOx, CO, particulate matter
- CO_2

Engine design

- Changing demands on the oil

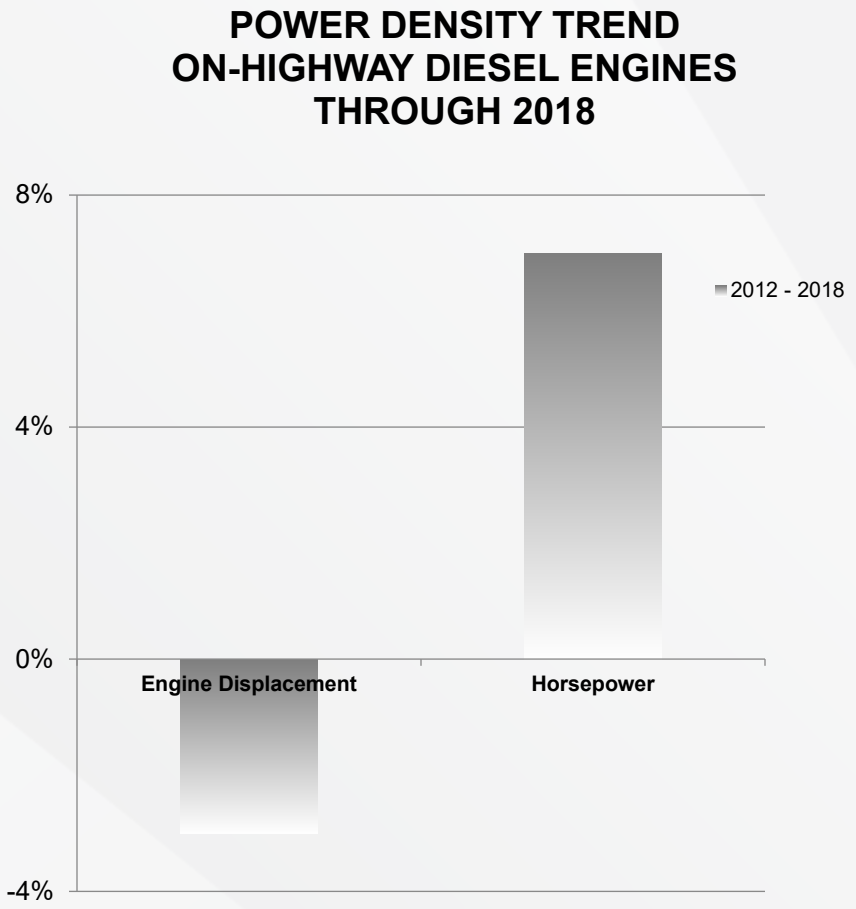
Market / Consumer

- Productivity
- Price - value
- Total Cost of Ownership (TCO)



Engine Design Changes

- Engine Downsizing
- Power-Generating Technologies
  - Advanced turbocharging
  - Waste heat recovery (WHR)
  - Advanced fuel injection
  - In-cylinder improvements
- Engine Down-Speeding
- Active Oil Temperature Management

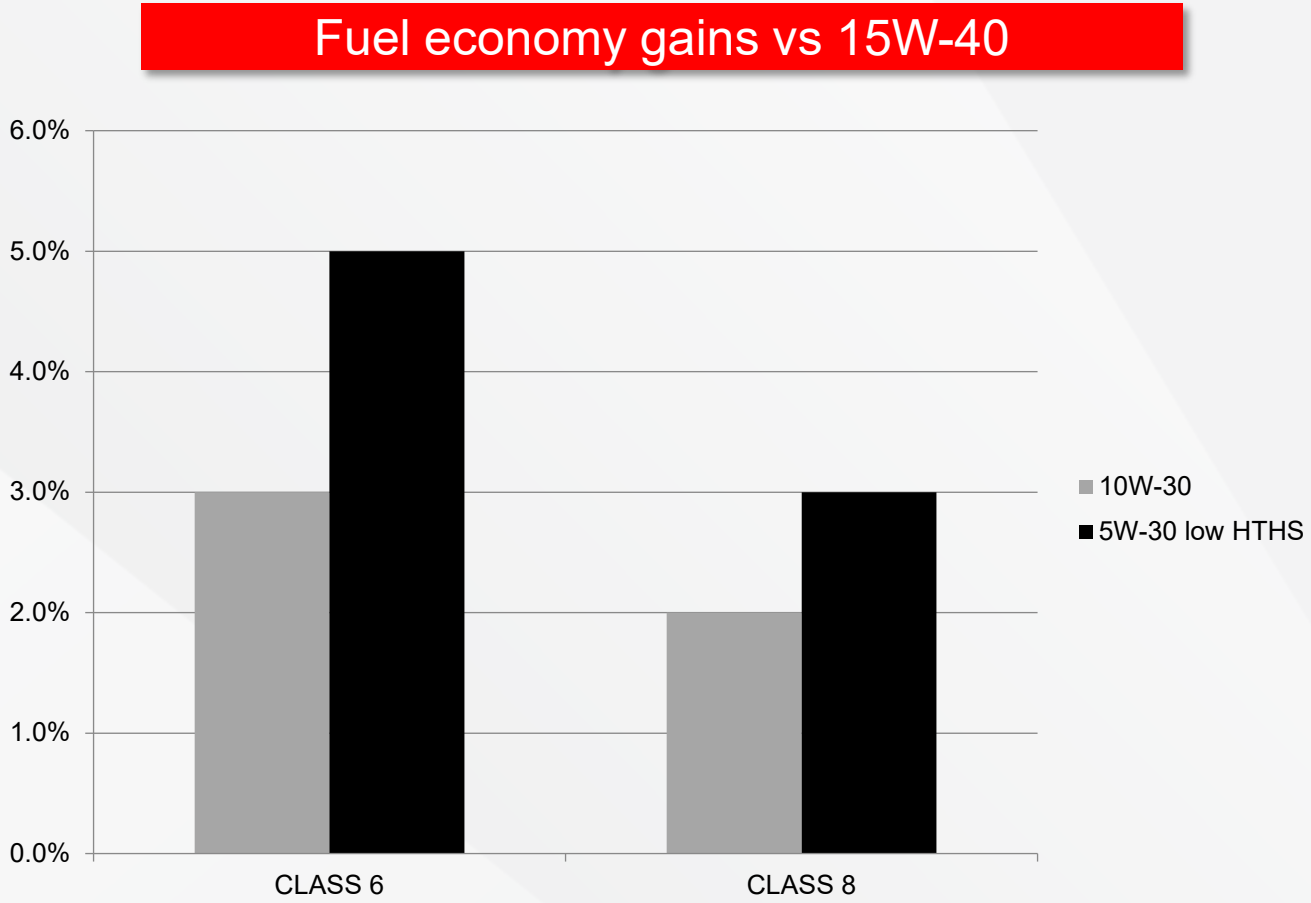


Smaller engines, more power, better fuel economy & lower emissions

Engine Oil and Fuel Economy

Realized fuel economy can vary widely

- Both Kinematic and HTHS viscosity impacts fuel economy
- If two oils have the same Kinematic Viscosity (e.g. CK-4 10W-30 vs. FA-4 10W-30), the one with the lower HTHS value will provide more fuel economy benefit
- Drive cycle significantly influences potential fuel economy % improvement



Multiple Measures of Viscosity

Kinematic Viscosity

- Traditional measure of viscosity
- Measured by simple gravitational flow at 40°C and 100°C
- Expressed as centistokes (“cSt”)

Absolute Viscosity

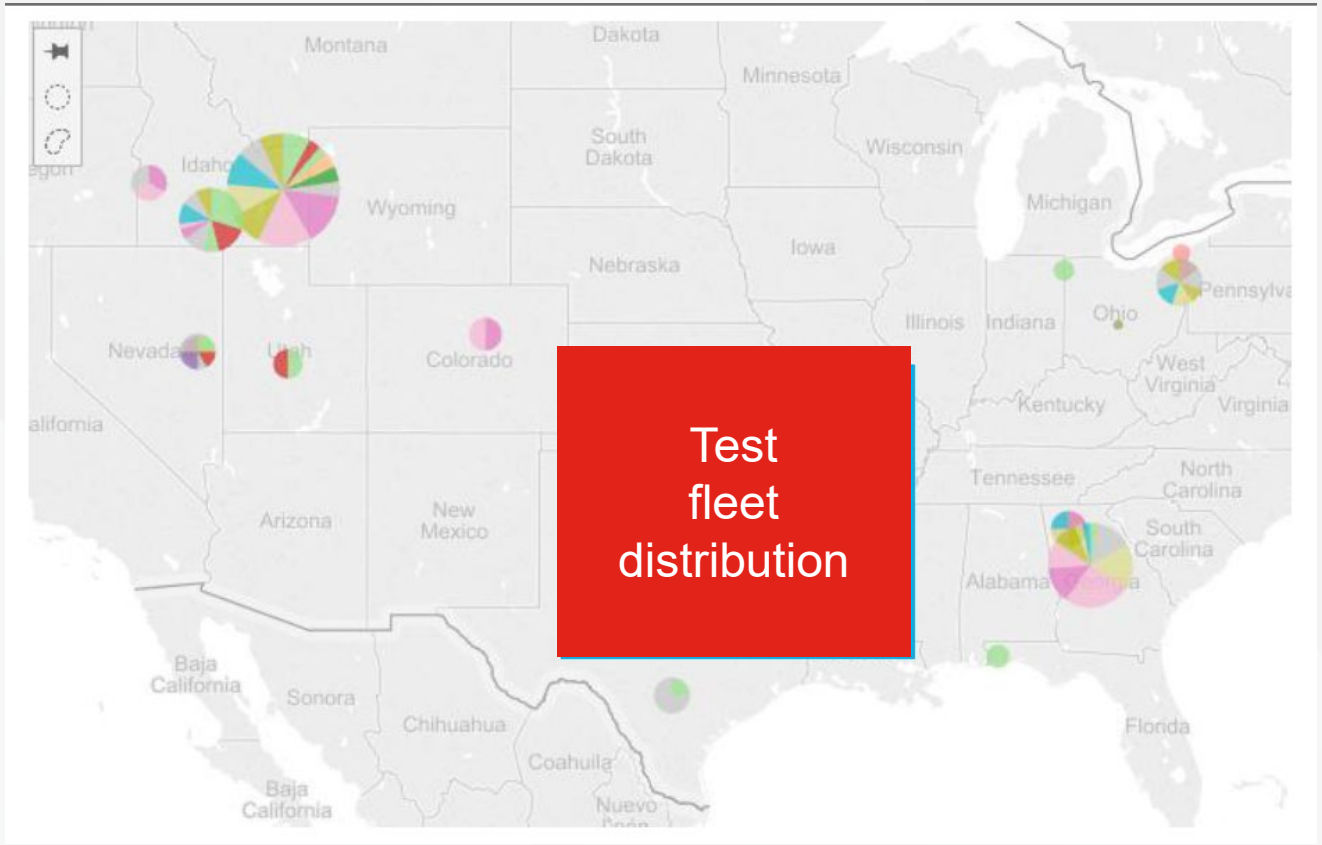
- High Temperature High Shear (“HTHS”)
- Measures internal fluid friction at 150°C and under shear conditions
  - Designed to mimic the area between the crankshaft and connecting rod bearings
- Expressed as centipoise (“cP”)
  - CK-4 = 3.5 cP minimum
  - FA-4 = 2.9 – 3.2 cP range

How do we know FA-4 oils work?

