

This class is so good;  
Please call your doctor  
If it last over four hours



# Welcome to Modern Diesel



**1910**

**Read As**

**Emission  
Controlled**



Automotive Training Authority

**ATA**

**Instructor**

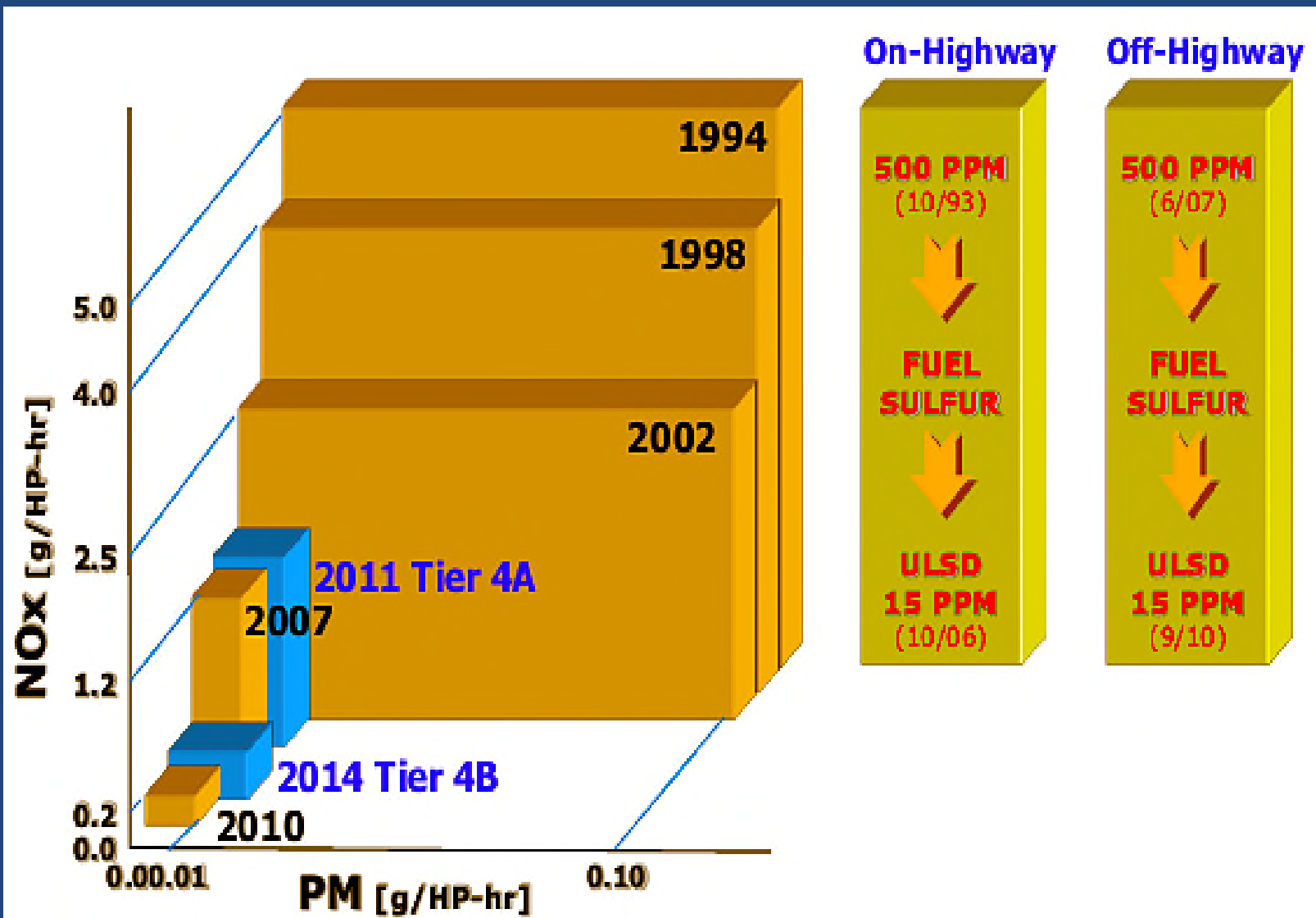
**Doc Nall**



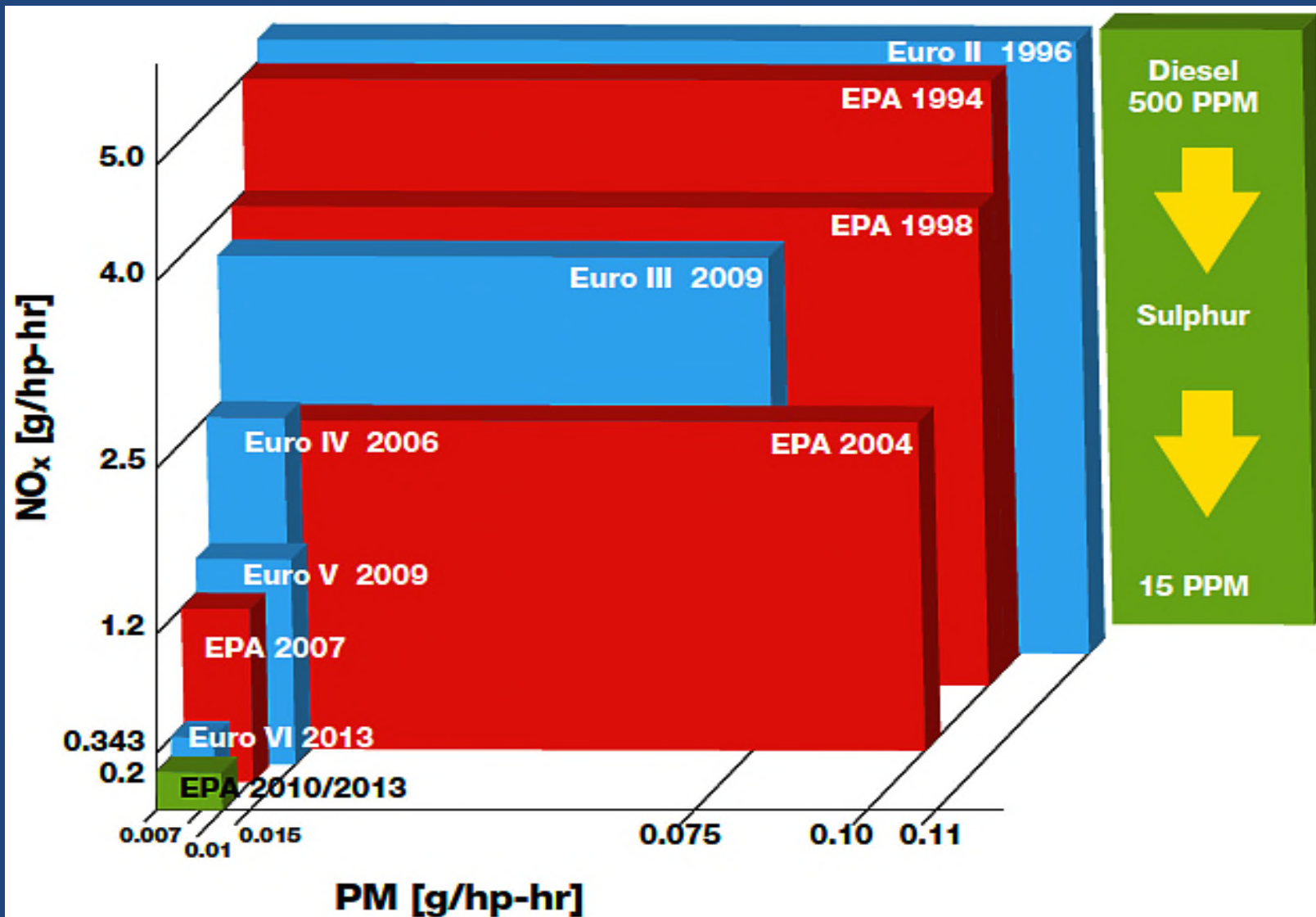
# Emissions



# Highway Diesel Emissions



# Off Road Diesel emissions



# Where does Tier 4 come from?

All emissions standards, including Tier 4, are a part of a federal law named the Clean Air Act

The purpose of this law is to reduce air pollution because of its hazards to human health and the environment

The Clean Air Act is managed by the Environmental Protection Agency (EPA)

# Emission Time Line

In 1948 for five days, a cloud of air pollution overtakes the industrial town of Donora, Pennsylvania, sickening 40% of the town and killing 20 people

# Emission Time Line

In **1952** London's Killer Fog - a toxic mix of fog and coal smoke - kills several thousand citizens over a four-day span

The world changes its view of air pollution

# Emission Time Line

In **1955** the Air Pollution Control Act of 1955 identifies air pollution as a **national problem** and provides **federal funding** for air quality improvement

# Emission Time Line

The Clean Air Act of 1963 sets emissions standards for stationary sources (power plants, steel mills, etc.) and recognizes the dangers of motor vehicle exhaust

# Emission Time Line

In **1965** the Motor Vehicle Pollution Act sets the first emissions reduction standards for automobiles

# Emission Time Line

In **1970** on April 22, more than 20 million Americans gather in streets, parks and auditoriums to support a healthy, sustainable environment

**Earth Day** is now an annual event

# Emission Time Line

In **1970** emission standards broaden and become more stringent to automobiles and stationary sources, such as factories

Congress creates the **Environmental Protection Agency (EPA)** in part to assist with the implementation of these expanded standards

# Emission Time Line

In **1975** as a result of emissions standards set in **1970**, catalytic converters begin to appear on automobile exhaust systems

# Emission Time Line

In **1977** the federal government extends timelines for emissions standards compliance, sets standards for **lead** amounts in gasoline, and takes steps to prevent destruction of ozone

# Emission Time Line

In **1980** the EPA lowers lead standards for gasoline and limits diesel particulate emissions (PM)

# Emission Time Line

In **1994-2010** Cars and light trucks begin and complete an emissions reduction process

The end result is comparable to what Tier 4 will be for heavy equipment

# Emission Time Line

In **1987-2010 Heavy-duty** trucks and buses begin and complete an emissions reduction process

HD is headed towards **Tier 4**

# Emission Time Line

In **1996 -2015** equipment manufacturers evolves to meet tiered emissions standards for diesel engines, with **Tier 4** being the final step in this process

# What is Tier 4?

Tier 4 standards will require significant emission reductions of particulate matter (PM) and Nitrogen Oxides (NO<sub>x</sub>)

PM is defined as the black smoke/soot found in diesel engine exhaust

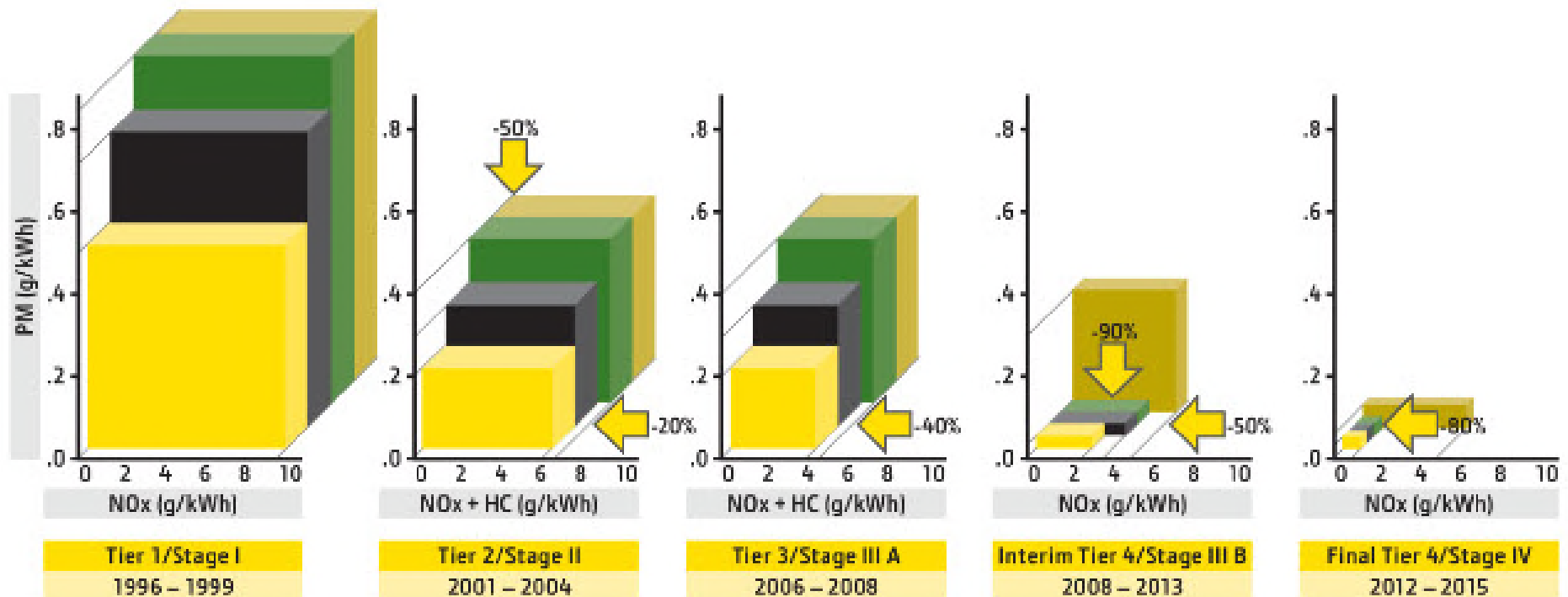
NO<sub>x</sub> is defined as nitrogen monoxide and nitrogen dioxide

# Timeline

The schedule is consistent for all manufacturers, however, each manufacturer has the ability to use “flex credits” on individual product lines

# Emission Improvements by Tier

The Changes are made over 9 years



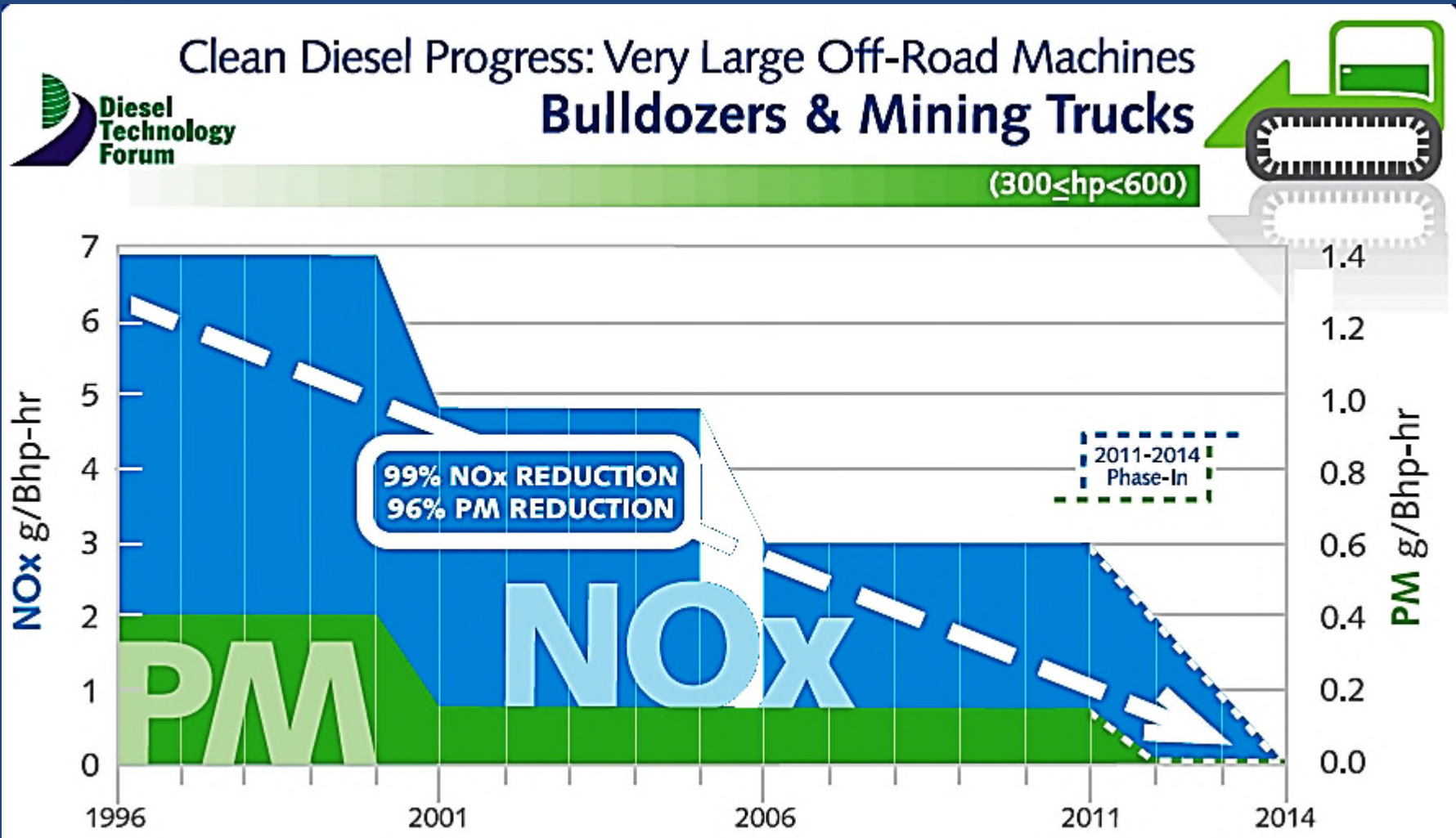
Must be addressed differently

$\text{NO}_x$  occur at high temperatures

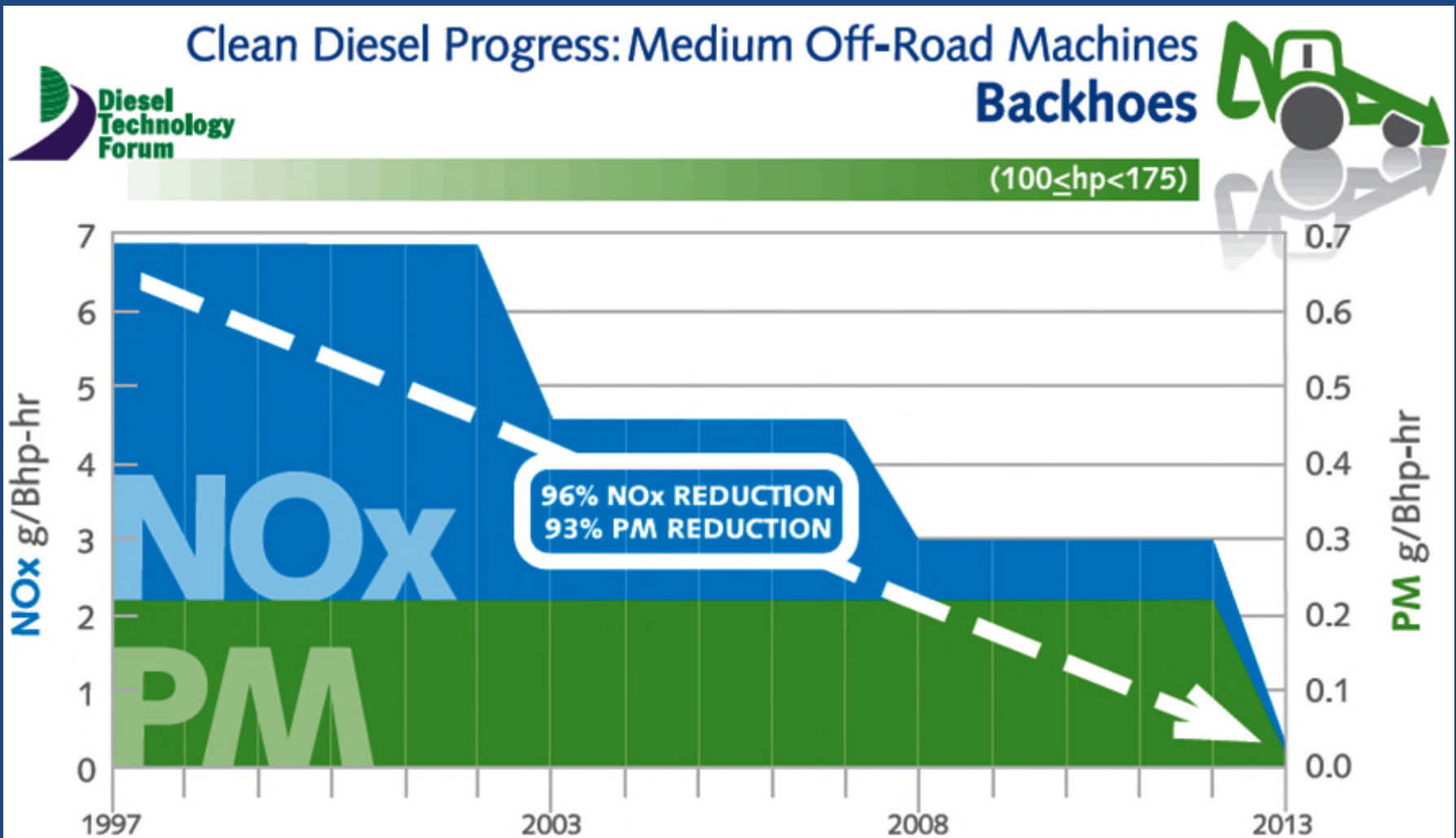
PM occur at low temperatures

Why can't we all just get along

# Percent Reduction NO<sub>x</sub> and Particulates



# Percent Reduction NO<sub>x</sub> and Particulates



# Smoke Bad



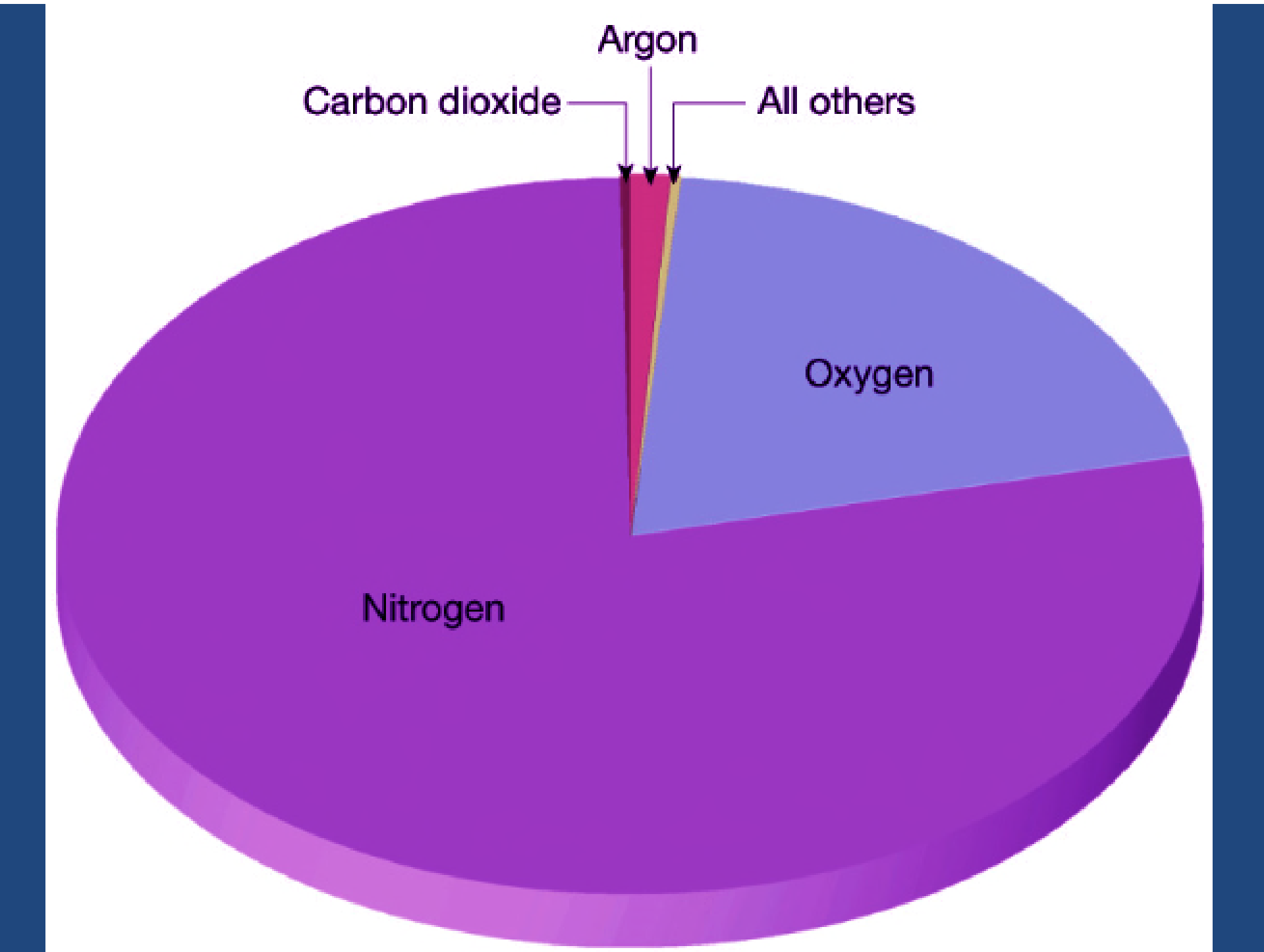




Nitrogen Oxides are a family of poisonous, highly reactive gases

These gases form when fuel is burned at high temperatures

It is a strong oxidizing agent and has a strong atmospheric reactions with volatile organic compounds (VOC) that produce ozone (smog) on hot summer days



NO<sub>x</sub>

NO<sub>x</sub>

X = Variable Un-Known

Value to find

No<sub>x</sub>

$$[X] \quad [2X = 4]$$

$$\text{then } X = 2$$



Nitric Oxide and Nitrogen Dioxide (NO<sub>x</sub>)

NO<sub>x</sub> is a generic term for the mono-nitrogen oxides NO and NO<sub>2</sub>

They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, at **high temperatures**

# Particulate Matter (PM)

Along with gaseous diesel emissions, there is a problem with Particulate Matter (PM)

The definition of particulate matter is determined by its sampling method

# Sampling Bag

1

2

3

Diesel



GDI



GDI Lev II



Diesel

DPF



# Diesel Tier 1, 1996 to 1999

Diesel injection was mechanical with in-line and rotary injector pumps

Injector pintle were opened by injection pressure

Adjustment to fuel delivery were mostly mechanical adjustments

# **Diesel New Technology**

**Fuel Systems**

**Air Induction**

**Combustion**

**Computer Controls**

**Ultra Low Sulfur fuel**

**Diesel oxidation catalysis (DOC)**

**Diesel Particulate Filter (DPF)**

**Selective Catalysis Reduction (SCR)**

# Clean Diesel Technology

The three key parts are:

Cleaner diesel fuel

Advanced engine technology

Aftertreatment

# Diesel Fuel

Diesel emits very small amounts of carbon monoxide, hydrocarbons and carbon dioxide

There are high amounts of nitrogen compounds

And particulate matter (soot)

Which lead to acid rain, smog

# NO<sub>x</sub>

EGR attempts to reduce combustion temperatures reducing NO<sub>x</sub> creation

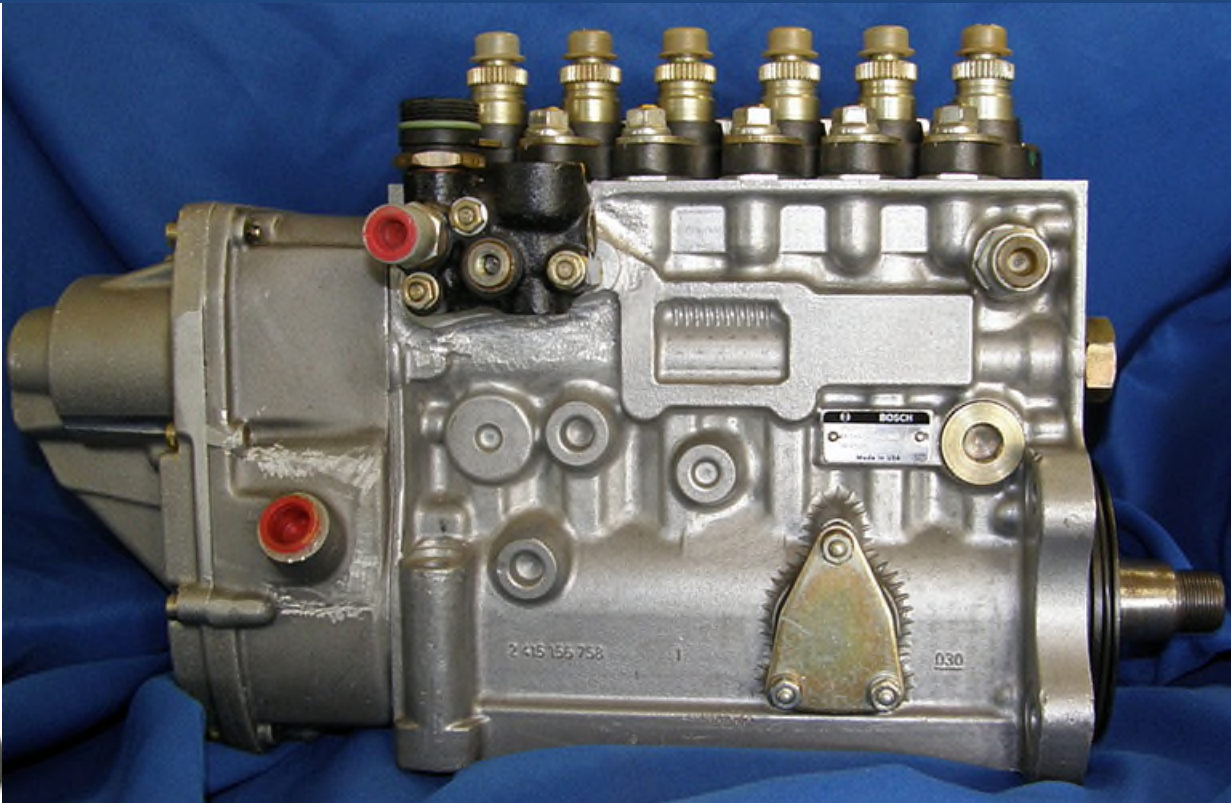
Selective Catalysis reduction reduces NO<sub>x</sub> after it is created

# Low Sulfur Content In Steps

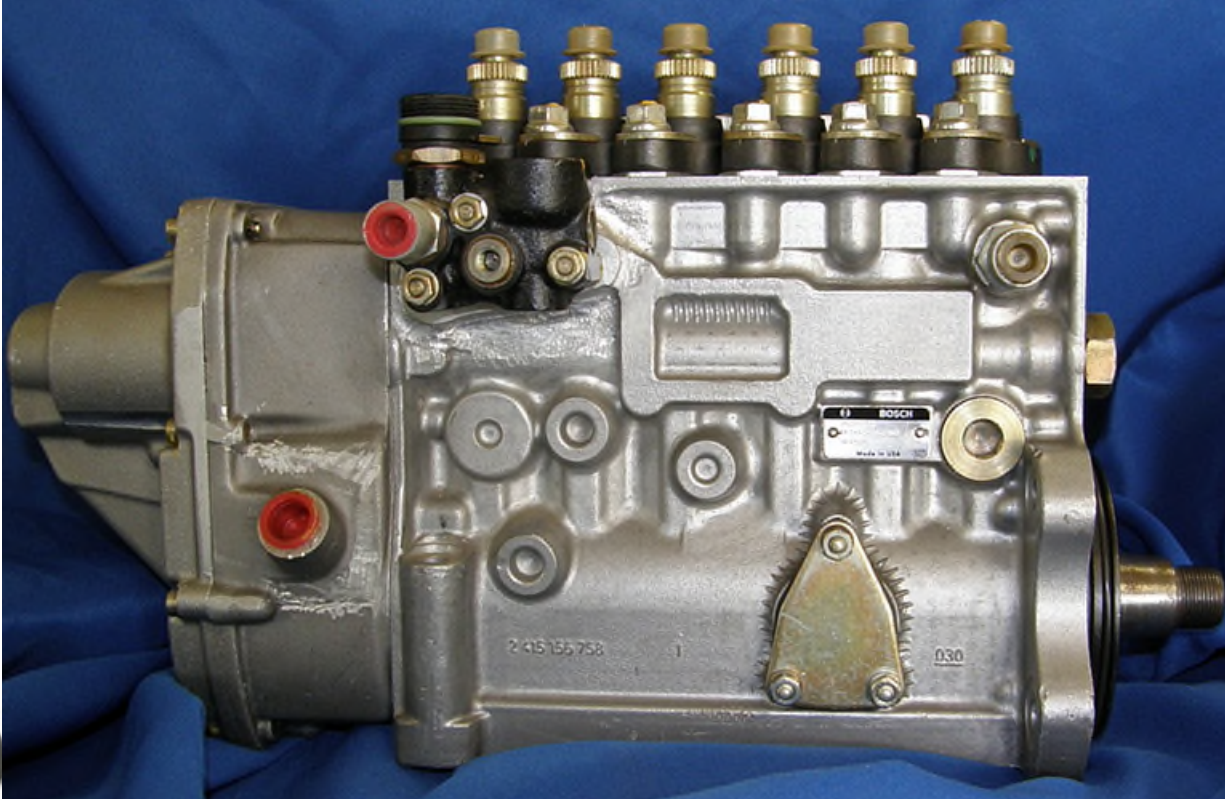
**500 ppm**

**15 ppm**

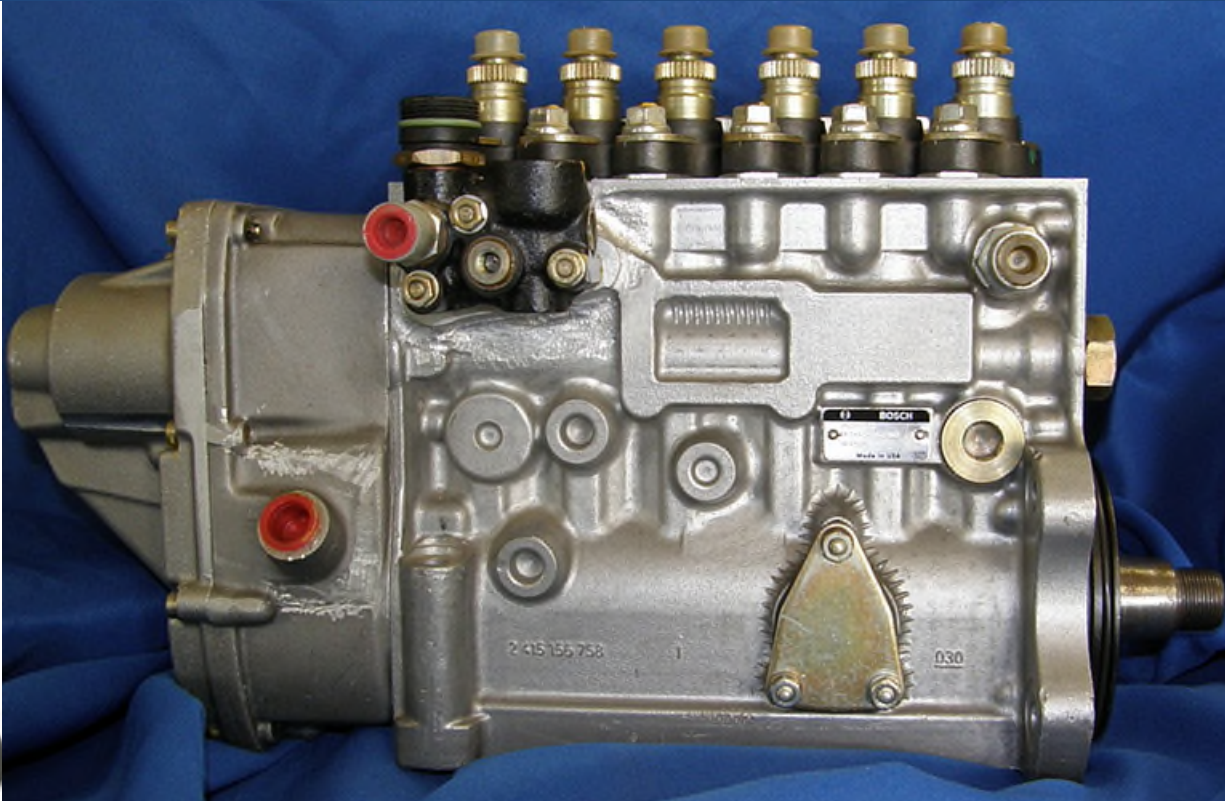
# Worked great What went wrong?



With conventional diesel injection systems, the fuel pressure has to be generated individually for each injection



With the common rail system pressure generation and injection are separate, the fuel is constantly available at the required pressure for injection



# Couldn't Deliver

A precise fuel amount

Which made the combustion process good enough for power and torque

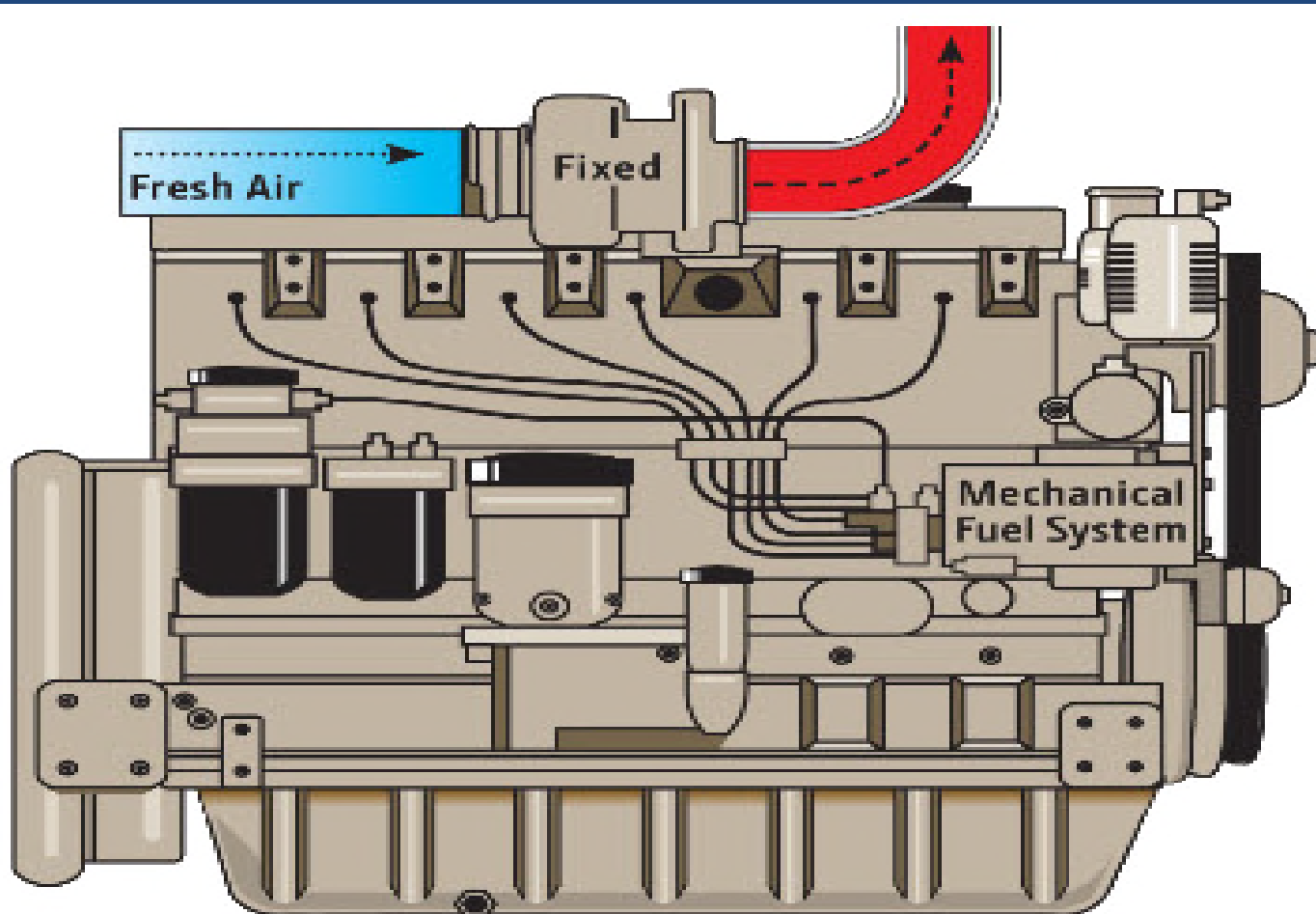
But wrong for good emissions

Clean emissions requires precisely adjusted pressure, exact injection timing for the correct combustion process

**FUEL  
SYSTEM  
TECHNOLOGY**

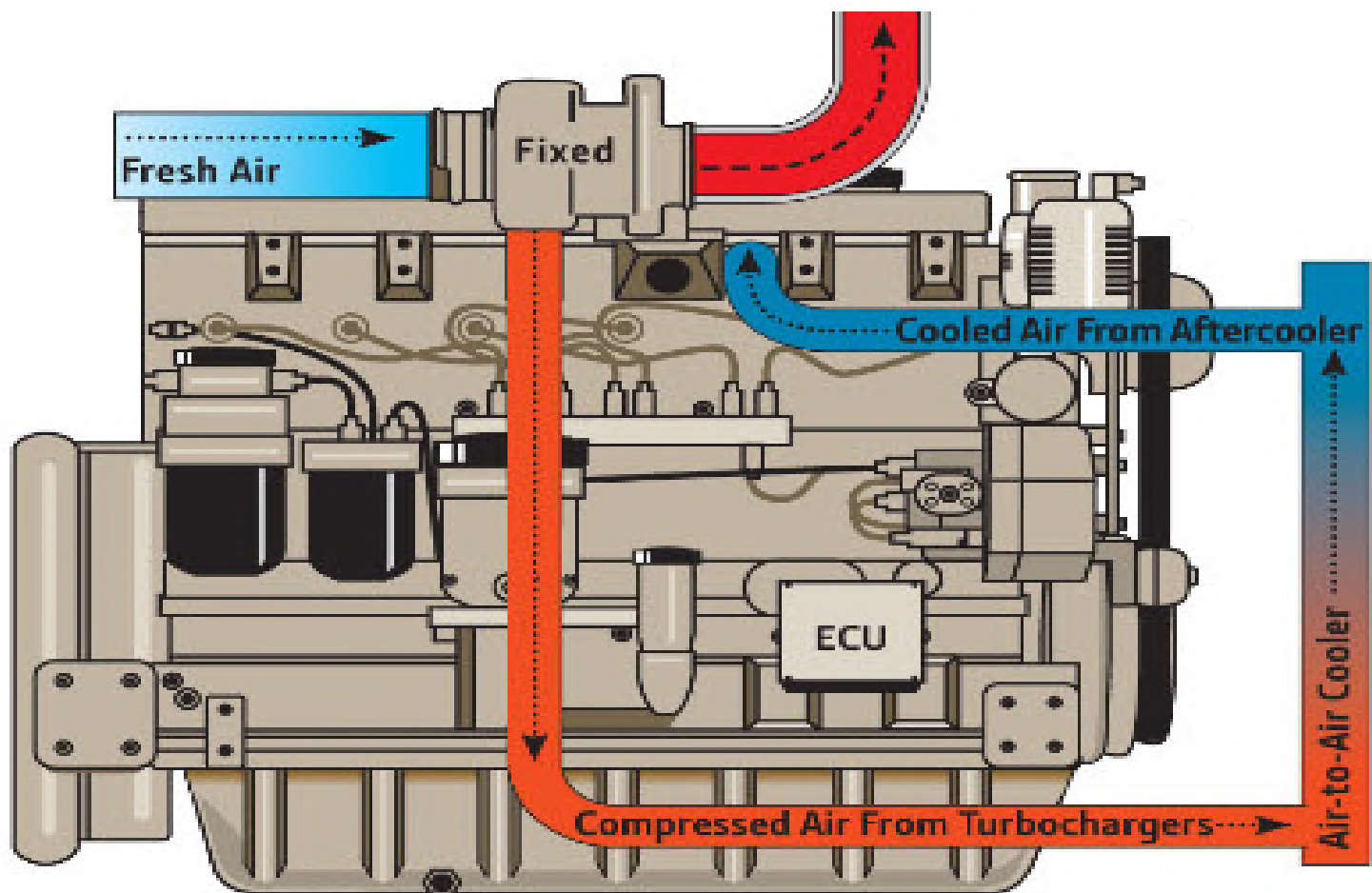
# Tier 1

Mechanical fuel injection with a fixed Turbo



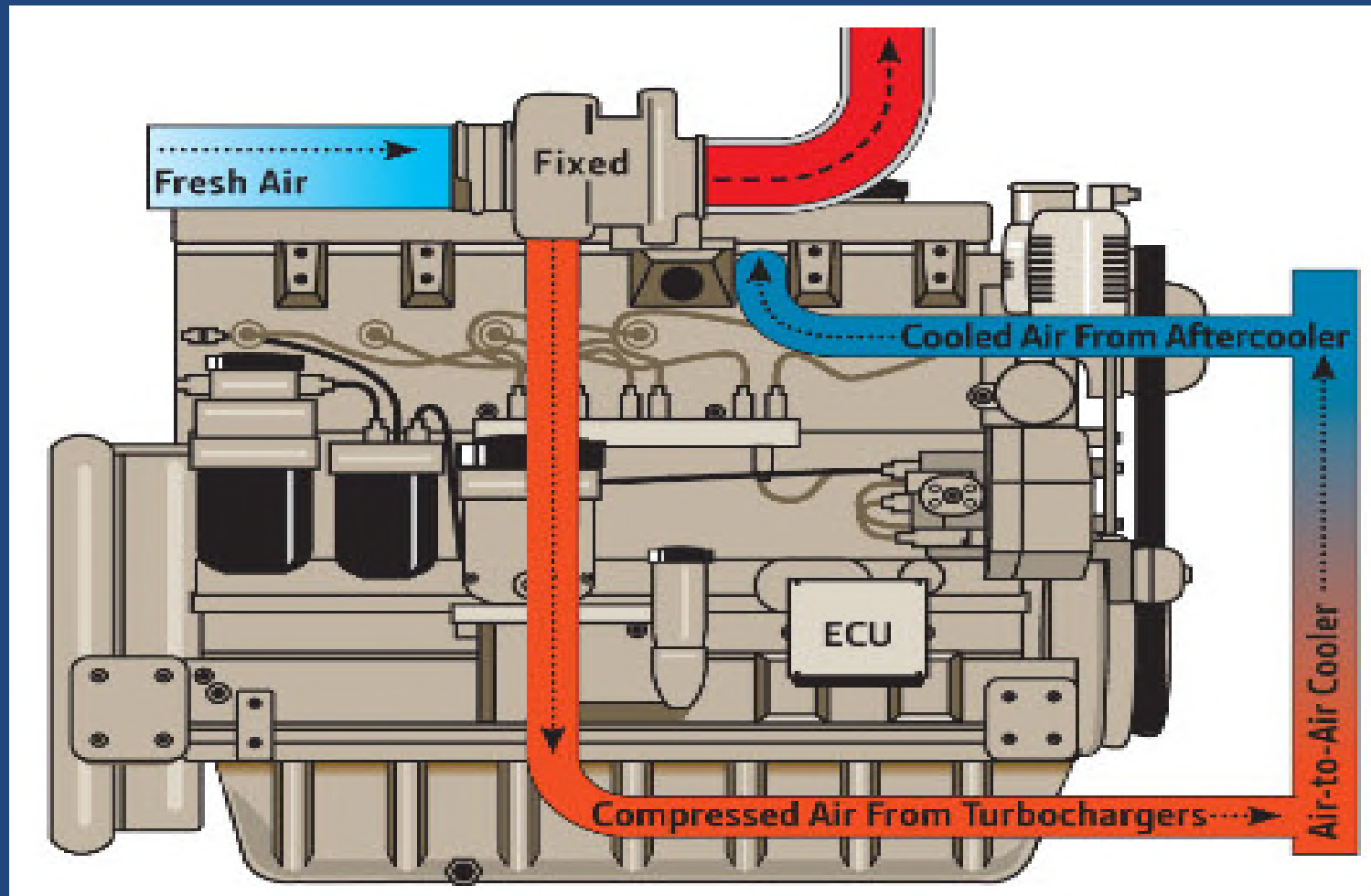
# Tier 2

High pressure common rail injection added



# Tier 2 Changes

ECM Fuel Control was added



# Combustion

Without precise fuel control for combustion, the air fuel ratio wasn't evenly distributed in the cylinder

Particulate matter (PM) forms in regions where fuel concentrations are too high (**Rich Mixture**)

There is **un-even combustion**

# Pressure

Cleaner emissions may be attained through high fuel-injection pressure

Higher pressure cause fuel to burn more completely

Dramatically reducing both soot and  $\text{NO}_x$

# The benefit of better combustion

High pressure transforms the fuel into an extremely fine mist as it leaves the injectors

Now it combusts more thoroughly, leading to

Lower costs – As the fuel burns more completely, the engine needs less of it to run

Cleaner exhaust – Less unburned fuel is left behind in the exhaust

# The benefit of better combustion

Better performance – **Multiple injections** during each combustion cycle means that combustion lasts longer, creating more energy and more output from the fuel

Longer-lasting combustion lowers peak engine cylinder pressure

This reduces engine noise levels, making operation more comfortable

# Fuel System Technology

High pressure fuel pumps

Modified fuel-injector nozzles so that they atomizes fuel at high pressure

Computer controlled

New Injector technology

# Fuel System Technology **Benefits**

The high pressure generates a fuel mist of **microscopic particles** that burns;  
Very quickly and practically soot-free



**High Pressure  
Common Rail  
Fuel Systems**

Common Rails are designed to support  
the

Injector Rate

Injection Pressure

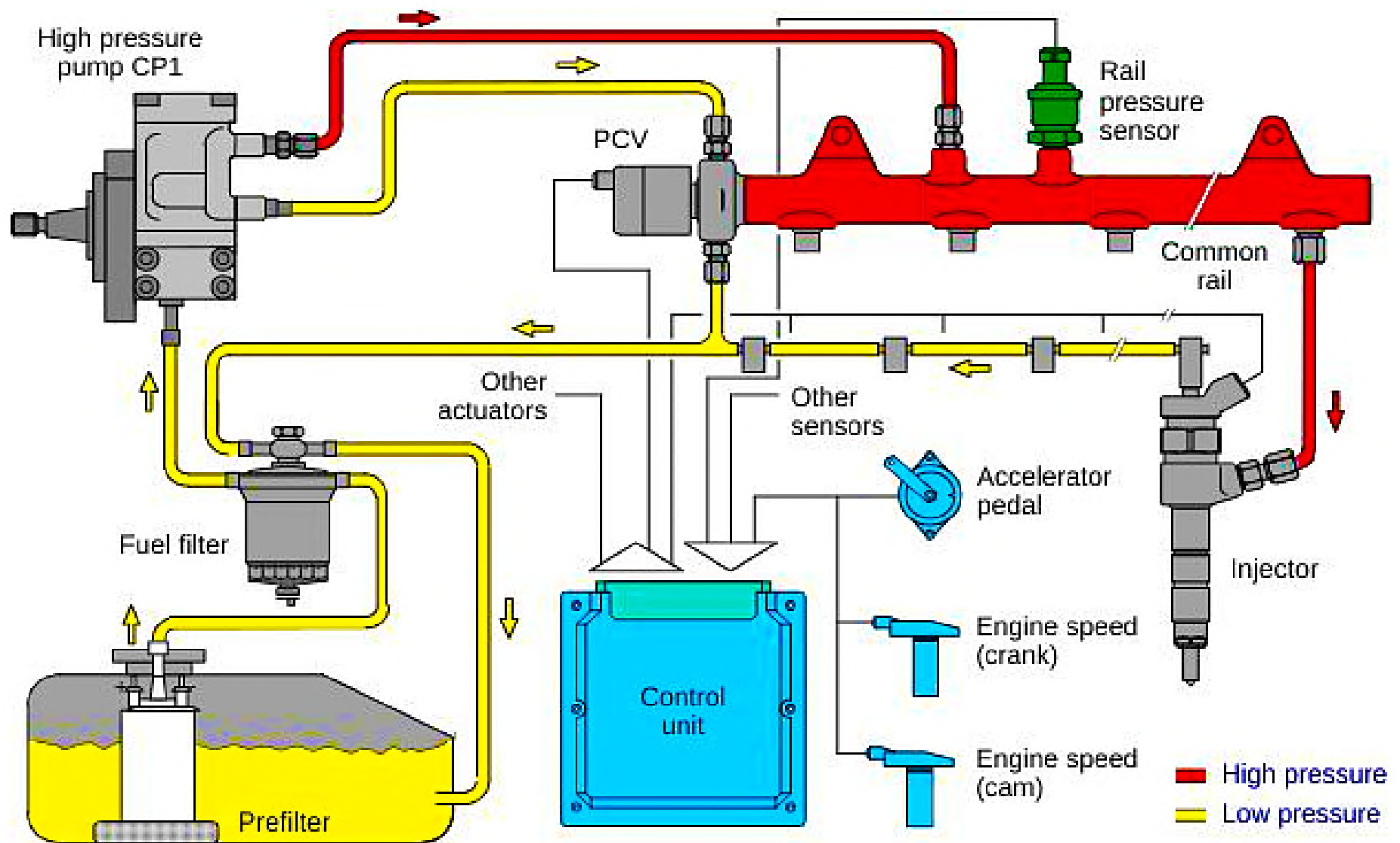
Has an impact on:

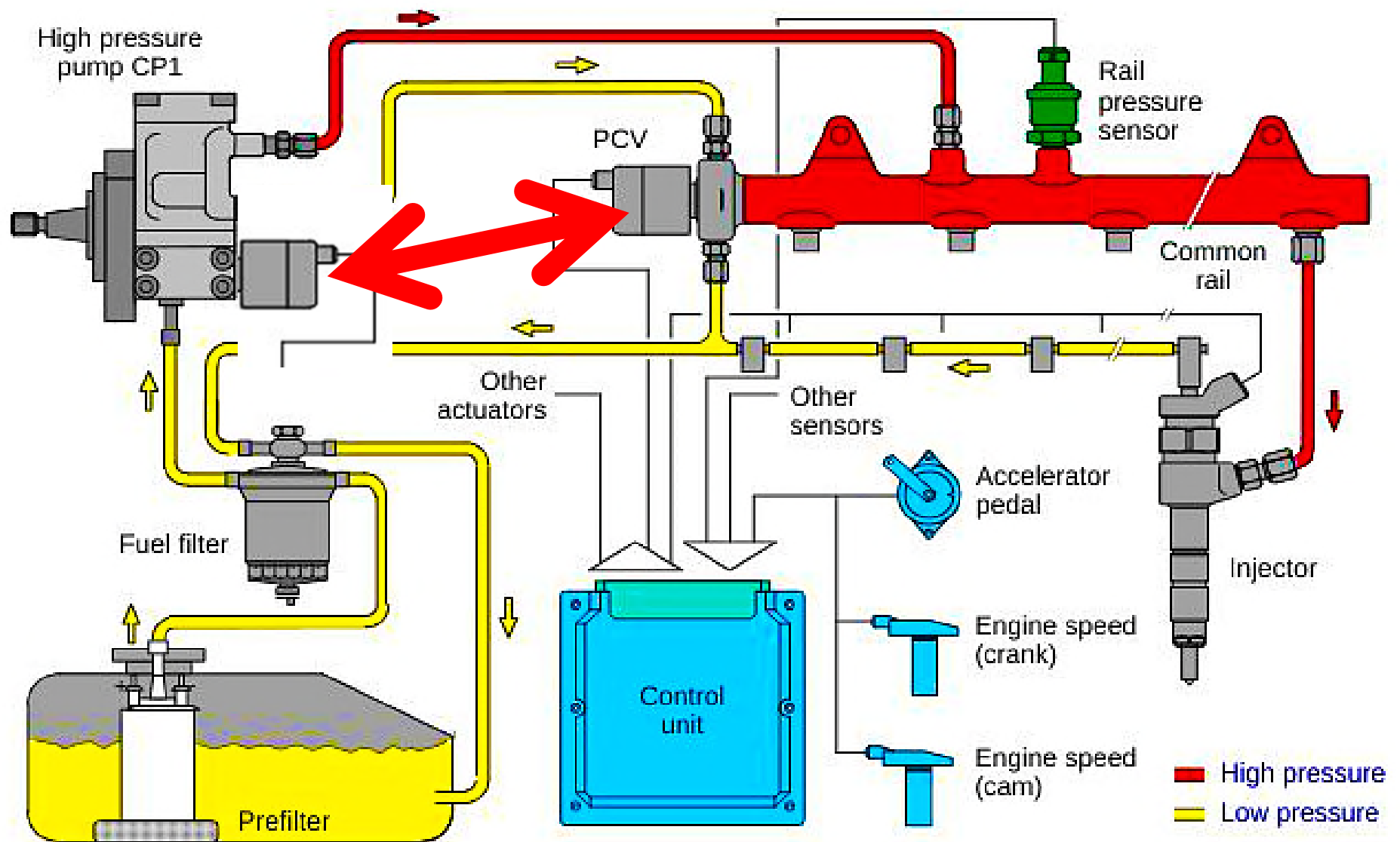
Engine noise

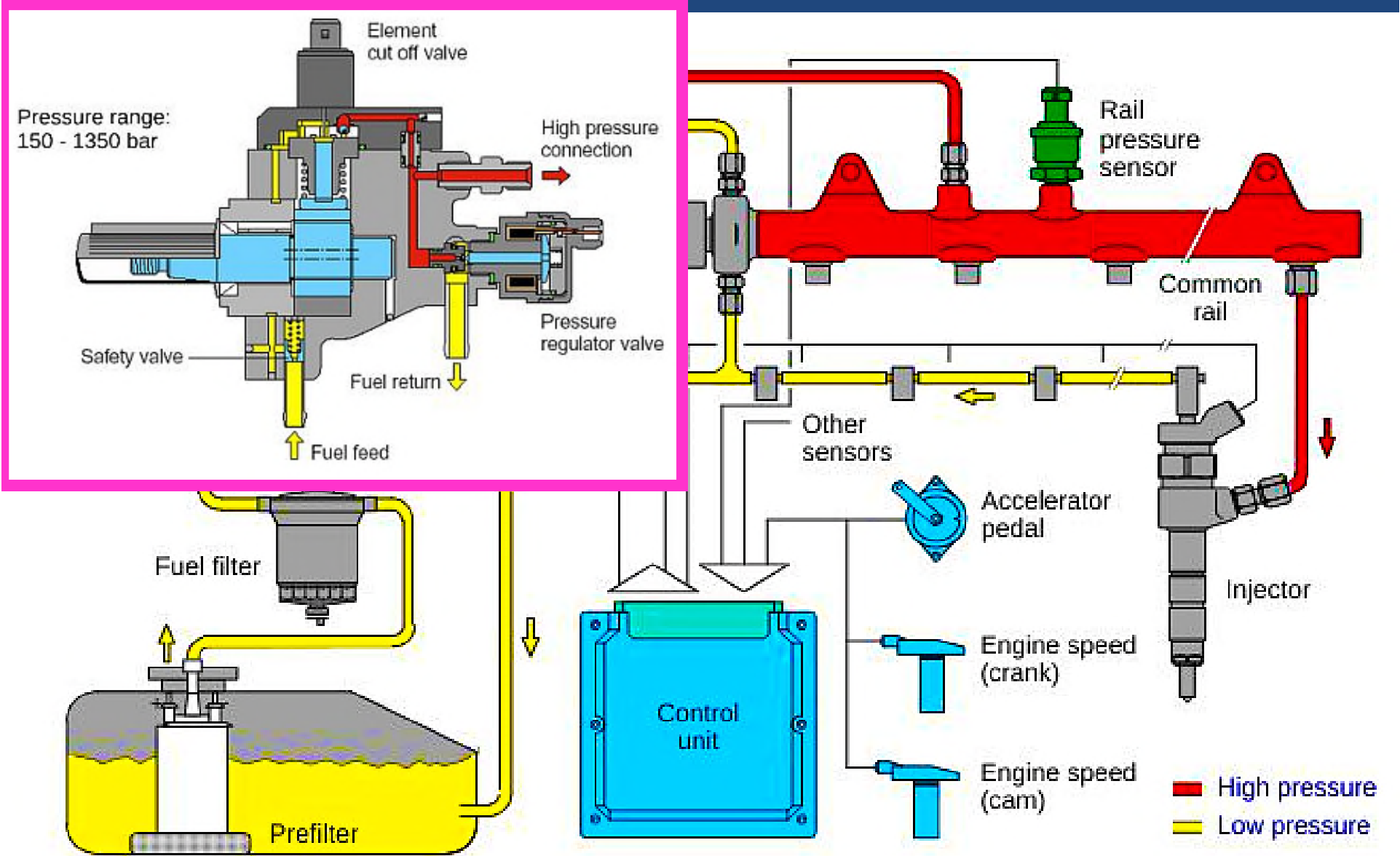
Emissions

Fuel consumption

Engine efficiency

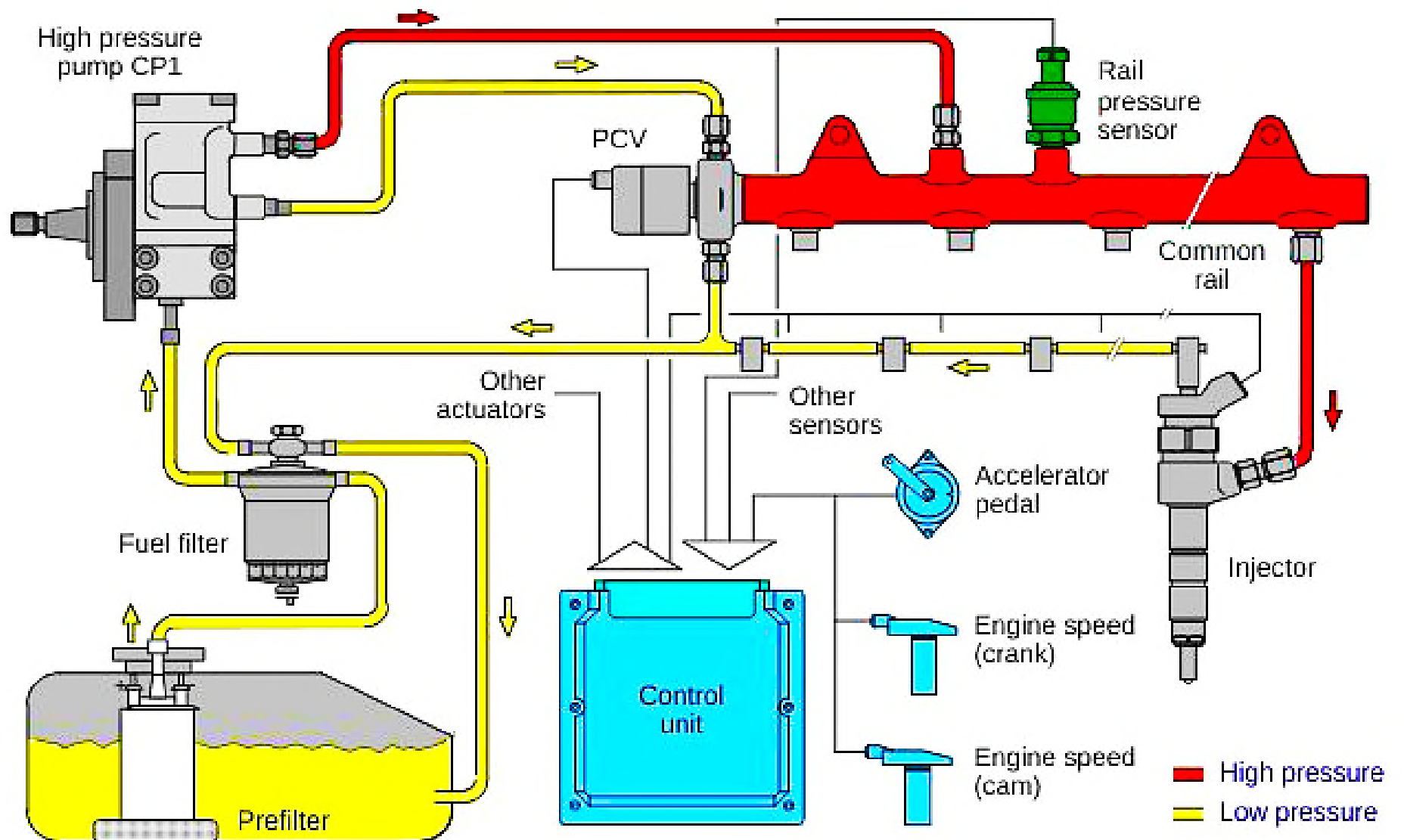




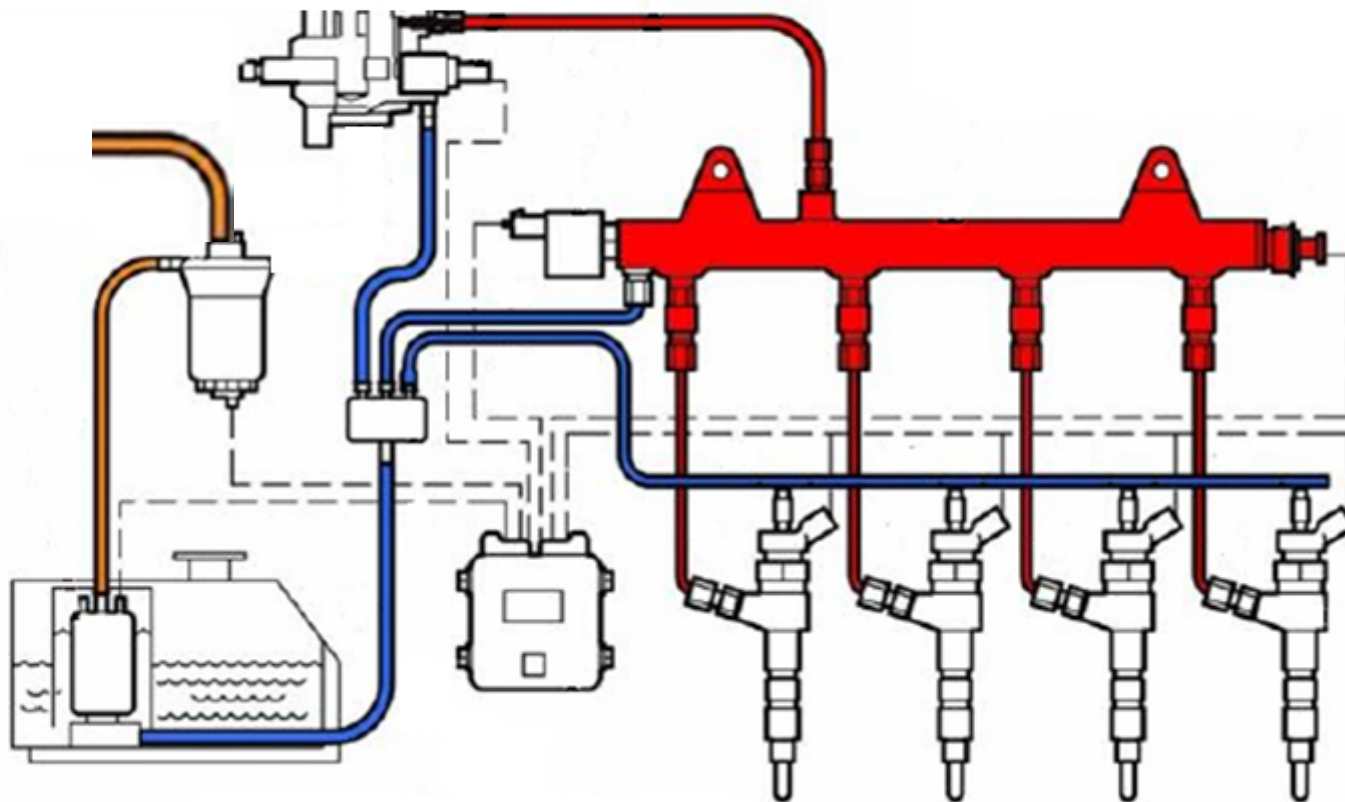


# Closed loop system

Common rail fuel systems are a **closed-loop high pressure control-system** that stabilizes the rail pressure within tight specifications by the **electronic control unit** for a given engine operating condition

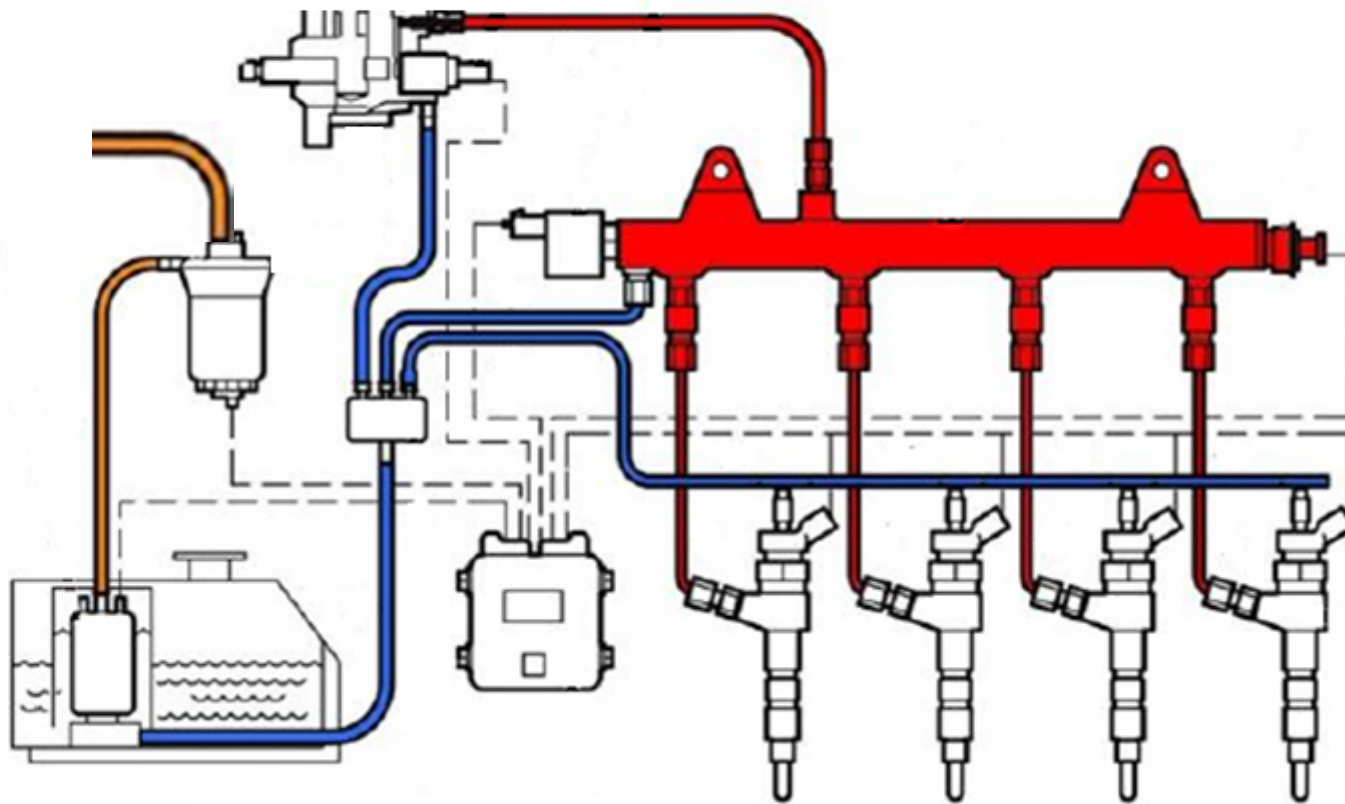


# Fuel System divided into 3

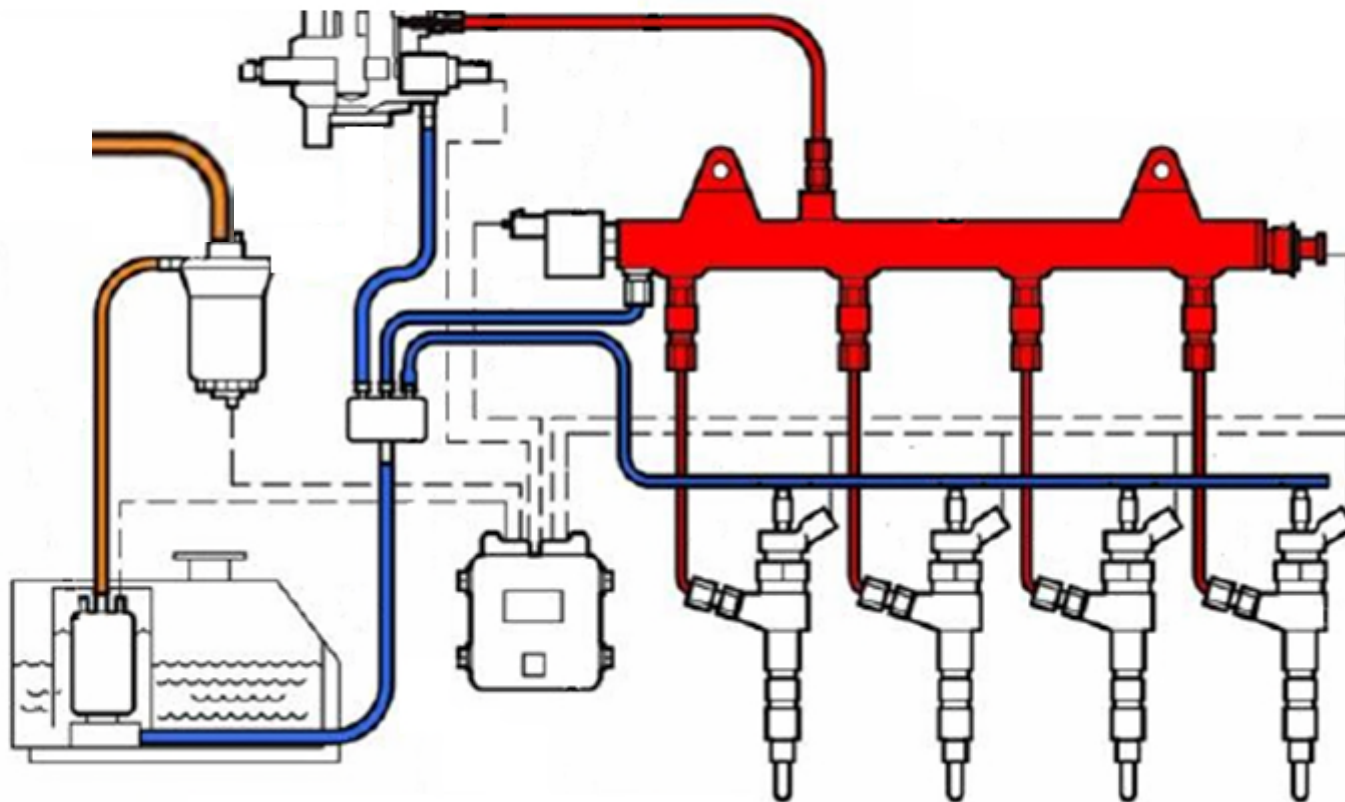


# Fuel System divided into 3

## Low pressure

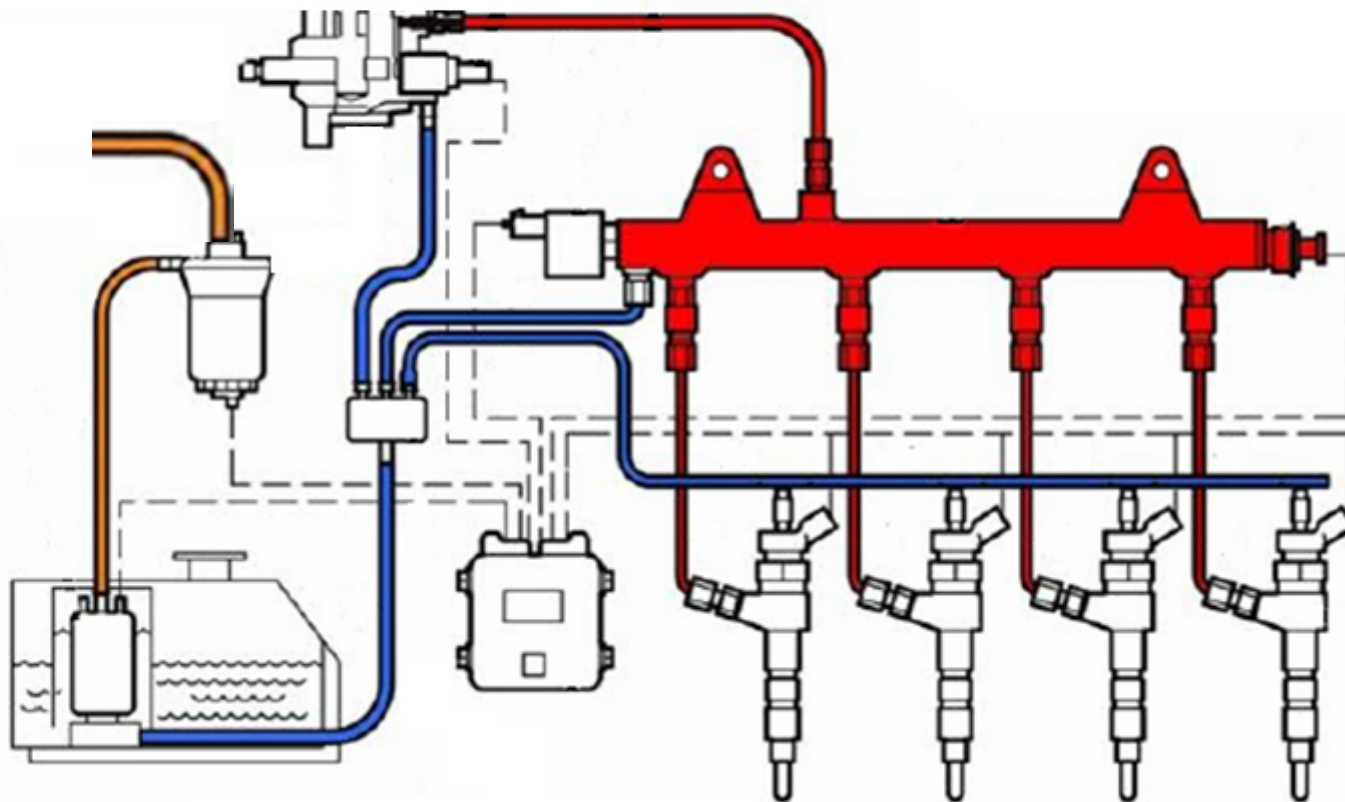


# Fuel System divided into 3 High pressure



# Fuel System divided into 3

## Fuel return



# Low Pressure Circuit

Fuel tank

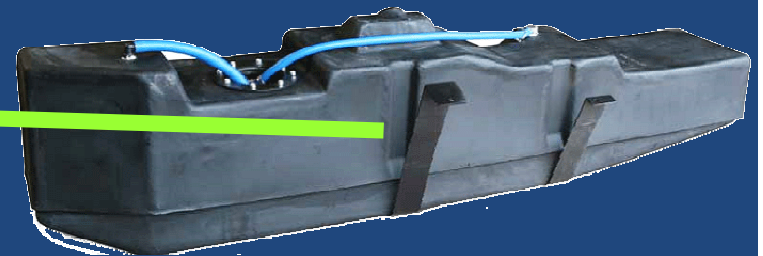
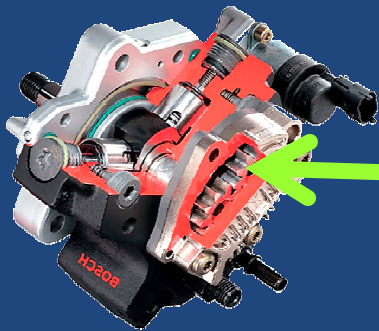
Lift pump optional

Primary and Secondary fuel filters

Water in fuel sensor

Water in fuel separator

Fuel heater



# Low Pressure Circuit

With a lift pump we test **PRESSURE**

No lift pump we test **VACUUM**

# High Pressure Circuit

High pressure pump

High pressure fuel lines

High pressure Common rail

High pressure fuel injectors

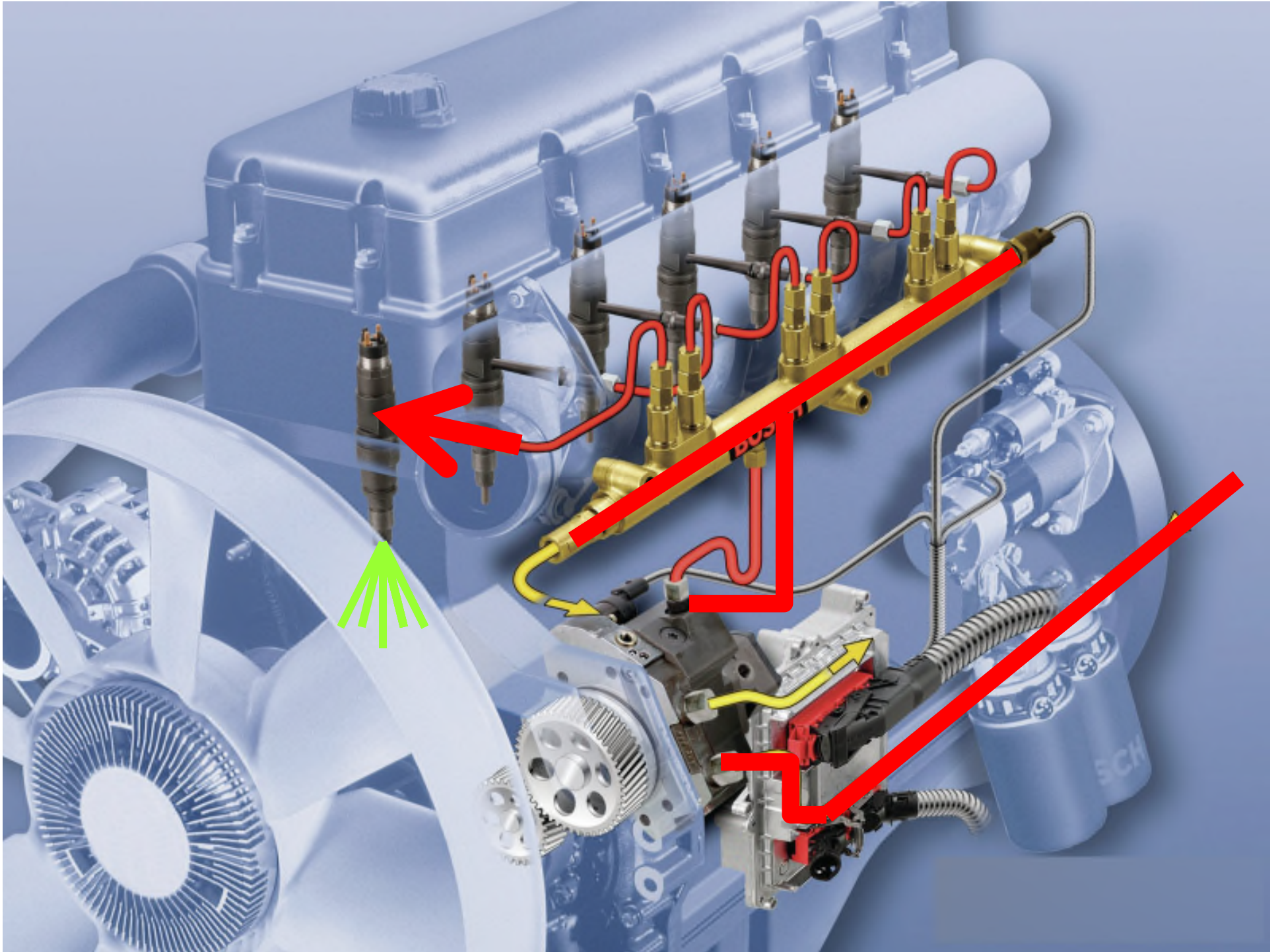
# Fuel Return Circuit

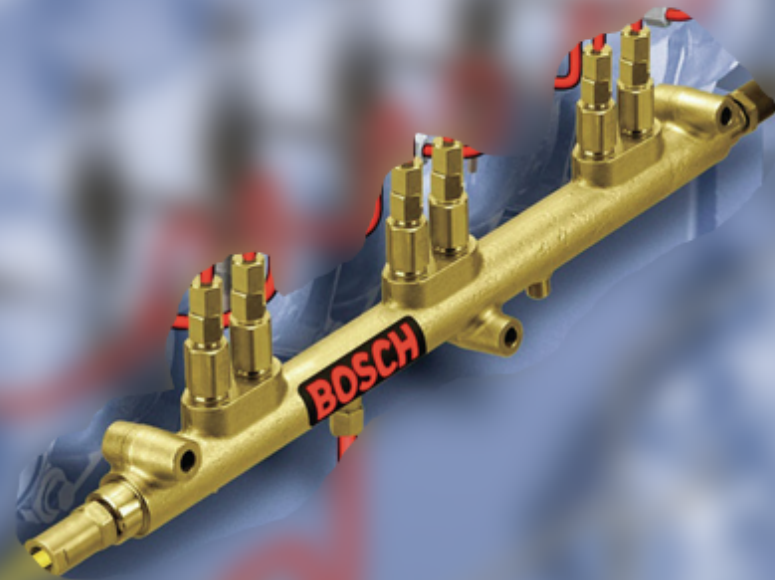
Un-used fuel is returned from

The high pressure pump

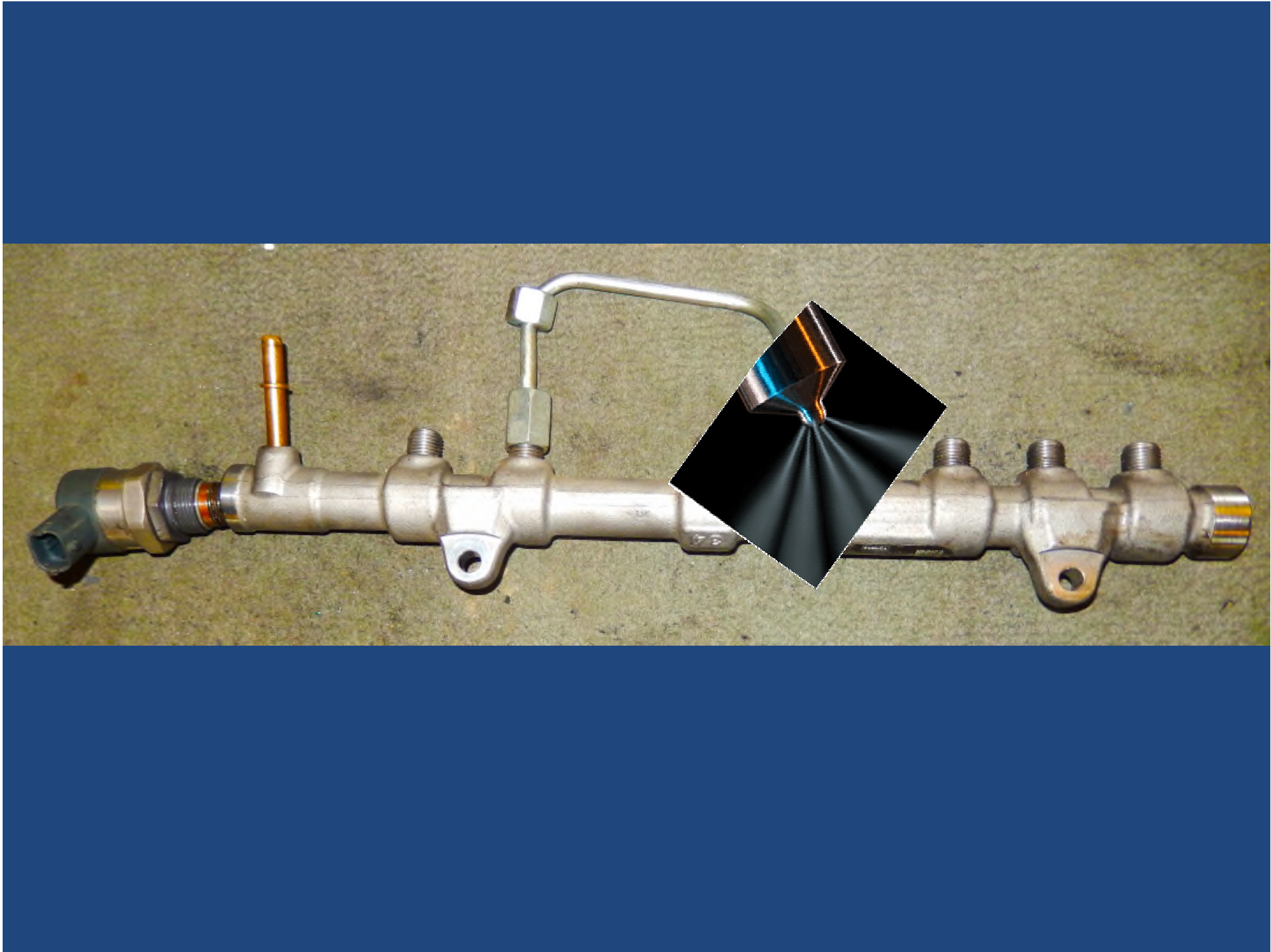
The common rail

Each injector





# Common Rail



# Common Rail System

The common rail stores pressurized fuel (It is a high pressure **accumulator**)

The common rail is supplied by the high pressure fuel pump

Fuel is distributed to the injectors from the rail

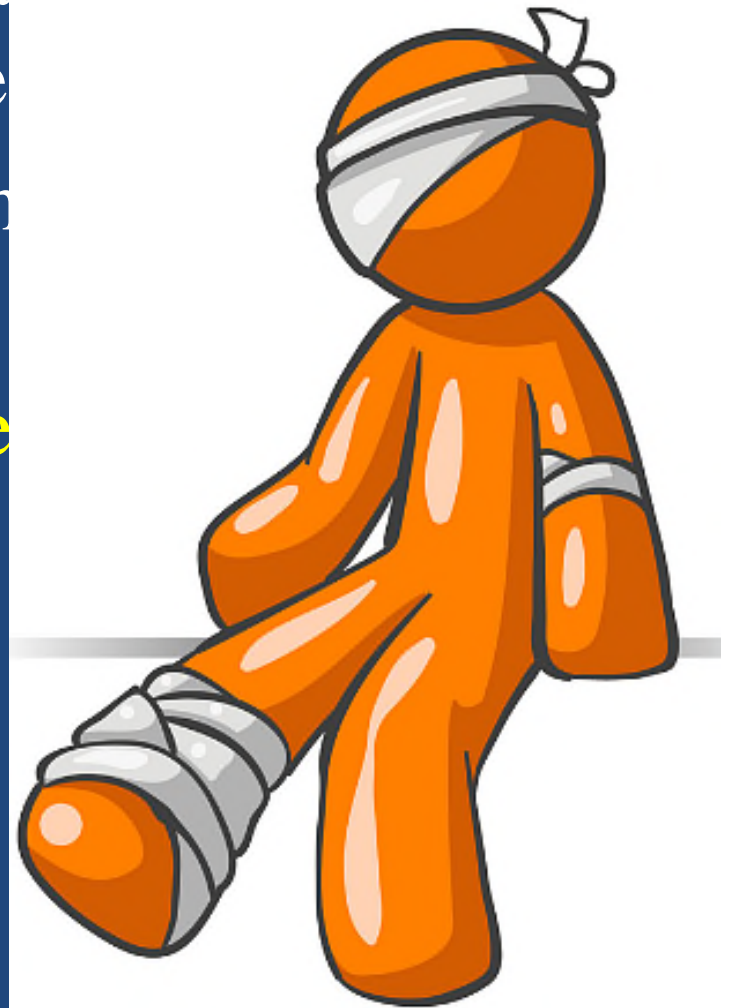
The common rail functions as a reservoir, and the fluctuation of fuel from fuel pump is stabled in the common rail, so the disturbance between injectors is greatly decreased

# Common Rail

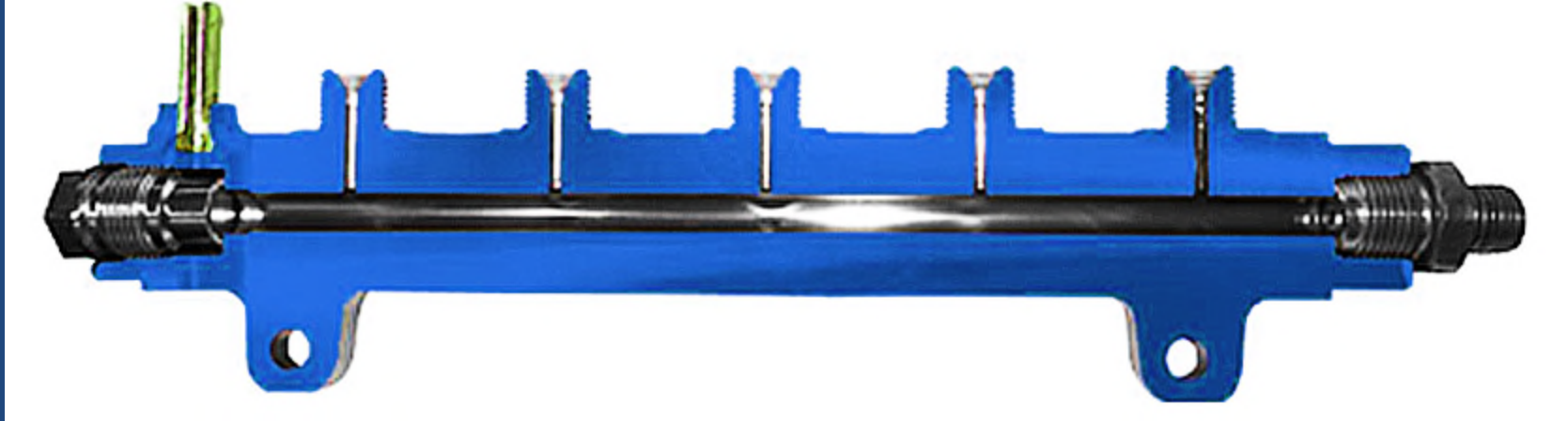
The rail dampens pressure vibrations caused by high pressure pump and the injector

Rail pressure ranges to approximately 400psi to 29,000psi

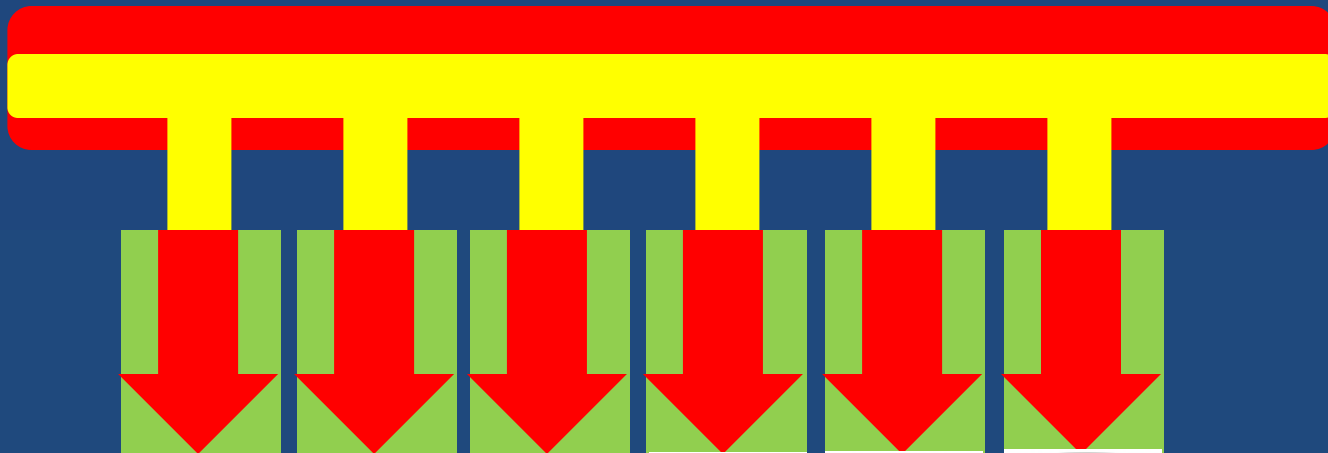
**High pressure can and will penetrate**



The rail holds approximately .5 to 2.5 Oz. of fuel



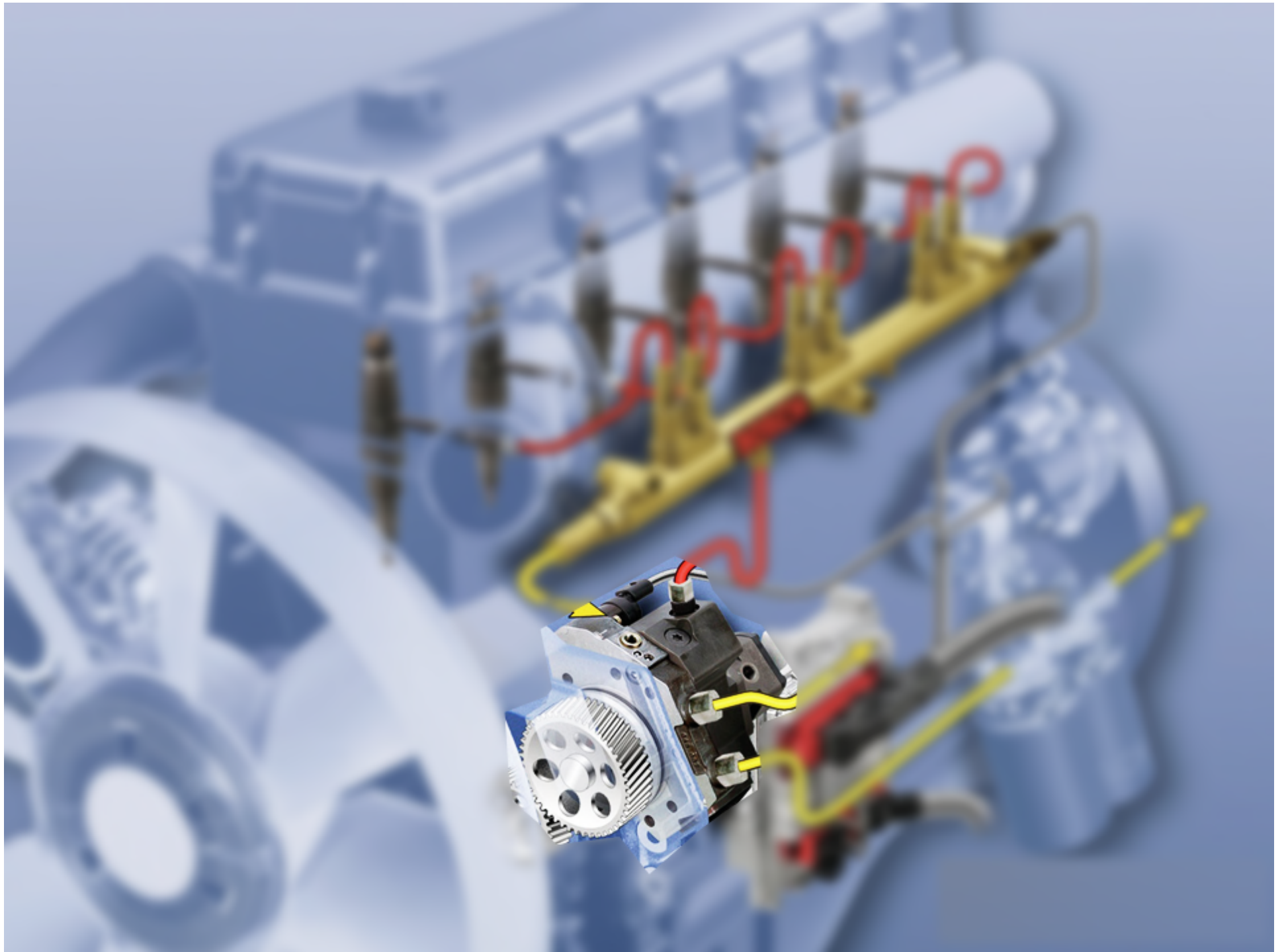
**Pressure on a confined  
fluid is equal in all  
directions**

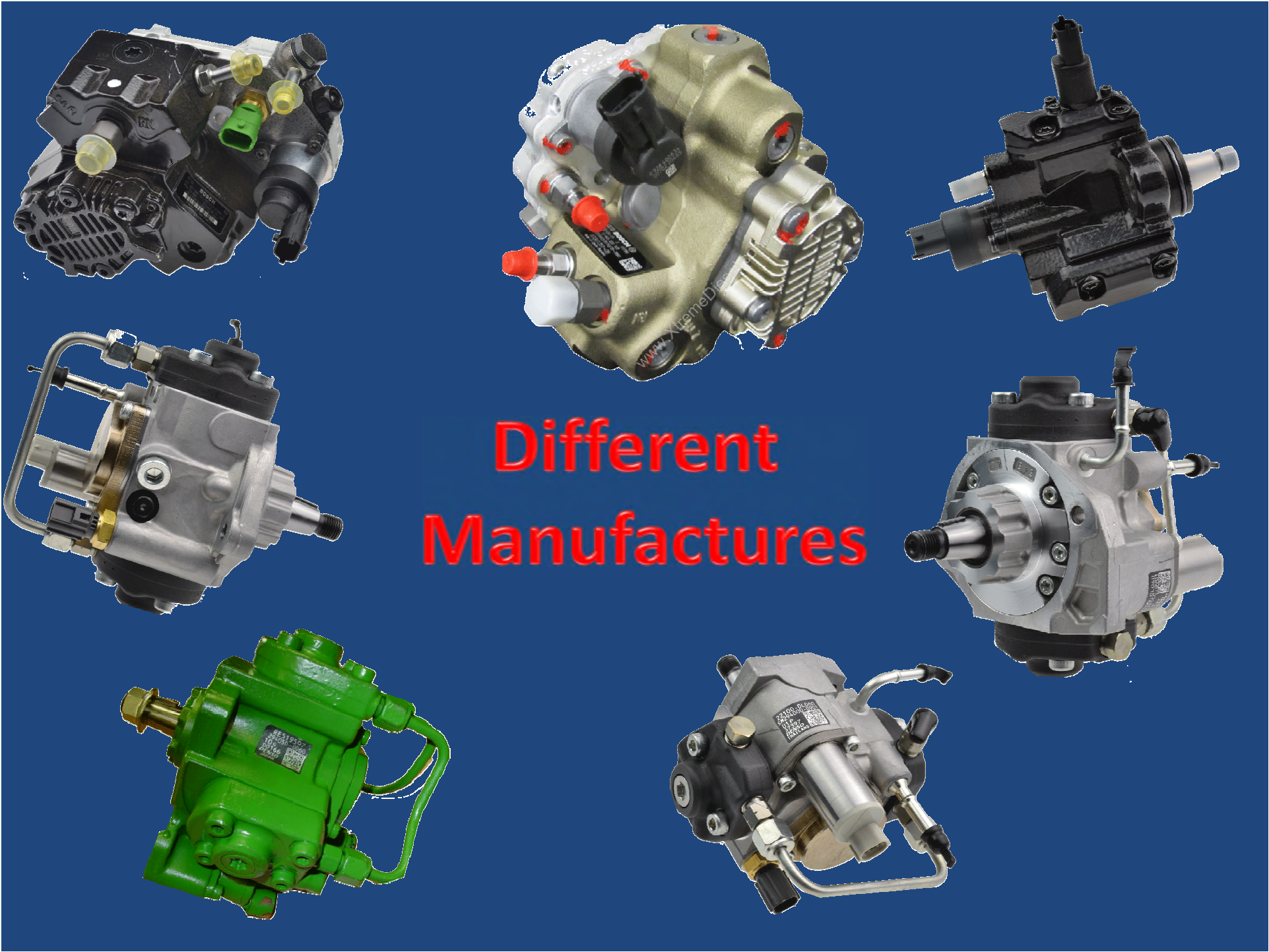


# Add time



**Same pressure and  
the same time  
equals the same  
amount of fuel  
each time**





**Different  
Manufactures**

# Different Manufactures

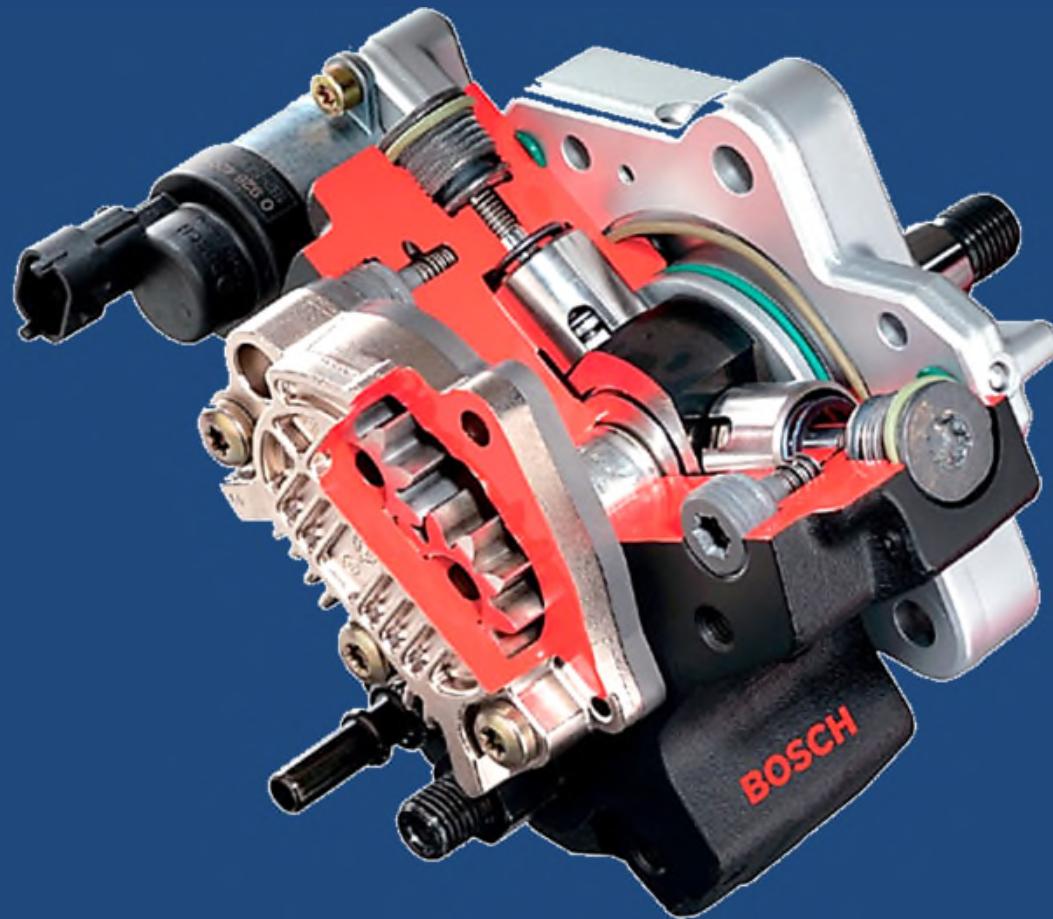
They have common function and operation

3 high pressure pumping chambers

4 opposed pumping chambers

# High Pressure Pump

Pump pressure is controlled by the ECU

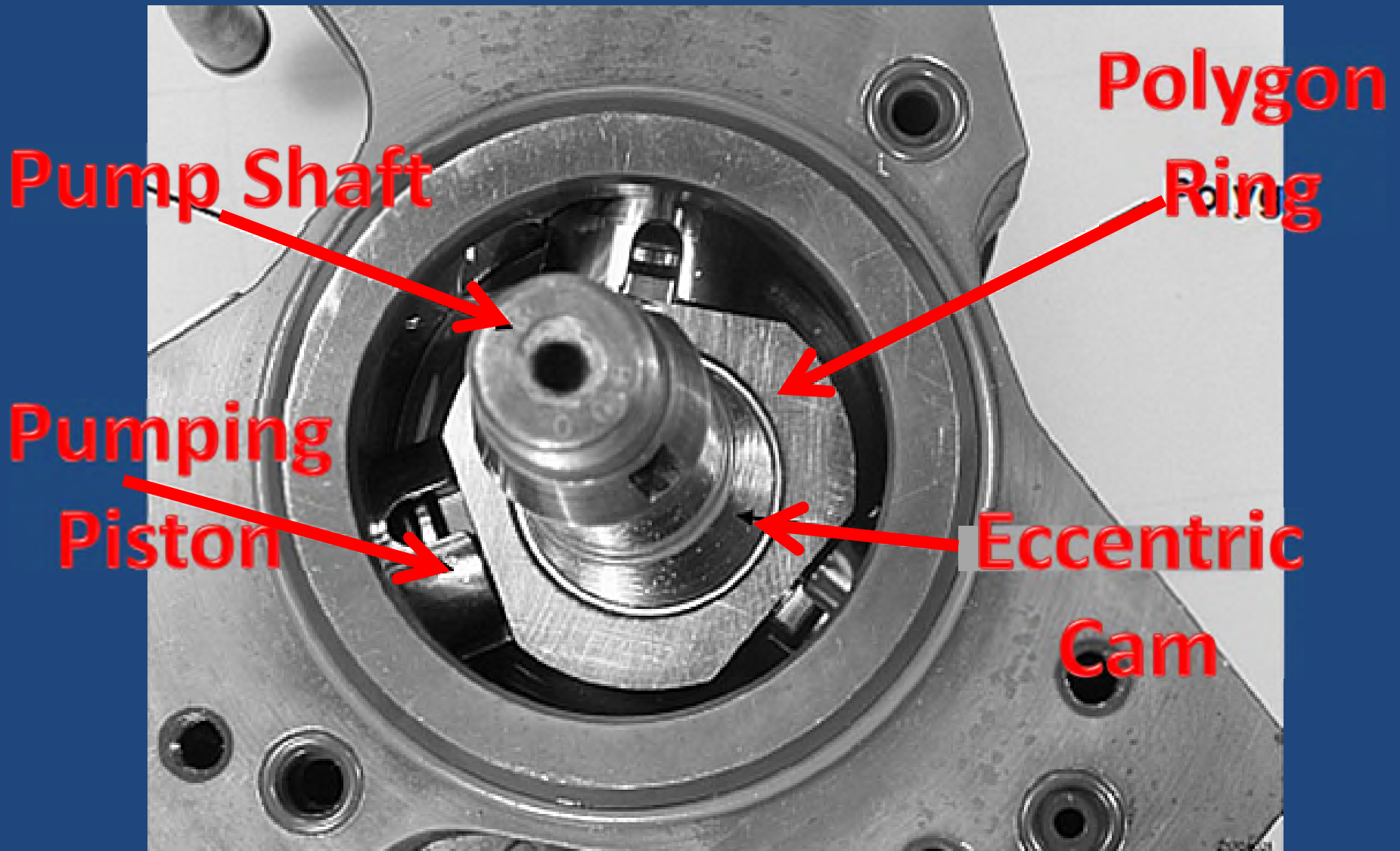


# High Pressure Pump

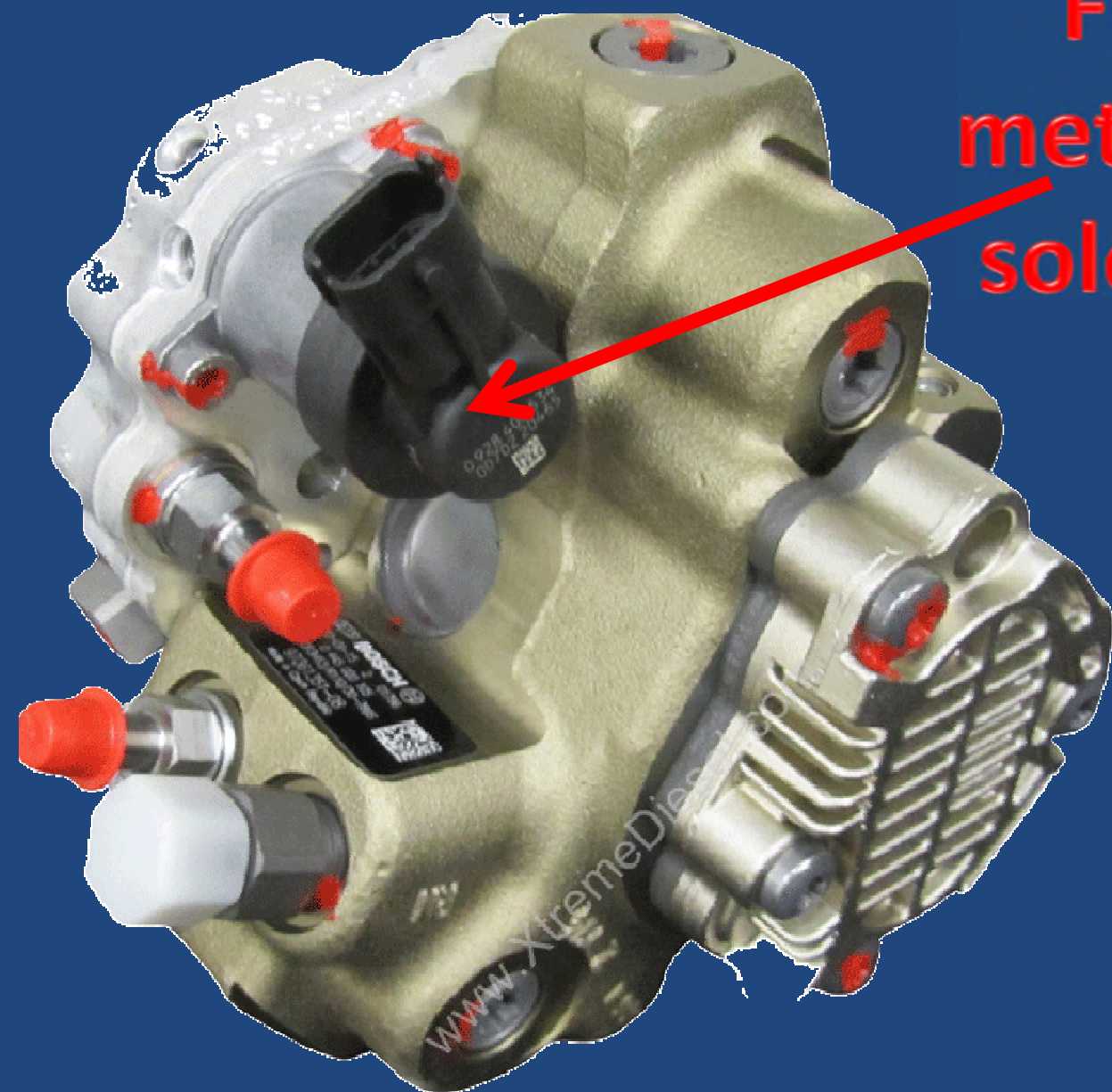
The pump maintains the rail pressure by **continuously** delivering fuel to the common rail

It precisely adjusted pressure for each injection event for the correct combustion process

