

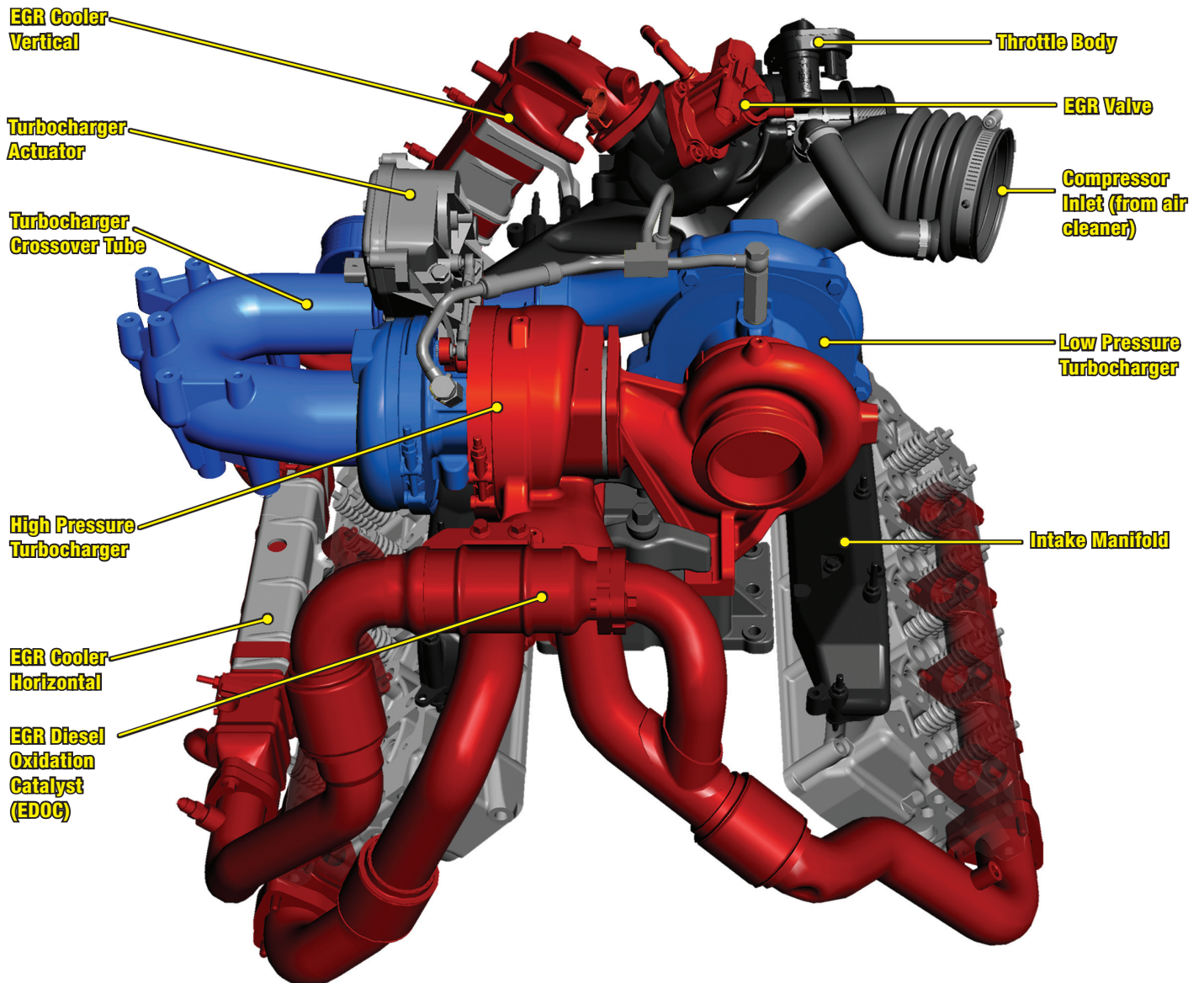
## Air Management System Components

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

## Air Management System Features

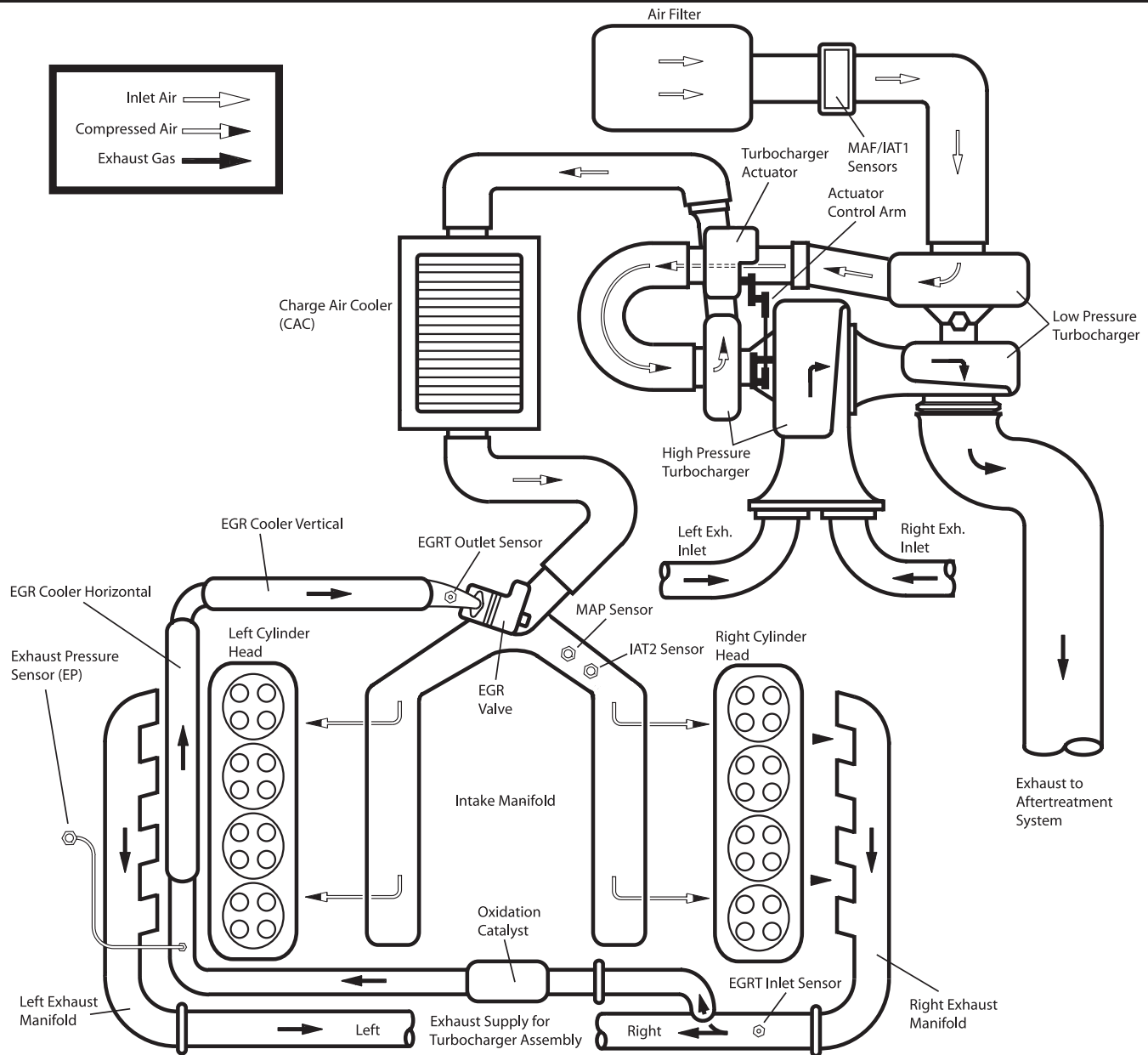
- The series sequential turbocharger is a low pressure/high pressure design working in series with a turbocharger actuator on the high pressure turbine controlling the boost pressures.
- The charge air cooler is utilized to reduce the temperature of the pressurized air therefore inducing a cooler/denser 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.

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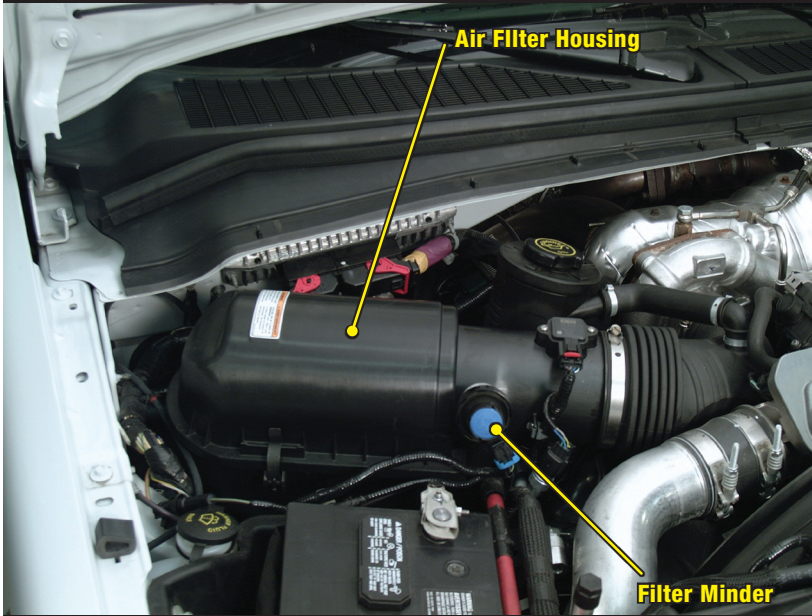
# AIR MANAGEMENT SYSTEM



## System Flow

- Air enters the system through the air filter where particles are removed from the air. The air filter has a filter minder on it to warn the operator of a restricted air filter.
- After the air is filtered, the mass of the air and temperature are measured by the mass air flow sensor (MAF) and the intake air temperature sensor #1 (IAT1).
- The filtered air is then directed past the crankcase ventilation system where crankcase vapors and fresh air are mixed.
- After mixing with crankcase vapors the fresh air mixture is drawn into the low pressure turbocharger compressor then the compressed air is sent to the high pressure turbocharger where it is further compressed before being sent to the charge air cooler (CAC).
- The (CAC) cools the compressed air via an air-to-air cooler, then the condensed air passes through the EGR throttle, mixes with cooled EGR gases, then enters the intake manifold.
- The intake manifold directs the cooled air to the intake ports of the cylinder heads.
- The burned air fuel mixture is pushed out of the cylinder into the exhaust manifold which collects the exhaust and routes it to the high pressure turbocharger's turbine wheel.
- The exhaust up pipe, connected to the passenger side exhaust manifold has a passage that directs exhaust to the exhaust gas recirculation (EGR) coolers and then to the EGR valve.
- The EGR valve controls the flow of exhaust into the intake system where the gases are mixed with intake air to reduce NO<sub>x</sub> (Oxides of Nitrogen) emissions and noise.
- The hot and expanding exhaust gases that are routed to the series sequential turbocharger turbines, spin the turbine wheels through flow and expansion. The spinning turbine wheels then spin the compressor wheels via common shafts.