- Test, test & test again
  - Bench testing
  - Engine stand testing
  - Field testing since late 2013
- Real world operation since launch in late 2016

PROOF OF PERFORMANCE

- 92MM miles of on-highway fleet testing
  - Starting in 2013 / Concluded 3Q19
  - 335 trucks
  - All N.A. OEM's represented
  - All regions of the country
  - Majority of testing on FA-4 10W-30
- Engine teardowns
  - PACCAR, Detroit Diesel (2X), Volvo, Cummins
    - 1.3MM mile Volvo (Nov '22)
  - Video support on P66 YouTube channel



Fuel Economy Testing

For Heavy Duty Diesel Engine Oils

FUEL ECONOMY TEST METHODS

Volume-Based

(Miles driven vs fuel consumed)

- Pro: Easy
- Con: Most variability; does not account for driving conditions or varying load

Mass-Based

(kg fuel to travel x miles)

- Pro: More precise than volume
- Con: Does not account for driving conditions or varying load

BSFC*

(real-time fuel flow & engine output)

- Pro: Accounts for driving conditions & load, detailed driving cycle analysis
- Con: Very complex

***Brake-Specific Fuel Consumption is the most accurate measurement method**

BRAKE-SPECIFIC FUEL CONSUMPTION

- Combines real-time fuel flow measurements with actual engine output
- Measures amount of fuel consumed to produce a certain amount of power
- BSFC = $\frac{Fuel\ Consumption\ (g/hr)}{Power\ Produced\ (kW)}$, final units of $\frac{\mathrm{g}}{\mathrm{kW-hr}}$
- Requires significant instrumentation & data collection
  - Custom fabricated torque transducer in the flywheel
  - Speed, GPS, fluid and environmental temperatures, weather conditions, load, fuel flow, torque, pressures

FORD TRANSIT TEST DEVELOPMENT

- Light duty diesel identified as a growing market segment
- Vehicles lend themselves better to level of instrumentation needed
- Market well-represented by Ford Transit van
  - 3.2L (5-cyl.) diesel engine
  - DOC, DPF & SCR after-treatment devices present
  - Class 4 allowed for significant loads

Excellent balance of real-world relevance and laboratory precision

TEST DEVELOPMENT STEPS

2015

Buy van;

Install “lite” instrumentation;

Deliver van to fleet & record 20k miles on-road data

2016

Recover van;

Install “heavy” instrumentation;

Reproduce fleet drive cycle on test track with professional drivers

2017 / 2018

Create / install automated throttle control to remove human error;

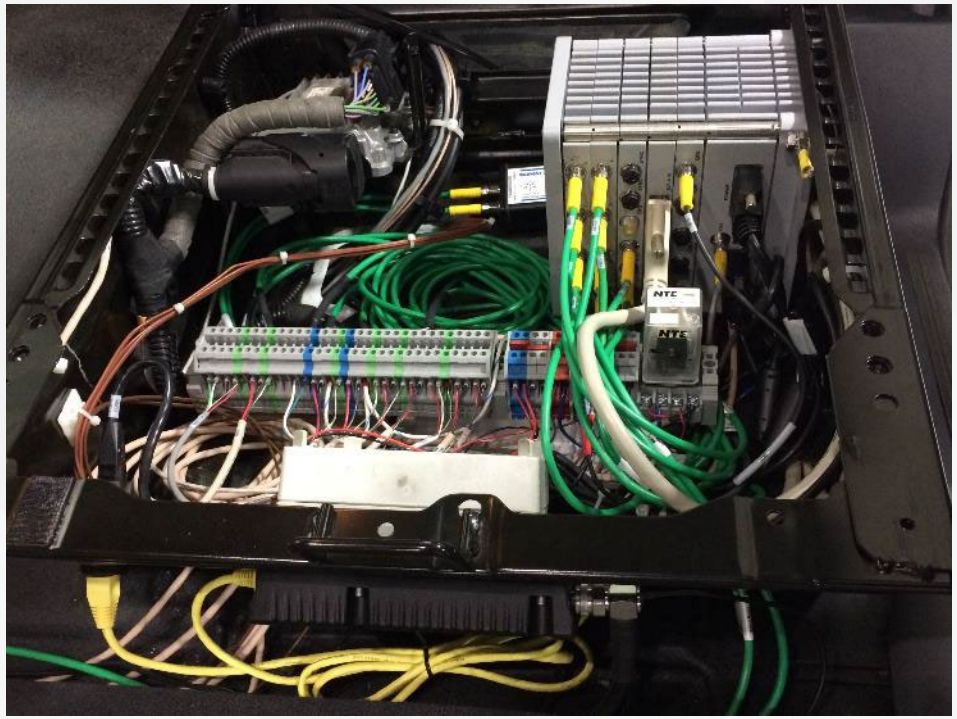
Retest

Data collection & analysis

TEST DEVELOPMENT – STEP 1

- Purchase vehicle

- Install instrumentation to measure:
  - Speed
    - Engine
    - Vehicle
  - Temperature
    - Oil
    - Transmission fluid
    - Axle oil
    - Coolant
  - GPS

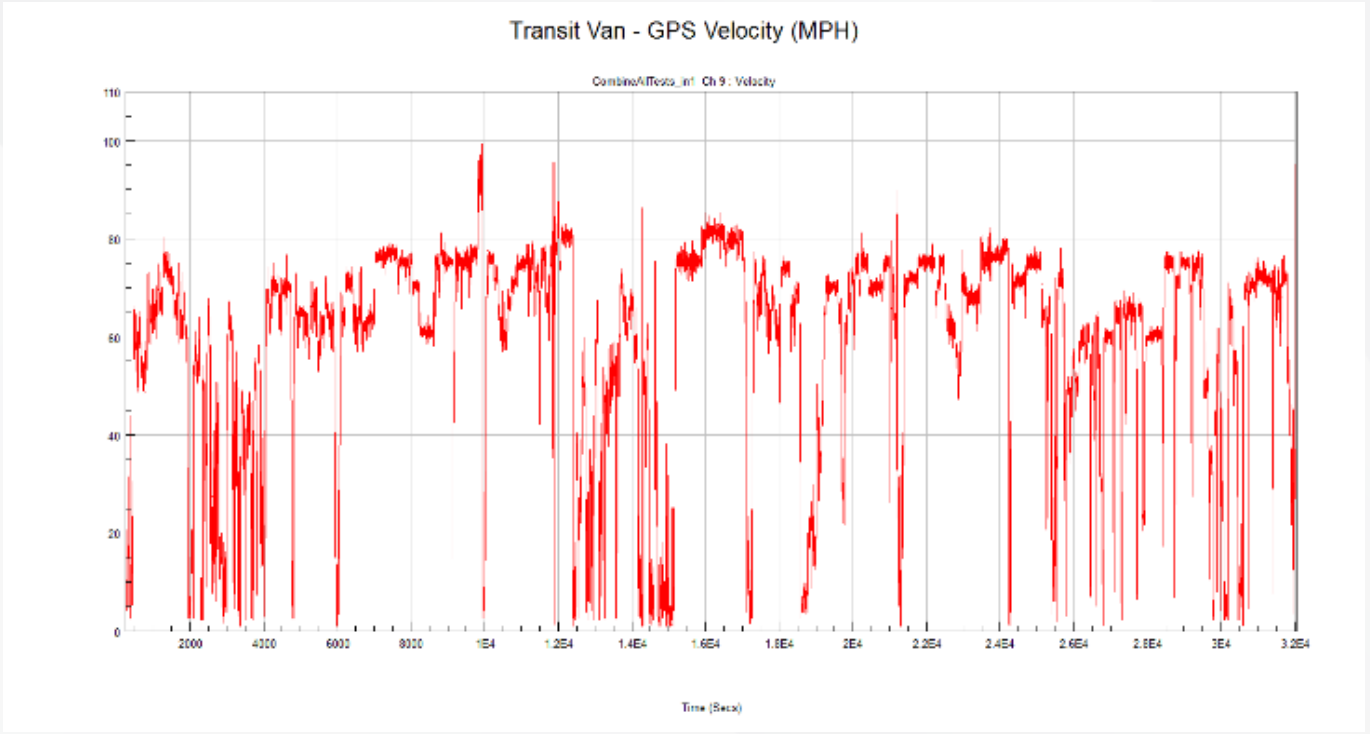


Just enough data to understand how the vehicle was being driven

TEST DEVELOPMENT – STEP 1

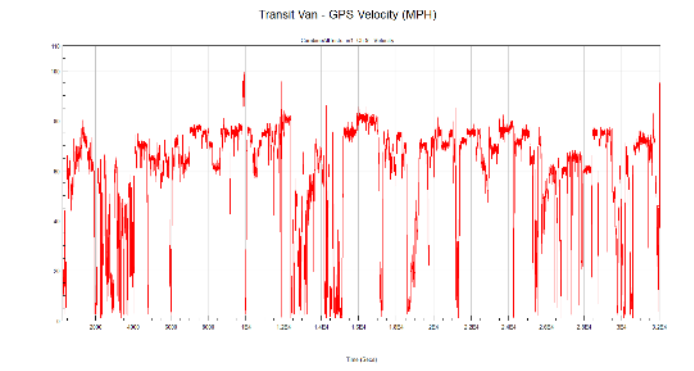
- Delivered vehicle to participating fleet
- Recorded 20,000 miles of real-world driving data

What type of driving did the vehicle do?