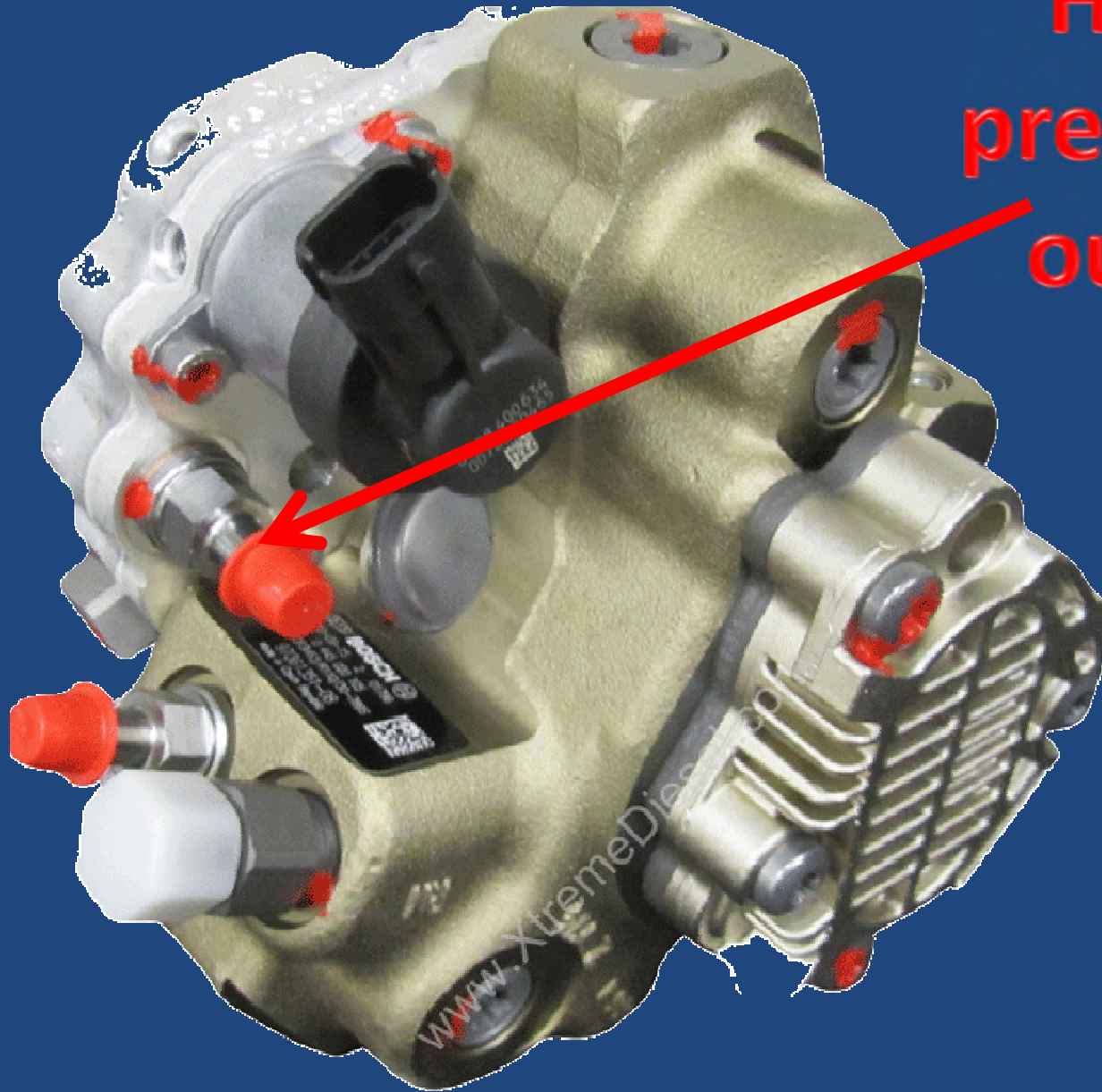
It is electrical controlled by the ECU



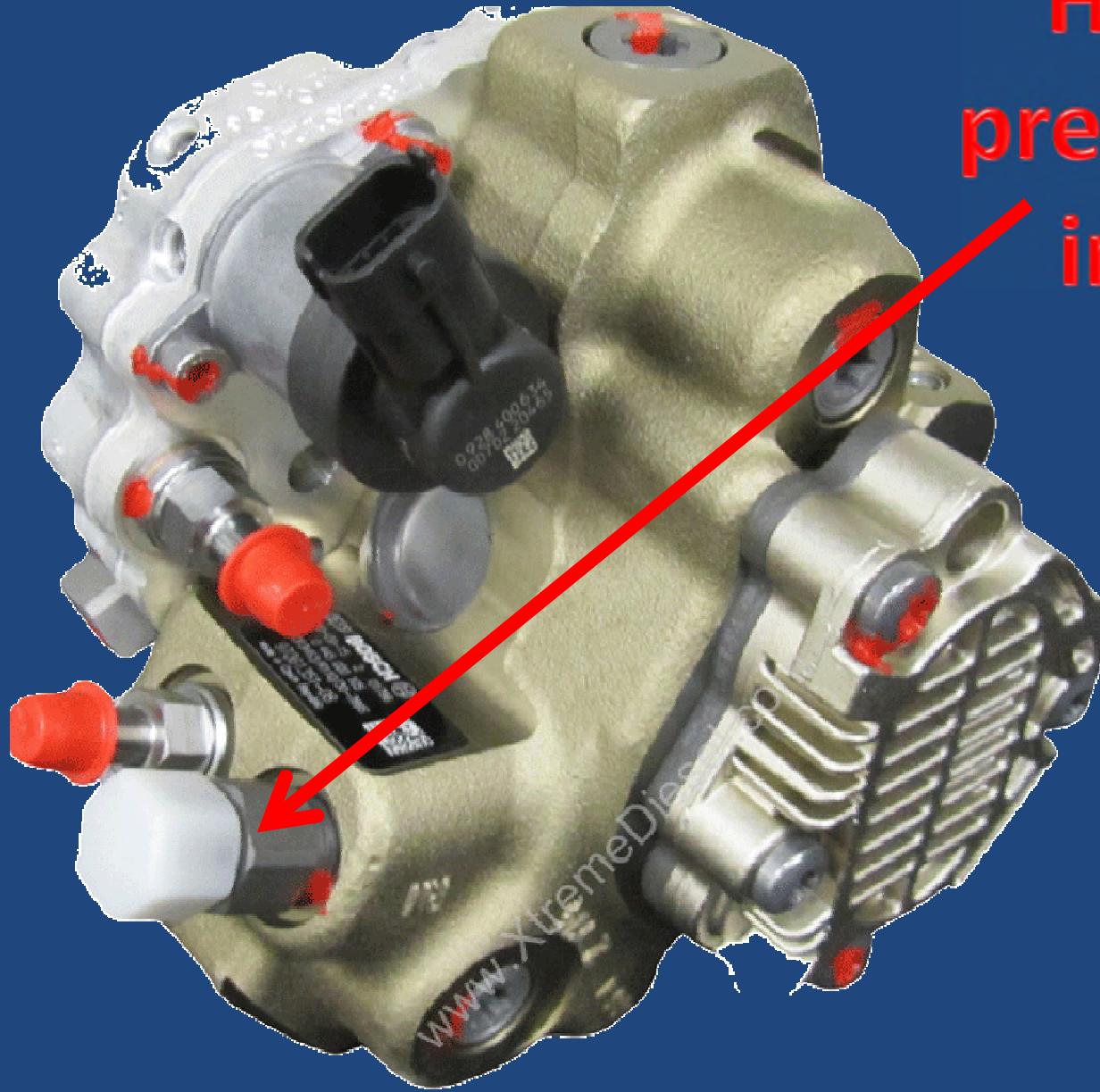
Fuel  
metering  
solenoid



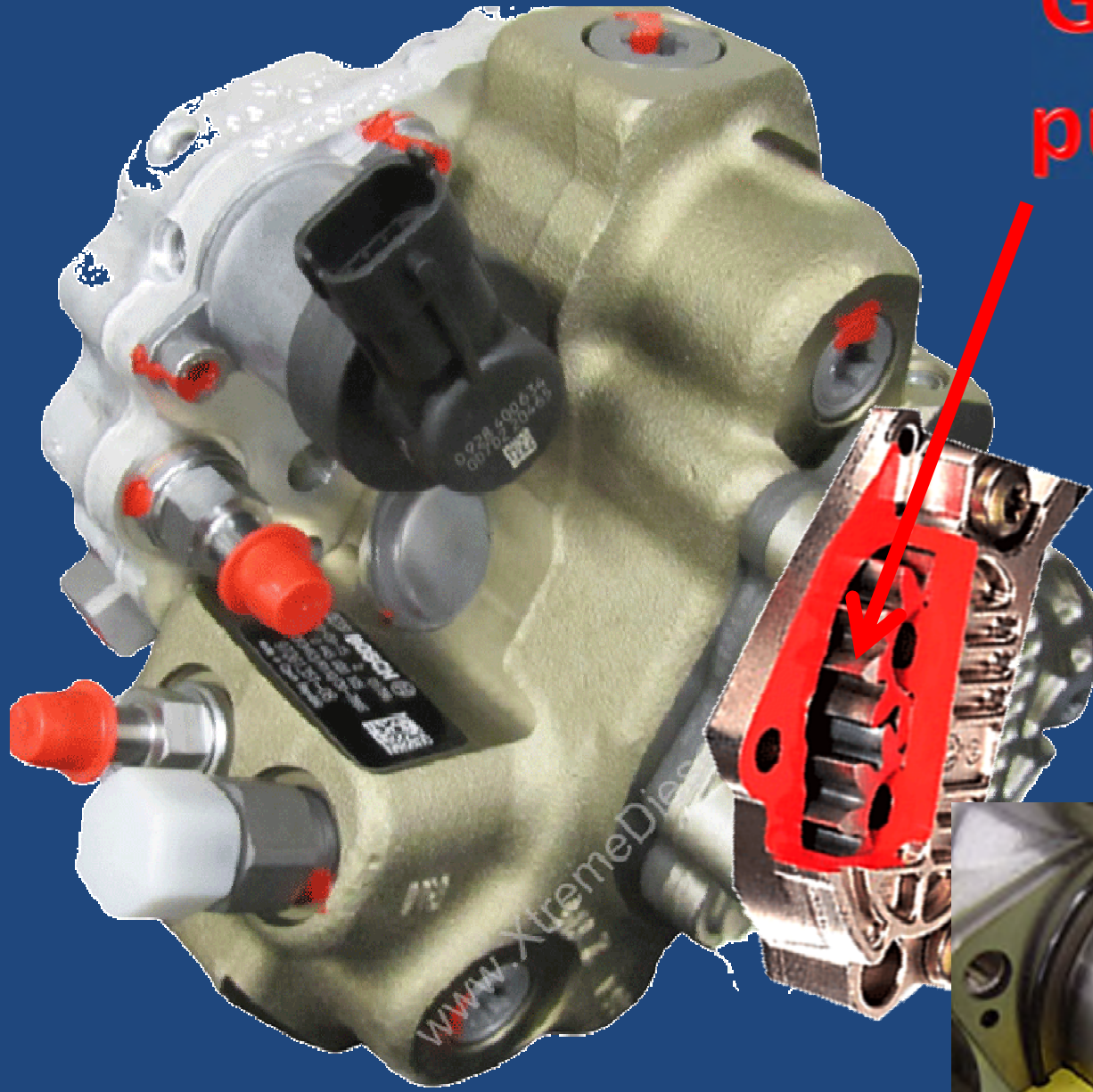
High  
pressure  
outlet

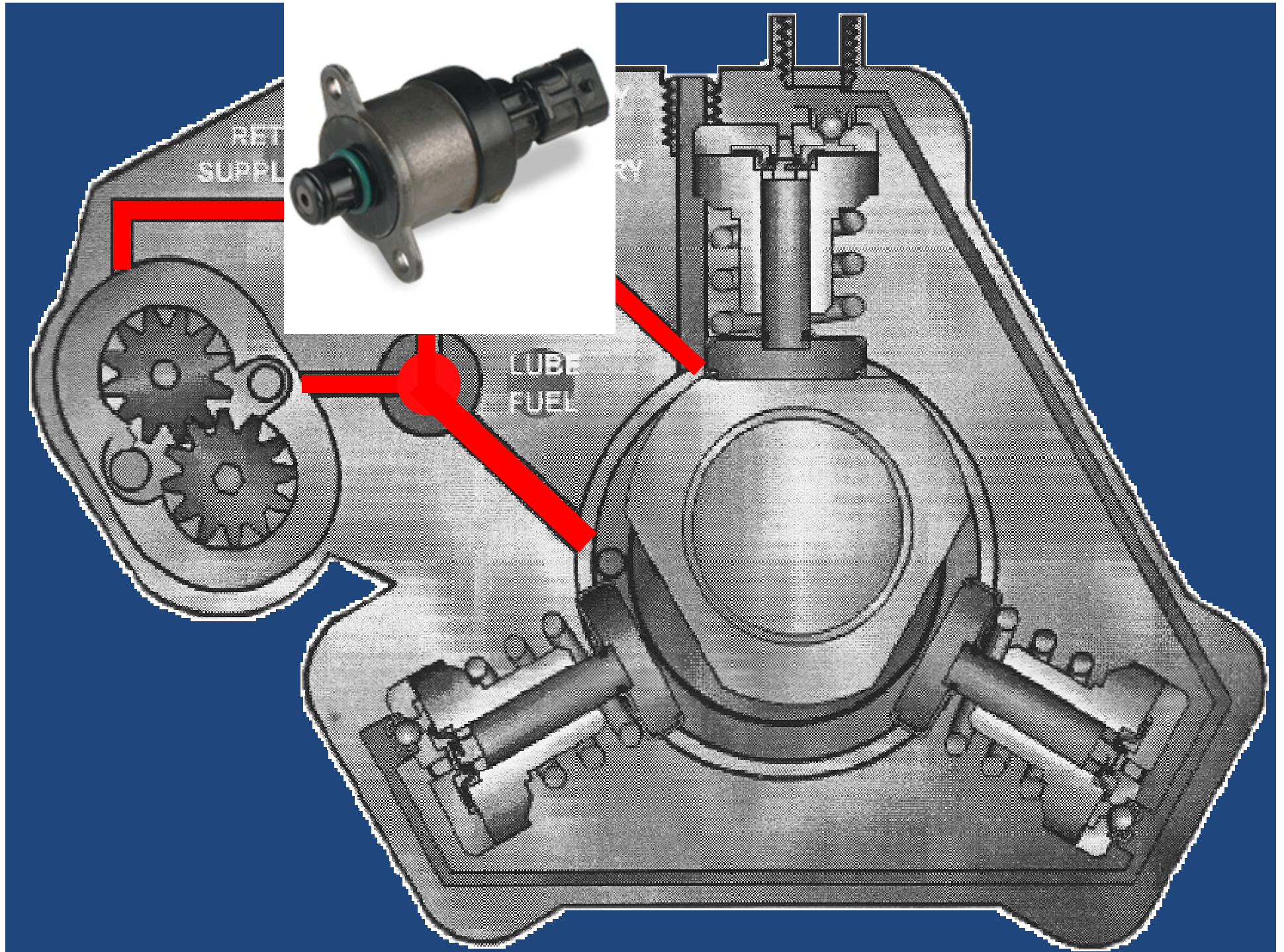


High  
pressure  
inlet



**Gear  
pump**





# Over flow valve

There are two channels in the injection pump

One to the FCA

One to regulate how much fuel is used for lubrication and how much is returned through the return circuit

# Fuel control solenoid

ECM controlled

Normally open (Activated to close)

This has it open during cranking

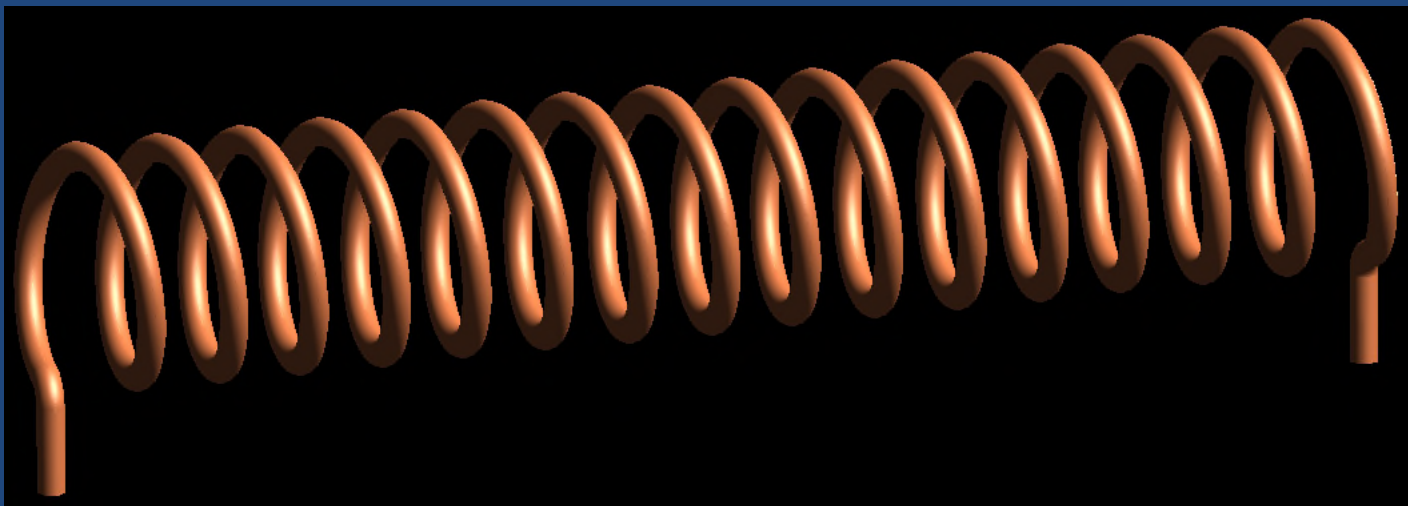
Then ECM controlled  
to control fuel



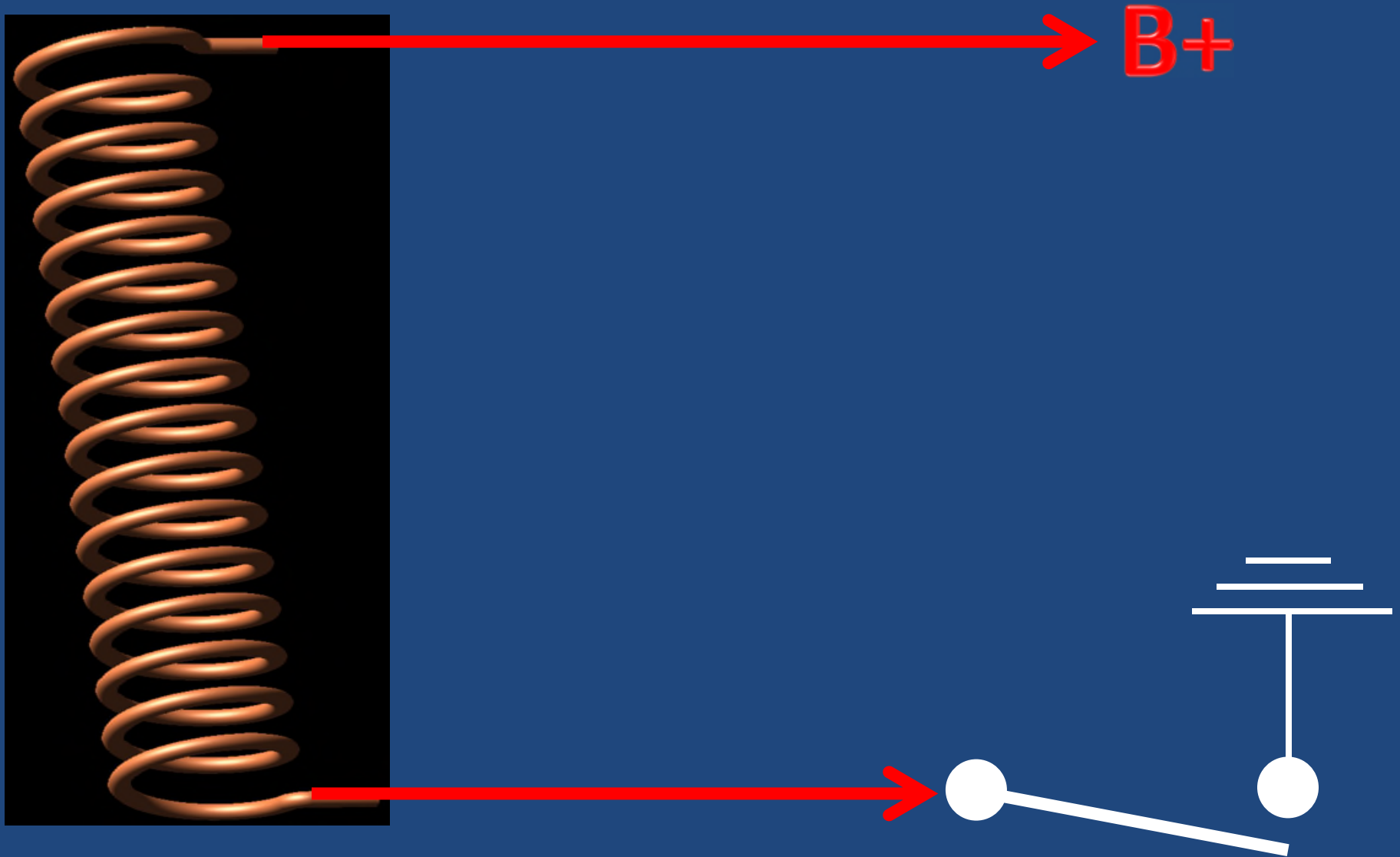
# Solenoid

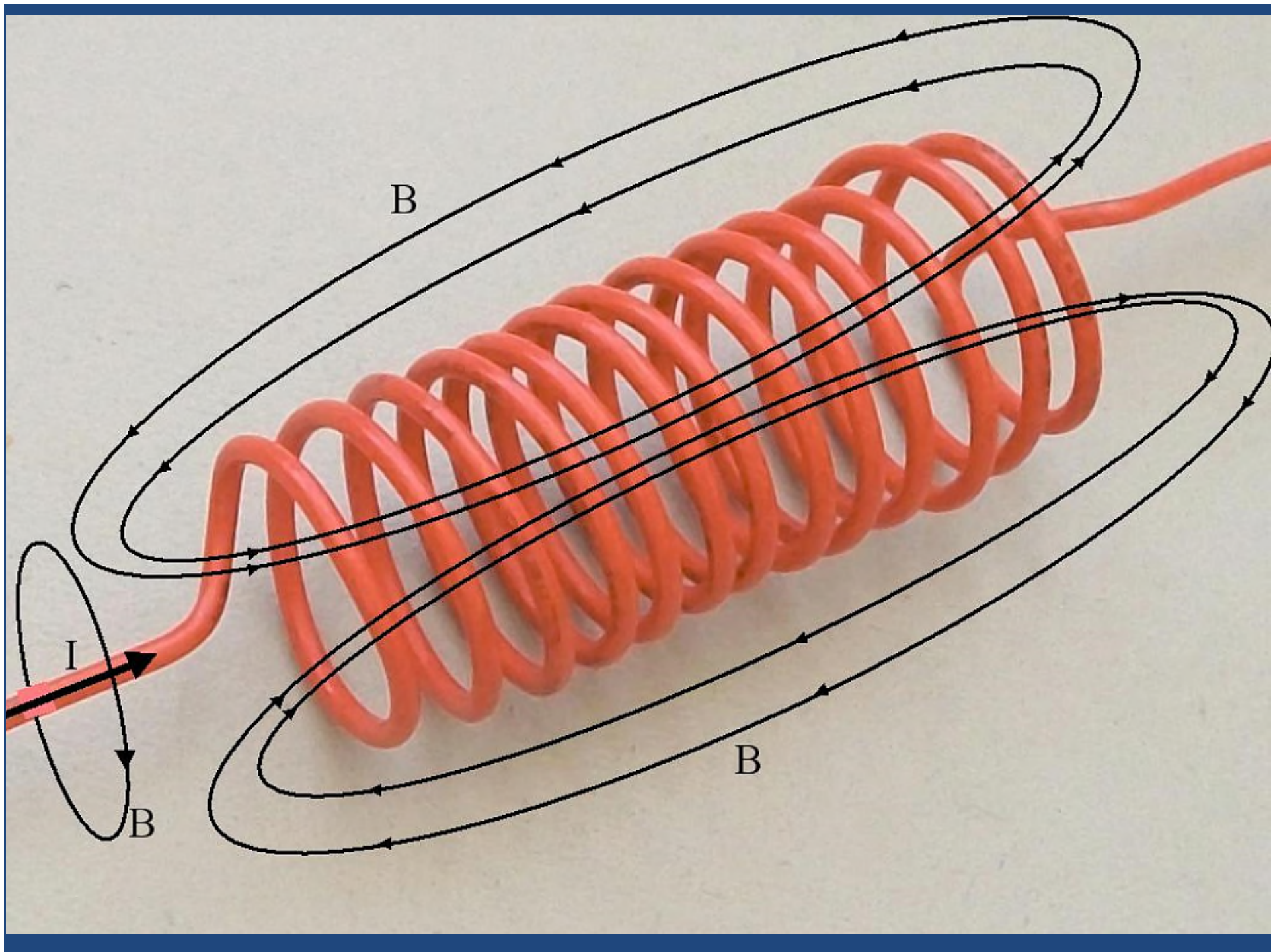
Electrical mechanical device that changes electrical energy into mechanical energy

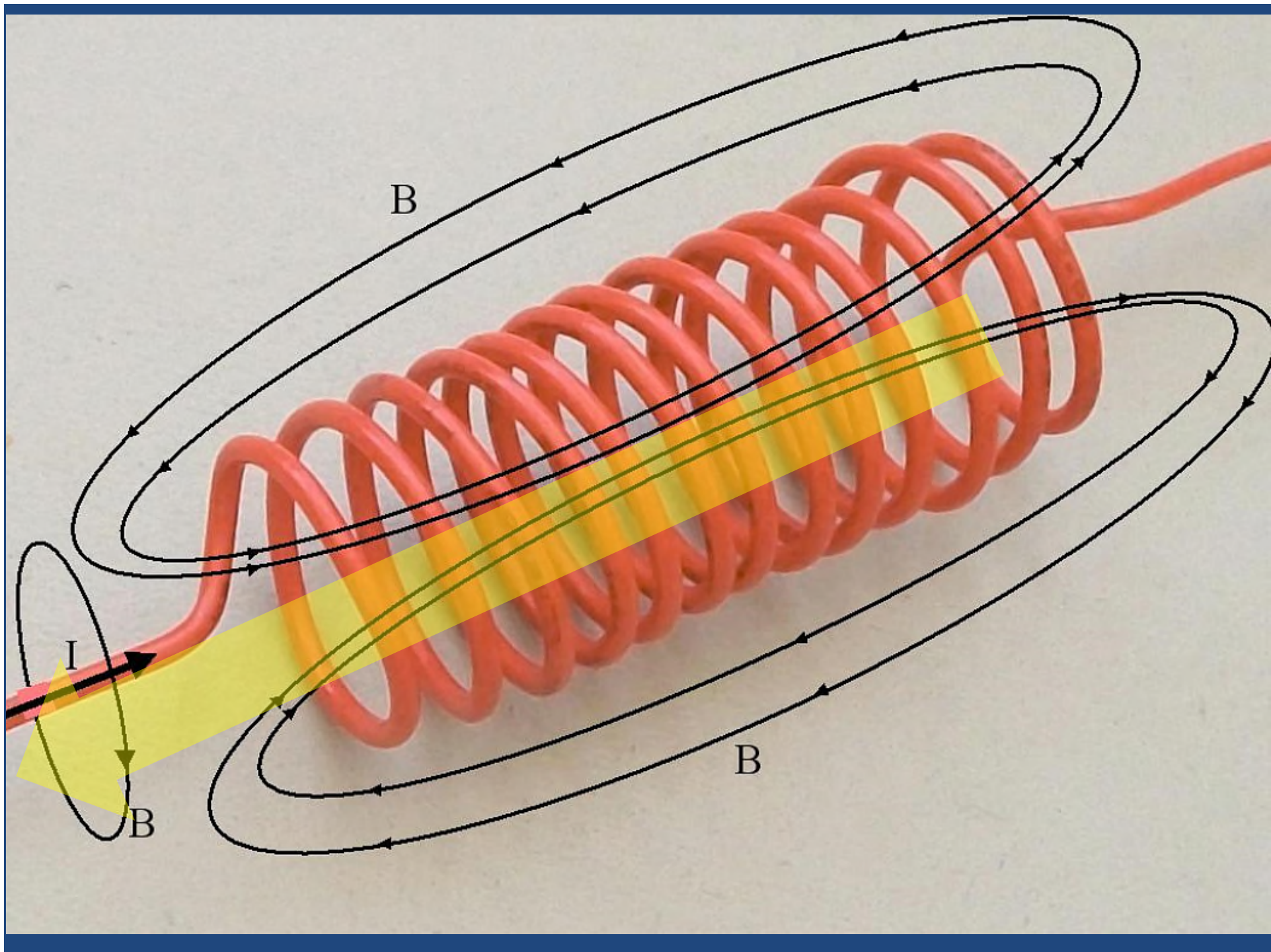
A solenoid is a type of electromagnetic used for the purpose of generating a controlled, uniform magnetic field

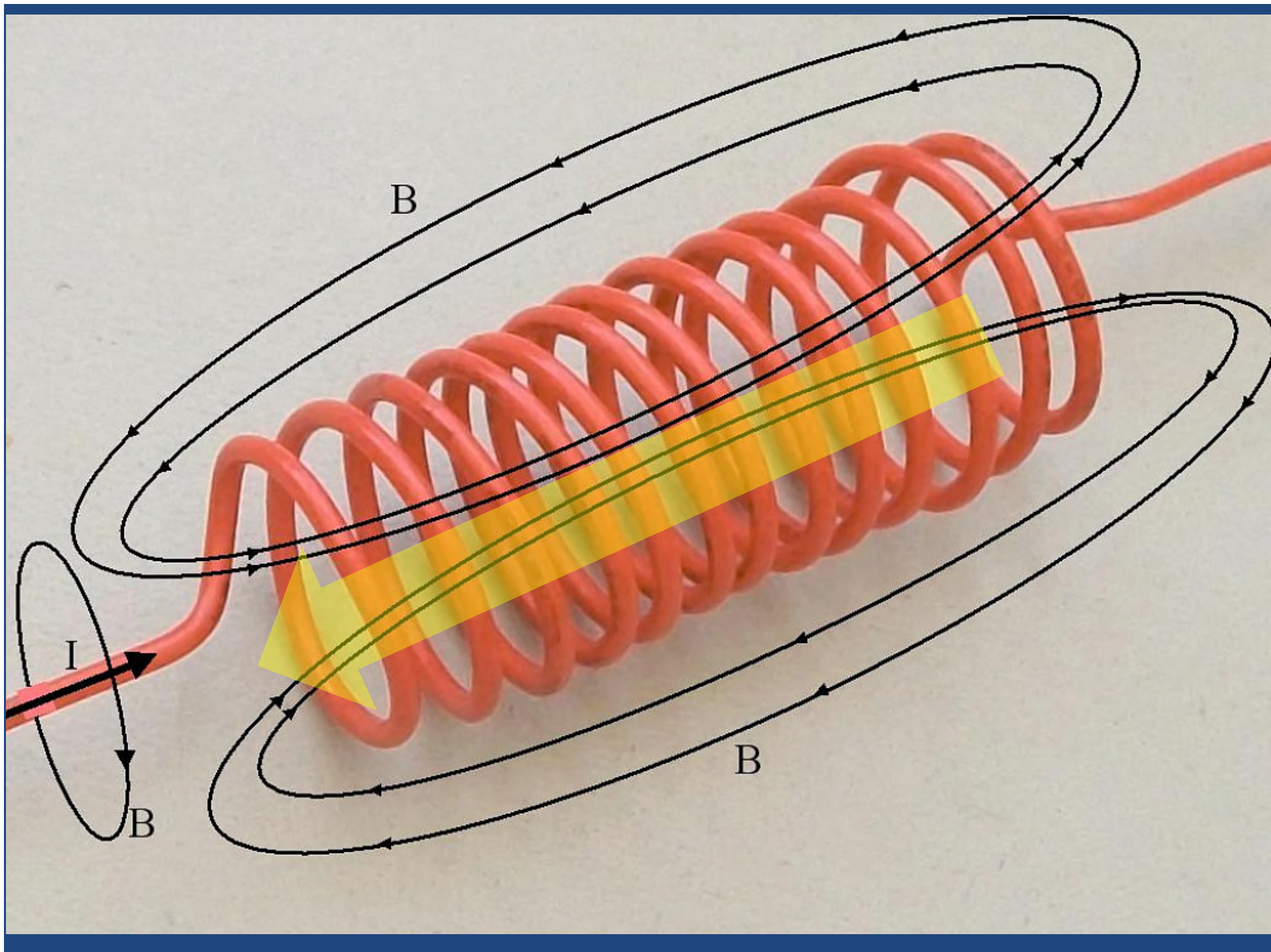


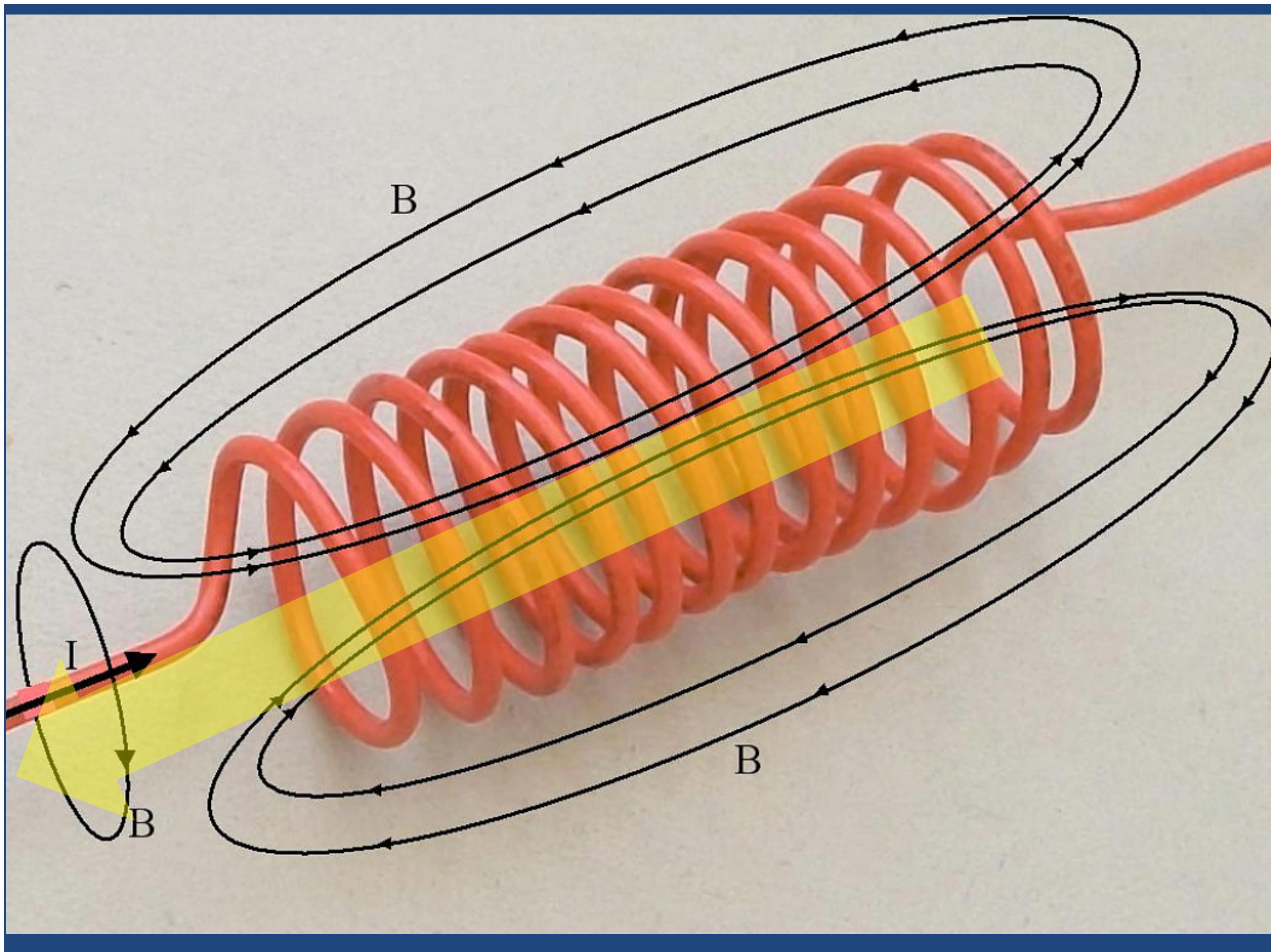
# Solenoid

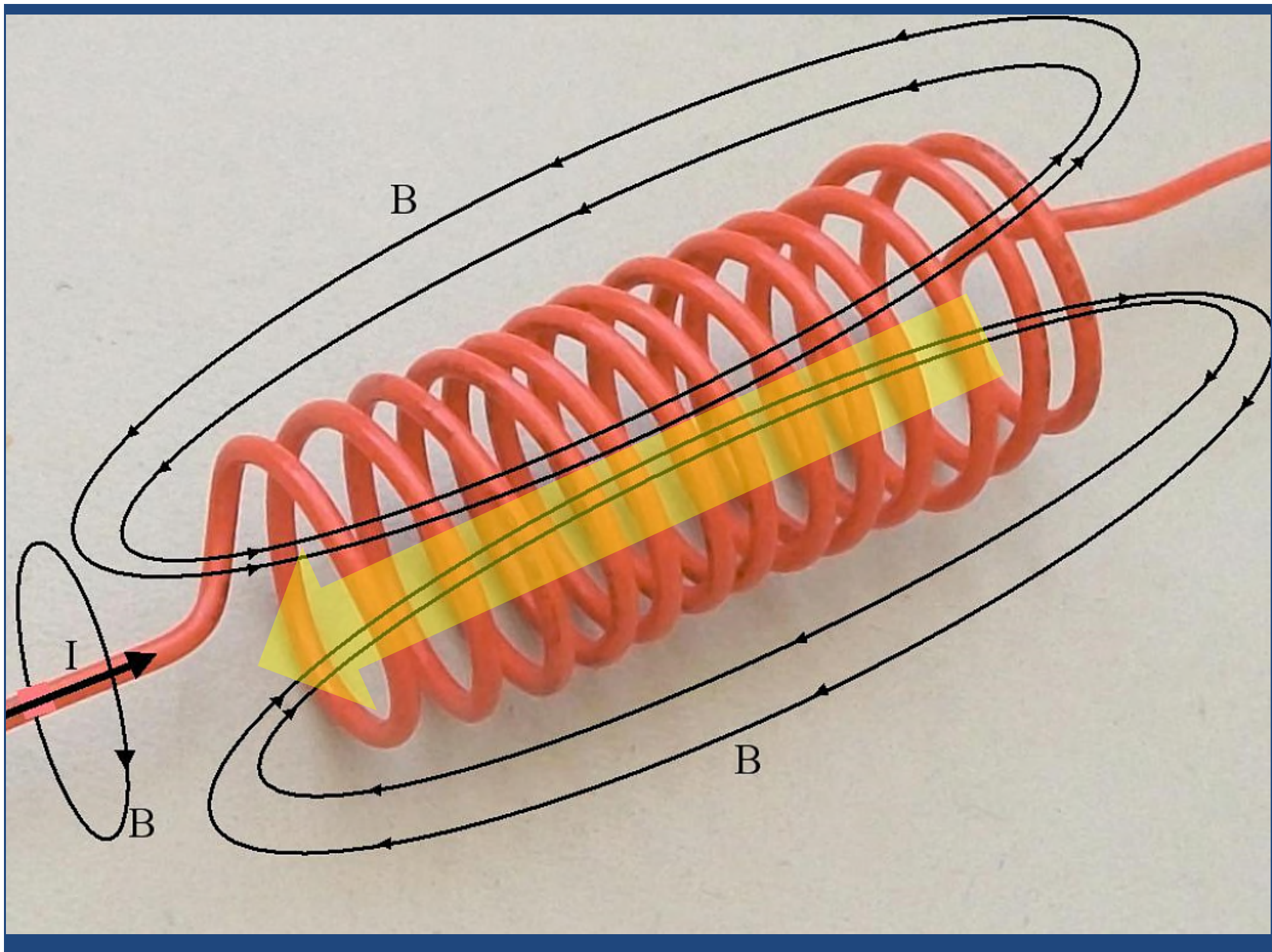


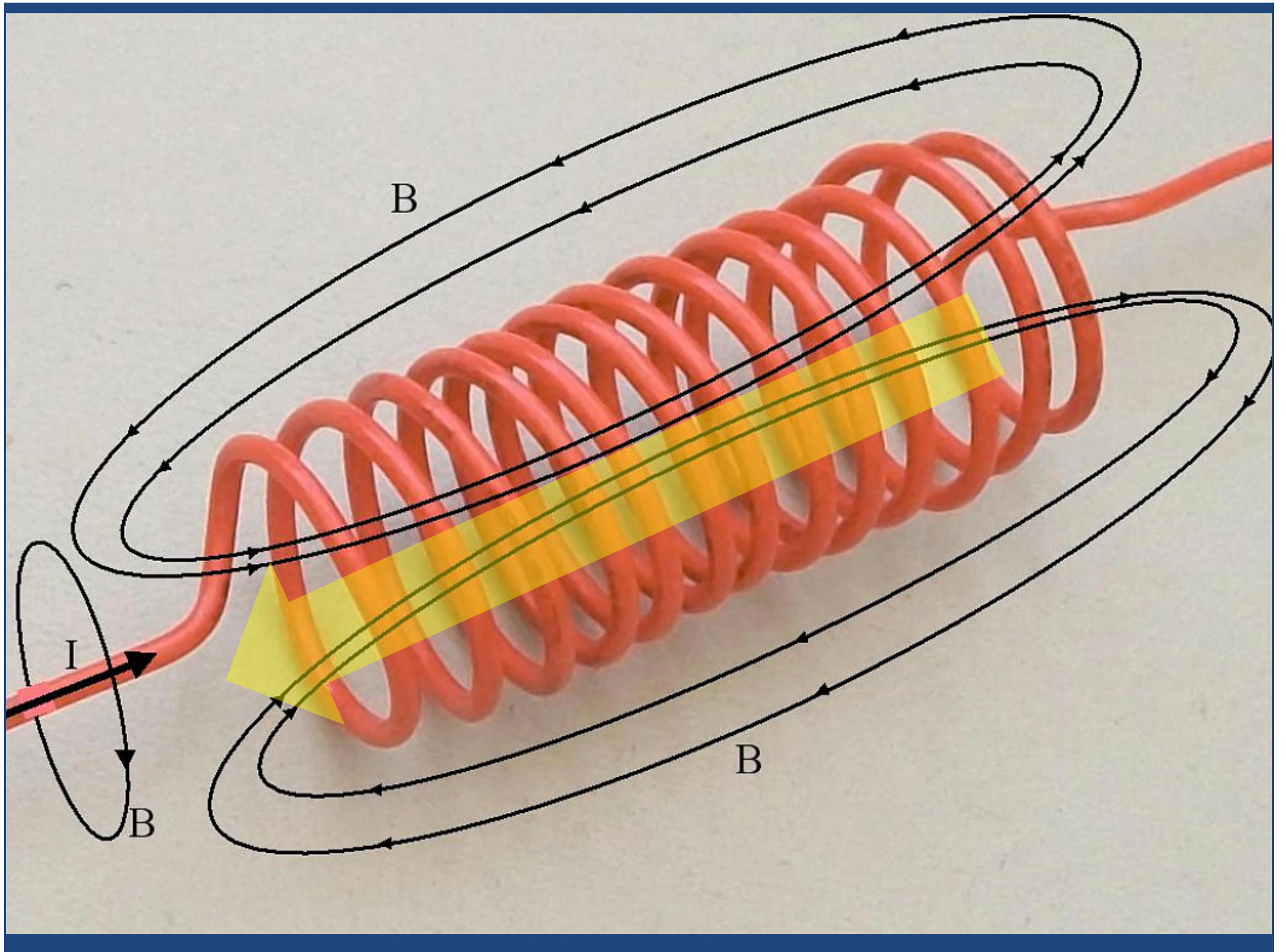


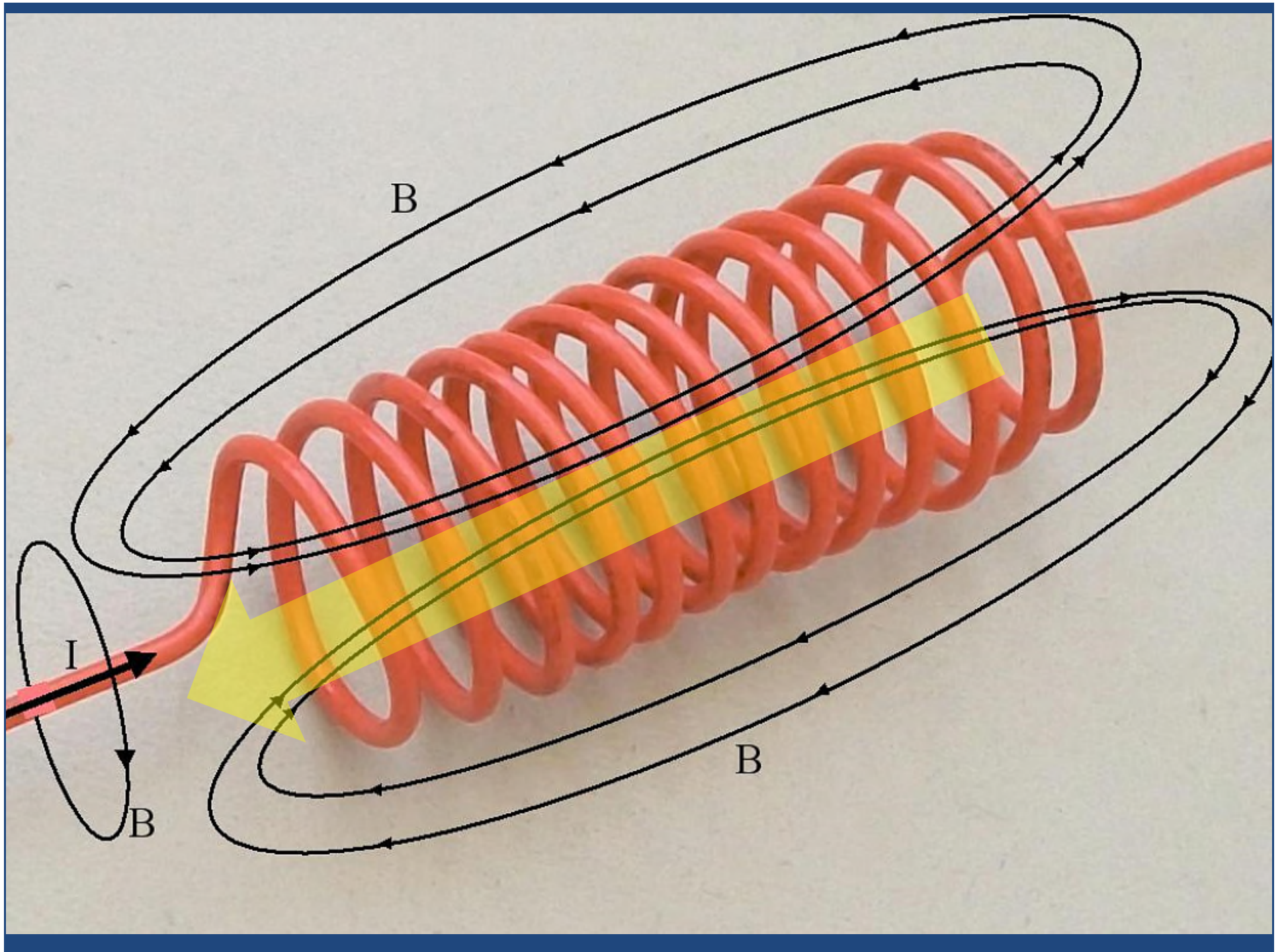


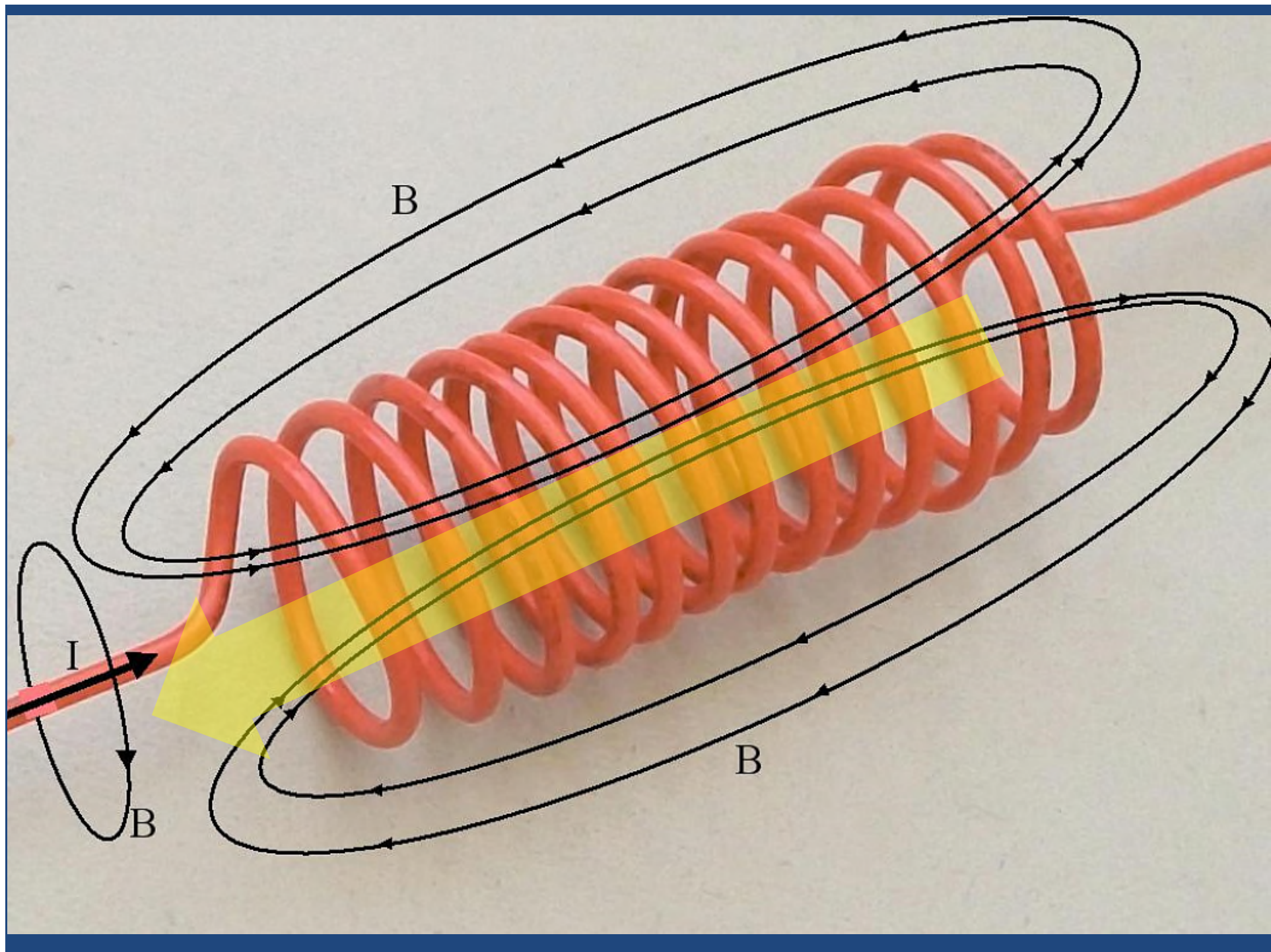


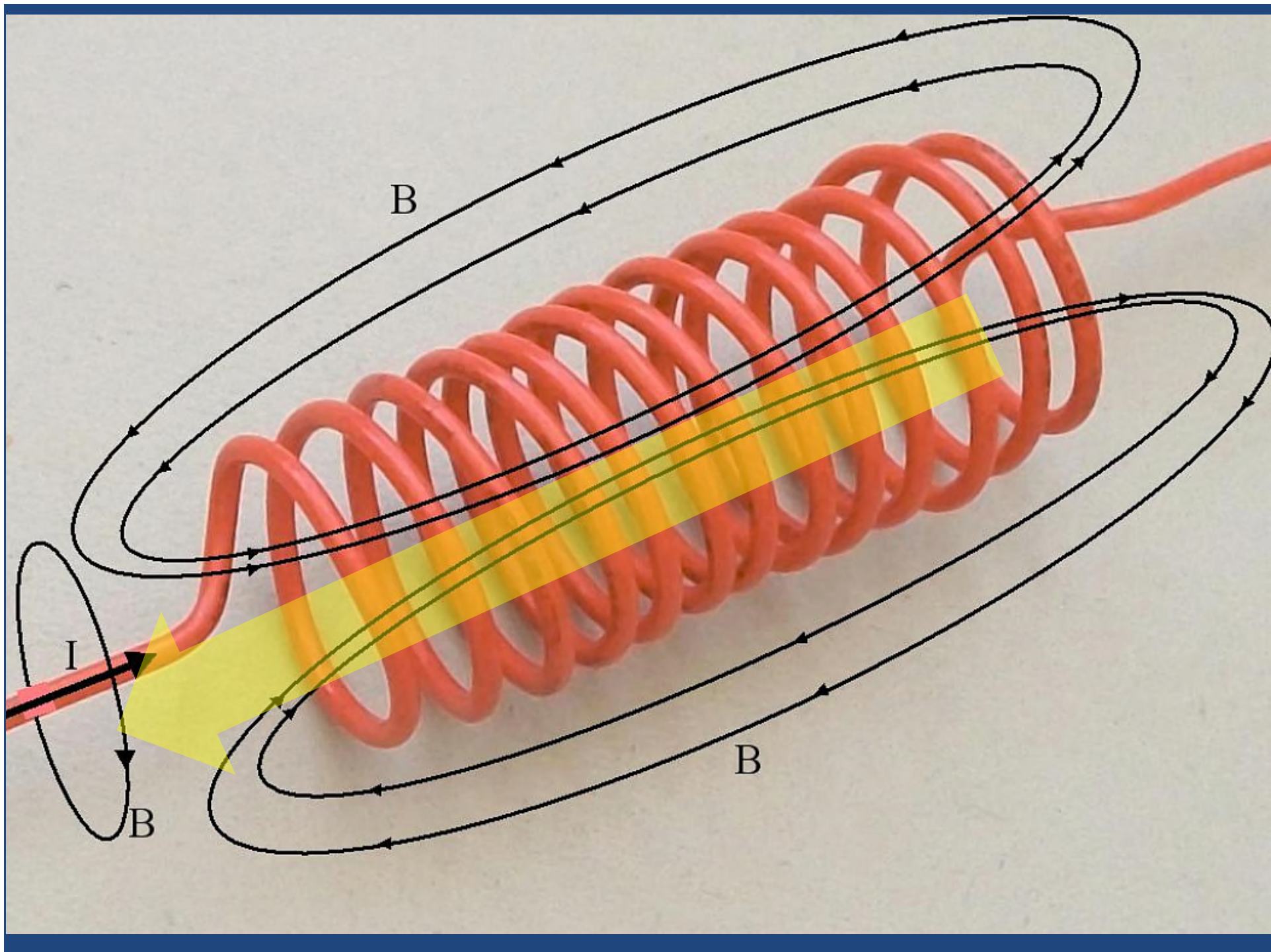


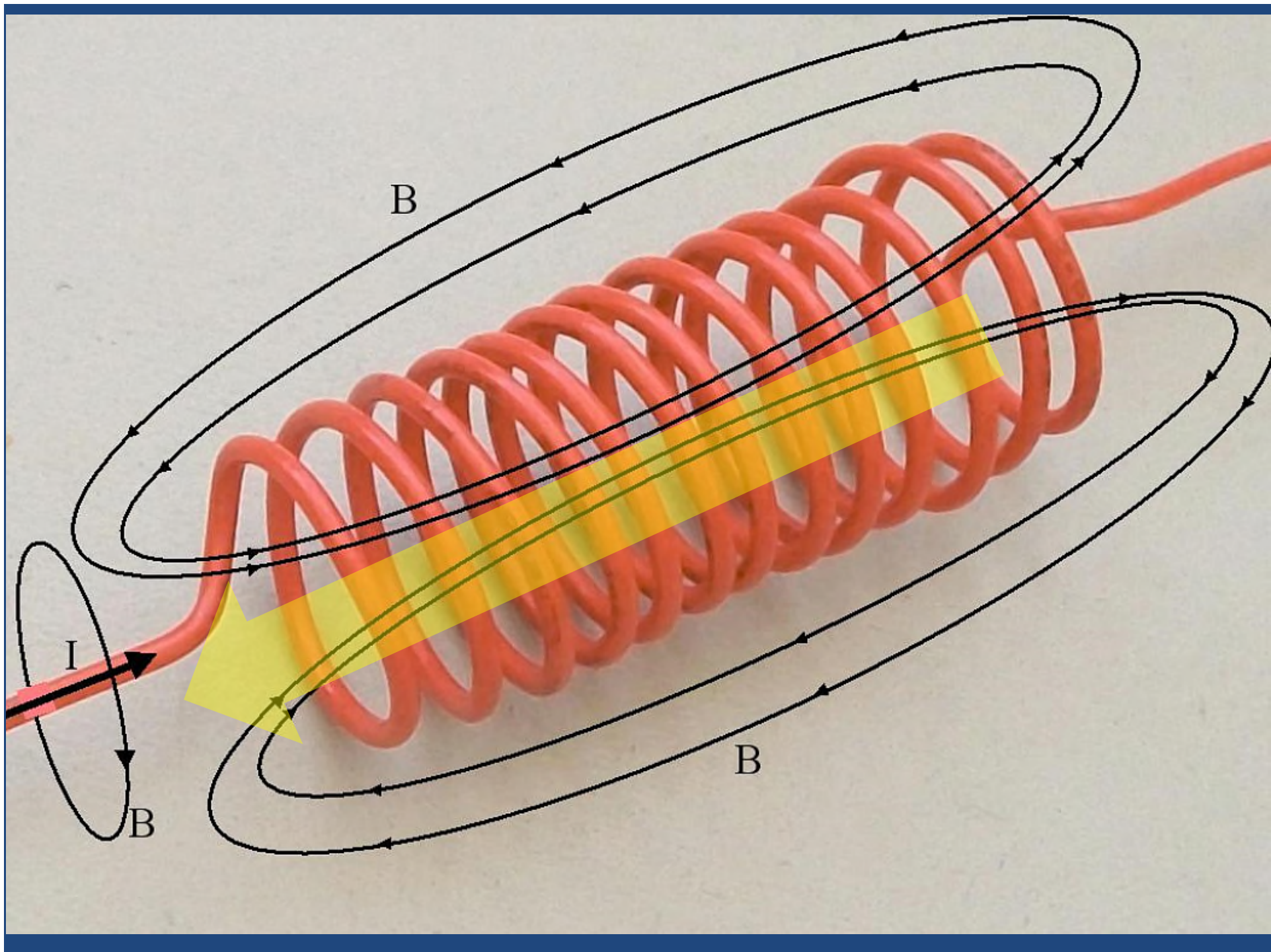










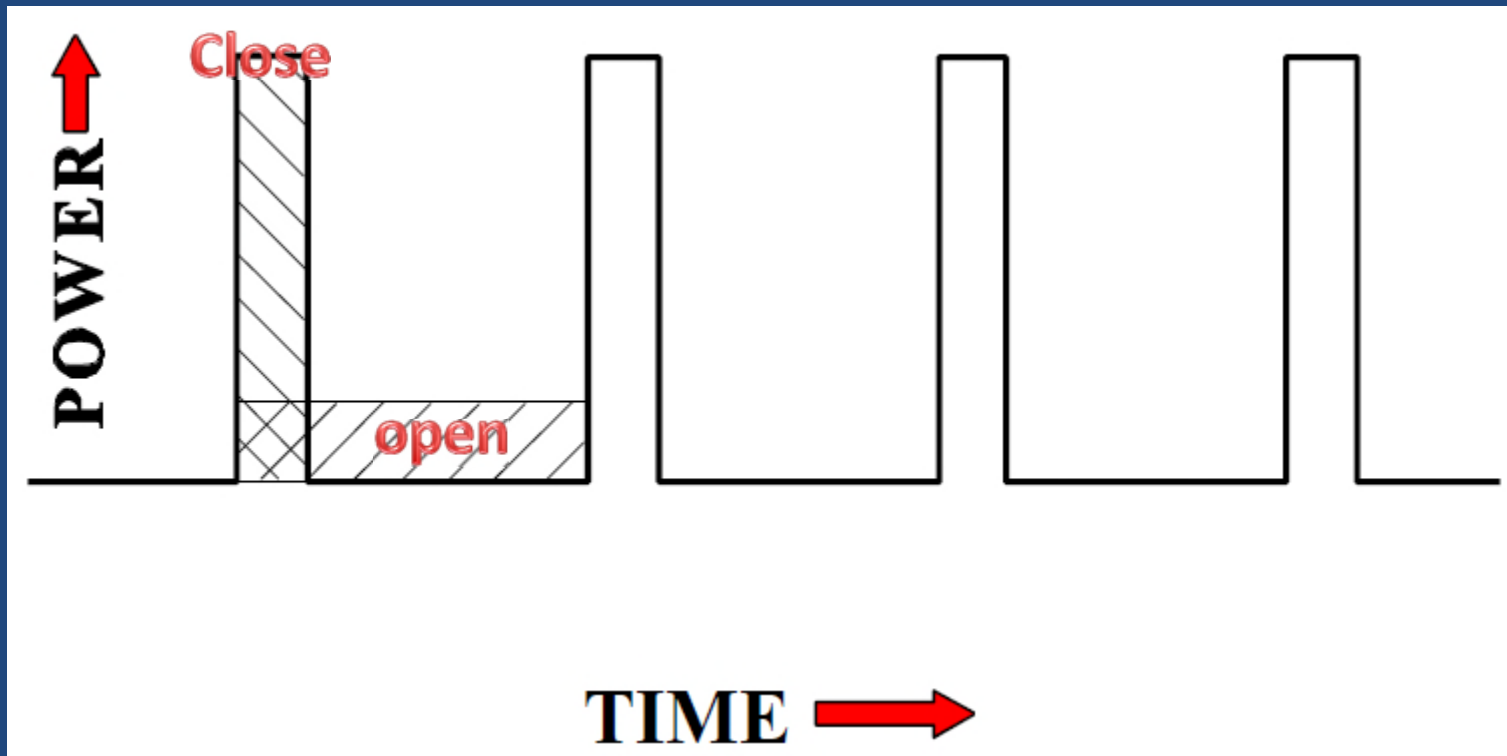


# Pulsed Width Modulated

PWM @ 150Hz to 200Hz

PWM is accomplished by driving the supply voltage high and low(er)

# Pulse Width Modulated Signal (PWM) Duty Cycle



High

33%

Low

High

50%

Low

High

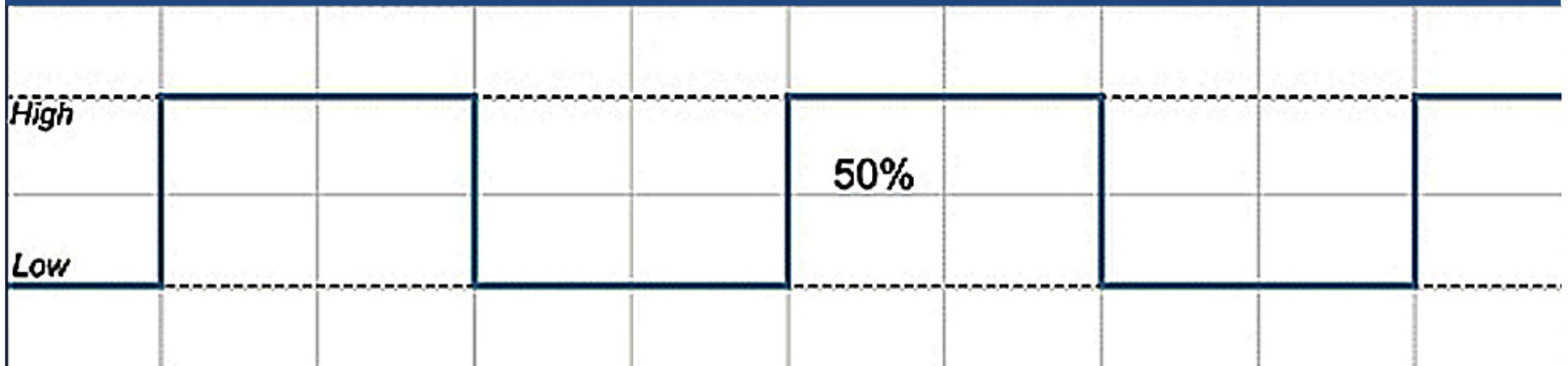
75%

Low

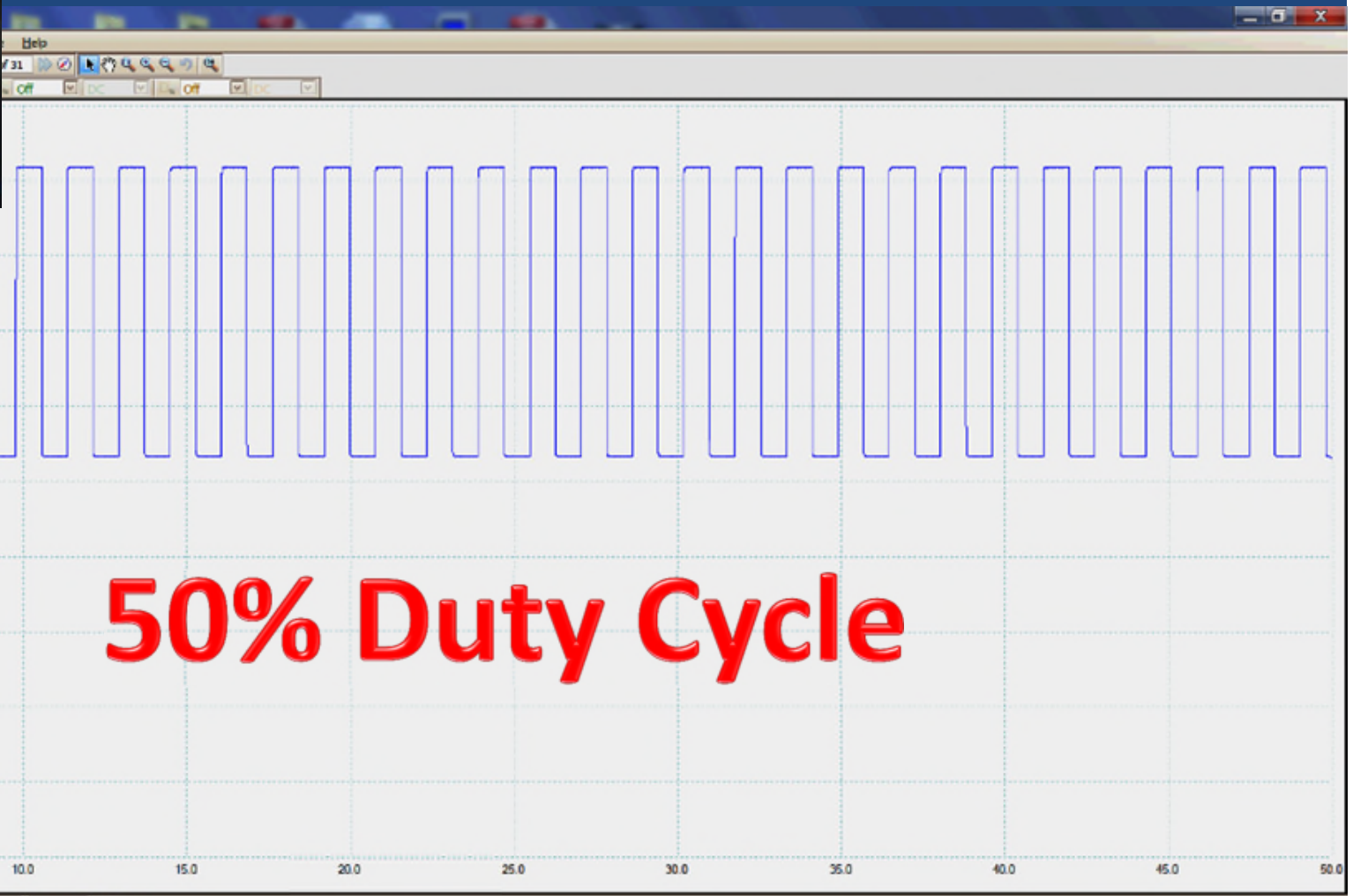
**50% high 50% low**

**50% on 50% off**

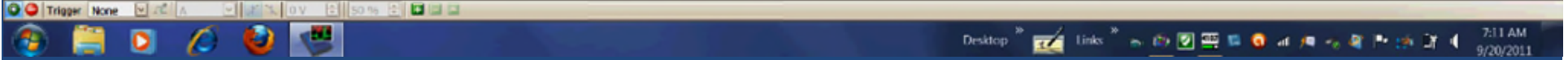
$$12V \div 2 = 6V$$

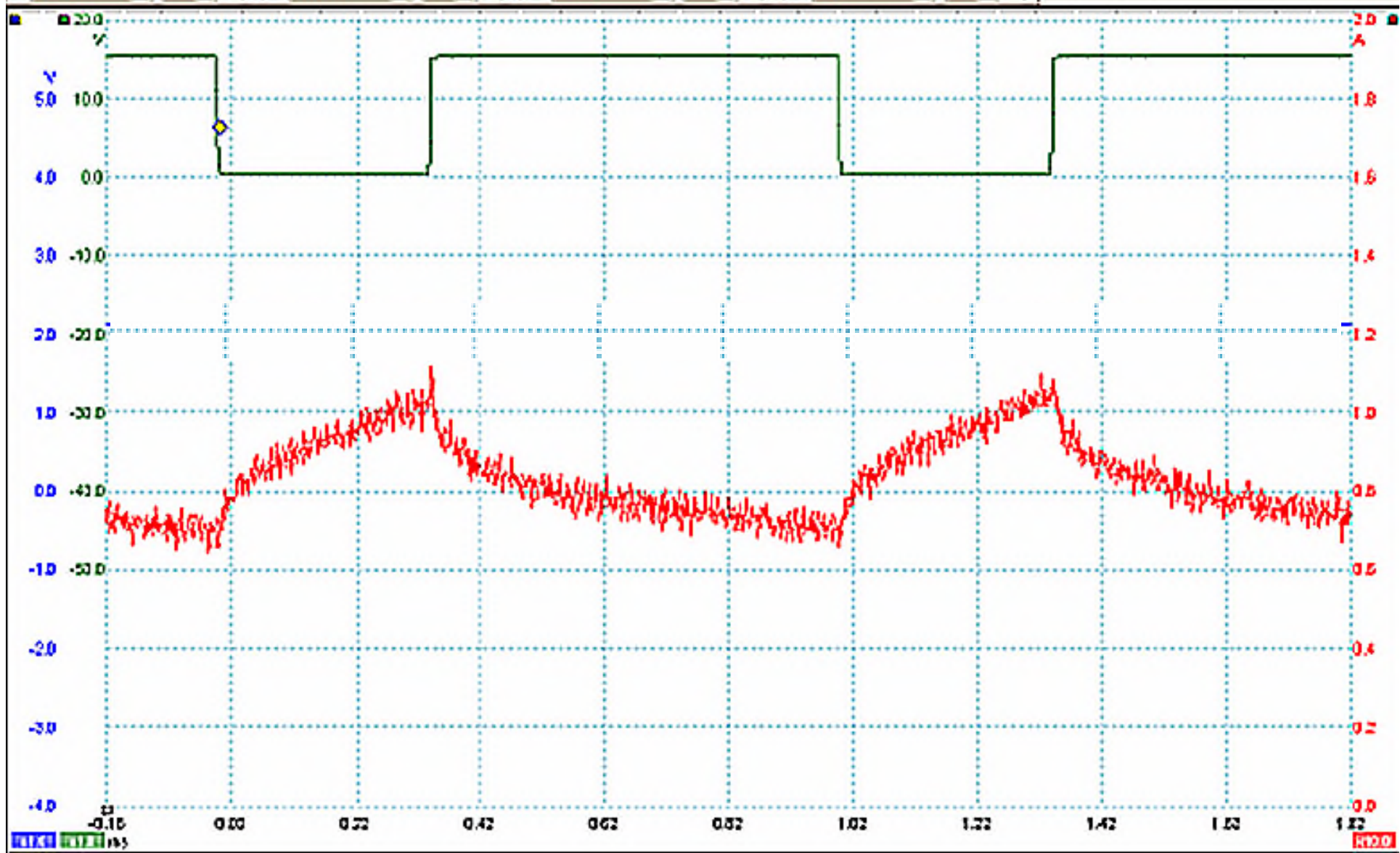


**Solenoid half open**



**50% Duty Cycle**





# Diagnostics Note

If fuel pressure in the fuel rail becomes too low, the PCM will command a lower duty cycle

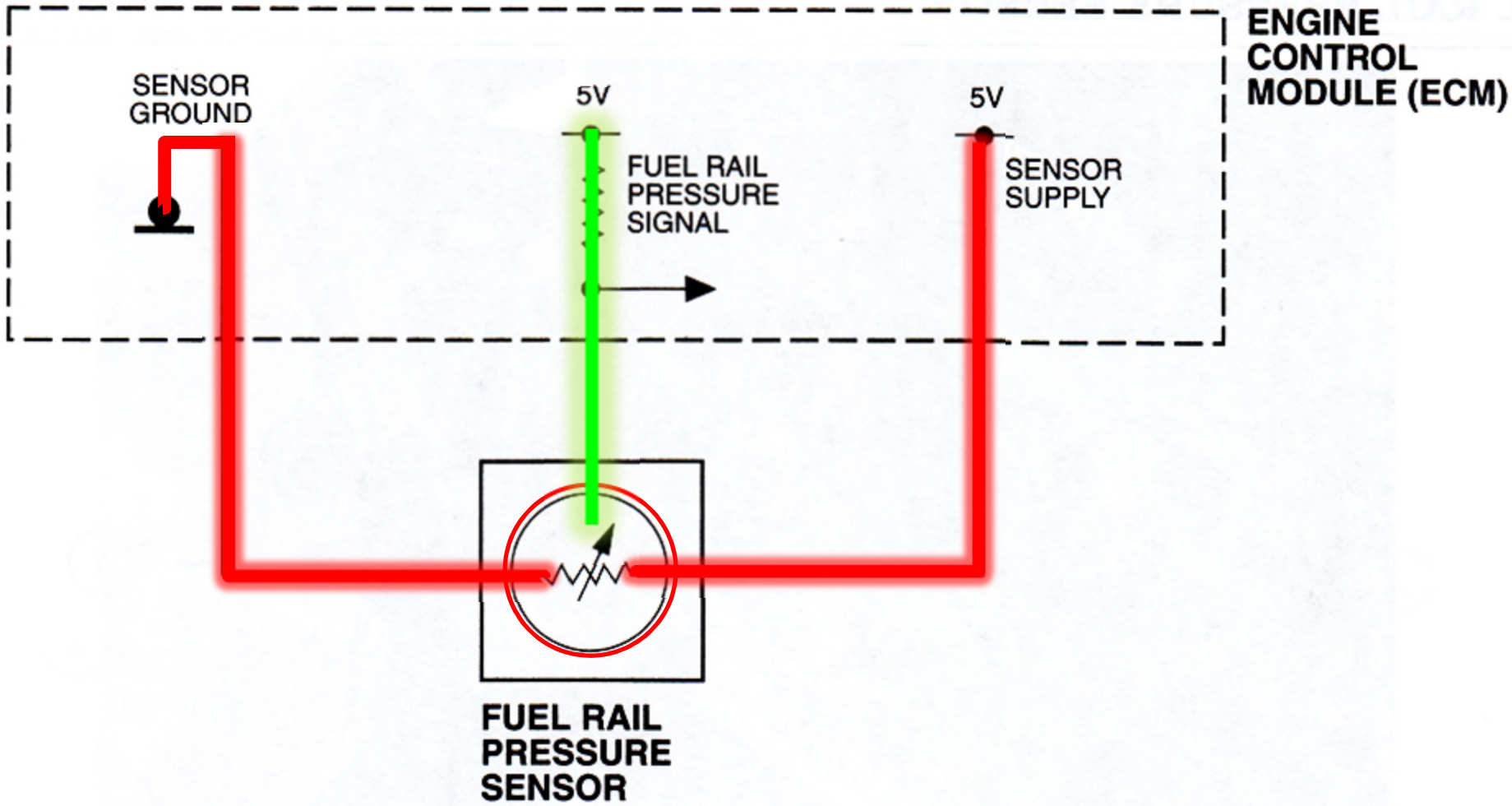
A lower than normal fuel rail pressure points to

A bad lift pump

A bad high pressure pump

An incorrect signal from the fuel rail pressure sensor

# Fuel Rail Pressure Sensing



# Types of pressure measurements

## Absolute pressure sensor

This sensor measures the pressure relative to a perfect vacuum

## Gauge pressure sensor

# Gauge Pressure

Typical machine gauges do not measure atmosphere, but pressures above atmosphere

This sensor measures the pressure relative to Atmospheric pressure

A tire pressure gauge is an example of gauge pressure measurement; zero is atmospheric pressure

# Two Categories

## Absolute pressure sensor

Force collector types

These types of electronic pressure sensors generally use a force collector

A diaphragm, piston, bourdon tube, or bellows

To measure strain (or deflection)

## Piezoresistive (Voltage Dividing, Wheatstone Bridge) (strain gauge)

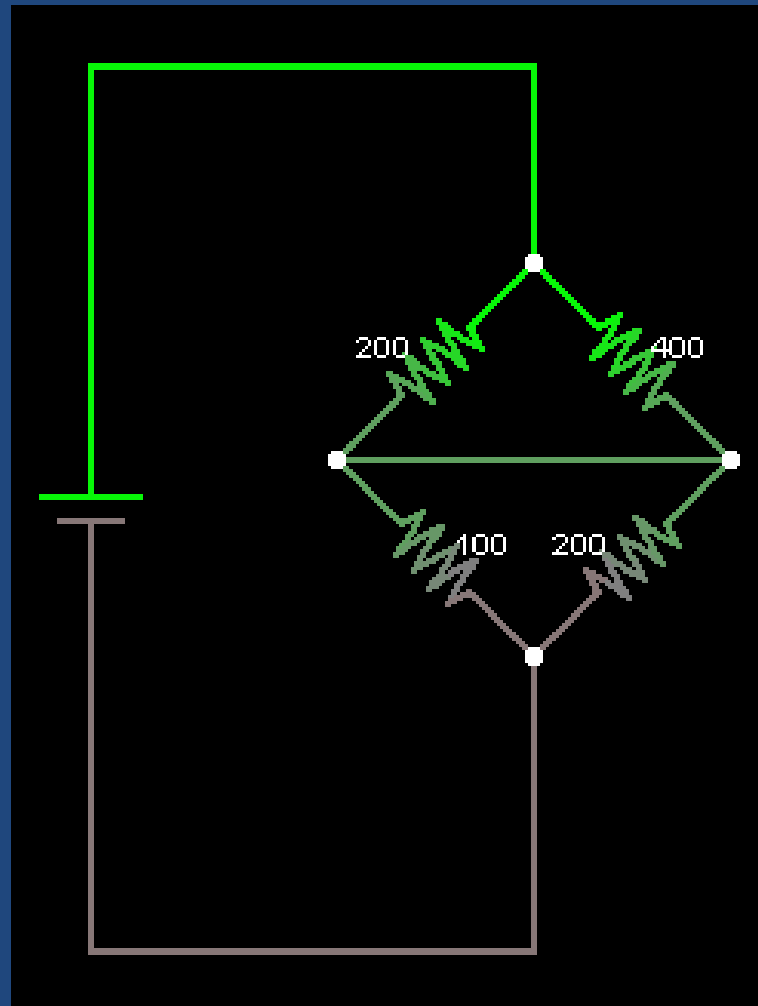
Uses the **piezoresistive** effect of bonded or formed Strain Gauge to detect strain due to applied pressure

The strain gauges are connected to form a **Wheatstone Bridge** circuit to maximize the output of the sensor

This is the most commonly employed sensing technology for general purpose pressure measurement

The **piezoresistive** element forms a Wheatstone Bridge

Pressure on the sensor causes a proportional change in voltage



# Wheatstone bridge

A Wheatstone bridge is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, when one leg includes the unknown component

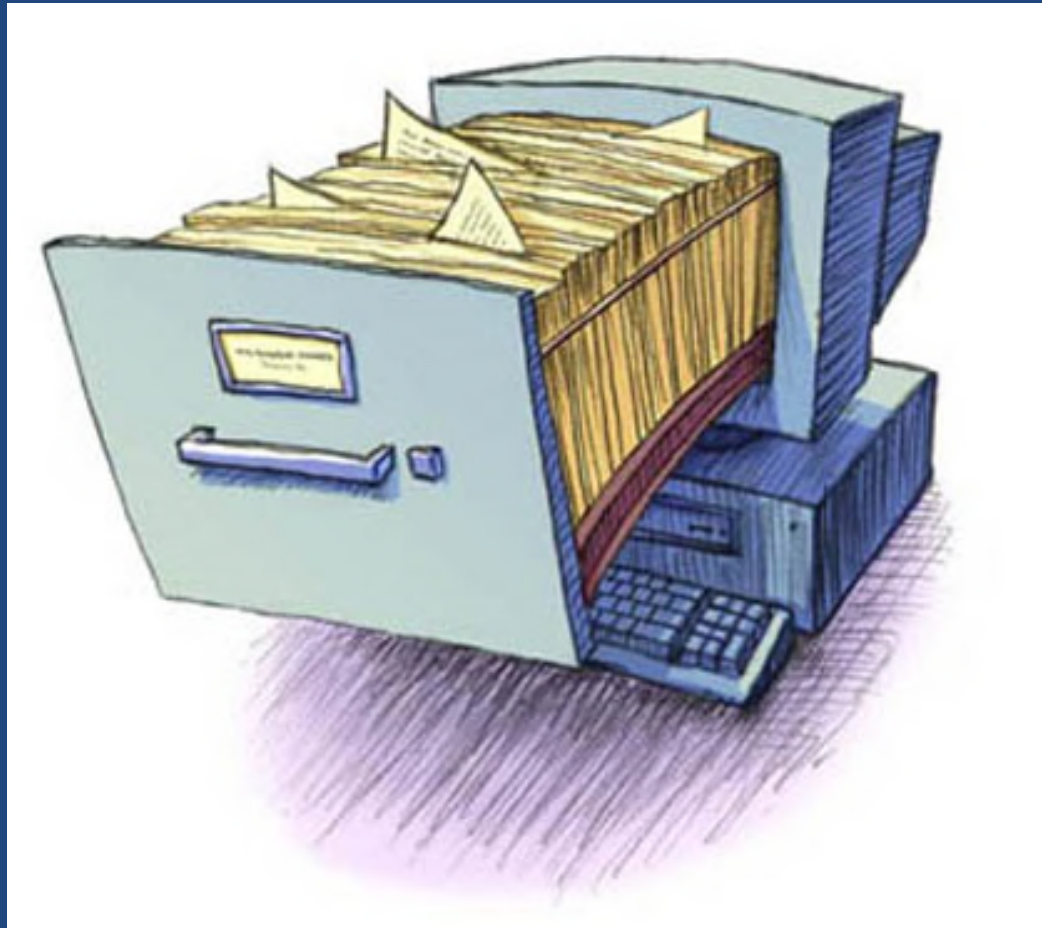
# Sensor and It's Signal

It generates a signal as a function of the pressure imposed by the confined fuel in the rail

The sensor sends an **electrical** signal to the ECM

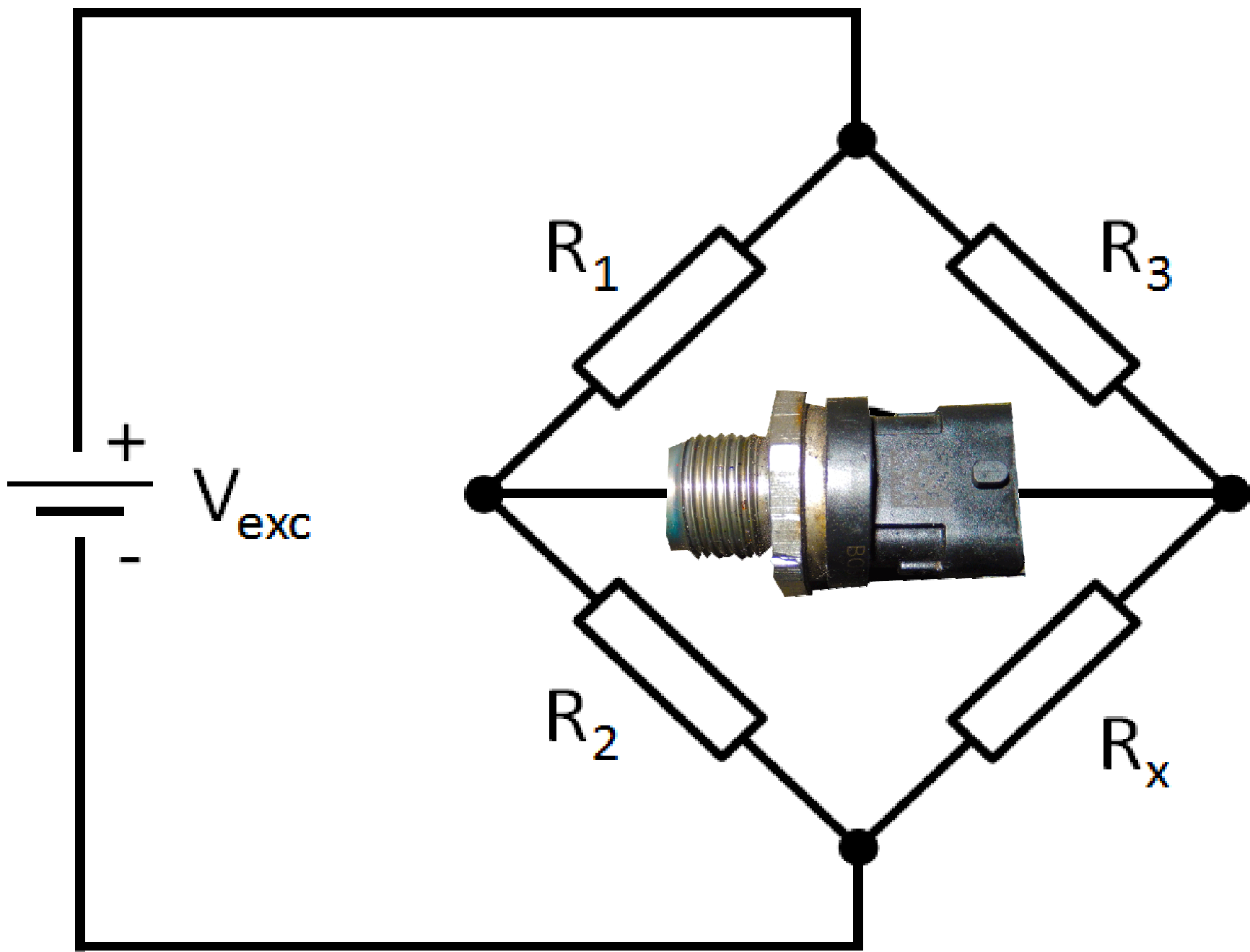
The ECM converts the **analog or digital** signal into a pressure value

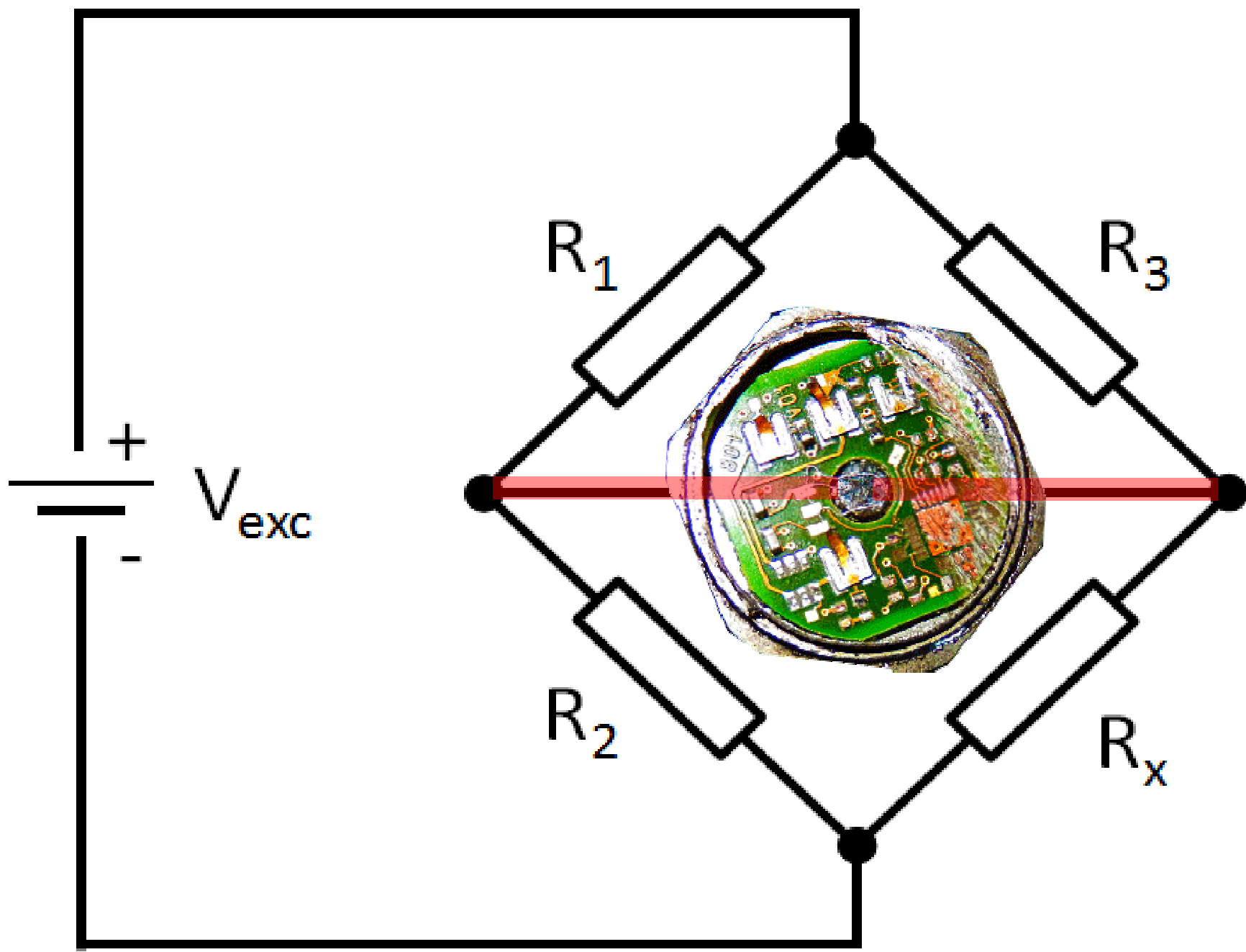
# ECM Looks Up What The Voltage Signal Is Reporting



## Look up Chart

<b>0.00V</b>	<b>0psi</b>
<b>0.001V</b>	
<b>0.002V</b>	
<b>0.003V</b>	
<b>0.004V</b>	
<b>0.005V</b>	
<b>0.006V</b>	
<b>0.007V</b>	
<b>0.008V</b>	
<b>0.009V</b>	
<b>1.00V</b>	<b>4175psi</b>





# Pressure Sensing

This is where the measurement of interest is pressure, **expressed as a force per unit area**

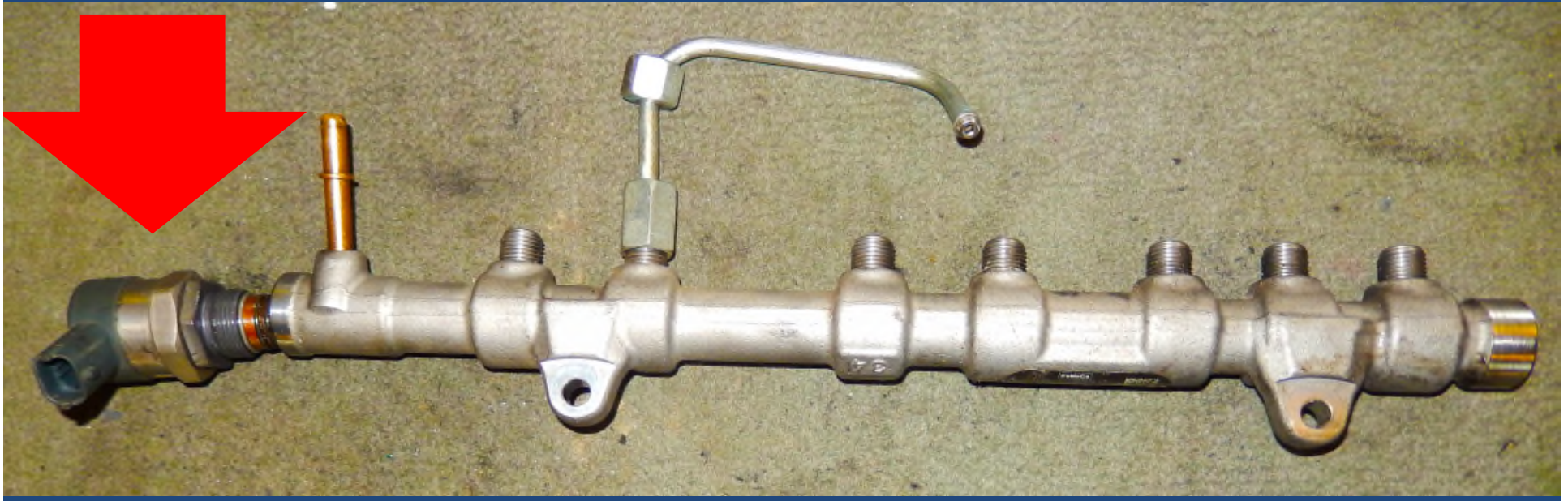
This is useful in weather instrumentation, aircraft, **Vehicles**, and any other machinery and **equipment** that has pressure functionality implemented

Technicians work with varying pressures

# Fuel Pressure Sensor

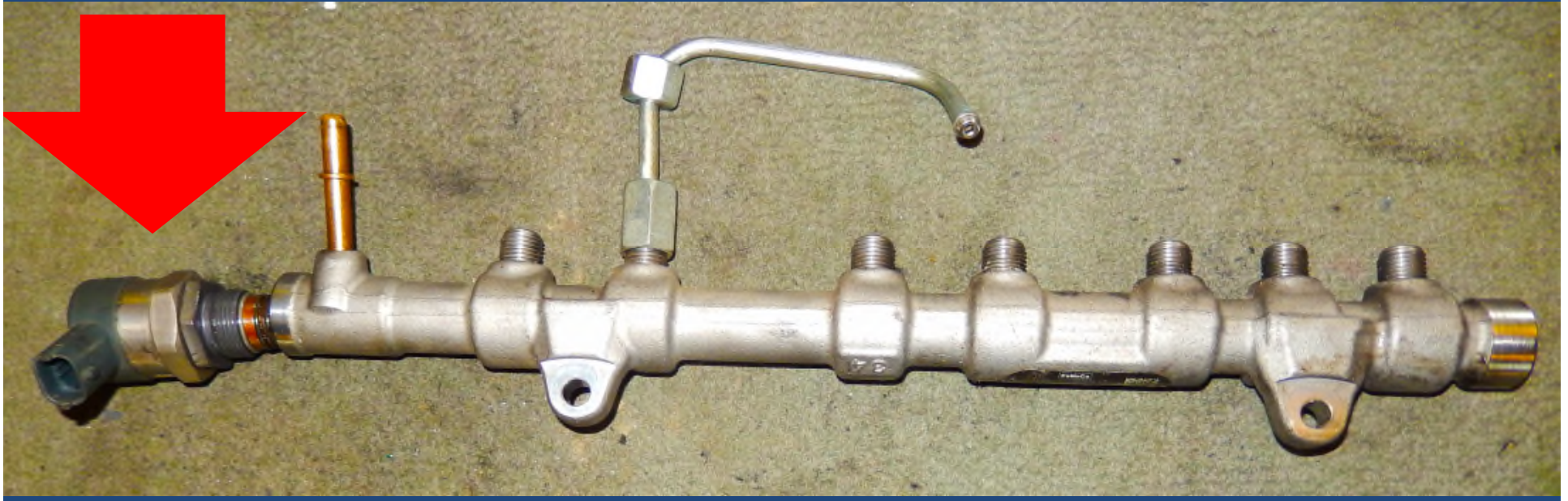
Mounted to the fuel rail directly or by a high pressure line

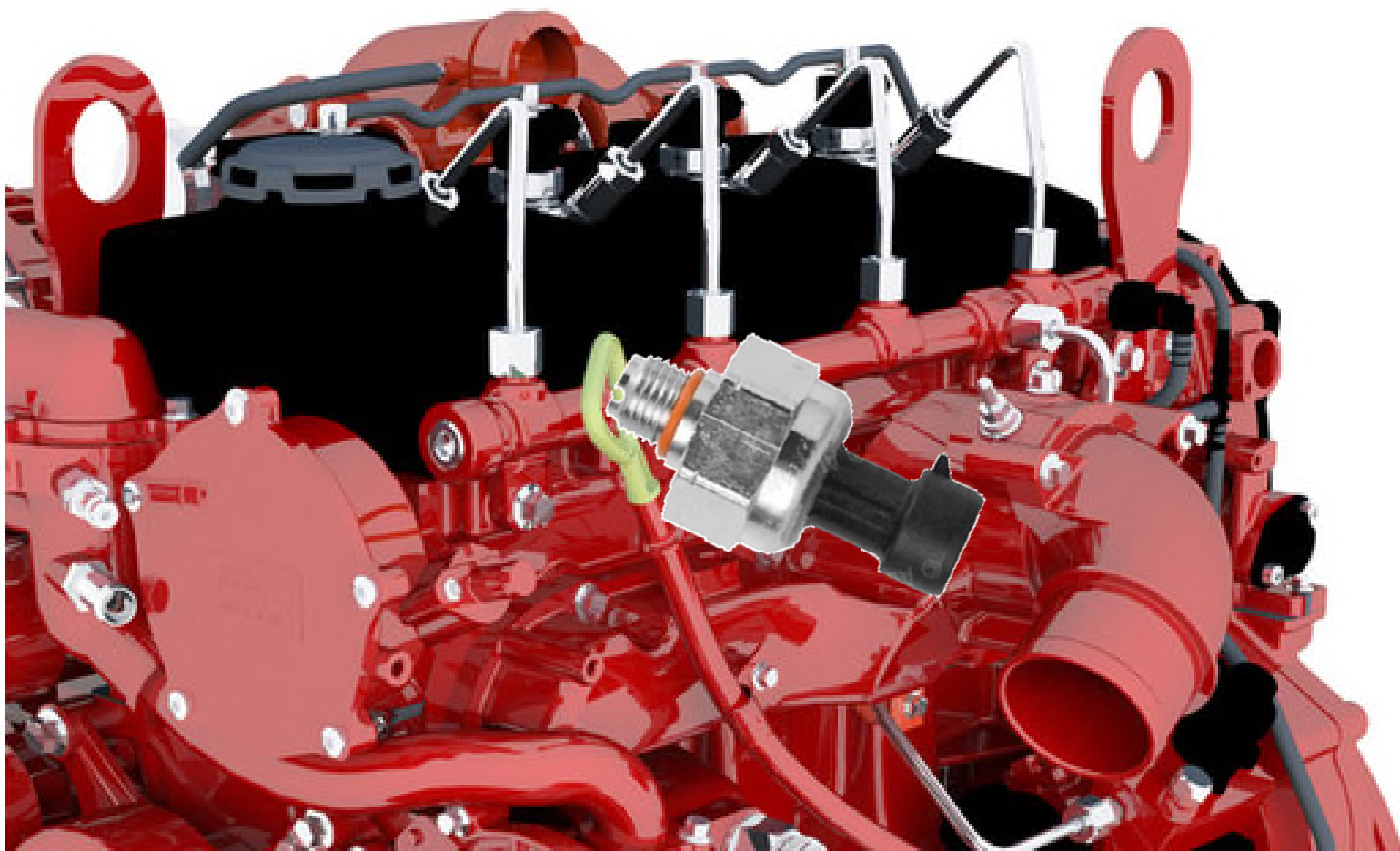
Measures the pressure in the rail

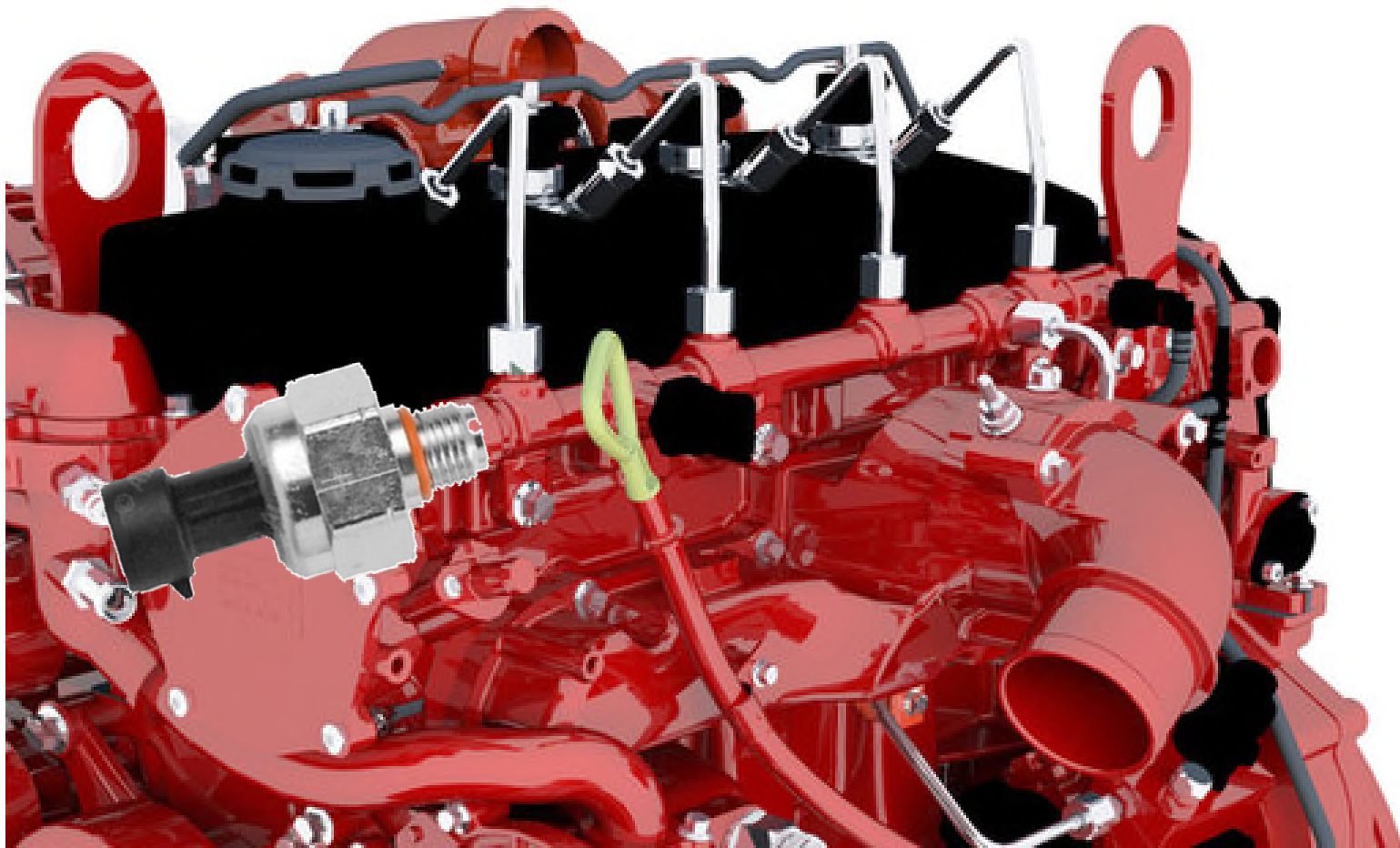


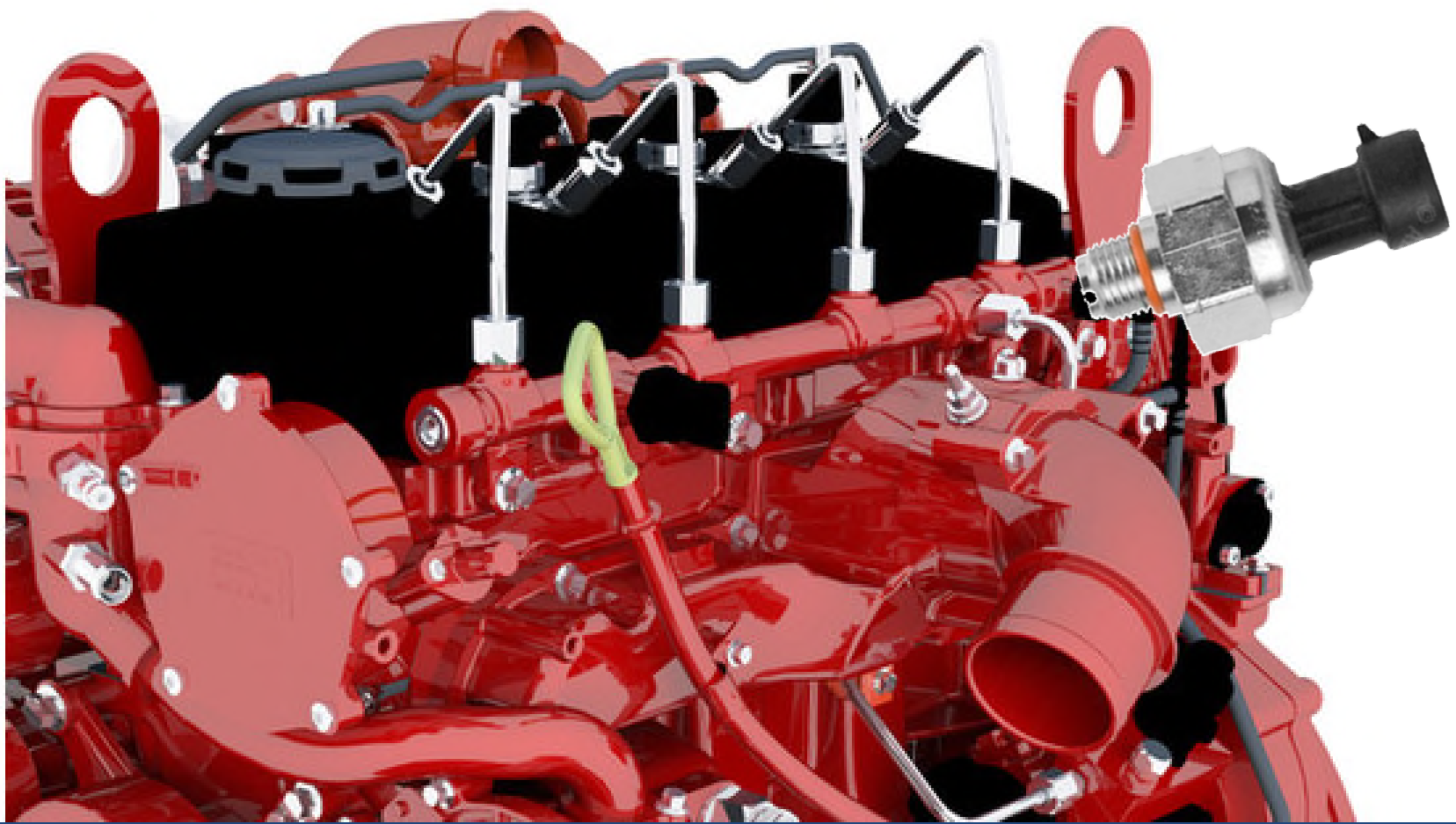
# Fuel Pressure Sensor

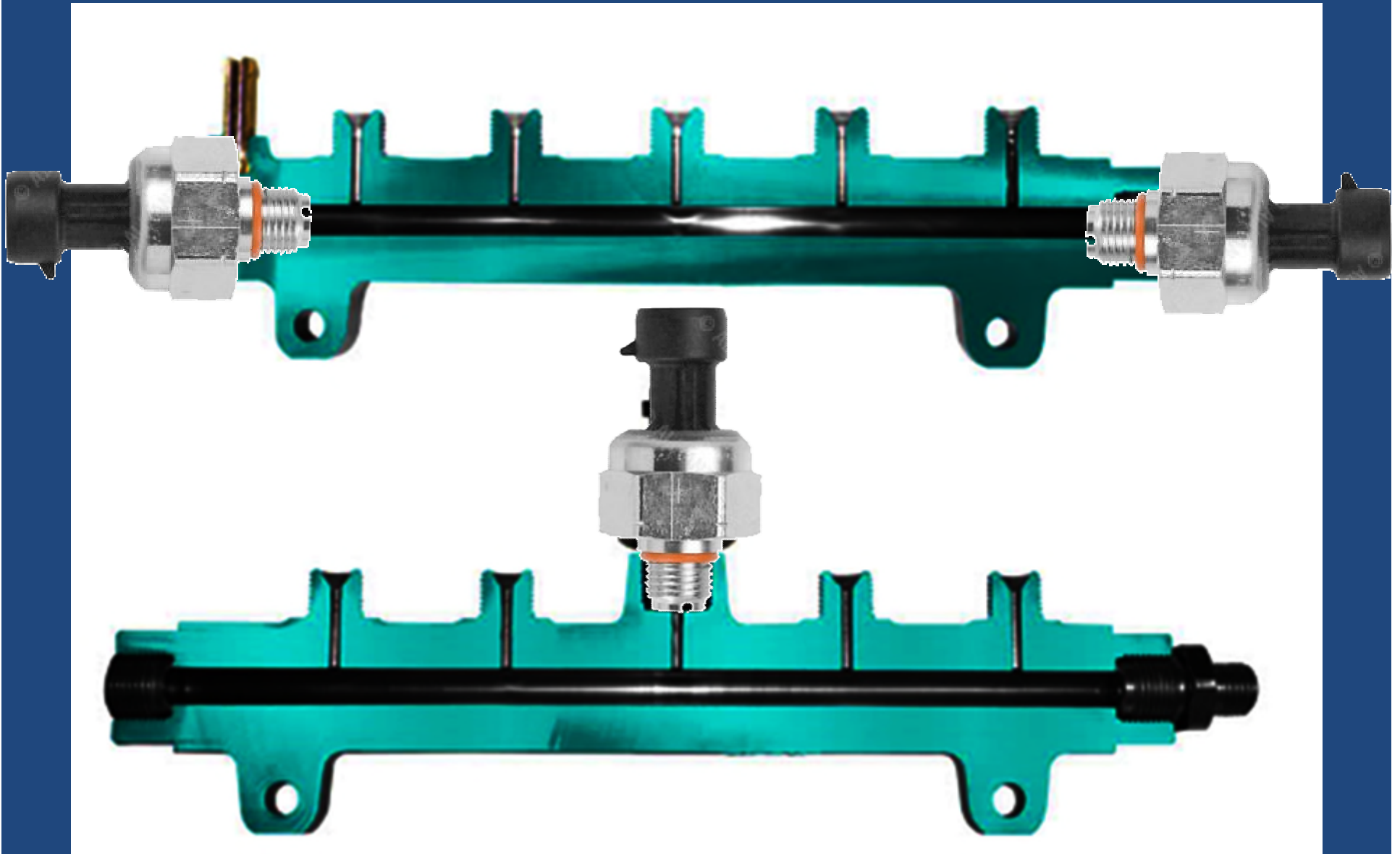
Used by the ECM as an input for the calculation for the % duty cycle applied to the fuel control solenoid











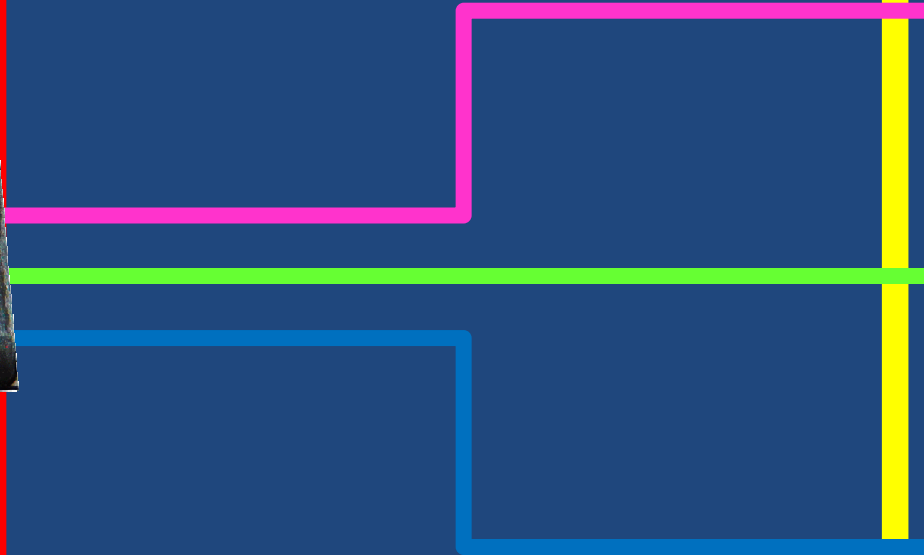
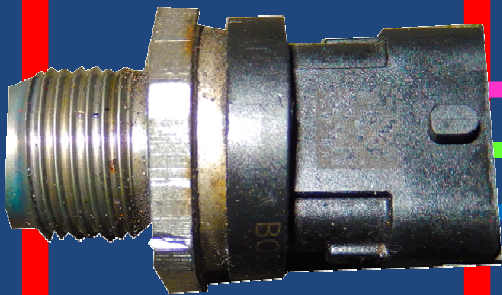
Sensor

