

Hyperlinked Table of Contents;

Contents

Automotive Training Authority (ATA) welcomes you: - 15 -

Bill Peek and Doc Nall: - 16 -

Objectives..... - 16 -

Three steps to Cleaner Emissions - 17 -

Diesel Particulate Matter (PM) - 18 -

Nitrogen Oxides (NO_x)..... - 18 -

Hydrocarbons (HC) - 19 -

Carbon Monoxide (CO)..... - 19 -

Diesel Emissions Reduction Act 2010 - 19 -

Fuel - 19 -

Oil - 20 -

Selective Catalytic Reduction (SCR)..... - 20 -

Exhaust Gas Recirculation (EGR) - 21 -

Regeneration - 21 -

Urea..... - 22 -

Technology choices - 22 -

Clean air - 22 -

Tier 3..... - 23 -

Tier 4..... - 23 -

Euro 4..... - 23 -

Euro 5..... - 23 -

Euro 6..... - 23 -

IMPORTANT SAFETY NOTICE: - 23 -

Compression Ignition Engine: - 24 -

Four Cycle Engine:..... - 25 -

COMPRESSION STROKE..... - 25 -

COMPRESSION IGNITION - 25 -

POWER STROKE	- 25 -
EXHAUST STROKE.....	- 25 -
Fuel Quality and Condition	- 26 -
Cloud Point	- 26 -
Pour Point.....	- 26 -
Low Temperature Flow Test (LTFT).....	- 26 -
Cold Filter Plugging Point (CFPP)	- 27 -
Cetane	- 27 -
Cetane boosters	- 27 -
Clean Fuel Sample.....	- 28 -
Organic contamination (slime)	- 28 -
Diesel fuel lubricity	- 29 -
Fuel Sample #1	- 29 -
Fuel Sample #2.....	- 29 -
Fuel Sample #3	- 29 -
Fuel Sample #4.....	- 30 -
Fuel Sample #5.....	- 30 -
Diesel Fuel Labeling Requirements	- 32 -
Sulfur in fuel	- 32 -
Ultra-Low Sulfur Diesel Fuel	- 32 -
The Power Stroke History	- 34 -
6.0 L Power Stroke.....	- 35 -
6.4 L Power Stroke.....	- 35 -
6.7 L Power Stroke	- 35 -
VIN label.....	- 37 -
VIN for Version A Engine.....	- 38 -
Calibration Number	- 39 -
Engine Access	- 40 -
OBD-II Complaint.....	- 40 -
Diagnostic test modes.....	- 41 -

Mode 1	- 41 -
Mode 2	- 41 -
Mode 3	- 41 -
Mode 4	- 41 -
Mode 5	- 41 -
Mode 6	- 41 -
Mode 7	- 41 -
Mode 8	- 41 -
Mode 9	- 41 -
Mode 10	- 42 -
Scan Data	- 42 -
Graphed Scan Data	- 42 -
Misfire Data	- 43 -
Mode 6 data.....	- 44 -
Engine Manufacturer Diagnostics (EMD)	- 44 -
6.0 L Fuel System.....	- 45 -
Fuel Tank	- 47 -
Fuel Pressure	- 47 -
Fuel Tank Module	- 49 -
Filters from a rusty fuel tank.....	- 50 -
6.0 L Fuel Flow	- 50 -
Horizontal Fuel Conditioning Module (HFCM)	- 51 -
Supply to Secondary Fuel Filter	- 52 -
The Secondary Fuel Filter Housing	- 53 -
Fuel Lines at Secondary Fuel Filter	- 54 -
Fuel test Port at Secondary Fuel Filter	- 55 -
Test Port is threaded for a pressure gauge.....	- 56 -
Fuel pressure Gauge Adapter.....	- 57 -
Fuel Pressure Regulator.....	- 58 -
Fuel pressure update kit.....	- 60 -

Secondary Fuel Pressure Filter Cover	- 61 -
Preferred Method to remove the cover.....	- 62 -
Secondary Fuel Filter Element.....	- 63 -
Draining fuel from the element.....	- 64 -
Pressure Regulator Passage	- 66 -
Fuel Inlet Check Valves	- 67 -
Fuel Inlet at Injector	- 68 -
6.0 L Fuel Delivery System Components	- 68 -
Horizontal Fuel Conditioning Module (HFCM)	- 69 -
Filter End Cap	- 70 -
Making a Fuel pressure test port.....	- 73 -
Connection for Fuel Pump Current.....	- 74 -
The fuel pump may be tested with a lab scope.....	- 75 -
Power Distribution Diagram.....	- 76 -
Normal Fuel Pump Current Flow.....	- 77 -
Abnormal Current Flow.....	- 77 -
Bi-directional fuel pump Control.....	- 79 -
Primary Fuel Filter	- 80 -
Fuel / Water Separator	- 81 -
Water in fuel sensor.....	- 82 -
Water in fuel switches Recall:	- 82 -
Drain Water when WIF Lamp is on.....	- 83 -
Use a hex wrench to open drain.....	- 84 -
Drain all water from HFCM	- 85 -
Diesel Thermo Recirculation Valve (DTRM).....	- 85 -
Hydraulically actuated, electronically controlled, Unit Injectors (HEUI).....	- 86 -
Stages of Injection	- 89 -
Injector Pulse Width.....	- 93 -
High Pressure Oil	- 96 -
Intensifier Piston	- 97 -

Hydraulic Intensifier.....	- 98 -
Fuel Pressure	- 99 -
Injection Nozzle	- 99 -
Fuel injector operation.....	- 100 -
Actual injector on time	- 101 -
Injector spray pattern.....	- 102 -
Injector removal	- 103 -
Air in fuel system	- 104 -
Starting Injector buzz test	- 105 -
Buzz test results.....	- 106 -
Injector/FICM Test.....	- 106 -
Fuel Management	- 106 -
Fuel Management System Major Components	- 107 -
Lubrication System.....	- 107 -
High Pressure Oil System (HPOP)	- 109 -
High Pressure Oil Pump	- 110 -
Oil Reservoir	- 111 -
Oil Cooler.....	- 112 -
Oil Cooler Housing & Filter Base.....	- 112 -
6.0 L Oil Cooler Failure	- 112 -
Oil filter, stand pipe and housing.....	- 113 -
Oil Filter Removal.....	- 113 -
Oil Filter Stand Pipe	- 114 -
Injection Control Pressure Regulator (IPR)	- 115 -
MFDES Mass Fuel Desired	- 116 -
IPR (% of duty cycle (IPC duty cycle).....	- 116 -
IPC, Injection Control Pressure (Oil).....	- 116 -
Minimum ICP pressure to open the injectors	- 117 -
Injection Control Pressure Sensor (ICP)	- 118 -
IPR and ICP	- 120 -

Bi-directional IRP control.....	- 121 -
IPR and ICP Scan Data Testing.....	- 121 -
Injector pressure regulator and injector control pressure PIDs.....	- 122 -
Actual IPC scan Data.....	- 122 -
IPC Diagnostic Check.....	- 122 -
High Pressure Oil System Air Pressure Check.....	- 123 -
High Pressure Oil Leak Test Adapter.....	- 123 -
Diagnostic Check.....	- 124 -
Snap to Connect, old and new.....	- 125 -
Stand Pipes and D plugs.....	- 126 -
High Oil Pressure Common Rail Leak Points.....	- 127 -
High Pressure Common Rails Old and New.....	- 128 -
Fuel Injection Control Module (FICM).....	- 129 -
Injector Coil Driver example.....	- 130 -
Injector Connectors.....	- 131 -
FICM B+ Supplies.....	- 132 -
FICM Main Injector Driver power (7 pin).....	- 133 -
FICM Main Injector Driver power (4 pin).....	- 134 -
4 and 7 Pin FICM Testing.....	- 134 -
FICM SYNC.....	- 135 -
Diagnosing FICM SYNC.....	- 136 -
Air Management System.....	- 136 -
Air Filter Housing Assembly.....	- 137 -
Air Filer.....	- 137 -
Air Minder and Warning Lamp.....	- 138 -
Mass Air Flow Sensor.....	- 139 -
MAF Sensing Element.....	- 140 -
The Mass Air Flow (MAF) sensor.....	- 140 -
Turbocharger.....	- 141 -
Turbocharger Energy Recovery.....	- 141 -

Boost.....	- 142 -
Variable Geometry Turbocharger (VGT).....	- 142 -
The Variable Geometry control valve.....	- 144 -
Variable Geometry control valve Scan Data.....	- 146 -
Variable Geometry control valve.....	- 146 -
Variable Geometry control valve Cam Follower.....	- 147 -
VGT Control valve.....	- 147 -
VGT Control Solenoid Connector.....	- 148 -
Checking VGT operation.....	- 149 -
VGT Control Valve Test.....	- 150 -
Adaptive Turbocharger Learn.....	- 150 -
MAP Reaction to VGT Changes.....	- 152 -
Charge Air Cooler.....	- 153 -
Intake Manifold.....	- 154 -
Inlet Air Temperature 1.....	- 155 -
Inlet Air Temperature 2.....	- 155 -
Thermistors.....	- 155 -
Emission Control.....	- 155 -
Exhaust Gas Recirculation (EGR).....	- 155 -
After-Treatment Systems.....	- 155 -
Exhaust Gas Recirculation (EGR).....	- 156 -
EGR Valve Position Sensor (EGRVP).....	- 156 -
EGR cooler.....	- 157 -
Checking the EGR cooler for leaks.....	- 158 -
Indication of Leaking EGR.....	- 160 -
Symptom of leaking EGR cooler.....	- 160 -
EGR Throttle Plate.....	- 161 -
Electronic Throttle Control.....	- 162 -
EP (Exhaust Pressure) Sensor.....	- 163 -
Turbo VGT duty cycle and Exhaust back pressure.....	- 164 -

Glow Plug Diagram.....	- 166 -
Glow Plug System.....	- 166 -
Glow Plug Control Module (GPCM).....	- 167 -
Typical Glow Plug DTC.....	- 168 -
Glow Plug Bi-directional Testing.....	- 168 -
Glow Plug Current Test.....	- 169 -
Test Connections for all Glow Plugs.....	- 170 -
Test Connections for one Glow Plug.....	- 171 -
Model Year 2004 6.0 L Power Stroke Changes.....	- 171 -
2005 Model Year 6.0 L Power Stroke Changes.....	- 172 -
Power Stroke 6.4 L engine.....	- 172 -
Common Rail High Pressure Fuel.....	- 174 -
6.4 L Fuel Management System Major Components.....	- 174 -
High Pressure Fuel Lines.....	- 175 -
High Pressure Piezo Injectors.....	- 176 -
6.4 L High Pressure Fuel System Flow:.....	- 176 -
Fuel Distribution Diagram.....	- 177 -
Horizontal Fuel Conditioning Module (HFCM).....	- 178 -
Secondary fuel filter housing.....	- 179 -
High Pressure Fuel Pump.....	- 179 -
Pressure Control and Volume Control Valves.....	- 181 -
Making a Fuel pressure test port.....	- 181 -
Low Current Fuel Pump Connection.....	- 182 -
The fuel pump may be tested with a lab scope.....	- 183 -
Power Distribution Diagram.....	- 184 -
Fuel Pump Diagram.....	- 185 -
Low Current Fuel Pump Waveform.....	- 186 -
Defective Fuel Pump Pattern.....	- 187 -
Bi-directional Fuel Pump Control.....	- 188 -
6.4 L Secondary Fuel Filter.....	- 189 -

Fuel Pressure Regulator.....	- 190 -
High Pressure Fuel Pump	- 191 -
Internal Transfer Pump	- 192 -
High pressure common fuel rails	- 193 -
6.4 L Fuel Injectors	- 194 -
6.4 L Injectors (Piezo Stack).....	- 195 -
Piezo injectors key benefits	- 196 -
Piezo Fuel Injectors	- 196 -
Fuel Injector Piezo Actuator	- 197 -
Hydraulic Coupler	- 197 -
Control Valve	- 198 -
Injector Nozzle Needle	- 198 -
Pilot and Main Injection Events.....	- 198 -
Multiple Injection Technology	- 199 -
Switching the polarity.....	- 199 -
Steel Fuel Lines	- 200 -
6.4 L Air Management System	- 201 -
Air Filter Housing Assembly	- 202 -
Air Mass and Temperature	- 202 -
Series Sequential Turbocharger	- 203 -
Turbocharger Actuator	- 204 -
VGT Control Valve Flow	- 205 -
Exhaust Pressure Sensor	- 207 -
Adaptive Turbocharger Learn.....	- 208 -
Charge Air Cooler (CAC).....	- 210 -
CAC temperature sensor	- 211 -
After-Treatment Systems.....	- 211 -
Exhaust Gas Recirculation (EGR)	- 212 -
EGR Valve Position Sensor (EGRVP).....	- 212 -
EGR cooler.....	- 213 -

Symptom of leaking EGR cooler	- 214 -
Checking the EGR cooler for leaks.....	- 215 -
EGR Throttle Plate	- 217 -
Electronic Throttle Control Motor	- 218 -
Glow Plug Control Module (GPCM).....	- 218 -
Typical Glow Plug DTC	- 219 -
Scan Tool Bi-directional Control	- 220 -
Glow Plug Current Flow.....	- 221 -
Glow Plug Test.....	- 221 -
Test All Glow Plugs	- 222 -
Testing One Glow Plug	- 223 -
Particulate Matter	- 223 -
Diesel Particulate Filter	- 225 -
Scan Data for Soot in Oil.....	- 226 -
Scan Data for Particulates.....	- 226 -
NOx Scan Data.....	- 227 -
DPF Regeneration	- 227 -
Operation During Regeneration	- 227 -
DPF Pressure Sensor	- 228 -
Diesel Particulate Filter Regeneration.....	- 229 -
Regeneration Process.....	- 229 -
Passive Regeneration.....	- 229 -
Active Regeneration	- 230 -
Manual Regeneration.....	- 230 -
Frequency of Regeneration.....	- 230 -
Non-Burnable Ash.....	- 230 -
Operation during Regeneration.....	- 231 -
Diesel Oxidation Catalyst (DOC)	- 231 -
Introduction of the 6.7 L (Scorpion)	- 232 -
Manifold Arrangement	- 233 -

Cooling Systems.....	- 233 -
Air Management System	- 234 -
Pickup Turbocharger (Wide Frame)	- 234 -
Chassis Cab Turbocharger	- 234 -
Charge Air Cooler (CAC).....	- 235 -
The 6.7 L uses a throttle plate.....	- 235 -
Glow Plugs.....	- 235 -
Fuel System.....	- 235 -
Selective Catalyst Reduction (SCR)	- 236 -
Reductant or Diesel Exhaust Fluid (DEF).....	- 236 -
Reductant or Diesel Exhaust Fluid (DEF).....	- 236 -
Diesel Exhaust Fluid.....	- 237 -
Reductant Tank	- 238 -
Reductant Dosing Module	- 239 -
Reductant Exhaust Mixer	- 239 -
Reductant Pump	- 240 -
Reductant Heaters.....	- 241 -
Reductant Fluid Level Sensors	- 242 -
Reductant Pressure Sensor.....	- 243 -
Reductant Pressure Sensor Data	- 244 -
NO _x Sensor Module.....	- 244 -
NO _x Sensor.....	- 245 -
Bio Fuel Training	- 245 -
Introduction.....	- 245 -
ASTM Specifications	- 247 -
Cetane Quality.....	- 248 -
Volatility	- 250 -
Viscosity	- 250 -
Carbon Residue	- 251 -
Sulfur Content	- 251 -

Flash Point.....	- 251 -
Low Temperature Operability	- 251 -
Ash.....	- 252 -
Corrosion Properties.....	- 252 -
Water and Sediment	- 252 -
Lubricity.....	- 252 -
Other Important Fuel Quality Issues	- 253 -
Gravity/Density	- 253 -
Heating Value (Energy Content)	- 254 -
Thermal Stability / Oxidation Stability	- 254 -
Microbial Contamination.....	- 254 -
Housekeeping and Fuel Handling Procedures.....	- 255 -
Diesel Fuel Additives	- 255 -
Premium Diesel Fuel	- 257 -
Cetane Number: Minimum 47	- 258 -
Diesel Engines and Diesel Fuel Driven by Regulations	- 259 -
Environmental Regulations	- 259 -
Strategies for Compliance – Engine Technology	- 262 -
Fuel Injection Basics	- 262 -
Fuel Injection Systems	- 263 -
Turbocharging	- 266 -
After-Treatment Technologies.....	- 267 -
Engine Oil and Coolant	- 268 -
Retrofit Technologies	- 268 -
Compliance Strategies – Diesel Fuel	- 269 -
Renewable Fuels Standard.....	- 270 -
Biodiesel and Biodiesel Blends	- 270 -
Biodiesel and Biodiesel Blends	- 271 -
Distillate Fuels	- 272 -
Other Properties of Interest.....	- 275 -

Lubricity.....	- 276 -
Cloud Point/Pour Point.....	- 276 -
Other Fuel Quality Considerations	- 276 -
The Benefits and Concerns of Biodiesel and Biodiesel Blend Use.....	- 277 -
Manufacturer Guidelines	- 279 -
Retail Dispenser Labeling.....	- 280 -
Identification of Biodiesel Product	- 281 -
Other Diesel Fuel Alternatives.....	- 282 -
Frequently Asked Questions.....	- 282 -
Engine and Vehicle Manufacturers' Positions on Biodiesel.....	- 285 -
Mercedes-Benz Position on Biodiesel as of January 19, 2007	- 285 -
Volkswagen of America Statement Biodiesel Fuel	- 286 -
Ford Motor Company Position	- 287 -
General Motors Corporation.....	- 288 -
Cummins	- 288 -
Case IH.....	- 291 -
Case IH Engine Biodiesel Blend Statement	- 293 -
General Biodiesel User Guides:.....	- 293 -
User Guides for Blends of B6 through B20	- 294 -
User Guides for Biodiesel Blends Greater than B20	- 294 -
Fuel Treatment for Biofuels.....	- 294 -
Mack Trucks, Inc.....	- 295 -
ASTM Standards	- 295 -
Certified Biodiesel Required	- 296 -
Storage of Biodiesel	- 296 -
Fuel Filter Change Intervals:	- 296 -
Detroit Diesel Corporation	- 296 -
International Truck and Engine Corporation.....	- 297 -
Volvo Truck Corporation	- 298 -
UD Trucks.....	- 299 -

John Deere.....	- 299 -
New Holland	- 304 -
Kubota Tractor Corporation.....	- 304 -
Kubota Products Approved for Use with Biodiesel.....	- 306 -
Fairbanks Morse Engine	- 306 -
Engine Manufacturers Association	- 307 -
Biodiesel Blends.....	- 307 -
Warranties	- 307 -
Conclusions	- 308 -
Additional Biodiesel Information Sources	- 309 -
Commonly Used Acronyms.....	- 310 -
Conversion Formulas.....	- 311 -

Ford Direct Injection Diesel (Power Stroke) Diagnostics and Repair

Automotive Training Authority (ATA) welcomes you:



Welcome to the Ford direct injection diesel (Powerstroke) diagnostics and repair class.

This class is brought to you by: **Automotive Training Authority (ATA). Haru Lindsey and Susan Hughes may be contacted at, 1(800) 575 4282 3231 Business Park Dr. Bldg. C 231 Vista, CA 92081 Fax: 1-888-255-7760.**

ATA offers detailed comprehensive courses from advanced diagnostics to repair troubleshooting techniques, in both a hands-on and classroom settings, held in every major City across the Nation. The classes are tailored to meet the needs of the Government Fleet

and aftermarket repair shops technician; one of our expert instructors will come to you and help your shop run more efficiently.

Automotive Training Authority is committed to providing our customers with quality technical training that is surpassed by no other. We go above and beyond re-writing Manufacturer's information, or simply reading from a book that someone else has written. All of our classes are based on "Real World" drivability problems that have been created by spending time in shops; researching and developing material that address the problems that technicians face day to day. Using a hands-on approach, our technical training courses provide you with the information needed to advance your mechanical skills.

Haru will assist you in setting up classes.

Please contact Susan if you have a question about your certificate or to offer a location to hold a class in the future.

Bill Peek and Doc Nall:

Bill Peek and Doc Nall have collaborated for over 25 years to bring you advanced automotive training. They have influenced automotive training since the 1980's. Together they changed automotive through Target Training Systems. Before Target Training all training was simply a copy of what the manufacturers were offering. Bill and Doc brought you specification based testing and complex diagnostics became simpler and shops were able to improve their efficiency and profits.

Contact Bill or Doc to discuss any special information your shop needs. As an example, we are working with fleets to create a specific version of the world famous "Smart Spec." Fleets tell us they don't need specifications on every vehicle manufactured, just the ones they have in their organization. Smart Spec can become "My Spec" through customizing it for your fleet. We come to your location and research the vehicles you have and deliver to your service department an interactive program filled with specifications and schematics so your technicians can become faster and more accurate when diagnosing problems. Think about it; a program that is custom made for your shop at your shop to be used by your technicians. Does your shop have needs to help improve its efficiency? **Contact Bill or Doc for additional information.** We can help! docnall@gmail.com
mpcbill@gmail.com

Objectives

- Diesel engine operation (Compression Ignition)
- Diesel Fuel

- Power Stroke Systems Overview
- Fuel System Operation
- Injector Operation
- High Pressure Oil System
- Air Management operation
- Turbocharging Operation
- Biodiesel issues, Biodiesel blends



7.3 Power Stroke The "Good"



6.0 Power Stroke The "Bad"



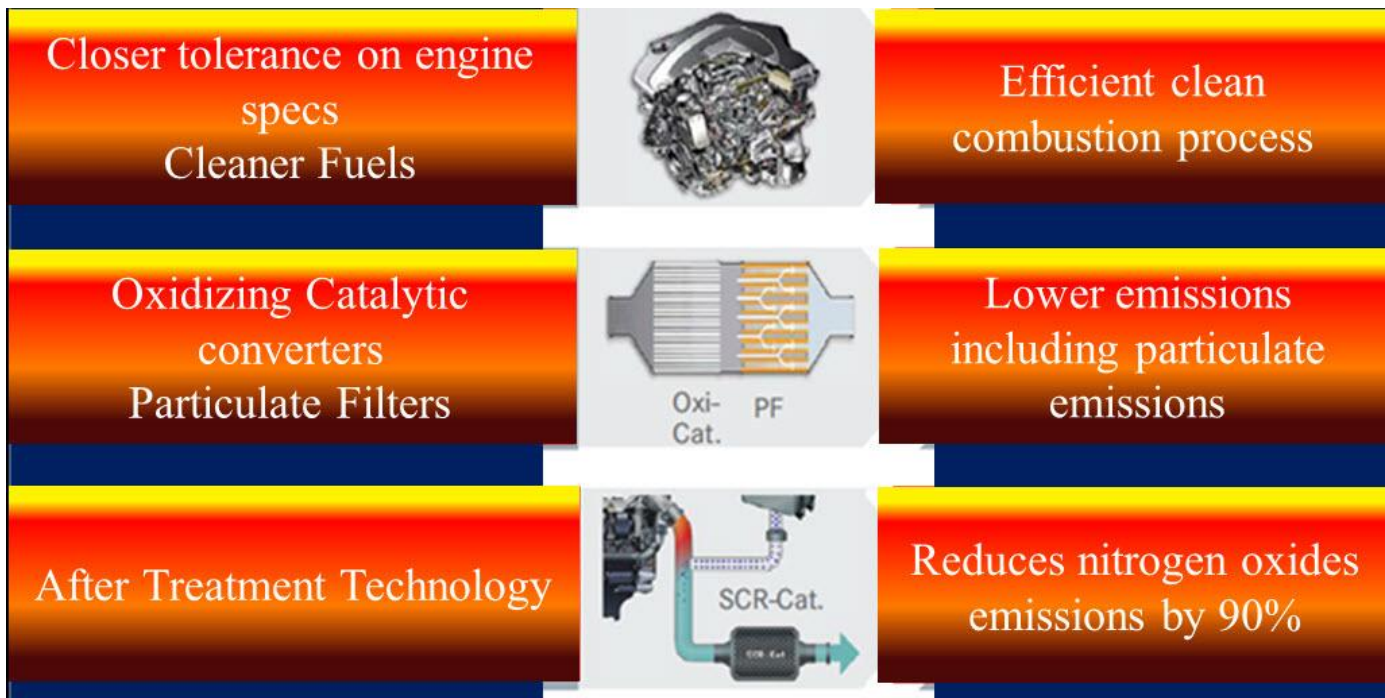
6.4 Power Stroke The "Ugly"

This course covers 6.0, 6.4, and the 6.7 L engines. The interactive DVD handout will have the entire training program for all three engines. In the class repeating the same information will be avoided. As an example; the glow plug systems on the 6.0 L and the 6.4 L are almost identical and would only be discussed one time, unless there are questions that need to be answered. Not repeating a subject when they are the same for each engine will keep the class moving and boring technicians will be avoided. The 6.7 L engine is so new there isn't enough information about real world problems. It will be covered in detail in a follow up class.



Three steps to Cleaner Emissions

The reason Ford abandoned the popular 7.3 L is because it wouldn't meet the emission standards. The changes with the 6.0 L were mostly because of problems but some of them were because of emissions. Diesel has seen many changes in order to meet the new



emission standards.

The way diesel fuel burns makes it one of the dirtiest of all motor transportation fuels. The numbers and characteristics of diesel exhaust pollutants require more sophisticated engine management and exhaust scrubbing technologies than any other fuel. For these reasons, diesel engines require more involved and complicated engineering and manufacturing standards.

There are several types of emissions that are regulated in the United States. Tailpipe emissions standards classify and regulate these recognized pollutants:

Diesel Particulate Matter (PM)

These are the ultra-fine particles that are suspended in the diesel exhaust. PM causes the black, sooty smoke that's given diesels a bad name.

Nitrogen Oxides (NO_x)

This is the broad family of oxides of nitrogen. Though there are several components, the regulated portions of NO_x are nitric oxide (NO) and nitrogen dioxide (NO₂). These are the acidic gases that contribute to smog formation and acid rain.

Hydrocarbons (HC)

These are generally referred to as unburned hydrocarbons—it's basically raw, unburned fuel that escapes through the exhaust.

Carbon Monoxide (CO)

Carbon monoxide is a lethal, odorless gas that forms in the exhaust stream during incomplete combustion of fuel.

Diesel Emissions Reduction Act 2010

In 2010 Engine manufacturers will have to meet the US Environmental Protection Agency's more stringent diesel emission standards. These regulations dramatically decrease discharges of particulate matter (soot and ash) and nitrogen oxide (NO_x), virtually eliminating these emissions from on-road diesel engines.

The standards reduce emissions to 0.2 gram per brake horsepower hour (g/bhp-hr) for NO_x and 0.01 g/bhp-hr for particulate.

Basically, particulate matter (PM) is formed by the incomplete combustions of fuel in diesel engines. NO_x is formed in small amounts when fuel is burned at high temperatures and pressures during an engine's combustion process.

Engine manufacturers are meeting the 2010 emissions standards through a variety of means. They are making engine modifications for cleaner combustion and adding exhaust Aftertreatment (EGA) devices. These remove pollutants from exhaust gases after they leave the engine's combustion chamber.

Meeting the reduced pollutants standards has required a change in diesel fuel to ultra-low sulfur diesel fuel (ULSD) and a reformulation of engine oils.

Fuel

Since 1993, diesel truck engines have been using low-sulfur diesel fuel, which emits 500 parts per million (ppm) of sulfur. Ultra-low sulfur diesel, required by the EPA for 2007-emission compliant engines, began replacing low-sulfur fuel starting in 2006.

ULSD is a cleaner burning fuel that inherently produces less particulate emissions in both older and new engines. It emits only 15 ppm of sulfur, a 97% reduction in the sulfur content compared to low sulfur diesel.

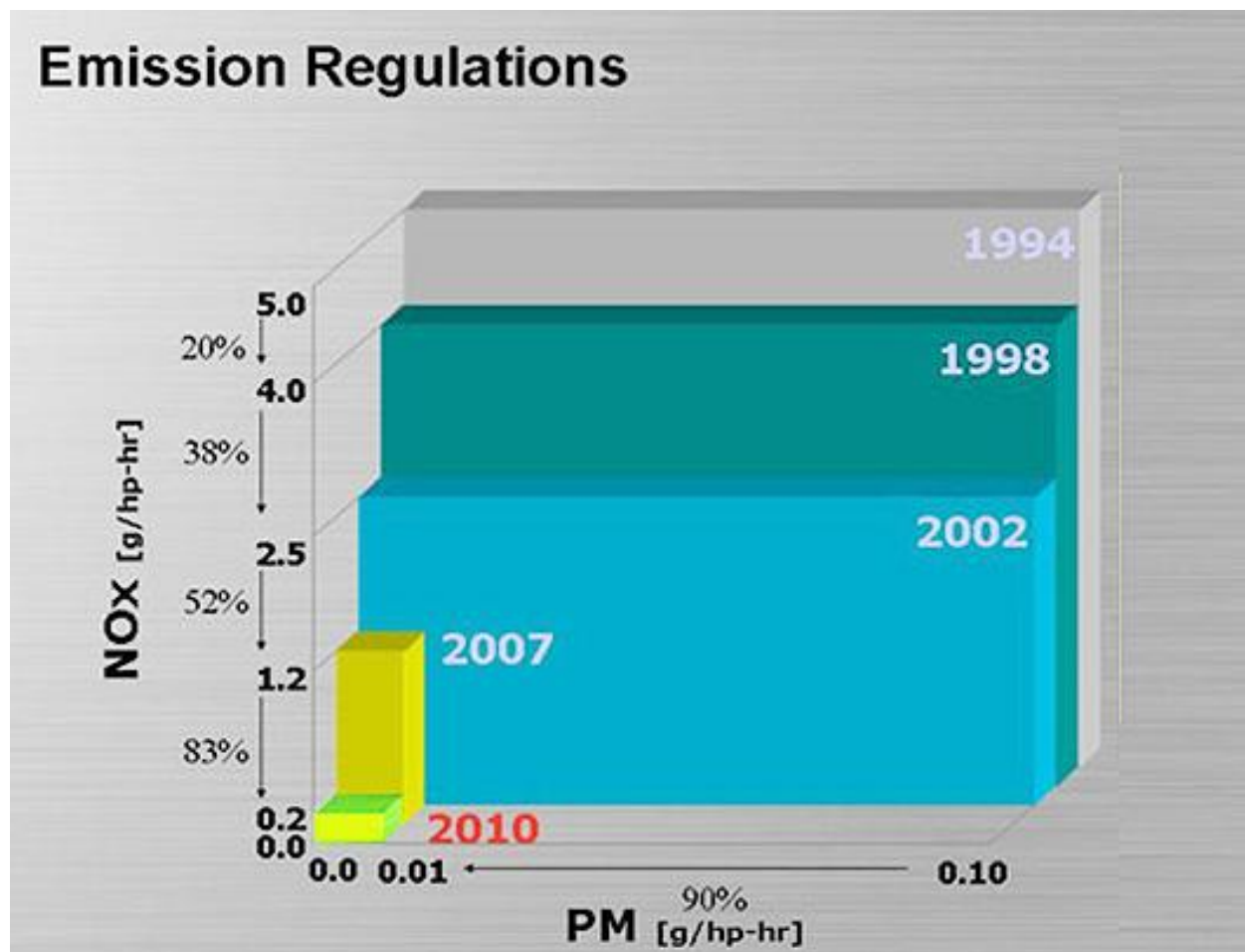
Oil

Lubricating oils had to be developed for compatibility with the new low-emissions solutions. Designated CJ-4, these oils are formulated with lower sulfated ash, phosphorus, and sulfur levels to ensure protection of the Aftertreatment devices and to provide better wear protection, higher oxidation protection, and better soot handling characteristics.

Beyond this, engine manufacturers are using a variety of means to comply with the 2010 diesel emissions regulations. Two particular technologies have evolved to control nitrogen oxide emissions: selective catalytic reduction (SCR) and exhaust gas recirculation (EGR). To handle particulate matter emissions, diesel particulate filter technology has been developed.

Selective Catalytic Reduction (SCR)

In essence, SCR is a system that works by a chemical reaction triggered by heat. A fine



mist of diesel exhaust fluid (DEF) is injected into the downstream exhaust. The exhaust's high temperature converts nitrogen oxide levels into harmless levels of nitrogen and water vapor and eliminates the diesel smell.

Diesel exhaust fluid, also known as urea, is an organic compound that is harmless to the environment. Urea already is widely distributed for many industrial and agricultural needs.

Urea consumption varies with duty cycle and other factors but is not expected to exceed 5% of fuel consumption.

SCR systems require a separate container for urea, along with extra wiring, hoses, and sensors to manage the injection flow of urea into the truck's exhaust stream.

Exhaust Gas Recirculation (EGR)

In simple terms, exhaust gas recirculation, also referred to as cooled EGR, captures a small proportion of exhaust gas and injects into the engine's combustion cycle, along with fresh air and fuel. This slows down the violence of the combustion itself, resulting in a lower level of nitrogen oxide emissions.

Unlike SCR, EGR does not require an additive.

Both EGR and SCR are proven approaches to emissions reduction and are used in a wide range of applications for diesel-powered commercial vehicles around the world.

Diesel particulate filters (DPF), installed in exhaust stream, typically contain a porous substance to “strain” and “catch” the microscopic-sized particulate matter from the exhaust stream and prevent these particles from reaching the atmosphere.

Regeneration

Over time, these traps “fill up” and need to be periodically cleaned by means of a regeneration process. Otherwise, the filter can plug up and adversely affect the engine's performance and fuel economy.

This regeneration process is typically achieved by burning off the trapped particulate matter.

The two types of regeneration are passive and active. With passive regeneration, particulate matter is continually burned off while a vehicle is driven. Active regeneration refers to a periodic burning of particulate matter by adding a small amount of diesel fuel into the exhaust gas.

Active regenerations typically won't be necessary for those applications where truck engines work hard enough to generate the heat necessary to continually burn off the trapped particulate matter, as in highway applications. They may, however, be required for applications such as city or suburban operations where vehicles do a lot of stop-and-go operation or prolonged idling, and engines don't generate enough heat for regeneration.

Drivers will not notice passive regeneration, as the engine continues to operate normally. The only sign of the regeneration is an indicator light on the dashboard.

Urea

Toward that end, a number of companies in the refining, packaging, and distribution segments of the nation's fuel market are preparing to provide diesel exhaust fluid availability.

Technology choices

Engine manufacturers are taking different approaches to meeting the more stringent 2010 US EPA-mandated diesel emission standards for their heavy-duty diesels.

Navistar is going with exhaust gas recirculation (EGR) technology for its Maxx Force engines.

Detroit Diesel, Mack, Paccar, and Volvo will be using selective catalytic reduction (SCR) technology.

Cummins will offer both EGR and SCR technologies.

Caterpillar, which recently announced it will exit the North American heavy-duty diesel truck engine market by 2010, will not be supplying 2010 compliant engines.

Clean air

On the federal level, the EPA has regulated on-highway diesel engine emissions standards through the Clean Air Act (CAA) since 1970. Emission regulations are phased in over a number of years, gradually reducing the legal levels of emissions for various sizes of diesel engines.

These phases are identified as Tiers. Higher Tier levels require greater reductions in emissions.

Tier 3

Tier 3 emission standards will take effect in 2012

Tier 4

Tier 4 emission standards will take effect in 2015.

The EPA estimates that Tier 3 standards will reduce NOx emissions from diesel engines by about 1 million tons per year, an effect similar to taking 35 million passenger cars off the road. Tier 4 standards are even more rigorous.

In the European Union, emissions standards are identified as Stages or Euro standards.

Euro 4

Euro 4 standards were implemented in 2006, setting PM emissions at 3.5 gram per kilowatt-hour (g/kWh) and NOx emissions at 0.02 g/kWh.

Euro 5

Euro 5 went into effect in 2009, requires a nearly 43% reduction in NOx emissions to 2.0 g/kWh. PM remains unchanged.

Euro 6

Euro 6 requirements, which will go it effect around 2013, are still being determined. It is expected, however, these regulations will decrease emissions of PM by 50% and NOx about 75% to 80%, compared with Euro 5 standards.

IMPORTANT SAFETY NOTICE:

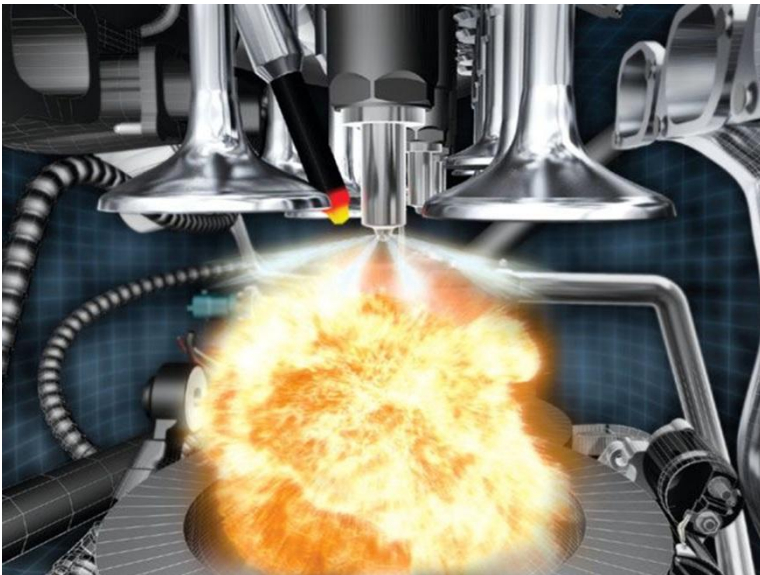
Appropriate service methods and proper repair procedures are essential for the safe, reliable operation of all motor vehicles, as well as, the personal safety of the individual performing the work. This manual provides general directions for accomplishing service repair work with tested, effective techniques. Following the directions will assure reliability. There are numerous variations in the procedures; techniques, tools, parts for servicing vehicles and the skill of the individual doing the work. This manual cannot possibly anticipate all such variations and provide advice or cautions as to each.

Accordingly, anyone who departs from the instructions provided in this manual must first establish that they do not compromise their personal safety or the vehicle integrity by their choice of methods, tools or parts. The following list contains some general WARNINGS

that you should follow when you work on a vehicle. Always wear safety glasses for eye protection. Use safety stands whenever a procedure requires you to be under the vehicle. Be sure that the ignition switch is always in the OFF position, unless otherwise required by the procedure. Never perform any service to the engine with the air cleaner removed and the engine running unless a turbocharger compressor inlet shield is installed. Set the parking brake when working on the vehicle. If you have an automatic transmission, set it in PARK unless instructed otherwise for a specific service operation. If you have a manual transmission, it should be in REVERSE (engine OFF) or NEUTRAL (engine ON) unless instructed otherwise for a specific service operation. Operate the engine only in a well-ventilated area to avoid the danger of carbon monoxide. Keep yourself and your clothing away from moving parts when the engine is running, especially the fan, belts, and the turbocharger compressor. To prevent serious burns, avoid contact with hot metal parts such as the radiator, turbocharger pipes, exhaust manifold, tail pipe, catalytic converter and muffler. Do not smoke while working on the vehicle. To avoid injury, always remove rings, watches, loose hanging jewelry, and loose clothing before beginning to work on a vehicle. Tie long hair securely behind the head. Keep hands and other objects clear of the radiator fan blades.

Compression Ignition Engine:

In a diesel engine, each piston draws in only air on the intake stroke. (Most modern diesels



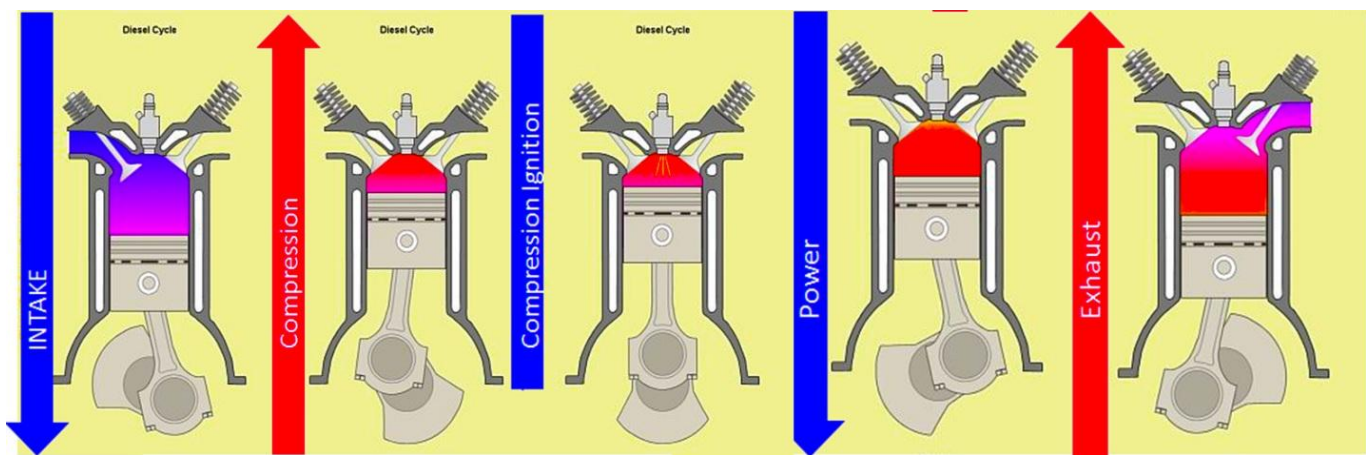
use a turbocharger, an exhaust-driven pump that pushes more air into the cylinder.) Unlike a gasoline engine, there is no restriction on the amount of air; the cylinder always draws in as much as it can. On the compression stroke, the air is compressed to about 1/25th of its original volume. Once the piston reaches the top of its stroke, diesel fuel -- which will only burn under intense pressure and heat -- is sprayed into the cylinder. Diesel fuel doesn't explode; it burns, and the

expanding gasses push the cylinder down. Injection of fuel continues much of the power stroke. As with a gas engine, the exhaust stroke pushes out the spent gases. The mixture is always changing -- diesels run lean (a lower amount of fuel for a given volume of air) when power demand is low, and rich (a higher amount of fuel for a given volume of air) when power demand is high. Diesel engines are classified as compression ignition engines

because they don't require a spark to ignite the air/fuel mixture. High compression, anywhere between 400-450 psi, in the cylinder superheats the air that is drawn into the cylinder. Through correct timing, fuel is injected into the cylinder and mixes with the air and ignites.

Four Cycle Engine:

INTAKE STROKE: — the intake stroke begins at top dead center, and as the piston moves down, the intake valve opens. The downward movement of the piston creates a vacuum in the cylinder, causing the air mixture to be drawn through the intake port into the combustion chamber. As the piston reaches bottom dead center, the intake valve closes.



COMPRESSION STROKE

The compression stroke begins with the piston at bottom dead center and rising up to compress the air in the cylinder. Since both the intake and exhaust valves are closed, there is no escape for the air, and it is compressed to a fraction of its original volume.

COMPRESSION IGNITION

At this point, the fuel is sprayed into the cylinder under very high pressure and is ignited by the heat of the compressed air.

POWER STROKE

The power stroke begins when the fuel and air mixture is ignited, burns and expands and forces the piston down. The valves remain power stroke ends as the piston reaches bottom dead center.

EXHAUST STROKE

The exhaust stroke begins when the piston nears the end of the power stroke and the

exhaust valve is opened. As the piston moves upward towards top dead center, it pushes the burnt gases, resulting from the ignition of the fuel and air mixture, out of the combustion chamber and through the exhaust port. As the piston reaches top dead center, ending the exhaust stroke, the exhaust valve closes, and the intake valve opens to begin the intake stroke for the next cycle. There is an overlap of the exhaust and intake valve to help remove all of the burnt gasses.

Fuel Quality and Condition

Without a spark to start ignition, the fuel quality and the condition of the fuel becomes very important. Before covering the engine itself it is an important consideration to discuss fuel. Diesel fuel accumulates water in the system because hot fuel is returned to the relative cooler tank and condensation is formed. The fuel forms an organic contamination called slime mode which must be removed. At lower temperatures the fuel may Gel, this is sometimes called fuel waxing. All of this can cause problems because fuel system itself is designed and built with very close tolerances. The system controls the fuel with high pressure and the close tolerances re required.

Cloud Point

The cloud point is the temperature at which a cloud of wax crystals first appears in a fuel sample that is cooled under conditions described by ASTM D2500. The cloud point is determined by visually inspecting for a haze in the normally clear fuel.

Pour Point

The pour point is the lowest temperature at which movement of the fuel sample can be determined when the sample container is tilted. The apparatus used is the same as for the Cloud Point and is shown in Figure 1. The sample must be cooled following the procedure described in ASTM D97. At every 3° C of cooling, the sample is inspected and when no movement is detected after 5 seconds, the test is stopped. 3° C is added to the temperature where no movement was observed and this is the pour point. Pour points are always expressed in multiples of 3° C.

Low Temperature Flow Test (LTFT)

The LTFT is designed to evaluate whether a fuel can be expected to pass through an engine fuel filtration system. The test determines the lowest temperature at which 180 ml of fuel can be drawn through a 17 micron screen in 60 seconds or less with 20 kPa of vacuum. The procedure is defined in ASTM D4539.

Cold Filter Plugging Point (CFPP)

The cold filter plugging point, as defined by International Petroleum Standard IP-309 and ASTM D 6371-99, is similar to the LTFT test. It determines the lowest temperature where 20 ml of fuel can be drawn through a 45 micron screen in 60 seconds with 200 mm of water (1.96 kPa) of vacuum.

Additives can lower a diesel fuel's gel point or cloud point and improve its cold flow properties. Most these are typically polymers that diminish the effect of wax crystals on fuel flow by modifying their size and shape.

Biodiesel fuel which is required to be mixed with diesel fuel in many states also adds to gelling. Biodiesel gels at higher temperatures than conventional diesel.

Cetane

Because a diesel engine ignites the fuel without a spark, proper Cetane levels are very important. The Cetane number is a measure of the ignition quality of the fuel. Cetane number affects combustion roughness.

The Results of Wrong Cetane Number are:

- Poor Ignition Quality
- Long Ignition Delay
- Abnormal Combustion
- Abnormally High Combustion Pressure
- Potential Uneven Thrust on Piston / Cylinder
- Louder Engine Knock

Excessive Engine Knock & Smoke at Cold Start Black smoke

With fuel playing an important role in combustion Cetane Booster is recommended by Ford for the Power stroke. There are many Power Stroke owners who rave about Fords Cetane booster.

Cetane boosters

PM-22-A Treats 125 gallons

PM-22-ASU Treats 35 gallons
PM-22-GAL Treats 1000 gallons

Clean Fuel Sample

The owner of this 2004 6.0 L Power Stroke credits Ford's Cetane booster for helping to



keep his truck on the road with 273000 miles on it. This truck was in the shop for maintenance and we noticed how clean the fuel system was. He said that he had used Cetane booster from the first day he owned the truck. Many of those in the know about Power Strokes claim that all of the problems credited to the 6.0 L can be avoided by the correct maintenance. When you pump fuel from the local station you have no idea of its quality so using the Cetane booster is a good idea.

An important consideration is that diesel fuel accumulates water in fuel system because hot fuel is returned to the fuel tank and causes condensation.

Organic contamination (slime)

Organic contamination (slime) Gels at lower temperature (Fuel Waxing). Because of the close tolerances in the fuel system fuel problems can and will cause many different problems up to a no start.

Diesel fuel lubricity

Diesel fuel lubricity is an important property, since the diesel fuel injection system relies on the fuel to lubricate its moving parts.

Fuel Sample #1

A sample of good clean fuel: It has a clear light golden color with no contamination settling to the bottom. Other good samples might be even clearer or a little darker.

Becoming familiar with the look, feel and odor of good diesel fuel may be valuable in identifying fuel related concerns. For example, gasoline in diesel will still look normal but one sniff will tell the real story! Don't be fooled by appearances alone.



Fuel Sample #2

The most common contamination we find. The amber fuel appears slightly cloudy and the water which is heavier than the fuel, settles to the bottom. This is what you want water in your fuel system to do! This allows water to separate and collect in the lowest point in the system for removal. Adding chemicals or additives intended to disperse the water into the fuel will cause damage to the fuel system including pumps, lines and injectors. Keep in mind that the fuel water separator has a limited capacity and ignoring the warning light on the dash may result in water making its way to the injectors.

Fuel Sample #3

This contamination was very fine silt that managed to plug two filters and destroy a fuel pump. The vehicle this sample came from was a tow-in which required a new HFCM, flushing of all fuel lines and the tank was removed and washed. This is an extreme example but it shows how dirt can cause big problems. A vehicle that is operated in very dirty or dusty environments should have its filters changed more frequently than the recommended

15,000 mile interval.

Fuel Sample #4

This is a sample of fuel that has been dyed red to indicate that it is for off road use only. **There are two concerns with red fuel.** Since dyed or marked off-road diesel fuel may contain regular sulfur levels or low sulfur levels it is not approved for highway use as high sulfur levels can damage exhaust emissions components. High levels of sulfur in fuel will also create higher levels of acid in the engine oil which can lead to engine wear and damage. The second reason is that off road fuel is frequently stored in *less than ideal* conditions or containers and is more likely to pick up contamination. The color can range from a light rosy red to a dark almost blackish red depending on the fuel quality and the amount of dye used to color it.

Fuel Sample #5

The contamination in this test tube did not settle and the dark color is worthy of concern. Since we can rule out dirt there are two possibilities. The first is that this fuel has had chemicals or waste oil dumped into it. Not good. If the fuel sample were black, oil contamination from the fuel system is possible in a HEUI fuel system. Another viable contaminant is algae also known as sludge. This algae is the result of fuel breakdown caused by age or microbial activity.

This is another good reason to keep fuel systems water free because bacteria can live in diesel fuel using the water for an oxygen supply. If someone tells you that you have bugs in your fuel take them seriously Algae will clog filters with a dark slimy film accompanied by a foul smelling odor.

Type and Function of Diesel Fuel Additives

Type of Additive	Function
Cetane Number Improver	Improves ignition quality by raising cetane number, better starts, reduces white smoke
Lubricity Improvers	Improve lubricity, better injector & pump lubrication
Detergents / Dispersants	Clean injectors, better spray patterns
Antioxidants	Extend storage life, inhibit oxidation, reduce gum and precipitate formation
Stabilizers	Inhibit oxidation & extend storage life
Metal Deactivators	Deactivate copper compounds in fuel, thereby promoting longer storage life
Biocides	Inhibit bacterial & fungi growth, help prevent fuel filter plugging
Pour Point Depressants	Low temperature operability, improve cold-flow properties
Cloud Point Depressants (Suppressants)	Reduce temperature at which paraffins solubilize
De-Icers	Prevent fuel line freezing
Anti-Foam Agents	Reduce foaming when filling tanks
Smoke Suppressants	Promote more complete combustion, reduce exhaust smoke
Rust Preventors	Reduce formation of rust in fuel systems & storage tanks
Demulsifiers / Dehazers	Used to increase the rate of water separation from the fuel
Dyes	To identify types of diesel for regulatory compliance

Summary of ASTM Specifications

Property	Importance
Cetane Number	Measure of ignitability (ignition quality), reduce knock and smoke
Cetane Index/Aromatics Limit	Limits aromatic content of fuel to prevent adverse emissions impact, reduce knock and smoke
Volatility	Deposits, wear, exhaust smoke
Viscosity	Injector wear & spray pattern, pump wear, filter damage
Sulfur Content	To protect emissions control equipment
Low Temperature Operability	Flow properties, filter plugging
Water & Sediment Content	Filter plugging, injector wear, increased corrosion
Lubricity	Injector & pump wear
Ash Content	Injector & fuel pump wear, piston & ring wear, engine deposits
Corrosion	Protect copper, brass, bronze fuel system parts
Flash Point	Safety during fuel handling & storage
Carbon Residue	Fuel system deposits, combustion chamber deposits

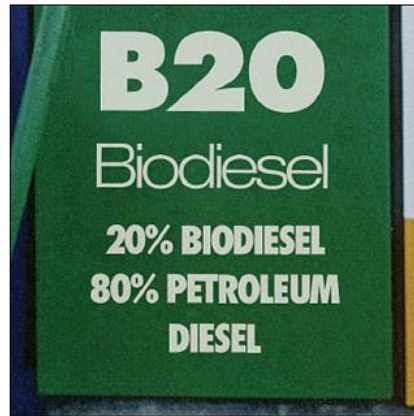
Diesel Fuel Labeling Requirements

Diesel Dispenser Labeling Requirements



<p>ULTRA-LOW SULFUR HIGHWAY DIESEL FUEL (15 ppm Sulfur Maximum)</p> <p><i>Required</i> for use in all model year 2007 and later highway diesel vehicles and engines.</p> <p>Recommended for use in all diesel vehicles and engines.</p>	<p>LOW SULFUR HIGHWAY DIESEL FUEL (500 ppm Sulfur Maximum)</p> <p>WARNING Federal Law <i>prohibits</i> use in model year 2007 and later highway vehicles and engines. Its use may damage these vehicles and engines.</p>	<p>NON-HIGHWAY DIESEL FUEL (May Exceed 500 ppm Sulfur)</p> <p>WARNING Federal Law <i>prohibits</i> use in highway vehicles or engines. Its use may damage these vehicles and engines.</p>
--	--	---

Normally, the diesel fuel sold at the primary vehicle island is ULSD. Low sulfur diesel grades with up to 500 ppm sulfur may be available at some locations through December 2010. It is illegal to use anything other than ULSD in the case of 2007 model year and newer vehicles because using higher sulfur level fuels will render exhaust after-treatment devices ineffective or, at minimum, less effective.



Sulfur in fuel

It is impossible to clean the air, or in particular to reduce air pollution from the transportation sector, without getting sulfur out of fuels. Sulfur is a pollutant directly, but more importantly, sulfur prevents the adoption of all major pollution control technologies. No significant air pollution reduction strategy can work without reducing sulfur to near-zero levels. Sulfur is a naturally occurring component of crude oil and is found in both gasoline and diesel. When those fuels are burned, sulfur is emitted as sulfur dioxide (SO₂) or sulfate particulate matter. Any reduction in fuel sulfur immediately reduces these sulfur compounds and, as sulfur levels decline past a certain point, the benefits increase to include total pollutant emissions.

Ultra-Low Sulfur Diesel Fuel

Ultra-low sulfur diesel (ULSD) is diesel fuel with 15 parts per million or lower sulfur content. The EPA requires 80% of the highway diesel fuel refined in or imported into the United States (100% in California) to be ultra-low sulfur diesel. One hundred percent must

be ULSD nationwide by 2010.

Currently, the vast majority of ultra-low sulfur diesel is produced from petroleum. However, biodiesel (along with some emerging advanced fuels) is inherently ultra-low sulfur and could help meet ULSD requirements in the future.

Ultra-low sulfur content in diesel fuel is beneficial because it enables use of advanced emission control technologies on light- and heavy-duty diesel vehicles. The combination of ULSD with advanced emission control technologies is sometimes called "clean diesel."

Conventional diesels typically use only 70% of the fuel of a comparable gasoline engine, significantly reducing per-mile CO₂ emissions. Even without pollution controls, diesels provide an automatic benefit for CO and HC control. Diesel fuel has the added benefit of low volatility, which virtually eliminates evaporative HC emissions. The primary concerns for diesel engines are NO_x and PM emissions. The impact of fuel sulfur on diesel vehicle emissions is dependent on the control technology contained on the vehicle which can range from no controls to very advanced Aftertreatment controls.

The Power Stroke History

Model Year	HP @ RPM	Torque @ RPM	Notes
1994	210 @ 3,000	425 @ 2,000	7.3 L direct injection, turbocharged 17.5:1 compression
1995	210 @ 3,000	425 @ 2,000	CA trucks receive split shot injectors.
1996	215 @ 3,000	450 @ 2,000	
1997	225 @ 3,000	450 @ 2,000	
1998	225 @ 3,000	450 @ 2,000	All 7.3L Power Strokes now have split shot injectors.
1999	235 @ 2,700	500 @ 1,600	7.3 receives intercooler, smaller turbo, larger 120cc injectors
2000	235 @ 2,700	500 @ 1,600	
2001	250 @ 2,600 (auto trans) 275 @ 2,800 (man trans)	505 @ 1,600 (auto trans) 525 @ 1,600 (man trans)	7.3 calibration increases horsepower and torque
2002	250 @ 2,600 (auto trans) 275 @ 2,800 (man trans)	505 @ 1,600 (auto trans) 525 @ 1,600 (man trans)	
2003 (7.3L)	250 @ 2,600 (auto trans) 275 @ 2,800 (man trans)	505 @ 1,600 (auto trans) 525 @ 1,600 (man trans)	Arrival of the 6.0 L Power Stroke. Both 6.0 and 7.3 offered for 2003.
2003 (6.0L)	325 @ 3,300	560 @ 2,000	VGT, EGR, OHV 4v 6.0
2004	325 @ 3,300	560 @ 2,000	7.3 discontinued, not available.
2005	325 @ 3,300	570 @ 2,000	6.0 L Torque increase
2006	325 @ 3,300	570 @ 2,000	
2007	325 @ 3,300	570 @ 2,000	
2008 (6.4L)	350 @ 3,000	650 @ 2,000	OHV 4v, common rail, sequential turbo 6.4 L introduced
2009	350 @ 3,000	650 @ 2,000	
2010	350 @ 3,000	650 @ 2,000	
2011	390 @ 2,800 (original) 400 @ 2,800 (updated)	735 @ 1,600 (original) 800 @ 1,600 (updated)	6.7L Ford Power Stroke replaces 6.4L International Power Stroke. Horsepower & torque upgraded in August/September.

Diesel story began in 1982, when the Ford Motor Company made a decision that would transform their Super Duty pickups into the most highly regarded and hottest-selling trucks in America. In pursuit of a whole new level of durability, power, torque and capabilities, Ford partnered with International Truck and Engine Corporation or ITEC (later re-named Navistar, Incorporated) to create a new standard in diesel engine technology that would help redefine the industry. That first power plant, the 6.9 L Indirect Injection (IDI) engine, featured a modest 170 HP and 315 lb-ft of torque. The truck world eagerly greeted that very first Power Stroke[®] diesel. Not long after, came the next generation Ford Super Duty truck with the amazing 7.3 L IDI diesel engine, produced from 1988-1993. 1994 through 2003 was when the First Power Stroke Turbo Diesel was named it was the legendary 7.3 L. The 7.3 L features included a waste-gated turbocharger, HUEI fuel injectors and an air-to-air intercooler. The 7.3 L engines were an instant hit in the trucking world. Production ran

non-stop through early 2003. By that time, this engine's performance and durability had made the Power Stroke® name a legend among truckers.

Diesel Power Magazine ranked the 7.3 L one of the top ten diesel engines ever produced. Today, over two million 7.3 L engine-equipped Ford Trucks are still in operation – more than Chevrolet, GMC, and Dodge diesels, *combined*. During its 9 year production run, the 7.3 L was widely acknowledged as a leader in diesel engine technology.

6.0 L Power Stroke

In 2003, the next-generation 6.0 L Power Stroke introduced Ford Truck customers to a new engine with more power and lower emissions than the 7.3 L. With its variable geometry turbocharger technology, exhaust gas recirculation system and advanced, second-generation fuel injection system, the new 6.0 L was a groundbreaking engineering breakthrough. The result was a major increase in horsepower and torque (325 HP and 570 lb-ft), even with a drastic reduction in engine displacement. This was the first engine design driven by emissions requirements.

6.4 L Power Stroke

In 2007 and through 2010 the Clean, Quiet 6.4 L was used. The Power Stroke legend reached new heights in 2007, with the launch of a new 6.4 L diesel. This engine's cutting-edge technology and reduced emissions pumped out an amazing 350 HP @ 3000 RPM with a peak torque output of 650 lb-ft at just 2000 RPM. Developed through more than 10 million miles of torturous durability testing, the 6.4 L proved to be the quietest and cleanest Power Stroke engine to date. Its twin turbochargers and high-pressure, common-rail fuel injection with piezoelectric fuel injectors also helped Ford Super Duty trucks meet the stringent 2007 diesel emissions requirements.

6.7 L Power Stroke

In 2011 the new, 2011 6.7 L Power Stroke engine makes its first appearance. Ford Power Stroke diesel engine technology has come a long way over the last three decades, but the party is far from over. For the 2011 model year, Ford introduced an all-new, built-from-scratch, state-of-the-art 6.7 L Power Stroke[®] diesel – and it's the most advanced diesel Ford has ever built. The 6.7 L is Lighter, more powerful and more fuel efficient (as well as B20 fuel compatible), this engine, built in Ford's Chihuahua, Mexico engine plant, takes diesel engineering to an entirely new level. New features include "Instant Start" glow plugs for quicker starts in even the coldest weather; a new, lightweight compacted graphite iron engine block (160 lbs. lighter than the current 6.4 L); aluminum cylinder heads (a Power Stroke first); and piston-cooling jets for longer engine life.

There are differences between the 6.0 L, 6.4 L and the 6.7 L engines. They are different engine altogether. This isn't an engine rebuilding course and the engine's themselves are not discussed. The class concentrates on drivability, fuel, air intake, and emission systems will be the main subjects.

As an example:

	6.0 L	6.4 L	6.7L
Displacement:	365 ci, 6.0 liters	390 ci, 6.4 liters	406 ci, 6.7 liters
Configuration:	V-8	V-8	V-8
Compression Ratio:	18.0:1	16.7:1	16.1:1
Bore (in):	3.74 in	3.86 in	3.90 in
Stroke (in):	4.13 in	4.13 in	4.25 in
Injection System:	Direct, HEUI gen 2	Direct , High Pressure Common Rail Injection	Direct, high pressure common rail
Aspiration:	Variable Geometry Turbocharger	Twin Sequential turbochargers	"DualBoost" single sequential turbocharger
Valvetrain:	4V OHV	4V OHV	4V OHV
Oil Capacity:	15 quarts	15 quarts	13 quarts
Weight:	966 lbs	1,150 lbs	990 lbs
Horsepower:*	325 @ 3300 RPM	350 @ 3500 RPM	400 @ 2800 RPM
Torque (lb-ft):*	570 @ 2000 RPM	650 @ 2000 RPM	800 @ 1600 RPM
Emissions Controls:	EGR	DPF, EGR, advanced injection control, active regeneration	DPF, SCR, EGR, active regeneration

The 6.0 L has Direct HUEI gen-2 uses a Variable Geometry Turbo Charger with an EGR.

The 6.4 L has Direct High Pressure Common Rail, Twin Sequential Turbochargers, EGR, DPF, advanced injection control, and active regeneration.

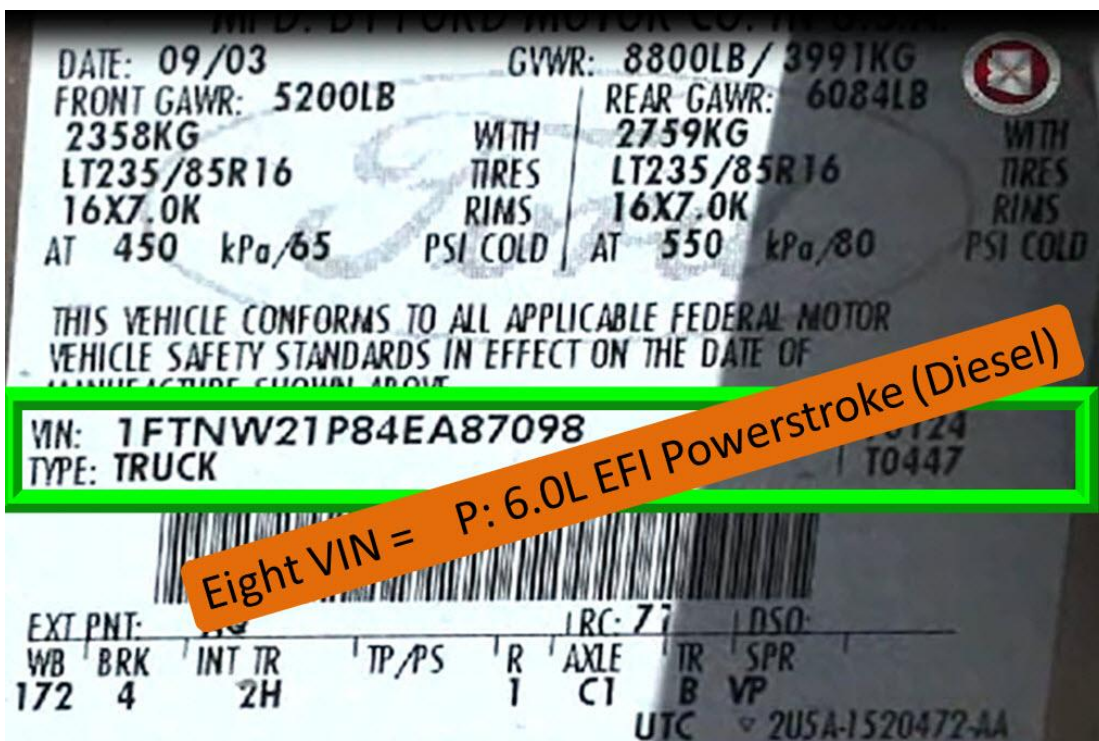
The 6.7 L has Direct High Pressure Common Rail, Dual Boost Single Sequential

Turbocharger, EGR, DPF, SCR, and active regeneration.

It is very important to know which year, model, and version of Powerstroke you're working on. The 6.0 L engine was a continuation of changes from the time it was introduced until the 6.4 L replaced it. Use the vehicle's labels to ensure you know what version of the 6.0 L you're working on.

The VIN label shows the model year, engine type, plant the vehicle was built in, and the sequence number. The sequence number is very important when ordering parts. As an example, model years, 2003 and 2004 had version A and B vehicles. When ordering parts the technician must know which version he is working on to get the correct parts. The 2003 and 2004 series A version used the round style EGR cooler, whereas the 2004 series B version used the square style EGR cooler.

VIN label



The 8th digit identifies the engine.

VIN for Version A Engine

VIN: 1FTNW21P84EA87098
TYPE: TRUCK

F0124
T0447

Sequence number

EXT PNT:	AQ	RC:	77	DSO:			
WB	BRK	INT TR	TP/PS	R	AXLE	TR	SPR

Example

The 2004 series A version uses a different style EGR cooler

You will need the version when ordering some parts for the 6.0 L engine because of the running changes that have been released.

Calibration Number



Finding the Ford service part (assembly) number used to replace an original engine begins with retrieving the production engine ID number from the calibration label located on the oil reservoir (94-95 MY) or on the left valve cover (96 MY to 2003) for 7.3 L engines. The calibration label is located on the Fuel Injection Control

Module (FICM) for 6.0 L engines 2003 to 2007 and on the Vertical EGR Cooler for the 6.4 L engine 2008-2010. The production engine ID number or tag number is the large 7-digit number at the top center of the label. Record the seven digit production engine ID number.

Engine Access



Technicians in the field report it is easier to lift the cab from the frame when doing engine work especially removing the cylinder heads. It takes about 1.5 hours to lift it up and another 1.5 hours to replace it.

OBD-II Complaint

The Powerstroke is an OBD-II complaint vehicle. That means you can use your scan tool to access the PCM and other computers on the vehicle. During this training course we will use the AutoEnginuity (AE) scan tool to show different scan data as well as Bi-directional controls. Even though OBD-II is the industry standard, each scan tool manufacturer has implemented it differently. The scan tool your shop uses will have different looking screens than the AE, and may have different functions. To work with the OBD-II system learns to use your scan tool correctly.

Diagnostic test modes

Mode 1

Data Stream-Used to access PIDs for diagnostics:

Mode 2

Freeze Frame Data-Freeze frame is a snap shot of important PIDs at the moment a diagnostic trouble code is set.

Mode 3

Diagnostic Trouble Codes (DTC)-Allows viewing of the diagnostic trouble codes:

Mode 4

Clearing DTCs-This mode will allow the technician to clear diagnostic trouble codes.

Mode 5

Oxygen Sensor Monitor

Mode 6

Non-Continuous Monitors-Mode 5 and 6 are often under mode 6. This is the test results of the last time the monitors ran.

Mode 7

Pending DTCs-Pending diagnostic trouble codes are set on the first trip of a two trip monitor.

Mode 8

Bi-Directional Controls-Bi-Directional Controls help the technician to control the computes outputs thorough the computer itself.

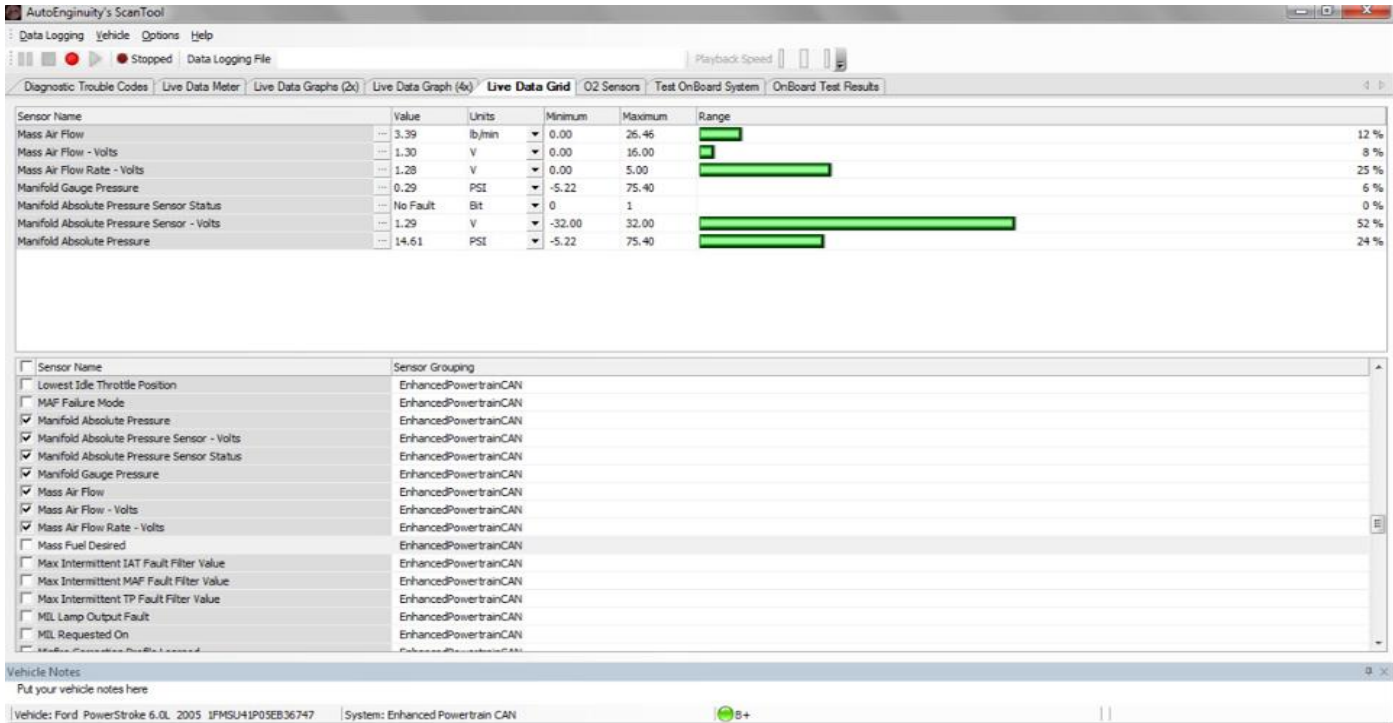
Mode 9

Vehicle ID- Allows the technician to read the vehicle's identification.

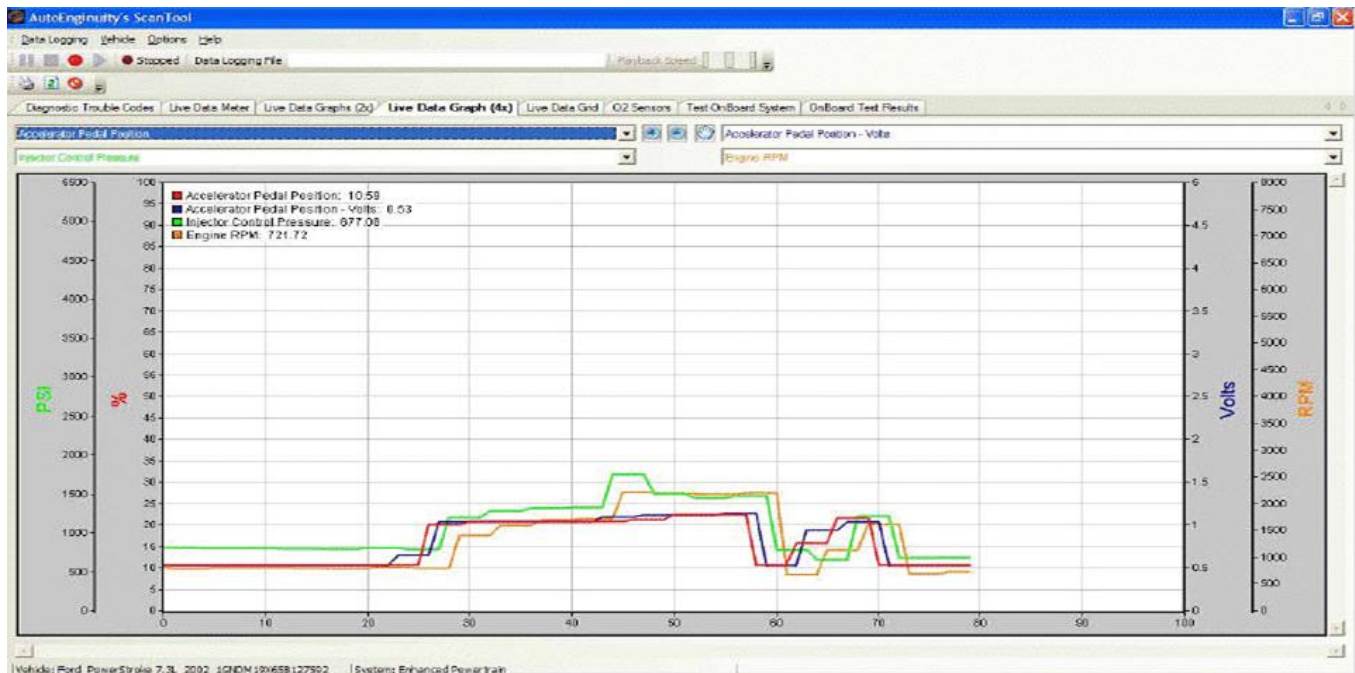
Mode 10

Permanent DTCs- Only on vehicles since 2010 these code cannot be erased by the technician. They are erased when the monitors runs and passes.

Scan Data



Graphed Scan Data



Misfire Data

AutoEnginuity's ScanTool

Data Logging Vehicle Options Help

Stopped Data Logging File Playback Speed

Diagnostic Trouble Codes Live Data Meter Live Data Graphs (2x) Live Data Graph (4x) **Live Data Grid** O2 Sensors Test OnBoard System OnBoard Test Results

Sensor Name	Value	Units	Minimum	Maximum	Range
Misfire Percent Delta Cylinder #1	0.00	%	0.00	4095.90	0 %
Misfire Percent Delta Cylinder #2	0.00	%	0.00	4095.90	0 %
Misfire Percent Delta Cylinder #3	0.00	%	0.00	4095.90	0 %
Misfire Percent Delta Cylinder #4	0.00	%	0.00	4095.90	0 %
Misfire Percent Delta Cylinder #5	0.00	%	0.00	4095.90	0 %
Misfire Percent Delta Cylinder #6	0.00	%	0.00	4095.90	0 %
Misfire Percent Delta Cylinder #7	0.00	%	0.00	4095.90	0 %
Misfire Percent Delta Cylinder #8	0.00	%	0.00	4095.90	0 %

Sensor Name	Sensor Grouping
<input type="checkbox"/> Misfire Count Cylinder #8 - High Byte	EnhancedPowertrainCAN
<input type="checkbox"/> Misfire Count Cylinder #8 - Low Word	EnhancedPowertrainCAN
<input type="checkbox"/> Misfire Count Total - High Byte	EnhancedPowertrainCAN
<input type="checkbox"/> Misfire Count Total - Low Word	EnhancedPowertrainCAN
<input type="checkbox"/> Misfire Monitor - Completed	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #1	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #2	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #3	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #4	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #5	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #6	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #7	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Misfire Percent Delta Cylinder #8	EnhancedPowertrainCAN
<input type="checkbox"/> Net Engine Torque	EnhancedPowertrainCAN
<input type="checkbox"/> No Speed Control Button Pushed	EnhancedPowertrainCAN

Vehicle Notes

Put your vehicle notes here

Vehicle: Ford PowerStroke 6.0L 2005 1FMSU41P05EB36747 System: Enhanced Powertrain CAN

Mode 6 data

The screenshot displays the 'OnBoard Test Results' window in AutoEnginuity's ScanTool. It is divided into several sections:

- Support and Status of OnBoard System Tests:**
 - General Systems:** Command Secondary Air Status (Not Reported), Power Take-Off Status (Inactive), Battery Voltage (12.62).
 - Continuously Monitored Systems:**

OnBoard Module/System	Status
Misfire Monitoring	Complete
Fuel System Monitoring	Not Supported
Comprehensive Component Monitoring	Complete
 - OnBoard Module/System Status Table:**

OnBoard Module/System	Status
Catalyst Monitoring	Not Supported
Heated Catalyst Monitoring	Not Supported
Evaporative System Monitoring	Not Supported
Secondary Air System Monitoring	Not Supported
A/C System Refrigerant Monitoring	Not Supported
Oxygen Sensor Monitoring	Not Supported
Oxygen Sensor Heater Monitoring	Not Supported
EGR System Monitoring	Not Complete
- Monitored Test Results (Mode 6):**

Monitor ID	Test ID	Value	Min Value	Max Value	Units
(SA1) Misfire Monitoring	(881) Total Engine Misfire and Emission Threshold Misfire Rate (Updated every 10	0.000	0.000	1.499	%
(SA1) Misfire Monitoring	(883) Highest Emission-Threshold Misfire and Emission Threshold Misfire Rate (Upc	0.000	0.000	1.000	%
(SA2) Misfire Monitoring	(808) Misfire Cylinder 1 Data	0.000	0.000	65535.000	Counts
(SA2) Misfire Monitoring	(80C) Misfire Cylinder 1 Data	0.000	0.000	65535.000	Counts
(SA2) Misfire Monitoring	(881) Cylinder 1 Misfire Rate and Emission Threshold Misfire Rate (Updated every	0.000	0.000	1.000	%
(SA3) Misfire Monitoring	(808) Misfire Cylinder 2 Data	0.000	0.000	65535.000	Counts
(SA3) Misfire Monitoring	(80C) Misfire Cylinder 2 Data	0.000	0.000	65535.000	Counts
(SA3) Misfire Monitoring	(881) Cylinder 2 Misfire Rate and Emission Threshold Misfire Rate (Updated every	0.000	0.000	1.000	%
(SA4) Misfire Monitoring	(808) Misfire Cylinder 3 Data	0.000	0.000	65535.000	Counts
(SA4) Misfire Monitoring	(80C) Misfire Cylinder 3 Data	0.000	0.000	65535.000	Counts
(SA4) Misfire Monitoring	(881) Cylinder 3 Misfire Rate and Emission Threshold Misfire Rate (Updated every	0.000	0.000	1.000	%
(SA5) Misfire Monitoring	(808) Misfire Cylinder 4 Data	0.000	0.000	65535.000	Counts
(SA5) Misfire Monitoring	(80C) Misfire Cylinder 4 Data	0.000	0.000	65535.000	Counts
(SA5) Misfire Monitoring	(881) Cylinder 4 Misfire Rate and Emission Threshold Misfire Rate (Updated every	0.000	0.000	1.000	%
(SA6) Misfire Monitoring	(808) Misfire Cylinder 5 Data	0.000	0.000	65535.000	Counts
(SA6) Misfire Monitoring	(80C) Misfire Cylinder 5 Data	0.000	0.000	65535.000	Counts
(SA6) Misfire Monitoring	(881) Cylinder 5 Misfire Rate and Emission Threshold Misfire Rate (Updated every	0.000	0.000	1.000	%

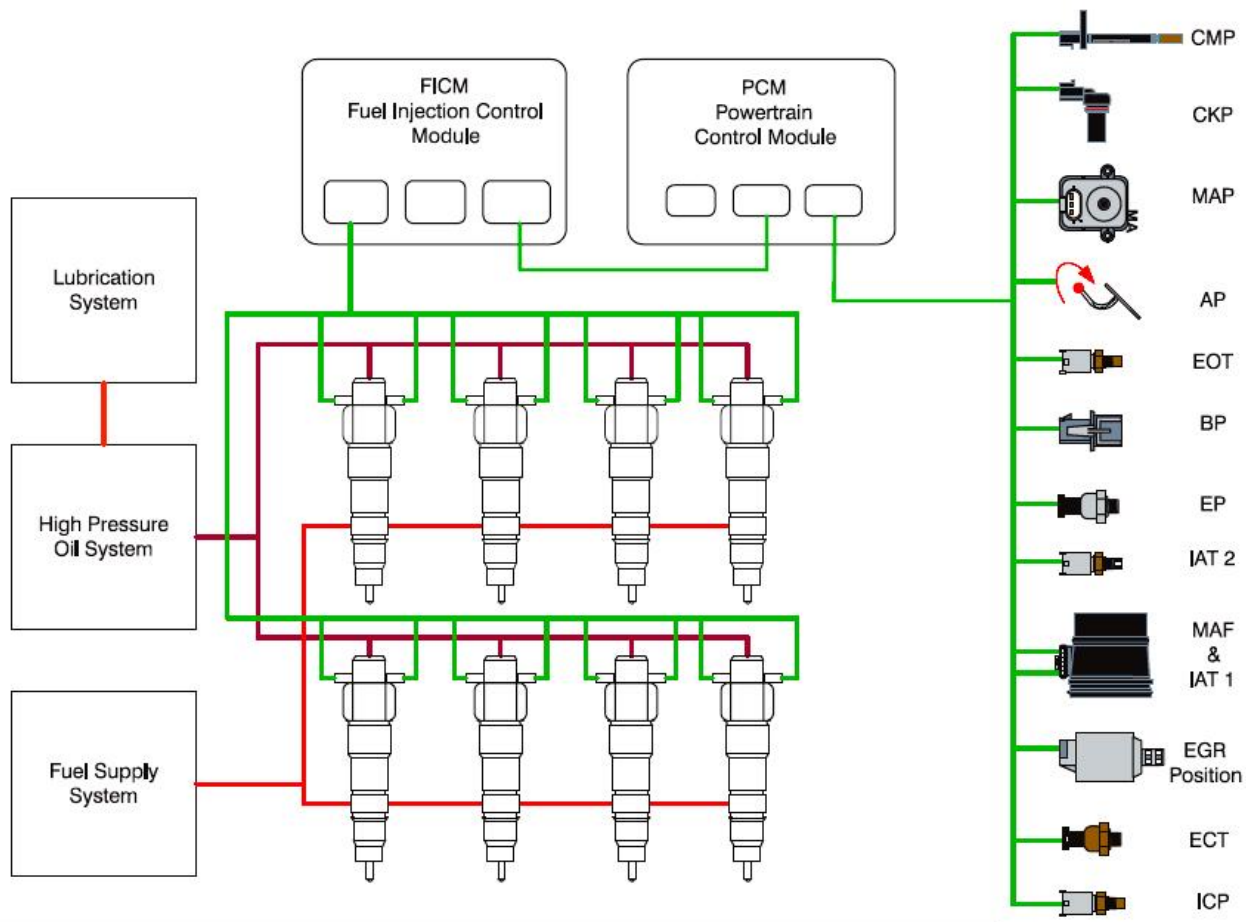
Engine Manufacturer Diagnostics (EMD)

There are vehicles that aren't required to be certified OBD-II. These are heavy duty vehicles over 14,000 certified to Engine Manufacturer Diagnostics under title 13, CCR section 1971 (e.g., 2007-2009 model year diesel and gasoline engines). The systems that are requiring functional monitoring are:

- Fuel delivery system
- Exhaust gas recirculation system
- Particulate matter trap
- ECM input inputs for circuit continuity and rationality, and emission-related
- Outputs for circuit continuity and functionality

The EMD requirements are very similar to OBD-I system requirements. Starting in the 2010 Model Year, EMD was updated to require functional monitoring of the NO_x after treatment system. EMD+ vehicles use the same PCM, CAN serial data communication link, J1962 Data Link Connector, and PCM software as the corresponding OBD-II vehicle.

6.0 L Fuel System



Without an ignition system, the fuel system is the obvious place to begin. The fuel system on the 6.0 L Power Stroke engine includes the high engine oil pressure system. In some Power Stroke information the high pressure oil pump is called the high pressure fuel pump. That is why the two squares on the left of this diagram are labeled lubrication system and high pressure oil system. It may sound confusing, but it will all be explained in this section of the class.

There are two control modules for the fuel system. The fuel injection control module (FICM) and the power train control module (PCM). They work together to time and activate the injectors. There are eight injectors one for each cylinder. There are inputs for the PCM just like any computer controlled engine.

Fuel delivery, electrical control, and hydraulic pressure are all used to deliver the fuel to each combustion chamber. The fuel delivery system moves fuel from the tank through a horizontal fuel conditioning module, three filters, water separator, to each injector. A fuel injector control module (FICM) electrically controls oil pressure to the each injector. The lubrication system supplies oil to the high pressure oil pump (HPOP). The injectors, part of

the fuel delivery system, increases the oil pressure up to 4000 psi to open the pintle allowing fuel to flow. The three systems must all be in good working condition and working with the other two. Because of this system, a poor performing engine lubricating system can and will cause a variety of drivability problems up to a crank no start. It is also important to remember that the PCM is plays a major part in getting the fuel to the cylinder. It controls the engine based off of, On Board Diagnostics generation II.

The high pressure oil pump delivers oil to the injectors. An electrical solenoid controlled by the FICM, Fuel Injection Control Module, starts and stops the flow of high pressure oil to the injector. The high pressure engine oil compresses the fuel to create the very high pressure to open the injector.

The injectors are controlled by the fuel injection control module (FICM) electrically. The solenoids in each injector doesn't control the fuel, they control the engine oil in the injector. There are two solenoids in each injector.

A high pressure oil pump (HPOP) supplies the injectors with engine oil. The oil supplies the hydraulic action required to increase fuel pressure in the injector.

Diesel engines are built to very close tolerances and are susceptible to even the smallest amounts of dirt. Use the highest levels of cleanness when work on the fuel system. You must always use the proper cleanliness precautions to prevent and dirt, even the smallest amount, to get on or into the fuel system.

Fuel Tank

A shot from inside tank



The fuel is stored in this fuel tank which was the source of rust that clogged the filters. Water in the fuel causes the tank to rust and can flake off. The rust can plug the pickup screen causing a no start condition. Fuel is filtered as it is drawn out of the tank. The filters may or not be serviceable depending on model year. The fuel flows through a Horizontal Fuel conditioning module (HFCM) where it is filtered for the second time. Then it flows through the secondary fuel filter housing where it is filtered for the third time. The fuel is then directed to the injectors, there is a filter screen on the injector where fuel is filtered for a third time.

Fuel Pressure

Fuel pressure is extremely important. There are diesel technicians or manuals that may say otherwise. There are diesel engines where fuel pressure isn't as important, but not the Power Stroke. **If low fuel pressure/volume becomes a problem it can cause damage to the fuel system as well as the engine.** In this section we will discuss:

- Static fuel pressure (Key-On-Engine-Off fuel pressure)
- Dynamic fuel pressure (Driving normally at road speeds), **this may only show up**

with higher engine speeds and heavy loads.

- Normal fuel pressure must always be maintained or damage to the injectors will be the result

The fuel pressure specification 45 to 60 psi is out of the manual and is talking about the OEM fuel pressure regulator. The higher fuel pressure specification up to 70 psi is with the updated version of the fuel pressure regulator.

Before we begin a discussion about the fuel system, be aware that fuel pressure problems are one of the common problems with the Power Stroke engines. Checking fuel pressure is important with the K-O-E-O, which tells us about static fuel pressure only. Testing fuel pressure dynamically while driving the truck tells us the pump can deliver fuel when the engine demands it. Don't assume anything when it comes to the fuel system. Check pressure after replacing any component especially the fuel pump. If a truck gets a replacement fuel pump and is sent out the door without checking pressure severe damage can result costing several thousand dollars to repair. Leave the fuel pressure gauge connected and check the pressure after any fuel system repair.

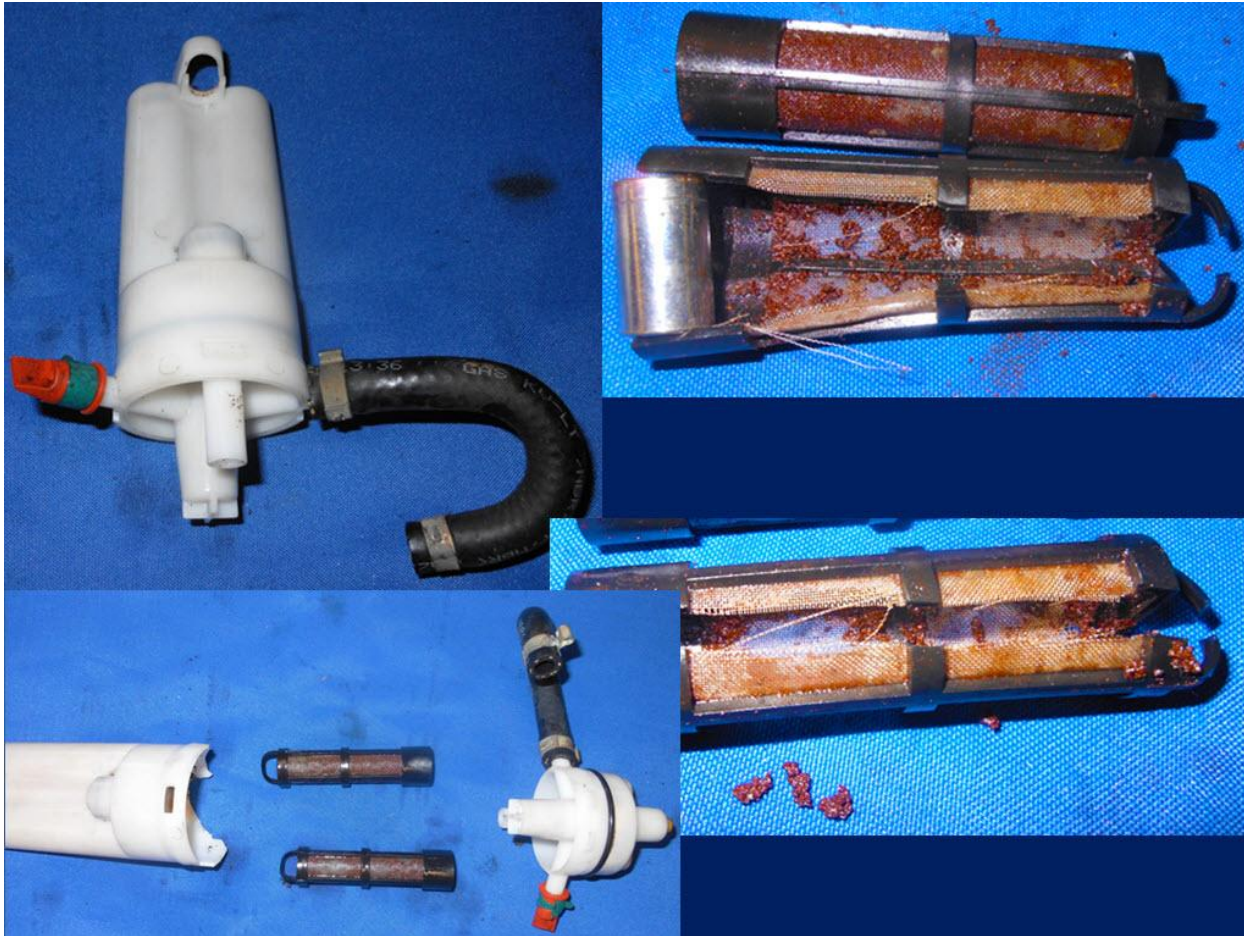
NOTE!