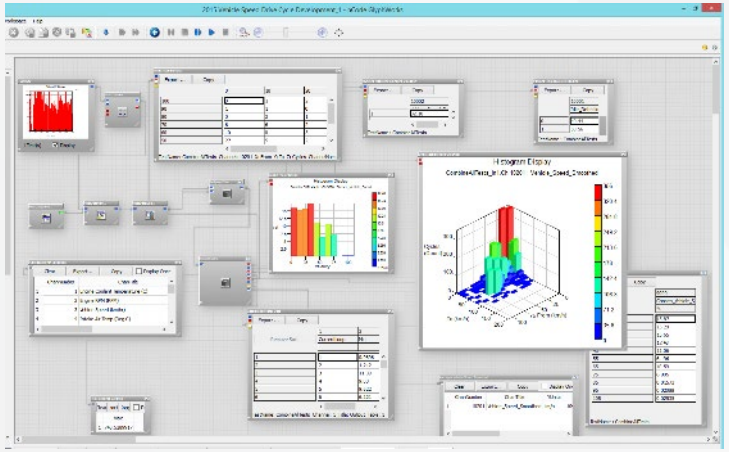


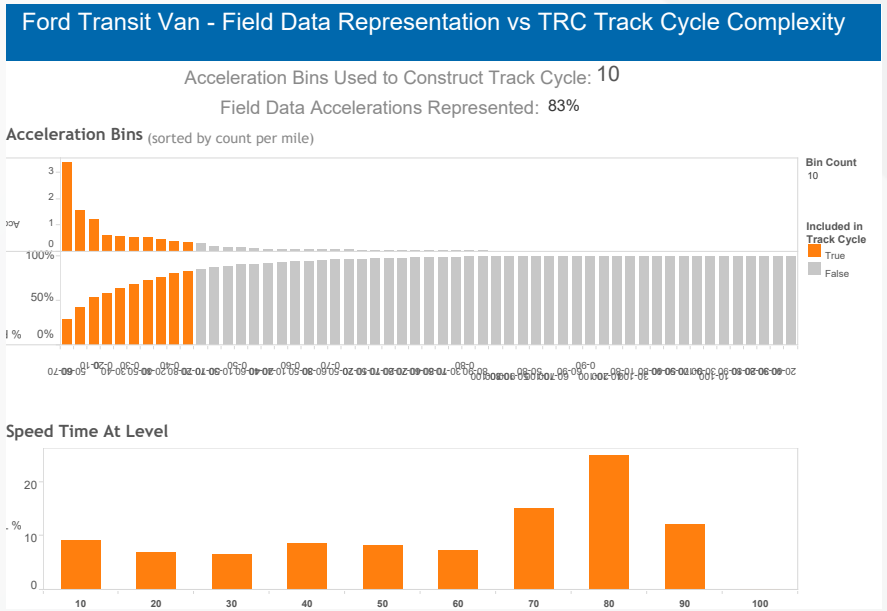
Mix of highway and local delivery

TEST DEVELOPMENT – STEP 2



Develop and use computer program to de-construct the drive cycle

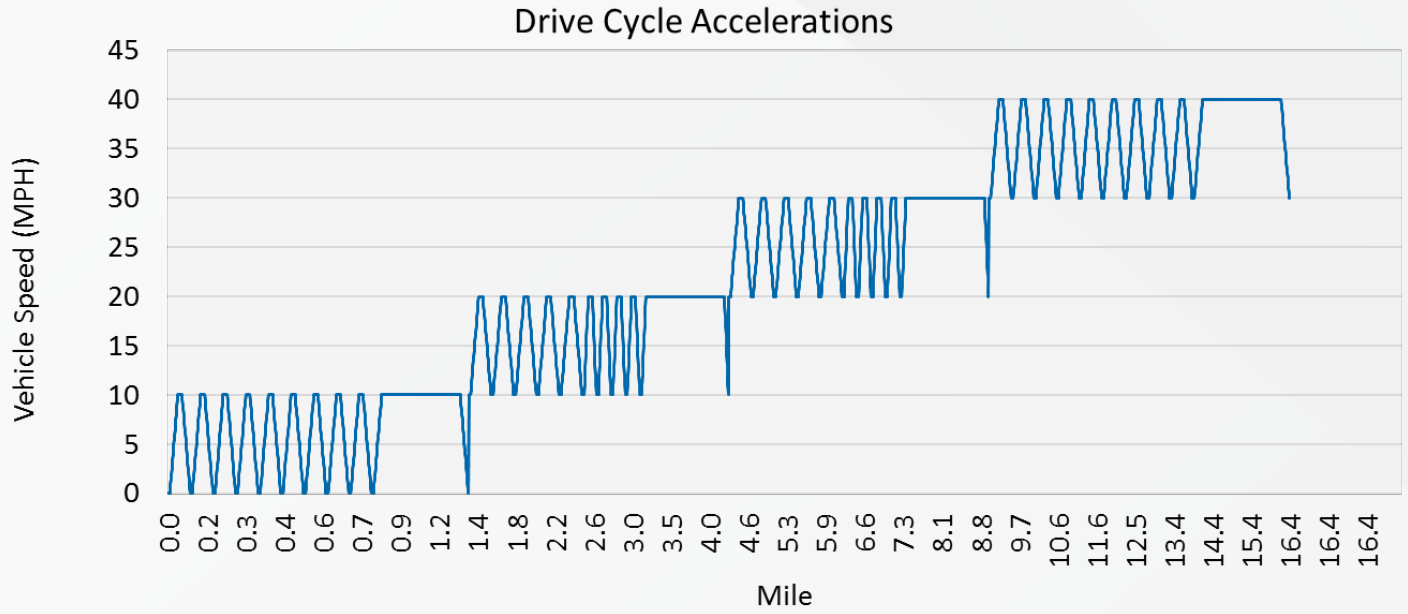




'Rebuild' cycle – determine what proportion of time the vehicle spent at each condition

TEST DEVELOPMENT – STEP 2

- Speed and acceleration buckets to develop a repeatable, drivable cycle
- ‘Building Block’ method allows for maximum flexibility
- Can be used to simulate nearly any drive cycle (standard or custom)



TEST DEVELOPMENT – STEP 2

- Install 'heavy' instrumentation

- Parameters Monitored
  - Speed
    - Engine
    - Driveshaft
  - Fuel Flow
  - Torque
    - Engine
    - Driveshaft
  - Temperatures
    - Engine Oil
    - Engine Coolant
    - Transmission Fluid
    - Gear Oil
    - Ambient Air
  - Pressures
    - Fuel
    - Ambient Air
    - Exhaust (Pre & Post-DPF)

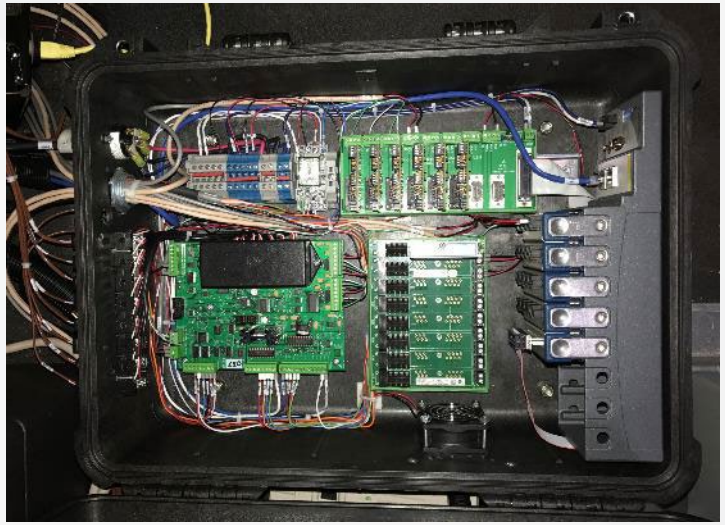
TAKING THE VAN TO THE TRACK

- Conduct fuel economy testing at test track with professional drivers to reproduce real-world driving cycle under controlled conditions
  - Testing conducted at Transportation Research Center (TRC) – Columbus, OH
  - 4,500 acre testing facility
  - 7.5 mile oval test track