ECM

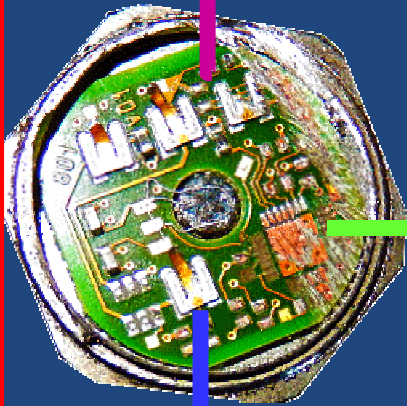
5V REF

Signal

Reference  
Low



Sensor

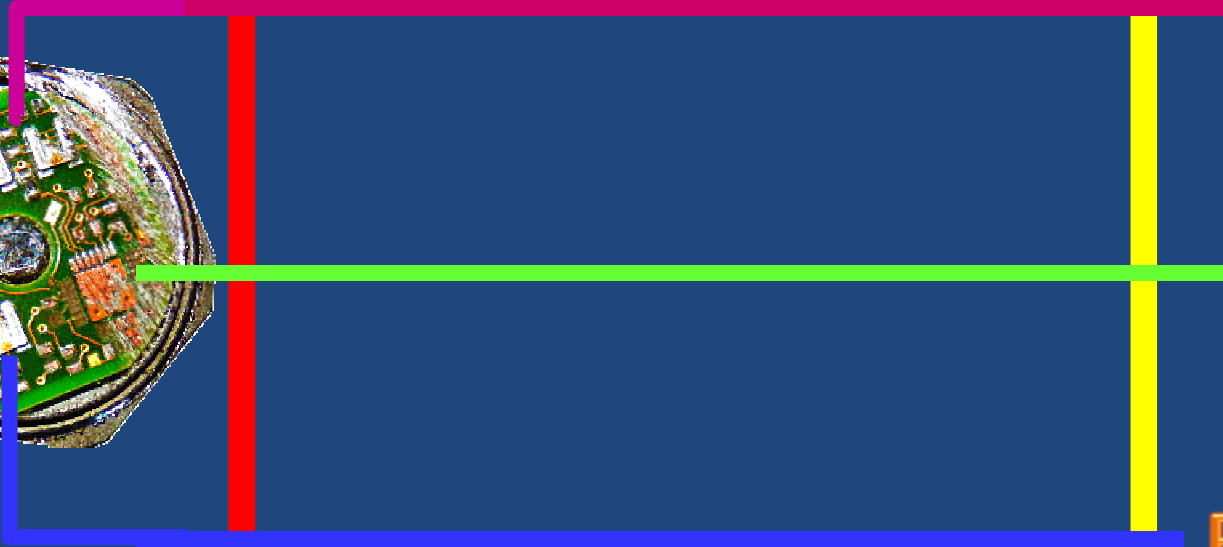


ECM

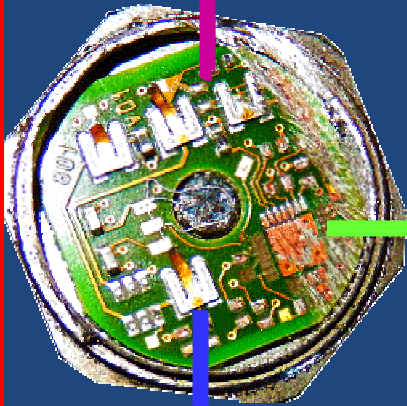
5V REF

Signal

Reference  
Low



Sensor



ECM

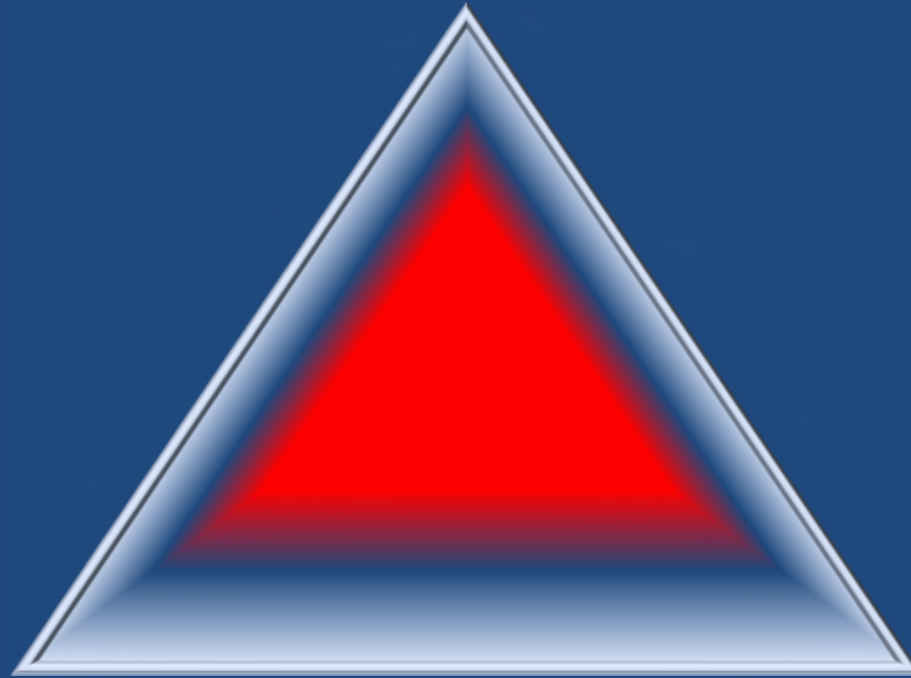


Reference  
Low

**So what do you  
do with this  
information?**

# Diagnositics

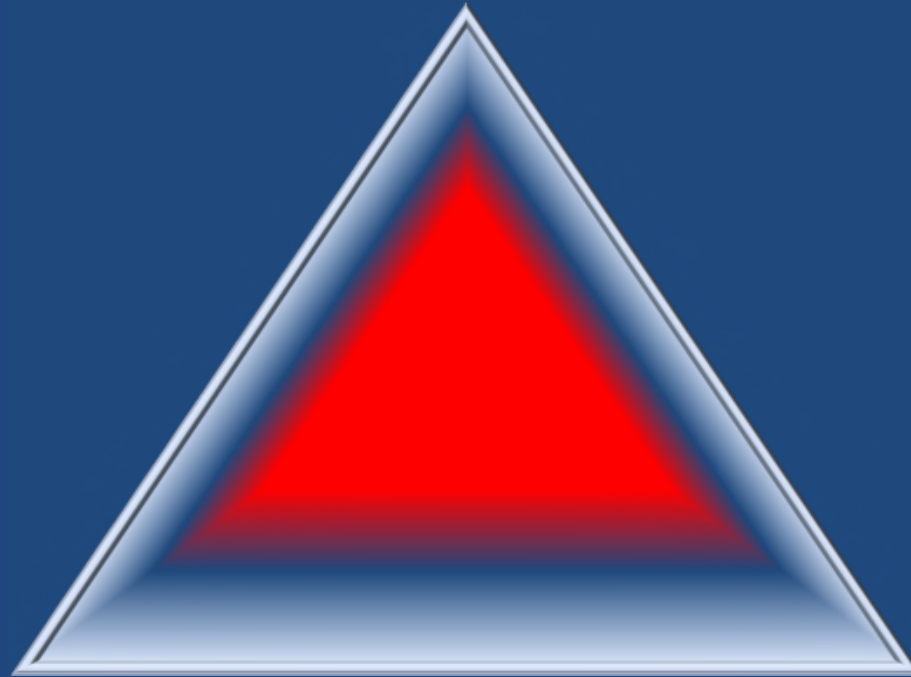
**Knowledge**



**Information**

**Equipment**

**Information**



**Equipment**

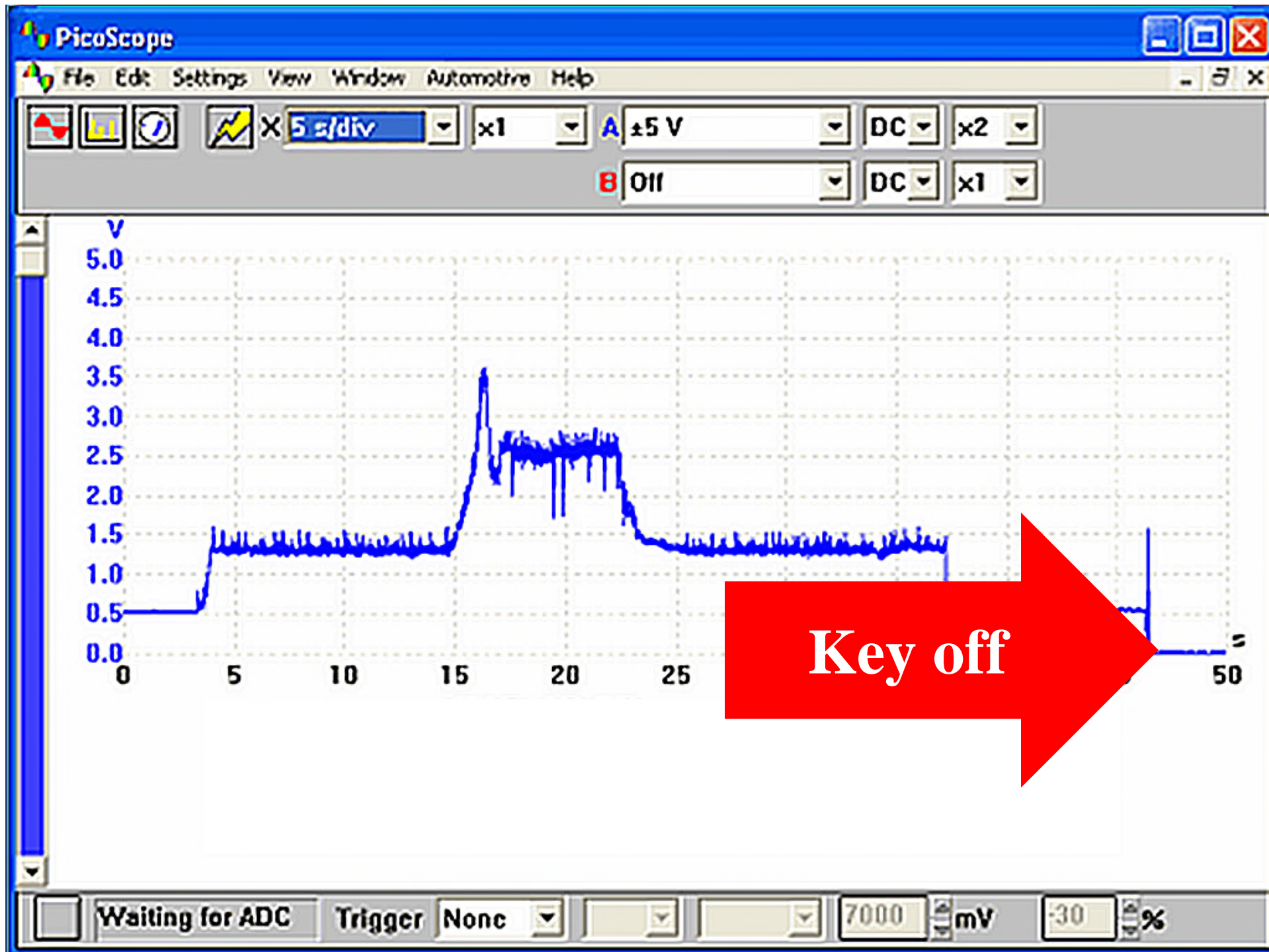
**Knowledge**

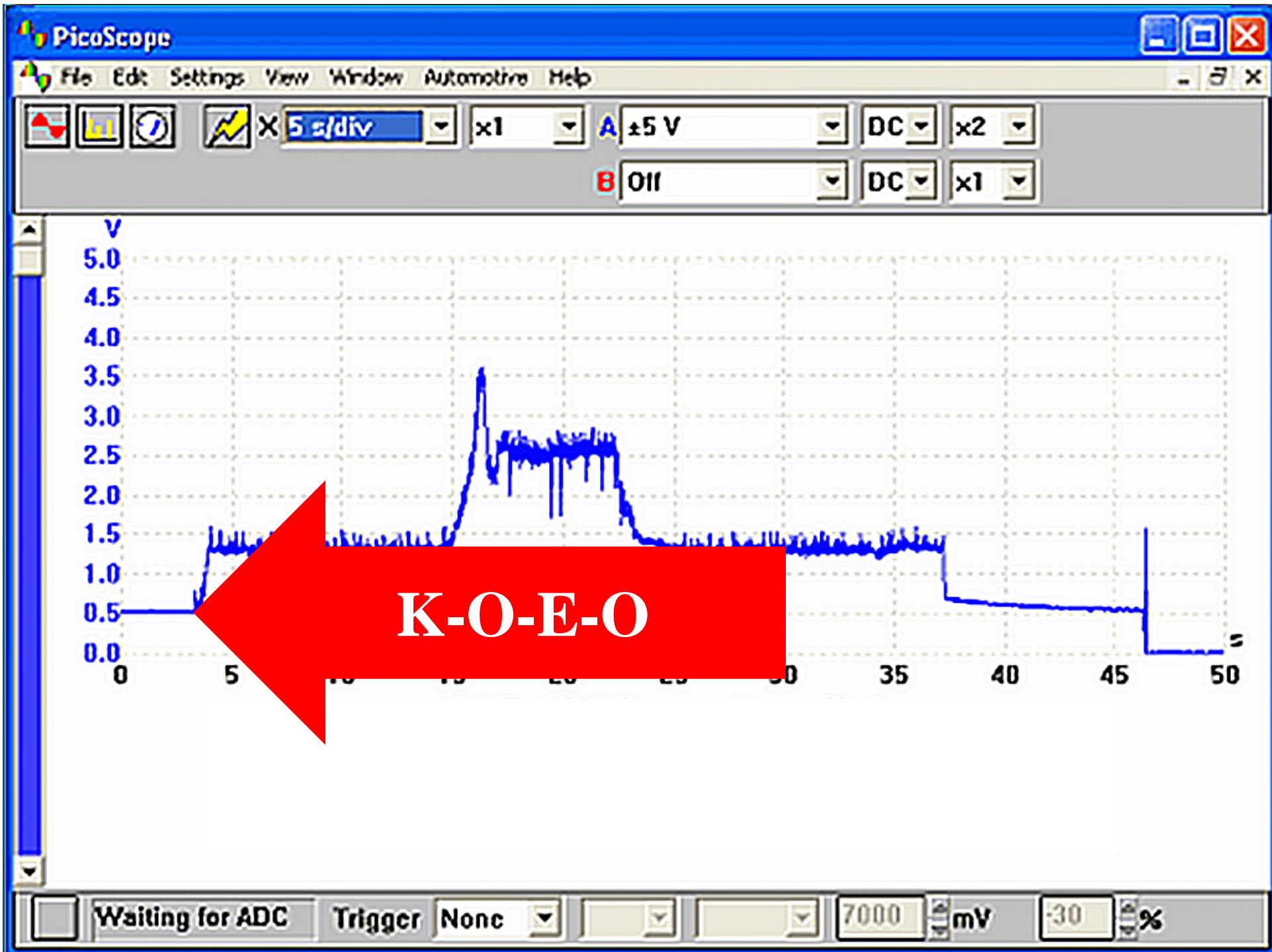
**Equipment**

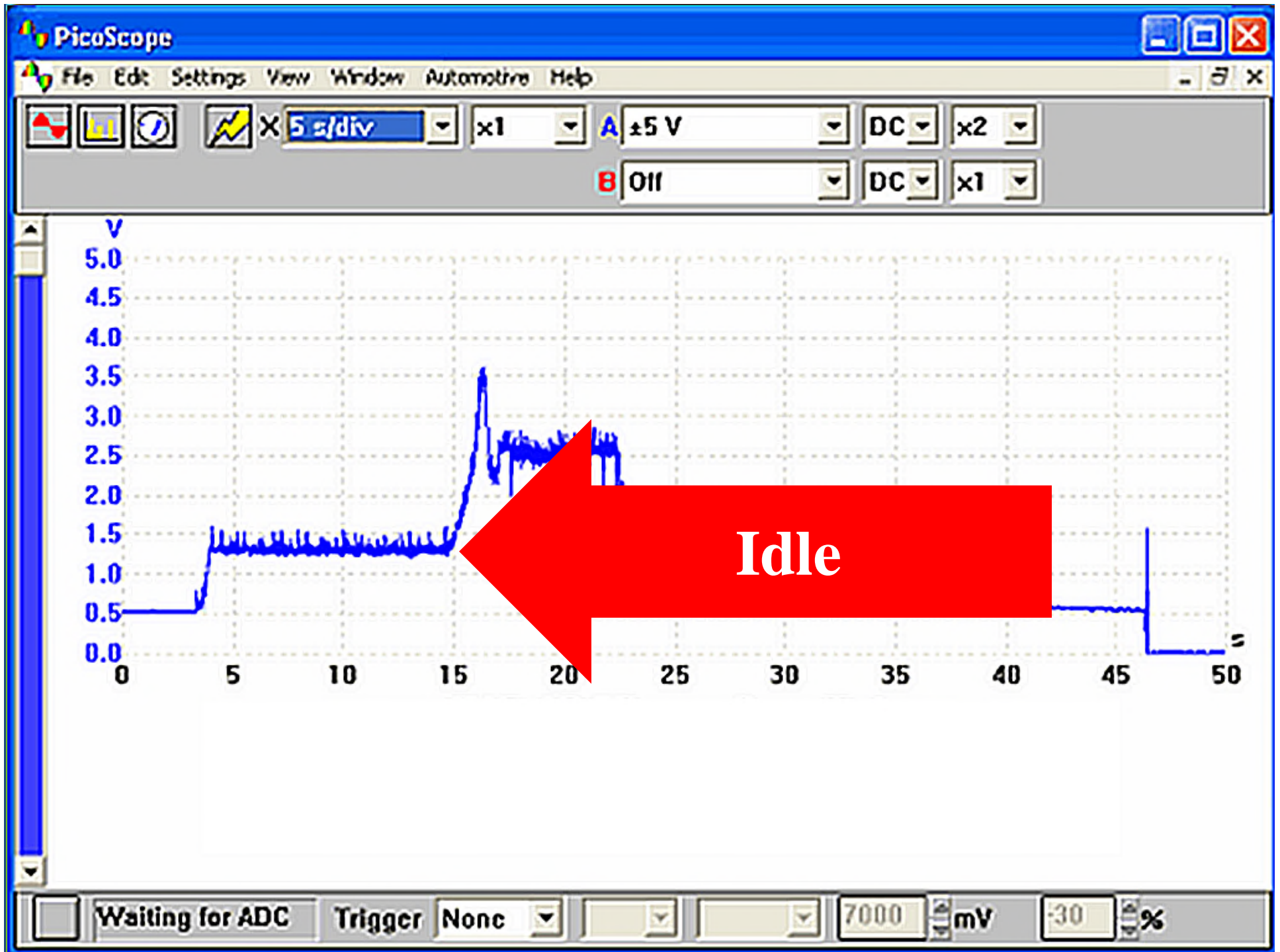


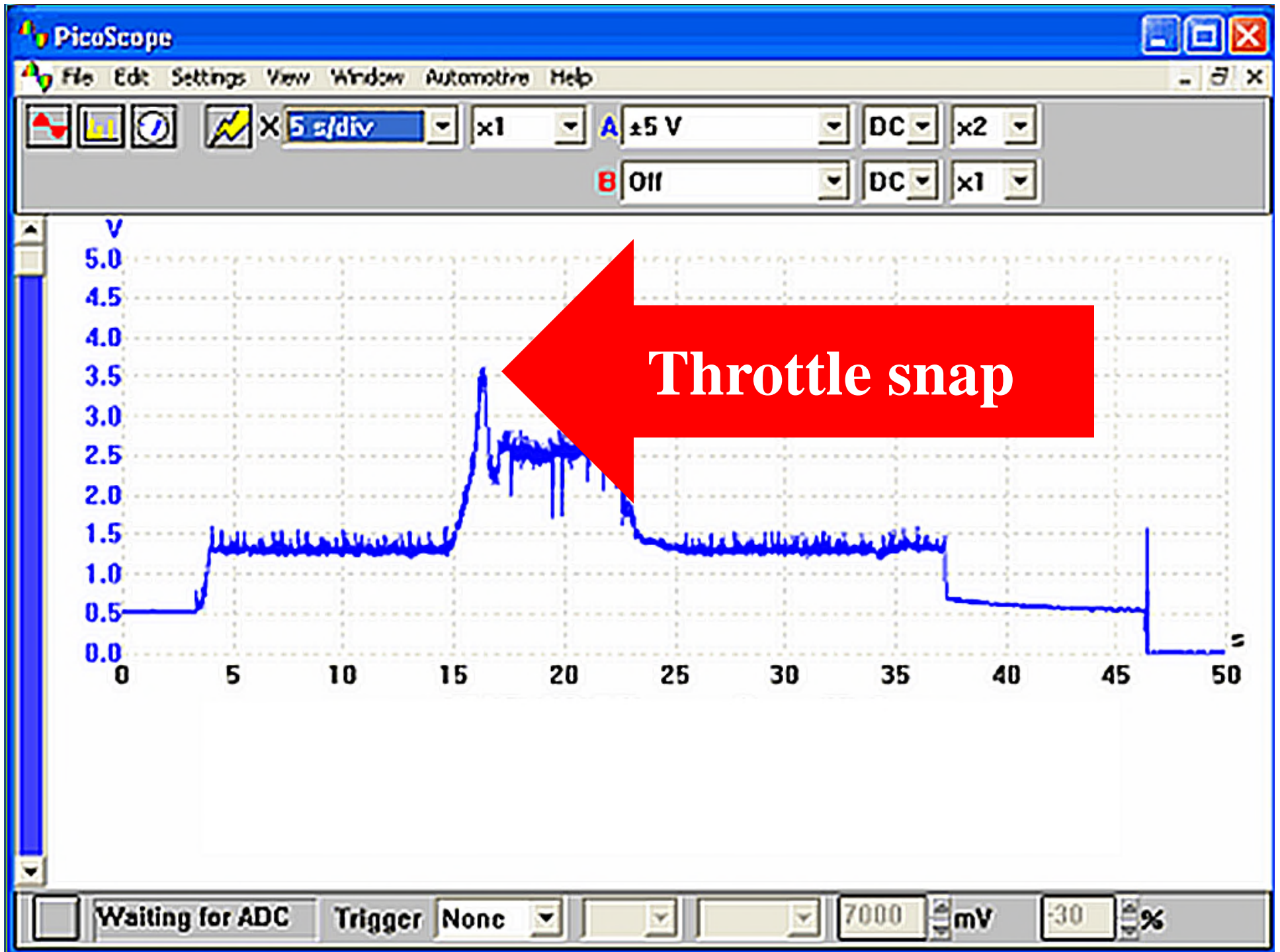
**Knowledge**

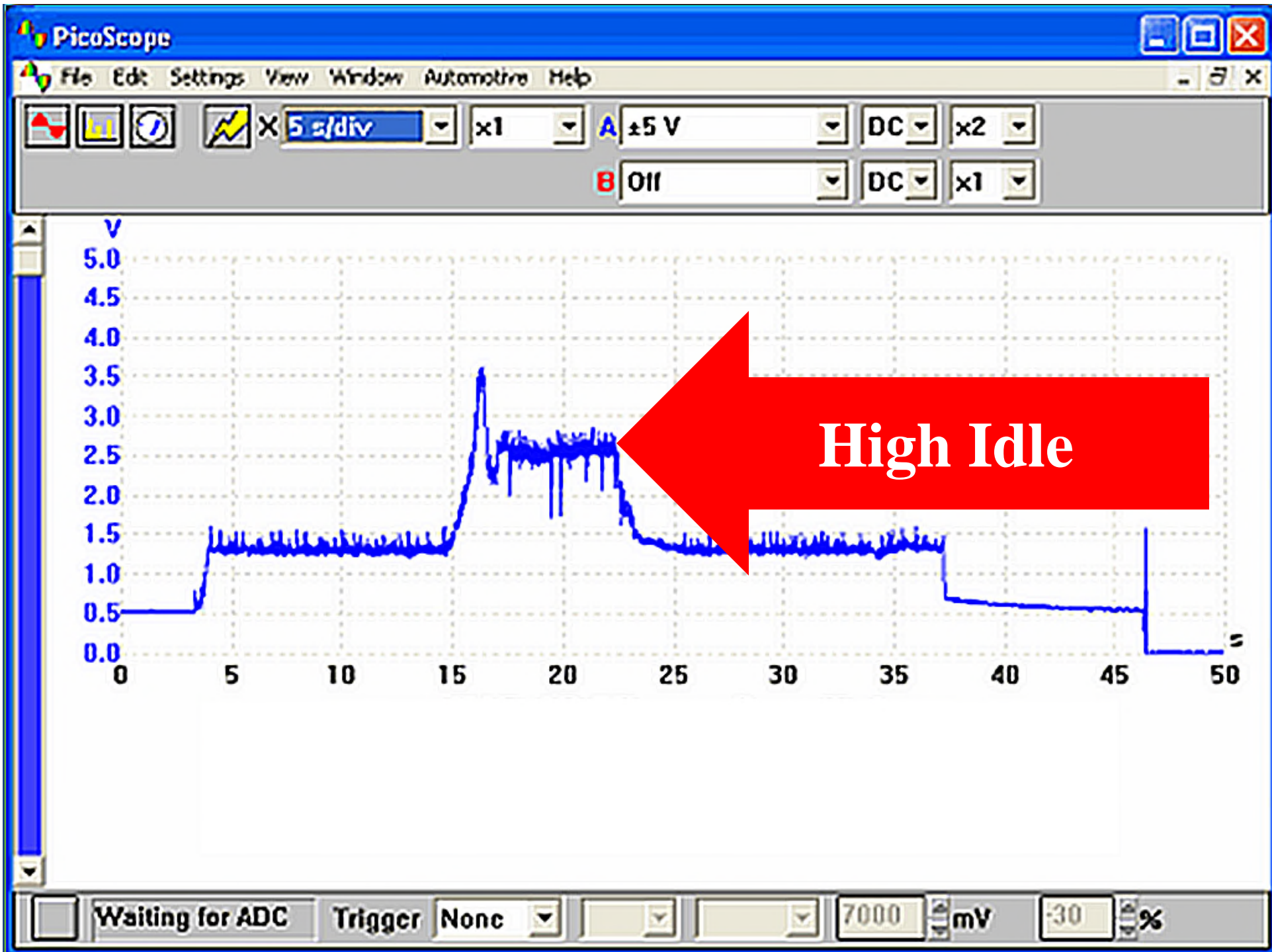
**Information**

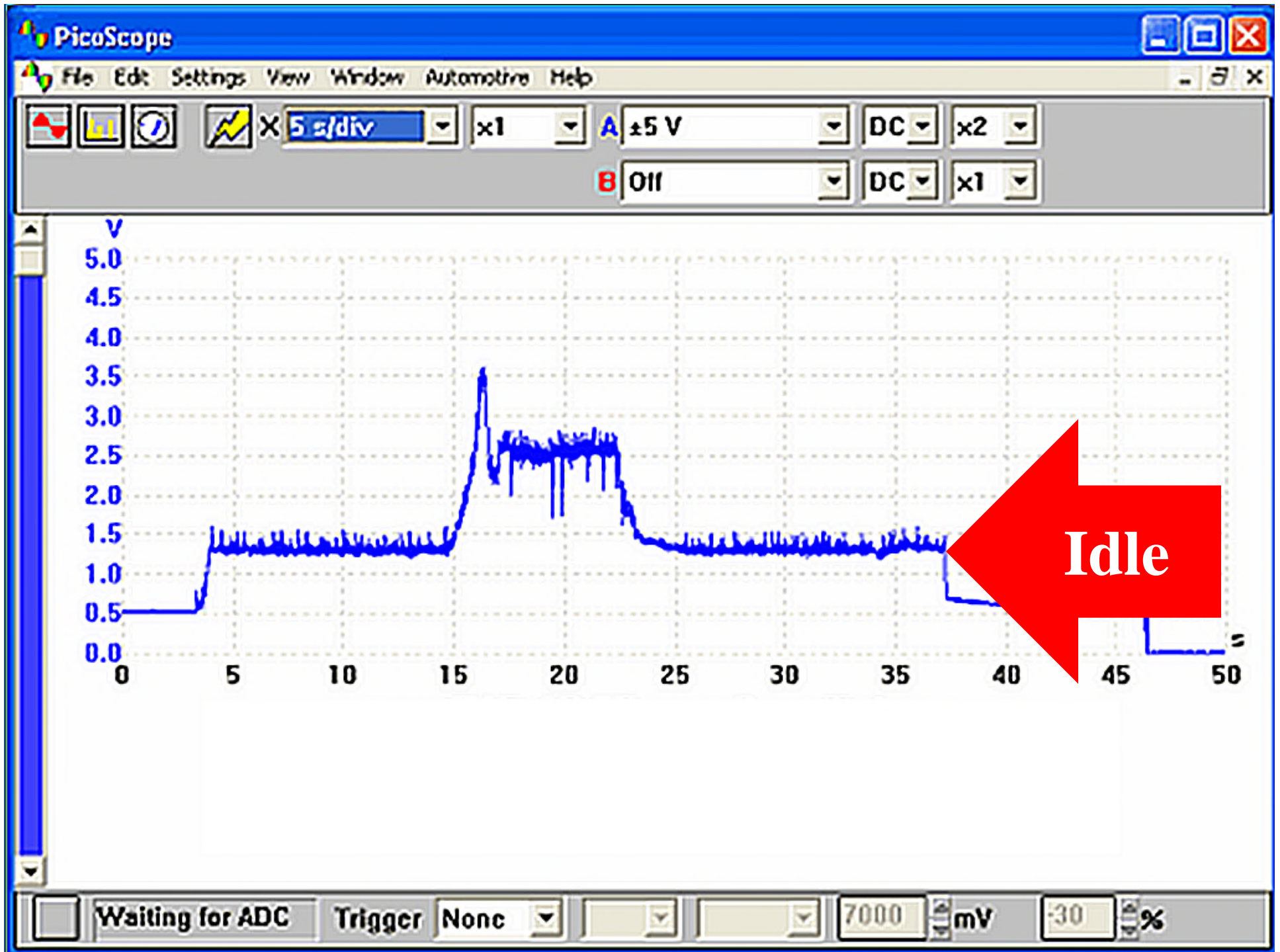


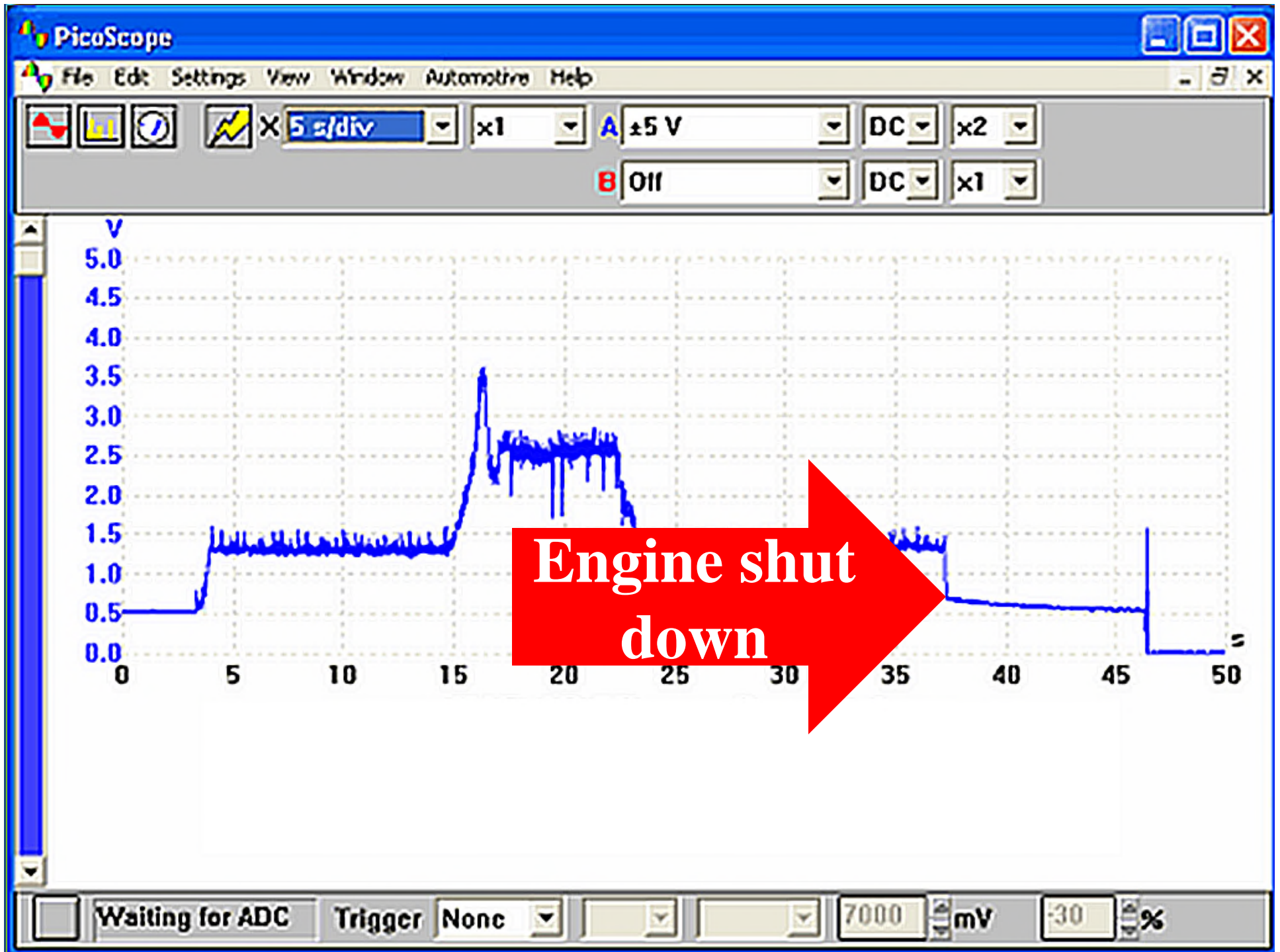


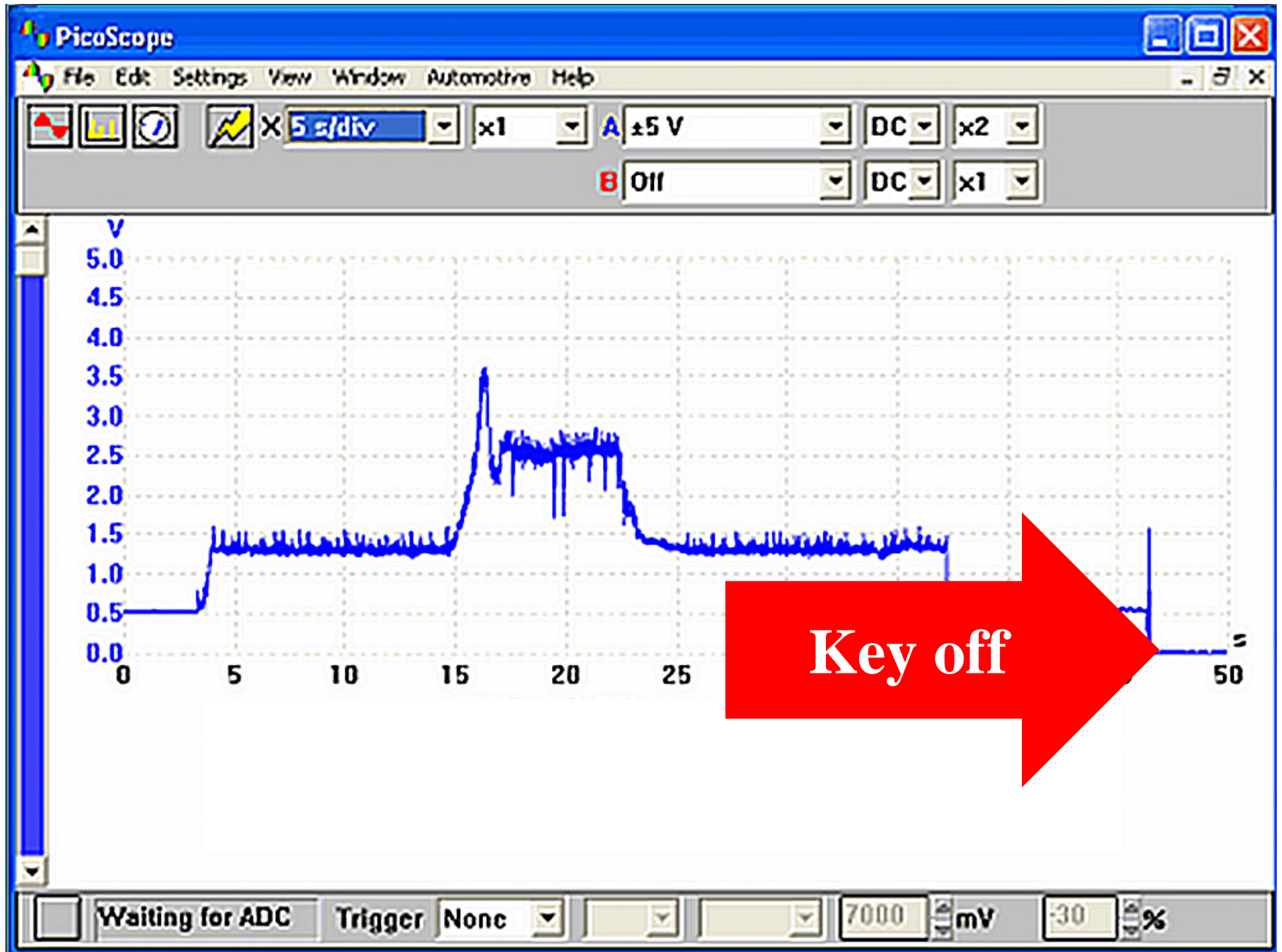


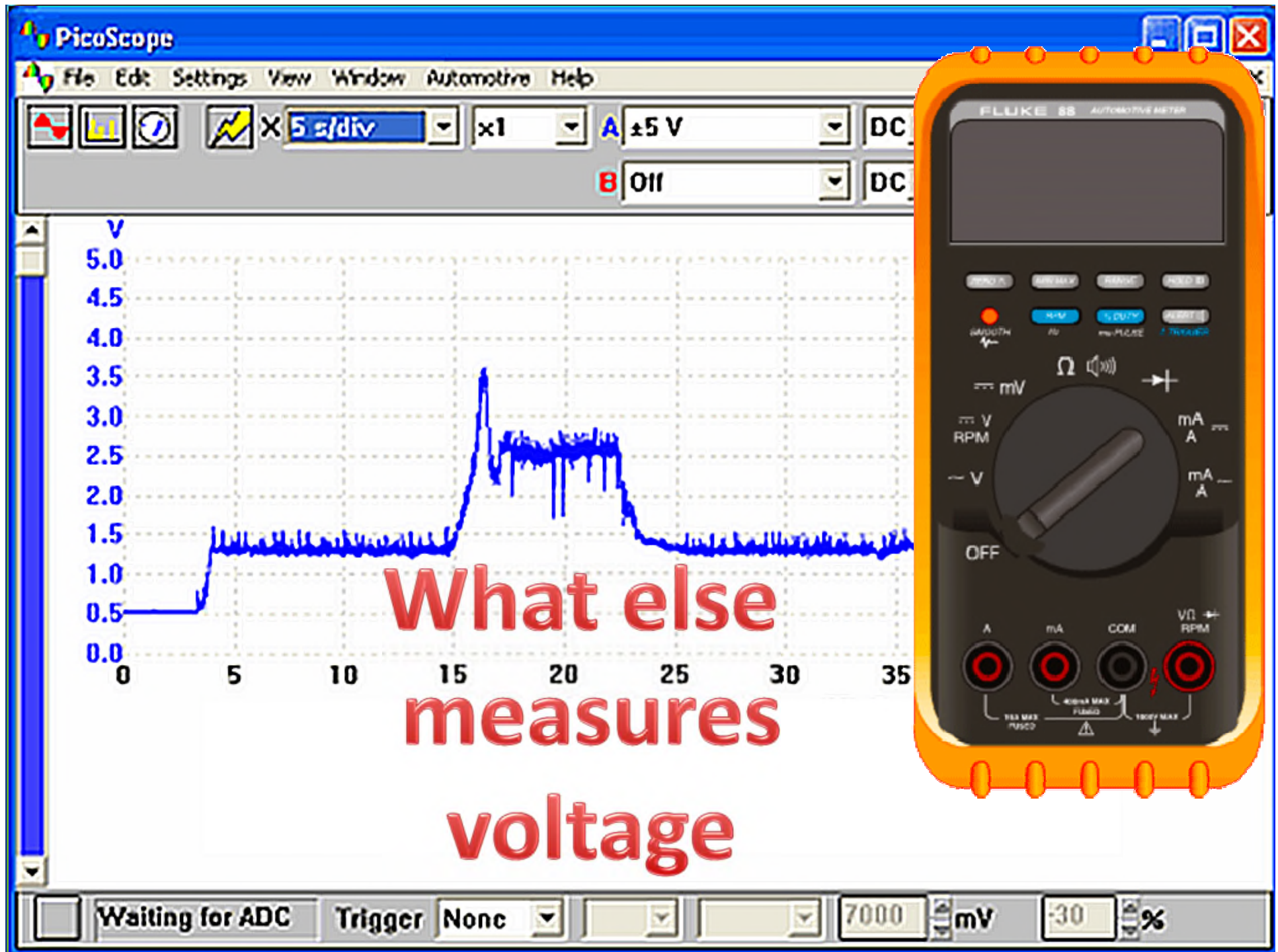


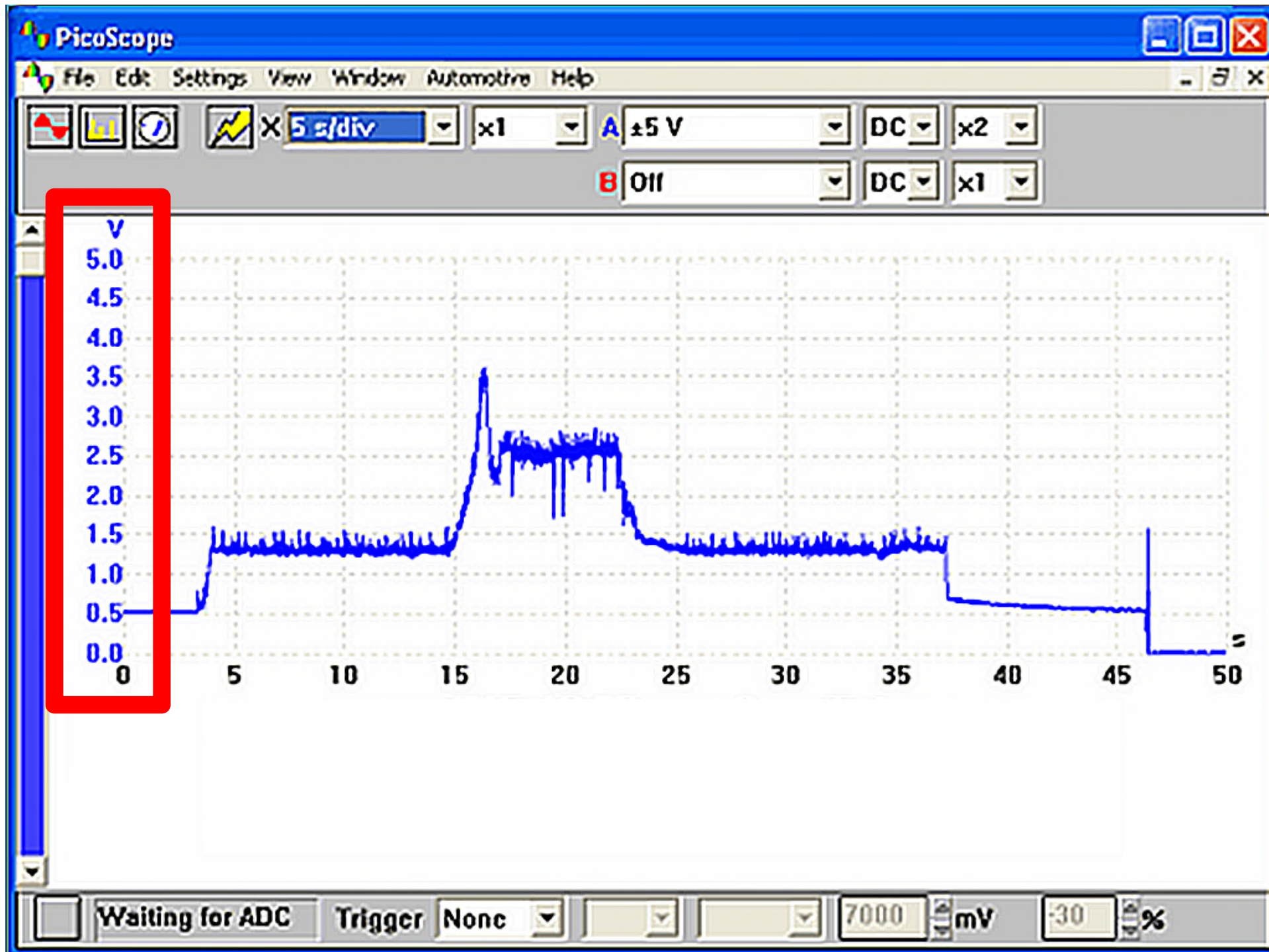




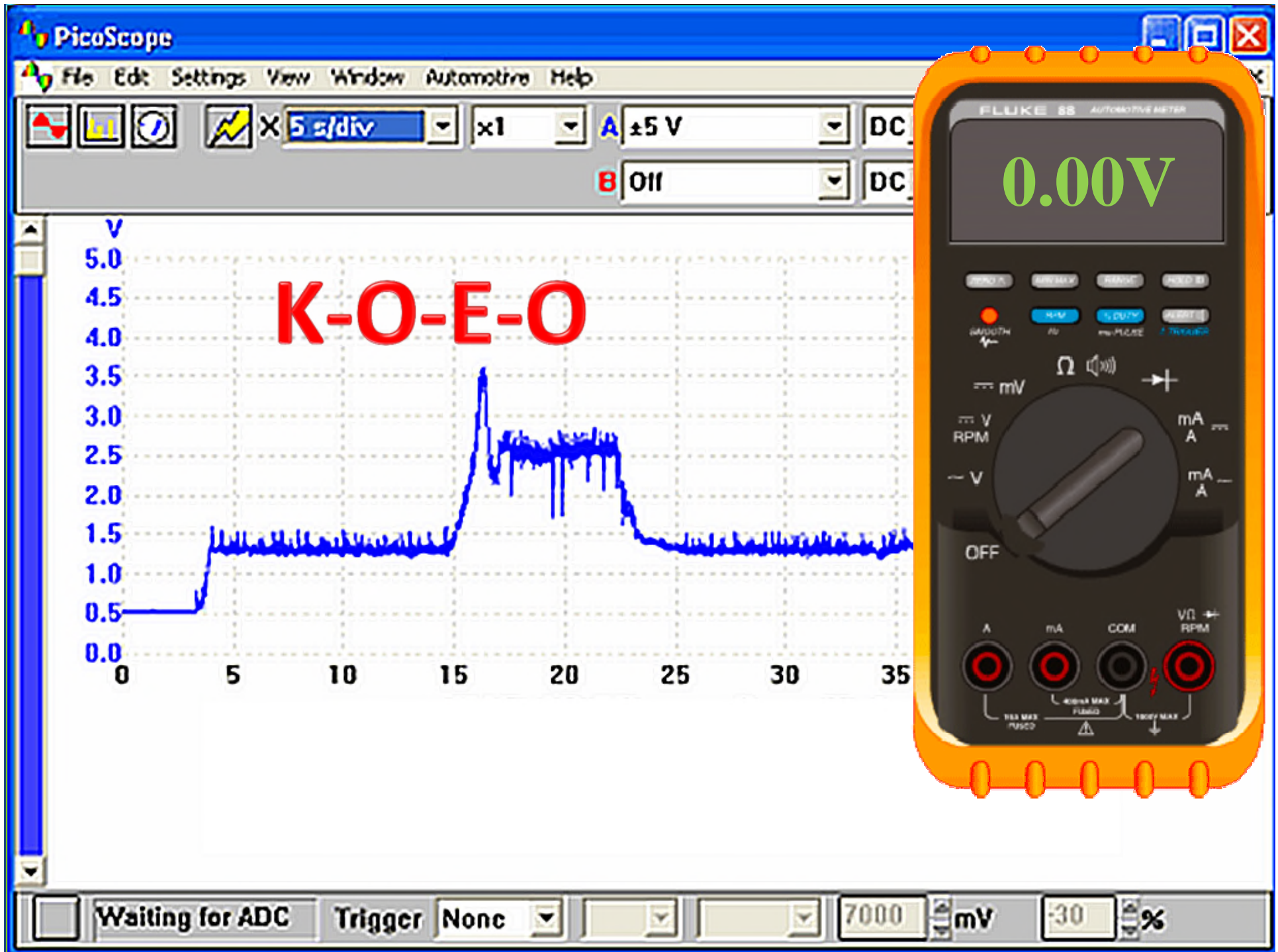


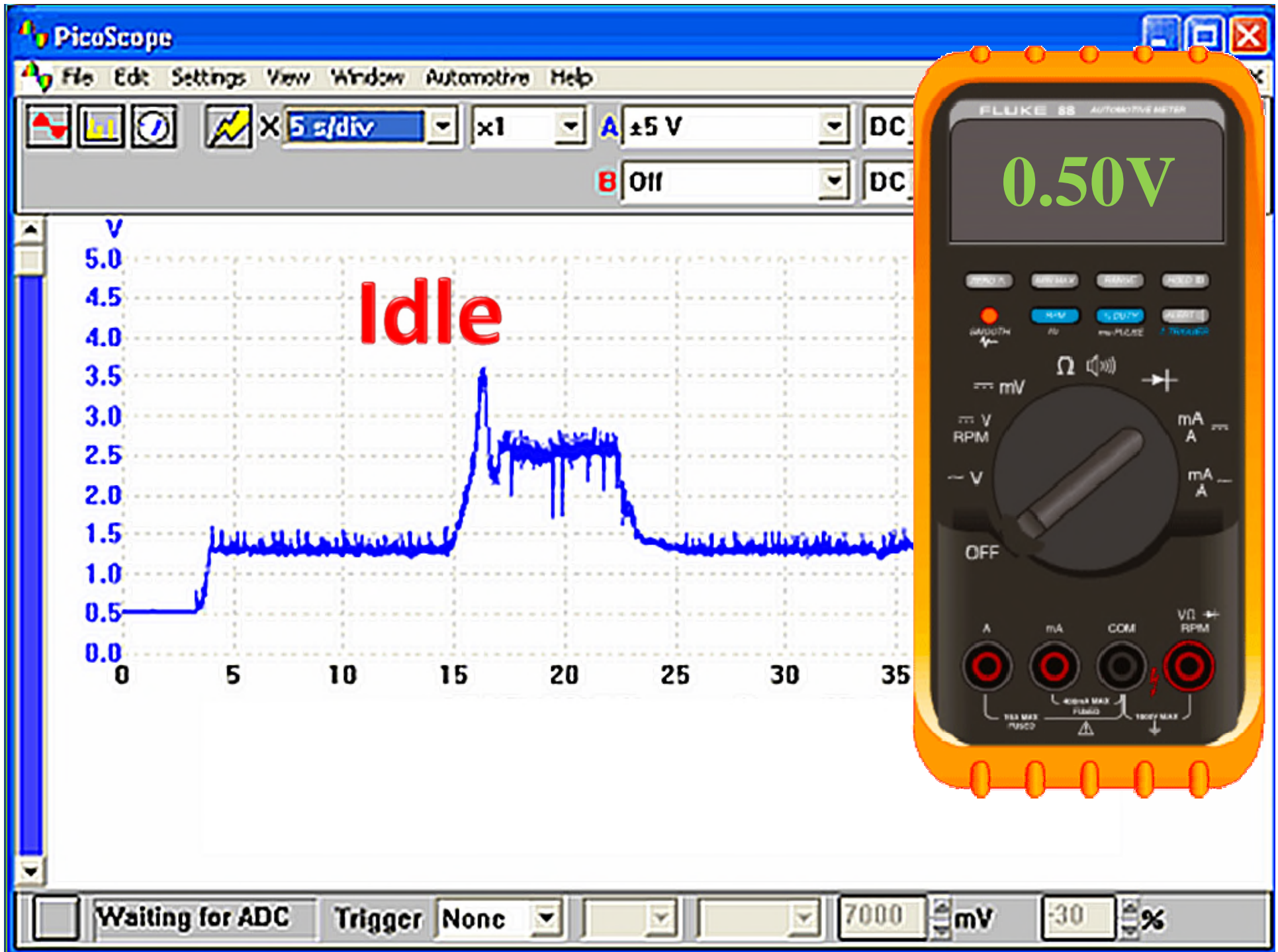


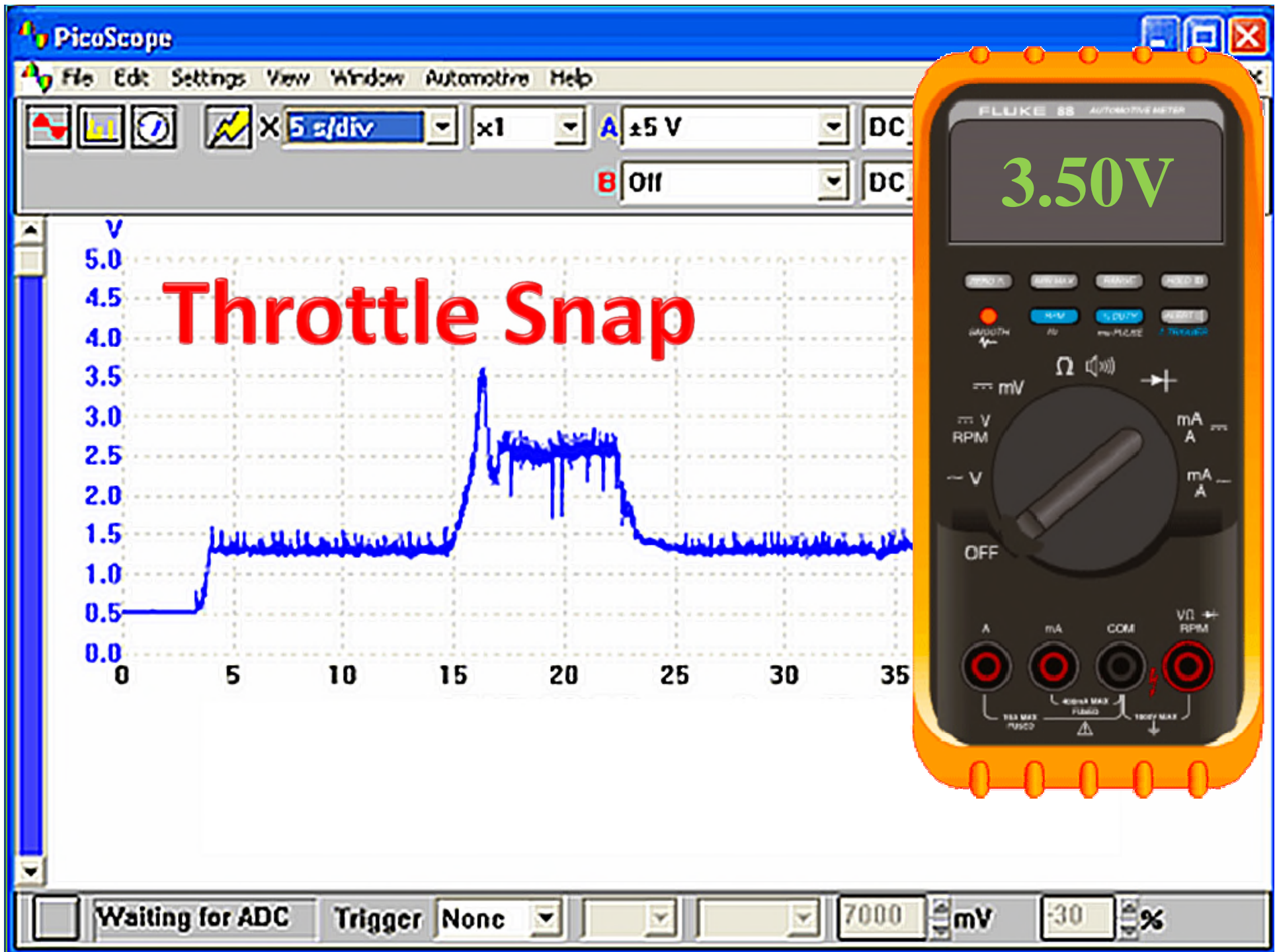


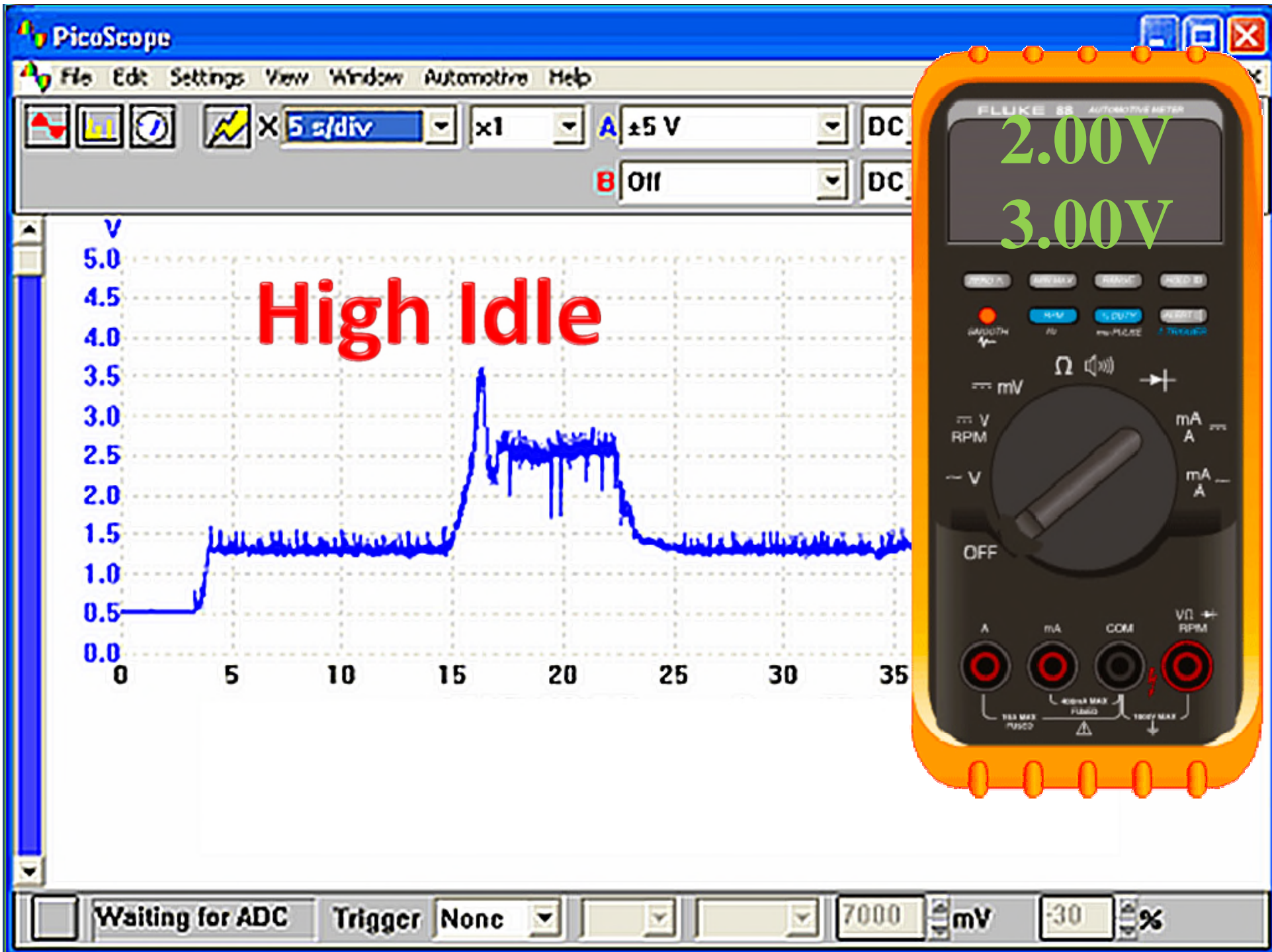


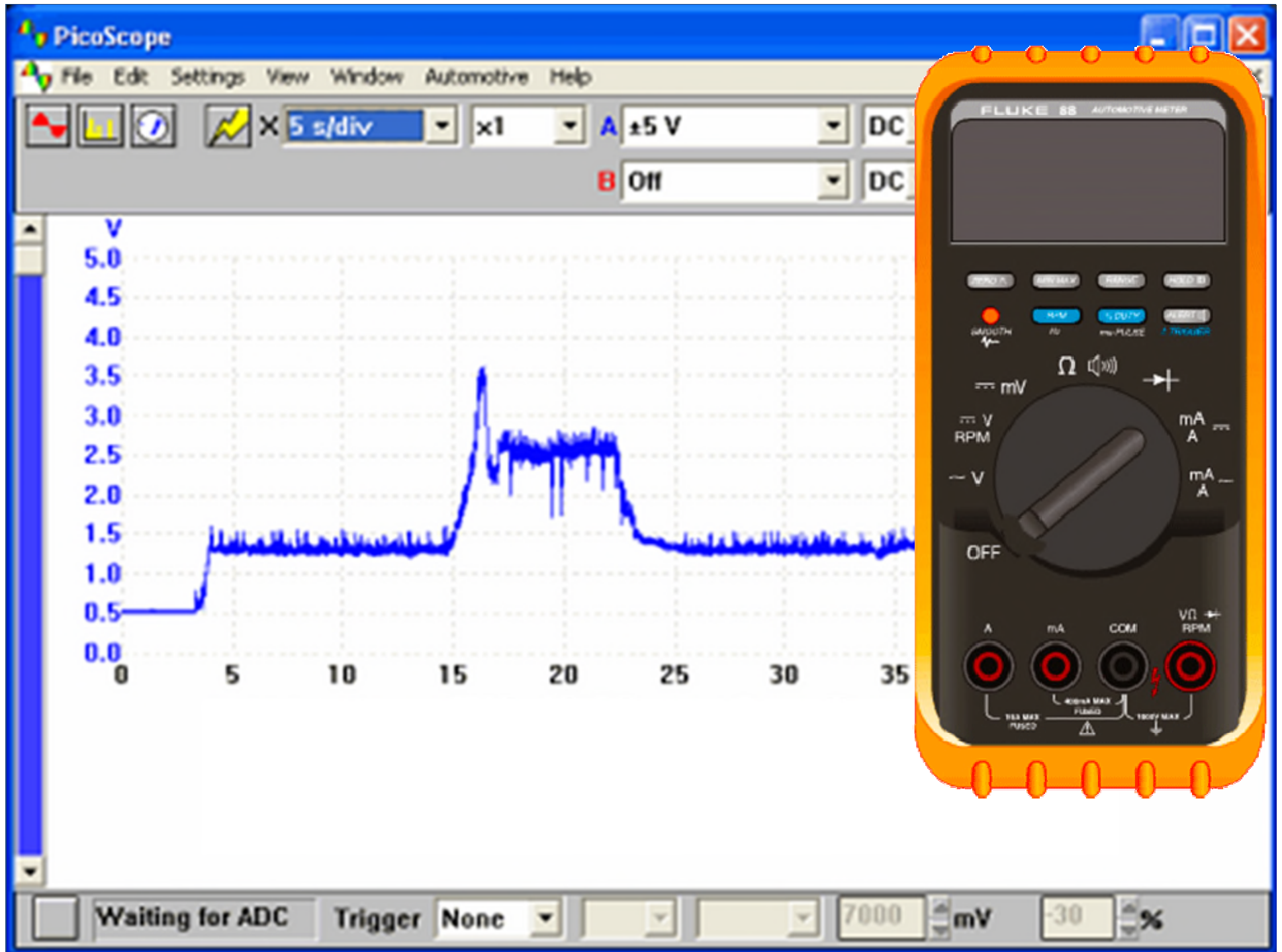






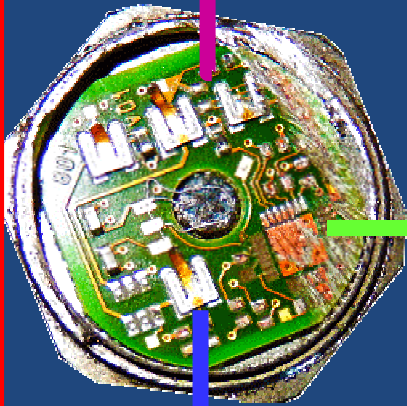






# Diagnostics

Sensor



ECM

5V REF

Signal

Reference  
Low



Sensor



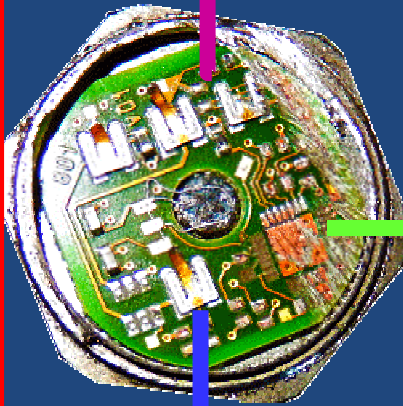
ECM

5V REF

Signal

Reference  
Low

5.00 Volts  
4.9 to 5.1 Volts



Sensor



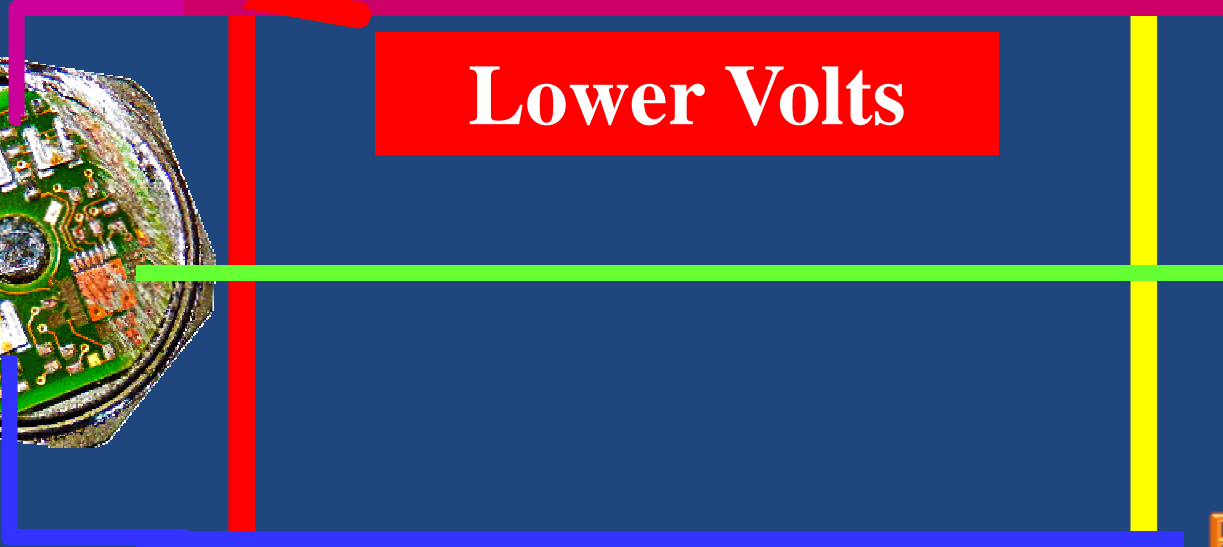
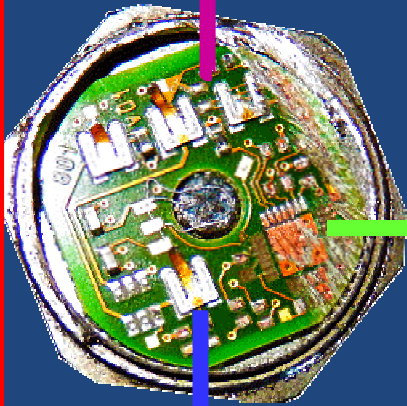
ECM

5V REF

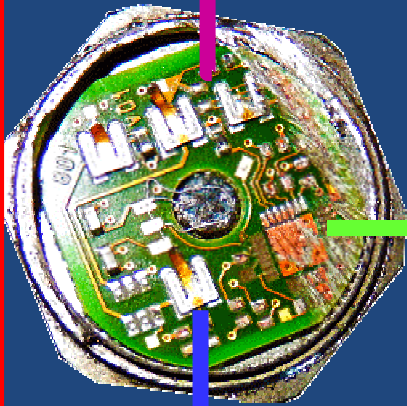
Signal

Reference  
Low

Lower Volts



Sensor



Lower Volts

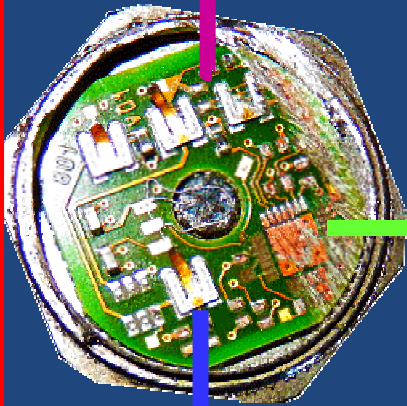
ECM

5V REF

Signal

Reference  
Low

Sensor



5.00 Volts  
4.9 to 5.1 Volts

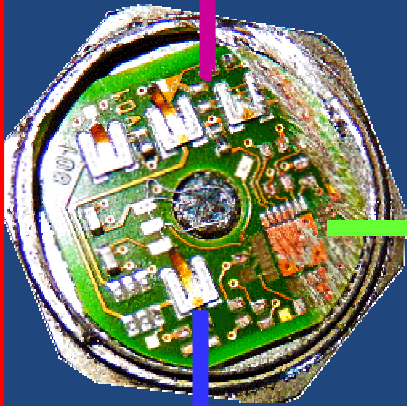
ECM

5V REF

Signal

Reference  
Low

Sensor



Lower Volts

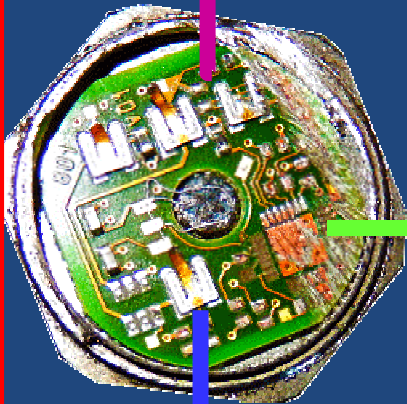
ECM

5V REF

Signal

Reference  
Low

Sensor



Lower Volts

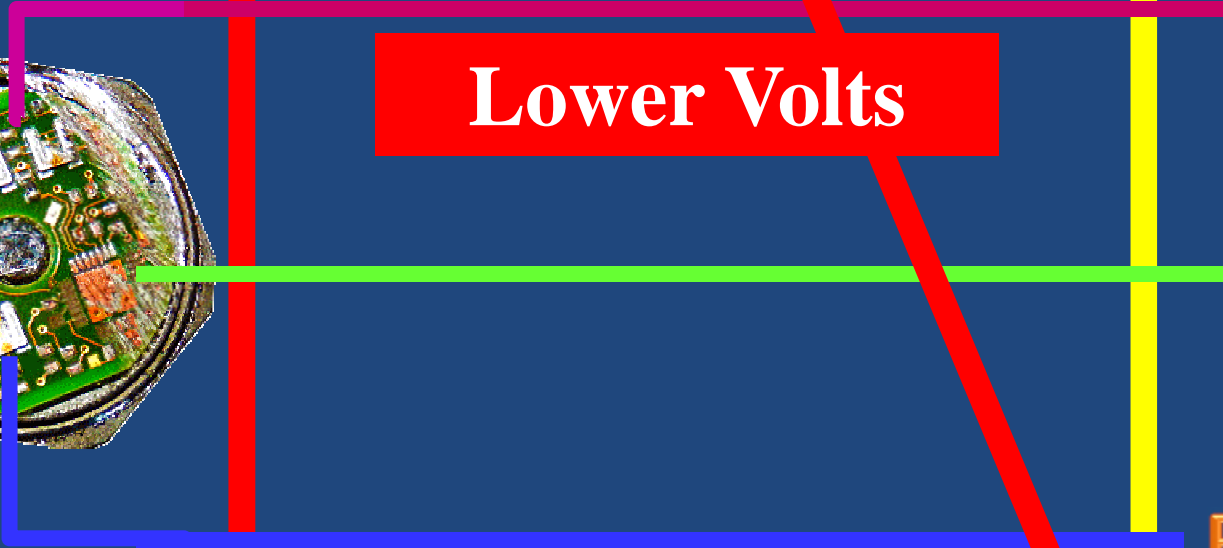
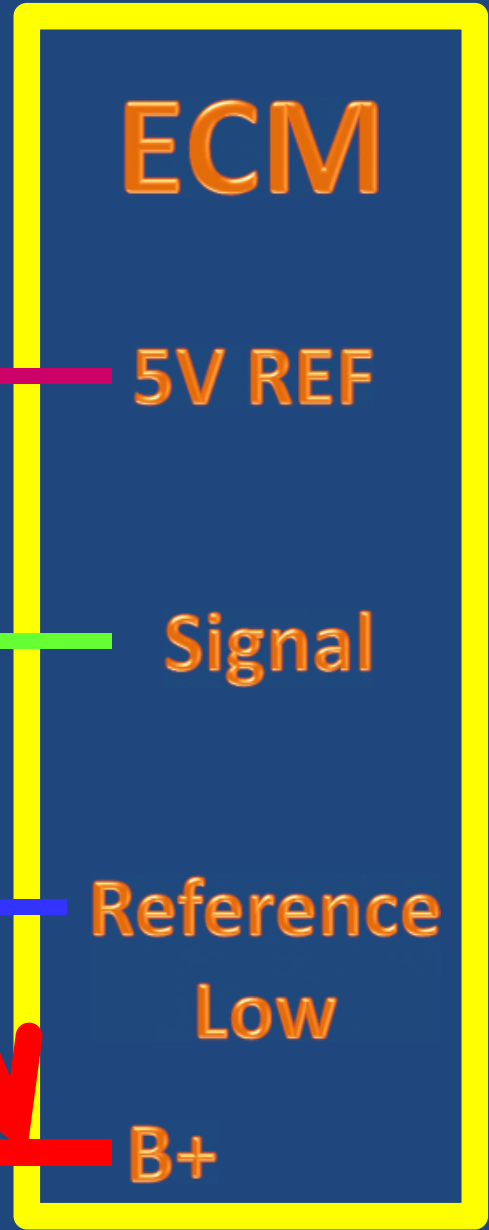
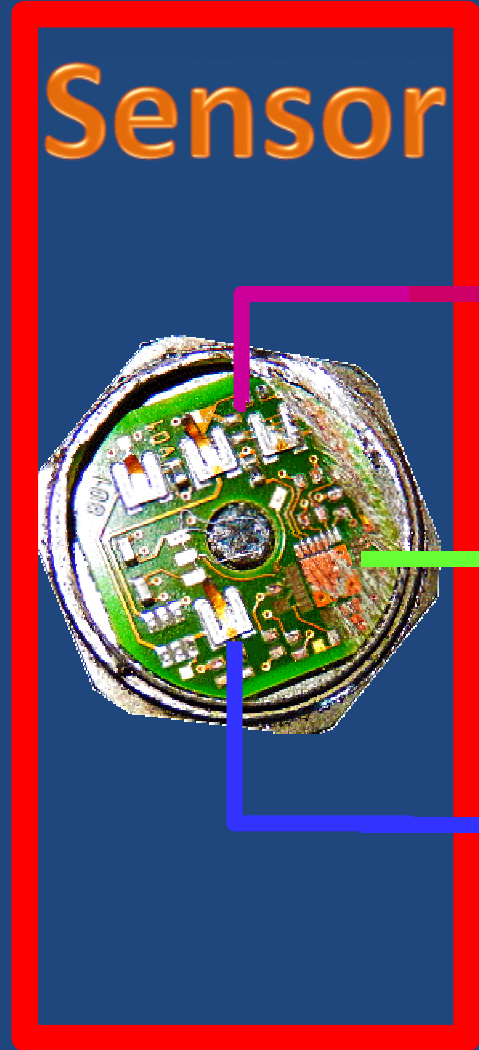
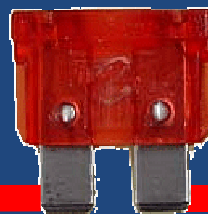
ECM

5V REF

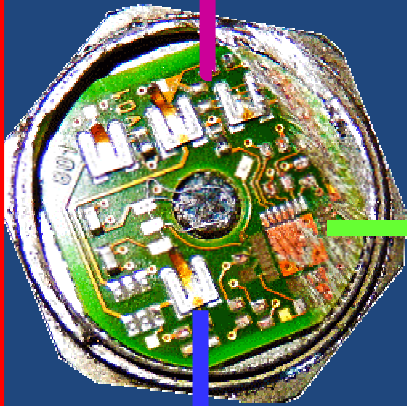
Signal

Reference  
Low

B+



Sensor



ECM

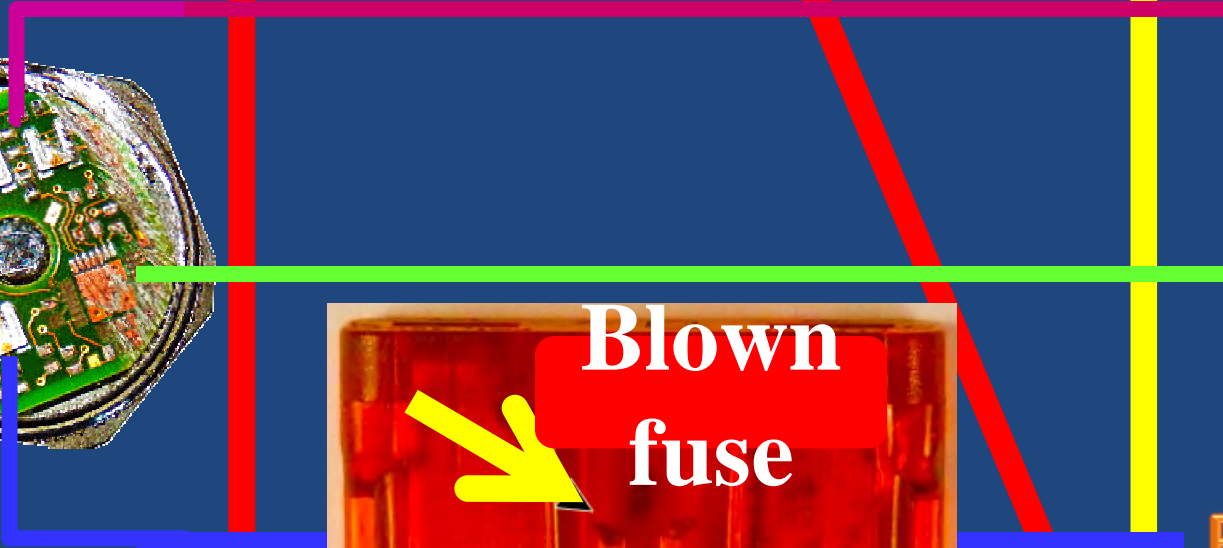
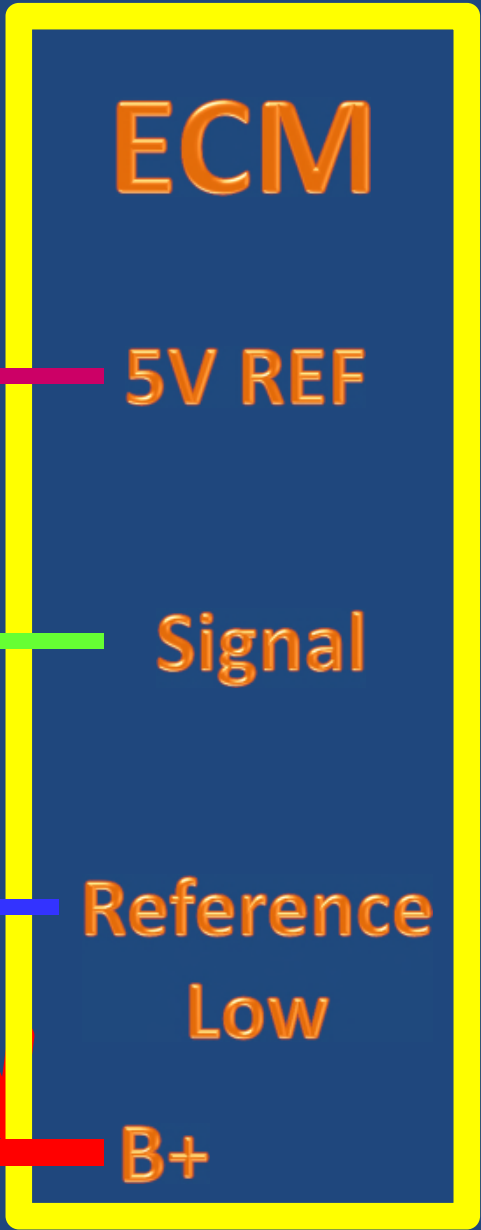
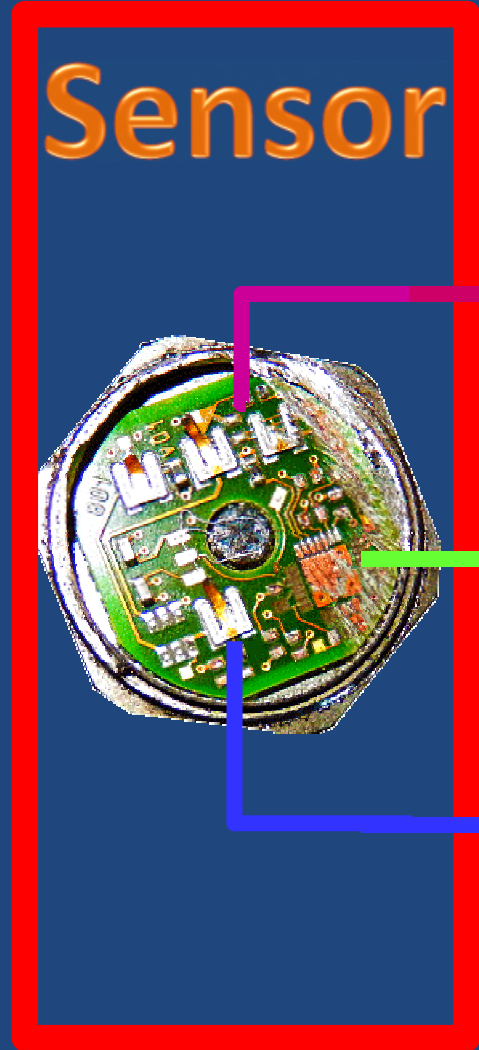
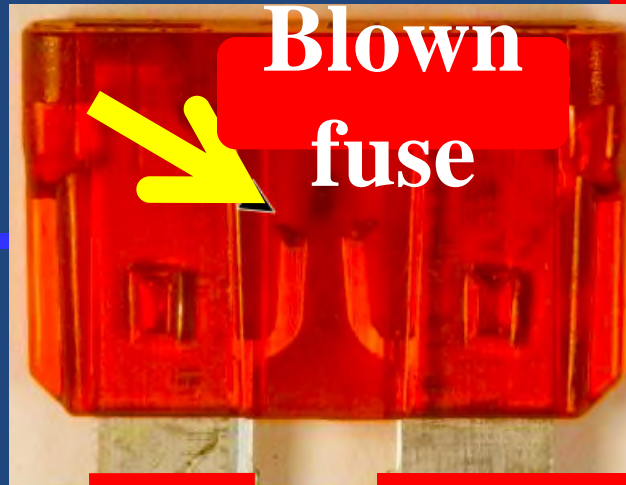
5V REF

Signal

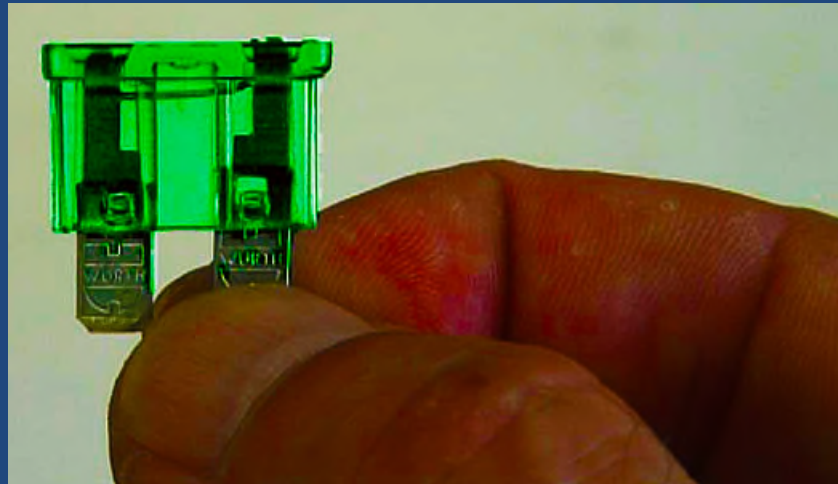
Reference  
Low

B+

Blown  
fuse



# What do you see on a DVOM With a Blown fuse?



- A. Zero Volts
- B. 5.00 Volts
- C. 2.50 Volts
- D. Transient Voltage

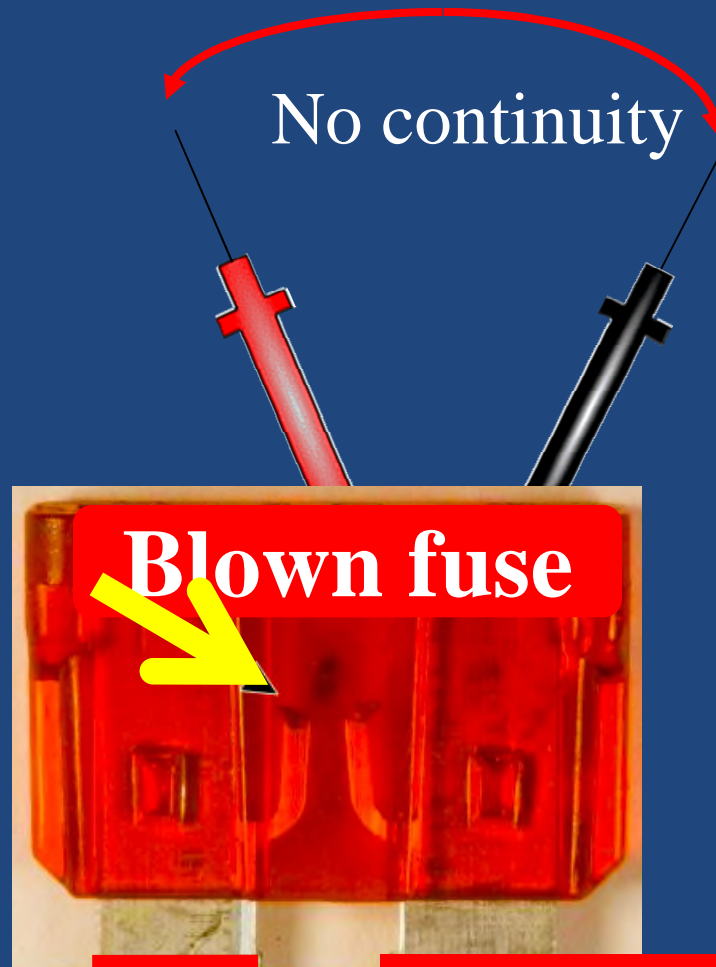
# This represents an electrical open circuit

Transient voltage  
(Floating around)



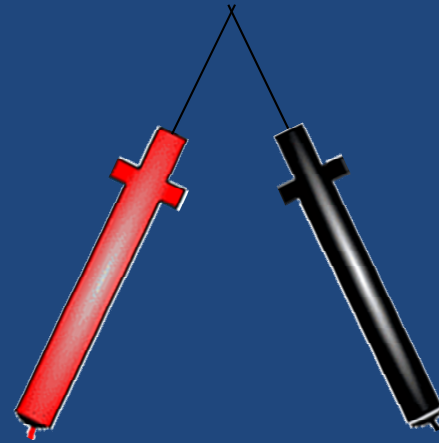
# An open circuit

Transient voltage  
(Floating around)

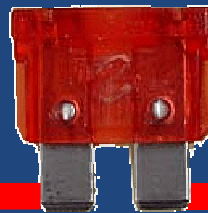
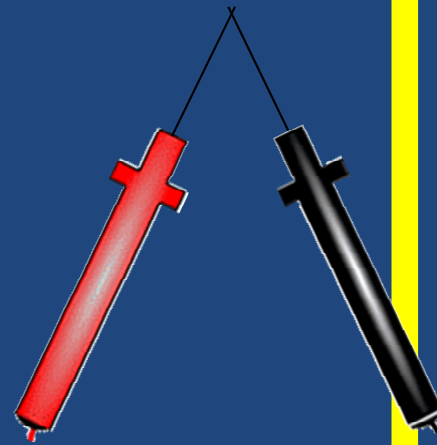


# This represents an electrical shorted circuit

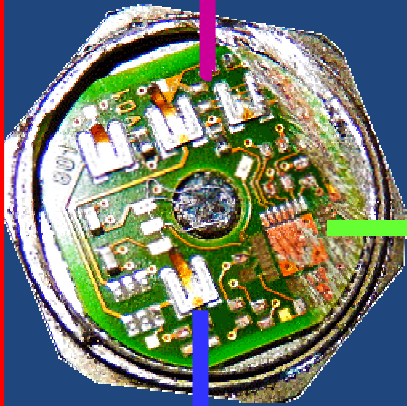
0.00 volts indicates a direct short between the DMM test leads



0.00 volts indicates a direct short between the DMM test leads



Sensor



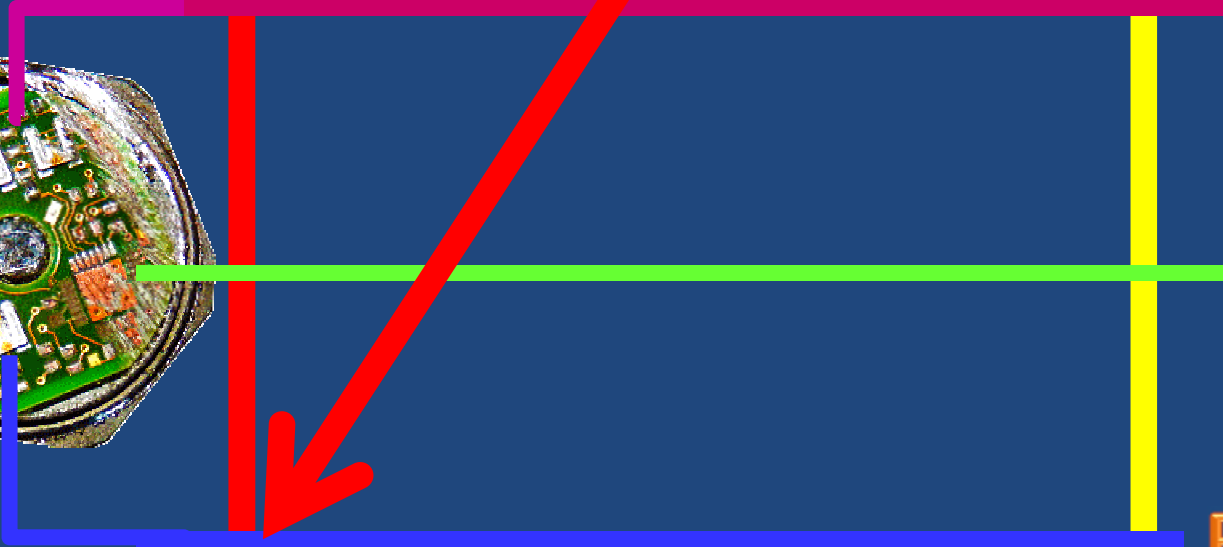
ECM

5V REF

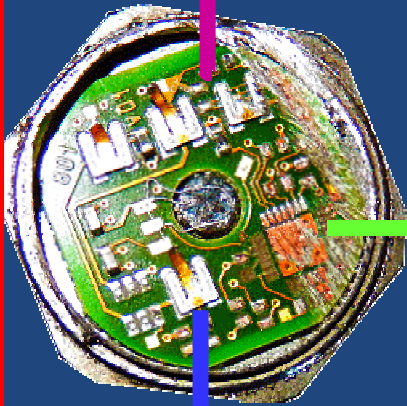
Signal

Reference  
Low

0.050V or less



Sensor



ECM

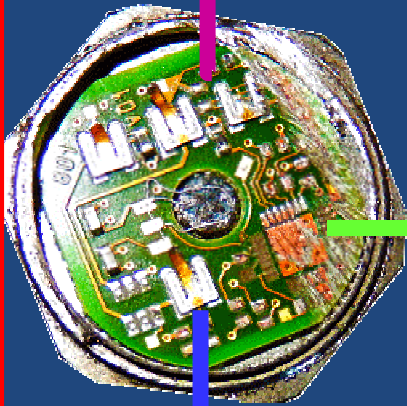
5V REF

Signal

Reference  
Low

0.050V or less

Sensor

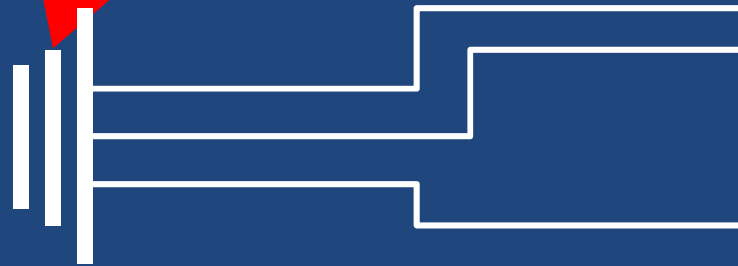


ECM

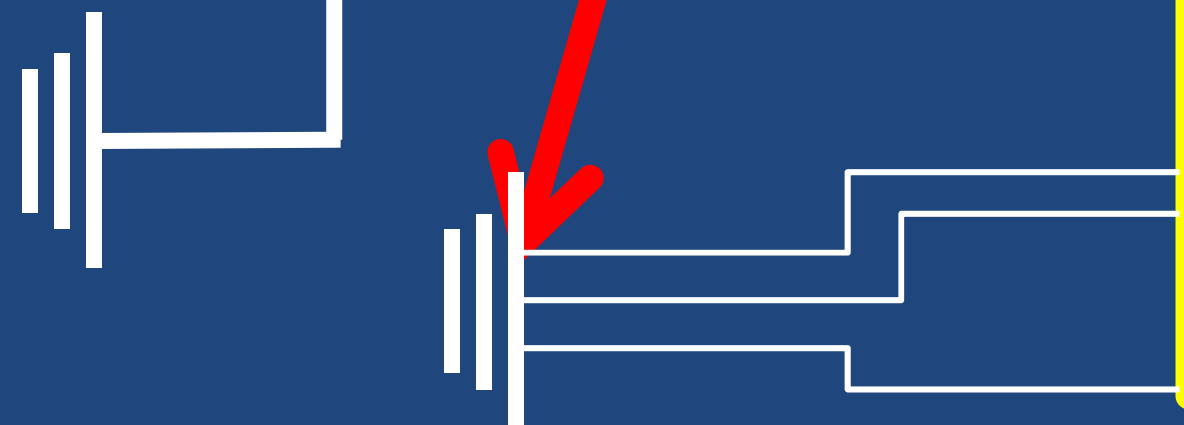
5V REF

Signal

Reference  
Low



Battery





**EXPLOSIVE**  
GASES CAN CAUSE  
BLINDNESS OR DEAFNESS

**NO**  
SMOKING  
FLAMES  
OR OPEN FIRE

**SULFURIC**  
**ACID**  
CAN BURN  
SKIN OR EYES OR  
CORRODE METALS

**GET**  
**MEDICAL**  
**HELP FAST**

**FLUSH EYES IMMEDIATELY WITH WATER**

**KEEP OUT OF THE REACH OF CHILDREN**  
**DO NOT TIP OR INVERT BATTERY**

**INSTALLATION** ALWAYS WEAR PROTECTIVE GLOVES AND LAST, BUT NOT LEAST, ALWAYS WEAR SAFETY GLASSES OR GOGGLES. ALWAYS WEAR YOUR SEATBELT AND PLEASE DON'T DRINK AND DRIVE. ALWAYS USE THE CORRECT TOOLS AND TECHNIQUES TO INSTALL THE BATTERY. ALWAYS USE THE CORRECT WIRE GAUGE AND COLOR. ALWAYS USE THE CORRECT WIRE TERMINALS. ALWAYS USE THE CORRECT WIRE TERMINALS. ALWAYS USE THE CORRECT WIRE TERMINALS. ALWAYS USE THE CORRECT WIRE TERMINALS.

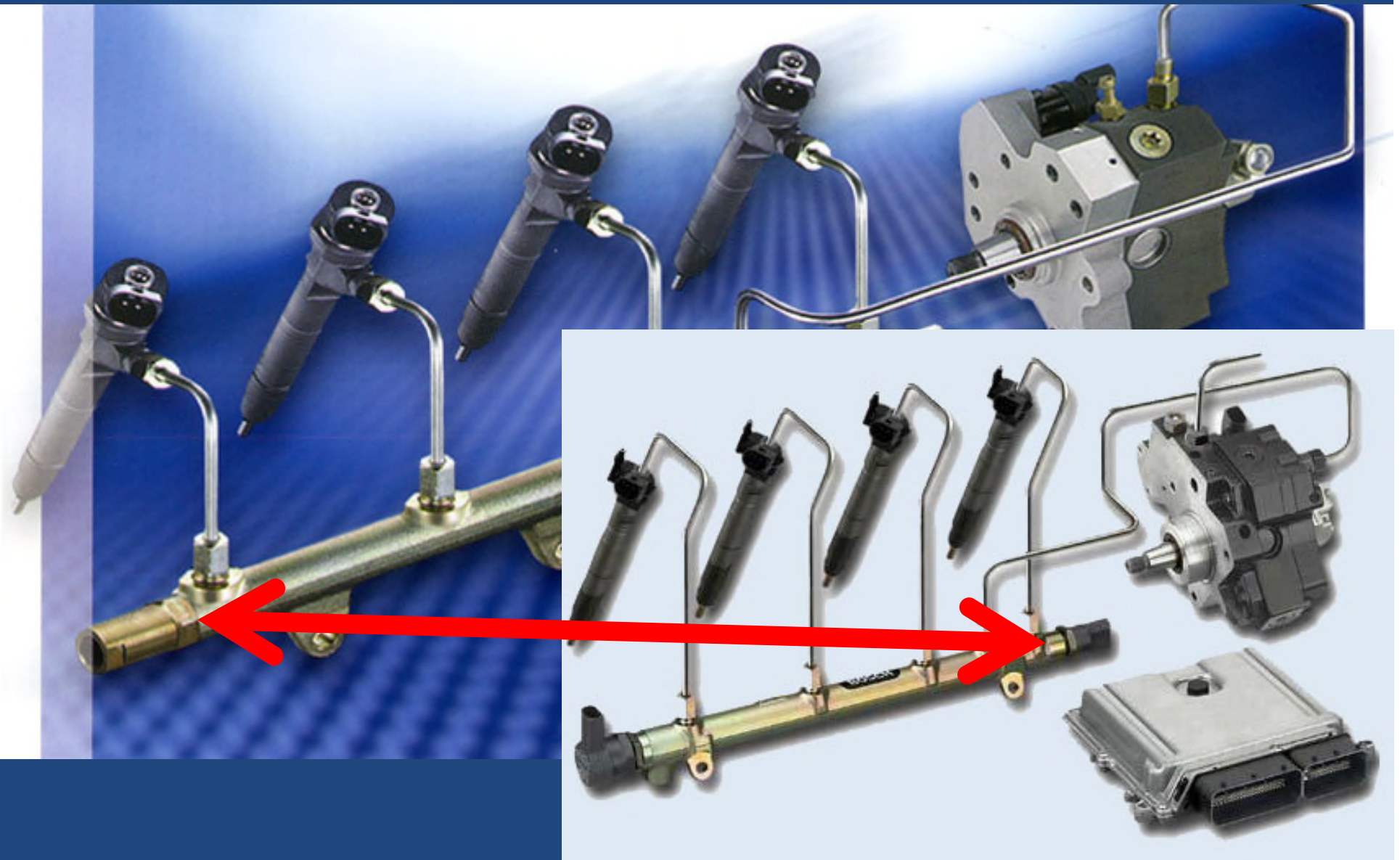
**RECYCLE**

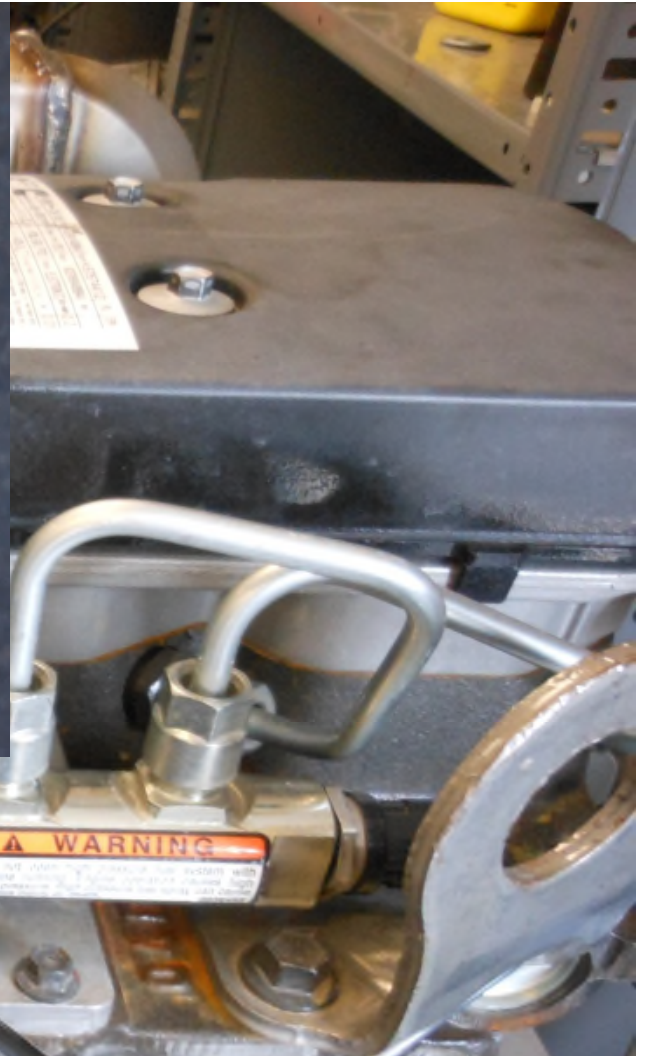
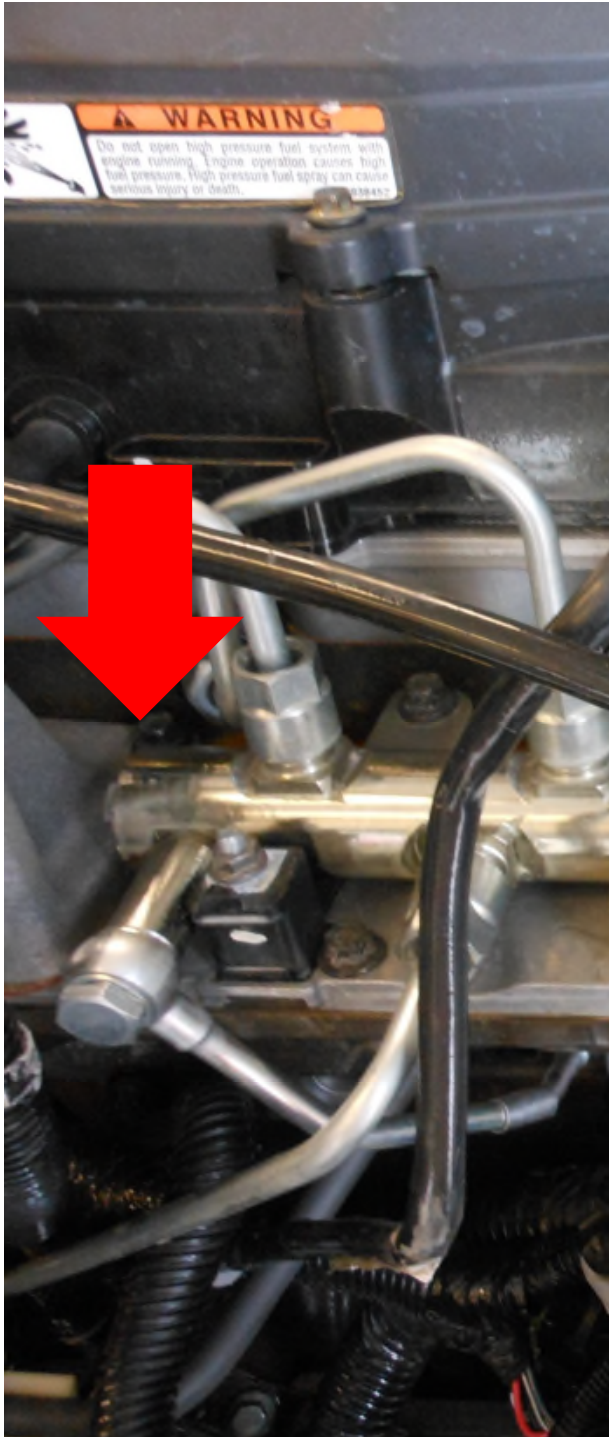
# Fuel Rail Pressure Limiting Valve

The valve is normally held closed by a calibrated spring

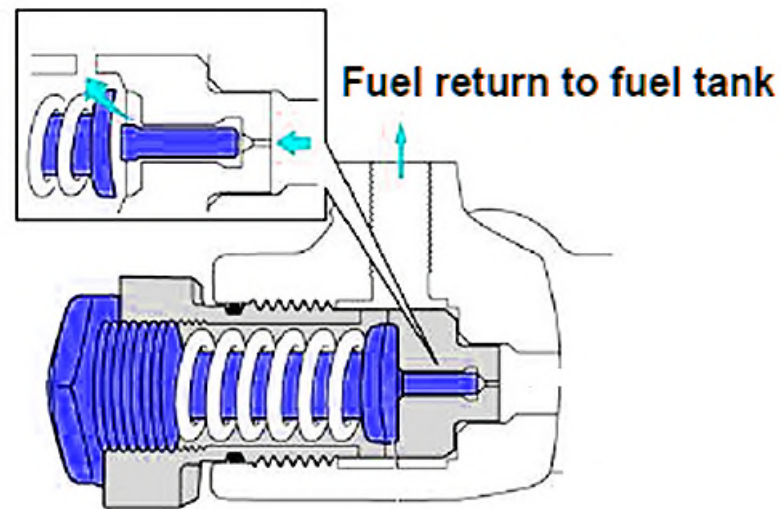
When fuel exceeds the pressure setting the spring begins to collapse and releases fuel into the return circuit

# Mounted in the system

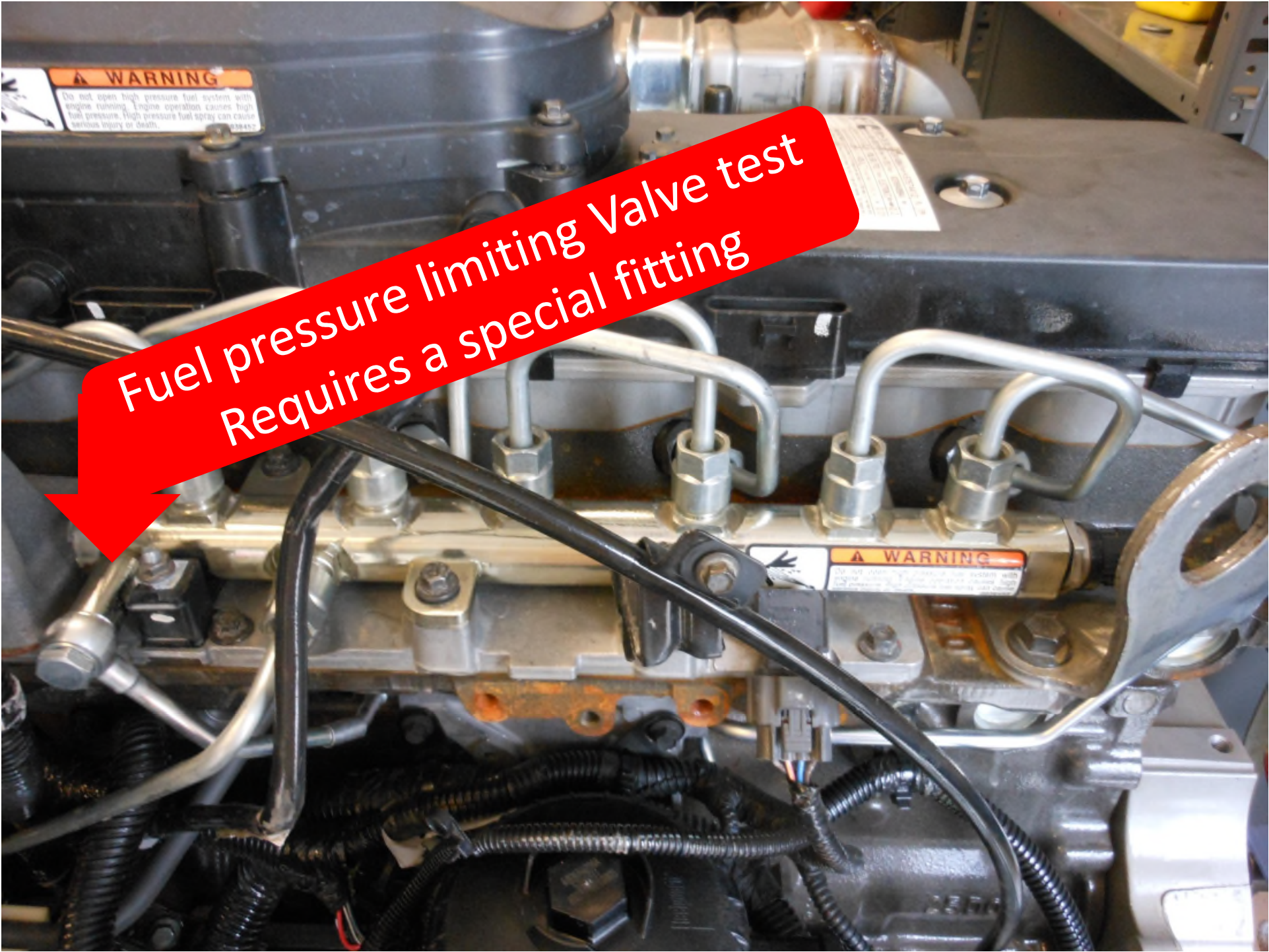




**Closes at 725psi**

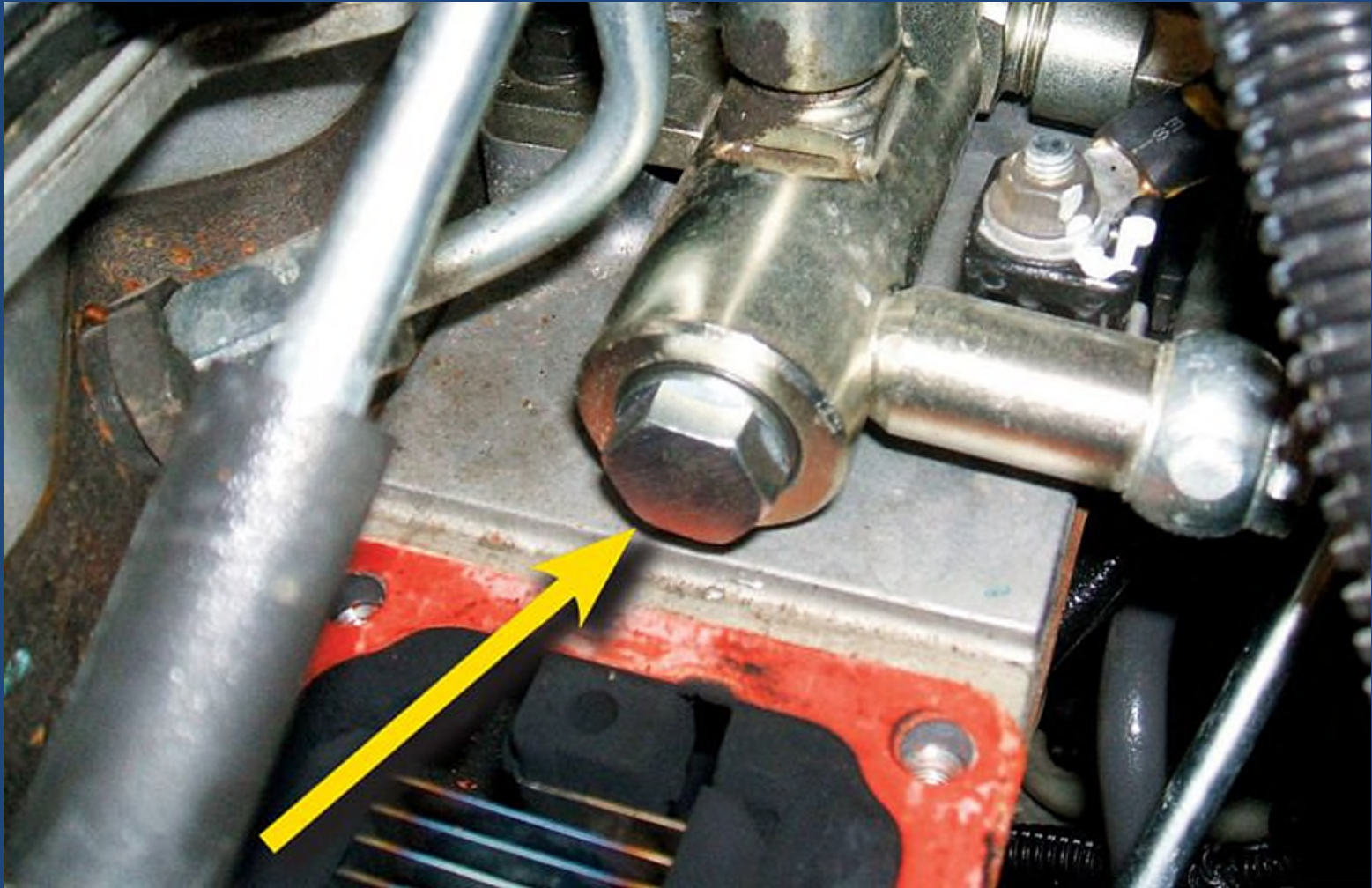


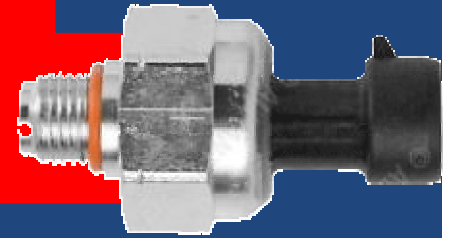
**Opens at 33,350psi**



Fuel pressure limiting Valve test  
Requires a special fitting







Fuel sensor  
Fuel Filter assembly  
Fuel Tank  
Fuel Return circuit

# Fuel pressure limiting Valve test

Connect the fitting, place the hose in a container

Start and run the engine at idle

No fuel should flow



**Engine at idle (warm)**  
**Zero fuel flow**



# Fuel pressure limiting Valve test

Command the fuel control solenoid off

Disconnect the fuel control solenoid

Fuel should flow



**Fuel control opened  
fuel flow WOW  
Get a bigger cup**

# Injectors

Solenoid Style

Piezo Style

Controlled by an ECM

# Injection Timing

The ECU precisely controls the injectors to allow multiple fuel injections during each combustion cycle

The benefit is better combustion

# ECP controls the injectors

An electronic pulse is sent to the solenoid to create a magnetic field that will lift the injector's needle from its seat

The pilot, main, and post injection pulses are all electronically controlled

# Pilot, Main, and Post Injection

The pilot injection events contributes  
To a quitter engine and a smooth idle

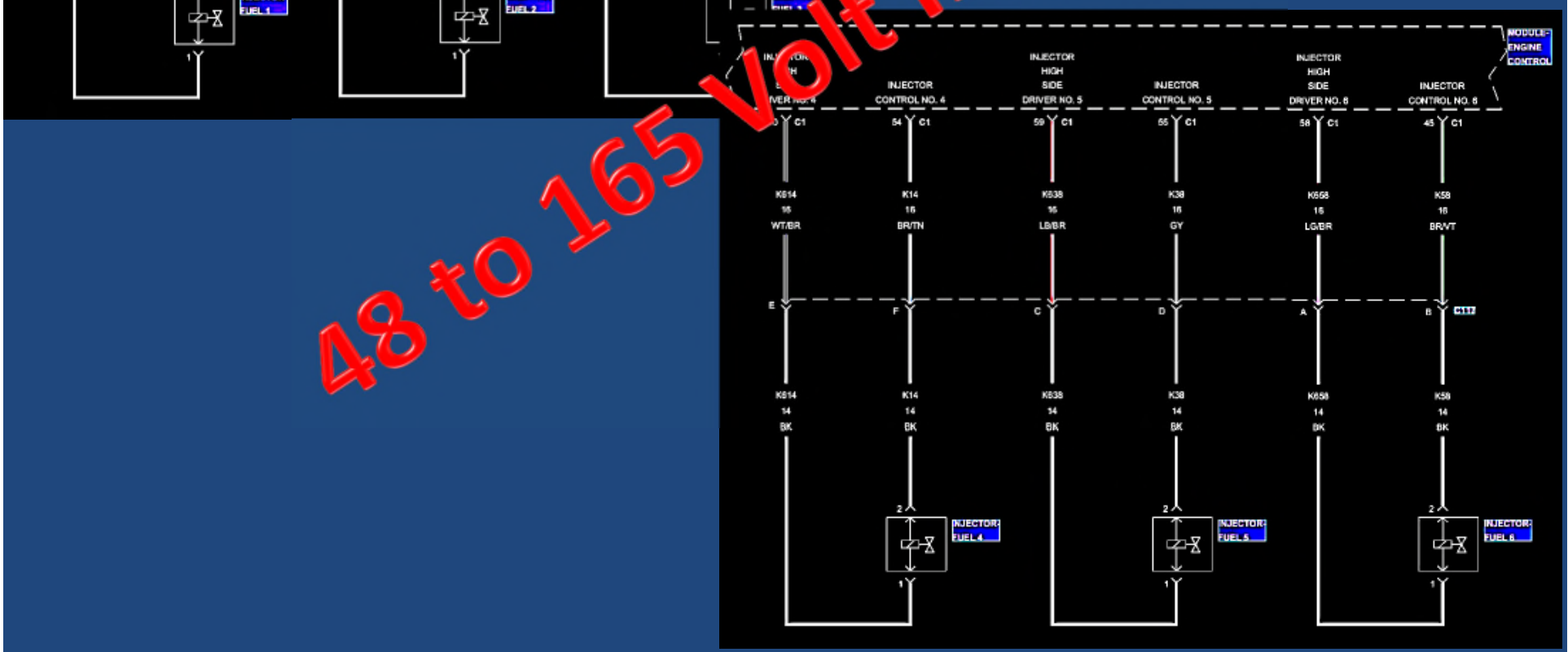
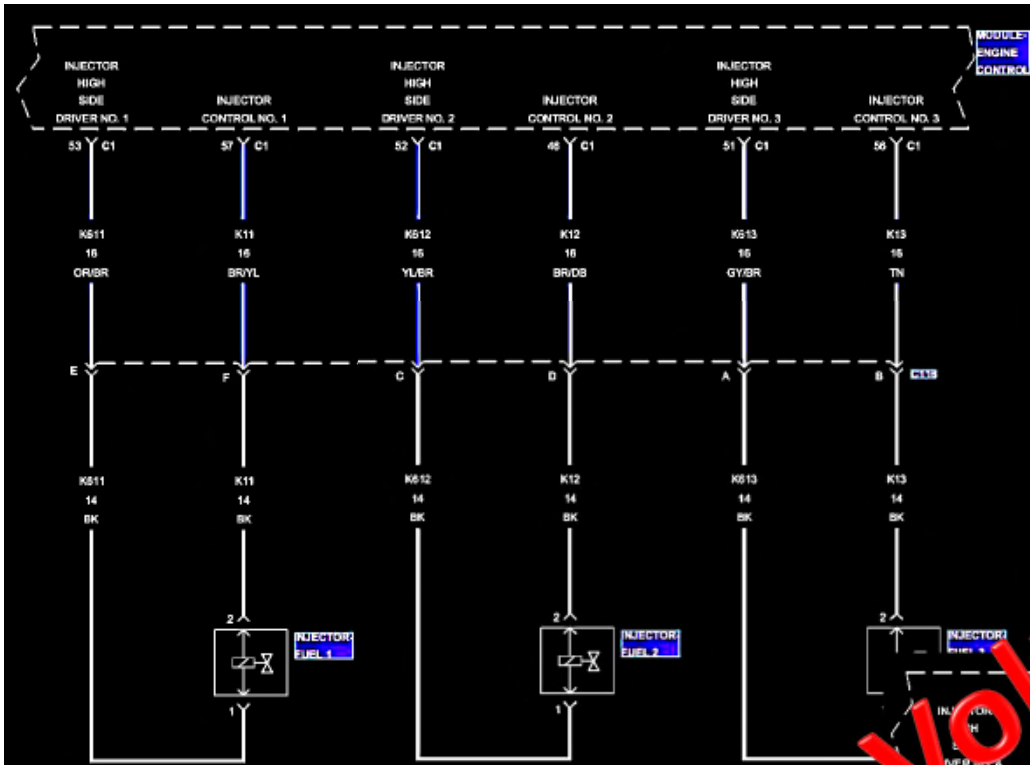
The main injection event  
develops power



# Pilot, Main, and Post Injection

The post injection events only occur during the regeneration process and heats the catalyst to burn off soot in the particulate filter





48 to 165 Volt Injectors

Cummins Inc.  
CM2100A  
P/N 4934056  
S/N 582  
D/C 07/14/2006  
ESN 57574412  
E/C S90165.14



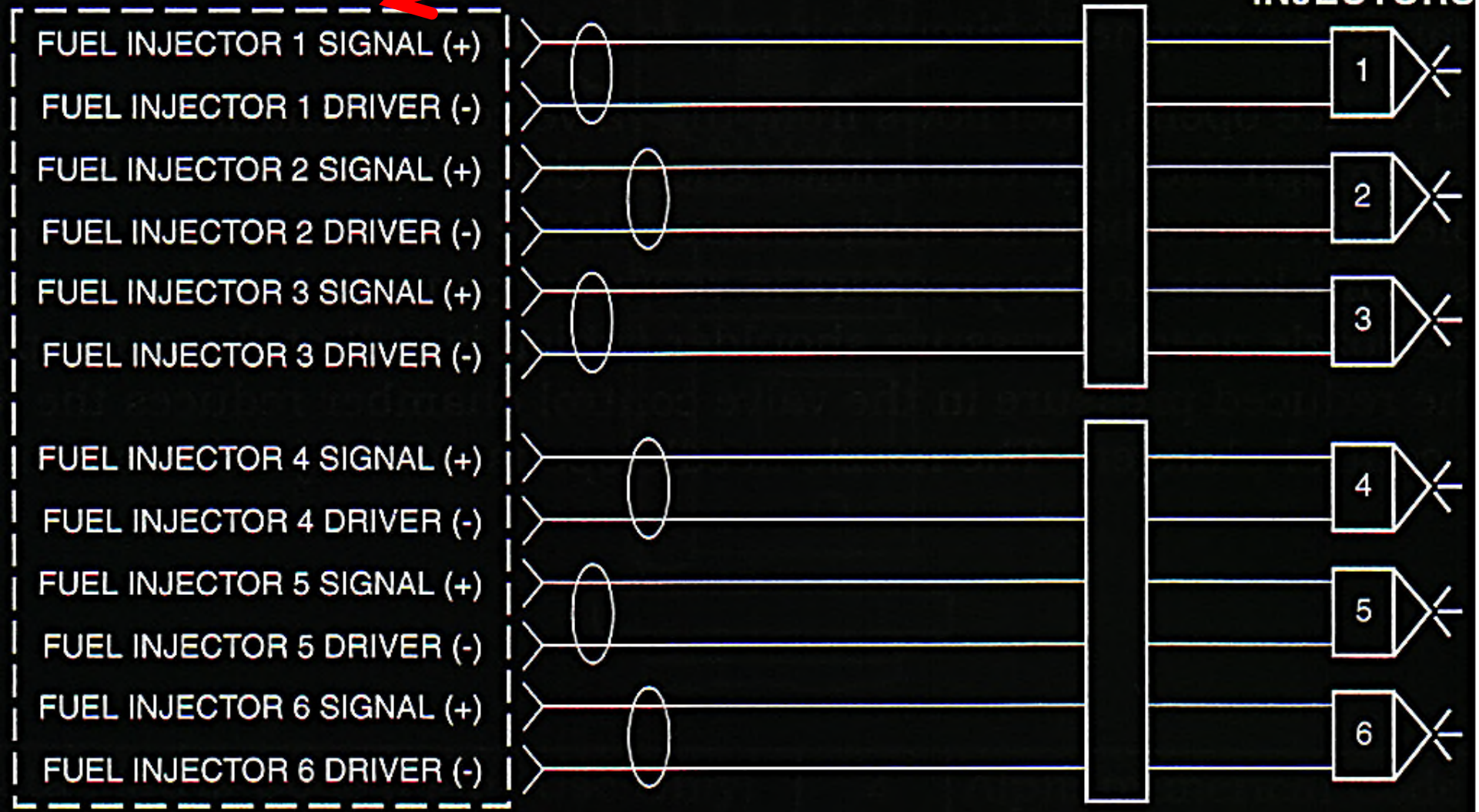
26  
000000  
000000  
LEADS



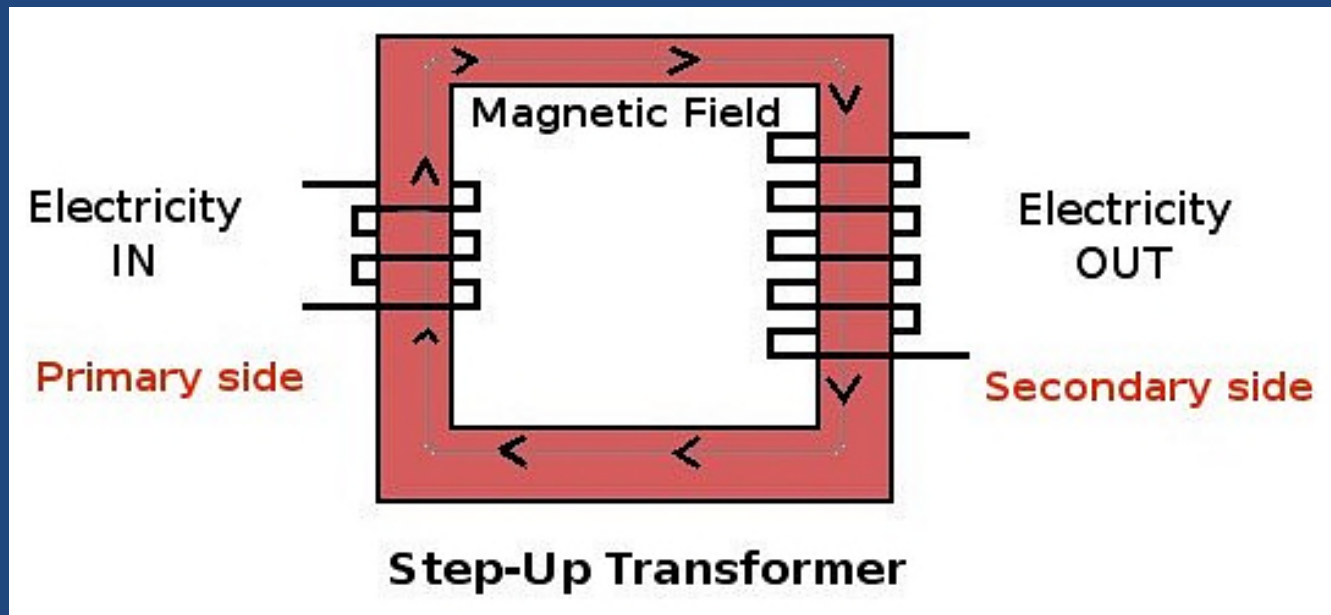
# Step up transformer inside

ENGINE  
CONTROL  
MODULE (ECM)