Doing research for the class, we spoke with many diesel technicians working on Power Strokes. All of them agreed that the specification of 45 psi to 60 psi was on the low side. **Some of them said that they want to see at least 60 psi and others told us that 70 psi was needed.** The ones who preferred 70 psi backed it up, saying Ford has released an updated fuel pressure regulator for 75 psi. Looking at the update kit it was clear that the spring was a different rate than the standard spring. **The updated spring had blue paint on it showing it wasn't standard.**

Fuel Tank Module



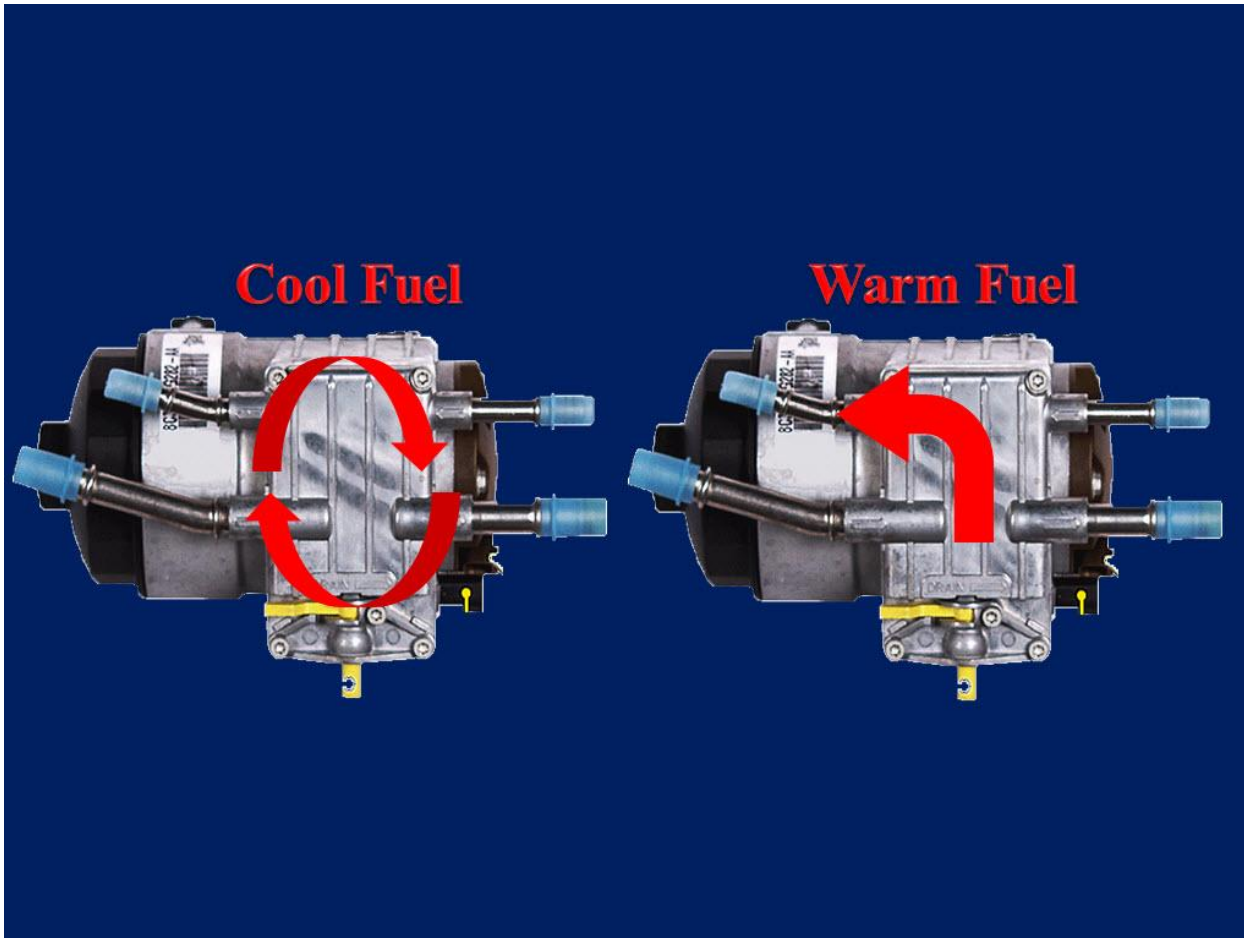
Filters from a rusty fuel tank



6.0 L Fuel Flow

The fuel tank module has a pick up screen, two fuel filters, and a fuel level sensor mounted on it also. The screen is held in place with a screw type hose clamp. Removing the clamps so the screen can slide off, after it is removed the filter hosing slides off. The filter housing holds two filters. These filters do a good job at collecting the rust from the fuel tank. So good in fact they plug up causing a no start condition.

Horizontal Fuel Conditioning Module (HFCM)



From the fuel tank the fuel flows to the Horizontal Fuel Conditioning Module (HFCM) where excess cool fuel is recirculated and warm fuel is returned to the tank.

Supply to Secondary Fuel Filter



The fuel line from the HFCM to the secondary fuel filter housing has a blue cover on it at the HFCM, but it doesn't go all the way up to the secondary fuel filter housing.

After the fuel is conditioned, heated, filtered and the water separated by the HFCM the clean pressurized (40 psi to 70 psi) fuel is sent to the secondary fuel filter housing.

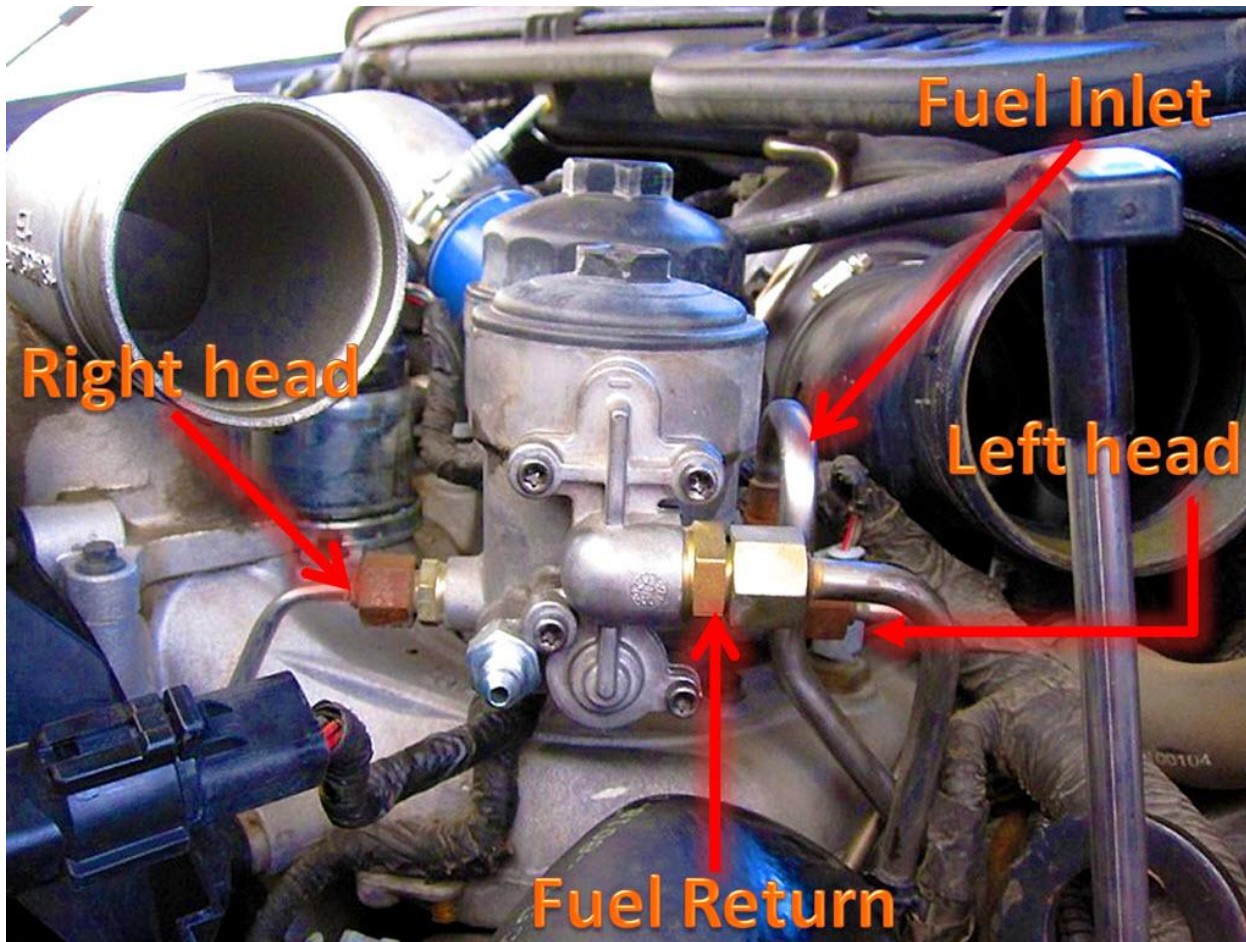
After the secondary filter the fuel flows to the cylinder heads past the check valves. 6.0 L engines have check valves at the cylinder head openings. Once the fuel has past the check valve, it does not return to the fuel supply system. There are drilled passages in the cylinder heads which direct the fuel to each injector. This is called a dead end fuel system because there isn't a return once the fuel enters the cylinder head.

The Secondary Fuel Filter Housing



The fuel enters the fuel bowl under pressure and leaves through the right and left cylinder head tubes to supply each injector with fuel. If the pressure regulator's pressure relief setting is reached fuel is returned to the HFCM.

Fuel Lines at Secondary Fuel Filter

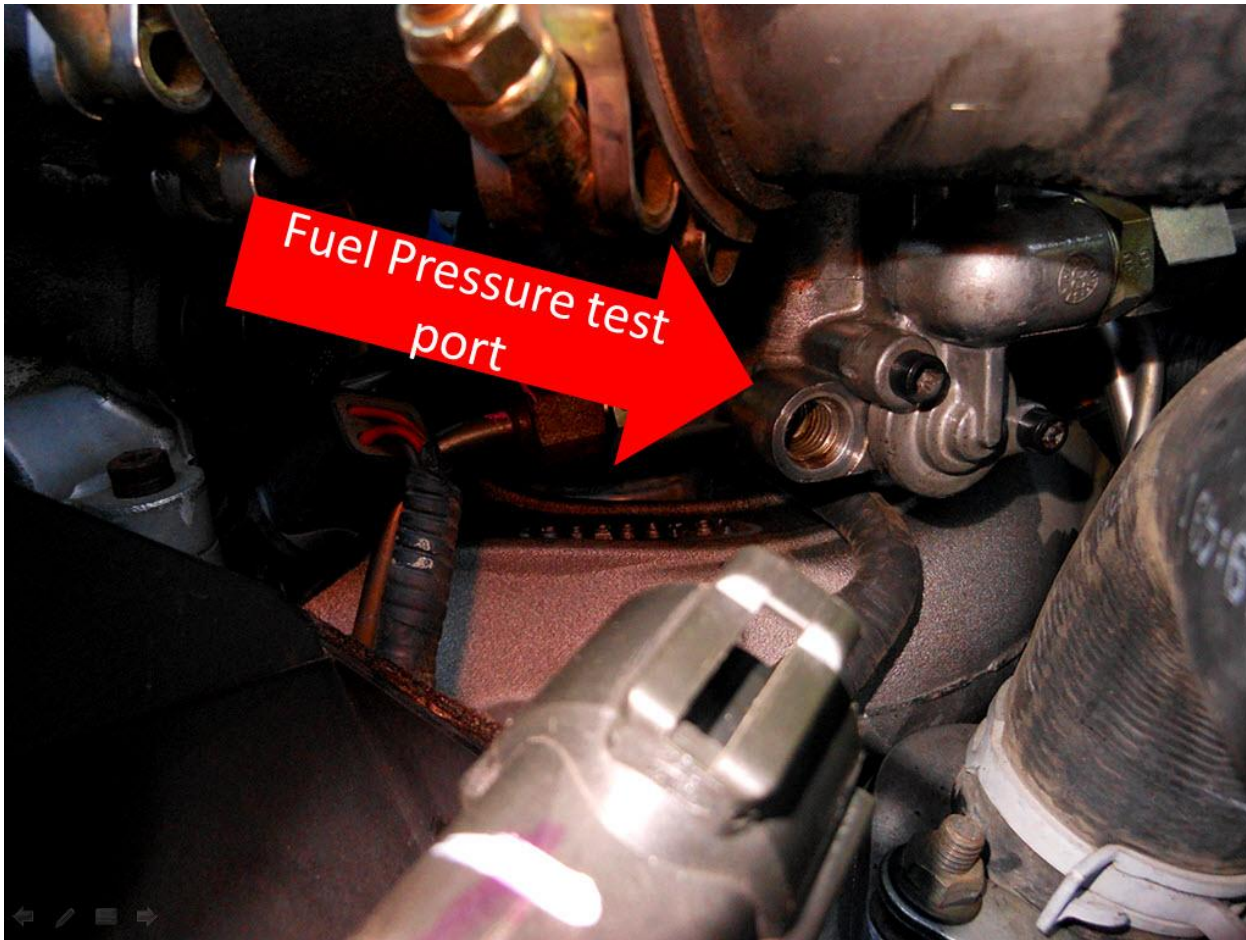


The secondary fuel filter housing is mounted at the top and front of the engine. There is an inlet, return, right, left, fuel lines connected to it. The right and left lines go to the cylinder heads.

Fuel test Port at Secondary Fuel Filter

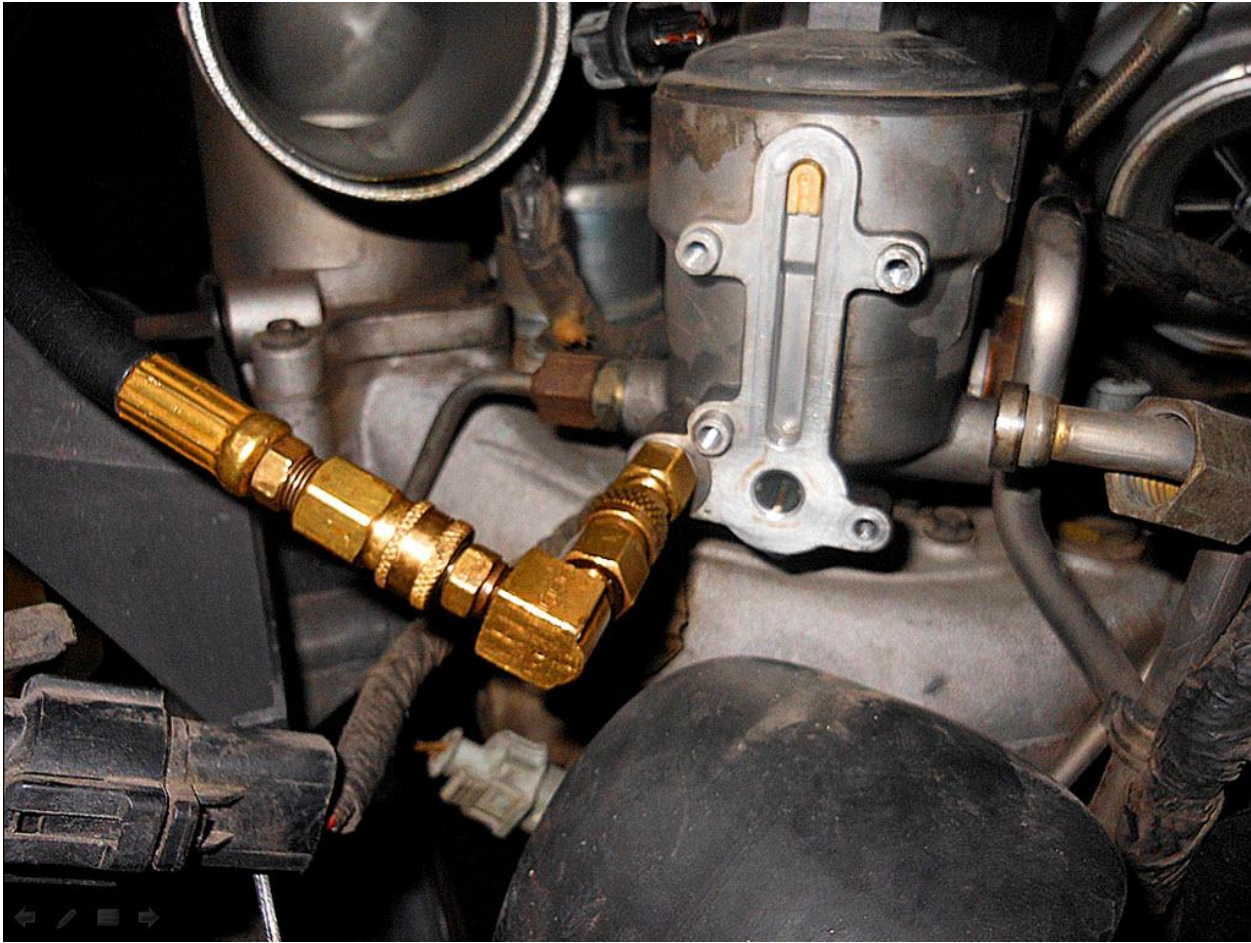


Test Port is threaded for a pressure gauge

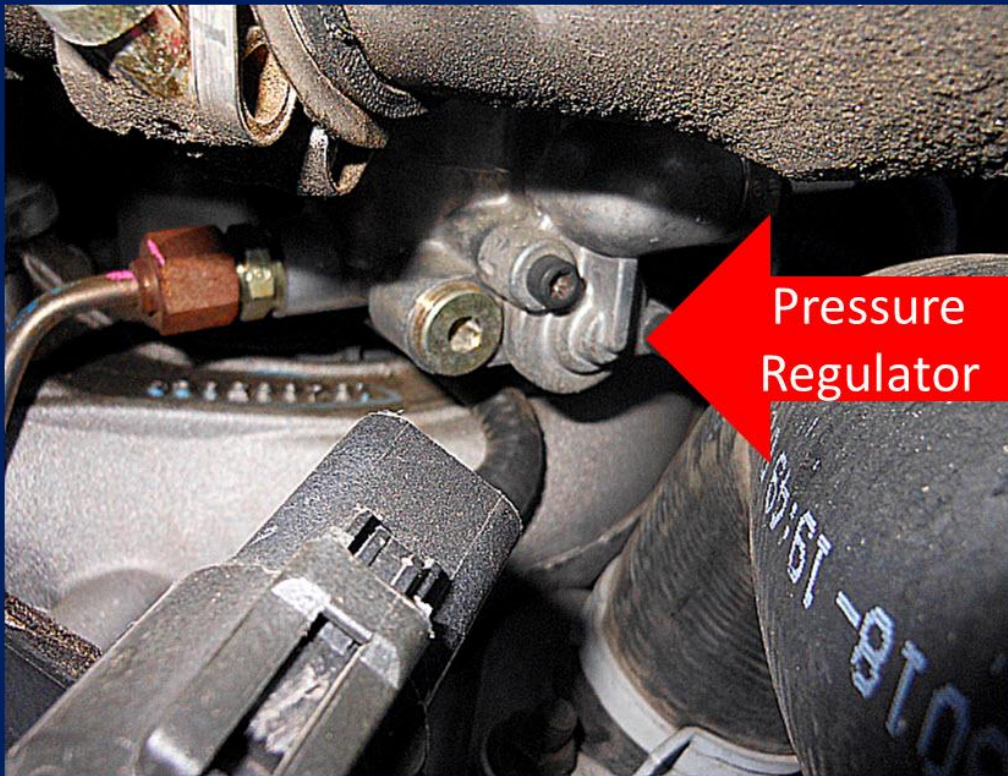


There is a fuel pressure test port on the housing for testing fuel pressure. It has a threaded port that a fuel pressure gauge can be connected to. It isn't a normal thread size that we could find in our fuel pressure test kit. Admittedly, our kit is a gasoline engine kit. We're not saying it is difficult to get an adaptor it is readily available, but just doesn't seem to be in a gasoline kit.

Fuel pressure Gauge Adapter



Fuel Pressure Regulator



The secondary fuel filter housing incorporates a fuel pressure regulator and an air bleed (to allow air to escape after a filter change). Fuel from the regulator is returned to the HFCM. The fuel pressure regulator is mounted to the secondary fuel filter housing. It regulates fuel pressure by routing unfiltered (by the secondary fuel filter) fuel from the filter housing to the HFCM via a spring loaded poppet style valve. The cracking pressure (pressure at which the valve begins to open) of the valve is 60 psi +/- 5 psi. Actual fuel pressure may be above or below this specification. The updated fuel pressure regulator's cracking pressure is 75 psi +/- 5 psi. The fuel pressure regulator is next to the test port.



It is inside the fuel pressure regulator manifold. The manifold is sealed to the housing with an “O” ring. The fuel return line is connected to the manifold.

Fuel pressure update kit

Ford#3C3Z-9T517-AG IH #1843065C98



The update kit for the fuel pressure regulator is Ford#3C3Z-9T517-AG IH #1843065C98.

The kit comes with a spring (blue) that will raise you fuel pressure 10-15 psi. The minimum specification is 45 psi. The magic fuel pressure number “seems” to be 40 psi at which the engine will not start. **Remember, fuel pressure maybe lower when engine speeds are elevated at heavy loads that can result in severe damage.** It's a good idea to test pressure before doing this update, but it is unlikely to over pressurize a properly working system.

Secondary Fuel Pressure Filter Cover



Preferred Method to remove the cover



When removing the secondary fuel filter cap, do not use a ½ inch drive in the hex head. Use a 24 mm socket. The hex head will distort and damage the cap. Lift the filter slowly and allow the fuel to drain from it. There will be fuel in the bowl look for clarity and take note of any clouding and for debris. The color of the fuel is important. Compare the appearance of the fuel to determine any problem as earlier discussed in the diesel fuel section.

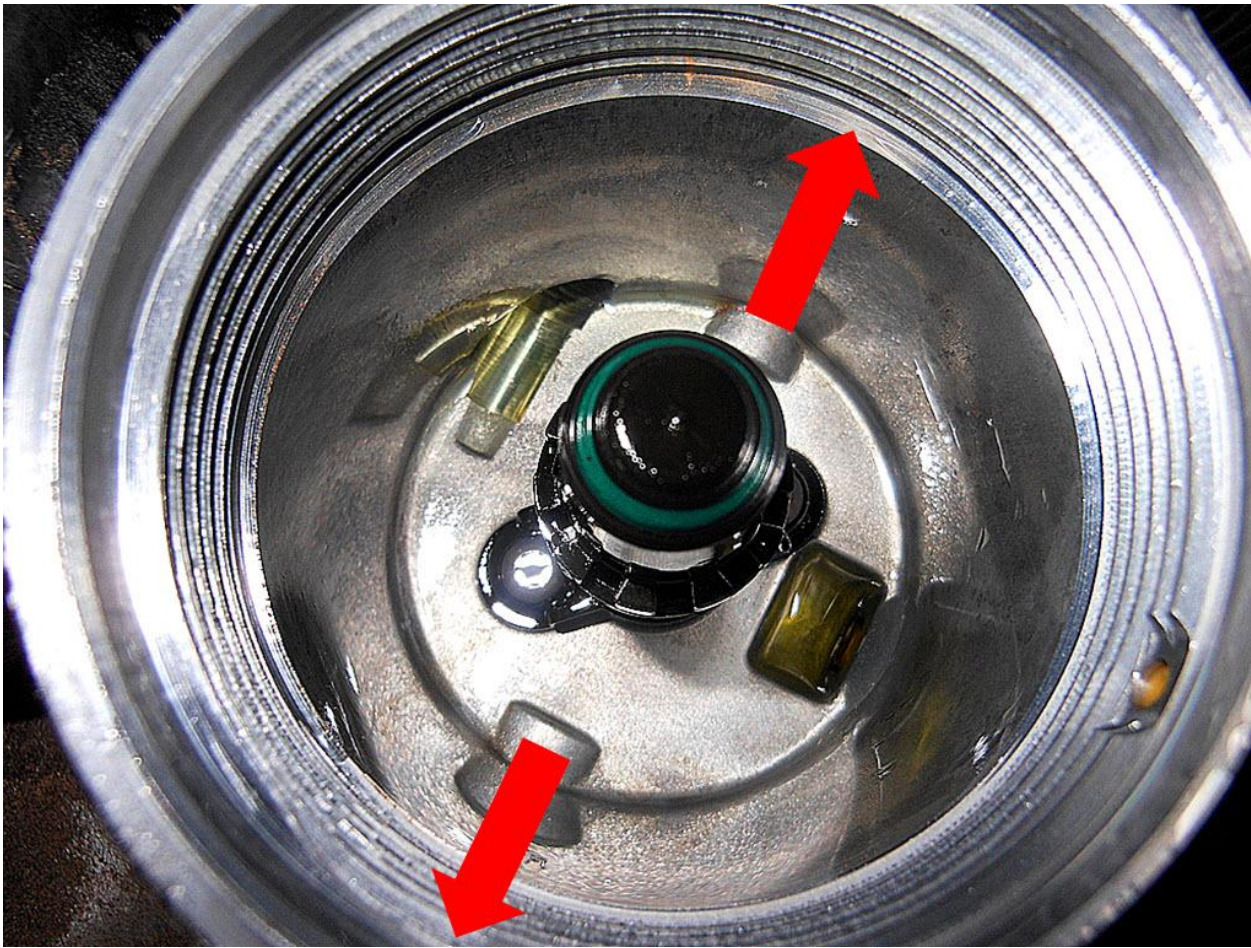
Secondary Fuel Filter Element



Draining fuel from the element

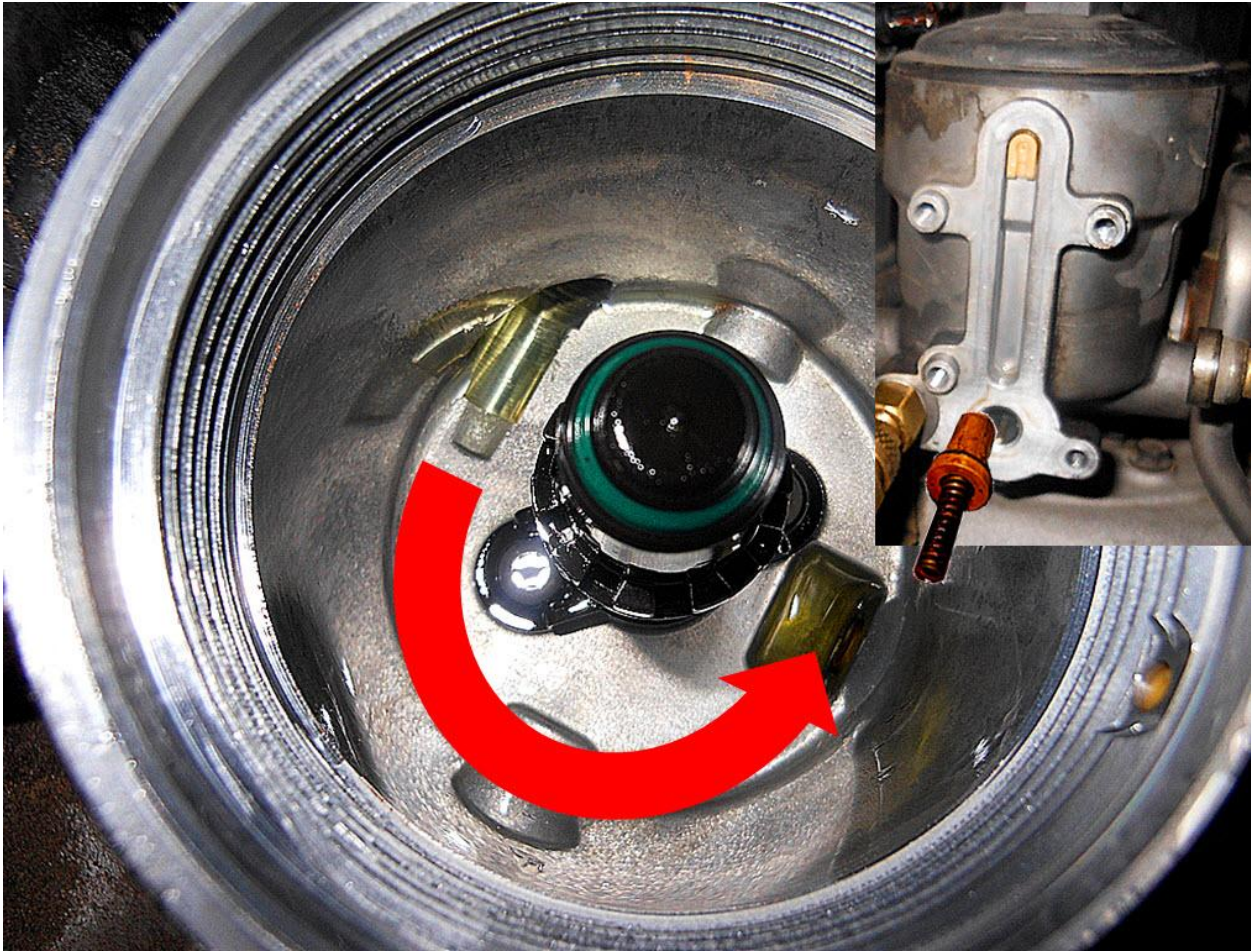


The fuel was removed from this bowl so we can see the inlet, return, left, and right ports. The fuel enters into the bowl and spins counter clock wise. Pressure directs the fuel to each cylinder head port. The pressure regulator will return fuel back to the HFCM if pressure exceeds the calibrated spring.



Take note of the clean appearance of this filter housing, correct problems if the housing is not clean like this one.

Pressure Regulator Passage



Fuel Inlet Check Valves



Each cylinder head has a fuel inlet check valve at the front of the cylinder heads. The check valve is inside the bolt, a banjo fitting attaches the fuel line to the head. The check valves are used to maintain constant fuel pressure in the fuel rail. The fuel lines are sealed to the head by two copper gaskets.

Note: It is important to replace the copper gaskets if the bolt has been removed.

The 6.4 L bolts will fit, but do not have a check valve in them, so do not confuse the bolts.

Fuel Inlet at Injector

The fuel flows through channels in the cylinder head to the injectors



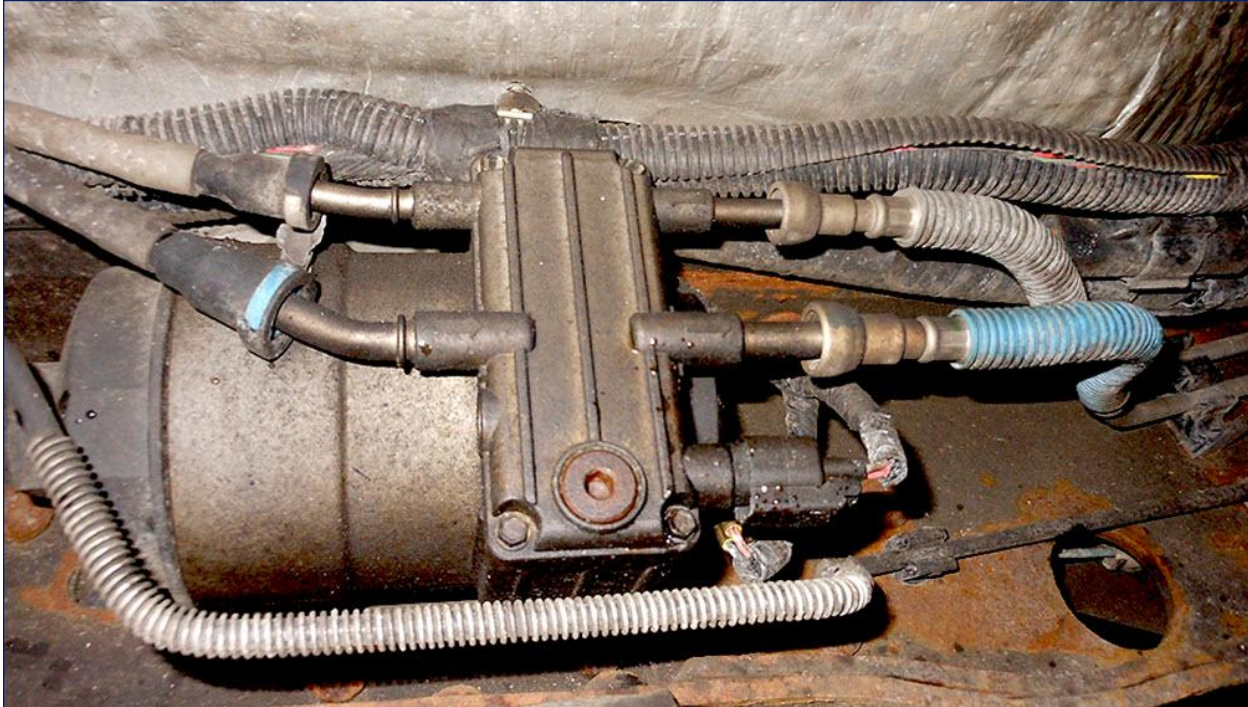
The fuel flows through channels in the cylinder head to the injectors where it enters through a screen at the bottom. By the time fuel enters the injector it has been filtered three times. If the pickup screen in the fuel tank is to be counted there would be four. This shows how serious the engineers are about keeping dirt out of the fuel system.

6.0 L Fuel Delivery System Components

- Horizontal Fuel Conditioning Module (HFCM)
- Secondary Fuel Filter
- Fuel Pressure Regulator
- Fuel Check Valves

Horizontal Fuel Conditioning Module (HFCM)

Horizontal Fuel Conditioning Module (HFCM)



It is mounted under the Cab on the left frame rail in between the fuel tank and the secondary fuel filter housing on the engine.

The horizontal fuel conditioning module (HFCM) has four fuel lines. They are the return to the tank, return to the HFCM, supply to the HFCM, and the supply to the engine. The fuel lines are all attached to the manifold of the HFCM and not to the body. The manifold also has the fuel/water drain valve which may be opened to allow water to drain out of the HFCM.

Inside the HFCM there are other components.

- Fuel Pump
- Fuel Filter
- Fuel/Water separator
- Water in fuel Switch
- Fuel Drain
- Fuel Heater

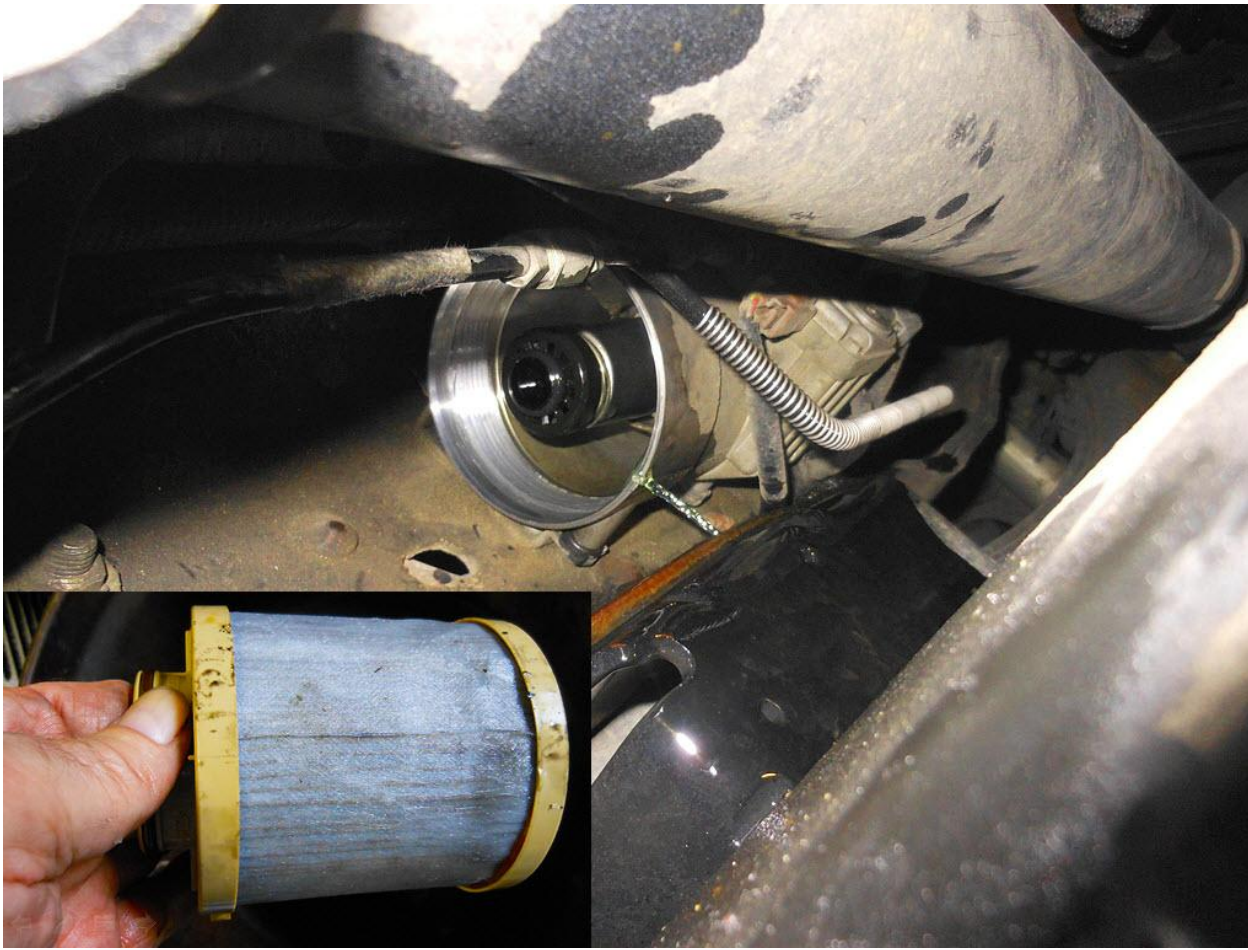
- Diesel Thermo Recirculation Valve (DTRM)

The fuel is pressurized to flow through the secondary fuel filter and on the engine. It filters the fuel with a 10 micron filter. The HFCM allows the water to separate from the fuel and supplies a drain to remove the water. There is a heater to heat the fuel. The heater was troublesome and has been removed. Replacement units do not have a heater. The DTRM either allows the fuel to return to the tank or returns it to the unfiltered side of the fuel filter in the HFCM depending on the temperature of the fuel.

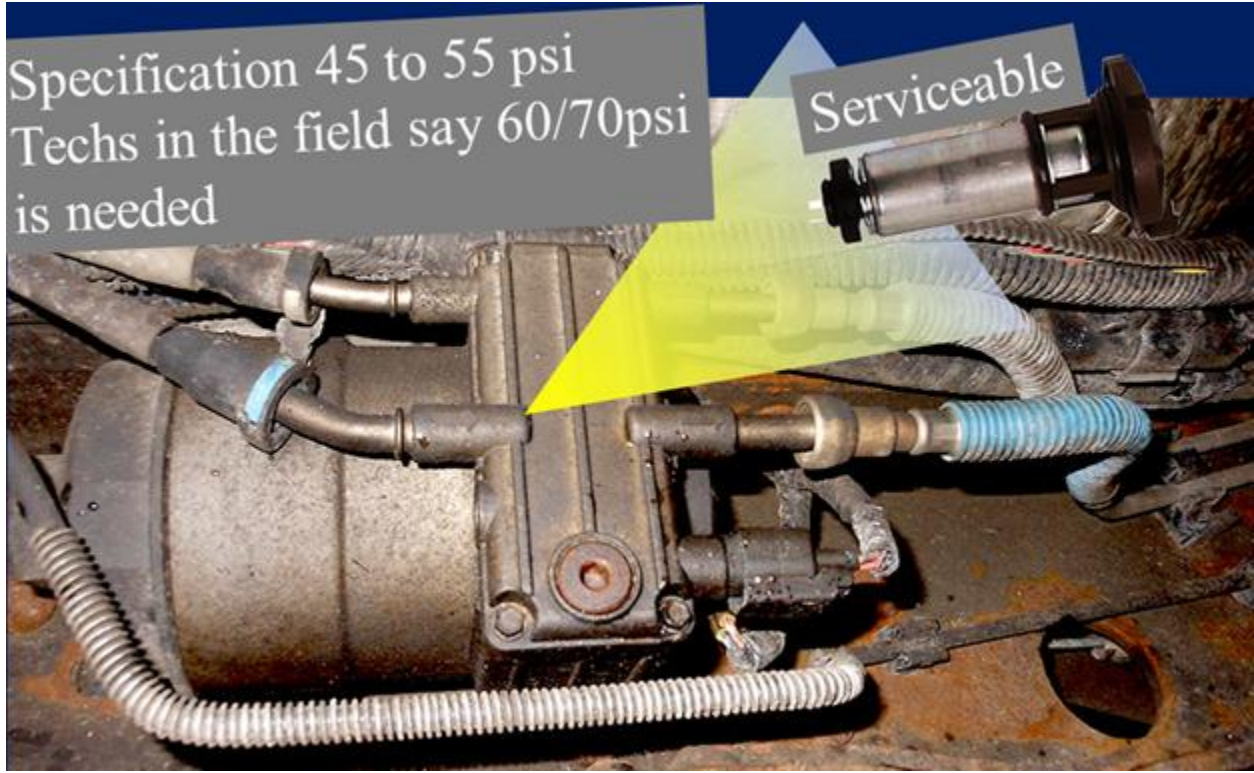
Filter End Cap



The end cap is where the filter is located. Removing it allows replacement of the filter. This is a different filter than the one in the secondary fuel filter housing. When changing the filter fuel will continue to drain so it is important to keep a pan under it.



The fuel pump in the HFCM should have a pressure of 60 psi. The Ford specification is 45 to 60 psi. Technicians in the field report that if both filters are new and the pump is working normally you'll see 60/70 psi. The fuel filter is serviceable. It is controlled by the PCM which supplies power to turn it on. It is our understanding that many technicians don't know this filter is there and fails to change it when they change the secondary filter on the top of the engine.



The fuel pressure test port is beside the fuel pressure regulator. It has a unique size fitting. There wasn't an adaptor in either of our fuel pressure test kits. You can get one from Ford.



Making a Fuel pressure test port



Make a fuel pressure fitting in the secondary fuel filter housing. If you don't have or don't want to buy a special adaptor for the Power Stroke engine one can be made. Drill and tap a hole into a fuel filter cap, then thread on a Schrader valve that fits your gauge. This will allow you to use the equipment your shop already has.

Connection for Fuel Pump Current



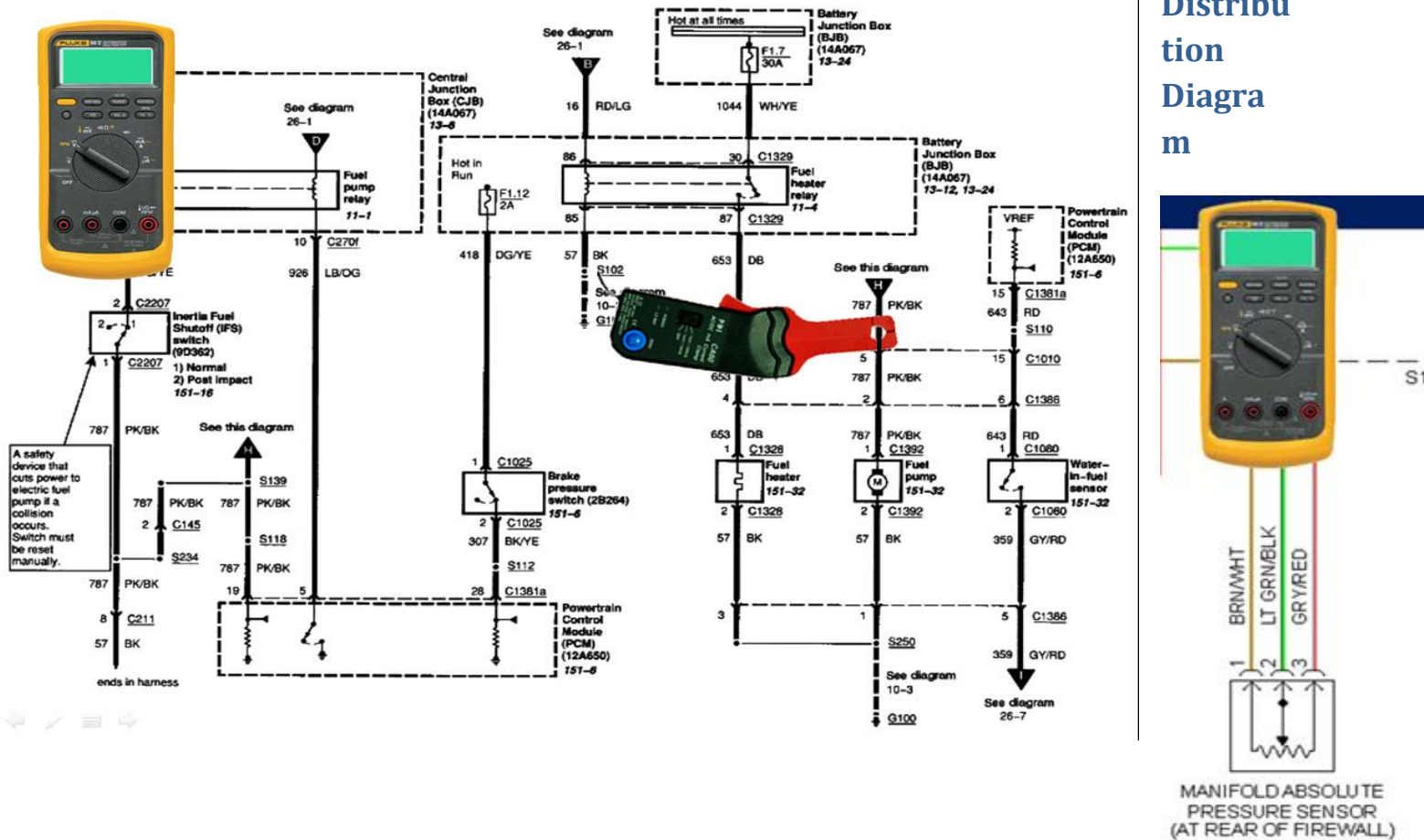
The fuel pump may be tested with a lab scope.

On some models the fuel pump circuit can be found on the drivers side near the firewall



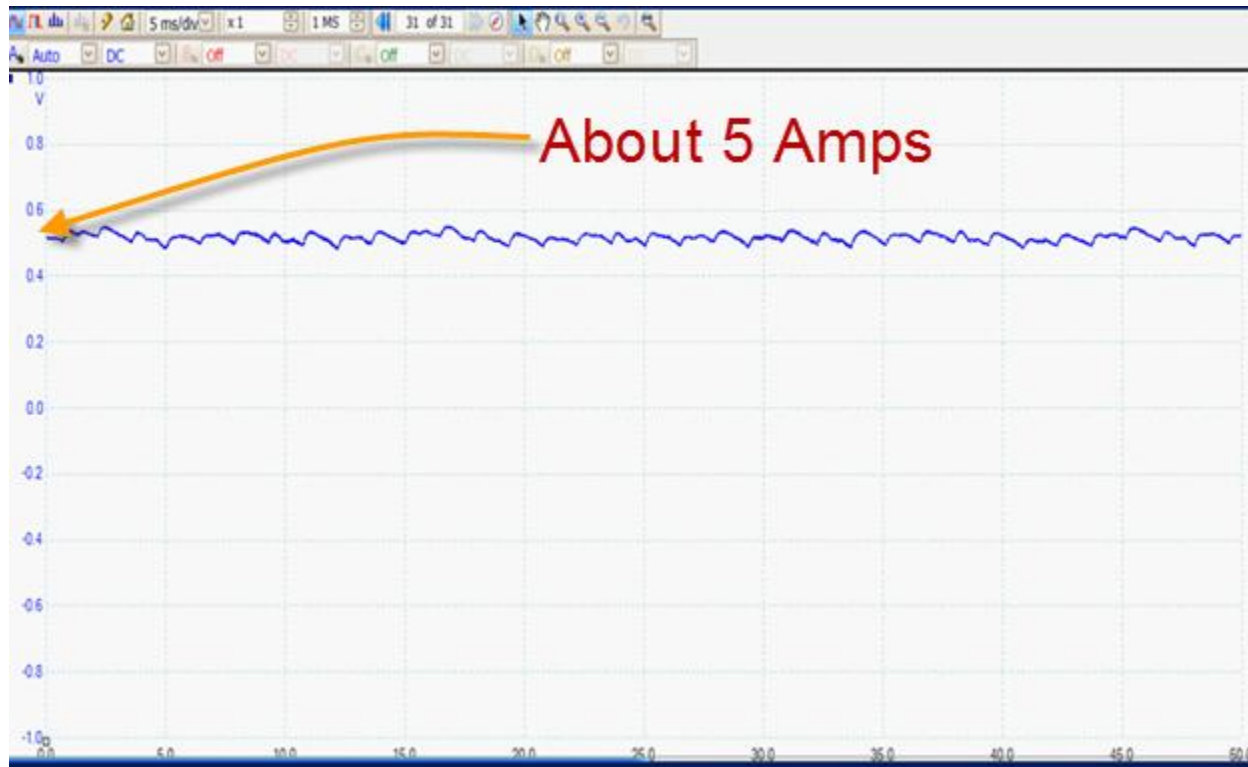
The low amp current probe in the image is around the fuel pump's battery positive circuit. The wave form can be viewed to determine; current flow, brush to commutator resistance, and RPM of the pump. Most technicians don't replace a pump based on the waveform alone. It is used with other diagnostic procedures like fuel pressure and volume testing. The second waveform is showing a bad fuel pump. **The waveform is from a 2004 6.0 L that would crank but not start. Fuel pressure was 32 psi.** Simple placing the low amp current probe around the fuel pump's battery positive circuit and cranking the engine showed the pump failing.

Power Distribution Diagram



To capture the fuel pump current waveform, place a low amp current probe around the battery plus of the fuel pump. Note that the probe may be placed around the negative of the fuel pump. It is a series circuit and the amperage that flows into the fuel pump must flow out. You do not have to use a digital storage scope (DSO) to just measure the current flow. A DVOM may be used. If you want to view the pump's RPM or condition you have to use a DSO. There isn't any difference in connecting the DSO or DVOM. Both take the same amount of work and time. The DSO supplies additional information that the DVOM doesn't. There are technicians that don't have/use the DSO because they are not familiar with it. **All it takes is training. We offer a "hands on" DSO class where the technicians bring their own equipment so that they train on the equipment they will use when they return to the shop.** It teaches how to get and manipulate a waveform.

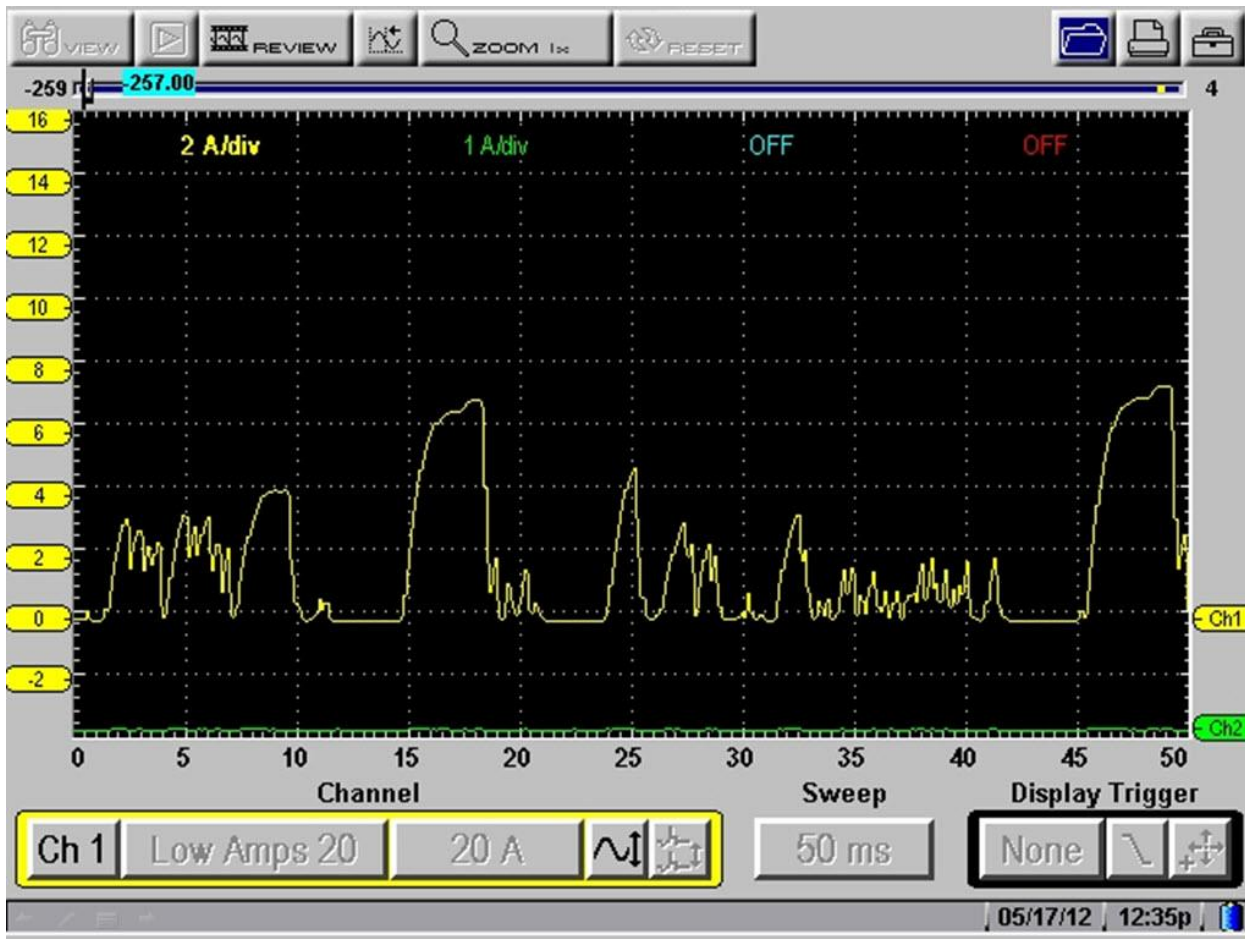
Normal Fuel Pump Current Flow



The typical current is about 8 amps, but this pump is down to 5 amps. Fuel pressure is 49 psi which meets the Ford fuel pressure specification but below our target of 60 psi. We know pumps with lower than normal current flow cannot deliver full volume, this may cause a problem at heavy loads with maximum fuel flow. **We use this type of testing to predict problems in the future. If this were a critical operation vehicle, like an emergency vehicle, we would replace the fuel pump.**

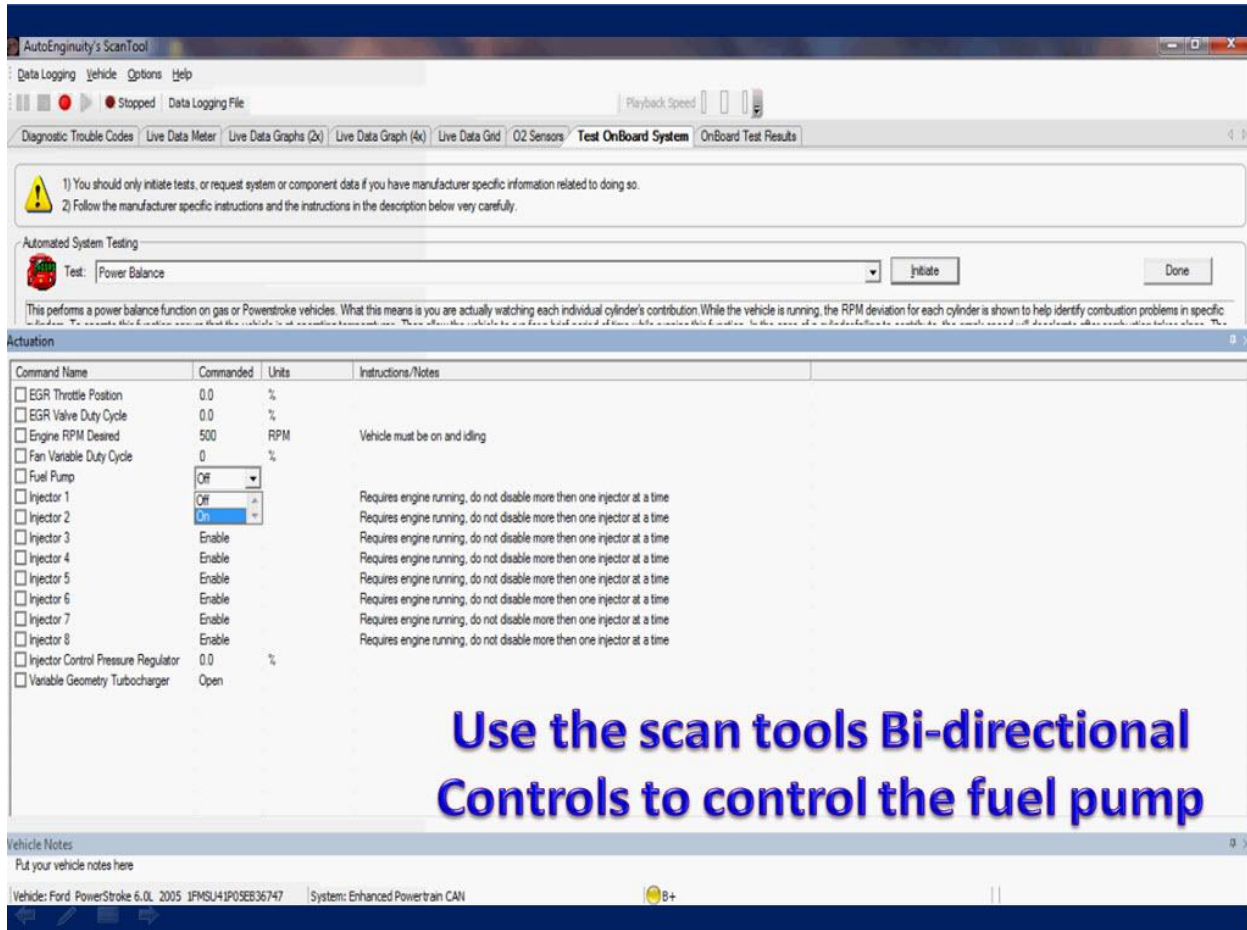
Abnormal Current Flow

Don't forget to zero the current probe. The current flow should be near 8 amps. The current is directly related to the fuel pressure. If current is low pressure can be low but volume is always lower than normal. If current is low check the battery voltage and the ground at the pump. The patterns wavy appearance is due to the fact the resistance changes as the brushes cross the commutator bars. There shouldn't be more than a 1 amp difference between the tops and bottoms of the pattern. Using a DSO and low amp probe is covered in the electrical and Lab Scope classes.



This is a fuel pump current waveform from an engine with an extended crank. If cranked long enough the fuel pressure would raise to the minimum to start the engine. The waveform shows current remaining below 4 amps most of the time and jumping to above 6 amps once in a while. It also shows pressure staying at 0 amps sometimes. It is important to note that it only takes a few minutes to get the waveform because the HFCM is easy to get to.

Bi-directional fuel pump Control

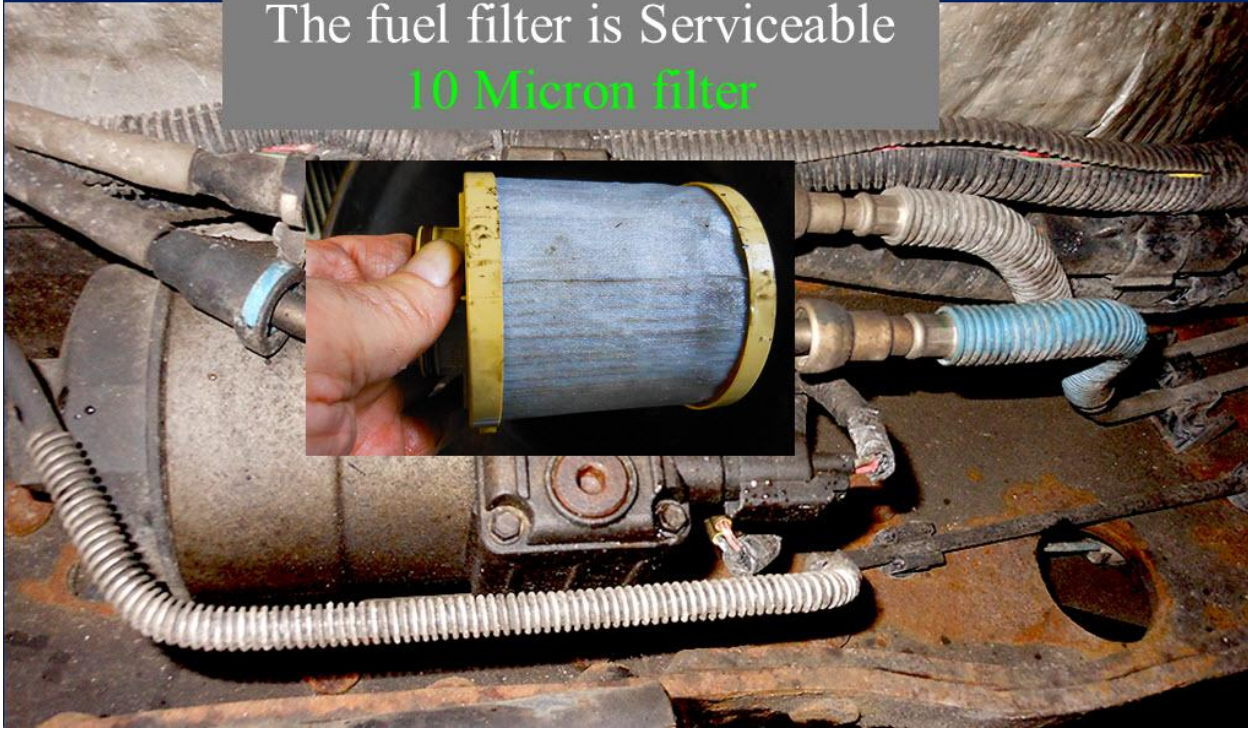


Use the Bi-directional controls on the scan tool to command the fuel pump on when testing. Using the Bi-directional commands will test different parts of the fuel pump and its circuit. If the fuel pumps runs when commanded, it indicates that the PCM and its circuits, as well as the pump itself are good. What it doesn't tell us is the computer input side of the fuel pump and its circuits. As an example, does the PCM know when to turn the pump on?

Primary Fuel Filter

Fuel Filter

The fuel filter is Serviceable
10 Micron filter



Inside the HFCM is a 10 micron filter. It is serviceable and easy to get to. Simply remove the cap on the end of the HFCM, remove and replace the filter. There is an “O” ring on the cap. A new one comes with the filter. Instructions say to lubricate the “O” ring with diesel fuel when installing it. The fuel filter cap should be torqued to 25 Nm.

Fuel/Water Separator

Once the fuel enters the filter water is separated and falls to the bottom of the HFCM



The fuel pump draws the fuel into the HFCM and pressurizes it is routed through the filter. Once the fuel enters the filter water is separated and falls to the bottom of the HFCM and collects there. The water in fuel switch/sensor is mounted where the water is collected. It is called a switch or sensor in the different manuals. It is a simple one wire sensor/switch. The WIF pulls the voltage reference to ground when the collected water covers the sensor's probes

Diesel fuel won't pull the voltage to ground because it isn't conductive enough. The water closes the electrical circuit. When the PCM sees the circuit is pulled to ground it turns on the water in fuel lamp.

Water in fuel sensor



After being heated, fuel enters the filter housing via a one-way check valve. Once in the filter housing, water is separated from the fuel. If large amounts of water are found in the fuel, a sensor in the separator warns the operator of this condition by illuminating a light on the dash. The Water in Fuel (WIF) light will come on when approximately 0.2 pints (100 cc) of water accumulates in the module.

Water in fuel switches Recall:

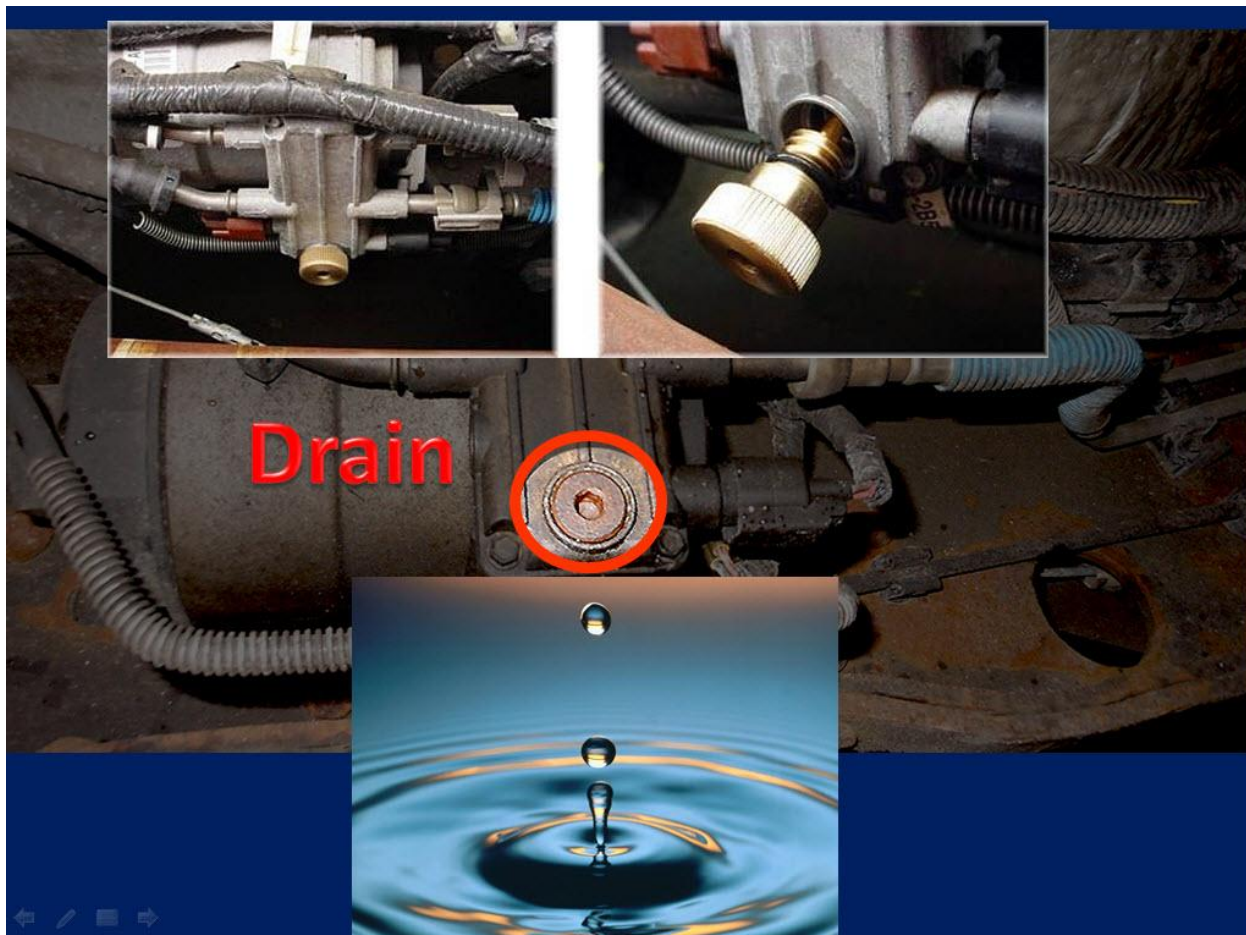
1. For intermittent / flickering WIF lamp condition reprogram the powertrain control module (PCM) to the latest calibration using the IDS release B32.11 or higher. Calibration files may also be obtained at the website.
2. If the WIF lamp continuously illuminates without the presence of water, this may be due to corrosion on the sensor pins or sediment build up in the water reservoir.
 - a. Drain the horizontal fuel conditioning module (HFCM) reservoir and look for significant corrosion debris or sediment in the fluid drained from the reservoir. Remove the WIF sensor and inspect for corrosion on the pins. Remove the WIF Sensor by first disconnecting the electrical connector, then using channel

locks, rotate the WIF sensor at least 45 degrees counterclockwise. If there is corrosion / sediment on the pins, proceed to Step b. If there is not, refer to PC/ED lead diagnostics and do not proceed with the TSB

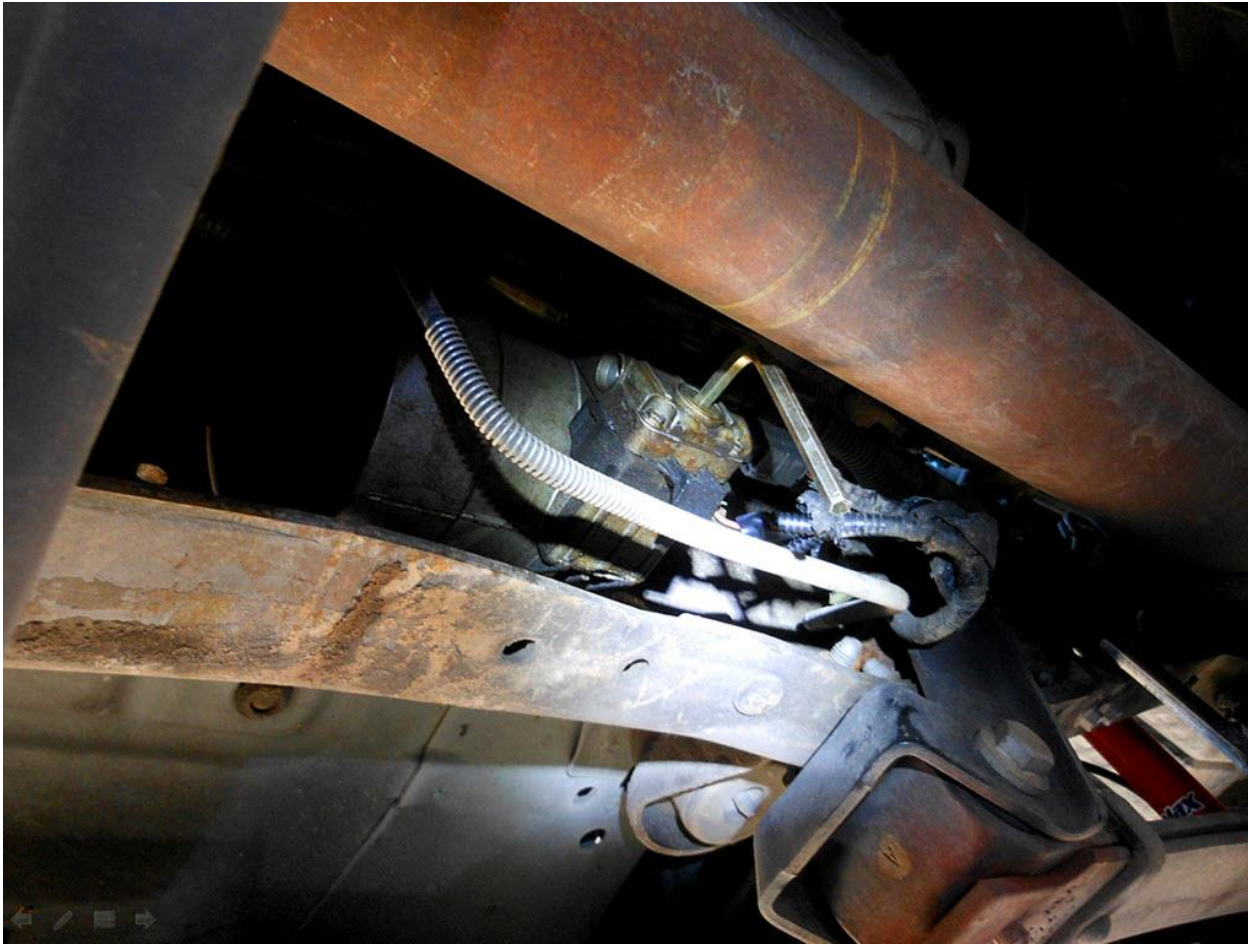
- b. If corrosion on the pins is causing the WIF lamp to illuminate, replace the WIF sensor with service kit, following the WIF sensor installation instructions in the kit.
- c. If there was significant corrosion debris or sediment drained from the reservoir, clean the housing of the HFCM of any debris following the HFCM cleaning procedure. It is not necessary to replace the Manifold or HFCM assembly.

Vehicles with both an intermittent and continuous WIF light due to corrosion are to follow actions 1 and 2 as described above, referring to the vehicle built dates and application.

Drain Water when WIF Lamp is on



Use a hex wrench to open drain



The drain for the water “feels” funny. It is mounted in an elastomer and moves around when you put a wrench on it. At first it feels like it is stripped or broken. The elastomer is to keep it from being over tightened. There is an updated drain screw that uses a thumb screw and not a wrench.

Drain all water from HFCM



NOTE!

Because there were so many problems, Ford discontinued the fuel heater for the 6.0 L. It seems no one is sure you can get them anymore.

Diesel Thermo Recirculation Valve (DTRM)

The fuel returning from the pressure regulator mounted on the secondary filter housing (engine mounted fuel filter) enters the HFCM through the return line. The DTRM will allow the fuel to return to the tank or returns it to the unfiltered side of the fuel filter in the HFCM. The DTRM starts to open (recirculating fuel back into the pump) at 80° F (27° C) and is fully open at 50° F (10° C).

Fuel Injectors (HEUI)

HEUI

Hydraulically actuated,
Electronically controlled,
Unit
Injector



The injectors on the 6.0 L Powerstroke are **hydraulically** actuated, **electronically** controlled Unit Injectors, HEUI for short. There isn't a high pressure fuel pump on this diesel engine. Each Injector is in fact its own Injection Pump. Each unit injector basically has two sections, one for fuel, and one for high Pressure engine Oil. Unless there is a mechanical failure the two fluids should never contact each other. The fuel provided by a low pressure fuel pump (in the HFCM) (55 psi), and the Engine Oil is delivered by a High Pressure Oil Pump (HPOP). The HPOP uses low pressure crankcase engine oil and pressurizes it to between 500 and 3000 psi based on the duty cycle of the IPR (injection pressure regulator) that is controlled by the PCM (Powertrain Control Module).

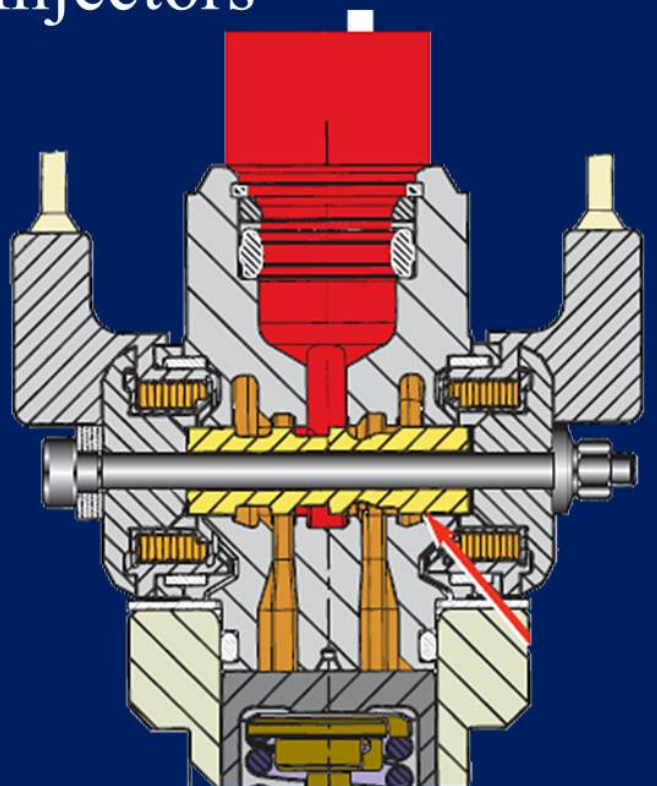
The engine is a V-block design with two cylinder heads and 8 cylinders. On the Left (Drivers) side you have cylinders 2,4,6,8 from front to back, and the right (passenger) side is numbered 1,3,5,7 front to back. In each head there are 4 round holes that feed all the way down to the combustion chamber in almost a reverse cone shape. The injector cups fit in the holes where the injectors are positioned in the head with the tip actually protruding into the top of the combustion chamber. Also in each head are two passageways that run the length of the head. The fuel rail (fuel passages) is inside the head, and the fuel system is a

deadhead design, meaning there is no return from the engine. That means the fuel moves relatively slowly through the head until it reaches the injector. During that time the oil is picking up heat directly from the engine. Precise fuel pressure is unimportant. The fuel pressure only needs to be enough to promote proper filling of the injector fuel cavity. Regardless of year, anything less than 50 psi and there won't be complete injector filling under load, anything over 100 psi and there is a risk of interfering with correct injector operation. There is a 50 psi window for fuel pressure that will have no effect on performance, power, emissions, or mileage. It could be stated that fuel pressure requirements are non-specific, More than enough, and less than too much. The injector is actuated with the High pressure oil.

Fuel Injectors

The injector uses two (2) 48 volt 20 amp coils to control a spool valve

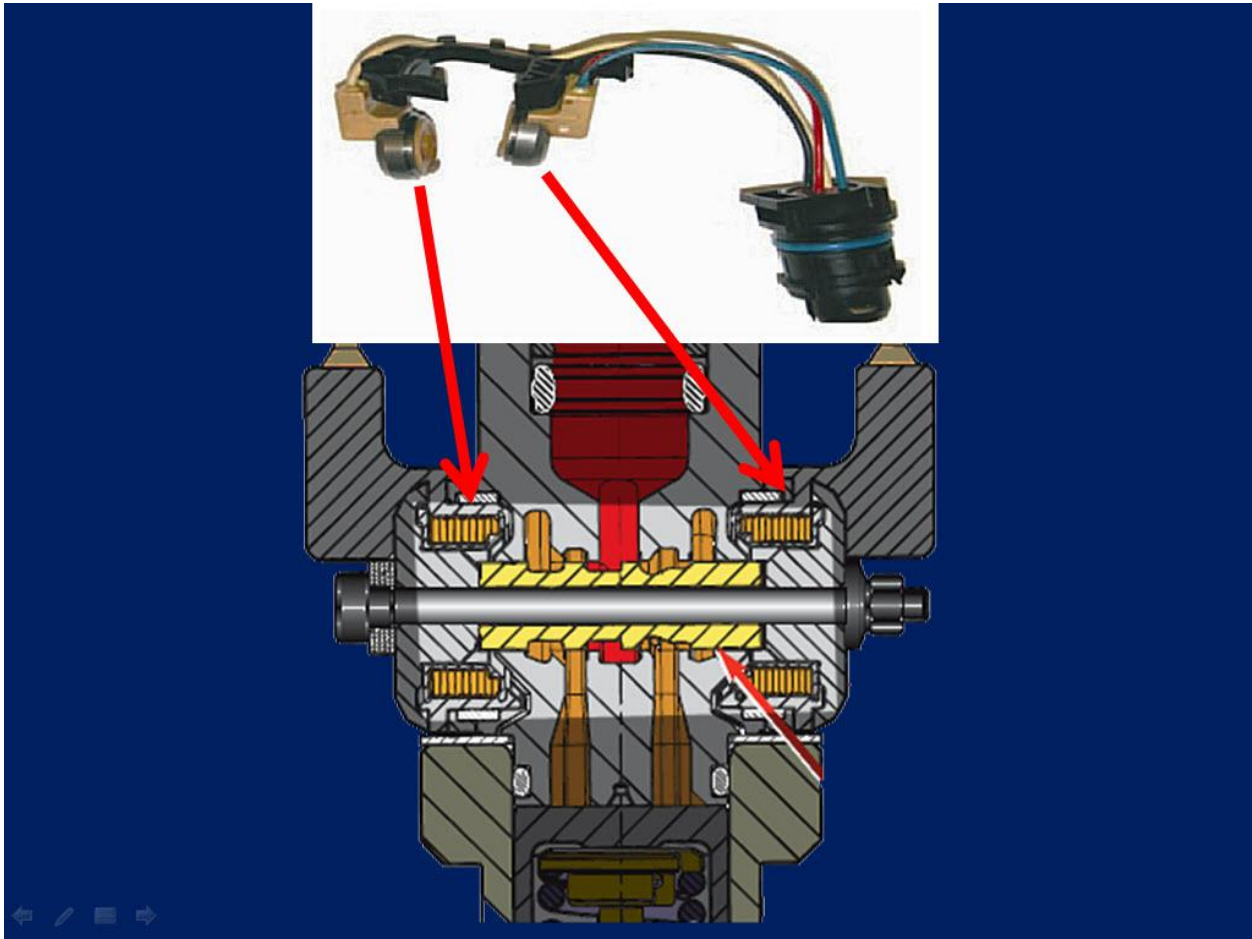
The spool valve directs oil flow in and out of the injector



Looking at this image we can clearly see that the top part of the injector is the high pressure oil area and the bottom is the fuel area.

The injector has an intensifier piston that multiplies the pressure of the high pressure oil by 7.1 times and transfers it to the low pressure fuel to create a maximum injection pressure of 26,000 psi for the 6.0 L. That is a max of 3,000 psi of HPOP for the 6.0 L. The high pressure engine oil pushes on a piston that then pressurizes and injects the fuel into the

cylinder.





1. The electrical open and close solenoids
2. Spool valve
3. Intensifier piston
4. Fuel path
5. Pintle and Nozzle
6. Surface area where fuel pressure pushes the pintle upward to open
7. The screen where fuel enters the injector
8. Stages of Injection

Stages of Injection

The injection cycle has three (3) stages.

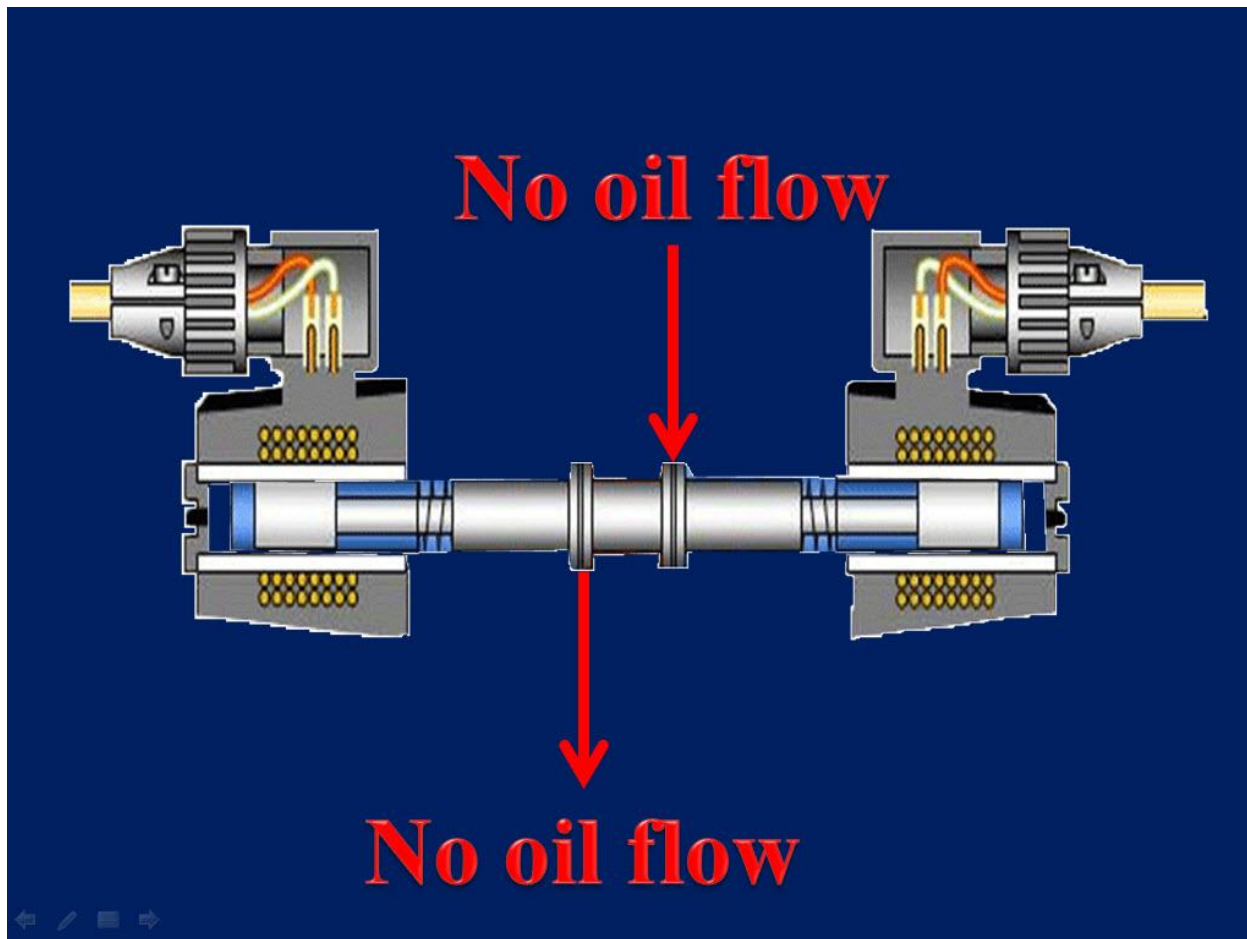
1. Fill.

2. Main injection.

3. End of main injection.

During some conditions, the injector will perform all three stages of the injection cycle two times per firing cycle. This is called pilot injection.

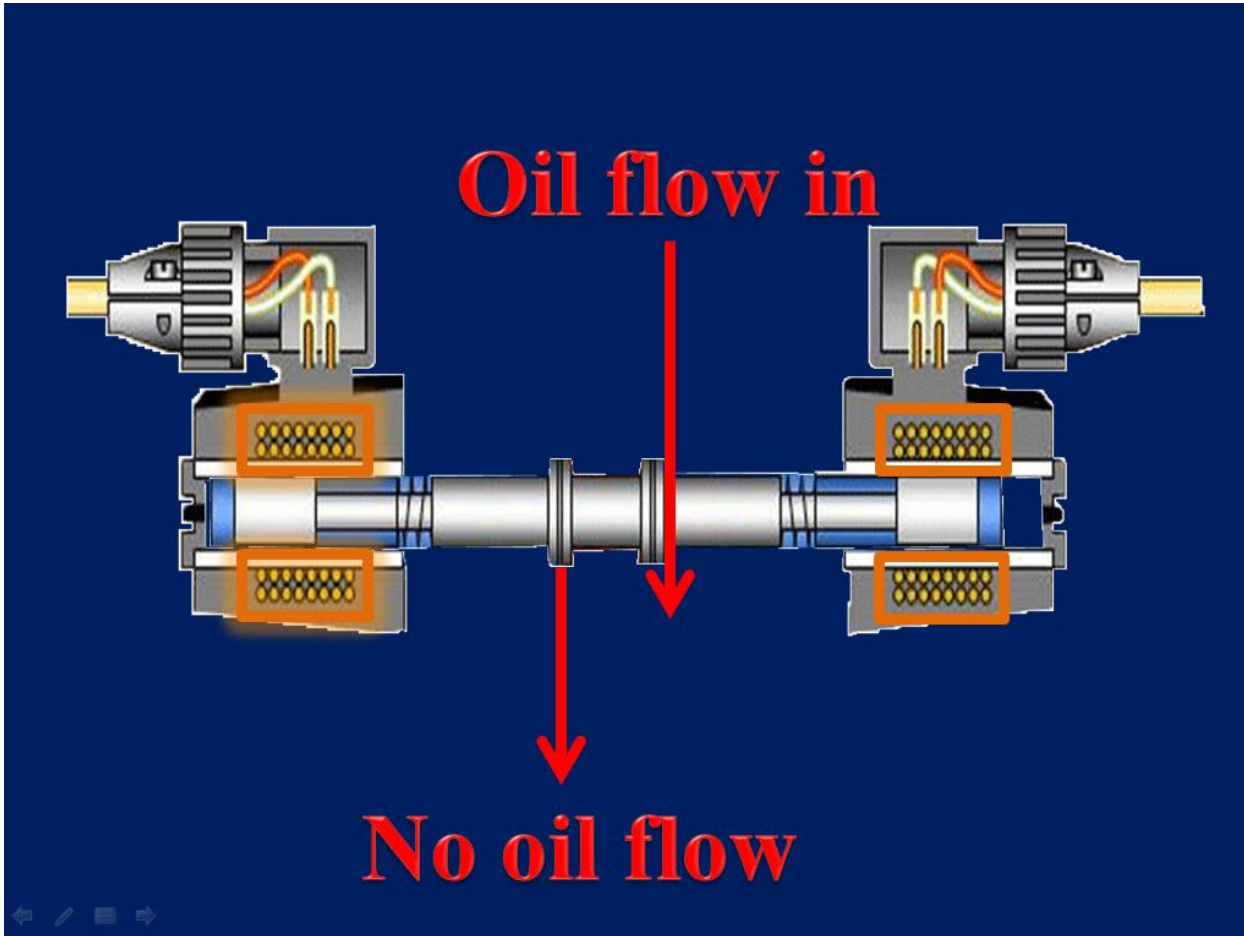
Fill Cycle: During the fill stage, the spool valve is in the closed position. High pressure oil from the oil rail is dead headed at the spool valve. Low pressure fuel fills the port below the plunger.



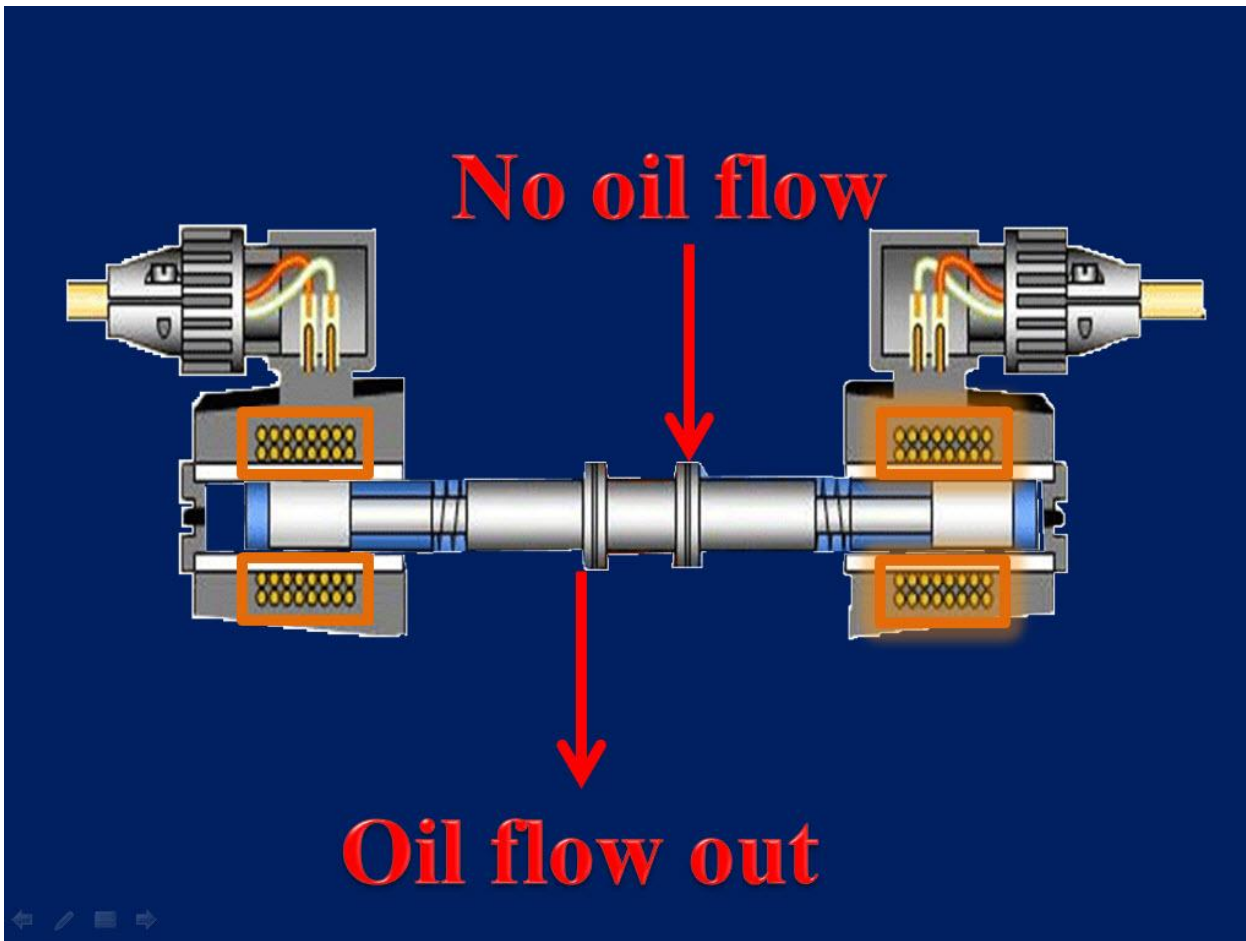
The needle control spring holds the needle on its seat so that fuel cannot enter the combustion chamber. **It is important to fill the injector without an air space that will result in hydraulic hammering; this is why we are so critical about fuel pressure and volume.**

Main Injection Step 1: Pulse width controlled current energizes the open coil, magnetic force moves the spool valve to the open position. High pressure oil flows past the spool valve into the intensifier piston chamber. Oil pressure overcomes the intensifier piston spring force and the intensifier starts to move. Fuel inlet check ball seats due to an increase

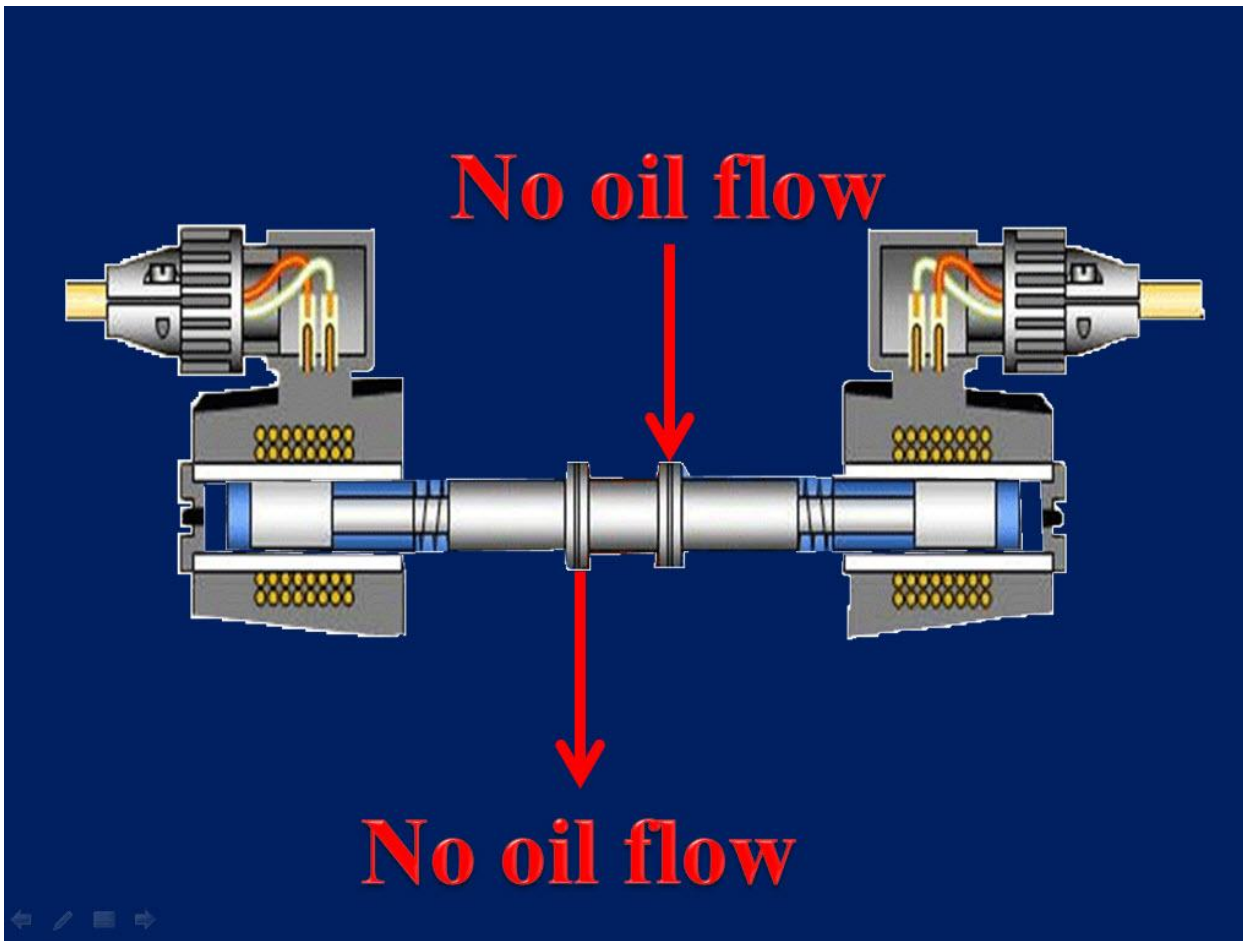
of fuel pressure under the plunger. Fuel pressure starts to build once the plunger passes the fuel spill port of the barrel. Force on the nozzle needle begins to build.