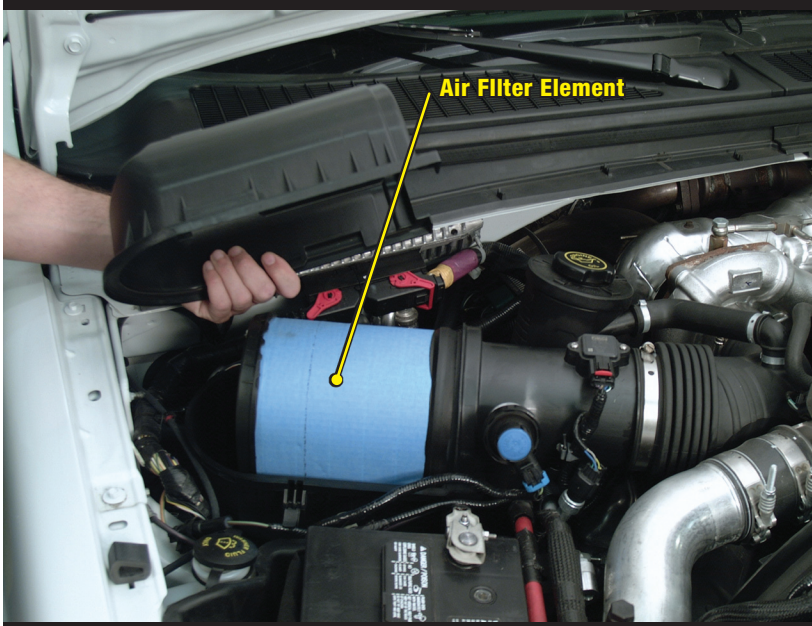
## AIR MANAGEMENT SYSTEM



### Air Filter Housing/ Filter Minder

- The air filter is located on the passenger side of the engine compartment between the battery and the cowl.
- A filter minder, device used to measure filter restriction, is located on the outlet side of the air filter housing just before the MAF sensor.
- Fresh air, from the passenger side fender area, is drawn into the air filter and particulates are removed from the air before going to the engine.

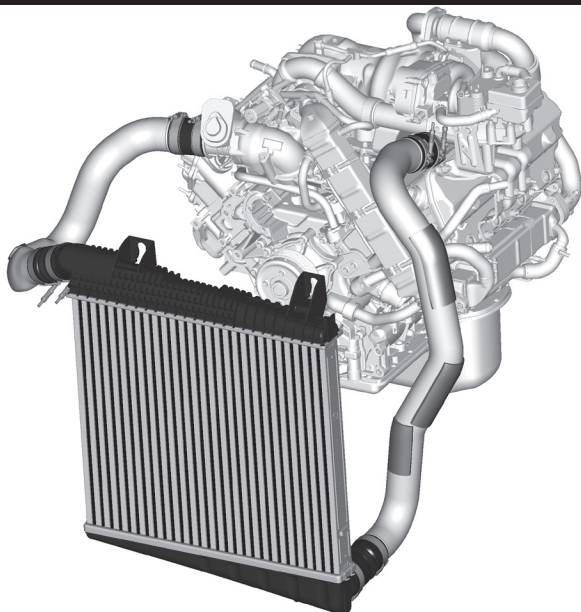
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### Air Filter Element

- The new air filter element is a replaceable cartridge separate from the housing.
- The air filter is capable of holding 750 grams of particulates before needing replacement.
- The filter element is a honeycomb design.

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### Charge Air Cooler (CAC)

- The CAC is located in the front of the radiator.
- The CAC 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.

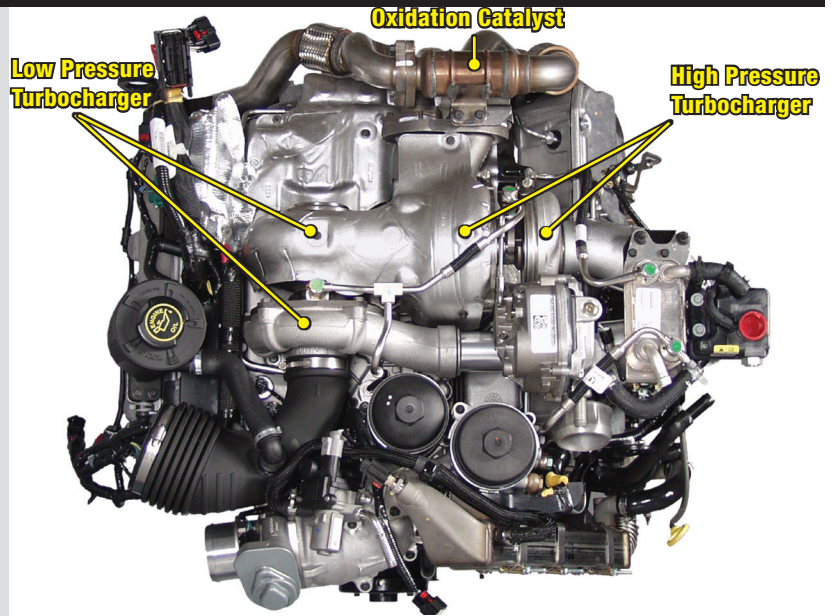
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## AIR MANAGEMENT SYSTEM

### Series Sequential Turbocharger & Turbocharger Actuator

- The series sequential turbocharger for the 6.4L Power Stroke® Diesel is designed to provide boost control at low and high speeds for improved throttle response.
- The turbocharger actuator is used to control the position of the variable vanes inside the high pressure turbocharger's turbine housing.
- 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.

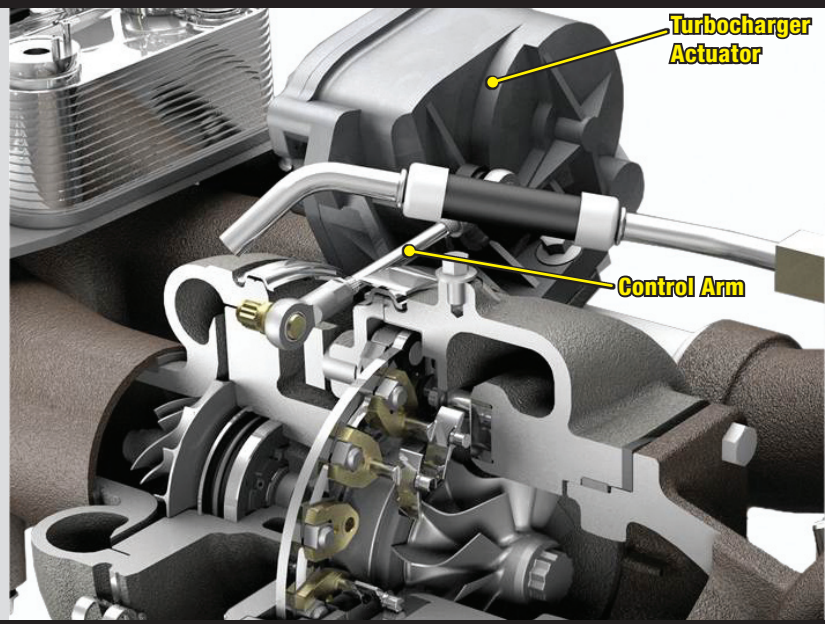
NOTE: There is an oxidation catalyst in the exhaust pipe for the EGR system that is utilized to crack hydrocarbons before they enter the EGR system.



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### Turbocharger Actuator

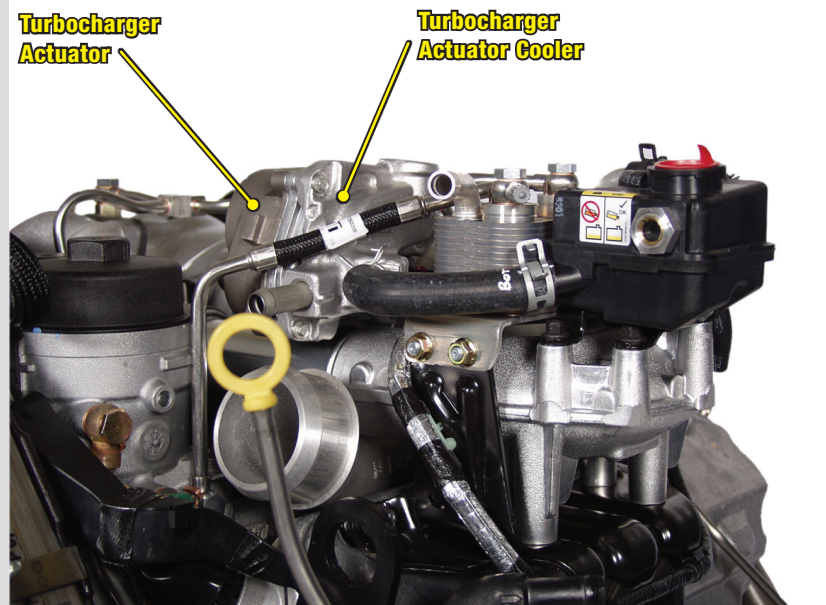
- The variable vanes inside the high pressure turbocharger's turbine housing are now controlled by the turbocharger actuator.
- The high pressure turbocharger's turbine housing contains vanes that control the effective size of the housing. These vanes are controlled by the turbocharger actuator by way of a control arm. The control arm connects the actuator to a pivot shaft which connects to the unison ring that moves the vanes.