FUEL  
INJECTORS



# Charging system voltage in What ever voltage needed Is designed



# 2 Injector drivers

ENGINE  
CONTROL  
MODULE (ECM)

FUEL INJECTOR 1 SIGNAL (+)

FUEL INJECTOR 1 DRIVER (-)

FUEL INJECTOR 2 SIGNAL (+)

FUEL INJECTOR 2 DRIVER (-)

FUEL INJECTOR 3 SIGNAL (+)

FUEL INJECTOR 3 DRIVER (-)

FUEL INJECTOR 4 SIGNAL (+)

FUEL INJECTOR 4 DRIVER (-)

FUEL INJECTOR 5 SIGNAL (+)

FUEL INJECTOR 5 DRIVER (-)

FUEL INJECTOR 6 SIGNAL (+)

FUEL INJECTOR 6 DRIVER (-)

1 for power

1 for ground

FUEL  
INJECTORS

1

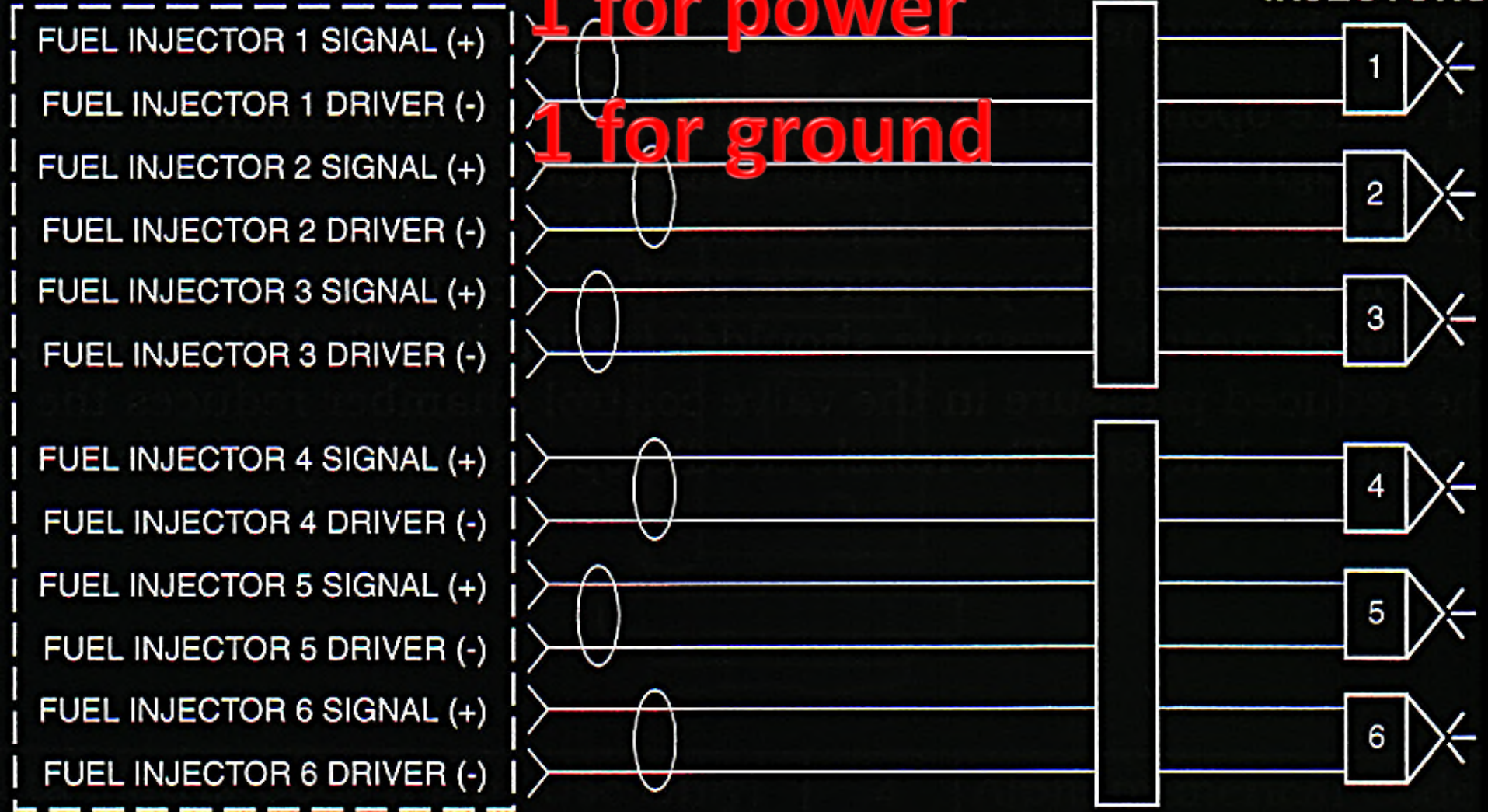
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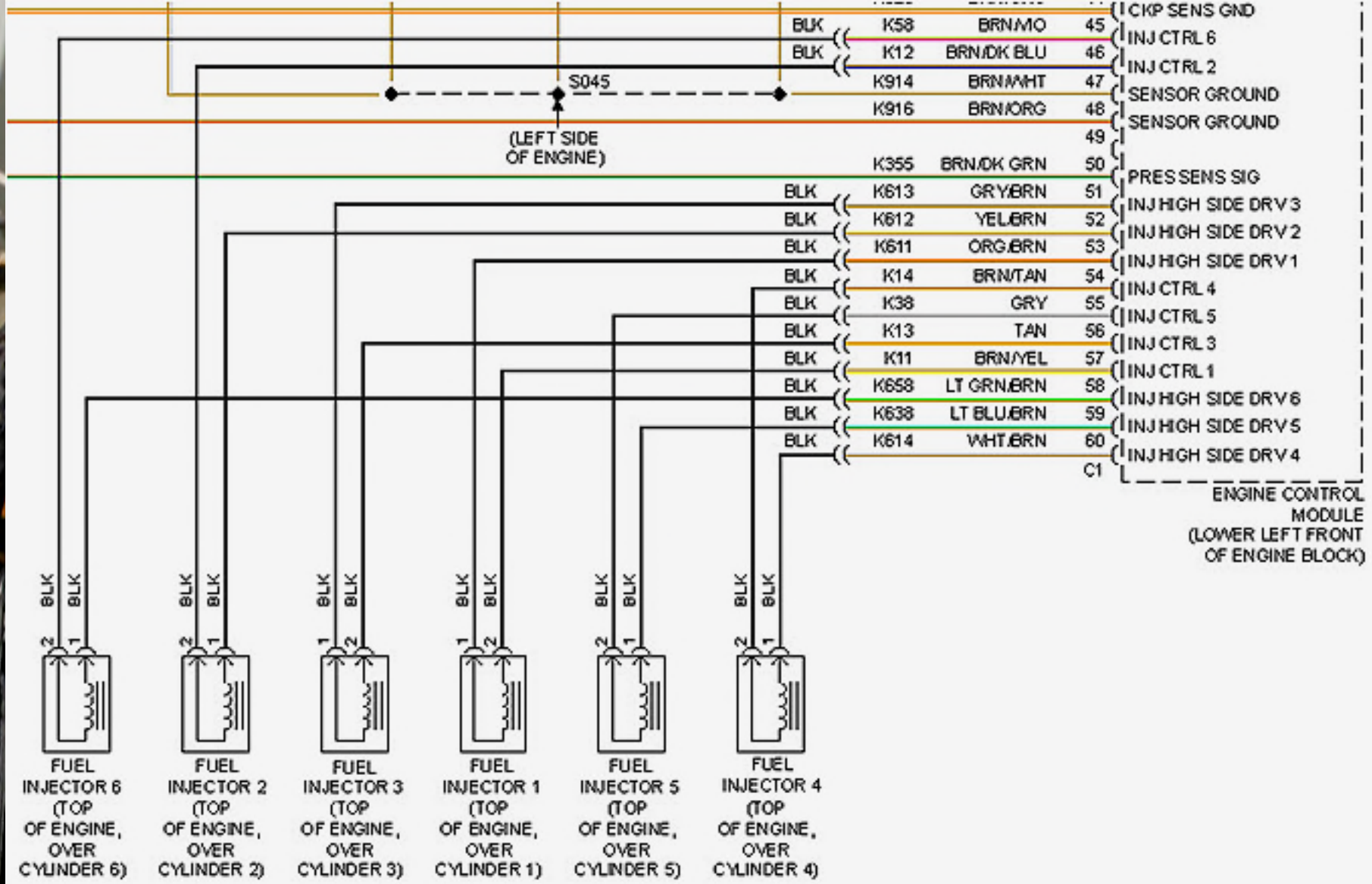
3

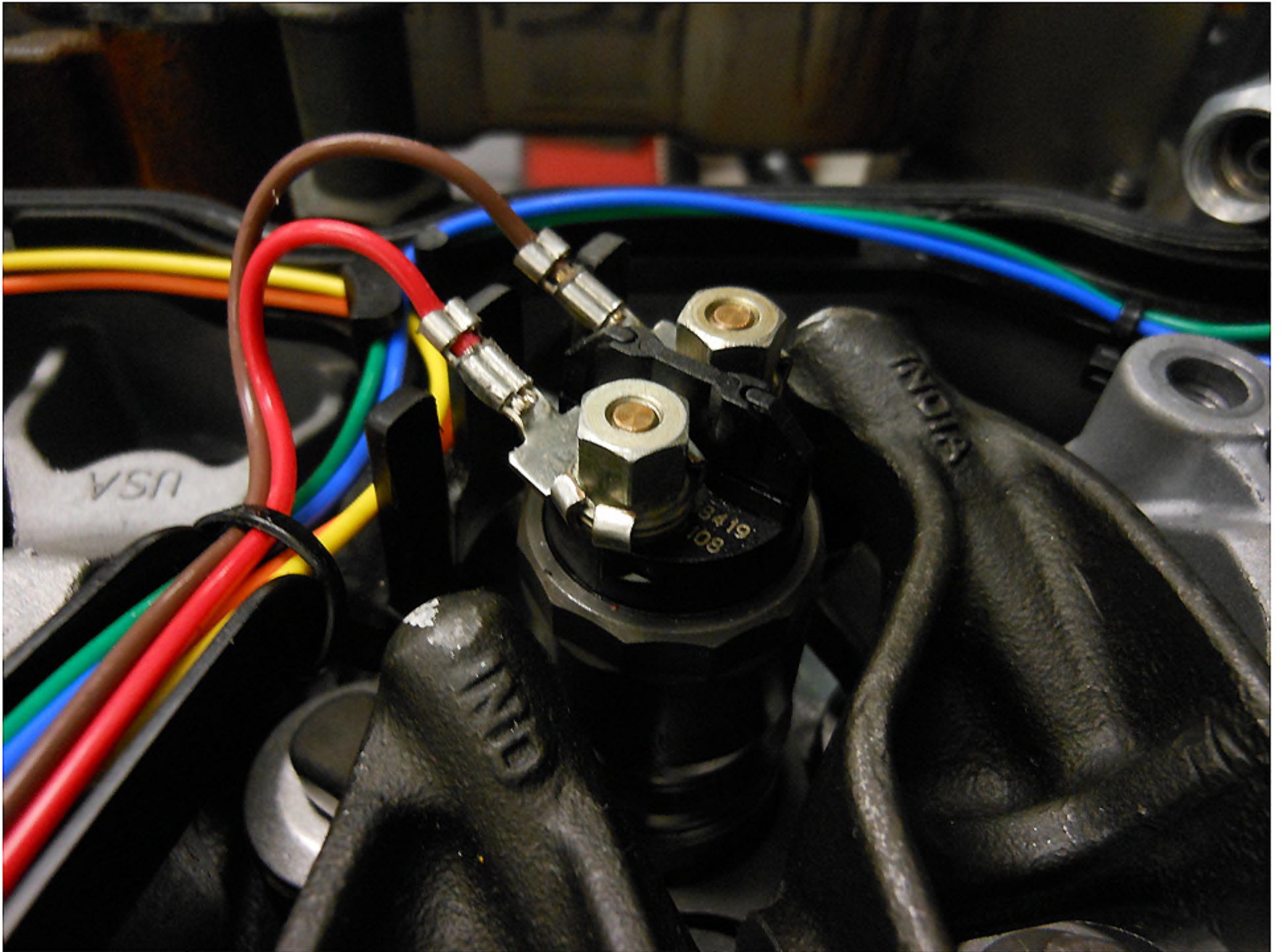
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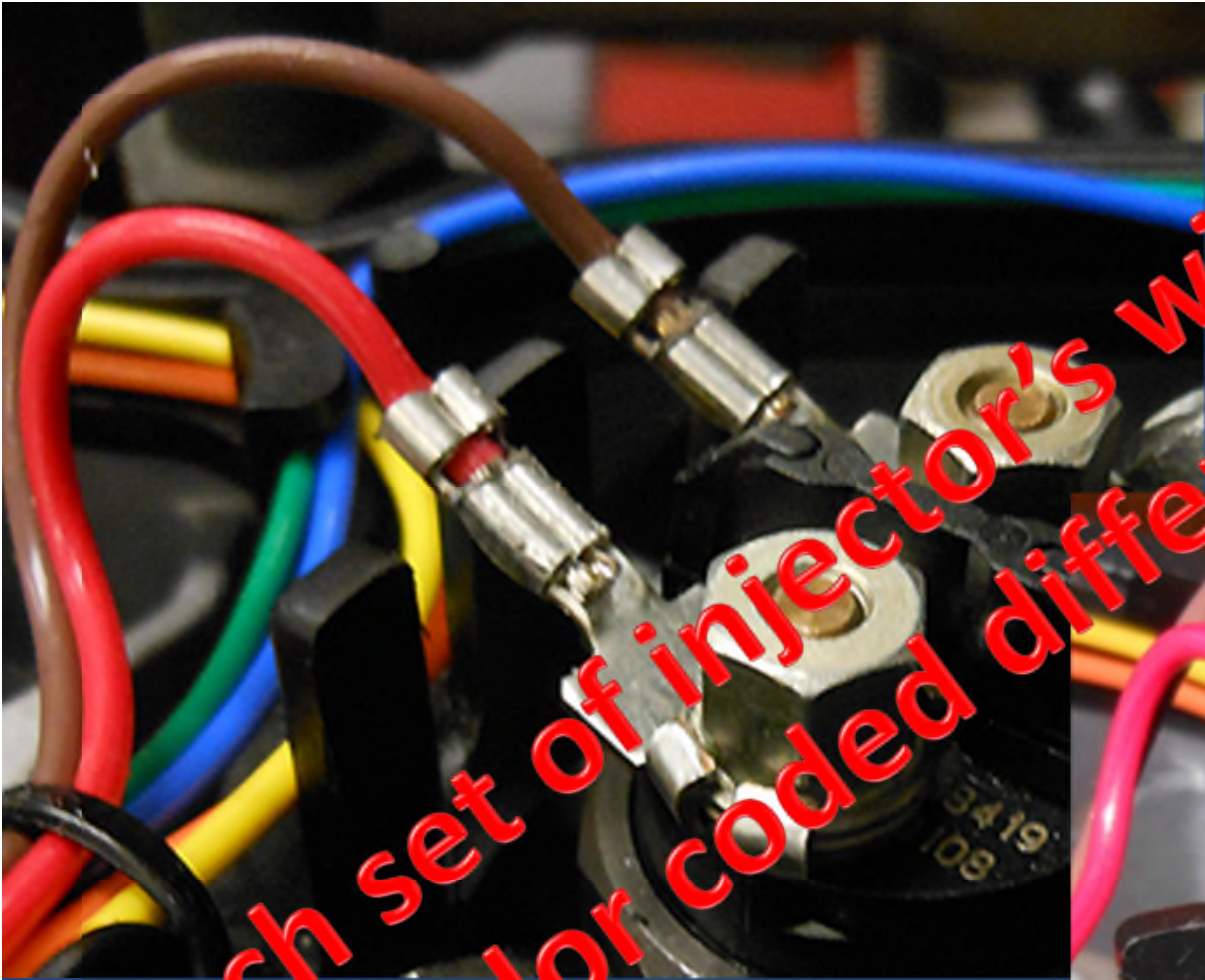
5

6





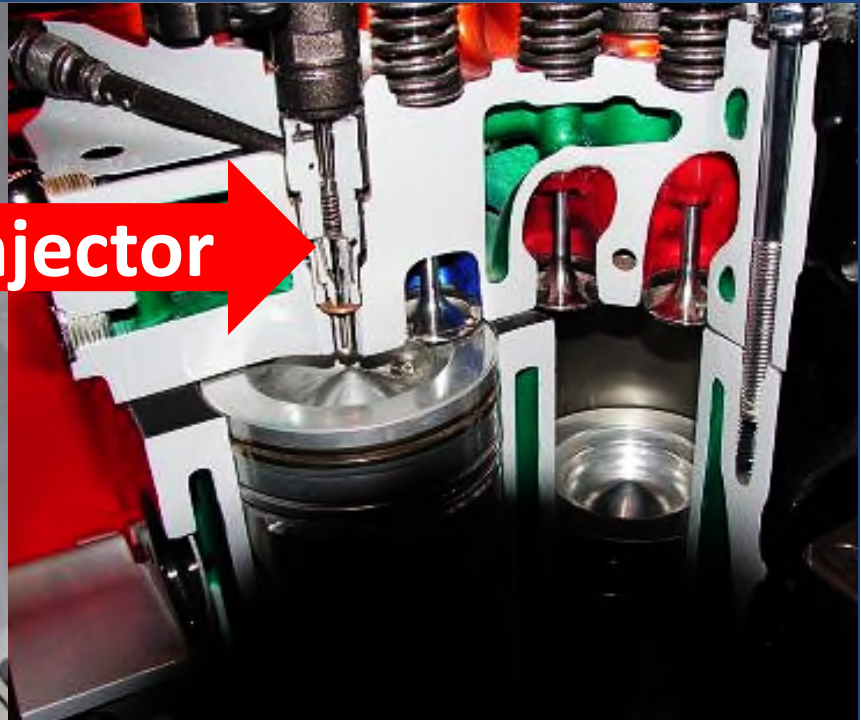




Each set of injector's wires  
are color coded differently



**Injector** 



# Smart driver technology

---

**A Wire**

# Minute Fluctuations

---

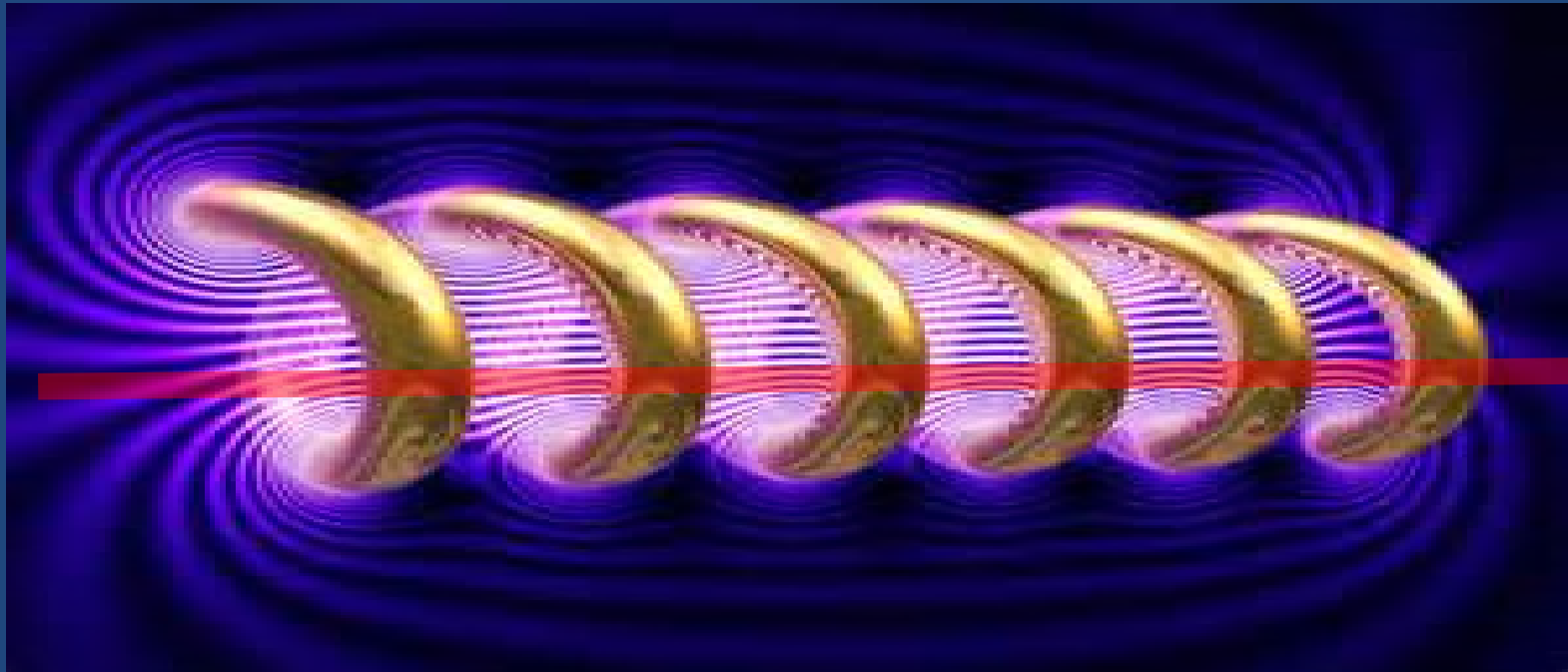
**A Wire**

# Minute Fluctuations

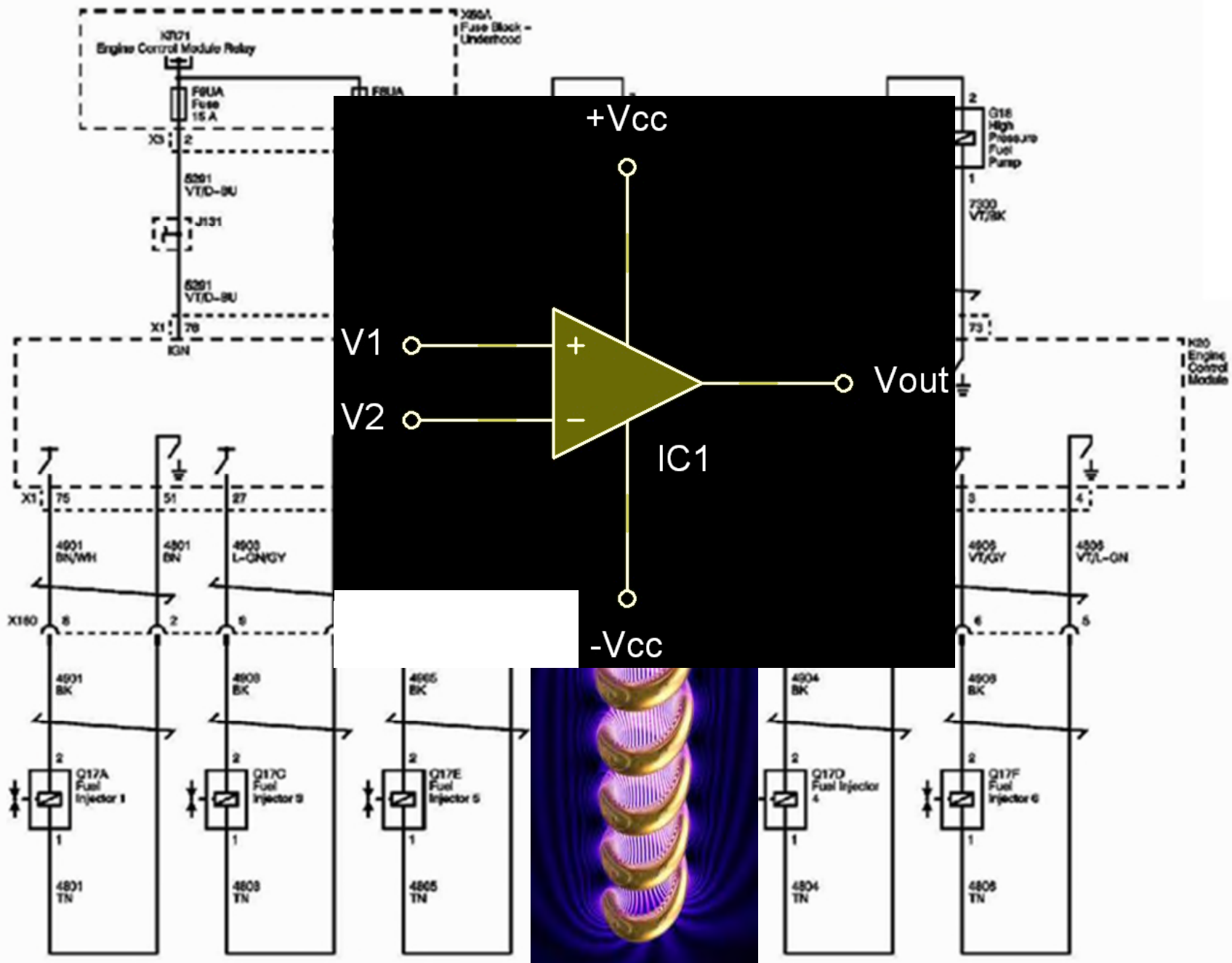
---

## Current Flows

# Minute Fluctuations



**Magnetic Field Appears**



# Smart Driver are the diagnostics

When the injector is opened current flows

This creates a magnetic field

The magnetic field pulses the smart driver

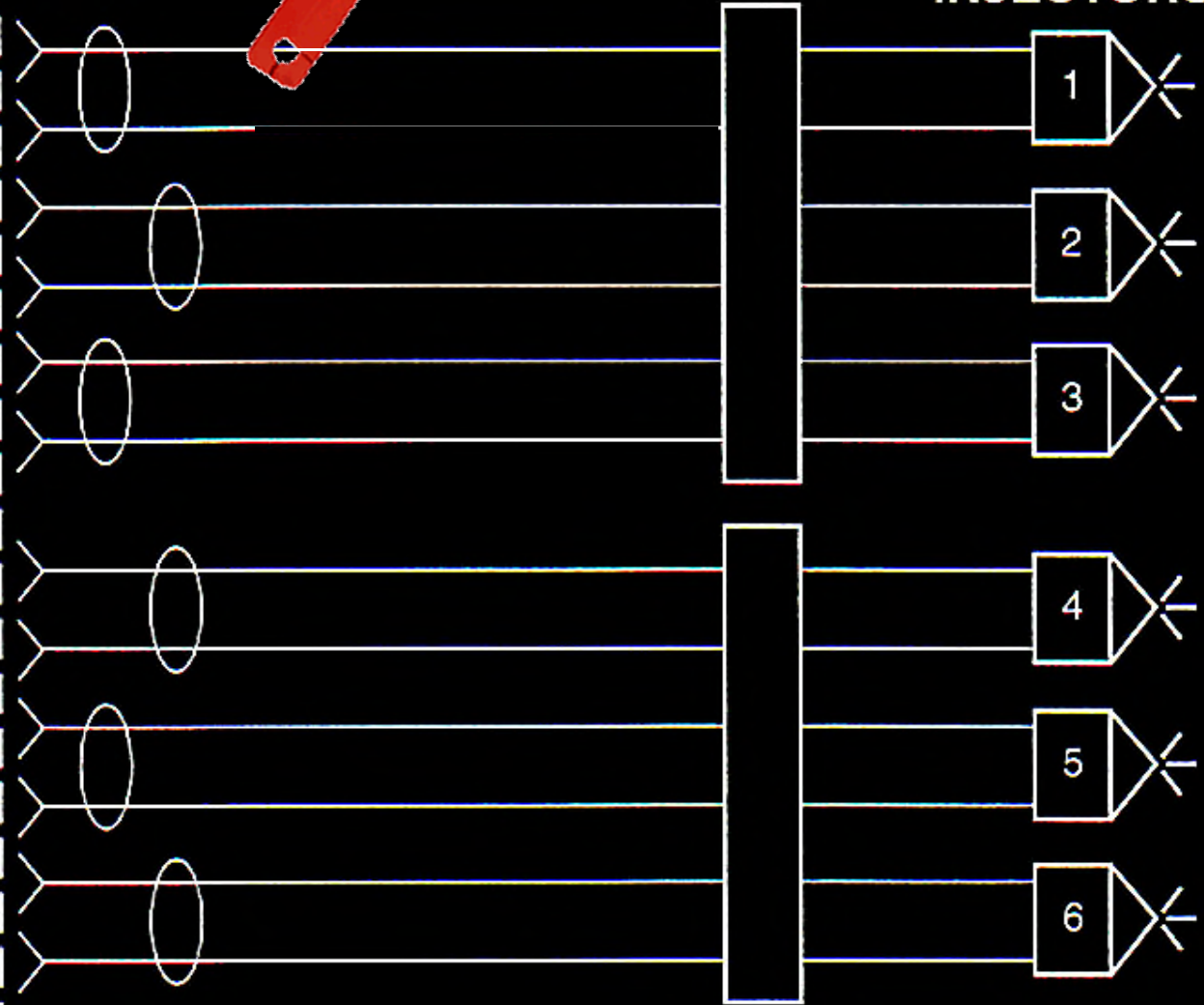
The smart driver sends a signal to the computer indicating that an injector event happened

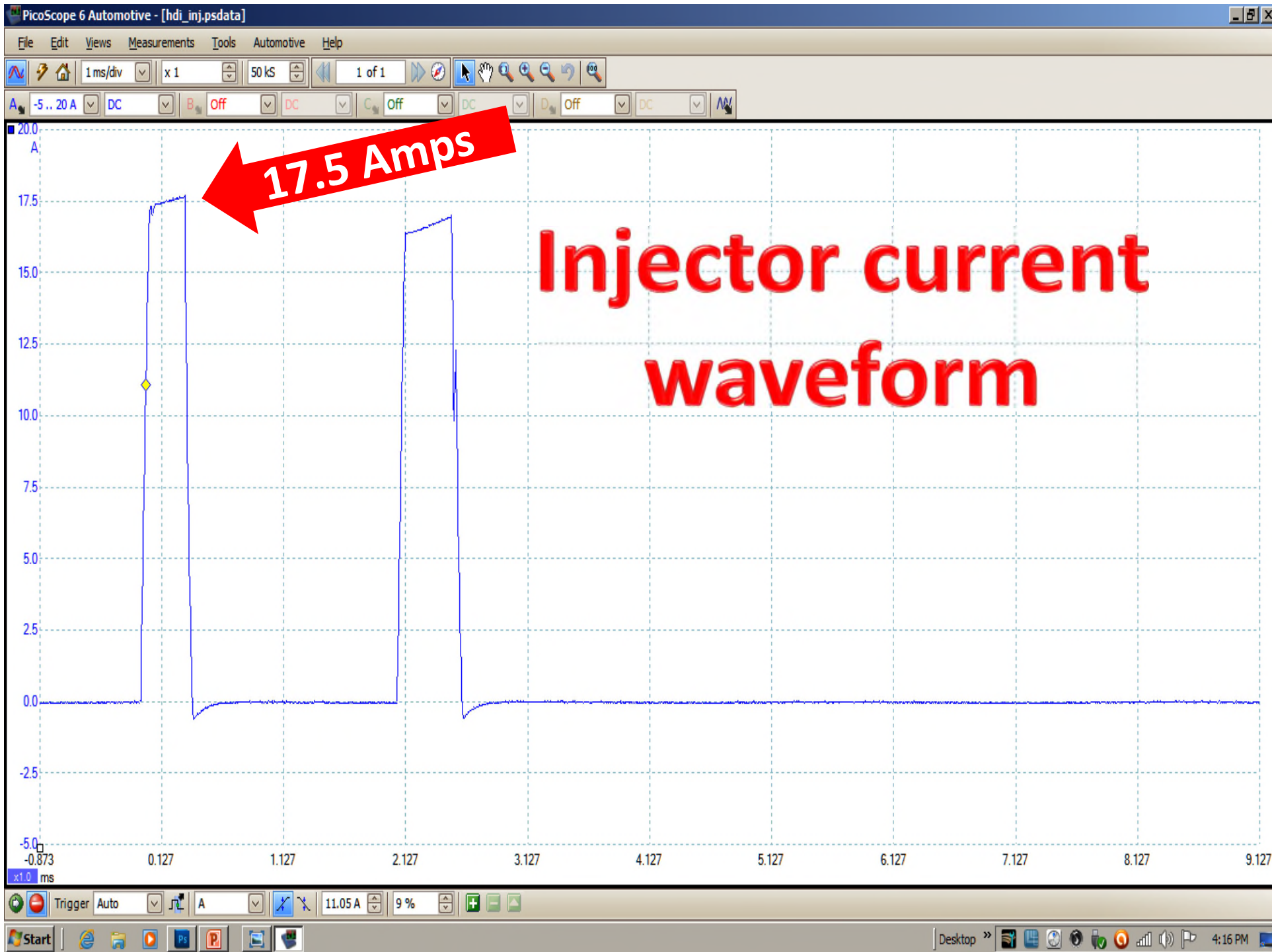
# ENGINE CONTROL MODULE (ECM)

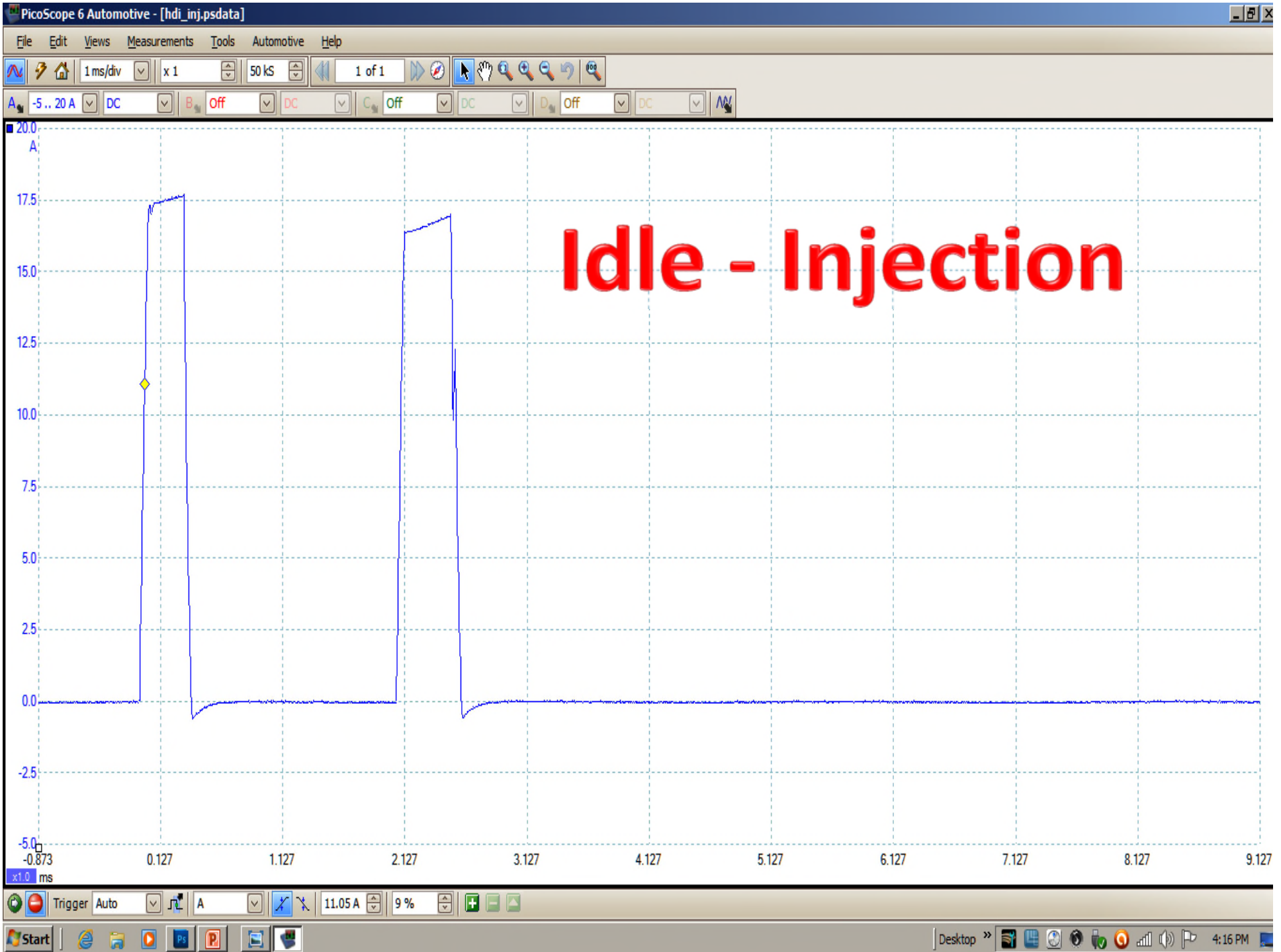
- FUEL INJECTOR 1 SIGNAL (+)
- FUEL INJECTOR 1 DRIVER (-)
- FUEL INJECTOR 2 SIGNAL (+)
- FUEL INJECTOR 2 DRIVER (-)
- FUEL INJECTOR 3 SIGNAL (+)
- FUEL INJECTOR 3 DRIVER (-)
- FUEL INJECTOR 4 SIGNAL (+)
- FUEL INJECTOR 4 DRIVER (-)
- FUEL INJECTOR 5 SIGNAL (+)
- FUEL INJECTOR 5 DRIVER (-)
- FUEL INJECTOR 6 SIGNAL (+)
- FUEL INJECTOR 6 DRIVER (-)

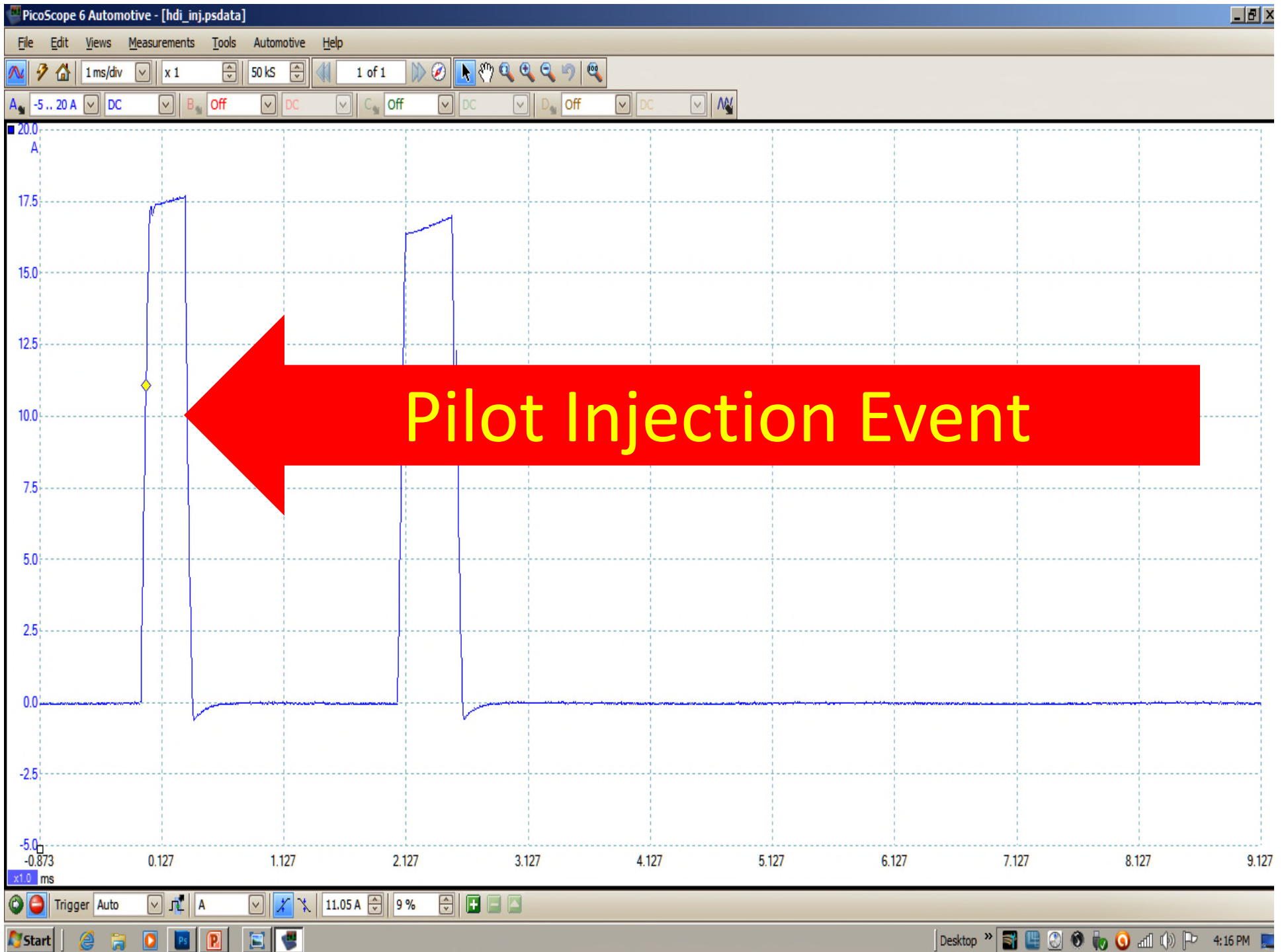


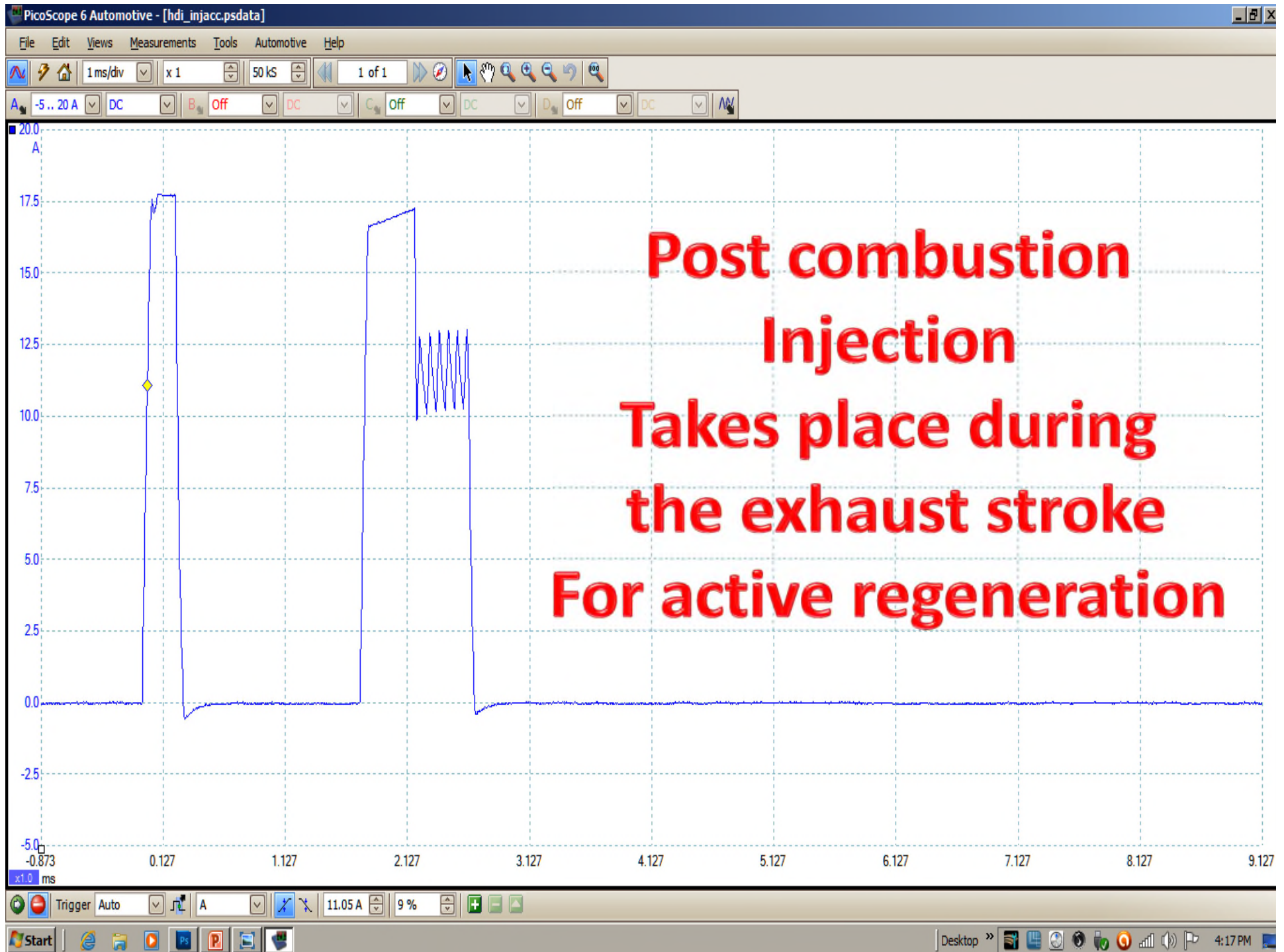
# FUEL INJECTORS



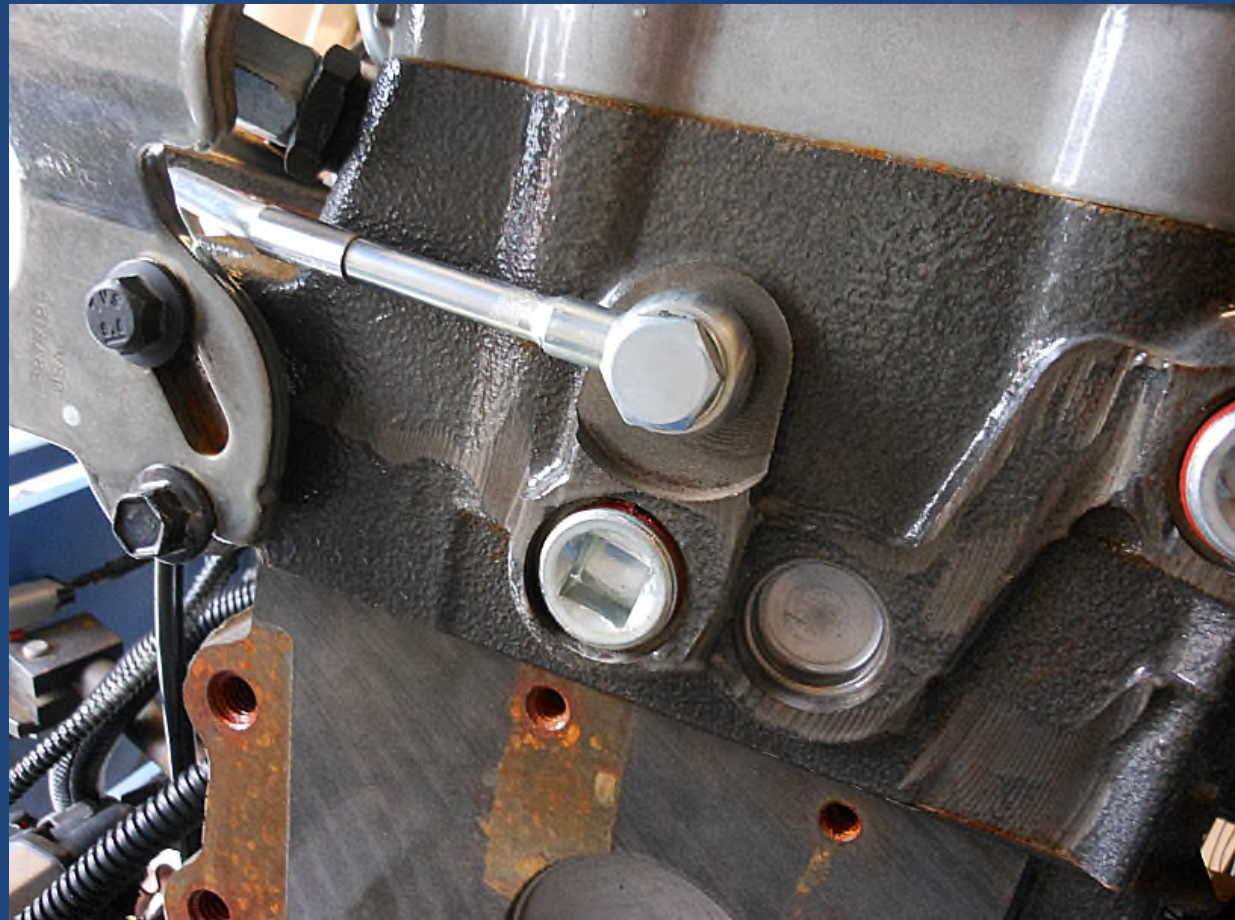


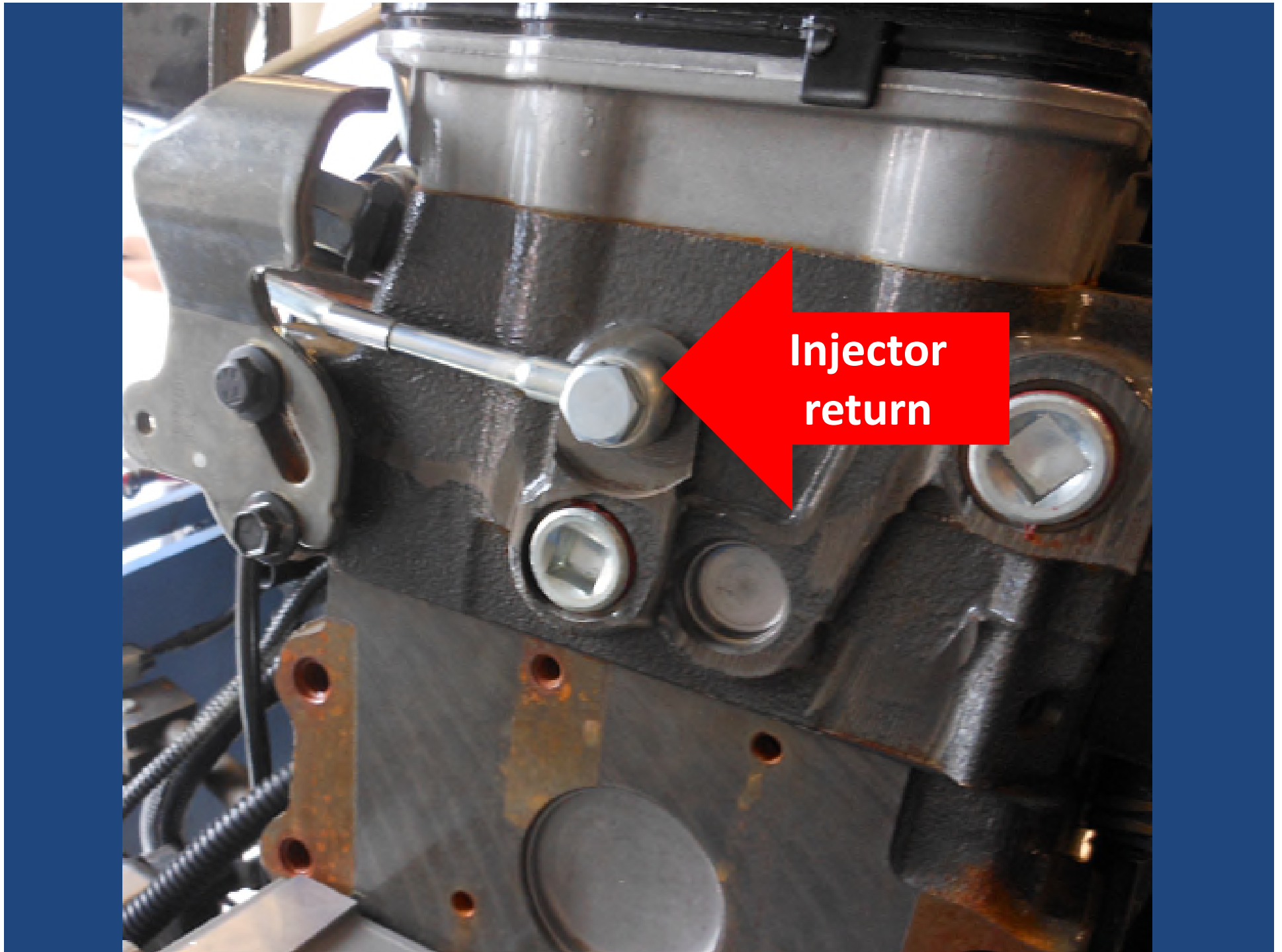




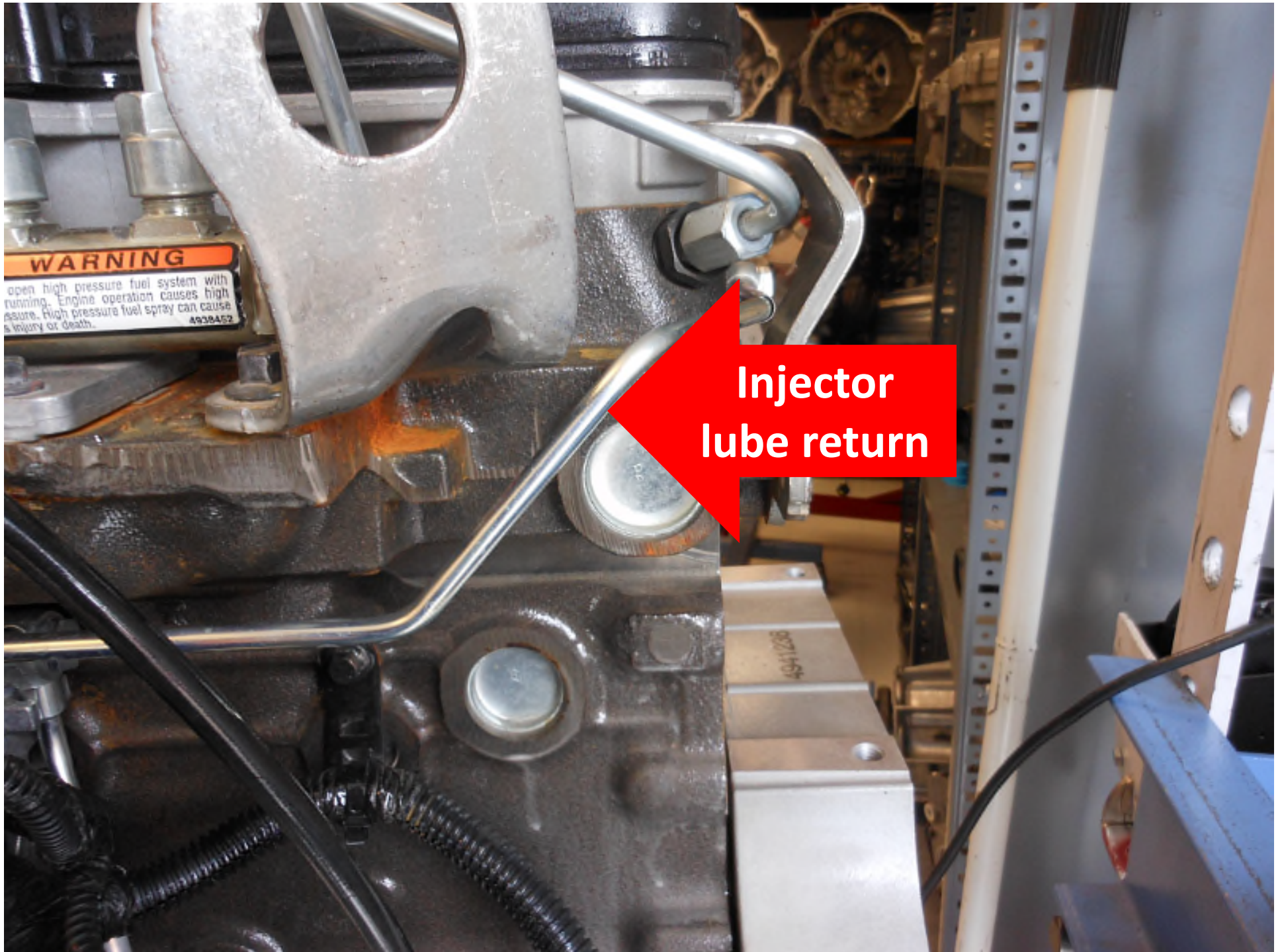


Some fuel is used to lubricate the pintle and goes into the cylinder then through to the return circuit





**Injector  
return**





# Injector return flow test

Remove the vehicle fuel return line from the engine fuel drain tube

Route this hose into a container to catch return fuel



# Injector return flow test

Actuate the fuel override test with the scan tool

Measure the amount of fuel in the graduated cylinder

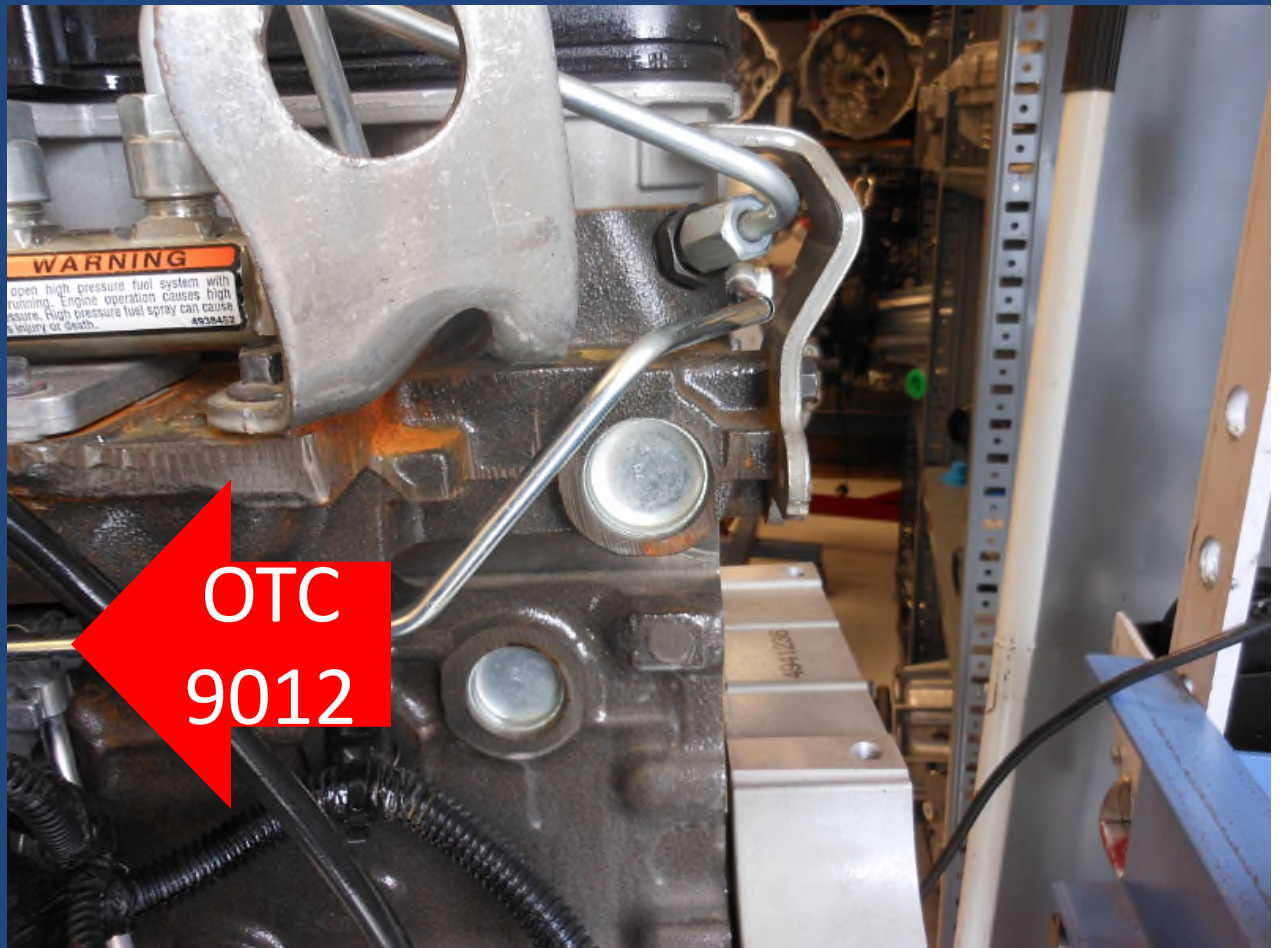
Fuel flow must be less than 180 ml / minute

# Injector return flow test (Engine Running)

Measure the return directly out of the fuel return line

Special note!  
9014 blocks  
fuel while 9012  
allows fuel to  
flow

Don't get your  
fittings mixed  
up



# Injector return flow test (Engine Running)

Start the engine and allow it to idle for 30 seconds


Activate fuel pressure override test with a scan tool

Rail pressure should increase to 26107 psi

Run test for 30 seconds (Scan tool will time out)

Fuel flow should be less than 210 ml in 30 sec.

Repeat test three times and take the average

 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

- Reset Duty Cycle Monitor
- Reset Trip Information
- Cylinder Contribution Test
- Fuel Pressure Override Test

Code	Description
------	-------------



- 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 Fuel Pressure Override Test


Initiate




Done

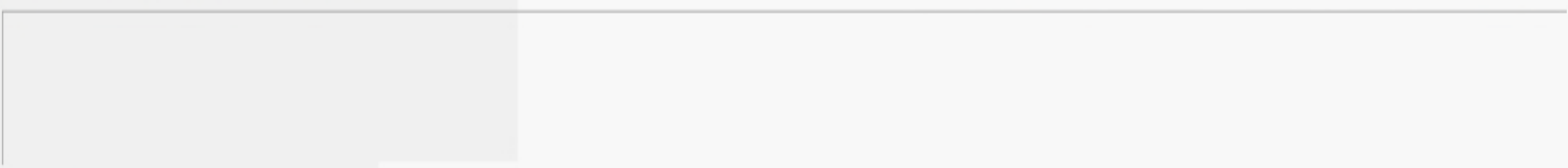


Code	Description
------	-------------

 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: Fuel Pressure Override Test



Code	Description
	Performing Test..



- 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



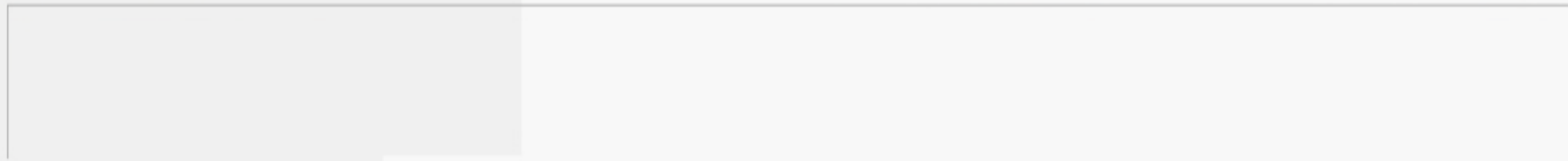
Test Fuel Pressure Override Test

Initiate

<

Done

>



Code	Description
	Press the done button when finished with test

If more than 210 ml in 30 seconds

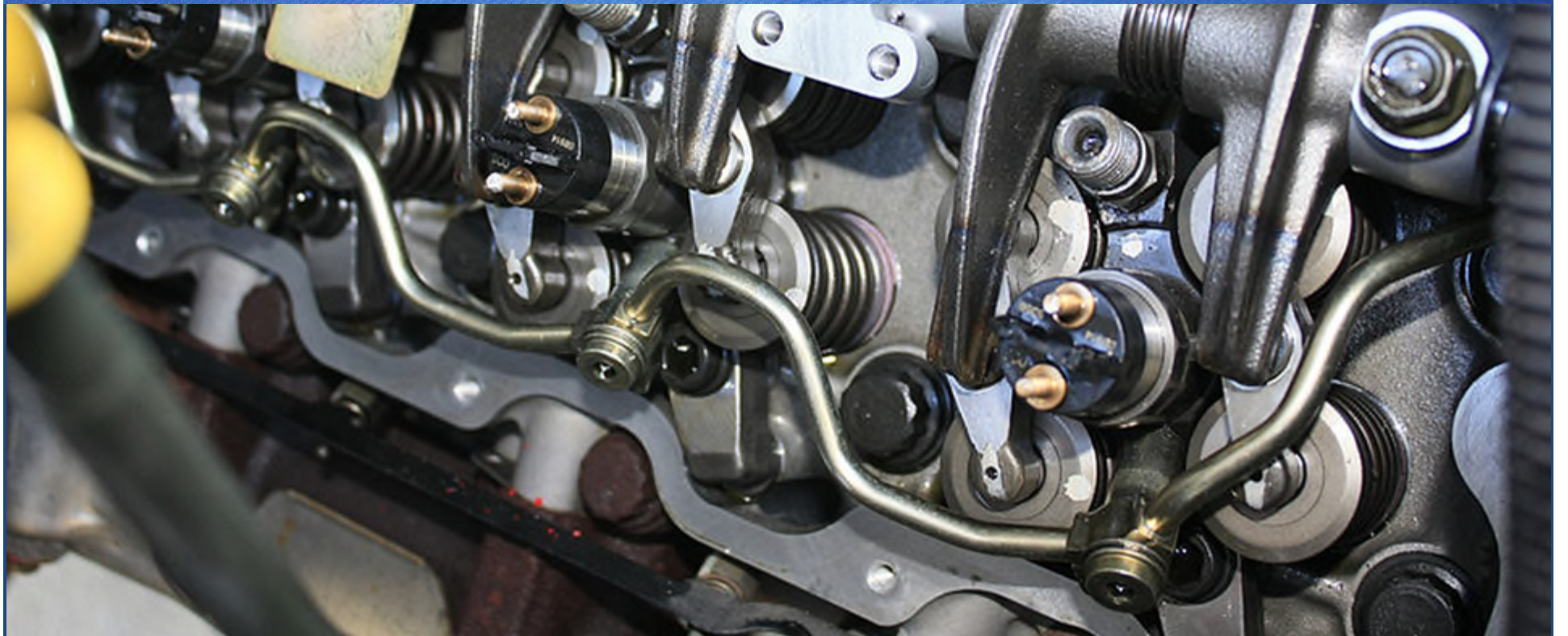
Re-torque all the high pressure fittings

Repeat tests

If there is still too much flow

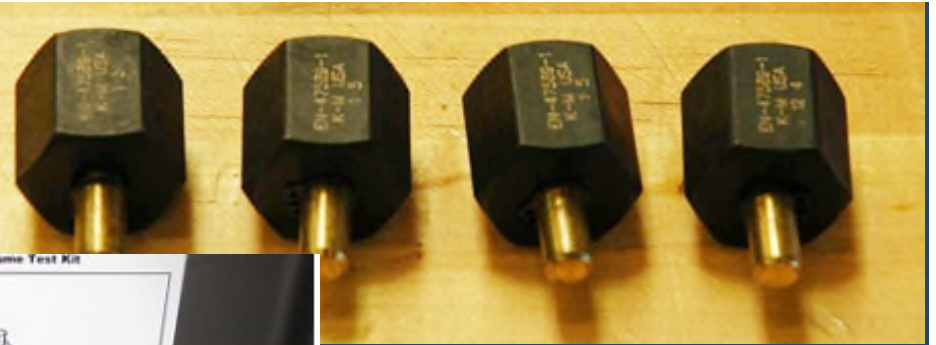
Cap off each injector one at a time

Repeat the test to determine which injector(s) are failing; worn injectors will have high return rates.





**Hoses**



**Plugs**



**Complete  
Kit**

**Graduated  
Containers**



**Adaptors**



# Injector return flow test

Start with engine at normal operating temperature

Install the SPX ???? fitting to the where ever

Check for diagnostic trouble codes first!

# Injector return flow test (Engine Running)

Start the engine and allow it to idle for 30 seconds

Activate fuel pressure override test with a scan tool

Rail pressure should increase to 26107 psi

Run test for 30 seconds (Scan tool will time out)

Fuel flow should be less than 210 ml in 30 sec.

Repeat test three times and take the average

# Fuel Flow Return Testing

# 2 Diesel Fuel with correct API rating (above 65°F) (**Don't test under 65°F**)

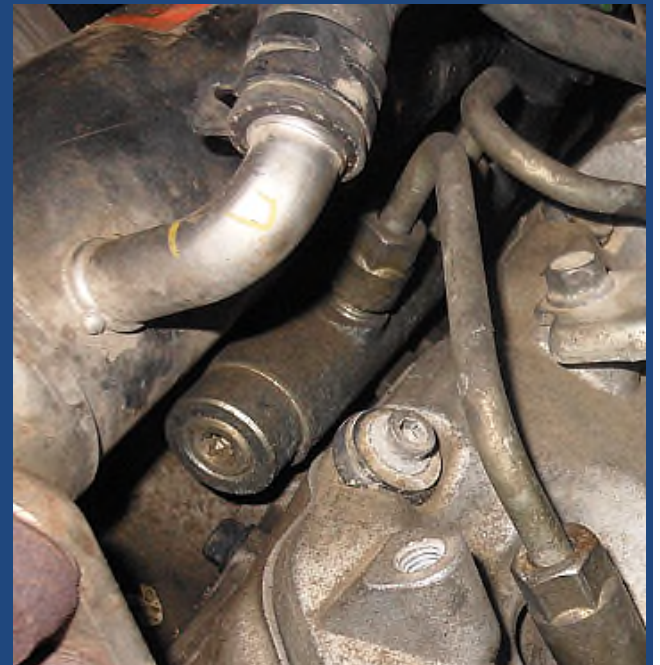
J 38641-B Diesel Fuel Quality Tester to measure the fuel specific gravity (API Rating)

30-34 = 3 ml - 12 ml ←

35-39 = 4 ml - 16 ml ←

40-44 = 5 ml - 20 ml ←

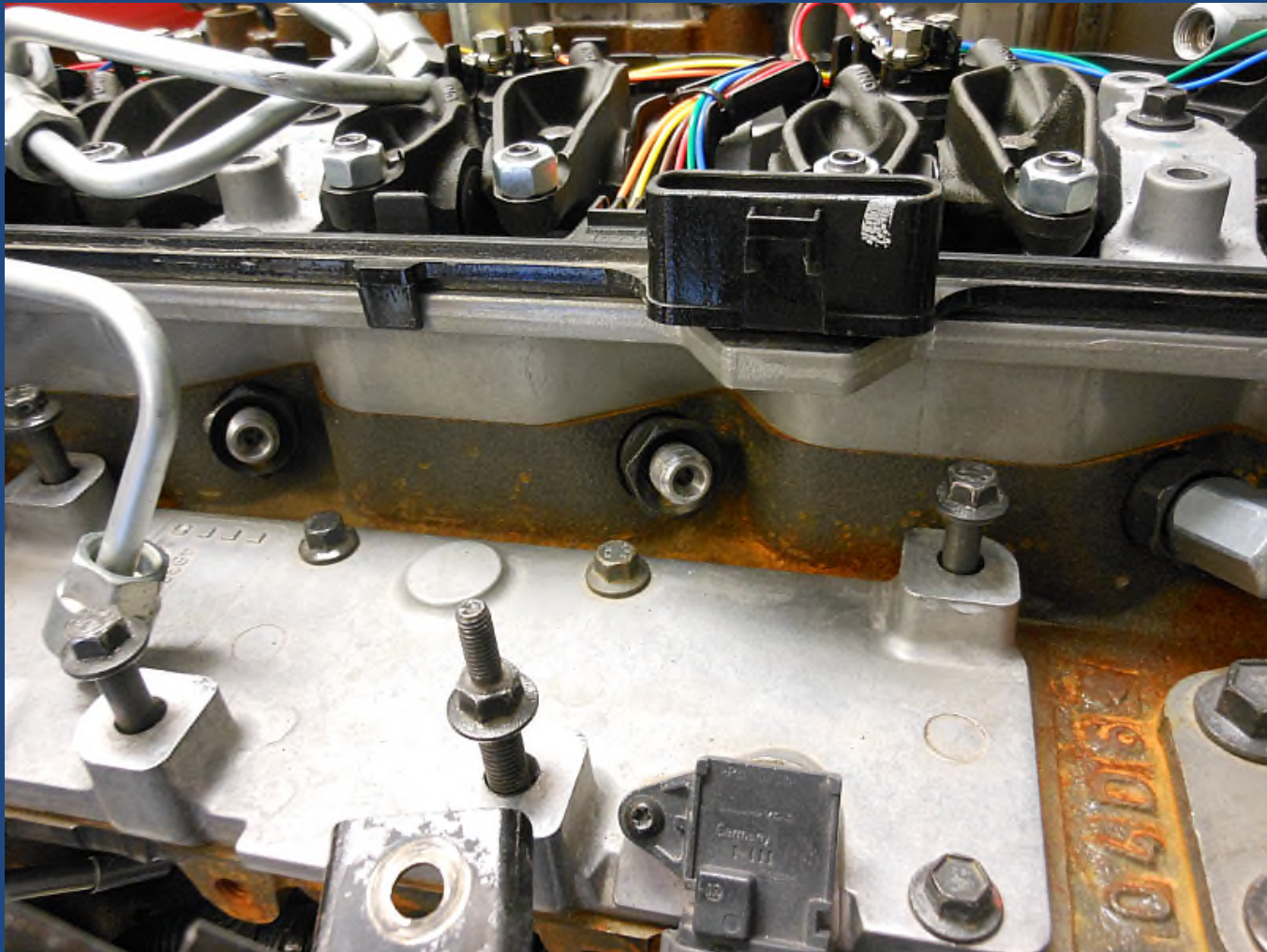
Unless you know the exact API rating the above values are only an approximate



# Too much return flow

Decide which injector is the problem

# Capping off injectors



This **Sucks** on with some manufactures  
(maybe all)

We have never replaced a Dodge Cummins  
injector where the truck wasn't back within a  
short time with the same problem

# Injector Problems

Bad injectors will cause **extended cranking**, **crank and not start**, **start and die**, **white smoke**, and **loss of power** problems

1. Returning too much fuel may be caused by
  - 1A. Worn internal components
  - 1B. Cracked bodies

If the body of the injector is cracked and returning too much fuel, the crankcase will also be overfull from diesel fuel

# Injector Correction Code

Each injector has a six digit alphanumeric correction code

The code identifies the injector's calibration

If replacing any or all of the injectors the new code must be programmed into the PCM

If the PCM is replaced the correction codes for each injector must be programmed into the new PCM

# Injector Quality Control Code

The codes relates to the calibrated flow rate of the injector

This allows the ECM to correct the injection quantity to compensate for manufacturing tolerances



# Wrong Correction Code

P268C Cylinder 1 injector data incompatible

P268D Cylinder 2 injector data incompatible

P268E Cylinder 3 injector data incompatible

P268F Cylinder 4 injector data incompatible

P2690 Cylinder 5 injector data incompatible


P2691 Cylinder 6 injector data incompatible

**AutoEnginuity's ScanTool** [Minimize] [Maximize] [Close]

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: Injector Quantity Adjustment Initiate < Done >

This test will enable the user to program the injector quantity adjustment values for each individual injector. In order to perform this test, the engine must NOT be running.

Code	Description
Click back (<) or next (>) to select the injector you wish to program and click on done when finished.	
	--> Injector #1: 6ZRYAC
	Injector #2: 8AZYBP
	Injector #3: 7Z8YA3
	Injector #4: 7Y8PBY
	Injector #5: 46ZWAC
	Injector #6: 5X85BC
	Exit



- 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: **Injector Quantity Adjustment**

Initiate

<

Done

>

This test will enable the user to program the injector quantity adjustment values for each individual injector. In order to perform this test, the engine must NOT be running.

Code	Description
	Please enter the new 6 digit coding value for Injector #1 Current Coding Value: 6ZRYAC Click done when you have finished entering the new value.

# Piezo Injectors

Piezo injectors are much faster than the solenoid type injector

Piezo injectors can fire as many as seven times for one intake cycle; five times seems to be the most common

# Piezo Injectors

Piezo injectors have 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

At turn off, the piezo stack shrinks, a spring closes the pintle

## Piezo injectors key benefits

They open and close much faster than conventional injectors

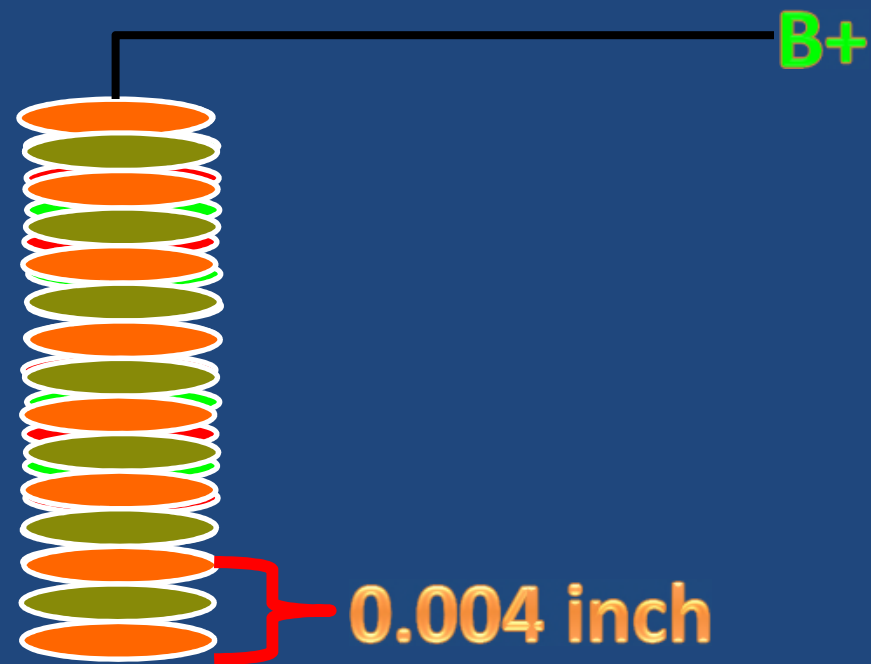
That allows a more precise control of the injection  
Which determines how much fuel is sprayed

They also provide feedback by producing minute fluctuations in the electricity used to activate them

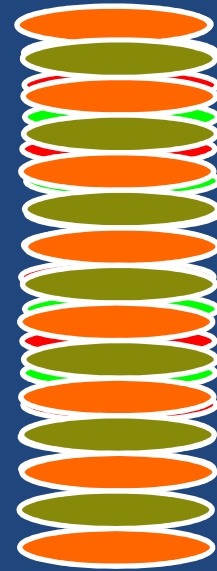
As an example, if the computer commands an IP time of 0.005 second, and the injector response shows that it opened for only 0.00496 second the computer can compensate for the lean condition on the next firing of that injector

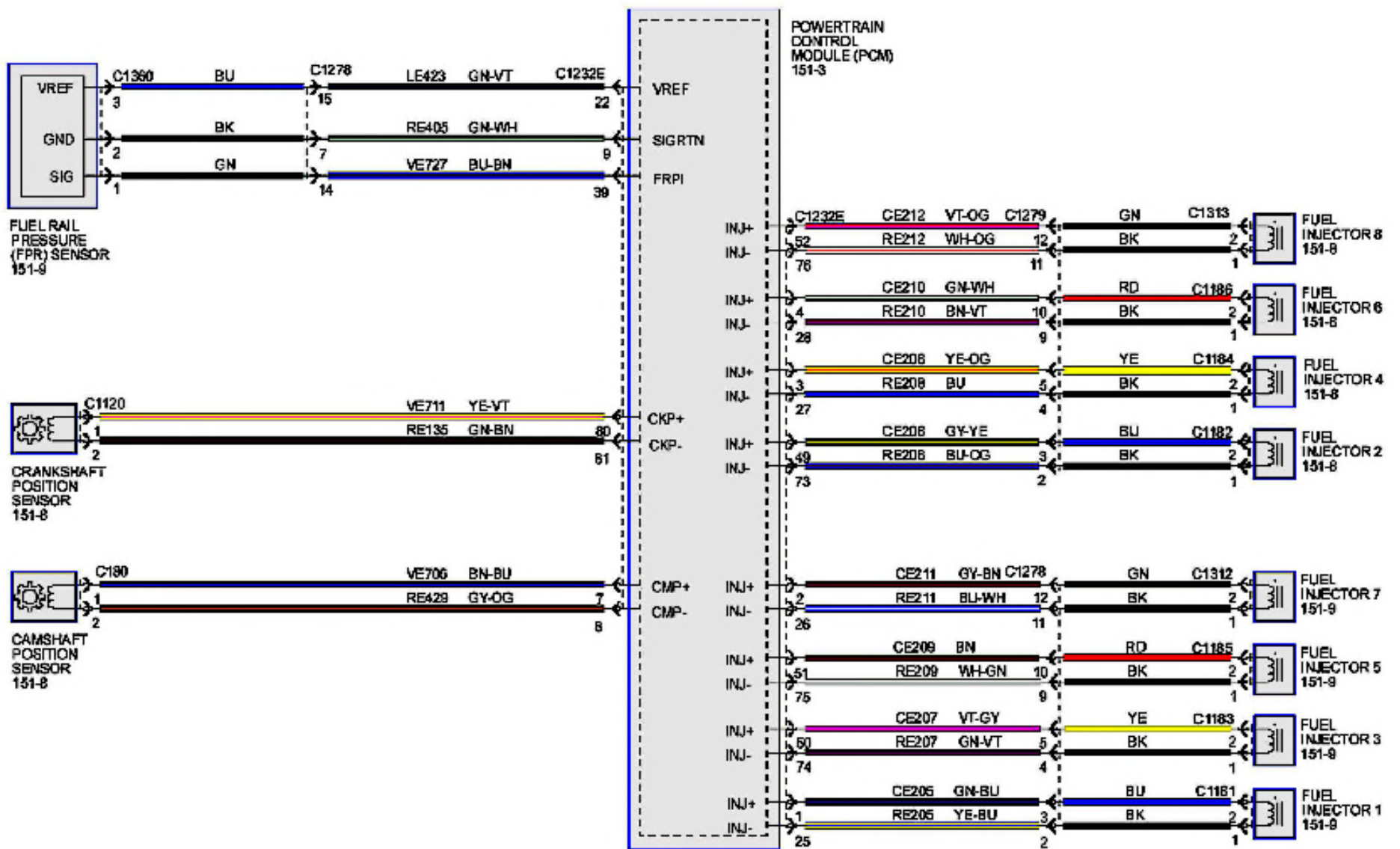


# The Piezo electric crystals Expand with an electrical field



**The Piezo electric injector is  
7 times faster than the  
Solenoid type injector**



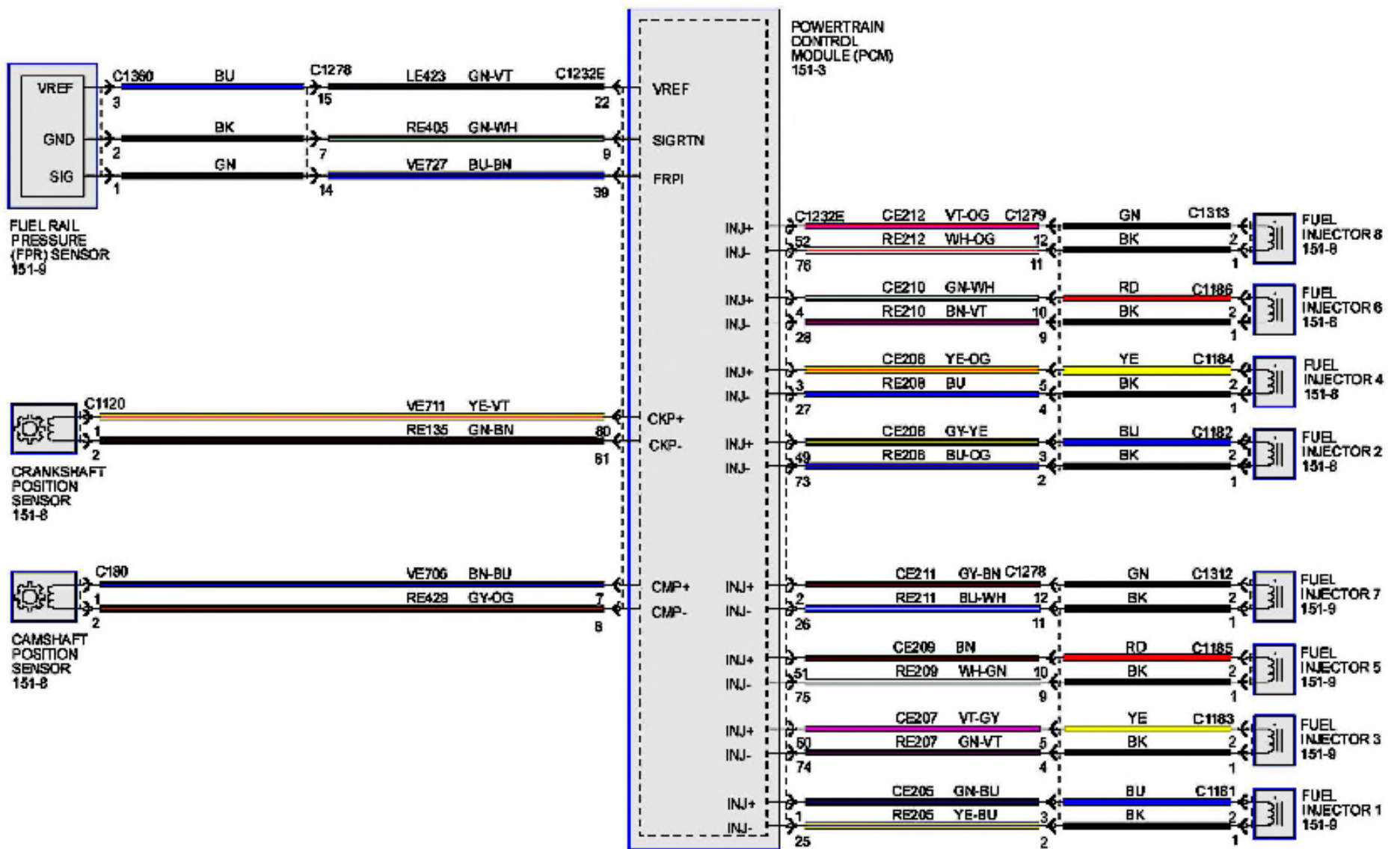


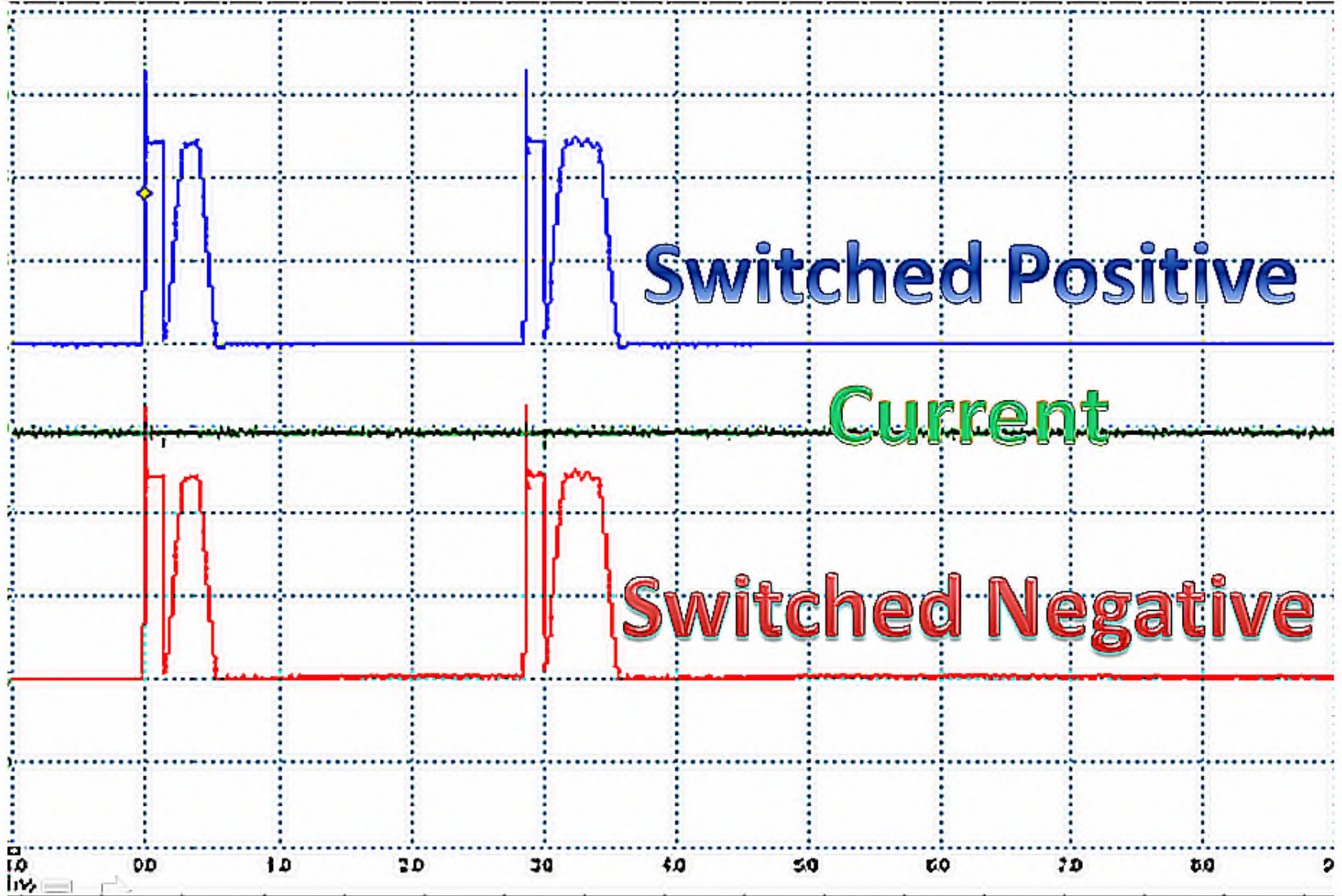
# Switching the polarity

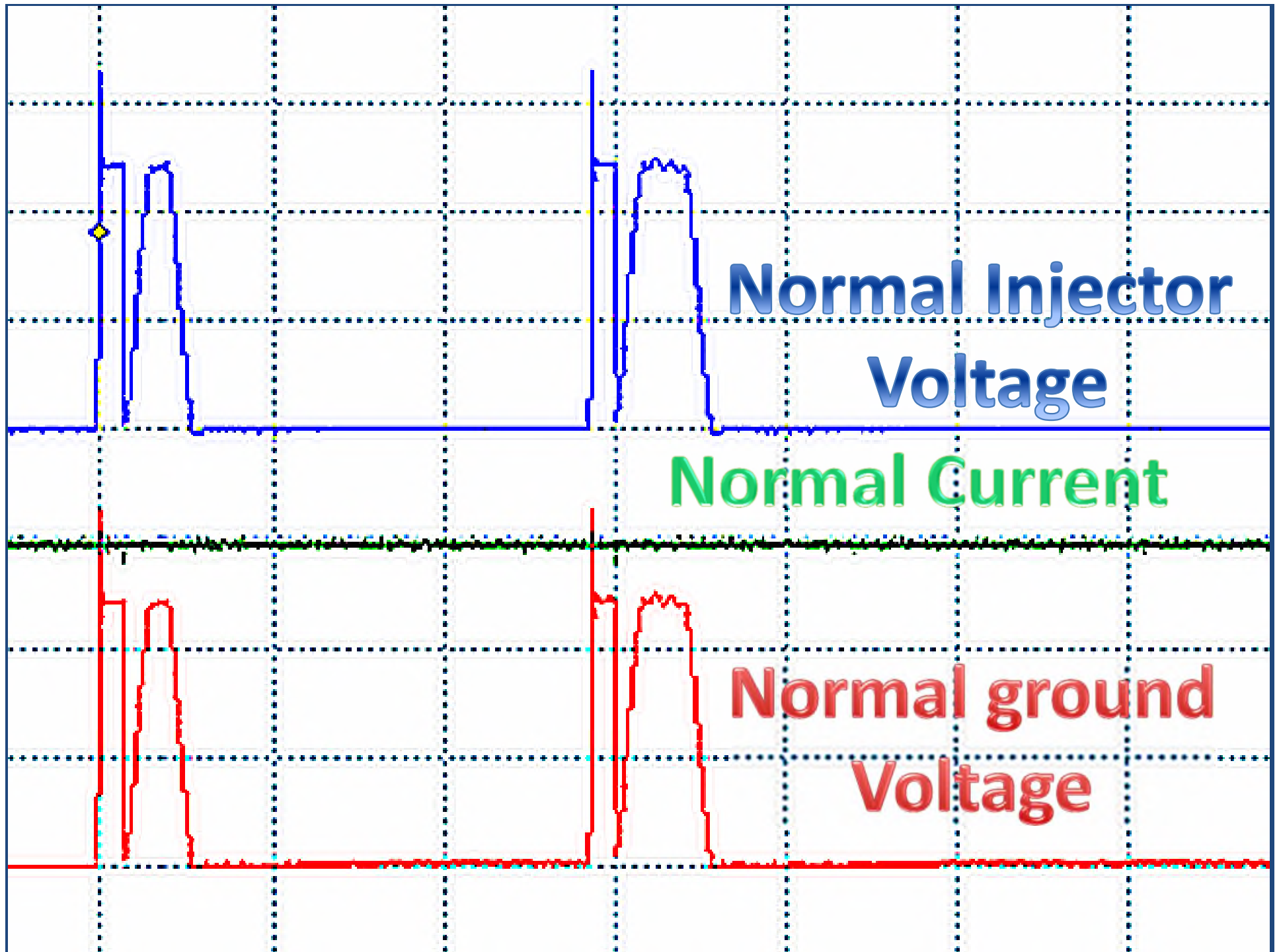
When the Engine Control Module (ECM) determines that the correct injector on time has been reached it switches the polarity of the piezo actuator which causes the piezo discs to return to a non-energized state

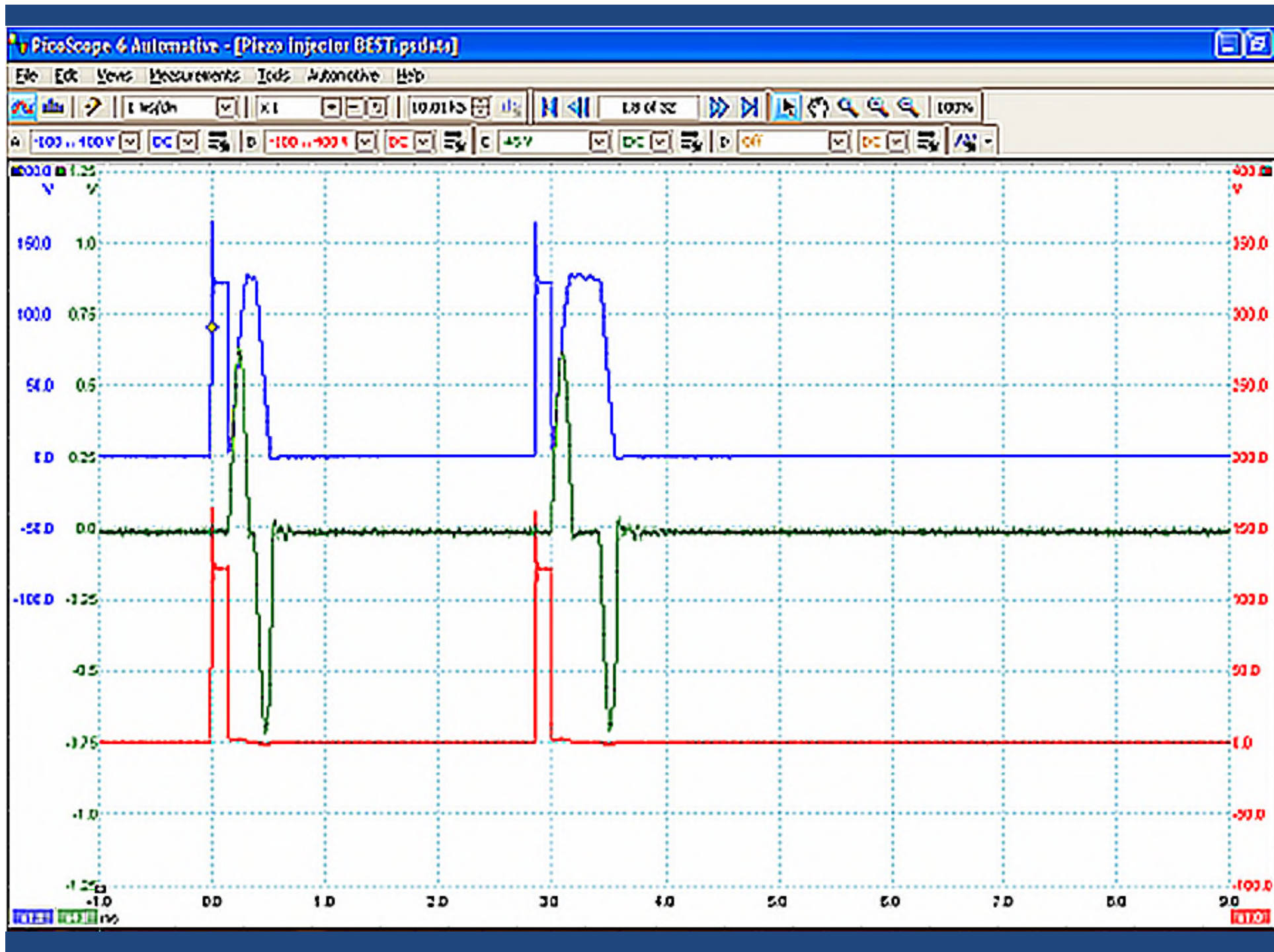
Energized = Expand

Non-Energized = Contracts







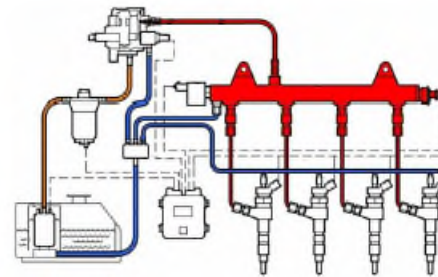


# Common Rail Diesel Fuel Systems

Fuel system diagnosis

## Basics first!

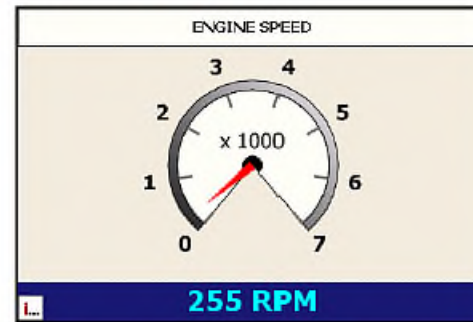
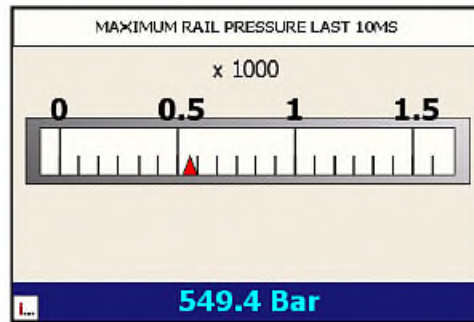
- Sufficient diesel in the fuel tank?
- Fuel contamination (eg from petrol).
- Fuel leaks and damage to components.
- Battery state of charge?
- Adequate low pressure fuel supply from fuel tank?
- Does engine start or crank and try to start?
- Is white smoke emitted from exhaust during engine cranking?  
(not always easy to see but indicates some fuel is entering cylinders).
- Are any DTC's stored in fault memory of engine ECM?



# Common Rail Diesel Fuel Systems

Fuel system diagnosis

Is the system capable of generating sufficient fuel pressure?



Typical minimum '**manufacturer specified**' value during engine cranking:  
approximately between 200 – 300 Bar

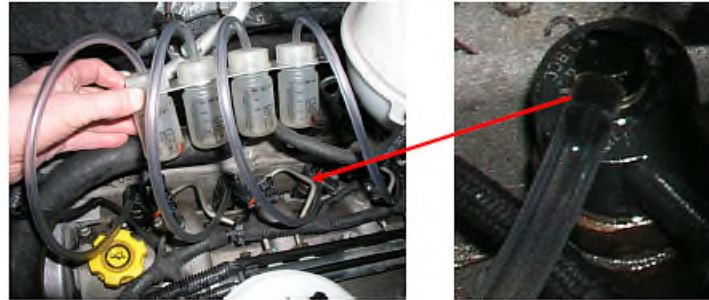
In practice, the figure is usually higher for a good system. Above example shows fuel pressure during engine cranking.



# Common Rail Diesel Fuel Systems

Fuel system diagnosis

Injector leak back test

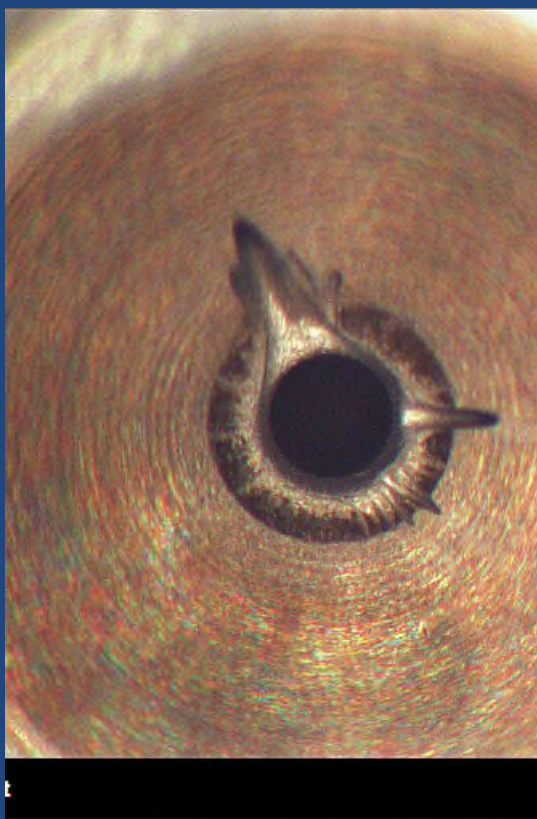


There should **not** normally be any fuel collected in receptacles during engine cranking.