Main Injection Step 2: The pulse width-controlled current is shut off after 800 seconds (micro second or millionth of a second) but the spool remains in the open position. High pressure oil from the rail continues to flow past the spool valve. The intensifier piston and plunger continue to move and pressure increases in the barrel. When fuel pressure rises above the VOP (Valve Opening Pressure) of about 3100 psi, the nozzle needle lifts off of its seat and injection begins.



End of Main Injection Step 1: When the FICM (Fuel Injector Control Module) determines that the correct injector on time has been reached (meaning that the correct amount of fuel has been delivered), it sends a pulse width-controlled current to the close coil of the injector. The current energizes the close coil. Magnetic force moves the spool valve to the closed position.



High pressure oil is dead headed against the spool valve.

End of Main Injection Step 2: The pulse width-controlled current is shut off after 800 seconds (micro seconds or millionth of a second) but the spool remains in the closed position.

The intensifier piston and plunger begin to return to their initial position. The oil above the intensifier piston flows past the spool valve through the exhaust ports. Fuel pressure decreases until the nozzle needle control spring forces the needle back onto its seat.

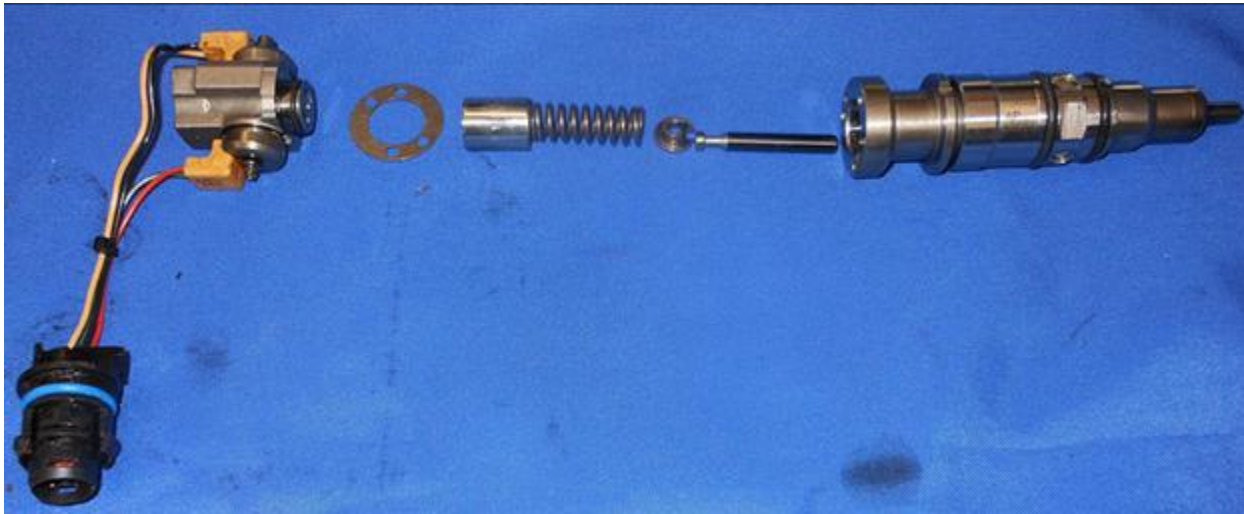
When neither coil is activated, no oil from the HPOP flows into it or out of it. When the opening coil is activated oil from the HPOP flows in and opens the pintle in the injector. To close the pintle, the FICM

Stops the current flow to the opening coil and activates the closing coil. The oil then flows out the injector.

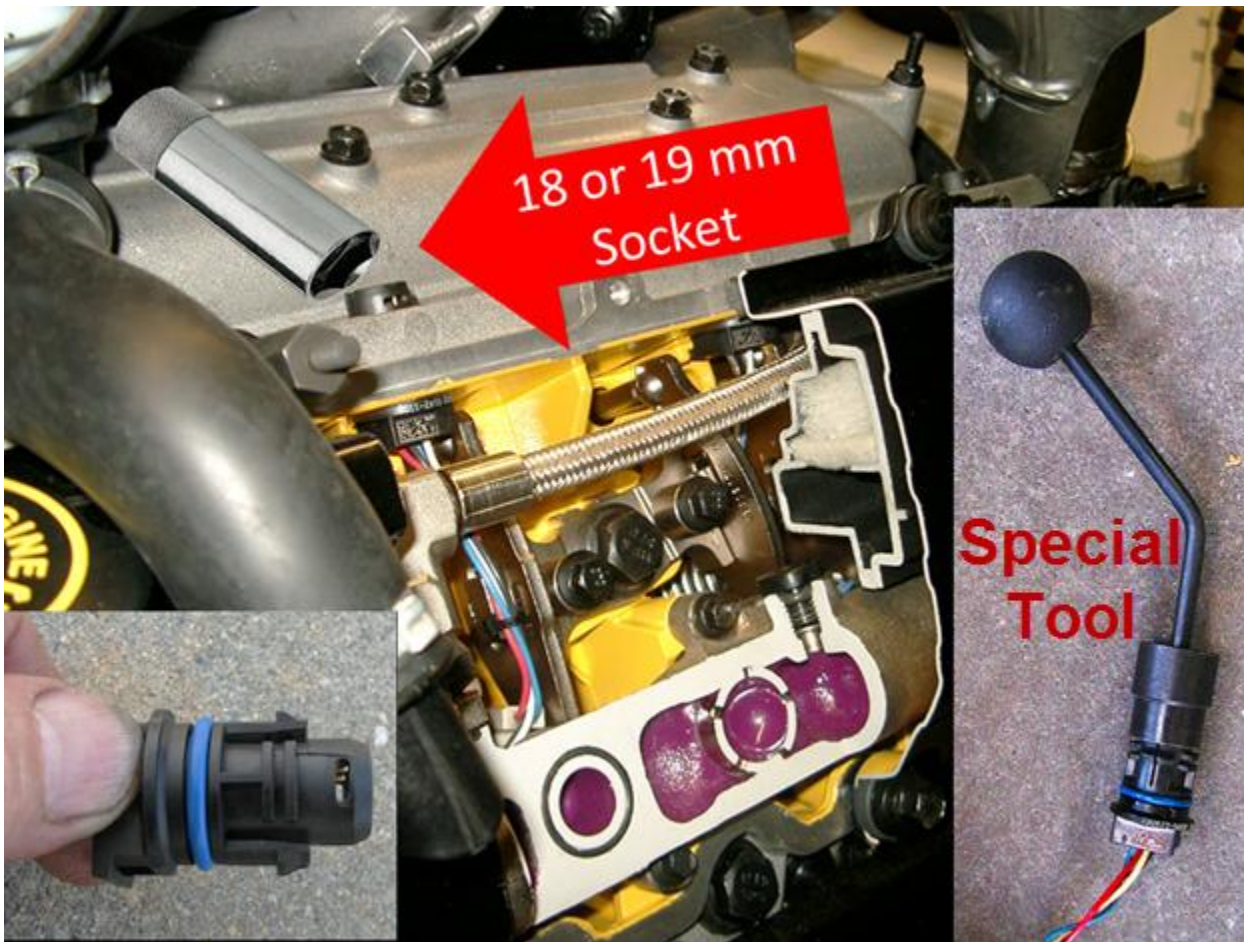
Injector Pulse Width

An 800 μ sec pulse is required to turn on the open solenoid (For oil to flow into the injector). Another 800 μ sec is used to turn on the close solenoid (For oil to flow out of the

injector). The time in between the opening and closing of the oil control valve is injector pulse width.

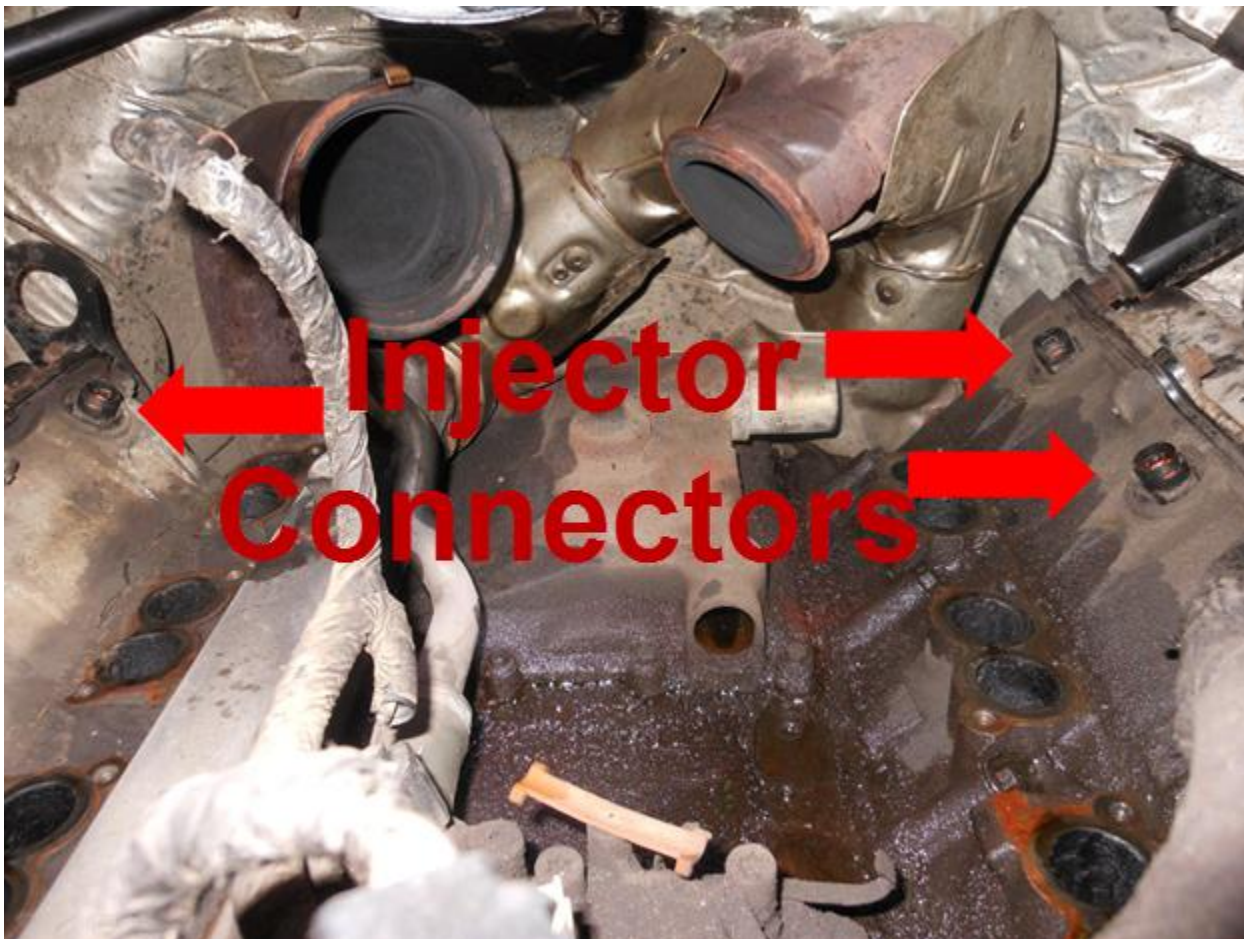


Injector & “O”-rings The injector has two (2) replaceable “O”-rings on the outside of the body, one internal non-replaceable “O”-ring in the top of the injector, and one replaceable copper combustion gasket on the tip of the injector. The injector's two coils have a single four pin connector that passes through the rocker arm carrier.



Each injector has an electrical connector that mounts into the head so that it is exposed to the injector harness when the valve cover is in place. There is a retaining clip holding the connector in the head, it must be removed first. Prior to 2004 the clip was orientated to the 9:00 position and 2004 and newer it is 12:00. There is a special tool available to remove the connector from the head. Many technicians use a socket to release the tabs. An 18 or 19 mm socket works well.

Each injector has an electrical connector that mounts into the head so that it is exposed to the injector harness when the valve cover is in place. There is a retaining clip holding the connector in the head, it must be removed first. Prior to 2004 the clip was orientated to the 9:00 position and 2004 and newer it is 12:00. There is a special tool available to remove the connector from the head. Many technicians use a socket to release the tabs. An 18 or 19 mm socket works well.



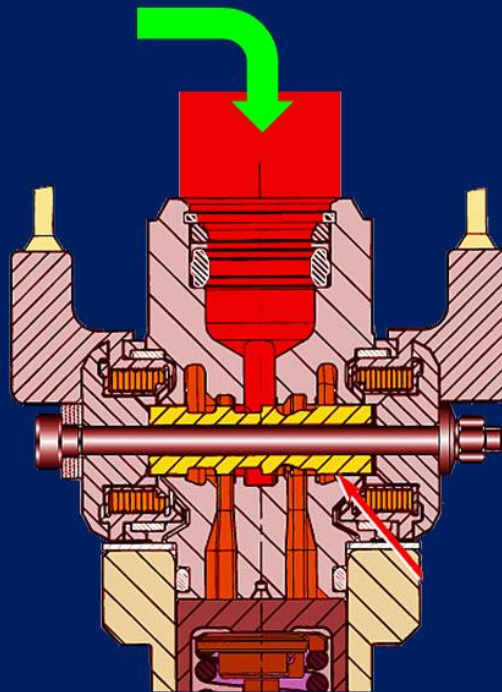


The nut for the bolt that holds the solenoids and spool valve in position works its way loose and falls off into the intake manifold valley.

High Pressure Oil

High oil pressure controlled

High pressure oil enters the top of each injector




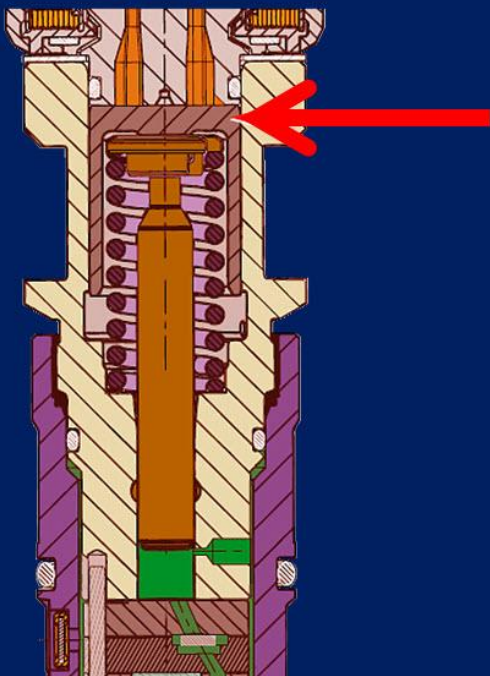
The engine oil from the HPOP enters the injector at the top. It doesn't do anything until the

FICM activates the opening coil, the oil flows into the injector, pushing against the intensifier piston which plunger multiplies the pressure seven times and pushes the plunger downward against a cavity filled with fuel. The fuel in the cavity is pressurized to create a force great enough to push the pintle open allowing the fuel to spray into the combustion chamber. The multiplication of pressure is 7.1 times greater at the plunger than what the injection control pressure (ICP). This is the system that supplies the high fuel pressure since there isn't a high pressure fuel pump.

Intensifier Piston

When the spool valve is in the open position, high pressure enters the injector and pushes the intensifier piston and plunger downward

Intensifier Piston



When the spool valve is in the open position, high pressure oil is allowed to enter the injector and pushes the intensifier piston and plunger downward.

Since the intensifier piston is 7.1 times greater in surface area than the plunger, the injection force is also 7.1 times greater at the plunger than what the injection control pressure (ICP) is.

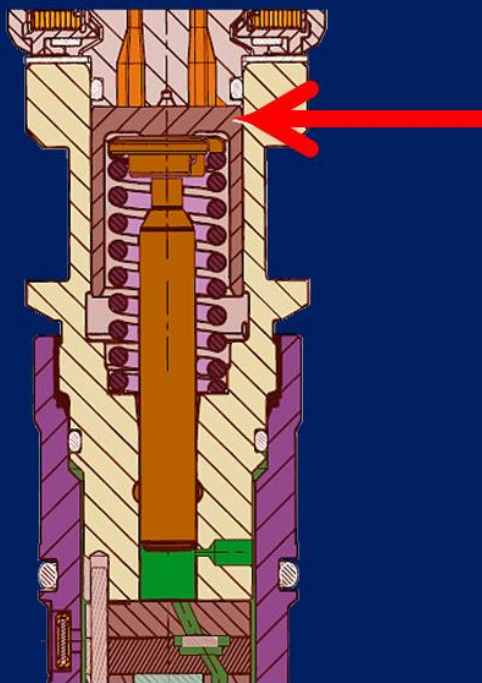
Hydraulic Intensifier

The intensifier piston is 7.1 times greater in surface area than the plunger

This multiplies the injection control pressure (ICP) 7.1 times

This creates a force 7.1 times greater to open the injector

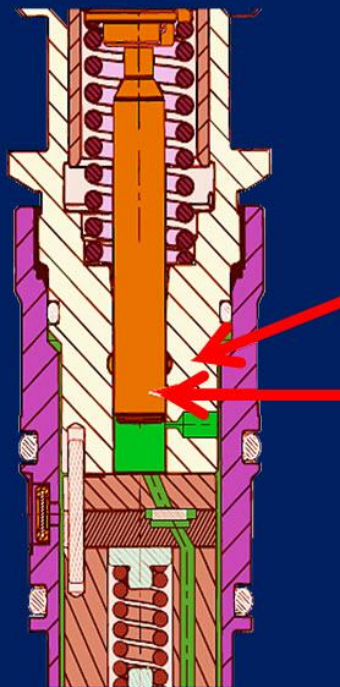
Intensifier Piston



The intensifier piston is 7.1 times greater in surface area than the plunger. This multiplies the injection control pressure (ICP) 7.1 times. This creates a force 7.1 times greater to open the injector. Multiply the 4000 psi control oil pressure by 7.1 and the pressure increases to 28,400 psi. When the increased pressure is applied to the fuel it raises fuel pressure up to 28,400 psi.

Plunger & Barrel

The bottom of the plunger and barrel is where the fuel injection pressure is built



The bottom of the plunger and barrel is where the fuel injection pressure is built.

Injection Nozzle

The injection nozzle needle is an inwardly opening type which lifts off its seat when pressure overcomes the VOP (Valve Opening Pressure) of approximately 3100 psi.

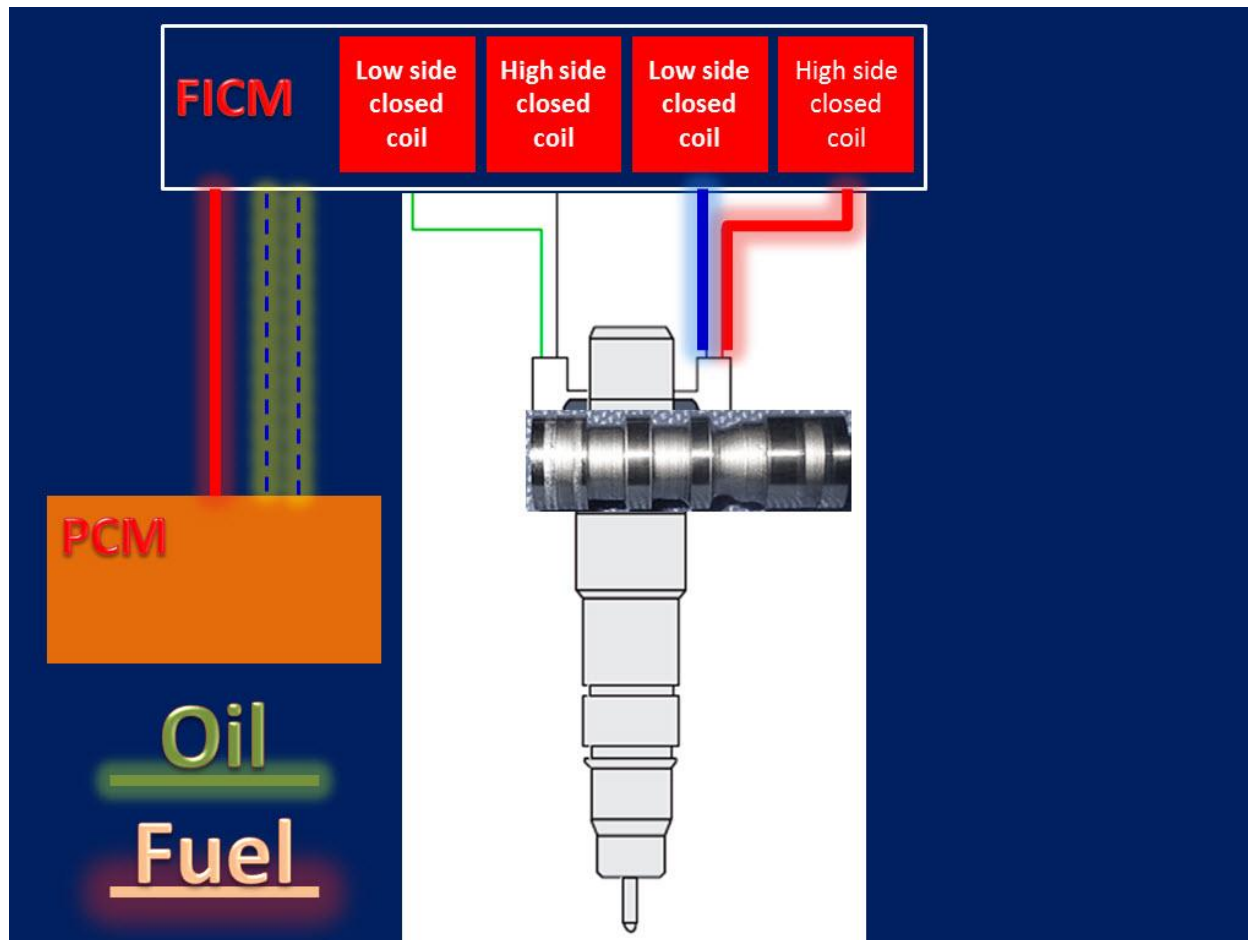
Fuel is atomized at high pressure through the nozzle tip.

Note!

The required pressure to open the injector nozzle is about 3100 psi of fuel pressure. We also know that injector control pressure (ICP) must be 500 psi of oil pressure or 0.8 volts (discussed later in the program) to create the 3100 psi fuel pressure needed during engine cranking. With that said, we understand that the intensifier piston multiplies by a factor of 7:1. At 500 psi (0.8 volts) oil pressure we would get 3500 psi. This course is not contradicting itself when we state that 3100 psi is required to open the injector and ICP must be 500 psi. In the service bay the fuel pressure inside the injector can't be measured but the ICP pressure is with the ICP sensor. When diagnosing, it is important to pay

attention to ICP. The diagnostics is: If fuel pressure is normal, 45-70 psi, and ICP is at a minimum 500 psi (0.8 volts) the multiplication must be correct because it is mechanical. Now if the injector is gummed up inside and the intensifier piston doesn't move or move far enough, the injector won't deliver the correct amount of fuel. The PCM would set a misfire code for that cylinder. If the problem wasn't severe enough to set a code and all the technician had was a customer complaint about a rough (lumpy) idle he could find it with a cylinder contribution test.

Fuel injector operation



Based on a signals from the PCM, the FICM turns on both the high and low side drivers for the open the injector solenoid. This causes the spool valve to shift its position and high pressure oil begins to flow into the injector. The oil pressure moves the intensifier piston downward and this compresses the fuel 7.1 times greater than high oil pressure. The open solenoid is on for an 800 μ sec pulse. The, now high fuel pressure overcomes the pintle spring and the pushes the pintle upward opening the injector and fuel flows into the combustion chamber.

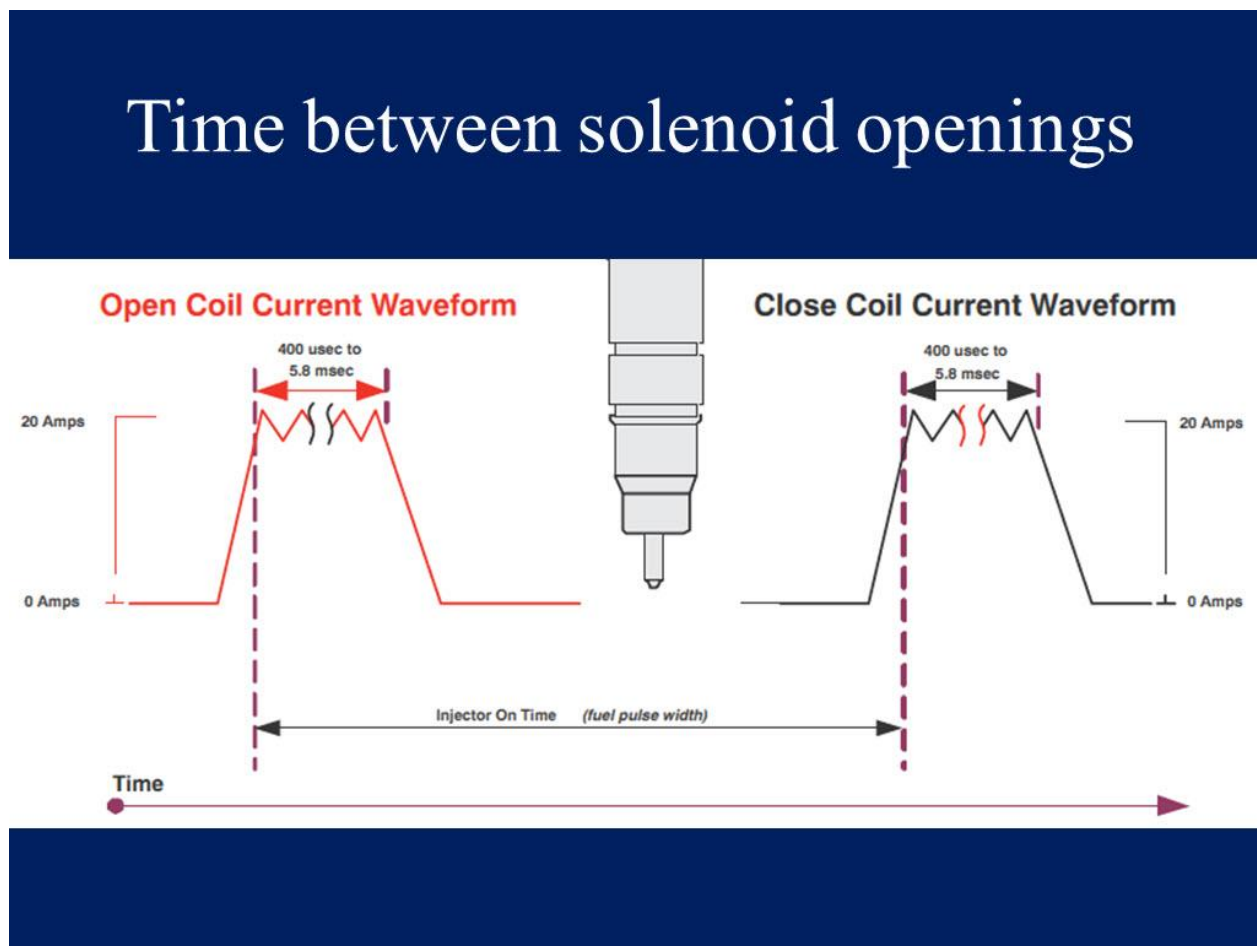
The FICM then turns on both the high and low side drives for the close solenoid. This

causes the spool valve to shift back to its normal position and high pressure oil stops flowing into the injector. Without oil pressure the intensifier piston returns to its normal position. The close solenoid is on for an 800 μ sec pulse. Fuel will continue to flow until fuel pressure falls below 3100 psi. The amount of time between the open and close solenoid pulses is the injector pulse width (PW).

NOTE!

If oil pressure cooler is plugged the injector control pressure won't equal the desired injector pressure. Also the pump may be faulty.

Actual injector on time



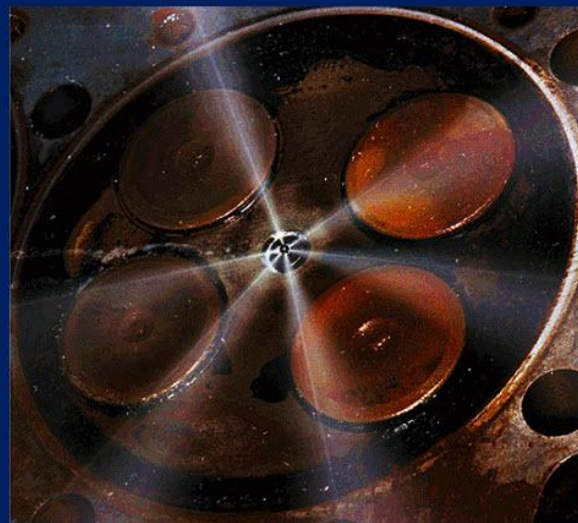
Time between solenoid openings is the injector pulse width (PW).

Injector spray pattern

The injector spray pattern on the left shows good fuel atomization where as the one on the right doesn't

Good

Not So Good



The two injector spray patterns in the images shows a good pattern on the left and a bad pattern on the right. The left injector fuel is being atomized completely. The pattern on the right shows that the fuel is being only partly atomized. The difference is that the cylinder on the right will be leaner than the one on the left. It wouldn't have complete combustion. If both of these injectors are on the same engine it would run rough and un-even at idle. If the one on the right would worsen over time the engine would run rough at other RPMs. A misfire would develop and set a misfire code.

The technician would be left the task of determining the root cause of the misfire. We have been covering the fuel system. Fuel pressure was important and how to check the fuel pressure was discussed. Use the image on the right and think of how fuel pressure or volume could cause the problem.

Having studied the injector operation you can vision this poor injector spray pattern being caused by one of the injector's internal components not doing its job.

As we move on to the Lubrication System think about how anything affecting the high oil pressure system affecting fuel delivery. At the beginning it was stated that fuel delivery

was dependent on three systems working together. The Lubrication System will tie the three together.

Injector removal

Fuel Injectors

No special tools are needed to remove the injectors from their bore



No special tools are required to remove the injectors from their bore.

The injector is slowly removed from its bore by removing the hold down clamp bolt. When installing an injector always torque to the correct specification.

The number one cause of 6.0 L injector failure is poor/lack of maintenance! The closest tolerances in the engine are found in the fuel injectors. Keeping the oil clean is paramount to maximum injector life. Extending oil change intervals will destroy 6.0 L injectors.

Poor quality fuel containing dirt and water will damage 6.0 L injectors. Clogged fuel filters caused by not replacing them at correct maintenance intervals are another reason for injector damage.

Air in fuel system



Look for air in the fuel system

Remove the secondary fuel filter

Crank the engine and look for air bubbles in the fuel filter housing

Can be from suction side or compression side

Could be from failed cooper sealing washing on the injectors

Or the injector cup

Loose injector hold down

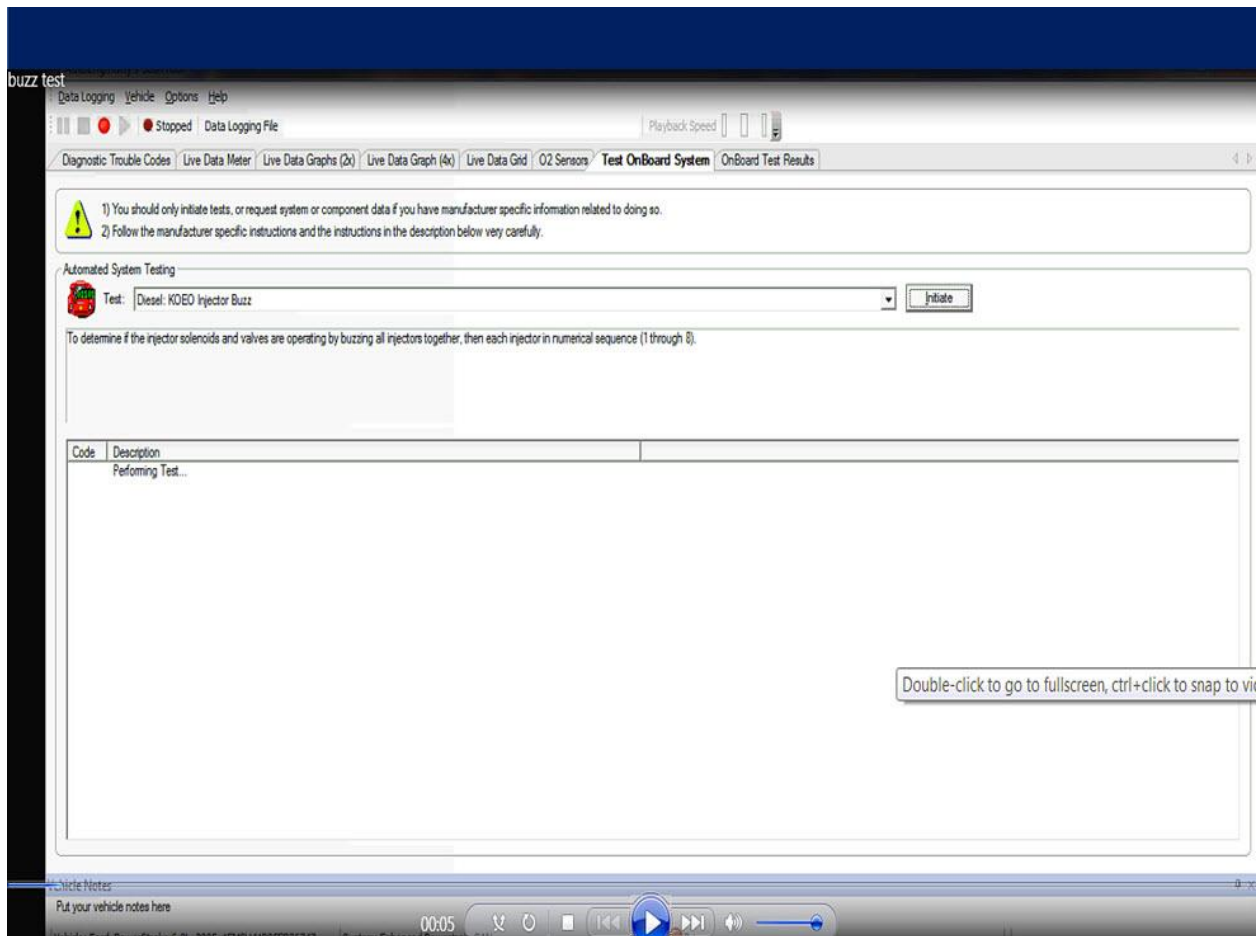
Air in the fuel (Cavitation) can cause the same drivability concerns a faulty injector can cause. To check for air in the fuel; remove the secondary fuel filter cap. Watch the fuel in the bowl while the engine is cranked. The bubbles can be from suction side or compression side. If there from the compression side; bubbles could be from failed cooper sealing washing on the injectors, or the injector cup. If the injector becomes loose it will also cause bubbles (air). There are one way check valves connecting fuel line to the cylinder heads on

the 6 liter. Fuel doesn't flow backward through them but combustion pressure will. Repair the fault and then cycle the key on and off until the bubbles disappear.

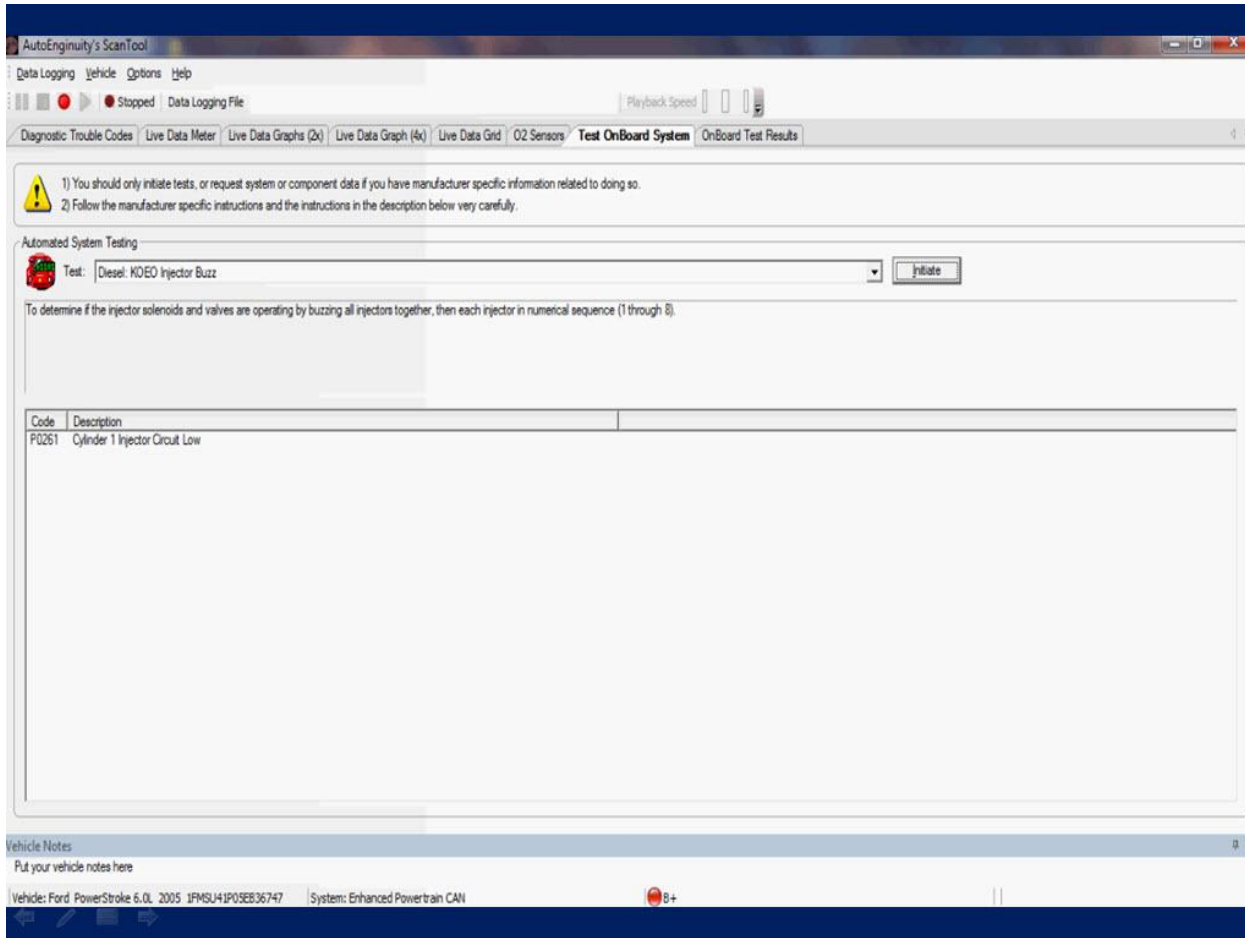
If the truck has been serviced, (fuel filters replaced) air may have entered the system. If there are bubbles (from service or anything else) the system must be bled. Repair the fault and then cycle the key on and off until the bubbles disappear.

The second images show no bubbles in the bowl during engine cranking.

Starting Injector buzz test



Buzz test results



Injector/FICM Test

The FICM and injectors can be tested with a “BUZZ” test. Use a scan tool’s bi-directional controls to command the test. The “BUZZ TEST” activated all injectors then each injector one at a time in the firing order. The injectors and its electrical circuit are being tested. Also the FICM’s ability to activate each injector is being tested. The audible sound heard while performing an injector buzz test is the poppet stopping at the upper and lower seat during actuation. The injector’s resistance is between .8 and .9 Ω on a cold engine (OHMS are temperature related).

Fuel Management

The management of fuel is accomplished through the control of the high pressure oil system. The fuel pressure inside the injector is created by oil pressure. This high oil pressure is created by a high pressure oil pump (HPOP). Engine oil pressure is increased as it flows through the HPOP.

The PCM controls the pressure by controlling a pressure regulator (IPR) and monitoring

pressure through a sensor (ICP).

Fuel Management System Major Components

Fuel Supply System

High Pressure Oil System

Lubrication System

Sensors

Injectors

Electrical Components

Actuators

Lubrication System

The lubrication system is comprised of a low-pressure system and a high-pressure system. The low-pressure system provides primary engine lubrication. The high pressure system provides the hydraulic pressure required to actuate the fuel injectors. The main problem is that it suffers from leaks in a number of areas. The high pressure oil system has a number of “O” rings that fail and cause drivability problems. One main reason for the “O” rings failing is allowing the engine to run too lean. A lean condition may be caused by a lack of fuel or the lack of high oil pressure for operating the injector. A vacuum leak can cause a lean condition. It is important to change the engine oil at or before the recommended service intervals. Oil viscosity is important in maintaining the oil pressure required to actuate the fuel injectors

Extended mileage oil changes can negatively affect engine performance, fuel economy, fuel injector life, and engine life.

088

Special Note!

The oil pressure gauge isn't a true gauge, it more of a warning lamp

7psi puts the gauge at Normal

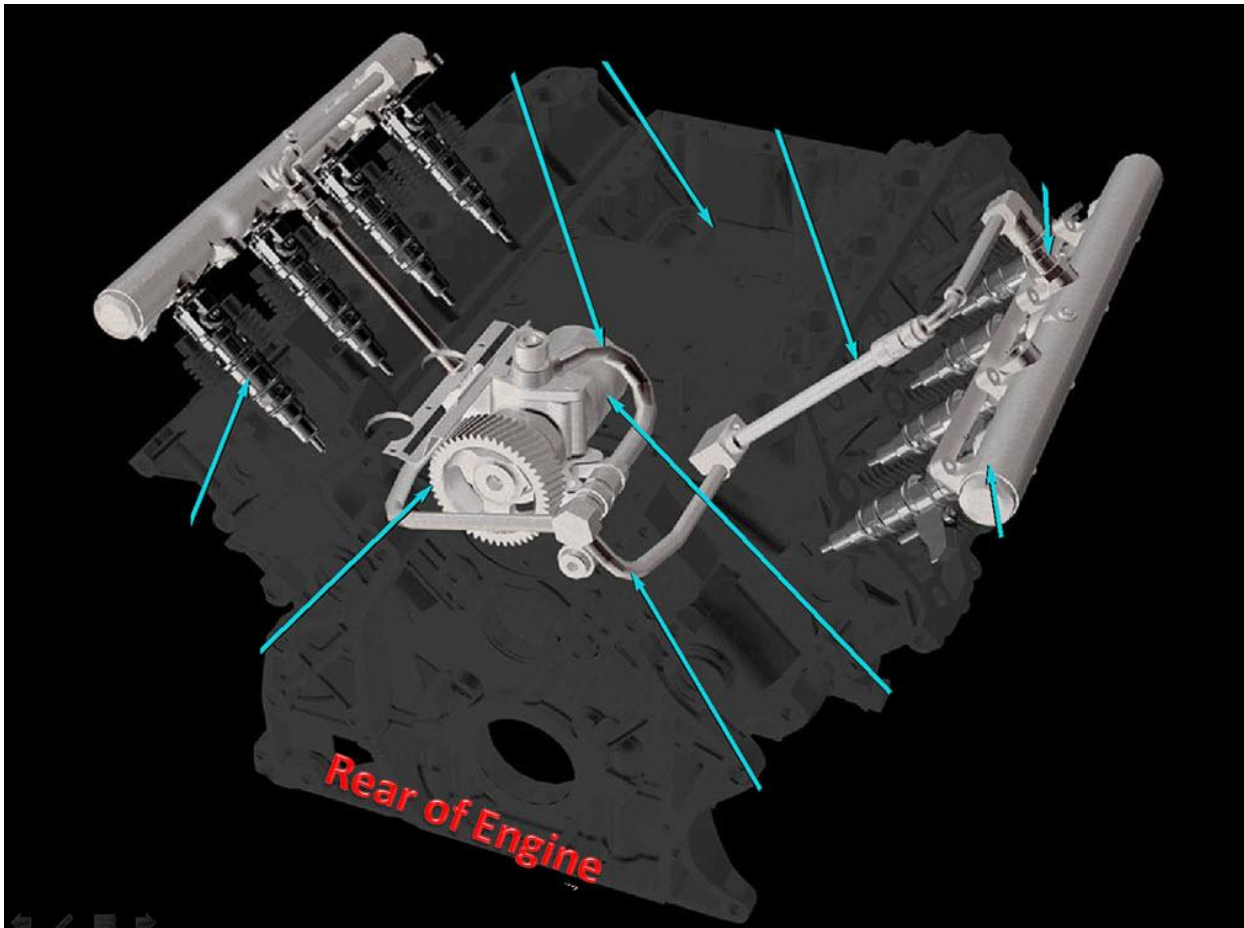
6psi shows no pressure on the gauge



NOTE!

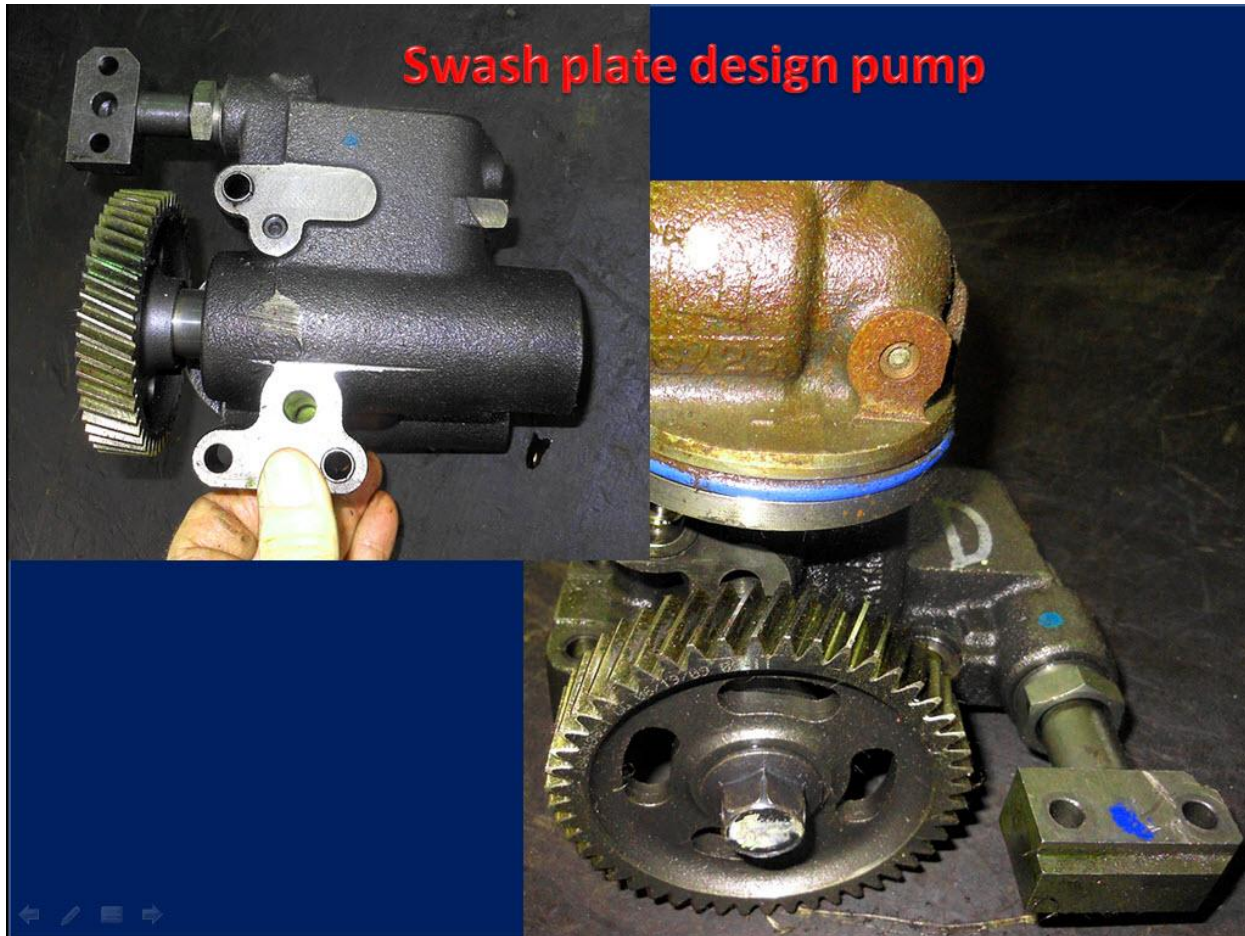
The oil pressure gauge isn't a true gauge, it more of a warning lamp. (Idiot light) when the oil pressure is 7 psi the gauge reads Normal. When oil pressure is 6 psi the gage shows no pressure.

High Pressure Oil System (HPOP)



The cooled and filtered engine oil from the low pressure oil pump (LPOP) is directed into the High Pressure Oil Pump (HPOP) reservoir where it supplies oil to the high pressure system. There the systems oil pressure is controlled by the injection pressure regulator (IPR). Maximum oil pressure is controlled by the pressure relief valve which opens at 4000 psi. There is plumbing from the pump to the high pressure oil rails for each head the top of the injectors are connected to the high pressure (oil) common rail.

High Pressure Oil Pump



The High Pressure Pump (HPOP) is mounted in the rear (firewall side) the engine. It sits between the two cylinder heads in the valley. The gear on the HPOP points to the rear of the engine and is driven by the cam shaft. There is a gear reduction between the cam and HPOP gears. The HPOP runs at the same speed as the crankshaft. The pump is a swash plate design pump. The snap to connect (STC) connector splits the high pressure oil to each cylinder head. There are oil galleys in each head that directs the oil to a stand tube. The stand tubes go through the cylinder heads and deliver the oil to the high pressure rails. The rails deliver the oil to each injector. There is “O” rings in the HPOP, IPR, STC, branch tubes, stand pipes, and rails. It is important to note that the STC, branch tubes, stand pipes, and rails have been updated many times throughout the 6.0 L life. Don’t panic when you take a system apart and it doesn't look the same as the last one you had apart. No matter which version the vehicle has you will be ordering replacement parts by VIN and part number.

Oil Reservoir

Oil Reservoir



The HPOP is supplied with oil from the oil reservoir on the top of the engine. If the engine oil isn't changed slug will build in the reservoir and the HPOP will starve for oil. This will damage the pump and if not attended to will lead to a lean running engine. Ensure that you read and understand the section on oil filters. To protect your customers from themselves it is important to understand the design of the filters to explain it to the truck's owner.

Oil Cooler



The reservoir is supplied with oil from the oil cooler.

Oil Cooler Housing & Filter Base

Oil flow is from the crankcase to the oil. The oil pump is turned by the crankshaft and creates oil pressure. The oil cooler removes heat from the engine oil by dissipating it through the engine cooling system.

Oil is routed from crankcase and enters the oil cooler. The oil then flows through the oil filter mounted in the oil filter base. Oil is filtered and sent to the reservoir to supply the high pressure pump (HPOP). When the coolant leaves the oil cooler it is directed to the EGR cooler.

6.0 L Oil Cooler Failure

Residual sand not removed during the casting process can clog the coolant side of the oil cooler. Old or sludgy oil can clog the oil side of the cooler. Failure can result in oil being

introduced into the cooling system, or coolant overheating, which may result in serious engine damage. Using proper engine oil and changing the oil at the recommended oil change intervals can also prevent failures. Ford also recommends changing the engine coolant at the recommended intervals.

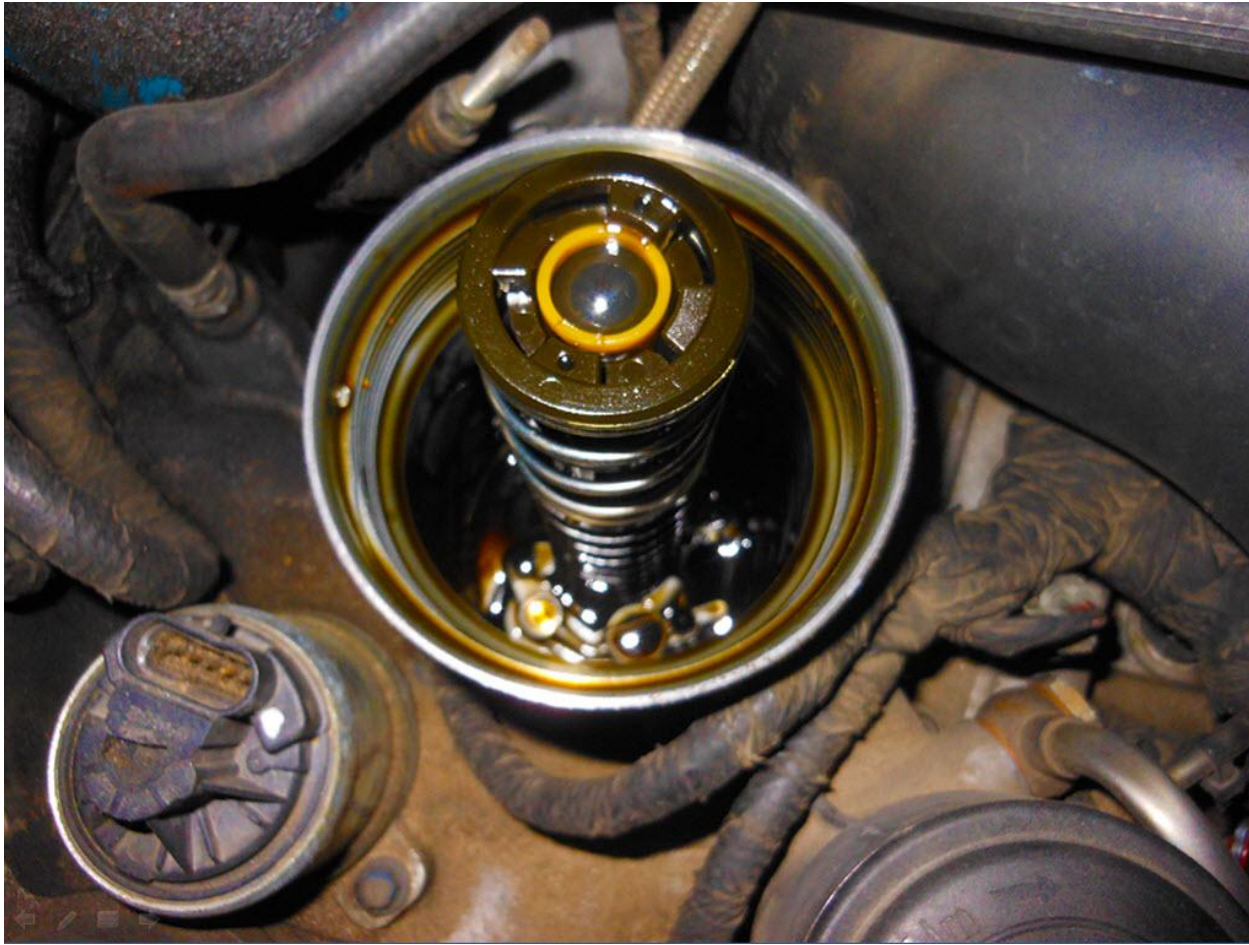
To tests for restricted oil cooler ensure that there isn't a head gasket leak. Connect a scan tool and display the Engine oil temperature (EOT) and the Engine Coolant Temperature (ECT) Accelerator Pedal Position Sensors (APP) PIDs. Graphing the three PIDs would make the test results easier to read diagnose. With a warm engine, perform a HARD test drive and record the three PIDs when the accelerator pedal is released. EOT should not be 15° F to 20° F higher than ECT 20° F is the maximum indicating that the cooler may just start getting restricted.

Oil filter, stand pipe and housing

Oil Filter Removal



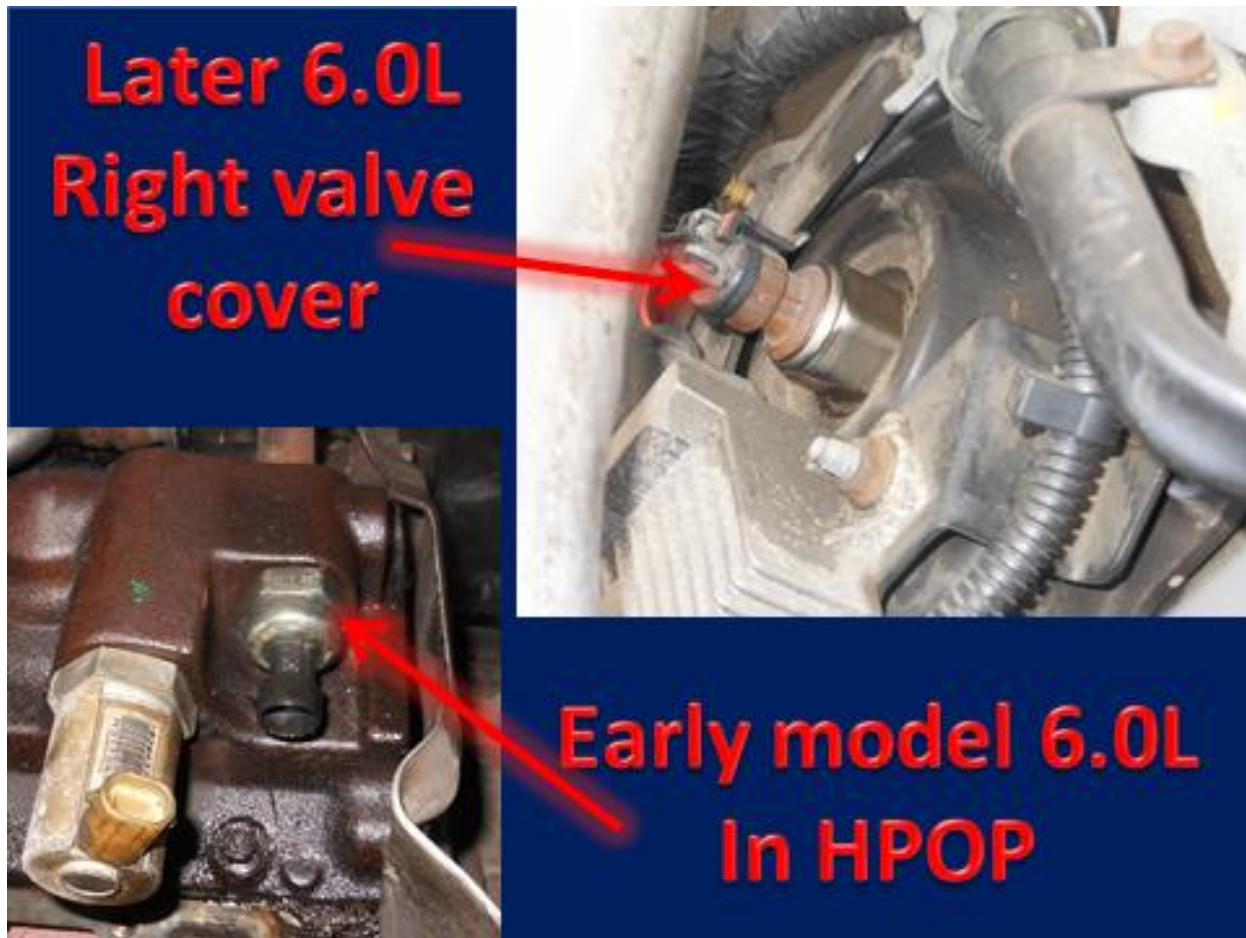
Oil Filter Stand Pipe



There is an oil by-pass valve on top of the oil filter stand pipe. The By-pass valve ensures the engine doesn't starve for oil when the filter is plugged or during cold starts.

The oil filter base also houses the anti-drain back check valve that keeps oil in the oil filter assembly after the engine is shut off. If the oil filter doesn't fit correctly, as in an Aftermarket filter, the oil drain valve doesn't close. The oil drain valve ensures that all the oil enters the filtration path and remains in the filter housing and doesn't drain when the engine is off. When changing the oil, it is important to remove the oil filter before opening the oil drain valve so oil will drain from the filter housing.

Injection Control Pressure Regulator (IPR)



The IPR and ICP are both installed into the high pressure pump cover. The ICP was later moved to the right valve cover.

The PCM controls the high pressure oil system by varying the duty cycle of the injector control pressure regulator (IPR). The IPR controls the oil bypass circuit of the high pressure pump. The ICP is mounted in the high pressure oil pump and on the right valve cover on later models.

0%=full return to sump (open valve) [0 psi oil pressure]

100%=full flow to injectors (closed valve) [4000 psi oil pressure]

The PCM monitors the system with the Injection Control Pressure Sensor (ICP) (input).

The PCM can control fuel delivery to the injectors by increasing the IPR duty cycle which increases fuel pressure by increasing the high pressure oil pressure.

MFDES Mass Fuel Desired

MFDES is an internal PCM calculation based on load demand (MG) are used to calculate the amount of pressure required to maintain the engine load.

IPR (% of duty cycle (IPC duty cycle))

IPR (% of duty cycle) reports the percent (%) of duty cycle the PCM is commanding.

IPC, Injection Control Pressure (Oil)

Scan data reports the oil pressure achieved.



This image is of the injector pressure regulators (IPR) found on the 6.0 L engine. The 7.3 L IPR is shown so that you may be familiar with it and not install one on a 6.0 L. There are two versions of the IPR for the 6 liter. Look at the filtering screens and you can see there is a “Peace Sign” on one version. These screens get plugged up reducing oil flow. The symptom is higher than normal oil pressure. The IPR is an oil by-pass valve and when plugged the oil flow is restricted and pressure remains high. The damage in the steel screens indicates metal particles have passed through the high pressure oil control system

and there is likely damage to other components.

The PCM controls Injector control pressure (ICP) by duty cycling the IPR. The IPR controls pump outlet pressure in a range between 450 and 3,000 psi. The electrical signal to the solenoid creates a magnetic field which applies a variable force on the poppet to control pressure. The FICM uses ICP signal to command the correct injection timing.

Zero percentage % would indicate the oil is fully return to sump (open valve) [0 psi oil pressure].

100 percent % would indicate the oil is fully flowing to injectors (closed valve) [4000 psi oil pressure].

Minimum ICP pressure to open the injectors

The ICP (Injection Control Pressure) sensor needs to be 500 psi to fire the injectors.

If there is a problem with the low pressure oil pump (LPOP) the high pressure pump will starve for oil

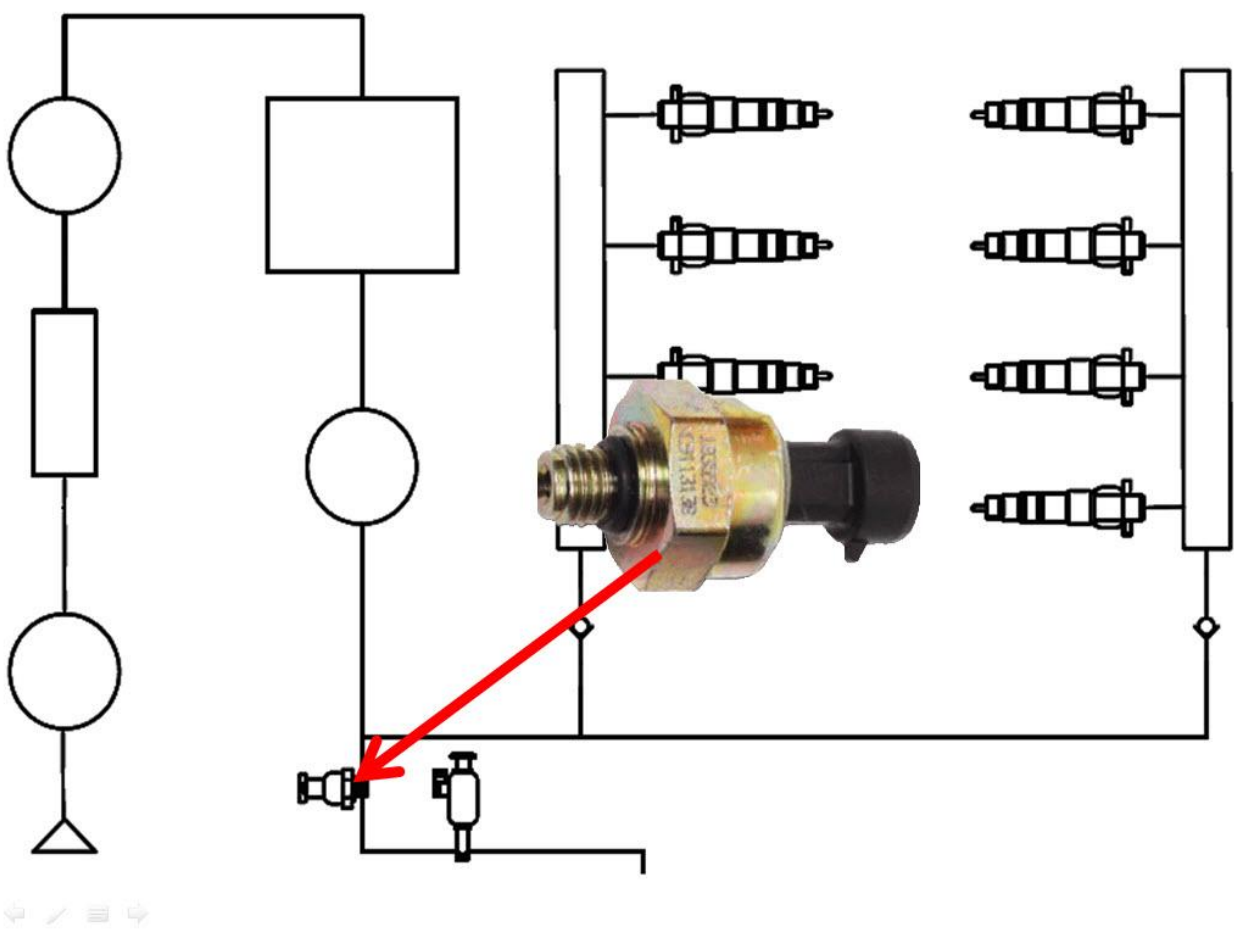
The minimum engine low pressure oil (Not HPOP pressure) specifications are: (The engine needs to be at normal operating temperature).

12 psi (82.7 kPa) at 700 rpm

24 psi (165.5 kPa) at 1,200 rpm

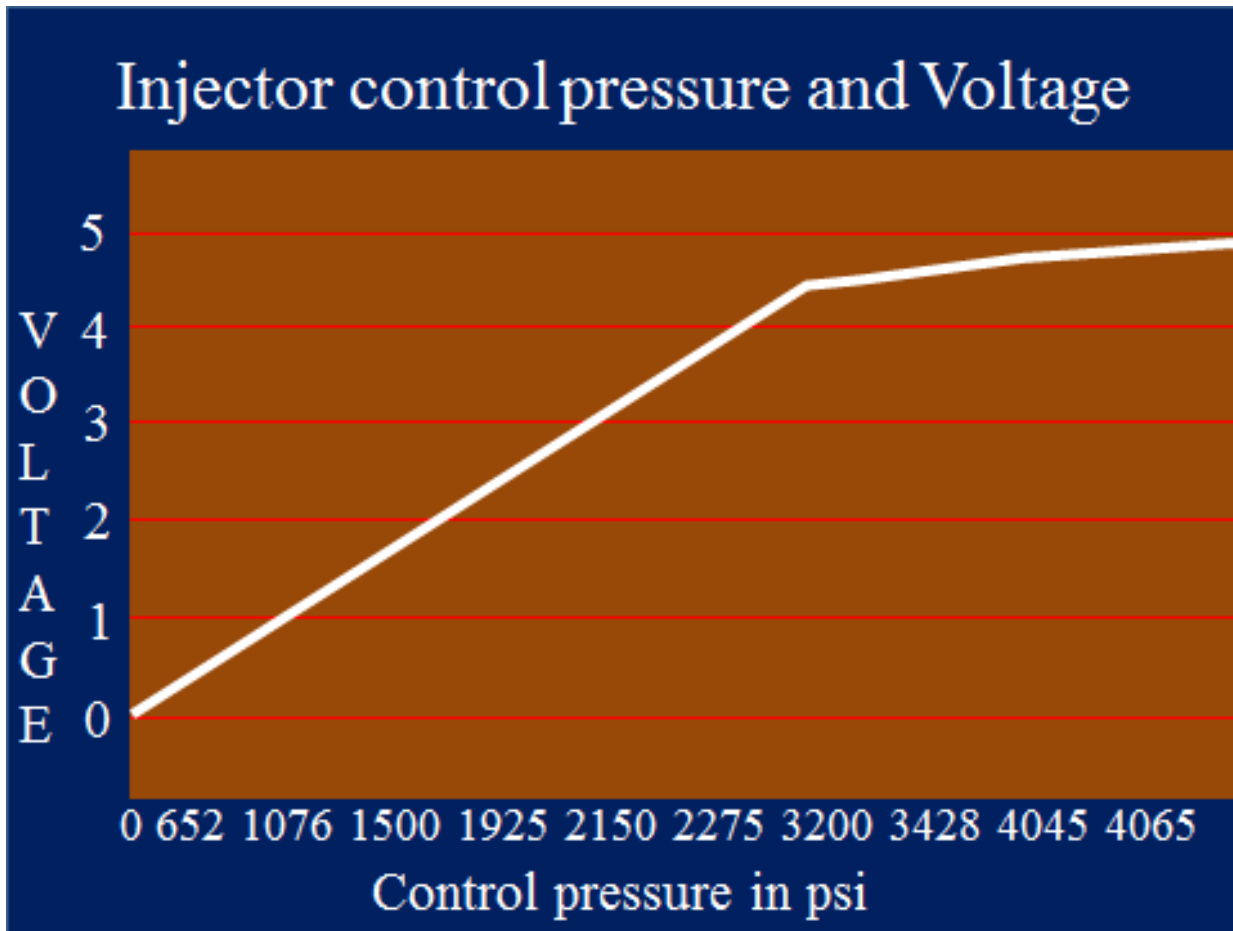
45 psi (310.3 kPa) at 1,800 rpm

Injection Control Pressure Sensor (ICP)



The PCM monitors the system with the Injection Control Pressure Sensor (ICP) (input). The ICP sensor is a three wire pressure sensor that reports the pressure in the HPOP oil pressure to the PCM.

099

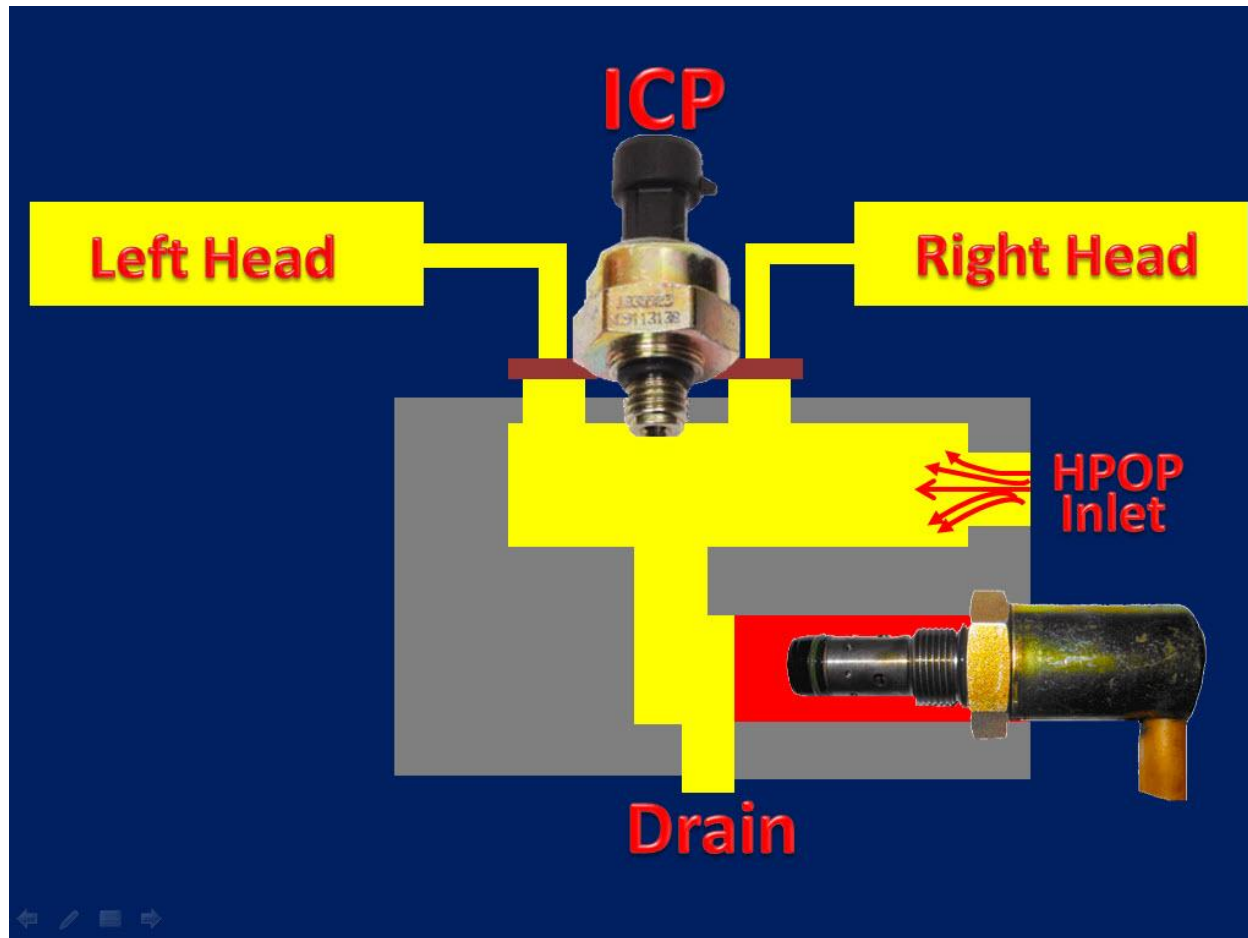


The ICP Sensor can cause variety of symptoms Stalling, Hesitation, Extended Crank and Surging. A quick check is to disconnect the ICP to see if the problem goes away. The engine will run in a default value of 700 to 750 psi. Remember. 500 psi minimum ICP oil pressure is required to fire an injector.

IPR and ICP working together

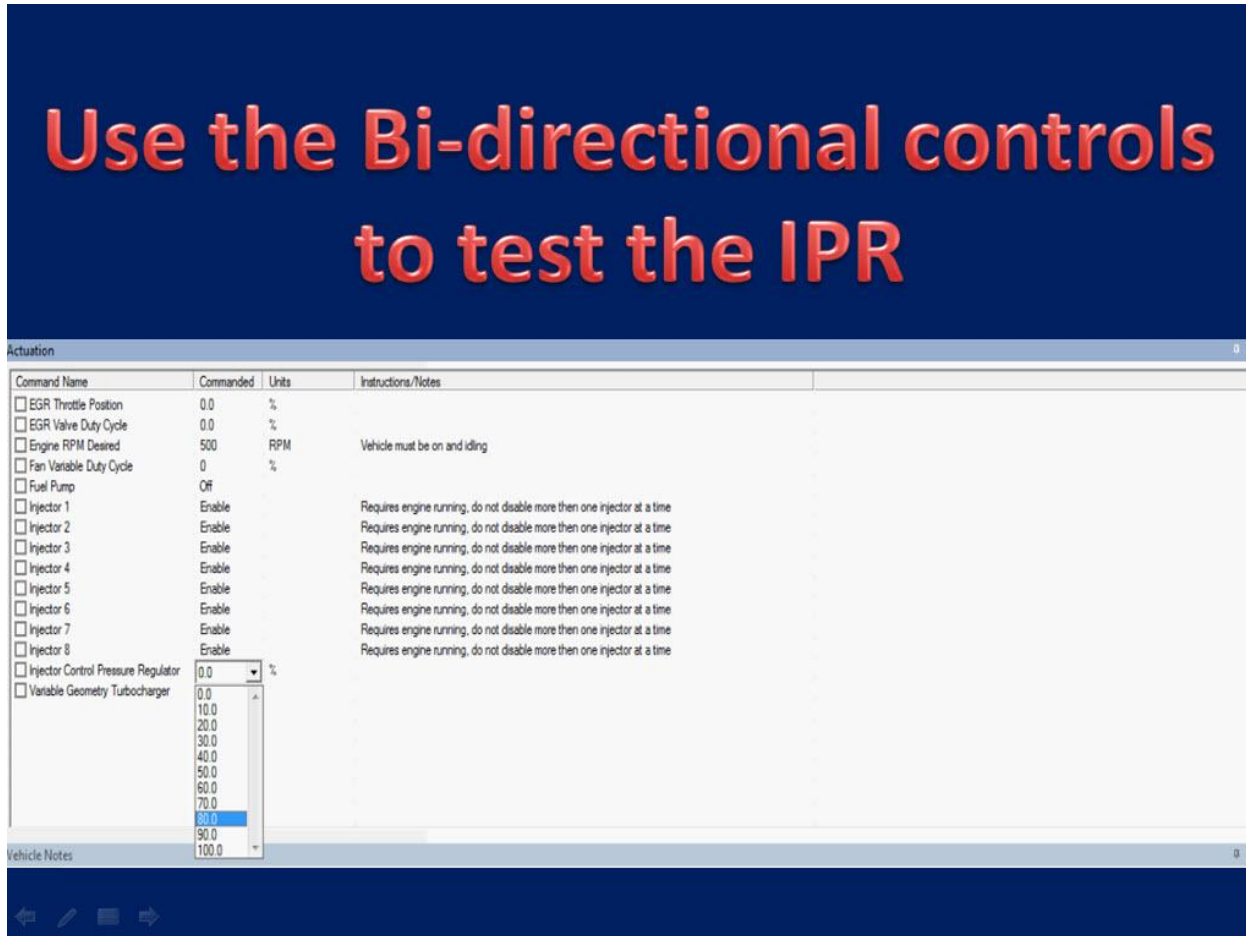
The IPR and ICP work together to control the high pressure oil pressure. The IPR (PCM controlled) controls the pressure by allowing oil to by-pass and return to the crankcase or blocks the oil to build pressure in the high pressure oil system. The ICP measures that pressure and reports to the PCM. The PCM controls the pressure by changing the duty cycle of the IPR.

IPR and ICP



The high pressure oil pump is mounted in the crankcase where it supplies high pressure oil to the injectors. The pump's inlet oil is supplied by the HPOP reservoir. The pressure is measured by the injector control pressure sensor (ICP) and reports to the PCM. The pressure is controlled by the injector control pressure regulator (IPR). It is a PCM controlled solenoid. The PCM duty cycles the electrical signal to the IPR to control how much oil is drained back into the engine's oil pan. When the duty cycle is high the drain is being blocked and when the duty cycle is low the drain is open to allow the oil and pressure to drain off. Blocking the drain raises oil pressure and opening it reduces the pressure. Normal pressure is between 450 and 4000 psi. If oil pressure exceeds the maximum allowable the pressure relief valve opens at 4000 psi for protection of the system. There is an edge filter in the HPOP. If it becomes blocked it stops the drain from flowing. It is serviceable and will set codes.

Bi-directional IRP control



Using bi-directional control with a scan tool for the IPR allows you to control the IPR's duty cycle. Raising the duty cycle increases the pressure. Watch the PID ICP and command the IPR at different values to determine if the IPR is working.

IPR and ICP Scan Data Testing

Connect a scan tool and select the IPR and ICP PIDs.

Turn the ignition to the on position with the engine off.

Monitor the ICP sensor PID.

If the ICP voltage is not between 0.15 and 0.35 volts with the ignition on, test the ICP's electrical circuit for correct voltage reference and signal return voltage.

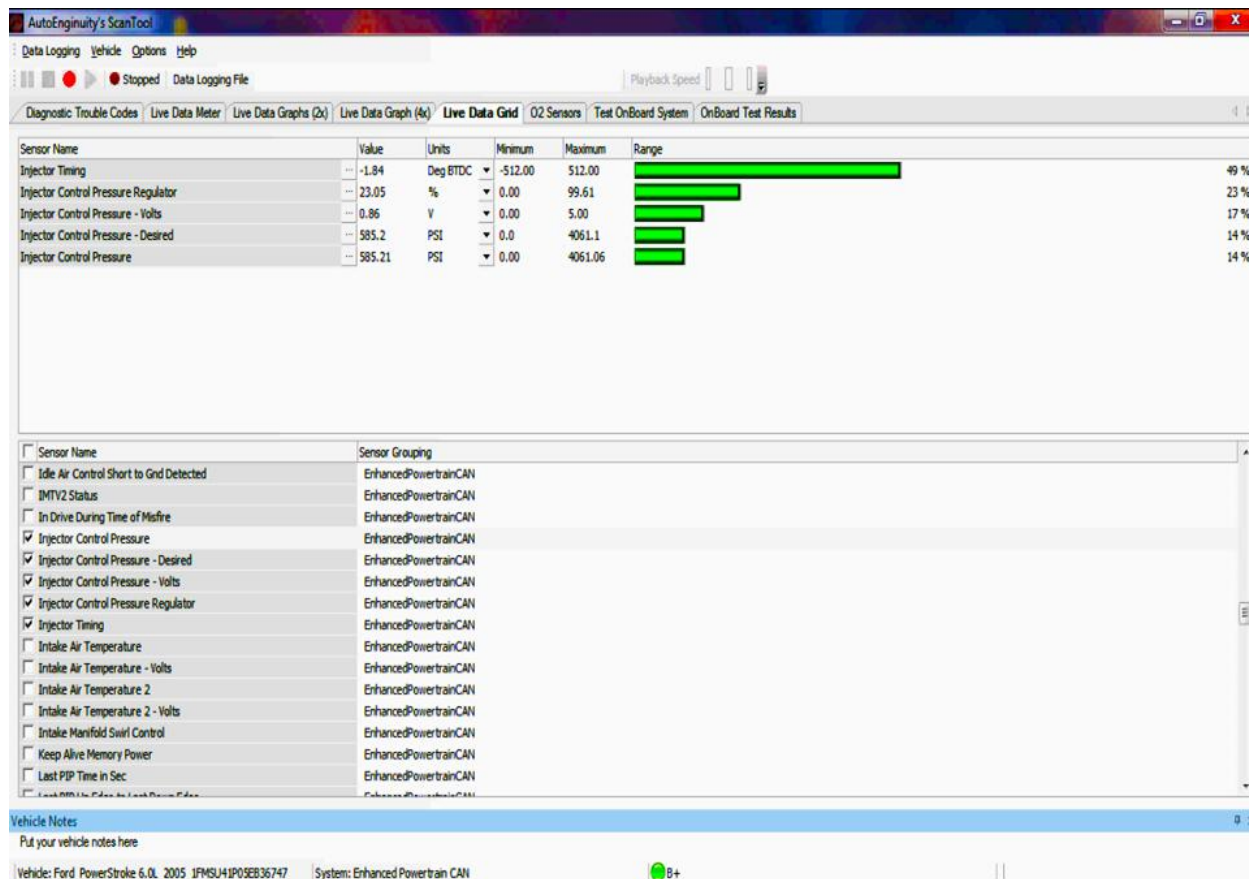
If the engine does not start when cranked, disconnect the ICP sensor and attempt to start the engine. If the engine starts with the ICP sensor disconnected, test the sensor and its circuit. When the ICP is disconnected the PCM uses a default value in place of the missing ICP signal. If the engine starts on the default, test the ICP's electrical circuit for correct

voltage reference, signal return voltage, and the signal. If the sensor has normal voltage reference (power) signal return (ground) and the signal isn't normal replace the sensor.

Injector pressure regulator and injector control pressure PIDs

Pull up the PIDs Injector control pressure and voltage. It requires 500 psi of oil pressure to open the injector pintle. The PID, injector control voltage needs to be a minimum of .8 volts.. The oil pressure is multiplied by 7.1 as explained in the injector section. Through the multiplication factor, fuel pressure needs to be around 3100 psi.

Actual IPC scan Data



The two PIDs, injector control pressure and injector pressure regulator can be used to diagnose, extended cranks, no starts, and runs rough. Pull up both PIDs on the scan tool.

IPC Diagnostic Check

IF: IPR is high (85 psi) and, ICP is Zero the HPOP is bad.

IF: IPR is high (85 psi) and, ICP is low and jumps around there may a high pressure oil leak.

High Pressure Oil System Air Pressure Check

If the engine does not start with the ICP sensor disconnected do the High Pressure Oil System Air Pressure Check.

Or if the engine starts after an extended crank time:

Or if the engine starts and runs rough or dies:

Do the High Pressure Oil System Air Pressure Check:

High Pressure Oil Leak Test Adapter



High pressure oil leaks will cause all sorts of drivability problems even up to and including a crank but no start. Test for high pressure oil leaks by removing the ICP sensor. This is threaded into the high pressure common oil rail or the HPOP. You can do the test without removing the valve cover. Replace the sensor with an air fitting. Connect air hoses and a pressure regulator.

To check the high pressure oil leaks you need to supply 175 psi to 200 psi of pressure to

the system.

Diagnostic Check

Supply 175 psi to 200 psi of pressure.

Using a Scan Tool command the IPR to 0% (fully open) (drains the oil from the system) (Air will flow through the IPR).

After 2-3 minutes, command the IPR to 85-90%.

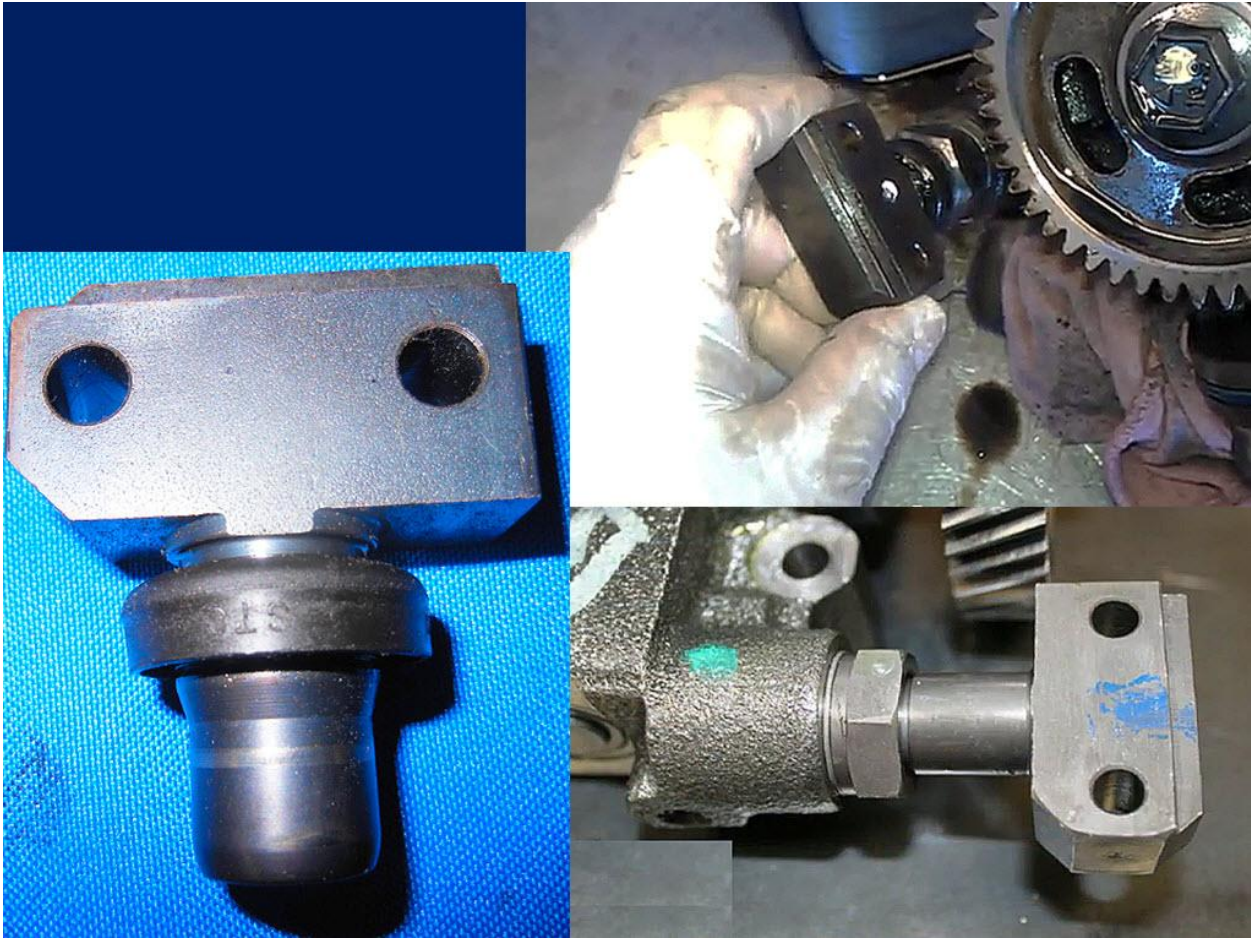
You should hear less air passing through the IPR (if you don't hear a change in the air, the IPR or its control circuit are at fault).

Use a stethoscope to locate the leak. Some noise around the intake valley is normal (the IPR can't be fully closed). Noise near the back of the intake valley may indicate a cracked pipe or fitting, failed "O" ring, or failed snap to connect connection from the HPOP to the branch tube. Air noise at valve covers indicates that the injectors, stand pipes, D-plug, or "O"-rings on the oil rails are leaking.

The stand pipes go through the common rail to the branch tube. The high pressure rail plug threads into the common rail and connects to the stand pipe.

The high pressure oil rail has special AWA (Acoustic Wave Attenuation) it dampens hydraulic noise. To accomplish this, an AWA fitting is placed in the center of the high pressure oil rail and two specially designed end caps are used. The high pressure oil common rail acts as an accumulator. High pressure oil is stored there waiting to enter the injector. The high pressure oil common rail was updated to increase oil volume and reduce hydraulic noise. The volume has increased from 15 cubic inches to 30 cubic inches. The additional volume helps to reduce injector fall off (keeps a constant pressure) to the injector under all engine conditions. If the rail has been drained for service engine start time will be extended for the first start after repair. There are Acoustic Wave Attenuation (AWA) fittings in the common rail to reduce noise. There are two AWA fittings one small and one large. They are in the center of the common rail. The fittings (through orifices in the fitting) change the flow of oil to reduce hydraulic noise.