TEST DEVELOPMENT – STEP 3
Eliminating Human Error

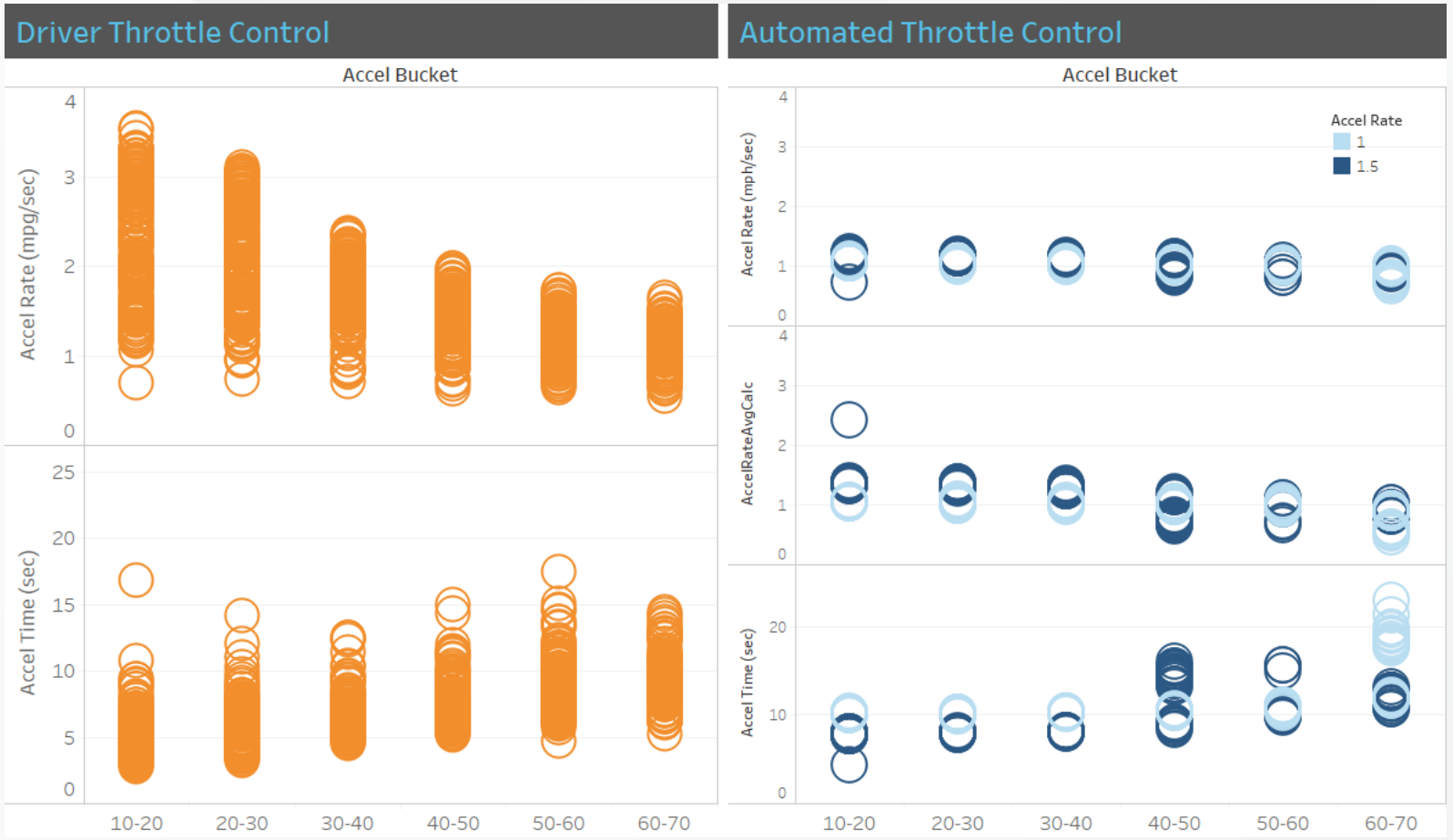
- Method for reducing human driver variability

- An automated accelerator pedal system was developed
  - Robust safety controls built into the system
  - Controls acceleration by directly feeding electrical current into the engine's control computer
  - Significantly improved drive cycle repeatability



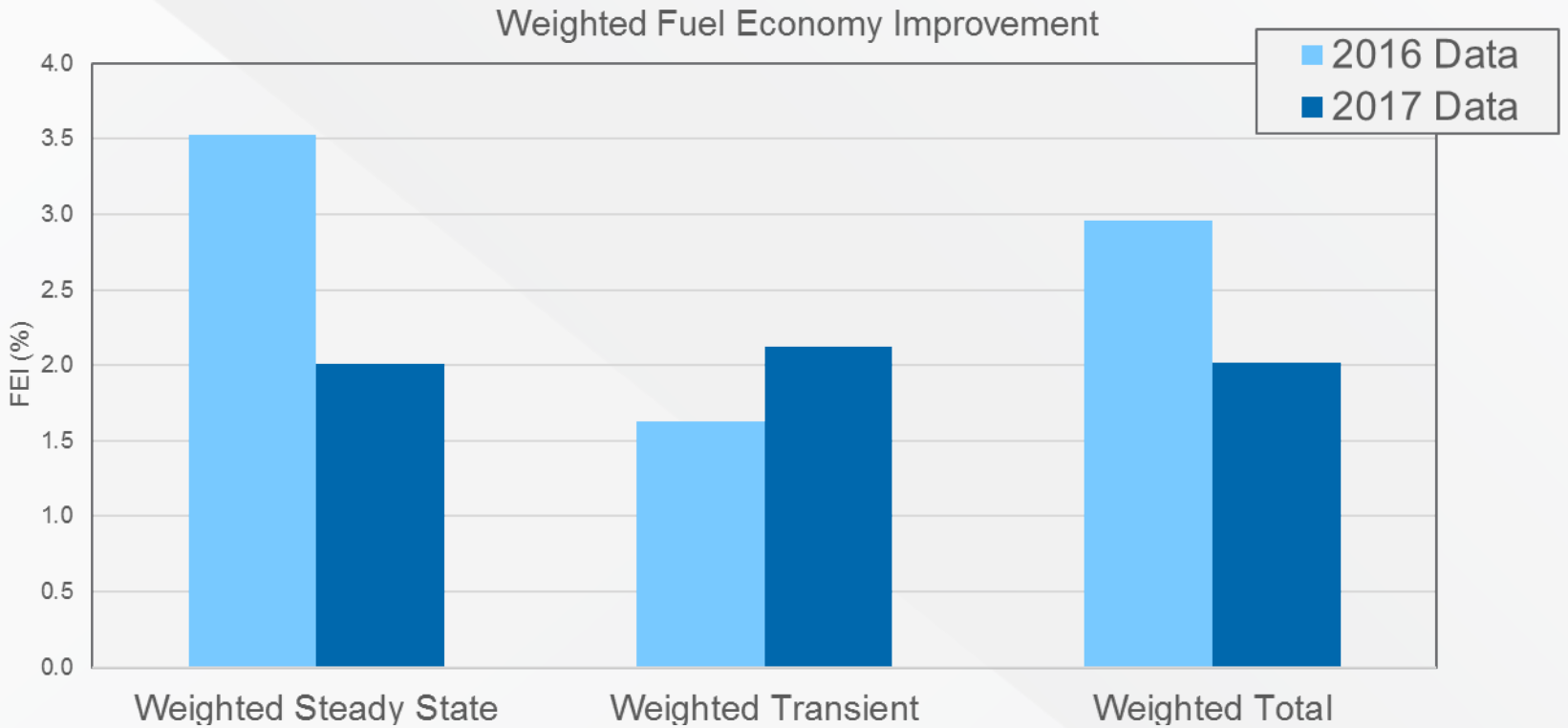
COMPARISON OF VARIABILITY

- Drastic improvement in repeatability with automated throttle control



Test Results

2 YEARS TEST RESULTS



% Fuel economy improvement FA-4 5W-30 vs CK-4 15W-40 baseline

2016 used driver inputs; 2017 used automated accelerator

FUEL ECONOMY SAVINGS VERSUS 15W-40

P66 / KENDALL PRODUCT	CLASS 7 – 8	CLASS 6
CK-4 10W-30	1%	1.5%
FA-4 10W-30 (syn blend)	1.5%	2%
FA-4 5W-30 (full syn)	2%	3%

FUEL ECONOMY FACTORS

Driver

Engine

Advanced lubricants

Semi-automated transmissions

Idle reduction systems

Low rolling-resistance tires

Aero skirting

Pursuit of fuel economy takes many forms and has been building for years. Only factor without capital cost is lubricant selection (immediate ROI).

FUEL ECONOMY TECHNOLOGY BENEFITS

FE Technology	Cost / Truck / Yr	FE Benefit	$ per % Savings
Low Rolling Resistance Tires (Drive)	$5,500	3%	**$1,833**
Low Rolling Resistance Tires (Steer)	$2,000	3%	**$667**
Aerodynamic Mud Flaps	$150	1%	**$150**
Trailer Tail	$733	5%	**$147**
Aerodynamic Wheel Covers	$115	1%	**$115**
Trailer Skirts	$417	7%	**$60**
FA-4 10W-30 Engine Oil*	$50	2%	**$25**

*Assumes $2/gal premium – 11 gal sump – 2.3 ODI/year

Even at a price premium, FA-4 stands out as a stronger ROI than other technologies

Wear Testing

DD13 Scuffing Test (ASTM D8074)

2010MY 12.8L DD13, inline six-cylinder, diesel with all emissions controls

2-Phase duty cycle for engine test
0 – 30 hours → Phase 1: 800Nm (~50% throttle)
31 – 200 hours → Phase 2: 1,800Nm (~80% throttle)

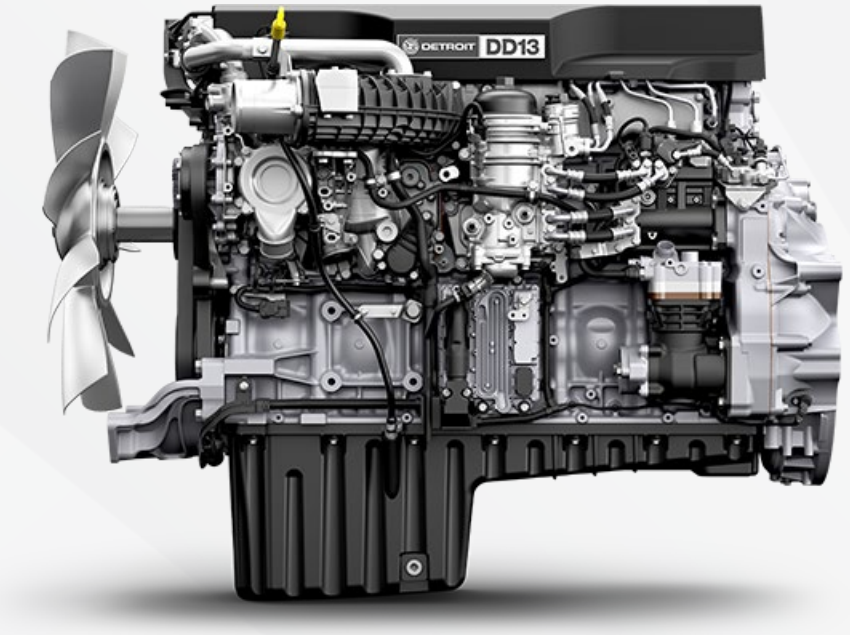
Evaluates resistance to adhesive wear between piston ring and cylinder liner interface

Crankcase pressure and used oil iron levels monitored for indicator of scuffing event