Example of acceptable leak back value with engine idling:

approximately 20ml per injector over a 2 minute period.  
(Always refer to manufacturer data for exact specifications)





# Benefits of Common Rail

Reduced emissions

Higher performance

Higher fuel efficiency

Reduced particulate emissions

Reduced noise





# Pressure Drop

The common rail maintains a constant pressure drop across the fuel injector spray nozzle  
Regardless of engine load

$$Eu_1 = 1.202 Re_1^{-0.048 \pm 0.044} \left( \frac{d}{D} \right)^{-4.380 \pm 0.248} \quad (2.5)$$

$$Eu_{tp} = Eu_1 \left[ 1 + 0.003 Re_1^{-0.536 \pm 0.063} Re_g^{0.797 \pm 0.060} \left( \frac{g \mu_{eff}^4}{\rho_1 \sigma_1^3} \right)^{-0.125 \pm 0.021} \left( \frac{d}{D} \right)^{0.205 \pm 0.166} \right] \quad (2.6)$$

$$Eu_1 = 1.202 Re_1^{-0.048 \pm 0.044} \left( \frac{d}{D} \right)^{-4.380 \pm 0.248} \quad (2.5)$$

$$Eu_{tp} = Eu_1 \left[ 1 + 0.003 Re_1^{-0.536 \pm 0.063} Re_g^{0.797 \pm 0.060} \left( \frac{g u_{eff}^4}{\rho_1 \sigma_1^3} \right)^{-0.125 \pm 0.021} \left( \frac{d}{D} \right)^{0.205 \pm 0.166} \right] \quad (2.6)$$

# Yea RIGHT!

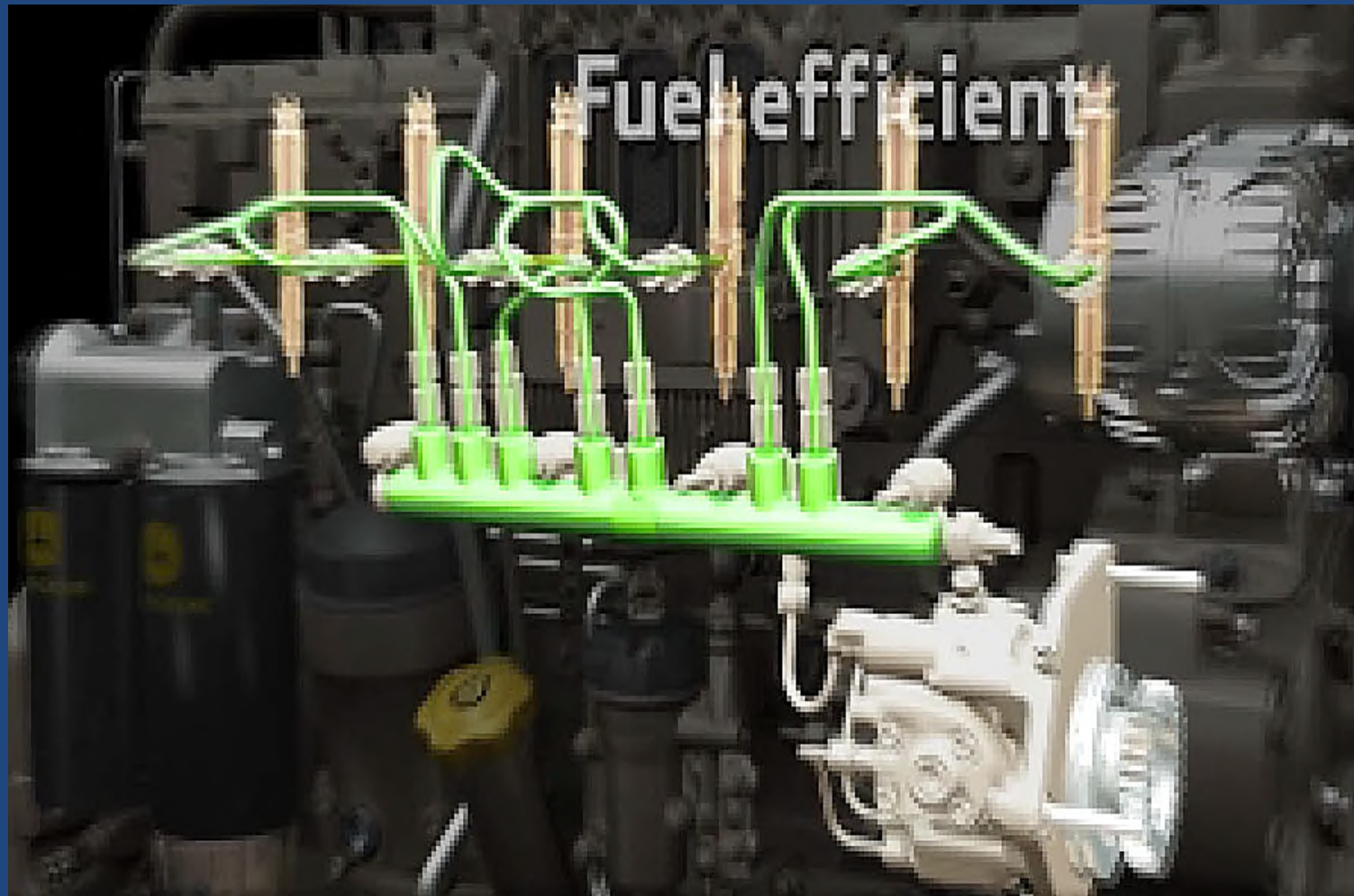
Were going to let the on board computer take care of that

**Fuel Control  
Solenoid**



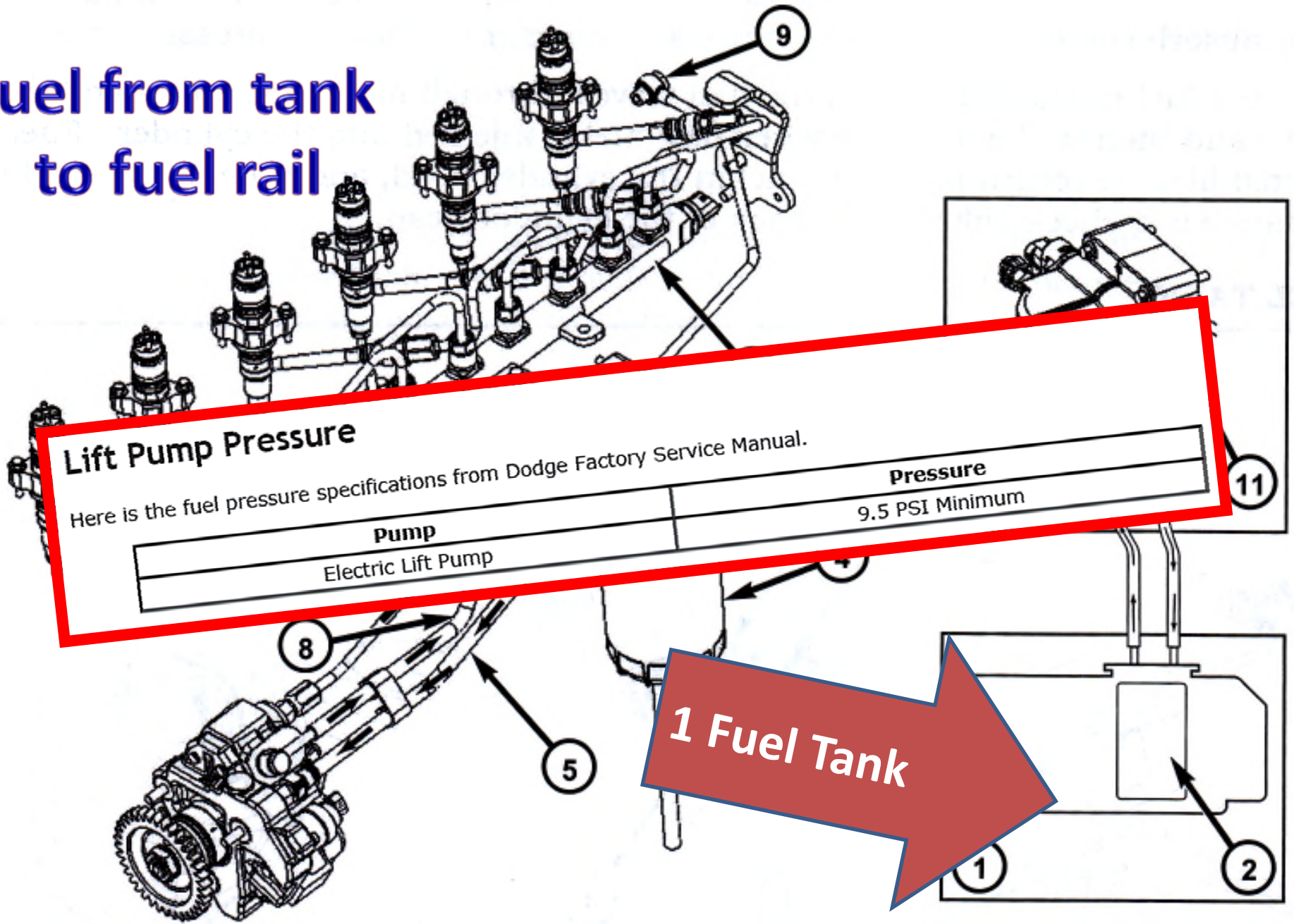
# Common Rail Injection

Common rail supplied by high pressure pump

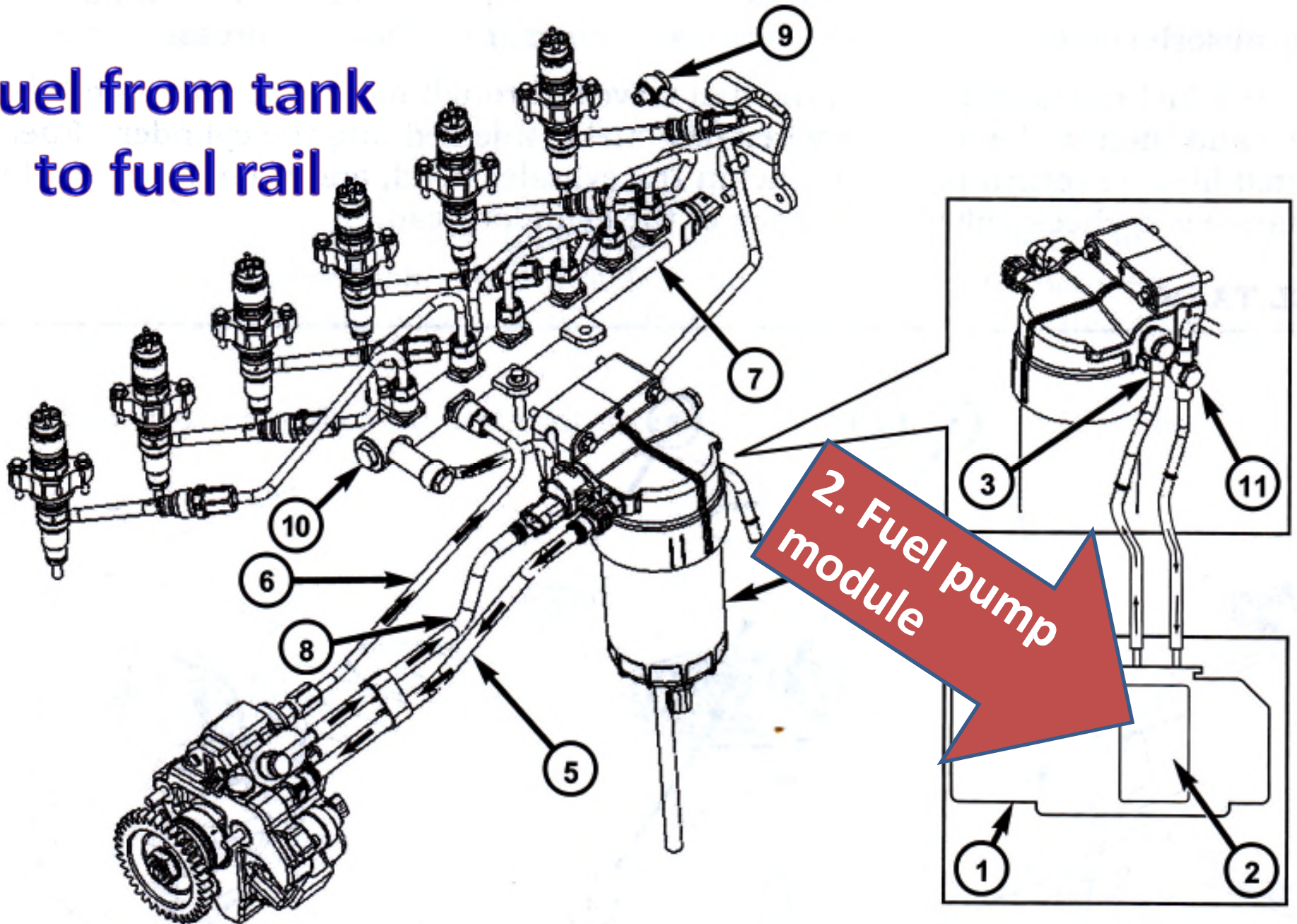




# Fuel from tank to fuel rail



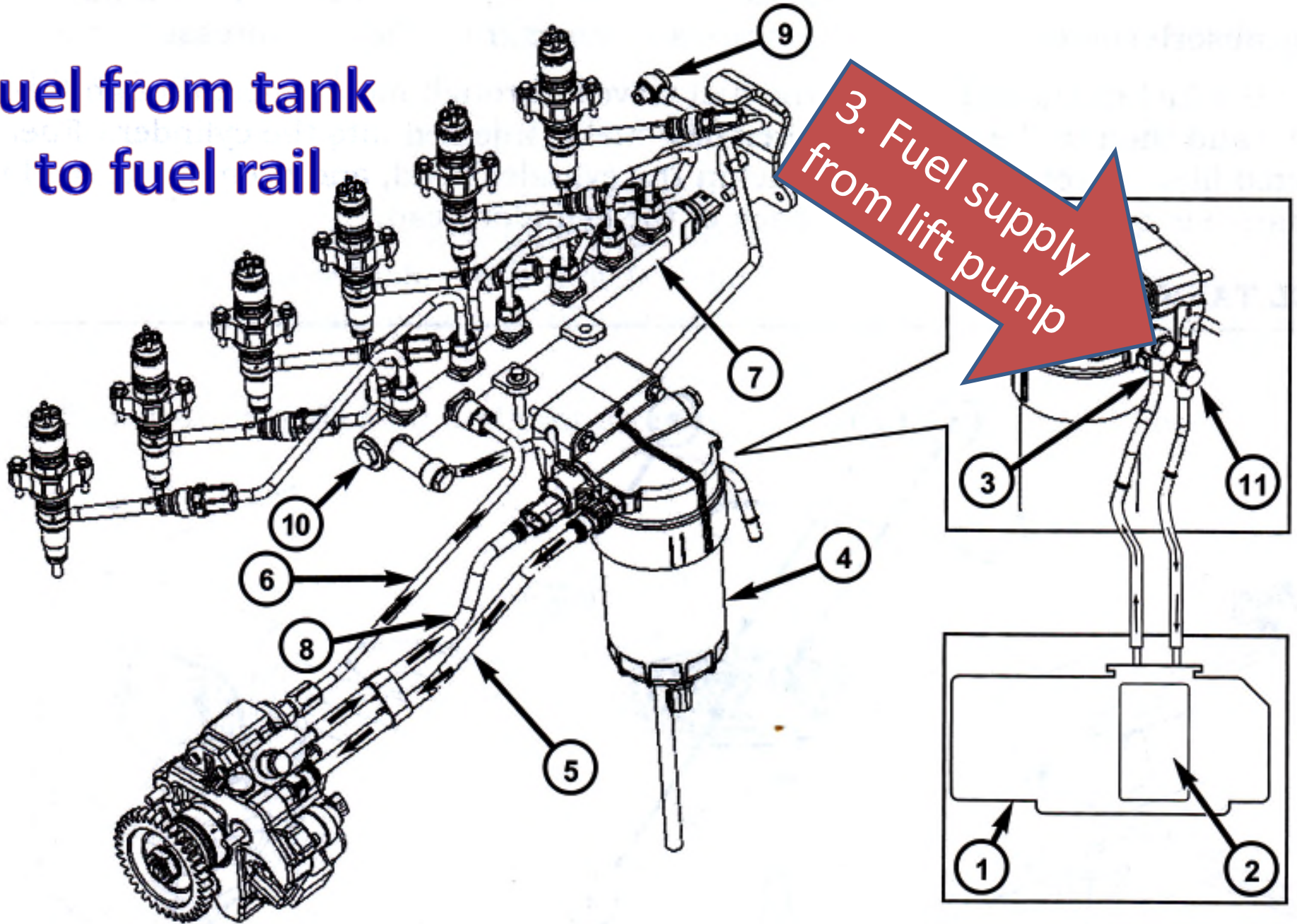
# Fuel from tank to fuel rail



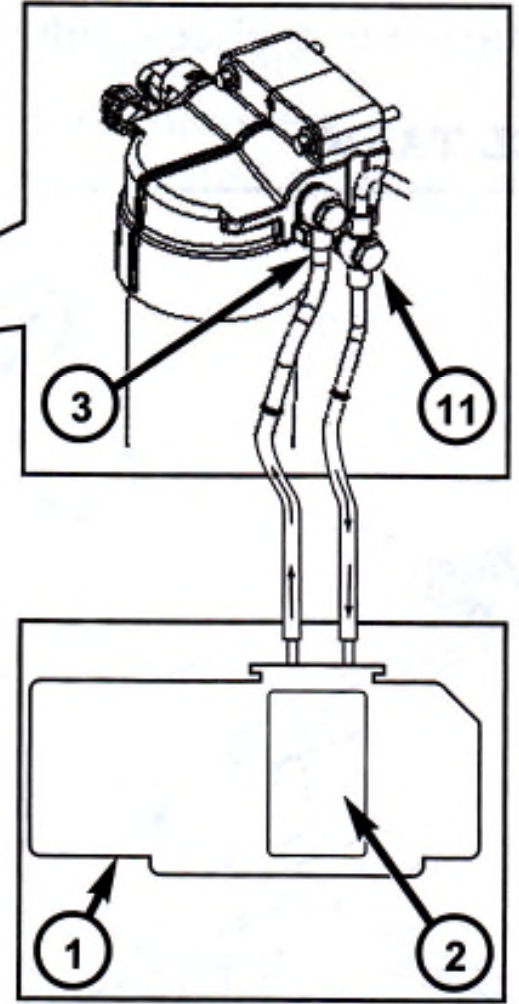
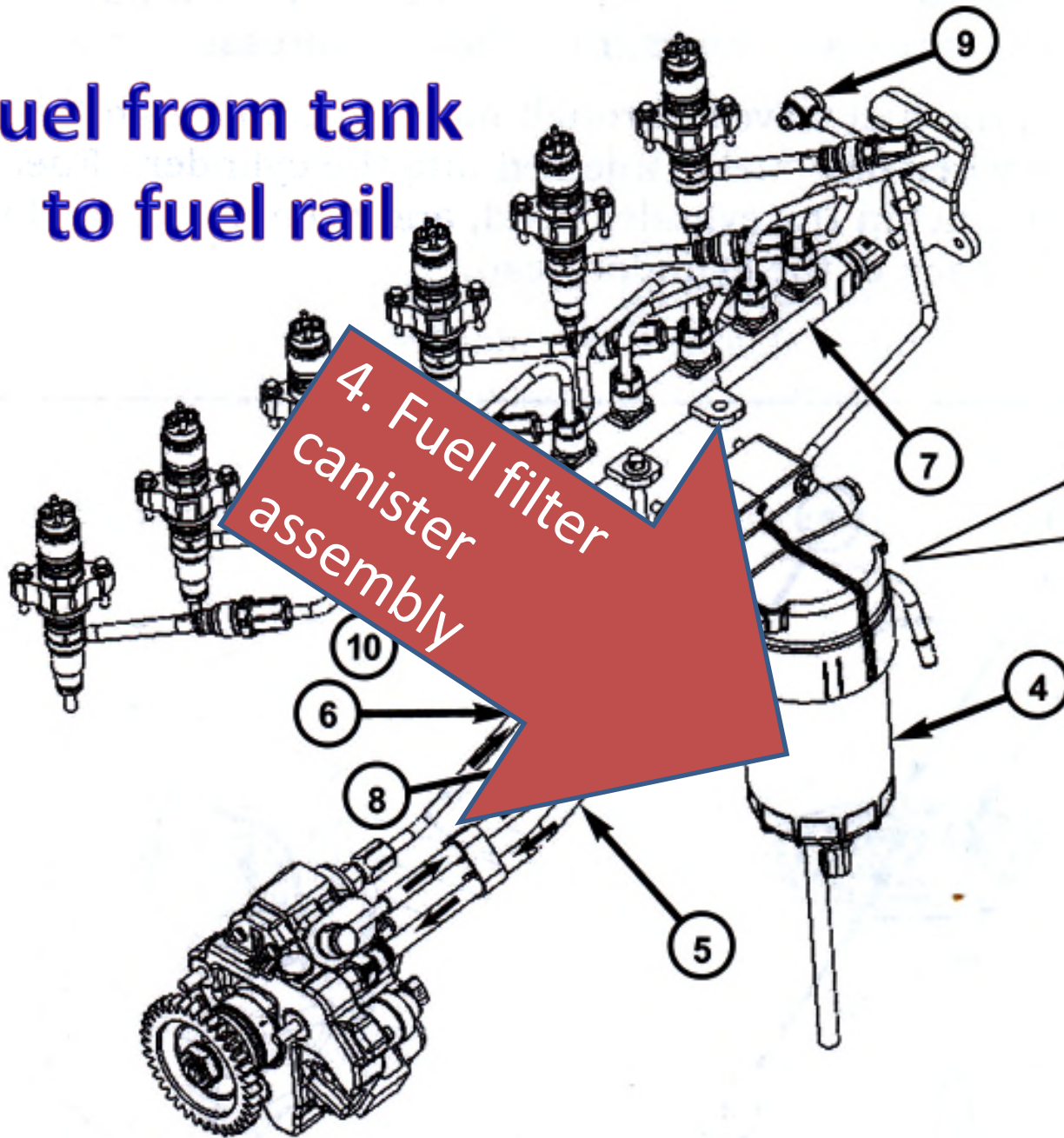
**5 Small holes supply fuel for the entire system when the tank is less than  $\frac{1}{4}$  full**



# Fuel from tank to fuel rail

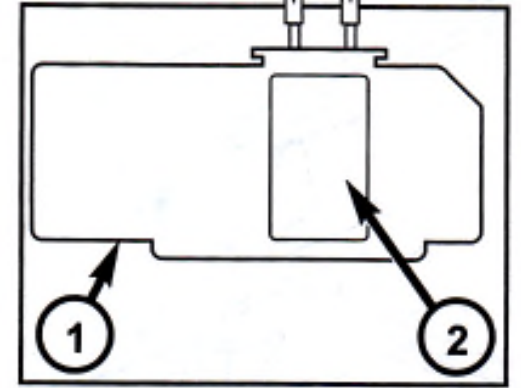
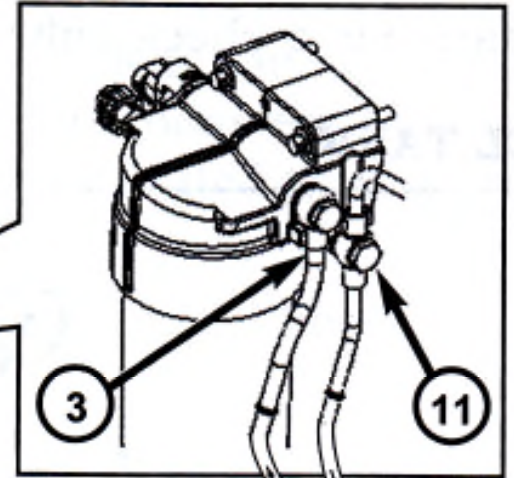
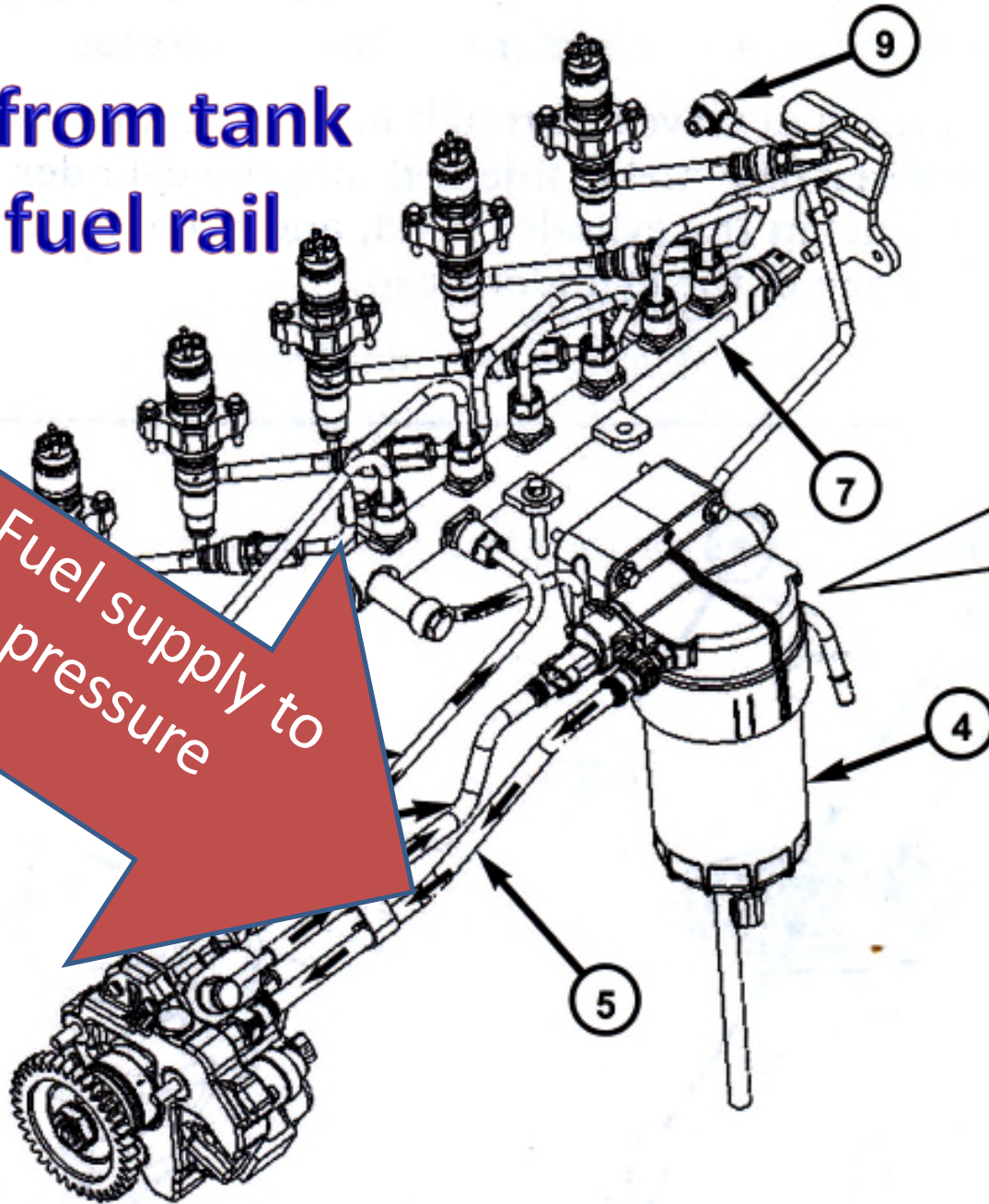


# Fuel from tank to fuel rail



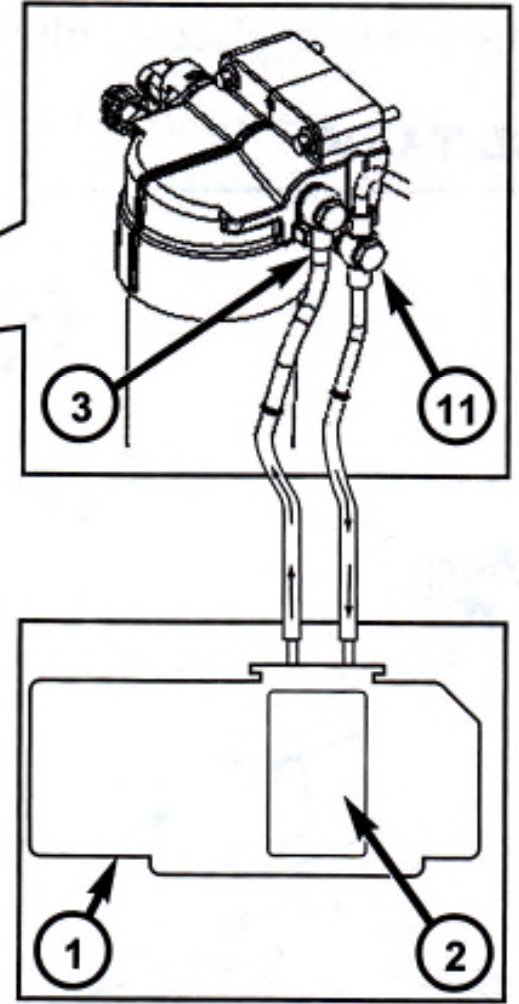
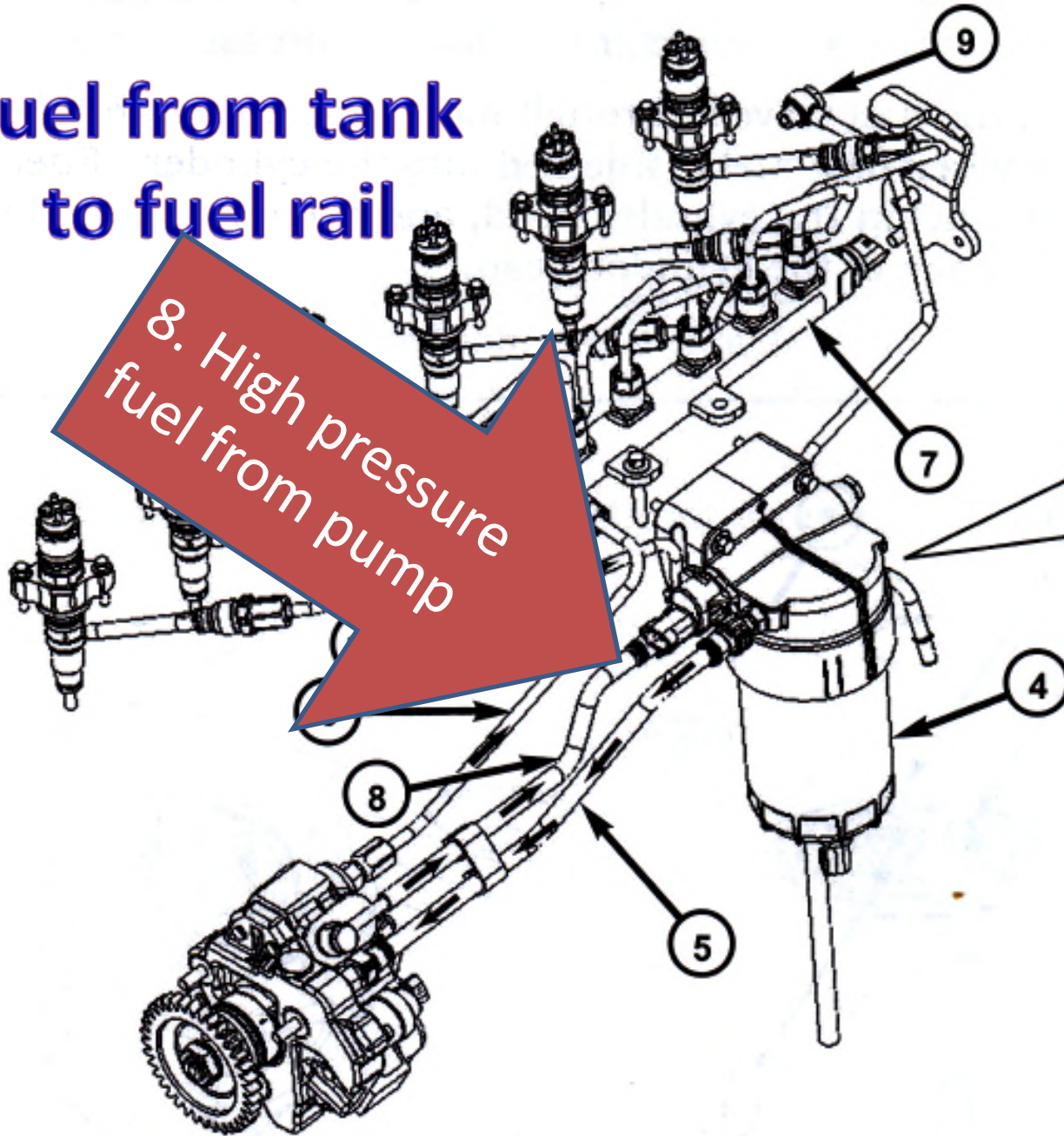
# Fuel from tank to fuel rail

5. Fuel supply to high pressure pump



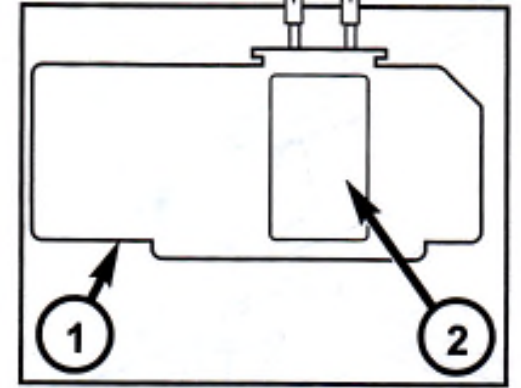
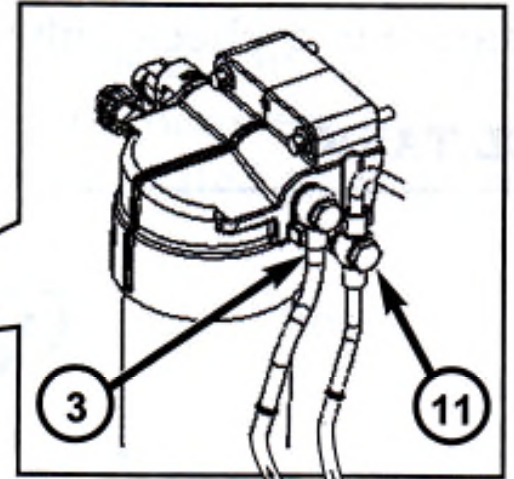
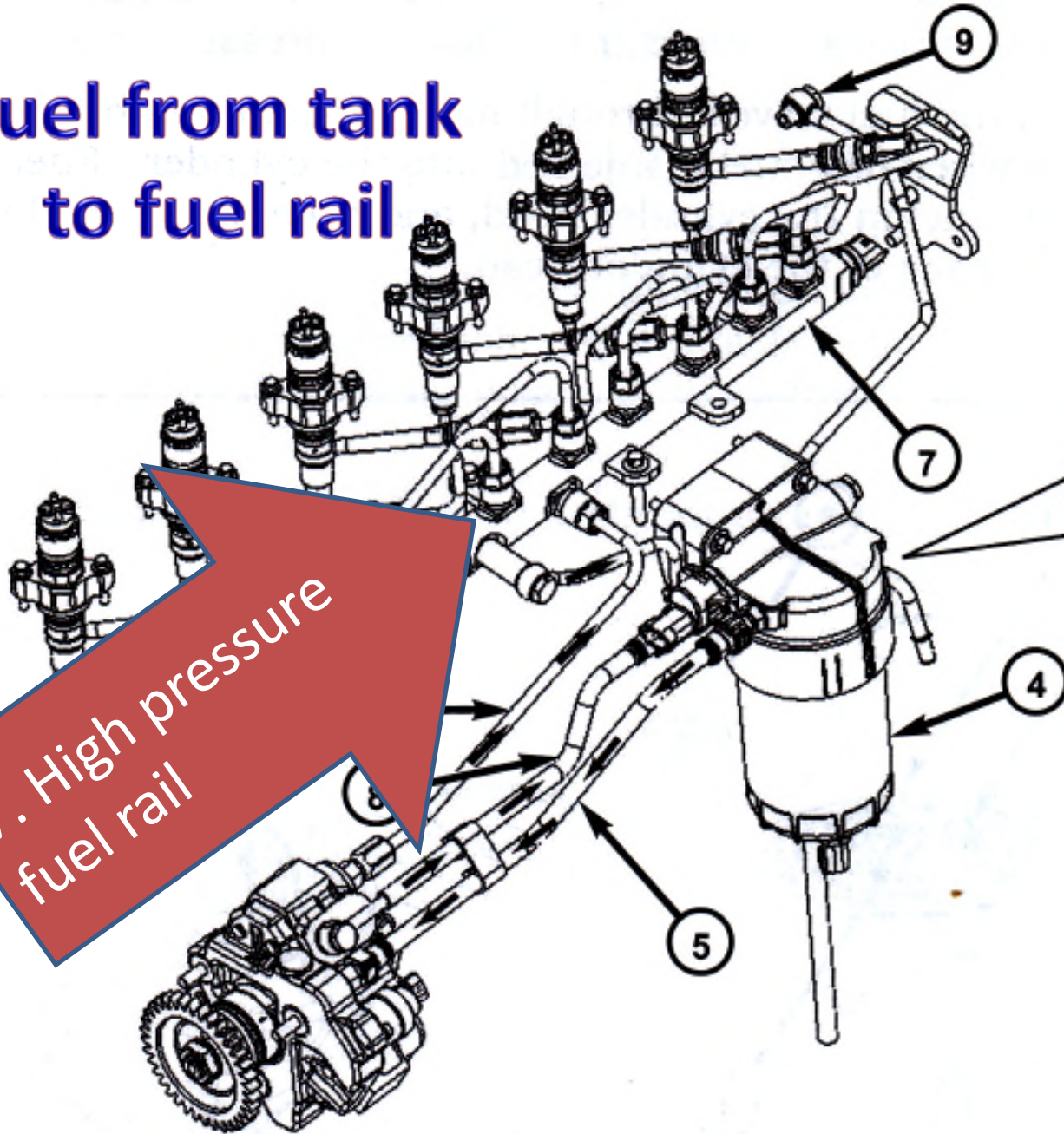
# Fuel from tank to fuel rail

8. High pressure fuel from pump



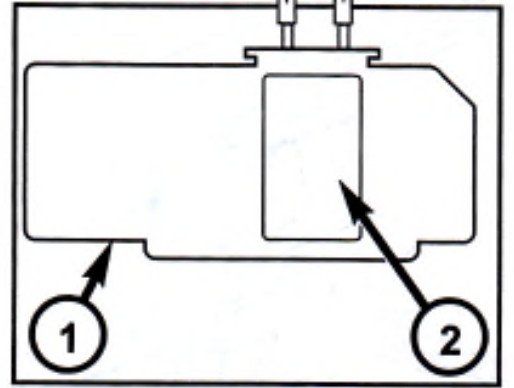
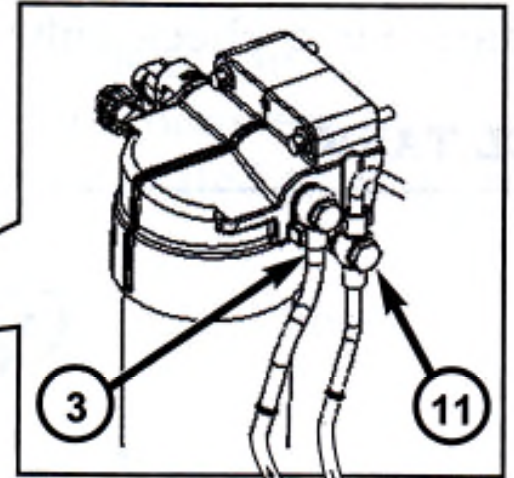
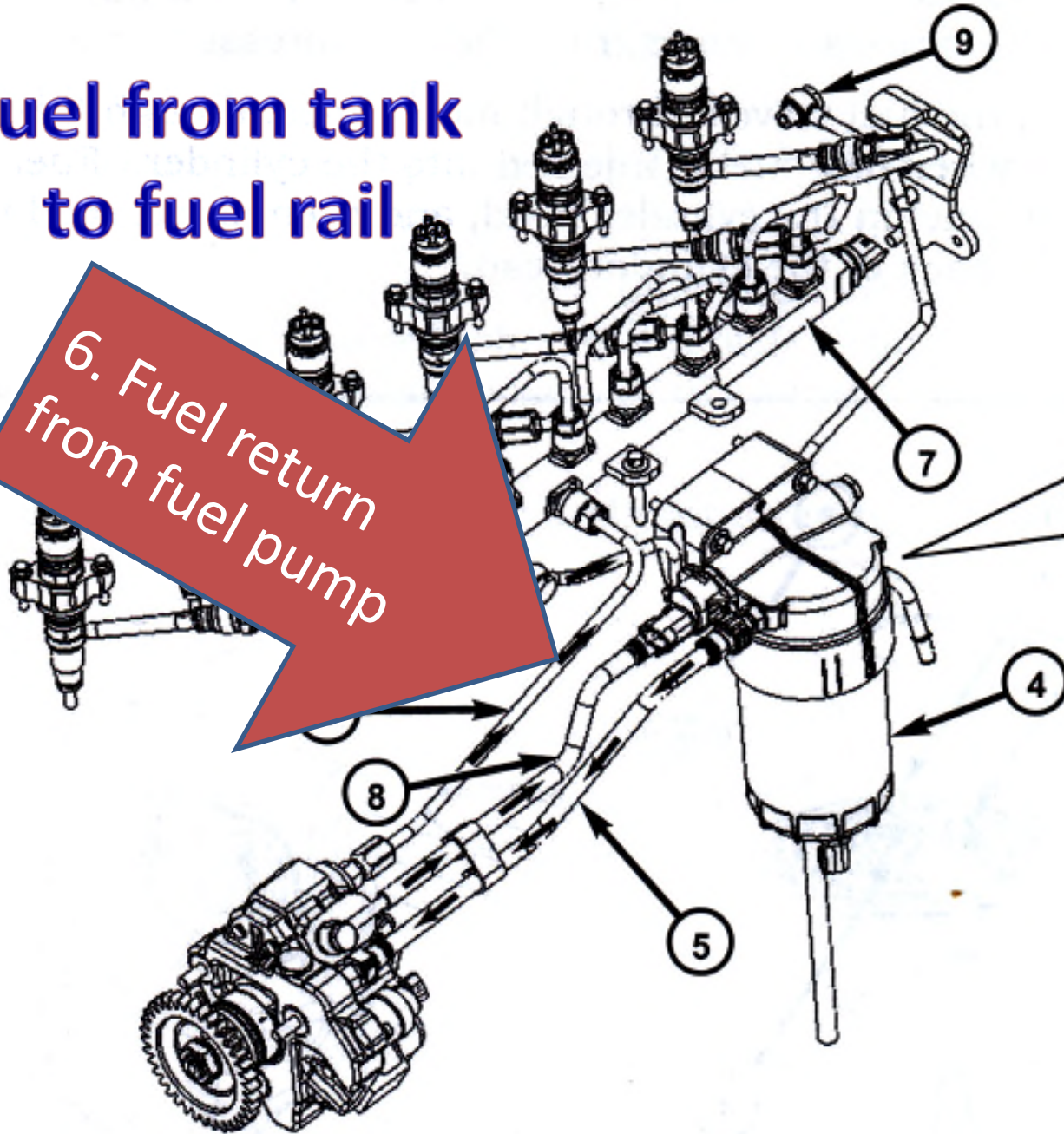
# Fuel from tank to fuel rail

7. High pressure fuel rail



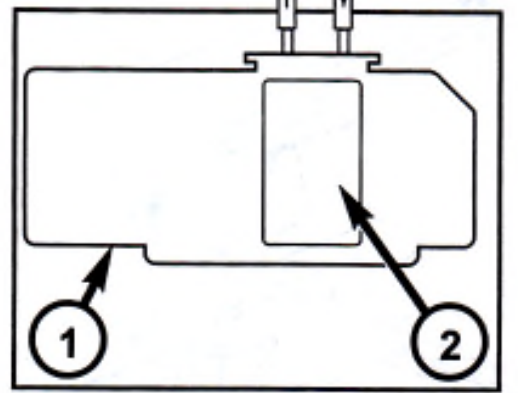
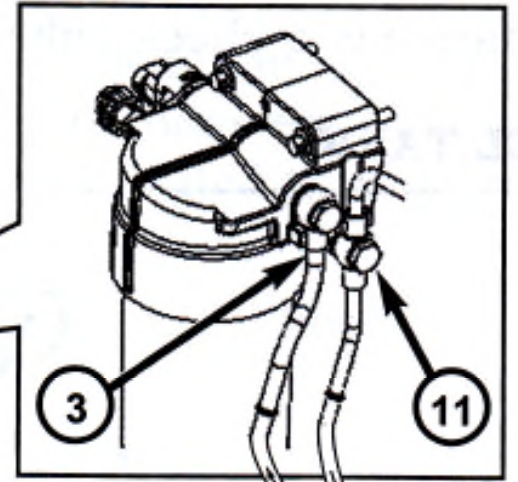
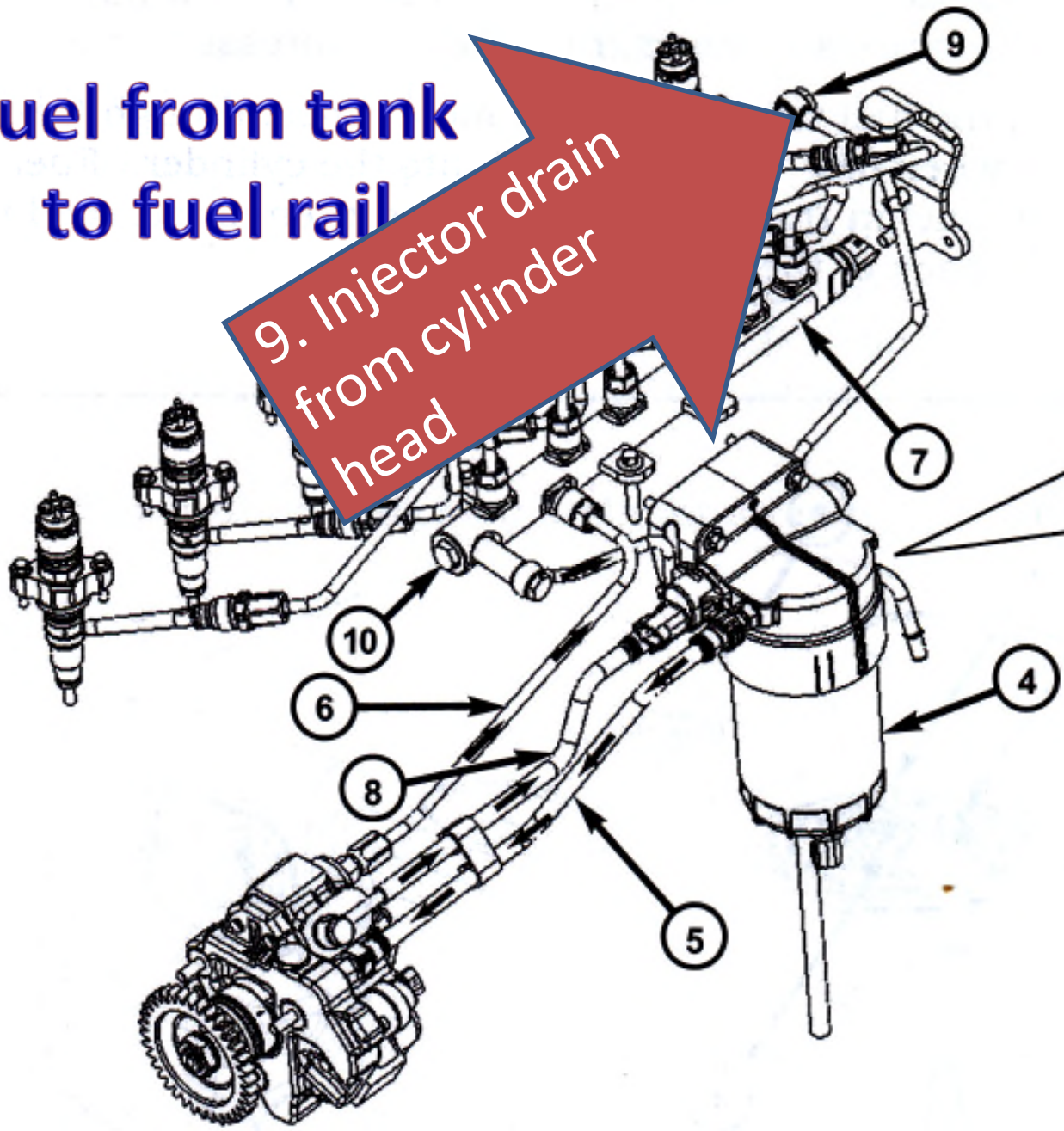
# Fuel from tank to fuel rail

6. Fuel return from fuel pump



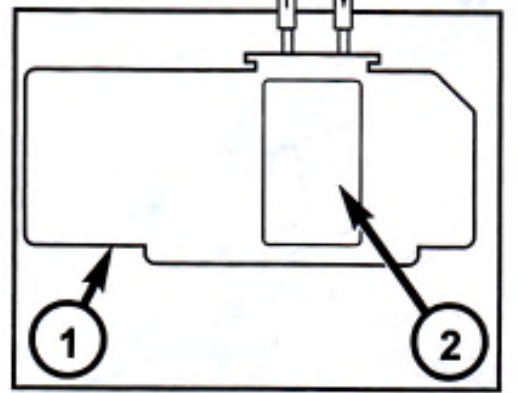
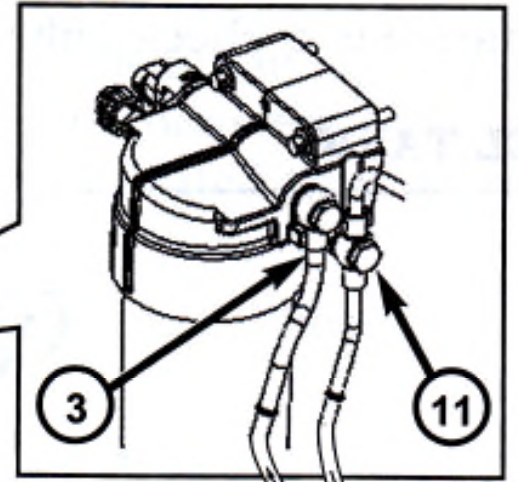
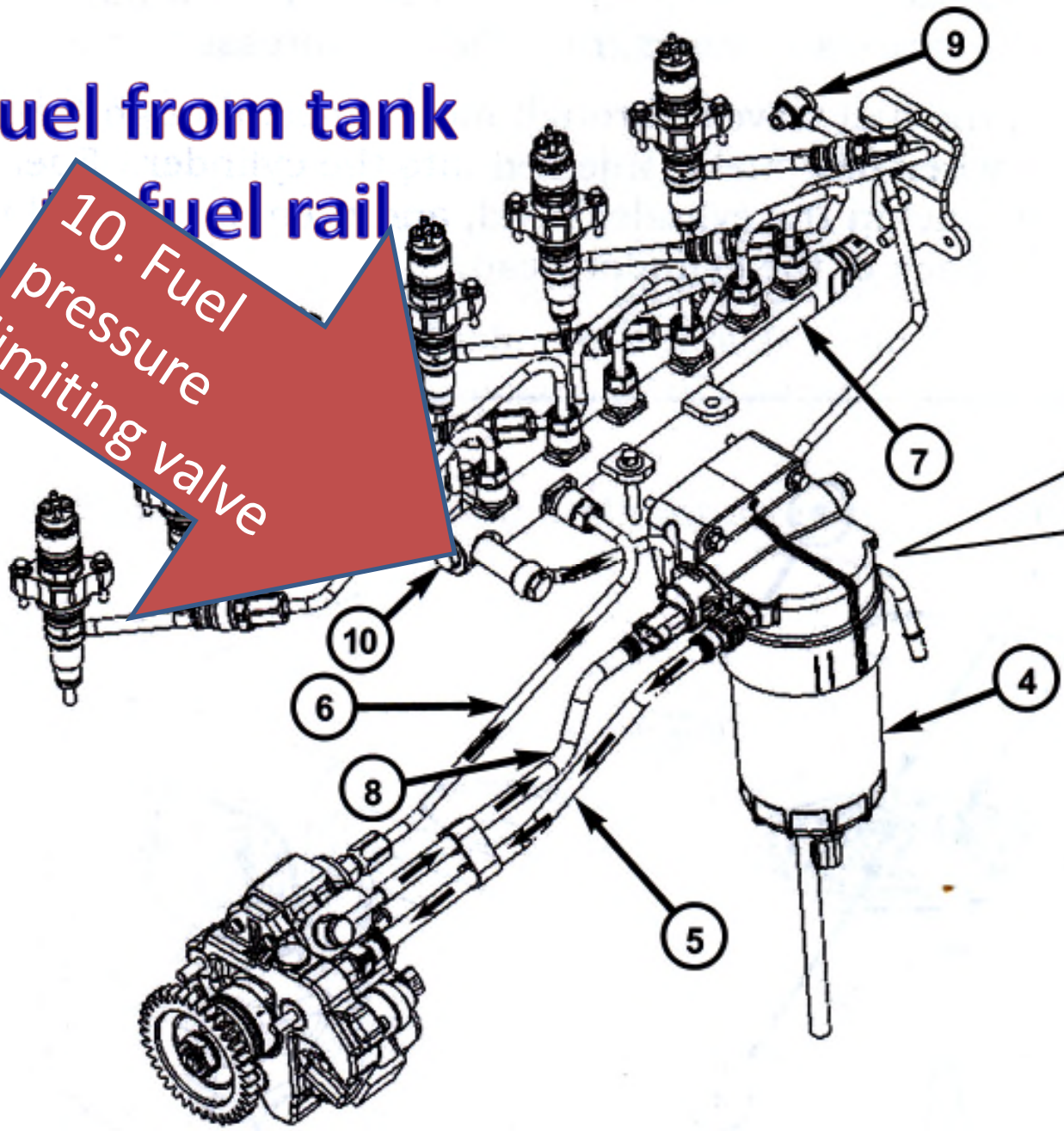
# Fuel from tank to fuel rail

9. Injector drain from cylinder head

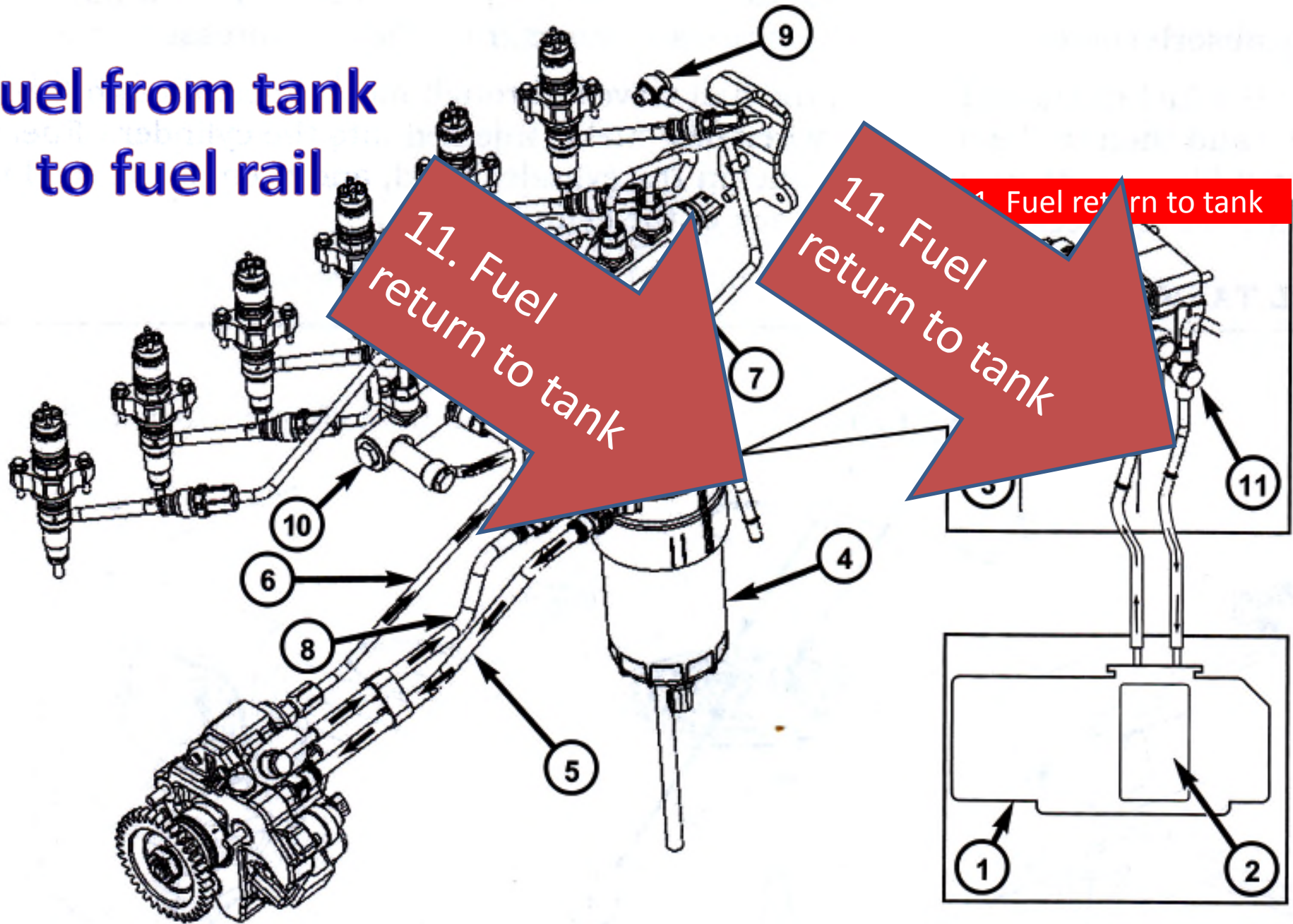


# Fuel from tank fuel rail

10. Fuel pressure limiting valve



# Fuel from tank to fuel rail



11. Fuel return to tank

11. Fuel return to tank

11. Fuel return to tank

1

2

# Fuel

Fuel enters the system from the fuel transfer (lift) pump, not all manufacturers use a lift pump.

The lift pump can be mounted to the engine, frame rail or be in the fuel tank.

The manufacturer selects the location of the pump.

# Fuel Transfer (lift) Pump

The pump is used to transfer fuel from the fuel tank to the injection pump.

Key-on pump operates for 25 seconds.

If engine cranks but doesn't start the pump will operate for 25 seconds.

At cold ambient temperatures the pump may operate while the wait to start lamp is on.

If engine stalls the pump stops immediately.

# Fuel Transfer (lift) Pump

If the injection pump is supplied fuel by a lift pump; the pump must operate to supply fuel without stressing the high pressure pump.

If the lift pump fails, the injection pump will continue to draw fuel through the lift pump; but the intermediate gear pump will be stressed pulling the fuel through the “dead” pump and will eventually fail.

# Symptoms of a bad lift pump

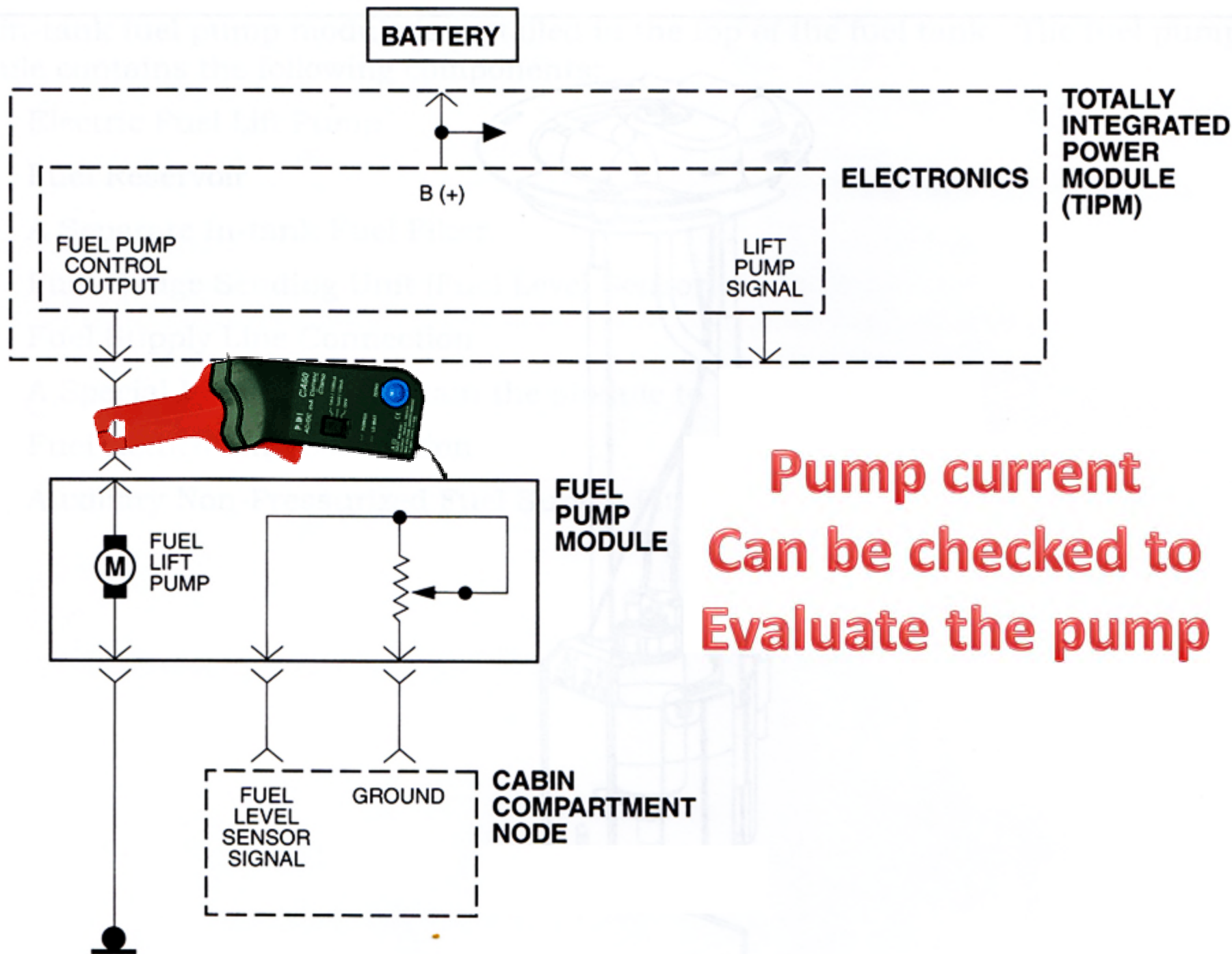
Hard starting

Idle RPM slowly getting lower

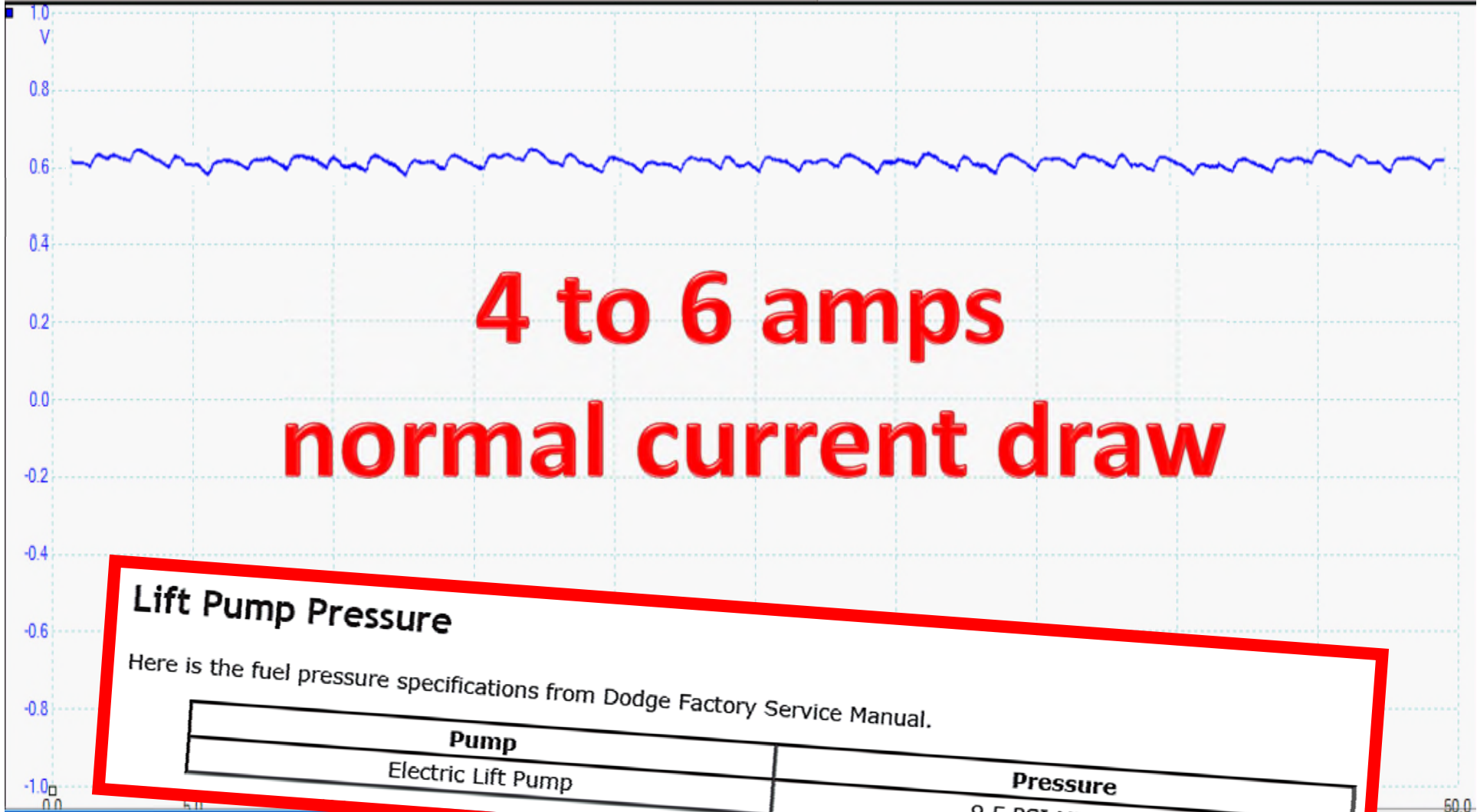
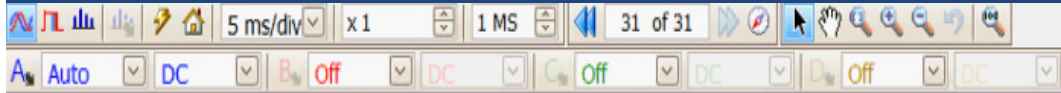
Lack of power/underpowered

Then ...

Crank but no start



**Pump current  
Can be checked to  
Evaluate the pump**



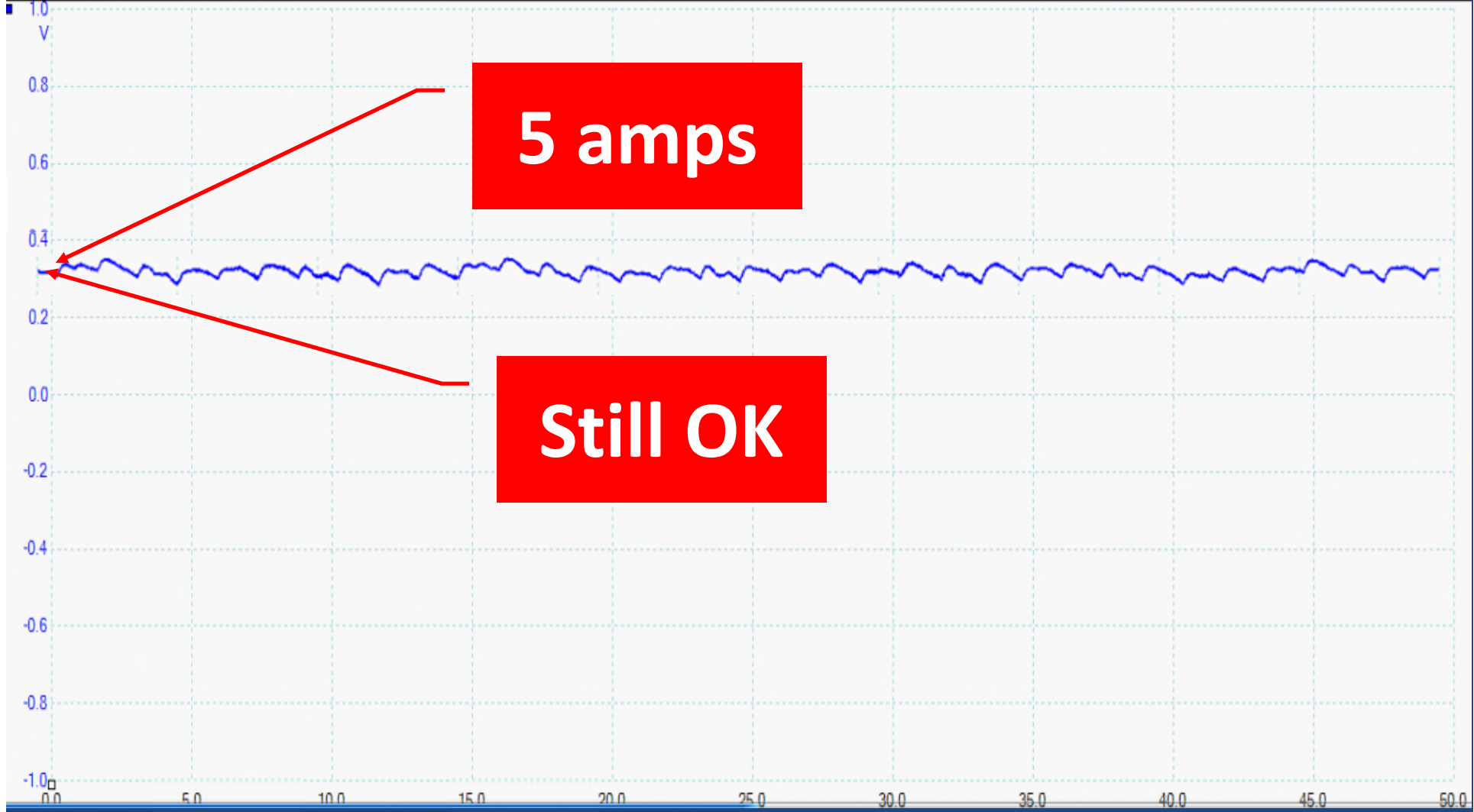
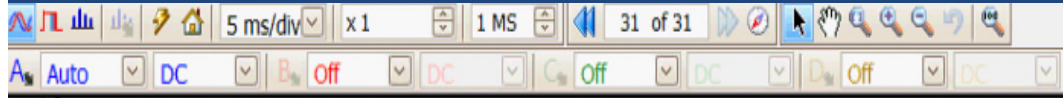
**4 to 6 amps  
normal current draw**

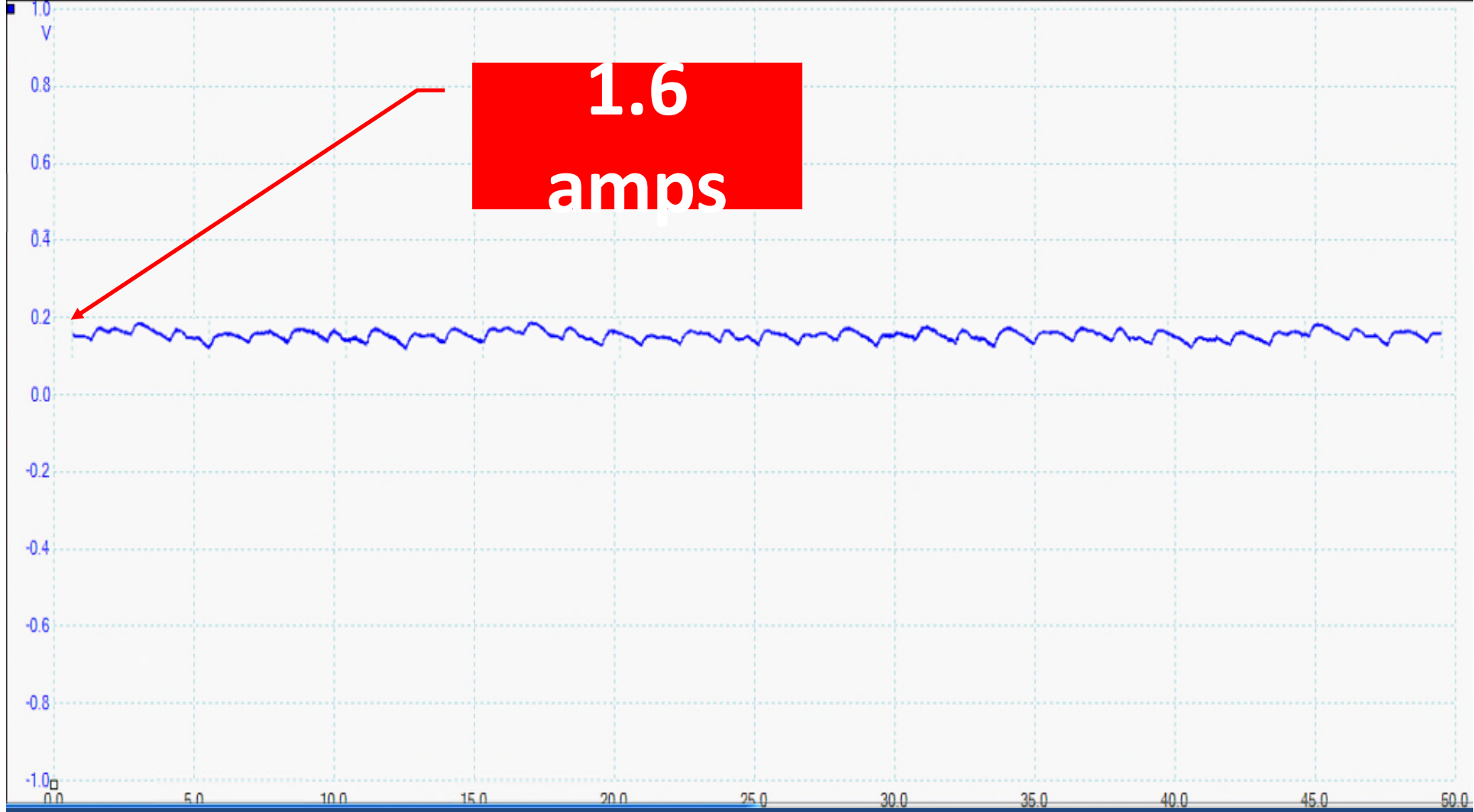
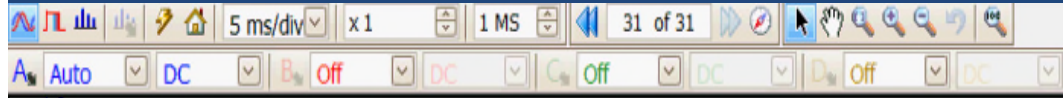
**Lift Pump Pressure**

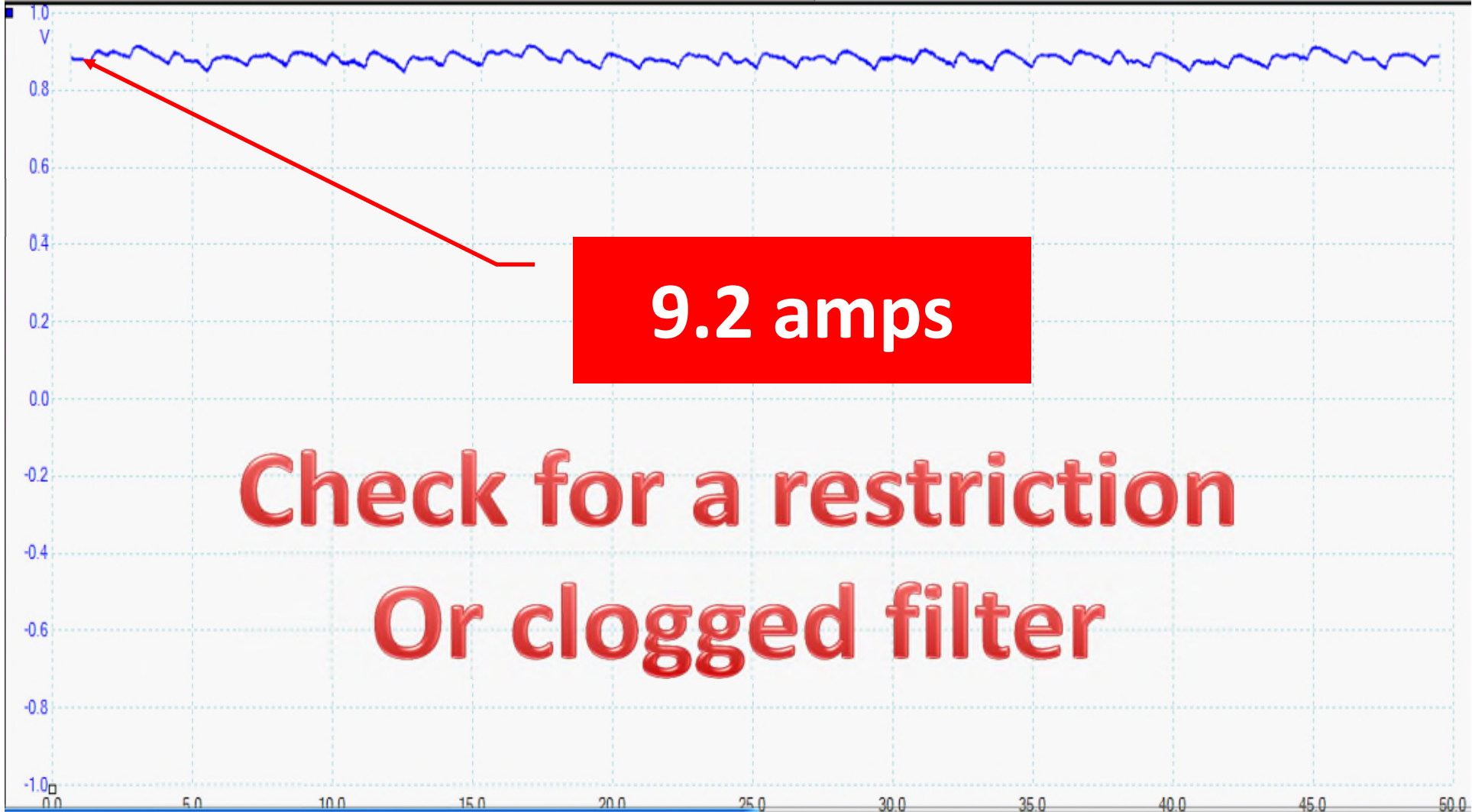
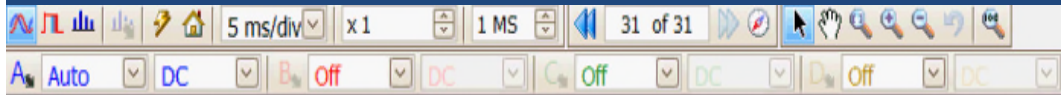
Here is the fuel pressure specifications from Dodge Factory Service Manual.

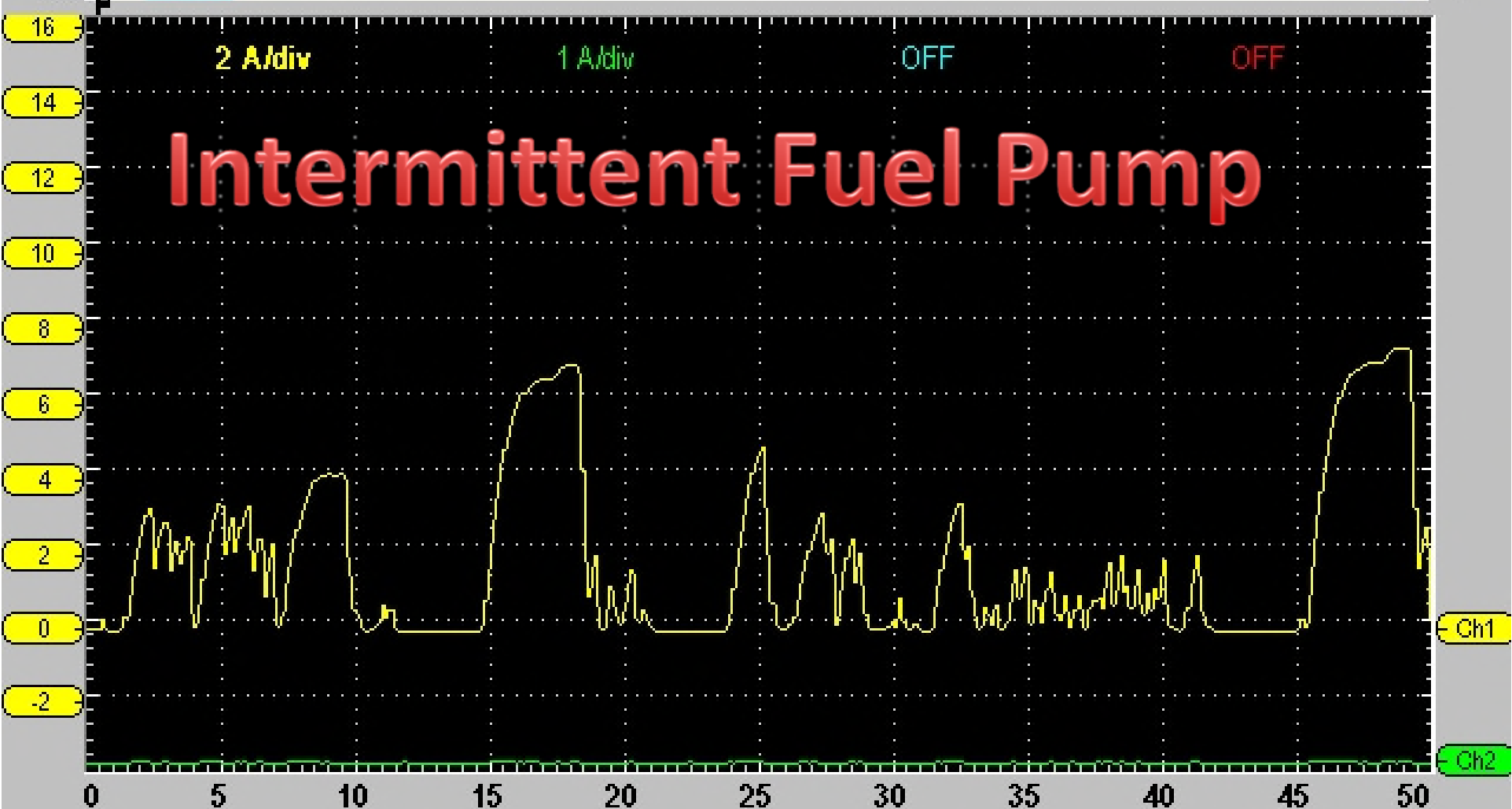
Pump	Pressure
Electric Lift Pump	9.5 PSI Minimum











Channel Sweep Display Trigger

Ch 1 Low Amps 20 20 A [Waveform Icon] [Zoom Icon] 50 ms None [Trigger Icon] [Level Icon]

# Lift Pump Flow Test

Fuel level must be at least  $\frac{1}{4}$  full

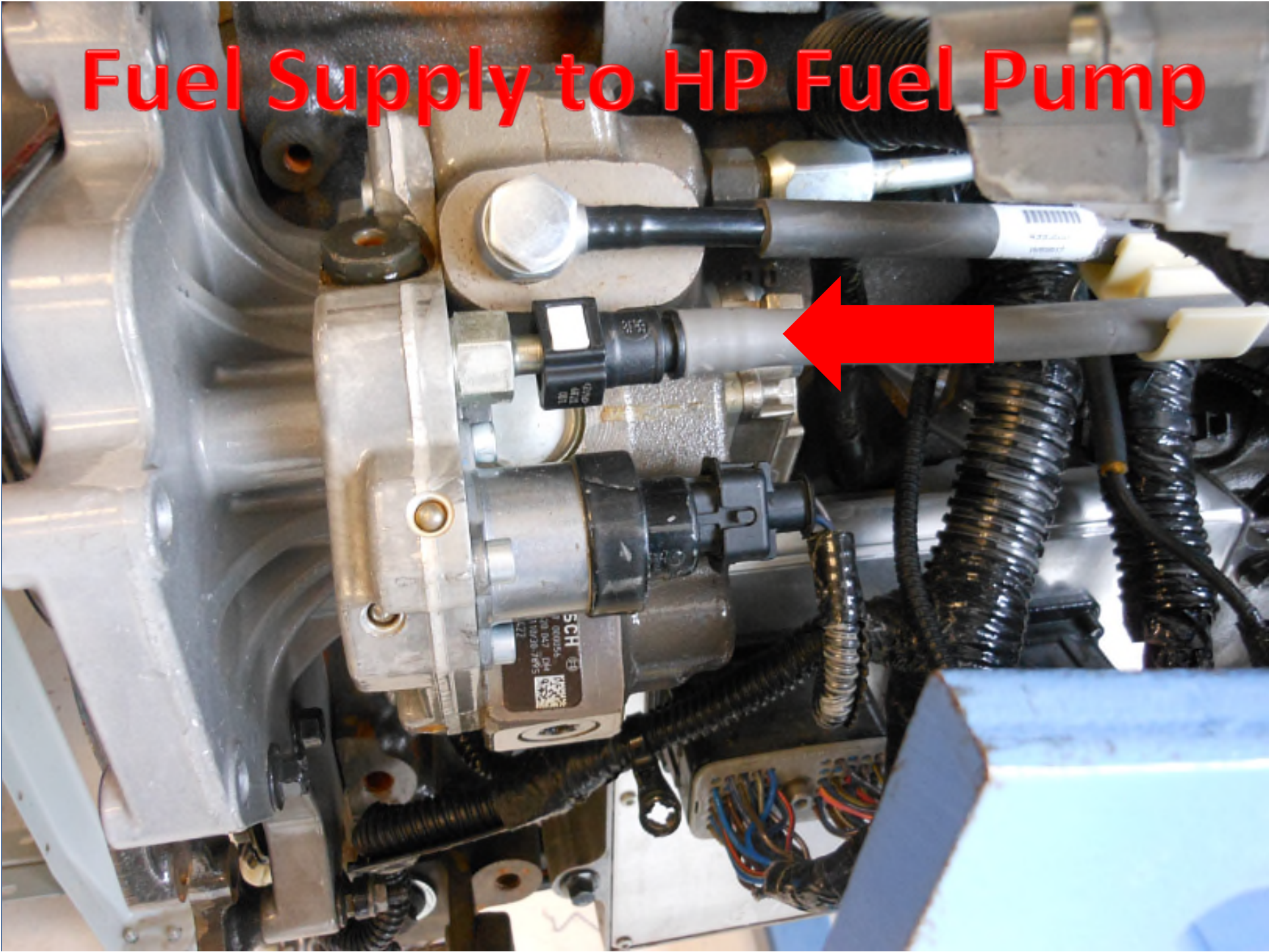
Connect a fuel pressure gauge to the supply line at the high pressure pump (easiest test point location)

Activate the lift pump to purge air

Activate the lift pump while filling a container

Should be 16.9 oz. (500 ml) in 10 seconds

# Fuel Supply to HP Fuel Pump



# Lift Pump Pressure Test

Fuel level must be at least  $\frac{1}{4}$  full

Connect a fuel pressure gauge to the supply line at the high pressure pump (easiest test point location)

Activate the lift pump; Pressure should be between 9.5 and 12 psi

Re-torque all the pressure fittings before replacing the pump

# Fuel

Fuel is forced through the fuel filter element; the filter must not restrict fuel flow.

Then enters the Fuel Pump/Gear Pump, which is attached to the rear of the fuel injection pump.

The Fuel Pump/Gear Pump is a low-pressure pump and produce pressures ranging from 80 psi to 180 psi to supply the HP piston pump.

# If Volume or Pressure is low

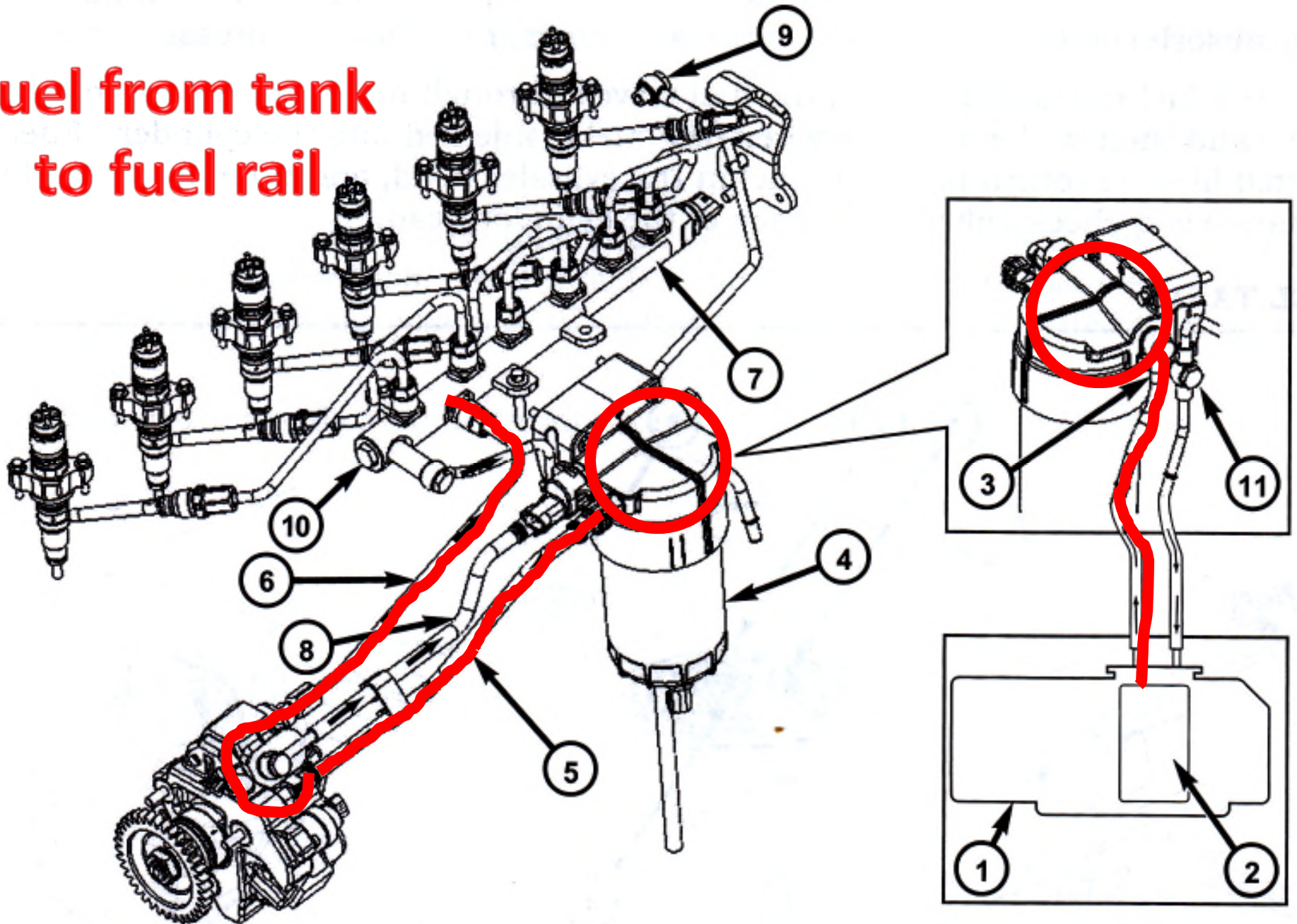
Test vacuum

# Fuel

Fuel then enters the fuel injection pump

Low pressure fuel is then supplied to the FCA  
(Fuel Control Actuator)

# Fuel from tank to fuel rail



# Fuel Control Actuator

The FCA is an electronically controlled normally open solenoid valve.

The PCM controls the amount of fuel that enters the high-pressure pumping chambers by opening and closing the FCA based on the demand for fuel pressure.

The FPS (Fuel Pressure Sensor) on the fuel rail monitors the actual fuel pressure and provides the signal as an input to the ECM that then controls the FCA to achieve the desired fuel pressure.

When the actuator is opened, the maximum amount of fuel is being supplied to the fuel injection pump



# Inputs and Outputs

In control terminology, the rail pressure is the *system output* while the position of the actuator used to control the rail pressure is the system input

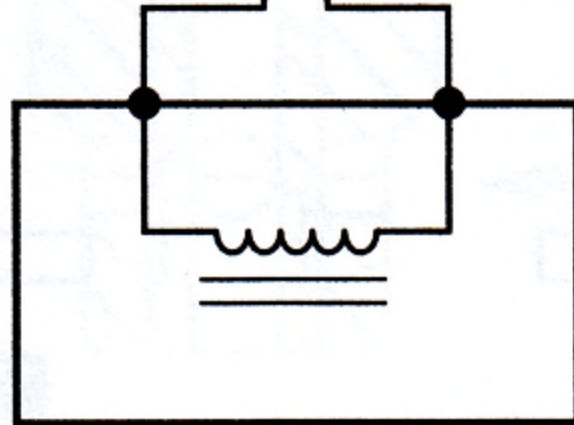
**ENGINE  
CONTROL  
MODULE (ECM)**

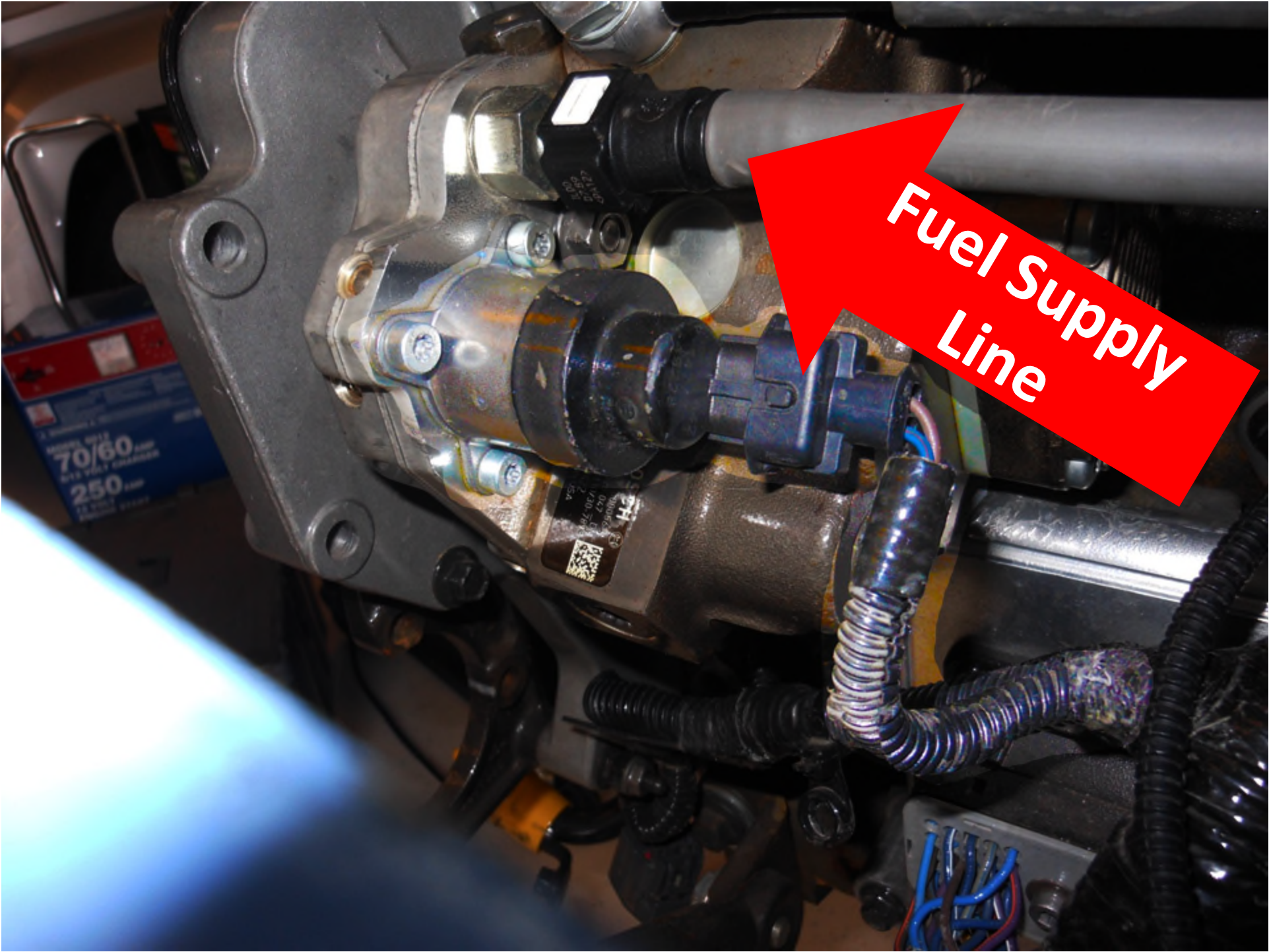
SIGNAL  
RETURN

PWM  
SIGNAL

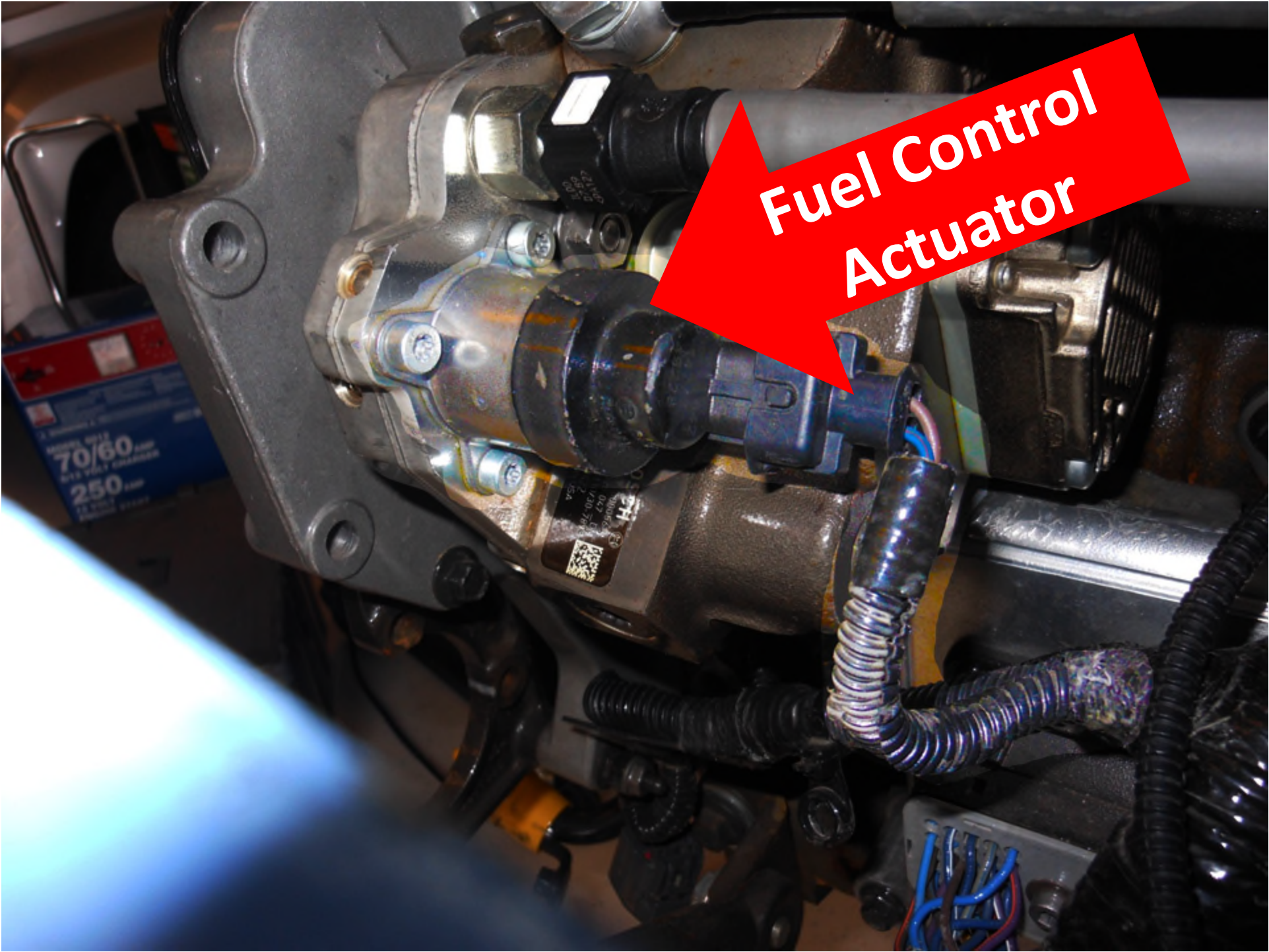
**High side driver  
ECM supplies B+ to  
the FCA**

**FUEL  
CONTROL  
ACTUATOR**



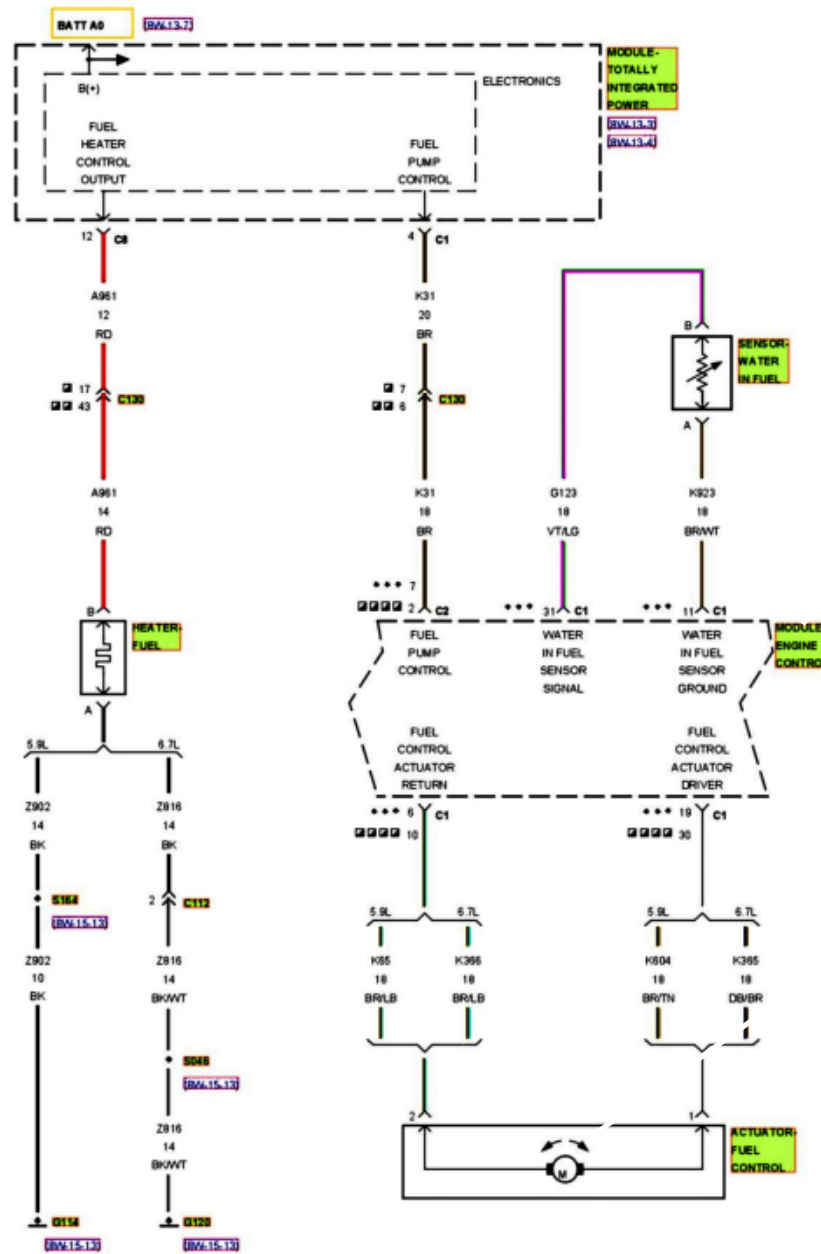


Fuel Supply  
Line



**Fuel Control  
Actuator**

DIESEL

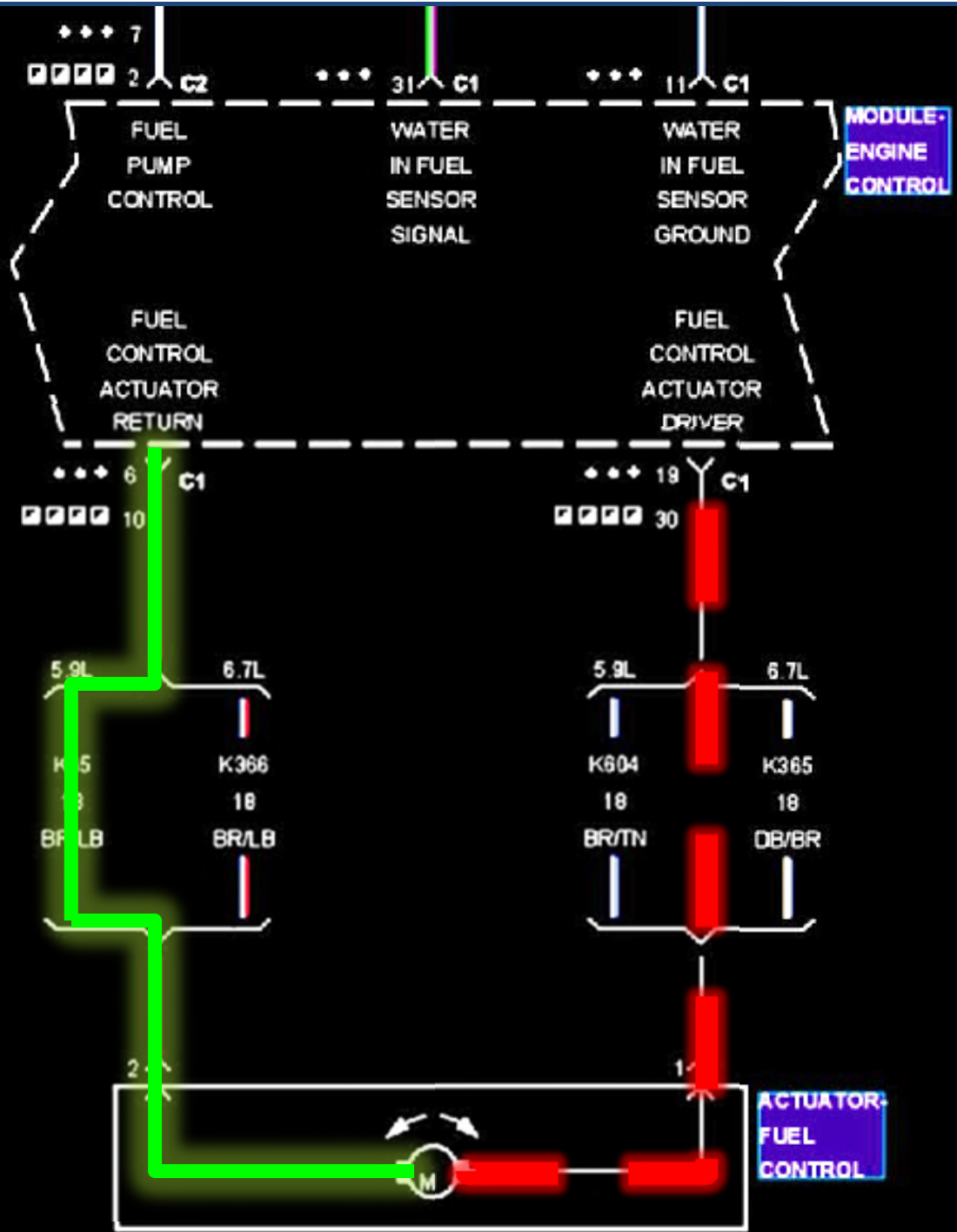


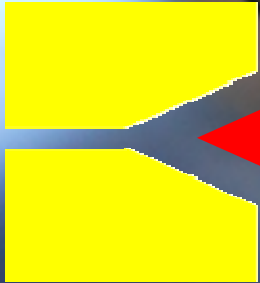
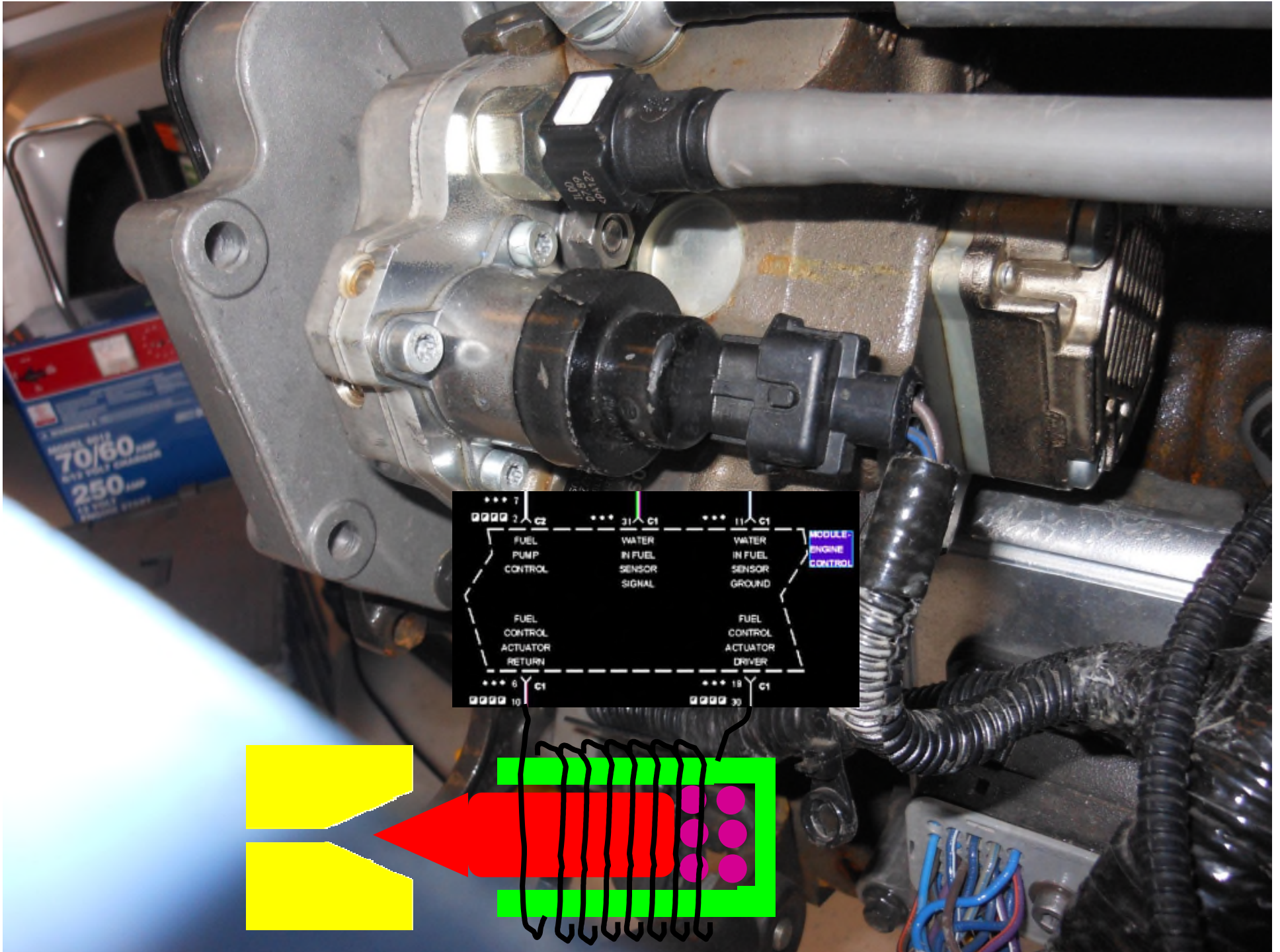
\*\*\* 5.9L DIESEL  
 6.7L DIESEL

6.7L A/T  
 EXCEPT 6.7L A/T

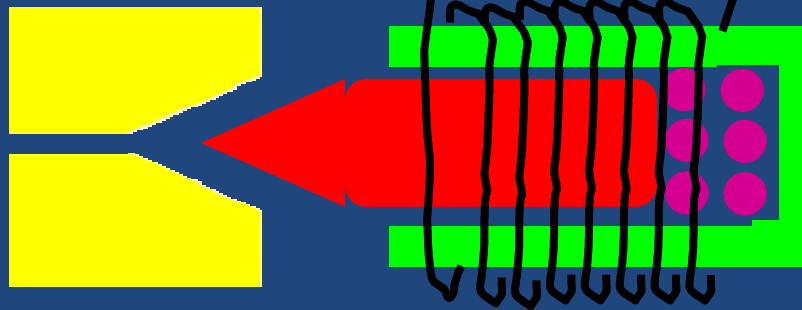
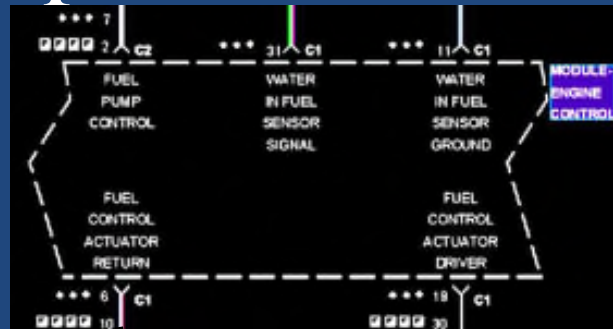
ECM

FCA





The PCM controls the FCA by varying the current, the solenoid is spring loaded to open, it is driven closed

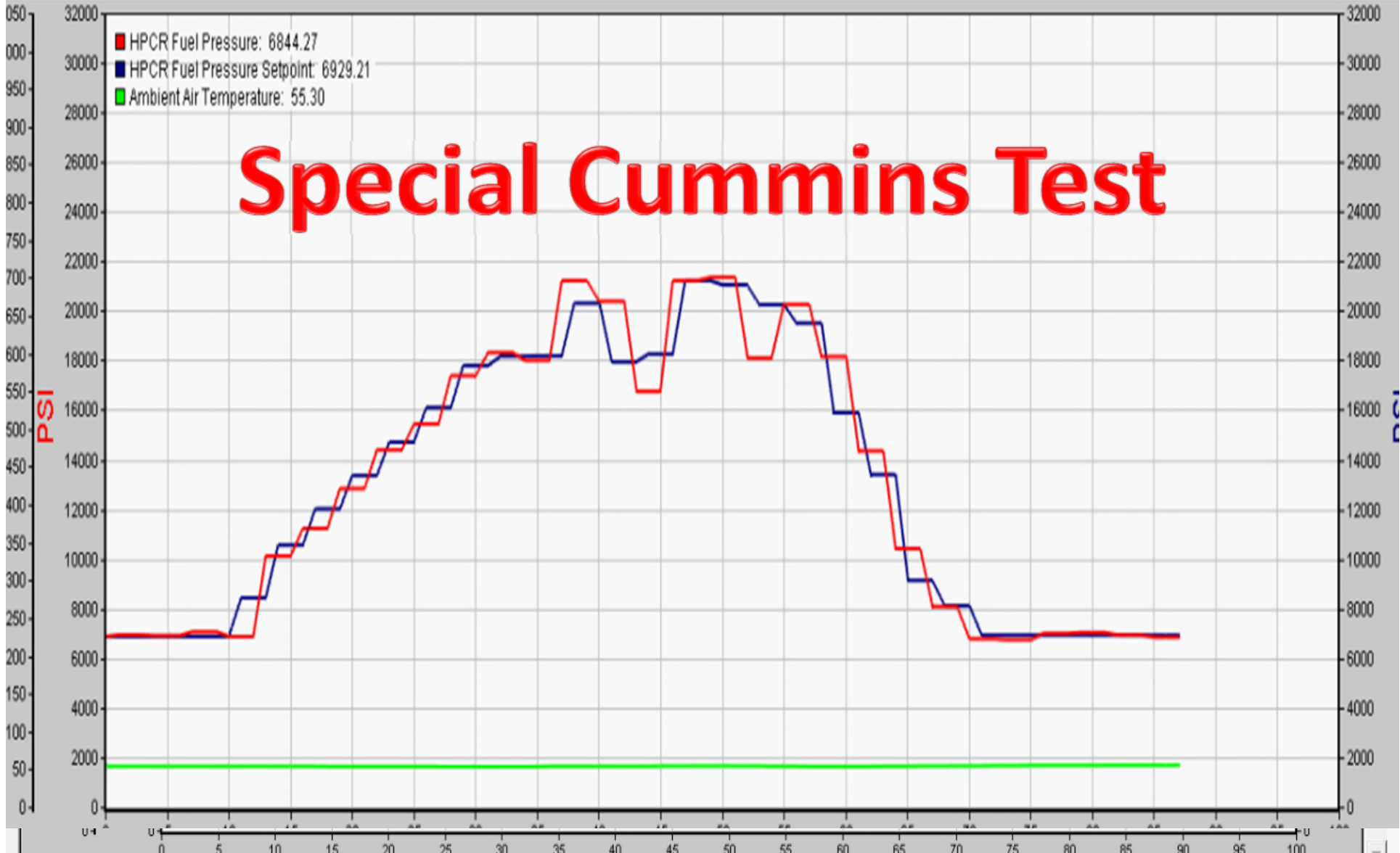


# Typical Cummins data

Sensor Name	Value	Units	Minimum	Maximum
HPCR Duty Cycle Output	36.73	%	0.00	100.01

Sensor Name	Value	Units	Minimum	Maximum
HPCR Fuel Pressure	4735.07	PSI	0.00	29011.89



# Special Cummins Test

■ HPCR Fuel Pressure: 6844.27  
■ HPCR Fuel Pressure Setpoint: 6929.21  
■ Ambient Air Temperature: 55.30

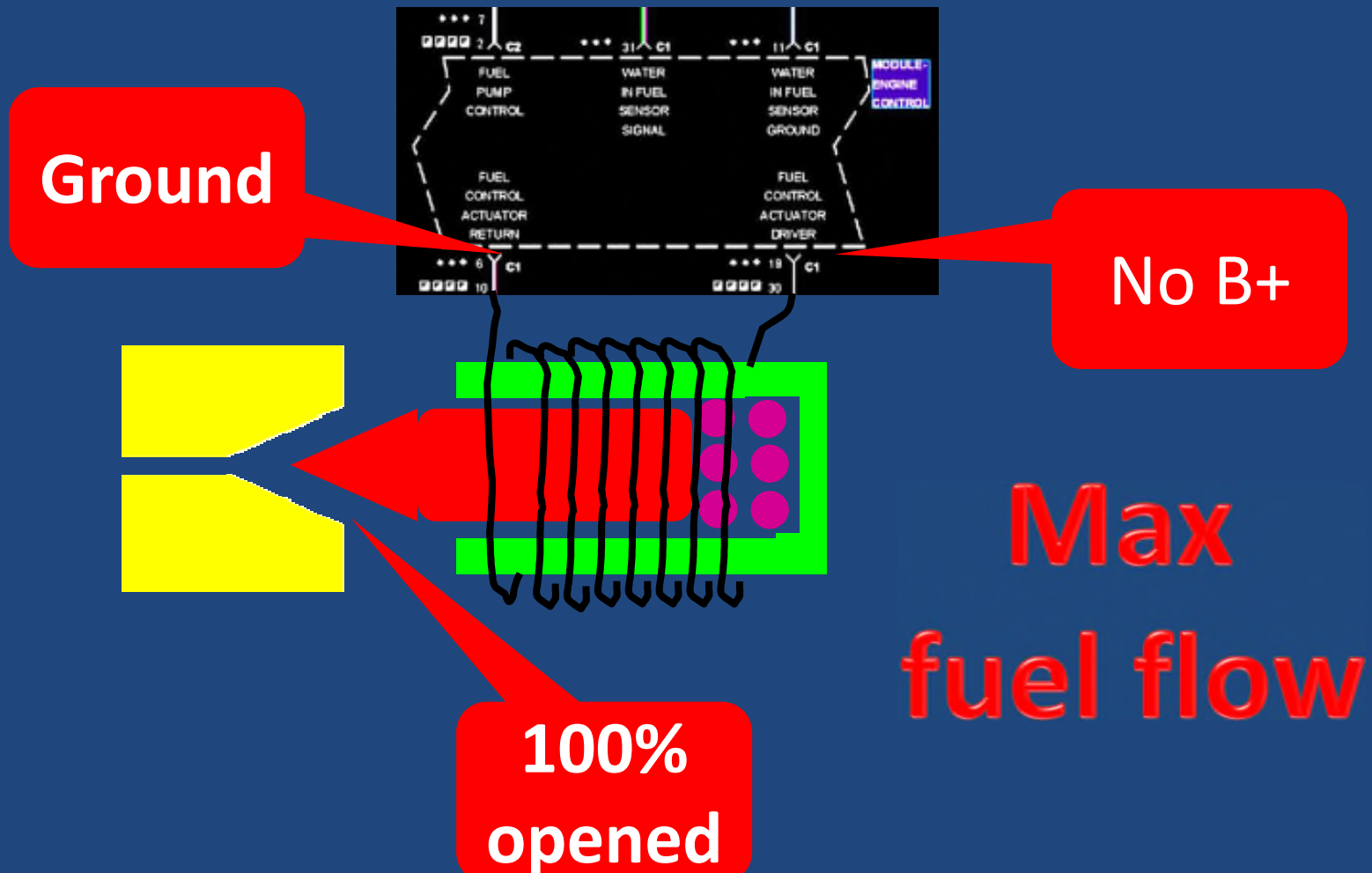
**Actuation**

Command Name	Comman...	Units	Instructions/Notes
<input type="checkbox"/> A/C Clutch	Actuate		Engine must not be running. The A/C clutch relay toggled on or off every 1.4 seco...

0:00:24 | 0:00:25

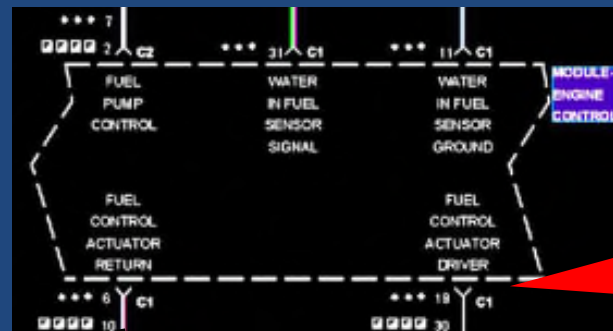
# No Fuel

## Normally Open Valve

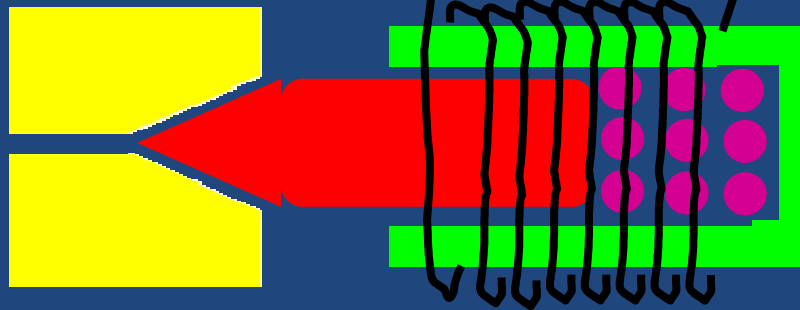


# Low Fuel Pressure

## 40 % Duty Cycle

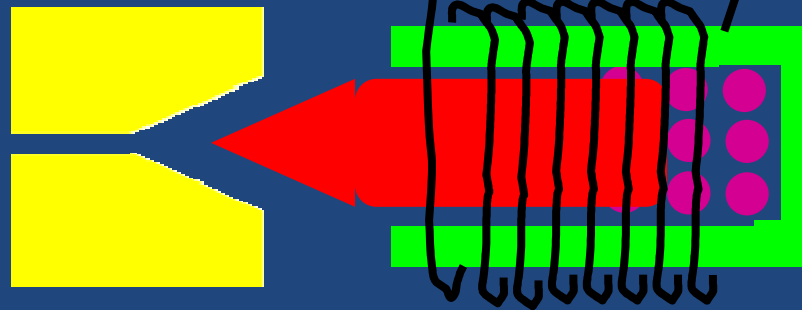
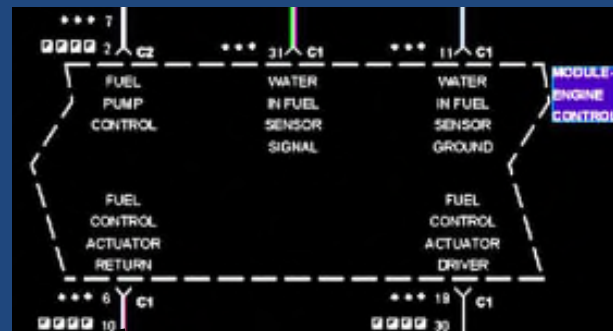


**Pulse width  
B+**



# High Fuel Pressure

## 75 % Duty Cycle



# Fuel Control Actuator

If fuel pressure in the fuel rail becomes too low, the PCM will command a lower duty cycle

During engine start up the PCM commands a lower duty cycle to provide maximum fuel volume

Pump	Pressure
Electric Lift Pump	9.5 PSI <u>Minimum</u>
Fuel Pump / Gear Pump	80-180 PSI Normally
High Pressure Injection Pump	9,151-23,200 PSI Normally

# Fuel Control Actuator test

Start the engine and allow to idle

Activate the Fuel Pressure Override Test with a Scan Tool

Allow the engine speed and fuel pressure to ramp up and stabilize

Turn off the test

If the RPM and pressure doesn't ramp up check for TSB's and replace the pump

# High Pressure Delivery Test

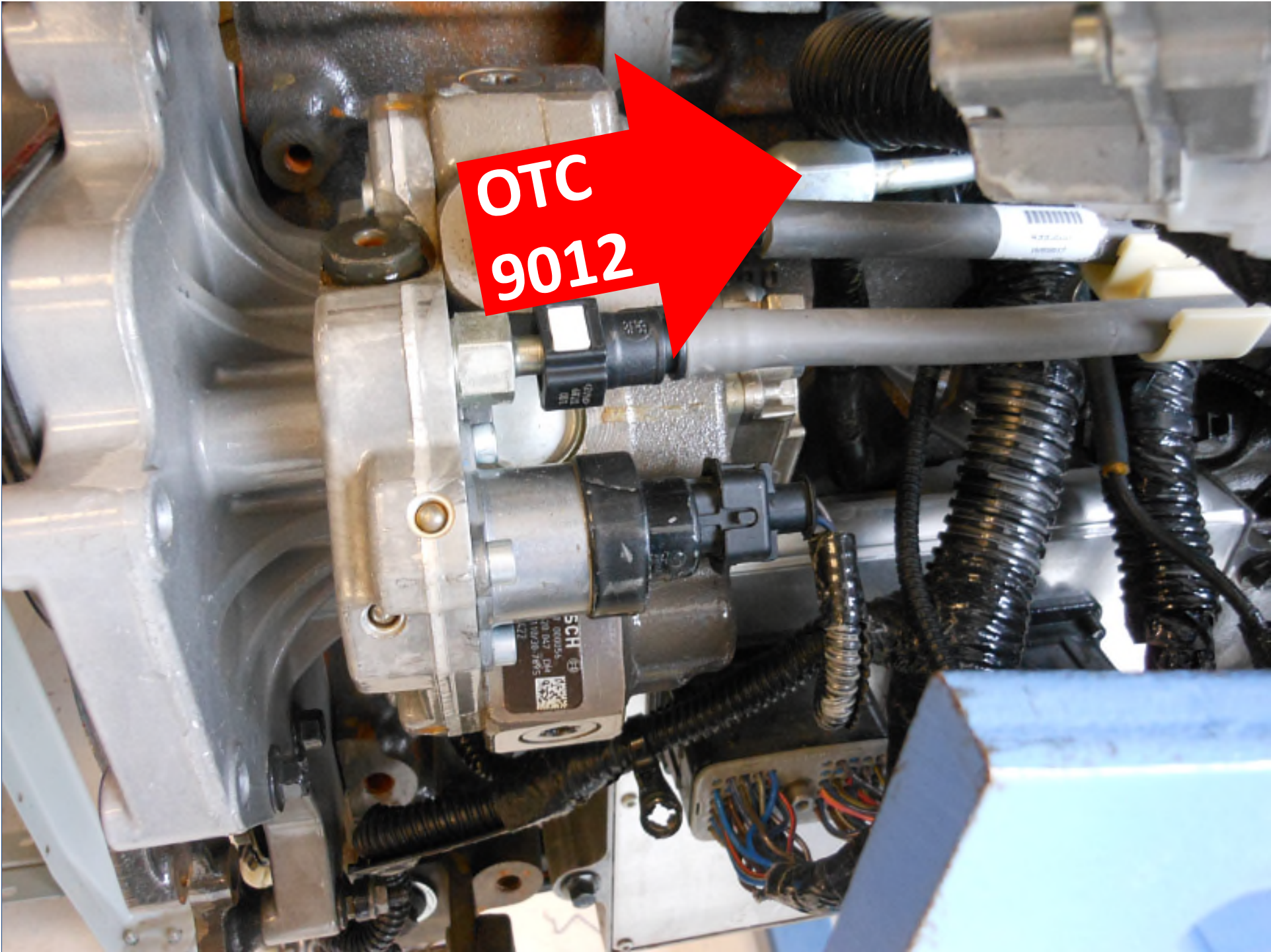
Engine off

Install test fitting 9012

Disconnect FCA connector

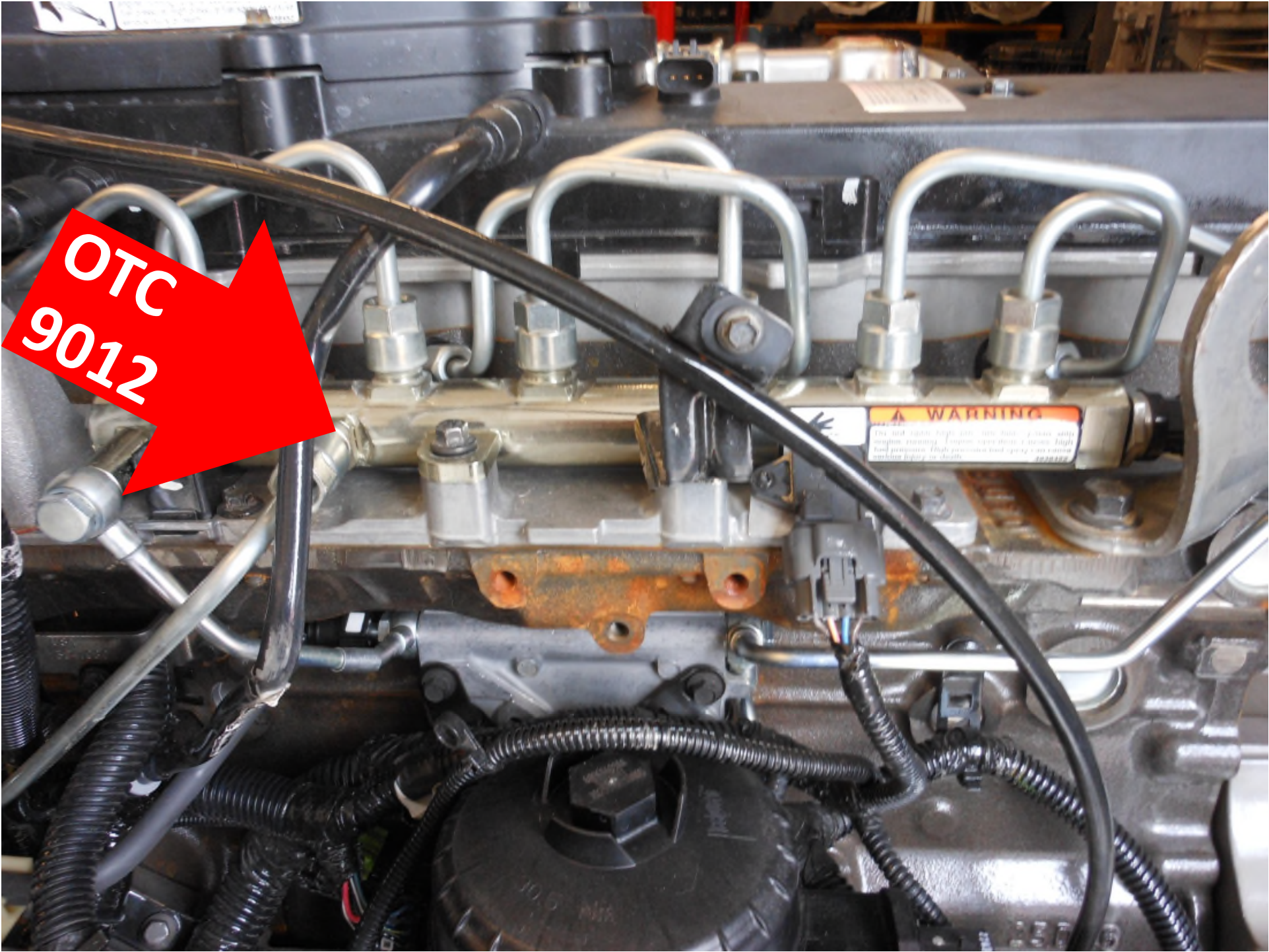
Disconnect the high pressure line at the fuel rail  
and route it into a container

Crank the engine for ten seconds three time for a  
total of 30 seconds



**OTC  
9012**

SCH 7 000256  
701 047 CH  
1 7028 785  
427



OTC  
9012

**WARNING**  
Do not open high pressure lines with engine running. Engine operation causes high fuel pressure. High pressure fuel spray can cause serious injury or death.