Snap to Connect, old and new

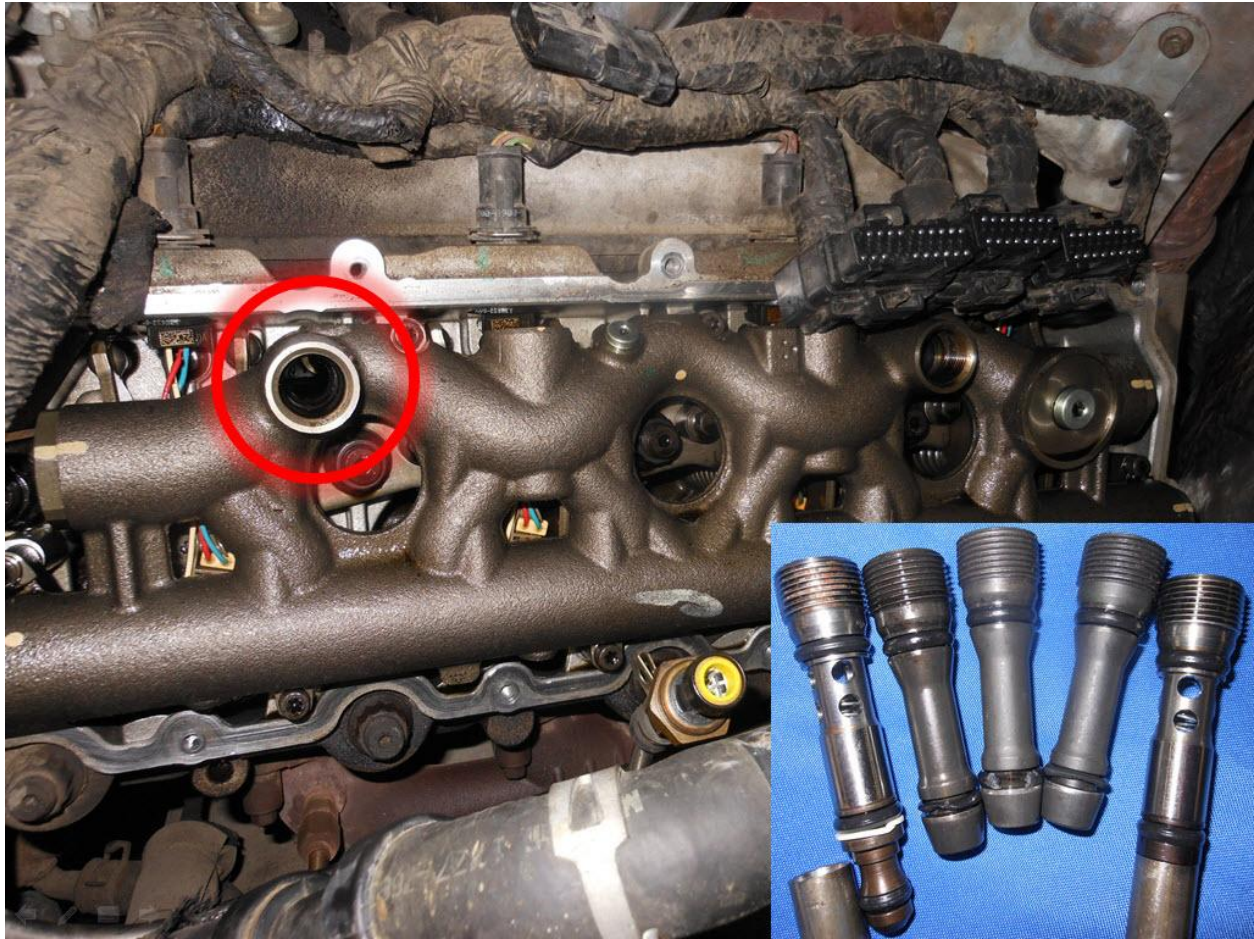


Stand Pipes and D plugs



Notice the condition of the “O”-rings on the “D” plugs.

High Oil Pressure Common Rail Leak Points

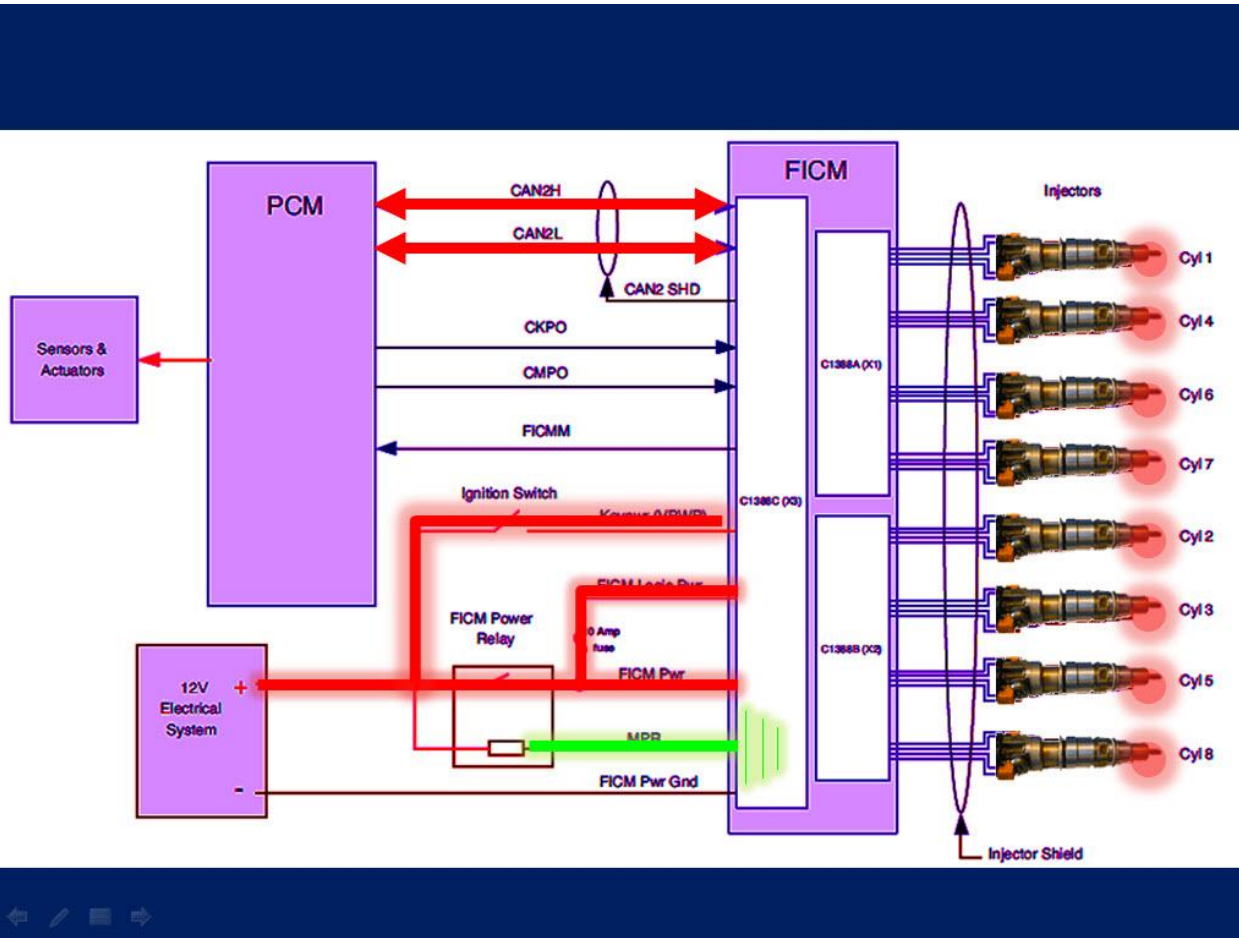


High Pressure Common Rails Old and New



Both types are a source of high pressure oil leaks.

Fuel Injection Control Module (FICM)



The FICM drives the injector solenoids based on fuel and timing commands from the PCM (via CAN Bus). It uses crankshaft position and camshaft position (CKPO/CMPO) to determine when to activate the injector (solenoids). The ignition switch supplies power to the FICM when it is switched to the on position.

The FICM supplies a ground to the FICM relay (MPR output). This provides the FICM PWR. The FICM will cycle the injectors when the key turned on. This is a pre-cycle for the injectors. The pulse width (PW) time of pre-cycle varies with engine temperature. The pre-cycle is done as a self-test. The FICM provides a feedback signal to the PCM indicating when it is providing control signals to the injector (fueling) Via CAN Bus.

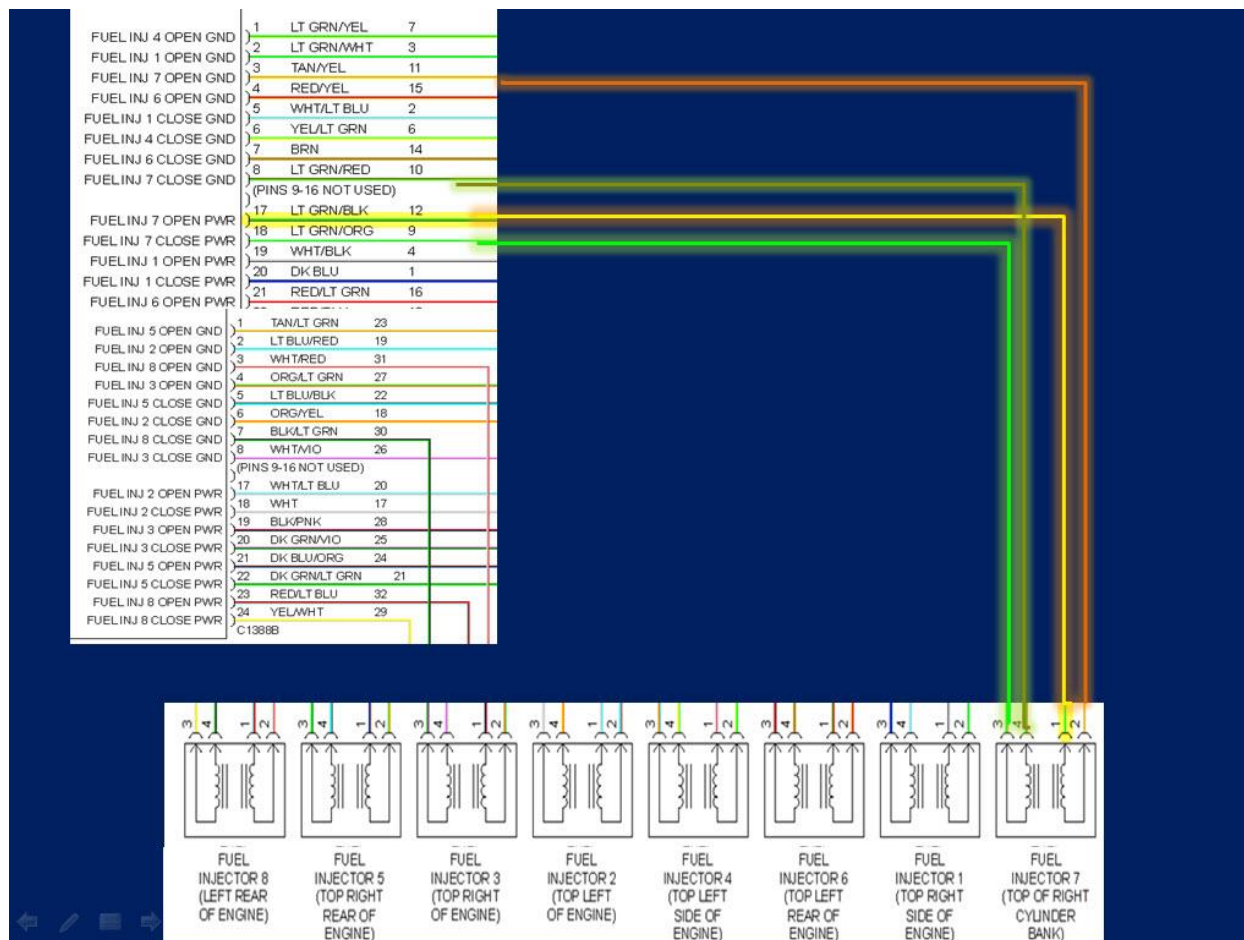
The FICM produces two control signals to drive each injector. One coil opens the injector (via a 20 A pulse). The other coil closes the injector (via a 20 A pulse). The net time between pulses is equivalent to the fuel pulse width (Fuel PW)

The coil on time is currently calibrated from “400 μ S to 5.8 ms”. The 5.8 ms is for cold starts. As the engine warms up the duration decreases and settles around 800 μ S depending

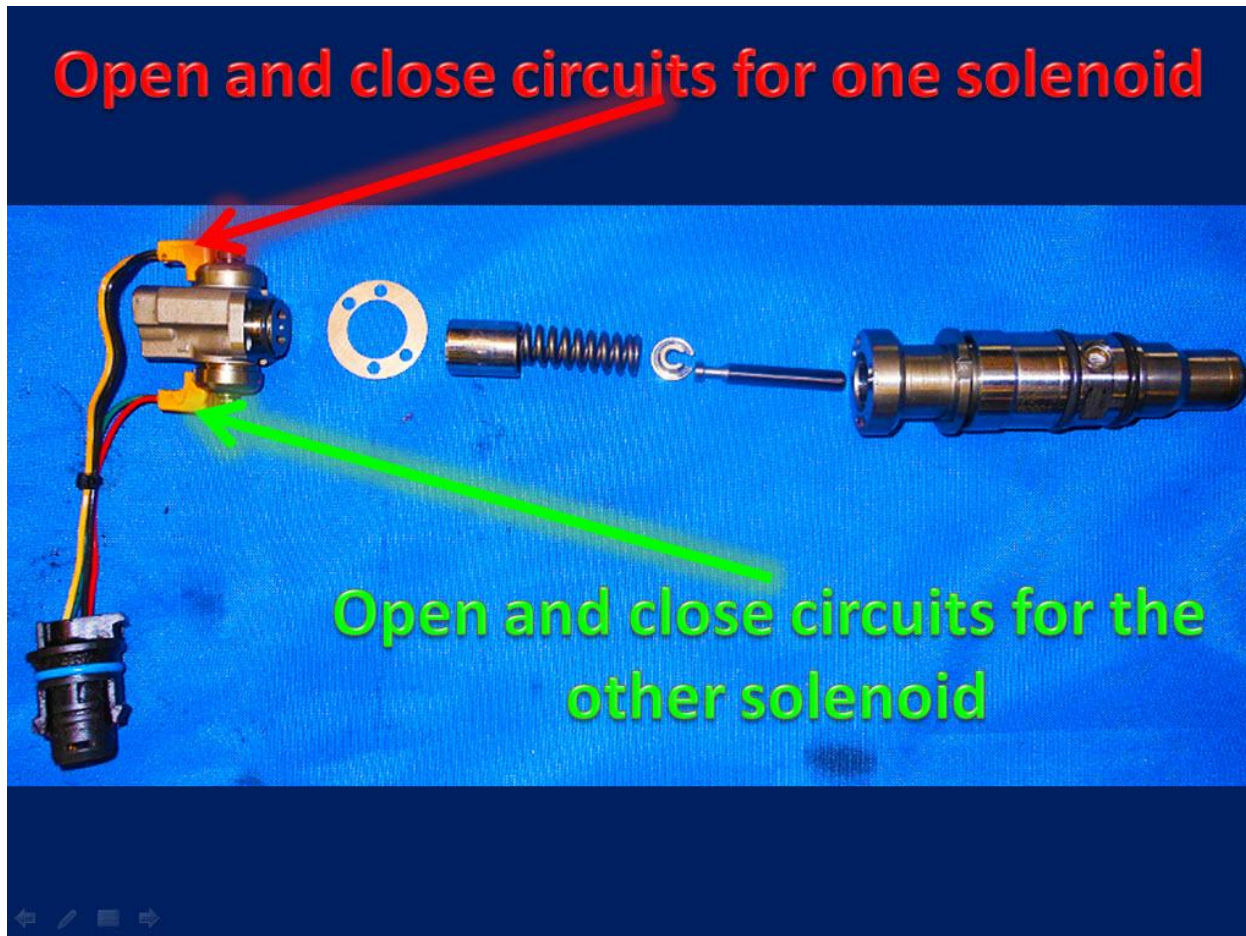
on the amount of fuel being commanded.

The FICM power relay supplies main and logic B+. FICM internally generates 48 V from the FICM main power circuit used to drive the injector solenoids. Logic B+ indicates the FICM power relay has closed.

Injector Coil Driver example



Injector Connectors



Each individual injector is controlled with four driver outputs from the FICM. There are high and low side drivers for the open and close coil of each injector. There is an open solenoid (to allow oil in) and there is a close solenoid (to allow oil out).

The net time between pulses is equivalent to the fuel pulse width (Fuel PW).

The coil on time is currently calibrated from “400 μ s to 5.8 ms”.

The 5.8 ms is for cold starts.

As the engine warms up the duration decreases and settles around 800 μ s depending on the amount of fuel being commanded.

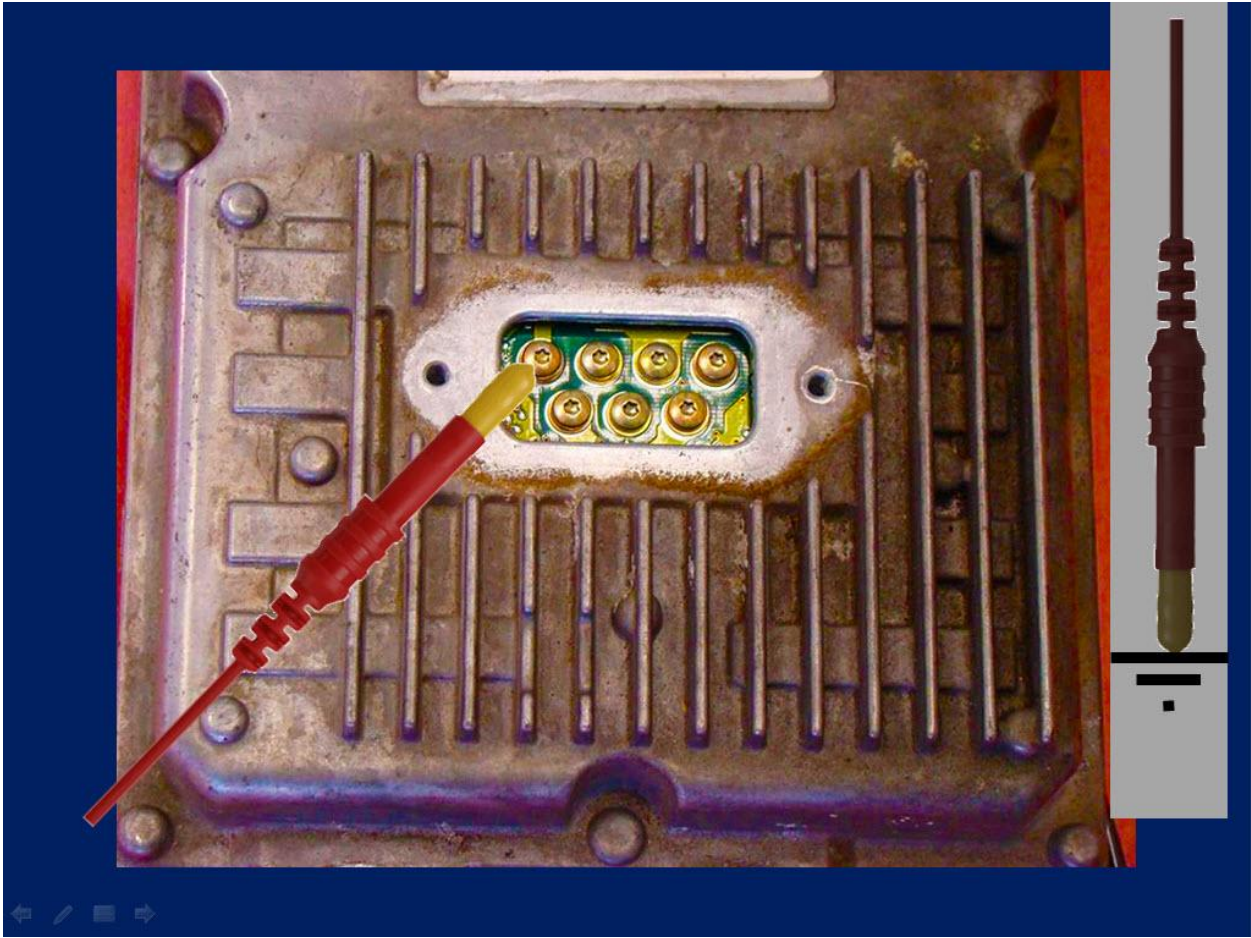
FICM B+ Supplies



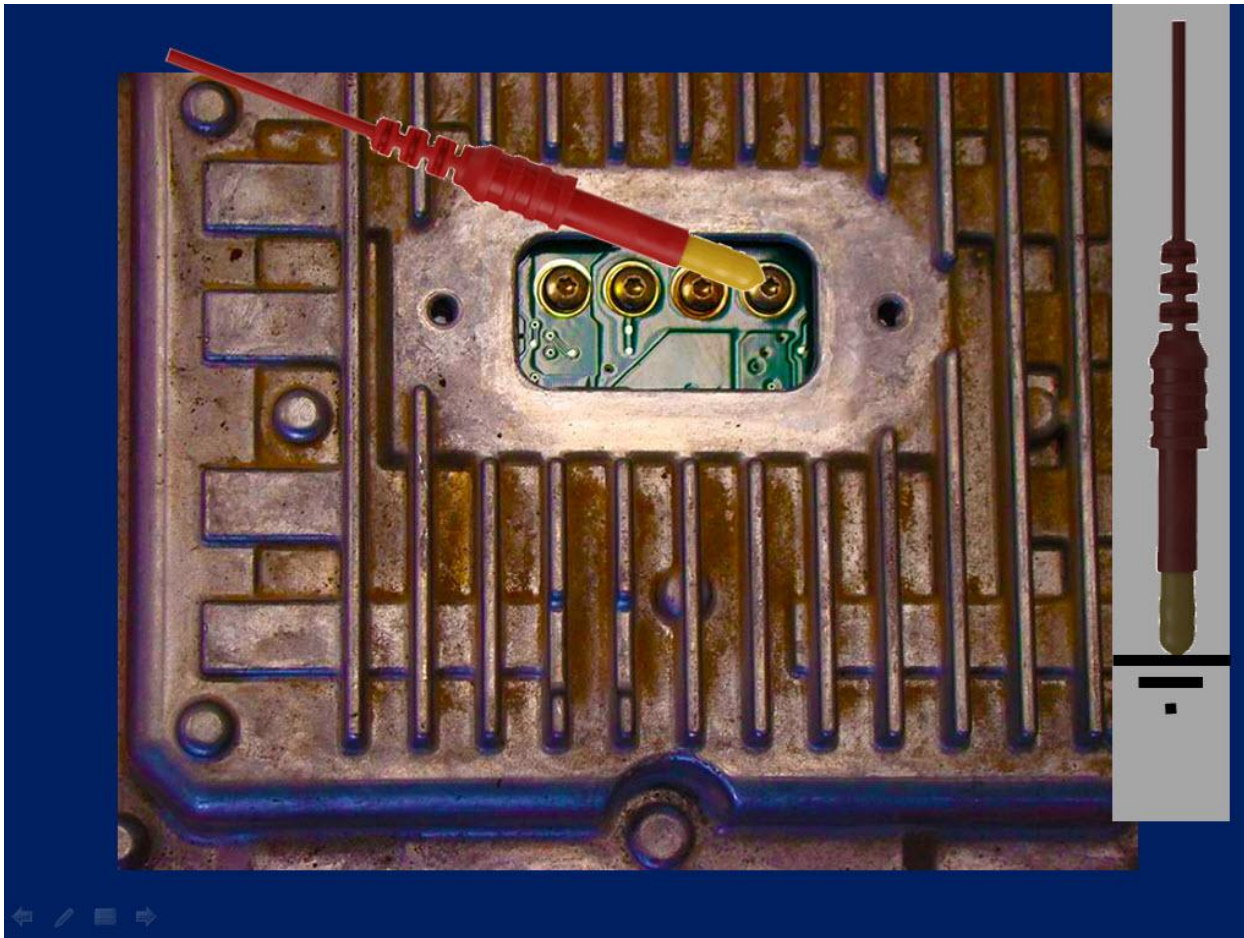
FICM main and logic power can be verified with scan data. The only component between the FICM and source is the ignition switch. The FICM logic power should be within a half of volt of system power.

The FICM main power is the power to activate the solenoids on each injector. It should be 48 volts plus or minus 1.0 volt. If you don't see 48 volts in scan data test for it at the FICM output pin.

FICM Main Injector Driver power (7 pin)



FICM Main Injector Driver power (4 pin)



There are two styles of FICMs, one for the early and one for the later versions. If the truck you're working on has a seven pin version place the test probe on the pin nearest the passenger's side in the row with four pins. If the truck you're working on has a four pin version place the test probe on the pin nearest the driver's side.

4 and 7 Pin FICM Testing

Disconnect the Glow Plug Control Module. This will set a code. This will keep the batteries from draining excessively while checking FICM.

Using a multi-meter set to DC volts and connect the ground lead to battery negative, and with the key ON measure the voltage at the screw on your right—closest to the driver's side fender. **Do not let the probe short against the case!** The voltage should be 48 volts. Anything between 47 and 49 is acceptable.

Have an assistant cycle the key and measure the voltage during the initial key-on pre-cycle of the injectors. Voltage should not drop below 46 volts. Then measure the voltage while the engine is cranking. If voltage stays at or above 45-46 volts, the **FICM** is normal.

Remember that abnormally low battery voltage can give a false low **FICM** voltage reading causing the FICM to fail this test when it is actually a good working one, so make sure your batteries are good.

FICM Fault Detection

FICM problems are usually accompanied w/multiple injector codes.

Examples:

P0610 Control Module Vehicle Options Error

P0611 Fuel Injector Control Module Performance

P0612 Fuel Injector Control Module Relay Control Circuit

The FICM circuit fault detection is unique. The FICM measures current to each injector coil. This is to determine if an injector coil is open or shorted.

Open coils produce low current which sets the injector circuit low codes (P0261, P0264, Shorted coils (side shorts) or short to grounds produce high current which sets the injector circuit high codes (P0262, P0265, P0283).

If after a long cranking with no start you get a lot of white smoke (raw un-burnt fuel) out the exhaust, the problem is probably in the injectors or glow plug system. If you do not get any smoke, the problem is probably in the FICM. This is common thought in the field. Make sure you complete all diagnostics before replacing any parts.

FICM SYNC

SYNC is achieved when the PCM receives a signal from the Crankshaft Position Sensor (CKP) indicating the sensor is working and the correct signal has been identified by the PCM. If the Crankshaft sensor is not working normally, the PCM will be unable to calculate engine speed or cylinder position, preventing fuel delivery. SYNC is totally derived from the CKP sensor. It is possible to have no Camshaft Position Sensor (CMP) sensor signal and still have SYNC (YES) and an RPM signal. No SYNC and no RPM signal, typically is a faulty CKP sensor/circuit problem. Once FICM SYNC is achieved, the FICM uses engine speed, Mass Fuel Desired (MFDES), Engine Oil Temperature (EOT), and Injector Control Pressure (ICP) to calculate fuel timing, pulse width, and pilot injection usage. If the CMPO and CKPO signals are not properly timed, FICM Sync may not occur.

Diagnosing FICM SYNC

Note: Always diagnose any SYNC issues before diagnosing FICM SYNC issues.

Using a scan tool, select the FICM SYNC PID. This PID will be viewed as a “YES” or “NO” (1 or a 0). KOER, FICM SYNC should always read “YES”. The repair manual tells us that the FICM SYNC PID should report “YES” K-O-E-O. Bill and I have seen many time that isn’t the case. We have seen normally operating FICM’s where the FICM SYNC PID reported NO K-O-E-O and didn’t change to “YES” until the engine was cranked. The FICM SYNC circuit sends information from the PCM to the FICM.

Engine Wiring Harness: FICM SYNC occurs through two circuits between the FICM and PCM. Verify engine wiring harness circuits CMPO and CKPO. If one of these two circuits has a short/open, FICM SYNC will not occur.

PCM: If the PCM is not working properly, FICM SYNC may not occur.

FICM: If the FICM is not working properly, FICM SYNC may not occur. The CMP If the CMP signal are corrupt (electrical or mechanical), FICM SYNC may not occur.

Air Management System

Air management is an important part of making a diesel engine run. Air comes in through a filter and goes to a turbocharger. There it is pressurized so more air than naturally aspirated only air can enter the intake. Exhaust gas is a part of air management. The exhaust gas is directed to the turbocharge inlet to supply the energy to run it. Some of the exhaust gas is directed to the cylinders to mix with the incoming air to help cool down the combustion temperature. The system also measurers the amount, pressure, and temperature of the incoming and exhaust air.

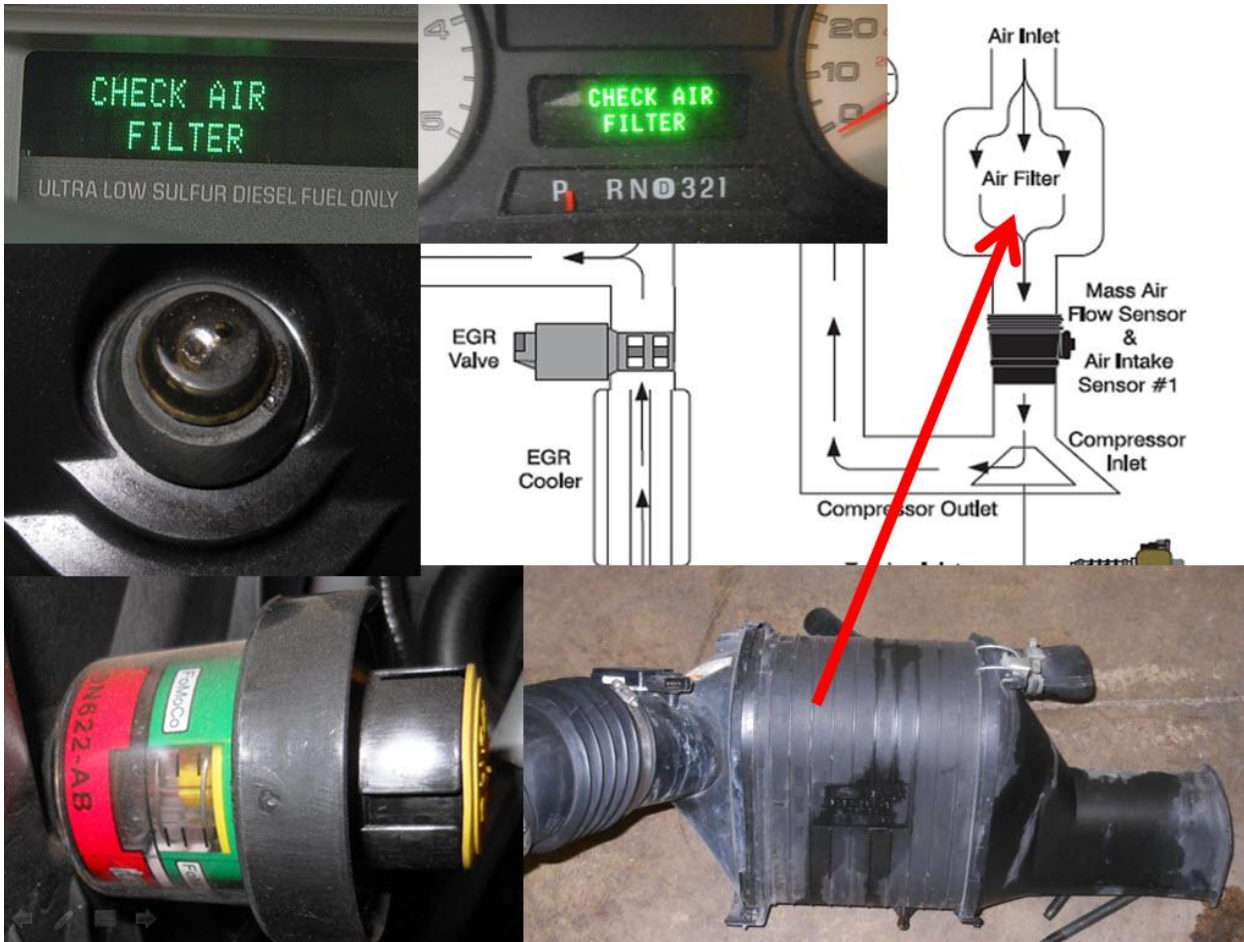
Air Filter Housing Assembly



Air Filer

Air enters the system through the air filter to remove dirt particles. The air filter has a filter minder on it to alert the driver of a restriction in the air filter. The air then flows through the Mass Air Flow (MAF) sensor where its temperature is and mass is measured. The filtered air is then directed past the crankcase ventilation system where crankcase vapors and fresh air are mixed. The air mixture is then drawn into the turbocharger compressor side so it can be compressed and sent to the charge air cooler (CAC). The CAC cools the air which condenses it then sends it to the intake manifold. The throttle body may or may not have a throttle Plate. The exhaust manifold collects the exhaust gases and routes them to the turbocharger turbine wheel. The exhaust pipe is connected to the exhaust gas recirculation (EGR) cooler. The exhausts gasses are cooled by the EGR cooler are sent to the EGR valve.

Air Minder and Warning Lamp

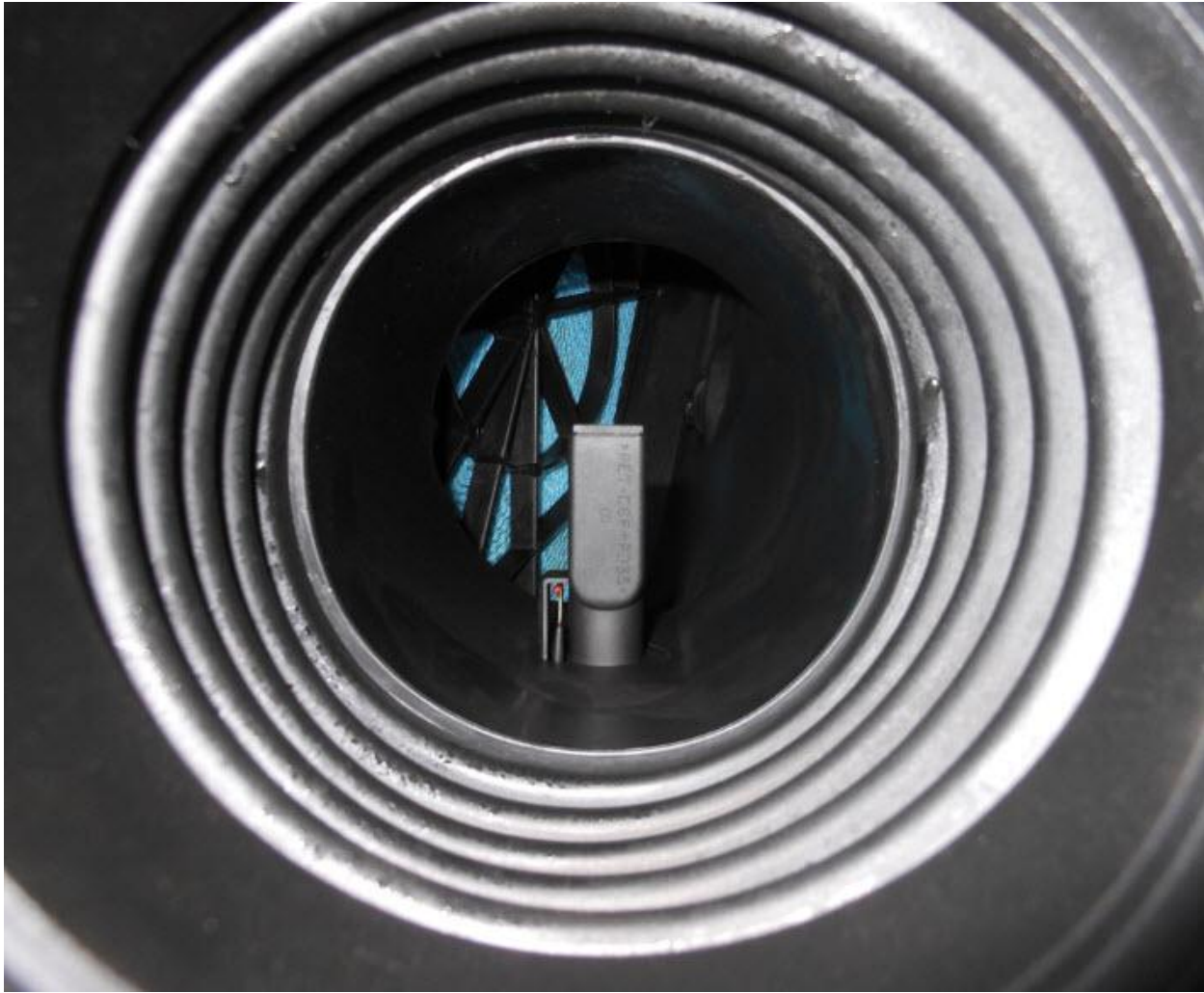


There is a filter minder on the filter housing and a warning lamp on the dash. The filter minder has an electrical switch that will illuminate the warning lamp on the dash. The lamp changes positions on the instrument panel cluster (IPC) depending on model year. When the lamp illuminates on the dash, it means to go look at the filter minder on the housing. The filter minder measures the filter restriction not the lamp. **The lamp alerts the driver to get out of the truck, open the hood, and check the filter minder not the filter element.** It is the filter minder that informs the owner to check the element. A restricted (it may not look dirty) filter will set the warning again.

Mass Air Flow Sensor



MAF Sensing Element



The Mass Air Flow (MAF) sensor

The Mass Air Flow (MAF) sensor has a hot wire sensing element to measure the mass of air being drawn into the engine. Air passes over the hot wire and cools the element. The hot wire is maintained at 392° F above ambient temperature as measured by circuit in the sensor. The current required to keep the temperature steady proportional to the amount of air flow. The MAF sensor outputs an analog voltage signal to the PCM.

The MAF sensor is not used for any engine control. It is used in the EGR monitor strategy to calculate the total clean air going into the engine. Once the total clean air is known, the amount of EGR required can be calculated.

NOTE! Failure of the MAF sensor has no effect on engine performance.

Turbocharger

A turbo charger is basically an exhaust gas driven air compressor and can be best understood if it is divided into its two basic parts, the exhaust gas driven turbine and its housing, and the air compressor and its housing. Each part performs different functions but, because they are joined together via a common shaft, the function of one impacts the function of the other. When the engine is under a load it feeds hot exhaust gas to the exhaust side of the turbo. This supplies enough energy to the exhaust turbine to spin the common shaft to generate enough power to turn the air compressor fast enough for it to work properly and boost the intake pressure.

The compressor increases the pressure of the air entering the engine, so a greater mass of oxygen enters the combustion chamber in the same time interval (an increase in fuel is required to keep the mixture the same air to fuel ratio). This greatly improves the volumetric efficiency of the engine, and thereby creates more power.

Turbocharger Energy Recovery

Generally, 1/3 of the heat energy obtained from burning the fuel in the cylinder is transferred to the crankshaft in a diesel engine. Another 1/3 of heat energy is dumped into the cooling system. The last 1/3 of the energy escapes through the engine exhaust.

This means that an engine producing 100 hp at the flywheel also dumps the equivalent of 100 hp into the cooling system and another 100 hp into the exhaust system.

A turbocharger converts 1/3 of the heat and pressure in the exhaust stream into compressor power. An engine producing 100 hp to the drivetrain is using 33 hp from the exhaust to power the turbocharger. At 200 hp, the turbocharger in a Power Stroke can extract 66 hp from the exhaust to power the turbocharger.

This means that an engine producing 100 hp at the flywheel also dumps the equivalent of 100 hp into the cooling system, and another 100 hp into the exhaust system.

A turbocharger converts 1/3 of the heat and pressure in the exhaust stream into compressor power.

An engine producing 100 hp to the drivetrain is using 33 hp from the exhaust to power the turbocharger.

At 200 hp, the turbocharger in a Power Stroke can extract 66 hp from the exhaust to power the turbocharger.

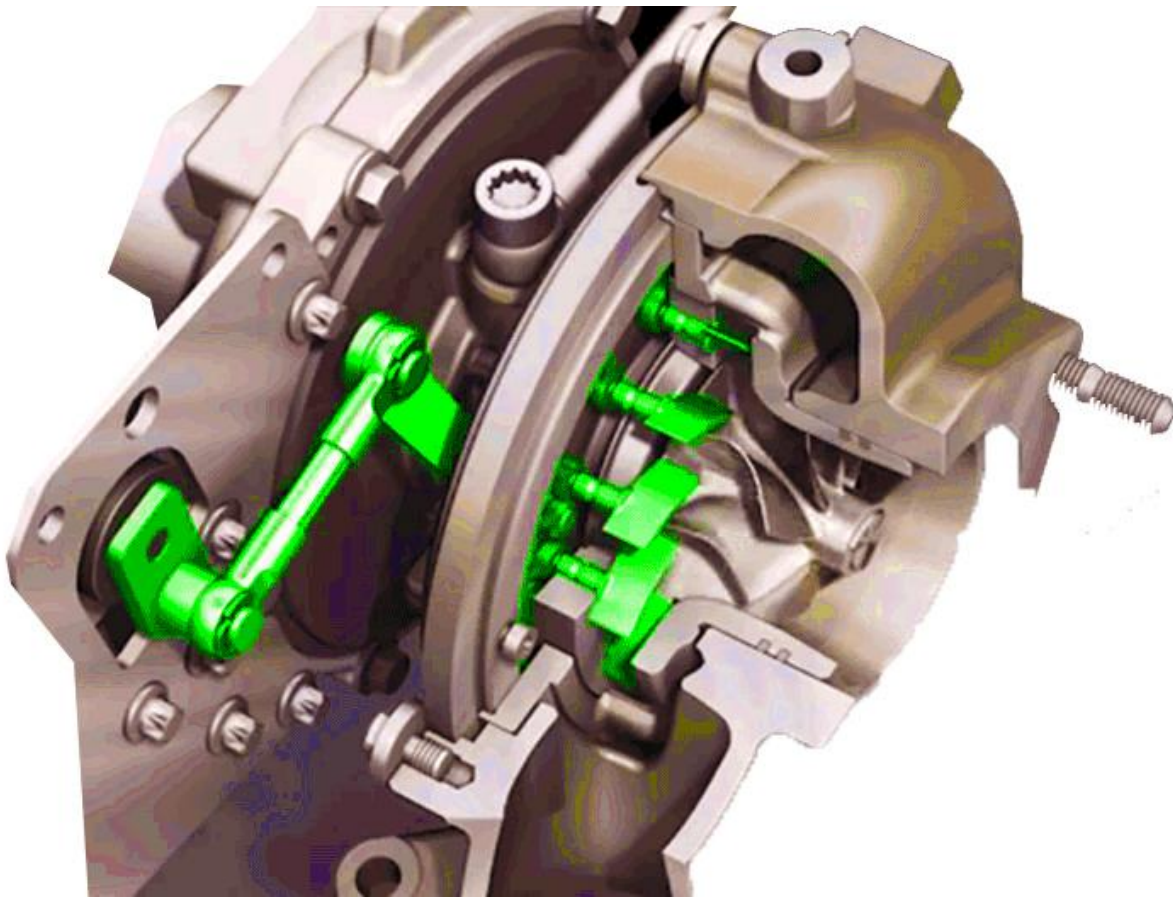
Boost

Boost is the pressure above atmospheric pressure (in psi) that the turbocharger generates.

Boost pressures are slightly less at the manifold than they are at the turbocharger outlet due to cooling and expansion of the air charge as it passes through the intercooler.

There is an issue with some 2003-2007 F-series, 2003-2005 Excursions, and 2004-2008 E-series vehicles. The issue is Lack of power, white smoke/black, and or a surge. There may be one or more diagnostic trouble codes. (P0238, P0299, P0404, P0478, P2262, or P2263). The problem is coking deposits inside the turbocharger. Replacing the turbo is an option for repair, but it is almost certain to happen again. Cleaning it will save the customer money, and don't forget to explain the problem will re-appear.

Variable Geometry Turbocharger (VGT)



The Variable Geometry Turbocharger (VGT) is electronically controlled and hydraulically actuated.

The turbocharger for the 6.0 L improves throttle response by providing boost control at

both low and high speeds. The Variable Geometry Turbocharger (VGT) is electronically controlled by the vehicle's PCM and is hydraulically actuated using pressurized lube oil. The VGT can also be referred to as Electronic Variable Response Turbocharger (EVRT) in some service manuals. The turbine housing has vanes that change the effective internal size of the housing (volume). The vanes are controlled hydraulically and electronically. During engine operation when the vanes are closed, the exhaust has a higher exhaust back pressure and creates additional heat to warm the engine faster during cold starts.

The Variable Geometry control valve

The VGT control valve is commanded by the PCM, based on:

Engine speed (CKP sensor)

Engine load (calculated value based on MFDES (Mass Fuel Desired) at a specified RPM).

The MAP sensor reads the pressure in the intake manifold (through a hose) and sends a signal to the Powertrain Control Module (PCM) to adjust the injector pulse width (PW) to match the amount of turbo boost. Essentially the PCM increases PW as the turbo boost increases. If the MAP signal is missing or incorrect the engine will run normal at lower rpm, but at high rpm (1800+), where you expect the turbo to kick in, there wouldn't be enough power. It would accelerate, but slowly and without the usual power.

The PCM uses Exhaust Pressure sensor (EP) to monitor the turbo's performance. The PID on a scan tool VGT% and is described in the amount of % closed. A low % means the vanes are commanded to an open state. A high % means the vanes are commanded to a closed state. The magnetic field generated by this signal moves a shaft in the control valve (VGTCV). Engine oil is controlled through to either side a piston inside the VGT control valve. When one side of the piston is pressurized, the opposite side is vented, depending on which side of the piston is pressurized, the vanes either open or close. When the VGTCV is commanded to the full open position, low or no duty cycle, oil from the oil supply line is directed to the open side of the actuator piston. Oil on the closed side of the piston is then directed through the hollow shaft of the actuator piston, back to the VGTCV, and then to drain.

Note: If the VGTCV is disconnected the valve will default to the open position. When the VGTCV is commanded to the full closed position, high duty cycle, oil from the oil supply line is directed through the actuator piston to the closed side of the piston. Oil on the open side of the piston is directed back to the VGTCV and then to drain. Once the desired turbocharger vane position is obtained, the VGTCV goes to a parked position and both the open and closed sides of the actuator piston are blocked off. During low engine speeds and load, little energy is available from the exhaust to generate boost. In order to maximize the use of the energy that is available, the vanes are closed. In doing so, the exhaust gas is accelerated between the vanes and across the turbine wheel increasing turbocharger wheel speed and "boost". In general, this allows the turbocharger to behave as a smaller (Low Volume) turbocharger. Closing the vanes also increases the back pressure in the exhaust manifold which is used to drive the exhaust gas through the EGR cooler and EGR valve into the intake manifold. This is also the position for cold ambient warm up. During moderate engine speeds and load, the vanes are commanded partially open. The vanes are set to this intermediate position to supply the correct amount of boost to the engine for optimal combustion as well as providing the necessary back pressure for EGR operation. During at high engine speeds and load, there is a great deal of energy available in the exhaust. Excessive boost under high speed, high load conditions can negatively affect component durability, therefore the vanes are commanded open preventing turbocharger over speed. Essentially, this allows the turbocharger to act as a large turbocharger, not creating excessive back pressure. Vanes Open Position Vanes mid Position Actuator Piston

Actuator Piston Actuator Piston Vanes Closed Position.

The vane actuator is controlled by hydraulic pressure. Engine oil is directed by an electrical solenoid to a spool valve which moves the actuator lever. The electrical signal sent to the solenoid is varied for precise control of the spool valve.

A solenoid is a coil wound into a tightly packed helix. The term solenoid refers to a long, thin loop of wire, often wrapped around an iron core, which produces a magnetic field, when an electrical current travels through it. Solenoids can create controllable magnetic field and can be used as an electromagnet.

The VGT control valve is commanded by the PCM, based on engine speed (CKP sensor) and load (calculated value based on Mass Fuel Desired (MFDES) at a specified RPM). The PCM uses Exhaust Pressure (EP) for closed loop control of the VGT and to monitor its performance.

The command can be viewed on a scan tool as VGT%. The PID is describing the % closed. A low % means the vanes are commanded to an open state. A high % means the vanes are commanded to a closed state.

During low engine speeds and load, little energy is available from the exhaust to generate boost. In order to maximize the use of the energy that is available, the vanes are closed.

The exhaust gas is accelerated between the vanes and across the turbine wheel increasing turbocharger wheel speed and providing additional “boost”. In general, this allows the turbocharger to behave as a smaller (Low Volume) turbocharger. Closing the vanes also increases the back pressure in the exhaust manifold which helps drive the exhaust gas through the EGR cooler and EGR valve into the intake manifold.

During moderate engine speeds and load, the vanes are commanded partially open.

The vanes are set to this intermediate position to supply the correct amount of boost to the engine for optimal combustion as well as providing the necessary back pressure for EGR operation. In general, this allows the turbocharger to behave as a Mid-size (Medium Volume) turbocharger.

During at high engine speeds and load, there is a great deal of energy available in the exhaust

Excessive boost under high speed, high load conditions can negatively affect component durability. Therefore the vanes are commanded open preventing turbocharger over speed.

This allows the turbocharger to act as a large turbocharger, not creating excessive back

pressure.

Variable Geometry control valve Scan Data

The screenshot shows the 'Live Data Grid' in AutoEnginuity's ScanTool. The 'Variable Geometry Turbo Duty Cycle' is highlighted in grey, showing a value of 0.00%. Other sensors shown include Engine RPM at 0 and Exhaust Back Pressure Absolute at 14.4 PSI. A list of sensors is visible below the grid, with 'Exhaust Back Pressure Absolute' checked.

Sensor Name	Value	Units	Minimum	Maximum	Range
Engine RPM	0	RPM	0	8000	0 %
Variable Geometry Turbo Duty Cycle	0.00	%	0.00	100.00	0 %
Exhaust Back Pressure Absolute	14.4	PSI	0.0	145.0	9 %

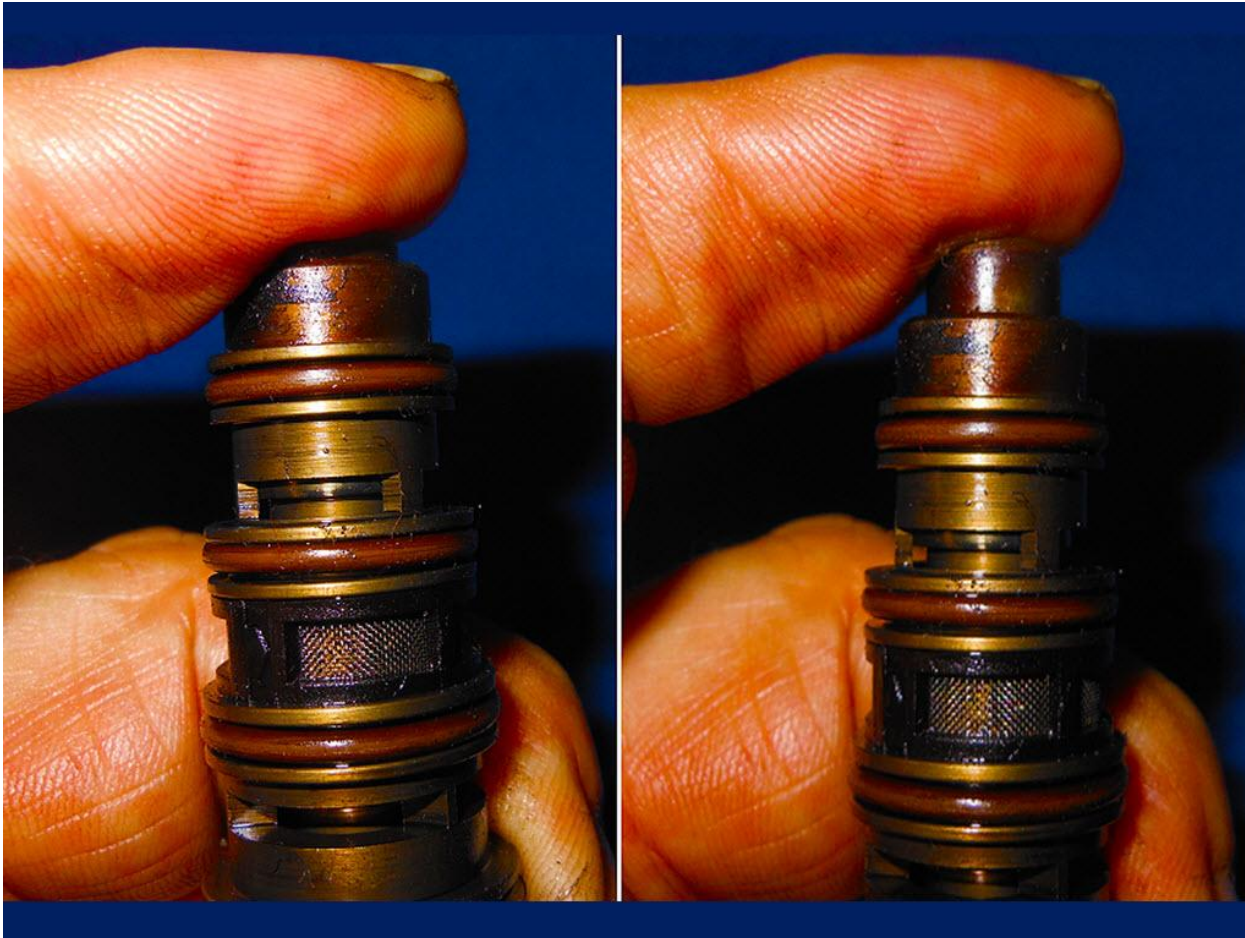
0.0 % duty cycle means vanes are wide open

100% duty cycle means vanes are closed

Variable Geometry control valve



Variable Geometry control valve Cam Follower

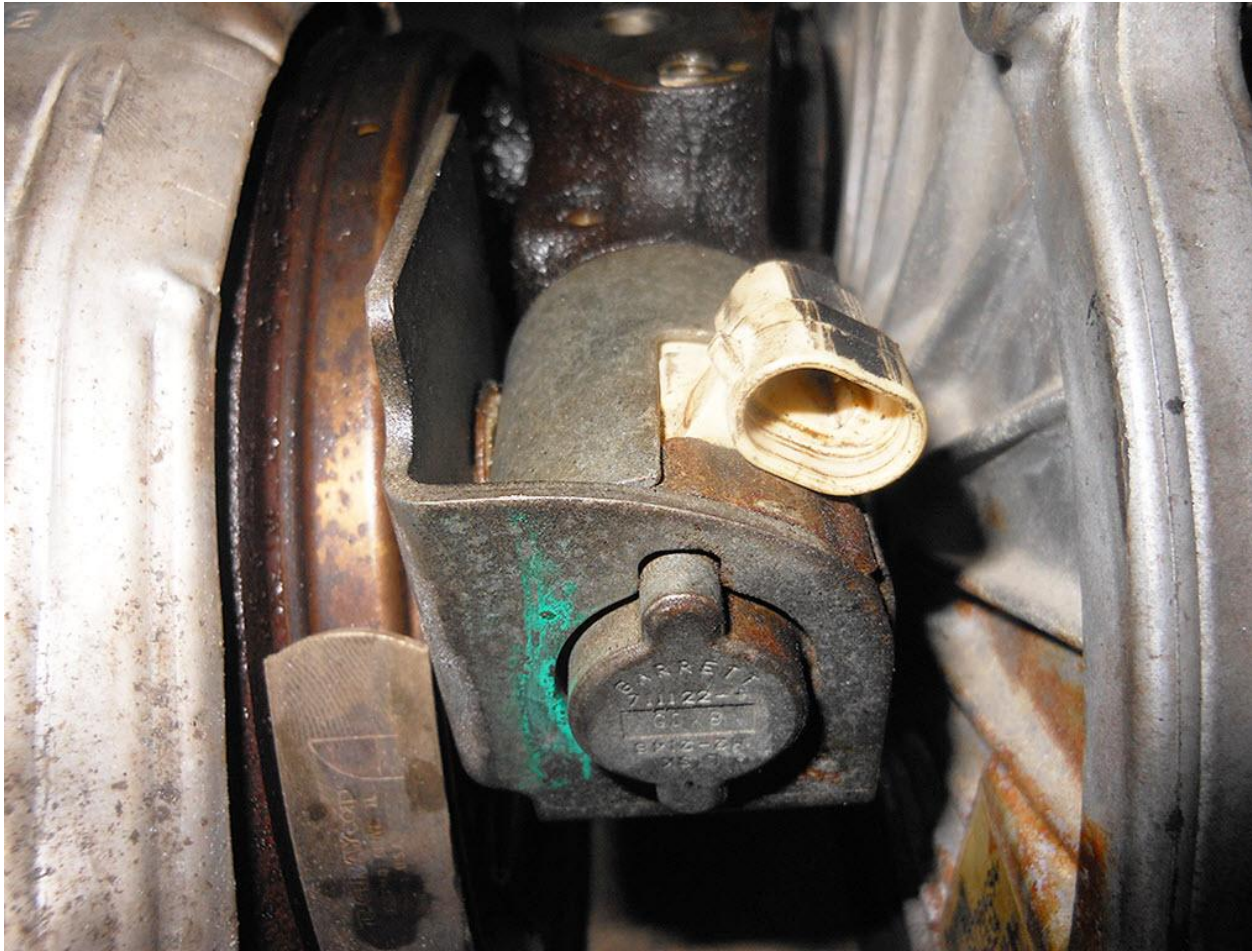


VGT Control valve

The VGT control valve is an electrically controlled solenoid. When it moves, it moves a spool valve. The spool valve directs oil to the actuator for the vanes. There is a cam follower on the tip of the VGT control valve. The cam follower rides on the Turbo's shaft. It provides feedback to the valve allowing it to reach a parked position during times the vanes are not commanded to move. The VGT control valve mounts in the middle between the turbine and the compressor sides of the turbo. During low engine speeds and load, little energy is available from the exhaust to generate boost. In order to maximize the use of the energy that is available, the vanes are closed.

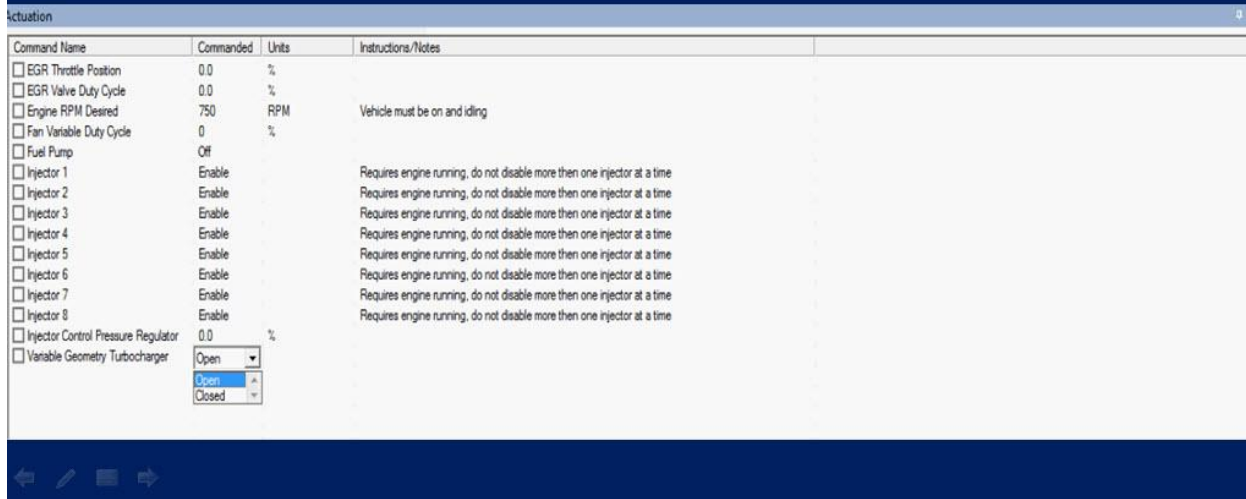
The exhaust gas is accelerated between the vanes and across the turbine wheel increasing turbocharger wheel speed and providing additional "boost". In general, this allows the turbocharger to behave as a smaller (Low Volume) turbocharger. Closing the vanes also increases the back pressure in the exhaust manifold which helps drive the exhaust gas through the EGR cooler and EGR valve into the intake manifold.

VGT Control Solenoid Connector



Checking VGT operation

Use the scan tool's Bi-directional controls to activate the VGT control valve and watch the VGT duty cycle and Exhaust backpressure Absolute PIDs



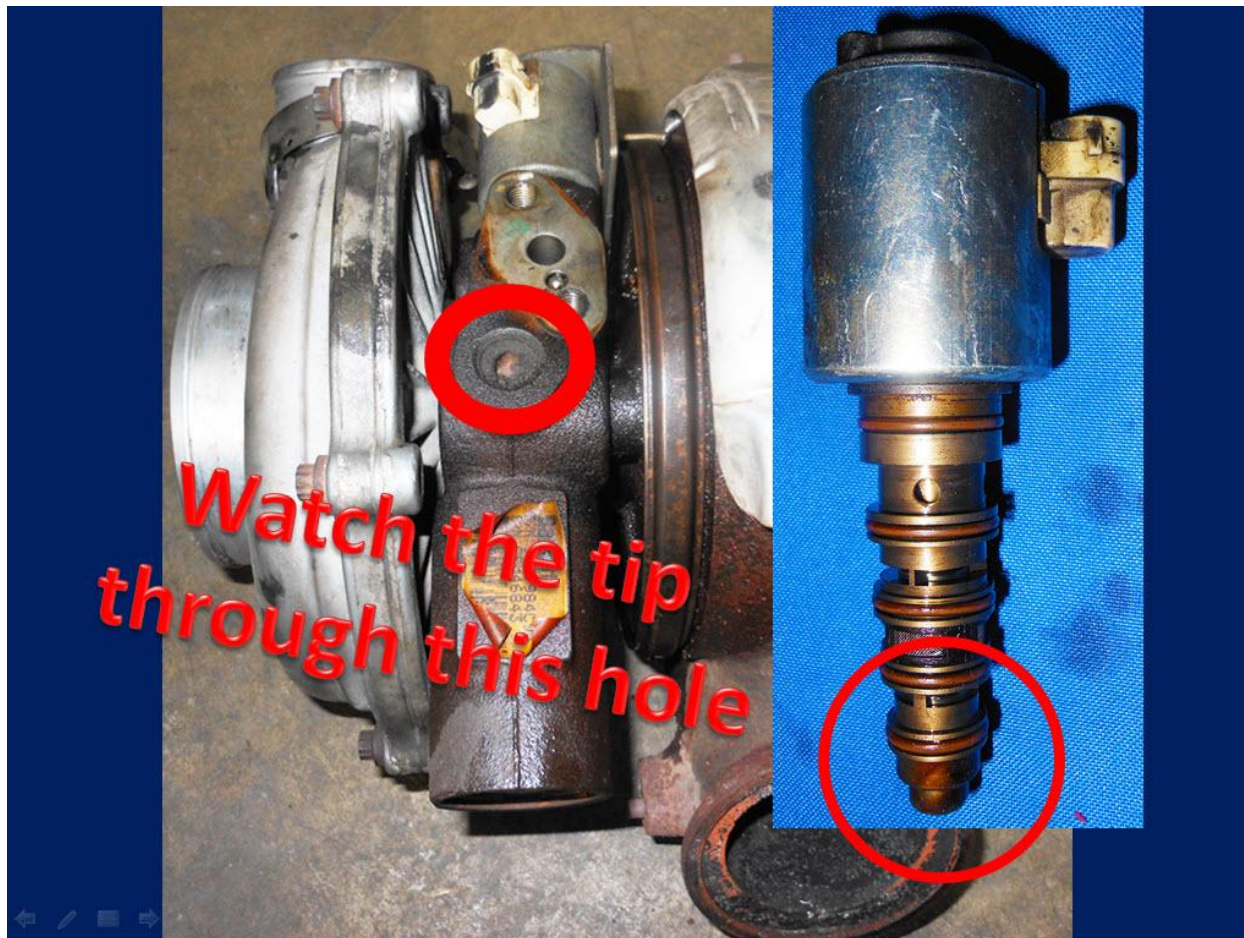
If there is low boost problem verify that there is no other concern that would can a low power condition Boost is created by the expansion of heat.

Any problem that can cause low power will create low boost (ex. injectors, EGR, exhaust leaks, fuel pressure and quality, etc.). As an example verifies that MAP, BARO, EP PIDs are within 1.5 PSI of each other with Key on Engine off (KOEO). Using a scan tool, look at PIDs for RPM then use the Bi-directional mode to command the engine to approximately 1200 RPM and the EGRDC# PID to 0%.

Then highlight the VGTDC# and increase it to 85% and record the EBP_G (Exhaust Pressure) & MGP (Manifold Gauge Pressure).

Next command the VGT to 0% and record the EBP_G and MGP PIDs. At 85% the EBP_G should be below 7.3 PSI and MGP should be above 0.87 PSI. At 0% the EBP_G should be below 0.73 PSI and MGP should be below 0.45 PSI.

VGT Control Valve Test



Remove plug from the top of the VGT actuator located near the oil supply tube. Apply an index mark on the VGT control valve cam follower (tip of the actuator). With the engine running, use the scan tool's Bi-directional feature. Increase the VGTDC# PID from 20% to 85% in steps and watch the VGT control valve cam lobe for movement at each step. If movement is not observed, replace/rebuild the turbocharger assembly.

Adaptive Turbocharger Learn

The adaptive turbocharger "learn" feature is designed to adapt the turbocharger function to provide optimized backpressure control. This adaptive learning is done during normal vehicle operation. The turbocharger is exercised over its full range duty cycle. It is cycled from 15-85% while the PCM monitors the MAP signal. Response Control adjustments within the PCM are "fine-tuned" based on the learning function for optimized control. This feature runs at idle when the following set criteria of entry conditions are met. This is referred to as the "learn process".

Entry Conditions for learn process;

Engine at base idle speed ($570 < \text{rpm} < 780$)

Engine Oil Temp (EOT) between 120° - 250° F (50° - 120° C)

Vehicle Speed (VS) below 9 mph

Pedal position (APP) below 1.5%

EGR commanded off (EGR DUTY=0)

No malfunctions for the critical sensors/actuators. No DTC's set for the following:

– MAP

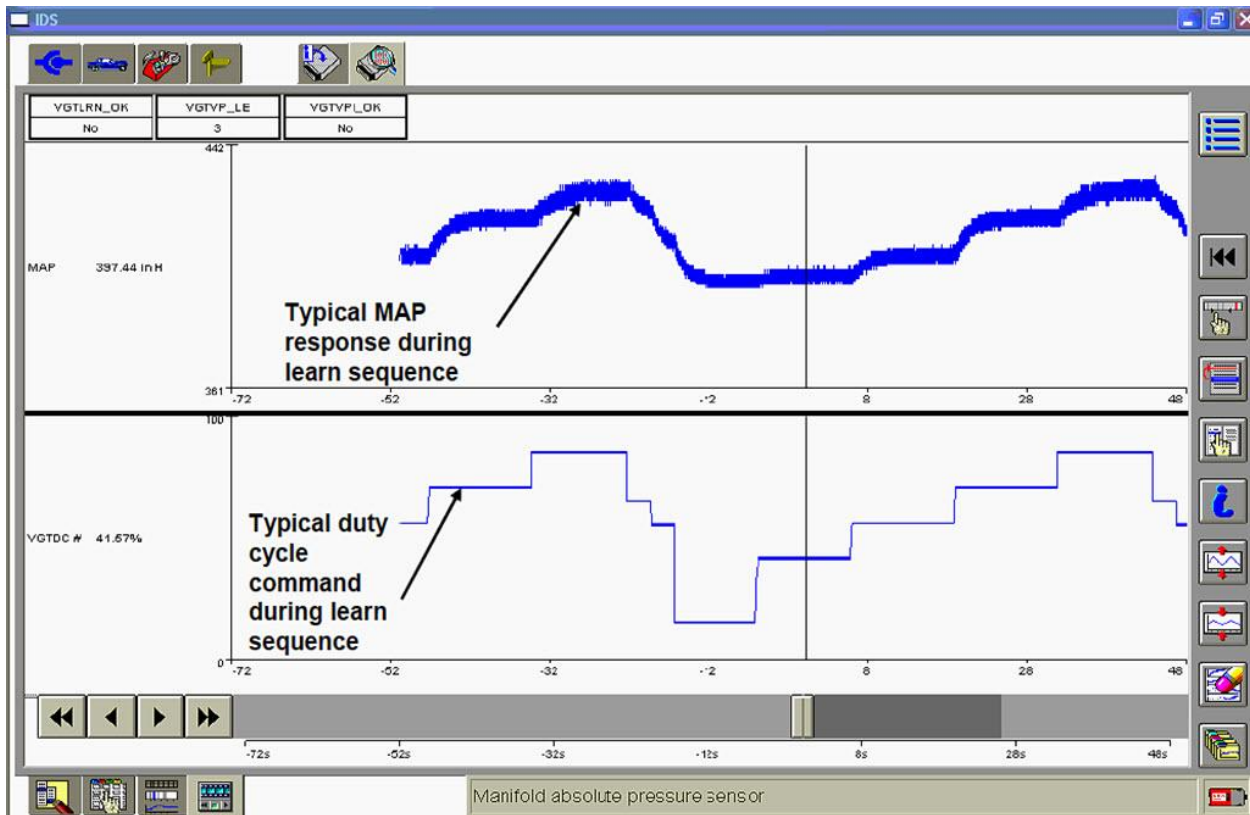
– EOT

– MAF

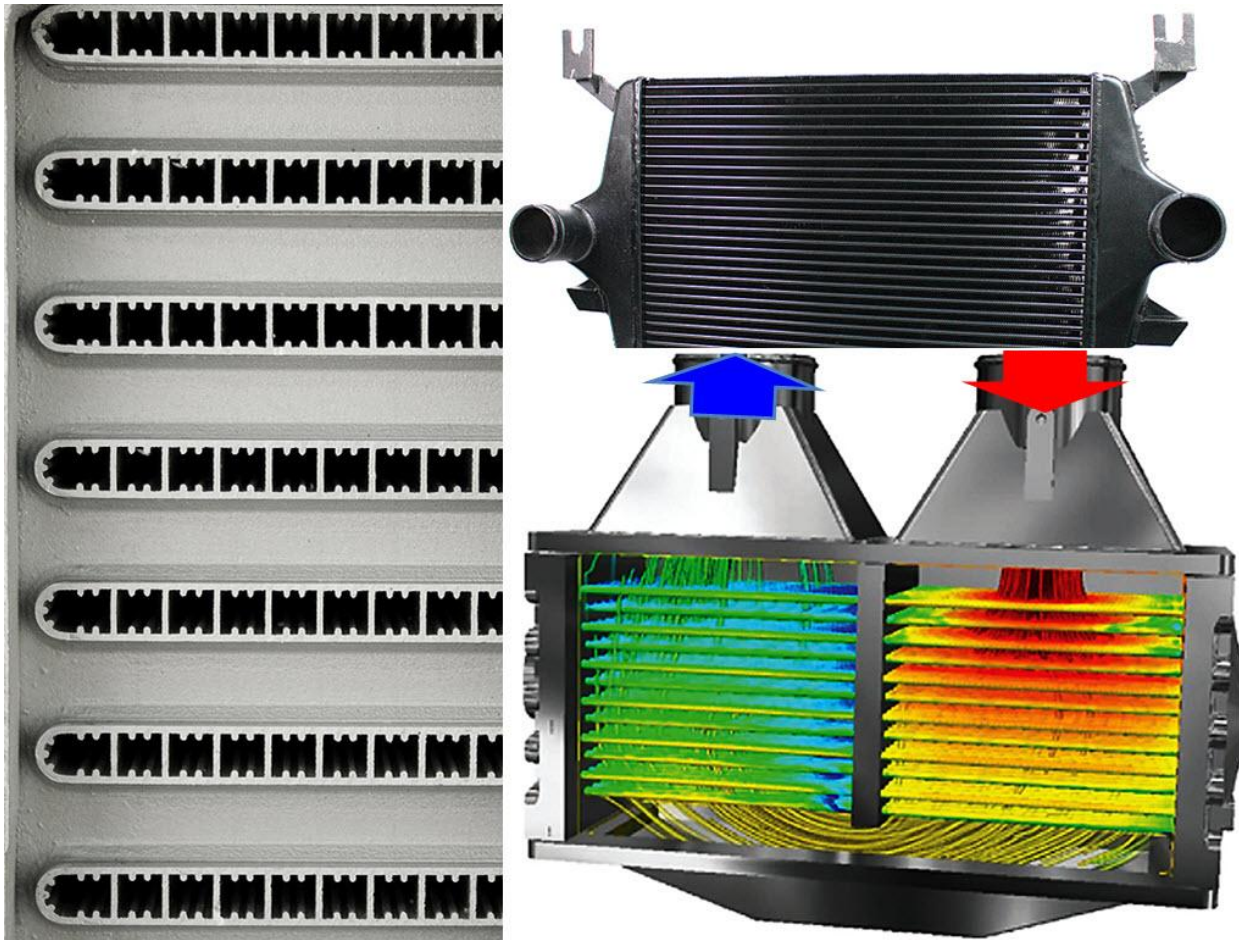
– BARO

This can be determined by monitoring the VGTLRN OK PID. The PID will indicate YES when the minimum number of turbo system learns cycles are complete. For continued “fine tuning” of turbo system it is typical for the PCM to execute learn sequences even if the PID indicates YES.

MAP Reaction to VGT Changes



Charge Air Cooler



The air coming out of the compressor side of the turbo is hot. It must be cooled before it enters the intake manifold. The air is cooled by the charge air cooler. The charge air cooler is located in the front of the radiator. It is an air to air cooler designed to lower the temperature of the air coming out of the turbocharger outlet before entering the intake manifold.

Intake Manifold



The intake manifold on the 6.0 L Power Stroke is made of aluminum and directs the flow of air to the intake ports in the cylinder heads. The intake manifold provides a path for coolant from the EGR cooler to the front cover. There is a passage for EGR gasses to go to the EGR valve where they mix with compressed (after turbo) intake air. The manifold absolute pressure sensor (MAP) port and the inlet air temperature 2 (IAT2) sensors are both mounted in the intake manifold. The passage at the rear of the manifold is to equalize pressure on both sides of the manifold.

Inlet Air Temperature 1

Inlet Air Temperature 1 (IAT1) is a thermistor style sensor and not used in any engine control. The IAT1 signal is used to assist in the operation of the air conditioning and engine cooling fan.

Inlet Air Temperature 2

The IAT2 is a thermistor style sensor used to indicate air temperature after passing through the charge air cooler.

Thermistors

Thermistors are temperature sensitive resistors. All resistors vary with temperature, but thermistors are constructed of semiconductor material with a resistivity that is especially sensitive to temperature. However, unlike most other resistive devices, the resistance of a thermistor decreases resistance with increasing temperature. That's due to the properties of the semiconductor material that the thermistor is made from. For some, that may be counterintuitive, but it is correct. Not only is the resistance change in the opposite direction from what you expect, but the magnitude of the percentage resistance change is substantial.

Emission Control

Exhaust Gas Recirculation (EGR)

The EGR system reduces emissions in the combustion chamber. It is an emission reduction system but not considered an after treatment system, because it works during and not after combustion.

After-Treatment Systems

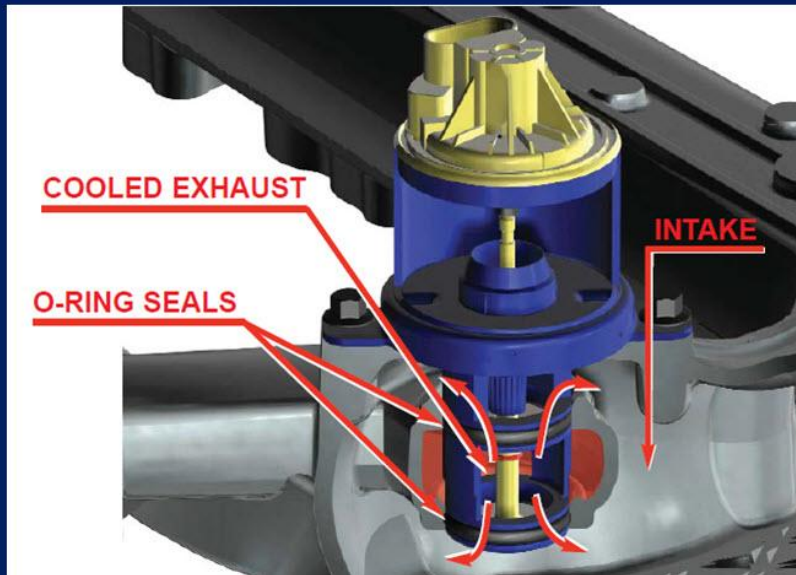
Diesel particulate filter (DPF)

Oxides of Nitrogen (NO_x)

Aftertreatment refers to the conditioning the exhaust gas that leaves the cylinder after the combustion process to remove the harmful emissions. Engineers will design intake and combustion chambers to help promote the complete burning of the fuel, but always fall short. There are always some harmful emissions remaining in the exhaust gas. Fuel companies develop fuels to reduce emissions and also fall short. Any process done to the exhaust gas is called after treatment.

Exhaust Gas Recirculation (EGR)

The PCM-controlled EGR (Exhaust Gas Recirculation) valve adds cooled exhaust gasses to the intake manifold to reduce NO_x emissions



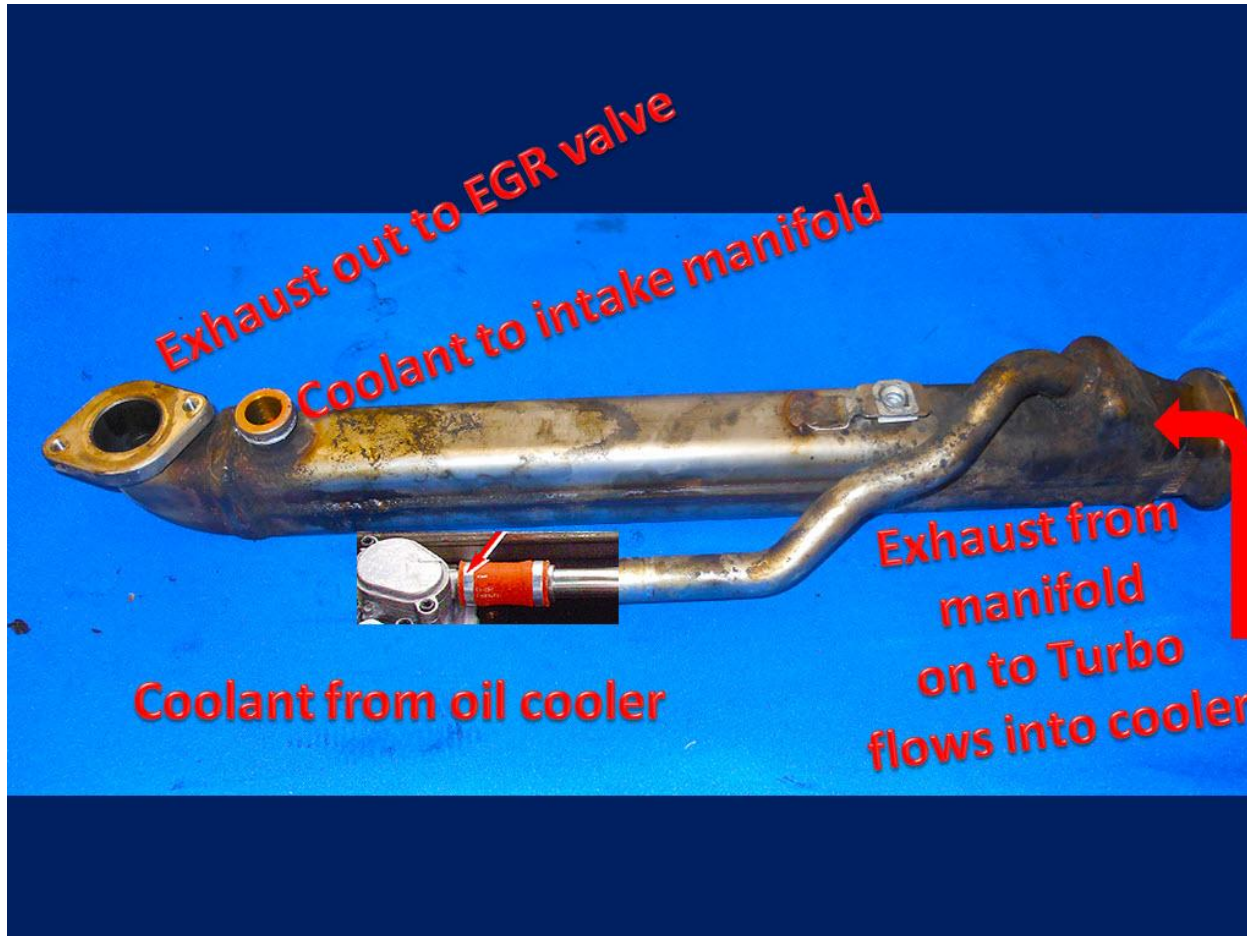
EGR is designed to reduce nitrogen oxide (NO_x) emissions. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. In a diesel engine, the exhaust gas replaces some of the oxygen entering the cylinder. Because NO_x forms primarily when a mixture of nitrogen and oxygen is subjected to high temperature, the lower combustion chamber temperatures caused by EGR reduces the amount of NO_x the combustion generates. Most modern engines now require exhaust gas recirculation to meet emissions standards.

EGR Valve Position Sensor (EGRVP)

The EGR Valve Position Sensor (EGRVP) is a three wire potentiometer sensor. It is located in the EGR sensor assembly. The PCM uses this signal to determine EGR position. The sensor isn't used with a MAP (Chart) programmed into the computer. A MAP would be used for the computer to measure the voltage of the EGR position sensor, look the voltage up on a MAP (Chart) to determine EGR flow. The computer uses inlet air temperature sensor 2 (IAT2) to measure the temperature of the EGR gas and intake air mixture. Increasing EGR flow also increases the temperature. The computer reads the EGR

sensor voltage and the IAT2 signal. Moves increases or decreases EGR and watches the IAT2 changes. The computer then looks at the EGR position sensor and determines flow.

EGR cooler



The EGR cooler is a coolant to air heat exchanger that is used to cool the exhaust gasses before they are sent to the EGR valve. The exhaust gasses are routed into the EGR cooler from the exhaust up pipes at the rear of the engine. The exhaust gasses are cooled by passing through metal tubes that are surrounded by engine coolant. Depending on conditions, the temperature drop across the cooler could be as much as 700° F. The cooled gasses are then routed to the EGR valve that is mounted in the intake manifold.

Cap off both ends. Use an air inlet valve at one of the ends. Connect to shop air and place the cooler into a bucket add water to check for leaks.

Checking the EGR cooler for leaks



This is an adapter used to apply pressure to the EGR cooler. Apply 15 to 20 psi and check for leaks in a bucket of water.



Check for bubbles to identify EGR cooler leaks.

Indication of Leaking EGR



EGR coolers failed a lot on the 6 liter after model year 2003. They blow out or start leaking internally. The exhaust gas and coolant mix together. The coolant in the exhaust creates white smoke like steam. Not white smoke like a too rich condition causes. The combustion pressure in the cooling system pushes coolant out of the degas bottle's cap.

Symptom of leaking EGR cooler

White smoke

White smoke (Steam) coming out of the tail pipe. When the EGR cooler leaks it dumps coolant into the hot exhaust which turns it into steam.

Missing Coolant

If it becomes necessary to top off the de-gas bottle too often.

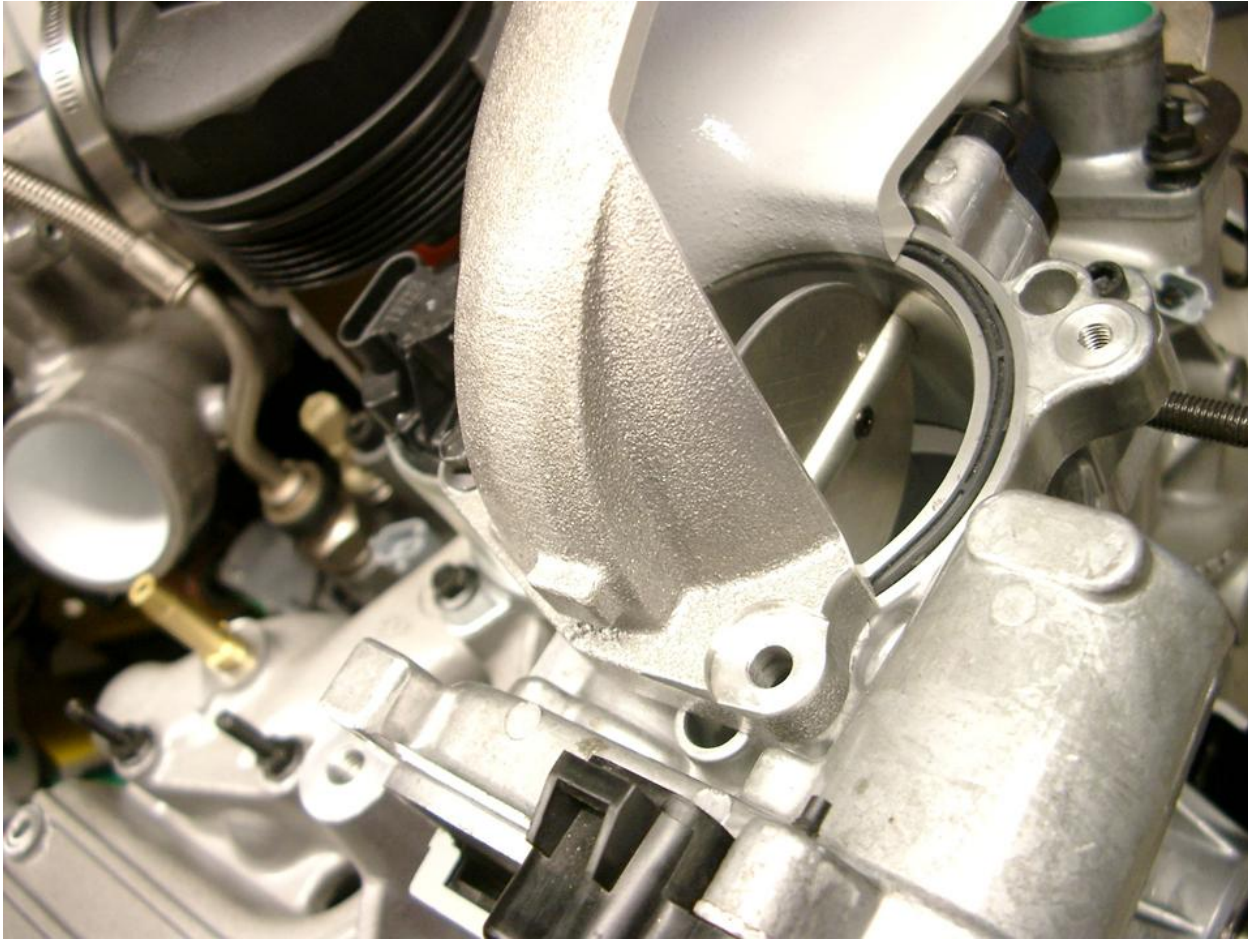
Wet, gooey EGR valve

Remove the EGR valve and look for the carbon to be dry. If it is wet and gooey

suspect a leaking EGR cooler.

131

EGR Throttle Plate



There is an EGR Throttle Plate assembly is mounted in the throttle bore. It isn't used to control air flowing through the bore. The purpose of this plate is to lower the manifold pressure to allow exhaust gases from EGR to flow easily into the intake manifold. The PCM will activate the EGRTP actuator and perform a full sweep of the throttle plate for each key cycle with the IAT temperature greater than 32° F.

Under certain engine operating conditions closing the EGR throttle plate helps in scavenging exhaust gasses from the EGR valve into the intake manifold.

The throttle plate is used to limit the amount of air entering the intake to increase EGR flow allowing the EGR system to be more effective. This is an electric throttle plate that is controlled by the PCM.

NOTE!

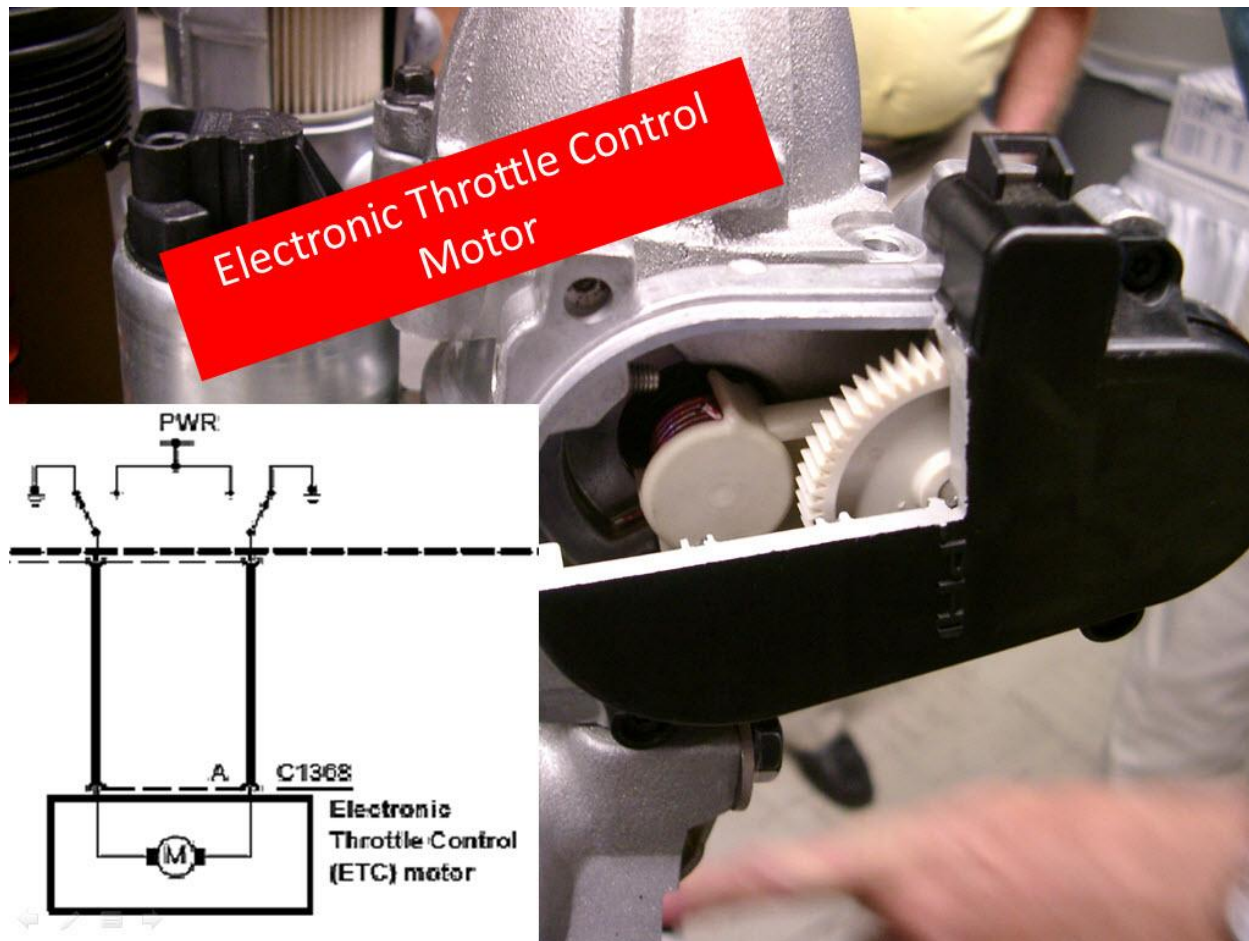
In 2003 Ford started adding a throttle plate. Some of the early 2003s had one and somewhere near the middle of the year they all had a throttle plate. There wasn't any PCM programming in 2003 to use the throttle plate.

Once again in 2004 Ford, used the throttle plate on the 6.0 L. The only way to be sure if the truck you're working on has the throttle plate is to look.

On the 2005 model year the throttle plate was replaced with a deflecting plate which supplied a permanent Venturi effect. There is a scoop near the EGR to improve EGR flow.

It also important to note, that the 6.0 L has sufficient exhaust back pressure and EGR requires only a small amount of help to start EGR flow.