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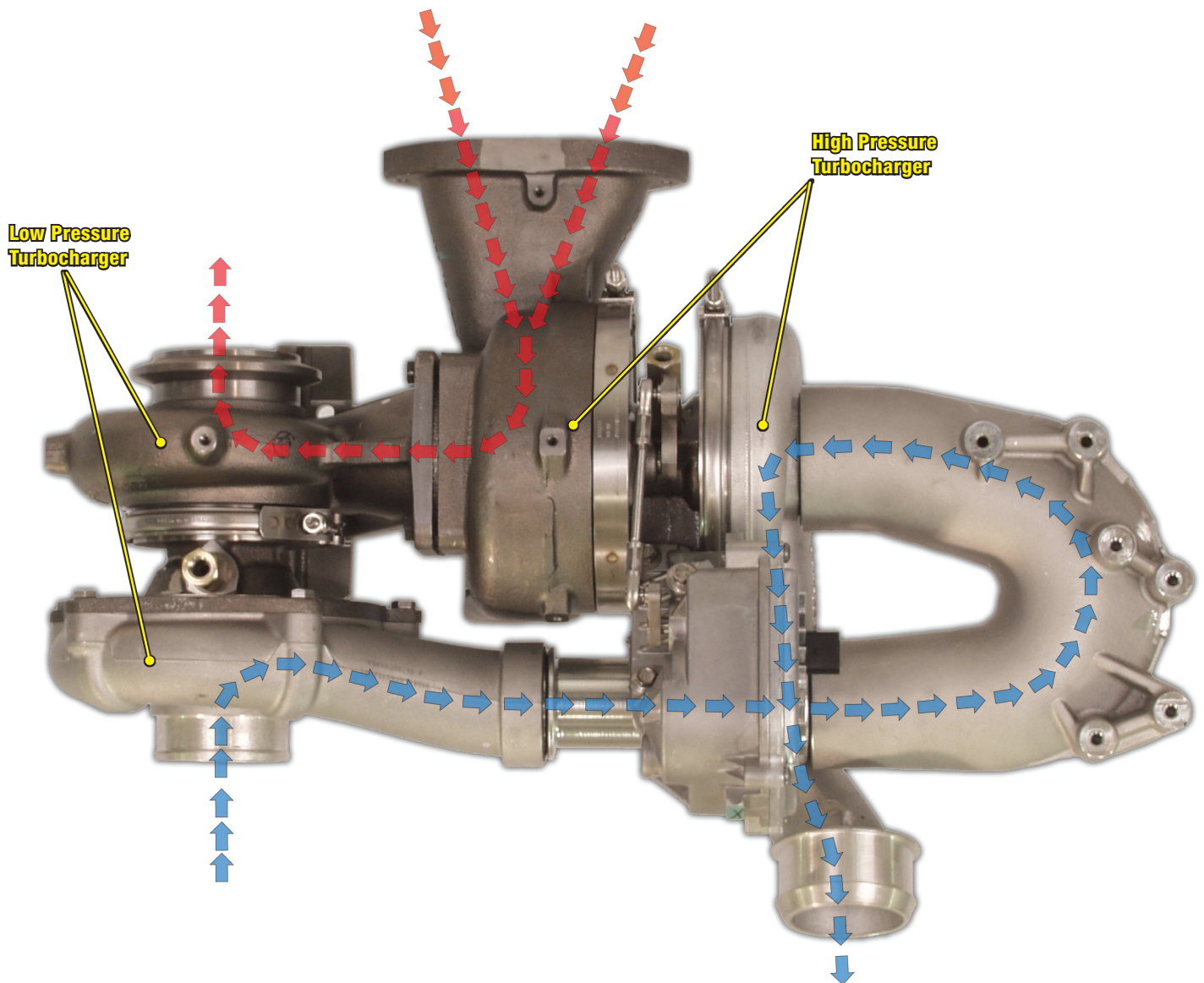
### Turbocharger Actuator Cooler

- The turbocharger actuator is fitted with a cooling plate to reduce the temperature of the electronics inside the actuator housing.
- The actuator cooler uses coolant from the fuel system cooler as the heat exchange medium.



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## AIR MANAGEMENT SYSTEM



### INTAKE AIRFLOW (Blue)

- Air enters the low pressure turbocharger from the air filter.
- The low pressure turbocharger compresses the air and sends the air through the extension tube and the crossover tube prior to entering the high pressure turbocharger.
- The high pressure turbocharger further compresses the air and sends the air to the charge air cooler (CAC) where the air is cooled by an air-to-air cooler prior to entering the intake manifold.

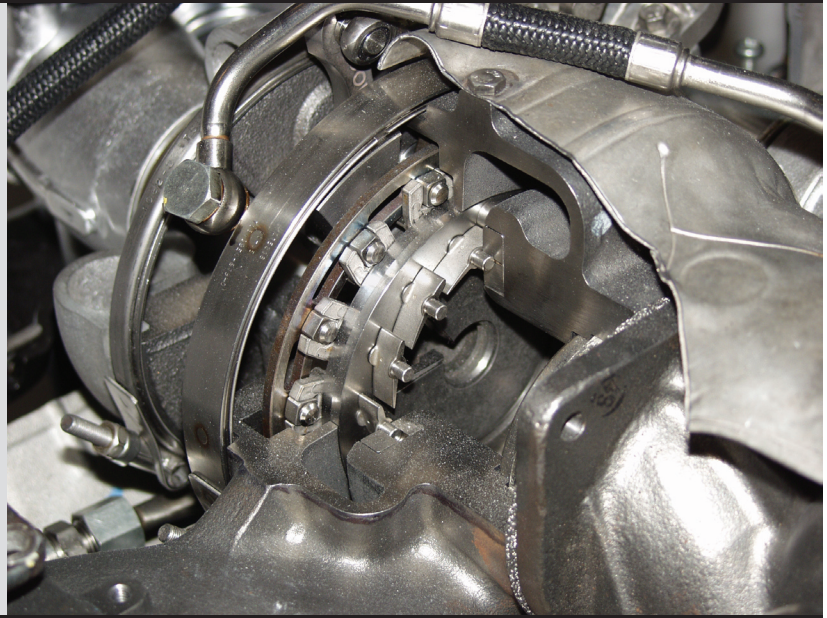
### EXHAUST AIRFLOW (Red)

- Exhaust gas enters the high pressure turbocharger turbine housing after being directed through the exhaust up-pipes at the rear of the engine.
- The high pressure turbocharger turbine contains the vanes which are controlled by the turbocharger actuator. These vanes continually change the velocity of the exhaust gas in the high pressure turbocharger turbine.
- After the exhaust gas has passed through the high pressure turbocharger turbine it immediately enters the low pressure turbocharger turbine.
- Once the exhaust gas has powered the low pressure turbocharger turbine the exhaust gas exits through the housing towards the rear of the engine where it is directed to the exhaust aftertreatment system.

## AIR MANAGEMENT SYSTEM

### Vanes Closed

- 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 small turbocharger, increasing the wheel speed quickly at low speed.
- 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.
- The closed vane position is also used for cold ambient warm up.

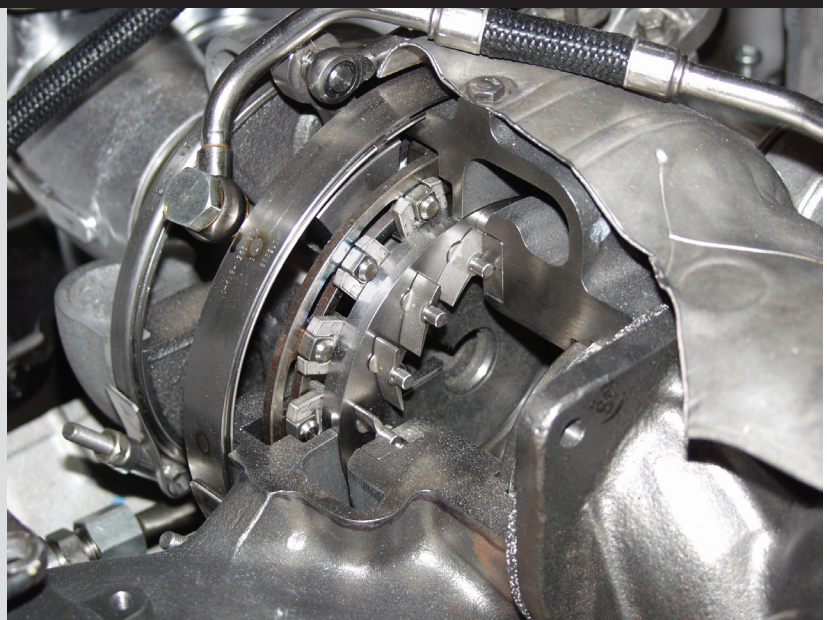


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### Vanes Partially Closed

- 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.

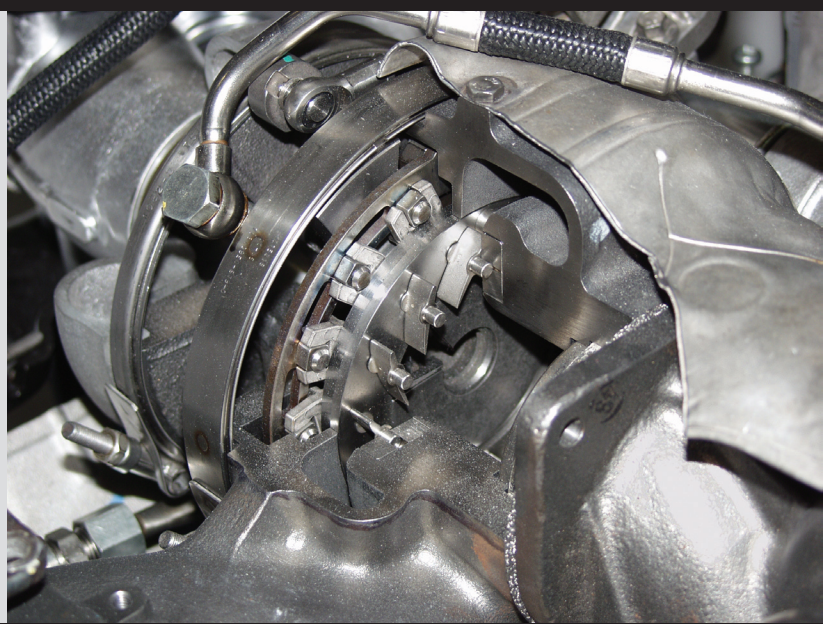
**Note:** There is actually an infinite number of vane positions between open and closed. The partially closed picture is for illustration purposes only.