End-of-test if blow-by >2 kPa or Fe rate >25ppm in 2-hr window

31 hours-to-scuff minimum to meet limits for DFS 93K222 / 93K223

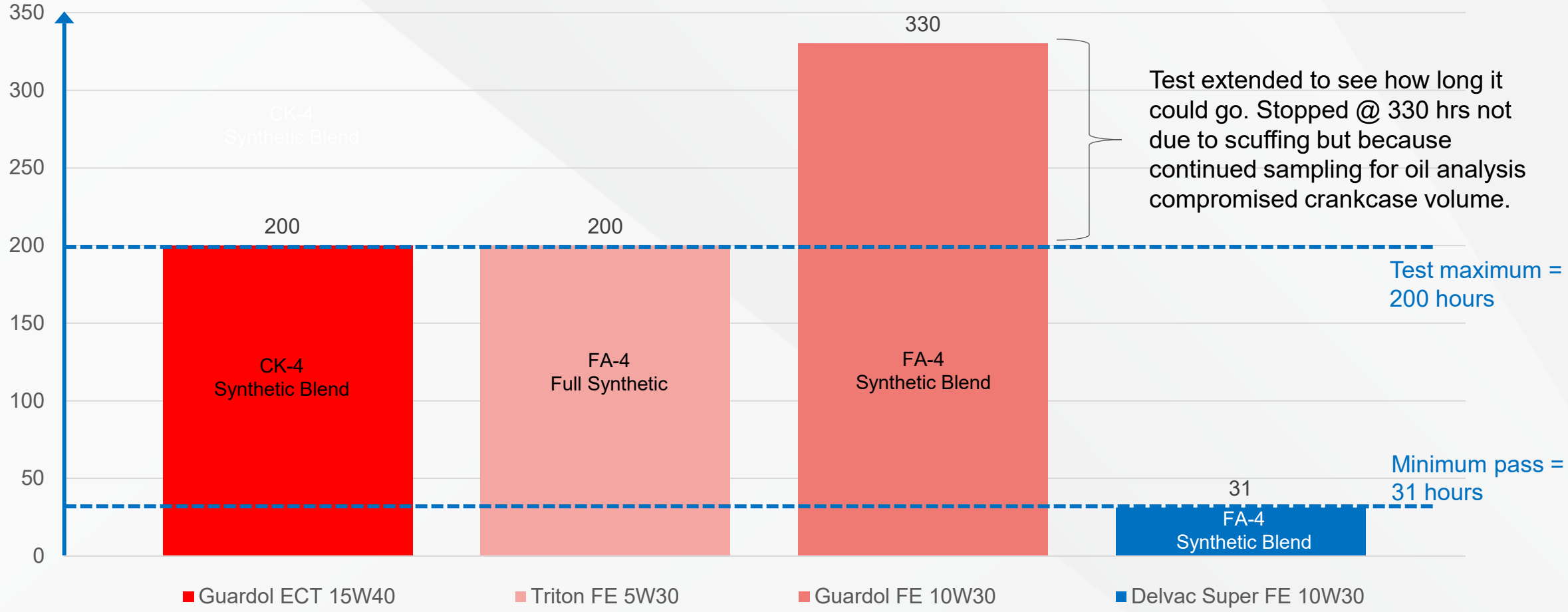
Fired Engine Test



DD13 SCUFF TEST RESULTS

Fired Engine Test

Higher = Better



Note: Test runs 200 hours or until scuffing is detected, whichever comes first.

Engine Teardowns

Detroit Diesel Teardown Video

Durability Case #1

2014 Detroit Diesel DD13	900,000 miles
45,000 miles ODI	Coast-to-coast service, tandem drivers (Atlanta, GA)

Averaged 2% fuel economy improvement (achieved 2.6% several times)