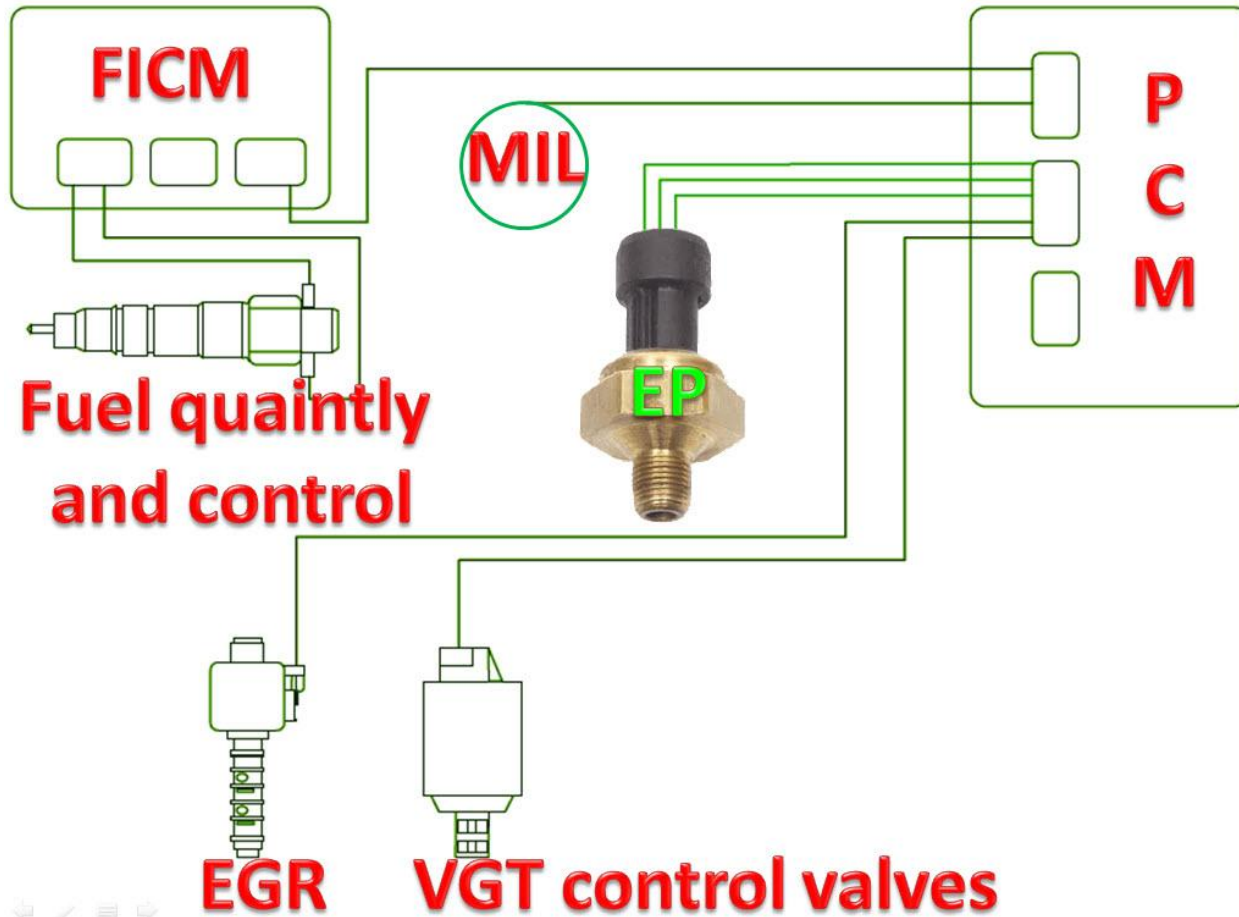
Electronic Throttle Control



The throttle plate is electrically controlled on Power Stroke engine that use throttle control

of EGR.

EP (Exhaust Pressure) Sensor



The EP sensor is a three wire sensor. There is a five volt reference, signal return, and the signal wires. The PCM uses the sensor to control the EGR and VGT systems. If the EP sensor goes bad and doesn't send the correct signal, the PCM will incorrectly control the RGR and or the VGT systems causing any number of drivability concerns.

Some of them are:

Intermittent surging at idle or driving at steady speed

- Excessive smoke
- Rough running
- Stumbles
- Lack of power
- Stalls

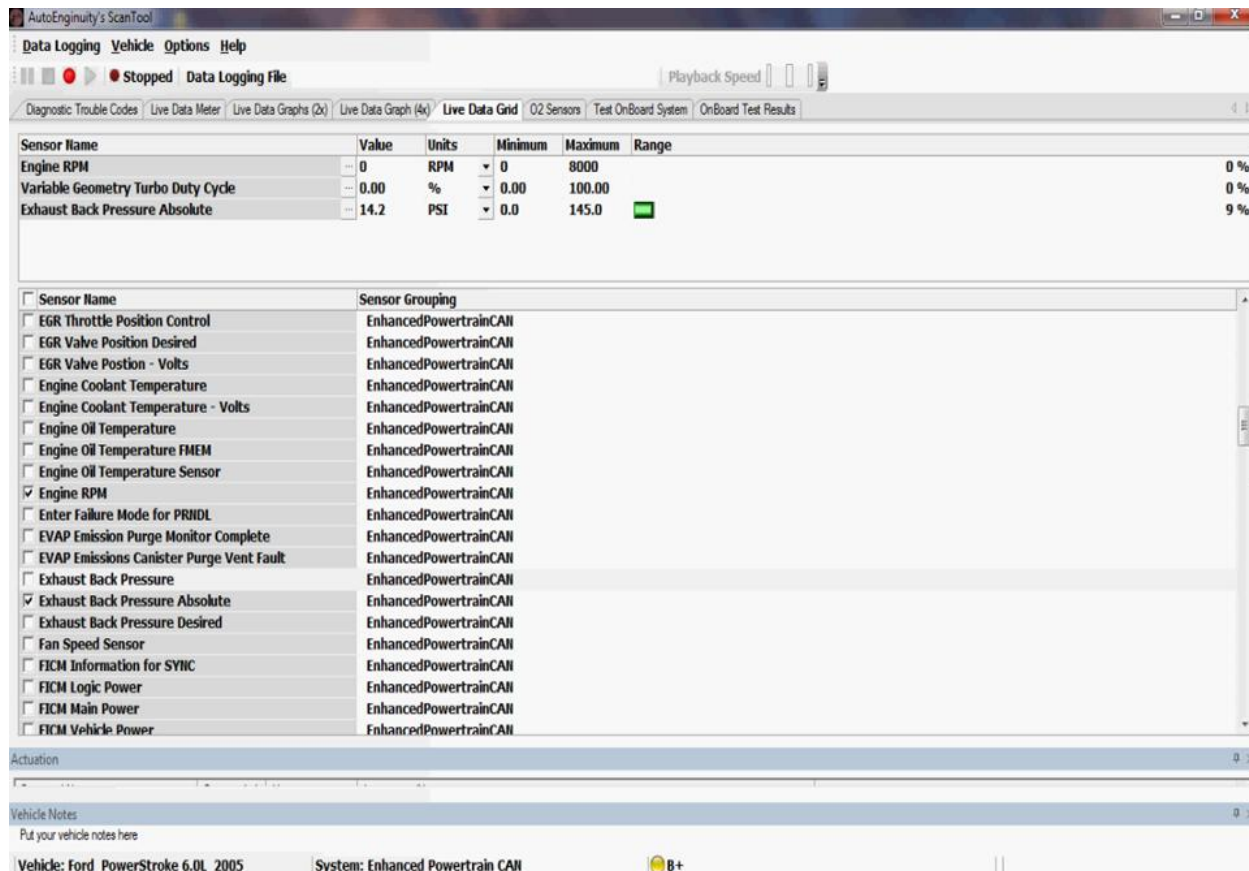
- Erratic idle
- Bucking
- Noisy engine operation
- Erratic EGR valve operation

All of the above may be caused by either the EGR or VGT turbo system. When they are not controlled correctly, both systems cause drivability problems. Diagnosing the EP sensor before diagnosing either the EGR or VGT may help to avoid replacing unnecessary components and save time.

The EP sensor is a variable capacitor sensor. It receives a 5-volt reference signal from the PCM.

It sends a linear analog voltage signal that indicates pressure to the PCM. The EP sensor measures the pressure in the left exhaust manifold. The signal is used for VGT and EGR valve control.

Turbo VGT duty cycle and Exhaust back pressure



To check the BP sensor look at the EP, MAP, and Baro at K-O-E-O, they should read the same with the engine off.

Tap the sensor to see if it changes (if it does check the connector then replace it). Compare to the VGT duty cycle The EP value should change as the turbo changes with the engine running.

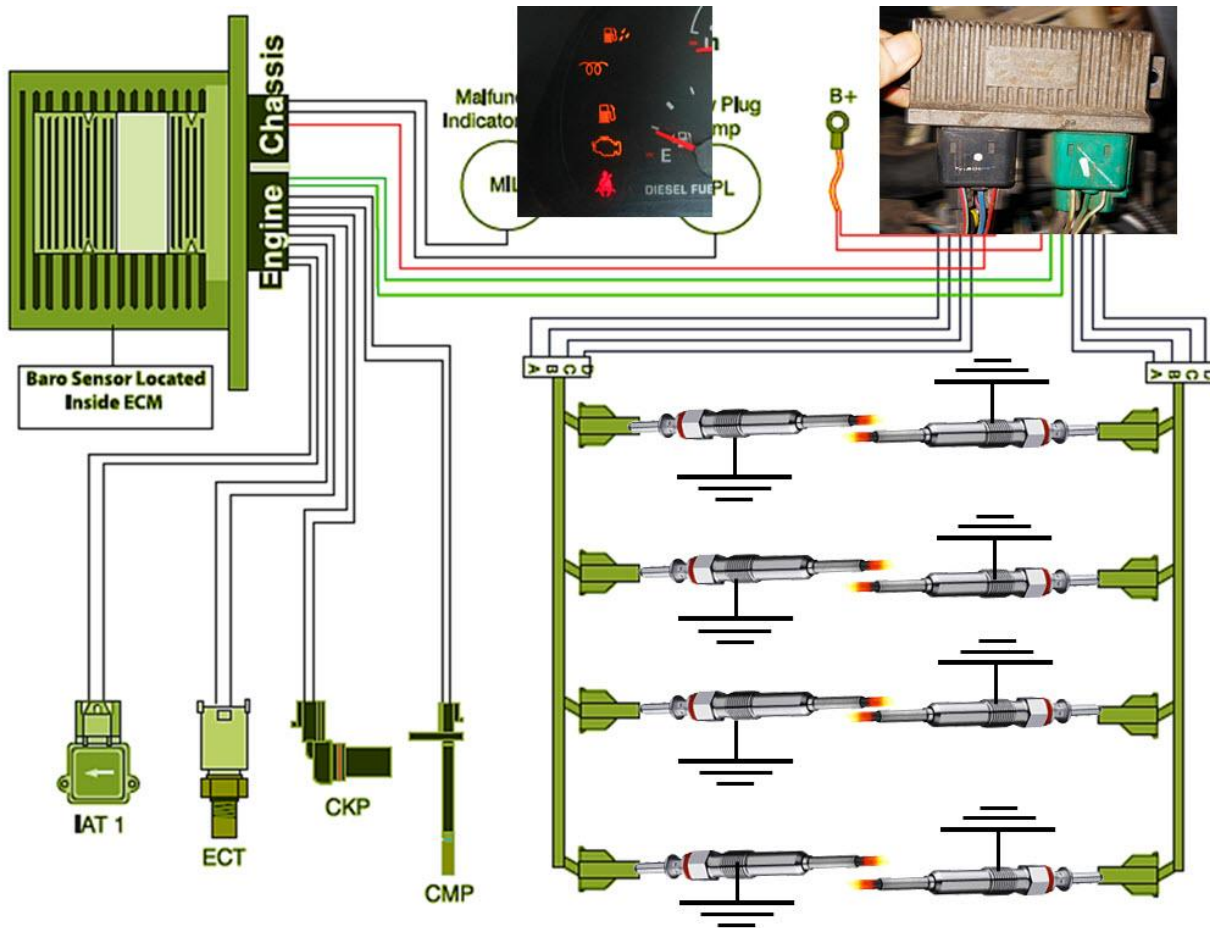
A Bad EP Sensor may cause:

Intermittent surging at idle or driving at steady speed;

- Excessive smoke
- Rough running
- Stumbles
- Lack of power
- Stalls
- Erratic idle
- Bucking
- Noisy engine operation
- Erratic EGR valve operation

The Exhaust Backpressure is Inferred and not measured. On the 6.0 L diesel engines use the EBP sensor for control of the turbocharger and EGR systems With the implementation of the 06E17 update the 2003 MY the Powertrain Control Module (PCM) eliminates the use of the exhaust back pressure sensor input. Exhaust Backpressure is now “inferred” through the use of inputs from the MAF, MAP, BARO, and EOT sensors. These sensors now provide a more critical function for turbocharger control. As a result, the new PCM function places increased importance on MAF input, MAP input, turbo performance, intake integrity, exhaust integrity. It is possible that drivability issues may arise or be more pronounced following an 06E17 system update. Aftermarket equipment such as intake or exhaust systems also may have a more adverse effect on vehicle operation following the update. Following calibration update or KAM clear it is necessary to allow the PCM to execute an adaptive turbocharger learn process which exercises the turbocharger at idle to “learn” control duty cycle for optimum performance.

Glow Plug Diagram



The glow plug system is used to warm the air in the cylinders to enhance cold weather startups and reduce start up smoke. The glow plug system is ECM controlled, and powered by the Glow Plug Control Module (GPCM).

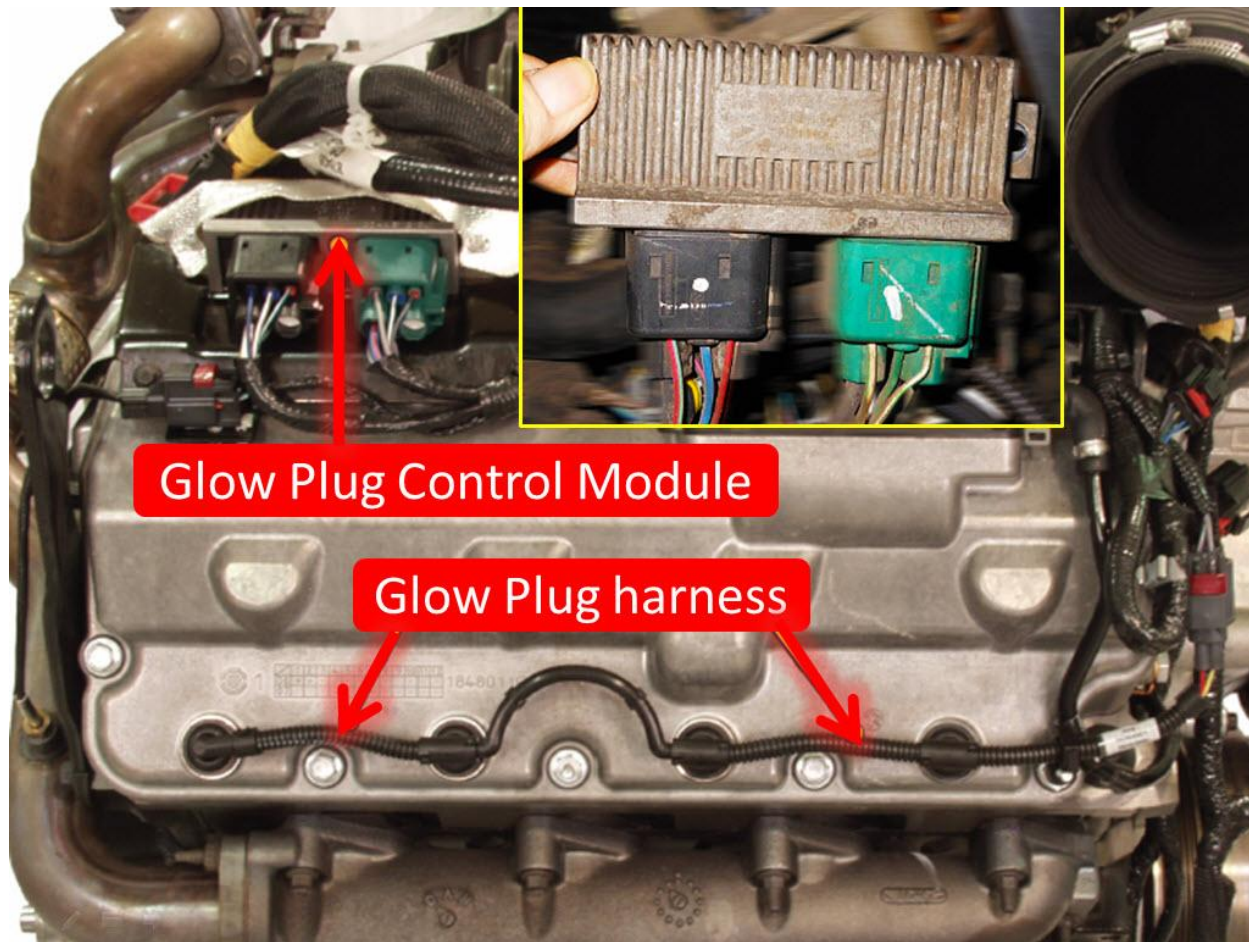
Glow Plug System

When a gas is compressed its temperature increases. The extremely high compression ratios of diesel engines raise the heat of the fuel-air mixture to the point of ignition through pressure alone. At very low temperatures this compression isn't enough to cause the fuel to burn. This is why a diesel engine has glow plugs. The glow plugs are heating elements mounted in each cylinder, they supply a very hot point that raises the temperature of the fuel-air mixture to the point of ignition. When one or two glow plugs fail the owner may notice that the engine is hard to start when the temperature is cold. If too many glow plugs fail the engine may not start on a cold day. The glow plug system is used to warm the air in the cylinders to enhance cold weather startups and reduce start up smoke. The glow plug system is controlled by the ECM, and powered by the Glow Plug Control Module (GPCM).

The circuit is completed by the GPCM, by sending the voltage to the individual glow plugs that are grounded through the body.

Each glow plug connection should measure between 0.5 and 2 ohms.

Glow Plug Control Module (GPCM)



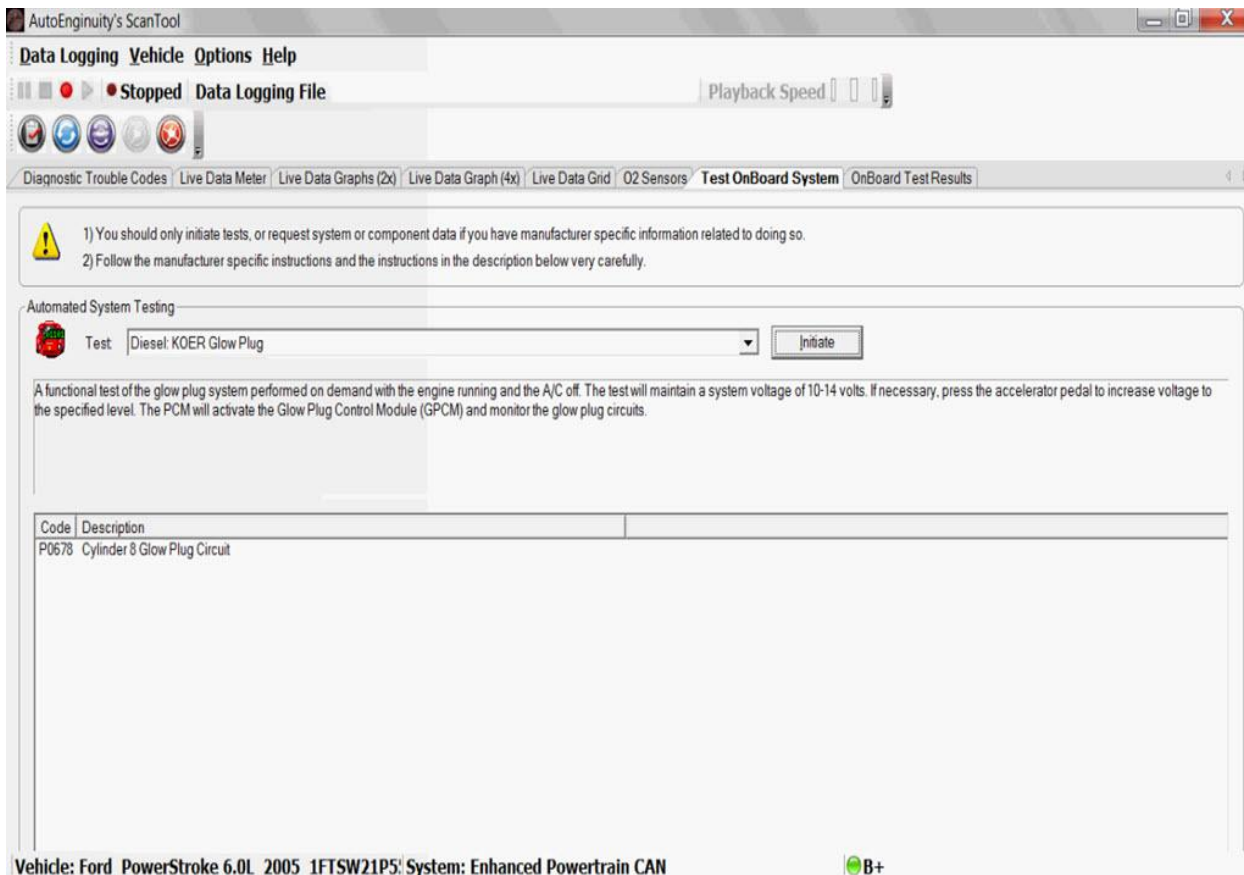
The GPCM commands the glow plugs on for 1 to 120 seconds depending on engine oil temperature and altitude (BARO). The BARO is inside the Power Control Module and cannot be serviced. The GPCM does not operate the glow plugs if the oil temperature is above 131° F.

The GPCM controls the current to the glow plugs. The GPCM has diagnostics and sends a signal to the PCM. It also has the ability to turn off one glow plug if a short is detected in that circuit. The glow plug harness has four connectors that supply power to the glow plugs and seal oil from escaping through the glow plug access holes.

The 6.0 L and the 6.4 L glow plugs look alike, (1.5 mm differences) so much so that Ford uses a color code on the seal. Black seals indicate that the glow plug is for a 6.0 L engine and the green seal is for a 6.4 L engine. It is mounted on the right side of the engine.

Typical Glow Plug DTC

Glow Plug Bi-directional Testing

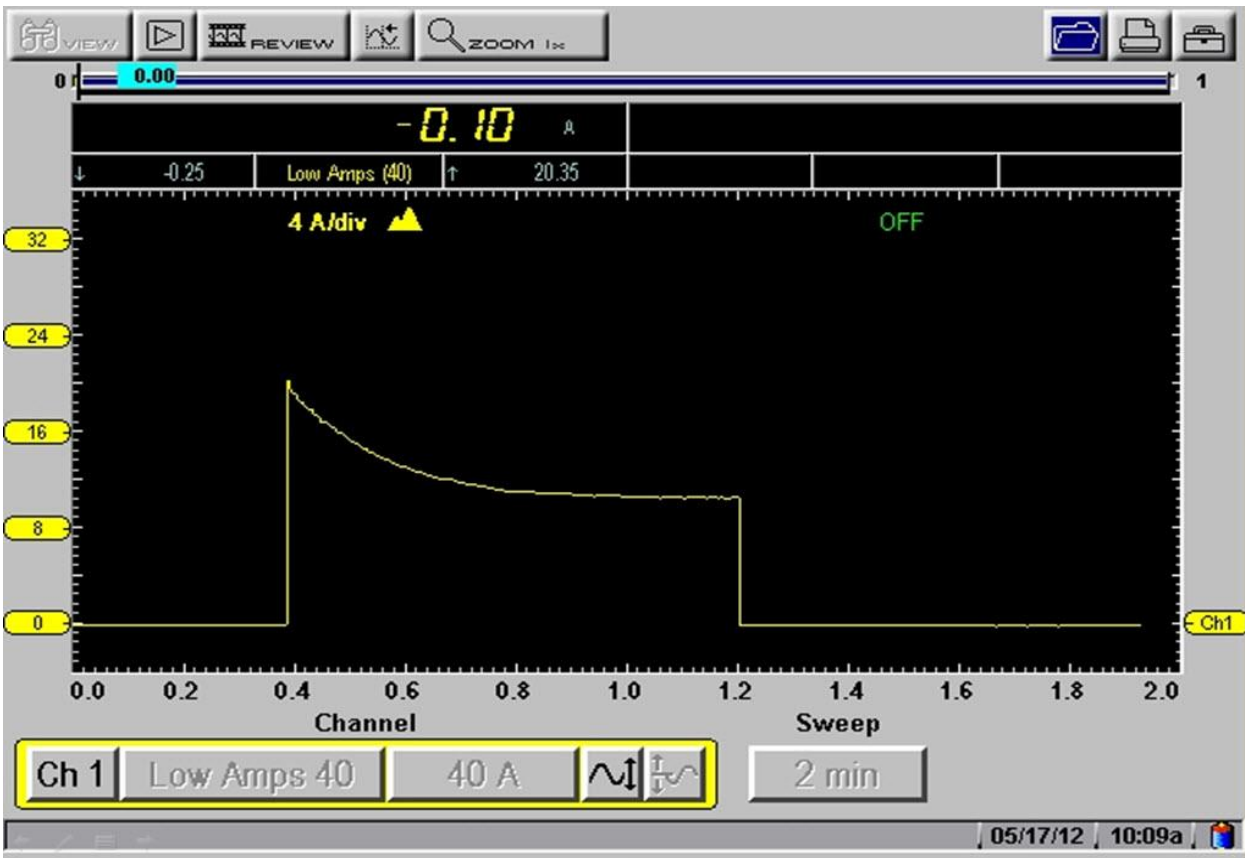


Glow Plug Current Test



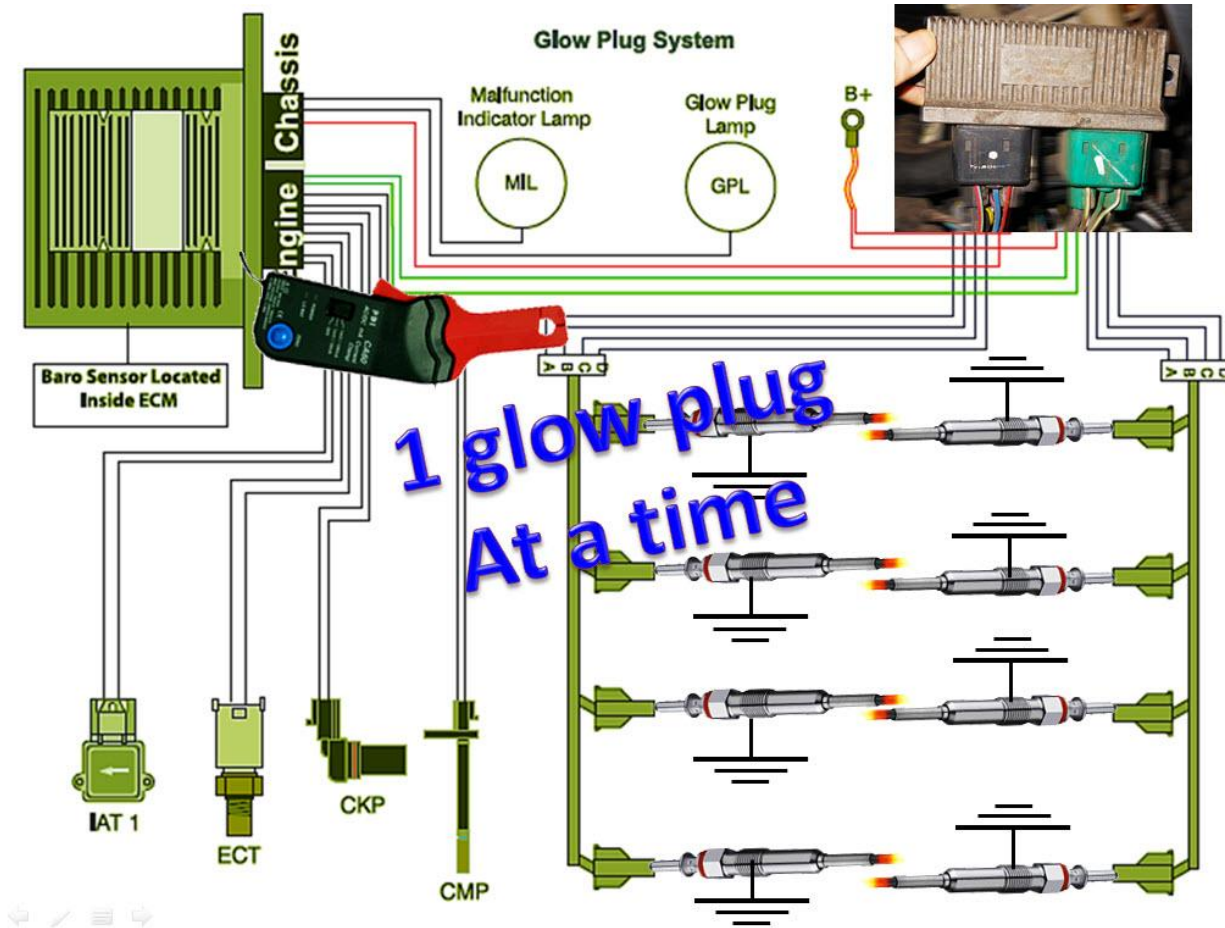
The glow plugs can be tested with the Bi-directional function of a scan tool. The test comma

nds the glow plug on and looks for opens (no current flowing) or shorts (too much current



If too much flows for too long, it can get high enough to blow the fuse, creating an open circuit

Test Connections for one Glow Plug



The current can be measured one glow plug, one bank, or all of them at a time.

6.0 L Power Stroke Engine Changes by Model Year

Model Year 2004 6.0 L Power Stroke Changes

The following changes affect engines manufactured after September 29, 2003.

1. Revised EGR cooler design. 2004-2007 EGR cooler is longer and a square design replaces the circular cooler found on 2003 engines.
2. New "wavy" high pressure oil rail and delivery system, increases volume of high pressure oil system.
3. Improved casting of the upper oil pan increases strength.
4. Upgraded camshaft design featuring different lobe separation angle, lobe lift, and duration characteristics, improves combustion efficiency, reducing emissions.

2004+ camshafts should not be used in 2003 model engines.

5. Modified piston bowl design for improved emissions reduction. Shorter glow plugs required. 04+ glow plugs not compatible in 2003 engines; piston contact and destruction can result.
6. Larger water pumps impeller to increase coolant flow and combat high temperatures resulting from the EGR cooler. (Impeller increased from 90 mm to 100 mm).
7. FICM receives larger vibration dampers to eliminate failure caused by engine harmonics.
8. New turbocharger turbine wheel with 3 additional fins to reduce noise caused by the turbo.
9. Injector plungers coated with DTC (diamond like Carbone) to increase injector life.
10. ICP sensor relocated to valve cover. The sensor can be removed/replaced without removing valve cover.

2005 Model Year 6.0 L Power Stroke Changes

1. New EGR valve with shaft seal reduces leaking of exhaust gases. Not interchangeable with 2003/2004 model year engines. Diverter plates incorporated into the intake manifold to distribute exhaust gases equally between banks.
2. EGR throttle plate removed. Scoop added in exhaust up pipe to direct exhaust flow into the EGR system. Throttle plate deemed redundant.
 - Updated turbocharger shaft bearings for improved turbo longevity and reduced shaft play.
3. New HPOP (high pressure oil pump) design. Flow is comparable to previous HPOP. Improved oil pressure and pump response at low engine speeds. Improved pump longevity.
4. New front engine cover with different coolant passage locations, to make room for new power steering pump design. Not interchangeable with 2003/2004 model 6.0 L Power Strokes.

Power Stroke 6.4 L engine



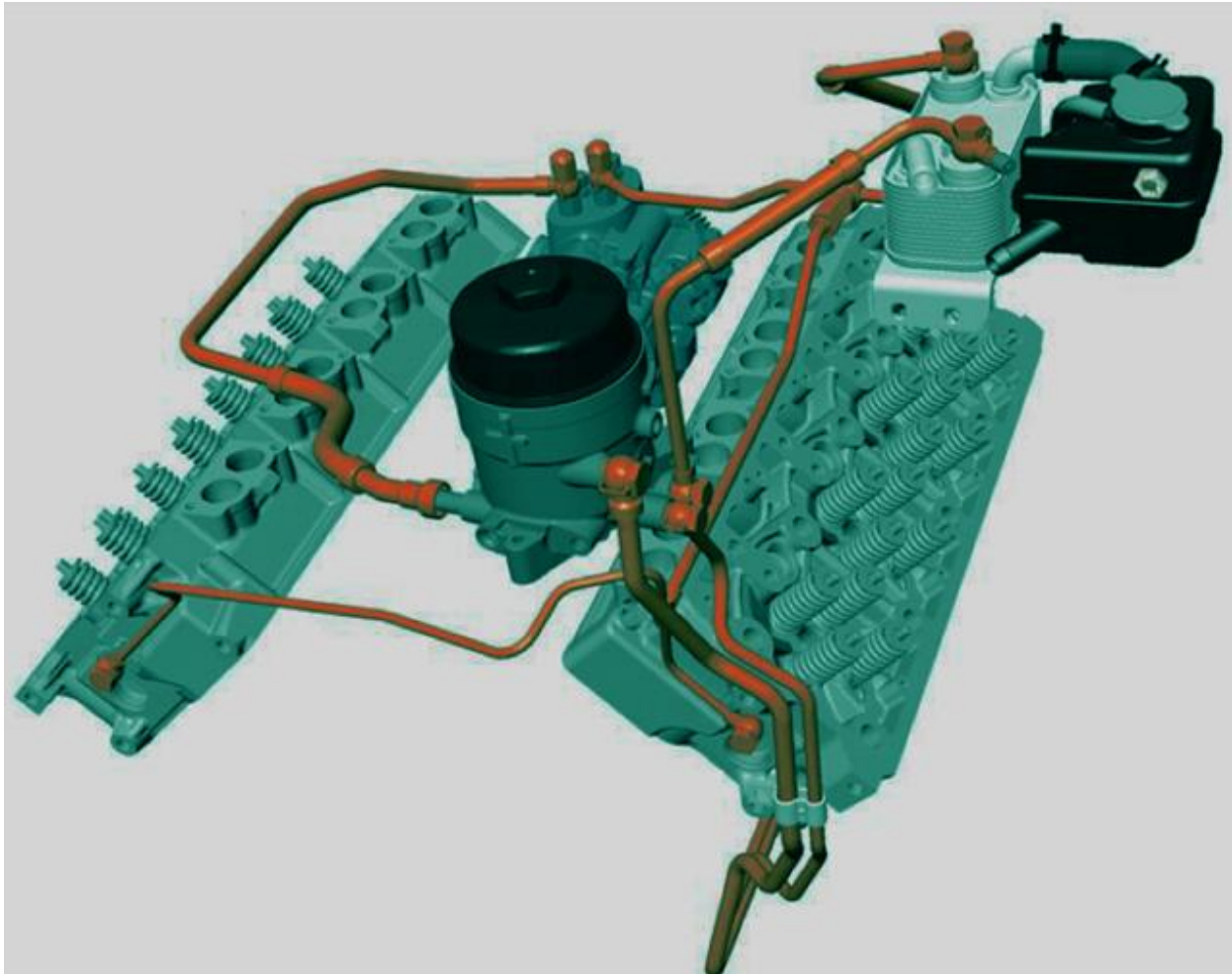
Moving onto the 6.4 L Powerstroke engine requires you to reset your brain. Although there are similarities between 6.0 and 6.4 engines, they are not the same. It may be confusing when we tell you, “This is just like the 6.0 L” and in the next statement we say, “This isn’t anything like the 6.0 L”. That is one of the reasons this book is so valuable, when you need information about either engine the index will take you to the correct one.

The 6.4 L Power Stroke Diesel has been designed to meet the tougher emissions standards set by the government. The 6.4 L Power Stroke Diesel has been designed to meet the customers’ expectations of high horsepower and torque over a wide RPM range. Meeting the more stringent customer and regulated demands are accomplished in part by: High Pressure Common Rail Fuel System, Series Sequential Turbocharger System, 4 valves per cylinder, and a diesel particulate filter to reduce emissions.

The new 6.4 L engine is designed to reduce emissions as well as noise by improvements in the rate, timing control, and through multiple injection firings. The high pressure system’s pressure relief function is now controlled by a PCV (Pressure Control Valve).

The PCV is mounted on the high pressure fuel injection pump.

Common Rail High Pressure Fuel



Another of the differences is the high pressure common rail fuel injection system with piezo electric fuel injectors' uses highly pressurized fuel and electronics to control fuel injection into the cylinders. This system is different from the 6.0 L fuel system. The fuel is pressurized up to 29,000 psi before it is sent to the injectors. The injectors are piezo electronic and not the HEUI found on the 6.0 L engine.

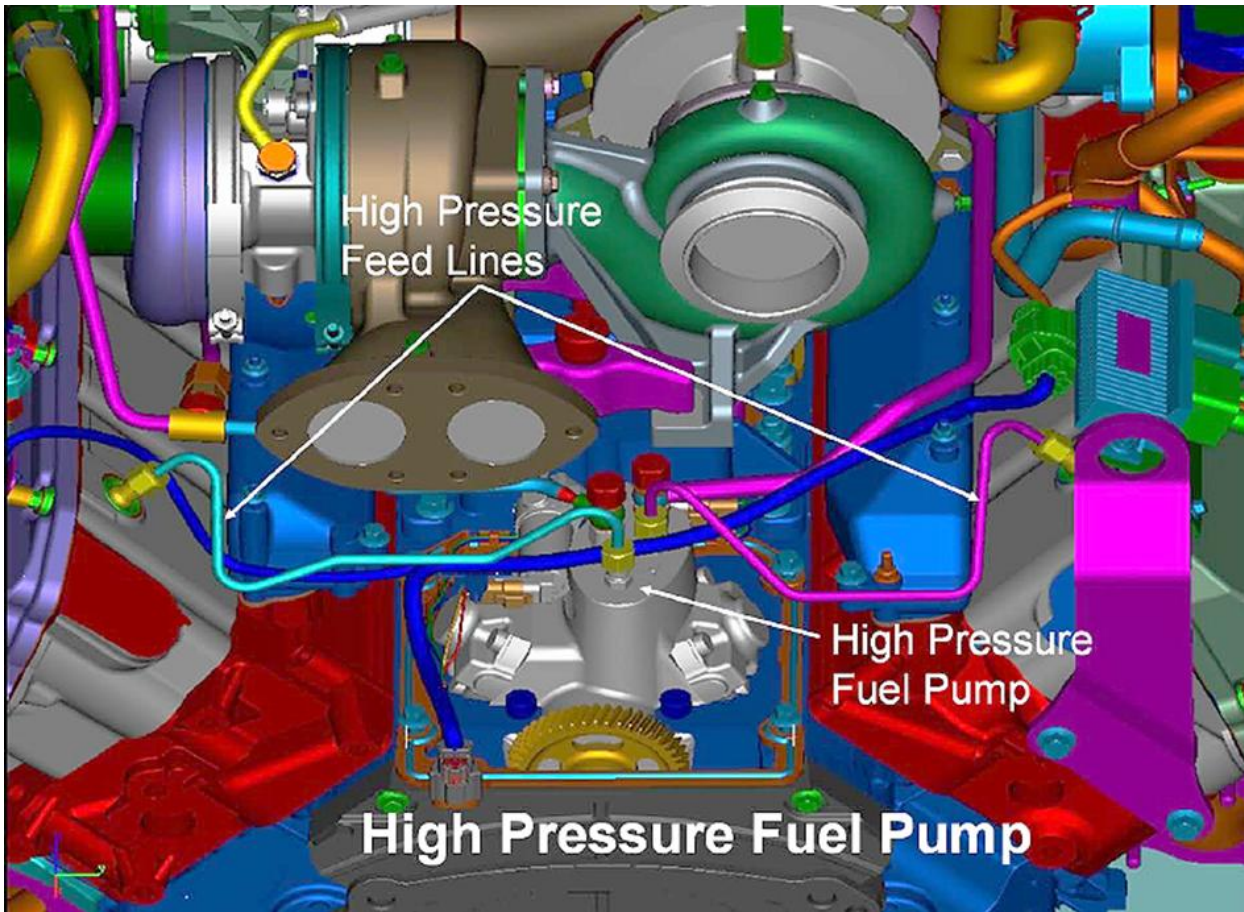
The fuel management system is made up of different sub systems. The systems work together, to meet the power and efficiency, requirements of the driver. Emissions regulations play a huge factor in the design of the 6.4 L fuel system.

6.4 L Fuel Management System Major Components

- Fuel Supply System
- High Pressure Fuel Injection Pump
- High Pressure Fuel Tubes
- Sensors
- Injectors

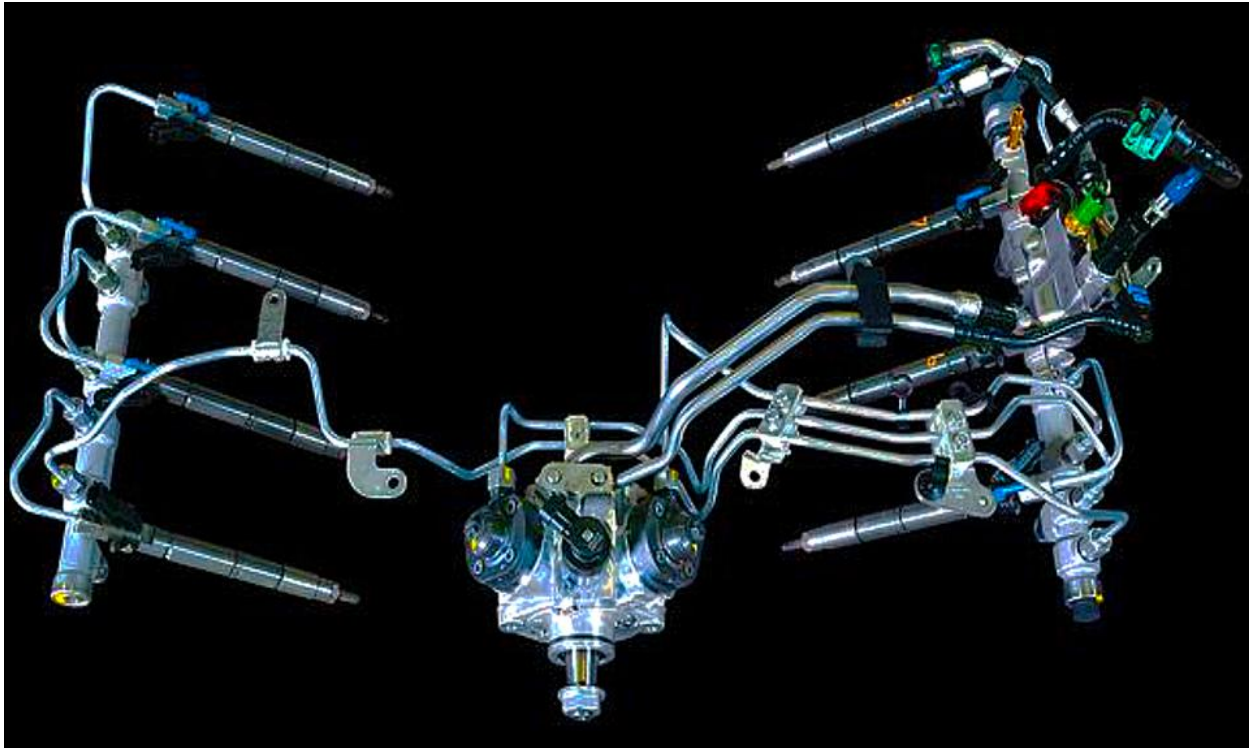
- Electrical Components
- Actuators

High Pressure Fuel Lines



The 6.4 L has two turbocharges connected in series. This isn't twin turbochargers in the true sense there is one turbo for each bank.

High Pressure Piezo Injectors



The high pressure common rail fuel injection system with piezo electric fuel injectors uses highly pressurized fuel and electronics to control fuel injection into the cylinders. This system is different from the 6.0 L fuel system. The fuel is pressurized up to 29,000 psi before it is sent to the injectors. The injectors are piezo electronic and not the HEUI found on the 6.0 L engine.

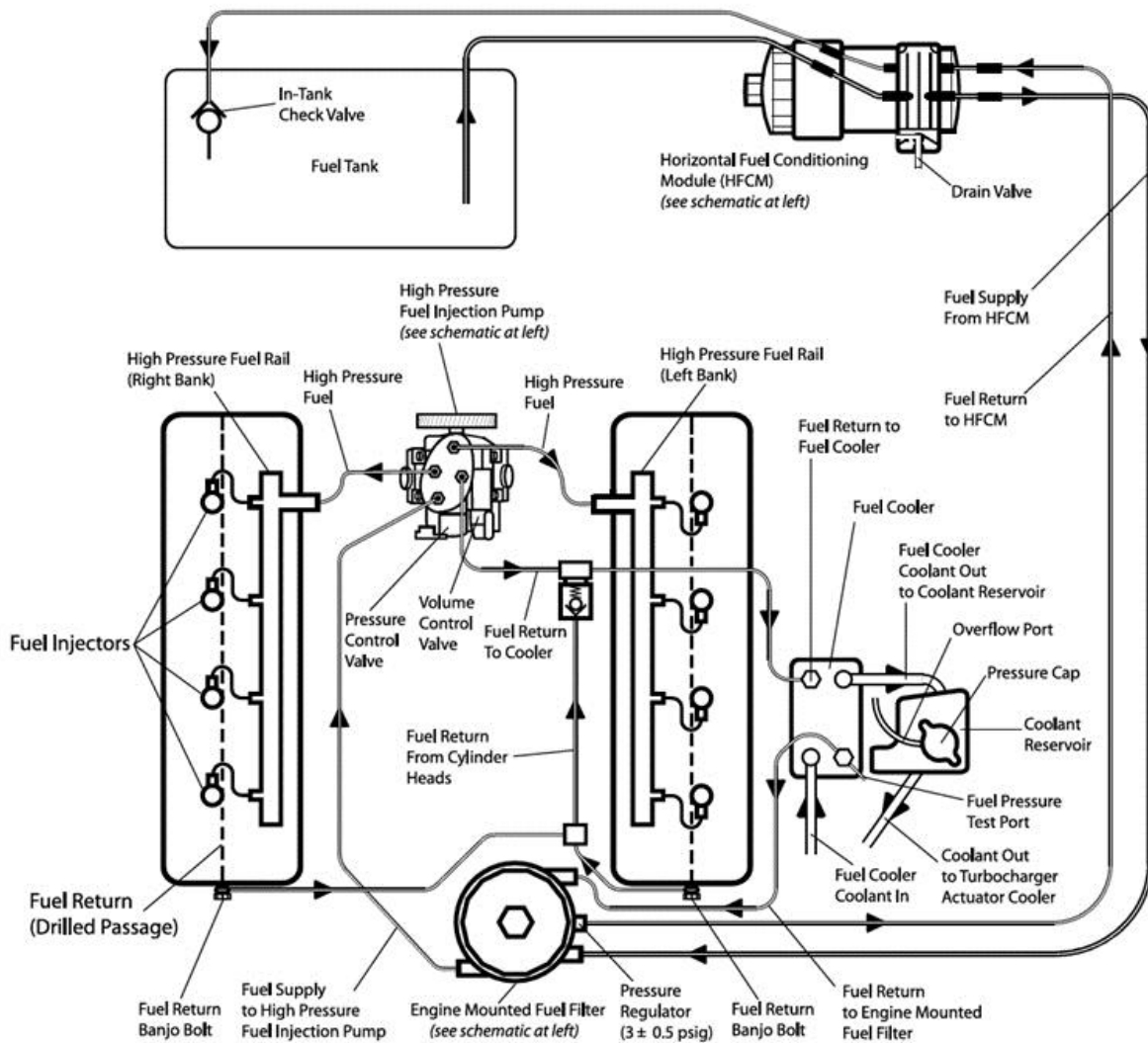
The fuel management system is made up of different sub systems. Emissions regulations play a huge factor in the design of the 6.4 L fuel system.

6.4 L High Pressure Fuel System Flow:

From the fuel tank;

- HFCM
 - Secondary fuel filter
 - High Pressure Pump
 - Fuel Rails
 - Injectors

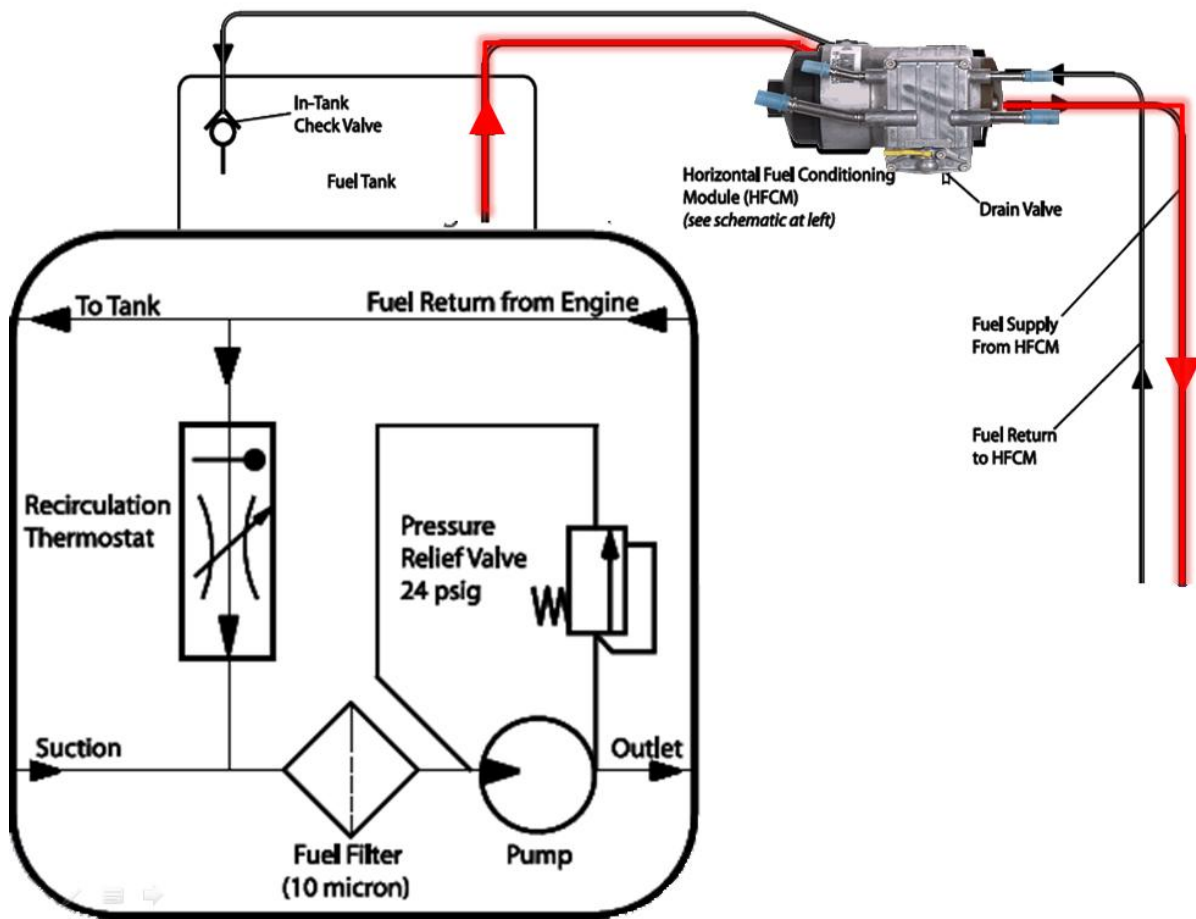
Fuel Distribution Diagram



From the technician's point of view, understanding the 6.0 L fuel system doesn't mean you understands the 6.4 L fuel system.

The 6.4 L isn't like the 6.0 L fuel system. There are some common names for the components, but that's all.

Horizontal Fuel Conditioning Module (HFCM)



The HFCM has different functions.

1. It has an electric fuel pump that draws fuel from the fuel tank and directs it to the secondary fuel filter housing on the engine.
2. It has 10 micron filter and water separator.
3. Fuel returned from the secondary fuel filter housing is controlled by the Diesel thermo recirculation valve (DTRM). The DTRM controls the flow of fuel returned from the engine mounted filter through the HFCM. If the fuel being drawn from the fuel tank is cooler than a specified temperature then return fuel from the engine is recirculated into the inlet of the pump. Fuel that returns from the pressure regulator in the secondary fuel filter housing enters the HFCM and a DTRM allows the fuel to return to the tank or returns it to the unfiltered side of the fuel filter in the HFCM. The DTRM starts to open (recirculating fuel back into the pump) at 80° F and is fully open at 50° F.
4. Inside the HFCM any water is separated from the fuel. The water can and should be

drained as with the 6.0 L HFCM.

The conditioned and pressurized fuel is routed to the secondary fuel filter housing on the engine.

Secondary fuel filter housing



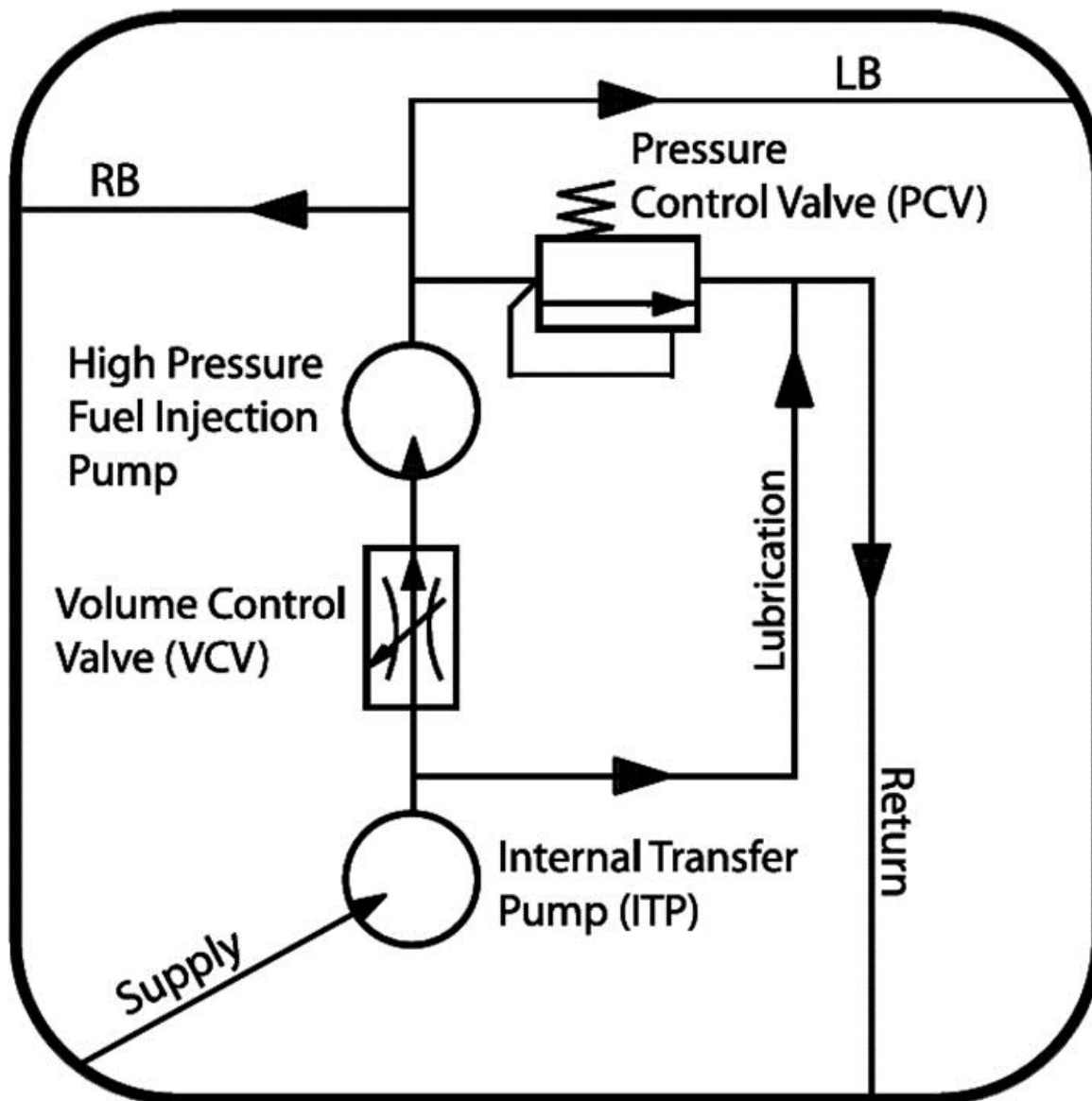
The secondary fuel filter housing is mounted on the top of the engine in front.

There is a 4 micron filter in the housing. All fuel isn't filtered.

There is a fuel pressure regulator that is located in the engine mounted fuel filter housing. It is in the standpipe. It regulates fuel pressure by returning unfiltered fuel to the HFCM with a spring loaded poppet valve. The pressure of the valve is 3 psi+/- 0.5 psi.

NOTE: The regulator is Not serviceable. If the regulator fails the housing will have to be replaced as a unit.

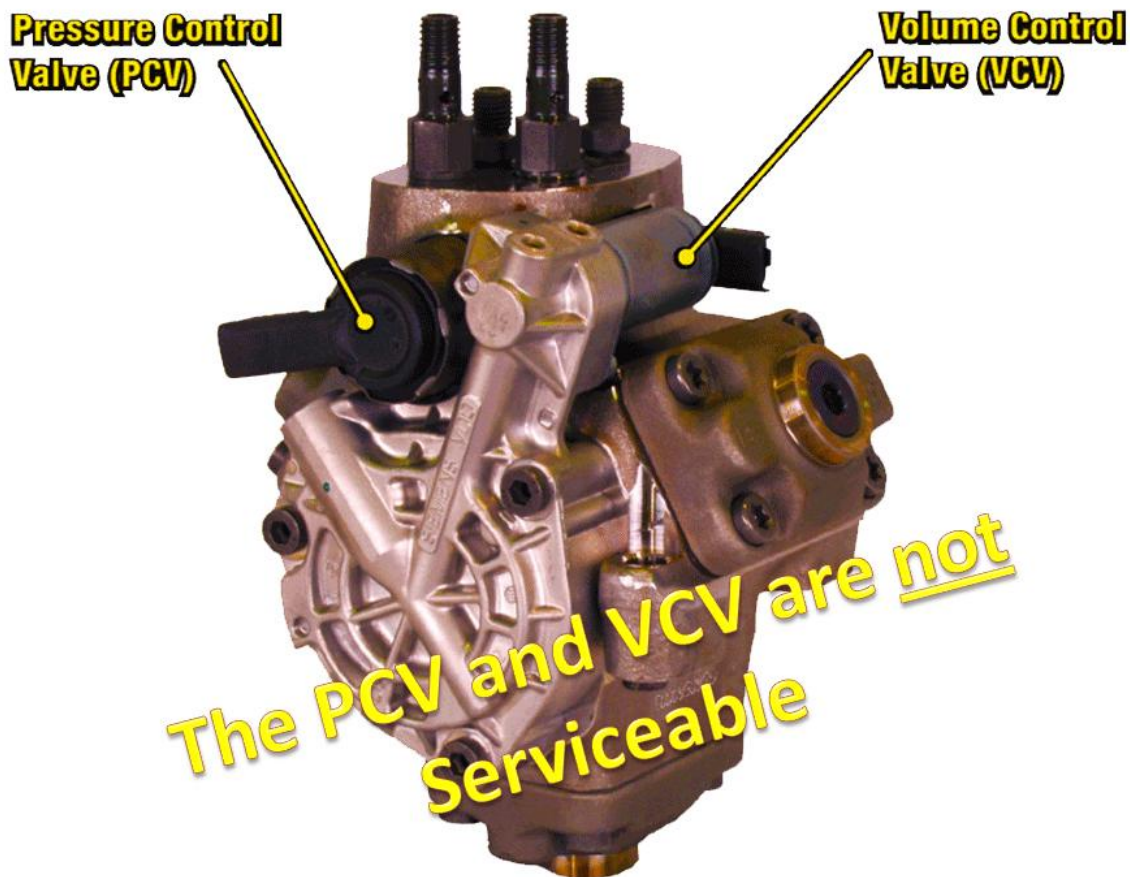
High Pressure Fuel Pump



The high pressure fuel pump is a self-contained unit. Everything described below is inside the pump. The description is how fuel flows through the pump.

After the fuel is filtered it is sent to the Internal Transfer Pump (ITP). The ITP is located in the high pressure fuel pump (HHP). The HHP is also called the High Pressure Fuel Injection Pump (HPFIP) in some manuals. The ITP increases fuel pressure slightly. Pressure is a function of any restriction in the flow. Pressure increases slightly because the area inside the ITP is smaller than the fuel line supplying it.

Pressure Control and Volume Control Valves



The volume control valve (VCV) controls how much fuel enters the pumping chambers of the High Pressure Pump (HPP).

Some fuel is directed to the lubrication valve to lubricate and cool the internal components. There is a one-way check valve so fuel cannot flow back out of the HPP pumping chambers.

The pressure control valve (PCV) controls the pressure in the system by restricting fuel flow to the return line.

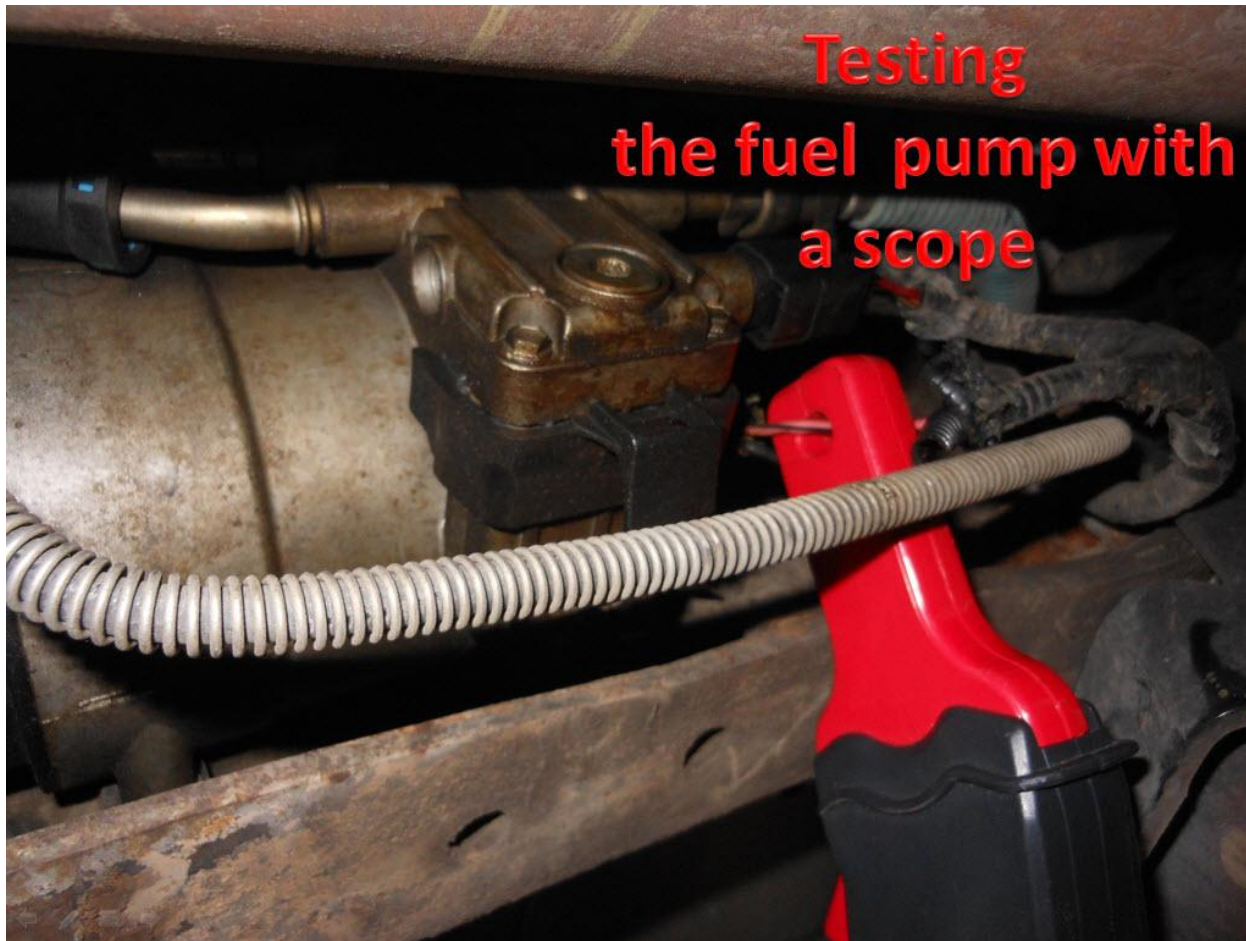
Fuel is then routed to each cylinder head's common rail where it is delivered to each injector under constant pressure.

Making a Fuel pressure test port

Make a fuel pressure fitting in the secondary fuel filter housing. If you don't have or don't want to buy a special adaptor for the Power Stroke engine one can be made. Drill and tap a hole into a fuel filter cap, then thread on a Schrader valve that fits your gauge. This will

allow you to use the equipment your shop already has.

Low Current Fuel Pump Connection



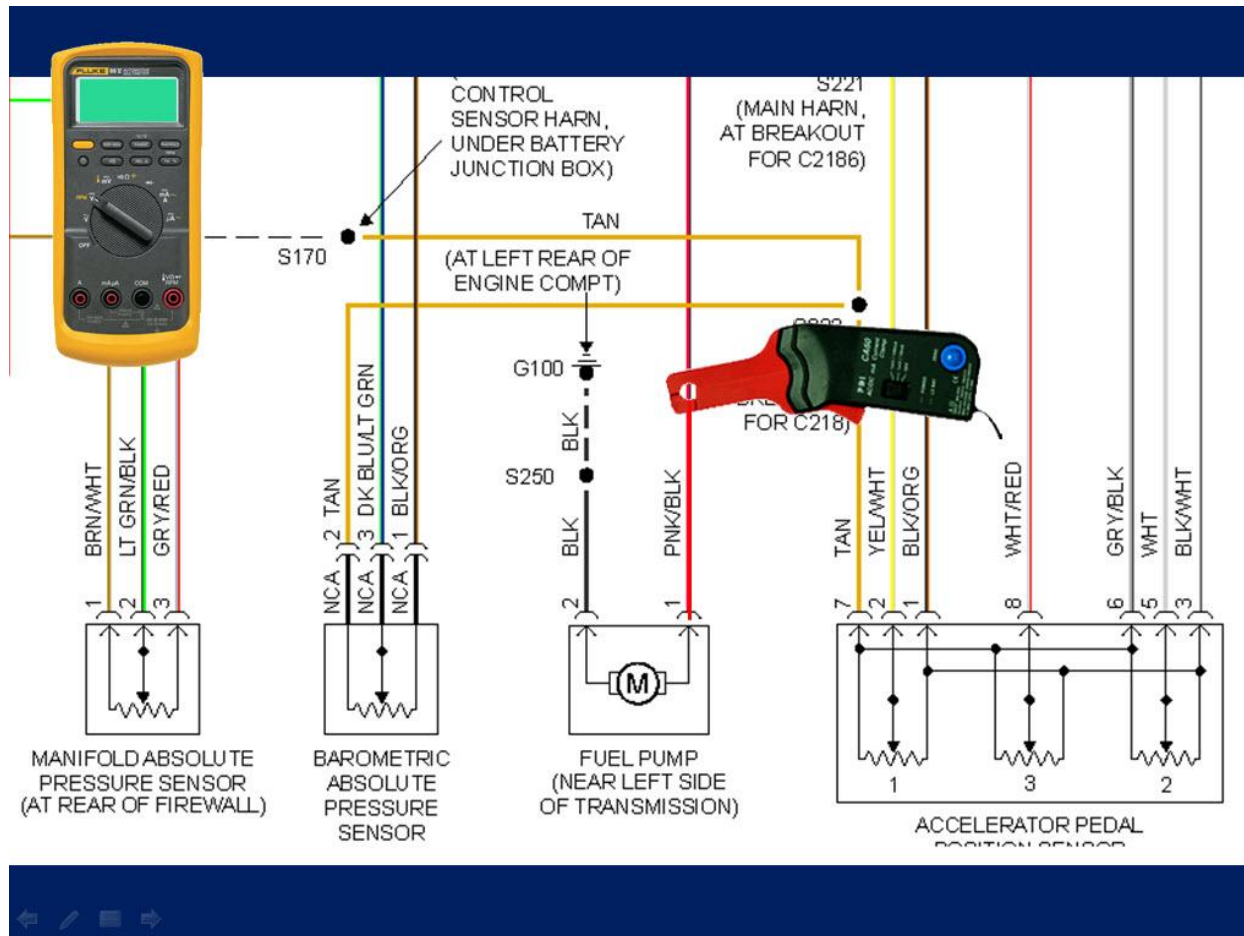
The fuel pump may be tested with a lab scope.

On some models the fuel pump circuit can be found on the drivers side near the firewall



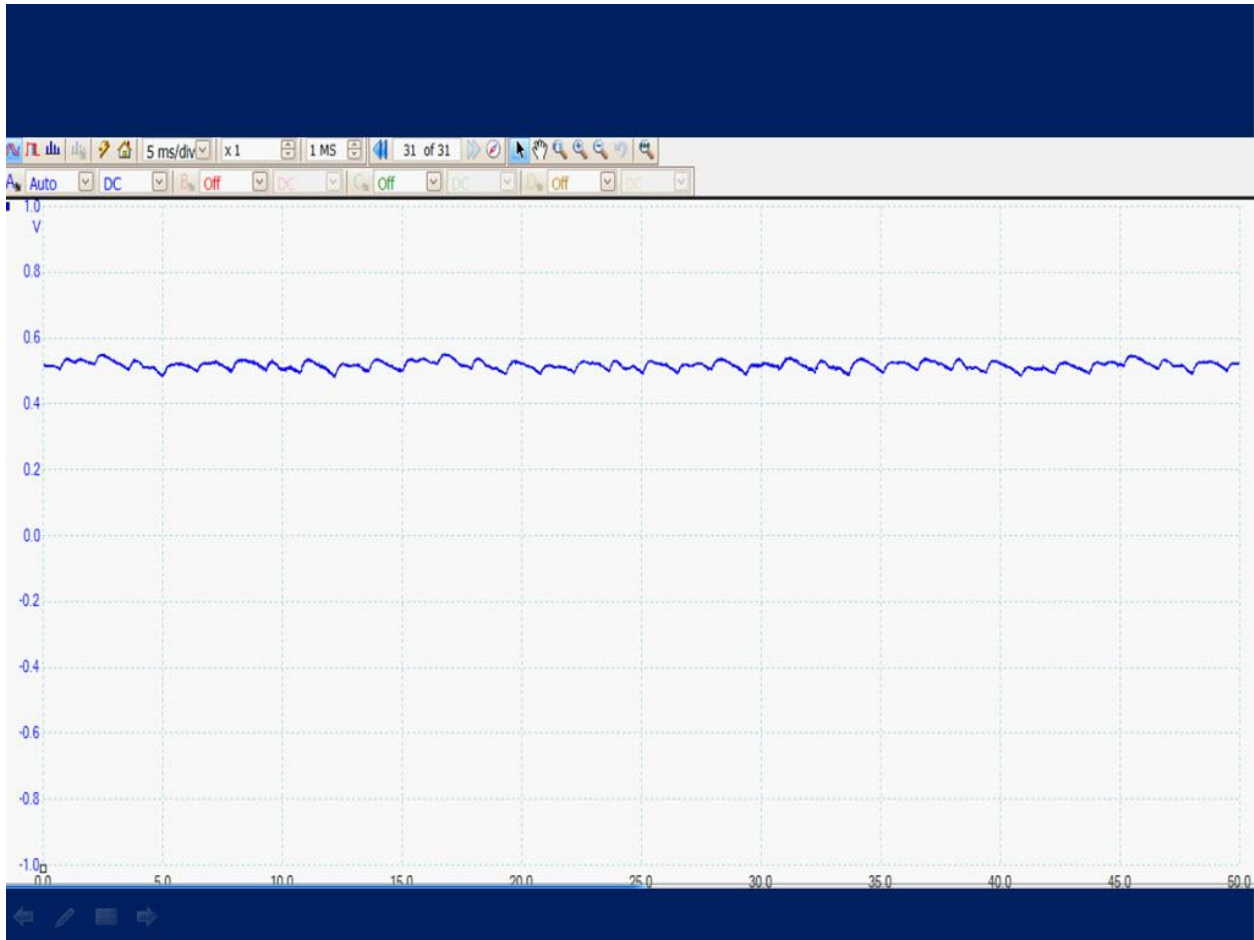
The low amp current probe in the image is around the fuel pump's battery positive circuit. The wave form can be viewed to determine; current flow, brush to commutator resistance, and RPM of the pump. Most technicians don't replace a pump based on the waveform alone. It is used with other diagnostic procedures like fuel pressure and volume testing. The second waveform is showing a bad fuel pump. The waveform is from a 2004 6.0 L that would crank but not start. Fuel pressure was 32 psi. Simple placing the low amp current probe around the fuel pump's battery positive circuit and cranking the engine showed the pump failing.

Fuel Pump Diagram

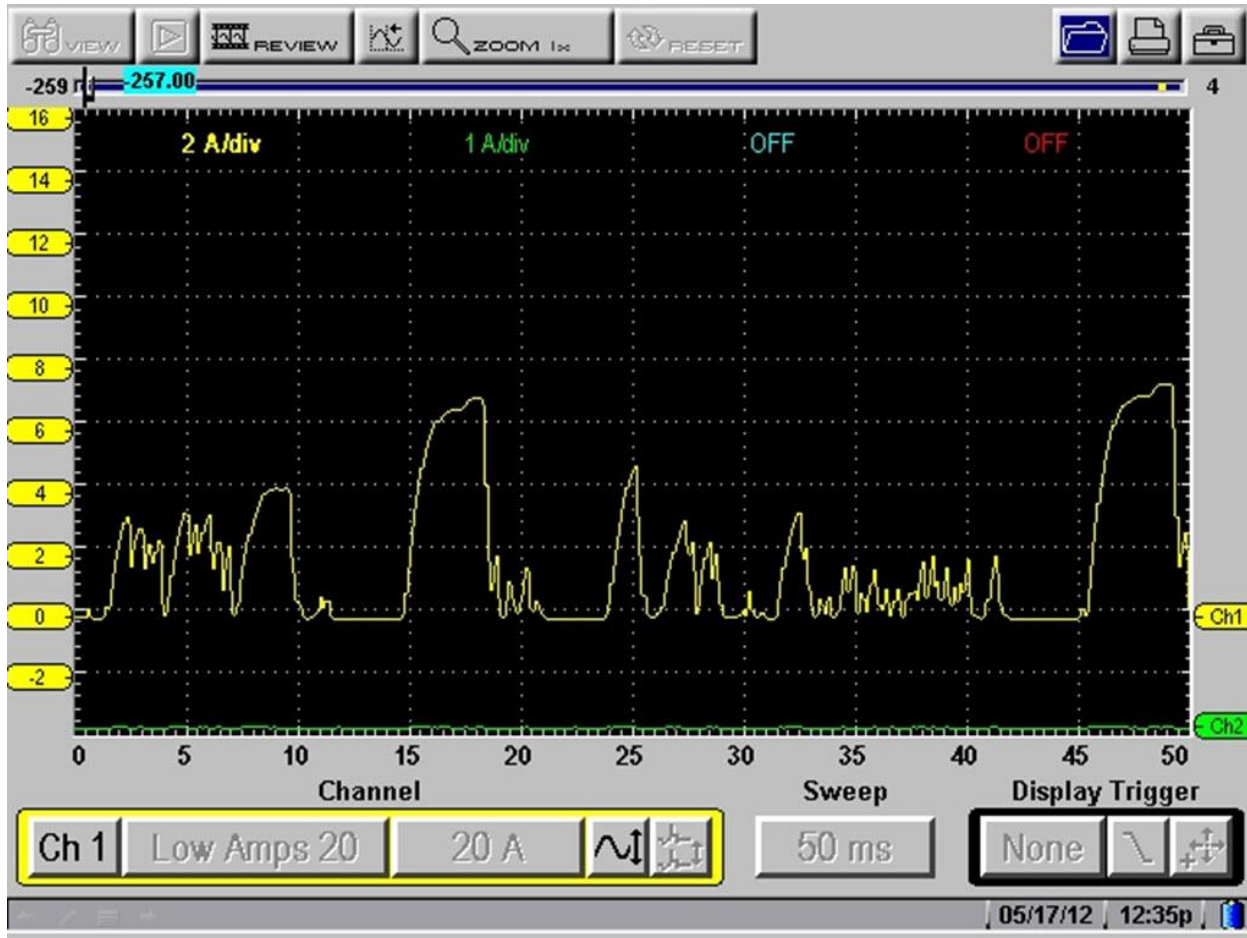


To capture the fuel pump current waveform, place a low amp current probe around the battery plus of the fuel pump. Note that the probe may be placed around the negative of the fuel pump. It is a series circuit and the amperage that flows into the fuel pump must flow out. You do not have to use a digital storage scope (DSO) to just measure the current flow. A DVOM may be used. If you want to view the pump's RPM or condition you have to use a DSO. There isn't any difference in connecting the DSO or DVOM. Both take the same amount of work and time. The DSO supplies additional information that the DVOM doesn't. There are technicians that don't have/use the DSO because they are not familiar with it. All it takes is training. We offer a "hands on" DSO class where the technicians bring their own equipment so that they train on the equipment they will use when they return to the shop. It teaches how to get and manipulate a waveform.

Low Current Fuel Pump Waveform



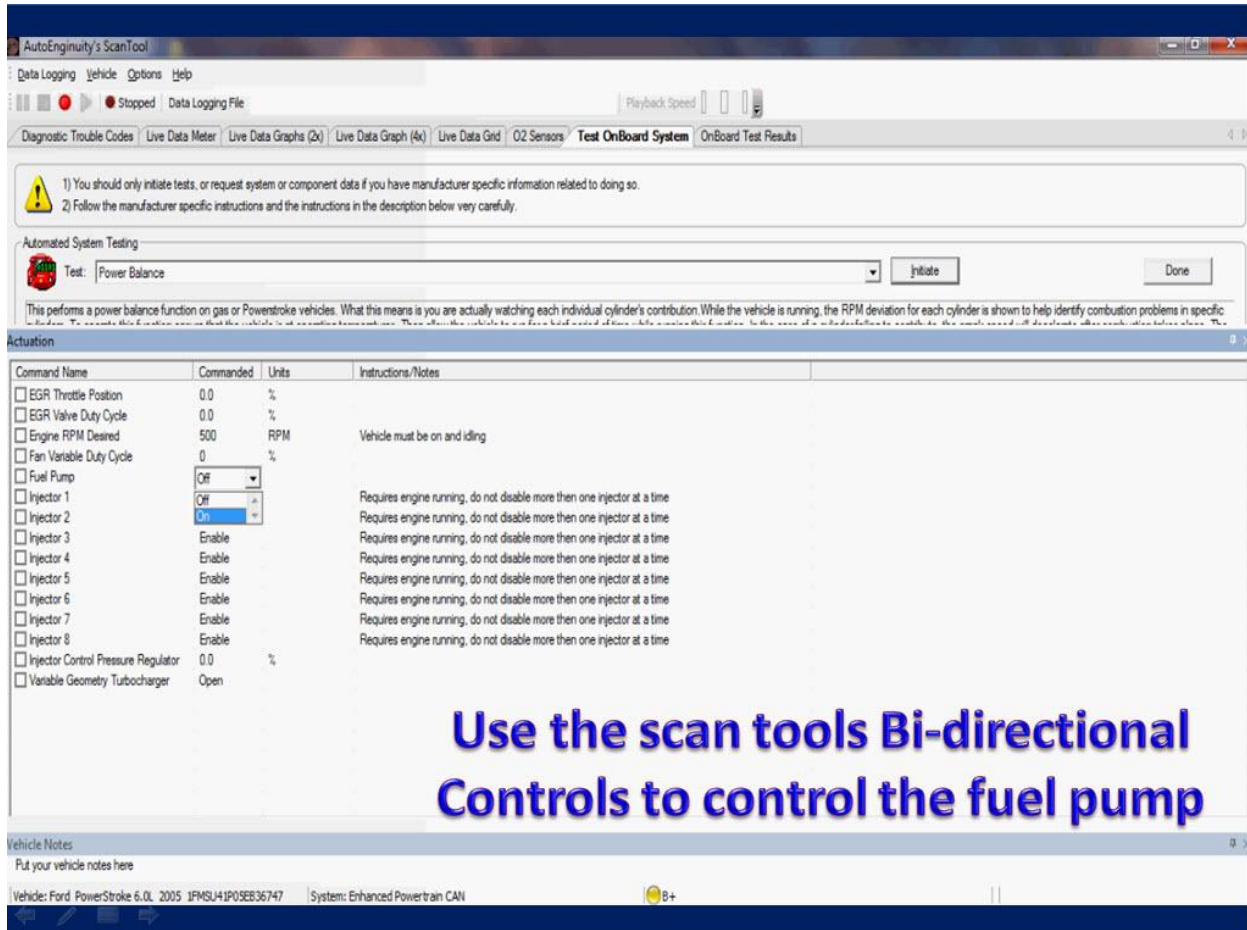
Defective Fuel Pump Pattern



Don't forget to zero the current probe. The current flow should be near 8 amps. The current is directly related to the fuel pressure. If current is low pressure will be low. If current is low check the battery voltage and the ground of the pump. The patterns wavy appearance is due to the fact the resistance changes as the brushes cross the commutator bars. There shouldn't be more than a 1 amp difference between the tops and bottoms of the pattern. Using a DSO and low amp probe is covered in the electrical and Lab Scope classes.

This is a fuel pump current waveform from an engine with an extended crank. If cranked long enough the fuel pressure would raise to the minimum to start the engine. The waveform shows current remaining below 4 amps most of the time and jumping to above 6 amps once in a while. It also shows pressure staying at 0 amps sometimes. It is important to note that it only takes a few minutes to get the waveform because the HFCM is easy to get to.

Bi-directional Fuel Pump Control



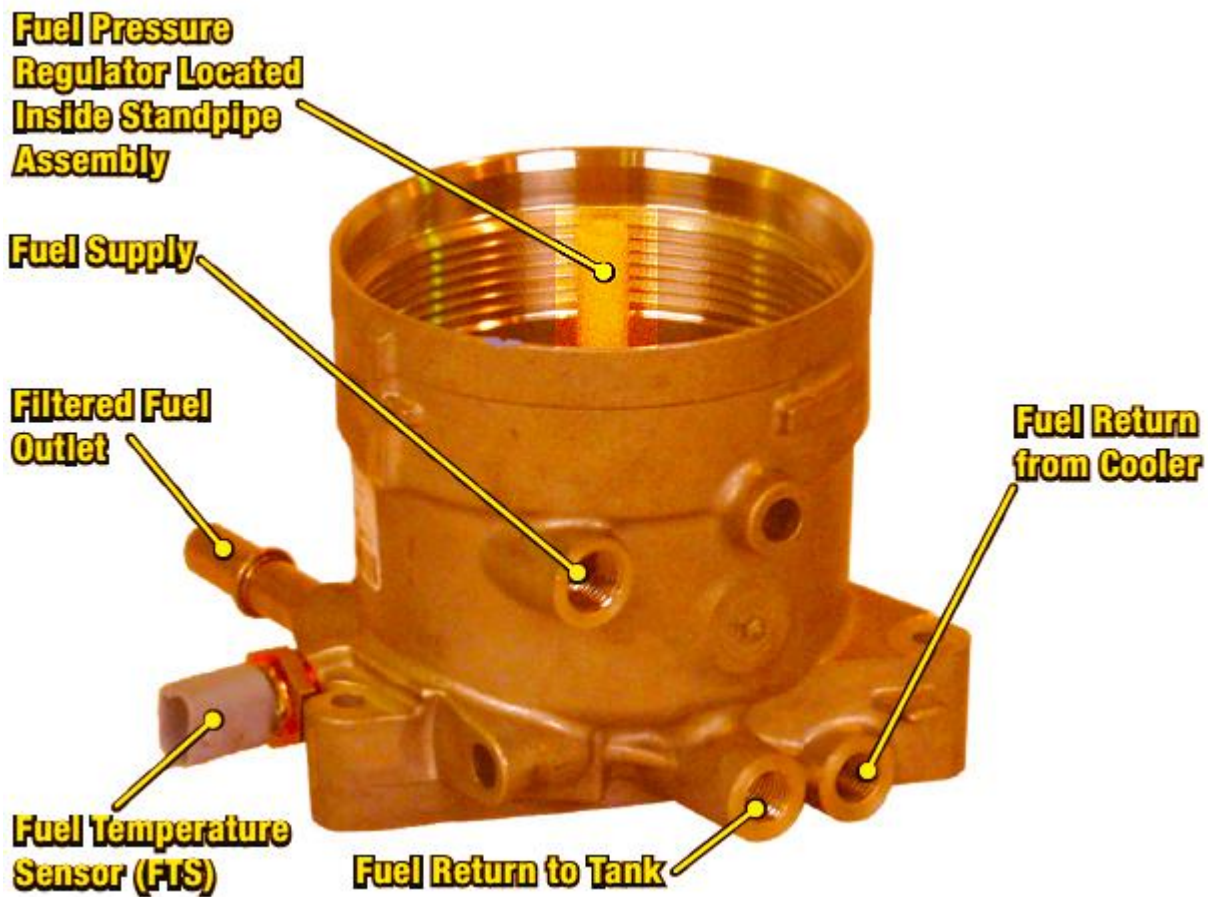
Use the Bi-directional controls on the scan tool to command the fuel pump on when testing. Using the Bi-directional commands will test different parts of the fuel pump and its circuit. If the fuel pumps runs when commanded, it indicates that the PCM and its circuits, as well as the pump itself are good. What it doesn't tell us is the computer input side of the fuel pump and its circuits. As an example, does the PCM know when to turn the pump on?

6.4 L Secondary Fuel Filter



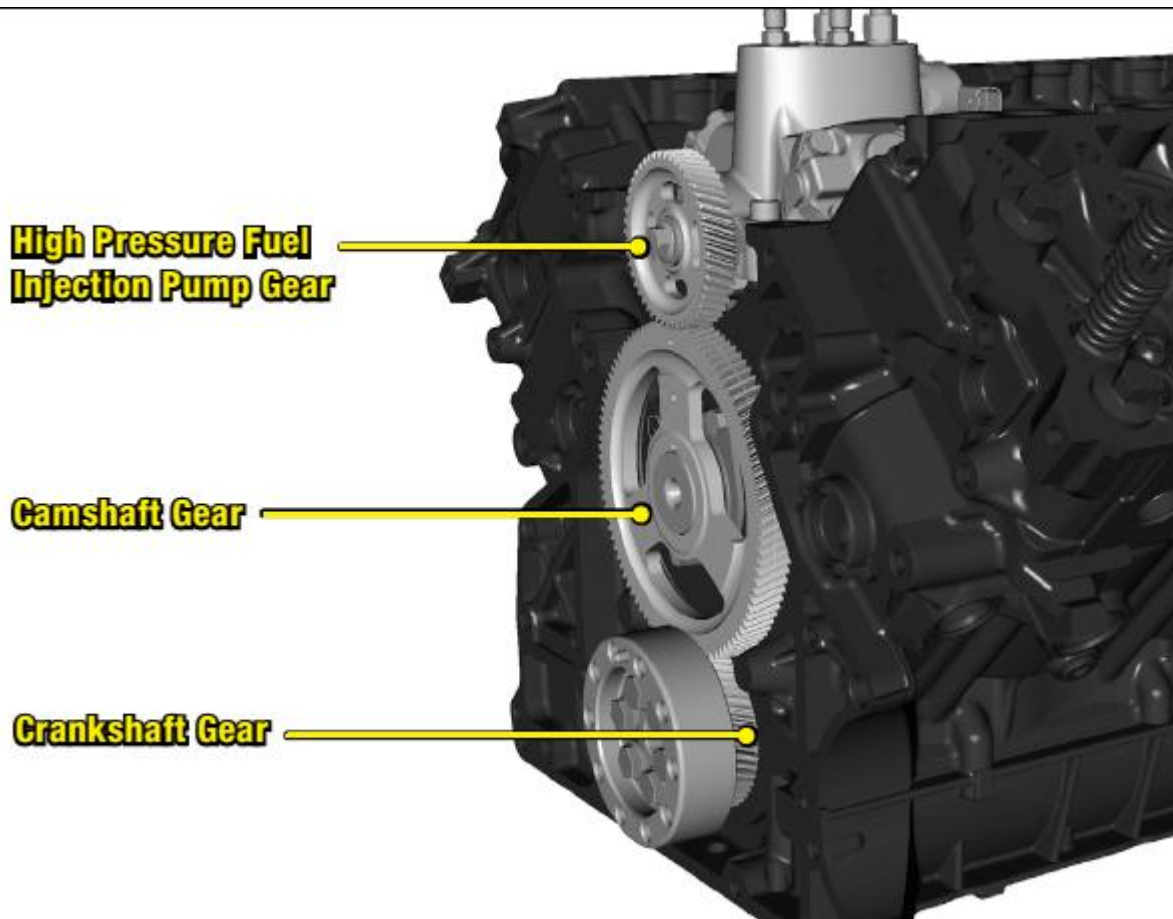
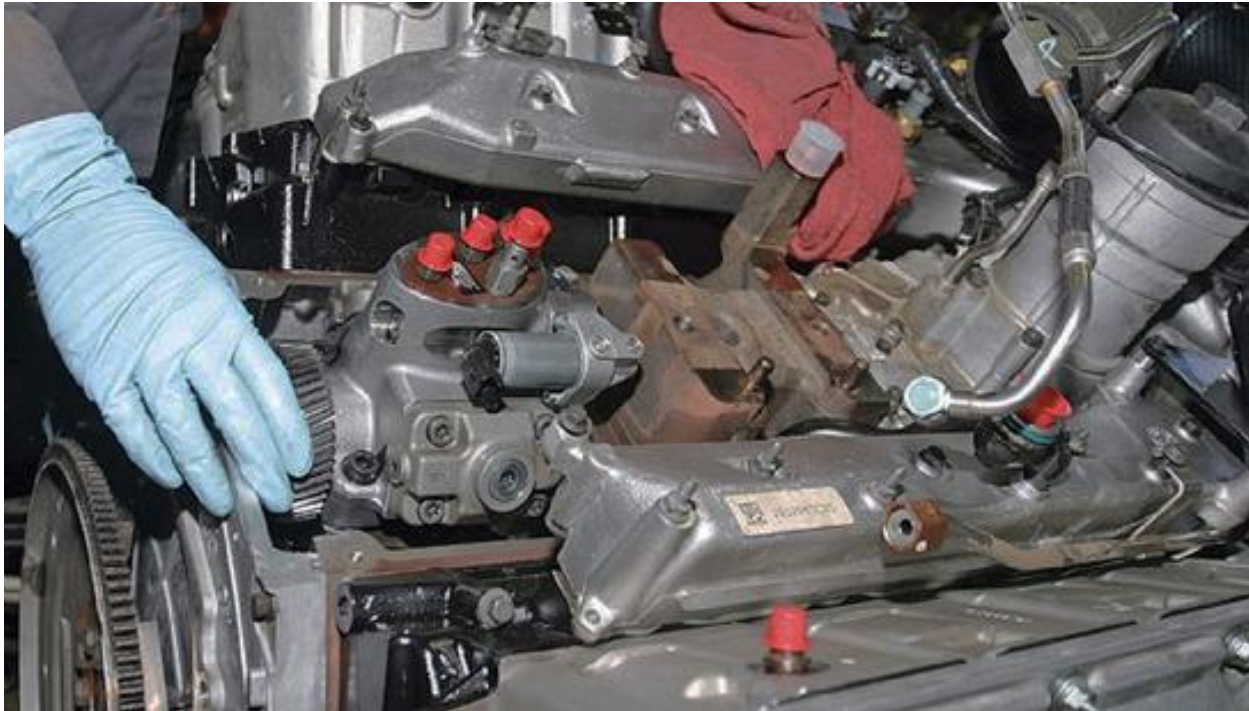
After the fuel is conditioned by the HFCM, the clean pressurized fuel is sent to the engine mounted fuel filter assembly where particles larger than 4 micron (cartridge style) are filtered out of the fuel. The engine mounted fuel filter assembly also regulates fuel pressure by releasing excess pressure via a return fuel line back to the HFCM. The fuel pressure regulator is in the standpipe. The engine mounted fuel filter also contains air bleed orifices to remove air and return it to the tank.

Fuel Pressure Regulator



The fuel pressure regulator is located inside the secondary fuel filter housing in the standpipe. It regulates fuel pressure by routing unfiltered fuel from the filter housing to the HFCM via a spring loaded poppet style valve. The regulated pressure of the valve is 24 psi+/- 0.5 psi. The fuel pressure regulator on the 6.4 L is not serviceable.