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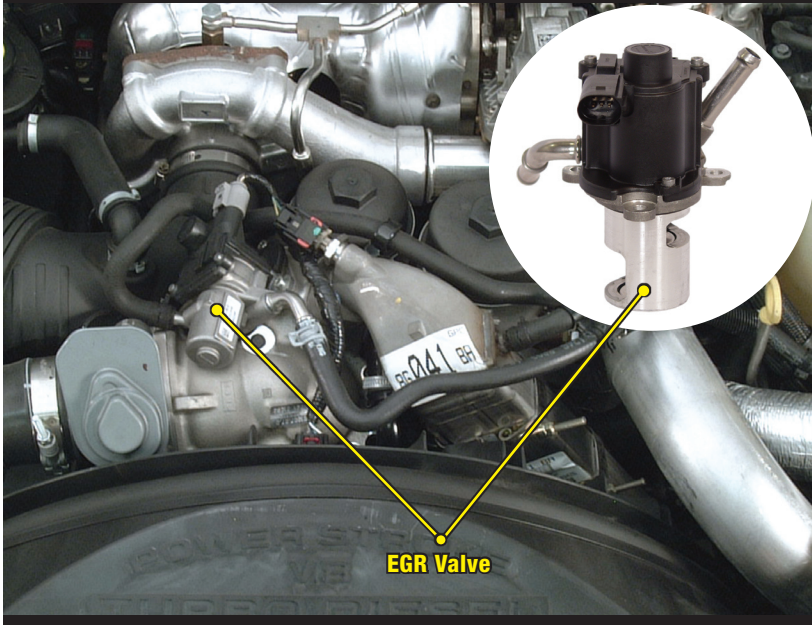
### Vanes Open

- 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 with minimal restriction.



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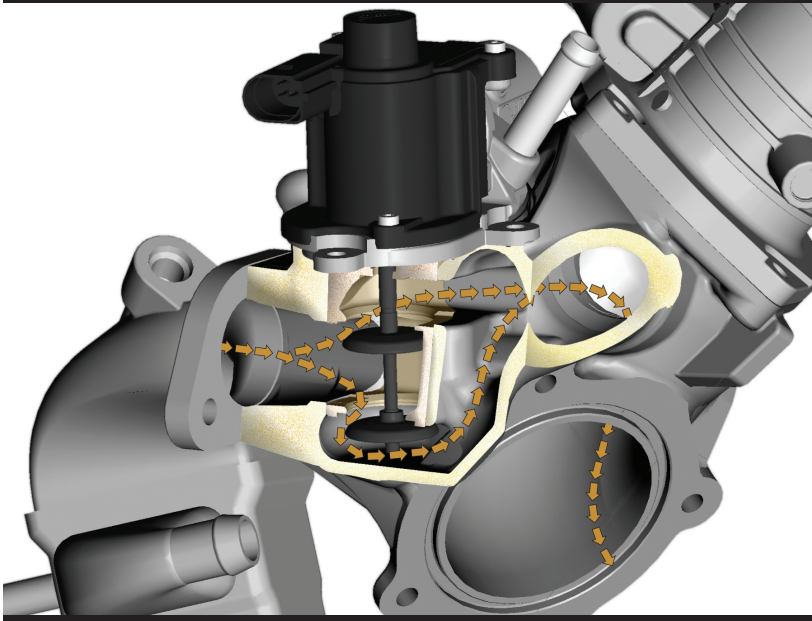
## AIR MANAGEMENT SYSTEM



### EGR Valve

- The ECM controlled EGR (Exhaust Gas Recirculation) valve adds cooled exhaust gases to the intake manifold to reduce NOx emissions.
- The EGR valve is opened during steady state throttle positions when exhaust back pressures are higher than intake manifold pressures (boost).

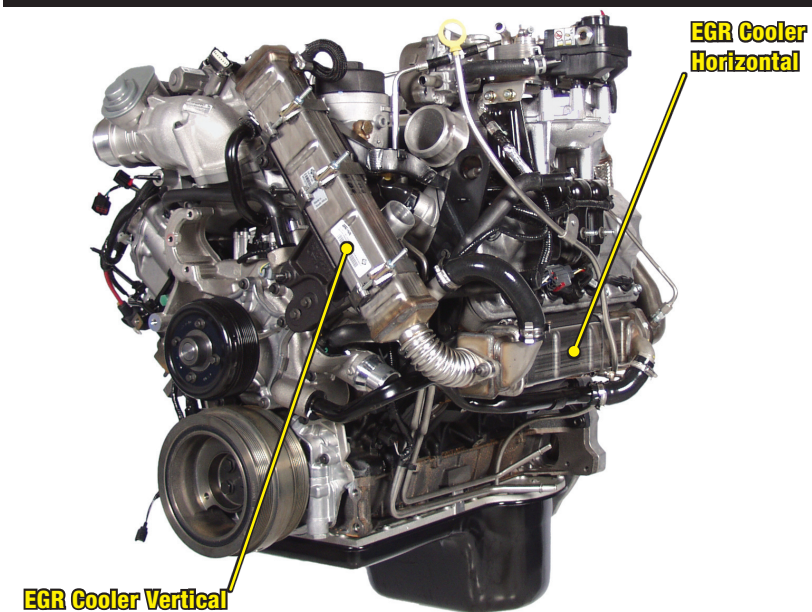
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### EGR Flow

- The EGR valve has two valves connected by a common shaft.
- Cooled exhaust gas enters the lower opening of the EGR valve after leaving the vertical EGR cooler.
- When the valve opens it allows the cooled exhaust gas to flow through two passages, one passage is through the upper opening of the EGR valve (upper valve) and the other is through a passage below the EGR valve (lower valve).
- Both passages merge together prior to being mixed with the filtered incoming air before being sent to the intake manifold.

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### Dual EGR Cooling System

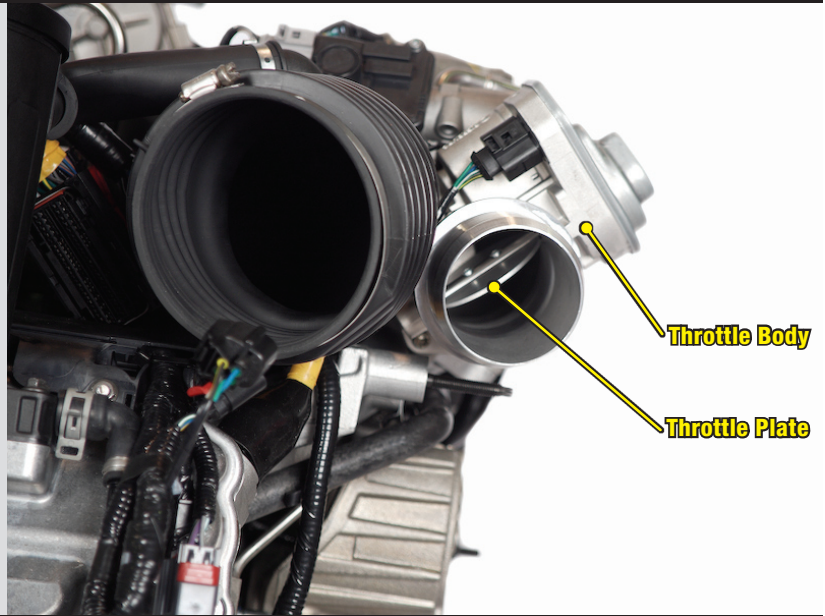
- The EGR cooling system is an air to coolant heat exchanger that is used to cool the exhaust gases before they are sent to the EGR valve.
- The exhaust is routed into the EGR coolers from the exhaust up pipes at the rear of the engine.
- The exhaust is cooled by passing through metal tubes that are surrounded by engine coolant. Depending on conditions, the temperature drop across the coolers could be as much as 850°F.
- The cooled exhaust is then routed to the EGR valve that is mounted to the inlet mixing chamber.

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## AIR MANAGEMENT SYSTEM

### Throttle Body

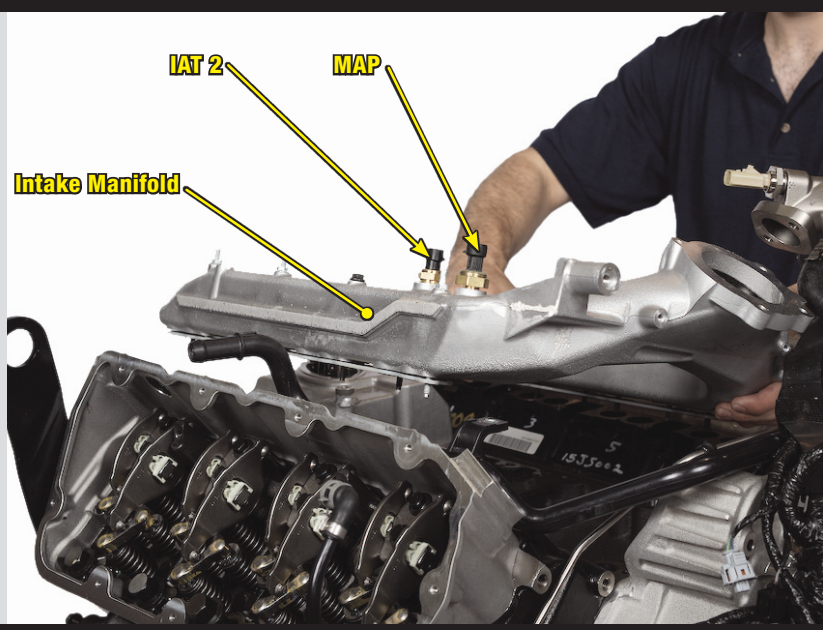
- The throttle body is used to assist with the exhaust aftertreatment system.