# High Pressure Delivery Test

Minimum flow at 150 RPM is 70 ml

Minimum flow at 200 RPM is 90 ml

If the test fails (Before replacing pump)

Ensure that the lift pump is delivering the correct amount of fuel and the fuel filter is free flowing

Then check the FCA

# High Pressure Pump Return Flow Test

Route the return line to a container

Allow the engine to idle for one minute

Fuel flow should be less than 1,150 ml / minute

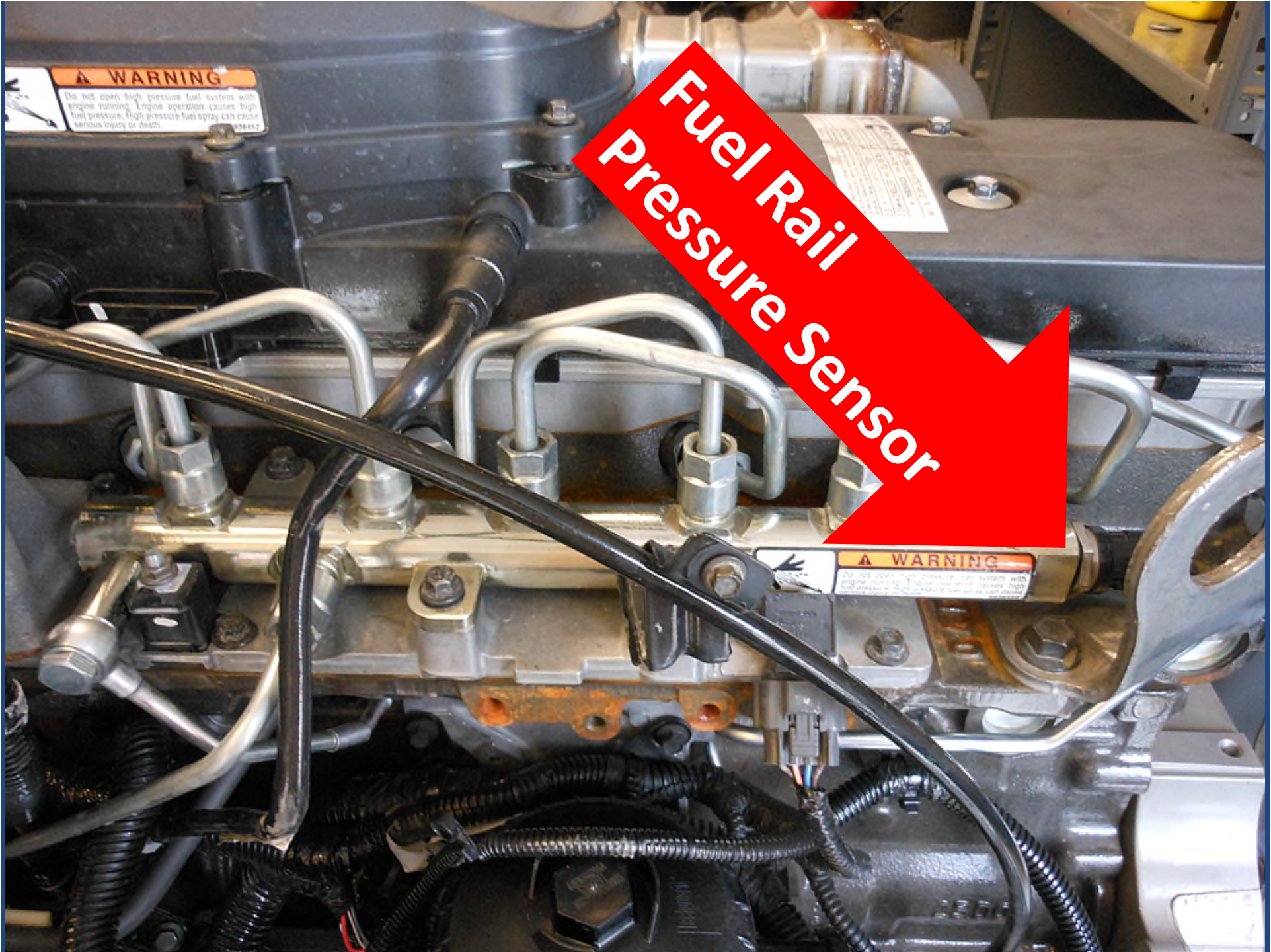
If this test fails check the high pressure pump's delivery

# Fuel Rail Pressure Sensor

The pressure is monitored by a pressure sensor and the difference between the nominal rail pressure value and the measured one is the input signal for the controller

Mounted to the end of the fuel rail

The sensor provides an output voltage signal to the PCM that corresponds to fuel pressure



Fuel Rail Pressure Sensor

**WARNING**  
Do not open high pressure fuel system with engine running. Engine operation causes high fuel pressure. High pressure fuel spray can cause serious injury or death.

**WARNING**  
Do not open high pressure fuel system with engine running. High pressure fuel spray can cause serious injury or death.

Fuel Rail  
Pressure Sensor

**WARNING**  
Do not open high pressure fuel system with  
engine running. Engine operation causes high



# Fuel Rail Pressure Sensor

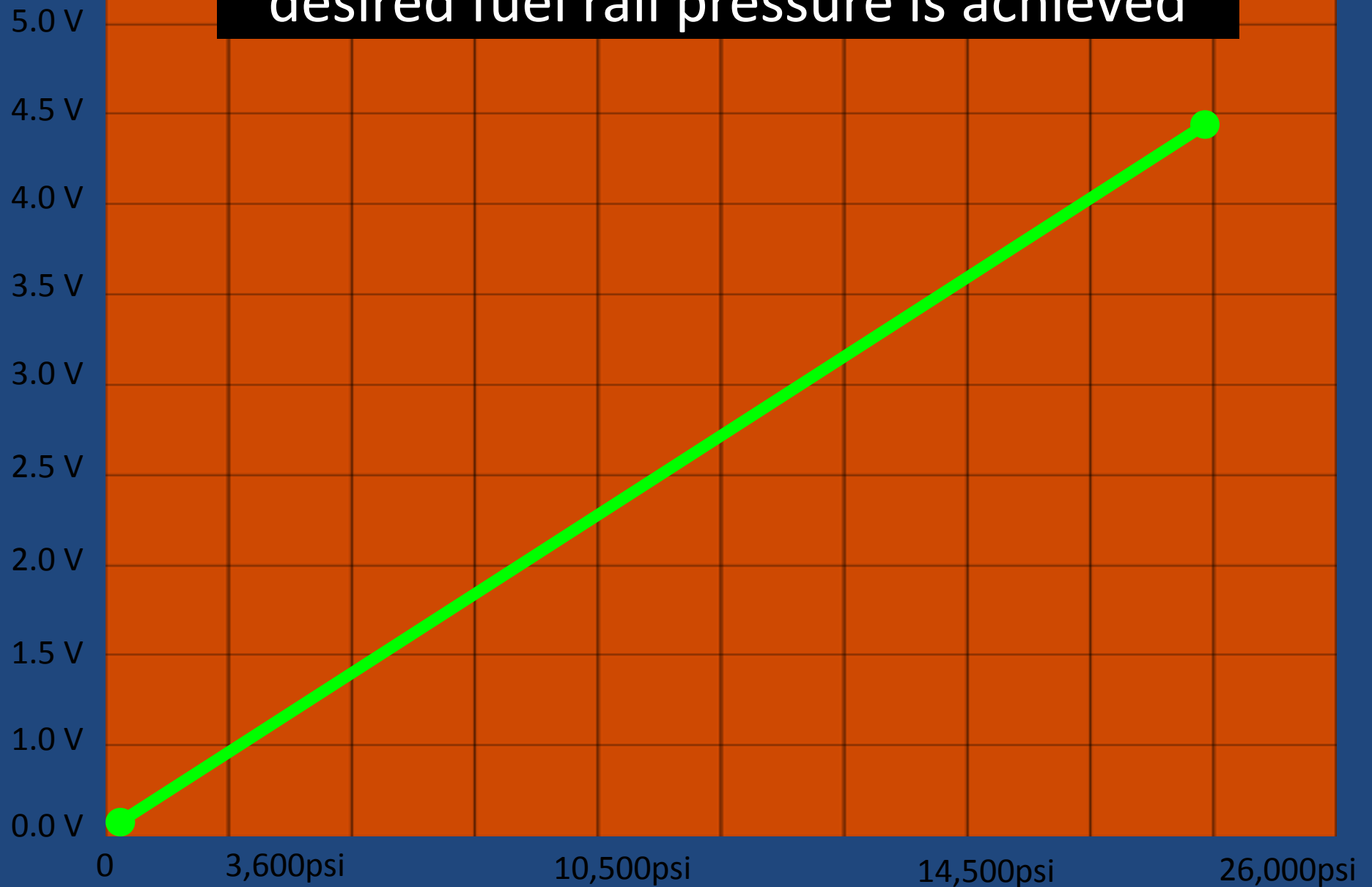
The sensor's output is linear from zero to maximum pressure

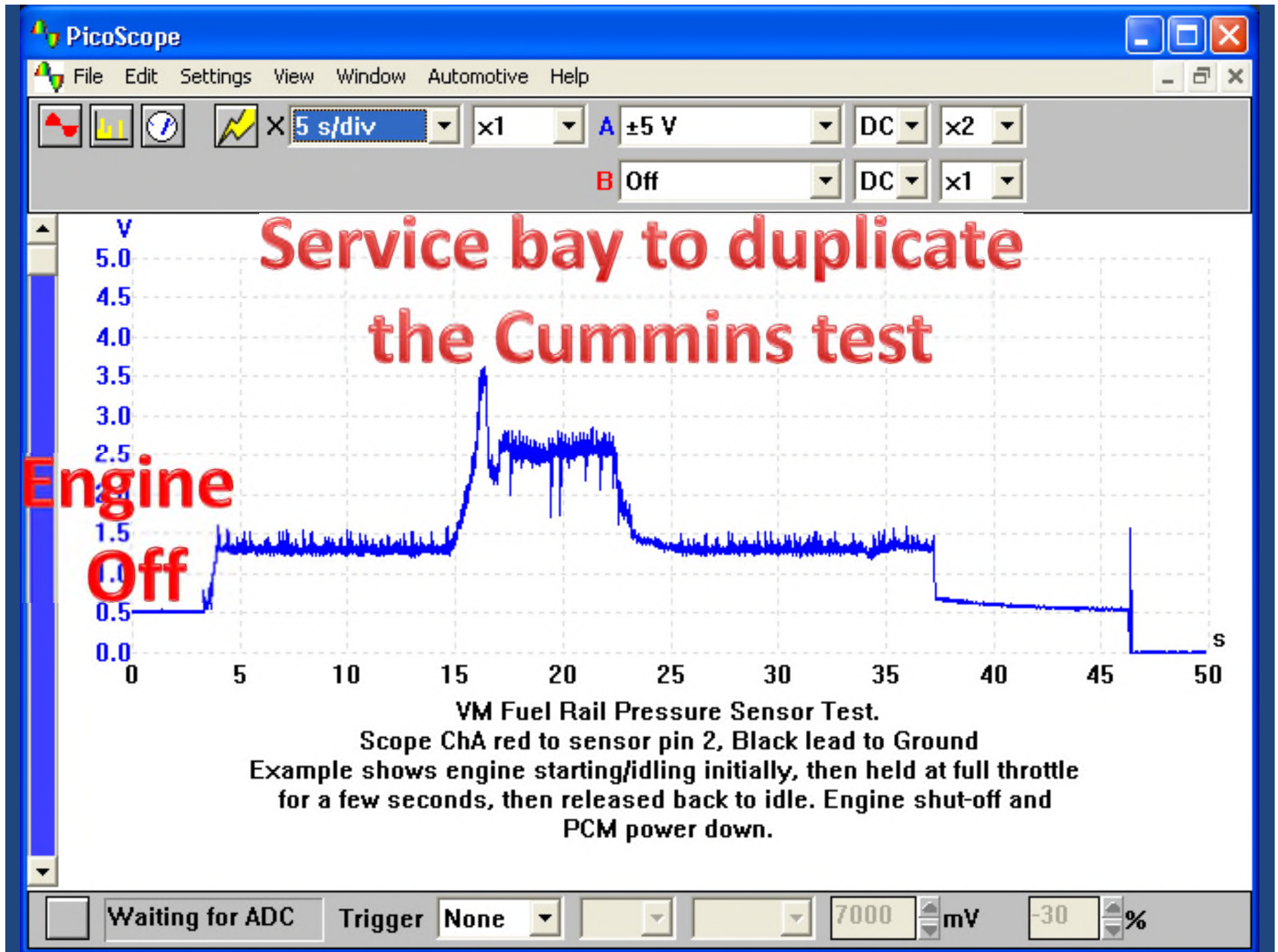
The ECM uses the signal from the fuel rail sensor to control the output of the fuel control actuator (FCA)

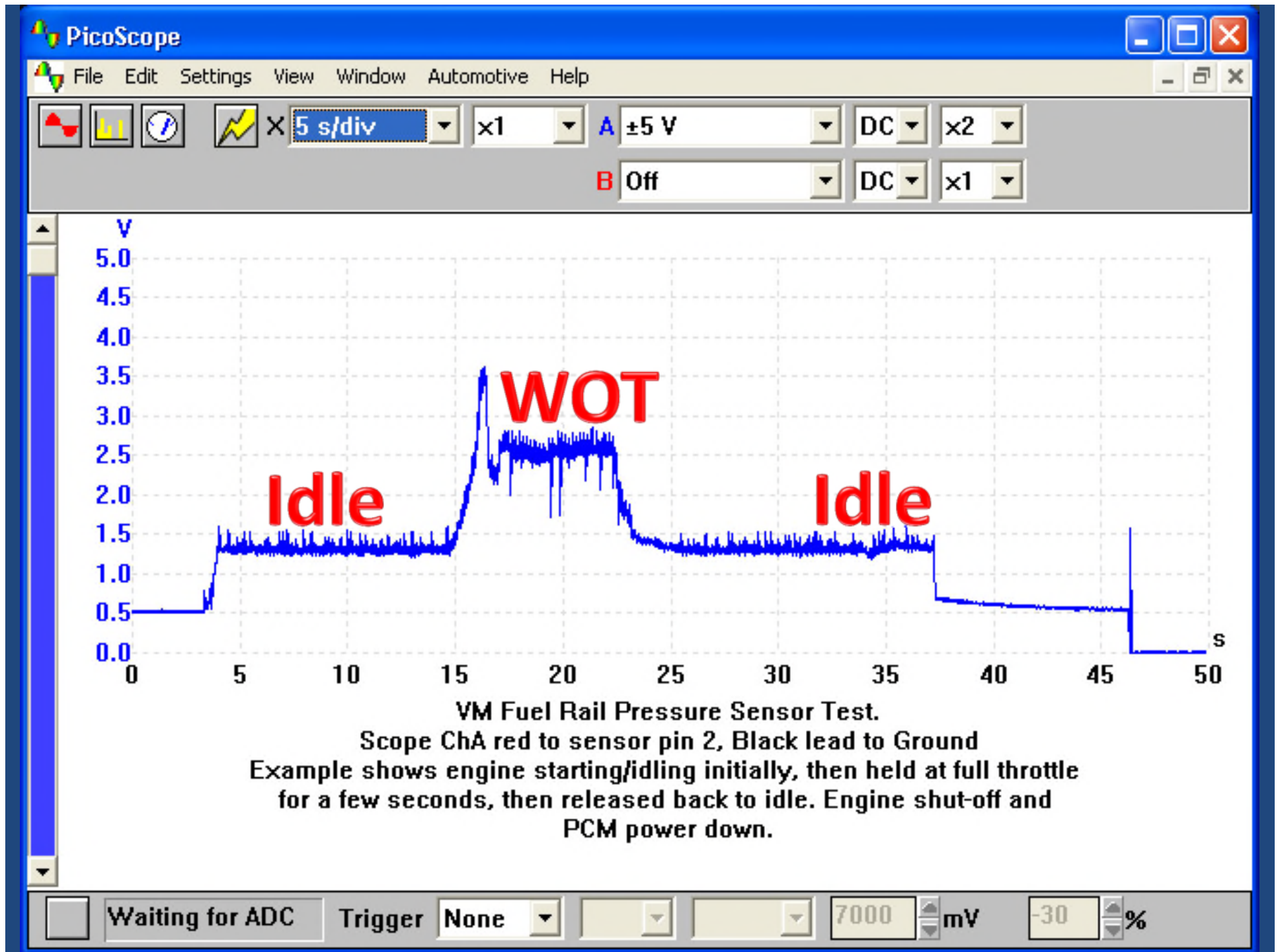
The ECM supplies a 5.0 volt reference

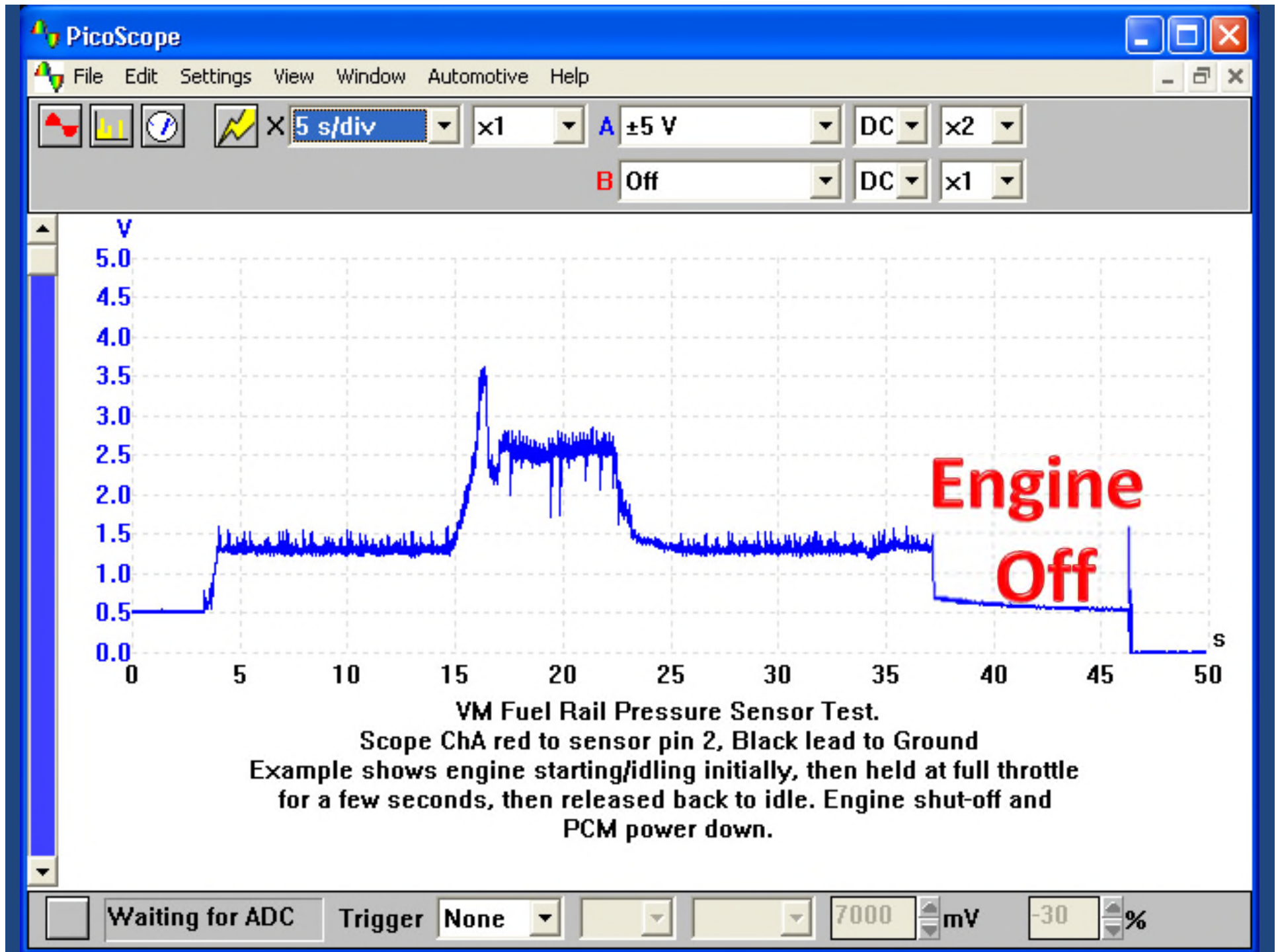
Pressure in the fuel rail varies the signal from 0.5 to 4.5 volts

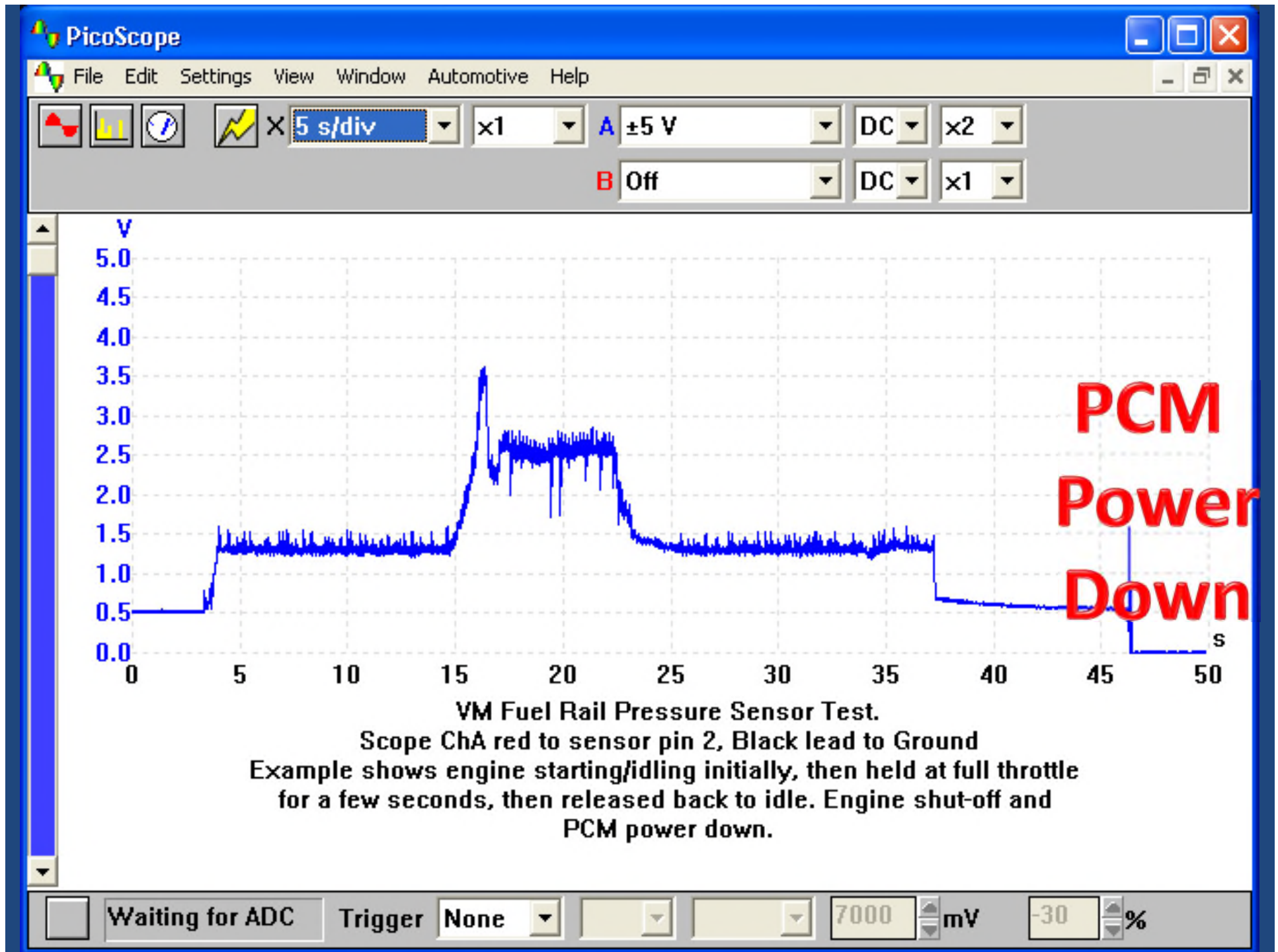
The PCM Actuates the FCA until the desired fuel rail pressure is achieved









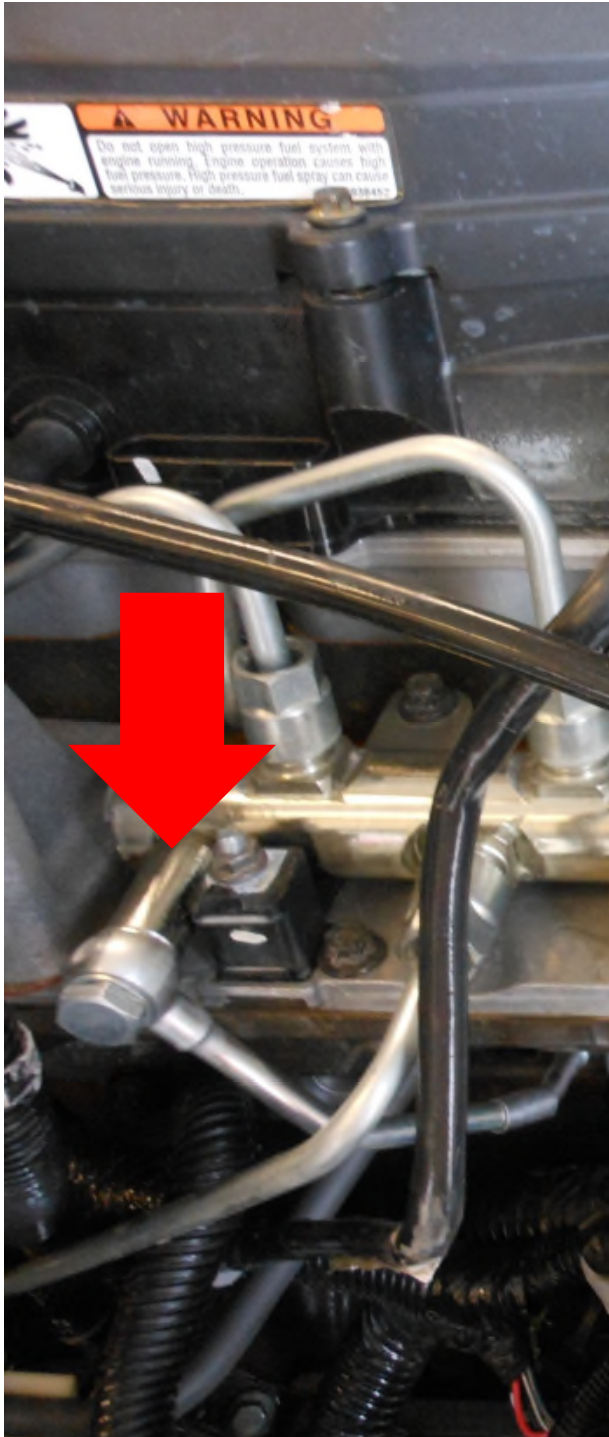


# Fuel Rail Pressure Limiting Valve

Threaded into the front end of the fuel rail  
It relieves fuel rail pressure if it exceeds 28,282  
psi.

The ECM determines the fuel limiting events  
based on the fuel rail pressure sensor

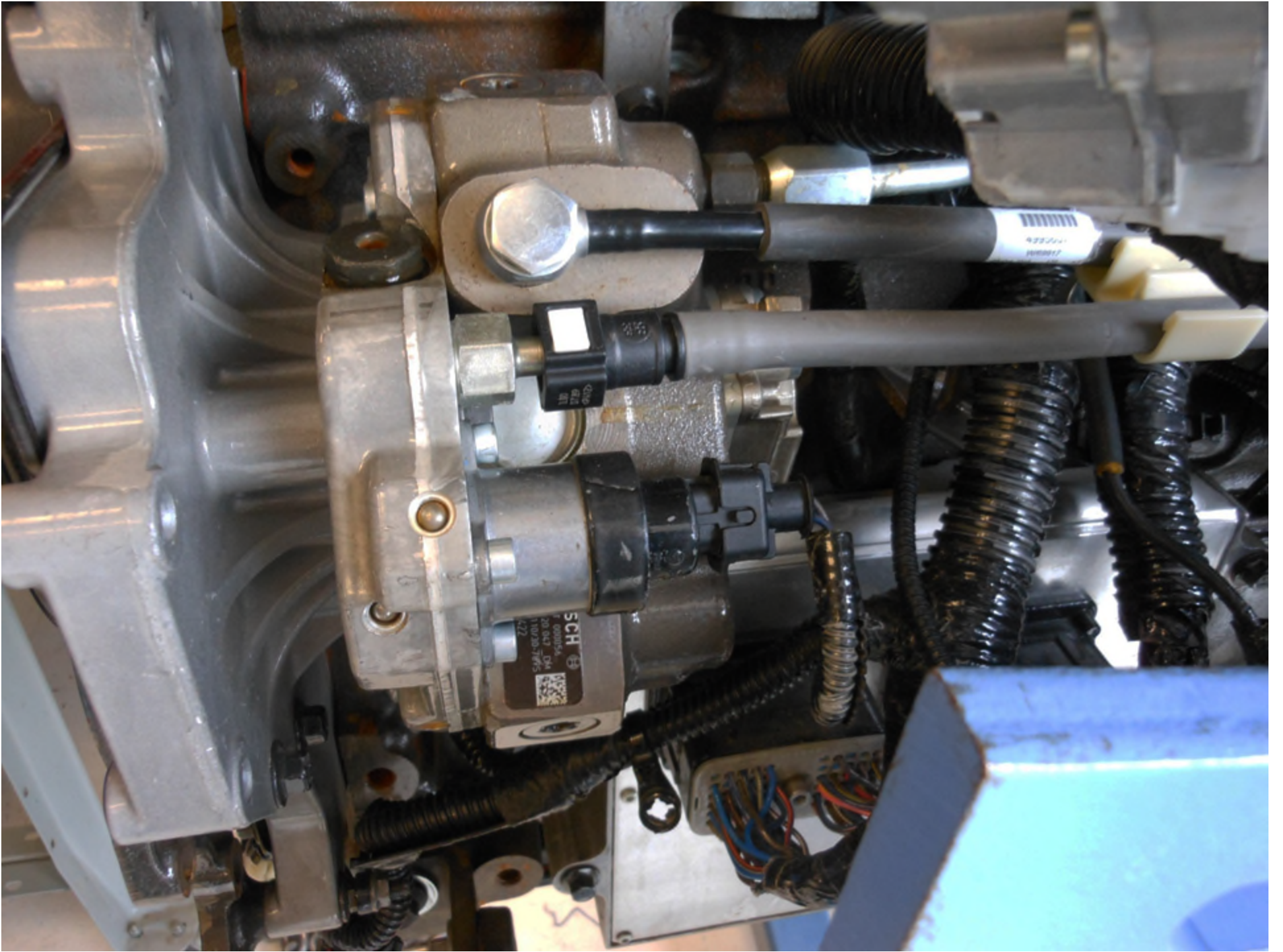
A DTC is set if there are too many (50) relief  
events.

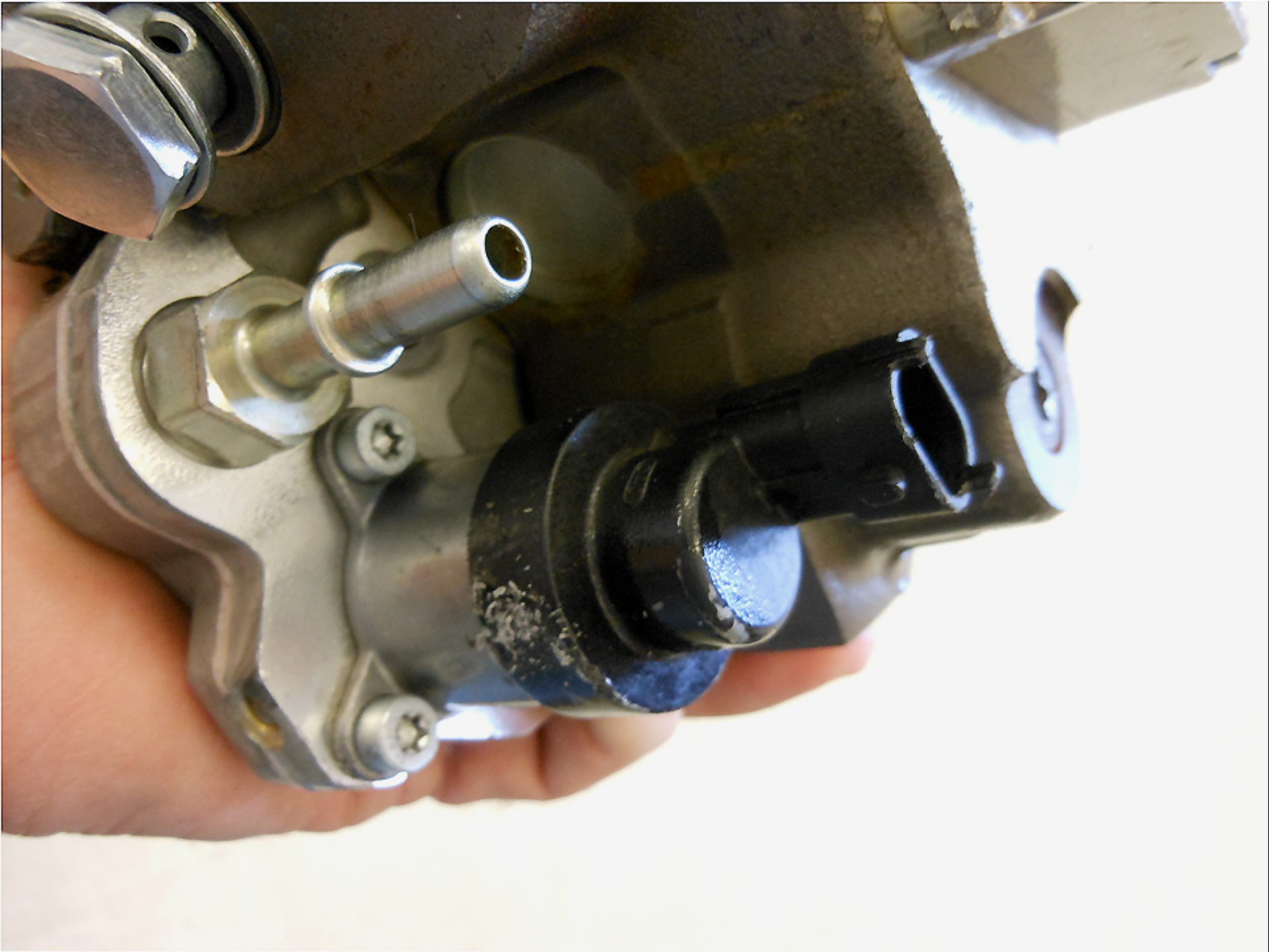


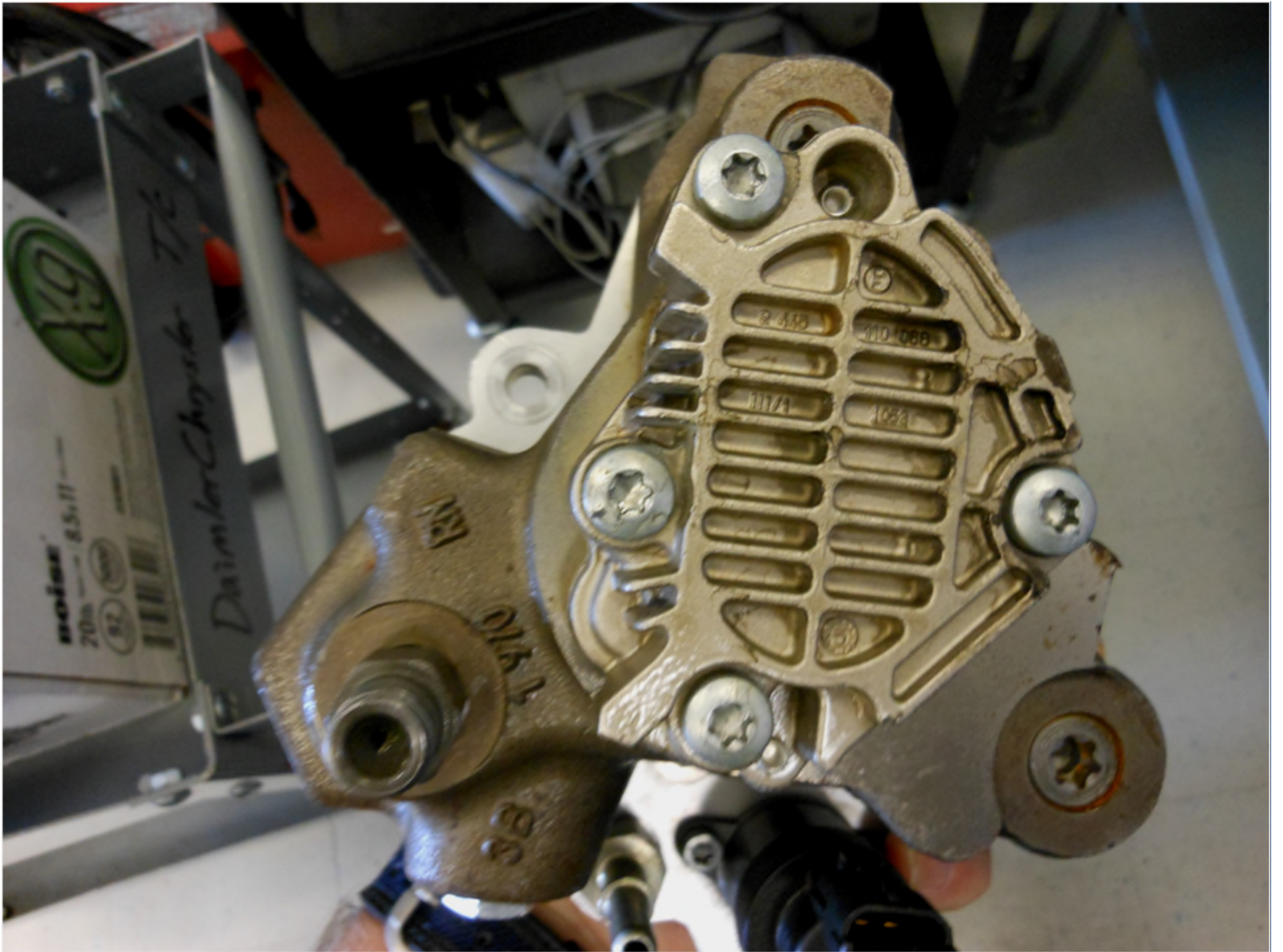


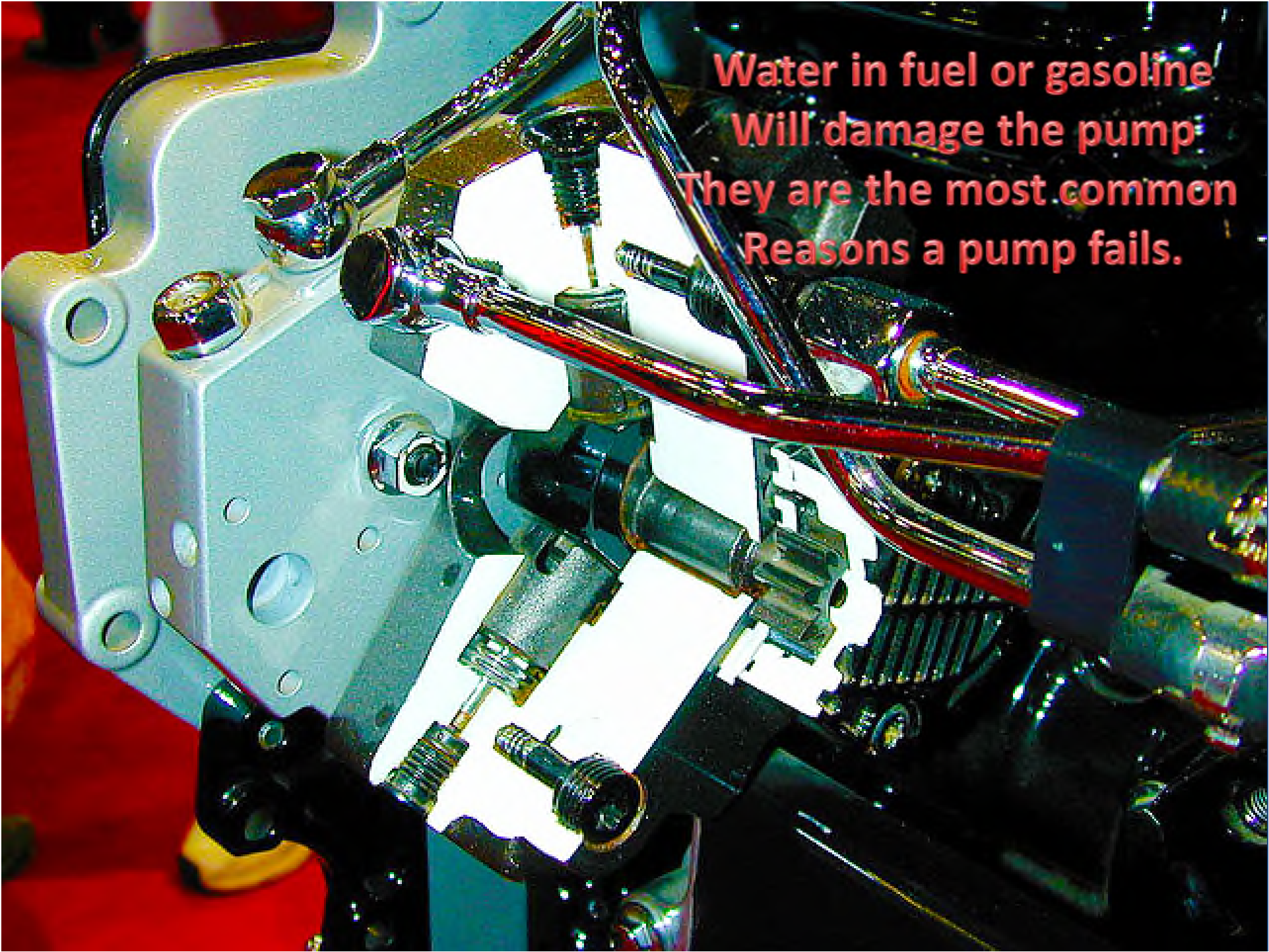
**Fuel pressure limiting Valve test**  
**Requires a special fitting**  
**SPX 9012 (\$16.95)**











**Water in fuel or gasoline  
Will damage the pump  
They are the most common  
Reasons a pump fails.**



**High Pressure Fuel Rail**

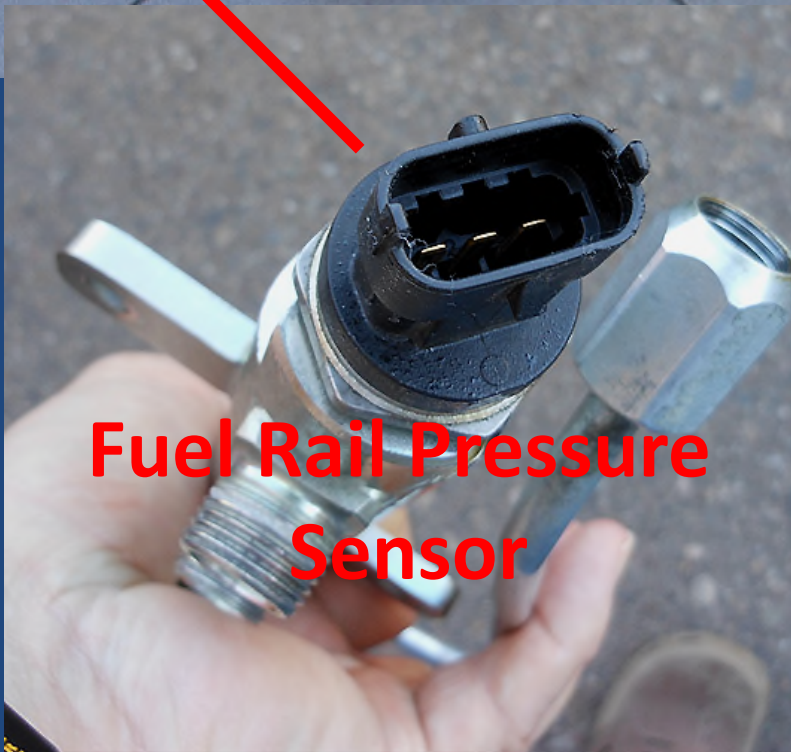
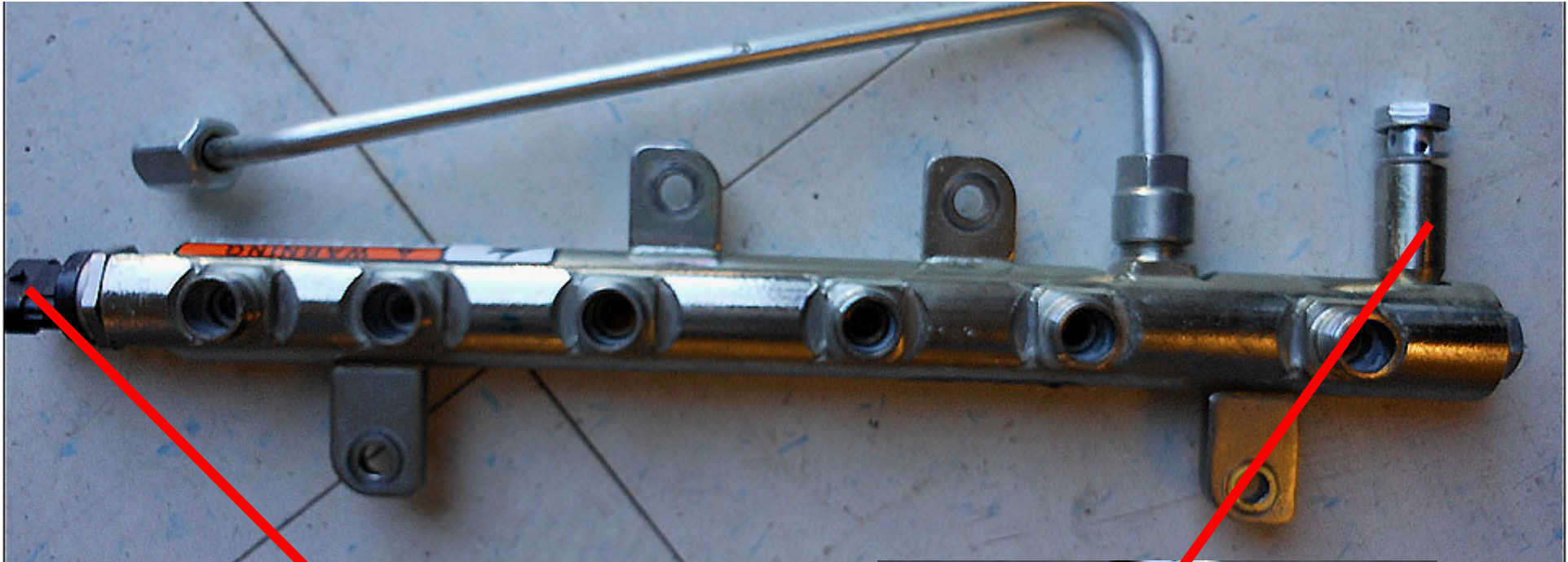
# Common Fuel Rail

Stores fuel and acts as an accumulator

Distributes high pressure fuel to the injectors through steel lines

Common to all cylinders

The pressure in the rail remains at an almost constant pressure to ensure the same pressure at each injector



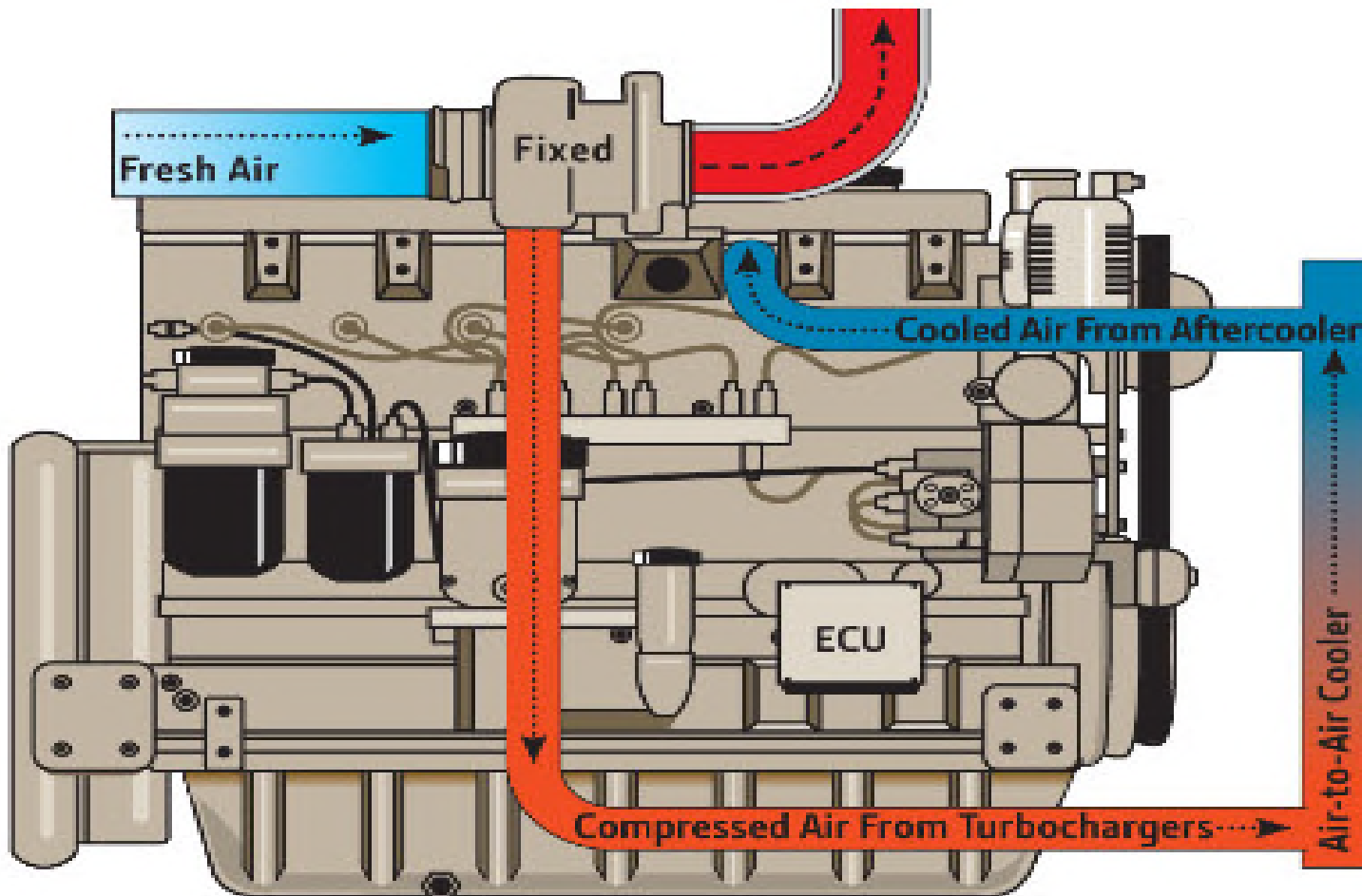
**Fuel Rail Pressure  
Sensor**



**Fuel Rail Pressure  
Limiting Valve**

# Tier 2

On Board Diagnostics are manufacturer's responsibility.



# HD OBD

HD OBD has new availability requirements for emission-related service information, also proposed in the January 24, 2007 action, that will make this information more widely available to the industry servicing vehicles over 14,000 pounds.

# HD OBD Monitors

In 2013, the U.S. Environmental Protection Agency (EPA) and California Air Resources Board (ARB) phased in heavy-duty OBD regulations (HD OBD) which requires all 2013 and above model year engines in heavy-duty on-highway vehicles weighing over 14,000 pounds to have an OBD system.

HD OBD regulations specify 13 major systems and parameters that an OBD system must monitor to ensure compliance.

# HD On Board Diagnostics

What are On-Board Diagnostic (OBD) Systems?

Self-diagnostic systems incorporated into the engine ECU

Monitors virtually every component that can increase emissions

Alert the driver (MIL)

Provide information (data, DTCs) to assist repair technicians

# HD On Board Diagnostics

Two “standards” to choose from for HD OBD:

SAE J1939

Defines connector, protocol, and messages Baud rate:  
500 k required for 2016+MY, 250 k or 500 k allowed  
for 2013-2015 MY

Used mostly by Cummins, DDC, Navistar, and Paccar

SAE J1979 & ISO 15765-4

Identical to connector, protocol, and messages used by  
light-duty vehicles since 2008 MY

Used mostly by GM, Ford, Hino, Volvo, Isuzu

# HD OBD Monitors

## 1. Fuel system monitor

Fuel system pressure control

Injection quantity

Injection timing

Feedback control

## 2. Misfire monitor

Detect continuous misfire

# HD OBD Monitors

## 3. EGR monitor

Low flow

High flow

Slow response

EGR cooler operation

EGR catalyst performance

Feedback control

# HD OBD Monitors

## 4. Boost pressure monitor

Underboost

Overboost

Slow response

Charge air under cooling

Feedback Control

# HD OBD Monitors

## 5. Non-methane hydrocarbons (NMHC) catalyst monitor

Conversion efficiency

Provide diesel particulate filter (DPF) heating

Provide selective catalytic reduction (SCR) feed gas (e.g. nitrogen dioxide [NO<sub>2</sub>])

Provide post DPF NMHC cleanup

Catalyst aging

# HD OBD Monitors

## 6. SCR nitrogen oxides (NO<sub>x</sub>) catalyst monitor

Conversion efficiency

SCR reductant:

- reductant delivery performance

- reductant tank level

- reductant quality

- reductant injection feedback control

# HD OBD Monitors

## 7. DPF monitor

DPF Filtering performance

Frequent regeneration

NMHC conversion

Incomplete regeneration

Missing DPF substrate

Active regeneration operation

# HD OBD Monitors

## 8. Exhaust gas sensors

For air-fuel ratio and NO<sub>x</sub> sensors:  
performance, circuit faults, feedback and  
monitoring capability

Other exhaust gas sensors

Sensor heater function

Sensor heater circuit faults

# HD OBD Monitors

## 9. Cooling system

Thermostat operation

ECT sensor circuit faults

ECT sensor circuit out-of-range

ECT sensor circuit rationality faults

# HD OBD Monitors

10. Closed crankcase ventilation (CCV)
11. Comprehensive component monitoring
12. Cold start emission reduction strategy
13. Other emission control system monitoring

A failure is defined as any change from as-built conditions which can raise the engine's output of any regulated emissions component past a defined level or result in inadequate control of an emissions system.

Some states restrict the purchase of older equipment unless a retrofit system is added to reduce emissions. The size of the fleet determines the level of reduction that is required.

Expect to see some equipment that have retrofit systems.

# HD On Board Diagnostics

HD OBD regulation defines specific parameters that must be reported

Data for emission-related troubleshooting and repair

Data for facilitating inspections

For 2016+ MY engines, engines must report:

- Fuel Rate (mg/stroke)

- Modeled Exhaust Flow (mass/time)

# HD OBD

Requirements for Diesel-Fueled/Compression-Ignition Engines;

1. Fuel System Monitoring
2. Engine Misfire Monitoring
3. Exhaust Gas Recirculation (EGR) System Monitoring
4. Turbo Boost Control System Monitoring
5. Non-Methane Hydrocarbon (NMHC) Converting Catalyst Monitoring
6. Selective Catalytic Reduction (SCR) and Lean NOX Catalyst Monitoring
7. NOX absorber System Monitoring
8. Diesel Particulate Filter (DPF) System Monitoring
9. Exhaust Gas Sensor Monitoring

# HD OBD required Data Page 1

Calculated Load

Driver's Demand Engine Torque

Actual Engine Torque

Reference Engine Maximum Torque

Engine Coolant Temperature

Engine Oil Temperature\*

Engine Speed

Time Elapsed since Engine Start

Fuel Level\*

Vehicle Speed\*

Barometric Pressure

ECU Voltage

- **Number of Fault Codes**
- **Monitor Readiness Status**
- **Distance Traveled since Fault**
- **Codes Cleared**
- **Number of Warm-ups since  
Fault Codes Cleared**
- **MIL status**
- **NOx NTE control area status**
- **PM NTE control area status**

# HD OBD required Data Page 2

PM filter inlet temperature\*\*

PM filter inlet pressure\*\*

PM filter outlet pressure\*\*

PM filter outlet temperature\*\*

PM filter delta pressure\*\*

Exhaust gas temp sensor\*\*

Turbo speed\*\*

VGT position\*\*

VGT commanded position

Turbo compressor inlet temperature\*\*

Turbo compressor inlet pressure\*\*

- Turbo turbine inlet temperature\*\*
- Turbo turbine outlet temperature\*\*
- EGR Temperature\*\*
- Reductant (Urea) Tank Level\*
- NOx sensor output\*\*
- PM sensor output\*\*
- Distance traveled while SCR inducement active

# HD OBD required Data Page 3

Normalized trigger for PM filter regeneration (e.g., how close is it to triggering an active Regen)

PM filter regeneration status

Average distance between PM filter regenerations

Accelerator Pedal Position

Fuel Rail Pressure\*\*

Commanded Fuel Rail Pressure

Fuel Injection Timing

Intake air Temperature\*\*

- Engine Intercooler Temperature\*\*
- Boost Pressure\*\*
- Mass Air Flow\*\*
- Ambient air temperature\*\*
- Commanded EGR valve position
- Actual EGR valve position\*\*
- EGR error between actual and commanded\*\*
- Fuel rate
- Turbo intake air temperature\*\*

**HD OBD data must be available  
on a generic HD OBD scan tool**

# HD OBD

Manufacturer enhanced diagnostic software has added functions like bi-directional controls and special diagnostic routines that are extremely useful.

Manufacturer enhanced diagnostic software can be expensive and they may require annual renewal

Enhanced diagnostic software is worthwhile when the cost is spread over a large number of vehicles

Generic software can be used in most service functions because the HD OBD specification provides an extensive coverage of the critical control systems

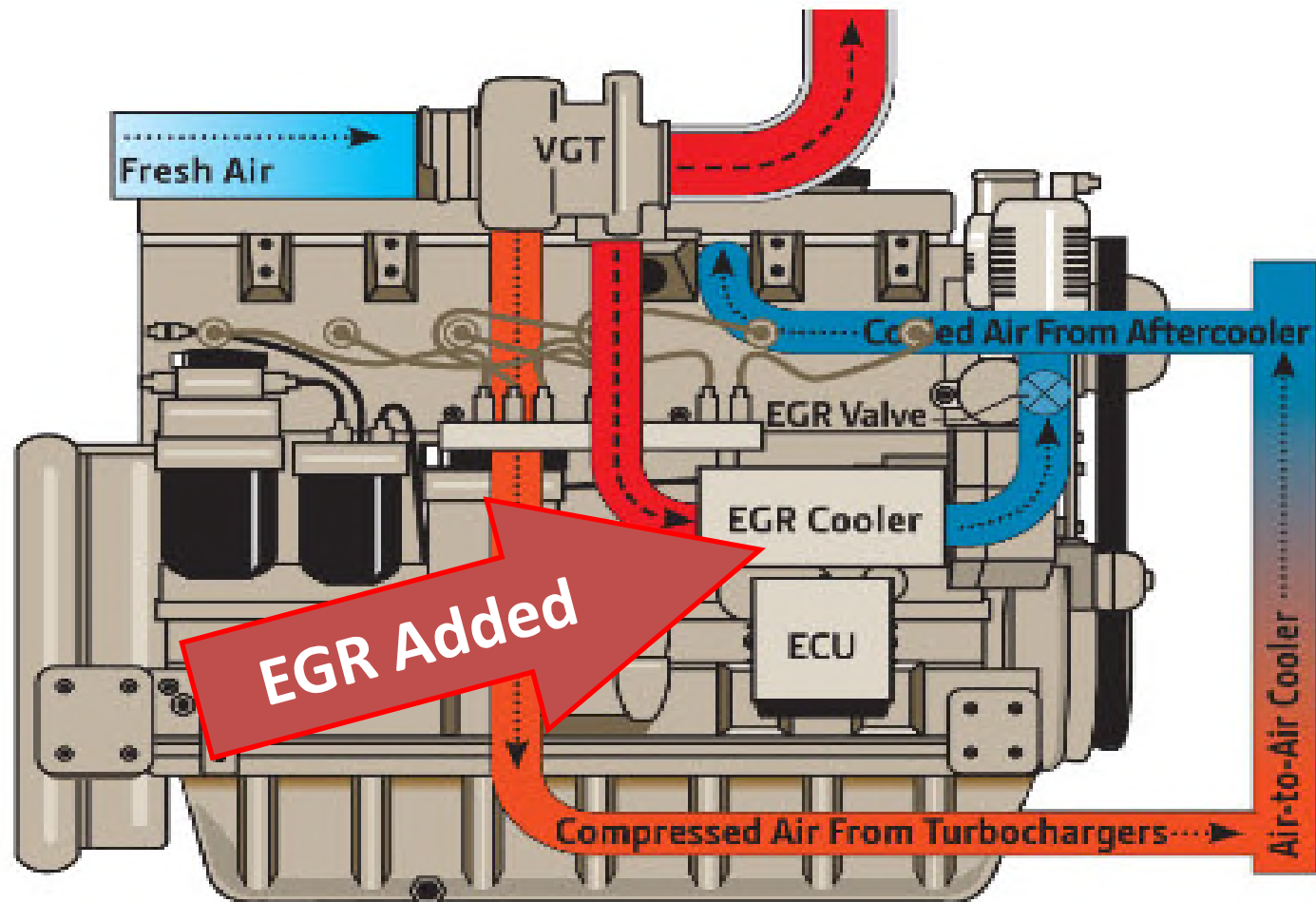
# Turbocharging

The density of intake air is increased through the turbocharging technology.

2. To raise the volumetric efficiency of the cylinder, the advanced techniques such as variable exhaust valve timing are used for improving the performance of intake and exhaust

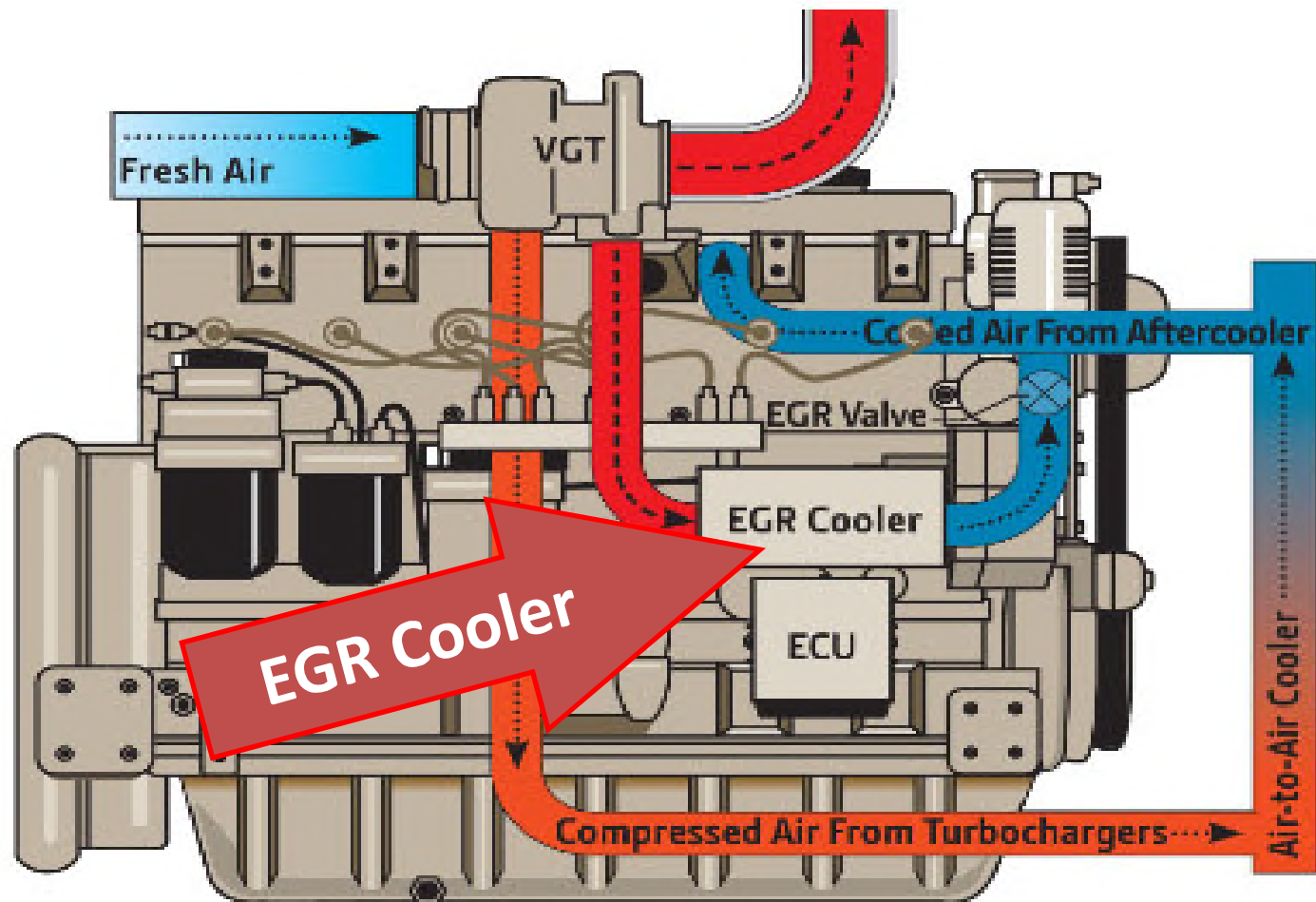
# Tier 3 Changes

EGR and VGT turbo added to Tier 2 to reduce NO<sub>x</sub> 50%.



# Tier 3 Changes

All EGR coolers can be a problem. EGRs that use coolant must have 15 psi radiator cap.



# Exhaust Gas Recirculation (EGR)

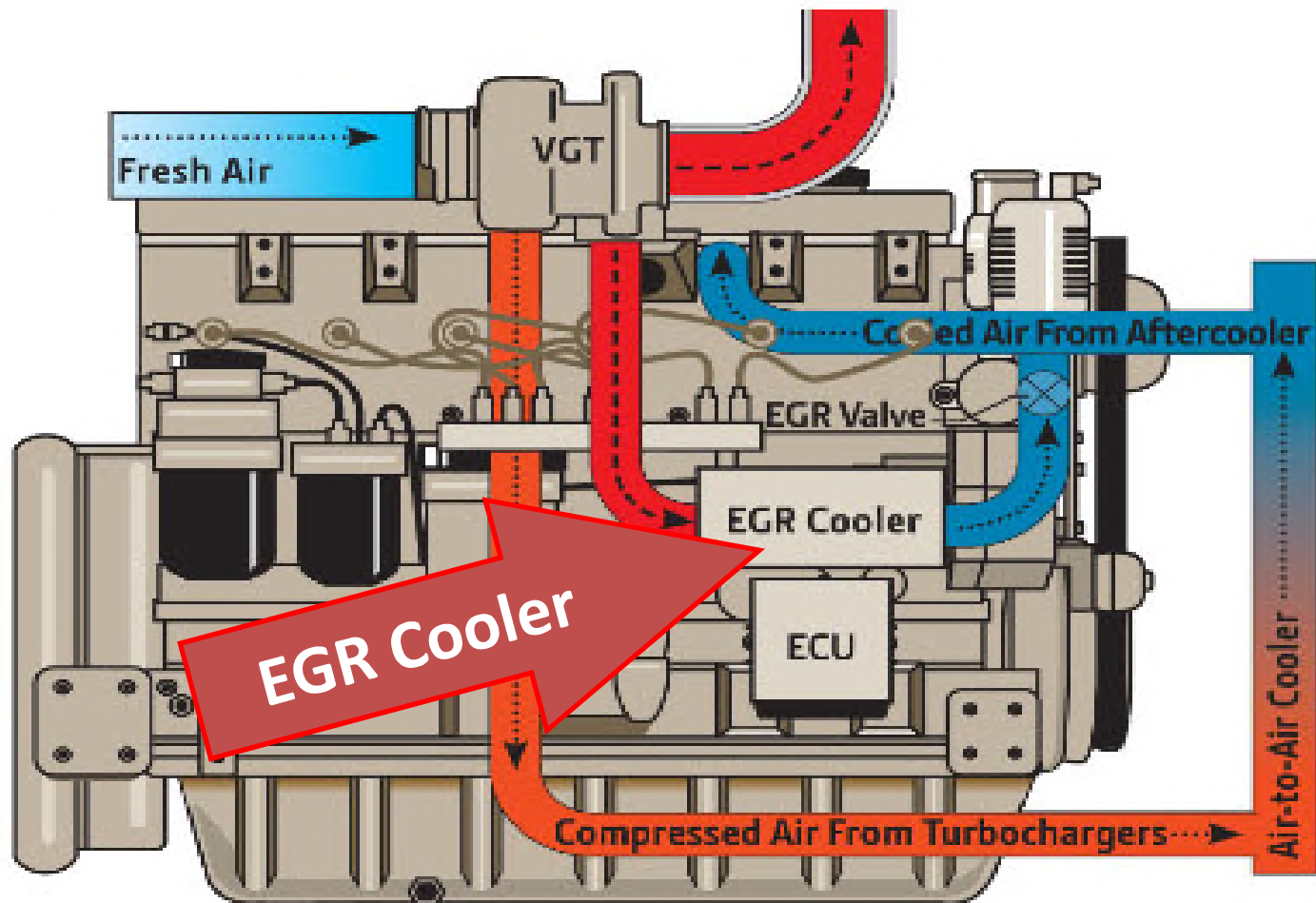
Also known as Cooled Exhaust Gas Recirculation, (CEGR ) (EGR), which requires enhanced cooling capacity, reduces NO<sub>x</sub> by recirculating exhaust back into the engine

This dilutes the amount of oxygen in the combustion chamber and lowers the combustion peak temperature

As a result, NO<sub>x</sub> formation is reduced but PM is increased

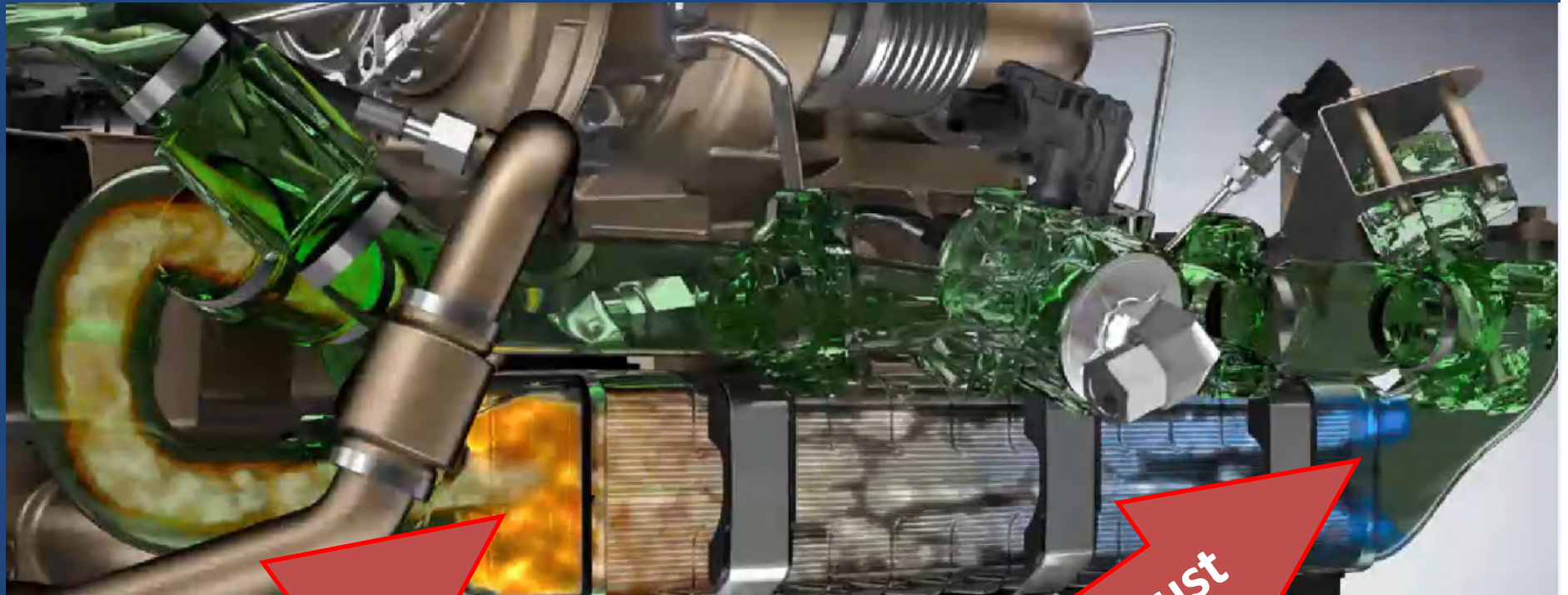
# EGR Cooler

The hot exhaust gas is cooled before it is mixed with the incoming air.



# EGR Cooler

The hot exhaust gas is cooled before it is mixed with the incoming air.



Hot exhaust

Cooled exhaust

# NO<sub>x</sub> Formation

NO<sub>x</sub> formation is a function of the high combustion temperature in diesel engines

The hotter the combustion temperature, the more NO<sub>x</sub> is created

If you want to reduce the NO<sub>x</sub> that is formed during combustion, you need to lower the peak combustion temperature by reducing the amount of oxygen molecules available

# EGR

EGR deprives the combustion event of some of its oxygen

By introducing cooled exhaust gas, which is lower in oxygen, into the intake system, thereby reducing the combustion temperature and lowering  $\text{NO}_x$  production

# Good news Bad news

The good news is that you don't have to add much extra to the system to accomplish  $\text{NO}_x$  reduction

The downside is that the lower-temperature diesel combustion is less efficient, so it creates more particulate matter and it burns more fuel

The trade off is lower  $\text{NO}_x$  for less fuel efficiency and more soot (That extra soot, also known as Particulate Matter or PM)

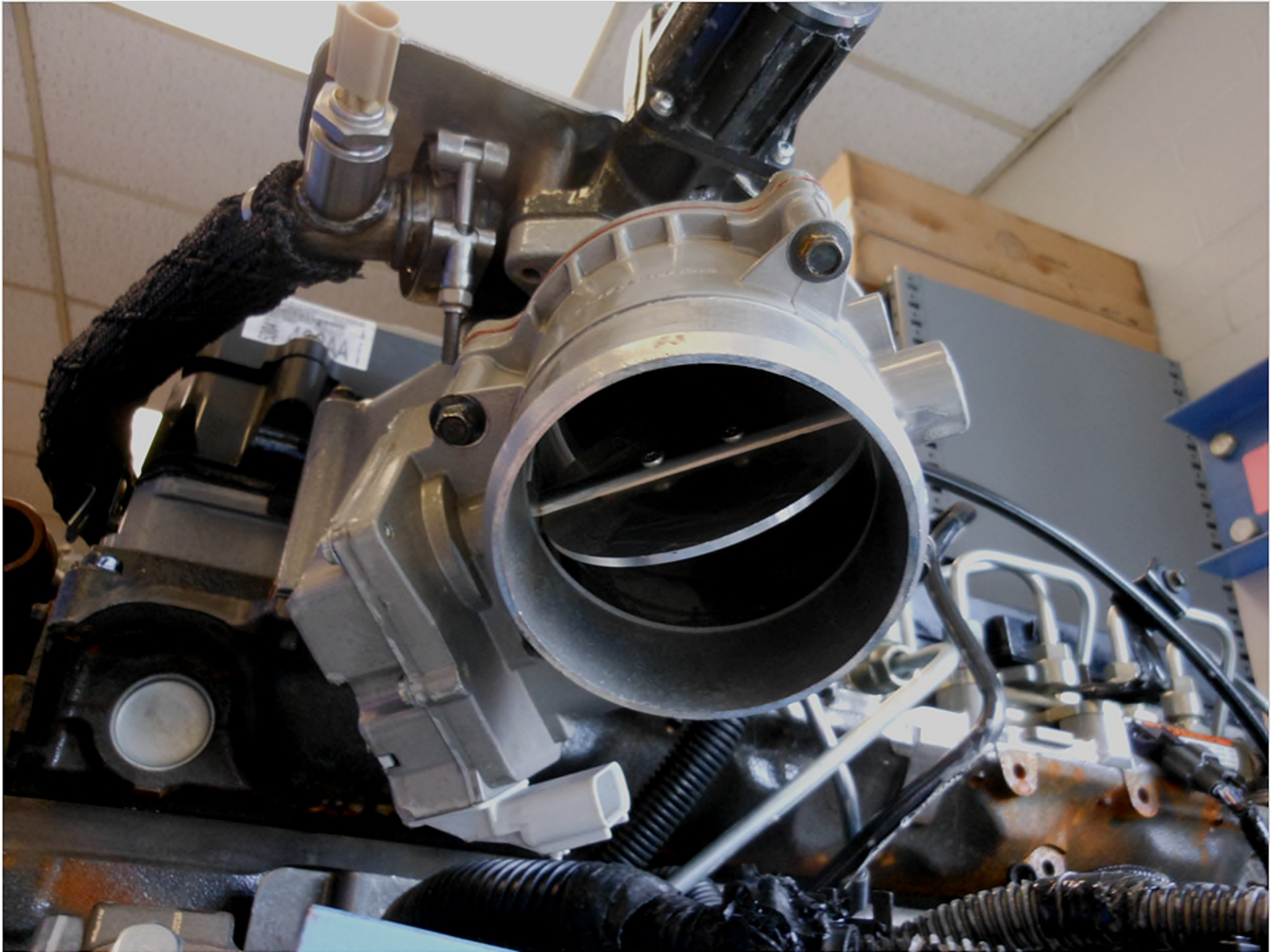
# EGR Airflow Throttle Control Valve

Located between the charge air cooler and the intake manifold

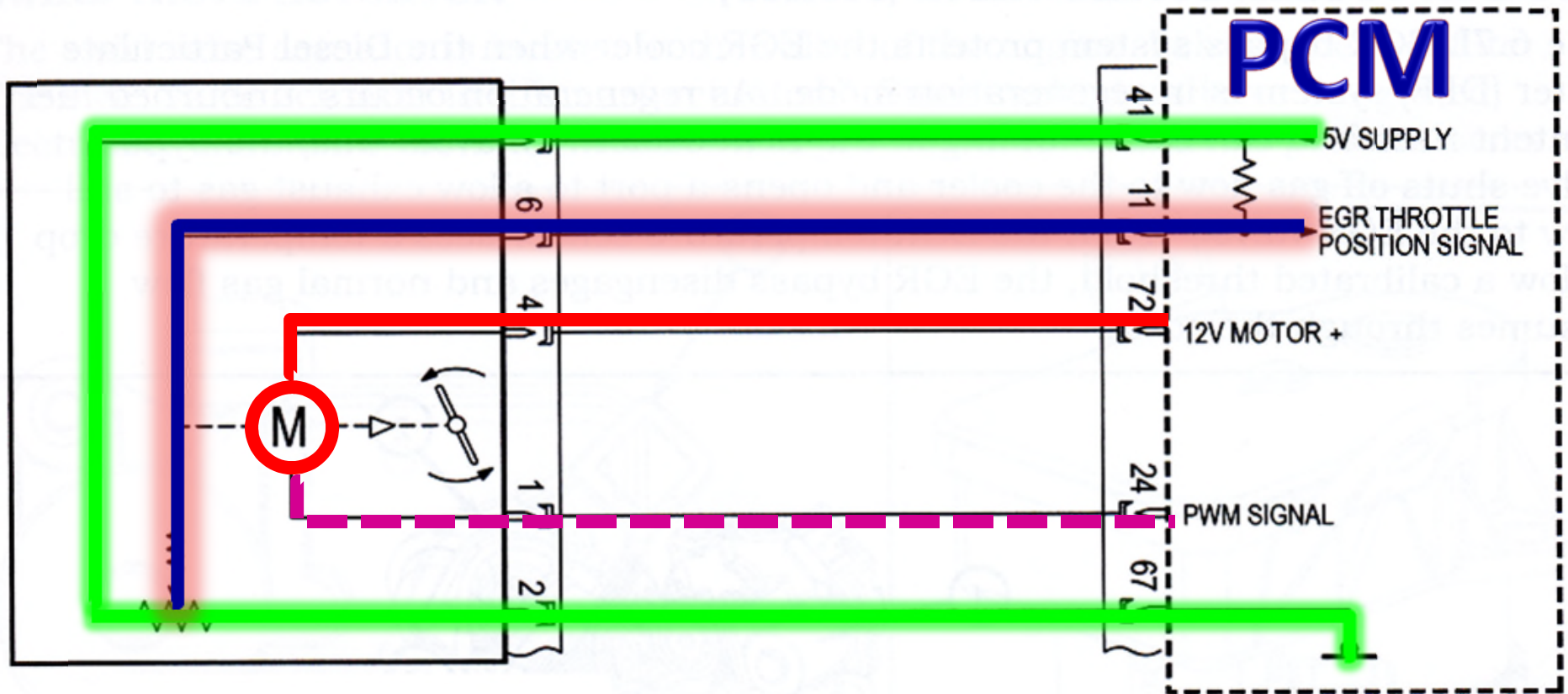
PCM controlled to increase EGR flow by creating a higher pressure differential between the exhaust system and the boost pressure in the intake; called Venturi effect

Allowing exhaust gas into the manifold

Normally open when not activated (non restricted)



# Throttle control valve and Throttle Position Sensor (TPS)

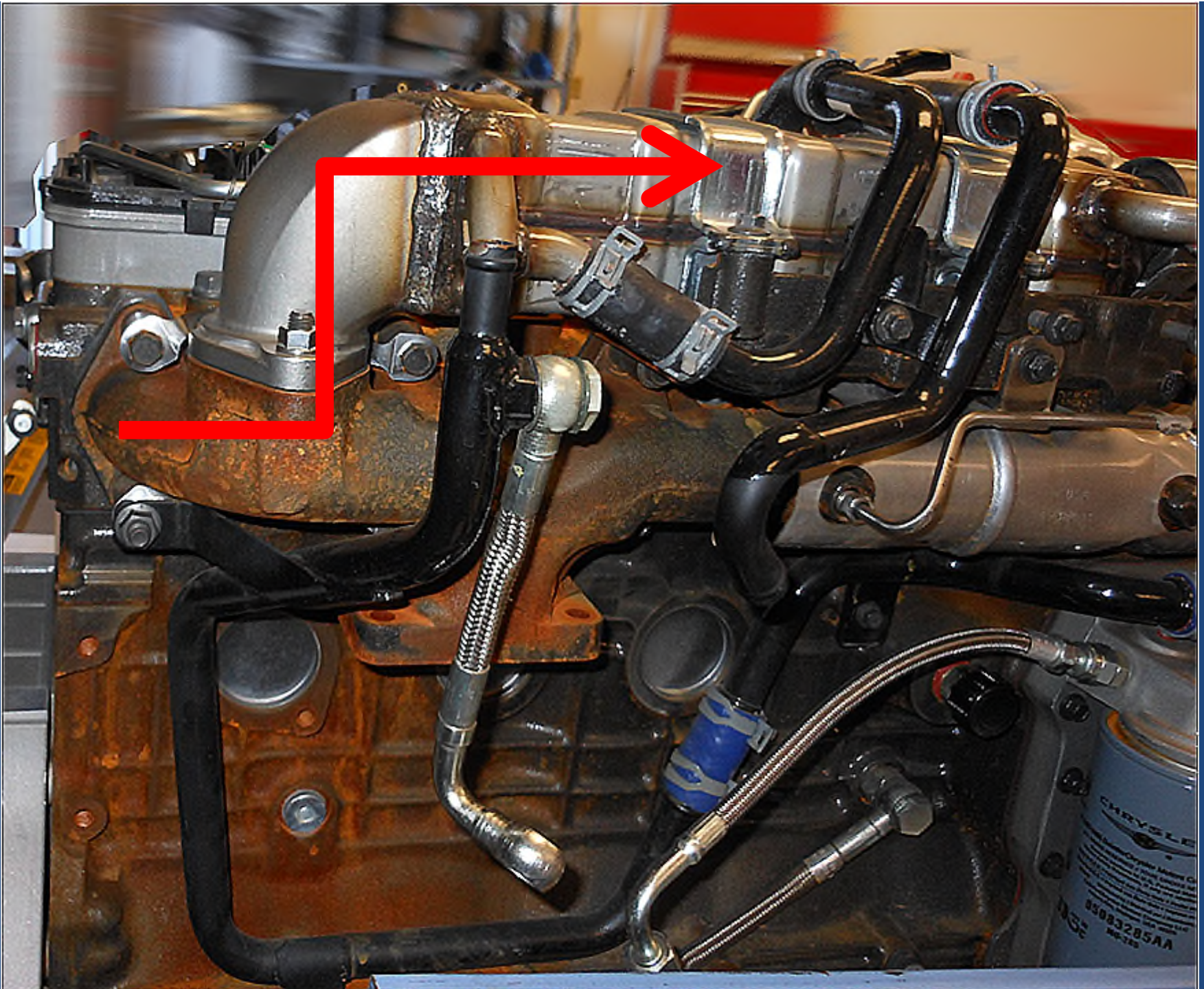


# Exhaust Gas Recirculation Valve (EGR)

Allows exhaust gas to enter the intake manifold

Hot exhaust gas exits the exhaust manifold and passes through the EGR cooler before being mixed with cooler inlet air by the EGR valve

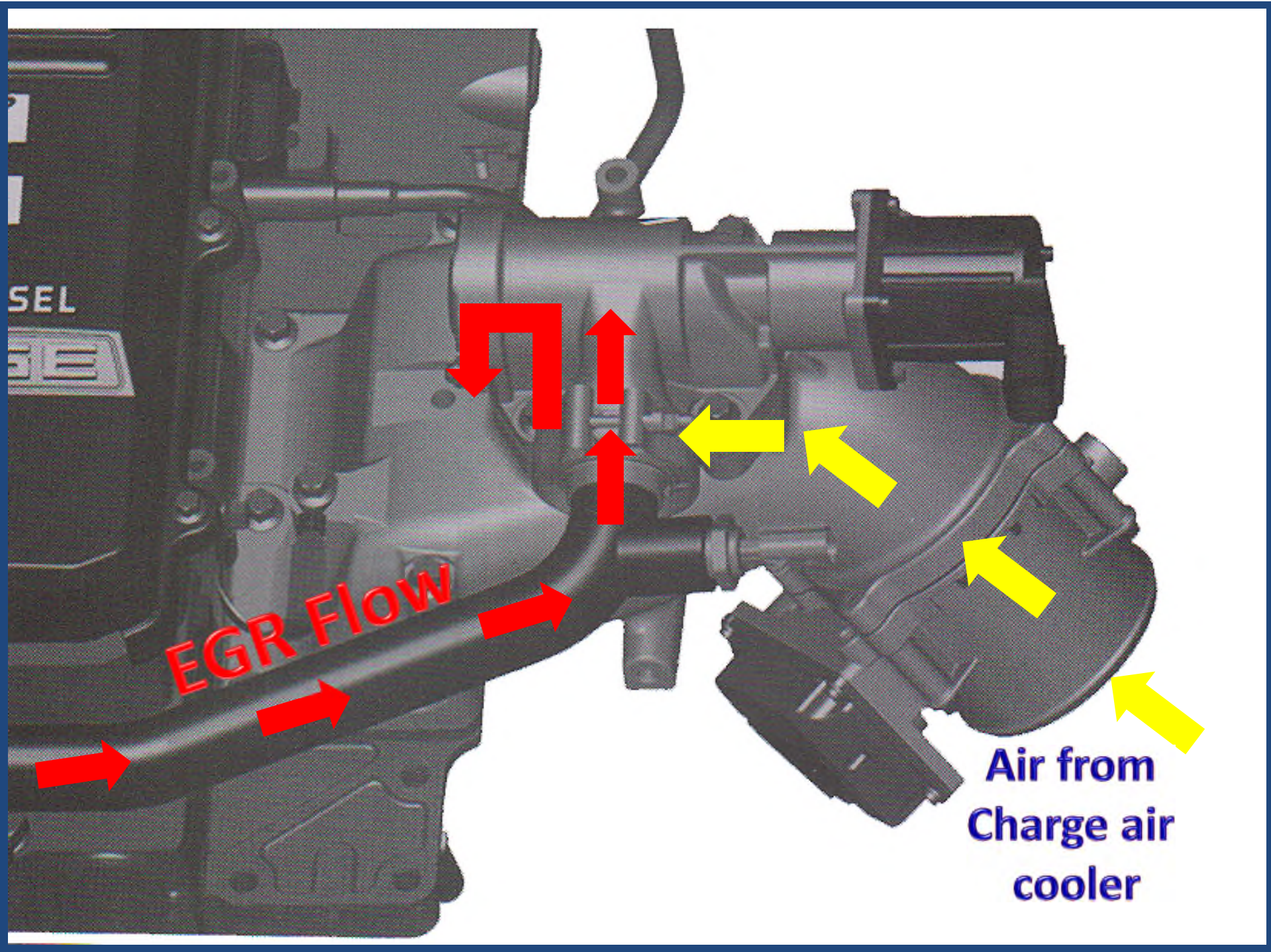
The ECU must manage EGR to reduce NO<sub>x</sub> while controlling the amount of soot created.



# Exhaust Gas Recirculation Valve (EGR)

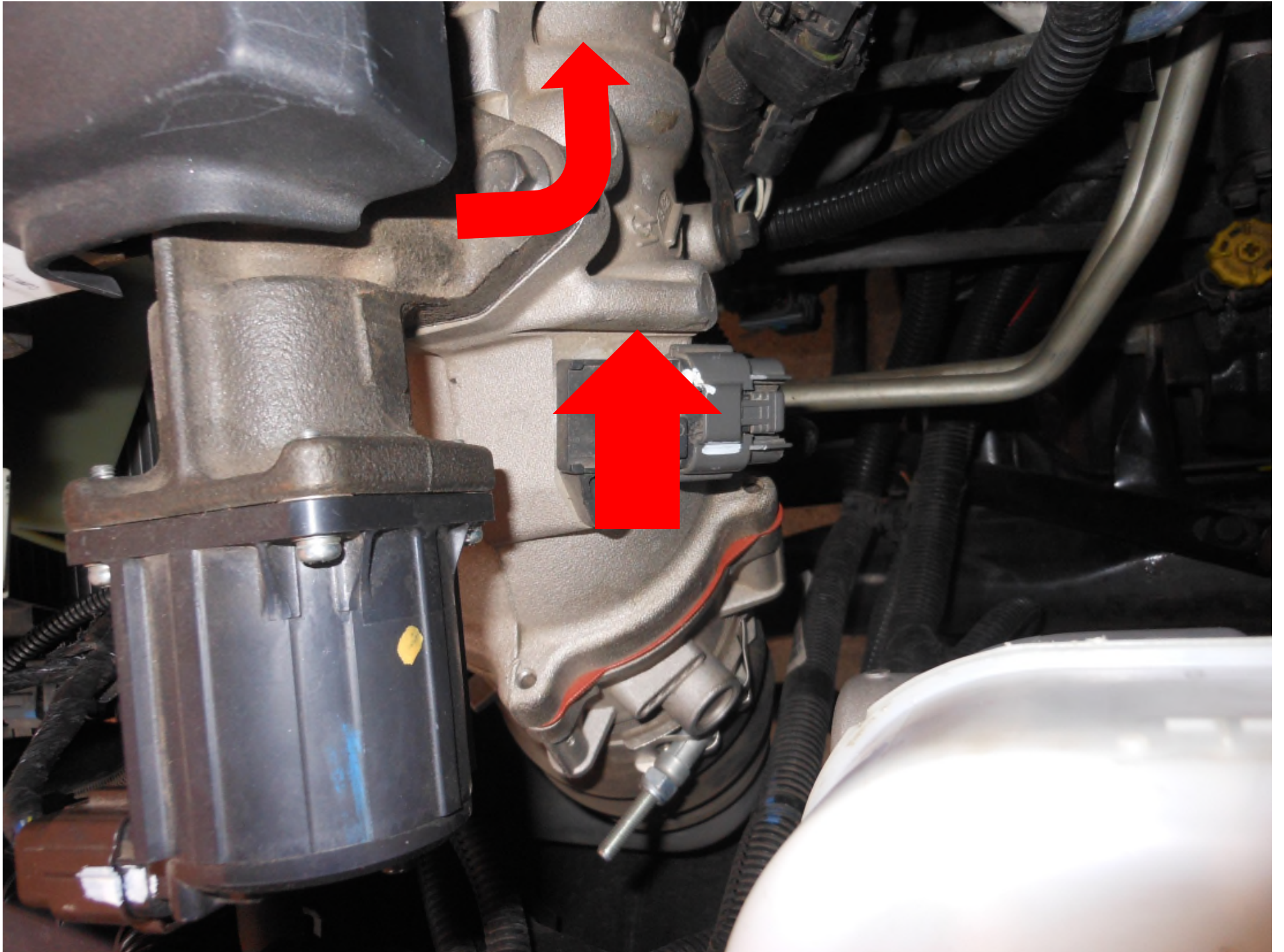
The mixture then enters the intake manifold

The exhaust gas and air mixture is designed to reduce  $\text{No}_x$  by reducing combustion temperature by reducing the oxygen percentage.



**EGR FLOW**

**Air from  
Charge air  
cooler**



# Exhaust Gas Recirculation Valve (EGR)

The EGR mixture is inert (non-combustible) and dilutes the intake charge

EGR is active at low, medium, and high engine loads

Control is based from engine load and speed

The PCM evaluates the inputs and uses a stored map to control EGR flow and throttle air valve

# EGR Rate

The PCM calculates the EGR flow rate based from:

MAF Sensor

Boost Pressure sensor

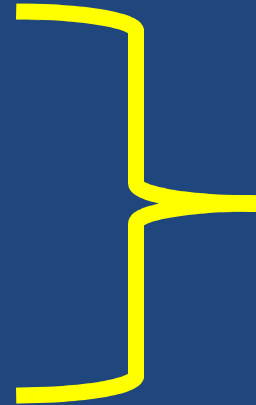
Intake air sensor

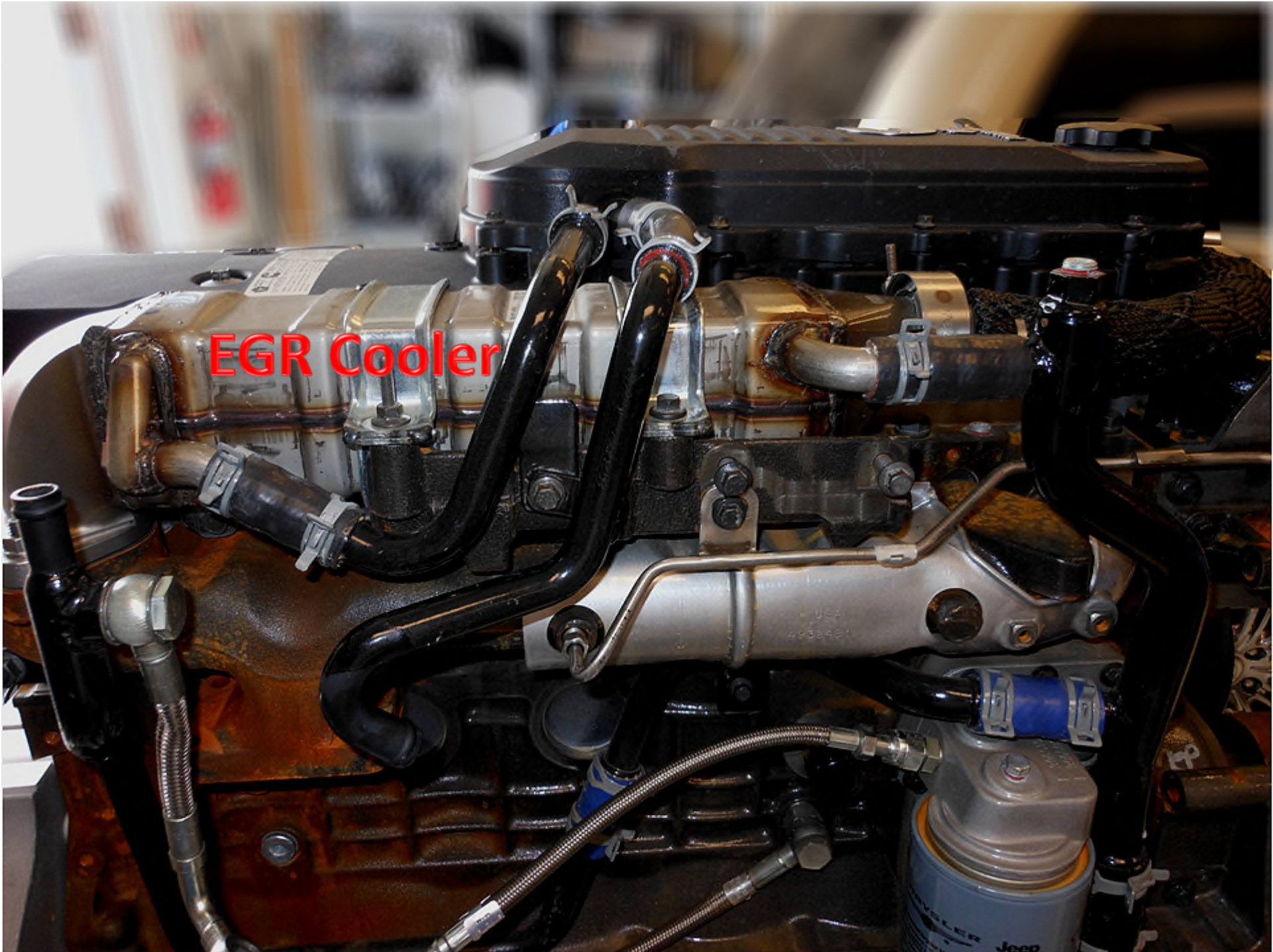
Inlet air pressure sensor

Accelerator pedal position sensors

Crankshaft position sensor

O<sub>2</sub> sensor





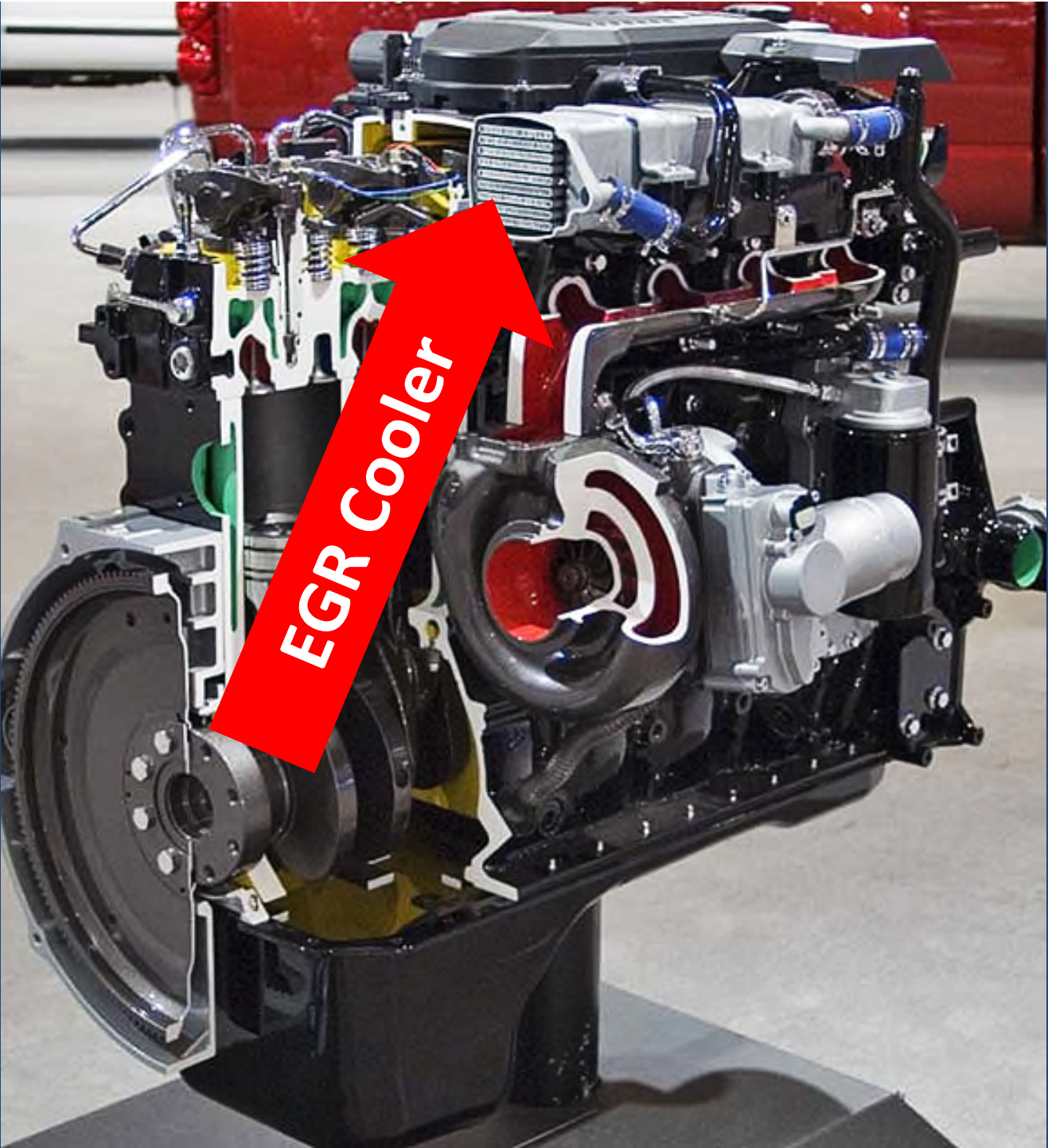
EGR Cooler

# EGR Cooler

Connected to the exhaust manifold so some exhaust flows into the cooler

The EGR cooler is cooled by engine coolant

The exhaust gas is cooled and enters the crossover tube which routes the gas into the EGR valve



**EGR Cooler**

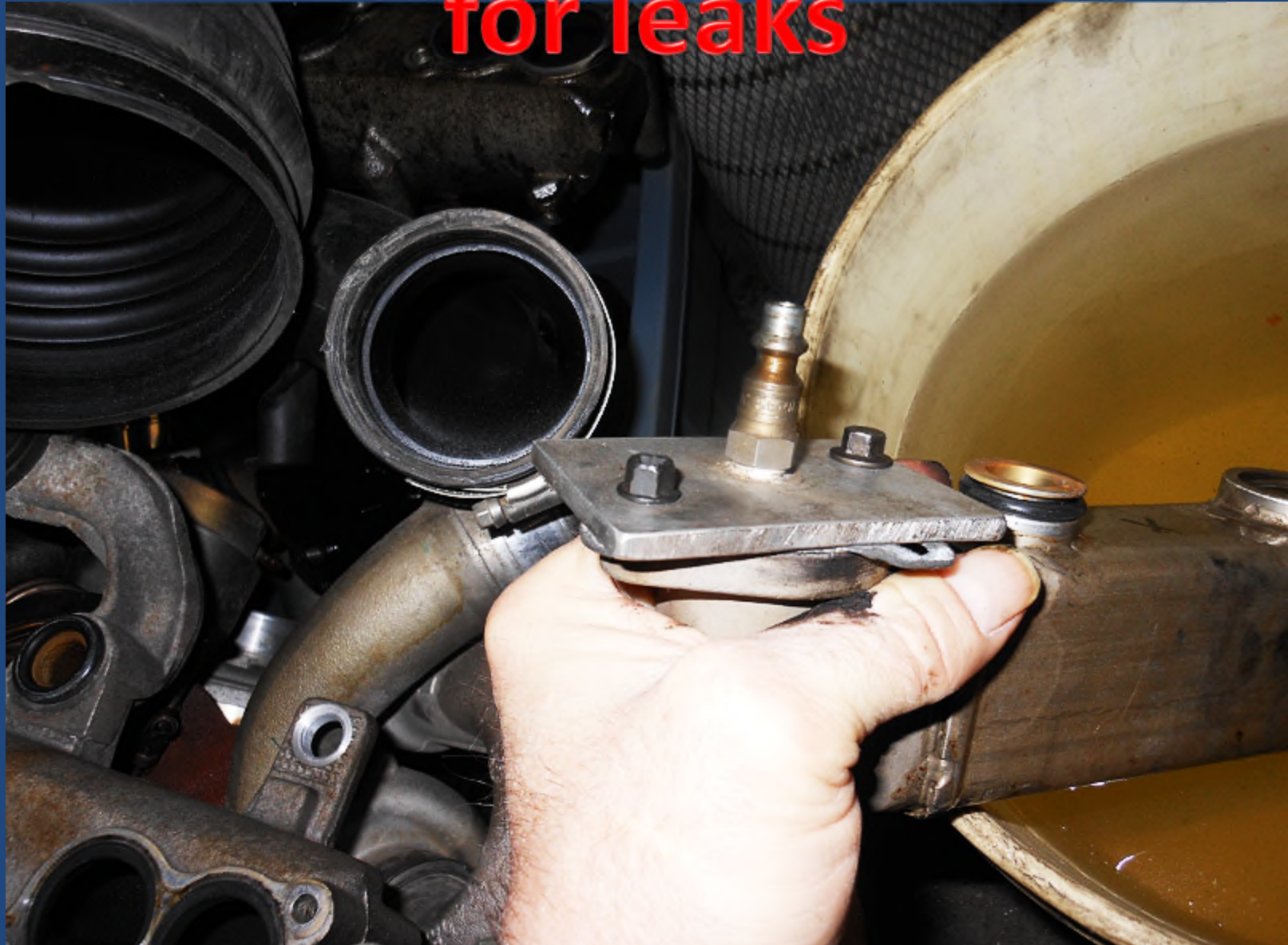
# Symptom of leaking EGR cooler

1. White smoke
2. Missing Coolant
3. Wet, gooey EGR valve

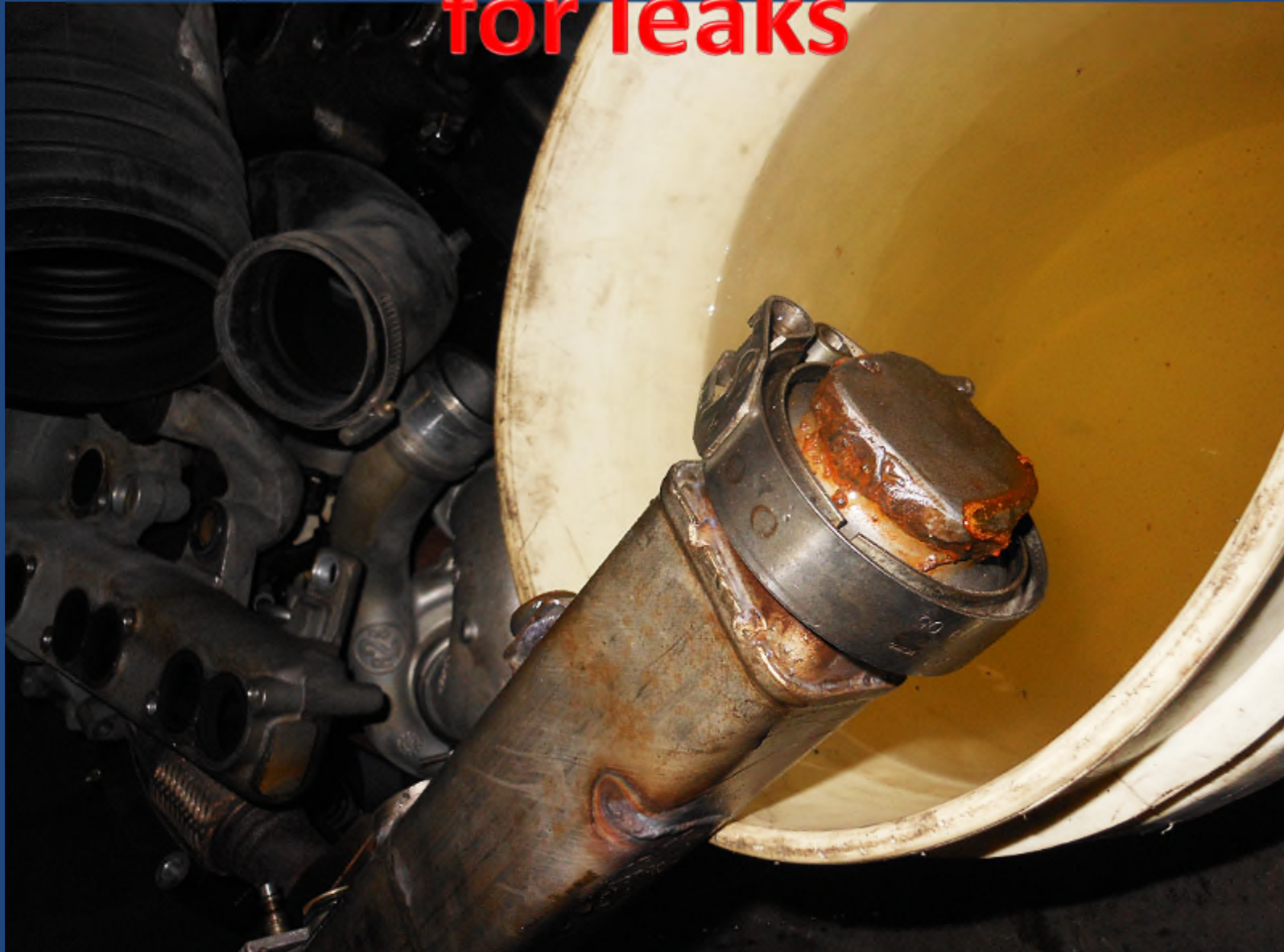


**EGR valve from an  
Engine with a bad  
EGR cooler**

# Checking the EGR cooler for leaks



# Checking the EGR cooler for leaks



# The infamous Ford 6.0 L EGR Coolers



# EGR Cooler By-Pass

Blocks exhaust gas flow through the EGR cooler and opens a valve allowing un-cooled EGR gas to flow to the EGR valve

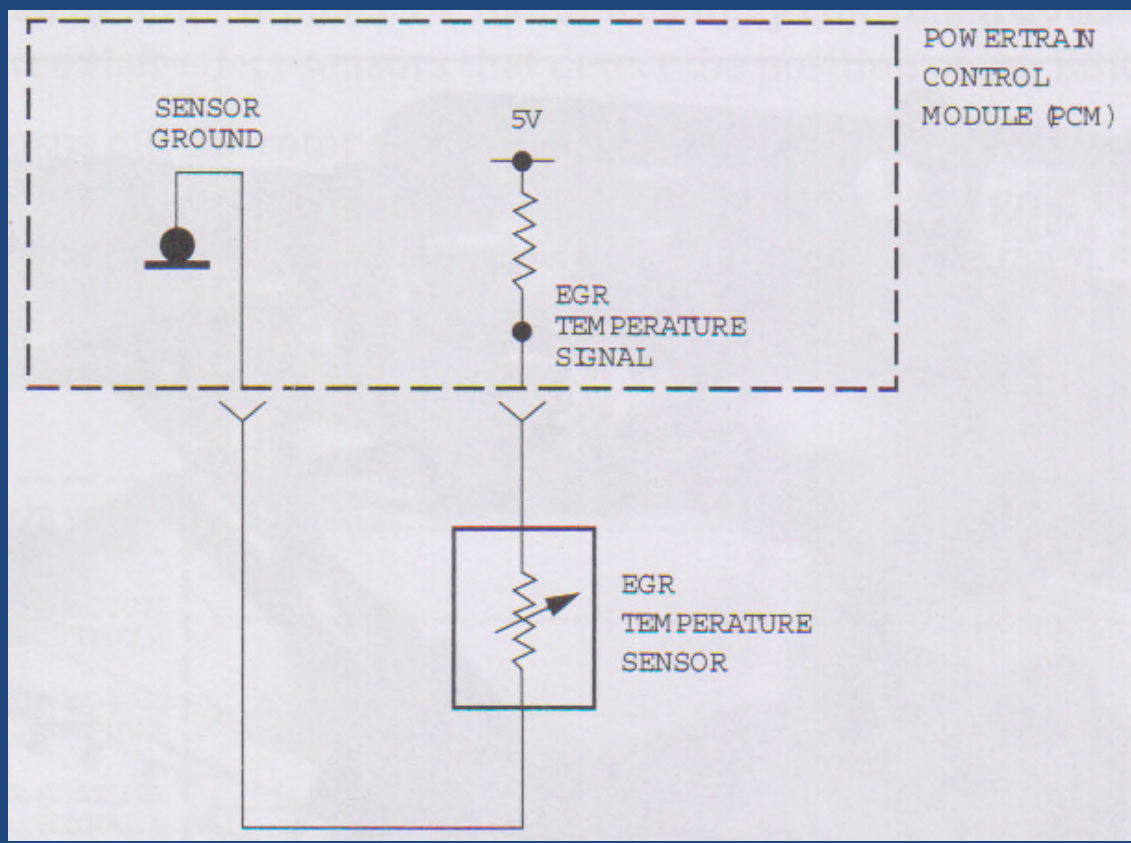
Activates during Aftertreatment regeneration only

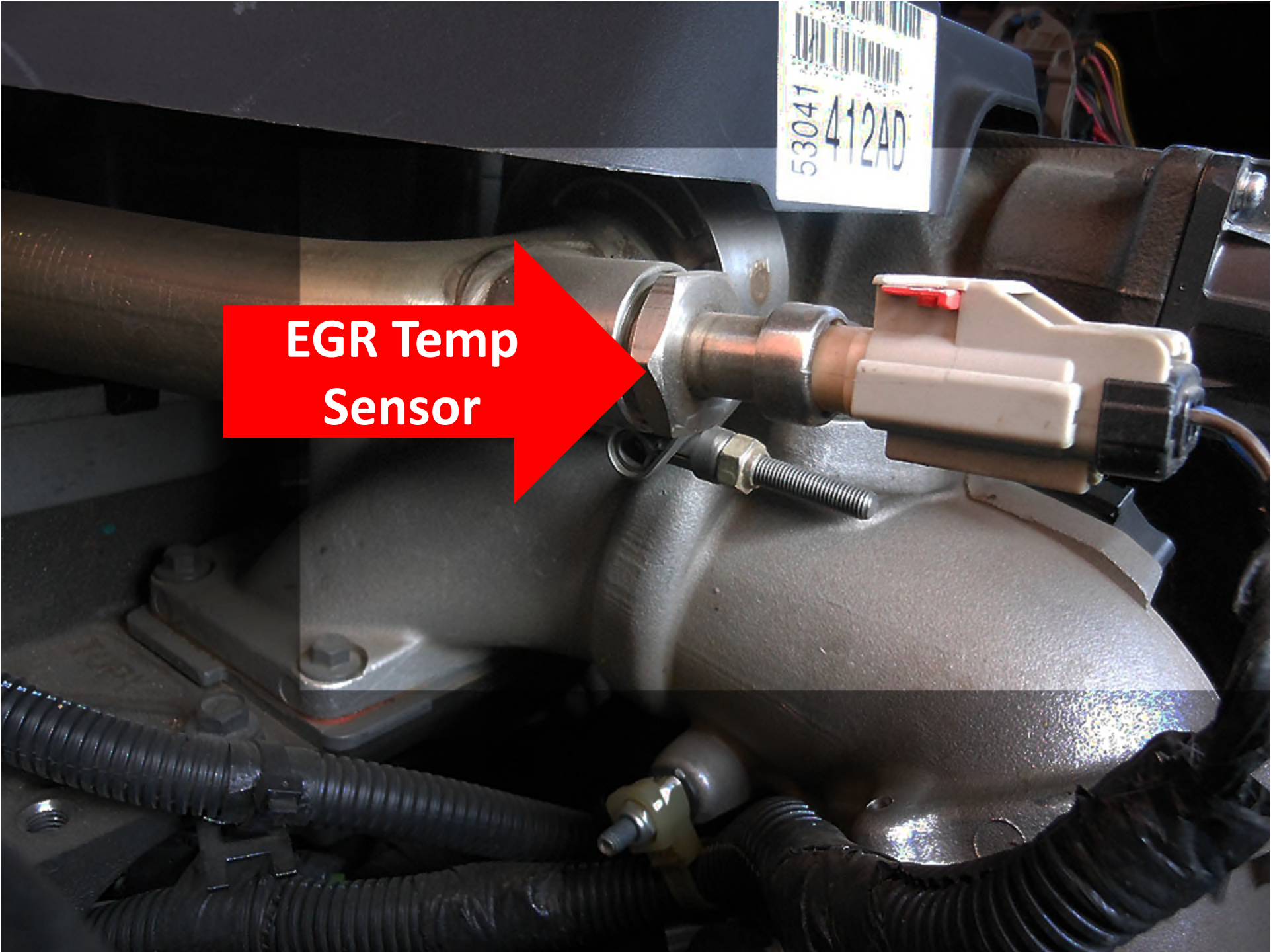
Unburned fuel can cause fouling of the cooler

Some vehicles do not use the EGR cooler By-Pass system

# EGR Temperature Sensor

When the temperature sensor indicates that the temperature has returned to normal after regeneration the EGR by-pass is de-activated





**EGR Temp  
Sensor**

# Radiator Pressure Cap

Ford's 6.0L Powerstroke had major problems with their EGR cooler.