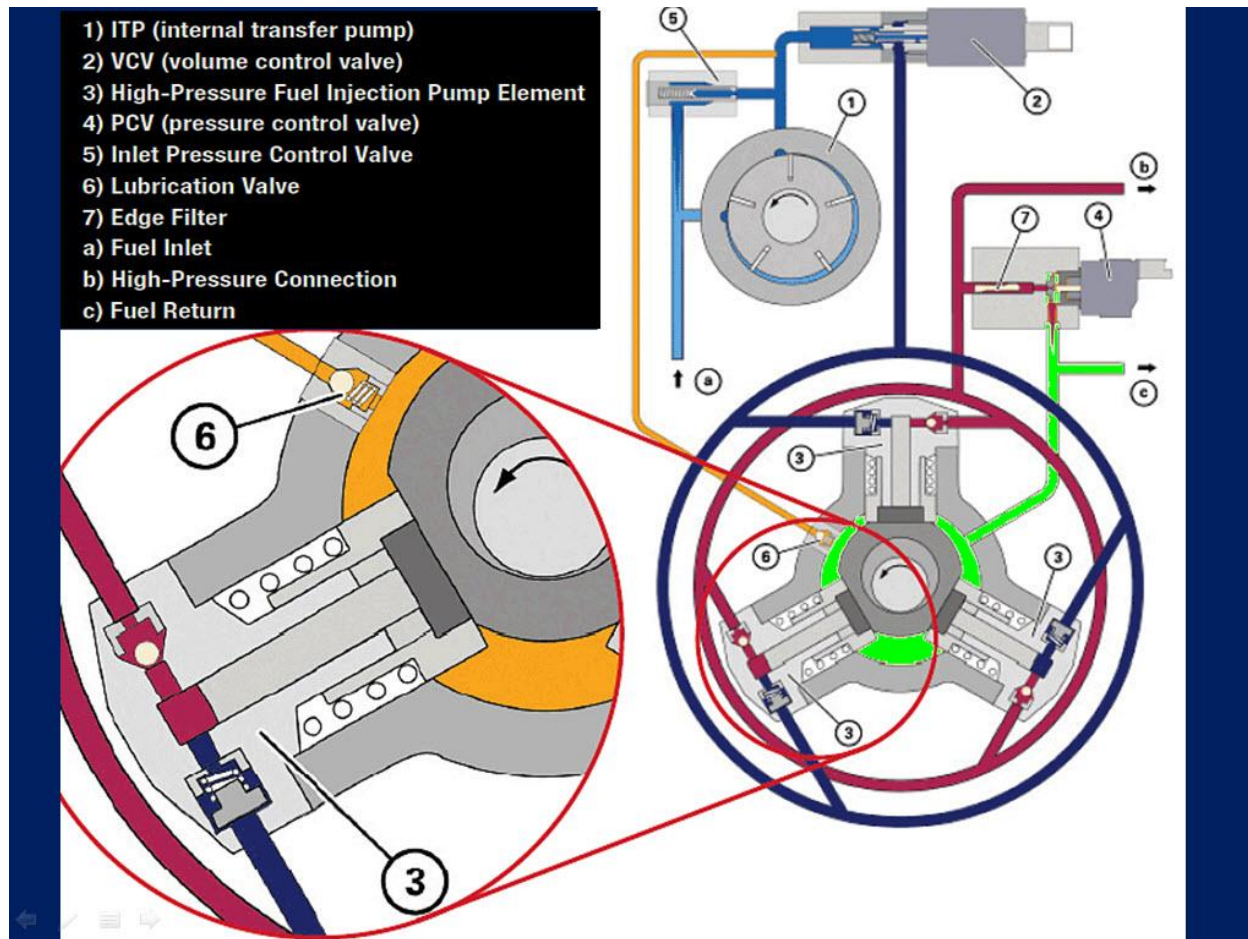
High Pressure Fuel Pump



After the secondary fuel filter fuel is supplied to the high pressure fuel injection pump (HPFIP) after the filter, the HPFIP is gear driven off of the camshaft. The HPFIP

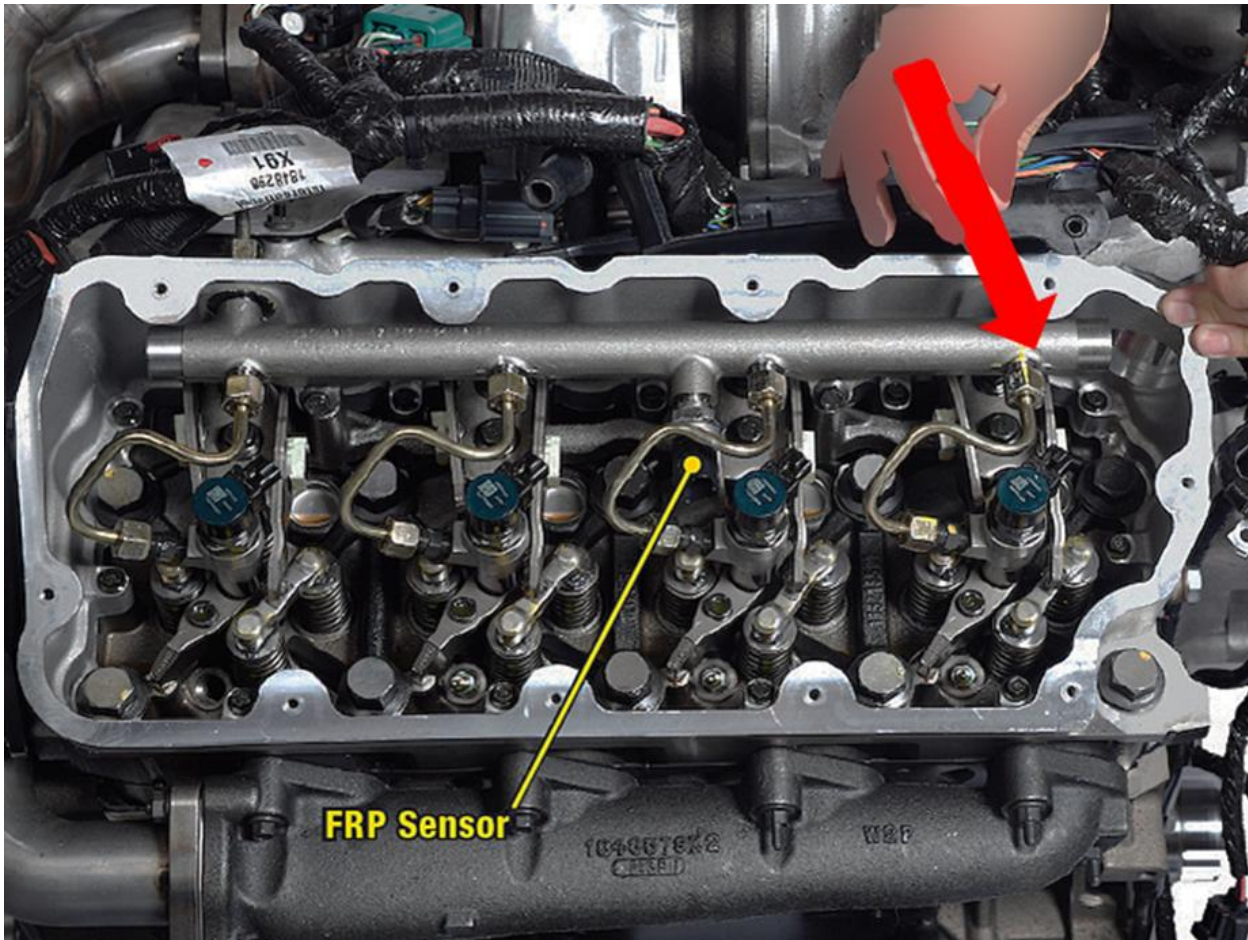
pressurizes the fuel and routes it to the two high pressure fuel common rails. The common rails supply the injectors with fuel.

Internal Transfer Pump



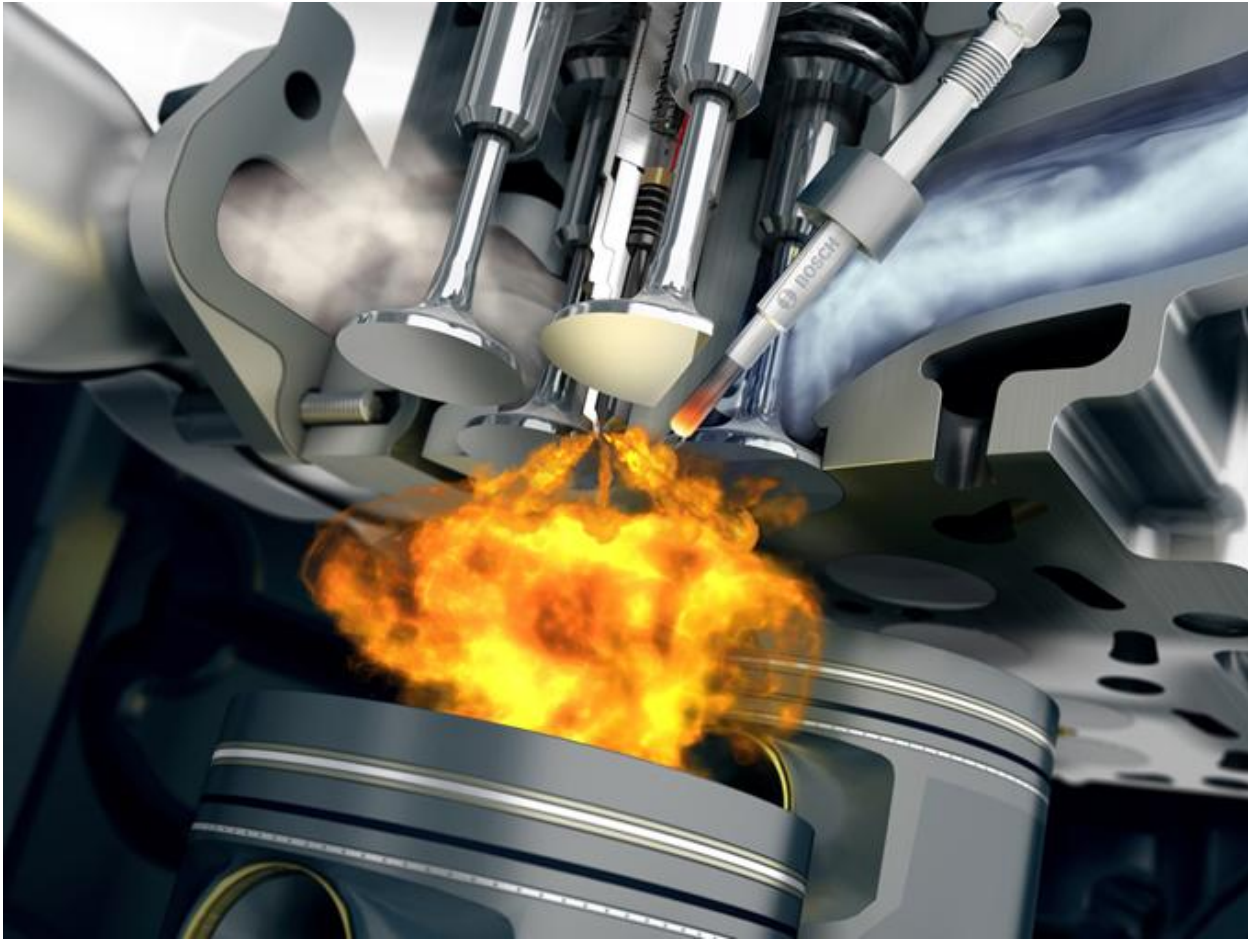
Fuel enters the Internal Transfer Pump where the pressure is increased then it enters the Volume Control Valve (VCV). The ITP is inside the high pressure fuel injection pump and is driven by the pump’s main shaft. The VCV controls how much fuel enters the main pump piston chambers. A portion of the fuel is directed by the ITP to a lubrication valve which cools and internal components. The VCV sends the fuel through a one way check valve to the pistons. When the piston starts to move on its compression stroke, the inlet check valve closes and the outlet check valve opens. The pressure control valve (PCV) controls the pressure in the system by restricting fuel flow to the return line (pressure is the resistance to flow).

High pressure common fuel rails



Extremely high pressure fuel is delivered to the fuel injectors from the fuel rail through high pressure fuel tubes the fuel injector. The fuel rails acts as an accumulator to ensure that that each injector has equal fuel volume and pressure.

6.4 L Fuel Injectors



This high injection pressure allows greater atomizes and more effectively, so that the mixture burns more completely in the combustion chambers. The complete burning of the fuel lowers fuel consumption, reduces emissions and supplies additional power and torque. It is the injectors that deliver the fuel to the combustion chamber.

159

6.4 L Injectors (Piezo Stack)



The injector has hundreds of little piezo slices stacked on top of each other so that the combined expansion increases the total motion. The stack produces 0.004 inch of movement—enough to move the pintle far enough to inject fuel. But because this motion is in the wrong direction—down, not up—the addition of two tiny levers allows the expansion of the piezo stack to cause the pintle to be lifted and the fuel spray to begin. When the injection is complete, the voltage cuts off, the piezo stack shrinks, and a spring closes the pintle.

Piezo injectors have a few key benefits that justify all of this bother. For one thing, they open and close much faster than conventional injectors. That makes for more precise control of the injection interval, which determines how much fuel is sprayed into the engine. Piezo units also provide feedback by producing minute fluctuations in the electricity used to activate them. For example, if the engine-control computer calls for an injector-opening time of 0.5 second, and the injector response shows that it opened for only 0.496 second, the computer can add a tiny bit of time to the next injection cycle to compensate. Such precise fuel metering makes for improved combustion, which leads to

better fuel economy and reduced emissions.

Not only are piezo injectors more accurate than conventional solid injectors, they also can perform some tricks that are completely beyond the capabilities of their predecessors. For one thing, by applying a little less electricity, the piezo crystals expand less so the injectors can open partway. A smaller opening means a longer injection time, which is beneficial when trying to accurately inject a tiny amount of fuel, such as when a car is nearly coasting. Because they act so quickly, piezo injectors also can inject several times (as many as seven in some diesels) during a single combustion cycle. This flexibility can reduce emissions in all engines as well as limit soot in diesels.

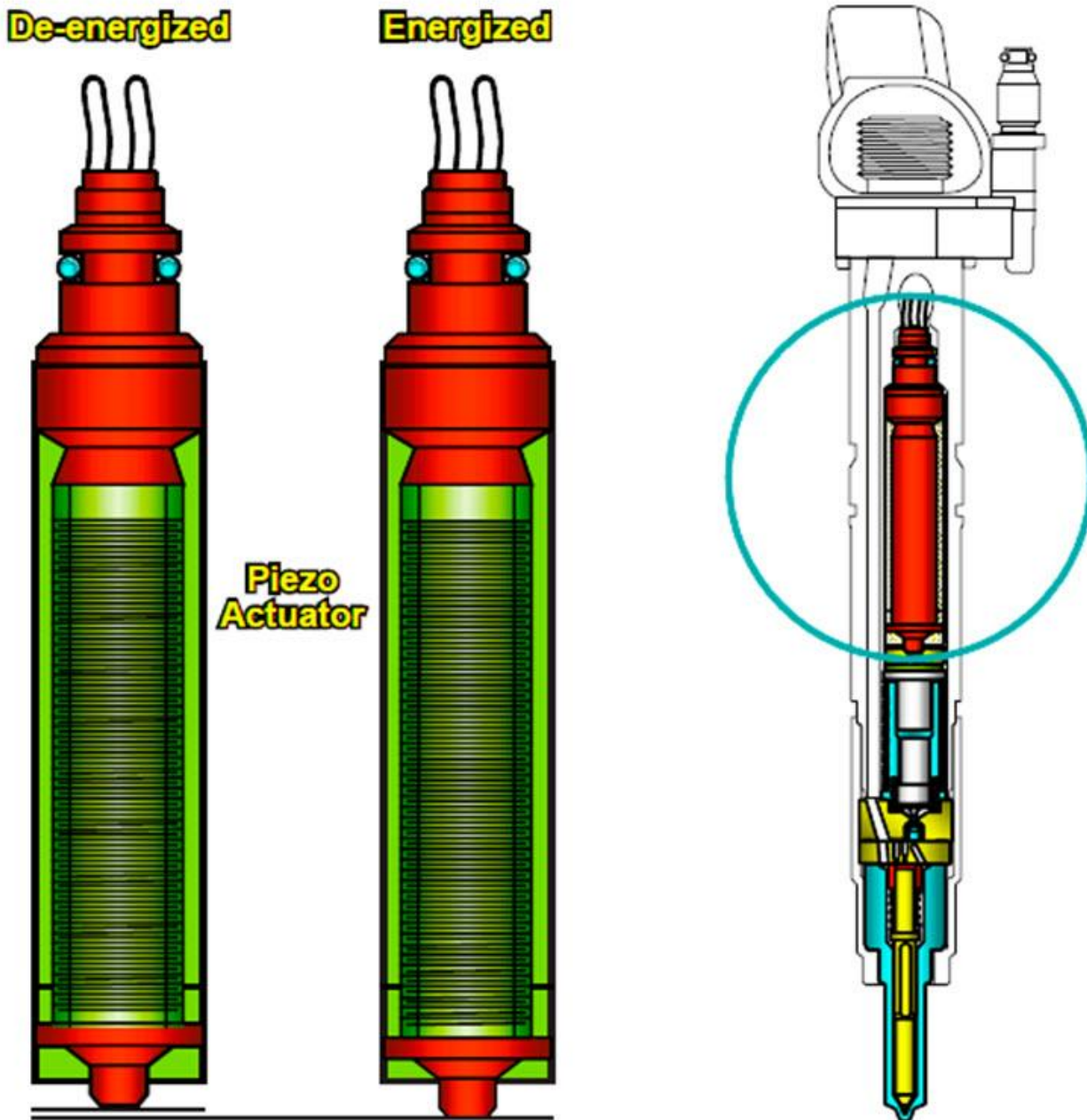
Piezo injectors key benefits

- They open and close much faster than conventional injectors.
- That allows a more precise control of the injection which determines how much fuel is sprayed.
- They also provide feedback by producing minute fluctuations in the electricity used to activate them. As an example, if the computer commands an injector pulse (IP) time of 0.5 second, and the injector response shows that it opened for only 0.496 second the computer can compensate for the lean condition on the next firing of that injector.

Piezo Fuel Injectors

There are eight fuel injectors; four mounted on each cylinder head. They are serviced without removing the valve covers. The Injector Quantity Adjustment (IQA) must be programmed into the PCM when a new injector is installed. The injector is a 19 mm piezo-actuated injector with an 8 hole nozzle. Each fuel injector is retained with a single clamp and bolt through the rocker cover to the cylinder head. A stepped copper gasket is used to better distribute the sealing load between the cylinder head and injector. This allows heat to transfer from the injector nozzle to the cylinder head. The step is installed towards the cylinder head.

Fuel Injector Piezo Actuator



The piezo actuator is a stack of piezo crystals. When current is applied to the crystals, the crystals expand. When the PCM supplied current is removed from the piezo crystals, they contract. When the crystals contract, they create voltage (current flow reverses). PCM supplies current to the piezo stack and when the injector is de-energized the current is removed from the piezo stack and stored by the PCM to actuate the injector on a companion cylinder

Hydraulic Coupler

The piezo stack is linked to the control valve of the fuel injector via a fuel-filled hydraulic

coupler. The upper piston of the coupler is a larger diameter than the lower piston. This difference in diameter causes an increase in the linear movement of the lower piston (more travel). Note: If the hydraulic coupler is not full of fuel, the lower piston will not move and fuel will not be injected into the combustion chamber. The hydraulic coupler is supplied with fuel by the low pressure fuel pump when the key is turned on and from return fuel when the engine is running.

Control Valve

The lower hydraulic coupler piston moves the control valve down to relieve high pressure from the top of the nozzle needle (the control chamber).

When the control valve is pushed fully down, it seals off an orifice in the intermediate plate, stopping that fuel flow path of high pressure fuel to the top of the nozzle needle. Fuel is allowed to flow past the control valve, also removing pressure from the top of the nozzle needle.

Injector Nozzle Needle

When the high pressure is relieved from the top of the nozzle needle, high pressure on the lower surfaces force the needle up and allows fuel to be sprayed into the combustion chamber. When the control valve is released, spring pressure and high pressure fuel moves the needle back up against the seat in the control valve housing, sealing the nozzle control chamber. High pressure fuel is again applied to the top of the nozzle needle, pushing the needle down to stop fuel flow into the combustion chamber.

Pilot and Main Injection Events

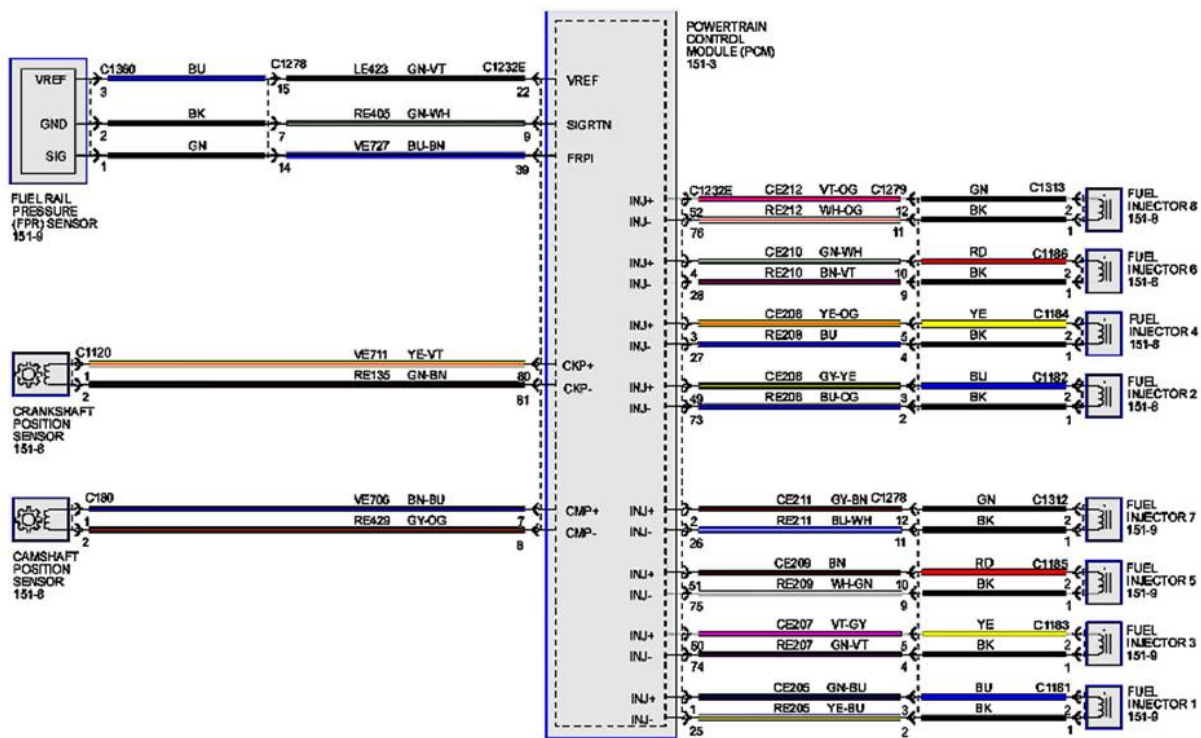
There 2 springs with different rates are integrated in the injector to hold the pintle closed. As the injection cycle begins the pintle is opened against the first spring. Only a small amount of fuel is injected (pilot). The result of this pilot cycle causes the pressure in the cylinder to rise slightly. This creates the right condition for igniting the remaining fuel with the main cycle.

The high pressure injection pump delivers more fuel than can pass through the pilot opening. This causes the pressure in the injector to rise. The increased pressure overcomes the force of the second spring and the pintle is opened further. This is the main injection cycle which delivers fuel at a higher pressure.

Multiple Injection Technology

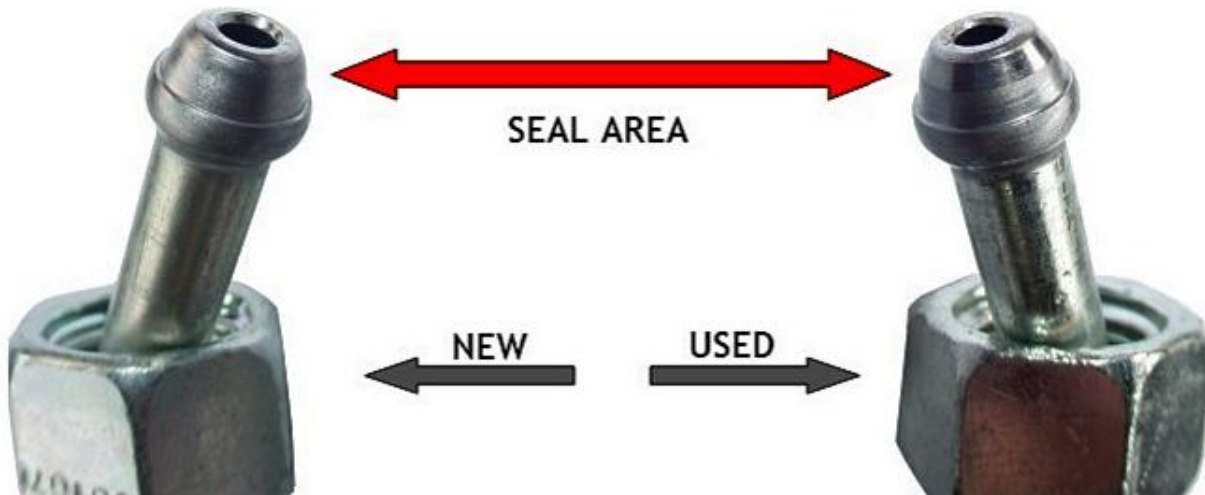
There may be up to 5 injection cycles per cylinder power stroke. The pilot cycle is used to reduce combustion noise by allowing cylinder pressure to rise slightly before the main injection cycle. Pre-injection cycle helps to distribute fuel to start the ignition combustion cycle. During the main injection cycle most of the fuel is supplied for power and torque. After-injection cycle also helps the distribution of fuel for ignition. Post injection cycle is used to raise exhaust temperature for regeneration and for NO_x reduction.

Switching the polarity



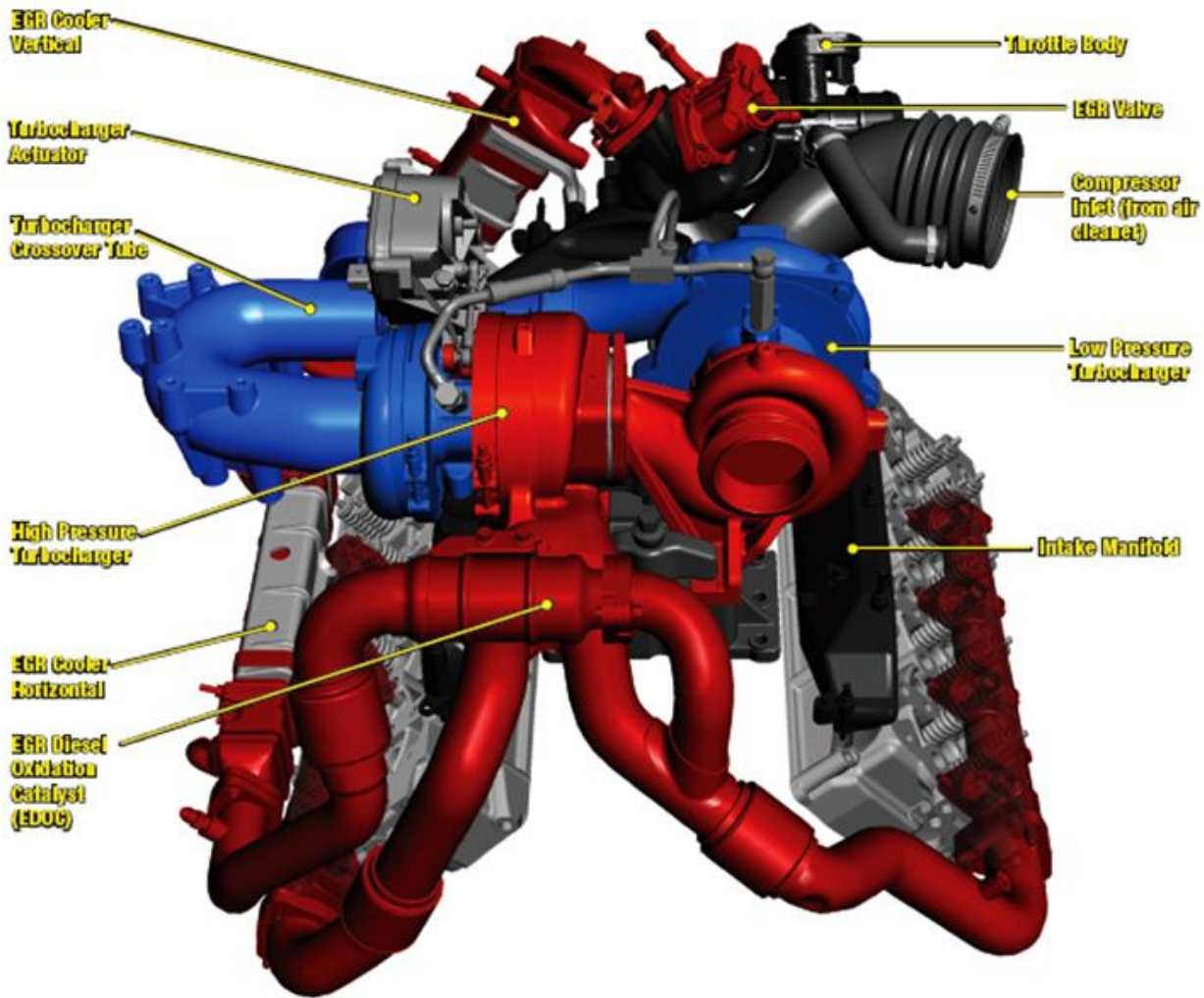
When the Power Control Module (PCM), determines that the correct injector on time has been reached, it switches the polarity of the piezo actuator. This returns the Piezo stack to a non-energized state and relaxed allowing the pintle to close.

Steel Fuel Lines



The steel fuel lines that are used to transfer high pressure fuel from the high pressure fuel pump to the fuel rails and the lines connecting to each fuel injector are for one time use only! **They need to be replaced anytime they are removed.** Use the correct torque from the service manual. Then tighten the fitting 1/6 of a turn or one flat. This will properly crush the flare end into the fitting and create a high pressure seal

6.4 L Air Management System



- Air Filter/Filter Minder
- Series Sequential Turbocharger
- Charge Air Cooler
- Exhaust Gas Recirculation (EGR) System
- Intake Manifold

The series sequential turbocharger is a low pressure/high pressure design working in series with a turbocharger actuator on the high pressure turbine controlling the boost pressures. The charge air cooler is utilized to reduce the temperature of the pressurized air therefore inducing a cooler/denser air charge into the intake manifold for maximum efficiency. An air filter/filter minder combination is utilized to clean the incoming air and provide a means for monitoring the condition of the air filter via the filter minder. The EGR system is designed to reduce exhaust emissions.

Air Filter Housing Assembly



Air enters the system through the air filter where particles are removed. The filter minder warns the operator of a restricted air filter. The filter minder sends a signal to the PCM indicating the amount of restriction. If the restriction reaches a pre-determined value the PCM illuminates the check air filter lamp. The lamp warns the driver to check the filter only not to replace it.

Air Mass and Temperature

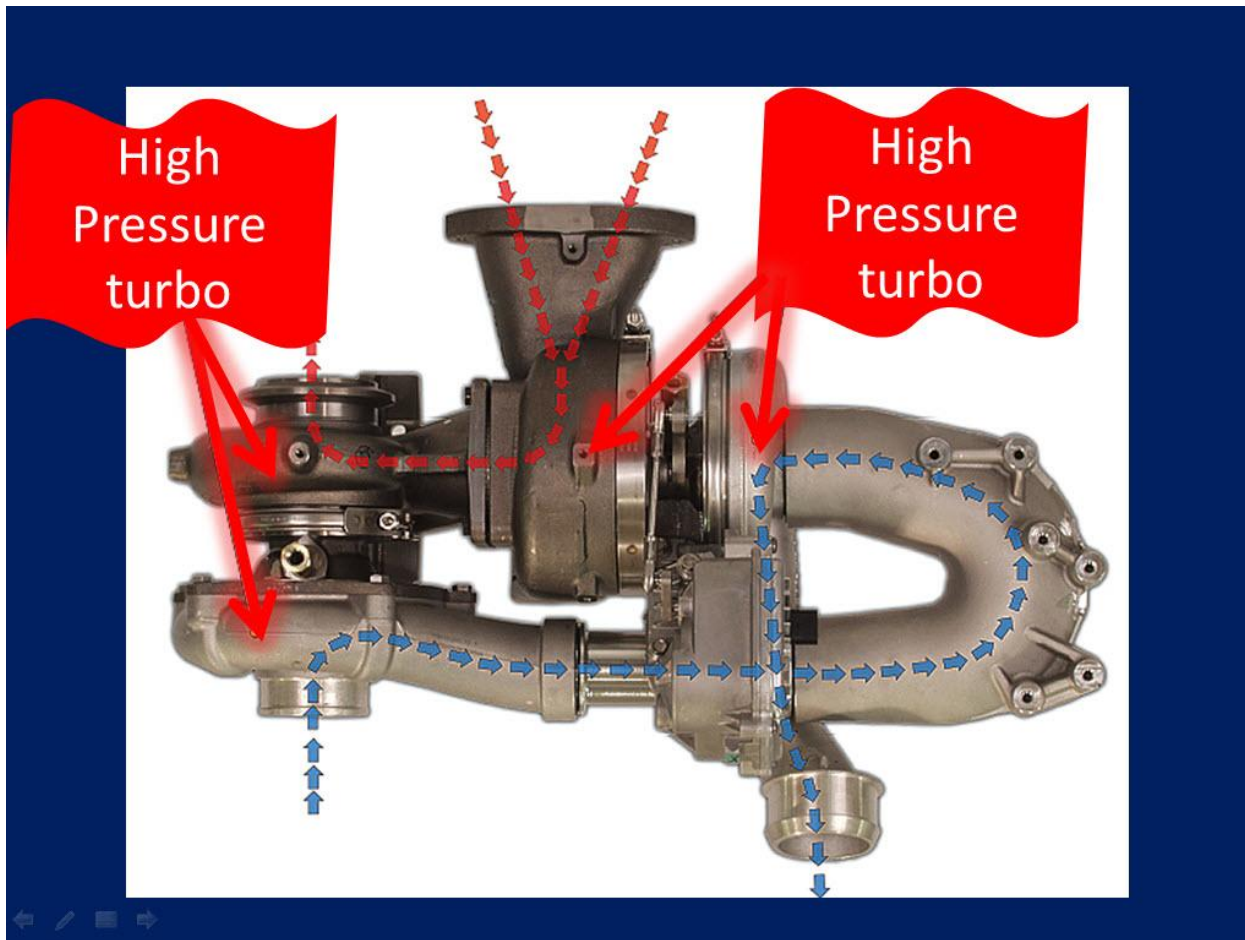
The Mass Air Flow (MAF) sensor has a hot wire sensing element to measure the mass of air being drawn into the engine. Air passes over the hot wire and cools the element. The hot wire is maintained at 392°F above ambient temperature as measured by circuit in the sensor. The current required to keep the temperature steady is proportional to the amount of air flow. The MAF sensor outputs an analog voltage signal to the PCM.

The MAF sensor is not used for any engine control. It is used in the EGR monitor strategy to calculate the total clean air going into the engine. Once the total clean air is known, the amount of EGR required can be calculated.

NOTE! Failure of the MAF sensor has no effect on engine performance.

The air temperature is measured the intake air temperature sensor #1 (IAT1). The IAT1 sensor's primary function is to measure intake air temperature to aid in controlling EVTG and the glow plug system.

Series Sequential Turbocharger



The 6.4 L Power Stroke Diesel has a series sequential turbocharger. The main components of this system are a smaller, no waste gate turbo providing boost to a larger variable geometry turbo. This system is designed to reduce turbo "lag" when accelerating from a stop. The system offers quick throttle response and more than enough air at higher RPM. The series-turbo system also provides better throttle response while in motion to give a power flow more like a naturally aspirated engine. A turbocharger actuator is the VGT uses an electronically controlled actuator, for controlling turbocharger speed along with exhaust backpressure and intake manifold boost pressure. When the vanes of the turbocharger are closed, the engine will have a higher exhaust back pressure and create more heat which will in turn warm the engine faster in cold ambient conditions.

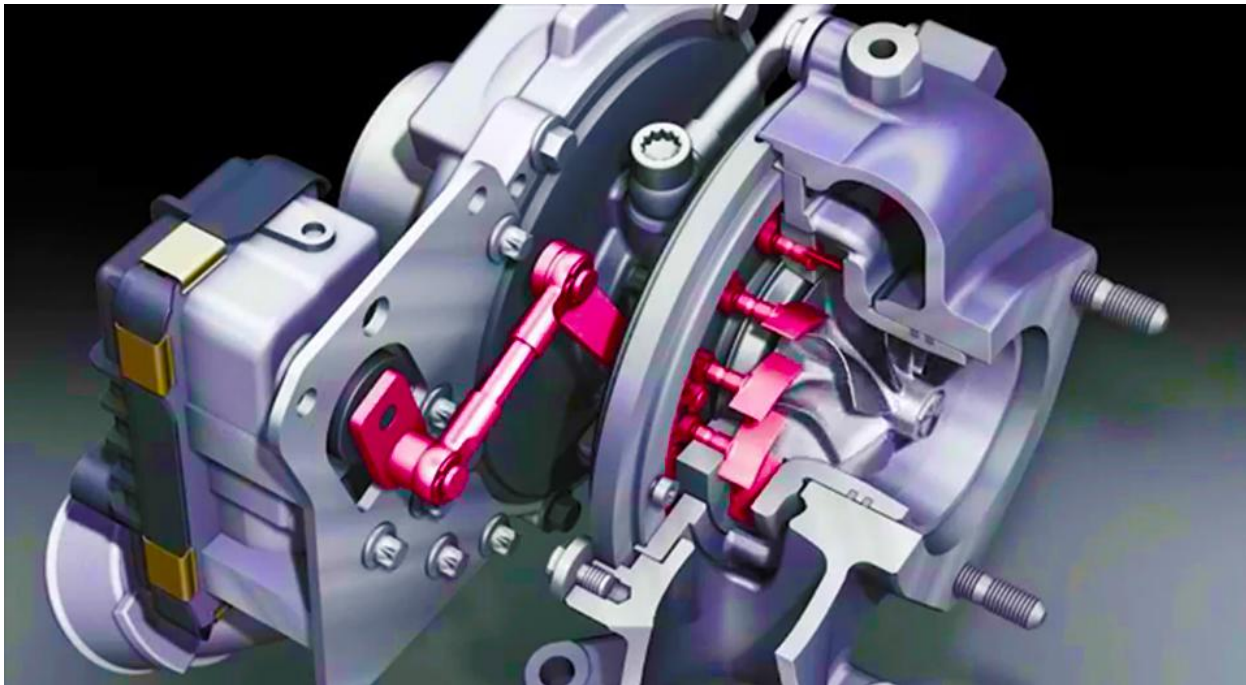
NOTE: There is an oxidation catalyst in the exhaust pipe for the EGR system that is utilized to crack hydrocarbons before they enter the EGR system.

Turbocharger Actuator



The variable vanes are controlled by the turbocharger actuator. The control arm connects the actuator to a pivot shaft which connects to the unison ring that moves the vanes

VGT Control Valve Flow



When the VGTCV is commanded to the full open position, low or no duty cycle, oil from the oil supply line is directed to the open side of the actuator piston. Oil on the closed side of the piston is then directed through the actuator piston, back to the VGTCV, and then to drain. Note: If the VGTCV is disconnected the valve will default to the open position. Once the desired turbocharger vane position is obtained, the VGTCV goes to a neutral position and both the open and closed sides of the actuator piston is blocked off. When the VGTCV is commanded to the full closed position, high duty cycle, oil from the oil supply line is directed through the actuator piston to the closed side of the piston. Oil on the open side of the piston is directed back to the VGTCV and then to drain.

During engine operation at low engine speeds and load, little energy is available from the exhaust to generate boost. In order to maximize the use of the energy that is available, the vanes are closed. In doing so, the exhaust gas is accelerated between the vanes and across the turbine wheel. In general, this allows the turbocharger to behave as a smaller turbocharger than it actually is. Closing the vanes also increases the back pressure in the exhaust manifold which is used to drive the exhaust gas through the EGR cooler and valve into the intake manifold. This is also the position for cold ambient warm-up. During engine operation at moderate engine speeds and load, the vanes are commanded partially open. The vanes are set to this intermediate position to supply the correct amount of boost to the engine for optimal combustion as well as providing the necessary back pressure to drive EGR.

During engine operation at moderate engine speeds and load, the vanes are commanded partially open. The vanes are set to this intermediate position to supply the correct amount of boost to the engine for optimal combustion as well as providing the necessary back pressure to drive EGR.

During engine operation at high engine speeds and load, there is a great deal of energy available in the exhaust. Excessive boost under high speed, high load conditions can negatively affect component durability, therefore the vanes are commanded open preventing turbocharger overspeed. Essentially, this allows the turbocharger to act as a large turbocharger.

Once the desired turbocharger vane position is obtained, the VGTCV goes to a neutral position and both the open and closed sides of the actuator piston is blocked off. When the VGTCV is commanded to the vanes full closed position, high duty cycle, oil from the oil supply line is directed through the actuator piston to the closed side of the piston. Oil on the open side of the piston is directed back to the VGTCV and then to drain.

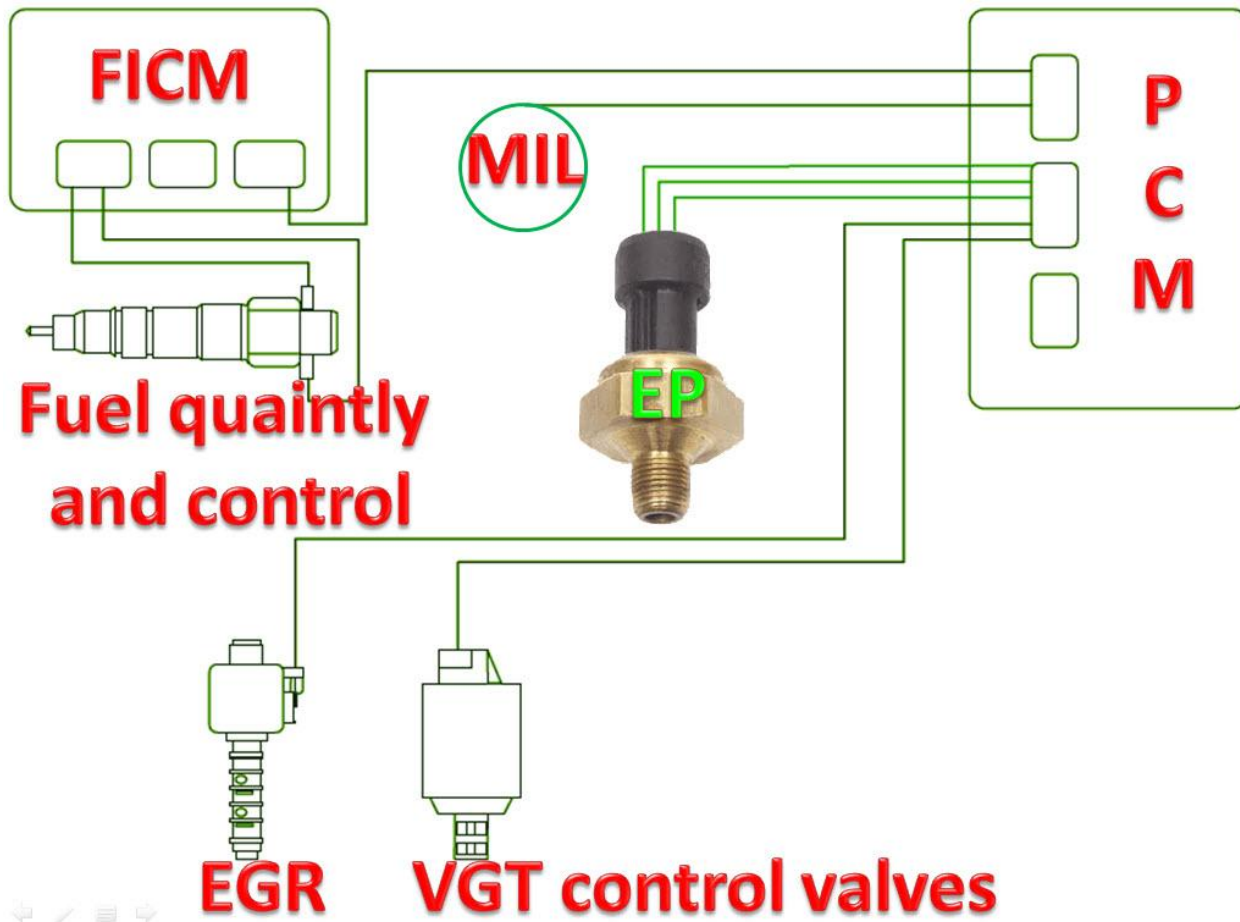
At low engine speeds and loads, little energy is available from the exhaust to generate boost to maximize the use of the energy that is available, the vanes are closed in doing so, and the exhaust gas is accelerated between the vanes and across the turbine wheel.

In general, this allows the turbocharger to behave as a smaller turbocharger than it actually is. Closing the vanes also increases the back pressure in the exhaust manifold which is used to drive the exhaust gas through the EGR cooler and valve into the intake manifold. This is also the position for cold ambient warm-up.

During moderate engine speeds and loads, the vanes are commanded partially open. The vanes are set to an intermediate position to supply the correct amount of boost to the engine for optimal combustion. This position also provides the necessary back pressure to drive EGR.

During engine operation at high engine speeds and load, there is a great deal of energy available in the exhaust. Excessive boost under high speed, high load conditions can negatively affect component durability, therefore the vanes are commanded open preventing turbocharger overspeed. Essentially, this allows the turbocharger to act as a large turbocharger.

Exhaust Pressure Sensor



The EP sensor is a variable capacitor sensor. It receives a 5-volt reference signal from the PCM. It sends a linear analog voltage signal that indicates pressure to the PCM. The EP sensor measures the pressure in the left exhaust manifold. The signal is used for VGT and EGR valve control.

If the EP sensor goes bad and doesn't send the correct signal, the PCM will incorrectly control the RGR and or the VGT systems causing any number of drivability concerns.

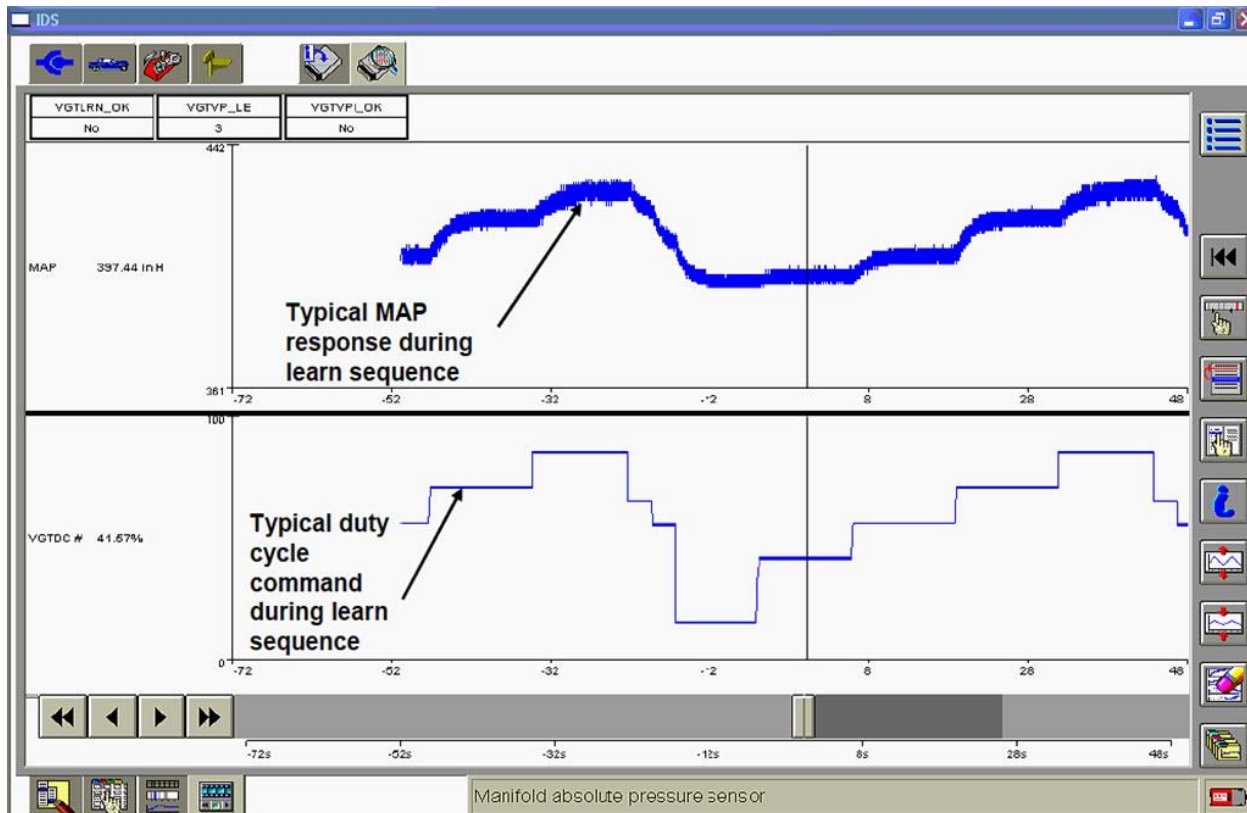
Some of them are:

- Intermittent surging at idle or driving at steady speed
- Excessive smoke
- Rough running
- Stumbles
- Lack of power
- Stalls
- Erratic idle
- Bucking

- Noisy engine operation
- Erratic EGR valve operation

All of the above may be caused by either the EGR or VGT system. When they are not controlled correctly they cause drivability problems. Diagnosing the EP sensor before diagnosing either the EGR or VGT may help to avoid replacing unnecessary components and save time.

Adaptive Turbocharger Learn



The adaptive turbocharger “learn” feature is designed to adapt the turbocharger function to provide optimized backpressure control. The turbocharger is exercised over its full range duty cycle from 15-85% while the PCM samples MAP response. Control adjustments within the PCM are “fine-tuned” based on the learning function for optimized control. This feature runs at idle when the following set criteria of entry conditions are met. This is referred to as the “learn process”.

Entry Conditions for learn process

- Engine at base idle speed ($570 < \text{rpm} < 780$)
- Engine Oil Temp (EOT) between $120^{\circ}\text{-}250^{\circ}\text{ F}$ ($50^{\circ}\text{-}120^{\circ}\text{ C}$)
- Vehicle Speed (VS) below 9 mph
- Pedal position (APP) below 1.5%

- EGR commanded off (EGR DUTY=0)

No malfunctions for the critical sensors/actuators. No DTC's set for the following:

- MAP
- EOT
- MAF
- BARO

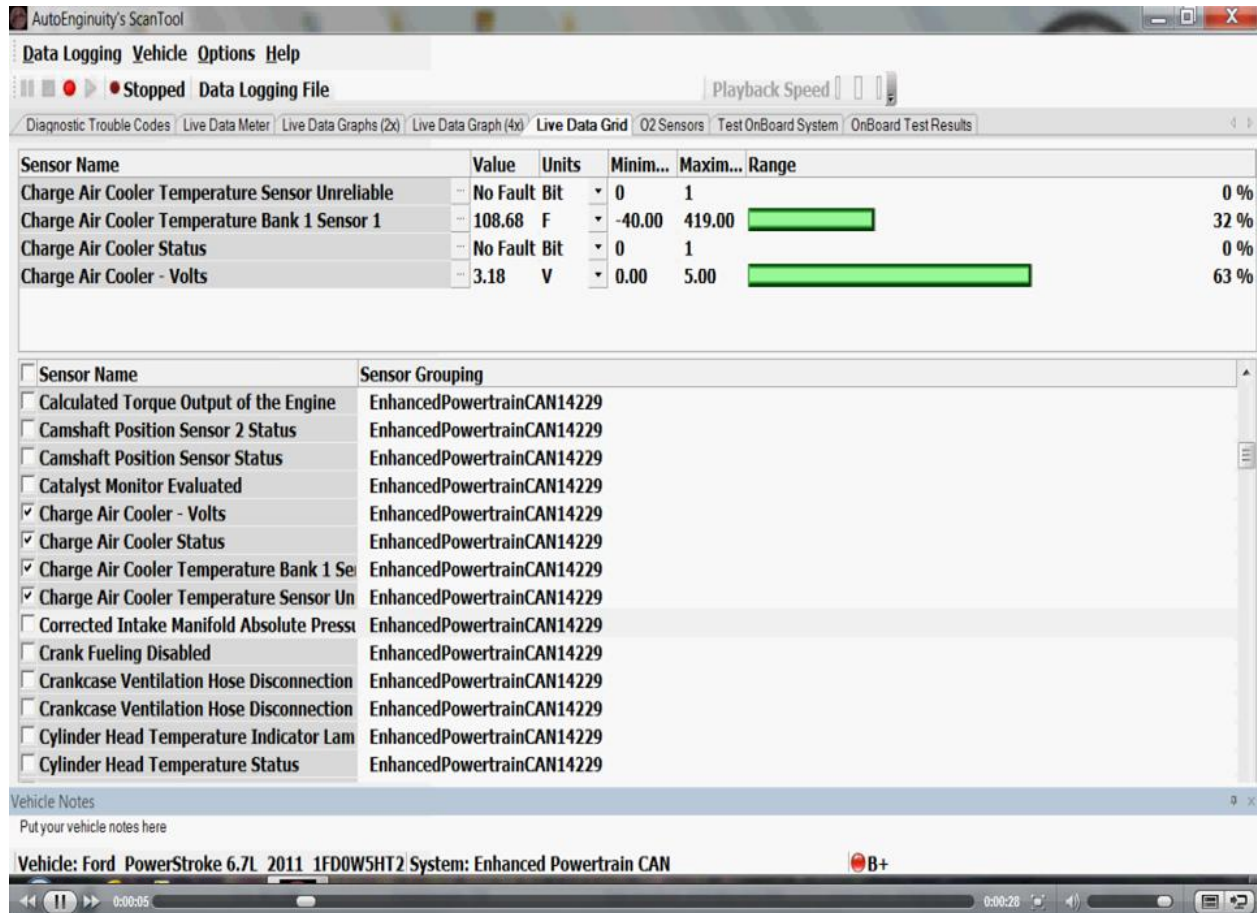
This can be determined by monitoring the VGTLRN_OK PID. The PID will indicate YES when the minimum number of turbo system learn cycles are complete. For continued "fine tuning" of turbo system it is typical for the PCM to execute learn sequences even if the PID indicates YES.

Charge Air Cooler (CAC)



The CAC located between the turbo charger and the engine air inlet manifold. When the air is compressed by the turbocharger it is heated, which causes its density to decrease cooling the air with a CAC the density of the air increases. This permits more air to enter the engine and increases the power and efficiency of the engine. The cooler air lowers the amount of NO_x generated during combustion.

CAC temperature sensor



The CAC has a temperature sensor mounted on the outlet which reports to the PCM the temperature of the air going to the intake.

After-Treatment Systems

Exhaust Gas Recirculation (EGR)

- Diesel particulate filter (DPF)
- Oxides of Nitrogen (NO_x)

After-treatment refers to, the conditioning the exhaust gas that leaves the cylinder, after the combustion process to remove the harmful emissions. Engineers will design intake and combustion chambers to help promote the complete burning of the fuel, but always fall short. There are always some harmful emissions remaining in the exhaust gas. Fuel companies develop fuels to reduce emissions and also fall short. Any process done to the exhaust gas is called after treatment.

Exhaust Gas Recirculation (EGR)

EGR is designed to reduce nitrogen oxide (NO_x) emissions. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders. In a diesel engine, the exhaust gas replaces some of the oxygen entering the cylinder. Because NO_x forms primarily when a mixture of nitrogen and oxygen is subjected to high temperature, the lower combustion chamber temperatures caused by EGR reduces the amount of NO_x the combustion generates. Most modern engines now require exhaust gas recirculation to meet emissions standards. The EGR valve is opened during steady state throttle positions when exhaust back pressures are higher than intake manifold pressures (boost).

EGR Valve Position Sensor (EGRVP)

The EGR Valve Position Sensor (EGRVP) is a three wire potentiometer sensor. It is located in the EGR sensor assembly. The PCM uses this signal to determine EGR position. The sensor isn't used with a MAP (Chart) programmed into the computer. A MAP would be used for the computer to measure the voltage of the EGR position sensor, look the voltage up on a MAP (Chart) to determine EGR flow. The computer uses inlet air temperature sensor 2 (IAT2) to measure the temperature of the EGR gas and intake air mixture. Increasing EGR flow also increases the temperature. The computer reads the EGR sensor voltage and the IAT2 signal. Moves increases or decreases EGR and watches the IAT2 changes. The computer then looks at the EGR position sensor and determines flow.

EGR cooler



The EGR cooler is a coolant to air heat exchanger that is used to cool the exhaust gasses before they are sent to the EGR valve. The exhaust gasses are routed into the EGR cooler from the exhaust up pipes at the rear of the engine. The exhaust gasses are cooled by passing through metal tubes that are surrounded by engine coolant. Depending on conditions, the temperature drop across the cooler could be as much as 700° F. The cooled gasses are then routed to the EGR valve that is mounted in the intake manifold. There are two EGR coolers on the 6.4 L engine.

Cap off both ends. Use an air inlet valve at one of the ends. Connect to shop air and place the cooler into a bucket add water to check for leaks.

Symptom of leaking EGR cooler



White smoke

- White smoke (Steam) coming out of the tail pipe. When the EGR cooler leaks it dumps coolant into the hot exhaust which turns it into steam.

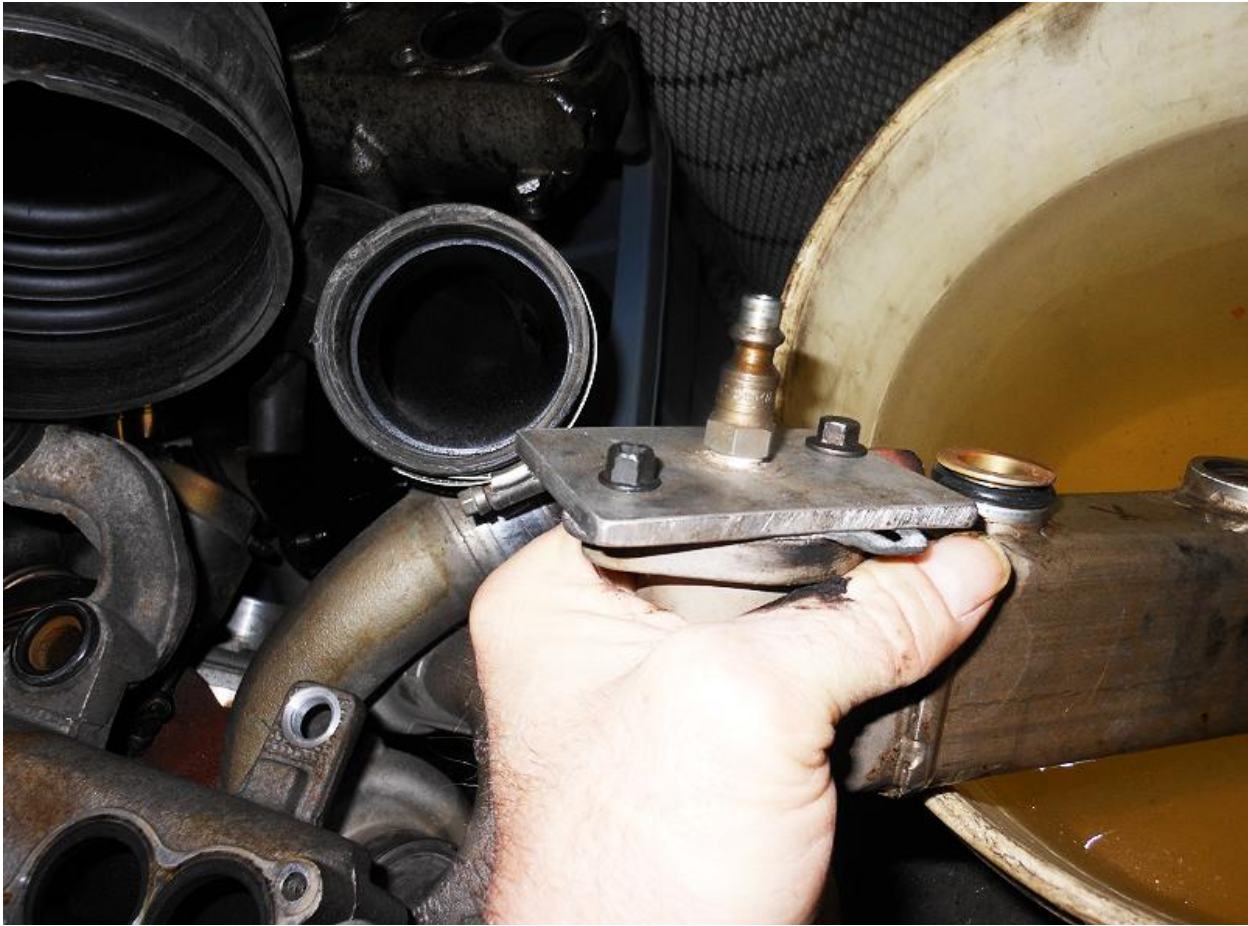
Missing Coolant

- If it becomes necessary to refill the de-gas bottle too often.

Wet, gooey EGR valve

- Remove the EGR valve and look for the carbon to be dry. If it is wet and gooey suspect a leaking EGR cooler.

Checking the EGR cooler for leaks

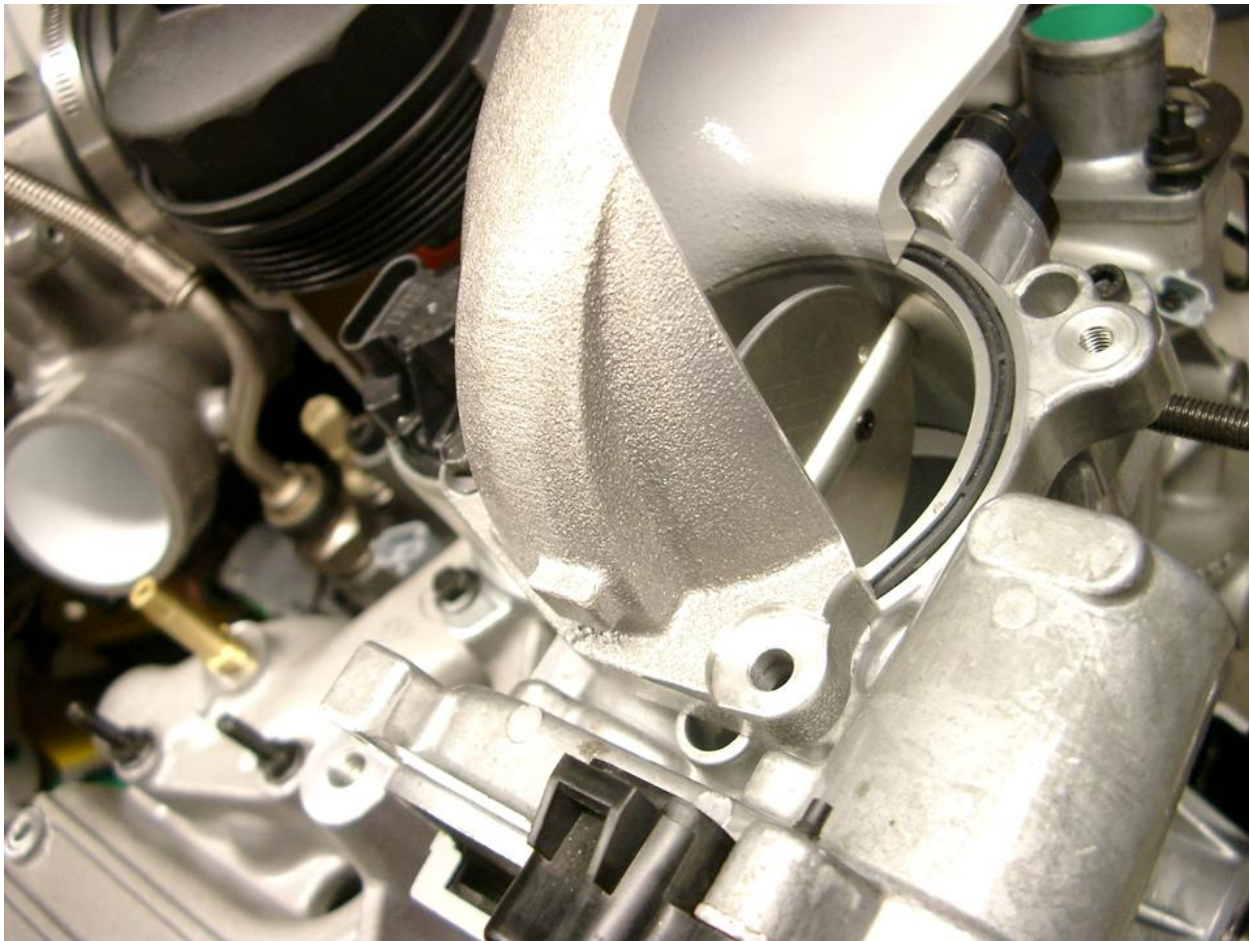


This is an adapter used to apply pressure to the EGR cooler. Apply 15 to 20 psi and check for leaks in a bucket of water.



Check for bubbles to identify EGR cooler leaks.

EGR Throttle Plate

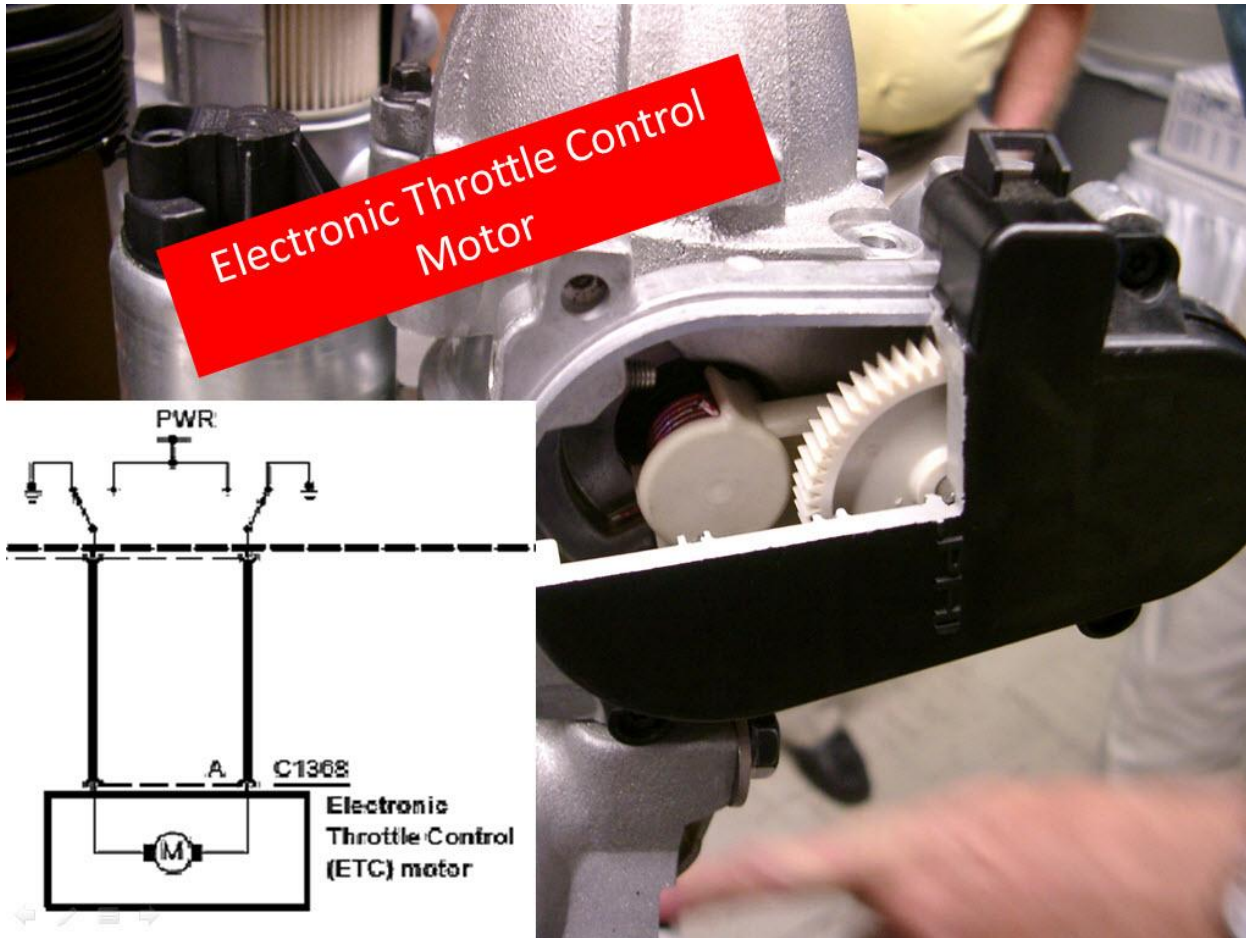


There is an EGR Throttle Plate assembly is mounted in the throttle bore. It isn't used to control air flowing through the bore. The purpose of this plate is to lower the manifold pressure to allow exhaust gases from EGR to flow easily into the intake manifold. The PCM will activate the EGRTP actuator and perform a full sweep of the throttle plate for each key cycle with the IAT temperature greater than 32° F.

Under certain engine operating conditions closing the EGR throttle plate helps in scavenging exhaust gasses from the EGR valve into the intake manifold.

The throttle plate is used to limit the amount of air entering the intake to increase EGR flow allowing the EGR system to be more effective. This is an electric throttle plate that is controlled by the PCM.

Electronic Throttle Control Motor



The throttle plate is electrically controlled.

Glow Plug Control Module (GPCM)

The GPCM commands the glow plugs on for 1 to 120 seconds depending on engine oil temperature and altitude (BARO). The BARO is inside the Power Control Module and cannot be serviced. The GPCM does not operate the glow plugs if the oil temperature is above 131° F.

The GPCM controls the current to the glow plugs. The GPCM has diagnostics and sends a signal to the PCM. It also has the ability to turn off one glow plug if a short is detected in that circuit. The glow plug harness has four connectors that supply power to the glow plugs and seal oil from escaping through the glow plug access holes.

The 6.0 L and the 6.4 L glow plugs look alike, (1.5 mm differences) so much so that Ford uses a color code on the seal. Black seals indicate that the glow plug is for a 6.0 L engine and the green seal is for a 6.4 L engine. It is mounted on the right side of the engine.

Typical Glow Plug DTC

AutoEnginuity's ScanTool

Data Logging Vehicle Options Help

Stopped Data Logging File Playback Speed

Diagnostic Trouble Codes Live Data Meter Live Data Graphs (2x) Live Data Graph (4x) Live Data Grid O2 Sensors **Test OnBoard System** OnBoard Test Results

1) You should only initiate tests, or request system or component data if you have manufacturer specific information related to doing so.
2) Follow the manufacturer specific instructions and the instructions in the description below very carefully.

Automated System Testing

Test Diesel KOER Glow Plug

A functional test of the glow plug system performed on demand with the engine running and the A/C off. The test will maintain a system voltage of 10-14 volts. If necessary, press the accelerator pedal to increase voltage to the specified level. The PCM will activate the Glow Plug Control Module (GPCM) and monitor the glow plug circuits.

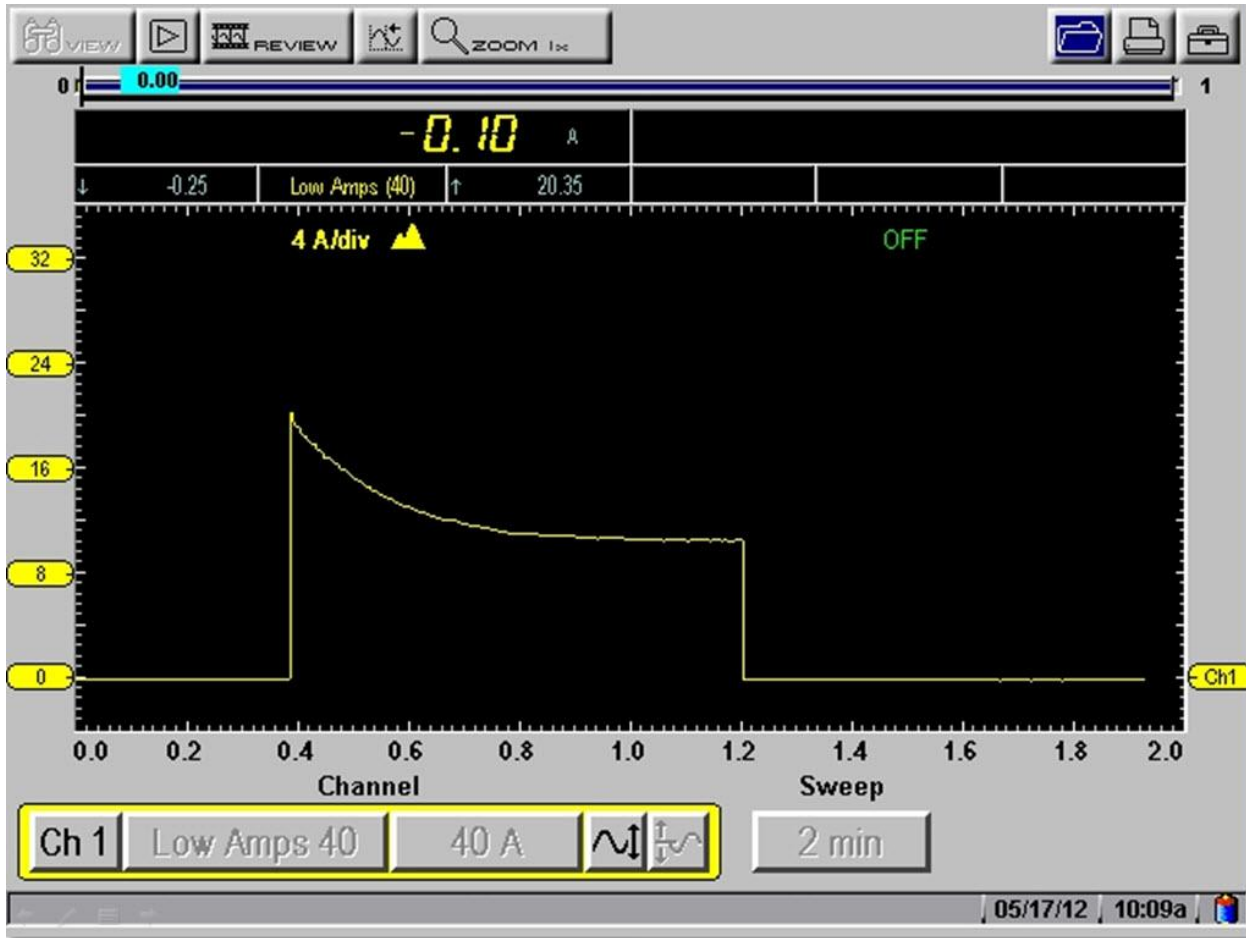
Code	Description
P0678	Cylinder 8 Glow Plug Circuit

Vehicle: Ford PowerStroke 6.0L 2005 1FTSW21P5 System: Enhanced Powertrain CAN

Scan Tool Bi-directional Control



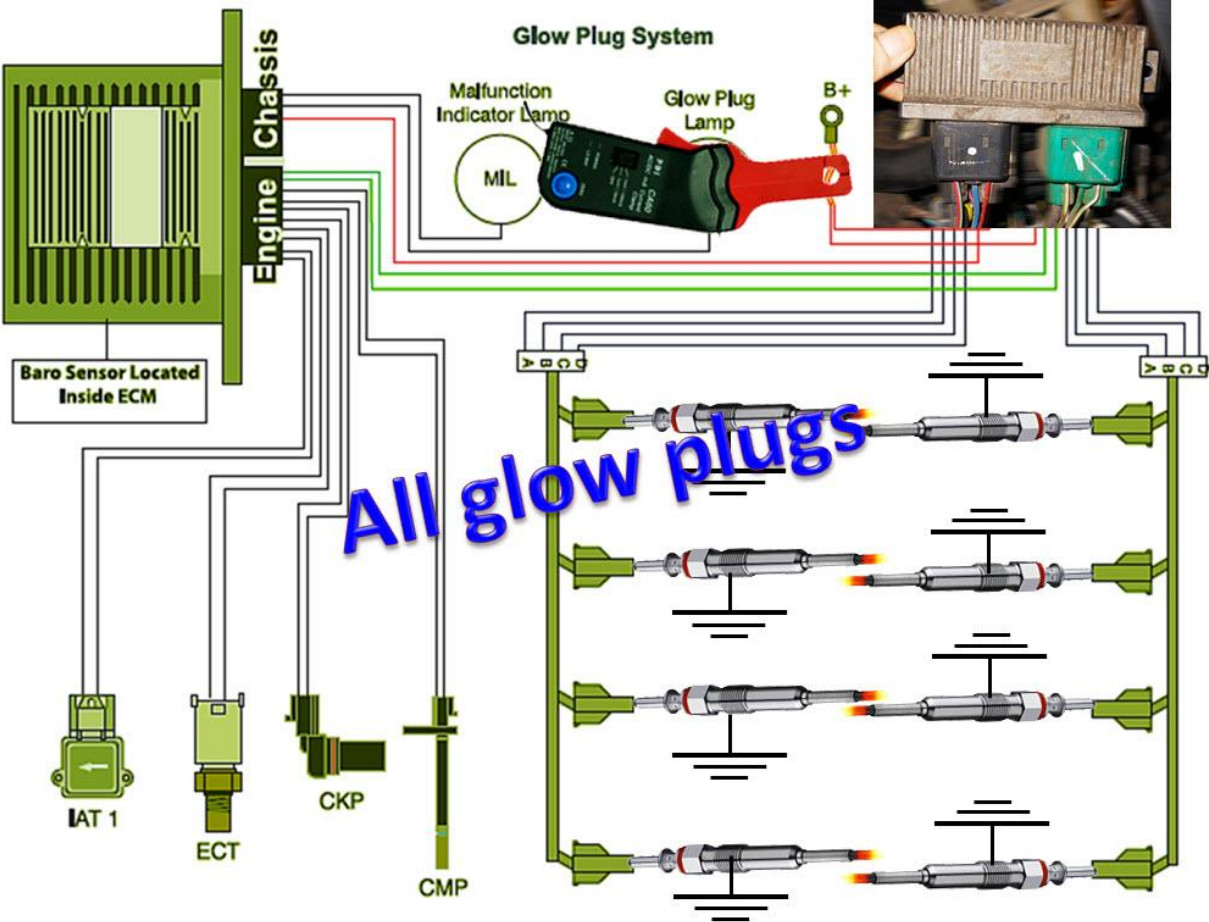
Glow Plug Current Flow



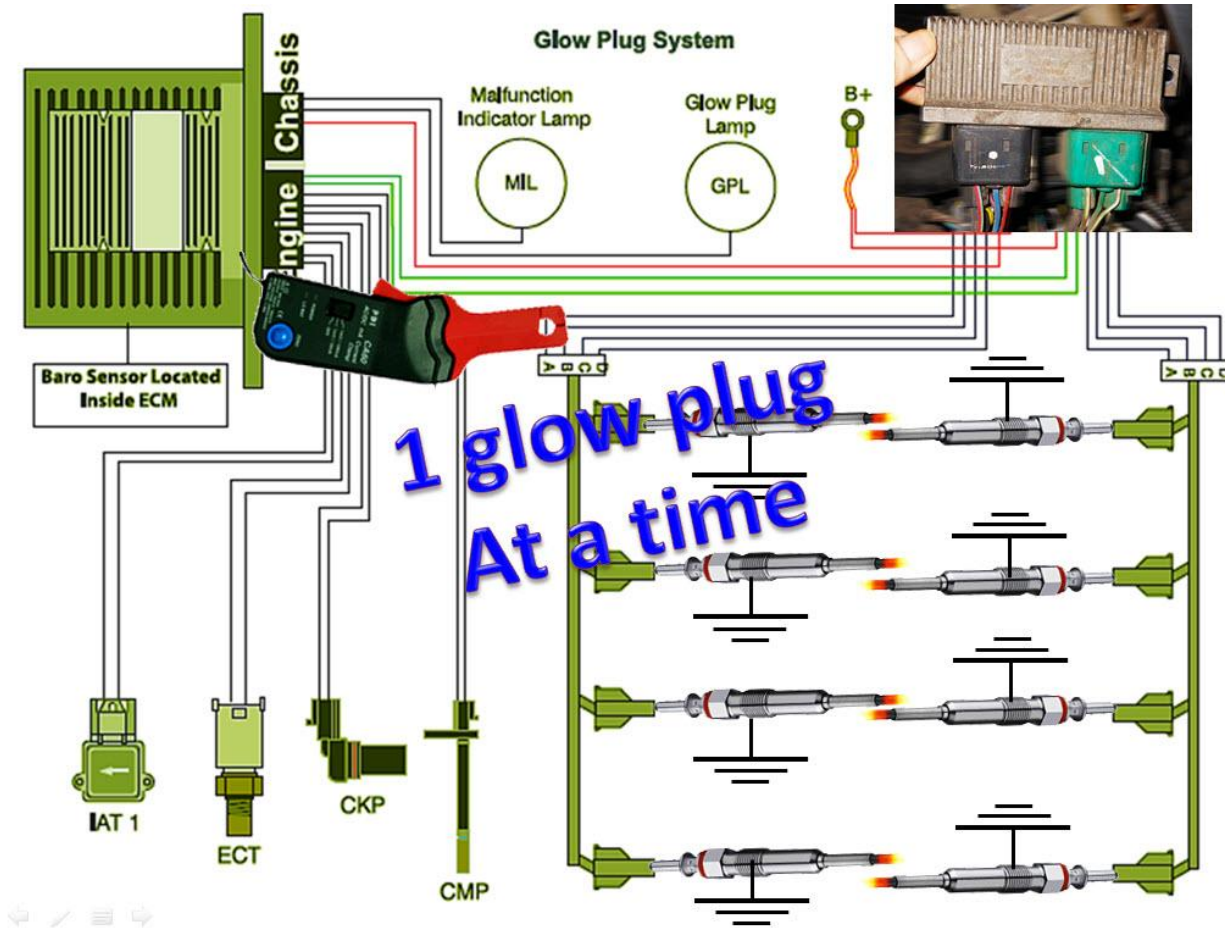
Glow Plug Test

The glow plugs can be tested with the Bi-directional function of a scan tool. The test commands the glow plug on and looks for opens (no current flowing) or shorts (too much current flow). If too much flows for too long, it can get high enough to blow the fuse, creating an open circuit

Test All Glow Plugs



Testing One Glow Plug



The current can be measured one glow plug, one bank, or all of them at a time.

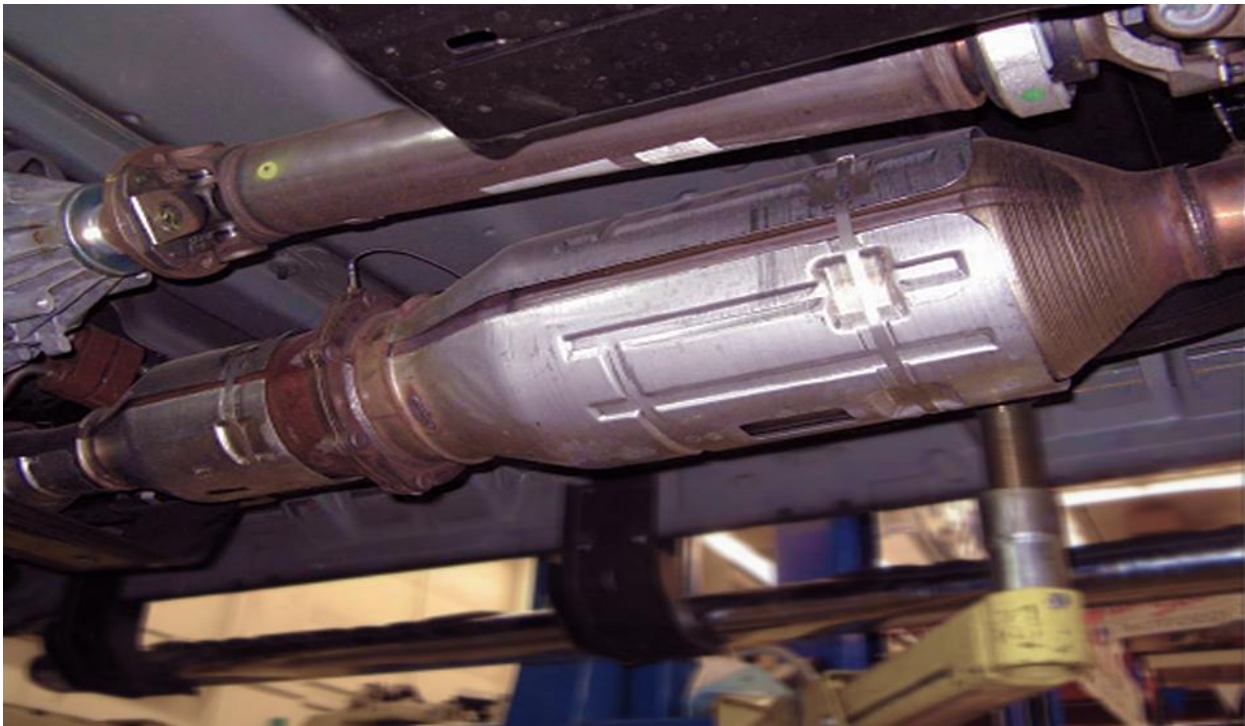
Particulate Matter

Carbon from incomplete combustion is a component of the particulate matter. There will be incomplete combustion because there is either more fuel to oxygen; too rich a mixture, or more oxygen to fuel; too lean a mixture. To get the mix precisely correct may be theoretically possible but would lead to a very expensive, complex engine management system as the air being introduced for each firing of each cylinder would have to be analyzed for its number of oxygen molecules and the number of molecules of petrol matched. Air is more dense in colder weather, leading to more oxygen introduced to the cylinder and fuel is not going to be precisely measured either. The aim of engine designers is to get as close as possible which will result in an efficient as possible engine.

Soluble Organic Fraction (SOL): The organic fraction of diesel particulates, including heavy hydrocarbons from both the fuel and engine lubricating oil. The term "soluble" originates from the analytical method used to measure SOF which is based on extraction of particulate matter samples using organic solvents. The SOL is often referred to as the "wet"

fraction of PM.

Sulfates formed from the sulfur in the fuel. Sulfur is in the crude oil and ends up in the diesel fuel. Even with the newest regulations from the EPA for Low Sulfur fuel, it is part of the particulate matter.



There are different versions of the DPF. Some engines use a larger filter.

Diesel Particulate Filter



This core is similar to a full flow catalytic converter honeycomb design with half of the channels blocked at the inlet and the other half blocked at the outlet forcing the exhaust gasses to flow through the walls between the channels. As the exhaust gasses flow through the walls, the particulate matter is trapped where it remains until it is burned off during regeneration. After regeneration, the resulting minute amount of ash remains where over time it too will build up and require removal. Ash removal can only be done manually which requires removal of the DPF to be cleaned in a reverse flow machine designed to remove ash and collect it for proper disposal. The substrate cores of both catalytic converters and particulate filters are similar in composition and construction.

Scan Data for Soot in Oil

The screenshot shows the 'Live Data Grid' tab in AutoEnginuity's ScanTool. The main data table is as follows:

Sensor Name	Value	Units	Minim...	Maxim...	Range
Calculated Soot in Oil	43048	mg	0	50000	86 %

Below the table is a list of sensors with checkboxes and their groupings:

Sensor Name	Sensor Grouping
<input type="checkbox"/> Brake Pressure Applied	EnhancedPowertrainCAN14229
<input type="checkbox"/> Calculated Engine Oil Volume	EnhancedPowertrainCAN14229
<input type="checkbox"/> Calculated Load Value	EnhancedPowertrainCAN14229
<input checked="" type="checkbox"/> Calculated Soot in Oil	EnhancedPowertrainCAN14229
<input type="checkbox"/> Calculated Torque Output of the Engine	EnhancedPowertrainCAN14229
<input type="checkbox"/> Camshaft Position Sensor 2 Status	EnhancedPowertrainCAN14229
<input type="checkbox"/> Camshaft Position Sensor Status	EnhancedPowertrainCAN14229
<input type="checkbox"/> Catalyst Monitor Evaluated	EnhancedPowertrainCAN14229
<input type="checkbox"/> Charge Air Cooler - Volts	EnhancedPowertrainCAN14229
<input type="checkbox"/> Charge Air Cooler Status	EnhancedPowertrainCAN14229
<input type="checkbox"/> Charge Air Cooler Temperature Bank 1 Se	EnhancedPowertrainCAN14229
<input type="checkbox"/> Charge Air Cooler Temperature Sensor Un	EnhancedPowertrainCAN14229
<input type="checkbox"/> Corrected Intake Manifold Absolute Press	EnhancedPowertrainCAN14229
<input type="checkbox"/> Crank Fueling Disabled	EnhancedPowertrainCAN14229

Vehicle Notes: Put your vehicle notes here

Vehicle: Ford PowerStroke 6.7L 2011 1FD0W5HT2 System: Enhanced Powertrain CAN

Scan Data for Particulates

The screenshot shows the 'Live Data Grid' tab in AutoEnginuity's ScanTool. The main data table is as follows:

Sensor Name	Value	Units	Minim...	Maxim...	Range
Distance Since Last Complete Regeneration	766.44	Miles	0.00	62129.3	1 %
Distance Since Last Complete DPF Regeneration	27.90	Miles	0.00	62129.3	0 %
Distance Since Diagnostic Trouble Codes Cleared	2354.4	Mileage	0.0	40000.0	5 %
Diesel Particulate Filter Regeneration Type	Passive	Bit	0	1	0 %
Diesel Particulate Filter Regeneration Status	Active	Bit	0	1	100 %
Diesel Particulate Filter Percentage Load - Inferred	-559.902	%	-655.000	5000.00	1 %
Diesel Particulate Filter Bank 1 Inlet Pressure	0.00	PSI	0.00	29.00	0 %
Diesel Particulate Filter - Volts	0.45	V	0.00	5.00	8 %

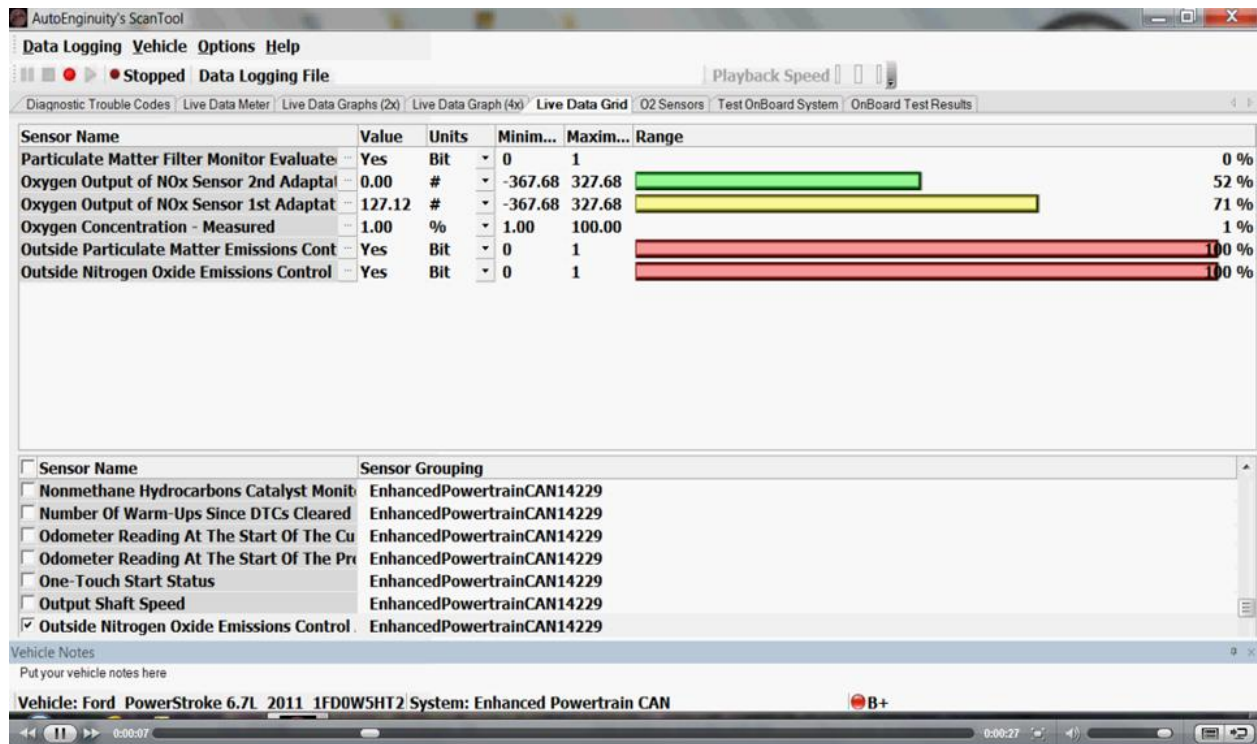
Below the table is a list of sensors with checkboxes and their groupings:

Sensor Name	Sensor Grouping
<input type="checkbox"/> Crankcase Ventilation Hose Disconnection	EnhancedPowertrainCAN14229
<input type="checkbox"/> Crankcase Ventilation Hose Disconnection	EnhancedPowertrainCAN14229

Vehicle Notes: Put your vehicle notes here

Vehicle: Ford PowerStroke 6.7L 2011 1FD0W5HT2 System: Enhanced Powertrain CAN

NOx Scan Data



DPF Regeneration

The problem associated with DPF's is that over time, soot collecting in the DPF can clog it, resulting in decreased performance and fuel efficiency. The PCM must detect a clogging filter and burn off the collected soot. To reduce DPF clogging an exhaust Aftertreatment known as regeneration is used. Sensors tell the PCM when excessive particulate matter has built up in the DPF, and the regeneration mode is triggered. During regeneration, the engine idle is increased to help heat the DPF, and diesel fuel is injected during the exhaust stroke (cylinders 5 and 7) allowing fuel to enter the exhaust system and burn in the DPF. The combustion of diesel fuel in the DPF generates the heat necessary to burn off soot cleaning it. The frequency and length of regeneration will fluctuate as both are determined by driving conditions. For most drive conditions, regeneration frequency will vary from 100 - 600 miles between regenerations and last from 10 to 40 minutes.