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### Intake Manifold

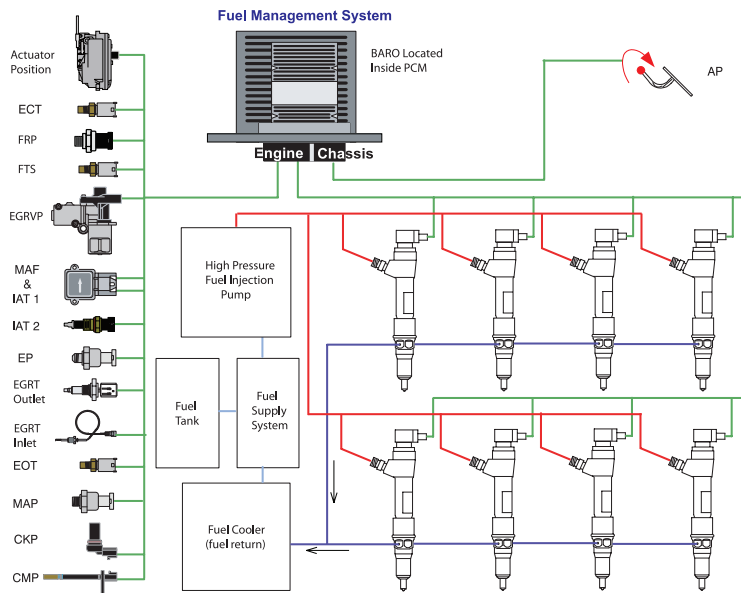
- The intake manifold on the 6.4L Power Stroke® Diesel is made of aluminum and directs the flow of air to the intake ports in the cylinder heads.
- The manifold absolute pressure sensor (MAP) and the intake air temperature 2 sensor (IAT2) are both mounted in the intake manifold.



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# FUEL MANAGEMENT SYSTEM



## High Pressure Common Rail Fuel System

- The high pressure common rail fuel injection system with piezo electric fuel injectors uses pressurized fuel and electronics to actuate and control fuel injection into the cylinders.

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## Fuel Management System Major Components

- Fuel Supply System
- High Pressure Fuel Injection Pump
- High Pressure Fuel Tubes
- Sensors
- Injectors
- Electrical Components
- Actuators

## High Pressure Common Rail Direct Injection Fuel System Components

- The fuel management system is comprised of several sub systems.
- Each system works together to deliver excellent power and efficiency while meeting the requirements of emissions regulations.

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## Fuel Management System Features

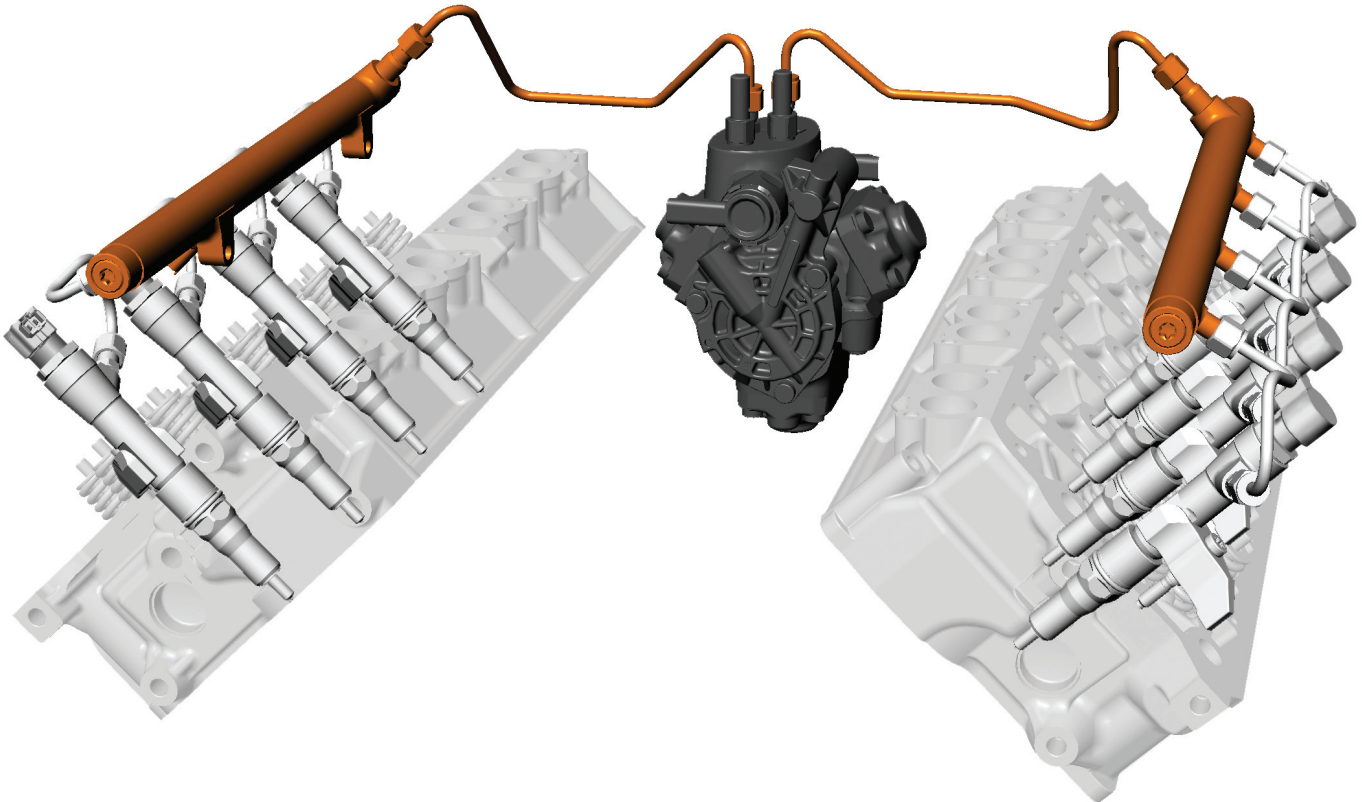
- Emissions
- Noise
- Rate Control
- Timing Control
- PCV (pressure control valve)
- VCV (volume control valve)

## High Pressure Common Rail Fuel System Advantages

- Emissions and noise have been reduced through improvements in rate, timing control, and multiple injections.
- The high pressure system's pressure relief function is now controlled by the PCV (Pressure Control Valve), which is mounted to the high pressure fuel injection pump.
- The piezo fuel injectors help reduce noise while delivering optimum performance.

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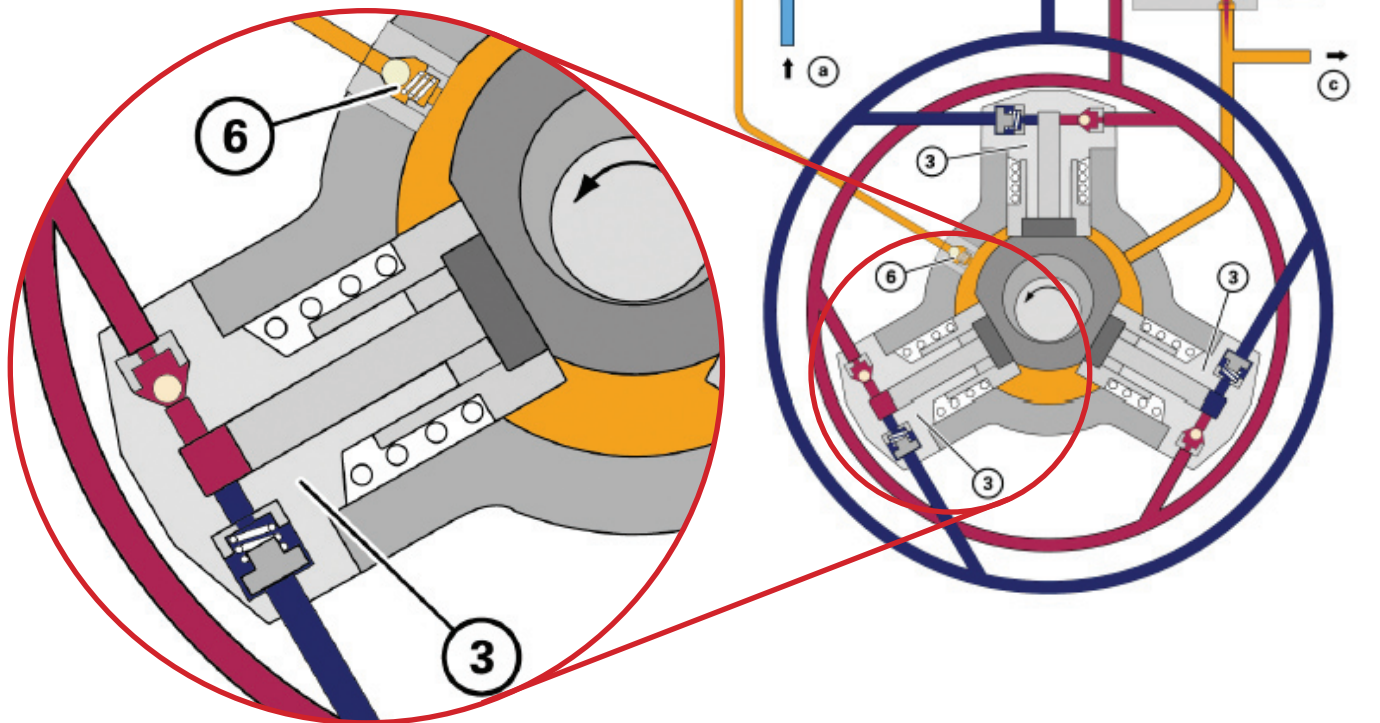
## HIGH PRESSURE FUEL SYSTEM



### High Pressure Fuel System Flow

- Fuel is supplied to the high pressure fuel injection pump after being filtered by both the HFCM (horizontal fuel conditioning module) and the engine mounted fuel filter.
- The high pressure fuel injection pump is gear driven off of the camshaft gear at the rear of the engine.
- Once the high pressure fuel injection pump pressurizes the fuel it is routed to two (2) high pressure fuel rail supply tubes, one for each bank.
- The high pressure fuel rail supply tubes route the fuel to the high pressure fuel rail located under the valve cover.
- The high pressure fuel rail inlet protrudes through the valve cover spacer at the back of the engine and oil is sealed by a rubber seal.
- The high pressure fuel rail routes fuel to each of the four (4) fuel injectors through four (4) separate fuel injector supply tubes all located under the valve cover.