Ford also had a problem with their radiator cap where most caps failed a pressure test.

The boiling point of coolant was too low, which caused a bad EGR cooler design fail more often.

If the coolant boils in the EGR cooler, it creates hot spots that can cause problems.

# Radiator Pressure Test Kit

Kits like this can be used to check the coolant system for leaks and check the pressure cap. 15 PSI will raise the boiling point of 50/50 coolant to 246° F which helps prevent hot spots in the EGR cooler.



# Other EGR Problems

EGR problems are increased when fuel has high water content.

Insure the cetane rating is sufficient for good combustion or EGR carbon build up can cause problems.

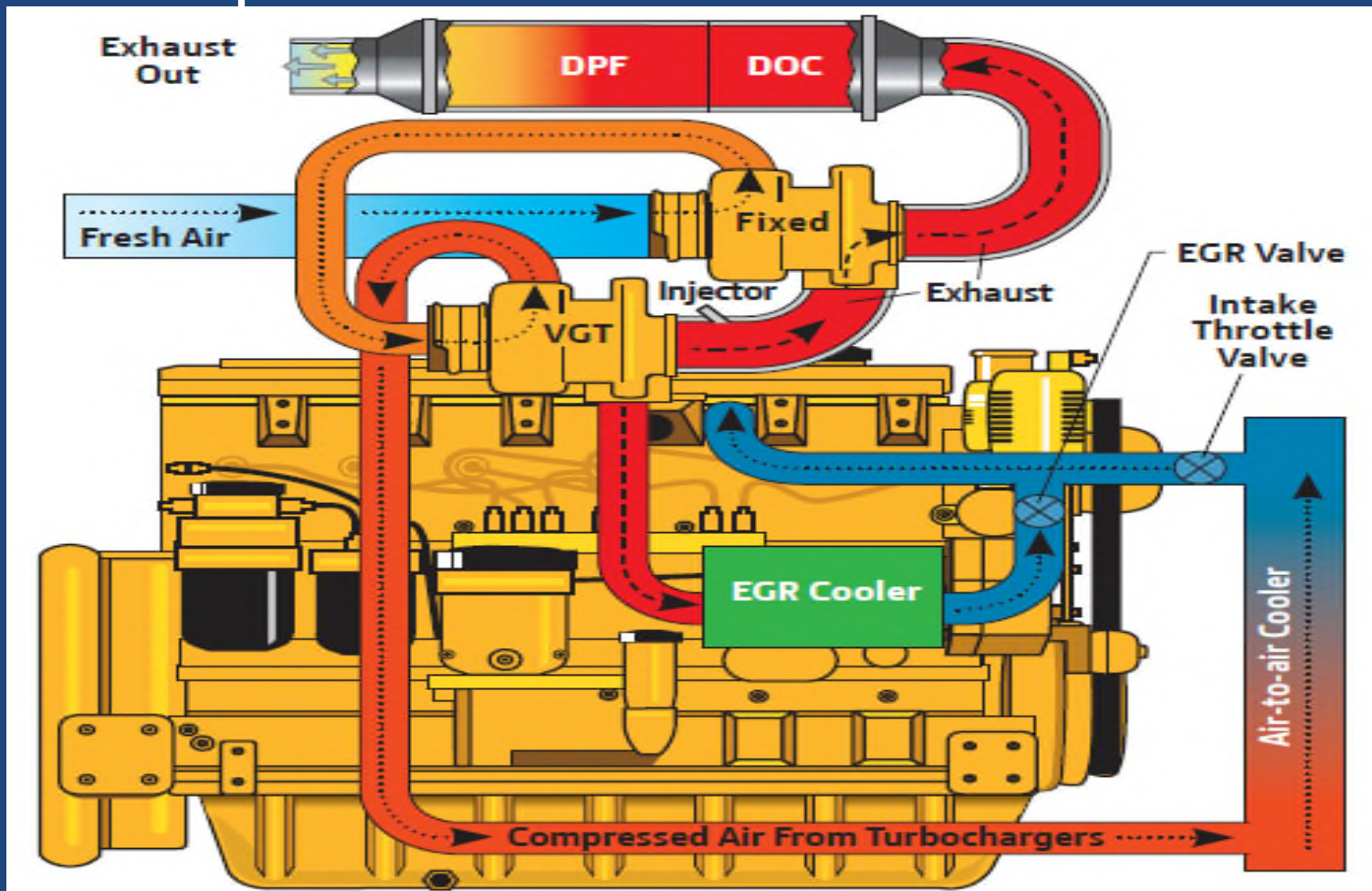
Use fuel additives if necessary to raise cetane rating and prevent biologic material for forming water in the fuel. This can be a problem with biofuel.

Biofuel will increase cetane but you must keep biologic growth to a minimum or water will form.

There is a additive reference in the class reference handout.

# Tier 4 Early

Manufacturers added diesel oxidation catalyst and diesel particulate filter.



# Retrofit Device Verification Programs

In-use off road equipment has long service life with the possibility of high emissions long into the future

There are verification programs to approve retrofit systems that demonstrate a reduction in emissions from off road equipment

There are two verification programs for retrofit technology in North America, the California Diesel Risk Reduction Plan and the U.S. EPA Voluntary Retrofit Program.

Some states are requiring government fleets to adapt retrofit programs to reduce diesel emissions.

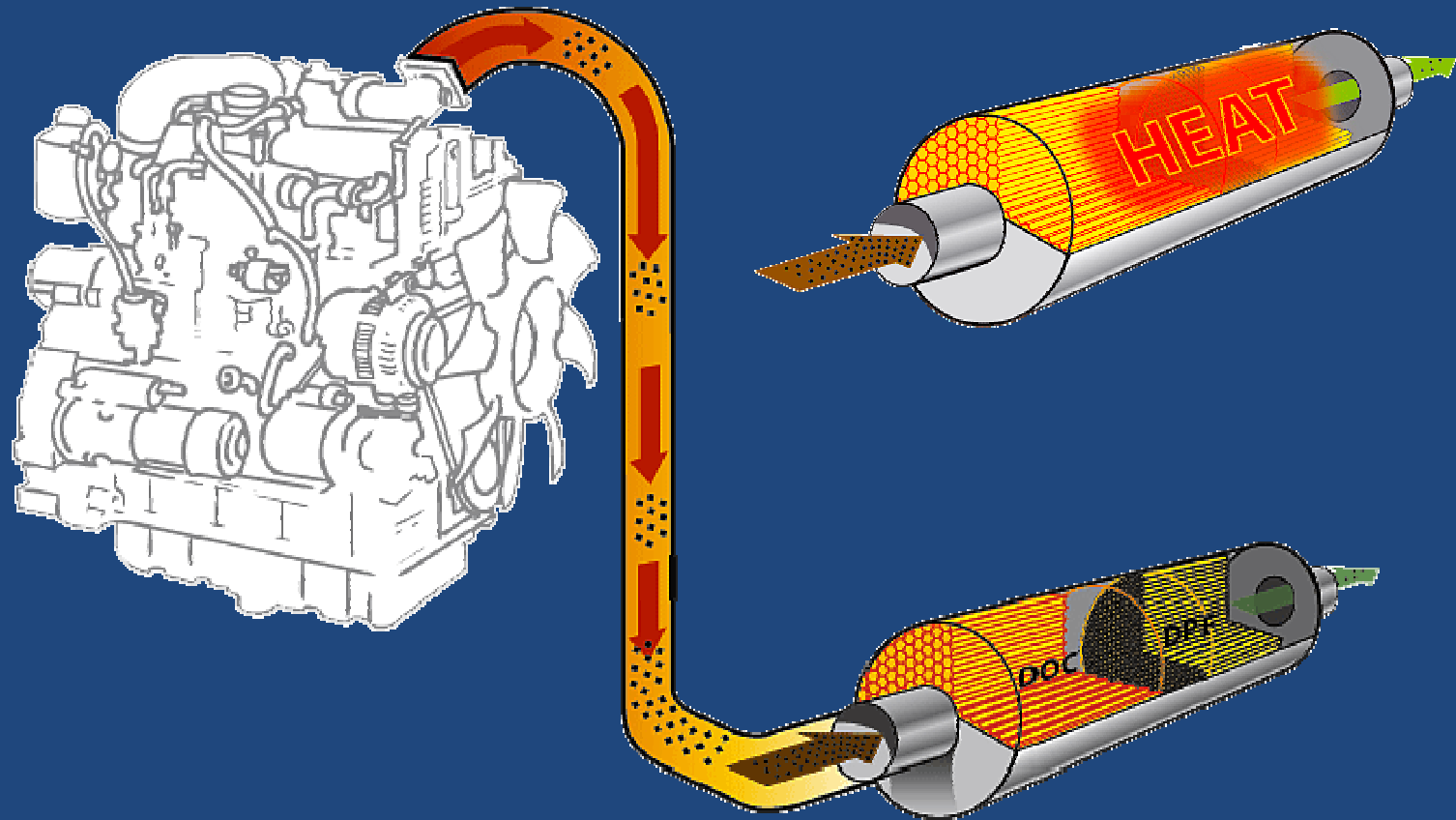
# Crankcase Ventilation Retrofit

The EPA strongly encourages school districts to consider combining closed crankcase systems with the other technologies, to most efficiently reduce the blow-by emissions that can come up into the cabin of the bus.

This is the most common retrofit currently.

Diesel particulate reduction systems are the second most used retrofit.

# DOC and DPF



# The DOC (Diesel Oxidation Catalyst)

The DOC is a special catalyst that reacts with engine exhaust upon contact. The reaction transforms PM emissions in the exhaust into harmless substances such as water and carbon dioxide

# Diesel Oxidation Catalyst Retrofit

Diesel oxidation catalysts (DOCs) installed on a vehicle's exhaust system can reduce total particulate matter by as much as 25% to over 50%, depending on the composition of the PM being emitted.

Oxidation catalysts can reduce more than 90% of the CO and HC emissions and more than 70% of the toxic hydrocarbon emissions in diesel exhaust.

# Wall-flow diesel particulate filters retrofit

Wall-flow DPFs are the most effective DPF strategy.

DPFs can achieve up to and, in some cases, greater than a 90% reduction in PM. DPFs are extremely effective in controlling the carbon fraction of the particulate known as black carbon.

Particulate filters can be combined with a Diesel Oxidation Catalyst or directly catalyzed to control up to 90% or more of the toxic HCs emitted by a diesel engine.

# Flow-through or partial filters retrofit

Flow-through filters employ catalyzed metal wire mesh structures or tortuous flow, metal foil-based substrates with sintered metal sheets to reduce diesel PM.

Flow-through filters are capable of achieving PM reduction of about 30% to 75%.

Because of their open structure, these devices are less prone to plugging and may be more suited to older diesel engines with higher engine-out PM levels.

# Exhaust gas recirculation (EGR) retrofit

Exhaust gas recirculation (EGR) systems have been retrofitted on heavy-duty diesel vehicles.

EGR is capable of achieving a 40% reduction in NO<sub>x</sub> emissions or more.

# Lean NO<sub>x</sub> Catalysts or HC-SCR retrofit

Lean NO<sub>x</sub> Catalysts or HC-SCR have been installed on heavy-duty on-road and off-road vehicles in combination with a DPF and are capable of achieving from 25-40% NO<sub>x</sub> reduction.

These devices rely on the use of on-board diesel fuel from the vehicle as the reducing agent.

# Lean NO<sub>x</sub> Trap Storage Catalysts (LNT) retrofit

Lean NO<sub>x</sub> Trap Storage Catalysts have been successfully used on new light and medium-duty vehicles with over 80% NO<sub>x</sub> conversion.

One experimental retrofit LNT system using syngas to regenerate the trap is being demonstrated on medium duty trucks.

# Retrofit Summary

The diesel oxidation catalyst (DOC) is a leading retrofit control strategy in both the on-road and off-road sectors throughout the world, reducing not only PM emissions but also CO and HC emissions.

DOCs do not generally oxidize or reduce the elemental carbon or black carbon constituents of diesel PM.

DPF filters are more effective on black carbon constituents of diesel emissions.

# DPF Retrofit Summary

The most common DPF is the wall-flow filter where a porous honeycomb structure is used having alternating channels plugged at opposite ends.

This effectively forces the exhaust gases containing the particles through the cell walls causing the particles to be filtered and deposited on the inside wall of the channel.

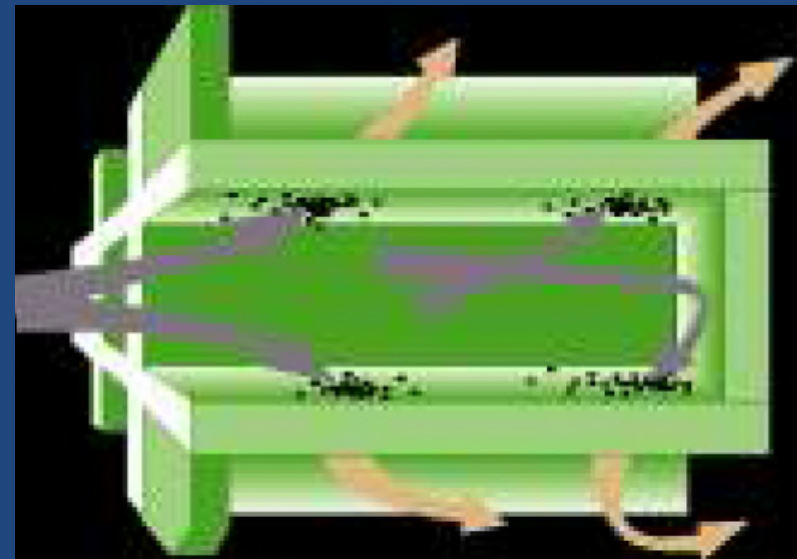
Wall-flow filters have the highest level of filtration efficiency (>90 percent) for particles, including ultrafine particles.

# Wall-flow DPF

The particulate matter that collects in the DPF must be eliminated.

The process of PM elimination is called regeneration.

There are several methods of regeneration.



# Catalyst-based regeneration

Catalyst-based regeneration using a catalyst applied to the surfaces of the filter.

A base metal or precious metal coating applied to the surface of the filter reduces the ignition temperature necessary to oxidize accumulated particulate matter.

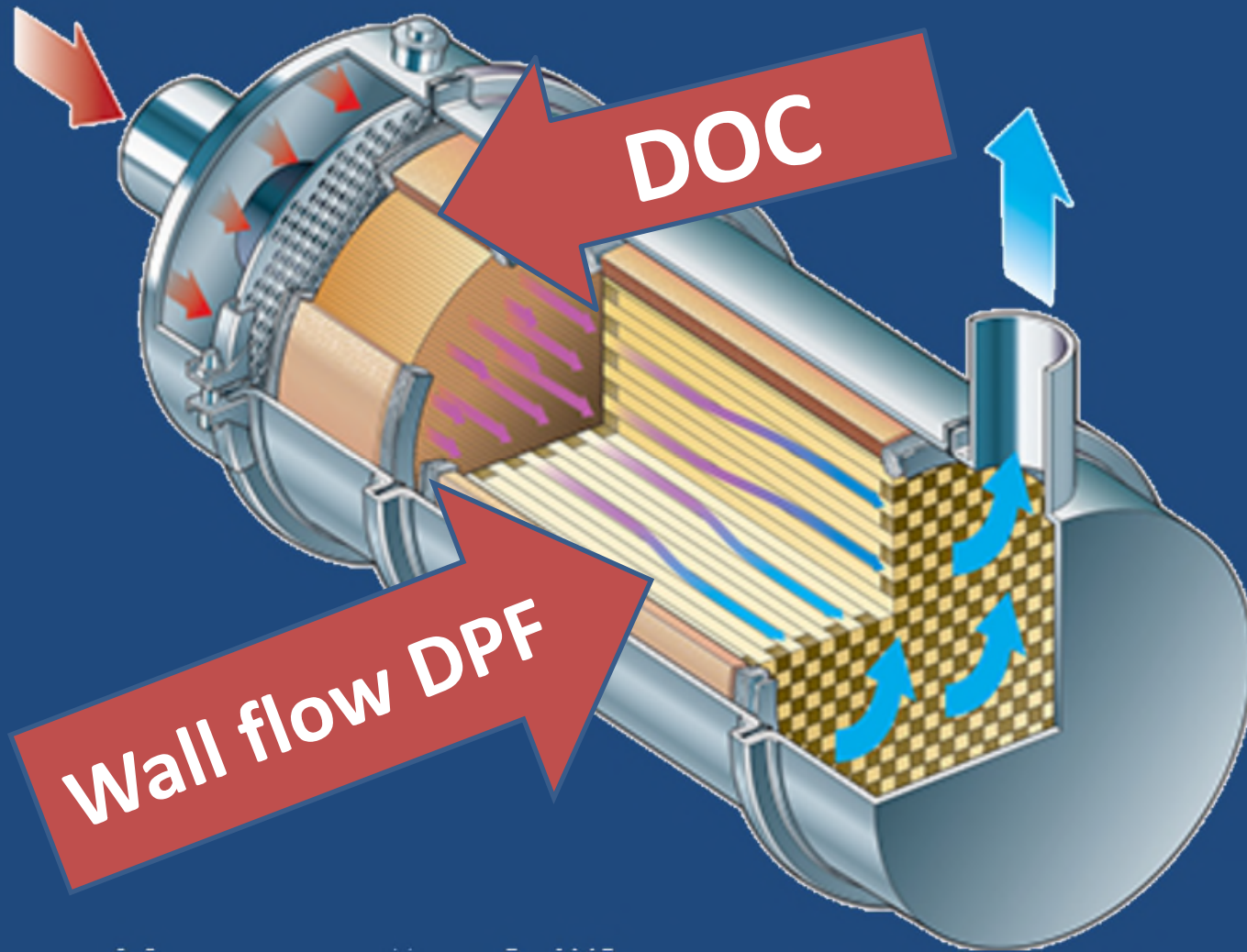
This is sometimes used with passive regeneration when electronic fuel control is not available.

# Catalyst-based regeneration with DOC

Catalyst-based regeneration using an oxidation catalyst placed upstream of the filter to facilitate oxidation of nitric oxide (NO) to nitrogen dioxide (NO<sub>2</sub>).

The nitrogen dioxide reacts with the collected particulate, substantially reducing the temperature required to regenerate the filter.

# Diesel Particulate Filter with DOC



# Cummins Retrofit DPF/DOC

The filter system has two chambers. The first is a Diesel Oxidation Catalyst to oxidize a portion of the NO in the exhaust to NO<sub>2</sub>.

The second chamber is a wall-flow DPF filter where the trapped soot is then destroyed by the NO<sub>2</sub> product DOC chamber.



# Post TDC Injection of Fuel

Post top-dead-center (TDC) fuel injection of small amounts of fuel in the cylinders of a diesel engine after pistons have reached TDC introduces a small amount of unburned fuel in the engine's exhaust gases.

Fuel can also be injected into the exhaust pipe. This unburned fuel can then be oxidized in the particulate filter to combust accumulated particulate matter.

Post TDC injection requires electronic fuel control.

# Classification of Regeneration Strategies

We will divide the types of regeneration in to two main categories;

Passive Regeneration

Active regeneration

Non-Regenerative DPF

We will discuss the aspects of both methods.

# Non-Regenerative DPF

Generally constructed from fiber matting in which materials such as steel wool and fiberglass are used.

These types of filter have a life of around 300 working hours.

When full, the element must be replaced with a clean one.

Used mainly on stand-by power generators which have low operating times.

# Passive Regeneration

DPF systems that are able to regenerate themselves using only the exhaust gas stream, without additional energy inputs, are known as passive systems.

Passive systems are favored, particularly for retrofit applications, because they require **no integration** with the engine, no source of energy other than the exhaust gases themselves, and no complicated control systems.

Applications with variable or unreliable duty cycles, or with exhaust conditions not suitable for passive systems, require active regeneration.

# Active Regeneration

Some applications use a diesel oxidation catalyst to increase the temperature of the exhaust gas when post injection adds fuel to the exhaust for active regeneration.

The oxidation catalyst removes CO and HC and oxidizes some of the NO in the exhaust gasses to NO<sub>2</sub>. This NO<sub>2</sub> then reacts with the PM trapped in the filter, producing NO and CO<sub>2</sub>.

The oxidation catalyst increases the temperature of the exhaust that results from catalytic action with the raw fuel added to the exhaust.

# PAT Fluid Injection

- Some applications use a special DPF fluid that is injected into the exhaust to lower the temperature necessary for regeneration.
- PAT fluid is an example used on some vehicles that do not generate sufficient exhaust heat for regeneration.



# Reasons DPF Filters Clog

Every vehicle type & engine combination can have differing reasons as to why the filter blocks.

The amount of particulates generated by the engine, the quality of the fuel, quality of the oil, excessive oil consumption, stop and go driving style, even the location of the DPF in the exhaust system can contribute excessive back pressure, filter clogging.

# Reasons DPF Filters Clog

**Temperature:** The DPF relies on high exhaust temperature to carry out a filter regeneration, around 600<sup>o</sup> C is necessary for regeneration, so a lot of short trips, expended idle time and low speed driving will not provide the high enough temperature to begin or complete a regeneration, so the filter can clog faster.

**High mileage vehicles:** vehicles with DPF systems deteriorate as they age and it is harder to complete regeneration.

The expected life is 5,000 hours but this does not account for high oil consumption or poor grade diesel fuel.

# Contributing Factors to Clogging

Not using the correct oil specified for your engine can significantly add to the soot buildup in the DPF.

100% Diesel Bio Fuel: Using these Bio Fuels can also contribute to extra soot build up loading in your DPF as the Bio Fuel may not burn as 'clean' (produces more particulates) as your regular Diesel fuel.

City Cycle driving: Vehicles only driven around town will experience a faster buildup of soot in the DPF because the regeneration process may not complete in stop and go traffic.

# Cleaning DPF

The easiest way to burn the accumulated soot is to drive a highway speeds for 30 minutes or so to use passive regeneration.

The important distinction in that statement is soot.

No amount of driving will burn ash from excess oil consumption or high ash oil.

There are fuel additives that are designed to help burn the soot.

# DPF Cleaning Fluid

- DPF cleaning fluid can be added to the fuel to try to clean excess soot. This is only effective if the soot is caused by soot and not ash. Ash cannot be burned.

- There are also preventative steps that can be taken to reduce the PM produced by the engine.
- Check pressure sensor operation
- Get the filter cleaned with ultrasonic cleaning



# Vehicle Preventive Maintenance

Preventive measures can help reduce the amount of soot produced by an engine

We cannot fix a bad system design, but we improve operating conditions with preventive maintenance.

Many low cetane fuels increase engine deposits resulting in more smoke, increased exhaust particulates that increase the frequent of regeneration.

# High Pressure Common Rail

Tougher emission standards could only be achieved by going to computer control of injection

Common rail computer controlled injection pressure is the most widely used strategy

The requirements are for all systems to provide on board diagnostic to assist in maintaining normal emission levels

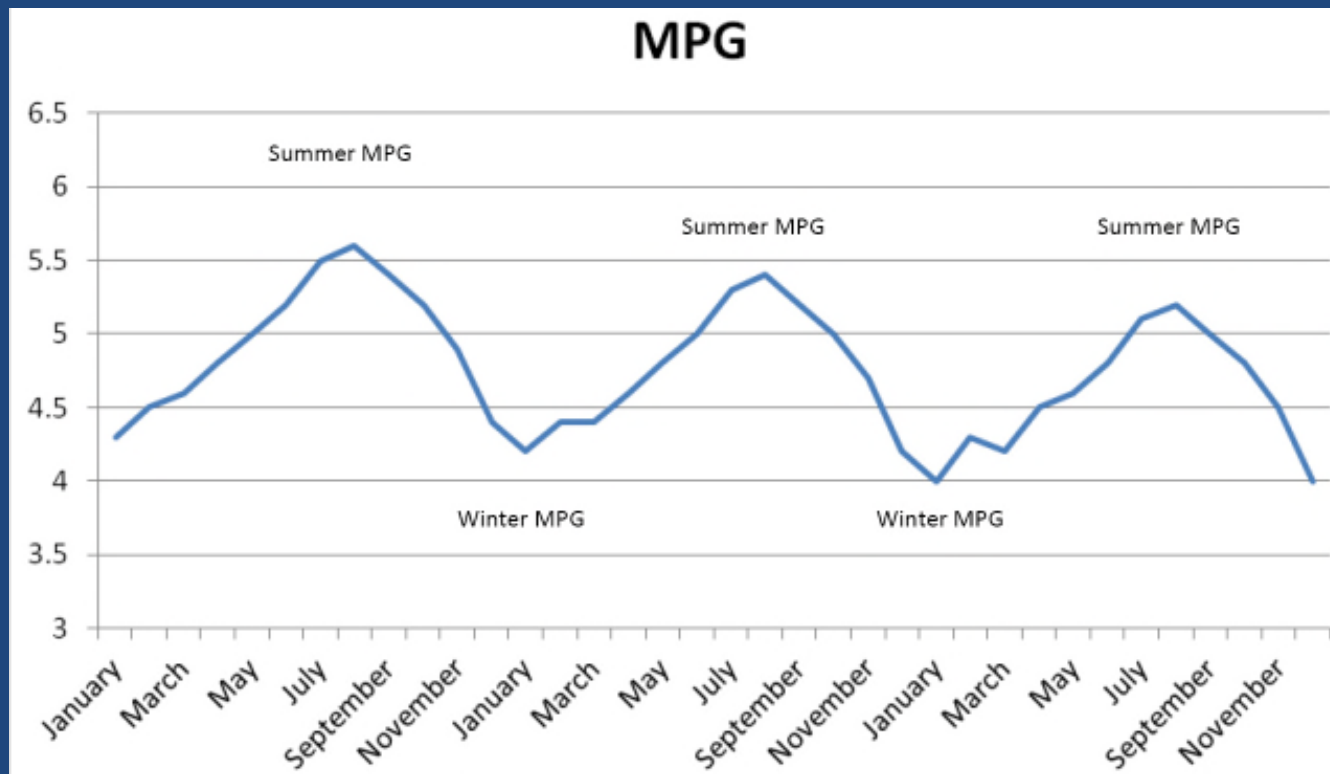
# High Pressure Common Rail

Common Rail Fuel Injection Systems being supplied on nearly all new diesel engines, *require* the use of extra diesel fuel Detergents, Stabilizers, Corrosion Inhibitors, Deposit Modifiers and Lubricity Agents in order to protect the fine tolerances.

# Winter Fuel Mileage

Fuel mileage goes down in winter without an additive.

Poor combustion produces more particulates.



# Winter Fuel Mileage

Many refiners and fuel suppliers ‘premixing’ (blending) kerosene and light distillates into the “winterized” diesel fuels are reducing the fuel's energy content.

**This 5 gallons of additive treats 5,000 gallons of diesel fuel at a cost of around \$125.**



# DPF Specifications

There are measurements that indicate the effectiveness of DPF filters.

Balance point- The point where passive regeneration equals the rate of particle accumulation from the exhaust.

There is no build up of particles in the filter when balance is achieved as long as ash content is low.

Filter regeneration rate- Measures the increase in backpressure over time to measure the efficiency of the filter. Fast Regen rates have slow accumulation of particles.

# Preventive Maintenance Summary

Winter fuel can use more protection with additives to base diesel fuel.

Stop and go vehicles can use additives to improve Cetane and additives that improve regeneration efficiency.

The assumption is that good regeneration will result in less frequent Regen.

These additives can also help other emission control components like EGR and turbo charges.

# B20 Diesel Fuel and DPF

B20 with 20% Biodiesel mixed with #2 ULSD had 67% reduction in particulate matter after the DPF.

The DPF filter had a higher generation rate which will reduce the frequency of regeneration cycles.

Biodiesel can have biological by products that cause fuel filter blockage if is not treated.

# Exhaust Gas Temperature Sensors

Temperature is measured in front of (inlet) and behind (outlet) the DPF

The PCM monitors the pressure from a temperature differential Sensor

The PCM uses the values to determine exhaust temperature for enabling conditions for regeneration and during regeneration

# DPF Diagnostics

## Cummins DPF Scan Data, 3 exhaust temps

Sensor Name	Value	Units	Minimum	Maximum
CTM DeSoot Boost Fuel Enable	... Disable	State	0	65535
DeSoot Enable	... Disable	State	0	65535
DeSOx Enable	... Disable	State	0	65535
Estimated Nox Accumulation via Fuel Consumption	... 0.85	Lb	0.00	13.11
Exhaust Gas Temperature Sensor 1	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 1 Estimate	... 1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 1 Volts	... 0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 2	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	... 0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	... 1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 3 Volts	... 0.09	V	0.00	5.00
Filtered Throttle for Regeneration Trigger	... 0	%	0	100
Measured Cat Inlet O2	... 1.00	%	0.00	100.00
Measured Cat Outlet O2	... 1.00	%	0.00	100.00
O2 Sensor 1	... 1.00	%	0.00	100.00
O2 Sensor 1 Heater Status	... Automatic	State	0	65535
O2 Sensor 2	... 1.00	%	0.00	100.00
O2 Sensor 2 Heater Status	... Automatic	State	0	65535
PT/Combustion Manager Interface Mode	... Normal	State	0	65535
Regeneration Manager Alpha Value	... 0000	HEX	0	65535
Soot Filter Delta Pressure	... 0.00	inHg	-100.00	100.00
Soot Filter Delta Pressure Volts	... 0.74	V	0.00	5.00
Time Since Regen Started	... 0.0	Sec	0.0	6553.5

# DPF Diagnostics

## Cummins DPF Scan Data, 3 exhaust temps

Sensor Name	Value	Units	Minimum	Maximum
CTM DeSoot Boost Fuel Enable	... Disable	State	0	65535
DeSoot Enable	... Disable	State	0	65535
DeSOx Enable	... Disable	State	0	65535
Estimated Nox Accumulation via Fuel Consumption	... 0.85	Lb	0.00	13.11
Exhaust Gas Temperature Sensor 1	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 1 Estimate	... 1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 1 Volts	... 0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 2	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	... 0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	... 1500.0	F	200.0	1500.0

Temperature

Temperature

Temperature

**When frequent Regen becomes a problem  
Monitor exhaust temp during normal vehicle operation  
Add DPF additives if the temperature is too low**

O2 Sensor 2 Heater Status	... Automatic	State	0	65535
PT/Combustion Manager Interface Mode	... Normal	State	0	65535
Regeneration Manager Alpha Value	... 0000	HEX	0	65535
Soot Filter Delta Pressure	... 0.00	inHg	-100.00	100.00
Soot Filter Delta Pressure Volts	... 0.74	V	0.00	5.00
Time Since Regen Started	... 0.0	Sec	0.0	6553.5

# DPF Diagnostics

## Cummins DPF Scan Data, 3 exhaust temps

Sensor Name	Value	Units	Minimum	Maximum
CTM DeSoot Boost Fuel Enable	... Disable	State	0	65535
DeSoot Enable	... Disable	State	0	65535
DeSOx Enable	... Disable	State	0	65535
Estimated Nox Accumulation via Fuel Consumption	... 0.85	Lb	0.00	13.11
Exhaust Gas Temperature Sensor 1	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 1 Estimate	... 1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 1 Volts	... 0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 2	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	... 0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	... 1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	... 1500.0	F	200.0	1500.0
O2 Sensor 1 Heater Status	... Automatic	State	0	65535
O2 Sensor 2	... 1.00	%	0.00	100.00
O2 Sensor 2 Heater Status	... Automatic	State	0	65535
PT/Combustion Manager Interface Mode	... Normal	State	0	65535
Regeneration Manager Alpha Value	... 0000	HEX	0	65535
Soot Filter Delta Pressure	... 0.00	inHg	-100.00	100.00
Soot Filter Delta Pressure Volts	... 0.74	V	0.00	5.00
Time Since Regen Started	... 0.0	Sec	0.0	6553.5

**Operating the vehicle at road speed for 30 minutes  
Should de-soot the DPF with passive Regen**

# DPF Diagnostics

## Cummins Scan Data, Post active injection

Sensor Name	Value	Units	Minimum	Maximum	R
CTM DeSoot Boost Fuel Enable	...	Disable	State	0	65535
DeSoot Enable	...	Disable	State	0	65535
DeSOx Enable	...	Disable	State	0	65535
Estimated Nox Accumulation	0.85	Lb	0.00	13.11	
Exhaust Gas Temperature Sensor 1	1832.0	F	0.0	2000.0	
Exhaust Gas Temperature Sensor 1 Estimate	1500.0	F	200.0	1500.0	
Exhaust Gas Temperature Sensor 1 Volts	0.09	V	0.00	5.00	
Exhaust Gas Temperature Sensor 2	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	...	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	...	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 3 Volts	...	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 4	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 4 Estimate	...	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 4 Volts	...	0.09	V	0.00	5.00
O2 Sensor 1 Heater Status	...	Automatic	State	0	65535
O2 Sensor 2	...	1.00	%	0.00	100.00
O2 Sensor 2 Heater Status	...	Automatic	State	0	65535
PT/Combustion Manager Interface Mode	...	Normal	State	0	65535
Regeneration Manager Alpha Value	...	0000	HEX	0	65535
Soot Filter Delta Pressure	...	0.00	inHg	-100.00	100.00
Soot Filter Delta Pressure Volts	...	0.74	V	0.00	5.00
Time Since Regen Started	...	0.0	Sec	0.0	6553.5

**Active Injection Enable**

**This data will show you when active regeneration is started**

# DPF Diagnostics

## Cummins DPF Scan Data, 3 exhaust temps

Sensor Name	Value	Units	Minimum	Maximum
CTM DeSoot Boost Fuel Enable	... Disable	State	0	65535
DeSoot Enable	... Disable	State	0	65535
DeSOx Enable	... Disable	State	0	65535
Estimated Nox Accumulation via Fuel Consumption	... 0.85	Lb	0.00	13.11
Exhaust Gas Temperature Sensor 1	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 1 Estimate	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 1 Volts	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 2	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 3 Volts	0.09	V	0.00	5.00
Filtered Throttle Position	...	...	...	100
Measured Cat Inlet Temperature	...	...	...	100.00
Measured Cat Outlet Temperature	...	...	...	100.00
O2 Sensor 1	...	...	...	100.00
O2 Sensor 1 Heated	...	...	...	65535
O2 Sensor 2	...	...	...	100.00
O2 Sensor 2 Heated	...	...	...	65535
PT/Combustion Pressure	...	...	...	65535
Regeneration Mode	...	...	...	65535
Soot Filter Delta Pressure	...	...	100.00	100.00
Soot Filter Delta Temperature	...	...	...	5.00
Time Since Regen Started	... 0.0	Sec	0.0	6553.5

Temperature

Temperature

Temperature

**Regeneration starts about 1,200° F  
Active Regen Starts when exhaust  
Temp does not reach 1,200° F During  
Normal vehicle operation and DPF  
pressure difference is high**

# DPF Diagnostics

## Cummins Scan Data, DPF pressure difference

Sensor Name	Value	Units	Minimum	Maximum	
CTM DeSoot Boost Fuel Enable	...	Disable	State	0	65535
DeSoot Enable	...	Disable	State	0	65535
DeSOx Enable	...	Disable	State	0	65535
Estimated Nox	...	13.11			
Exhaust Gas Temperature	...	2000.0			
Exhaust Gas Temperature	...	1500.0			
Exhaust Gas Temperature Sensor 1 Volts	...	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 2	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	...	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	...	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 3 Volts	...	0.09	V	0.00	5.00
Filtered Throttle for Regeneration Trigger	...	0	%	0	100
Measured Cat Inlet O2	...	1.00	%	0.00	100.00
Measured Cat Outlet O2	...	1.00	%	0.00	100.00
O2 Sensor 1	...	1.00	%	0.00	100.00
O2 Sensor 1 Heater Status	...	Automatic	State	0	65535
O2 Sensor 2	...	1.00	%	0.00	100.00
O2 Sensor 2 Heater Status	...	Automatic	State	0	65535
PT/Combustion Manager Interface	...	Normal	State	0	65535
Regeneration Manager Alpha Value	...	0000	HEX	0	65535
Soot Filter Delta Pressure	...	0.00	inHg	-100.00	100.00
Soot Filter Delta Pressure Volts	...	0.74	V	0.00	5.00
Time Since Regen Started	...	0.0	Sec	0.0	6553.5

**High DPF (soot) filter pressure indicates the DPF is clogging**

**DPF Pressure Difference**

# DPF Diagnostics

## Cummins Scan Data, Regen running time

Sensor Name	Value	Units	Minimum	Maximum	
CTM DeSoot Boost Fuel Enable	...	Disable	State	0	65535
DeSoot Enable	...	Disable	State	0	65535
DeSOx Enable	...	Disable	State	0	65535
Estimated Nox Accumulation via Fuel Consumption	...	0.85	Lb	0.00	13.11
Exhaust Gas Temperature Sensor 1	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 1 Estimate	...	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 1 Volts	...	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 2	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	...	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	...	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	...	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 3 Volts	...	0.09	V	0.00	5.00
Filtered Throttle Position	...	100	%	0.00	100.00
Measured Cat Inlet O2	...	1.00	%	0.00	100.00
Measured Cat Outlet O2	...	1.00	%	0.00	100.00
O2 Sensor 1	...	1.00	%	0.00	100.00
O2 Sensor 1 Heater Status	...	Automatic	State	0	65535
O2 Sensor 2	...	1.00	%	0.00	100.00
O2 Sensor 2 Heater Status	...	Automatic	State	0	65535
PT/Combustion Manager Interface Mode	...	Normal	State	0	65535
Regeneration Manager Alpha Value	...	0000	HEX	0	65535
Soot Filter Delta Pressure	...	0.00	inHg	-100.00	100.00
Soot Filter Delta Pressure Volts	...	0.74	V	0.00	5.00
Time Since Regen Started	...	0.0	Sec	0.0	6553.5

**Displays the running time of the current active regeneration cycle**

**Running Regen Time**

# DOC Diagnostics

## Cummins Scan Data, DOC O2 levels

Sensor Name	Value	Units	Minimum	Maximum	R
CTM De				6535	
DeSoot				6535	
DeSOx				6535	
Estimat				0.11	
Exhaus				100.0	
Exhaust Gas Temperature Sensor 1 Estimate	1500.0	F	200.0	1500.0	
Exhaust Gas Temperature Sensor 1 Volts	0.09	V	0.00	5.00	
Exhaust Gas Temperature Sensor 2	1832.0	F	0.0	2000.0	
Exhaust Gas Temperature Sensor 2 Estimate	1832.0	F	0.0	2000.0	
Exhaust Gas Temperature Sensor 2 Volts	0.09	V	0.00	5.00	
Exhaust Gas Temperature Sensor 3	1832.0	F	0.0	2000.0	
Exhaust Gas Temperature Sensor 4	1500.0	F	200.0	1500.0	
Exhaust Gas Temperature Sensor 5	0.09	V	0.00	5.00	
Filtered Throttle for Regeneration	0	%	0	100	
Measured Cat Inlet O2	1.00	%	0.00	100.00	
Measured Cat Outlet O2	1.00	%	0.00	100.00	
O2 Sensor 1	1.00	%	0.00	100.00	
O2 Sensor 1 Heater Status	Automatic	State	0	65535	
O2 Sensor 2	1.00	%	0.00	100.00	
O2 Sensor 2 Heater Status	Automatic	State	0	65535	
PT/Combustion Manager Interface Mode	Normal	State	0	65535	
Regeneration Manager Alpha Value	0000	HEX	0	65535	
Soot Filter Delta Pressure	0.00	inHg	-100.00	100.00	
Soot Filter Delta Pressure Volts	0.74	V	0.00	5.00	
Time Since Regen Started	0.0	Sec	0.0	6553.5	

**The Diesel Oxidation catalyst will burn some of the oxygen during active Regen**

**DOC Oxygen Difference**

# Forced Regen

Forced Regen is activated to clean the DPF

Sensor Name	Value	Units	Minimum	Maximum
CTM				35
DeSo				35
DeSO				35
Estim				11
Exha				0.0
Exha				0.0
Exha				0
Exhaust Gas Temperature Sensor 2	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Estimate	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 2 Volts	0.09	V	0.00	5.00
Exhaust Gas Temperature Sensor 3	1832.0	F	0.0	2000.0
Exhaust Gas Temperature Sensor 3 Estimate	1500.0	F	200.0	1500.0
Exhaust Gas Temperature Sensor 3 Volts	0.09	V	0.00	5.00
Filtered Throttle for Regeneration Trigger	0	%	0	100
Measured Cat Inlet O2	1.00	%	0.00	100.00
Measured Cat Outlet O2	1.00	%	0.00	100.00
O2 Sensor 1	1.00	%	0.00	100.00
O2 Sensor 1 Heater Status	Automatic	State	0	65535
O2 Sensor 2	1.00	%	0.00	100.00
O2 Sensor 2 Heater Status	Automatic	State	0	65535
PT/Combustion Manager Interface Mode	Normal	State	0	65535
Regeneration Manager Alpha Value	0000	HEX	0	65535
Soot Filter Delta Pressure	0.00	inHg	-100.00	100.00
Soot Filter Delta Pressure Volts	0.74	V	0.00	5.00
Time Since Regen Started	0.0	Sec	0.0	6553.5

**Forced Regen is when the operator selects Regen  
To force the system to Regen  
Beware of the high temperature of the DPF**

# Injection for Diesel Oxidation Catalyst

Active regeneration is used to help burn the soot in the diesel particulate filter.

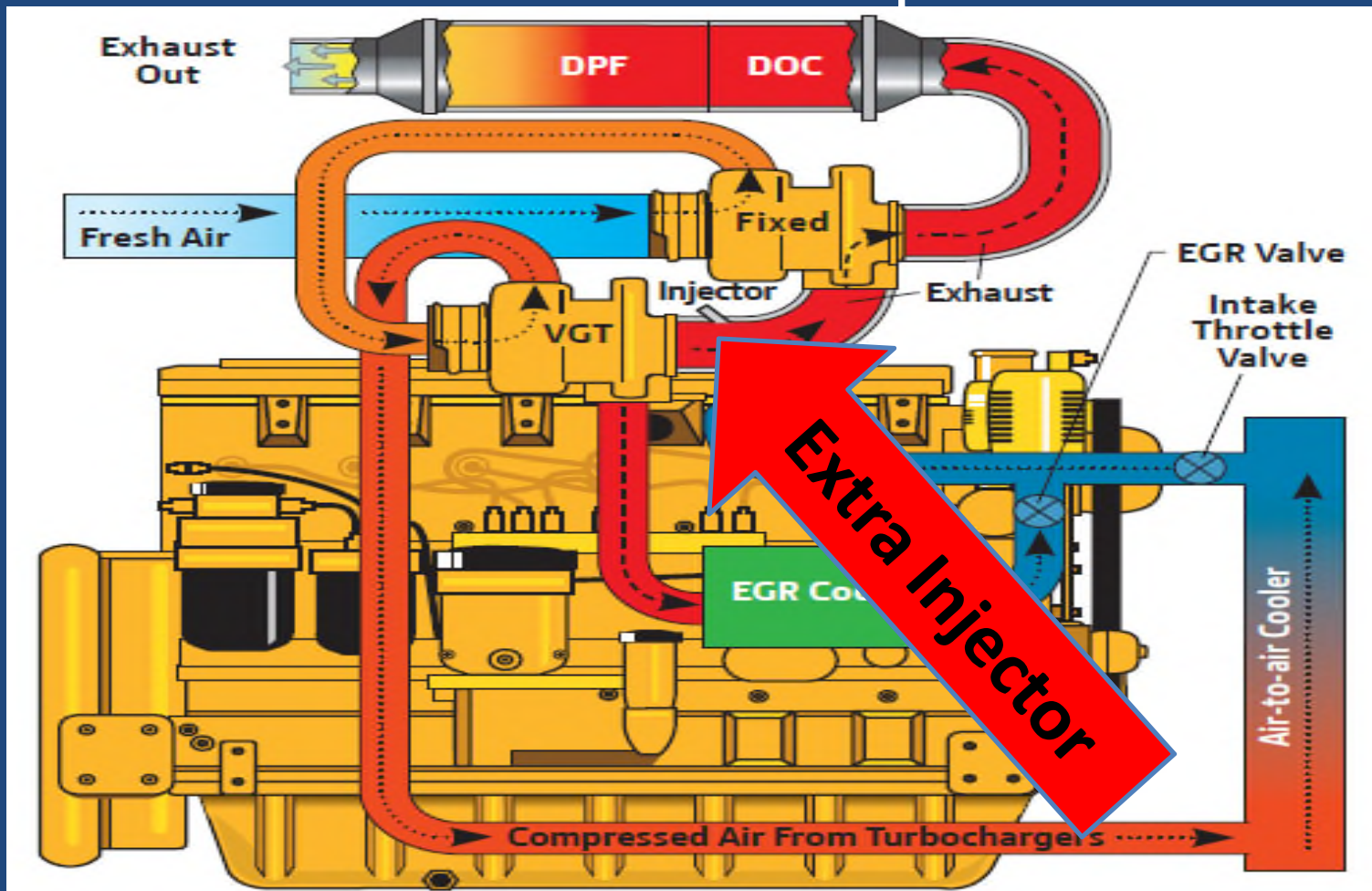
Fuel can be injected with a post injection pulse of the fuel injections to increase the fuel going to the diesel oxidation catalyst.

Fuel can be injected into the exhaust before the diesel oxidation catalyst.

Some manufacturers inject a fluid that increases the diesel particulate filter when the temperature is frequently too low for good soot burn off.

# Tier 4 Early

An extra fuel injector can be added to the exhaust to raise the exhaust temperature.



# After-Treatment Systems

## EGR – DPF - NO<sub>x</sub>

Exhaust Gas Recirculation (EGR)

Diesel particulate filter (DPF)

Oxides of Nitrogen (NO<sub>x</sub>)

Selective Catalyst Reduction

# Particulate Matter

Carbon from incomplete combustion

Soluble organic fractions from fuel and lubricating oils

Sulfates formed from the sulfur in the fuel



# Professional Cleaners Available



OTC 5280

\$20,750 List



Donaldson DPF Pulse Cleaner

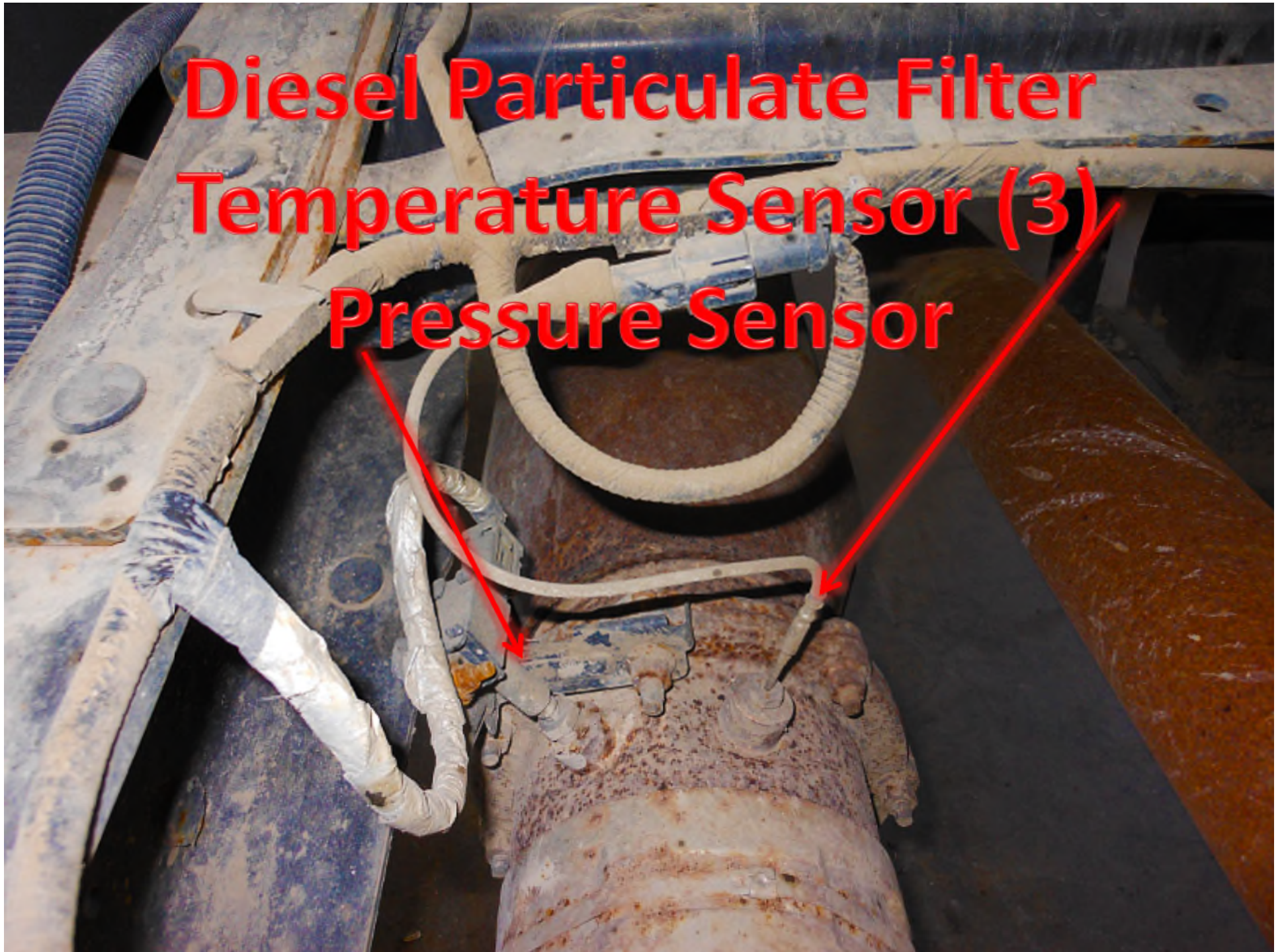
Not provided. Estimated street price of \$15K. When sold with Thermal Regenerator – \$25K



FSX TrapBlaster 7

\$44,800 plus cost of air dryer and dust collector

**Diesel Particulate Filter  
Temperature Sensor (3)  
Pressure Sensor**







Sensor Name	Value	Units	Minim...	Maxim...	Range	
EVAP Emission Purge Monitor Complete	No	Bit	0	1		0 %
Exhaust Back Pressure	0.77	V	0.00	5.00		15 %
Exhaust Back Pressure Absolute	15.3	PSI	0.0	145.0		10 %
Exhaust Back Pressure Desired	4.39	PSI	0.00	145.00		3 %
Exhaust Gas Temperature After Catalyst 1	165.2	F	-40.0	6500.0		3 %
Exhaust Gas Temperature After Catalyst 2	109.4	F	-40.0	6500.0		2 %
Exhaust Gas Temperature Before Catalyst	186.8	F	-40.0	6500.0		3 %
Fan Speed Sensor	0.00	RPM	0.00	8000.00		0 %
FICM Information for SYNC	0	Bit	0	1		0 %
Fuel Injector #1 Fault	0	Bit	0	1		0 %
Fuel Injector #2 Fault	0	Bit	0	1		0 %
Fuel Injector #3 Fault	0	Bit	0	1		0 %
Fuel Injector #4 Fault	0	Bit	0	1		0 %
Fuel Injector #5 Fault	0	Bit	0	1		0 %
Fuel Injector #6 Fault	0	Bit	0	1		0 %
Fuel Injector #7 Fault	0	Bit	0	1		0 %
Fuel Injector #8 Fault	0	Bit	0	1		0 %
Fuel Level Input Sensor	0.00	%	0.00	200.00		0 %
Fuel Pulse Width	0.00	uSec	0.00	524280.		0 %
Fuel Pump Fault	0	Bit	0	1		0 %
Fuel Rail Pressure Transducer Status	0	Bit	0	1		0 %
Fuel Rail Pressure	0.00	PSI	0.00	24650.0		0 %
Fuel Rail Pressure Input - Volts	0.00	V	0.00	10.00		0 %

Sensor Name Sensor Grouping

Vehicle: Ford PowerStroke 6.4L 2008 1FDXF46R1E System: Enhanced Powertrain CAN

B+

# Engine Power De-Rate Mode

If the PCM sees an over temperature condition on the sensors (Over 1700°F) it will De-Rate the engine's power output, and possible shut it down, and keep it from cranking for one hour

Also de-rate power if:

EGT sensors Open circuits

Low Fuel Pressure

Engine Oil Temperature over 275°F

# Regeneration

To reduce DPF clogging an exhaust aftertreatment known as regeneration is used

As the vehicle is driven and when the exhaust temperature nears 1000°F the soot build up begins to burn off

This is known as **Passive regeneration**

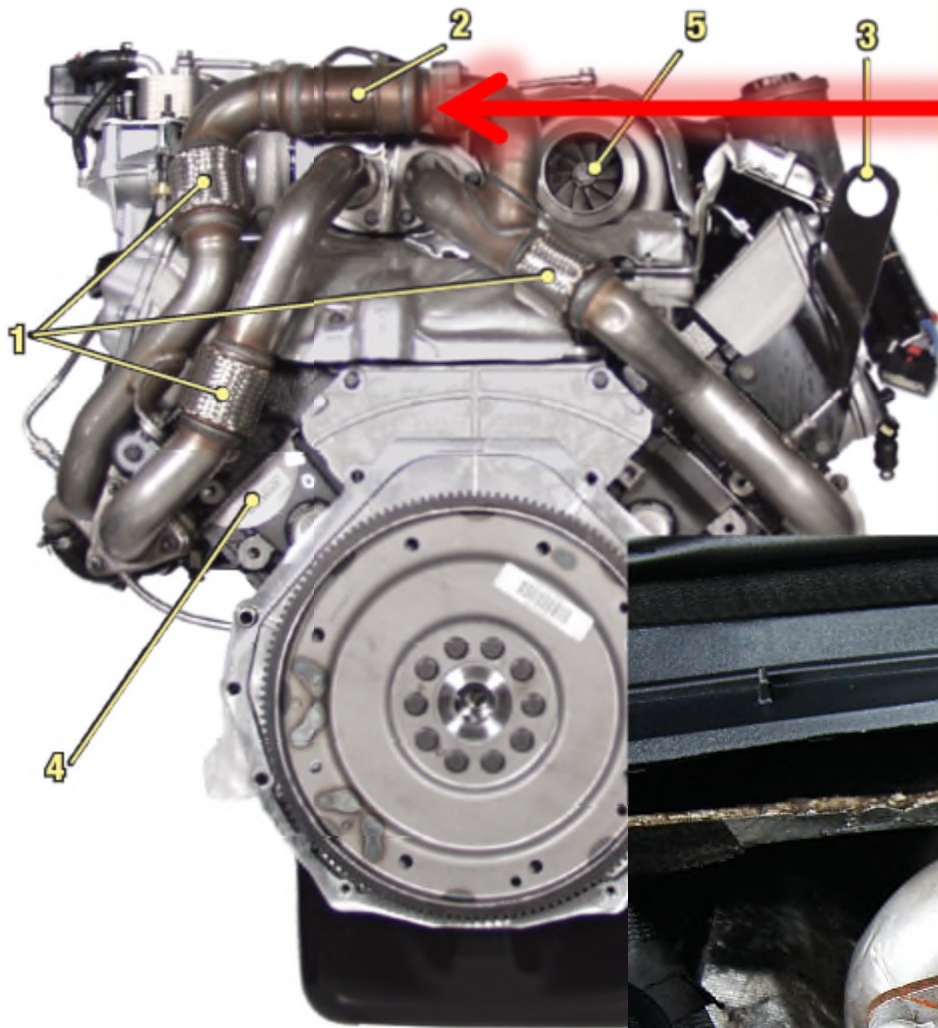
# Diesel Oxidation Catalysts (DOC)

A Diesel Oxidation Catalyst (DOC) utilizes a chemical process to react with the added fuel in the exhaust to create heat for active regeneration.

They are normally a honeycomb shaped configuration coated in a catalyst designed to trigger a chemical reaction to react with the extra fuel.

# Diesel Oxidation Catalysts (DOC)

Oxidation catalysts work by oxidizing CO, HC and the soluble organic fraction of the PM to CO<sub>2</sub> and H<sub>2</sub>O in the oxygen rich exhaust stream of the diesel engine and creating heat to improve performance of the diesel particulate filter

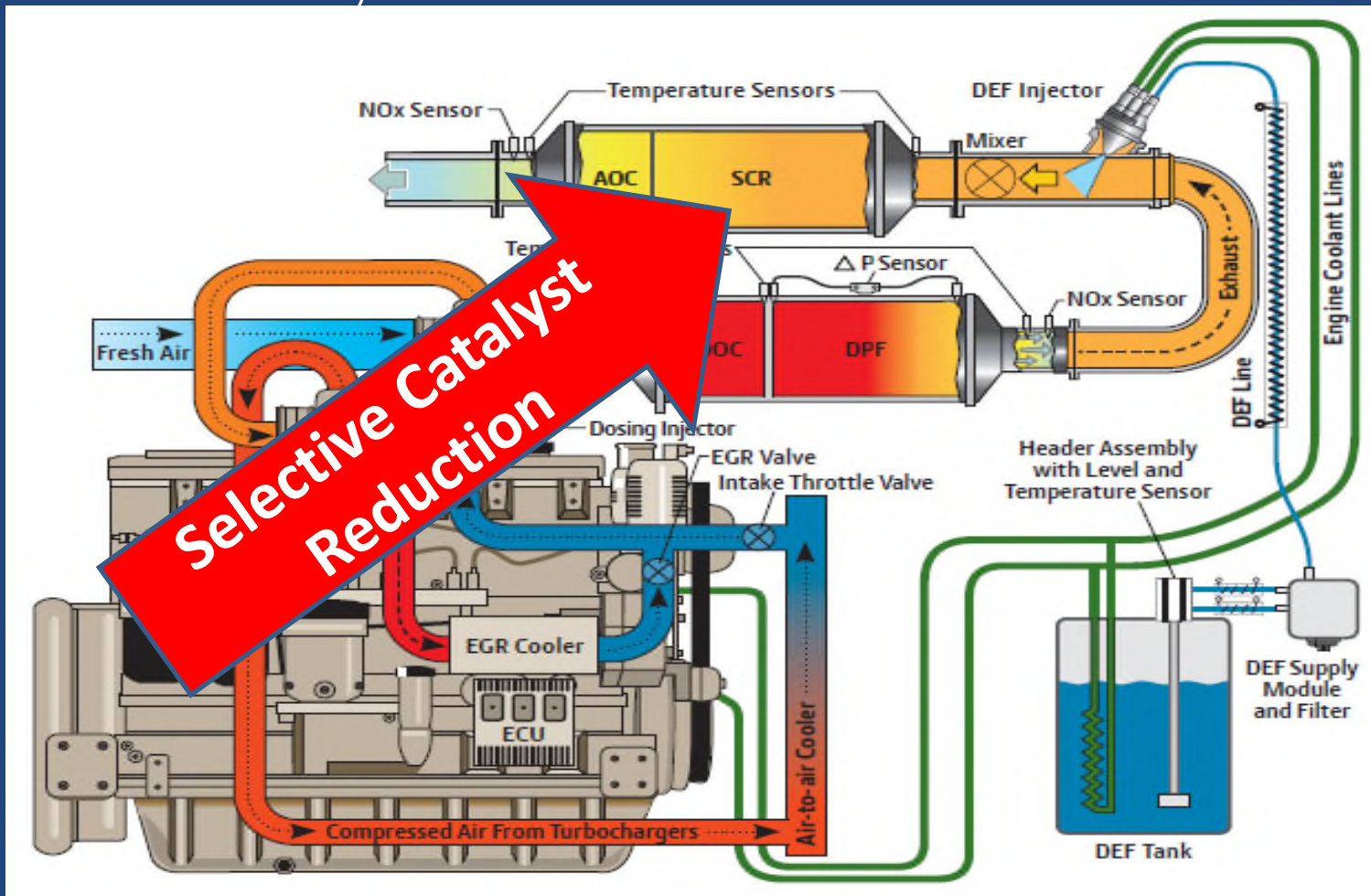


**DOC**



# Tier 4 Stage IV

Most manufacturers added the selective reduction catalyst to reduce NO<sub>x</sub> levels.



# Selective Catalyst Reduction (SCR)

The SCR reduces NO<sub>x</sub> in the exhaust

To do this the SCR system uses a ceramic catalyst that has been coated with copper and iron, and injecting DEF into the exhaust stream



# DEF Shelf Life

Constant ambient  
storage temperature:

Shelf life  
in months

**50°F**

**36**

**77°F**

**18**

**86°F**

**12**

**95°F**

**6**

**104°F**

**2**

# DEF Tank

The DEF tank stores the DEF for normal use, it needs to be refilled on a schedule that does not leave it in hot conditions for months.





# Diesel Exhaust Fluid (DEF)

Reductant, also known as Diesel Exhaust Fluid (DEF) is 32.5% urea and a water solution

When injected into the exhaust, there is a chemical reaction that converts  $\text{NO}_x$  into  $\text{N}_2$  and  $\text{H}_2\text{O}$

The freezing point of reductant is  $12^\circ\text{F}$

Reductant is caustic; don't spill onto connectors, wiring harnesses or the paint

# Reductant Dosing Module

The reductant dosing module is controlled by the PCM

The reductant dosing module injects reductant into the exhaust system to reduce  $\text{NO}_x$  coming out of the tailpipe

The injector is coated to resist the corrosive properties of the reductant





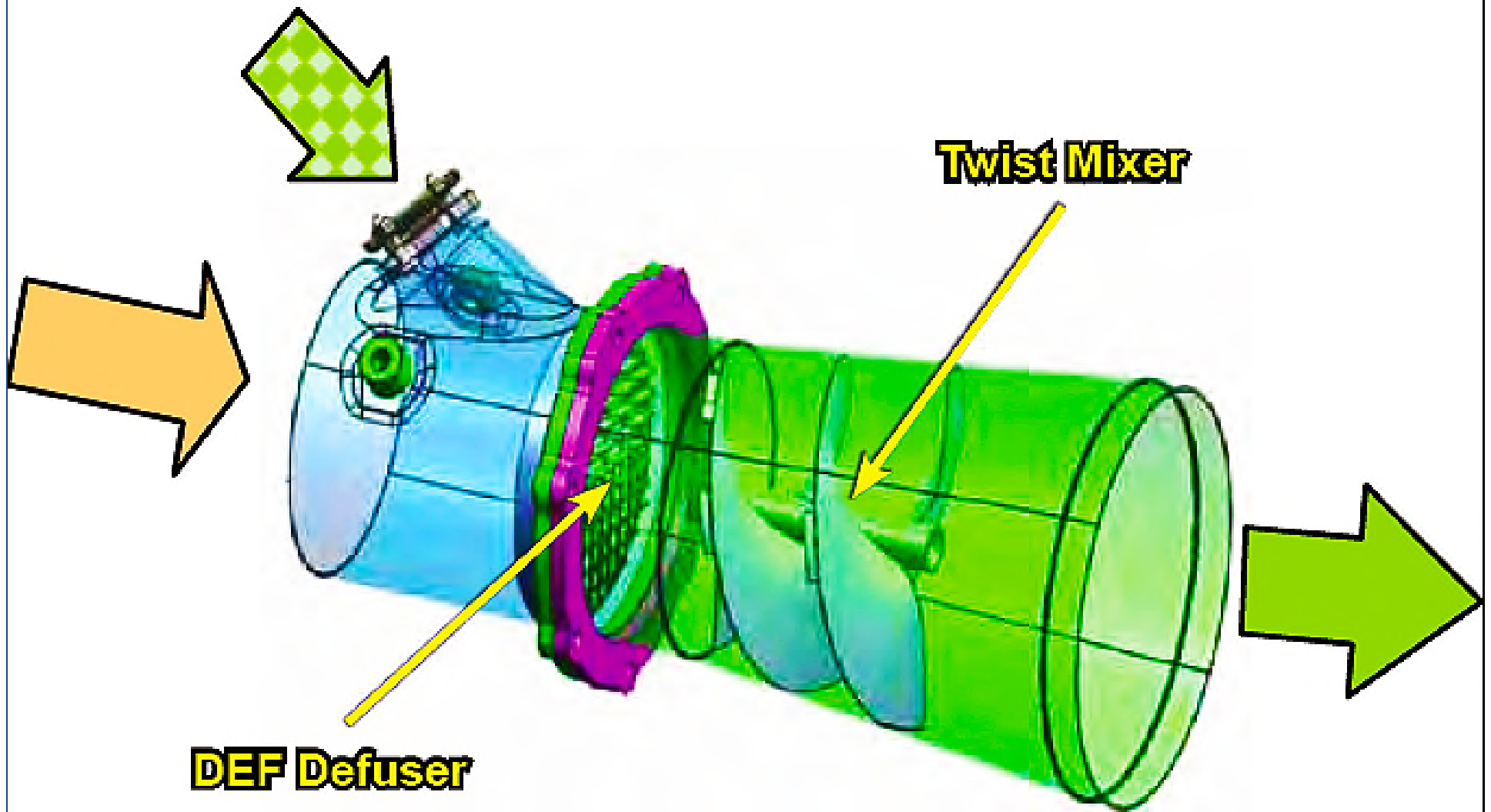
# DEF Exhaust Mixer

There is an exhaust mixing system in the exhaust stream to mix the DEF 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 DEF in the exhaust gases for maximum efficiency



# DEF Pump

The DEF 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 DEF was to freeze

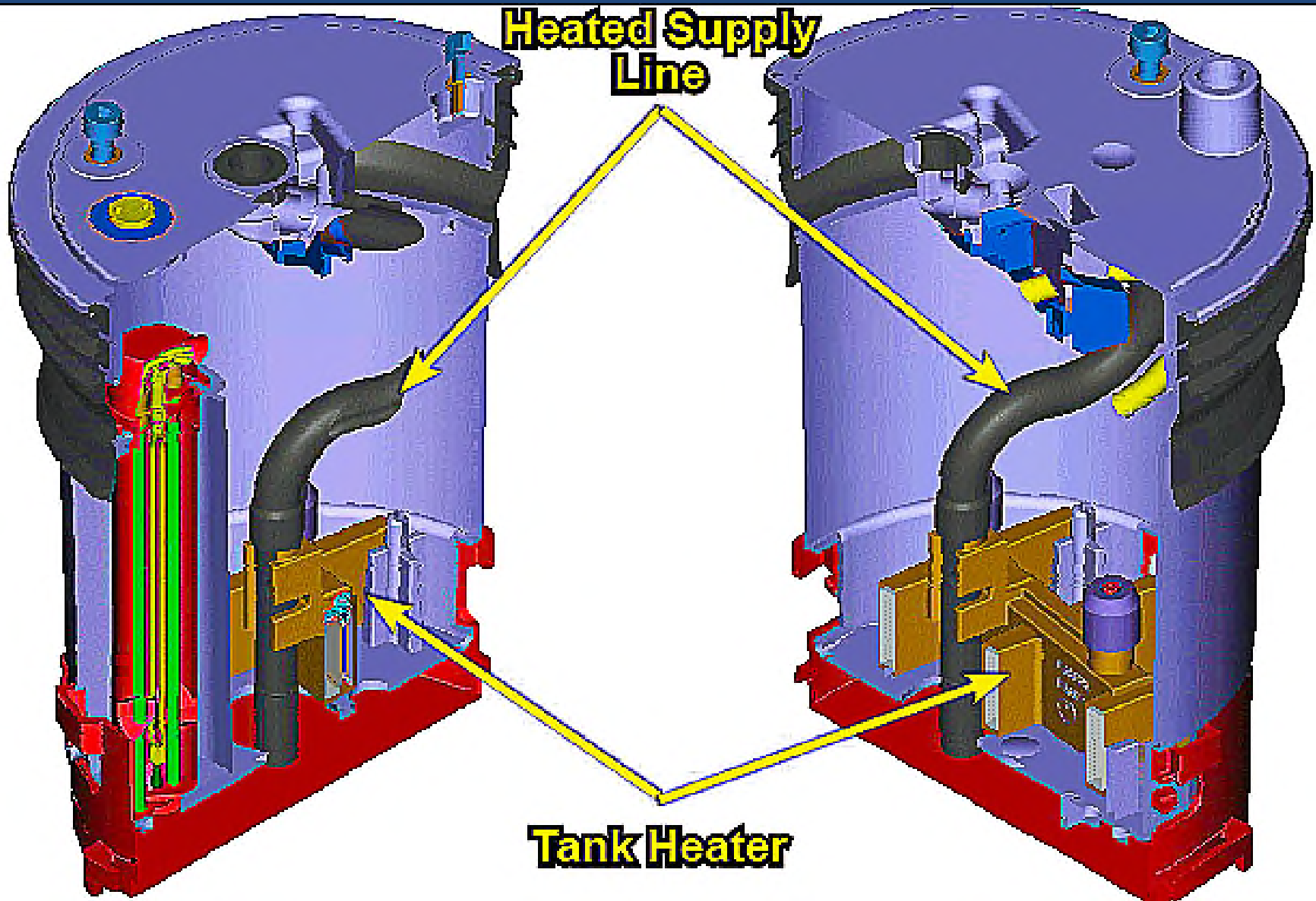
# DEF Heaters

Below a specified temperature the PCM commands the Glow Plug Control Module (GPCM) to activate the heaters in the DEF system

The DEF 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

The heaters in the pump and lines allow the DEF to flow to the injector without freezing

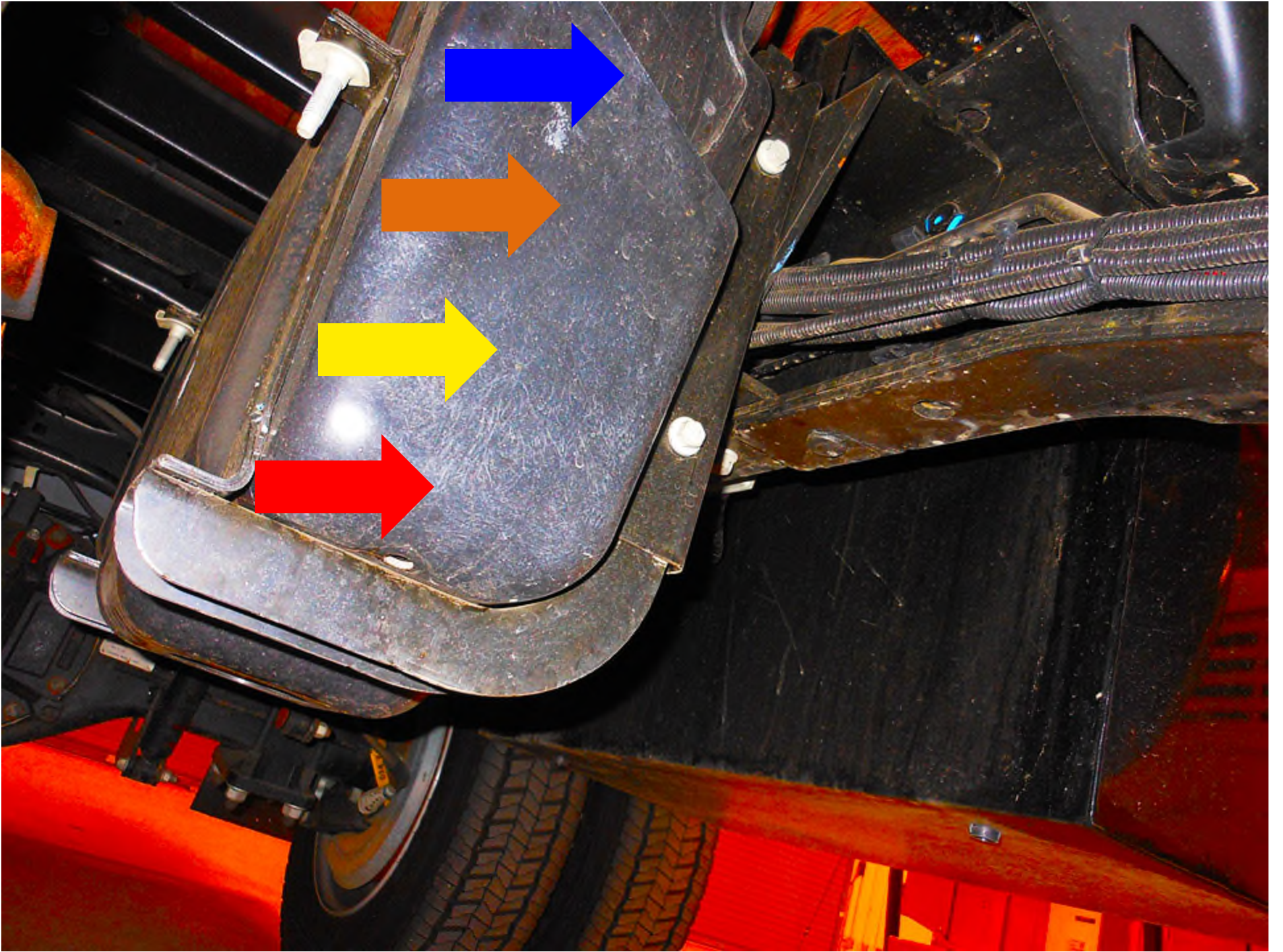


# DEF Fluid Level Sensors

The DEF fluid level sensor operates by using four electrodes that are mounted on the sensor at different level

The DEF solution closes the electric circuit between electrodes for each level interface

The signal is then sent to the PCM



# DEF Pressure Sensor

The PCM monitors the DEF pressure sensor to calculate how much reductant to be injected into the exhaust

The DEF pressure sensor is also be used to shut the pump off when the lines are being drained after the ignition is shut off

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 - Co	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 Tank	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 - I	No	Bit	0	1		0 %

<input type="checkbox"/> 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+

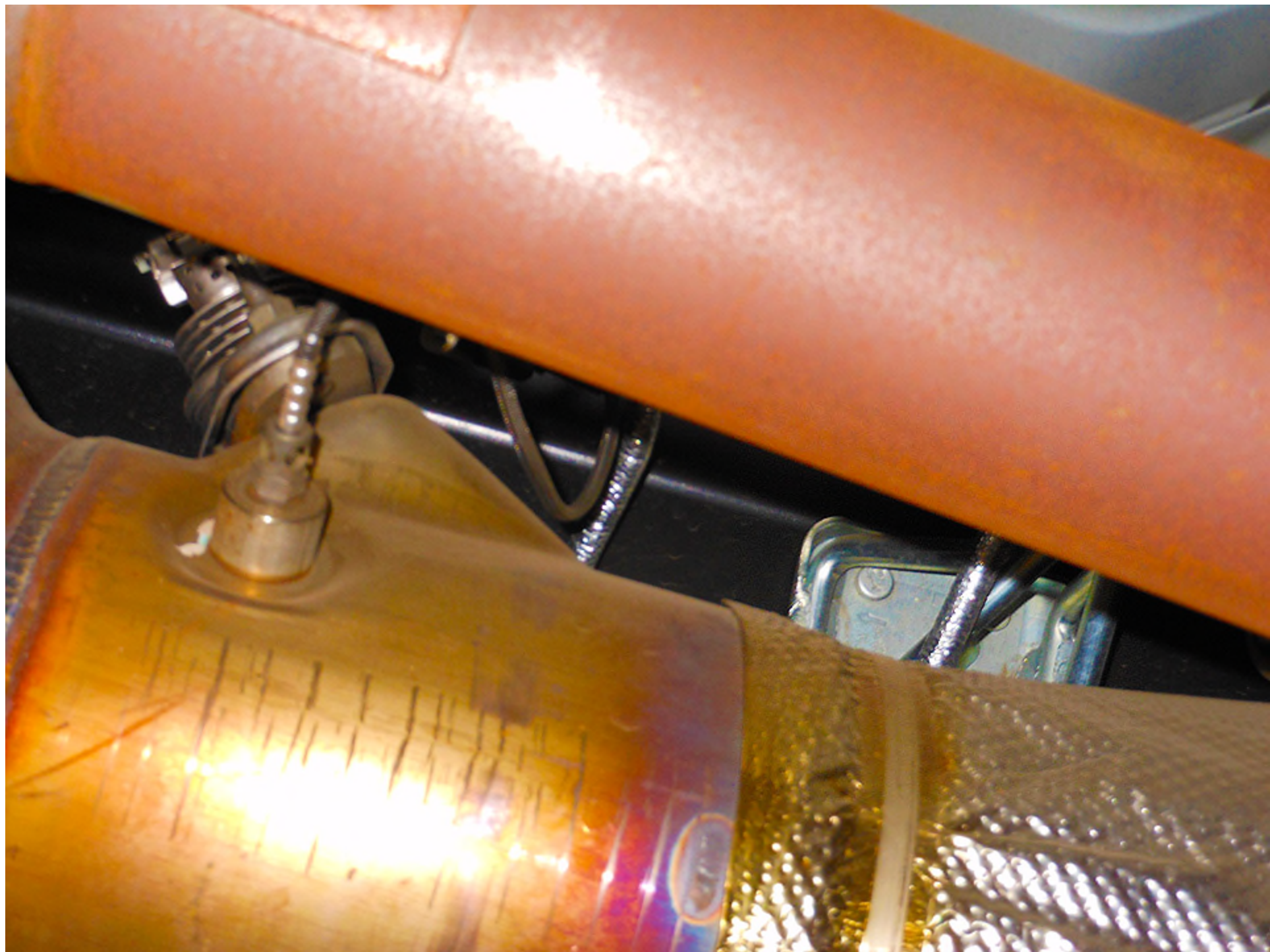
0:00:02 0:00:29

# NO<sub>x</sub> Sensor Module

The NO<sub>x</sub> sensor module is mounted to the vehicle frame under the body

It controls the NO<sub>x</sub> 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<sub>x</sub> and O<sub>2</sub> concentrations as well as sensor and controller errors



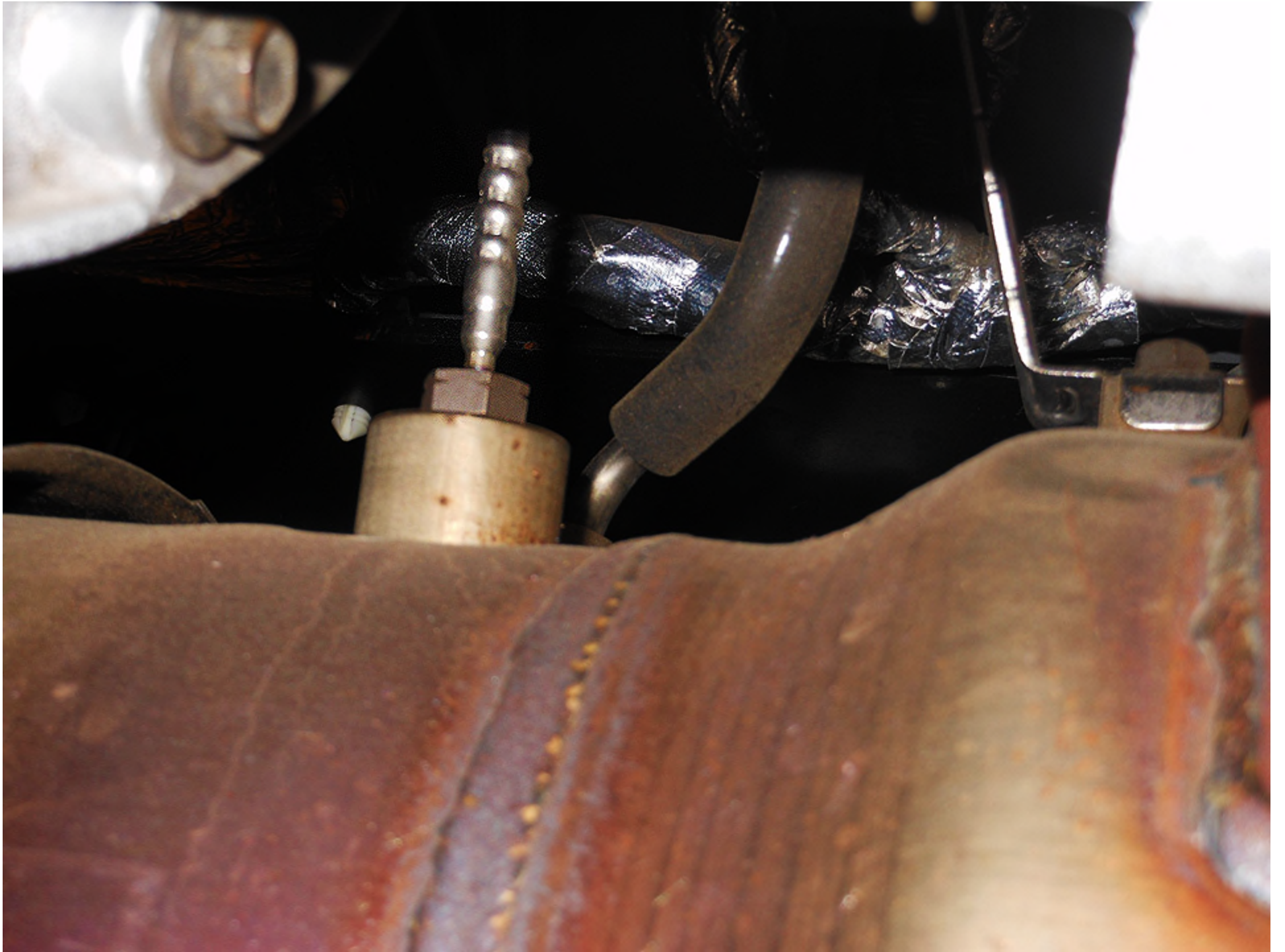
# NO<sub>x</sub> Sensor

The NO<sub>x</sub> sensor is used primarily to sense O<sub>2</sub> and NO<sub>x</sub> 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<sub>x</sub> sensor module



# NO<sub>x</sub> Reduction Science

NO<sub>x</sub> is very hard to get rid of once it is formed  
It doesn't like to break apart

One way to get it to break apart is to introduce something that will compete with the nitrogen for the oxygen molecules

Urea, or (NH<sub>2</sub>)<sub>2</sub>CO, injected into the exhaust stream to do exactly that (Exhaust Diesel Fluid [EDF])

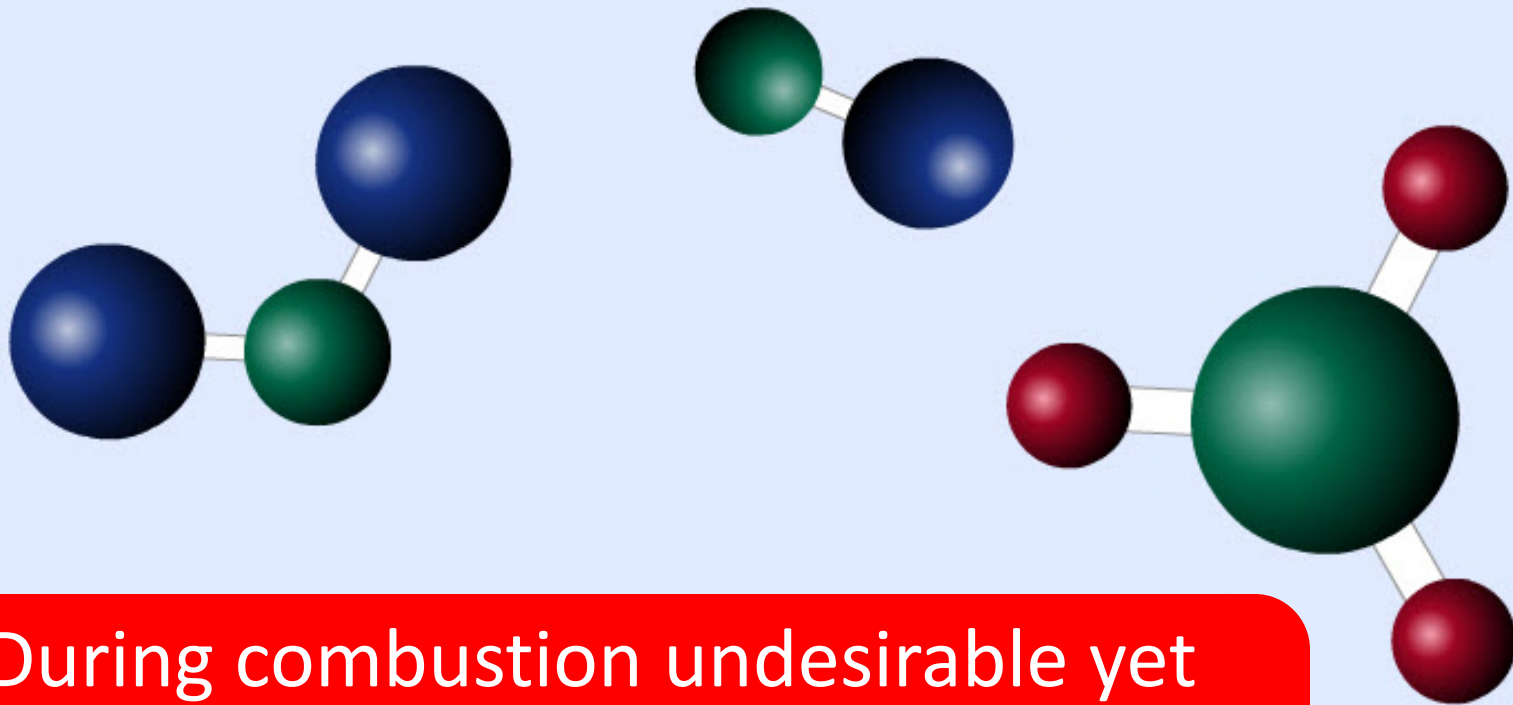
In the presence of a catalyst (heat) it turns into ammonia and reacts with the NO<sub>x</sub> to create nitrogen and water vapor, or  $2\text{N}_2 + 3\text{H}_2\text{O}$

# NO<sub>x</sub> Reduction

EGR is designed to reduce the formation of NO<sub>x</sub>

Exhaust Fluid removes NO<sub>x</sub> after it is formed

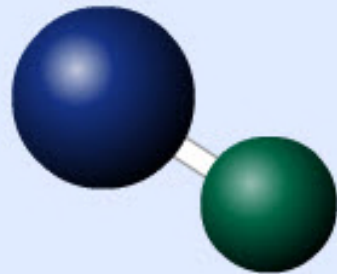
NO is one Oxygen and one Nitrogen atom  
NO<sub>2</sub> is two Oxygen and one Nitrogen atom



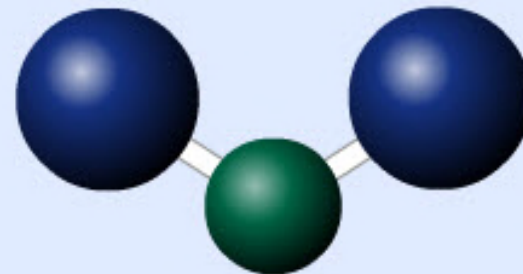
During combustion undesirable yet unavoidable nitrogen oxides NO<sub>x</sub> are produced

$\text{NO}_2$  is created during combustion because of the heat

### Nitrogen oxides



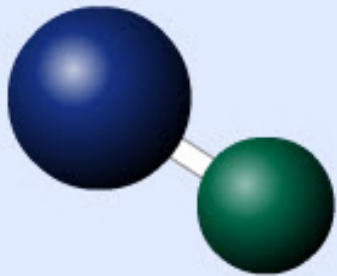
NO



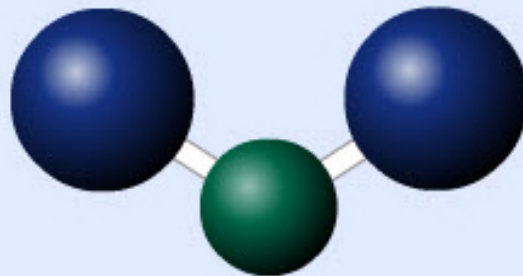
NO<sub>2</sub>

Ammonia ( $\text{NH}_3$ ) is introduced and metered to perfectly balance the  $\text{NO}$  &  $\text{NO}_2$  to neutralize each other

### Nitrogen oxides

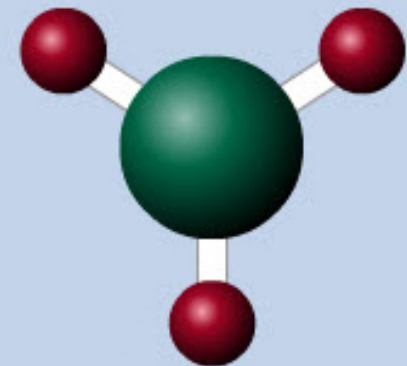


$\text{NO}$



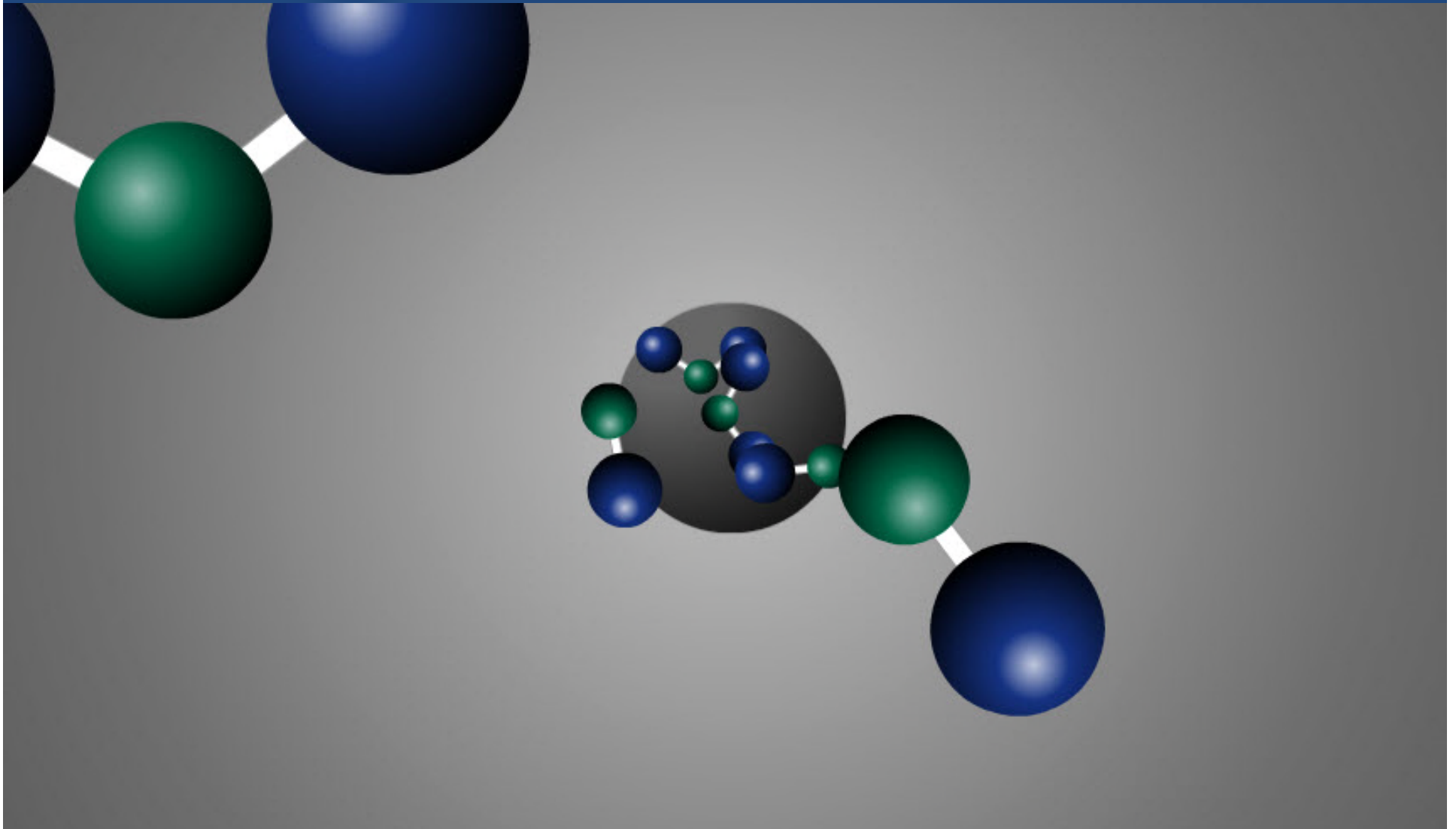
$\text{NO}_2$

### Ammonia



$\text{NH}_3$

# Oxides of Nitrogen in the exhaust

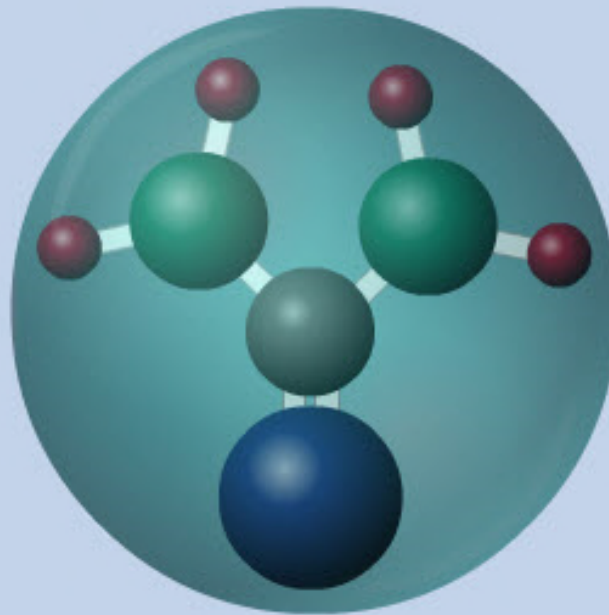


Urea reacts the  $\text{NO}_x$  and creates a watery solution

## Urea

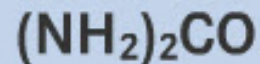
base for the ammonia

67.5% water  
and 32.5%  
automotive  
grade urea



Urea is a  
compound of  
nitrogen that  
turns to  
ammonia when  
heated

ISO 22241-1



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

<input type="checkbox"/> 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 Regenera	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+



- Fuel
- Power Balance
- Relative compression
- Transmission
- OBD Test modes
- Service Functions

- Reset/clear specific functions
  - SCR System
  - DPF Regeneration system

- SCR system emptying
- System Refill activation
- Parameter Reset
- Visual Leak Check
- Dosing measurement test



There are SCR system test available in the scan tool

There are SCR system test available in the scan tool

**This procedure  
depressurizes and  
empties the line**

- Fuel
- Power Balance
- Relative compression
- Transmission
- OBD Test modes

Service Functions ▶ Reset/clear specific functions

- SCR System
- DPF Regeneration system

- SCR System emptying
- System Refill activation
- Parameter Reset
- Visual Leak Check
- Dosing measurement test



**Perform this procedure  
after replacing the tank to  
reset the refill strategy**

- Fuel
- Power Balance
- Relative compression
- Transmission
- OBd Test modes

Service Functions ▶ Reset/clear specific functions

- SCR System ▶
- DPF Regeneration system

- SCR system emptying
- System Refill activation
- Parameter Reset
- Visual Leak Check
- Dosing measurement test





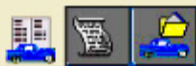
**This procedure  
pressurizes the system for  
a visual inspection**

- Fuel
- Power Balance
- Relative compression
- Transmission
- OBD Test modes

Service Functions ▶ Reset/clear specific functions

- SCR System ▶
- DPF Regeneration system

- SCR system emptying
- System Refill activation
- Parameter Reset
- Visual Leak test
- Dosing measurement test



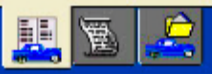


### SCR Visual Leak Check



Reduct_TNK_P	Reduct_TNK_DC	Reduct_RV_DC	Reduct_INJ_DC
0 psi	0 %	0 %	0 %

Press the tick when ready to start





### SCR Visual Leak Check

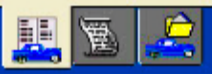


Reduct_TNK_P	Reduct_TNK_DC	Reduct_RV_DC	Reduct_INJ_DC
71.576 psi	14.7 %	0 %	0 %

Pressure build up successful  
Begin visual tank inspection  
If you want to abort this test click the stop button



Press the tick when finished



Look up the specification for the amount injected in the service manual

**This procedure will inject a commanded amount of DEF to be collected and measured**

- Fuel
- Power Balance
- Relative compression
- Transmission
- OBD Test modes

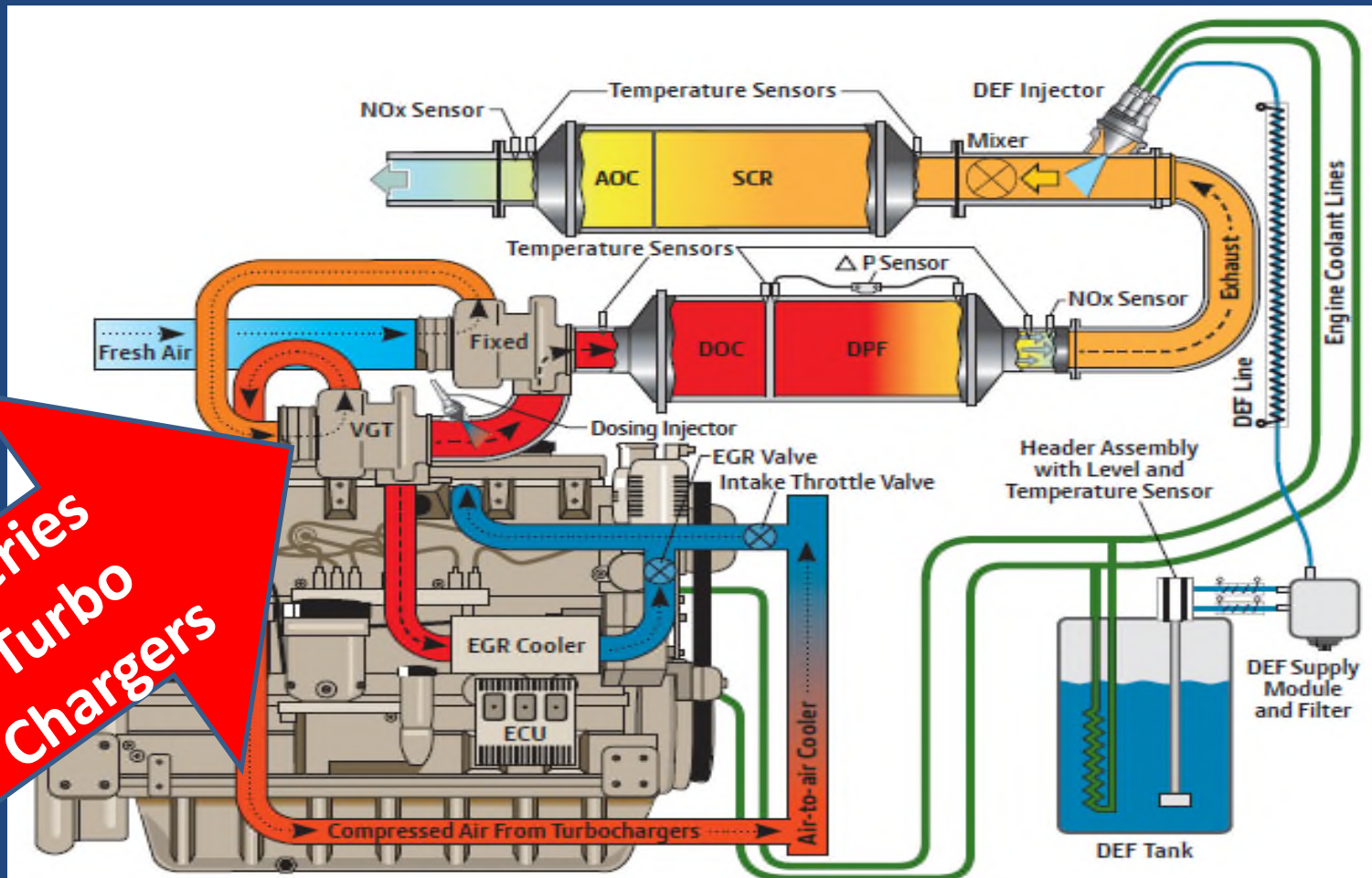
Service Functions ▶ Reset/clear specific functions

- SCR System ▶
- DPF Regeneration system

- SCR system emptying
- System Refill activation
- Parameter Reset
- Visual Leak Check
- Dosing measurement test

# Tier 4 Stage IV

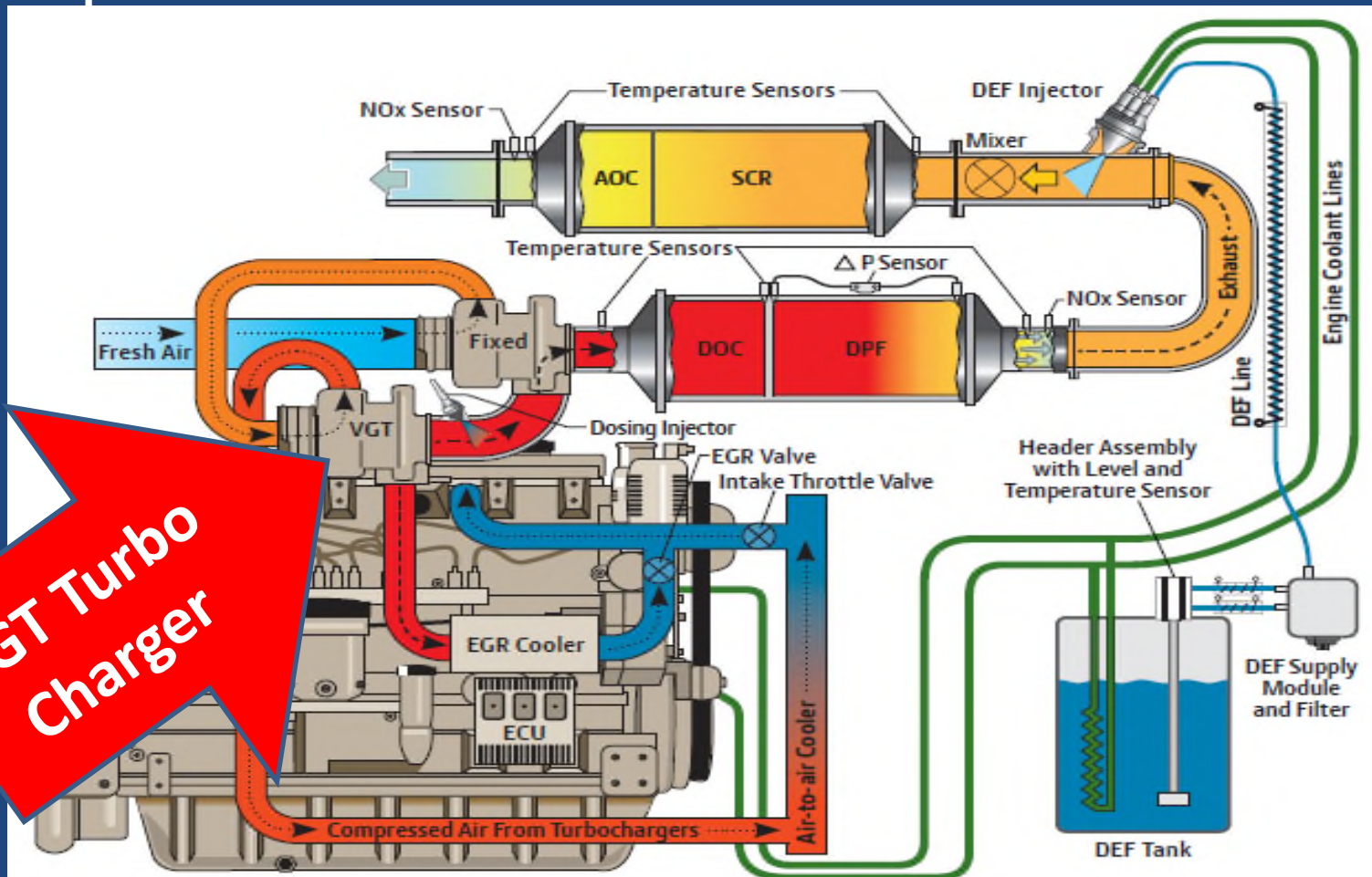
Series turbo charges are used by some manufactures.



Series  
Turbo  
Chargers

# Tier 4 Stage IV

A VGT turbo charger is used to improve low speed performance.



**VGT Turbo  
Charger**

# VGT Command Control

The command can be viewed on a scan tool as VGT% and is described in the % closed

A low % means the vanes are commanded to an open state

A high % means the vanes are commanded to a closed state

# Get it Correct

A low duty cycle % opens the vanes

A high duty cycle % closes the vanes

Open vanes are for High Speed/Load

Closed vanes are for Low Speed/Load

# Vane commanded position

High speed /Load low duty cycle vanes open

There is a great deal of energy available in the exhaust

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

The vanes are closed at low speed

# Vane commanded position

In between speeds /Loads moderate Varying duty cycle

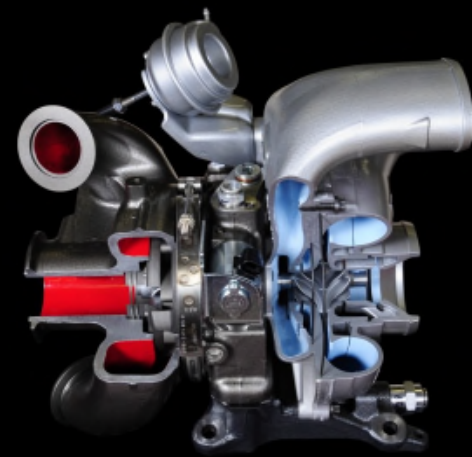
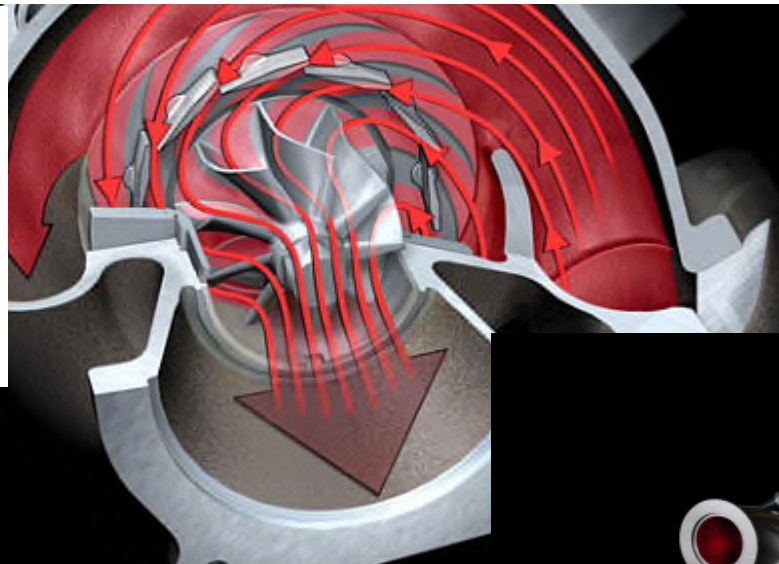
During Engine operation at moderate engine speeds and load, the vanes are commanded partially open

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 for EGR operation

**VANES OPEN**



**VANES CLOSED**





**Compressor**



**Control  
Plate**



**Vanes**



**Mounting**



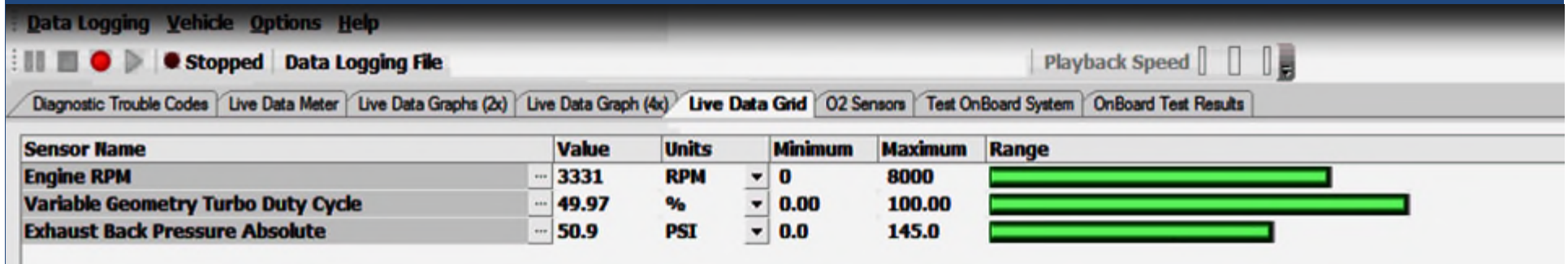
**Turbine**

# Test Drive

If the VGT command sticks at 85% or 15% for more than a few seconds;

The VGT vanes might be sticking

The Exhaust Back Pressure (EBP) should go to a minimum of 40 psi, if not check for exhaust leaks



The screenshot shows a diagnostic software interface with a menu bar (Data Logging, Vehicle, Options, Help) and a toolbar (Data Logging File, Playback Speed). Below the toolbar are several tabs: Diagnostic Trouble Codes, Live Data Meter, Live Data Graphs (2x), Live Data Graph (4x), Live Data Grid, O2 Sensors, Test OnBoard System, and OnBoard Test Results. The 'Live Data Grid' tab is active, displaying a table of sensor data with green progress bars for the Range column.

Sensor Name	Value	Units	Minimum	Maximum	Range
Engine RPM	3331	RPM	0	8000	
Variable Geometry Turbo Duty Cycle	49.97	%	0.00	100.00	
Exhaust Back Pressure Absolute	50.9	PSI	0.0	145.0	

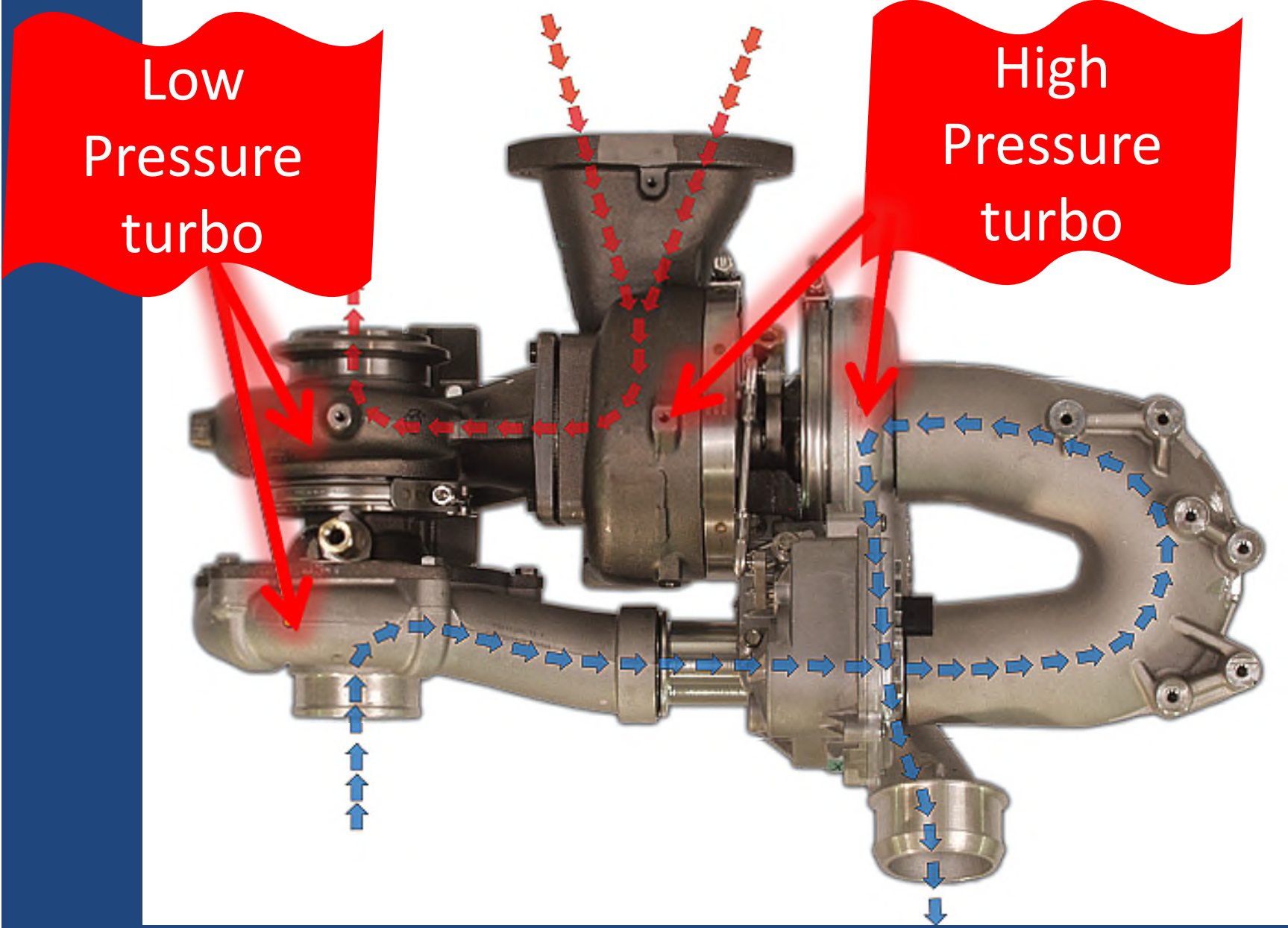
# Series Turbo Chargers

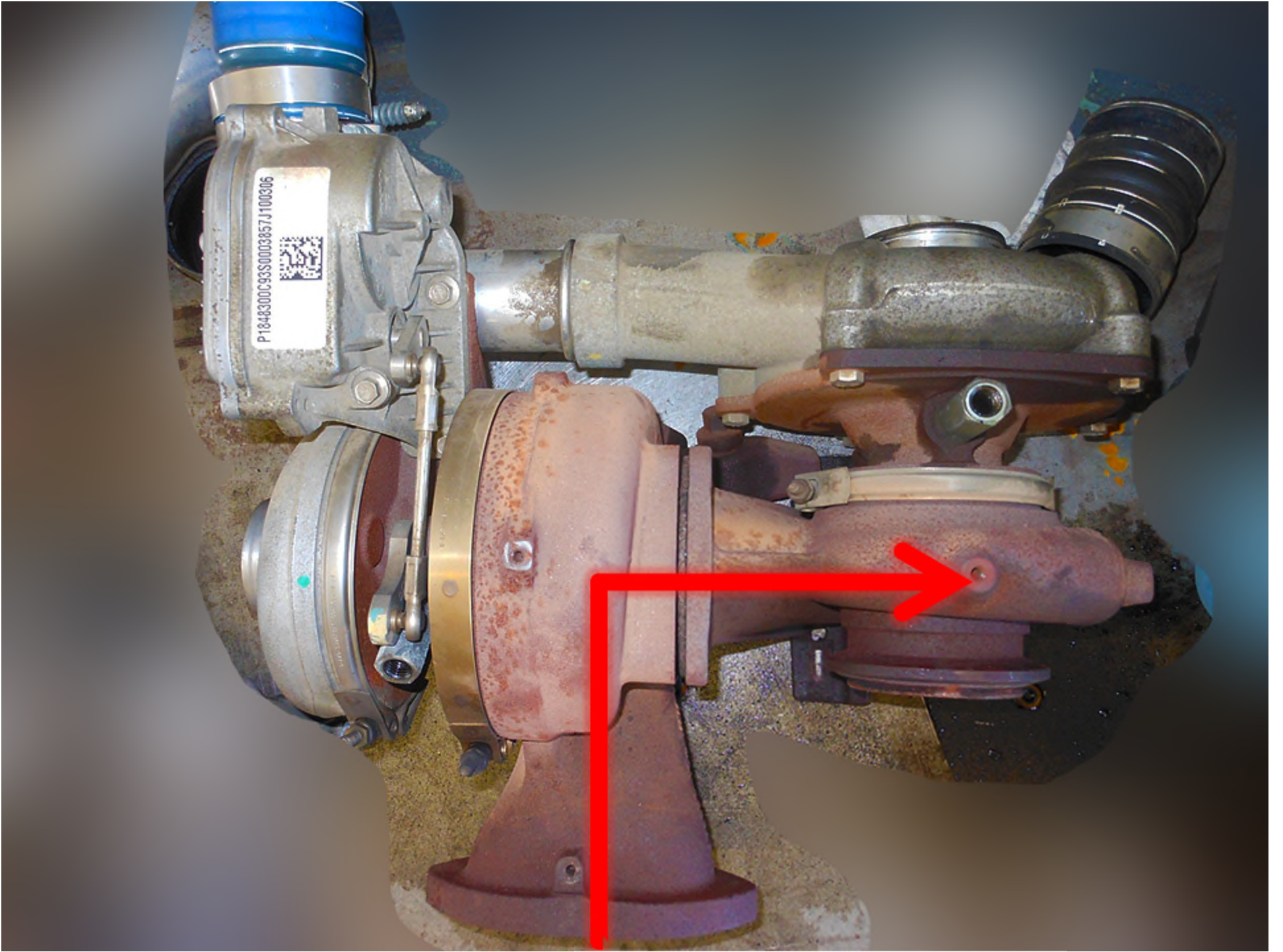
The VGT turbo feeds the larger turbo.