Engine Teardown
2014 DD13 900K miles

Piston 1 - Thrust

Piston 1 - Anti-Thrust

Engine Teardown
2014 DD13 900K miles

Piston 1 - Front

Piston 1 - Rear

Engine Teardown
2014 DD13 900K miles

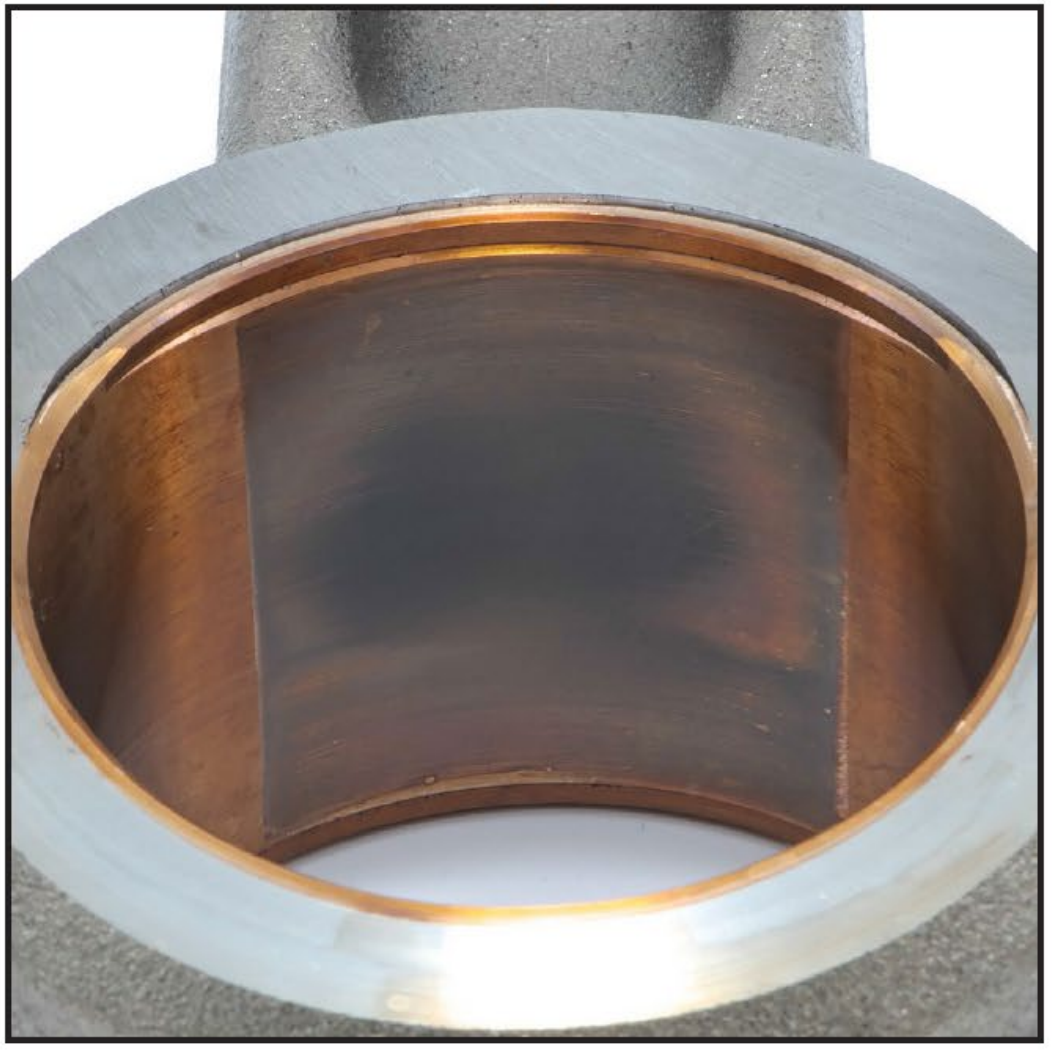
Piston 1 - Crown

Piston 1 - Undercrown

Engine Teardown
2014 DD13 900K miles

Piston 1 - Wrist Pin

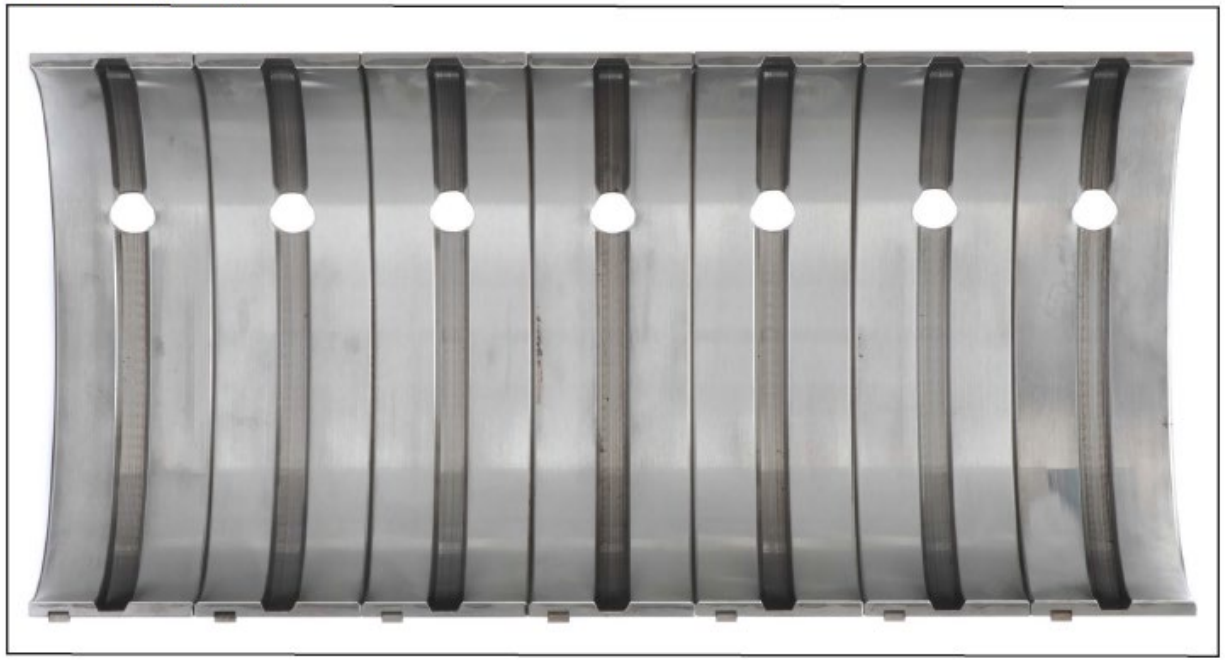
Piston 1 - Rod Bushing



Engine Teardown
2014 DD13 900K miles

Engine Teardown
2014 DD13 900K miles

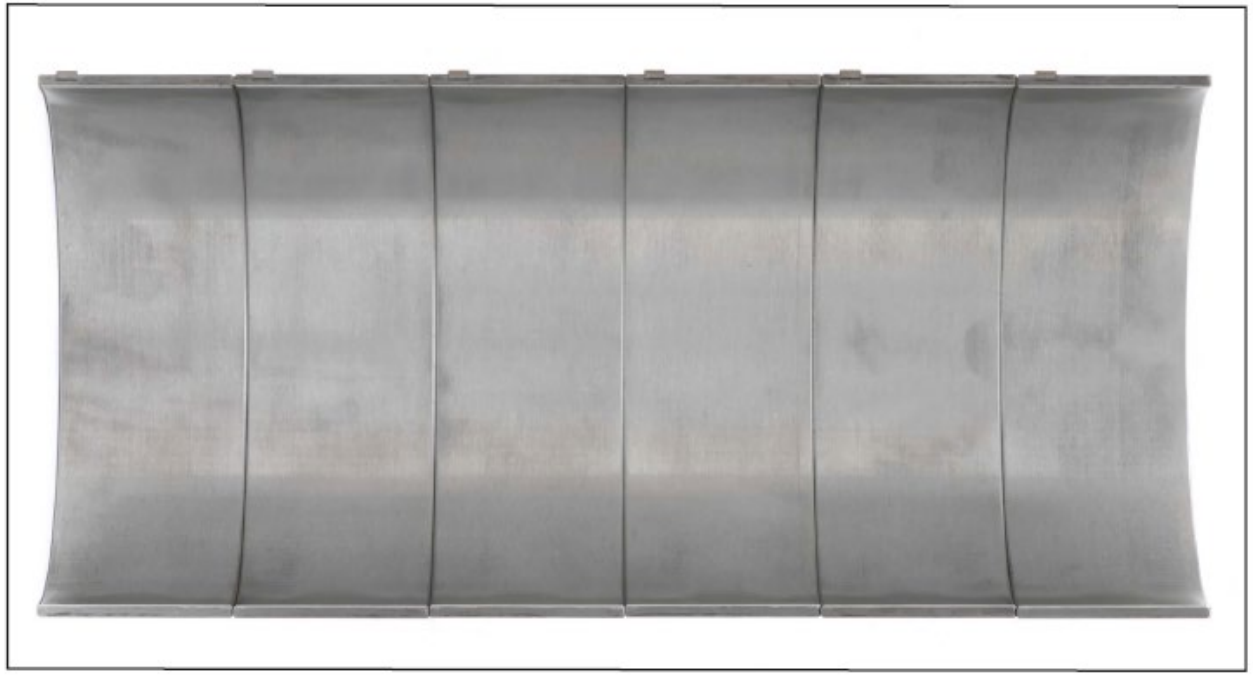
Main Bearing - Upper



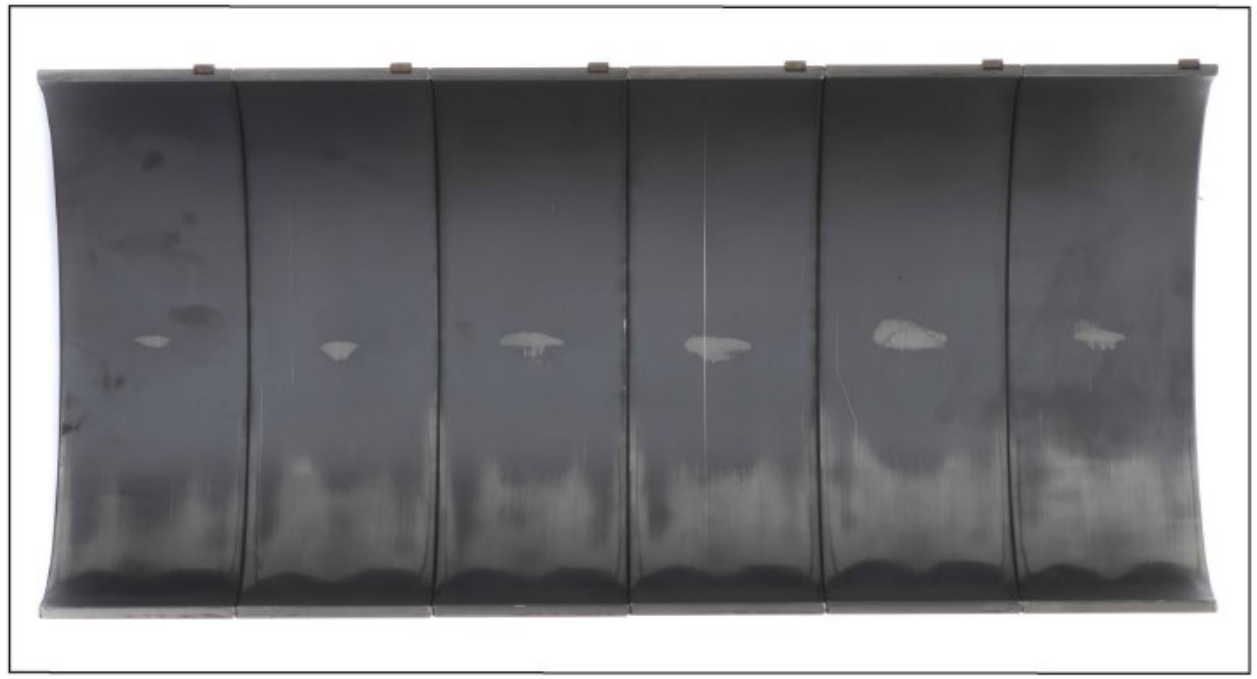
Main Bearing - Lower

Engine Teardown
2014 DD13 900K miles

Rod Bearing - Upper

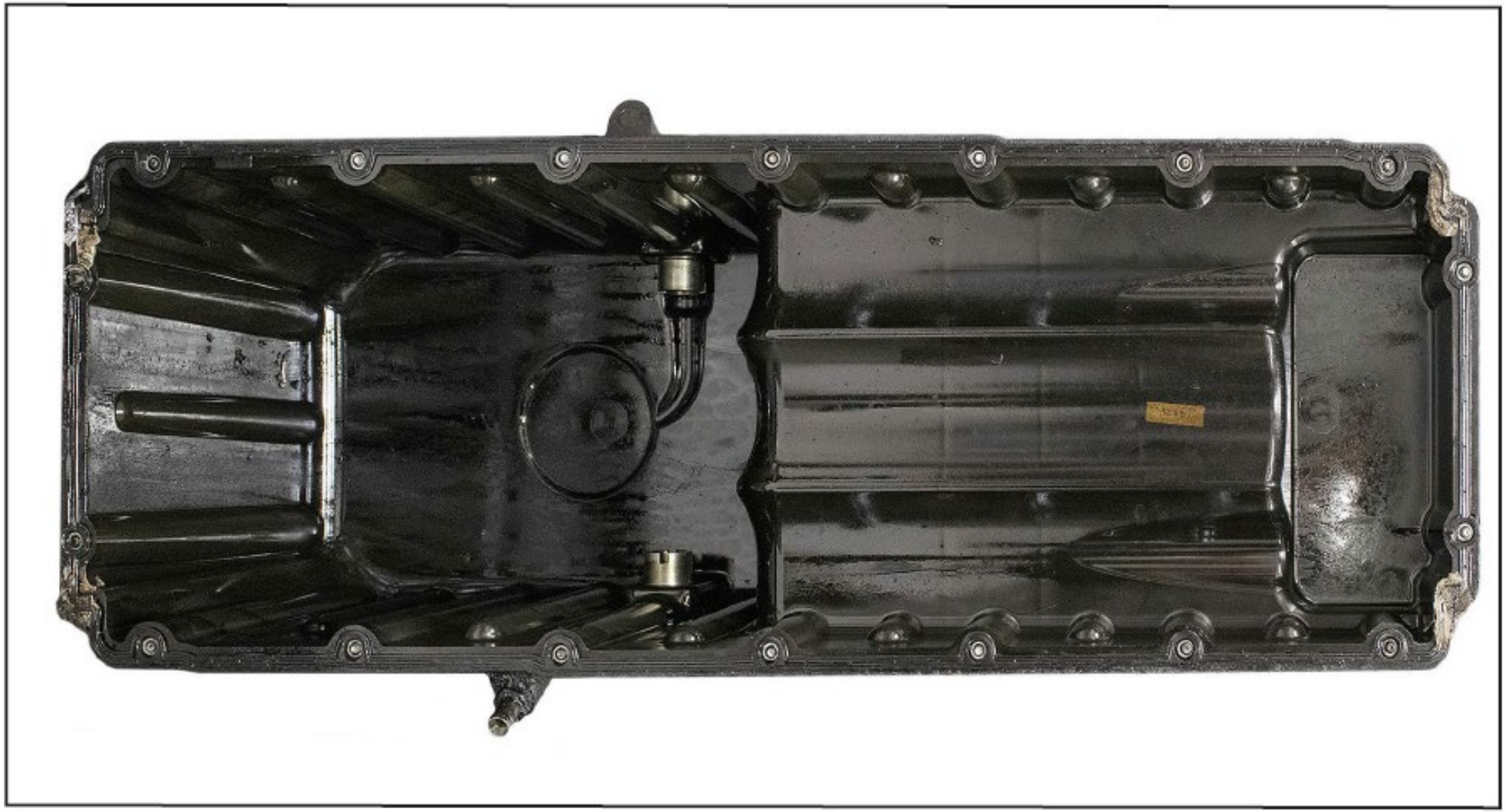


Rod Bearing - Lower