- 1) ITP (internal transfer pump)
- 2) VCV (volume control valve)
- 3) High-Pressure Fuel Injection Pump Element
- 4) PCV (pressure control valve)
- 5) Inlet Pressure Control Valve
- 6) Lubrication Valve
- 7) Edge Filter
- a) Fuel Inlet
- b) High-Pressure Connection
- c) Fuel Return



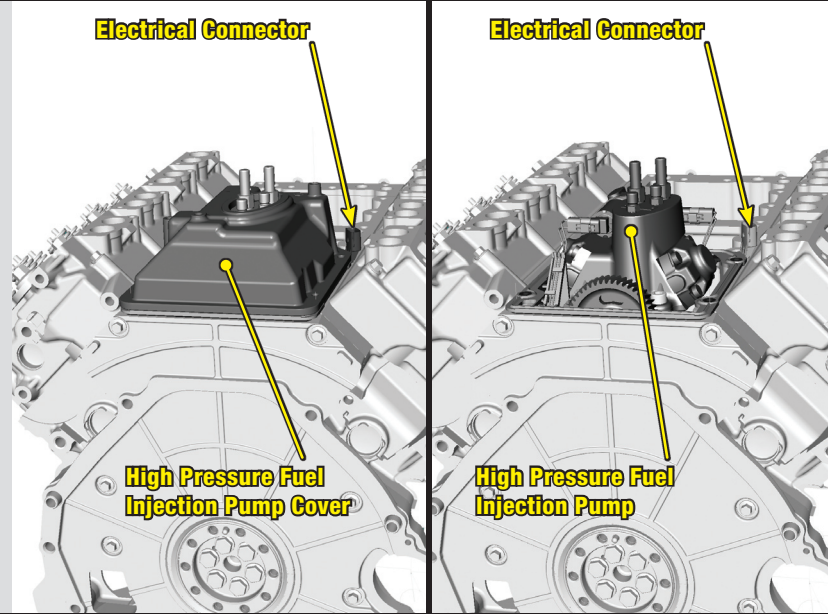
## High Pressure Pump Operation

- After being filtered at the engine mounted fuel filter, fuel is directed to the high pressure fuel injection pump.
- Before fuel enters the Volume Control Valve (VCV) the pressure is stepped up by the Internal Transfer Pump (ITP). The ITP is located inside the high pressure fuel injection pump and is driven by its main shaft.
- The VCV controls how much fuel enters the three (3) main pump pistons.
- A portion of the fuel leaving the ITP is sent to a lubrication valve which allows fuel to lubricate and cool the internal mechanical components of the high pressure fuel injection pump.
- The high pressure fuel injection pump main shaft has an offset journal that actuates each of the three (3) pistons as the shaft rotates.
- The offset journal of the main shaft utilizes a free-spinning hub to make contact with the three (3) pistons.
- The pistons start their compression stroke via the offset journal and are returned to rest via spring pressure.
- The pistons receive fuel from the VCV through a one way check valve. Fuel is drawn into the cylinder while the piston is returning to rest.
- The outlet check valve ball is closed while fuel is being drawn in due to the suction (low pressure area) of the piston returning to rest and the pressure exerted by the other two pistons.
- Once the piston starts its compression stroke, the inlet check valve closes via spring and fuel pressure and the outlet check valve opens due to increasing fuel pressure forcing the check valve ball away from its seat.
- 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).

## FUEL MANAGEMENT SYSTEM

### High Pressure Fuel Injection Pump & Cover

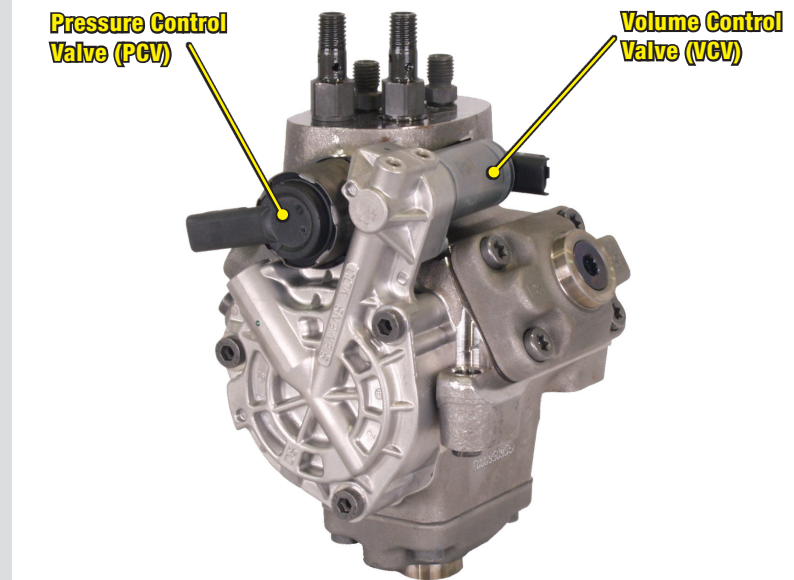
- The high pressure fuel injection pump is installed in the crankcase.
- The pump is a three (3) piston rotary style pump that is driven by the rear gear train.
- Each bank of cylinders has its own pump outlet and high pressure fuel supply tube.



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### PCV (Pressure Control Valve) VCV (Volume Control Valve)

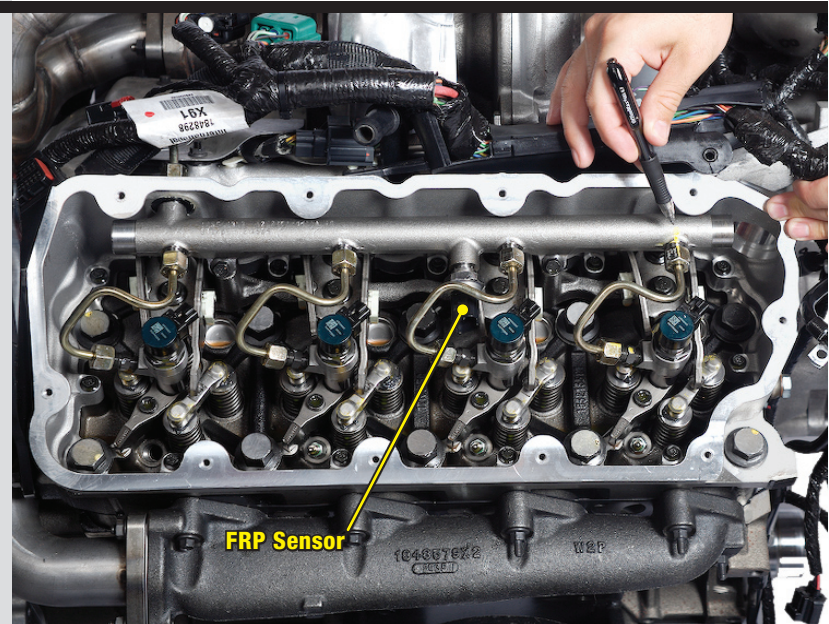
- The PCV and VCV are both installed in the high pressure fuel injection pump.
- The PCV and VCV ARE NOT SERVICEABLE.



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### High Pressure Fuel Rail & Fuel Rail Pressure Sensor (FRP)

- Fuel under extremely high pressures is delivered to the fuel injectors from the fuel rail by way of the fuel injector supply tubes.
- The FRP sensor is located on the engine's right side high pressure fuel rail.



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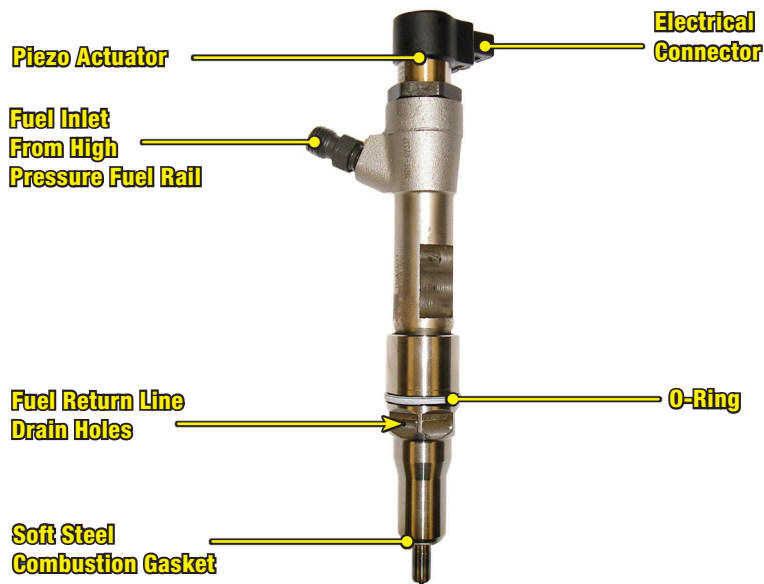
## Piezo Electric Fuel Injector

- Piezo Electrically Actuated
- High Electrical Efficiency
- High Voltage Supply
- Up to 5 Injections Per Combustion Event
- Self extracting hold down clamp

## Fuel Injector Features

- The injector uses a Piezo Actuator to electrically control the injections with extreme precision.
- The Piezo Actuator is turned on for approximately 0-400  $\mu$ s (micro second or millionth of a second) for 2 injections.
- No special tools are needed to remove the injectors from their bore. The injector is slowly removed from its bore by removing the self-extracting hold down clamp bolt.

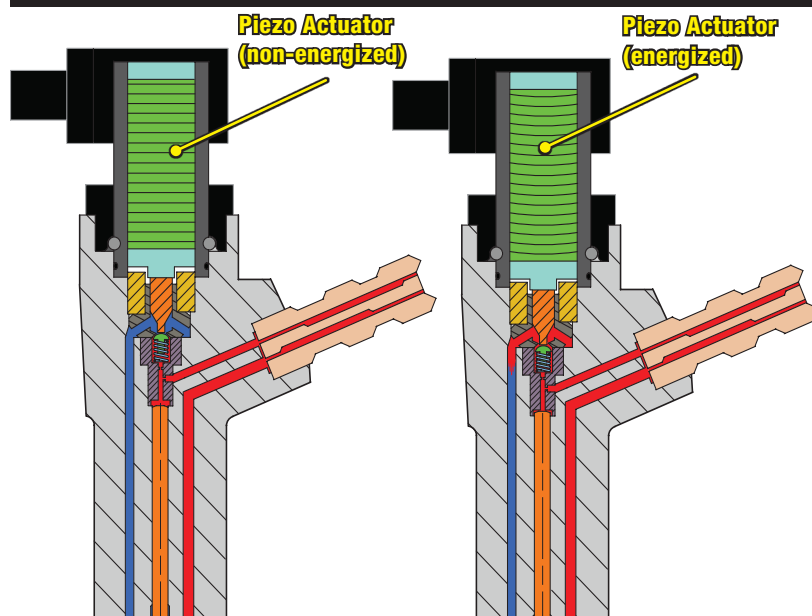
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## Injector & O-ring

- The injector has one (1) replaceable o-ring on the outside of the body, and one (1) replaceable soft steel combustion gasket on the tip of the injector.
- The injector's piezo actuator has a single two (2) pin connector that is located under the valve cover.
- The fuel charging harness has a single main connection point at the front of the valve cover spacer.