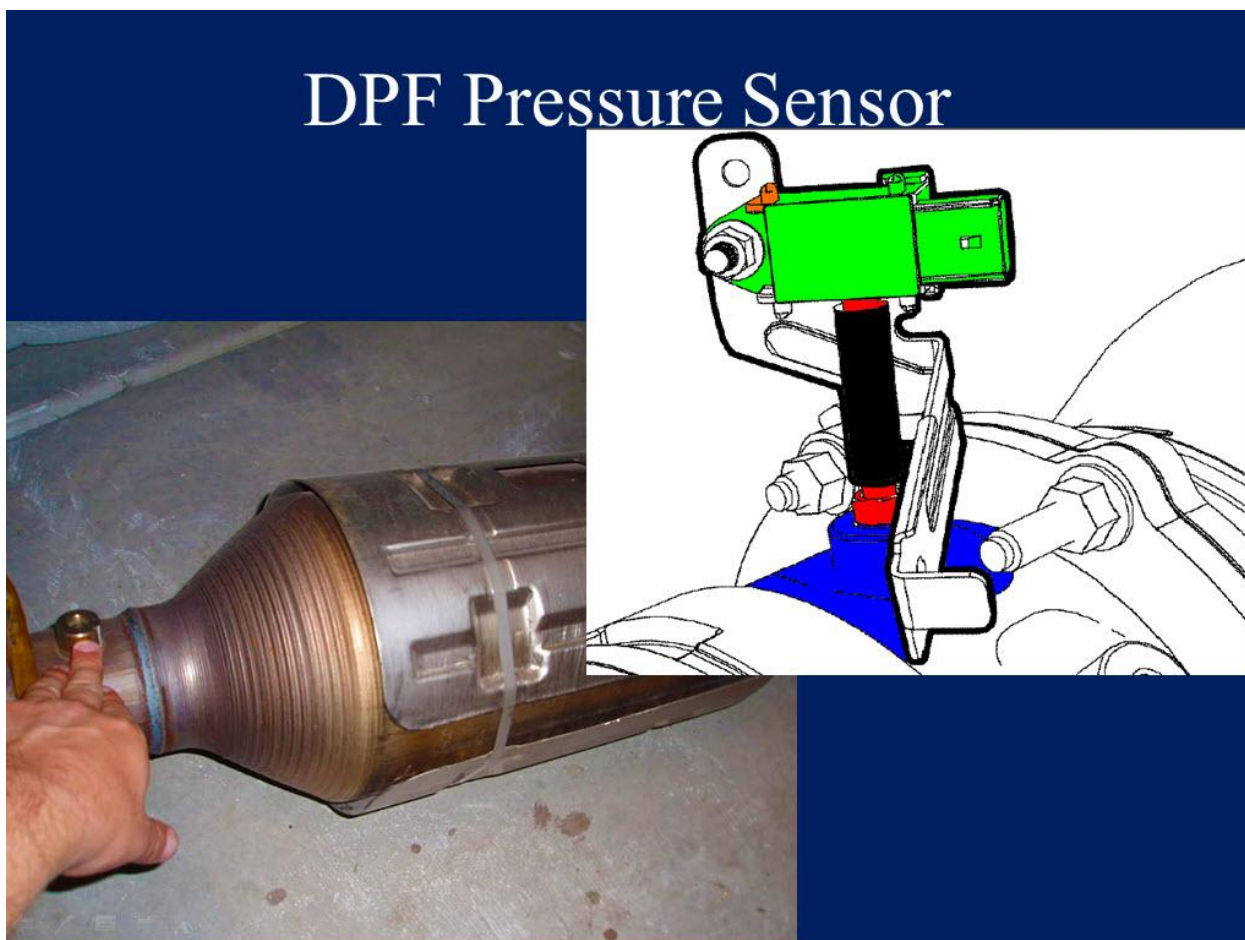
Operation During Regeneration

1. During regeneration engine idle speed may be between 1100 to 1200 RPM in park/neutral with foot off brake.
2. High idle speed drops to within 50 RPM of normal idle when the brake pedal is touched, PRNDL is actuated, or clutch is actuated.
3. White smoke in cold ambient is normal and the amount will be increased during

regeneration.

4. Powertrain power is limited to 325 horsepower (HP).
5. Engine responsiveness may be slightly different than normal operation.
6. During initiation of regeneration, exhaust smell may be noticed - especially on new vehicles.
7. Powertrain sound will be different including air induction noise (including flutter on deceleration or engine shut down), exhaust noise, and changes in engine radiated noise.
8. During regeneration, exhaust temperatures are elevated.
9. The following is also normal and may be observed by a technician using a diagnostic tool. It is not likely that a customer would be aware of these:
10. The throttle body is only active during the regeneration process and during shutdown.
11. EGR is not operating during regeneration.

DPF Pressure Sensor



The DPF pressure sensor is an input to the PCM and measures the exhaust pressure before the DPF. The sensor is a differential-type sensor that is referenced to atmospheric pressure.

The DPF pressure sensor is used by the PCM to monitor the amount of exhaust pressure produced by the DPF. An active regeneration is performed when the reading reaches a specified point. It has a working range of 0psi - 11.6psi. The specifications for the sensor are 0.04psi at idle, 1.61psi at 18% throttle, and 4.9psi at WOT. That would be a new DPF without any ash loading. Regeneration starts at different pressures at different times. The starting point for regeneration at idle is a lower pressure than at highway speeds.

The powertrain control module (PCM) monitors the rationality of the diesel particulate filter pressure sensor during idle and part load operating conditions. The test fails when the diesel particulate filter pressure sensor signal value at idle is less than 0.022 psi. The test also fails when the diesel particulate filter pressure sensor signal value at part load is less than a minimum value or greater than a maximum value. These minimum and maximum values are based on the volume of exhaust.

Diesel Particulate Filter Regeneration

To reduce DPF clogging an exhaust Aftertreatment known as active regeneration is used.

Sensors tell the PCM when excessive particulate matter has built up in the DPF, and active regeneration mode is triggered. During regeneration, the engine idle is increased to help heat the DPF, and diesel fuel is injected during the exhaust stroke, allowing fuel to enter the exhaust system and burn in the DPF. The combustion of diesel fuel in the DPF generates the heat necessary to burn off soot cleaning it.

Regeneration Process

As soot gathers in the Aftertreatment system, the exhaust begins to become restricted. Regeneration is the process in which soot is burned off from the inside of the DPF. Regeneration is commanded by the PCM. The PCM starts regeneration of the DPF if the soot load exceeds a calibrated value. The PCM determines the load condition of the DPF, based on the exhaust gas pressure upstream of the DPF. The DPF pressure sensor provides the pressure input to the PCM. This soot can be cleaned by passive, active, or manual regeneration. Manual regeneration is performed by using the IDS.

Passive Regeneration

Passive regeneration takes place when exhaust temperatures exceed 300° C (572° F). This

process does not affect engine performance and is transparent to the driver.

Active Regeneration

Active regeneration occurs when exhaust temperatures are insufficient to achieve passive regeneration and the DPF pressure sensor is indicating the need for regeneration. The PCM automatically activates the left bank fuel injectors only during the exhaust stroke to raise exhaust temperature to begin regeneration while the vehicle is in motion. Engine performance is not affected by active regeneration; however the engine or exhausts tone may change.

Manual Regeneration

The IDS can be used to perform a manual regeneration of the DPF in the shop and set the ash value under stationary conditions to clean and calibrate the system. The Malfunction Indicator Lamp (MIL) may illuminate when service or maintenance of the DPF is necessary.

CAUTION: The manual regeneration of the DPF produces high temperatures in the exhaust system. Due to high exhaust gas temperatures, always follow the Workshop Manual Cautions, Warnings, and procedures when performing a manual DPF regeneration.

Frequency of Regeneration

The mileage between regenerations varies significantly, depending on vehicle usage.

Post Regeneration

After regeneration, the PCM reads the pressure at the DPF pressure sensor and compares it with a calibrated value. From this comparison, the PCM determines the ash quantity inside the DPF.

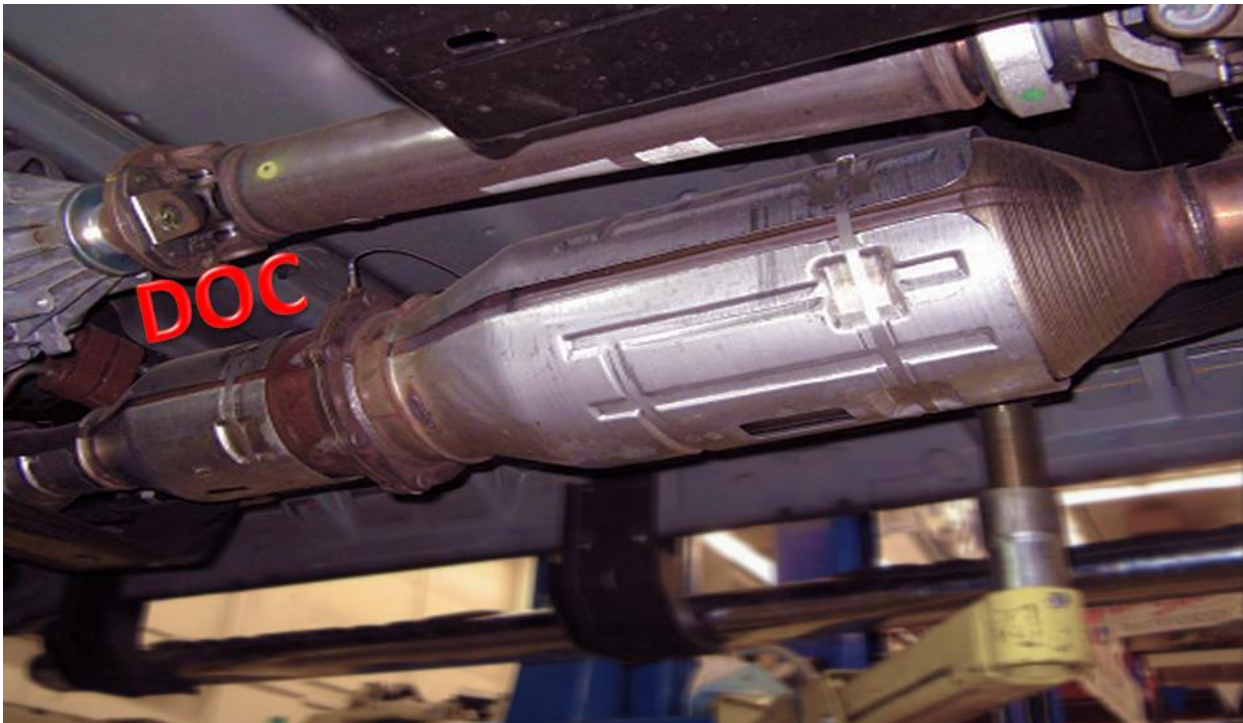
Non-Burnable Ash

Over time a slight amount of non-burnable ash builds up in the DPF which is not removed during the regeneration process. Ash comes from the fuel, oils and other materials that remain after the DPF regeneration process. The DPF may need to be removed for ash cleaning and replaced with a new or remanufactured part. Handle the DPF with care. Dropping the DPF may cause internal damage.

Operation during Regeneration

Engine idle speed may be between 1100 to 1200 RPM in park/neutral with foot off brake. High idle speed drops to within 50 RPM of normal idle when the brake pedal is touched, PRNDL is actuated, or clutch is actuated. White smoke in cold ambient is normal and the amount will be increased during regeneration. Powertrain power is limited to 325 horsepower (HP) ration during regeneration Engine responsiveness may be slightly different than normal operation. During initiation of regeneration, exhaust smell may be noticed - especially on new vehicles. Powertrain sound will be different including air induction noise (including flutter on deceleration or engine shut down), exhaust noise, and changes in engine radiated noise
During regeneration, exhaust temperatures are elevated.

Diesel Oxidation Catalyst (DOC)



A Diesel Oxidation Catalyst (DOC) is a device which utilizes a chemical process in order to break down pollutants from diesel engines in the exhaust stream, turning them into less harmful components. They are normally a honeycomb shaped configuration coated in a catalyst designed to trigger a chemical reaction to reduce particulate matter. They use a chemical process to break down pollutants in the exhaust stream turning them into less harmful components. They are normally a monolith honeycomb shaped configuration substrate coated with platinum group metal catalyst designed to trigger a chemical reaction

to reduce particulate matter. Oxidation catalysts work by oxidizing CO, HC and the soluble organic fraction of the Particulate Matter (PM) to CO₂ and H₂O in the oxygen rich exhaust stream of the diesel engine. Diesel exhaust contains sufficient amounts of oxygen, necessary reactions. The concentration of O₂ in the exhaust gases from diesel engine varies between 3 and 17%, depending on the engine load. Conversion of diesel particulate matter is an important function of the diesel oxidation catalyst. The catalyst is very activity in the oxidation of the organic fraction (SOF) of diesel particulates. Conversion of SOF may reach and exceed 80%. The remaining PM will be trapped in the PM filter. The DOC has limited abilities to reduce nitrogen oxides in diesel exhaust. NO_x conversions of 10-20% are usually observed.

Introduction of the 6.7 L (Scorpion)

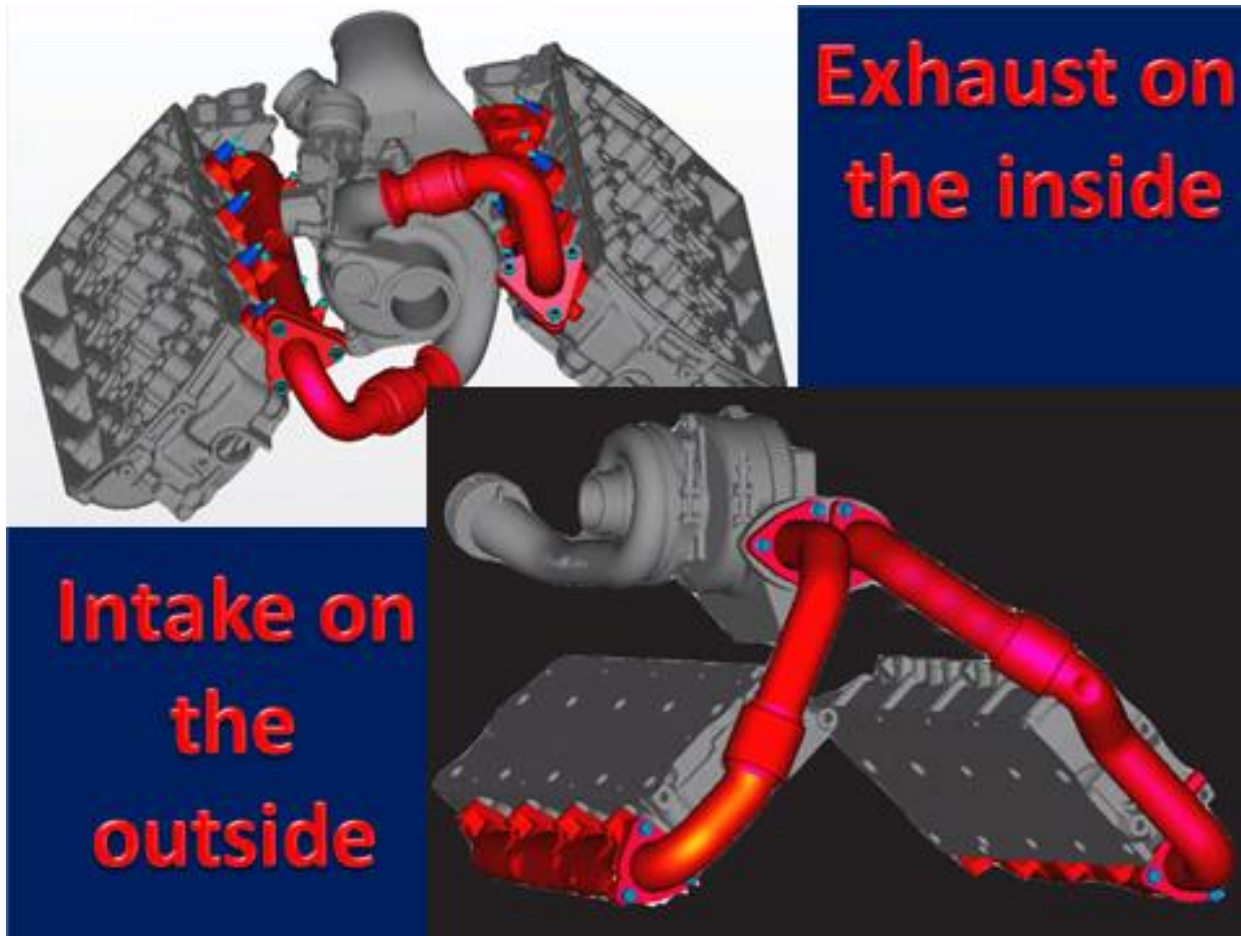
Ford says, the capability and reliability found in the new 6.7-liter diesel engine starts with the engine block. The new Power Stroke's block is made from compacted graphite iron (CGI), which is about twice as strong as regular gray cast iron. While this is the first use of a CGI block in North America in this class of vehicle, Ford has successfully used the material in engine blocks in other products around the world. Unique inboard exhaust and outboard intake architecture, an automotive-industry first for a modern production diesel engine, reduces overall exhaust system volume, which leads to better throttle response for the customer; additionally, reduced exhaust system surface area minimizes heat transfer to the engine compartment and improves NVH (noise, vibration, harshness) The new engine architecture enables easier service work for all major engine components, potentially reducing down time. On turbocharger service, for example, the body/cab no longer has to be removed from the frame to access the turbo; also, the high-pressure fuel pump, EGR (exhaust gas recirculation) components and thermostats are directly accessible from the front of the vehicle.

The single-sequential turbocharger – an industry first is key to the new diesel engine's performance. The unit has two compressor wheels driven off one turbine impeller. This approach combines the benefits of a single inertia wheel – faster response without lag – with the thrust of a larger turbocharger, with the ability to force more compressed air into the engine for more power. The new 6.7-liter Power Stroke V-8 turbocharged diesel will employ an Aftertreatment system to help comply with 2010 federal regulations to reduce nitrogen-oxide levels in diesel emissions by more than 80 percent compared with the previous standard. The Ford Aftertreatment system is a three-stage process; a key component is the use of Diesel Exhaust Fluid (DEF).

Injection of DEF to reduce NO_x is a proven technology that's been used throughout the

automotive industry. Unlike other solutions used to control NOx, the DEF system allows the diesel engine to run at its optimum range in terms of fuel mixture. Some systems require the engine to run richer – which can be harmful to diesel engines – in order to control the NOx.

Manifold Arrangement



Ford has reversed the intake and exhaust manifolds on the 6.7 L engine. The exhaust is inboard of the cylinder heads and the intake outboard.

Cooling Systems

There are two separate cooling systems on the 6.7 L. The engine: a high-temperature system that runs at 194° F. And a low-temperature system that cools an air-to-water intercooler, transmission fluid, fuel cooler, and EGR system with a 122-degree a belt-driven pump mounted low on the driver side, circulates the high temperature coolant, while a separate belt-driven pump mounted higher on the passenger side circulates the low temperature coolant.

Air Management System

Air is drawn through the air filter then past the Mass Air Flow (MAF) and Intake Air Temperature (IAT) sensors. The MAF sensor measures the mass of the air entering the engine and IAT measures the temperature. Then the air enters the compressor side of the turbocharger the air is compressed causing the it to heat up sending the air to an air to the Charge Air Cooler (CAC). From the CAC to intake throttle body and into the intake manifold inside the lower intake manifold the air mixes with EGR gases. Exhaust gases exit the exhaust ports into the inboard exhaust manifolds. Exhaust gases are directed to the dual inlet of the turbo. The turbine wheel spins the compressor. Some of the exhaust from the passenger side manifold for EGR.

Pickup Turbocharger (Wide Frame)

The turbocharger pickup models use a Dual Boost turbocharger. This turbocharger has one exhaust turbine, two intake compressors. The exhaust turbine has variable vanes that change with engine oil pressure from a PCM controlled solenoid.

Chassis Cab Turbocharger

The chassis cab use a standard Variable Geometry Turbocharger (VGT) operated with engine oil pressure that is controlled by the PCM.

Charge Air Cooler (CAC)



The CAC is not the radiator type.

The 6.7 L uses a throttle plate

The intake throttle body promotes flow of EGR gases to the intake manifold by creating a differential between exhaust pressure and intake pressure.

Glow Plugs

The glow plugs are mounted in the cylinder heads and are accessible through the valve cover. They are controlled by the PCM.

Fuel System

The HFCM is now called the Diesel Fuel Conditioning Module (DFCM). It draws fuel from the fuel tank and sends it to the secondary fuel filter then on to the high pressure fuel pump.

The 6.7 L uses Piezo Fuel Injectors similar to the injectors on the 6.4L.

Selective Catalyst Reduction (SCR)



The SCR system components include the:

Reductant or Diesel Exhaust Fluid (DEF)

- Reductant tank
- Reductant dosing module
- Reductant pump and heater assembly
- Reductant pressure line heater assembly
- Reductant tank heater and sensor assembly
- Reductant purge valve
- Reductant pressure sensor
- NOx sensor and module exhaust mixing system.

Reductant or Diesel Exhaust Fluid (DEF)

Reductant, also known as Diesel Exhaust Fluid (DEF) is 32.5% urea/ water solution. When

injected into the exhaust, there is a chemical reaction that converts NO_x into N₂ and H₂O. The freezing point of reductant is -11°C (12°F). Reductant is very caustic; take care not to spill onto connectors, wiring harnesses or the vehicle's paint.

Diesel Exhaust Fluid



Reductant Tank



The reductant tank stores the reductant or Diesel Exhaust Fluid (DEF) under normal use it needs to be refilled at the same interval as the oil change.

Reductant Dosing Module



The reductant dosing module is controlled by the PCM. It is a simple two wire solenoid type injector. The reductant dosing module injects reductant (DEF) into the exhaust system to reduce NO_x coming out of the tailpipe. The injector is coated to resist the corrosive properties of the reductant.

Reductant Exhaust Mixer

There is an exhaust mixing system in the exhaust stream to mix the reductant with the exhaust gas. The mixer is made up of an atomizer and a twist mixer. The atomizer breaks up and vaporizes the reductant droplets. The twist mixer evenly distributes the reductant in the exhaust gases for maximum efficiency.

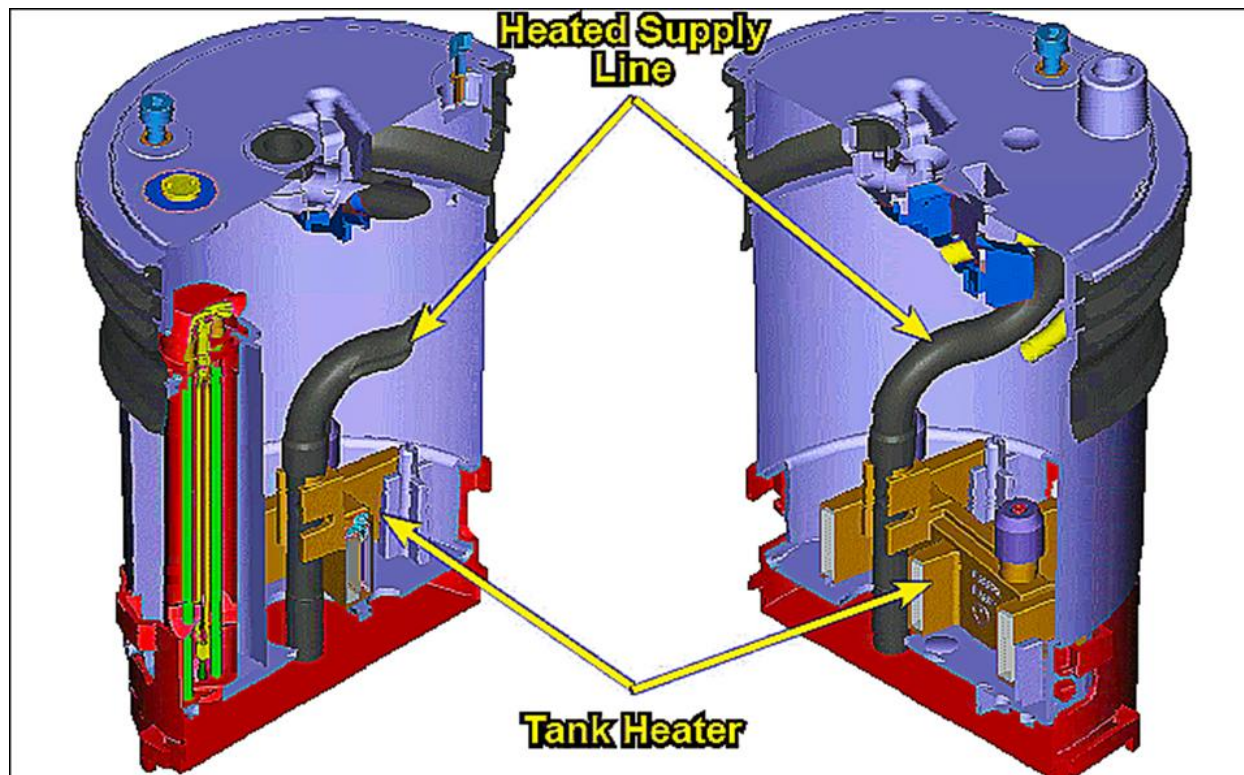
Reductant Pump



The reductant pump supplies urea to the dosing module

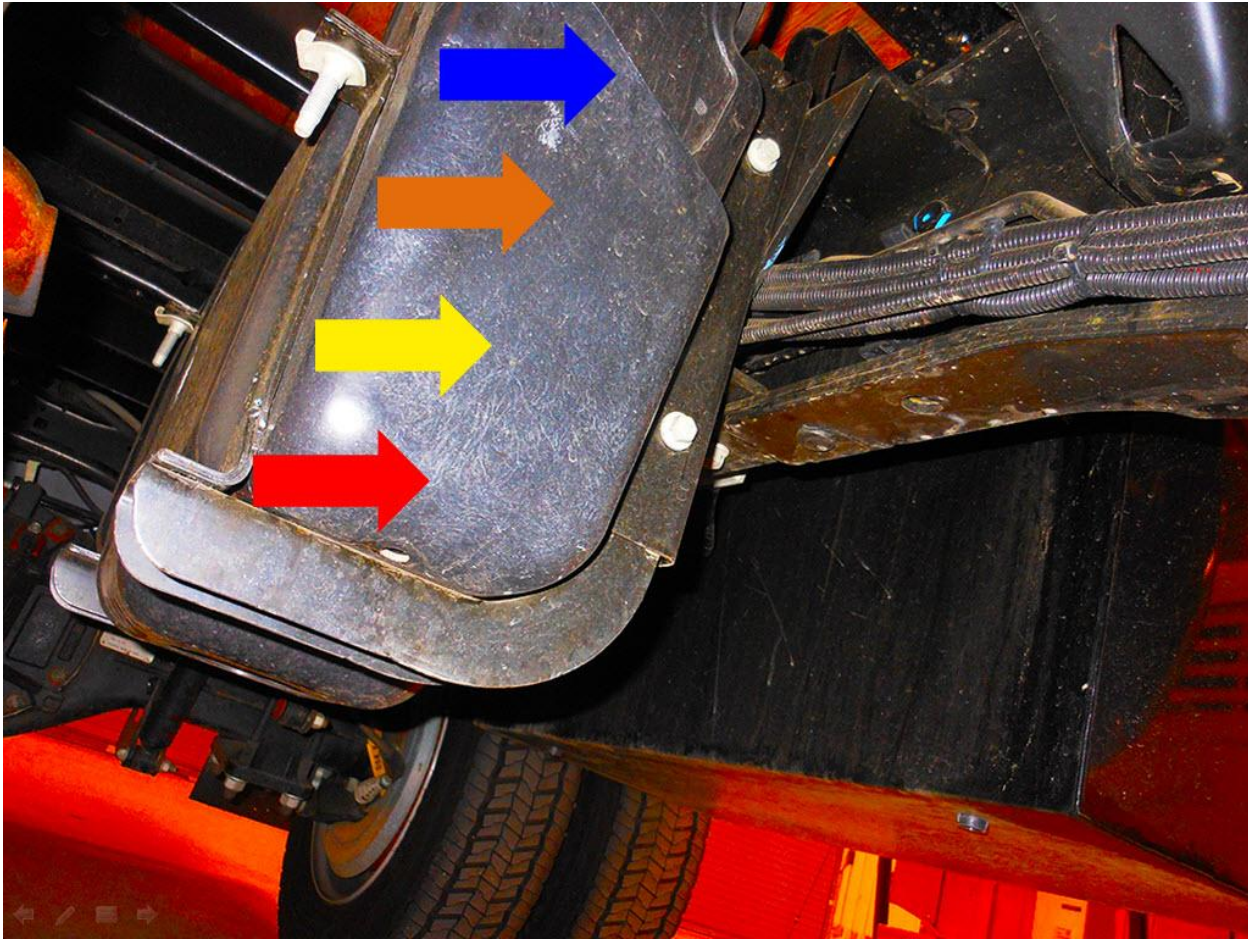
One unique function of the pump is that when the ignition is turned off, the pump pulls all of the reductant out of the lines. This prevents damage to the lines if the reductant was to freeze.

Reductant Heaters



Below a specified temperature the PCM commands the Glow Plug Control Module (GPCM) to activate the heaters in the reductant system. The reductant system has heaters in the tank, pump, and lines. The heaters in the tank thaw the DEF if it is frozen and allow it to flow to the pump without freezing. The heaters in the pump and lines allow the DEF to flow to the injector without freezing.

Reductant Fluid Level Sensors



The reductant fluid level sensor operates by using four electrodes that are mounted on the sensor at different level. The reductant solution closes the electric circuit between electrodes for each level interface. The signal is then sent to the PCM.

AutoEnginuity's ScanTool

Data Logging Vehicle Options Help

Stopped Data Logging File Playback Speed

Diagnostic Trouble Codes Live Data Meter Live Data Graphs (2x) Live Data Graph (4x) Live Data Grid O2 Sensors Test OnBoard System OnBoard Test Results

Sensor Name	Value	Units	Minim...	Maxim...	Range
Ammonia Level On Selective Catalytic Reductant	2205	mg	0	65535	3 %

Sensor Name	Sensor Grouping
<input type="checkbox"/> Ambient Air Temperature - Volts	EnhancedPowertrainCAN14229
<input type="checkbox"/> Ambient Air Temperature Sensor Input Un	EnhancedPowertrainCAN14229
<input checked="" type="checkbox"/> Ammonia Level On Selective Catalytic Red	EnhancedPowertrainCAN14229
<input type="checkbox"/> Average Distance Between DPF Regenerat	EnhancedPowertrainCAN14229
<input type="checkbox"/> Average Distance Between Regeneration	EnhancedPowertrainCAN14229
<input type="checkbox"/> Average Reagent Consumption	EnhancedPowertrainCAN14229
<input type="checkbox"/> Average Reagent Consumption - Demande	EnhancedPowertrainCAN14229
<input type="checkbox"/> Barometric Pressure	EnhancedPowertrainCAN14229
<input type="checkbox"/> Barometric Pressure - Volts	EnhancedPowertrainCAN14229
<input type="checkbox"/> Barometric Pressure Unreliable	EnhancedPowertrainCAN14229
<input type="checkbox"/> Battery Positive Voltage	EnhancedPowertrainCAN14229
<input type="checkbox"/> Boost Pressure Fault	EnhancedPowertrainCAN14229
<input type="checkbox"/> Boost Pressure Monitor Evaluated	EnhancedPowertrainCAN14229
<input type="checkbox"/> Brake Pedal Position	EnhancedPowertrainCAN14229

Vehicle Notes

Put your vehicle notes here

Vehicle: Ford PowerStroke 6.7L 2011 1FD0W5HT2 System: Enhanced Powertrain CAN B+

AutoEnginuity's ScanTool

Data Logging Vehicle Options Help

Stopped Data Logging File Playback Speed

Diagnostic Trouble Codes Live Data Meter Live Data Graphs (2x) Live Data Graph (4x) Live Data Grid O2 Sensors Test OnBoard System OnBoard Test Results

Sensor Name	Value	Units	Minim...	Maxim...	Range
Reductant tank Temperature	57	F	32	572	14 %
Reductant Tank Level Amount	14.43	L	0.00	65.54	22 %
Reductant Tank Level	0.00	%	0.00	100.00	0 %
Reductant Tank Heater Current - Measure	0	uA	0	6500	0 %
Reductant Tank Heater Control	Off	Bit	0	1	0 %
Reductant Reverting Valve Duty Cycle - Cc	0	State	0	255	0 %
Reductant Pump Duty Cycle - Commanded	0.00	%	0.00	100.00	0 %
Reductant Pressure Sensor Voltage	0.50	V	0.00	6.50	7 %
Reductant Mode Based On Reductant Tanl	OK	State	0	4	75 %
Reductant Line Pressure	0.00	PSI	0.00	37.12	0 %
Reductant Line Heater Control - Measured	0	uA	0	6500	0 %
Reductant Line Heater Control	Off	Bit	0	1	0 %
Reductant Injector Duty Cycle	0.00	%	0.00	100.00	0 %
Reductant in Reductant Tank is Frozen - Ii	No	Bit	0	1	0 %

Sensor Name	Sensor Grouping
<input type="checkbox"/> Oxygen Output of NOx Sensor 2nd Adaptal	EnhancedPowertrainCAN14229
<input type="checkbox"/> Particulate Matter Filter Monitor Evaluate	EnhancedPowertrainCAN14229
<input type="checkbox"/> PCM ID Status Stored	EnhancedPowertrainCAN14229

Vehicle Notes

Put your vehicle notes here

Vehicle: Ford PowerStroke 6.7L 2011 1FD0W5HT2 System: Enhanced Powertrain CAN B+

0:00:02 0:00:29

Reductant Pressure Sensor

The PCM monitors the reductant pressure sensor to calculate how much reductant to be injected into the exhaust. The reductant pressure sensor is also used to shut the pump off when the lines are being drained after the ignition is shut off.

Reductant Pressure Sensor Data

AutoEnginuity's ScanTool

Data Logging Vehicle Options Help

Stopped Data Logging File Playback Speed

Diagnostic Trouble Codes Live Data Meter Live Data Graphs (2x) Live Data Graph (4x) Live Data Grid O2 Sensors Test OnBoard System OnBoard Test Results

Sensor Name	Value	Units	Minim...	Maxim...	Range	
Reductant tank Temperature	57	F	32	572		14 %
Reductant Tank Level Amount	14.43	L	0.00	65.54		22 %
Reductant Tank Level	0.00	%	0.00	100.00		0 %
Reductant Tank Heater Current - Measure	0	uA	0	6500		0 %
Reductant Tank Heater Control	Off	Bit	0	1		0 %
Reductant Reverting Valve Duty Cycle - Cc	0	State	0	255		0 %
Reductant Pump Duty Cycle - Commanded	0.00	%	0.00	100.00		0 %
Reductant Pressure Sensor Voltage	0.50	V	0.00	6.50		7 %
Reductant Mode Based On Reductant Tanl	OK	State	0	4		75 %
Reductant Line Pressure	0.00	PSI	0.00	37.12		0 %
Reductant Line Heater Control - Measured	0	uA	0	6500		0 %
Reductant Line Heater Control	Off	Bit	0	1		0 %
Reductant Injector Duty Cycle	0.00	%	0.00	100.00		0 %
Reductant in Reductant Tank is Frozen - Ii	No	Bit	0	1		0 %

Sensor Name Sensor Grouping

- Oxygen Output of NOx Sensor 2nd Adaptal EnhancedPowertrainCAN14229
- Particulate Matter Filter Monitor Evaluate EnhancedPowertrainCAN14229
- PCM ID Status Stored EnhancedPowertrainCAN14229

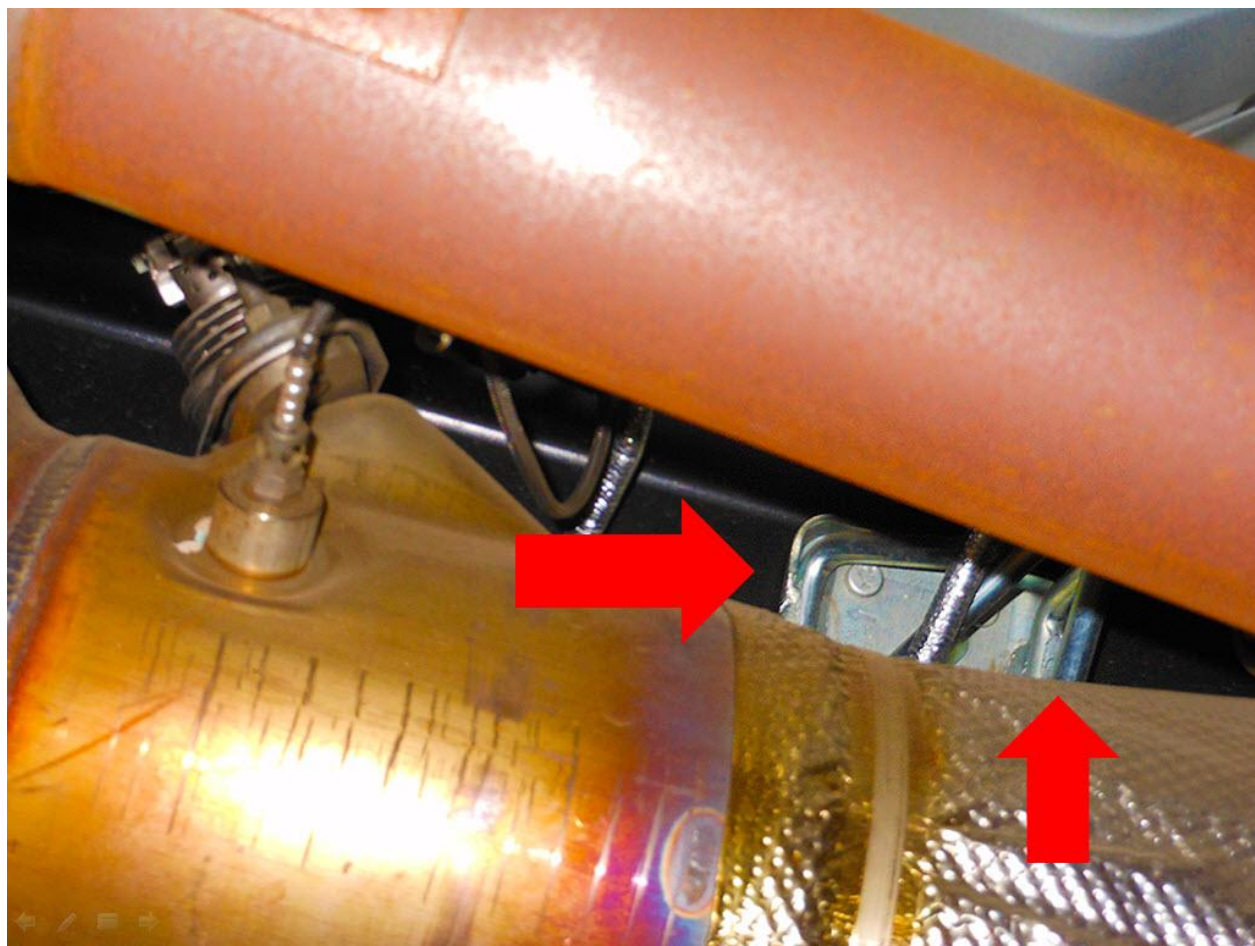
Vehicle Notes

Put your vehicle notes here

Vehicle: Ford PowerStroke 6.7L 2011 1FD0W5HT2 System: Enhanced Powertrain CAN

0:00:02 0:00:29

NO_x Sensor Module



The NO_x sensor module is mounted to the vehicle frame under the body. It controls the NO_x sensor mounted in the diesel Aftertreatment exhaust system downstream of the SCR and DPF. It communicates to the PCM via the CAN2 to report NO_x and O₂ concentrations as well as sensor and controller errors.

NO_x Sensor

The NO_x sensor is used primarily to sense O₂ and NO_x concentrations in diesel exhaust gas. The sensor is mounted in a vehicle's exhaust pipe. The sensor is mounted downstream of the SCR and DPF. The sensor interfaces with the NO_x sensor module.

Bio Fuel Training

Introduction

For a number of years now there has been an ever-growing list of governmental regulations to address concerns about the environment and dependency on foreign oil. Initially many of these regulations were focused on gasoline-powered automobiles and the fuel that powers them.

More recently there has been a growing list of regulations that require reduced emissions from diesel engines. In addition, regulations for cleaner diesel fuel have been adopted to both reduce emissions and to enable technologies that, while reducing emissions, require cleaner fuels to function properly. Recent concerns related to petroleum use and greenhouse gas emissions are also influencing state and federal policies and regulations.

The Clean Air Act has been the driving force for these changes. The first Clean Air Act was adopted in 1963 and was amended in 1967, 1970, 1977, and most recently in 1990. The first federal emissions requirements for diesel-powered vehicles were in 1971 (1969 in the case of California regulations). Since that time there has been ever-tightening diesel engine emission standards as well as requirements for cleaner diesel fuels. In fact, by the late 1990s, the emissions of a new model heavy-duty diesel truck were about 10 percent for particulate matter (PM) and 27 percent for oxides of nitrogen (NO_x) compared to similar pre-control era diesel trucks. But additional emissions reductions were required. The most recent emissions reductions are very stringent and require more dramatic technological advances in emissions control technology. In order to operate properly, these more advanced technologies require diesel fuel with ultra-low sulfur levels.

While various regulations limit certain fuel properties to meet environmental objectives, there are also specifications that control the performance properties of diesel fuel to ensure that it performs satisfactorily across a broad range of engine applications, with a broad range of uses

and duty cycles. In the case of the U.S. fuels market, such guidelines are established by ASTM International.

Environmental issues are not the only thing driving changes in diesel fuel. Energy security also plays a role. Our growing dependence on foreign crude oil and imported transportation fuels has revived interest in renewable fuels including “biodiesel.” The Energy Policy Act of 2005 contained a “Renewable Fuels Standard” which requires that a growing amount of our transportation fuels must be renewable fuels such as biodiesel and ethanol. This has resulted in the increased use of biodiesel as a blend component of diesel fuel.

Increasingly the diesel vehicle operator turns to his service shop for fuel-related information and advice. Questions often focus on the type of diesel (sulfur level), on-road grades versus off-road, premium diesel, cetane ratings, use of over-the-counter additives, and biodiesel. But it is often difficult for the service technician to obtain factual information written with the service shop in mind. This is, in part, because only a few years ago this information was considered “nice to know” but not “need to know.” That has changed, and today it is important for the diesel service and repair technician to understand diesel fuel quality issues, both for diagnostic reasons and to have the ability to provide accurate information to the vehicle or equipment operator.

This manual is designed to aid in that effort. Fuel specifications and their relationship to vehicle performance are covered. Changes in fuel composition are discussed in detail. The impact of government regulations on diesel fuel composition are also discussed. Due to its recent expanded use in the marketplace, biodiesel is also covered.

Like its sister publication, *Changes in Gasoline*, this manual is designed to separate fact from fiction. It is based on numerous technical references, primarily from diesel engine and fuel system manufacturers, and the petroleum industry. It is designed to aid you in identifying any fuel-related problems and to also assist you in explaining fuel issues to your customers. Although targeted to the service and repair community, others may also find this manual useful in discussing diesel fuel issues with consumers.

It is our hope that this information will prove to be a useful shop reference for diesel fuel information.

In order to understand fuel quality standards and how they affect diesel engine performance, it is important to have a basic understanding of diesel fuels, how and why quality standards are set, and how these standards relate to the operability, performance, emissions, fuel economy and durability of a diesel engine and related systems.

ASTM Specifications

Diesel fuel comes in several different grades, depending upon its intended use. Like gasoline, diesel fuel is not a single substance, but a mixture of various petroleum-derived components, including paraffins, isoparaffins, naphthenes, olefins and aromatic hydrocarbons, each with their own physical and chemical properties. Diesel fuel must satisfy a wide range of engine types, differing operating conditions and duty cycles, as well as variations in fuel system technology, engine temperatures and fuel system pressures. It must also be suitable for a variety of climates. The properties of each grade of diesel fuel must be balanced to provide satisfactory performance over an extremely wide range of circumstances. In some respects, the prevailing quality standards represent certain compromises so that all the performance requirements may be satisfied. By controlling specifications and properties, it is possible to satisfy the requirements of millions of compression ignition engines with a single grade of diesel fuel. The most commonly used guidelines for diesel fuel quality are established by ASTM International. ASTM specifications are established by consensus, based on the broad experience and close cooperation of producers of diesel fuels, manufacturers of diesel engines and fuel systems (and users of both), as well as other interested partners such as state fuel quality regulators. Often ASTM turns to organizations such as SAE International and the Coordinating Research Council to produce reliable technical data to aid in the development of fuel specifications. ASTM standards are continuously reviewed and updated when the need arises.

ASTM standards are viewed as voluntary compliance standards, although Federal and State regulations often require diesel fuels to meet all, or a portion of, ASTM specifications.

The ASTM standard for diesel fuels is “ASTM D 975 – Standard Specification for Diesel Fuel Oils.” This standard currently covers seven grades of diesel fuel oils. These grades include numbers 1-D (S15), 1-D (S500), 1-D (S5000), 2-D (S15), 2-D (S500), 2-D (S5000) and 4-D. The grades are listed in order of increasing density and viscosity. In other words, a 2-D grade is denser and of higher viscosity than grade 1-D. The parenthetic numbers such as (S15) refer to the maximum sulfur level for the grade. Thus 2-D (S15) refers to No. 2 diesel with a maximum of 15 parts per million (ppm) sulfur. Grades designated S500 are low sulfur diesel (maximum 500 ppm sulfur), while S15 designates ultra-low sulfur diesel. The S5000 grades, as well as No. 4-D, are for off-road use only. (Note that off-road grades or on-road grades sold for off-road use are required to contain a red dye so that they can be easily identified for taxation purposes.)

Although all of these grades are technically diesel fuel oils, in the U.S. when the word diesel fuel is used, it is primarily in reference to No. 2-D grades, since that is the grade generally used in all on-road vehicles as well as the majority of off-road applications. Grade No. 2-D is also the focus

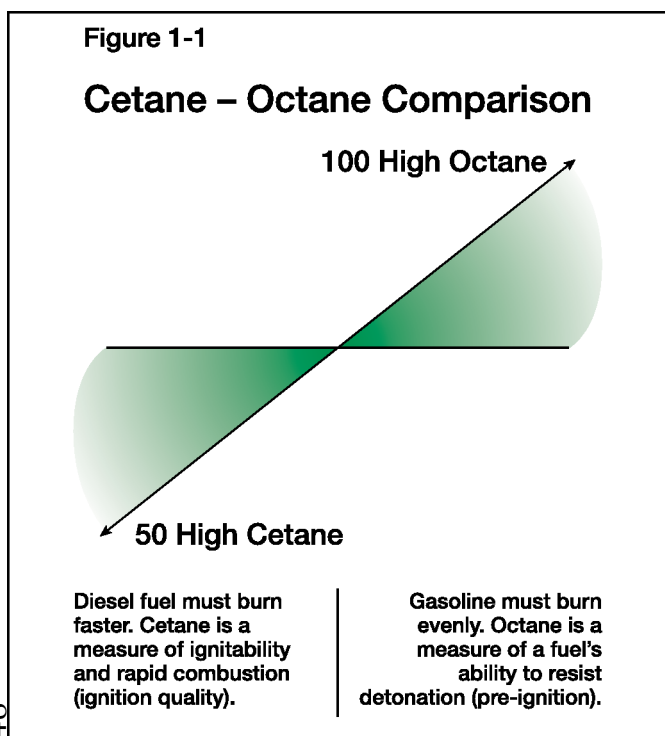
of this manual.

In addition to the property limits in ASTM D 975, numerous test methods are encompassed in the specification to accurately measure the specified properties. While the ASTM standards ensure acceptable fuel quality, some petroleum companies and pipeline operators may require more stringent standards. In addition, SAE International Surface Vehicle Standard J 313 – Diesel Fuels, provides diesel fuel quality guidelines and the Engine Manufacturers Association (EMA) also stipulates certain fuel quality parameters. Other countries may rely on ASTM D 975 while some, such as European countries and Japan, have their own standards which may vary slightly from the ASTM property limits.

The aforementioned standards focus primarily on standards related to engine performance. There are also federal, and in some cases state, specifications that focus on the environmental impact of diesel fuel. While compliance with these specifications is required, diesel fuel should still meet the standards established by ASTM.

The intent here is to tie all these standards together and relate them to performance. In order to make the manual more reader-friendly, some technical issues are represented in non-technical terms so the reader is not burdened with unnecessary chemistry and engineering topics.

Cetane Quality



Probably the most familiar diesel fuel property to end users and the service and repair professional is ignition quality, as expressed by cetane number.

Cetane number is a measure of the ignition quality of the fuel. Cetane number affects combustion roughness. Consumers often think the cetane number is similar to the octane number for gasoline, but that is not the case. Octane is a measure of a spark ignition engine fuel's (gasoline) ability to resist engine knock (pre-ignition from compression). Diesel cetane ratings work in the opposite direction. The higher the cetane rating, the more easily it ignites. Reaching desired cetane levels also limits the aromatic content of diesel fuel.

Diesel fuel cetane ratings are calculated by calibrating a fuel to a mixture of reference fuels

in a specially designed Cooperative Fuel Research (CFR) engine.

Acquisition and operating costs for a CFR engine are expensive, and it is not the easiest test to perform. Various tests have been developed to calculate the cetane number from certain fuel properties. These tests usually involve some combination of fuel density and distillation properties. The two more commonly used cetane number estimate formulas are referred to as cetane indexes to distinguish their results from the engine test. The most common cetane indexes are ASTM D 976 and ASTM D 4737. There are other cetane index methods that incorporate various fuel properties, but they are not as widely used as the ASTM methods. One problem with cetane indexes is that they report the cetane index number of the fuel. If cetane improver additives have been used in the fuel, it will raise the cetane number of the fuel, but this will not be adequately reflected in the cetane index calculation.

Cetane number requirements of an engine will vary depending on engine size, speed and load variations, starting conditions and atmospheric conditions.

Since a diesel engine ignites the fuel without a spark, proper cetane levels are very important. The air/fuel mixture is ignited by the combination of compression and heating of the air due to compression. The fuel is injected into the cylinder at the precise time ignition is desired to optimize performance, economy and emissions.

While gasoline engines time the spark to ignite the fuel, a diesel engine controls ignition by the injection of the fuel using either mechanical injectors or, more recently, by electronically controlled fuel distributors and individual injectors. This also necessitates much higher fuel pressures to overcome the pressure in the combustion chamber during the compression stroke. More simply put, in a spark ignition engine the amount of air is changed to control speed and power, while in the diesel engine the amount of air remains constant while the amount of fuel is varied. Diesel engines can operate at very lean mixtures when idling (e.g., 80:1) or move to richer mixtures during high load conditions (e.g., 20:1).

Given the operating conditions, it is easy to see why cetane level is important. In addition to improving fuel combustion, increasing cetane level also tends to reduce emissions of nitrogen oxides (NO_x) and particulate matter (PM). These emissions tend to be more pronounced when starting with lower cetane number fuels. Increasing the cetane number value above that required for a given engine may not, however, improve engine performance. Some tests have shown that excessively high cetane number fuels may cause smoking (higher PM emissions).

The minimum cetane number for diesel fuel (Grades No. 1 and 2) is 40. The fuel should also meet a minimum cetane index of 40 or, alternatively, contain no more than 35 volume

percent aromatics. Some manufacturers may recommend higher cetane number fuels, so the vehicle or equipment owner's manual should always be consulted.

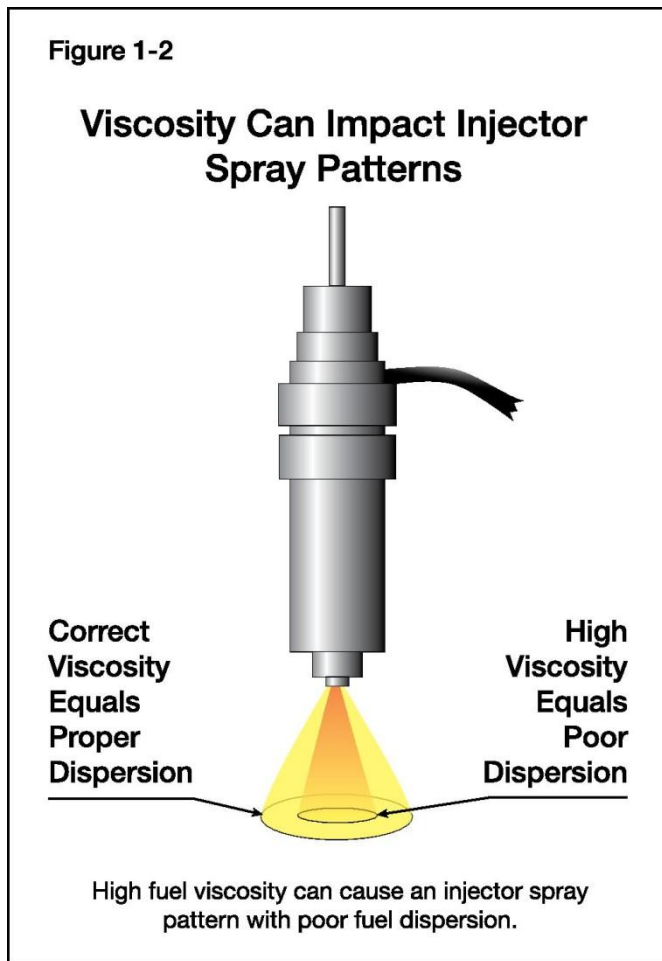
Results of Inadequate Cetane Number
Poor Ignition Quality
Long Ignition Delay
Abnormal Combustion
Abnormally High Combustion Pressure
Potential Uneven Thrust on Piston / Cylinder
Louder Engine Knock
Excessive Engine Knock & Smoke at Cold Start

Volatility

Unlike spark-ignition engines, the power and economy of diesel engines are comparatively insensitive to fuel volatility. There is some indirect impact in that less volatile fuels have higher heat-ing values (energy content). Conversely fuels with higher front-end volatility

tend to improve starting and warm-up performance and reduce smoke.

Ideal fuel volatility requirements will vary based on engine size and design, speed and load conditions, and atmospheric conditions. As an example, more volatile fuels may provide bet-ter performance for fluctuating loads and speeds such as those experienced by trucks and buses. ASTM D 975 only sets a minimum/maximum range for the temperature at which 90 percent of the fuel will evaporate. This is referred to as T90, and the range for No. 2 grades of diesel fuel is 282°C to 338°C. This limits the level of high boiling point components that could lead to increased engine deposits.



Viscosity

The viscosity of diesel fuel is an important property which impacts the performance of

fuel injection systems. Some injection pumps can experience excessive wear and power loss due to injector or pump leakage if viscosity is too low. If fuel viscosity is too high, it

may cause too much pump resistance, filter damage and adversely affect fuel spray patterns.

In general, fuels with low viscosity tend to have poorer lubrication properties.

ASTM D 975 requires a kinematic viscosity range of 1.9 minimum to 4.1 maximum mm²/S at 40°C, for No. 2 diesel fuels (note that the term mm²/S replaces the former term of centistokes [cst]).

Carbon Residue

A carbon residue test is performed to approximate the engine deposit-forming tendency of diesel fuels. In the ASTM specification, this is referred to as the “Ramsbottom Carbon Residue on 10 mass percent Distillation Residue.” This number is limited to a maximum of 0.35 mass percent for No. 2 diesel.

Sulfur Content

Engine wear and deposits can vary due to the sulfur content of the fuel. Today the greater concern is the impact that sulfur could have on emission control devices. As such, sulfur limits are now set by the U.S. Environmental Protection Agency (EPA), and those limits have been incorporated into ASTM D 975. For No. 2 grade low sulfur diesel, the limit is a maximum of 0.05 percent mass (500 ppm) and, for ultra-low sulfur diesel, it is 15 parts per million (ppm) maximum

Flash Point

ASTM D 975 includes a flashpoint requirement. This is not related directly to engine performance. The flashpoint is controlled to meet safety requirements for fuel handling and storage. The flashpoint is the lowest fuel temperature at which the vapor above a fuel sample will momentarily ignite under the prescribed test conditions. For No. 2 diesel grades, the flashpoint is a minimum of 52° C.

Low Temperature Operability

The cloud point of a diesel fuel is the temperature at which the amount of precipitated wax crystals becomes large enough to make the fuel appear cloudy or hazy. Wax may form because normal paraffins occur naturally in diesel fuel. As the temperature of the fuel is lowered, these paraffins become less soluble in the fuel and precipitate out as wax crystals. In some fuel systems, cloud point can indicate the onset of fuel-filter plugging. Although ASTM D 975 provides a test method for determining cloud point, it does not set a specific

temperature. This is because it is impractical to set low temperature properties for all ambient temperatures. Also, depending on equipment design and operating conditions, satisfactory operation may be achieved even below the cloud point. Cloud point and other low temperature operability limits such as low temperature filterability, cold filter plugging point, and pour point are generally specified by contract between the fuel supplier and fuel purchaser, who can best determine the necessary limit based on intended use and anticipated climate.

Pour point is the lowest temperature at which the fuel will flow and is used to predict the lowest temperature at which the fuel can be pumped. As mentioned above, other tests include the “Filterability of Diesel Fuels by Low Temperature Flow Test” (LTFT) and the “Cold Filter Plugging Point” (CFPP) test. One or more of these can help predict a diesel fuel’s low temperature operability properties.

Ash

Abrasive solids or soluble metallic soaps may be present in diesel fuel. These ash-forming materials can result in injector and fuel pump wear, as well as piston and ring wear, in the case of abrasive solids, and engine deposits may also increase. The primary concern with soluble soaps is their contribution to engine deposits. ASTM D 975 sets a maximum limit of 0.01 mass percent ash content for both No. 1 and No. 2 diesel fuels.

Corrosion Properties

A copper strip corrosion limit (under specified test conditions) is used to predict possible problems with copper, brass or bronze fuel system components.

Water and Sediment

Because diesel fuel moves through various pipelines and tanks, and in some cases is moved by waterborne vessels, the potential exists for water and sediment to contaminate the fuel. Water and sediment contamination can contribute to filter plugging and fuel injection system wear. These contaminants may also lead to increased corrosion. The ASTM limit for water and sediment in diesel fuel is a maximum of 0.05 percent by volume.

Lubricity

Diesel fuel lubricity is a very important property, since the diesel fuel injection system relies on the fuel to lubricate moving parts. As with low-viscosity fuels, if lubricating properties are inadequate, it will lead to increased wear on injectors and pumps. In years past, naturally occurring lubricity agents in diesel fuel provided adequate protection. More

recently, certain refinery processes such as those used to comply with new low sulfur and aromatics requirements, tend to remove these naturally occurring materials. Lubricity additives are often required to avoid catastrophic fuel pump or injector failures. As little as one tank full of poor lubricity fuels can cause such catastrophic failures.

Current test methods for assessing fuel lubricity continue to be improved. Work on diesel fuel lubricity and the best test procedure to measure wear is ongoing within several organizations, including ASTM. The two most common test methods are the “Scuffing Load Ball-on Cylinder Lubricity Evaluator” (SLBOCLE) test and the “High Frequency Reciprocating Rig” (HFRR) test. The current version of ASTM D 975 specifies the HFRR test method, and the current requirement is a maximum of 520 microns at 60°C (measurement of wear).

Summary of ASTM Specifications

Property	Importance
Cetane Number	Measure of ignitability (ignition quality), reduce knock and smoke
Cetane Index/Aromatics Limit	Limits aromatic content of fuel to prevent adverse emissions impact, reduce knock and smoke
Volatility	Deposits, wear, exhaust smoke
Viscosity	Injector wear & spray pattern, pump wear, filter damage
Sulfur Content	To protect emissions control equipment
Low Temperature Operability	Flow properties, filter plugging
Water & Sediment Content	Filter plugging, injector wear, increased corrosion
Lubricity	Injector & pump wear
Ash Content	Injector & fuel pump wear, piston & ring wear, engine deposits
Corrosion	Protect copper, brass, bronze fuel system parts
Flash Point	Safety during fuel handling & storage
Carbon Residue	Fuel system deposits, combustion chamber deposits

Other Important Fuel Quality Issues

There are other properties that petroleum companies may monitor and control which are not specified in ASTM D 975.

Gravity/Density

The gravity or density of a fuel, along with other parameters, can be used to indicate certain fuel composition ranges. This information can then provide directional predictions of fuel

economy, power, deposits, wear and exhaust smoke. For instance, a diesel fuel with a low API gravity (increased density) contains more energy per gallon (heating value). Such a fuel would tend to improve fuel economy. However, excessively low API gravity could result in increased engine deposits and smoke. Gravity is not the sole determining factor in predicting such performance properties. Gravity is, however, a useful test in the field, since such tests can be done with a hydrometer. Sometimes gravity is expressed as specific gravity. This measurement is the inverse of API gravity. Fuels of low API gravity will have high specific gravities. In the SI Metric System, these measurements have been replaced by absolute density (for API gravity) and relative density (for specific gravity).

Heating Value (Energy Content)

The heating value of a fuel is a measure of the energy content. Energy content can impact the thermal efficiency of producing power. While ASTM does not specify a heating value, this property continues to be of interest to engine manufacturers. The heating value of a fuel can be expressed in a number of ways such as Joules per kilogram (J/Kg), Joules per liter (J/L), and British Thermal Units/per gallon (btu/gal.). The latter is used here, since it is more commonly understood by the service and repair community. However, since diesel fuel consumption may be expressed in kilograms per kilowatt hour (kg/kw-h) or pounds of brake horsepower per hour (lb/bhp-h), measurements on both a weight and volume basis are of interest to the designers and manufacturers of engines. The typical energy content of No. 2 diesel fuel is 130,000 btu/gal. compared to about 114,200 btu/gal. for gasoline. Fuel economy is discussed in more detail later in the manual.

Thermal Stability / Oxidation Stability

Diesel fuel is usually sold within a few weeks to a few months of its manufacture. Thermal stability is known to degrade during storage. Fuels stored for extended periods can contain contaminants, such as peroxides, from the oxidation of the fuel. These contaminants can increase deposits and lacquer buildup in fuel pumps and injectors, as well as increase filter plugging. Manufacturers use an ASTM test method to predict the thermal stability of diesel fuel.

Microbial Contamination

Certain bacteria and fungi are present in diesel fuel tanks. These “bugs,” which feed on hydro-carbons, if left to grow unchecked, can contribute to filter plugging and corrosion as well as other operational problems. Avoidance of microbial contamination can be achieved through proper “housekeeping” techniques and, when necessary, the use of

biocides.

Housekeeping and Fuel Handling Procedures

A number of fuel handling and storage procedures are employed throughout the petroleum distribution network to avoid contamination. For instance, keeping storage tanks free of water is very important, because water promotes corrosion. Also, since microbial growth generally occurs at the interface of the diesel fuel and tank “water bot-toms,” keeping tanks free of water helps prevent microbial contamination.

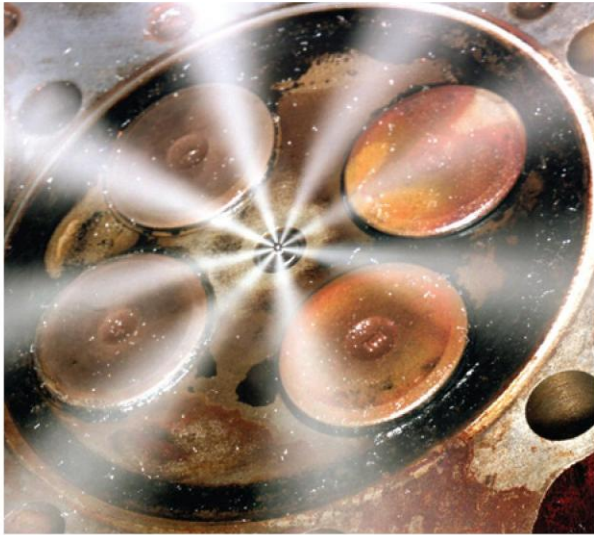
Diesel Fuel Additives

There are a number of commercial diesel fuel additives that the petroleum industry may use to meet and maintain diesel fuel properties. It is appropriate to make a few distinctions with regard to commercial diesel fuel additives. Additives and fuel components are not the same. Components add volume to the fuel and fall into hydrocarbon classes such as naphthenes, isoparaffins and aromatics. Additives, on the other hand, are added at very low levels, usually at the parts-per-million level, and do not add significant volume to the fuel. Also, commercially available additives are generally added only when the need to do so has been determined by the fuel manufacturer. This is as opposed to over-the-counter (OTC) additives, which are added without knowing if there is really a need. While there are always exceptions, OTC additives are of limited use, since the additives are already in the fuel if there is a need for them. There are numerous additives available that are designed to be used in diesel fuel. The US EPA maintains a list of approved additives. Cetane improvers are used to raise cetane numbers and improve ignition quality. The addition of lubricity improvers provides as opposed to over-the-counter (OTC) additives, which are added without knowing if there is really a need. While there are always exceptions, OTC additives are of limited use, since the additives are already in the fuel if there is a need for them. There are numerous additives available that are designed to be used in diesel fuel. The US EPA maintains a list of approved additives. Cetane improvers are used to raise cetane numbers and improve ignition quality. The addition of lubricity improvers provides better lubricity, thereby promoting better lubrication in fuel pumps and injectors. Detergents and dispersants help prevent fuel injector deposits and clean dirty injectors, which promotes better spray patterns.

The diesel fuel injector tip is exposed to very harsh operating conditions which contribute to carbon buildup (injector coking). When this occurs, not only may fuel flow be reduced, but the fuel does not atomize as well.

Figure 1-3

Injector Spray Patterns – Clean versus Deposits



A clean injector such as the one in the photo on the left provides good atomization of the fuel. Once injectors build up deposits, as the injector in the photo on the right, the fuel does not atomize properly.

Courtesy of the Lubrizol Corporation

Figure 1-4

Fuel Economy Penalty From the Use of 1-D in 2-D Diesel

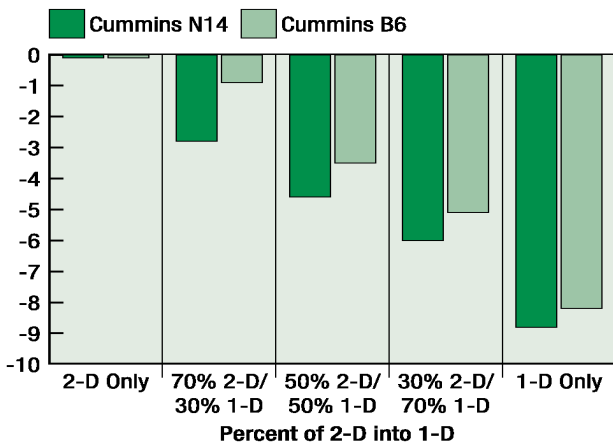
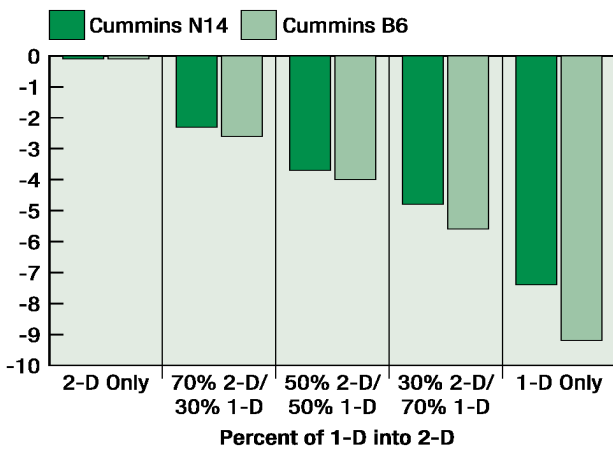


Figure 1-5

Power Loss Penalty From the Use of 1-D in 2-D Diesel



Several types of additives can be used to inhibit oxidation, thereby reducing formation of gum and precipitates. This extends the storage life of the fuel. This group of additives includes antioxidants, stabilizers and metal deactivators. Biocides may be used to reduce the formation of bacteria and fungi, which helps prevent fuel filter plugging.

In colder temperatures, pour point depressants may be added to improve cold flow properties. Cloud point depressants reduce the temperature at which paraffins (waxes) solidify, thereby lowering the cloud point. In some cases, deicers may also be used to prevent fuel line freezing.

The use of low temperature operability additives, such as pour point depressants and cloud point depressants, provides an advantageous alternative to blending with No. 1 diesel. In years past, winterized diesel was recommended for sub-zero temperatures. This

was accomplished by blending No. 1 diesel into No. 2 diesel, which would lower the temperature at which the fuel would start to gel, because of the blend's lower cloud point. Unfortunately, No. 1 diesel has a lower heating value (lower btu content per gallon) than No. 2 diesel, so this approach results in a fuel economy penalty and power loss. As an example, a 50/50 blend of No. 1 and No. 2 diesel may reduce fuel economy by nearly 5 percent and result in a power loss of up to 4 percent (see Figures 1-4 and 1-5) compared to No. 2 diesel.

Cloud point depressant additives can be used to change the size and shape of wax crystals that form at low temperatures. These alterations allow fuel to more readily pass through the wax that may accumulate in the fuel filter without the reduction in power and fuel economy described above for fuel blending.

Other additives include antifoaming agents to reduce fuel foaming during fill-ups, smoke suppressants which reduce smoke by promoting improved combustion and rust preventors that are sometimes added to reduce rust formation in fuel systems and in storage tanks. Emulsifiers and dehazers may be used to promote the rate of water separation from the fuel. Finally, certain dyes may be utilized to identify grades of diesel for regulatory compliance purposes.

There are also additives that may be used for reasons other than fuel vehicle performance. Examples of these include antidrag additives, which are used to improve pipeline flow rates, and conductivity improvers, which improve the dissipation of static charge.

Table 1-3 on the following page recaps the common diesel fuel additives and their relevance to vehicle performance and safety.

Premium Diesel Fuel

The growing population of late-model, high-technology diesel vehicles has led to some companies offering a premium diesel fuel.

The ASTM specifications do not specify what constitutes a premium diesel fuel. Premium gasoline is defined primarily by a higher octane number. Many engine manufacturers and state regulators believe a premium diesel fuel requires more than just a higher cetane number. The National Conference on Weights and Measures (NCWM) has adopted standards for premium diesel fuel. These requirements are set forth in the National Institute of Standards and Technology (NIST) Handbook 130, Engine Fuels, Petroleum Products and Automotive Lubricants Regulation. The requirements of the NIST Handbook 130 are model regulations, not federal requirements. However, many states adopt the requirements of the NIST Handbook 130, or use them as guidance in developing their own regulations.

Their requirements represent input from fuel manufacturers, engine manufacturers and state regulators. The portion of the regulation applying to premium diesel specifies that any diesel fuel designated as premium, super, supreme, plus or premier conform to the following:

Cetane Number: Minimum 47

Low Temperature Operability: A cold flow performance measurement which meets the ASTM D 975 tenth percentile minimum ambient air temperature chart and maps by either the Cloud Point Test or the Low Temperature Flow Test. These requirements apply October 31st through March 31st.

Thermal Stability: A minimum reflectance measurement of 80 percent as determined by ASTM Test Method D 6468 (180 minutes, 150°C).

Lubricity: A maximum wear scar diameter of 520 microns (by ASTM Test Method D 6079 – certain enforcement retesting may be applicable).

The combination of these is meant to ensure that premium diesel provides superior ignition quality and improved low temperature operability characteristics. In addition, the potential for fuel degradation in storage is reduced, and a specific level of lubrication is required. This standard was last amended in 2003. As with ASTM Standards, the NCWM and NIST constantly review their requirements to determine if updates are necessary.

In many states that do not specifically regulate what properties premium diesel should possess, the fuel may only meet one or two of the NIST requirements. However, absent regulations to the contrary, marketers may still designate such fuels a premium grade.

Type and Function of Diesel Fuel Additives

Type of Additive	Function
Cetane Number Improver	Improves ignition quality by raising cetane number, better starts, reduces white smoke
Lubricity Improvers	Improve lubricity, better injector & pump lubrication
Detergents / Dispersants	Clean injectors, better spray patterns
Antioxidants	Extend storage life, inhibit oxidation, reduce gum and precipitate formation
Stabilizers	Inhibit oxidation & extend storage life
Metal Deactivators	Deactivate copper compounds in fuel, thereby promoting longer storage life
Biocides	Inhibit bacterial & fungi growth, help prevent fuel filter plugging
Pour Point Depressants	Low temperature operability, improve cold-flow properties
Cloud Point Depressants (Suppressants)	Reduce temperature at which paraffins solubilize
De-Icers	Prevent fuel line freezing
Anti-Foam Agents	Reduce foaming when filling tanks
Smoke Suppressants	Promote more complete combustion, reduce exhaust smoke
Rust Preventors	Reduce formation of rust in fuel systems & storage tanks
Dyes	To identify types of diesel for regulatory compliance

Diesel Engines and Diesel Fuel Driven by Regulations

Over four decades ago, federal regulations began to control the emissions from automotive spark-ignition engines. This necessitated an increasing level of sophistication in fuel systems, engine management systems, and exhaust after treatment. At the same time, it became necessary to modify gasoline to accommodate these more sophisticated systems. More recently, a similar transition has been occurring with diesel engines and diesel fuel.

Environmental Regulations

The EPA set its first limits for emissions from heavy-duty diesel engines in 1971. In 1985, the U.S. EPA adopted stringent emission standards that took effect in 1991 and 1994. In 1990, the EPA imposed limits on diesel fuel sulfur content to help buses and trucks meet these standards. These limits took effect in 1993. Then in 2000, the EPA developed a comprehensive national control program that, beginning with the 2007 model year, regulates the heavy-duty vehicle and its fuel as a single system. The EPA also required a 97 percent reduction in the sulfur levels of 80 percent of on-road diesel fuel in mid-2006. This level will apply to all on-road diesel fuel effective December 2010. It should be noted that the State of California sets its own limits on diesel emissions. They are generally the same as federal requirements, although they are sometimes more restrictive or may take effect at

an earlier date than federal requirements. For instance, CARB has controlled the aromatic content of diesel fuel since 1993 but allows alternate formulas to achieve compliance. The exhaust components of interest in diesel exhaust are different than those in spark-ignited engines. Likewise, the units of measurement are different for heavy-duty diesel engine emissions. The regulated pollutants of interest are carbon monoxide (CO), hydrocarbons (HC), oxide of nitrogen (NO_x) and particulate matter (PM). For a diesel engine, CO and HC are fairly low. The primary focus is on NO_x and PM.

Light-duty vehicle emissions of gasoline-powered and diesel-powered vehicles are measured in grams per mile. These units of work are not appropriate for heavy-duty diesel engines. Diesel engines may be used in several different brands of vehicles or equipment. Also, there are much larger differences in the size and loads of diesel engines. In the case of diesel engine emissions, the unit of measure is grams per brake horsepower hour (g/bhp-hr), which provides a single measurement standard applicable for heavy-duty engines of all sizes.

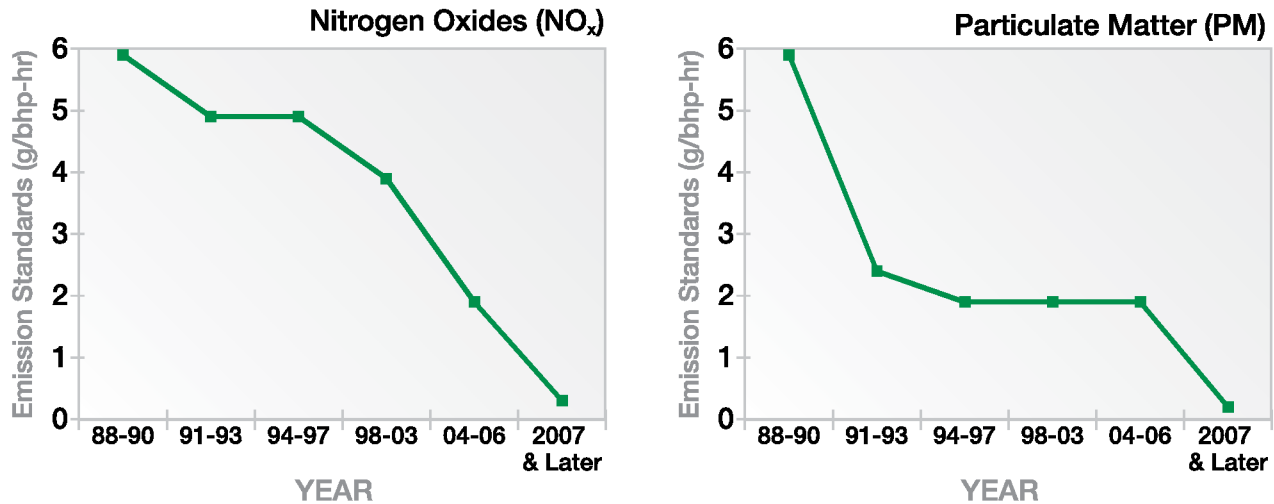
The table below provides an example of the ever-tighter standards on heavy-duty highway diesel engine emissions during the 1990s.

Historical Federal Heavy-Duty Highway Diesel Engine Emission Standards				
Year	CO (g/bhp-hr)	HC (g/bhp-hr)	NO _x (g/bhp-hr)	PM (g/bhp-hr)
1990	15.5	1.3	6.0	0.60
1991-1993	15.5	1.3	5.0	0.25
1994-1997	15.5	1.3	5.0	0.10
1998+	15.5	1.3	4.0 ¹	0.10 ²

1. This standard had to be met by 1996 in California.
 2. Urban buses must meet a 0.05 g/bhp-hr PM Standard.

Figure 2-1

United States Heavy-Duty Truck Engine Standards, (GVW>3.5t) Beginning with the 1988 Model Year



These charts demonstrate the emissions requirements for NO_x and PM for the 1998 through 2012 Model Years.

More stringent NO_x and PM standards were implemented in 2004 and 2007, as depicted in the above figure.

A similar trend exists for light-duty vehicles sold in the U.S. Beginning with the 2004 model year, diesel-powered passenger vehicles were required to meet the same PM and NO_x standards as their gasoline-powered counterparts.

As noted earlier, California often adopts similar or slightly more restrictive standards, or may adopt standards earlier. For instance, the heavy-duty diesel engine NO_x standard of 4.0 g/bhp-hr was adopted by the U.S. in 1998, but it was adopted two years prior to that in California.

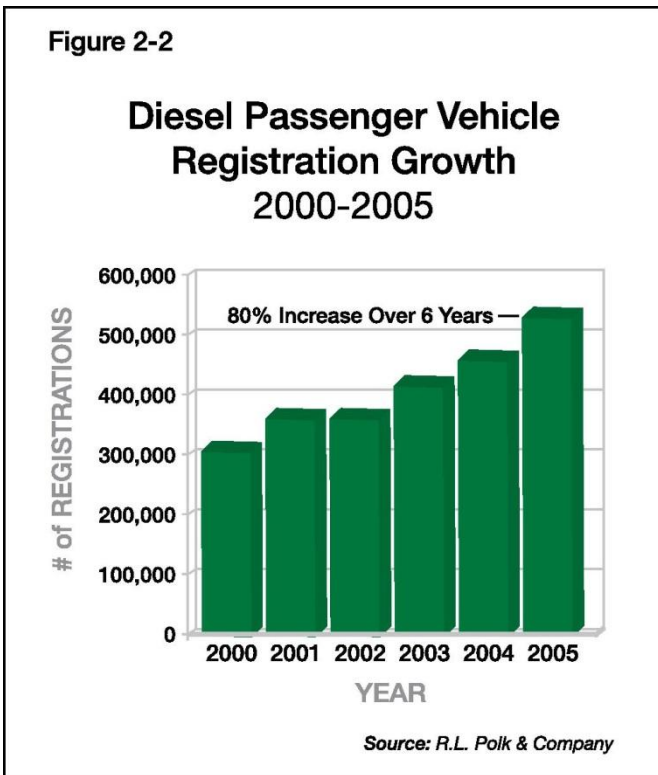
Also important to note is that while this manual focuses primarily on on-highway diesel engines and fuels, emissions standards on off-road diesel engines are also being tightened. In 1997, the EPA finalized emissions standards for new and remanufactured locomotives and locomotive engines. In 1999, the EPA adopted emission standards for new, large marine engines. Similarly, California's Air Resources Board (CARB) has been adopting standards for off-road diesel equipment. In July 2007, CARB announced a rule which will require the addition of soot filters on existing equipment and encourage replacement of older, dirtier engines with newer emissions-controlled engines.

More stringent requirements are forthcoming. Beginning in 2010, the U.S. will require on-board diagnostics (OBD) on heavy-duty truck and bus engines. This requirement will be phased in between 2010 and 2016. The OBD system will monitor all systems and parts that

could affect emissions, including the fuel system, catalytic system, EGR and particulate filters.

Past, present and future regulations have all stimulated a dramatic change in diesel engines, fuel systems and after-treatment technologies. Once viewed as dirtier than their gasoline counterpart, diesel engines are receiving renewed attention because, on a unit-of-work basis, diesel fuel emits fewer greenhouse gases than gasoline. Since NOx and PM have now been lowered dramatically, diesel engines and the fuels that power them can be part of the environmental solution instead of being part of the problem. For instance, a newer model heavy-duty truck, even of 1998 vintage, emits only about 27 percent of the NOx and 10 percent of the PM of pre-emission-control trucks. A new 2007 diesel truck will emit one-sixth of the soot of one produced in 1998. By the 2010 model year, NOx emissions will have been reduced by 90 percent compared to the 2004 level.

In the light-duty vehicle segment, the clean and quiet diesel engines that power passenger vehicles have resulted in higher sales of these vehicles in the U.S. Annual registrations in 2005 were up 80 percent compared to those in 2000.



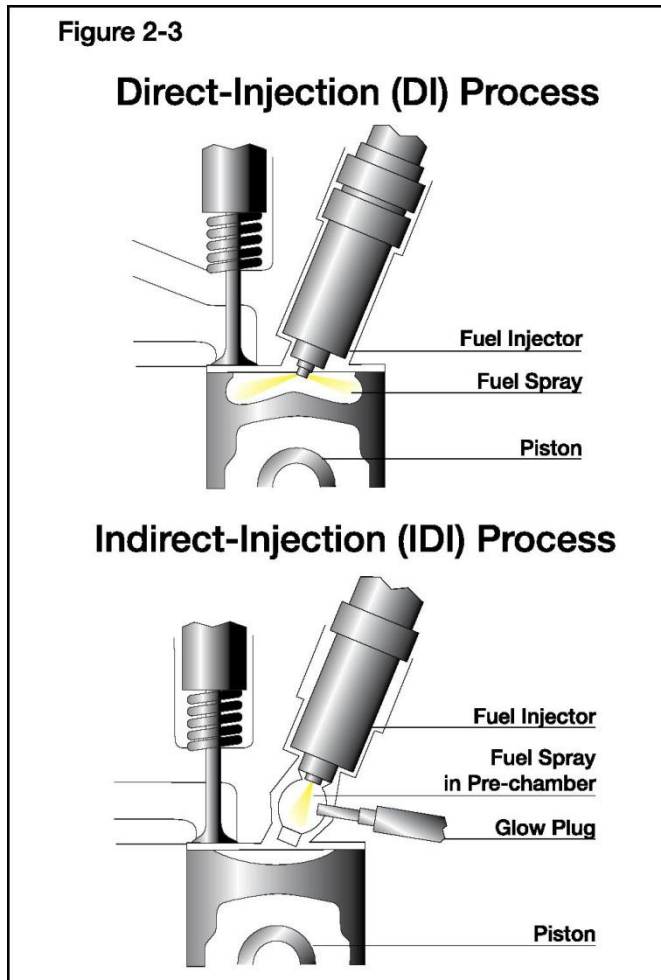
Strategies for Compliance – Engine Technology

In order to achieve these more stringent standards, the diesel industry has had to focus on several strategies to achieve compliance. Initially, this effort focused on better management of fuel flow and the combustion process. The strategies vary somewhat between passenger vehicles (light-duty) and large trucks (heavy-duty) due to different emission standards.

Fuel Injection Basics

Fuel injectors must produce a fine spray that will vaporize rapidly to ensure fast mixing of the fuel vapor and air. Placement of the injector in the cylinder head is carefully calculated to determine the best position and angle to enhance fuel vapor and air mixing. The design of the piston top and intake ports can help create a swirling motion of the air / fuel mixture in the cylinders.

Because the fuel is injected into an environment of hot compressed air, it must be injected late in the compression stroke, just before the piston reaches top dead center (TDC). This necessitates injection under very high pressures, as much as 2000 bar (29,000 psi).



There are two basic fuel injector designs, each with various subcategories. In a direct-injection (DI) system, the fuel is introduced directly into the cylinder. DI engines usually have compression ratios in the range of 15:1 to 18:1. Indirect-injection (IDI) injects the fuel into a small pre-chamber between the injector and the cylinder. IDI engines typically operate at higher compression ratios, in a range of 20:1 to 24:1. IDI systems create a more rapid mixing of the fuel and air. There are, however, some drawbacks. IDI systems lose more heat during compression. This is why IDI engines have higher compression ratios to reach the necessary air temperature. This usually results in fuel economy that is significantly lower than

a DI engine. IDI engines may also be hard to start, which is why glow plugs are installed in the pre-chamber.

The primary interest in IDI systems is their ability to operate at higher engine speeds when there is less time to inject and mix the fuel per engine cycle.

Fuel Injection Systems

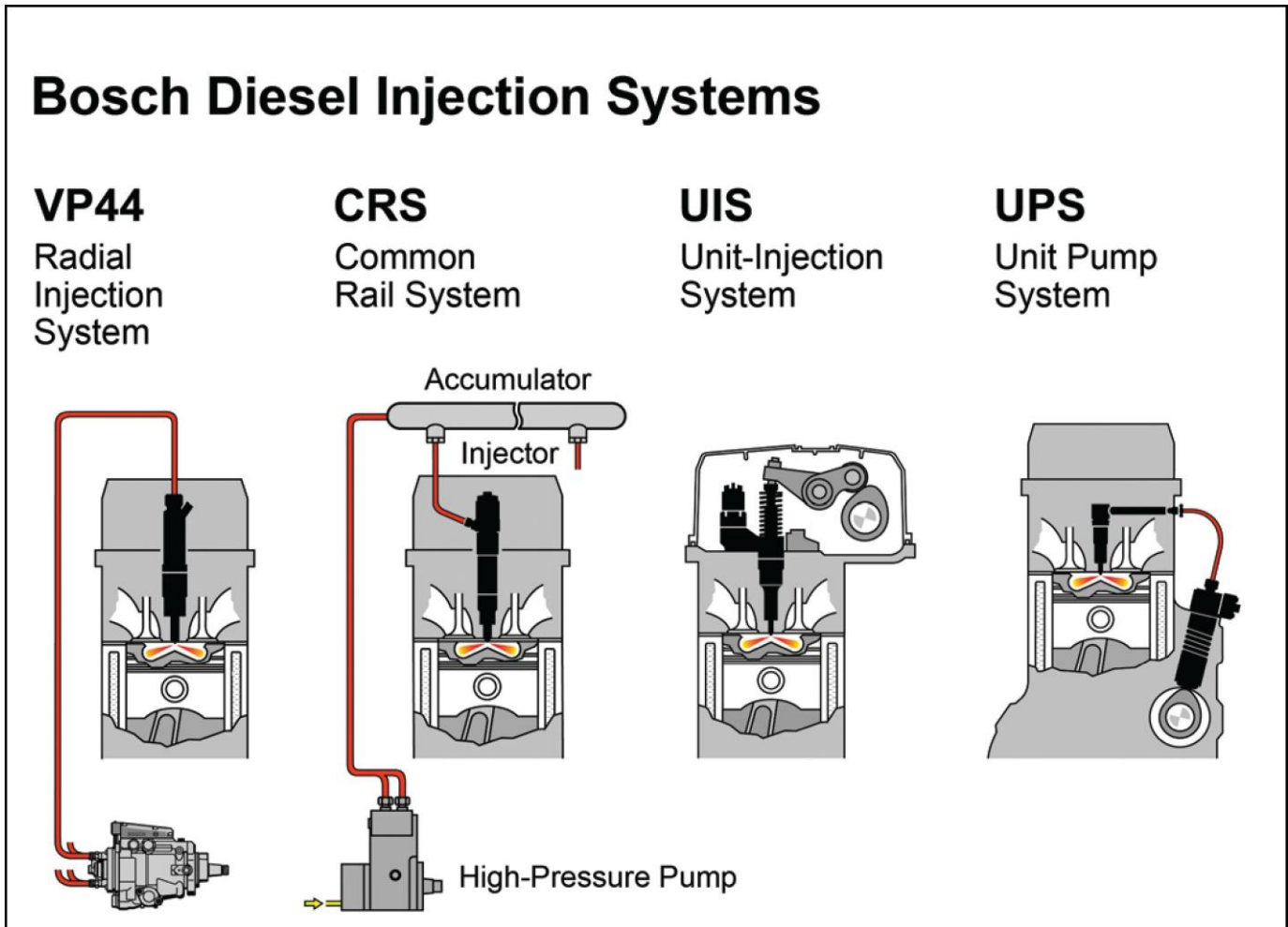
Among direct injection systems, there are several design options. These include the radial distributor injection system, the common rail system, the unit injector system and the unit-pump system. These systems are depicted in the following figures.

The distributor injection systems are typically found in passenger cars and light- to medium-duty trucks. Distributor injection systems for DI systems reach an injection nozzle pressure of up to 1,950 bar. These systems may be mechanically controlled or electronically controlled.

The common rail system's distinguishing feature is that the injection pressure is

independent of engine speed and the volume of injected fuel. Pressure is generated by a high-pressure pump. The type of pump and control system varies between passenger vehicles and commercial vehicles. These systems operate at pressures of 1,600 bar or higher.

Earlier this decade, Bosch introduced the third generation of its common rail system for diesel engines. This high-pressure system operates at 1,600 bar and utilizes piezoelectric

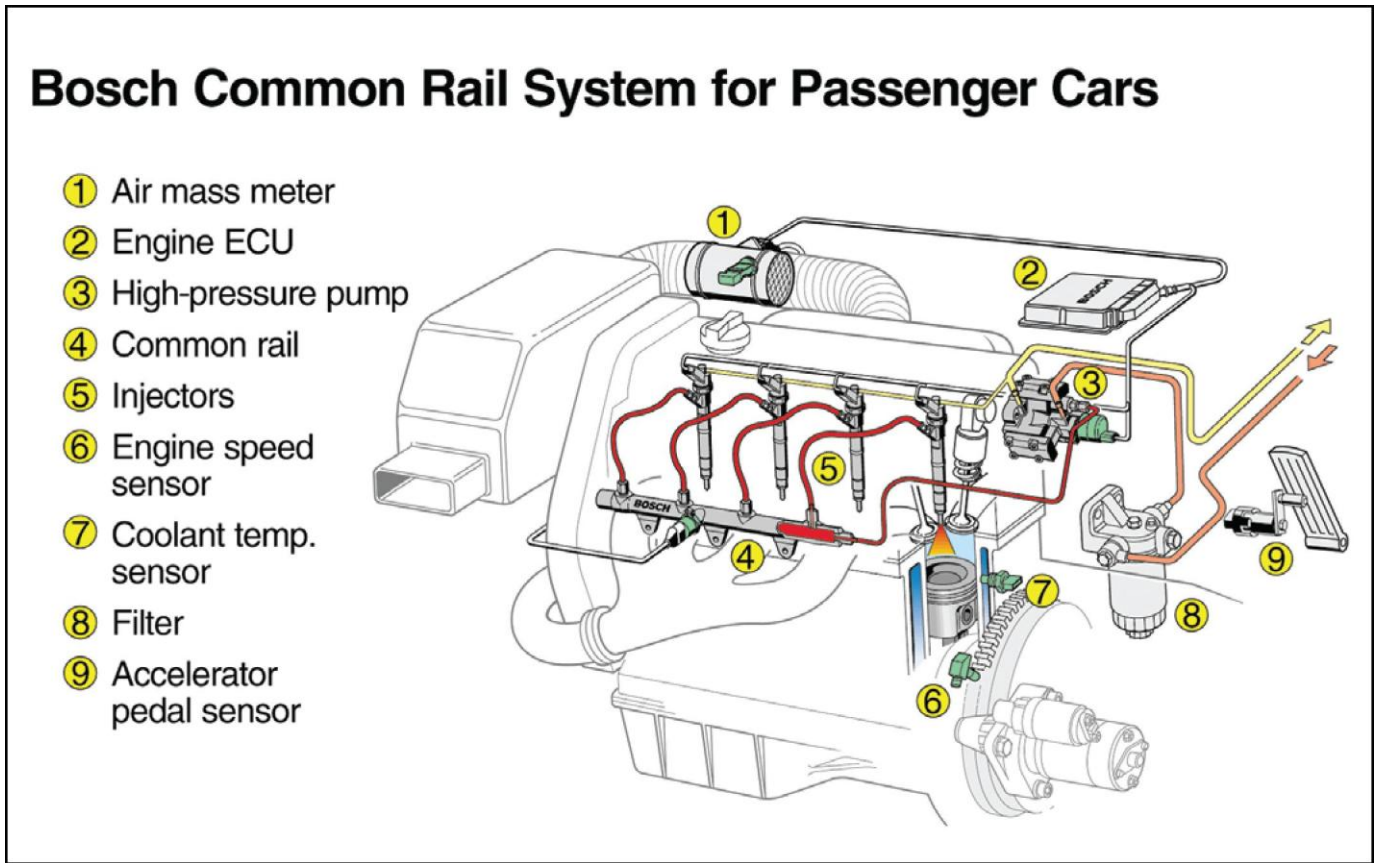


fuel injectors for precise fuel metering. Emissions are reduced by 15-20 percent, while fuel economy is improved. Also, especially important for passenger vehicles, noise is reduced (see discussion on piezoelectric injectors later in this section).