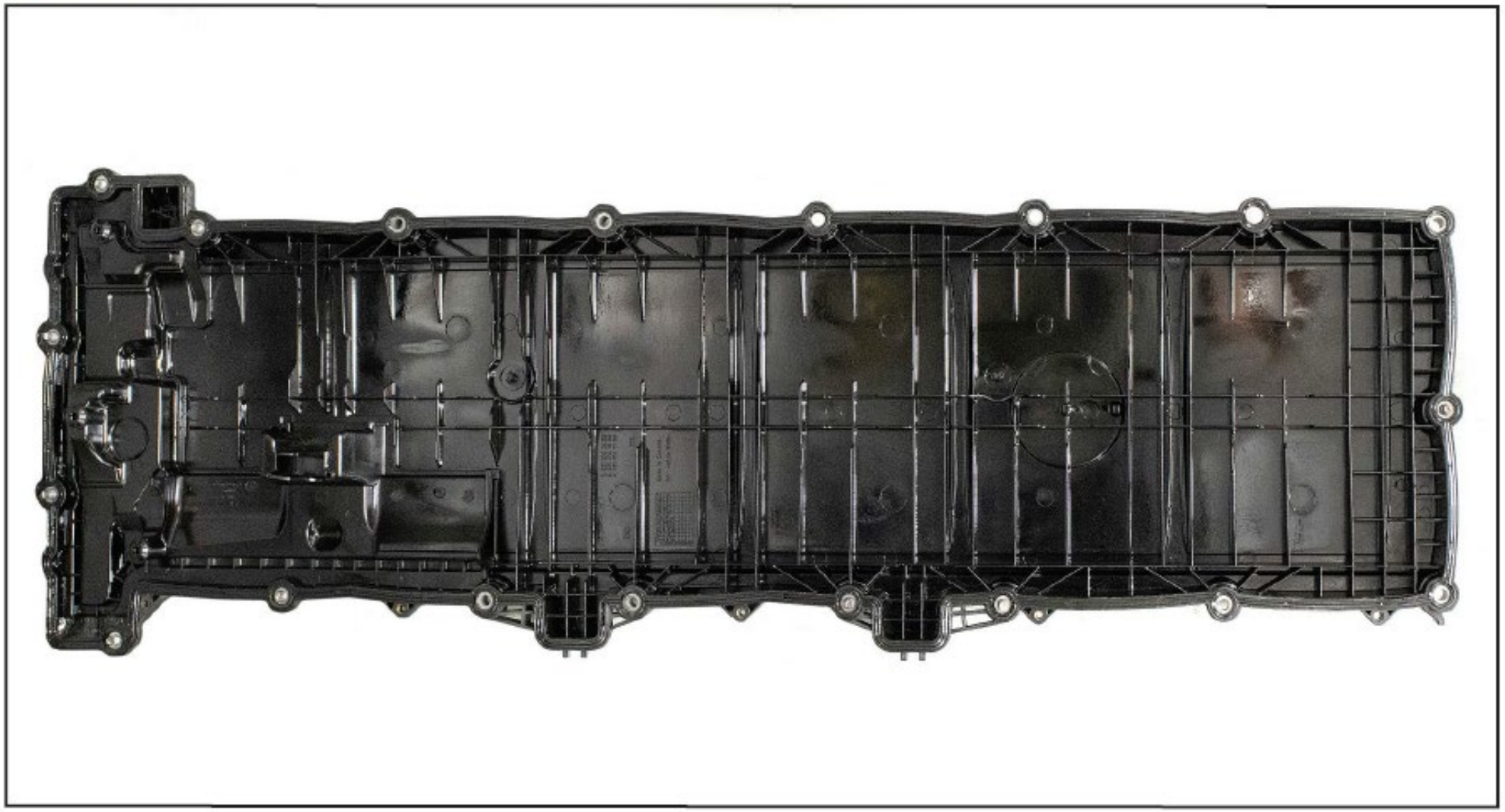
Engine Teardown
2014 DD13 900K miles

Oil Pan



Engine Teardown
2014 DD13 900K miles

Rocker Cover



Volvo Teardown Video

Durability Case #2

2016 Volvo D13

762,000 miles

30,000 miles ODI

Coast-to-coast service (Youngstown, OH)

Engine Teardown
2016 Volvo D13 762K miles

Piston 1

Piston 1

Piston 1

Piston 1

Piston 1

Piston 1

Engine Teardown
2016 Volvo D13 762K miles

Piston 1

Piston 1

Engine Teardown
2016 Volvo D13 762K miles

Piston 1 - Crown

Piston 1 - Undercrown

Piston 1

Piston 1

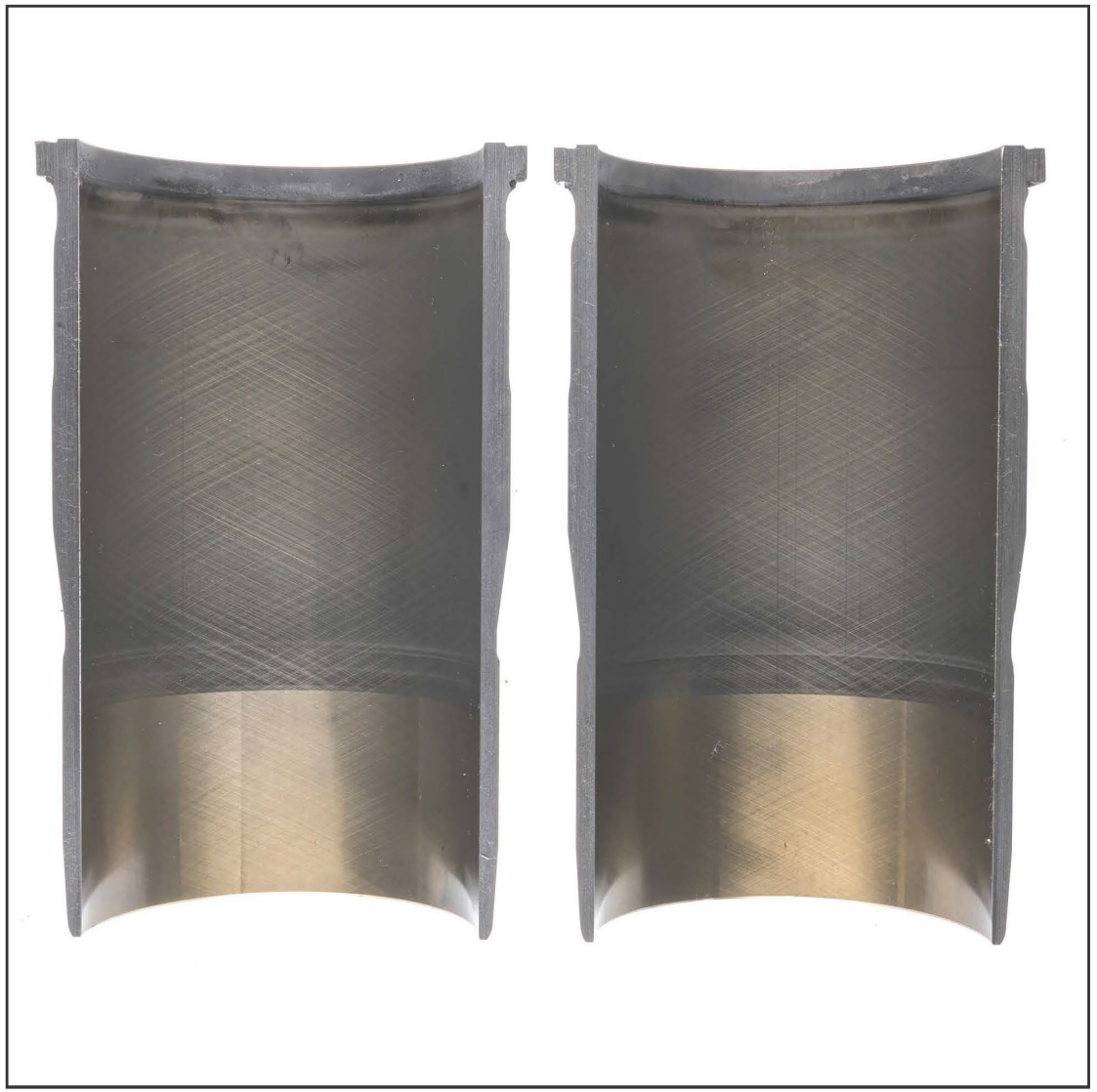
Engine Teardown
2016 Volvo D13 762K miles

Piston 1 - Wrist Pin

Piston 1 - Rod Bushing

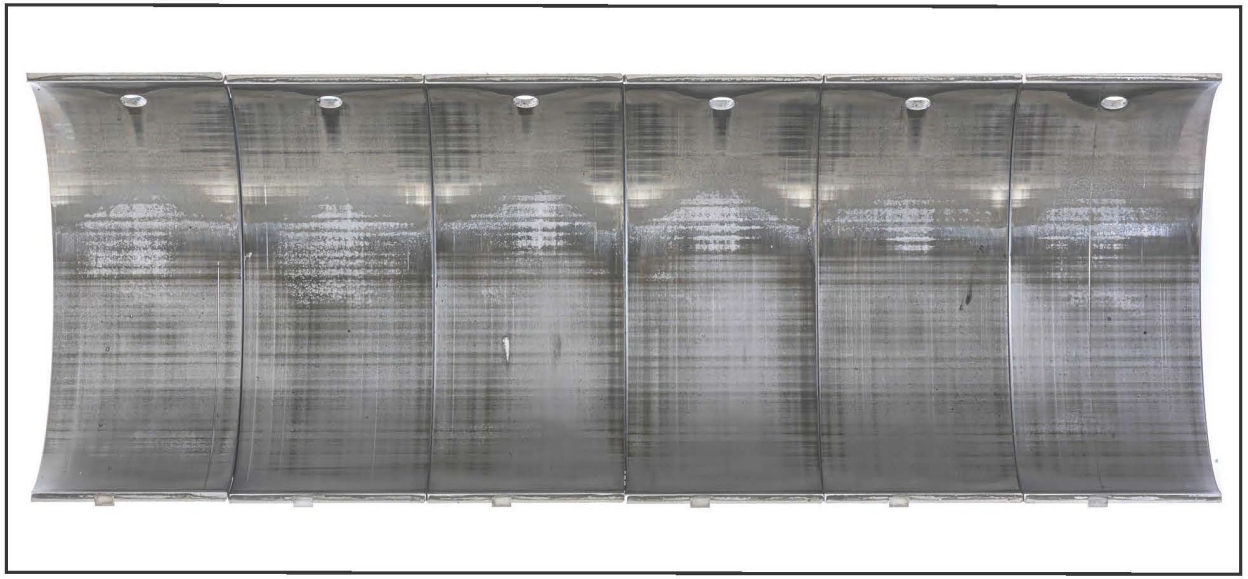
Engine Teardown
2016 Volvo D13 762K miles