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## Piezo Actuator

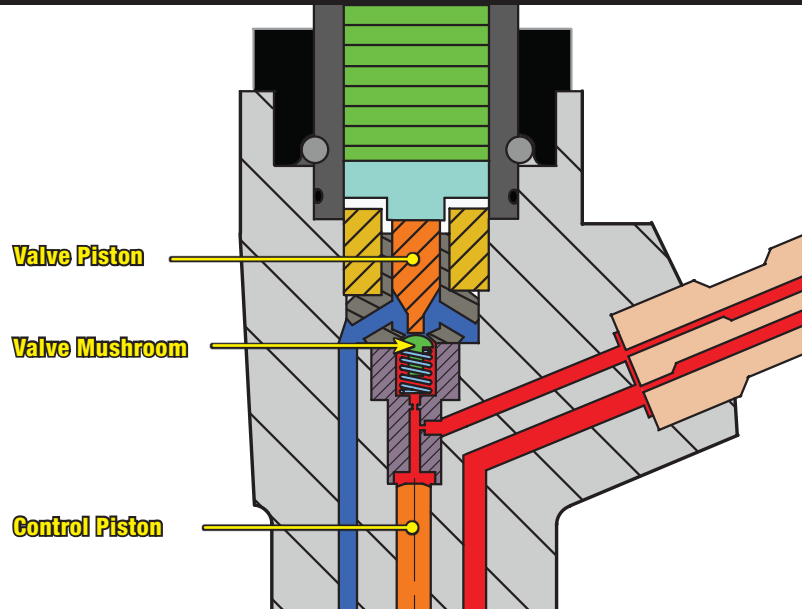
- The piezo actuator is an electrically energized device that acts similar to a solenoid but is much more precise.
- A piezo actuator is a composition of piezo discs, that when electrically energized, cause the discs to deform resulting in an expansion. This expansion results in a longitudinal motion thus controlling the injector.
- When energized, the piezo actuator pushes downward against the valve piston. The piezo actuator is returned to its non energized state via the ECM switching the polarity of the electrical feed to the injector.

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# FUEL MANAGEMENT SYSTEM

## Valve Piston

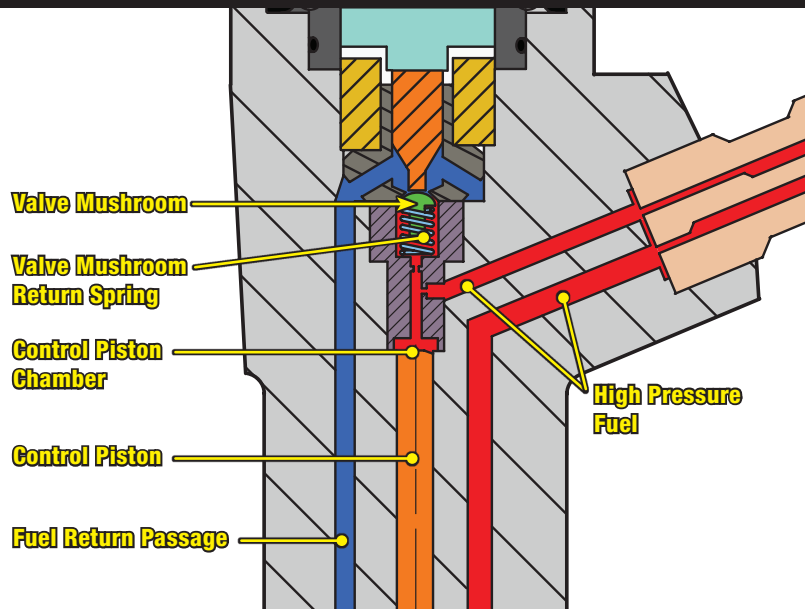
- The valve piston is utilized for one main purpose:
  - 1) It transfers the up and down movement from the Piezo Actuator to the Valve Mushroom.



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## Valve Mushroom, Return Spring, and Control Piston

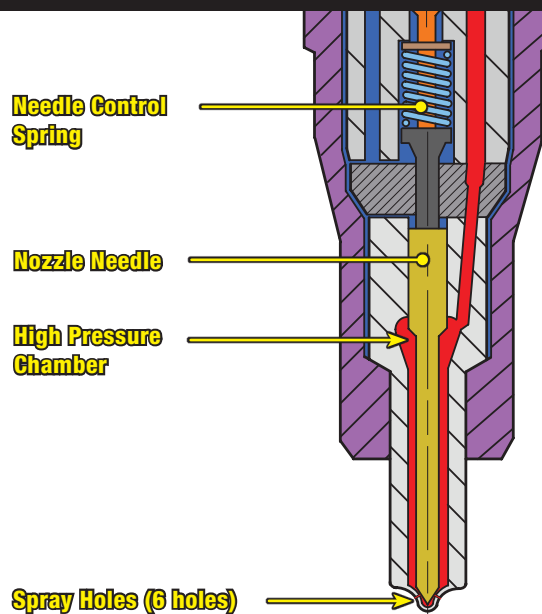
- The valve mushroom is a hydraulic check valve that allows high pressure fuel to bleed off into the fuel return passage directly above it whenever the Piezo Actuator is energized.
- The valve mushroom is held in a closed (sealed) position whenever the Piezo Actuator is not energized via high pressure fuel and spring pressure.
- The control piston utilizes its large surface area for a downward force to overcome the pressure exerted by the smaller surface area of the nozzle needle in the high pressure chamber to keep the nozzle needle in a closed position.



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## Nozzle Needle

- The nozzle needle is an inwardly opening type which lifts off its seat every time the pressure in the high pressure chamber exceeds the pressure in the control piston chamber, i.e. when the piezo is actuated.
- The needle control spring is used to hold the nozzle needle in a closed position.
- Fuel is atomized at high pressure through the nozzle tips six spray holes.



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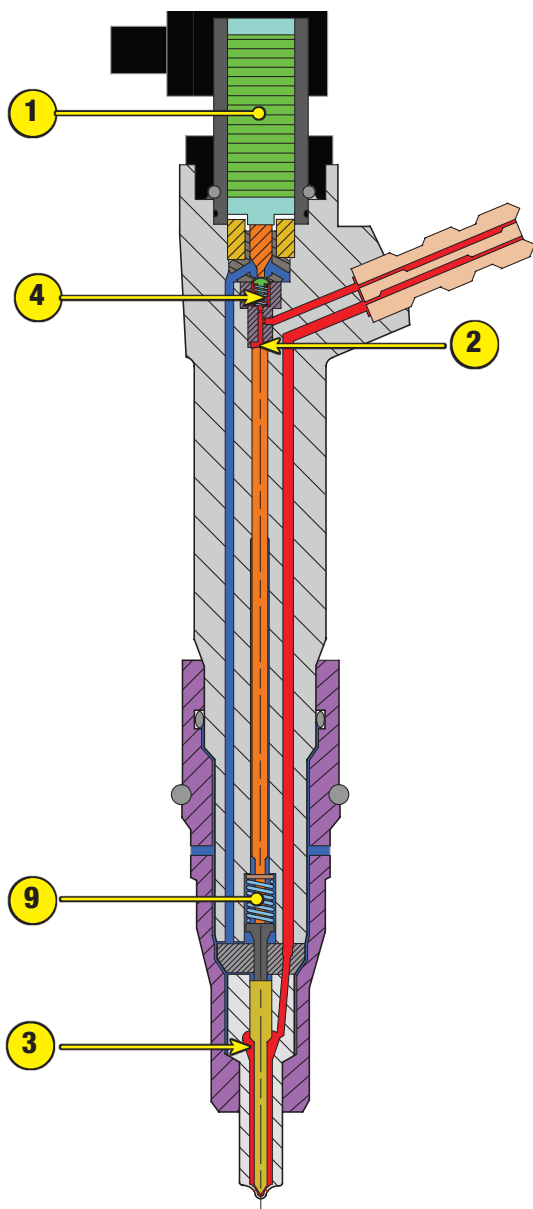
## Two Stages of Injection

- Main Injection
- End of Main Injection

## Stages of Injection

- The injection cycle has two (2) stages.
- Main injection.
- End of main injection.
- This injection system is capable of performing both steps of the injection cycle up to 5 times per firing cycle.

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## Pre-Main Injection

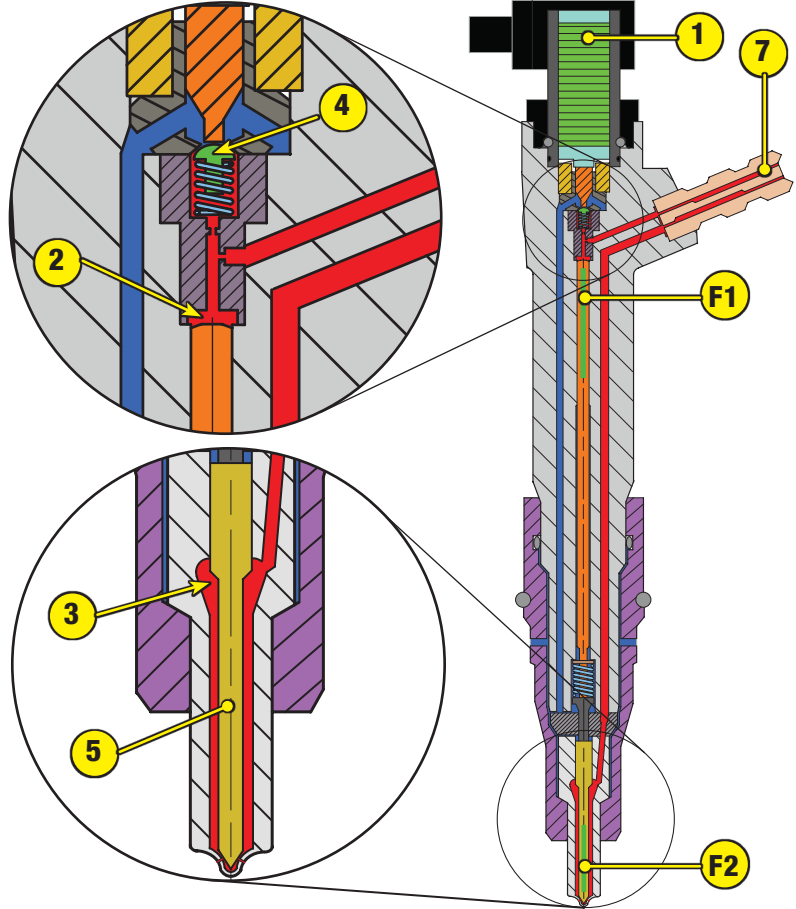
- The piezo electric fuel injector is constantly being filled with fuel via the high pressure fuel injection pump.
- High pressure fuel from the high pressure fuel injection pump enters the following areas:
  - control piston chamber (2).
  - spring side of the valve mushroom (4).
  - high pressure chamber (3).
- The needle control spring (9) holds the needle on its seat so that fuel cannot enter the combustion chamber.
- The piezo actuator (1) is in a non-energized state.