Newer versions of this system operate at 1,800 bar. Denso Corporation has also introduced an 1,800 bar common rail injection system, using piezoelectric injectors for passenger cars. Delphi's Multec common rail injector system uses a patent-ed technology called Accelerometer Pilot Control (APC). APC monitors combustion quality in the cylinder and provides input to the engine management system, allowing calibrations optimized to operating conditions. Although this system does not use piezoelectric injectors, Delphi is developing such injectors. These and other manufacturers also continue with their

development programs, constantly trying to improve fuel management and combustion. Consequently, there are more types of diesel fuel injector systems available today than only a few years ago.

Unit-Injector systems can be found in both commercial vehicles and passenger cars. In commercial engines, the unit-injector is a complete module installed in the cylinder head. It has an integrated high-pressure pump and solenoid valve. As depicted in the preceding



figure, this system is operated by a rocker arm, which is driven by an injection cam on the camshaft. Injection pressures on the unit-injector system can reach 2,000 bar. For passenger cars, the system is more compact and employs a mechanical-hydraulic pilot injection (double triggering of the solenoid valve) across the engine's operating range to reduce combustion chamber noise.

The unit pump system is also found in both passenger cars and commercial vehicles. The unit pump system is similar to the unit-injector system. This system is also placed directly in the engine cylinder block, but is operated by roller tappets on the engine's camshaft. This system can also operate at 2,000 bar. The passenger car system is similar, but operated by rocker arms driven by an overhead valve (OHV) camshaft.

These are very basic descriptions of typical systems. Far more detailed descriptions are available in other publications (See Appendix B – Additional Information Sources).

Fuel injection systems may employ conventional magnetic injectors or, increasingly, the piezoelectric injector. Piezoelectric injectors utilize a special ceramic material with a crystalline structure. The crystalline structure responds when voltage is applied and allows the unit to be controlled up to five times faster than a magnetic injector. This enables much more precise metering of the fuel, allowing multiple partial injections (up to six injections per cycle). These injections consist of pilot-injections, the main-injection and post-injection. The pilot-injection produces softer combustion, eliminating the “diesel knock” noise at cold start. Post-injection improves the combustion event, thereby reducing soot particles. As emission standards have become more stringent, there has been a major move to piezoelectric injectors.

With ever-more-precise metering systems, it is critical that diesel fuel properties are controlled and consistent.

Turbocharging

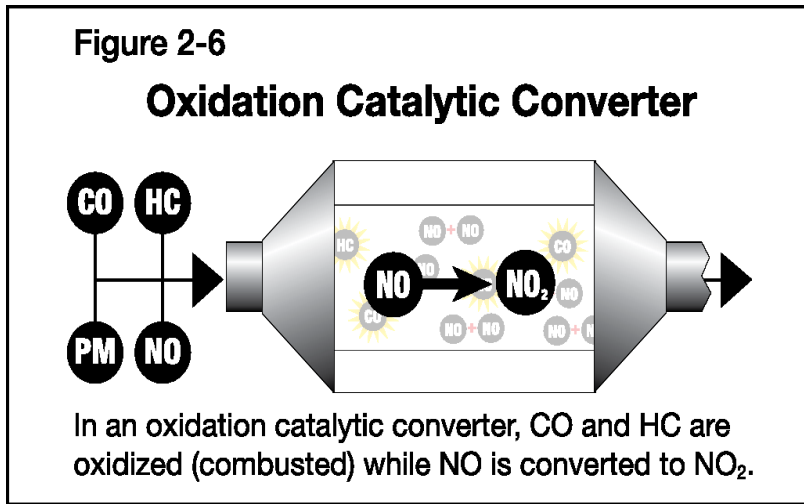
While a great deal of effort has been directed at emission controls, manufacturers are also spending a great deal of effort to improve fuel efficiency, increase power and reduce noise. One way to accomplish this is turbocharging. The latest innovation with turbocharging is the dual-stage turbo (sometimes called series turbo-charging). Such systems use two turbochargers, each of which operates over specific portions of the engine range to optimize performance. These systems can increase specific output to 100 hp per liter of displacement and increase torque as much as 140 lb-ft. Obviously, packaging of the extra turbo can present challenges, and these systems add significant expense, which tends to limit their use to higher-priced vehicle categories. Use of these systems is also promoting development of alloy pistons to deal with the resulting higher peak cylinder pressures. Variable Geometry Turbochargers (VGT), which are currently more common, accomplish much the same effect as dual stage turbocharging.

EGR: Exhaust Gas Recirculation (EGR) is one of the most effective strategies for reducing NO_x emissions. The EGR system recirculates spent combustion gases into the intake system, which dilutes the oxygen concentration and increases the heat capacity of the air fuel charge. EGR coolers (after coolers) can be used to pre-cool the exhaust gases to reduce combustion temperatures, further reducing NO_x emissions. EGR may, however, increase engine wear. Other drawbacks are that EGR can negatively impact fuel economy and increase PM emissions. Work continues to find the optimum balance to decrease NO_x emissions without increasing PM emissions.

In addition, manufacturers are working on variants of EGR. For instance, in early 2006, Caterpillar announced it had developed a Clean Gas Induction System that draws clean

inert gases from downstream of the particulate filter and injects them into the air intake. Since this gas is soot-free, it doesn't contribute to the engine wear that would result from the use of cooled EGR gases. The low intake manifold gas temperatures reduce NOx and

Caterpillar expects that the typical 3 percent fuel economy loss associated with cooled EGR will be eliminated.



After-Treatment Technologies

With the more stringent emission requirements that took effect for the 2007 model year, more is required than better control of fuel combustion, air intake and cooled

EGR Systems. Engine-out emissions must undergo various forms of after-treatment. The following provides an overview of the more common after-treatment systems.

Diesel Oxidation Catalytic Converters are already in widespread use. In this system, the engine-out exhaust emissions of PM, NO, CO and HC enter the converter. The CO and HC are reacted with a catalyst that further reduces emissions while the NO is converted to NO₂.

The oxidation catalytic converter is placed as close to the engine as possible in order to reach operating (light-off) temperature as quickly as possible. A sensor is placed post converter as a feedback device to the engine management system to determine that the system is functioning properly.

There is also NOx Storage Catalytic Converters (SCC), commonly referred to as NOx adsorbers or NOx traps. These converters are placed downstream of the oxidation catalytic converter. The SCC has a special coating that traps NOx from the exhaust gas. The unit has two different operating modes. In normal lean operations ($\lambda > 1$), NO is oxidized to form NO₂ and via nitrate formation is stored in the converter on an alkaline metal oxide.

The second operations mode is the regeneration mode. This mode accomplishes the periodic purging of the NOx accumulator. This necessitates rich exhaust gases ($\lambda < 1$), which dissolve the nitrate bond and reduce it to nitrogen via a noble metal coated converter. This entire operating mode can occur in 30 to 60 seconds, with actual regeneration requiring only a few seconds. These systems require numerous temperature and pressure sensors to identify when regeneration is necessary. NOx emissions can be

reduced by as much as 85 percent.

As discussed later in this section, it is the development of these more sophisticated emission control systems that has led to the need for very low sulfur levels in diesel fuels.

Engine Oil and Coolant

Although this manual's focus is on diesel fuels, it is important to mention that a new engine oil designation has been developed for 2007 model year engines and exhaust after-treatment systems. In February 2006, the American Petroleum Institute's (API) Engine Oil Committee issued requirements for the newly designated engine oil category API CJ-4. API CJ-4 engine oil meets the highest standards developed to date, and it will have lower ash levels to meet 2007 requirements and to ensure that diesel particulate filters can achieve the EPA's requirement of 150,000 miles between service intervals.

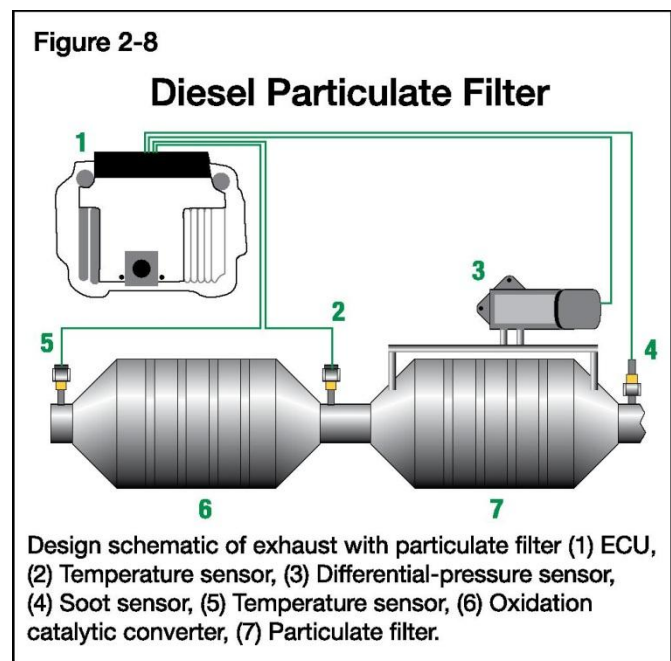
Fleet operators will need to decide what engine oils they wish to keep in inventory. One option is to stock an API CJ-4 for 2007 model year vehicles (or newer) and continue to stock the CI-4 Plus engine oil for older models. Another option is to simply use API CJ-4 in all vehicles. Due to the increased operating temperatures and correspondingly high temperature of engine oil and coolant, and in some cases a higher level of EGR gases, oil change intervals are more important than ever. Some fleet operators are even reviewing and updating their engine oil analysis programs.

Also, because of resultant higher engine oil temperatures, some fleet operators are reevaluating the use of premium extended-life coolants which can reduce coolant temperatures.

Retrofit Technologies

One thing somewhat unique with diesel engines/vehicles is the ability to retrofit older systems with newer technology. Diesel engines/ vehicles have useful lives many times that of spark-ignition engines. New technologies would normally not have an

immediate impact, since the fleet takes a long time to turn over. But a number of retrofit technologies are available for older diesel engines/vehicles. The EPA has a voluntary retrofit program. Several municipal fleets have adopted, or are considering adopting,



retrofit strategies.

There are a number of retrofittable technologies. High Efficiency Diesel Particulate Filters are available, along with the low-pressure EGR systems to use in conjunction with them. Diesel Oxidation Catalysts can also be retrofitted, as can Selective Catalytic Reduction and NOx Adsorbers.

Retrofit equipment must, however, be approved by the U.S. EPA.

Compliance Strategies – Diesel Fuel

Sulfur is a natural component of crude oil and products refined from it. Sulfur dioxide (SO₂) is produced when fuels containing sulfur are com-busted. Sulfur dioxide is a major precursor to acid rain. It is also a lung irritant. Furthermore, it can reduce the effectiveness of exhaust after-treatment devices. In 1993, regulations from the EPA and the CARB went into effect. The EPA set a maximum of 500 ppm for on-road diesel fuel, while the CARB required the same level for both on-road and off-road diesel fuels. This fuel was referred to as low-sulfur diesel. The CARB also limited the maximum aromatic content to 10 volume percent, but provided an alternative compliance mechanism which allows refiners to formulate fuels that, though higher in aromatics, would meet the same or lower emissions of a fuel containing 10 volume percent aromatics. However, for the newest technology exhaust after-treatment devices to operate effectively, sulfur must be kept to much lower levels.

In mid-2006, the EPA required that the majority of diesel fuel produced or imported for on-road use contain no more than 15 ppm sulfur, and this fuel is referred to as Ultra-Low Sulfur Diesel (ULSD). All on-road diesel and most off-road diesel will be required to meet a 15 ppm standard beginning in 2010, with locomotive and marine fuels produced by most refiners required to meet the standard in 2012.

Owners of 2007 model year or newer vehicles must use ULSD, because fuels with higher sulfur levels than ULSD can render their advanced exhaust after-treatment devices ineffective. Model year 2006 and earlier models of on-road vehicles may be fueled with low sulfur diesel where it is still available. Currently 80 percent of on-road diesel fuel must be ULSD. By December 1, 2010 all on-road diesel must be ULSD. The sulfur content of diesel may be identified by decals on the fuel dispenser (see below).

The hydro-treating process that is used to reduce sulfur levels in diesel will also reduce the level of naturally occurring components that provide lubrication properties to diesel fuel. Diesel fuel manufacturers will add the necessary additives to ensure that ULSD meets the lubrication requirements of ASTM D 975. The hydro-treating process can also reduce the

energy content of the fuel by 1 to 2 percent. Under normal operating conditions, this small change should not affect overall power, but may reduce fuel economy slightly.

Renewable Fuels Standard

In addition to environmental regulations, there are also energy regulations that are causing changes in diesel fuel composition. The 2005 Energy Policy Act requires that an ever-increasing amount of the Nation's transportation fuel supply come from renewable sources, such as ethanol and biodiesel. The use of biodiesel is increasing so rapidly that the next chapter is dedicated entirely to that subject.



Normally, the diesel fuel sold at the primary vehicle island is ULSD. Low sulfur diesel grades with up to 500 ppm sulfur may be available at some locations through December 2010. It is illegal to use anything other than ULSD in the case of 2007 model year and newer vehicles because using higher sulfur level fuels will render exhaust after-treatment devices ineffective or, at minimum, less effective.

Biodiesel and Biodiesel Blends

The Energy Policy Act of 2005 requires an ever-increasing amount of the Nation's transportation fuel supply to be from renewable sources. While this legislation does not require the use of a specific renewable fuel, at present the focus has been on ethanol (for use in spark-ignition engines) and biodiesel. In 2006, actual production of biodiesel reached only 225 million gallons. By mid-2007, U.S. production capacity of biodiesel reached 1.3 billion gallons, with another 1.8 billion gallons of capacity under construction. This will bring nameplate production capacity of biodiesel to over 3 billion gallons per

year in the near future.

Biodiesel and Biodiesel Blends

Biodiesel can be made from a variety of sources including the oil from oil seeds such as soybeans, palm kernel and canola, to name only a few. It can also be made from animal fat-based feedstocks such as beef tallow and recycled cooking oils (e.g., french fryer oil). In the United States most plants are set up to run soybean oil as the feedstock, although some plants can run multiple feedstocks, including corn oil. The selection of soybean oil for U.S. plants is simply a reflection of the abundant U.S. supply of soybeans. In other countries, such as India and Malaysia, other feedstocks such as palm oil are used due to their greater availability in those nations.

Regardless of the feedstock used, the process to produce biodiesel is essentially the same. From a chemical standpoint, vegetable oils are triglycerides of fatty acids and possess properties that are not desirable in diesel fuel. For instance, they may cause injector coking. While diesel engines running on French fryer oil may make for a great media story, it does not make for great diesel fuel quality. Almost all engine manufacturers recommend against the use of raw pressed, or partially refined, vegetable oils that have not been processed through transesterification.

In order to overcome the unfavorable properties of vegetable oils and animal fats, they are reacted with an alcohol (usually methanol, but ethanol or other alcohols could be used). The triglycerides are combined with methanol and reacted with a catalyst to yield biodiesel and glycerin. Essentially this reaction uses the alcohol to remove the glycerin, which is undesirable in diesel fuel. This process is called transesterification, and the resulting biodiesel is technically a Fatty Acid Methyl Ester (FAME) when methanol is the alcohol used. The resulting biodiesel has chemical and physical properties similar to conventional diesel fuel.

Although biodiesel can be, and is in some cases, used as a fuel by itself, it is more commonly used as a blend component in conventional diesel. Biodiesel levels typically range from 2 volume per-cent (B2) to 20 volume percent (B20) of the total biodiesel blend, with the remainder of the blend being conventional diesel.

While biodiesel production and use are increasing significantly in the U.S. it has been widely available only over the past few years. Engine and fuel system manufacturers have been engaged in various research projects to determine which biodiesel blend levels are appropriate for their products. In addition, as biodiesel blend sales have increased, manufacturers are rapidly gaining field experience to aid in such decisions.

ASTM Specifications

As is the case for diesel fuels, ASTM International has a specification for biodiesel. That specification is ASTM D 6751- Standard Specification for Biodiesel Fuel Blendstock (B100) for Middle

Distillate Fuels

This specification applies to biodiesel for use as a blend component in diesel. ASTM has not yet developed a specification for blends such as B5 and B20, but expects to do so in the future.

ASTM D 6751 includes limits on several of the same properties that ASTM D 975 requires for No. 2 diesel fuel. However, there are additional property requirements for biodiesel.

Additional requirements for biodiesel include a maximum limit of 5 ppm for calcium and magnesium (combined). Calcium and magnesium may be present as abrasive solids or soluble metallic soaps, so their presence must be limited, because abrasive solids would contribute to injector and pump wear as well as piston and ring wear. Soluble metallic soaps contribute to engine deposits. Calcium and magnesium may also collect in particulate filters, increasing back pressure, and may result in the need for shorter service intervals.

Alcohol content is limited in one of two manners. Either the alcohol content must not exceed 0.2 mass percent, or the flash point must be 130° C minimum. This is done to ensure that the alcohol used in the transesterification process is properly removed from the fuel.

While ASTM D 975 has a limit on ash, ASTM D 6751 specifies a “sulfated ash” maximum of 0.02 mass percent. In addition to limiting abrasive solids and soluble soaps (see above), this specification. limits any unremoved catalysts from the biodiesel production process. Carbon residue is limited to 0.05 mass percent, but a different test method is used than that for No. 2 diesel fuels. An acid number specification limit of 0.50 maximum mg KOH/g is placed on biodiesel to control the level of free fatty acids or processing acids. High acidity can increase fuel system deposits. It may also increase fuel system corrosion. High acid values may also be an indication of fuel degradation from oxidation. Free glycerin is limited to 0.02 mass percent and total glycerin is limited to 0.24 mass percent. High levels of free glycerin can contribute to injector deposits and clogging of the fuel system. Free glycerin can also build up in the bottom of storage tanks. The total glycerin includes free glycerin plus any glycerin content of any unreacted or incompletely reacted oils or fats. Low levels of total glycerin confirm a high conversion rate of oils and fats. High levels of total glycerin can contribute to injector deposits and fuel filter plugging and could impact

low-temperature operability.

A limit is placed on phosphorus, because it can damage exhaust after-treatment catalysts. The ASTM maximum limit for phosphorus in biodiesel is 0.001 mass percent (10 ppm). U.S. biodiesel (soybean oil based) has routinely been in the 1 to 2 ppm range, but biodiesel from other feedstock sources could contain higher phosphorus levels.

Sodium and potassium may be present as abrasive solids or soluble metallic soaps, resulting in problems similar to those described for sulfated ash. Finally, an oxidation stability rating of 3 hours minimum under specified test conditions is required. This test provides an indication of the storage life of biodiesel, which is known to degrade more quickly than standard diesel fuel. The remainders of the requirements are similar to those for standard diesel fuel. Table 3-1 lists the ASTM D 6751 requirements for biodiesel and a brief recap of why they are necessary.

ASTM Requirements for Biodiesel (B100)

Property	Units	Grade S15 Limits	Importance
Calcium and magnesium, combined	ppm (µg/g)	5 max	To protect against wear of injectors, pumps, pistons & ring and also engine deposits & premature failure of particulate filters
Flash point	°C	93 min	Safety during fuel handling & storage
Alcohol control - One of following must be met:			To ensure alcohol from manufacturing process is properly removed
1. Methanol content	% mass	0.2 max	
2. Free water	°C	130 min	
Water and sediment	% volume	0.050 max	Filter plugging, injector wear, increased corrosion
Kinematic viscosity, 40°C	mm ² /s	1.9-6.0	Injector wear & spray pattern, pump wear, filter damage
Sulfated ash	% mass	0.020 max	Limits unremoved catalyst from fuel to protect against wear in injector pumps, pistons, rings & reduce engine deposit
Sulfur	% mass (ppm)	0.0015 max (15)	To protect emissions control equipment
Copper strip corrosion		No. 3 max	Protect copper, brass, bronze fuel system parts
Cetane number		47 min	Measure of ignitability (ignition quality)
Cloud point	°C	ReportD	Low-temperature operability
Carbon residue	% mass	0.050 max	To reduce deposits in fuel system and engine
Acid number	mg KOH/g	0.50 max	Protect against fuel system deposits & corrosion
Free glycerin	% mass	0.020	Injector deposits & fuel system clogging
Total glycerin	% mass	0.240	Injector deposits, filter plugging & low-temperature operability
Phosphorus content	% mass	0.001 max	Protect catalysts in exhaust after-treatment devices
Distillation temperature, 90% recovered	°C	360 max	Affects fuel economy and power under varying loads/speeds
Sodium and potassium, combined	ppm (µg/g)	5 max	Limits unremoved catalyst from fuel to protect against wear in injector pumps, pistons, rings & reduce engine deposit
Oxidation stability	hours	3 min	Storage stability, prevent degradation of fuel

Comparison of Selected ASTM Specifications of No. 2 Diesel and Biodiesel

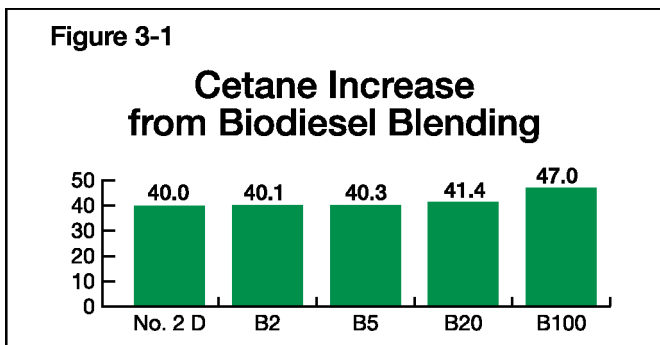
Property	No. 2 D	B100
Flash point °C min	52	93
Water and sediment, % vol	0.05	0.05
Kinematic viscosity mm ² /s at 40°C		
min	1.9	1.9
Sulfur ppm (µg/g max)	15	15
Copper strip corrosion	No. 3 max	No. 3 max
Cetane number minimum	40	47
Cloud point	-	-
Carbon residue maximum % mass	0.15	0.05

The previous table lists property limits for B100, and the text preceding it discusses property limits unique to the biodiesel specification. It also includes property limits similar to the No. 2 diesel specification for certain categories.

The table lists a comparison of ASTM specified

properties for No. 2 Diesel and B100. The Flash Point for B100 is a minimum 93° C compared to 52° C for No. 2 diesel. This still allows biodiesel to fall under the nonhazardous category under National Fire Protection Association codes.

The only other major differences between the two fuels in the above table are viscosity and cetane. In the case of viscosity, it is desirable to express a range. Minimum viscosity is specified because of potential loss of power due to injector pump leakage and injector leakage. Maximum viscosity is limited because of practical considerations of the engine size and design, as well as the operating parameters of the injection system. The upper limit of viscosity for biodiesel is higher than for No. 2 diesel. Blending biodiesel which has a viscosity rating near the maximum limit could cause the biodiesel blend to exceed the maximum viscosity limit specified for No. 2 diesel, especially for higher concentration biodiesel blends.

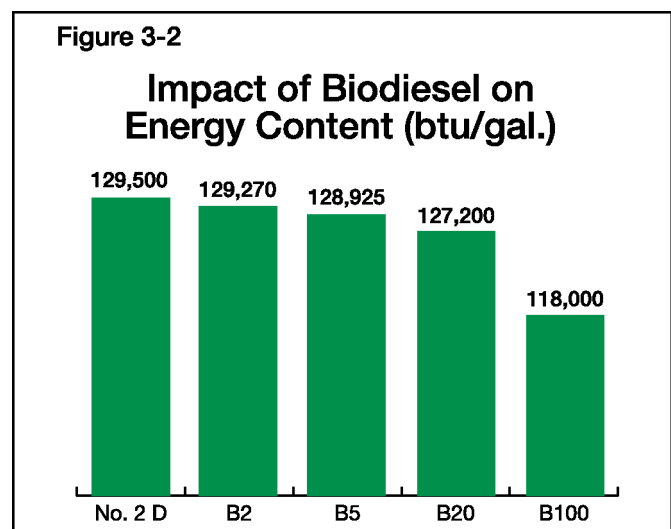


The cetane number requirement for biodiesel is 47 compared to 40 for No. 2 diesel. The impact this has on the blend depends on the blend level. For B2, the cetane number only increases to 40.1 and for B5 to a still-modest 40.3. For B20, the cetane number increases to 41.4.

Other Properties of Interest

There are other properties of interest which are not specified in the ASTM Specification. These include the following:

Energy Content: No. 2 diesel has a btu content of approximately 129,500 btu/gal. Biodiesel's energy content is approximately 118,000 btu/gal. The impact this has on the biodiesel blend depends on the blend level. The following figure depicts the energy content of different blend levels using 129,500 btu/gal. for No. 2 diesel and 118,000 btu/ gal. for B100.



As the graph shows, the decrease in energy content for B2 is less than 0.2 percent and for B5 still below 0.5 percent. For B20 blends, the energy content is 1.8 percent lower. Such modest changes should not result in

noticeable power loss or significant changes in fuel economy. On the other hand, B100 has about 8.9 percent lower energy content, which may result in lower power and noticeably lower fuel economy.

Lubricity

There is not currently a lubricity specification in ASTM D 6751. However, biodiesel is known to improve the lubricity of No. 2 diesel. In fact, biodiesel is often added at the 2 volume per-cent level to improve the lubricity of No. 2 diesel, making B2 probably the most common biodiesel blend. The lubricity of No. 2 diesel is limited to 520 microns of wear in the HFRR test, while B100 typically achieves levels of below 300 microns.

Cloud Point/Pour Point

As noted earlier, there are no limits set for cloud point or pour point for No. 2 diesel. It is known that B100 has a cloud point about 7°C higher than No. 2 diesel and a pour point of 20°C to 25°C above No. 2 diesel. In other words, the low-temperature operability of B100 is poorer than that of No. 2 diesel. This is usually not noticeable at the B2 and B5 blend levels. However, at higher levels, biodiesel blenders may need to use additives to improve low-temperature operability.

It is important to again note that information presented here is based largely on soy methyl ester (SME). However, biodiesel (FAME) can be made from a variety of feedstocks, and the different feedstocks may result in biodiesel with slightly different properties. For instance, SME can tolerate lower temperatures than animal-based biodiesel before reaching its cold filter plug point. Similarly, the cetane number can vary. This is largely a function of the carbon content of the final FAME, which can vary with feedstock type. However, for the B2 to B20 blend levels, these differences are rarely perceptible. ASTM D 6751 is intended to apply to all biodiesel produced from any feedstock.

Other Fuel Quality Considerations

Biodiesel (B100) possesses certain properties that make it more sensitive to storage conditions than No. 2 diesel. This makes proper storage, transport and blending of biodiesel very important. Biodiesel is hygroscopic, meaning it absorbs water. Over a period of time the water content of biodiesel can rise to its saturation point (around 1200 ppm). This can increase the risk of corrosion as well as microbial contamination. Fuel storage systems must be kept free of water. Additional steps could include treatment with moisture dispersants and biocides. Biodiesel has a greater solvency effect than No. 2 diesel. It will remove sediment and residual contaminants in storage tanks. Storage tank cleaning and

preparation are very important. Biodiesel may deteriorate more quickly than No. 2 diesel. This necessitates steps such as monitoring product turnover as well as painting above-ground storage tanks a reflective color to reduce product temperature during storage.

While the above steps are not part of the ASTM specifications, they are part of the BQ-9000 Accreditation Program. This program is a cooperative and voluntary accreditation program for biodiesel producers as well as marketers of biodiesel and biodiesel blends. The National Biodiesel Accreditation Program (NBAP) oversees the BQ-9000 program. Commissioners to the NBAP board are approved by the Board of Directors of the National Biodiesel Board (NBB). The NBAP Commissioners represent a wide scope of stakeholders (interested parties) who have full authority to operate the BQ-9000 program.

BQ-9000 accredited producers adhere to the standards set forth in ASTM D 6751 and ensure the company is using proper sampling, testing, storage and shipping procedures. BQ-9000 Certified Marketers agree to procedures that ensure the proper storage, blending and handling of biodiesel and biodiesel blends. This is important because, as previously noted, proper procedures in this area are important for delivering on-specification product.

The BQ-9000 program also includes accreditation audits, surveillance audits and periodic recertification audits. In summary, the BQ-9000 program combines accepted quality management systems with the ASTM D 6751 specification, and also covers storage, handling, testing, shipping, etc. BQ-9000 producers can prove that any batch of the B100 they have produced meets the ASTM specifications.

Some diesel engine and vehicle manufacturers recommend that biodiesel and biodiesel blends be purchased from a BQ-9000 accredited producer or BQ-9000 certified marketer (see Appendix A).

The Benefits and Concerns of Biodiesel and Biodiesel Blend Use

The driving force for biodiesel production and use is primarily public policy benefits. The use of biodiesel reduces U.S. dependence on foreign crude oil, lowers greenhouse gas emissions and lowers PM emissions. Biodiesel production also contributes to the rural economy. However, public policy benefits are not the focus of this manual.

The performance and operability benefits of biodiesel include reduced net CO₂ emissions, reduced HC and CO emissions and lower visible smoke. Biodiesel also has a higher cetane number and contains no aromatics. It has a low sulfur content and improves lubricity. Biodiesel is also nontoxic and biodegradable.

The performance and operability concerns most often expressed by the diesel engine and

Benefits and Concerns – Biodiesel and Biodiesel Blends

- Benefits:**
1. Higher cetane
 2. Improved lubricity
 3. Low sulfur content
 4. Reduces HC and CO emissions
 5. Reduces PM emissions
 6. Lowers visible smoke
 7. Zero aromatics
 8. Reduces net CO₂ emissions on life-cycle basis

- Concerns:**
1. Materials compatibility – especially with higher blend levels
 2. Potential for increased water content and microbial contamination
 3. Increase in NO_x emissions
 4. Implications for emission control equipment
 5. Impact on low-temperature operability if not properly additized
 6. Reduced power and fuel economy (on B100) – lower energy content
 7. Thermal and oxidative stability poorer than No. 2 diesel
 8. Solvency effect may plug filters on initial use
 9. Requires special care and handling
 10. Spills could damage paint

vehicle manufacturers include several topics. First, there are concerns about materials compatibility. Biodiesel may cause corrosion of certain metals. These include zinc, copper-based alloys, tin, lead and zinc. Certain elastomers and seal materials may also harden or swell. These effects may be more pronounced on older vehicles or equipment and may increase with biodiesel concentration in the blend.

There is also concern with the potential for increased water contamination, which could increase corrosion as well as the potential for microbial contamination. Biodiesel may also increase NO_x emissions, especially at higher blend levels. The catalyst can typically handle small increases in engine-out NO_x emissions. This is of particular concern with engines certified to the more stringent 2007 NO_x emission standards, because it could have implications for the

emission certification equipment, the life of which must be warranted for very lengthy periods.

Biodiesel may negatively impact low-temperature operability unless additized.

Additization may also be necessary to address manufacturers' concerns that the thermal

and oxidative stability of biodiesel is poorer than No. 2 diesel. At higher blend levels, and especially at the B100 level, power output and fuel economy are reduced. Manufacturers have also expressed concern about potential damage to paint due to biodiesel's solvency effect. This solvency effect can also loosen sediments and contaminants in the fuel tank and plug fuel filters upon initial use of biodiesel.

Concerns about the special handling of biodiesel have also been mentioned, because it is difficult to confirm that all proper handling guidelines have been followed.

Lastly, although not a performance issue, it should be mentioned that biodiesel costs more to produce than petroleum-based diesel fuel. At present, biodiesel tax credits help keep biodiesel reasonably competitive with petroleum-based diesel.

Manufacturer Guidelines

For the service technician, it is important to know what diesel engine and equipment manufacturers recommend as approved biodiesel blend levels, as well as any increased service requirements or special maintenance needs. Most manufacturers have expressed their support for increasing the production and use of biodiesel. However, it is important to recognize that it is only recently that biodiesel blends have been more widely marketed in the U.S. Manufacturers have only a limited amount of field experience, complemented by research and testing programs, upon which to base their recommendations for biodiesel use. As such, the guidelines currently vary from one manufacturer to another. Most manufacturers permit the use of B2 and B5. Some permit the use of B20 or permit its use under special circumstances. Only a few manufacturers permit the use of B100.

Manufacturer approval of biodiesel blend use may cover an entire product line, but more often applies only to specific vehicles, model years or engine families.

The fuel injection equipment (FIE) manufacturers have thus far limited their use recommendations to the B5 level.

Regardless of the permitted blend level, nearly every manufacturer stipulates certain use requirements and usually increased maintenance or service intervals.

Most manufacturers require that the biodiesel used in the blend meet the specifications set forth in ASTM D 6751 (in some cases meeting the European Standard EN 14214 may also be required). Several also specify, or recommend, that the biodiesel or biodiesel blend be supplied by a BQ-9000 accredited producer or BQ-9000 certified marketer. Most also note that, similar to their position on diesel fuel and gasoline, warranty claims resulting from the use of off-specification or low-quality fuel may not be honored.

Several manufacturers recommend more frequent fuel filter changes, with some specifying certain filter media. In the case of farm tankage or storage tanks for fleet operations, some manufacturers recommend adding a biocide to the fuel, adding an in-line filter to the storage tank dispensing system, and adding a fuel/water separator. Some manufacturers also recommend keeping storage tanks as full as possible to reduce the potential for condensation of water on storage tank walls. Many also recommend adding an antioxidant to stored product to improve its shelf life or recommend that biodiesel not be stored for more than three months before it is used.

Certain manufacturers have expressed concern that uncombusted biodiesel (especially at higher blend levels) may get past piston rings and dilute engine oil. Such manufacturers recommend checking engine oil levels daily to see if the oil level increases (an indication of potential engine oil dilution). They may also recommend increased oil change intervals due to such concerns. However, there is considerable technical data indicating engine oil dilution should not be a problem for conventional fuel systems.

Other manufacturer recommendations include using lower blend levels, such as B2 or B5, during cold weather due to concerns about cold flow properties. An alternative recommendation offered by some is to add a cold flow improver additive to address low-temperature operability concerns. Additional recommendations may include warnings about spilling biodiesel on painted surfaces, because it could cause paint damage. A number of manufacturers also provide recommendations about storing vehicles or equipment. Several recommend that their products not be stored for extended periods with biodiesel in them.

Finally, several manufacturers note that their biodiesel research and testing programs, especially at higher blend levels, are ongoing. They note that as they gain more field experience and complete additional testing, recommendations may be revised.

While this section presents an overview, Appendix A provides excerpts from owner's manuals, service bulletins and other sources stating several major diesel engine and vehicle manufacturers' positions and recommendations on biodiesel. As noted above, these positions and recommendations could change, so the specific owner's manual or manufacturer's Web site should be reviewed.

Retail Dispenser Labeling

Requirements to label biodiesel content on the retail fuel dispenser vary among states. Some may not have adopted any biodiesel labeling laws yet. Others often require labeling only for blends containing more than 5 volume percent biodiesel. Several states have

adopted the biodiesel labeling requirements from NIST Handbook 130, or have used the requirements as a model to develop label-ing regulations.

The wording contained in NIST Handbook 130 was developed by the NCWM Petroleum Subcommittee with input from all interested parties. The Engine Fuels, Petroleum Products, and Automotive Lubricants Regulation in NIST Handbook 130 states in part:

Identification of Biodiesel Product

Biodiesel and biodiesel blends shall be identified by the capital letter B followed by the numerical value representing the volume percentage of biodiesel fuel. (Examples: B10, B20, B100)

Required labeling of Retail Dispensers

Containing Between 5% and 20% Biodiesel. – Each retail dispenser of biodiesel blend containing more than 5% and up to and including 20% biodiesel shall be labeled with either:

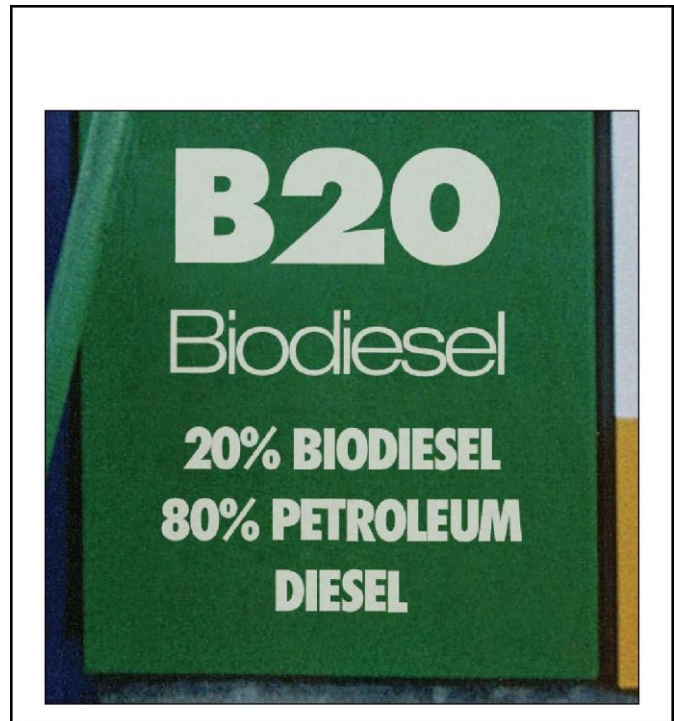
The capital letter B followed by the numerical value representing the volume percentage of biodiesel fuel and ending with “biodiesel blend”. (Examples: B10 biodiesel blend; B20 biodiesel blend), or

The phrase “biodiesel blend between 5% and 20%” or similar words.

Labeling of Retail Dispensers Containing More Than 20% Biodiesel. – Each retail dispenser of biodiesel or biodiesel blend containing more than 20% biodiesel shall be labeled with the capital letter B followed by the numerical value representing the volume percentage of biodiesel fuel and ending with either “biodiesel” or “biodiesel blend”. (Examples: B100 biodiesel; B60 biodiesel blend)

Exemption. – Biodiesel blends containing 5% or less biodiesel by volume are exempted from the requirements of Section 3.15.

The above requirements exempt blends of B5 or lower. However, most retail outlets label biodiesel blends voluntarily.



Most marketers view renewable fuels as a marketing advantage, because it is a product many consumers prefer. Consumers should check retail dispenser labels to determine the biodiesel content of the blend being dispensed.

Other Diesel Fuel Alternatives

While biodiesel is the most widely used form of renewable diesel fuel used, other alternatives are being pursued. Some alternatives are based on renewable feedstocks, while others are not. For instance, work is ongoing with gas-to-liquid (GTL) fuels. This process can convert gases to a very clean, high cetane product with properties very similar to diesel fuel. This alternative fuel is, however, still fossil fuel-based. Other processes are being explored, such as biomass-to-liquids (BTL), which could convert various forms of biomass to diesel-like fuels. This product is referred to as renewable diesel, but it is not biodiesel, which more commonly refers to transesterified vegetable oils or animal fats. Obviously, biodiesel is also a renewable diesel, but the term ‘biodiesel’ is the common terminology.

Some may occasionally see the term “E-diesel.” E-diesel is a blend of No. 2 diesel fuel containing up to 15 volume percent ethanol and certain proprietary additives, although ethanol is more commonly blended at the 7.7 volume percent blend in E-diesel. This is not presently a commercially available fuel, but it is being used in some demonstration fleets. Diesel engine and vehicle manufacturers have expressed strong reservations about diesel fuels containing ethanol. A great deal more research will be required on this product. As such, when, or if, E-diesel would be introduced as a commercially available fuel is uncertain.

Frequently Asked Questions

This section lists some of the more common frequently asked questions (FAQs) that the diesel service technician encounters, along with appropriate answers. This section is meant to provide a quick reference guide for dealing with consumers, diesel operators and others who may be seeking advice or recommendations on diesel fuel use.

Q: Should I use ULSD in my 2007 or newer model year diesel vehicle?

A: Yes, ULSD is required to protect emissions control equipment.

Q: Can I continue to use low sulfur diesel (instead of ULSD) in my pre-2007 model year diesel vehicle?

A: Some low sulfur diesel may be available until December 2010. Until that time you may

use it in your pre-2007 vehicles. Beginning December 2010 ULSD will be the only legal on-road diesel fuel.

Q: What cetane level diesel fuel should I purchase?

A: Cetane number is not always posted on the retail dispenser. However, the minimum ASTM requirement of 40 should provide adequate cetane quality for nearly all engines and operating conditions.

Q: What over-the-counter additives should I add to my diesel fuel?

A: Refiners add any necessary additives based on extensive fuel test results. It is not necessary to add over-the-counter additives. In the case of biodiesel blends, certain additives such as biocides or antioxidants may be recommended, but this normally applies to product in the retail storage tank – not the vehicle tank.

Q: Should I use premium diesel fuel?

A: The definition of premium diesel fuel varies in different areas of the country. If the premium diesel meets the requirements of NIST Handbook 130 (see page 10), you may experience improved operations, especially during cold weather.

Q: Do I need any special engine oil for my 2007 or newer model year diesel vehicle?

A: Yes, 2007 and newer model year vehicles require engine oil meeting API's engine oil category API CJ-4.

Q: Will the use of ULSD affect power or fuel economy?

A: There should be no noticeable decrease in overall power under normal operating conditions. Fuel economy may be reduced slightly (1 percent - 2 percent) because the process used to remove sulfur from the fuel can reduce the fuel's energy content.

Q: Will ULSD have similar low-temperature operability to low sulfur diesel?

A: With only one winter season of use, it is difficult to answer definitively. Based on testing, it was thought that the low-temperature operability of ULSD would be similar to low sulfur diesel. However, at least one major truck stop operator did report low-temperature operability problems in the 2006/2007 winter period. As more experience is gained, it may be necessary to modify low-temperature operability additive treat rates.

Q: What is Biodiesel?

A: Biodiesel can be made from the oil in oil seed crops and also from animal fats. It then

under-goes a process called transesterification, which removes glycerin from the fuel. The result is a product very similar to diesel fuel.

Q: Can I simply operate my vehicle on raw vegetable oil?

A: No, raw pressed oils contain undesirable components and can, among other things, increase fuel system and engine deposits. Most manufacturers recommend that you not use vegetable oils or animal fats that have not been transesterified (i.e., converted to biodiesel).

Q: Can I use biodiesel or biodiesel blends in my diesel engine?

A: Approval for using biodiesel varies among diesel engine and equipment manufacturers. Most approve of the use of B2 and B5. Some permit the use of B20 in certain engines. Most do not currently approve the use of B100. The owner's manual or engine/vehicle manufacturer Web site should be consulted to confirm the level of biodiesel that is approved for use.

Q: If I use a biodiesel blend, do I need to make any engine or fuel system adjustments?

A: Blends up to B20 can be used with little or no modifications. Some manufacturers do recommend certain modifications for higher-level biodiesel blends, especially those above B20.

Q: Are there any special handling considerations for biodiesel?

A: Yes. Biodiesel can pick up moisture, so it is very important to take steps to eliminate any potential for water getting into storage tanks as well as vehicle tanks.

Q: Will biodiesel cause fuel filter plugging?

A: Biodiesel has a solvency effect and will remove sediment and gums built up in the fuel system. These materials become trapped in the fuel filter, which may require a change. This is normally a one-time occurrence upon initial biodiesel use. Once the system is clean, fuel filter change intervals should be similar to that for No. 2 diesel.

Q: Will my vehicle perform satisfactorily on biodiesel blends?

A: A blanket answer is difficult for all vehicles and all blend levels. In general, most drivers have found performance to be satisfactory on blends up to B20.

Q: If I use biodiesel, will my fuel economy be affected?

A: Depending on the blend level, it may be. The energy content of a B2 blend is only 0.2

percent lower than No. 2 diesel and a B5 blend is 0.5 percent lower. The energy content of B20 is 1.8 percent lower.

Q: What is BQ-9000 Biodiesel?

A: BQ-9000 is an accreditation program for biodiesel producers and marketers. Biodiesel producers that are BQ-9000 accredited, and BQ-9000 certified biodiesel marketers, agree to meet ASTM standards for biodiesel as well as special handling steps to ensure delivery of an on-specification product. Participants undergo various audits to maintain their accreditation or certification.

Engine and Vehicle Manufacturers' Positions on Biodiesel

It has only been a few years since biodiesel blends started becoming more widely available in the U.S. Engine and vehicle manufacturers are not all in agreement on what level of biodiesel is appropriate. Most permit the use of B5 (95% conventional diesel/ 5% biodiesel). Some permit the use of B20 (80% conventional diesel/20% biodiesel) at least in their newer engines and vehicles. Most do not yet permit the use of blends higher than B20. This appendix provides information on the position of various manufacturers on the use of biodiesel. This information has been compiled from various sources including company position statements or press releases, technical bulletins and the fuel recommendations section of owners' manuals. In many cases the information is excerpted from its source, and it should be noted that manufacturers may also have recommendations for other fuel parameters such as cetane number, the use of additives (or restriction on such use), fuel filter requirements and other fuel-related issues.

Mercedes-Benz Position on Biodiesel as of January 19, 2007

Mercedes-Benz USA now approves the use of B5 biodiesel (standard diesel with a maximum 5% biodiesel content) in all Common Rail Injection Diesel "CDI-engines" - including BLUETEC engines. As biodiesel can be refined from a variety of raw materials resulting in widely varying properties, the only approved biodiesel content is one that meets the ASTM D 6751 specification and that has additionally the necessary oxidation stability (min. 6h, proved with EN14112 method) to prevent damages to the system from deposits and/or corrosion.

Please ask your service station for further information. If the B5 biodiesel blend is not sufficiently labeled to clearly indicate that it meets the above standards, please do not use it. The Mercedes-Benz limited warranty does not cover damage caused by the use of fuels not meeting Mercedes-Benz approved fuel standards.

Volkswagen of America Statement Biodiesel Fuel

As a result of a major joint research project between the Volkswagen Group and the prominent agricultural products firm Archer Daniels Midland Company, and improvements in the specifications for biodiesel fuel in North America, Volkswagen has determined that diesel fuel containing up to five percent biodiesel meets the technical specifications for Volkswagen vehicles equipped with TDI engines imported to the United States. Therefore, the diesel fuel commonly known as “B5 biodiesel” is acceptable for use in all our TDI vehicles.

Volkswagen hopes that by approving B5 biodiesel for usage in our TDI vehicles, we will encourage biodiesel development and increase the biodiesel industry’s role in developing high quality renewable fuels for motor vehicles. This, combined with the exceptional fuel economy that Volkswagen TDI owners already experience, has the potential to be a small part of the energy independence we all seek. Volkswagen sees biodiesel as a key element of a comprehensive long-range fuel strategy that relies on efficient, clean diesel technology and the use of an increasingly broad portfolio of renewable fuels.

We do want to take a moment to speak to you about fuel quality. While this historic decision by Volkswagen is a first step in a renewable fuel strategy for our cars, it is not a departure from our strong recommendation that you use only high-quality fuel, nor from our long-standing fuel requirements for warranty purposes, whether diesel, biodiesel, or gasoline. We will continue to view fuel issues in the same fair manner as we always have in the past, but we must stress that vehicle damage that results from misfueling or from the usage of substandard or unapproved fuels cannot be covered under our vehicle warranties.

Volkswagen recommends that you use standard diesel fuel, or biodiesel blend fuels of up to five percent (B5), purchased from a mainstream retailer substandard fuels, or higher level blends of biodiesel, damage your engine or fuel system, such damage cannot be covered under warranty. If a fuel problem related to substandard diesel fuel or biodiesel blend fuel occurs with your vehicle, you may be asked to provide the source or sales location of the fuel.

In summary:

1. Volkswagen recommends the use of standard diesel fuel or commercially supplied biodiesel blends of no more than five percent (“B5”) biodiesel.
2. Never use any fuel, whether diesel, B5 biodiesel, or otherwise, that fails to meet the

latest petroleum industry specifications or that is not purchased from a commercial retail diesel pump. If you are unable to determine whether a particular fuel blend is B5 biodiesel that meets the latest biodiesel industry specifications, ask your service station for more information.

3. Never use any fuel for which the contents cannot be identified.

Ford Motor Company Position

Fuels containing no more than 5% biodiesel may be used in Ford diesel powered vehicles. Consistent with WWFC (World-Wide Fuel Charter) category 1-3, “Fatty Acid Methyl Esters (FAME) used in commercial fuel must meet both the EN 14214 and ASTM D 6751 specifications”.

There are still some unresolved technical concerns with the use of biodiesel at concentration greater than 5%. Some of the concerns are:

- Requires special care at low temperatures to avoid excessive rise in viscosity and loss of fluidity
- Storage is a problem due to higher than normal risk of microbial contamination due to water absorption as well as a higher rate of oxidation stability which creates insoluble gums and sediment deposits
- Being hygroscopic, the fuel tends to have increased water content, which increases the risk of corrosion
- Biodiesel tends to cause higher engine deposit formations
- The methyl esters in biodiesel fuel may attack the seals and composite materials used in vehicle fuel systems
- It may attack certain metals such as zinc, copper based alloys, cast iron, tin, lead, cobalt, and manganese
- It is an effective solvent, and can act as a paint stripper, whilst it will tend to loosen deposits in the bottom of fuel tanks of vehicles previously run on mineral diesel
- Ford believes that it is unlikely that the emission benefits of biodiesel will be sufficient to achieve Tier 2 emission standards without catalysts and particulate filters. Ford is working aggressively on technologies, including engine improvements, new catalysts and particulate filters that will remove HC, CO, NO_x and soot from diesel exhaust. Renewable fuels or blends containing renewable components can help reduce the total lifecycle CO₂ impact and may be used when

available, but they are not the key step to achieving Tier 2 emission standards.

General Motors Corporation

Beginning with the January 2004 production cycle, GM's Duramax Diesel engines will be approved for B5, a blend of 5% biodiesel fuel, giving fleets another choice for fueling and for complying with state and federal requirements.

Cummins

Frequently Asked Questions

The Use of B20 Biodiesel Blends in Cummins Engines.

1. What Cummins engines can be used with B20 biodiesel?

The current approved engine models are as follows:

On-Highway: ISX, ISM, ISL, ISC and ISB engines certified to EPA '02 and later emissions standards, and ISL, ISC and ISB engines certified to Euro III

Off-Highway: QSX, QSM, QSL, QSC, QSB6.7 and QSB4.5 engines certified to Tier 3/Stage IIIA, QSM Marine and QSM G-Drive

2. What are the general fuel specification requirements?

B100 biodiesel must conform to the American Society of Testing Materials (ASTM) specification - ASTM D6751. ASTM D6751 has been revised to now include a stability requirement which was not included in the previous specification. This is a critical requirement when B100 is blended with petrodiesel to produce a B20 blend.

B20 needs to conform to the Engine Manufacturers Association (EMA) recommended test specification for B20. There is currently no ASTM specification for B20 blends. It is expected that ASTM will issue a specification for B20 in the near future.

In Europe, specifications for biodiesel are issued under EN 14214. EN 14214 is published by CEN, the European Committee for Standardization or Comité Européen de Normalisation. <http://www.cen.eu/cenorm/index.htm>

Customers are required to purchase the biodiesel blend from a BQ-9000 Certified Marketer. The B100 fuel used in the blend must be sourced from a BQ-9000 Accredited Producer. BQ-9000 Certified Marketers and Accredited Producers can be found at www.bq-9000.org.

3. Where can I find further information as it relates to the use of biodiesel in Cummins engines?

Cummins has recently updated the Fuels Requirements - Service Bulletin. The bulletin number is 3379001-11. It can be obtained on Cummins QuickServe web site at [quickserve. www.cummins.com](http://quickserve.www.cummins.com).

4. Are there any special requirements for fuel filters?

Cummins requires the use of a StrataPore™ fuel filter media and strongly recommends using Cummins Filtration filters equipped with StrataPore media. If StrataPore media is not used, then an equivalent filter that meets specific performance standards must be used. For more information, please visit www.cumminsfiltration.com.

5. Do I need to modify any service intervals when switching from petrodiesel to biodiesel?

Due to the solvent nature of biodiesel and the potential for “cleaning” of the vehicle fuel tank and lines, new fuel filters must be installed when switching to biodiesel on used engines. Fuel filters will need to be replaced at half the standard interval for the next two fuel filter changes. After this initial period, you may revert to the intervals specified in your Operation and Maintenance Manual. For 2007 on-highway MidRange engines only, oil sampling will be necessary for the first six months of operation with biodiesel to monitor fuel dilution of the lubricating oil.

6. Are there any biodiesel fuel storage guidelines?

Use biodiesel fuel within six months of its manufacture. Biodiesel has lower oxidation stability compared to petrodiesel. Avoid storing equipment with biodiesel blends in the fuel system for more than three months.

7. What materials are incompatible with biodiesel?

Natural rubber, nitrile and butyl rubber are particularly susceptible to degradation. Also, copper, bronze, brass, tin, lead and zinc can cause deposit formations. The use of these materials and coatings must be avoided for fuel tanks and fuel lines.

Note: Contact your vehicle manufacturer to determine if any of the OEM-supplied

components are at risk with biodiesel in order to prevent engine or vehicle damage.

8. Why didn't Cummins include engines prior to 2002?

The main reason not to include engines earlier than 2002 is due to materials compatibility concerns. Some fuel systems in pre-2002 engines contain components that are not compatible with a B20 biodiesel blend. 2002 and later engines contain fuel system components that are compatible.

9. How does using biodiesel affect the engine warranty?

Cummins engine warranty covers failures that are a result of defects in material or factory workmanship. Engine damage, service issues and/or performance issues determined by Cummins to be caused by the use of biodiesel fuel not meeting the specifications outlined in the Fuels Requirements - Service Bulletin (3379001-11) are not considered to be defects in material or workmanship, and are not covered under Cummins engine warranty.

This is no different from Cummins position with any regular diesel fuel. Cummins does not cover the damage caused by products from other companies that may have insufficient quality. It is important to ensure when using any diesel fuel or a B20 biodiesel blend with a Cummins engine that the fuel meets industry acceptable quality standards.

10. What are the implications to emissions certification?

It should be emphasized that Cummins, in common with all other engine manufacturers, only certifies engines to meet the prescribed EPA (or other local regulatory agency) registered fuels. It is the customer's responsibility to use the correct fuel prescribed by these regulations and as recommended by the engine manufacturer.

The EPA has regulated the United States high-way diesel fuel quality since 1993 to ensure that it is compatible with engine emissions standards and air quality goals. It is the responsibility of the customer to obtain the proper local, regional or national exemptions required for the use of biodiesel in any emissions-regulated Cummins engine.

11. Will Cummins support the use of B20 biodiesel in engines not listed in this document?

Cummins fully supports the use of environmentally beneficial alternative fuels. All of our automotive and industrial engines are compatible with B5 biodiesel to help encourage the greater use of renewable, domestically grown fuel. Cummins is continuing the evaluation of biodiesel concentrations higher than 5 percent for many more of our products such as our A Series, B3.3 and QSB3.3 as well as our High-Horsepower engines. We are aware of

the growing interest in B20 fuel blends and fully support this interest in renewable fuels. As we reach conclusions and the completion of these evaluations, we will modify our position on engine compatibility accordingly.

Some OEMs using Cummins engines not listed in this bulletin may have specific releases regarding the use of biodiesel that apply only to their application. Consult the OEM if in doubt.

12. Is B20 approved for the Dodge Ram Turbo Diesel?

For Cummins engines in Dodge Ram trucks, biodiesel fuel can be blended with an acceptable diesel fuel up to a 20 percent volume concentration (B20) for municipal, government and commercial fleets only. This applies to selected model year vehicles. Please consult DaimlerChrysler for specific requirements and approved vehicle models.

Case IH

Biodiesel: What You Need to Know Now

Diesel fuel blended with biodiesel is drawing wider interest as an alternative fuel. Farm equipment manufacturers, including Case IH, endorse the use of it, and various regulatory agencies even require biodiesel use. A Minnesota directive mandates that diesel fuel sold in that state contains at least 2% biodiesel (B2).

Biodiesel is often blended with diesel fuel by fuel distributors. The most common blends are B2, B5 or B20. Pure 100% biodiesel (B100) can also be used unblended as a fuel in some diesel engines.

To determine the maximum biodiesel blend appropriate for your machine, review the product sections of this Web site. Biodiesel ratings by model appear in the left column. Biodiesel is a diesel fuel replacement manufactured from vegetable oils, recycled cooking greases or oils or animal fats. Soybeans are a primary source for biodiesel.

Biodiesel blends are proving to reduce emissions, improve fuel lubricity and reduce fossil fuel demands while creating new demand for soybeans.

Currently, commercial biodiesel production and distribution is located primarily in the Midwestern United States. Whether you use it voluntarily or because it's mandated, there are a few things you need to be aware of.

Storage issues

As an organic material, diesel fuel is a food source for various types of microbes that feed and grow at the fuel/water interface. Water works its way into storage systems from humidity, condensation, etc.

Because on-farm fuel supplies are used fairly quickly (rather than stored unused for months), algae and other types of organic growth haven't been much of an issue with pure diesel fuel.

However, biodiesel is a richer food source. It is more highly oxygenated, and presents more interfaces with water. This microbial activity creates sludge that can plug filters.

Similarly, biodiesel can have a cleaning effect that loosens accumulated sediment in storage tanks and equipment tanks. Although the U.S. Department of Energy says that "B20 is sufficiently diluted so that most (cleaning effect) problems are insignificant," field reports indicated this is a possibility even with the B5 blends, especially if your fuel storage and handling systems are old or have not been carefully maintained.

So what should you do to successfully use biodiesel? Basically, remember the old adage, "Use clean fuel. Keep it clean."

1. Purchase your biodiesel blend from a trusted fuel supplier.
2. Treat your storage tanks for moisture with a moisture dispersant. A biocide is recommended.
3. Add or upgrade in-line filters.
4. Add a fuel/water separator.
5. Take steps to minimize in-tank condensation, by keeping tanks topped off.
6. If your on-farm fuel storage system is due for replacement, adopting biodiesel can be a good reason to do so.

Take similar steps to clean and protect equipment fuel systems. Be prepared to replace fuel filters more often, especially in the early stages of your biodiesel blend usage. Fuel filters for current diesel engines are very efficient, but they cannot do their job if they become overloaded with contaminants.

Biodiesel blends, especially B2 and B5, appear to be good alternatives to pure diesel fuel and improve lubricity and emissions.

While B100 biodiesel contains about 8% less energy per gallon than No. 2 diesel, the U.S. Department of Energy says that blends of B5 or less “do not cause noticeable differences in performance compared to No. 2 diesel.” B20 blends, the department says, will lose only 1% to 2% in power, torque and fuel economy. Using pure B100 can reduce power and torque by 4% to 7%.

Case IH Engine Biodiesel Blend Statement

Case IH fully supports the use of B5 blends in all current and past engines for Case IH agricultural equipment, as well as B20 in more than 90% of the models now being sold in Europe and North America, including Magnum™ tractors. Nearly half of the models sold globally, including the flagship Axial-Flow® 8010 combine, are approved following proper protocols for B100. Your local Case IH dealer has all the details on specific technical requirements for use.

Take a look at the left-hand column of the individual product pages on this Web site, or consult your Case IH dealer to determine which blends are approved for your equipment.

Biodiesel used in Case IH engines must meet the requirements of U.S. standard ASTM6751 or European standard EN14214. When using blends greater than B5 (B6-B100), certain handling and maintenance requirements come into play, and customers are advised to speak with their dealers for the specific recommendations covering their biodiesel blend of choice.

Case IH is committed to working with its partners to push toward higher-level biodiesel that will be a compatible fuel source in future low-emissions compliant engines. Case IH continues the aggressive field tests to evaluate performance with B100 on those engines not yet approved.

General Biodiesel User Guides:

- Use biodiesel from a trusted source that is a BQ-9000 accredited producer or certified marketer/distributor. Preblends are recommended over on-farm blending, which can result in a non-homogenous mixture.
- Use storage tanks that are clean and free of sediment.
- Avoid copper, brass, lead, tin and zinc in tanks and fittings.
- Minimize water forming through condensation by keeping tanks topped off.
- Use a biocide in primary storage tanks.
- Add fuel filters and water separators on your primary storage tank.
- Follow recommended maintenance schedules for equipment fuel filters and water

separators. Expect to change filters more frequently, especially during the early stages of biodiesel blend use.

User Guides for Blends of B6 through B20

- Check your engine oil level daily. If the oil level increases contact your Case IH dealer.
- Use B6 through B20 only if the outside temperature is greater than 16 degrees F (-9 degrees C).
- Clean up biodiesel spills immediately to avoid paint damage.
- Avoid storing equipment more than three months with biodiesel in the fuel system, due to potential stability problems with biodiesel. If necessary, run the engine on pure diesel fuel for 20 to 30 minutes to flush the biodiesel out of the system.
- Avoid storing biodiesel in on-site fuel tanks for longer than 3 months.
- The oil and filter change interval for electronic NEF and Cursor engines using a high pressure common rail fuel system is reduced to 300 hours. See your operator's manual.

User Guides for Biodiesel Blends Greater than B20

- Follow the General Biodiesel Guides and those for Blends B6 through B20.
- Use greater than B20 blends only if the outside temperature is greater than 41 degrees F (5 degrees C).
- Keep biodiesel storage tanks protected from direct sunlight or frost.
- The use of blends of 20% biodiesel (B20) or more requires greater attention to fuel quality and handling, additional vehicle maintenance and service, and in some cases an update kit is necessary to make your machine greater than B20 compatible.
- Visit your Case IH dealer, who will provide the details of the special requirements for your equipment and request your agreement to meet them.

Fuel Treatment for Biofuels

Biodiesel blends are more prone to microbial growth than straight diesel fuel.

Case IH dealers carry fuel treatments that prevent microbial growth and the resulting slime that can clog filters. These include Fleetguard's Fleet-tech Microbicide and a Valspar fuel additive (part number B50546, 16 ounce, or part number B50547, 23 ounce).

Mack Trucks, Inc.

Service Bulletin Number SB 210043 Date 6/28/07 Model E Tech™ ASET™, MP7, MP8 (Excerpt)

Use of Biodiesel Fuel in Mack Diesel Engines – E Tech™, ASET™, MP7 and MP8 Engines

Does not apply to Mack Trucks Australia

Mack Trucks, Inc. Approval of Biodiesel Products:

The only Biodiesel fuel approved by Mack Trucks, Inc. for use in E-Tech™, ASET™, MP7 (both US04 and US07 emission-compliant) and MP8 engines is Soy Methyl Ester (SME or SOME) in blends up to a B5 concentration (5% blend).

Although higher concentrations are available, concentrations up to B5 (maximum) are the only blends currently approved by Mack Trucks, Inc.

NOTE

MACK engines are certified to comply with U.S. EPA and California Air Resources Board (CARB) emissions standards based on the use of reference test fuels commonly available in the United States and specified in the Maintenance and Lubrication Manual, TS494. Use of alternative fuels, including Biodiesel, may affect engine emissions. Mack Trucks, Inc. does not warrant, and is not responsible for ensuring that the engines will comply with U.S. EPA and CARB emissions standards when operated on fuels not specified by Mack Trucks, Inc.

Warranty Policy:

The engine warranty covers defects in material and workmanship on the part of the manufacturer. Failures caused by fuel are not warrantable.

ASTM Standards

The American Society for Testing and Materials (ASTM) standard D 6751 defines B100 Biodiesel. Any B100 product used in the manufacture of the blend intended for use in a MACK vehicle must conform to the ASTM D 6751 standard.

ASTM standard D 975 defines the minimum accepted values for the properties of petroleum-based diesel fuel. Any petroleum-based diesel fuel used in a MACK vehicle, either alone or when blended with B100 Biodiesel for the maximum approved concentration (up to B5), must meet the ASTM D 975 standard.

Certified Biodiesel Required

The National Biodiesel Accreditation Commission conducts quality certification and accreditation programs for producers and marketers of Biodiesel products. For details on these programs, visit the BQ-9000 Quality Management Program web site at www.bq-9000.org. The B100 Biodiesel used in the approved blend must be produced by a BQ-9000 Accredited Producer and the blend must be supplied by a Certified Marketer.

Storage of Biodiesel

The standard storage and handling procedures used for petroleum-based diesel fuel apply to Biodiesel (reference the Maintenance and Lubrication Manual, TS494, for information concerning the handling and storing of diesel fuel). Compared to petroleum-based diesel fuel, Biodiesel fuel has lower oxidation stability, and there are greater concerns for water contamination and microbial growth. Biodiesel should be stored in a clean, dry, dark environment. Acceptable storage tank materials include aluminum, steel, fluorinated polyethylene, fluorinated polypropylene or Teflon®. Storage containers which contain copper, brass, lead, tin or zinc should not be used. Every effort should be taken to make sure that the Biodiesel product is used within six months of the date of manufacture.

Fuel Filter Change Intervals:

Biodiesel has solvent qualities better than those of petroleum-based diesel fuel. Because of this, Biodiesel will break down petroleum-based diesel fuel residuals found on the insides of fuel tanks, fuel lines, etc., and as a result, fuel filters will become clogged with particulates. It is recommended that fuel filters be changed at half the normal interval for the first two filter changes when the transition to Biodiesel fuel is made. After that, the standard specified filter change intervals can be used, or shorter intervals if a reduced filter change interval was being used prior to the changeover to Biodiesel.

Detroit Diesel Corporation

Biodiesel fuels are alkyl esters of long chain fatty acids derived from renewable resources. Detroit Diesel Corporation highly recommends biodiesel fuels made from soybean or

rapeseed oil through the proper transesterification reaction process. Other feedstock source of biodiesel fuels such as animal fat and used cooking oils are not recommended by DDC. Biodiesel fuels meeting ASTM D 6751 specification, prior to blending can be mixed up to 5% maximum by volume in petroleum diesel fuel. The resulting mixture must meet the fuel properties listed in Table 5-1 (of these recommendations) and ASTM D 975 specification. Failures attributed to the use of biodiesel fuel will not be covered by Detroit Diesel product warranty. Also, any engine performance problem related to the use of biodiesel fuel would not be recognized nor considered DDC's responsibility.

International Truck and Engine Corporation

Technical Service Information TSI –05-12-21

Date May 2005 Subject Biodiesel Fuels (Excerpt)

Engine Family: All Diesel Engines, Except Green

Diesel Technology TM

(Ultra Low Sulfur Fuel Only)

Description:

International's stated opinion on the use of biodiesel follows the official position of the Engine Manufacturers Association (EMA) on biodiesel fuel. Refer to the following website for further information (www.enginemanufacturers.org).

Low Biodiesel Blends (up to 5%)

The properties of these blends are within diesel specification limits and meet the ASTM D 975 Diesel Standard. All blends up to B5 biodiesel should not cause engine or fuel system problems. International Truck and Engine Corporation will warranty engines using fuels up to and including the B5 blend.

Higher Biodiesel Blends (greater than 5%)

The characteristics of higher biodiesel blends are not within ASTM D975 diesel specifications. A blend of 20% biodiesel and diesel fuel (B20) is typically used in commercial fleets that are subject to environmental concerns in the urban environment.

Work is underway within ASTM to issue a specification for B20. Until then, the user must rely on the fuel supplier to properly blend the components and insure quality.

B100 (neat biodiesel) is generally not recommended for use in engines. Special uses of

B100 are considered (such as in National Parks), but these are the exception from common commercial applications. B100 biodiesel costs more than diesel fuel and its availability is limited.

International Truck and Engine Corporation's stated warranty policy does not deny warranty coverage solely for the use of higher biodiesel blends, but only if the failure is attributed to higher biodiesel blends.

- Engine Performance and Durability of B100 and High Biodiesel Blends
- Maximum power output using B100 is reduced by 5-7%.
- Low temperature viscosity of biodiesel is higher than viscosity of diesel fuel and some flow impairment may occur in fuel filter and lines.
- Elastomers and various seal materials may harden or swell. Sealing materials must be monitored when using biodiesel blends, especially in older engines.
- Thermal and oxidative stability of biodiesel blends is inferior to that of diesel fuel. In general, fleets fueled by B20 must consume their fuel blend inventory within a 6 month period.
- Water separation efficiency when operating with higher biodiesel blends is inferior to that of conventional diesel fuel. This may lead to corrosion of engine fuel supply and fuel injection hardware. Furthermore, water may combine with biodiesel Fatty Acid Methyl Esters (FAME) to create acids that greatly accelerate corrosion.
- The use of higher biodiesel blends may reduce the engine oil service life and drain interval. Oil sampling and analysis may be used to determine the effect on engine oil service life.

Fuel Tank Care

Any residue or microbial growth in the tank will compound with the use of biodiesel. This can cause serious plugging of filters and deposits in the fuel system. Fuel tanks should be thoroughly cleaned and dried before operating with any biodiesel blends. Adding biocides will help minimize growth.

Volvo Truck Corporation

Vegetable oils and/or esters of vegetable oils, also called "biodiesel", such as for example rapemethylester (RME) are available on certain markets both as in its pure state and as a mixture in diesel fuel.

Volvo Truck Corporation does not accept more than 5% RME in diesel ready mixed from

the oil company since nitric oxide emissions increase drastically and the injection system can be damaged. Volvo does not intend carrying out long-term tests on engines for these fuels as no standard exists. If, in spite of this, the customer wishes to use fuels based on vegetable oils, we recommend that the oil changing intervals be halved in order to eliminate the risk of dilution of the engine oil. It is oil companies who are responsible for ensuring that the mixture of biodiesel meets the diesel standards. The customer must not add mixtures in the biodiesel in the diesel tank afterwards.

The cold properties for these fuels are not particularly good. Pure REM can produce deposits already at -10° C. They even have washing like characteristics which causes faster clogging of the fuel filters.

UD Trucks

Nissan Diesel America, Inc. Service Operations has listed “B5” as an approved fuel for the UD Truck line. B5 is a blend of 95% petroleum diesel and 5% biodiesel, the approved fuel must conform to the ASTM D 6751 standard.

John Deere

Guidelines of Biodiesel Fuels used in Diesel

Engine – Updated February 6, 2007 (Excerpt)

What is & isn't Biodiesel

A fuel comprised of mono-alkyl esters of long chain fatty acids (known as Fatty Acid Methyl Esters or FAME) derived from vegetable oils or animal fats, officially designated as B100 or 100% Biodiesel in compliance with ASTM D6751 (USA) or EN 14214 (Europe) industry specifications. The standard manufacture process to make biodiesel is called transesterification. Soybean Methyl Ester – SME, predominantly in USA

Rapeseed (or Canola) Methyl Ester – RME, predominantly in Europe

Palm Methyl Ester – PME, predominantly in Asia

Other feedstocks include but not limited to:

Animal Fats (beef tallow, pork lard)

Yellow Greases (waste cooking oil or recycled

greases)

Cotton Seed

Sunflower Seed

Coconut Oil

Sesame Seed

Biodiesel blended with regular diesel fuel is named Biodiesel Blend, designated as BXX (B2, B5, B20, etc.) where XX is the volume percent of biodiesel used in the blend.

NOTE: Raw pressed / partially refined vegetable oils or recycled greases that have not been processed into biodiesel through transesterification are NOT biodiesel and Must Not Be Used in any form or concentration.

Biodiesel Advantages

- Renewable energy alternative, biodegradable & nontoxic
- Reduce dependency on petroleum imports
- B2 level provides significant lubricity improvement
- High cetane, zero aromatics, and minimal sulfur content
- Lower engine PM, HC, CO and life-cycle CO₂ emissions
- Less visible smoke

Biodiesel Technical Challenges

- Increased engine NO_x emission
- Cold weather flow degradation
- Stability & storage issues (moisture absorption, oxidation, microbial growth)
- Hygroscopic nature impacts filtration system (water separator efficiency reduction)
- Thermal degradation at elevated temperatures
- More crankcase dilution caused by higher fuel density & viscosity
- Elastomer seal, gasket, and other material compatibility (Cu, Pb, Zn, and Sn)

- Lower energy content (less power & fuel economy)
- Property variation due to different feedstocks
- Higher cost if there were no government tax incentive

Deere Recommendation

Biodiesel blend up to B5 (5% biodiesel mixed with regular petrodiesel by volume) can be used in John Deere diesel engines, provided that the neat biodiesel or B100 meets ASTM D 6751 (USA) or EN 14214 (Europe) specification as shown in Table A. Furthermore, the petrodiesel portion should meet the requirements of ASTM D 975 (USA) or EN 590 (Europe) commercial standards. Deere also requires that biodiesel and its B5 blend to be purchased from a BQ-9000 accredited producer or BQ-9000 certified marketer / distributor.

We must make certain that our decisions about biodiesel usage and the effect on machine performance are based on factual test experience. Deere is a responsible biodiesel supporter and understands the future prosperity of biodiesel industry rests on product quality control, field customer appreciation, long-term supply and distribution.

Biodiesel blend above B5 could have increasingly more performance issues. The higher the biodiesel concentration, the more likely the risk associated with its negative aspects. There is no industry standard to regulate the quality & performance of biodiesel blend at this time. In particular, certain properties of biodiesel blend may deviate significantly from its B100 and petrodiesel constituents (synergism or antagonism) and could manifest a highly nonlinear relationship. The following shall be observed during routine practice.

Fuel Quality Assurance

- Ensure the quality of B100 and biodiesel blend (right concentration, uniform mixture)
- One-time splash blending in an immobile tank is inadequate for homogeneous mixing
- Recommend in-line (or proportional) blending to achieve good mixture
- B100 should be kept warm prior to blending in the winter to preclude wax formation
- Keep storage and vehicle tanks as full as possible to minimize moisture condensation

- Monitor water content and microbial growth of the biodiesel fuels regularly
- Sampling fuel periodically to confirm the % level of biodiesel is consistent
- Limit the storage tanks from extreme temperature exposure (direct sun or frost)
- Storage life should be reduced accordingly (one year for B2, six months for B20, etc.)
- Buy fuel from a BQ-9000 accredited producer or a BQ-9000 certified marketer

Vehicle Maintenance Protocol

- Drain and clean fuel storage tank before and after using biodiesel
- All tank caps and covers shall be installed properly to prevent water from entering
- Clean spills immediately to avoid paint corrosion if using B20 or higher blends
- Fuel filter may need to be replaced more often initially due to premature plugging for that biodiesel is a minor solvent capable of removing deposits within the fuel system
- Wax formation of biodiesel in cold environment may also cause filter plugging, use lower blends or better yet 100% petroleum diesel during the winter or storage period
- Check engine oil sump level daily prior to starting, a rising level may indicate crankcase fuel dilution and need for oil change (biodiesel is less stable)
- Switch to regular diesel for extended periods of storage / idle of the vehicle

Performance Related Issues

- Power loss, and in some instances dangerous power (fueling rate) growth, from B100 or other high concentration biodiesel blends
- Higher biodiesel blend may cause leakage in seals and hoses of Buna-N, Nitrile and natural rubber, use fluorocarbon or Viton type of materials instead which are compatible with biodiesel.
- Corrosion of fuel injection equipment particularly for higher biodiesel blend
- Injector nozzle deposits from B20 or higher biodiesel blend
- Lacquering and seizure of internal injection system components

- Injection pump failure caused by water ingestion
- Formation of sludge and sediments
- Reduced engine service life

Consult fuel supplier for additives to improve storage and performance of biodiesel.

Suggested type of additives would be:

- Oxidation stabilizer
- Cold flow enhancer
- Micro biocide

High pressure common rail (HPCR) and rotary fuel injection pumps are most sensitive to biodiesel usage with regard to deposit formation. When using higher biodiesel blend or B100 in a rotary fuel injection pump, the engine oil level must be checked daily if the ambient temperature is -10°C (14°F) or lower. If oil becomes diluted with fuel, oil change intervals must be shortened. Correct oil service intervals may be established by using OilScan or OilScan Plus programs. Another factor due to cold temperature is the Cloud Point (CP) where wax crystals start to form which makes the fuel cloudy, or Cold Filter Plugging Point (CFPP) where wax crystals have grown to some threshold size beginning to plug the filter. Biodiesel demonstrates relatively high CP or CFPP as compared with petroleum diesel fuel.

Our product warranty only covers defects in material and workmanship as manufactured and sold by John Deere. Failures caused by the use of poor quality fuels, be that biodiesel or regular petroleum diesel, are not defects of material and/or workmanship as supplied by John Deere, hence cannot be compensated under our warranty. On the other hand, using biodiesel blends above B5 does not automatically void warranty. Users of John Deere emission certified engines are responsible for obtaining the proper local, state, and national exemptions required for the use of biodiesel.

Emission certified engines are equipped with fuel injection pumps (FIP) that are compatible with biodiesel blends up to B5 maximum in accordance with the common position statement from diesel fuel injection equipment (FIE) manufacturers.

NOTE: Experience shows that biodiesel is not always conforming to the established standards. Furthermore, the specifications listed in Table A are broadly defined which results in variation of the biodiesel quality. It should be clarified that ASTM D 6751 is recommended for blending up to B20 maximum in USA, whereas EN 14214 can be used

as a commercial RME B100 fuel in Europe. The B100 composition may change appreciably due to different feedstocks. This quality variation could cause fuel injection system malfunction particularly with wide range of engine design and operating conditions seen in the field. That is why FIE manufacturers, John Deere and Engine Manufacturers Association in general recommend B5 maximum for the time being. Operator must ensure the supply of good quality biodiesel that will not harm any parts of the engine fuel system. To that extent, we require that the biodiesel (B100) and blended biodiesel (B5) be purchased from a BQ-9000 accredited producer or BQ9000 certified marketer / distributor. For regular petroleum diesel its energy content is usually proportional to the level of fuel density and/or aromatics. This rule cannot be applied to biodiesel blends due to opposite trends existed from biodiesel with higher density and lower energy content.

John Deere has developed its own global standards of B100 and B20 for testing purposes with additional requirements such like thermal and oxidation stabilities, among others.

New Holland

New Holland, Penna. (May 17, 2006) – New Holland today informed the National Biodiesel Board (NBB) it fully approves use of up to B20 blends (20% biodiesel/ 80% petroleum-based diesel) on all equipment currently produced with New Holland engines. Biodiesel is a renewable fuel produced from oilseed crops, primarily soybeans in the United States and canola in Canada, and animal fats. It can be blended with conventional diesel. The biodiesel must meet the specified industry standard for fuel quality of ASTM D6751 to ensure optimum performance and durability of the engine.

New Holland strongly recommends the use of approved fuels and compliance with strict handling, storage and maintenance requirements to maintain the integrity of the fuel.

The necessary technical advice and specific maintenance programs are available through New Holland's expert dealer network to ensure the biodiesel is handled properly and critical areas such as fuel hoses and injectors receive further inspection so customers can confidently work with high-quality B20 biodiesel blends without compromising the machine's performance or durability. The biodiesel industry has also instituted a voluntary fuel quality program called BQ-9000 for biodiesel producers and marketers.

Kubota Tractor Corporation

Kubota Tractor Corporation (KTC) announces a global Kubota decision to approve the use of "B5" biodiesel fuels in specified Kubota diesel-powered products. Biodiesel fuels, most

often offered in a blended-petroleum format, are derived mostly from vegetable oils, and are offered in the United States as an alternative source for energy.

Biodiesel Fuel (BDF) blended with diesel fuel may be used in the Kubota diesel powered products listed below only if the blended fuel meets the following conditions:

1. BDF concentration must not exceed 5% by volume (B5 blend). Greater concentrations increase the likelihood of corrosion and failure of the aluminum, zinc, rubber, and plastic parts of the fuel system.
2. The petroleum diesel fuel base must meet the American Society for Testing and Materials (ASTM) D975 fuel specification (or the European EN590 specification). The pure biodiesel base must meet minimum requirements provided by ASTM D6751 (or EN14214) prior to blending. Raw pressed vegetable oils are NOT acceptable for use in any concentration.
3. Kubota strongly recommends that B5 blend be purchased from a BQ-9000 accredited producer or certified marketer. Kubota discourages local blending of BDF, because it is difficult to meet the quality requirements explained above.
4. Users of Kubota Emission Certified Engines are responsible for obtaining any required local, state, or national regulatory approvals for the use of BDF.

Enhanced engine care may be required even if the fuel meets the above standards. Kubota has the following concerns and recommendations regarding the use of B5 blend:

1. B5 blend attracts moisture and may contain higher water content than conventional diesel fuels. Keep storage and vehicle tanks as full as possible and ensure all caps and covers are installed properly to prevent water from entering and collecting in the fuel system.
2. Follow the oil change intervals recommended by Kubota in your operator's manual. Extended oil change intervals may result in premature wear or engine damage.
3. B5 blend is biodegradable and degradation of the fuel supply is accelerated by the presence of water, oxygen and other impurities.
 - To avoid damage caused by fuel degradation, B5 blend should not be used if it has been stored for more than 3 months.
 - If an engine is going to be placed in storage, the B5 blend should be flushed out by operating the engine for at least 30 minutes on conventional diesel fuel.

4. In consideration of the particular properties of BFD it is very important to follow the maintenance interval and procedures regarding the fuel system as specified in the operator's manual.
 - Microbial contamination and growth may cause corrosion in the fuel system and frequent plugging of the fuel filter.
 - Cold weather conditions can lead to fuel system plugging, hard starting or other problems.
 - BFD attracts moisture and may contain higher water content than conventional diesel fuels.
5. B5 blend will damage painted surfaces. Clean up spills immediately.
6. Tampering with the factory adjustments on fuel system components is a violation of EPA regulations, and can result in denial of warranty coverage.

Kubota's statement of allowance to use B5 blend in no way changes the published warranty terms and conditions. Fuel system failures that can be attributed to the quality of fuel used are ineligible for warranty coverage. Please see your local Kubota dealer for more information.

Kubota Products Approved for Use with Biodiesel

BX1500, BX1800, BX2200, BX1830, BX2230, BX1850, BX2350, BX22, BX23, BX24, BX1500, BX1800, BX2200, BX1830, BX2230, BX1850, BX2350, BX22, BX23, BX24, B7410, B7510, B21, B26, L2800, L3400, B7610, L4400, B7800, B2630, B3030,, L3130,, L3430, L3830, L4330 ,L4630, L5030, L3240, L3540, L3940, L4240, L4740, L5240, L5740, L39, L48, MX5000, M4900, M5700, M4800SU, M6800, M8200, M9000, M5040, M6040, M7040, M8540, M9540, M96S, M108SM95S, M105S, M105X, M125X, M108X, M110, M120, M95S, M105S, M105X, M125X, M108X, M110, M120, G2160, GR2100, GF1800, F2880, F3680, F2260, F2560, F3060, ZD18, ZD21, ZD25, ZD28, ZD321, ZD326, ZD331 RTV900, RTV1100, K008-3, KX41-3, KX71-3, KX91-3S, KX121-3S, KX161-3S, KX080-3, U15, U25S, U35S, U45S, R420S, R520S.

Fairbanks Morse Engine

Fairbanks Morse Engine, an EnPro Industries company, announced today the approval to utilize up to B100 (100% bio-diesel) in its Opposed Piston (OP) Model 38D 8 1/8 diesel and dual fuel engines for continuous operations. "Our extensive tests have demonstrated that utilizing B100 fuels that comply with the ASTM D6751 testing and specification had

little impact on fuel consumption and power ratings, and had positive impacts on emissions by substantially lowering particulate matter (PM) and CO values”, said Joe Eves, engineering manager – OP and FM/ALCO engines.

Bio-fuel usage in medium speed reciprocating engines is nothing new to Fairbanks Morse Engine. Experience ranges from Dutch Harbor, Alaska where UniSea, Inc. utilizes up to 100% fish oil to power six Fairbanks Morse 2.3 MW generator engines to a Dupage County, IL cogeneration facility where digester gas is burned in a Fairbanks Morse 1.5 MW generator engine. In addition, San Francisco State University has been utilizing up to B80 since the late 1990’s. Recently, Fairbanks Morse Engine concluded another successful test utilizing B100 (soy-diesel) in a continuous application in Story City, IA.

Engine Manufacturers Association

Biodiesel Blends

A consortium of diesel injection equipment manufacturers (“FIE Manufacturers”) issued a position statement concluding that blends greater than B5 can cause reduced product service life and injection equipment failures. According to the FIE Manufacturers’ Position Statement, even if the B100 used in a blend meets one or more specifications, “the enhanced care and attention required to maintain the fuels in vehicle tanks may make for a high risk of non-compliance to the standard during use.” As a result, the FIE Manufacturers disclaim responsibility for any failures attributable to operating their products with fuels for which the products were not designed.

Based on current understanding of biodiesel fuels and blending with petroleum-based diesel fuel, EMA members expect that blends up to a maximum of B5 should not cause engine or fuel system problems, provided the B100 used in the blend meets the requirements of ASTM D 6751, DIN 51606, or EN 14214. If blends exceeding B5 are desired, vehicle owners and operators should consult their engine manufacturer regarding the implications of using such fuel.

Warranties

Engine manufacturers are legally required to provide an emissions warranty on their products (which are certified on EPA’s diesel fuel specification) and, typically, also provide commercial warranties. Individual engine manufacturers determine what implications, if any, the use of biodiesel fuel has on the manufacturers’ commercial warranties. It is unclear what implications the use of biodiesel fuel has on emissions warranty, in-use liability, anti-tampering provisions, and the like. As noted above,

however, more information is needed on the impacts of long-term use of biodiesel on engine operations.

Conclusions

- Depending on the biomass feedstock and the process used to produce the fuel, B100 fuels should meet the requirements of either ASTM D 6751 or an approved European specification.
- Biodiesel blends up to a maximum of B5 should not cause engine or fuel system problems, provided the B100 used in the blend meets the requirements of ASTM D 6751, DIN 51606, or EN 14214. Engine manufacturers should be consulted if higher percentage blends are desired.
- Biodiesel blends may require additives to improve storage stability and allow use in a wide range of temperatures. In addition, the conditions of seals, hoses, gaskets, and wire coatings should be monitored regularly when biodiesel fuels are used.
- Although the actual loss will vary depending on the percentage of biodiesel blended in the fuel, the net effect of using B100 fuel is a loss of approximately 5-7% in maximum power output.
- Neat biodiesel and biodiesel blends reduce particulate, HC and CO emissions and increase NOx emissions compared with petroleum-based diesel fuel used in an unmodified diesel engine. Neither B100 nor biodiesel blends should be used as a means to improve air quality in ozone non-attainment areas.
- Biodiesel fuels have generally been found to be nontoxic and are biodegradable, which may promote their use in applications where biodegradability is desired.
- Individual engine manufacturers determine what implications, if any, the use of biodiesel fuel has on manufacturers' commercial warranties.
- Although several factors affect the cost of biodiesel fuel, its average cost exceeds that of petroleum-based diesel fuel. The relative cost of converting an existing fleet to biodiesel blends, however, is much lower than the cost of converting to other alternative fuel.

For information on Diesel Fuel Injection Equipment see: "Diesel Fuel Injection Equipment Manufacturers Common Position Statement on Fatty Acid Methyl Ester Fuels As a Replacement or Extender for Diesel Fuels" (June 2004).

Additional Biodiesel Information Sources

<p>ASTM International Web site: www.astm.org (Publication orders: Phone 610-832-9585)</p>	<p>\$ Specifications and test procedures</p>
<p>SAE International Web site: www.sae.org Phone: 877-606-7323</p>	<p>\$ Reference manuals and technical papers; also <i>Bosch Automotive Handbook (6th Edition)</i></p>
<p>Chevron Products Company Web site: www.chevron.com</p>	<p><i>Technical Review – Diesel Fuels</i></p>
<p>American Petroleum Institute (API) Web site: www.api.org</p>	<p>Various information papers on diesel fuels and biodiesel</p>
<p>National Biodiesel Board Web site: www.biodiesel.org</p>	<p>Various information on biodiesel</p>
<p>BQ-9000 Information Web site: www.bq-9000.org</p>	<p>Information on BQ-9000 Program</p>
<p>U.S. Department of Energy Web site: www.osti.gov/bridge</p>	<p><i>Biodiesel Handling & Use Guidelines</i> (free if downloaded electronically)</p>
<p>ENG-TEK: Diesel Performance Center Web site: www.eng-tek.com.au</p>	<p>Various engine/systems information</p>
<p>National Institute for Automotive Service Excellence (ASE) Web site: www.asecert.org</p>	<p>Diesel technician certification tests</p>
<p>Bosch Web site: www.bosch.com</p>	<p>Fuel systems and exhaust after-treatment information</p>
<p>U.S. Environmental Protection Agency (EPA) Web site: www.epa.gov</p>	<p>Diesel engine and fuel regulations</p>
<p>California Air Resources Board (CARB) Web site: www.arb.ca.gov</p>	<p>California diesel engine and fuel regulations</p>
<p>National Renewable Energy Laboratory (NREL) Web site: www.nrel.gov</p>	<p>Various information on biodiesel and other alternative fuels</p>
<p>Engine Manufacturers Association (EMA) Web site: www.enginemanufacturers.org</p>	<p>Position statements on diesel and biodiesel</p>
<p>Alliance of Automobile Manufacturers Web site: www.autoalliance.org</p>	<p>Position statements on diesel and biodiesel; also Worldwide Fuels Charter</p>

Commonly Used Acronyms

API	American Petroleum Institute	J/kg	Joules per kilogram
BTL	Biomass to liquids	J/L	Joules per liter
Btu	British thermal unit	Kg/kw-h	Kilograms per kilowatt hour
Btu/gal.	British thermal units per gallon	KOH	Potassium Hydroxide
B2	Biodiesel blend containing 2 percent biodiesel	Lb/bhp-h	Pounds per brake horsepower per hour
B5	Biodiesel blend containing 5 percent biodiesel	Lb-ft	Pound foot
B20	Biodiesel blend containing 20 percent biodiesel	LTFT	Low temperature flow test
B100	100 percent biodiesel	NBB	National Biodiesel Board
CARB	California Air Resources Board	NBAP	National Biodiesel Accreditation Program
CFPP	Cold filter plugging point	NCWM	National Conference on Weights & Measures
CFR	Cooperative Fuel Research	NIST	National Institute of Standards & Technology
CO	Carbon monoxide	NO	Nitrogen oxide
CO ₂	Carbon dioxide	NO ₂	Nitrogen dioxide
°C	Degrees Celsius (centigrade)	NO _x	Oxides of nitrogen
°F	Degrees Fahrenheit	OBD	On-board diagnostics
DI	Direct injection	OHV	Overhead valve
DPF	Diesel Particulate Filter	OTC	Over-the-counter
ECM	Engine control module	PM	Particulate matter
ECU	Electronic control unit	PME	Palm Methyl Ester
EGR	Exhaust gas recirculation	ppm	Parts per million
EMA	Engine Manufacturers Association	psi	Pounds per square inch
EPA	U.S. Environmental Protection Agency	RME	Rapeseed Methyl Ester
FAME	Fatty acid methyl ester	SCC	Storage catalytic converter
FIE	Fuel injection equipment	SCR	Selective catalytic reduction
g/bhp-hr	Grams per brake horsepower per hour	SLBOCLE	Scuffing load ball-on cylinder lubricity evaluator
GTL	Gas to liquids	SME	Soy Methyl Ester
GVW	Gross vehicle weight	SO ₂	Sulfur dioxide
HC	Hydrocarbons	T ₉₀	Temperature at which 90 percent of fuel will evaporate
HFRR	High frequency reciprocating rig	TDC	Top dead center
hp	Horsepower	ULSD	Ultra-low sulfur diesel
hrs	Hours	VGT	Variable Geometry Turbocharger
IDI	Indirect injection		

Conversion Formulas

Conversion of	Formula
bar to psi	# bar x 14.5038 = psi
psi to bar	# psi ÷ 14.5038 = bar
°C to °F	(# °C x 1.8) + 32 = °F
°F To °C	(# °F – 32) ÷ 1.8 = °C