Liner 1

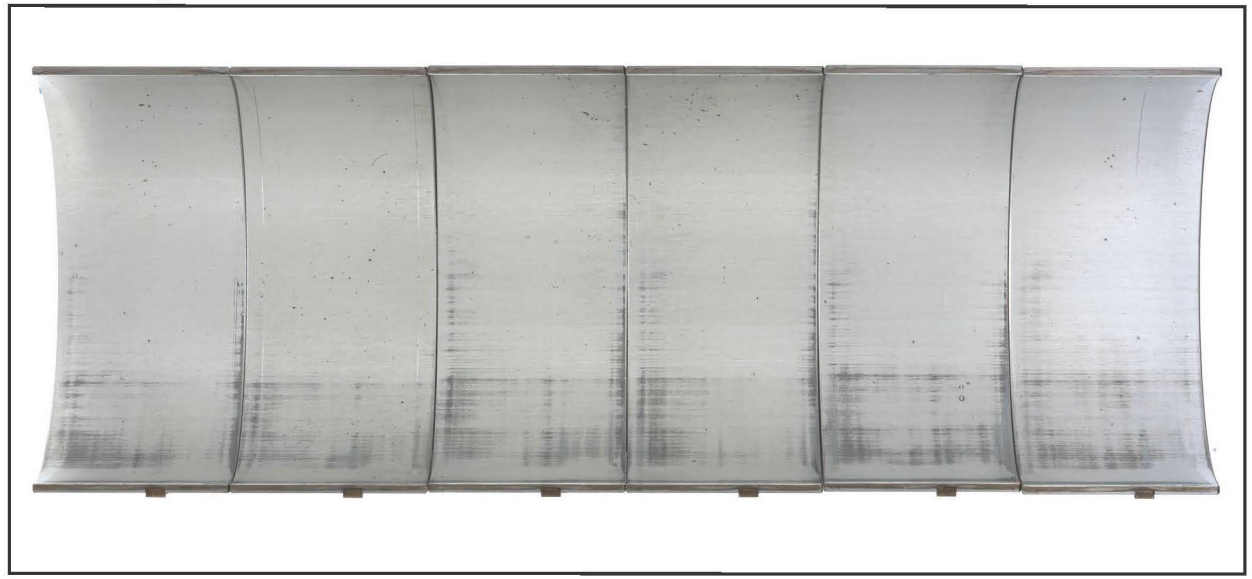


Engine Teardown
2016 Volvo D13 762K miles

Rod Bearing - Upper

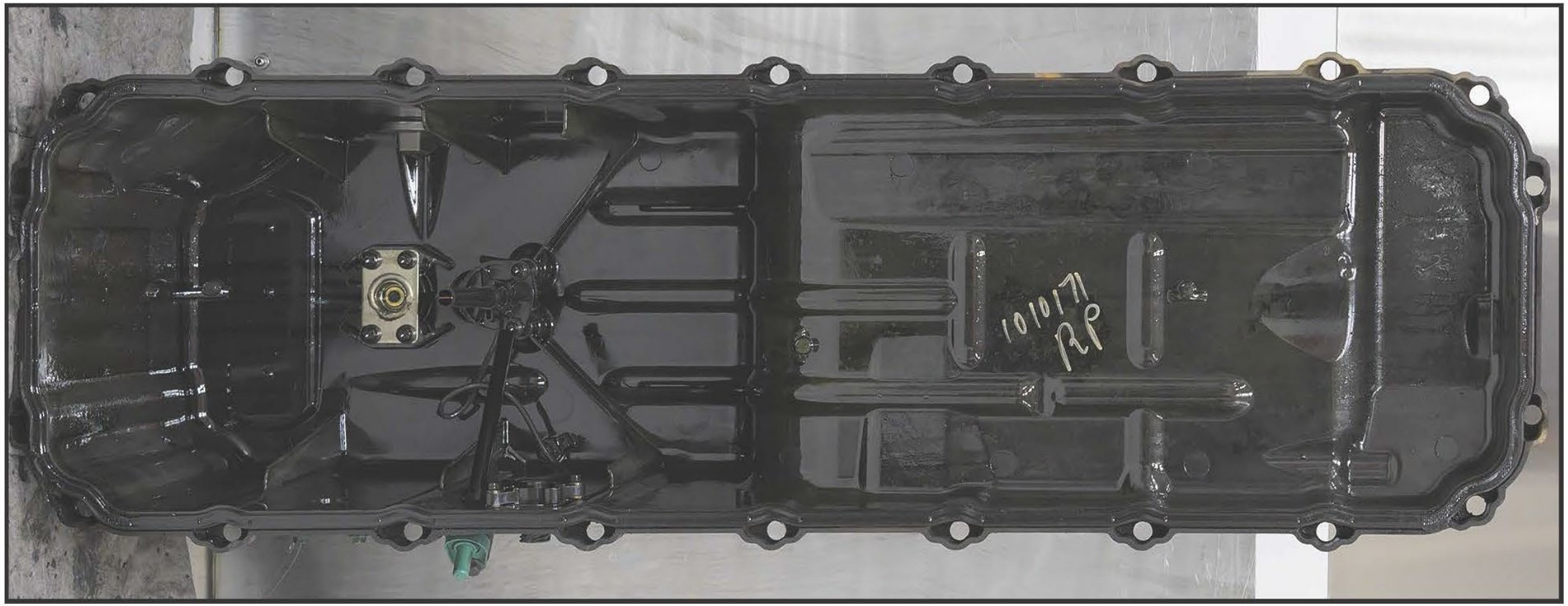


Rod Bearing - Lower



Engine Teardown
2016 Volvo D13 762K miles

Oil Pan



Engine Teardown
2016 Volvo D13 762K miles

Rocker Cover

What is holding people back from adopting FA-4?

Obstacles to FA-4 Adoption

- Fleet shops resistant to carrying multiple bulk engine oils
  - Fleets with wider range of vehicle age are less likely to switch all equipment to FA-4
  - Floor space, fear of misapplication are concerns

- Manufacturers of refrigeration units have not endorsed it and primarily recommend SAE 15W-40

- Class 8 OEM's have mixed support for FA-4
  - Detroit Diesel allows with back-serviceability to 2010 model year
  - Cummins allows FA-4 in 2017 and newer X15 efficiency model only
  - International allows FA-4 in 2017 and newer A-26 efficiency model only
  - PACCAR has not released a formal position on FA-4 yet
  - Mack / Volvo will not recommend FA-4 until their next-gen engine designs are released (EOS 5 / VDS 5)

Who Is A Good Candidate for FA-4?

- Early-adopters / experimental mindset
- Newer mix of on-highway equipment
- Higher percentage of Detroit Diesel, Cummins, Paccar & Navistar units
- Good data control to measure and track results
  - Spend a little more on premium engine oil to save a lot more in diesel fuel
  - Fuel purchasing and maintenance budgets likely controlled separately
  - May require group decision-making to achieve a win for the greater good

How confident are we in our data?

WARRANTY

We will extend our standard limited product warranty to include fleets using API FA-4 Phillips 66 Guardol FE 10W-30 and Kendall Super-D FE 10W-30 in the following engine models:

- **All 2010 and newer Detroit Diesel (DTNA) engines**
- **All 2014 and newer Cummins, PACCAR, Int'l / Navistar and Volvo* / Mack* engines**

**Prior to switching to FA-4, Volvo / Mack owners should discuss with their sales reps the potential for temporary lower oil pressure under certain conditions.*

PHILLIPS 66 LUBRICANTS

Phillips 66® API FA-4 Products Limited Warranty

Phillips 66 Commercial Lubricants Division guarantees that its Phillips 66 Guardol® FE 10W-30 meets or exceeds the specifications stated by Phillips 66, and that it is free from defects. Therefore, Phillips 66 will pay for parts and labor deemed reasonably necessary to repair damage to engines or other pieces of equipment if it can be demonstrated that the damage was caused solely and directly by a breach of this warranty by Phillips 66.

This warranty protects the following equipment against lubricant-related failure in on-highway service:

- 2010 and newer Detroit Diesel (DTNA) engines
- 2014 and newer Cummins, International / Navistar, PACCAR and Volvo / Mack engines

This warranty protects your equipment against lubricant-related failure as long as:

- It is serviced with Phillips 66 Guardol FE 10W-30 (API FA-4) and the equipment is used under normal operating conditions in over-the-road service
- The engine or equipment was operated as specified by the engine or equipment manufacturer's maintenance schedule
- The lubricant was changed as specified by the engine or equipment manufacturer maintenance schedule
- Written documentation or maintenance records are provided that show the engine or equipment was serviced and maintained at regular intervals as specified by the manufacturer
- The proper lubricant level has been maintained in the engine or equipment through documentation of frequency of oil make-up
- A historical record of lubricant brands and types used during the life of the engine or equipment is provided, and the date of last use prior to switching to Phillips 66 Guardol FE 10W-30
- Phillips 66 is provided with a new and used sample of the Phillips 66 Guardol FE 10W-30, with the plant fill codes, that are believed to be the cause of the engine or equipment failure, and Phillips 66 personnel are allowed to inspect the damaged engine or equipment, take samples, and perform lab tests on the samples
- Prompt notice of the problem is given to allow Phillips 66 to investigate the problem
- This warranty shall be void if: (1) the damage is related to use of other competitive lubricants; (2) the damage is related to engine or equipment modification; or (3) the owner/operator has failed to operate or maintain the engine or equipment as required by the manufacturer

PHILLIPS 66 IS NOT RESPONSIBLE FOR (AND HEREBY DISCLAIMS ALL LIABILITY FOR) SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES OR LOSSES. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES REGARDING PHILLIPS 66 BRANDED LUBRICANTS, EXPRESSED OR IMPLIED, INCLUDING BUT NOT LIMITED TO THOSE OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.

To submit a claim under this warranty, please contact your Marketer Sales Representative, Lube Engineer or call a Hotline Consultant @ 1-877-445-9198 to report the problem so we can resolve it promptly.

THANK YOU