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# FUEL MANAGEMENT SYSTEM

## Main Injection Step 1

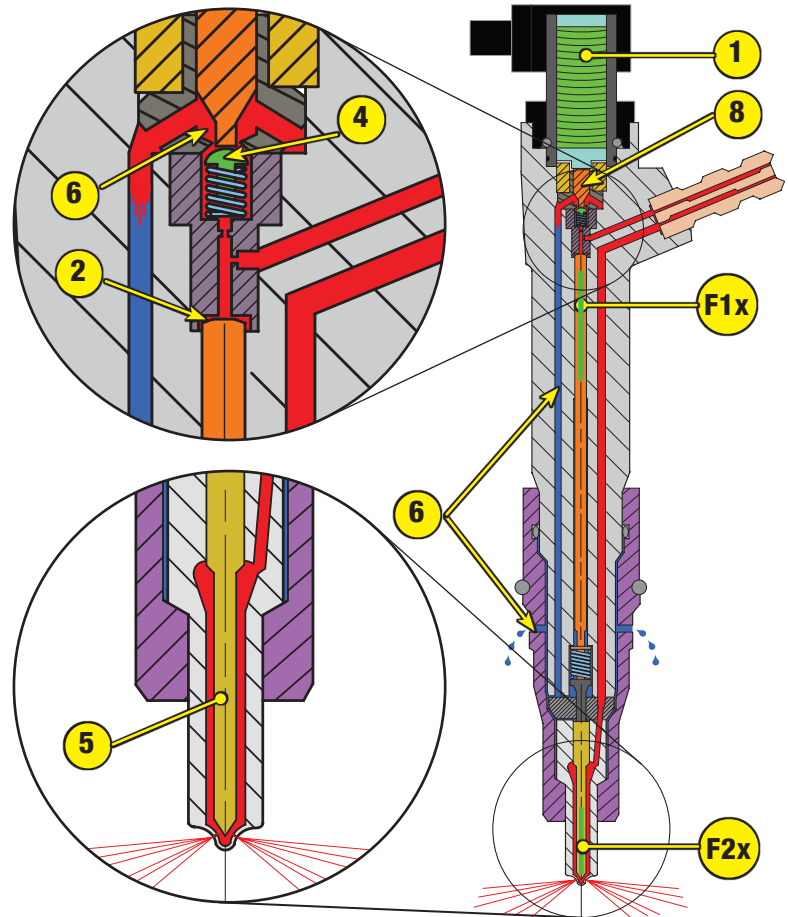
- Fuel under pressure from the rail (7) reaches the control piston chamber (2) and the high pressure chamber (3) of the nozzle needle (5).
- The bore hole to the fuel return line is closed via the valve mushroom (4), which is held closed by a spring and high pressure fuel.
- The surface area of the control piston is much larger than the surface area of the nozzle needle in the high pressure chamber.
- The force (F1) exerted by the control piston due to its larger surface area along with the force of the needle control spring overcomes the force (F2) exerted by the smaller surface area of the nozzle needle in the high pressure chamber which holds the nozzle needle closed.



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## Main Injection Step 2

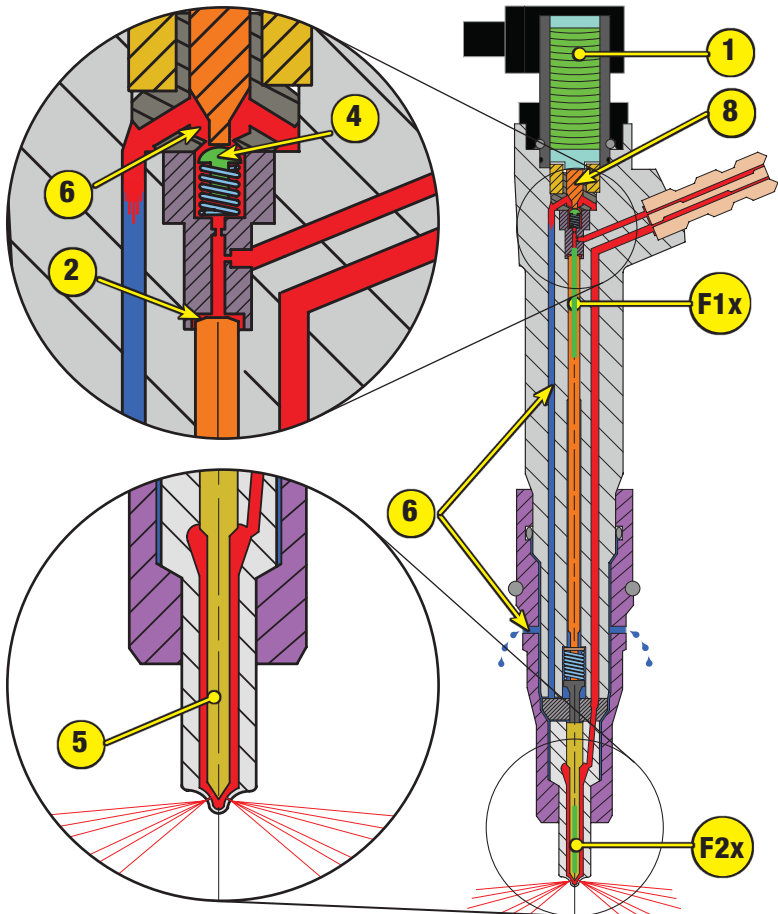
- When the piezo actuator (1) is commanded on, the actuator is energized (which causes the piezo discs to deform and create a downward force) and pushes the valve piston (8) downward.
- The downward force of the valve piston pushes the valve mushroom (4) and spring down which opens up a bore hole that connects the high pressure fuel to the fuel return line (6).
- When this happens it allows a small amount of high pressure fuel to enter the fuel return line (6) effectively dropping the pressure in the control piston chamber (2).
- This pressure drop is enough for the force (F2x) on the nozzle needle (5) in the high pressure chamber to overcome the force (F1x) in the control piston chamber (2).
- This allows the nozzle needle (5) to move upward uncovering the six spray holes and allowing high pressure fuel to atomize and enter the combustion chamber.



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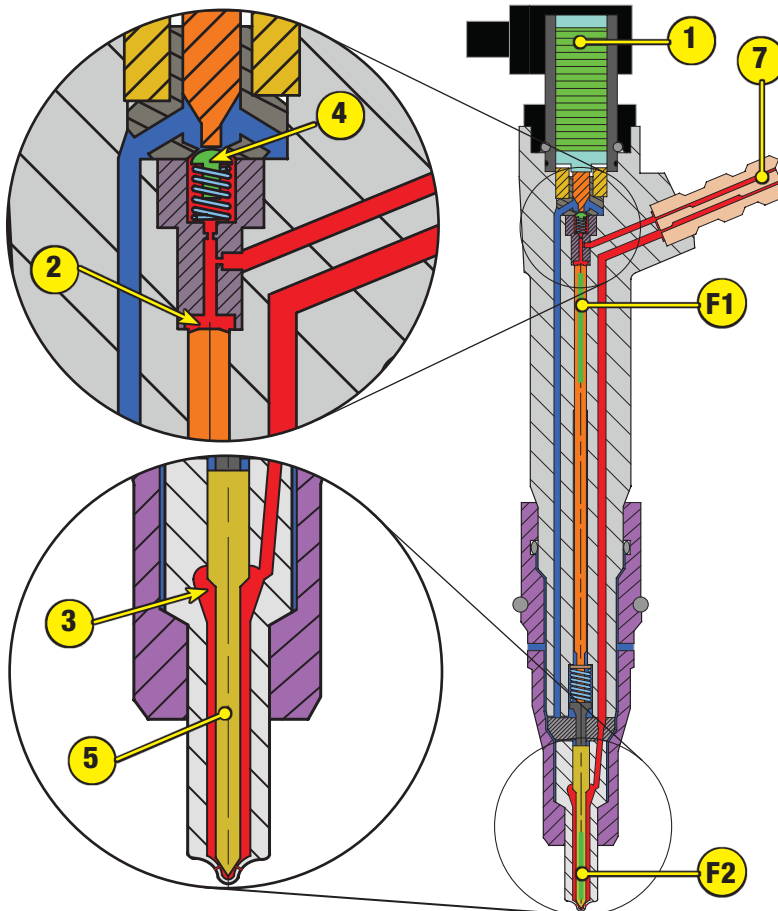
## FUEL MANAGEMENT SYSTEM



### End of Main Injection Step 1

- The high pressure fuel, that is allowed to escape past the valve mushroom (4) into the fuel return line (6), is routed down a drilled passage to the drain holes in the sides of the injector just below the O-ring seal towards the base of the injector.
- The fuel is then routed through the cylinder head and exits through a banjo fitting on the front side of the cylinder head before being returned to the fuel supply system.

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### End of Main Injection Step 2

- When the Engine Control Module (ECM) determines that the correct injector on time has been reached, it switches the polarity of the piezo actuator (1) which causes the piezo discs to return to a non-energized state.
- Switching the polarity of the piezo actuator (1) enables the valve mushroom (4) to seat via spring pressure and completely block the bored passage that connects the high pressure fuel to the fuel return line.
- Seating the valve mushroom (4) allows the pressure to build in the control piston chamber (2) and equal that in the high pressure chamber (3).
- Once these two chambers have equalized in pressure the downward force (F1) of the control valve will overcome the upward force (F2) of the nozzle needle due to the larger surface area of the control valve.
- The control valve then moves downward effectively closing the nozzle needle (5), blocking any fuel from entering the combustion chamber.

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