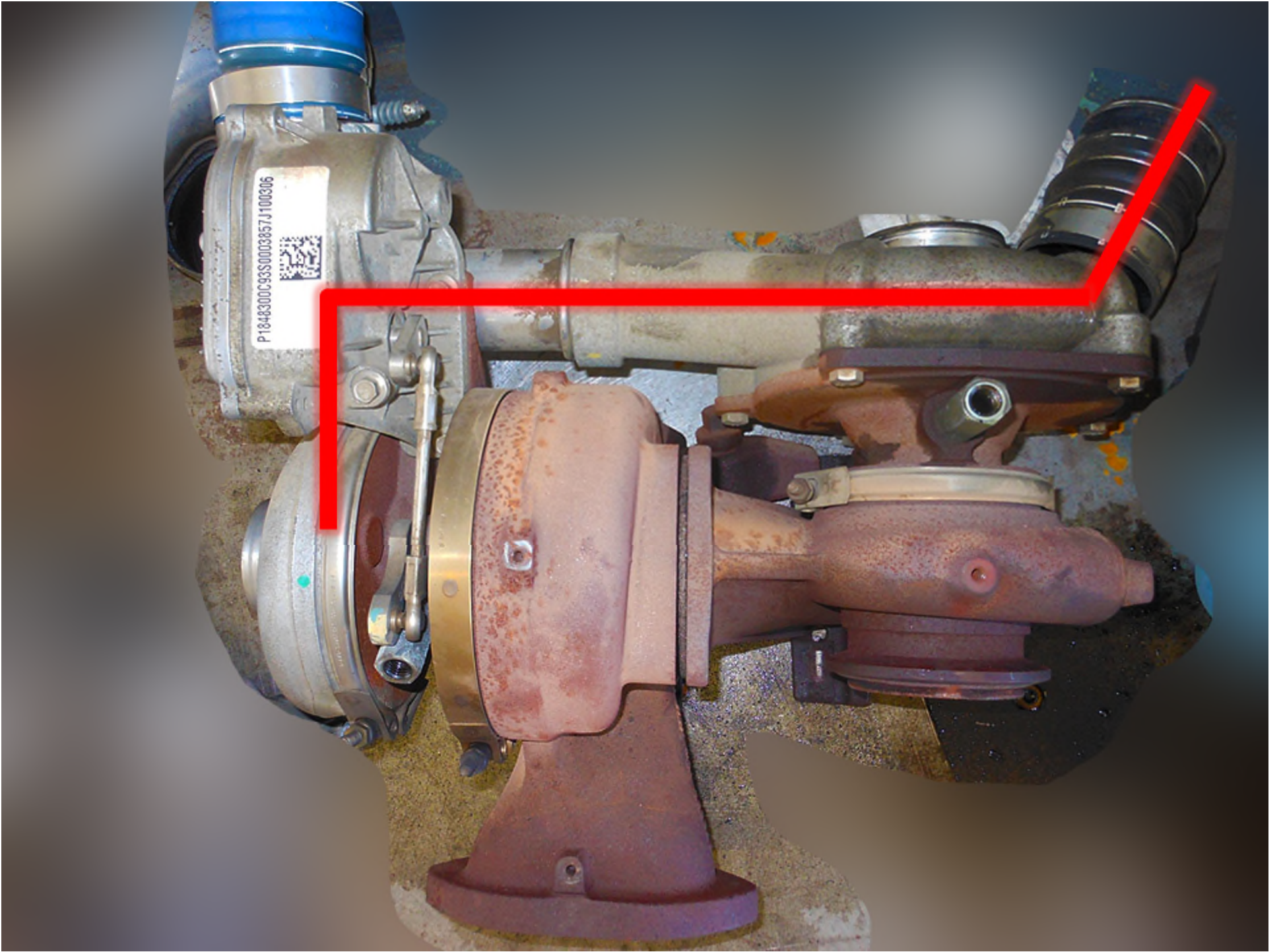
The VGT turbo is optimized for low speed operation but may not provide sufficient boost at high loads

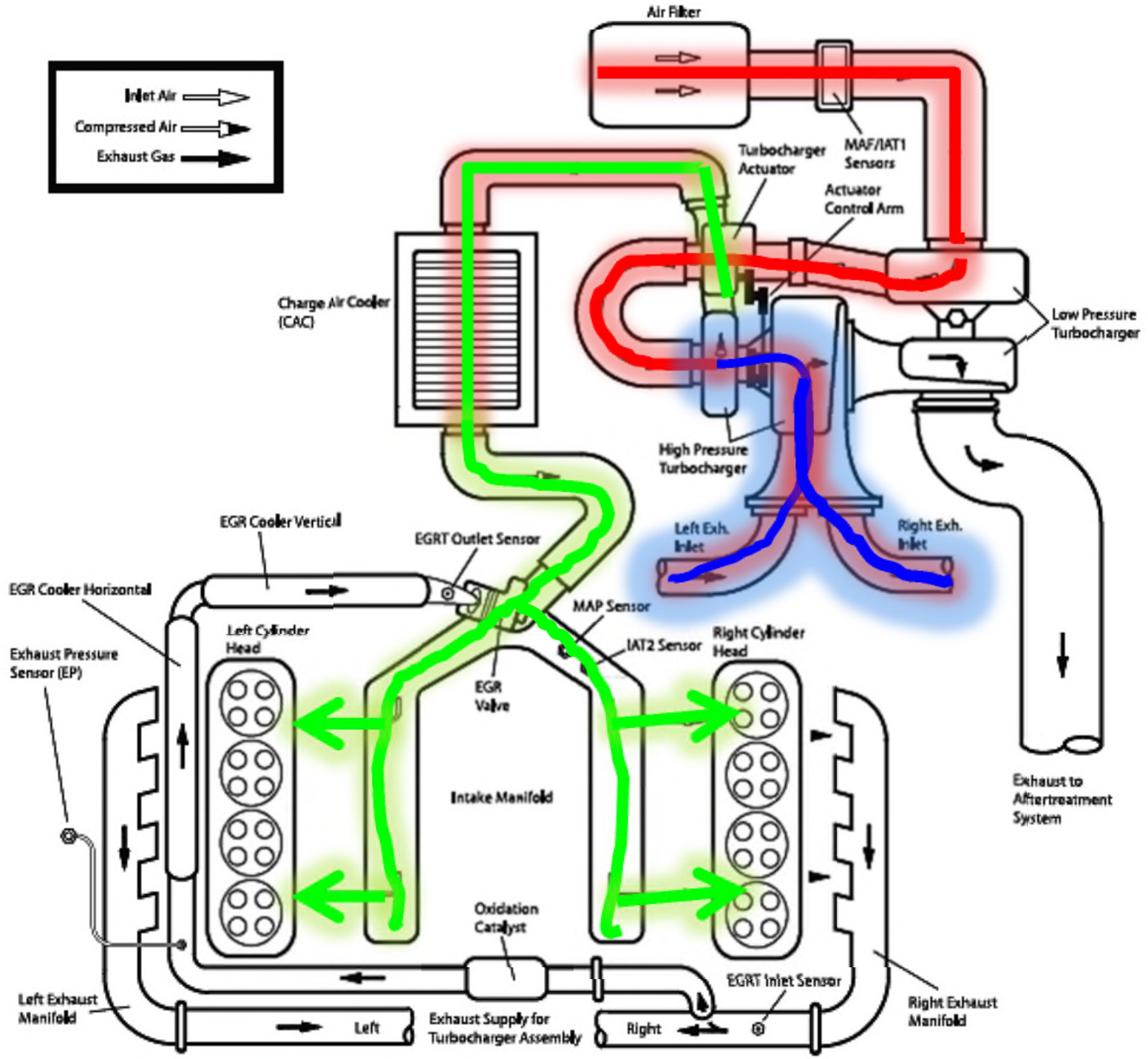
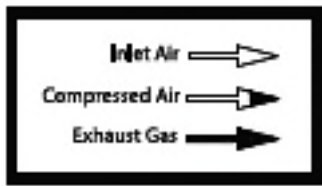
The second larger turbo kicks in when the VGT turbo has reached its limits.

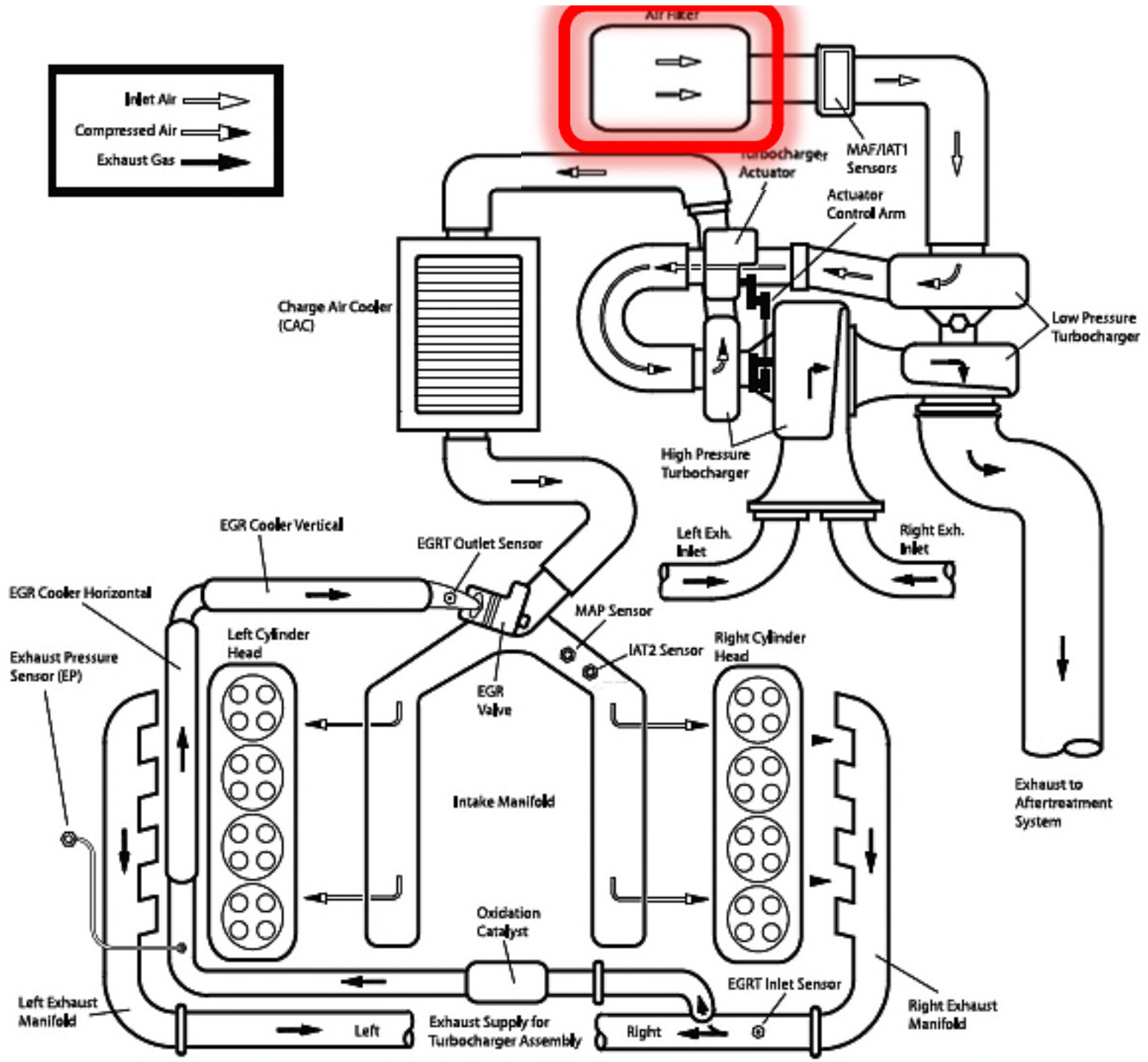
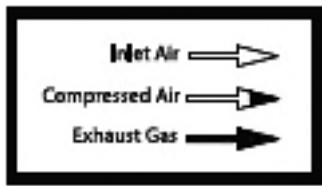
The two give a full range of boost with minimum turbo lag.







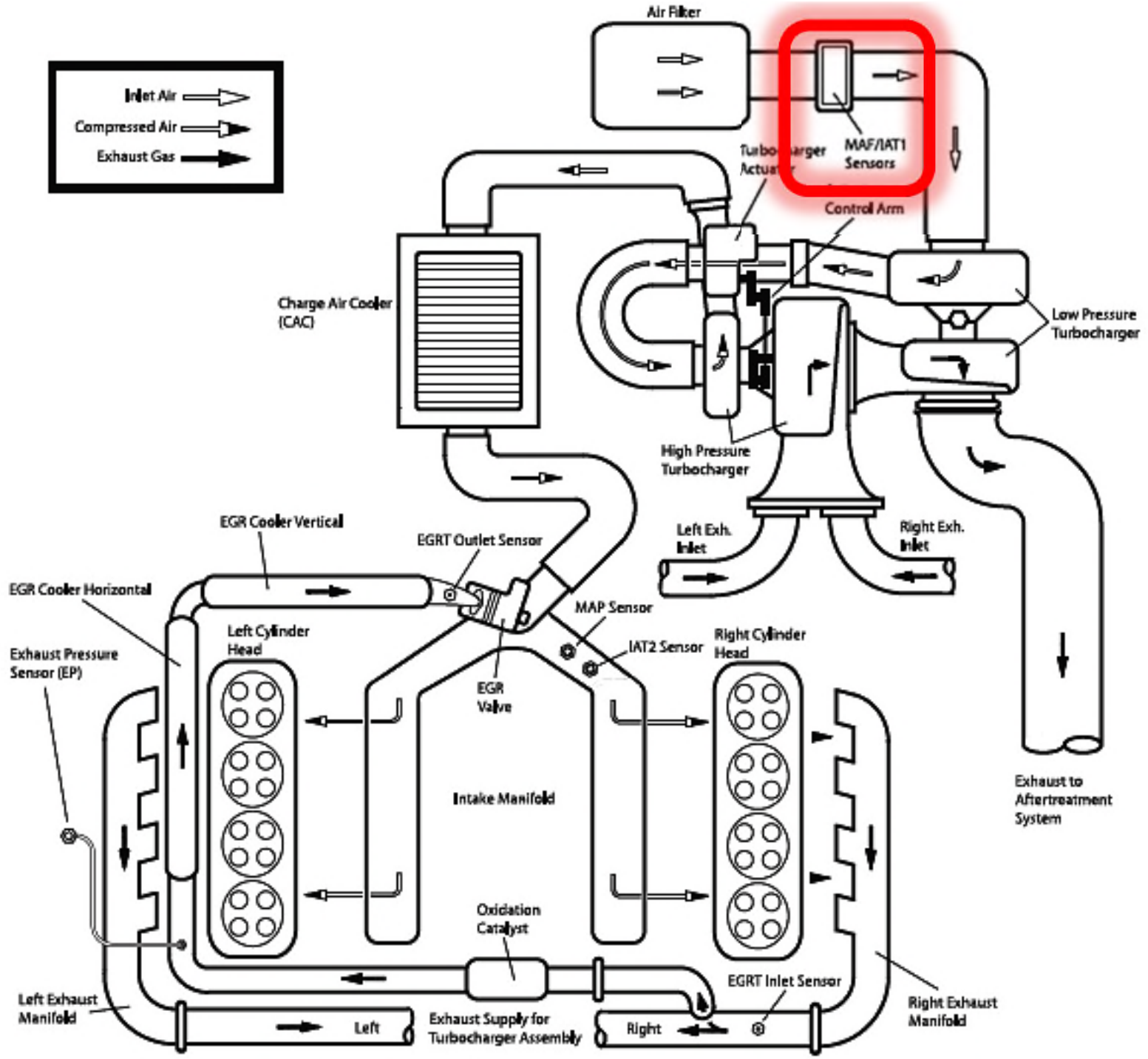
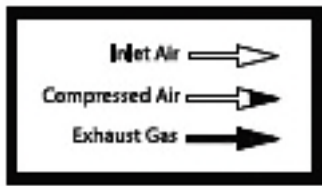


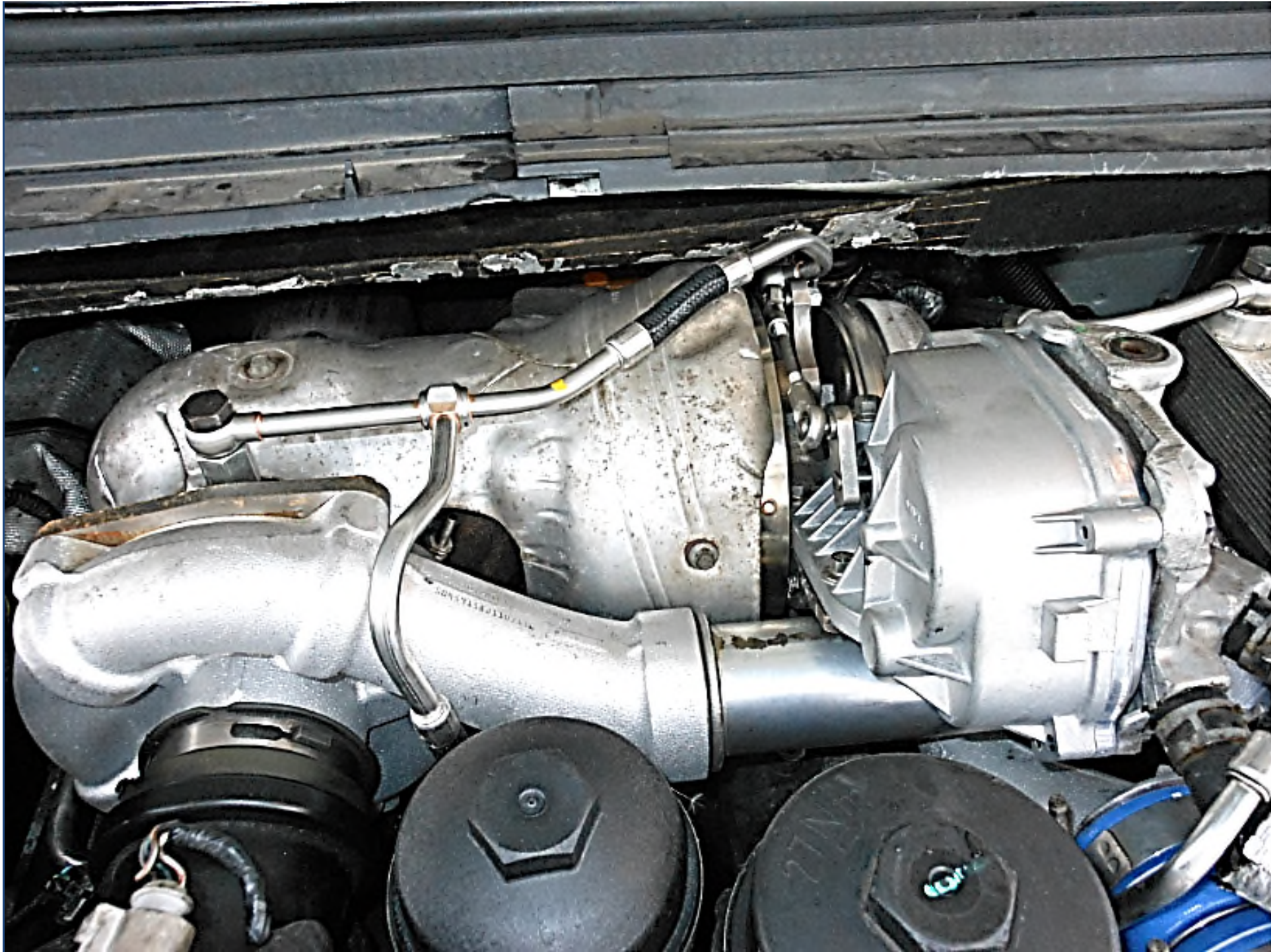


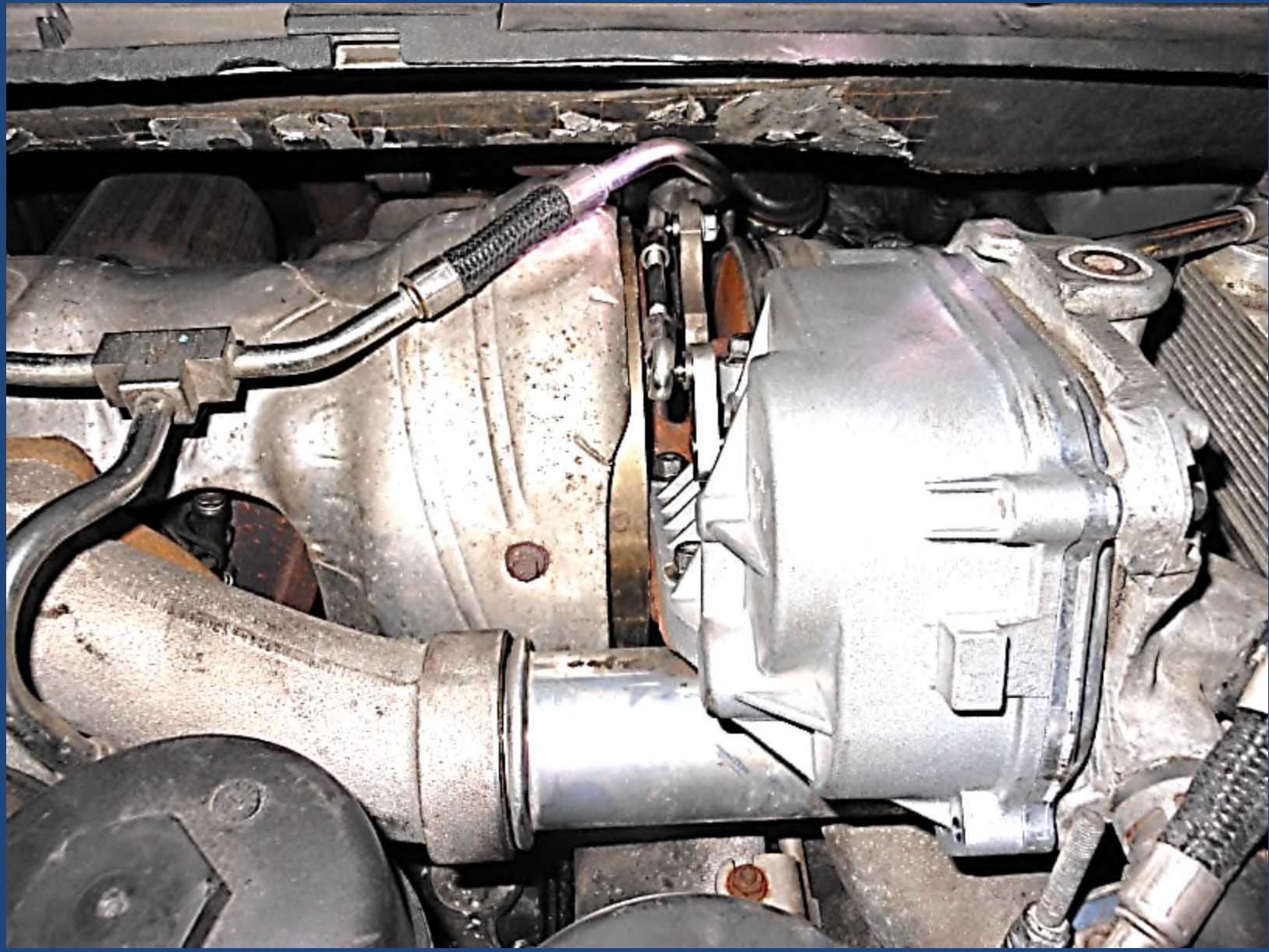
Air enters the system through the air filter where particles are removed

The a filter minder warns the operator of a restricted air filter









# Series Sequential Turbocharger

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.

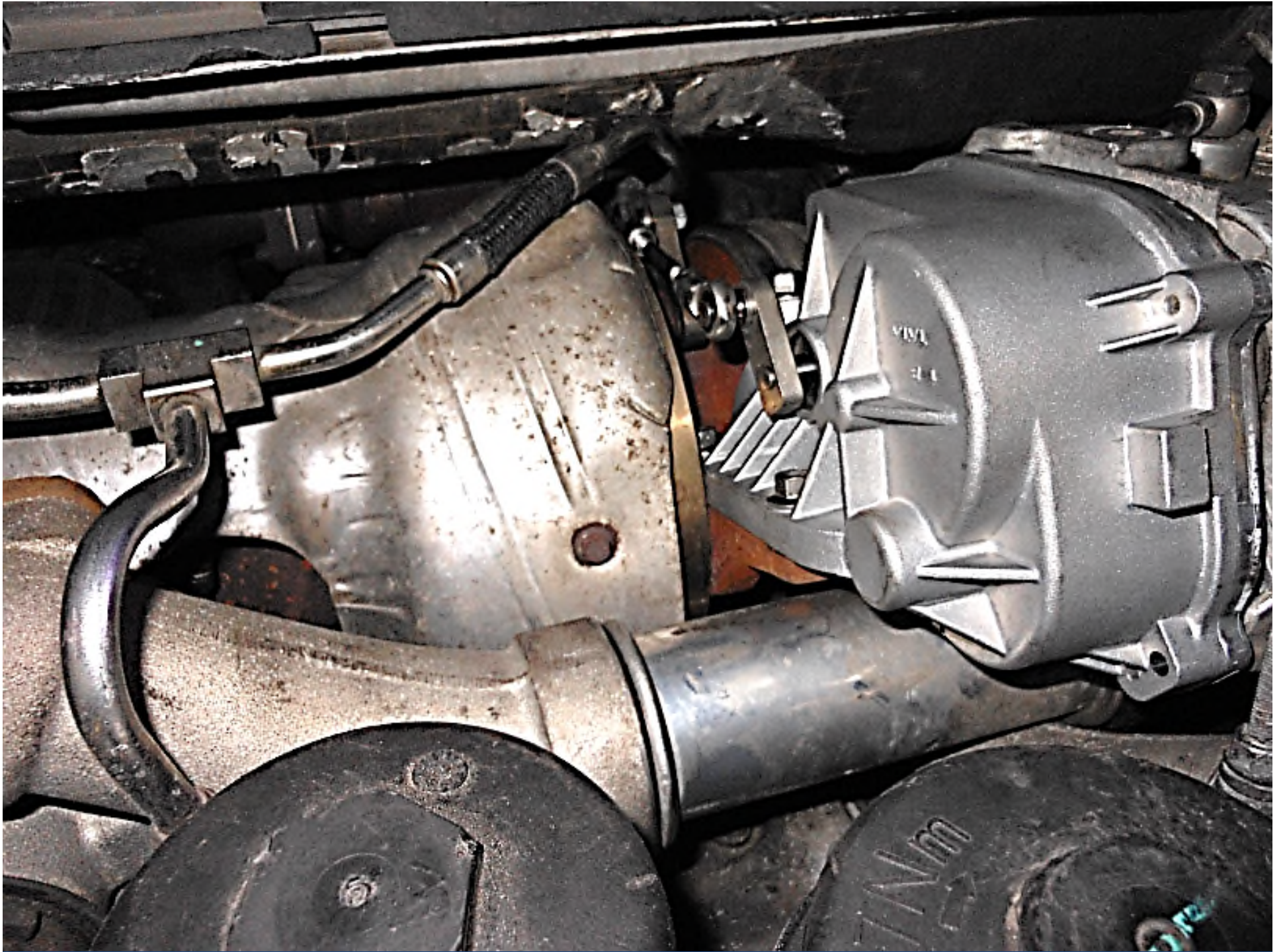
The closed vanes also increase the velocity of the air going to the turbine.

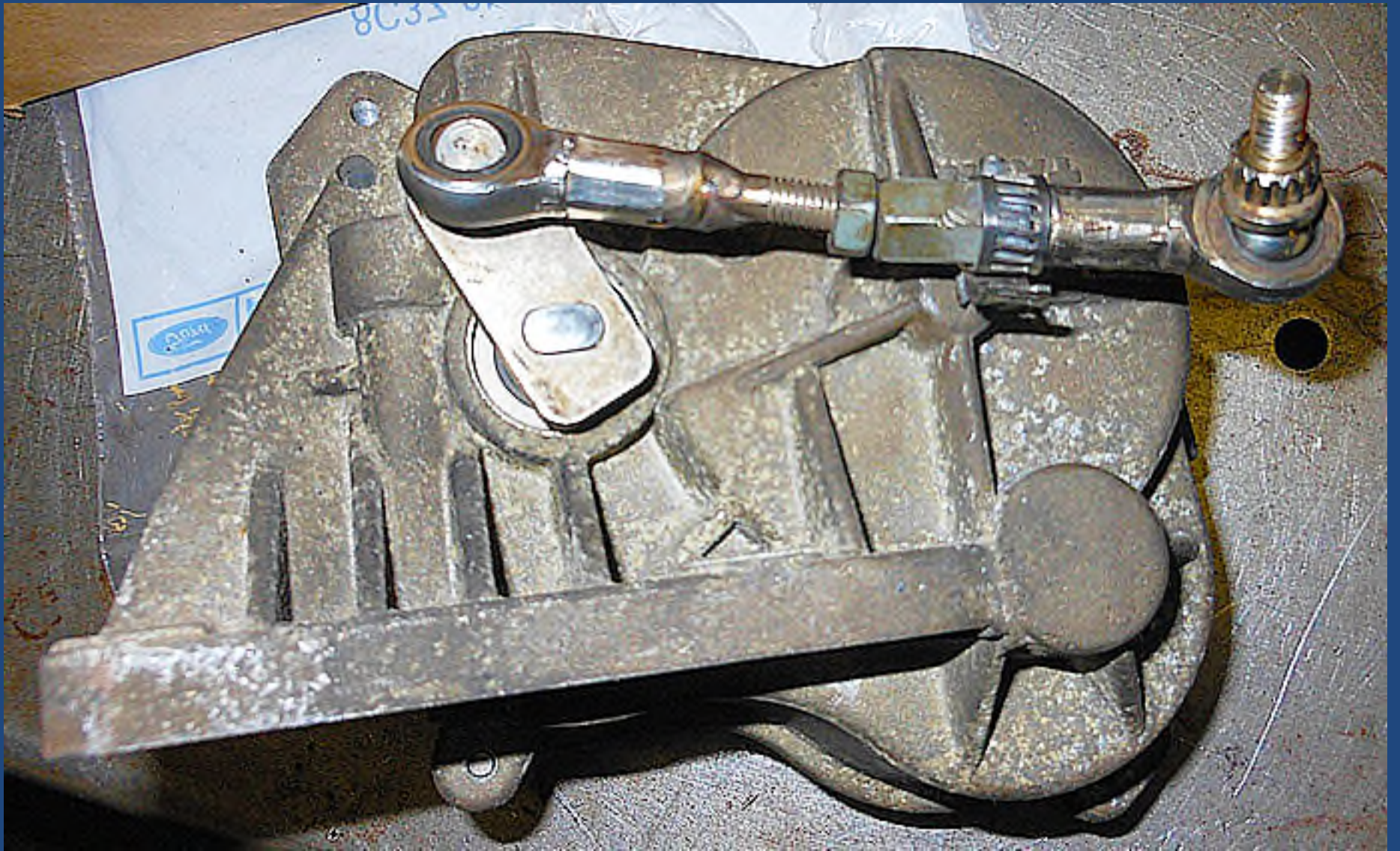
# Turbocharger Actuator

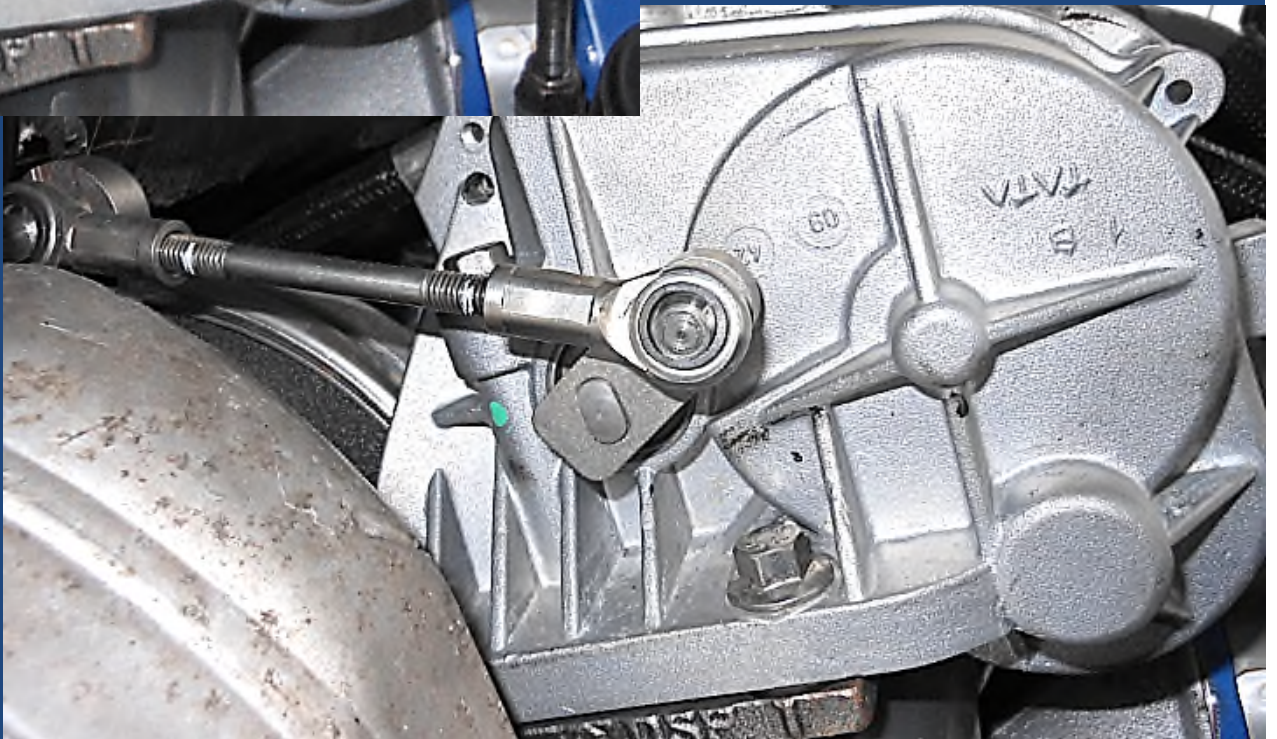
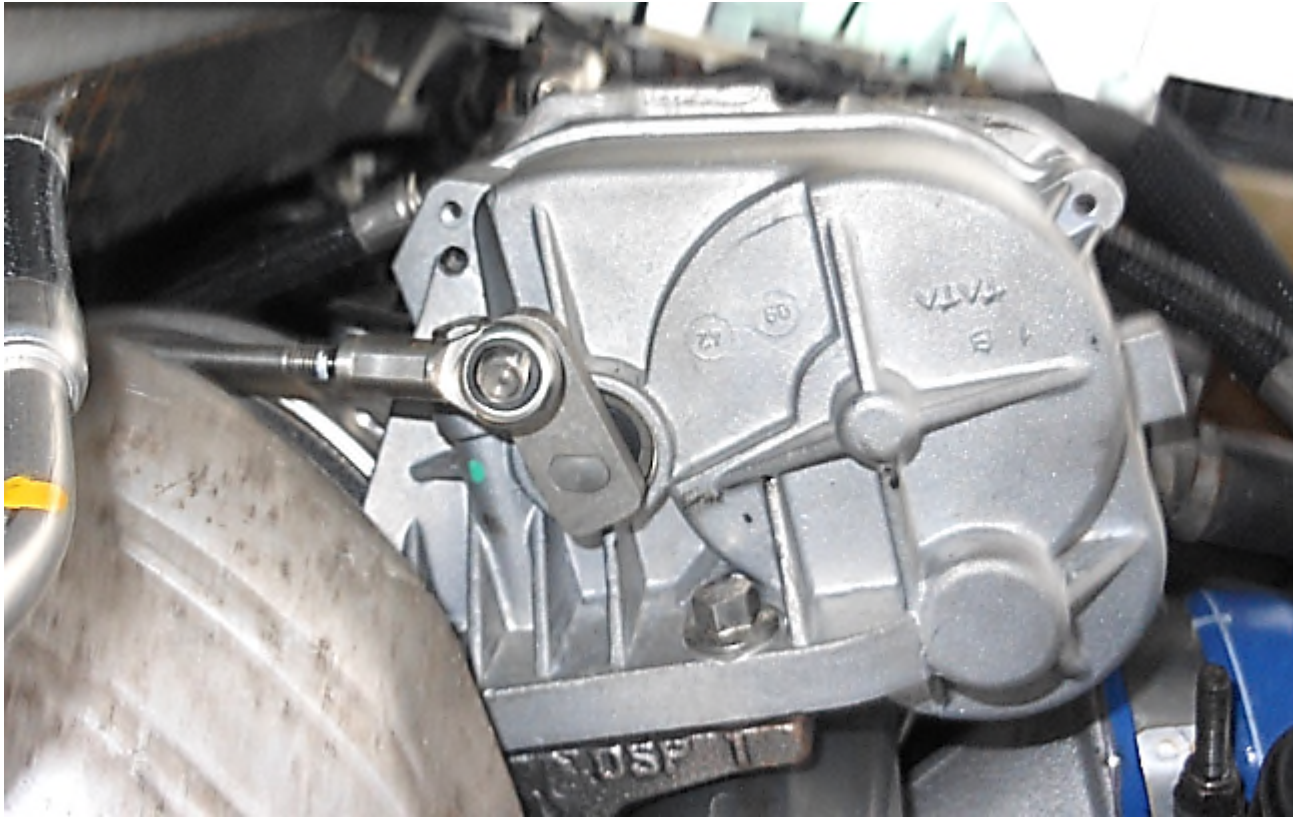
The actuator can be an electrical stepper motor.

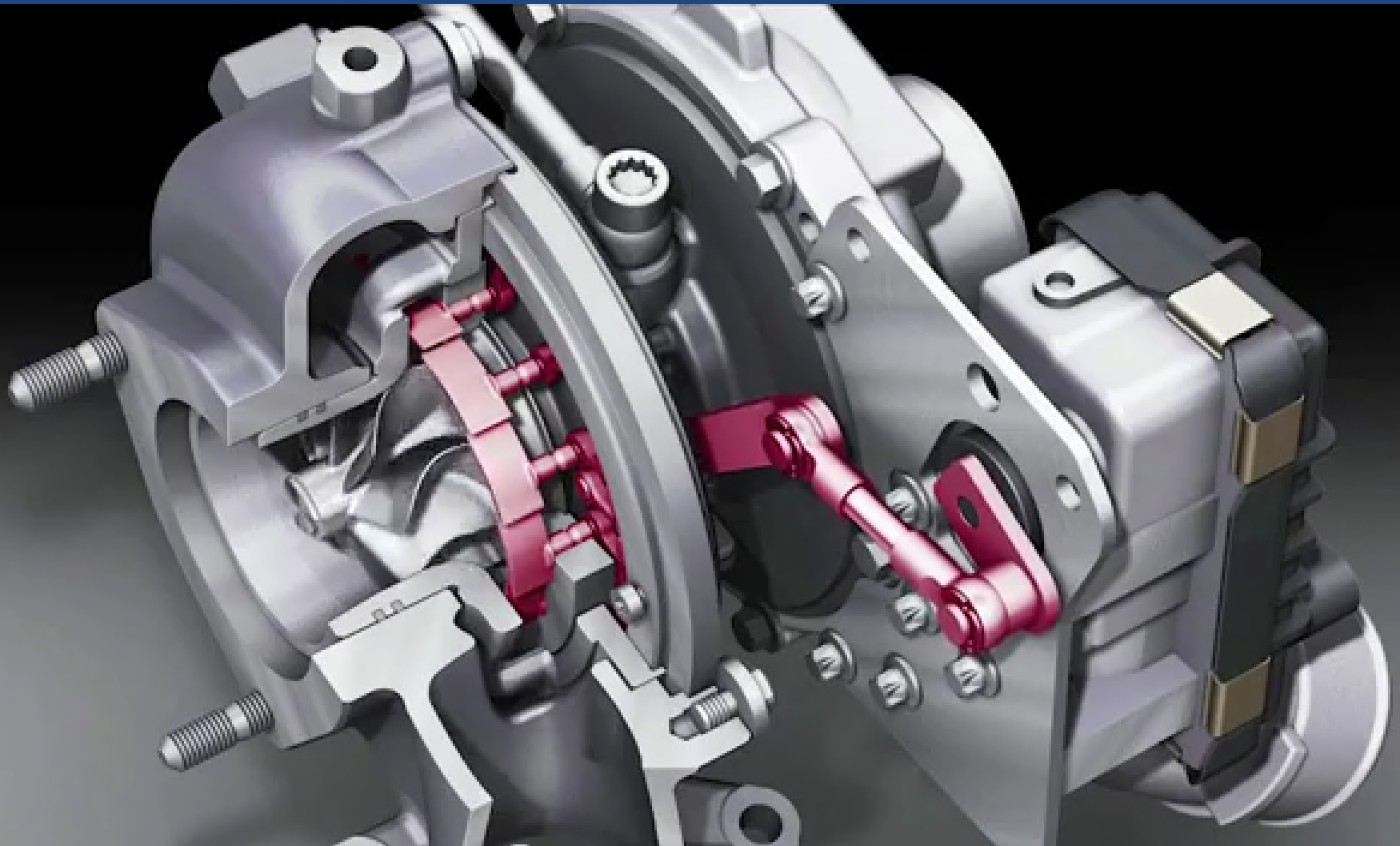
The variable vanes are controlled by the turbocharger actuator

The control arm connects the actuator to a pivot shaft which connects to the unison ring that moves the vanes







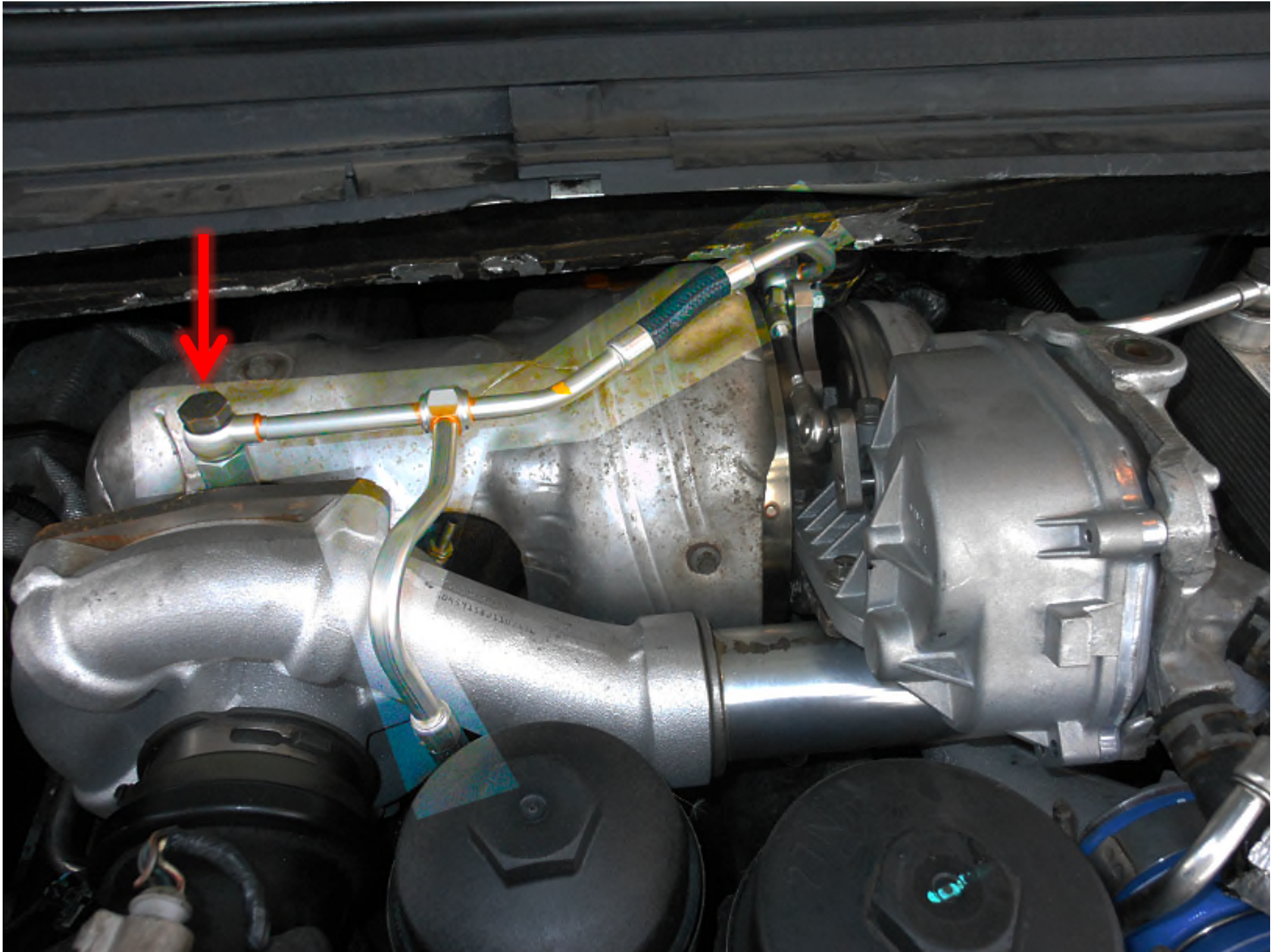


# Common Reason for failing

The oil supply line has the wrong banjo bolt in it

The wrong bolt has two feed holes and not four

The turbocharger starves for oil and the bearings go bad



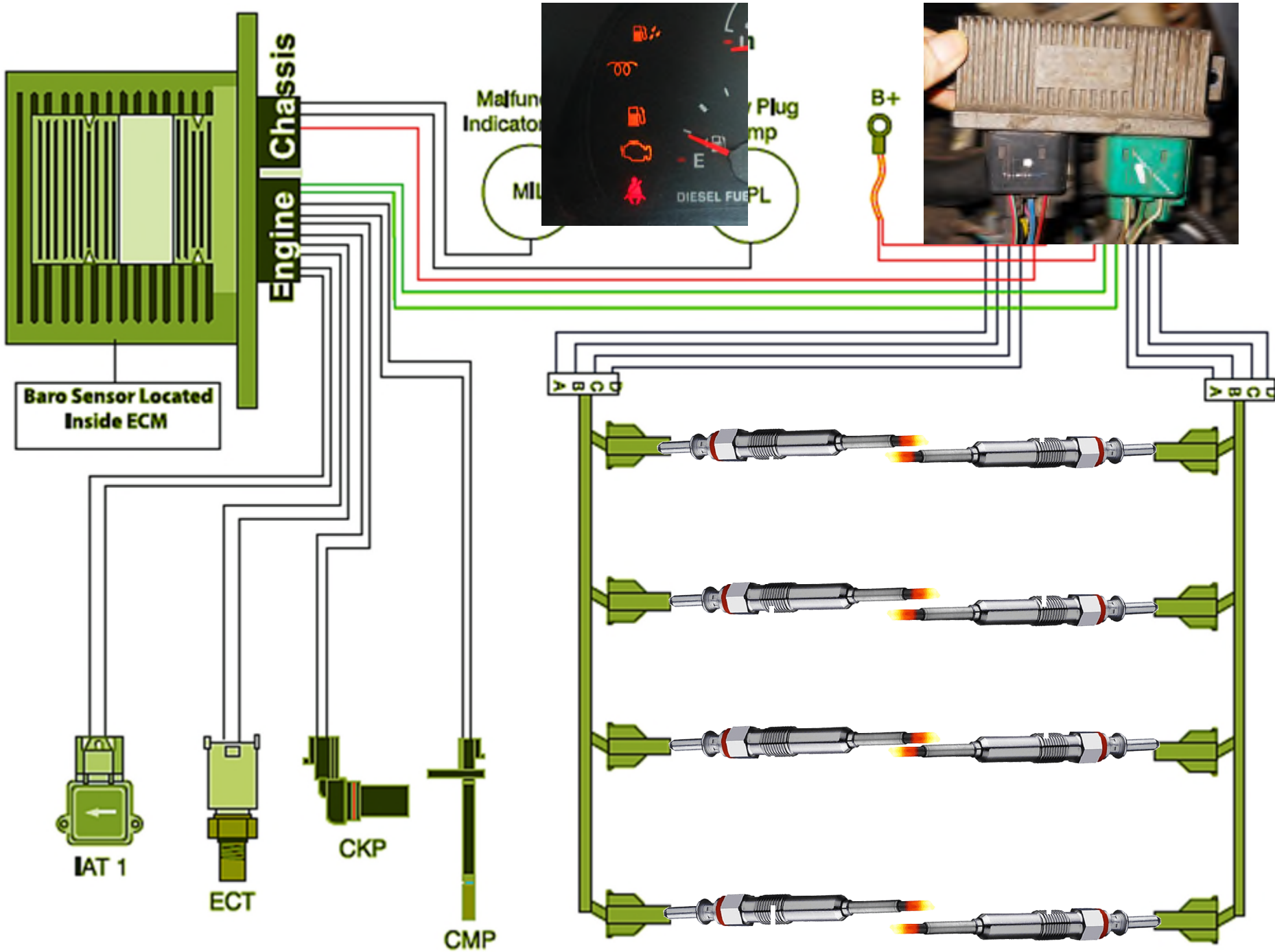
# Glow Plugs

Some manufactures use glow plugs while other s use grid heaters

\We will discuss glow plugs first.

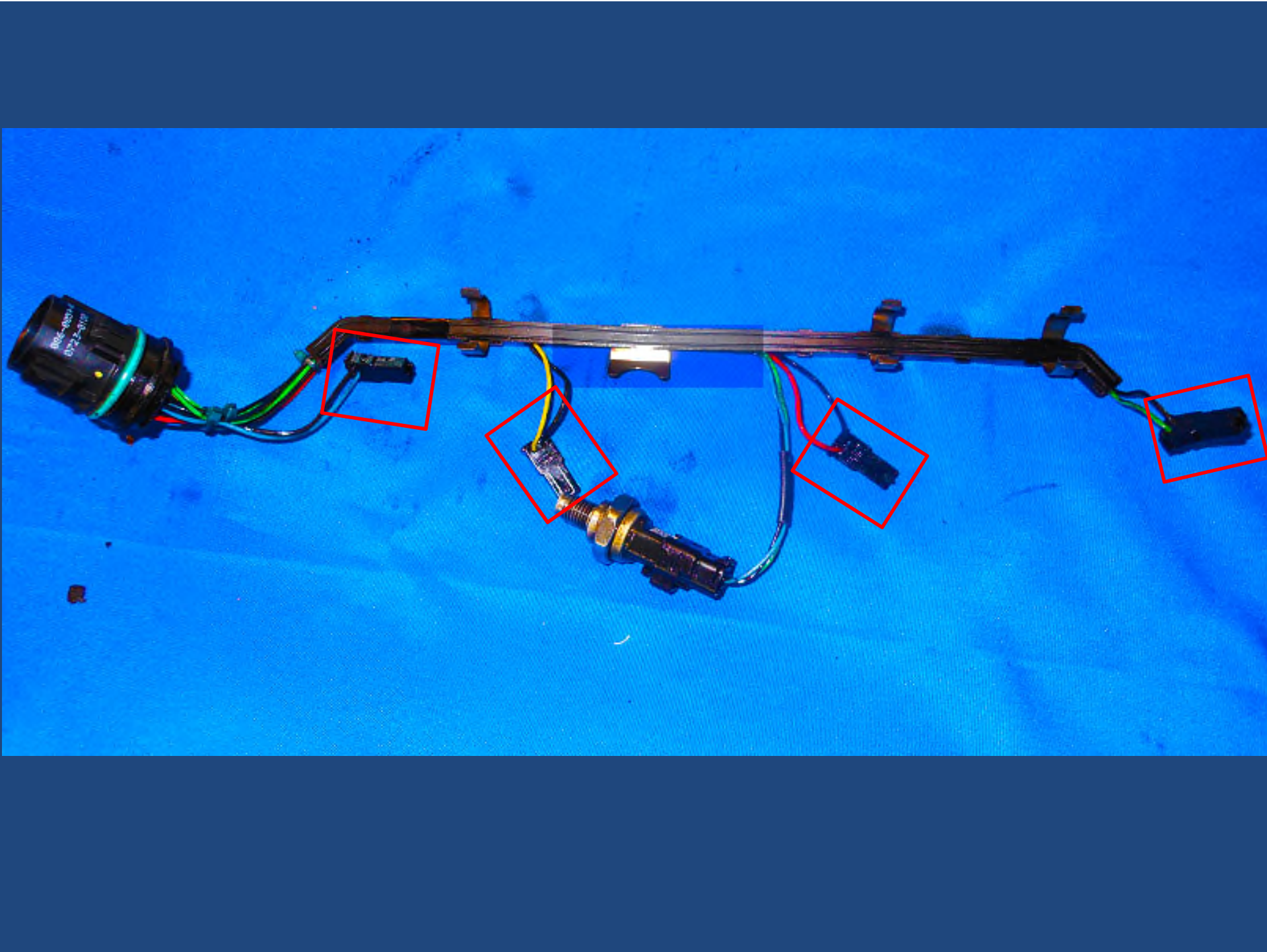
The glow plug system is used to warm the air in the cylinders to enhance cold weather startability and reduce start up smoke

The glow plug system is ECM controlled, and powered by the GPCM



**Glow plug harness**







# Glow Plug Control Module (GPCM)

On time is dependent on oil temperature and altitude

The GPCM commands the glow plugs on for 1 to 120 seconds

The GPCM does not operate if the oil temperature is above 131°F

Sensor Name	Value	Units	Minimum	Maximum	Range
Glow Plug Lamp Time	0.0	Sec	0.0	8191.9	0 %
Glow Plug Indicator Lamp Commanded On	No	Bit	0	1	0 %
Glow Plug Control Time	0.0	Sec	0.0	8191.9	0 %

**Glow plugs not turned on  
because oil temperature  
over 131°F**

<input type="checkbox"/> Sensor Name	Sensor Grouping
<input type="checkbox"/> Generator 2 Fault Detected	EnhancedPowertrainCAN
<input type="checkbox"/> Generator Fault Inductor Light Fault	EnhancedPowertrainCAN
<input type="checkbox"/> Generator Lamp Circuit	EnhancedPowertrainCAN
<input type="checkbox"/> Generator Output Fault Detection	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Glow Plug Control Time	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Glow Plug Indicator Lamp Commanded On	EnhancedPowertrainCAN
<input checked="" type="checkbox"/> Glow Plug Lamp Time	EnhancedPowertrainCAN
<input type="checkbox"/> Heated Exhaust Oxygen Sensor 11 Status	EnhancedPowertrainCAN
<input type="checkbox"/> Heated Exhaust Oxygen Sensor 21 Status	EnhancedPowertrainCAN
<input type="checkbox"/> Heated Exhaust Oxygen Sensor System Evaluated	EnhancedPowertrainCAN
<input type="checkbox"/> High Speed Fan Control	EnhancedPowertrainCAN
<input type="checkbox"/> IAT Failure Mode	EnhancedPowertrainCAN
<input type="checkbox"/> Idle Air Control Short to Gnd Detected	EnhancedPowertrainCAN
<input type="checkbox"/> IMTV2 Status	EnhancedPowertrainCAN
<input type="checkbox"/> In Drive During Time of Misfire	EnhancedPowertrainCAN

Vehicle Notes  
Put your vehicle notes here

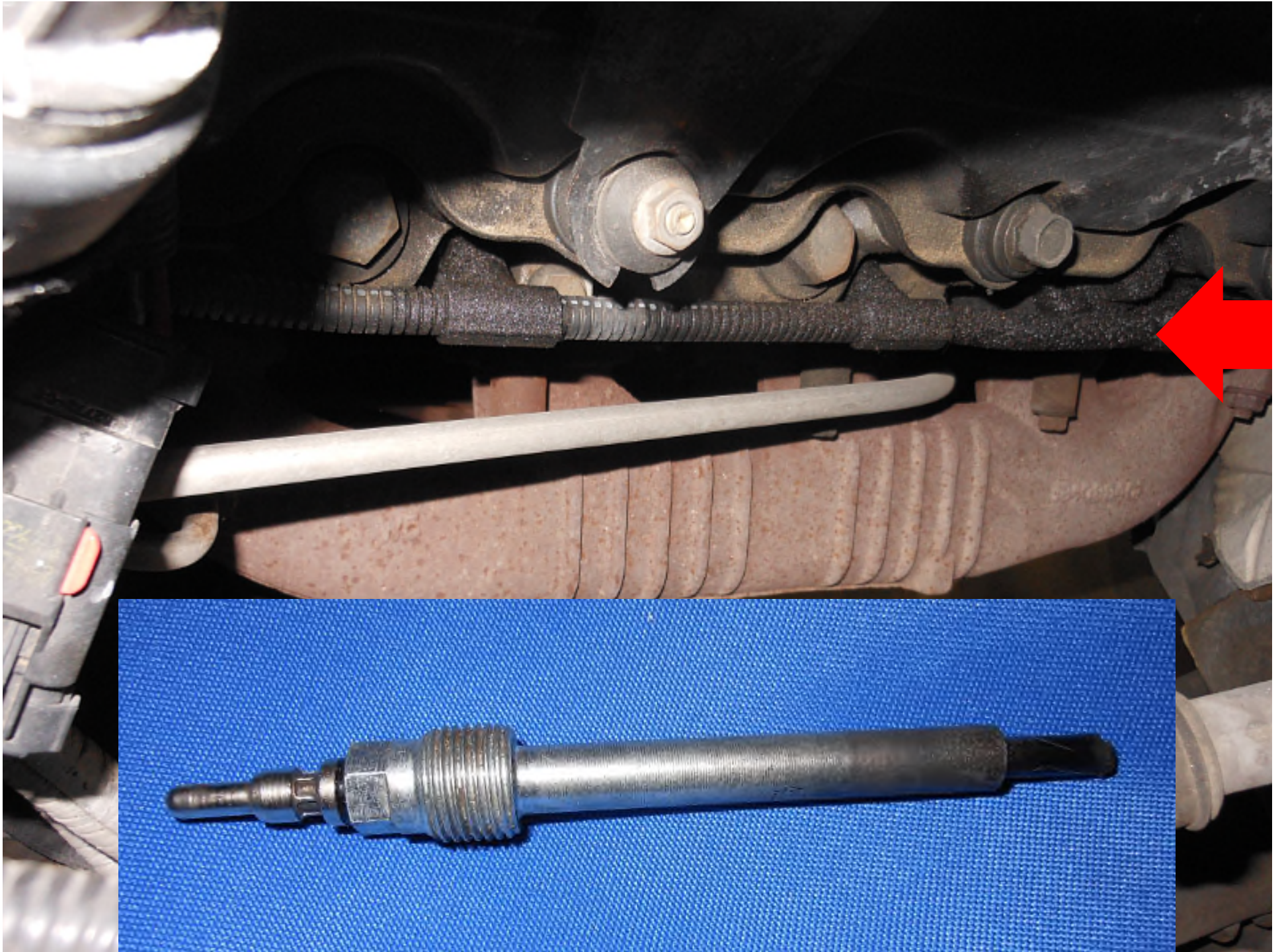
# Glow Plug Control Module(GPCM)

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



Near the ICP



# 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



- 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

Initiate

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
	Performing Test..



 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







REVIEW



ZOOM 1x



0 | 0.00 | 1

-0.10 A

↓ -0.25 Low Amps (40) ↑ 20.35

4 A/div ▲

OFF

32  
24  
16  
8  
0

Ch1

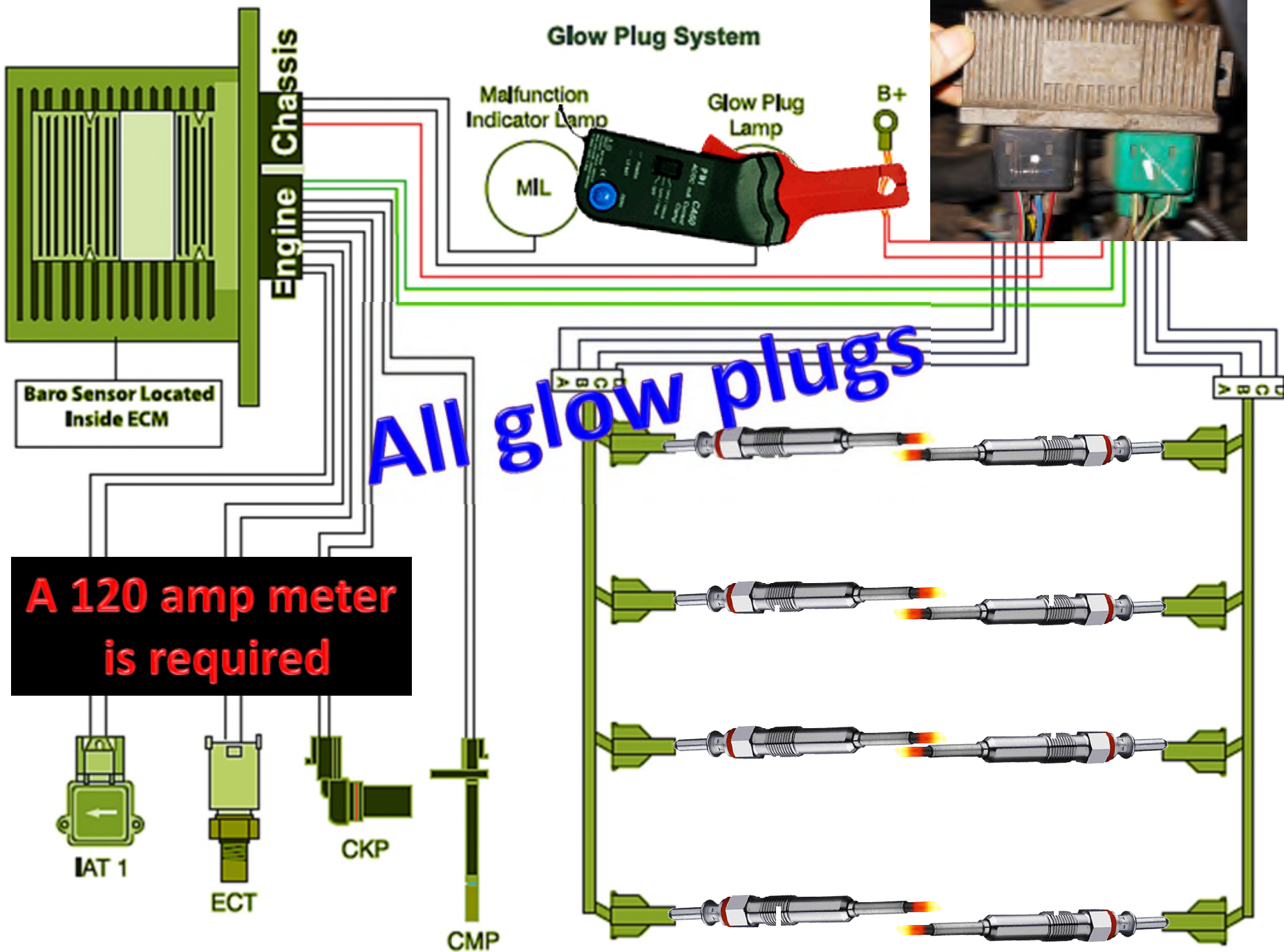
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

Channel

Sweep

Ch 1 | Low Amps 40 | 40 A |

2 min



### Glow Plug System

Malfunction Indicator Lamp  
MIL

Glow Plug Lamp

B+



All glow plugs

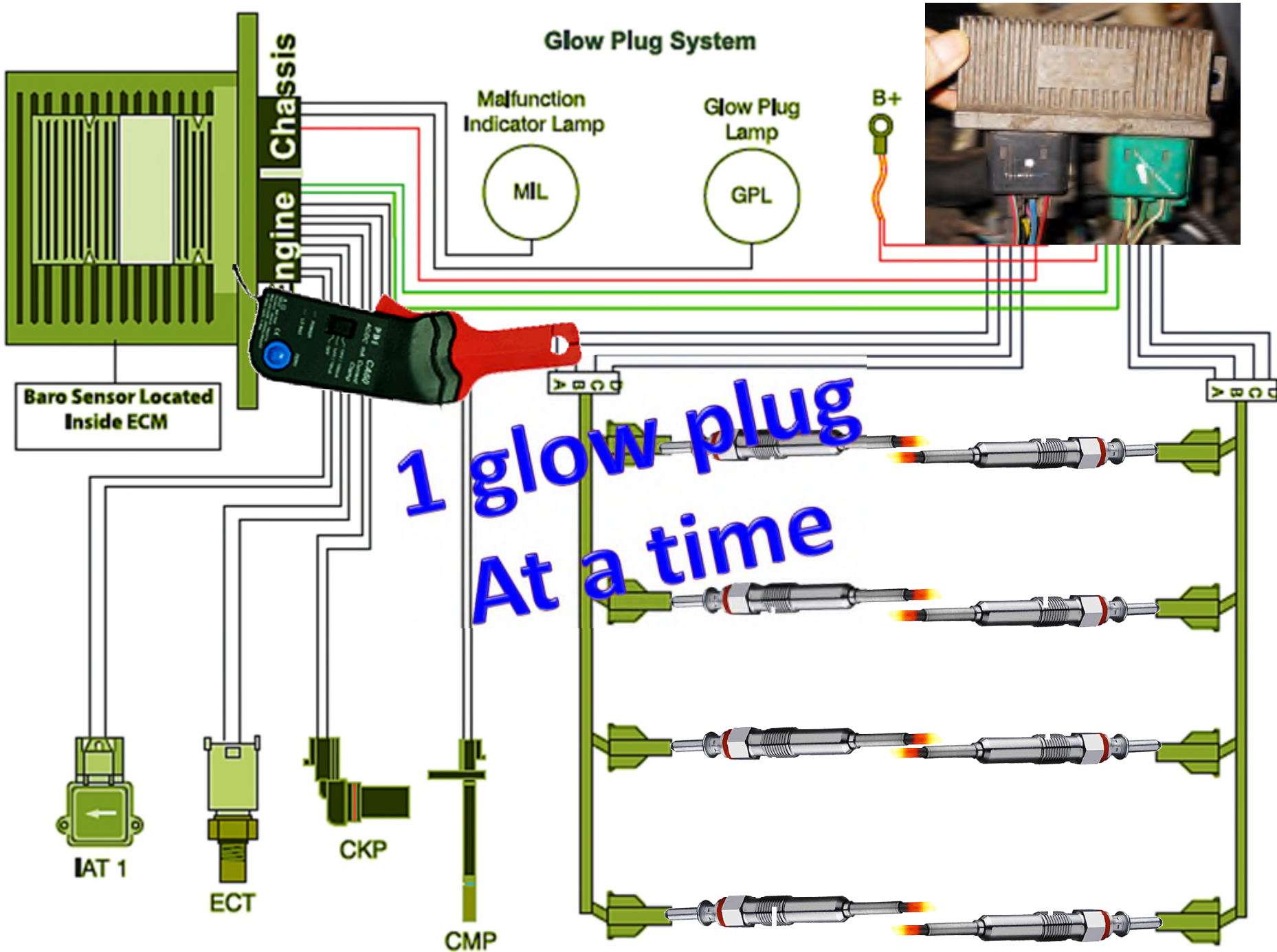
A 120 amp meter is required

IAT 1

ECT

CKP

CMP



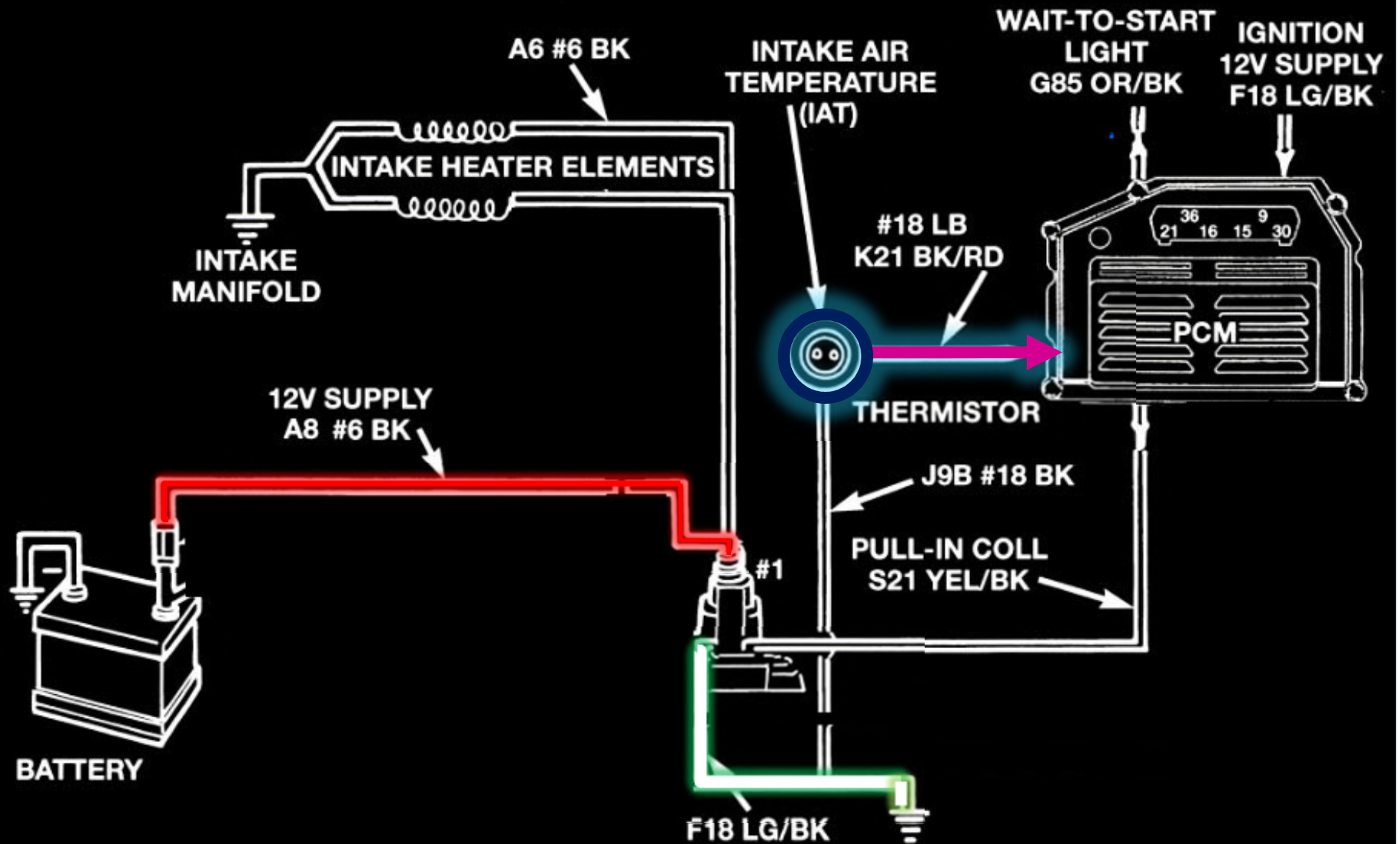
# Intake Air Heater(s)

One or two air intake air heaters are used to pre-heat the intake air for starting

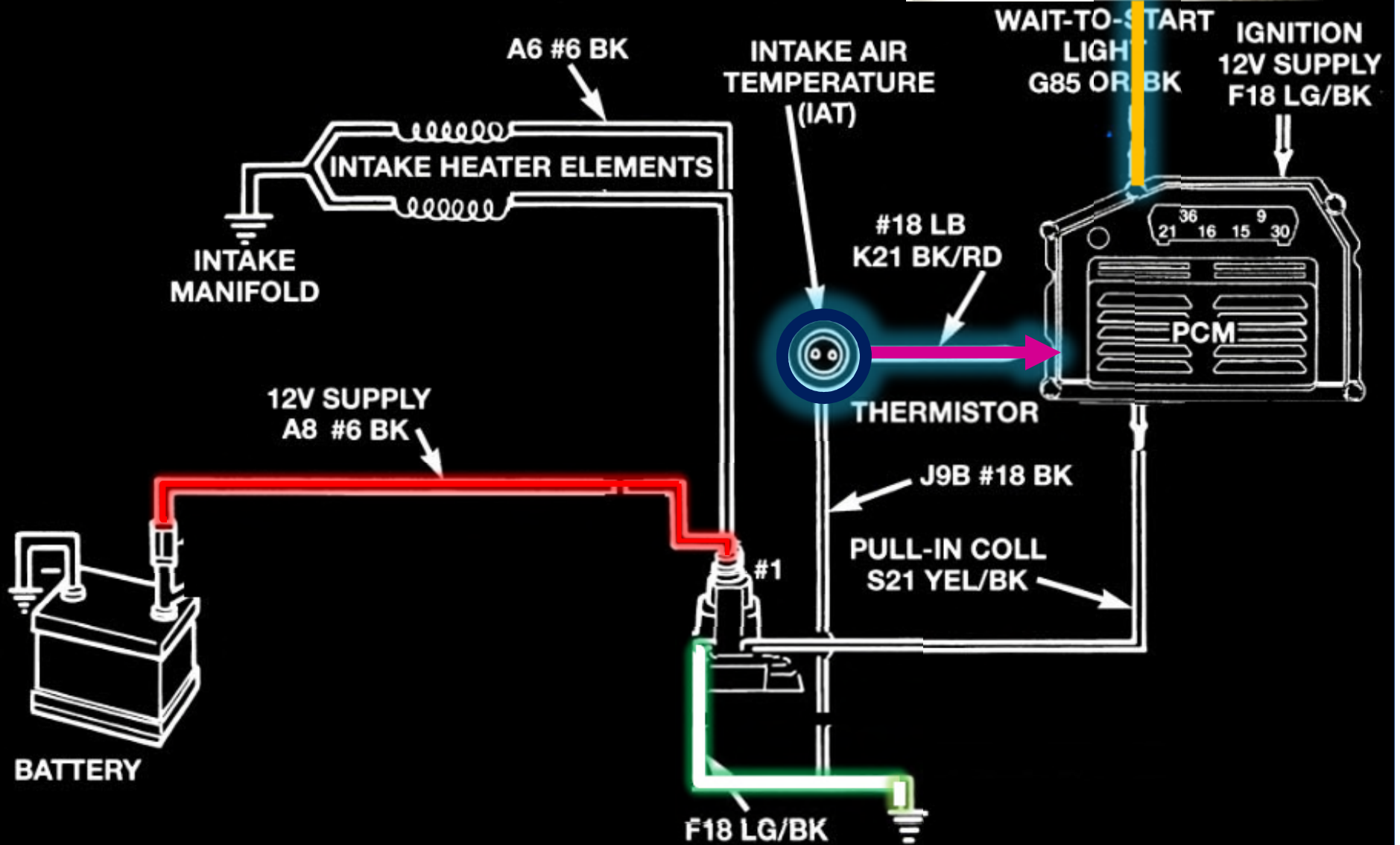
The heaters are simple grid type heaters

The amount of time the heaters are on, is based from the inlet air temperature sensor

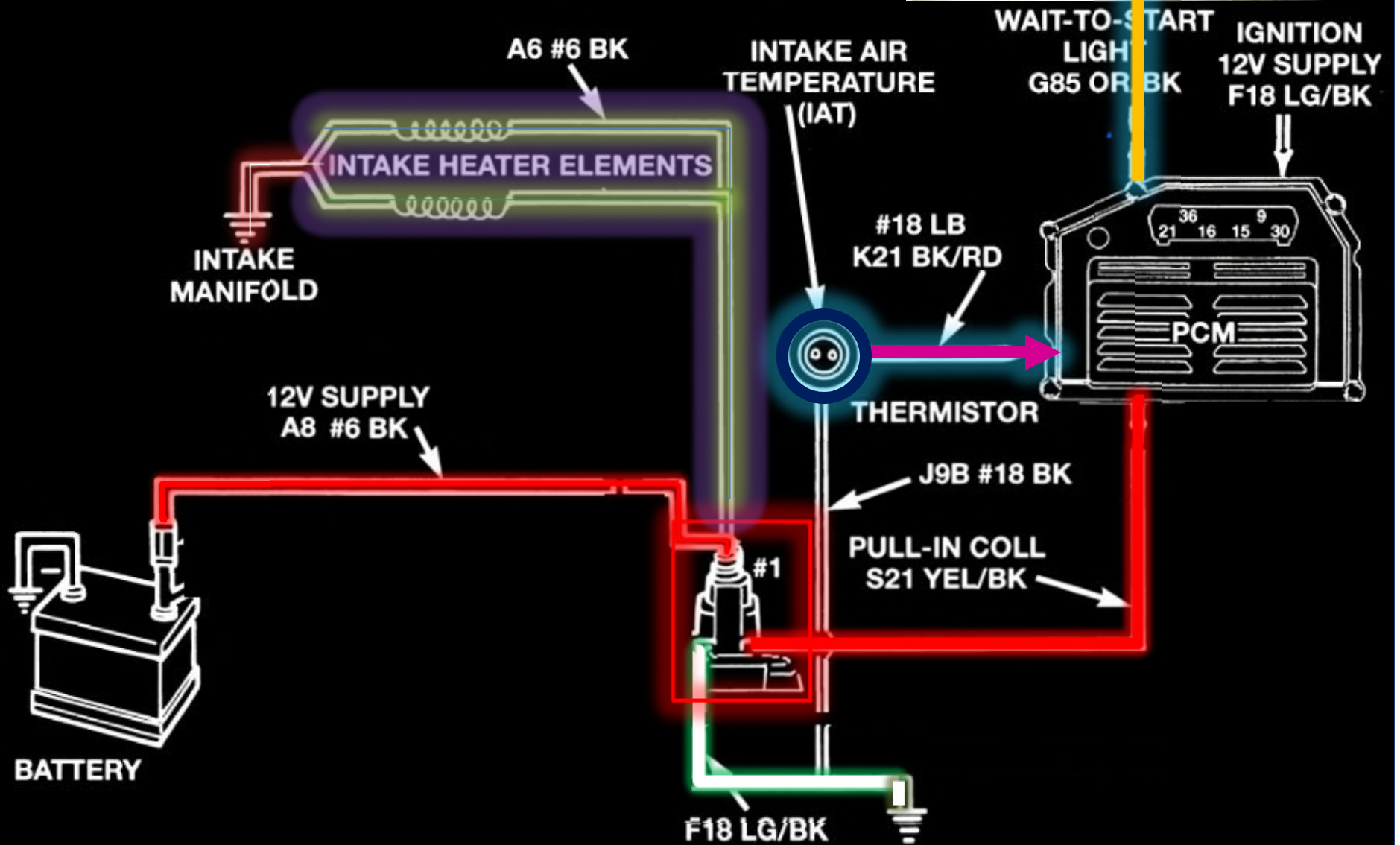
# Inlet Air Heater



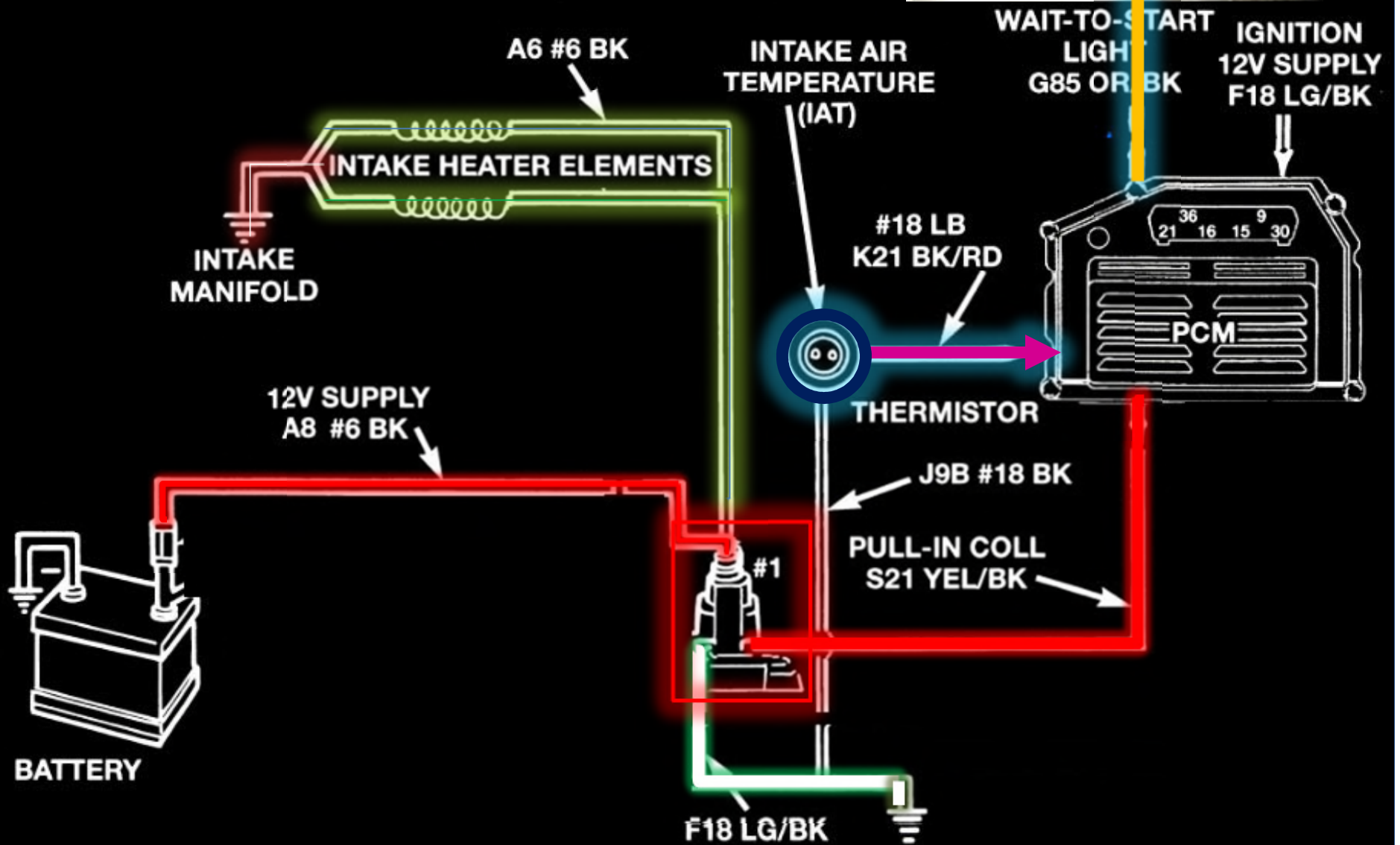
**WAIT TO START**

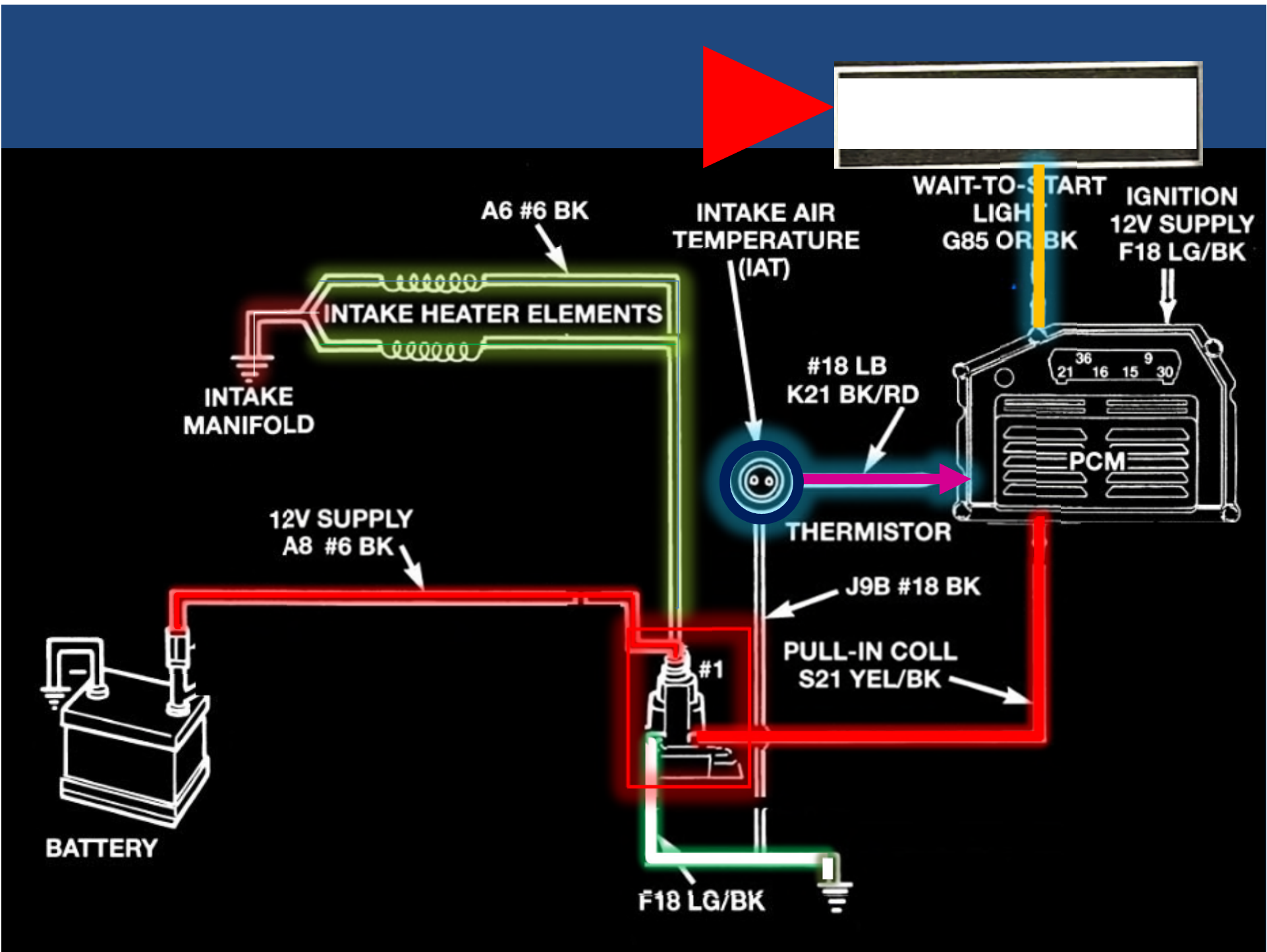


**WAIT TO START**



**WAIT TO START**







RPM x 1000

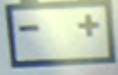
New Style

oo

Old Style

WAIT TO START

18



0

ULTRA LOW SULFUR  
DIESEL FUEL

F



# Starting the engine correctly

At temperatures below 60°F depress the accelerator pedal half way

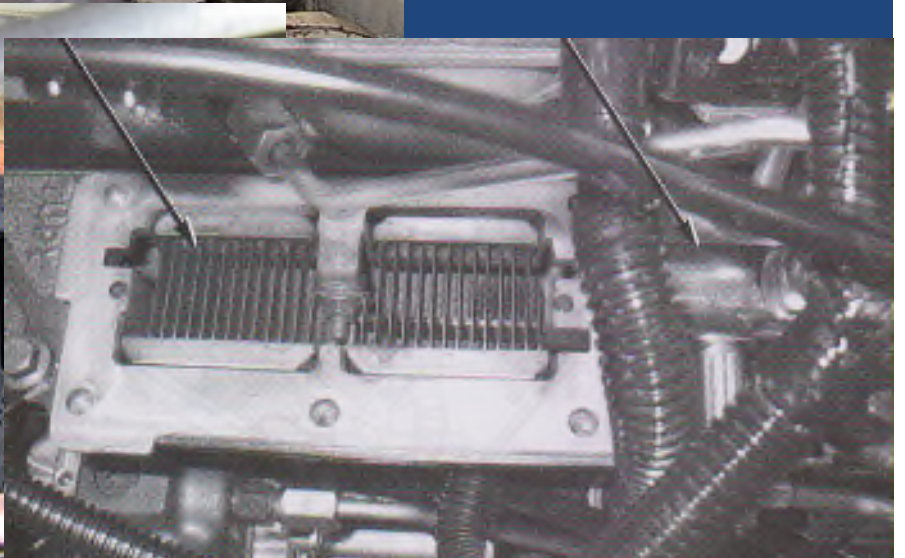
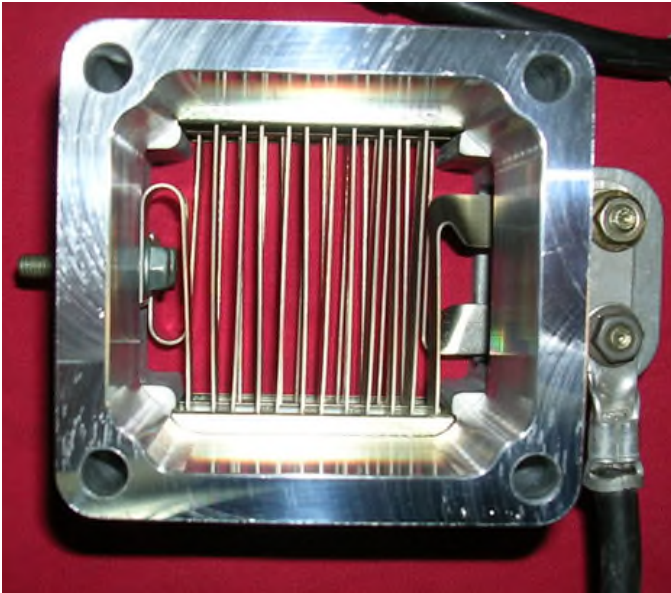
And wait until the wait to start lamp goes out, before cranking the engine

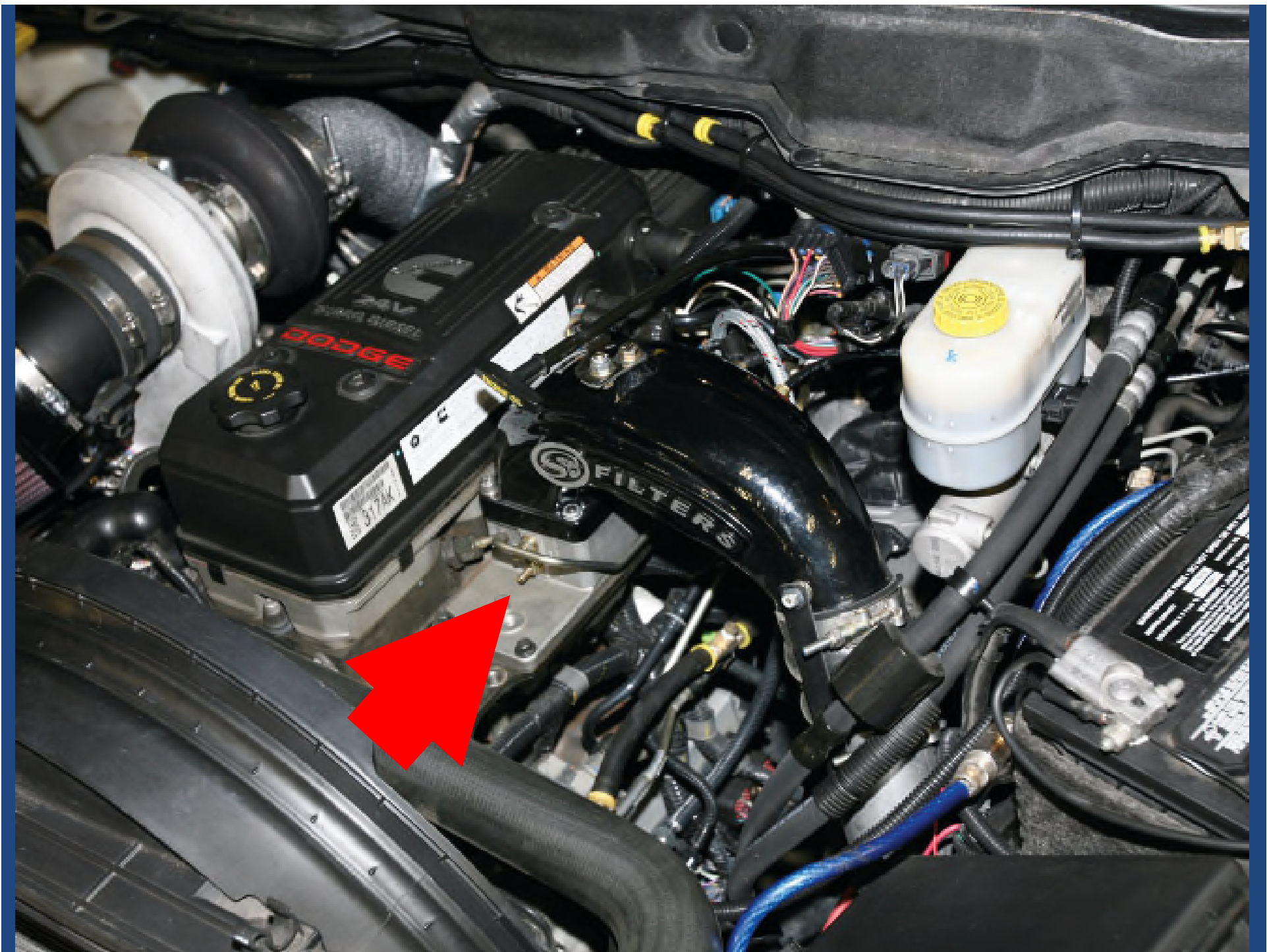


# Start engine correctly

This allows the intake air heaters to warm the incoming air

The heaters will continue to operate for an equal amount of time after the engine starts





# Wait to start lamp turn on times

Pre-heat times based  
based  
from intake temperature

Pre-heat times  
from Baro In Hg

19.99 to 29.00

-40°F to 0°F

30 seconds

0°F to 15°F

15 seconds

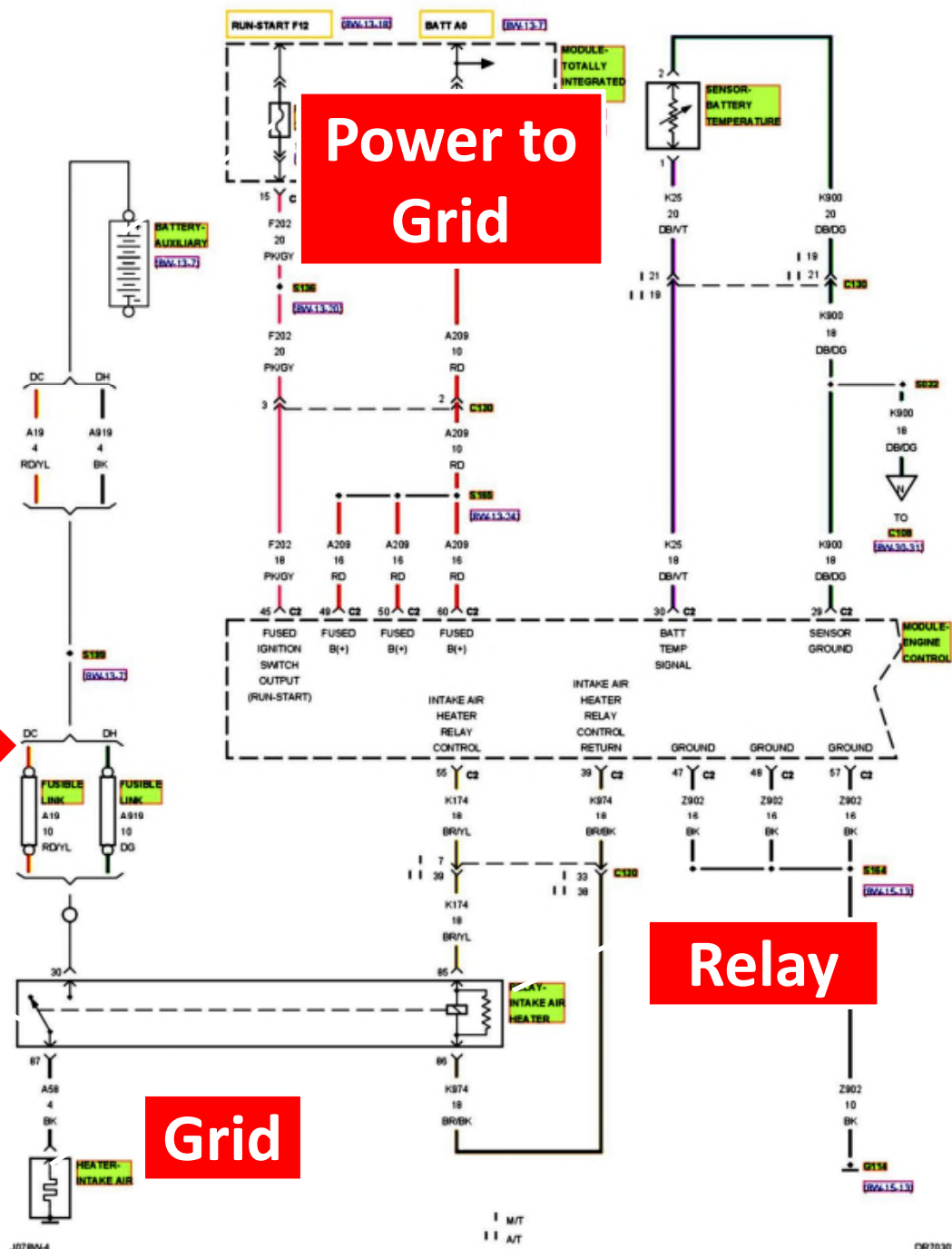
15.09°F to 66°F

10 seconds

66.09°F

0 seconds

6.7L DIESEL



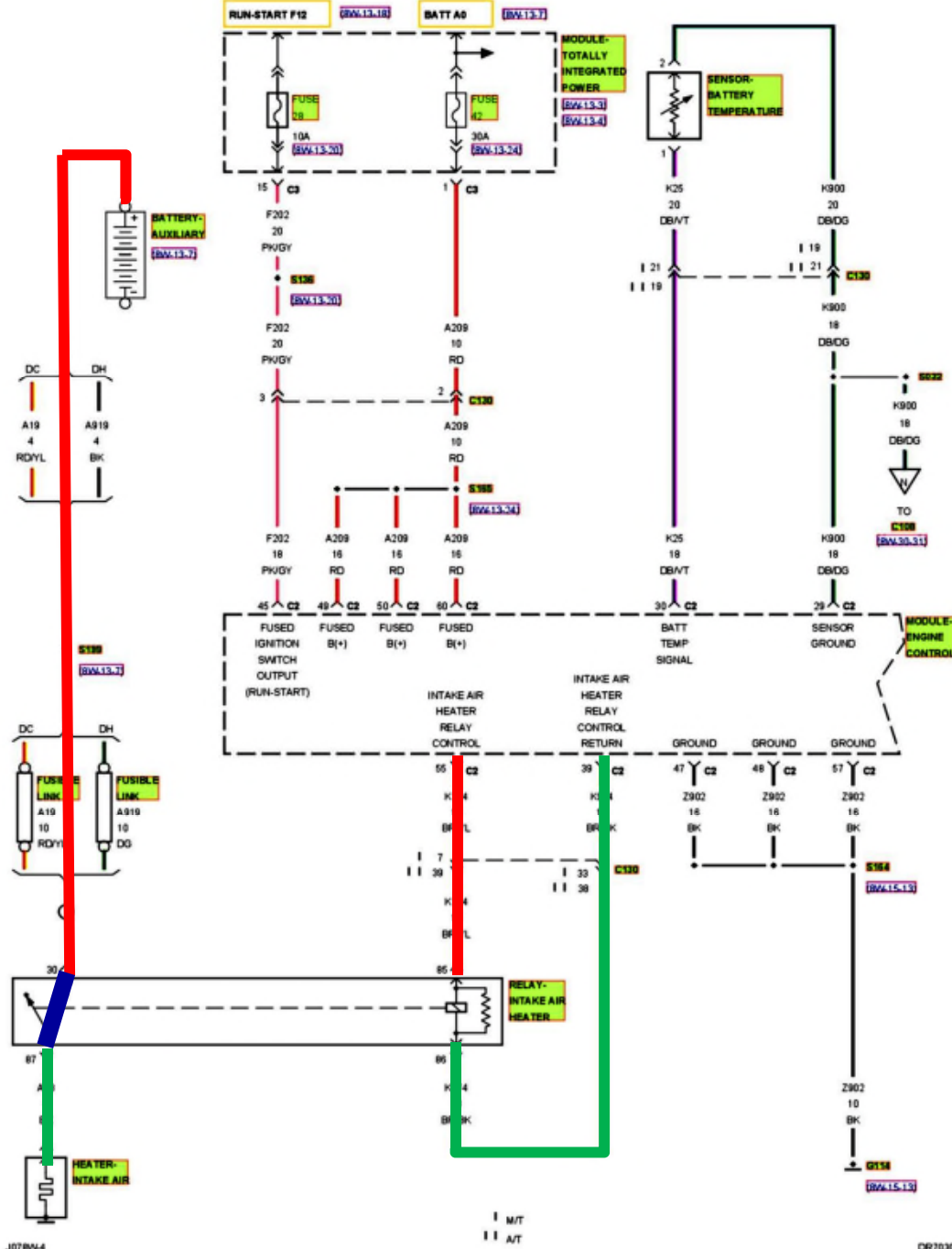
Power to Grid

Relay

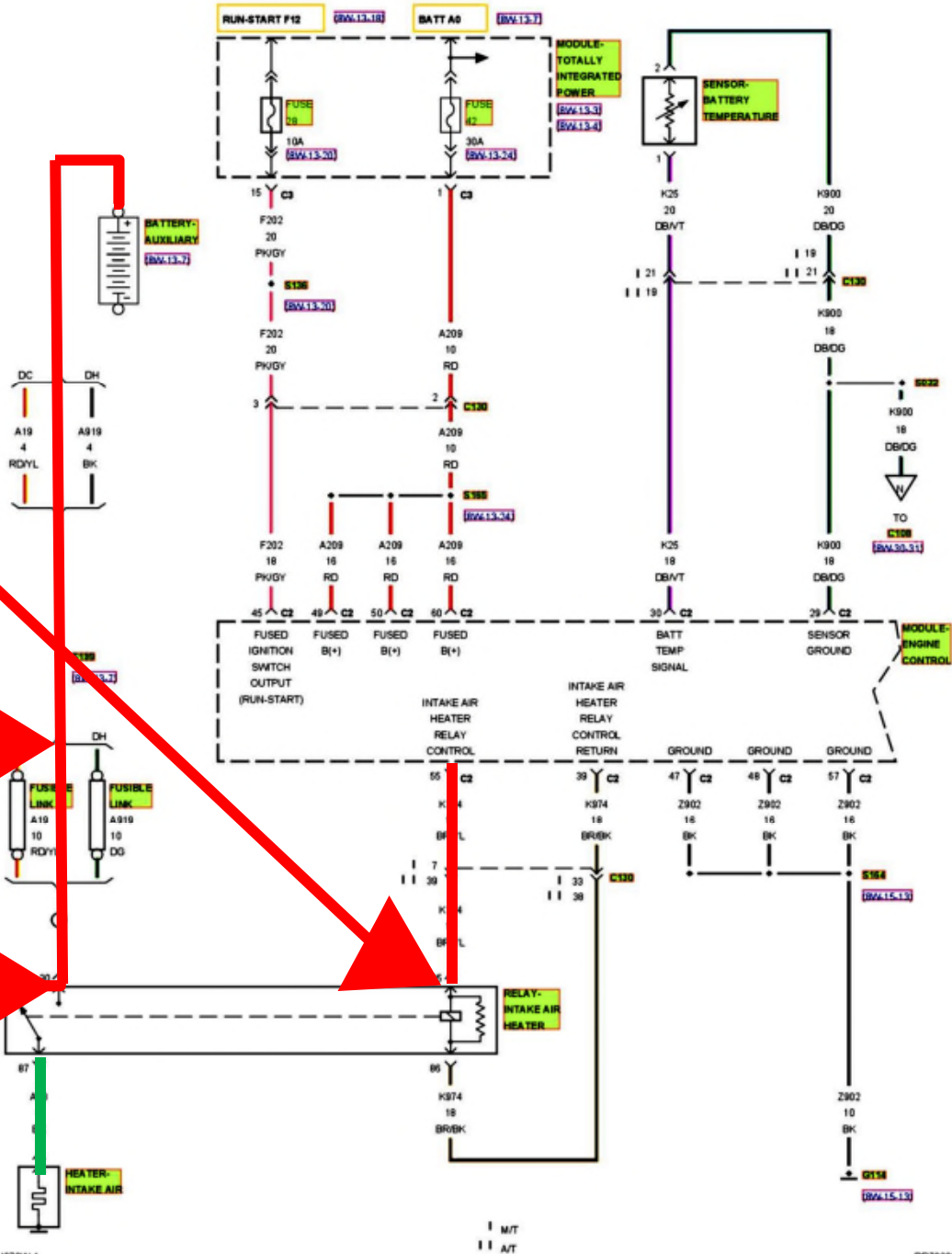
Grid

Grid Control

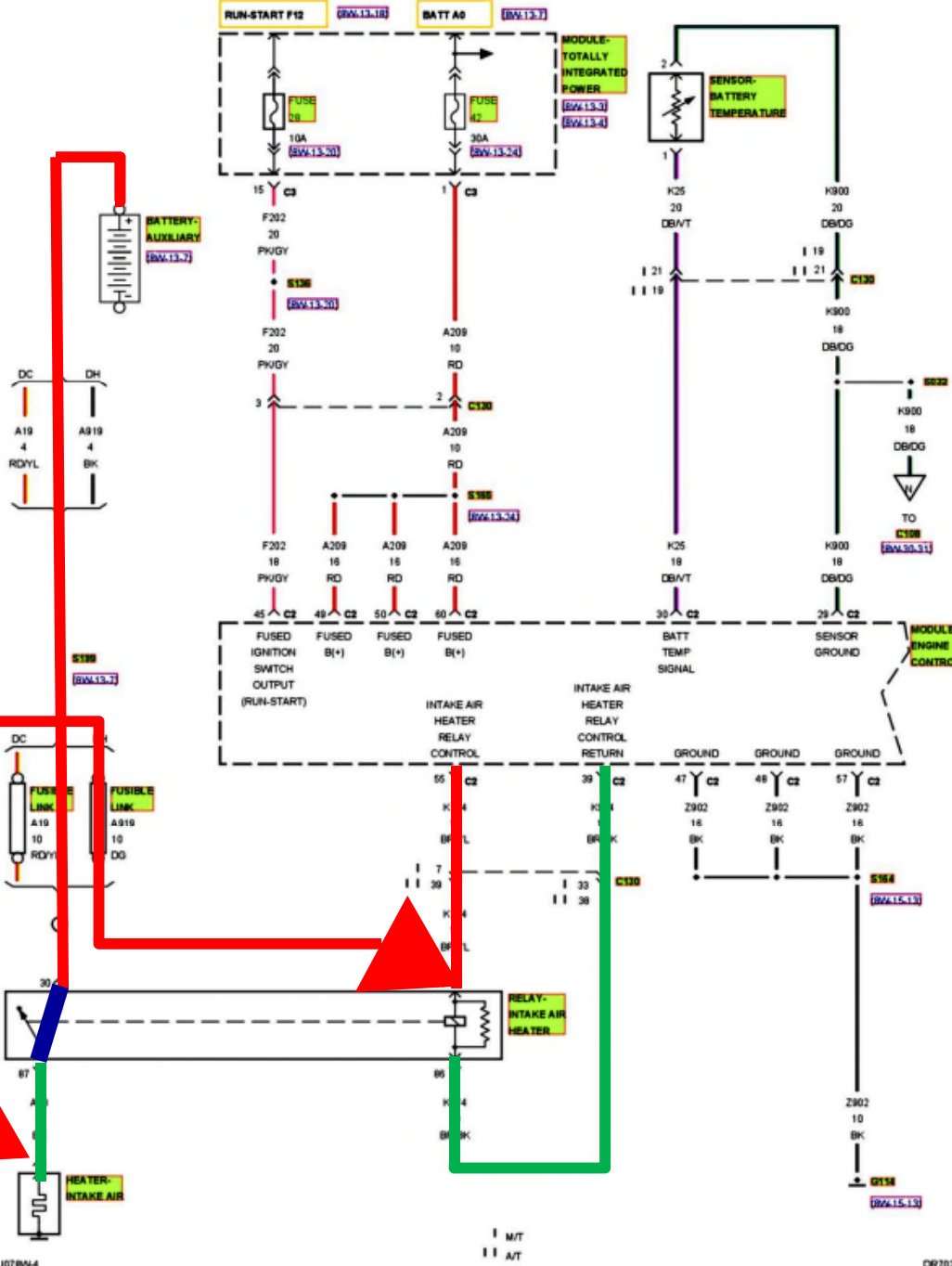
6.7L DIESEL



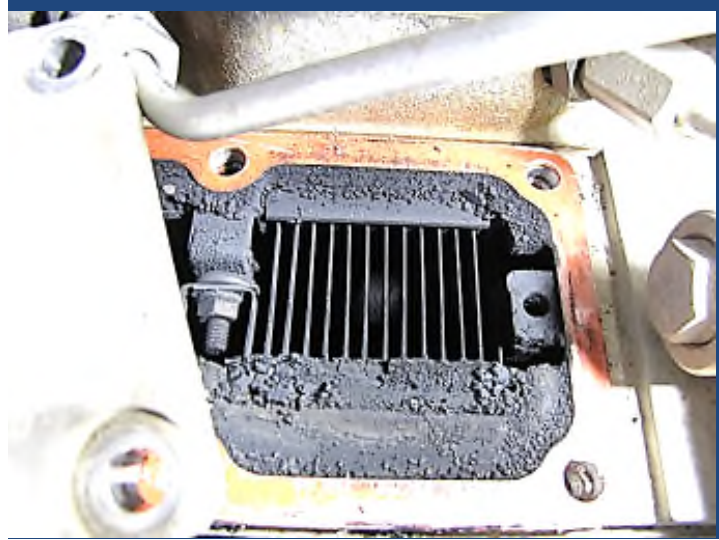
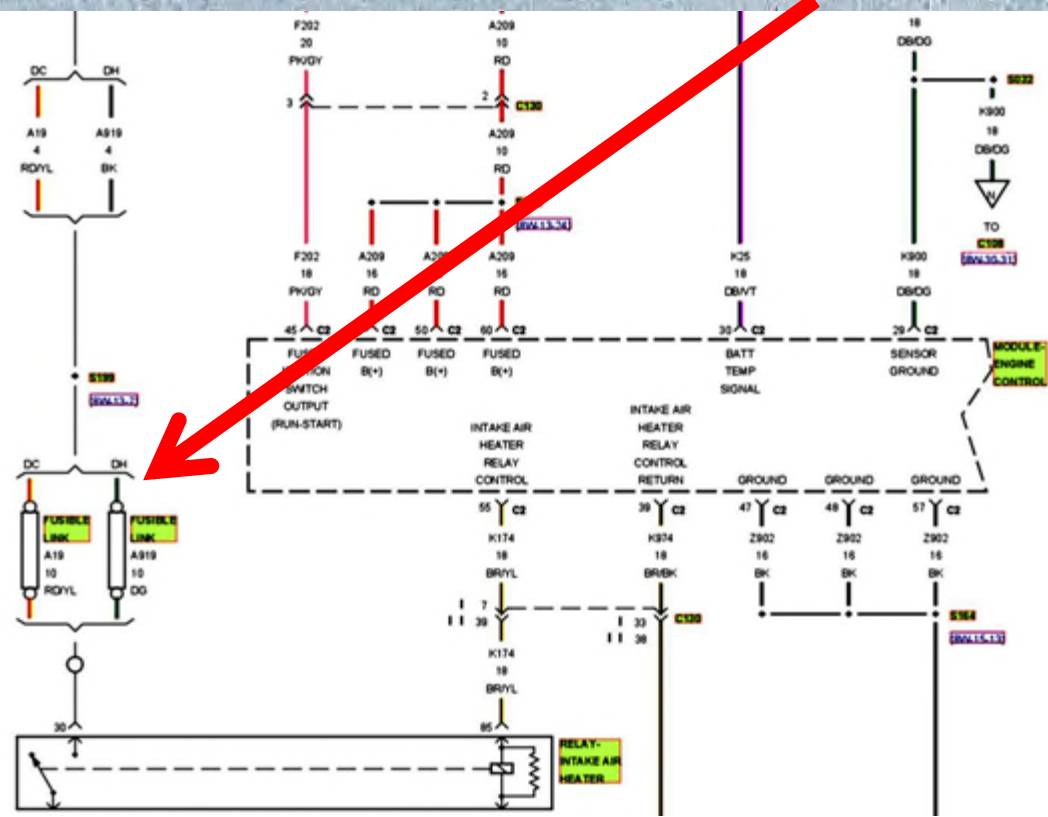
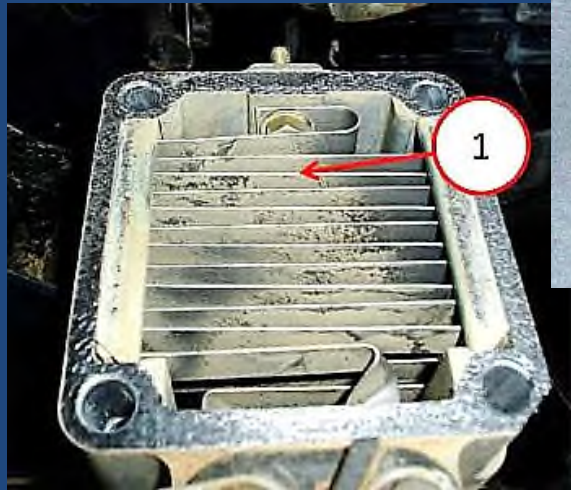
6.7L DIESEL

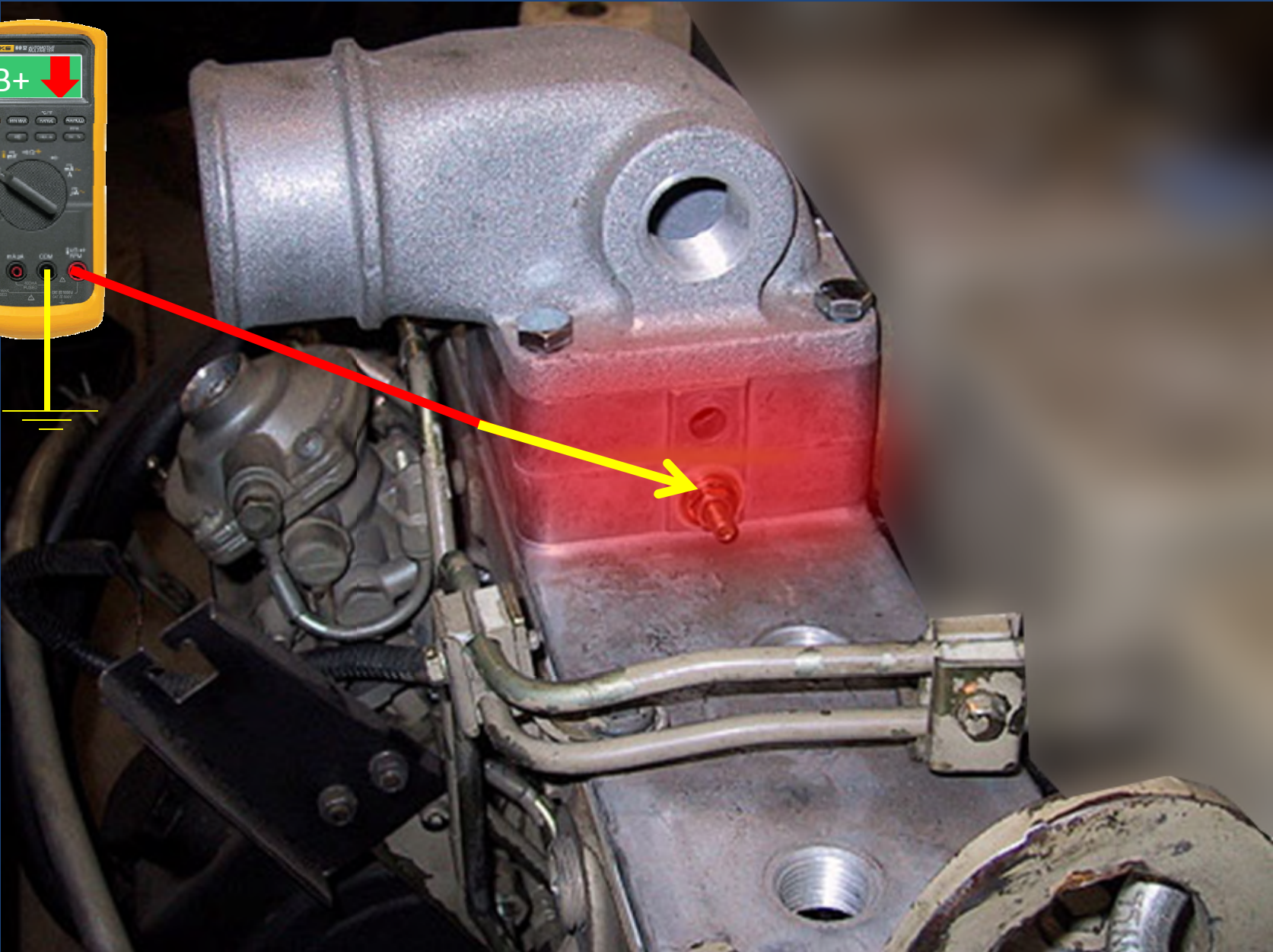


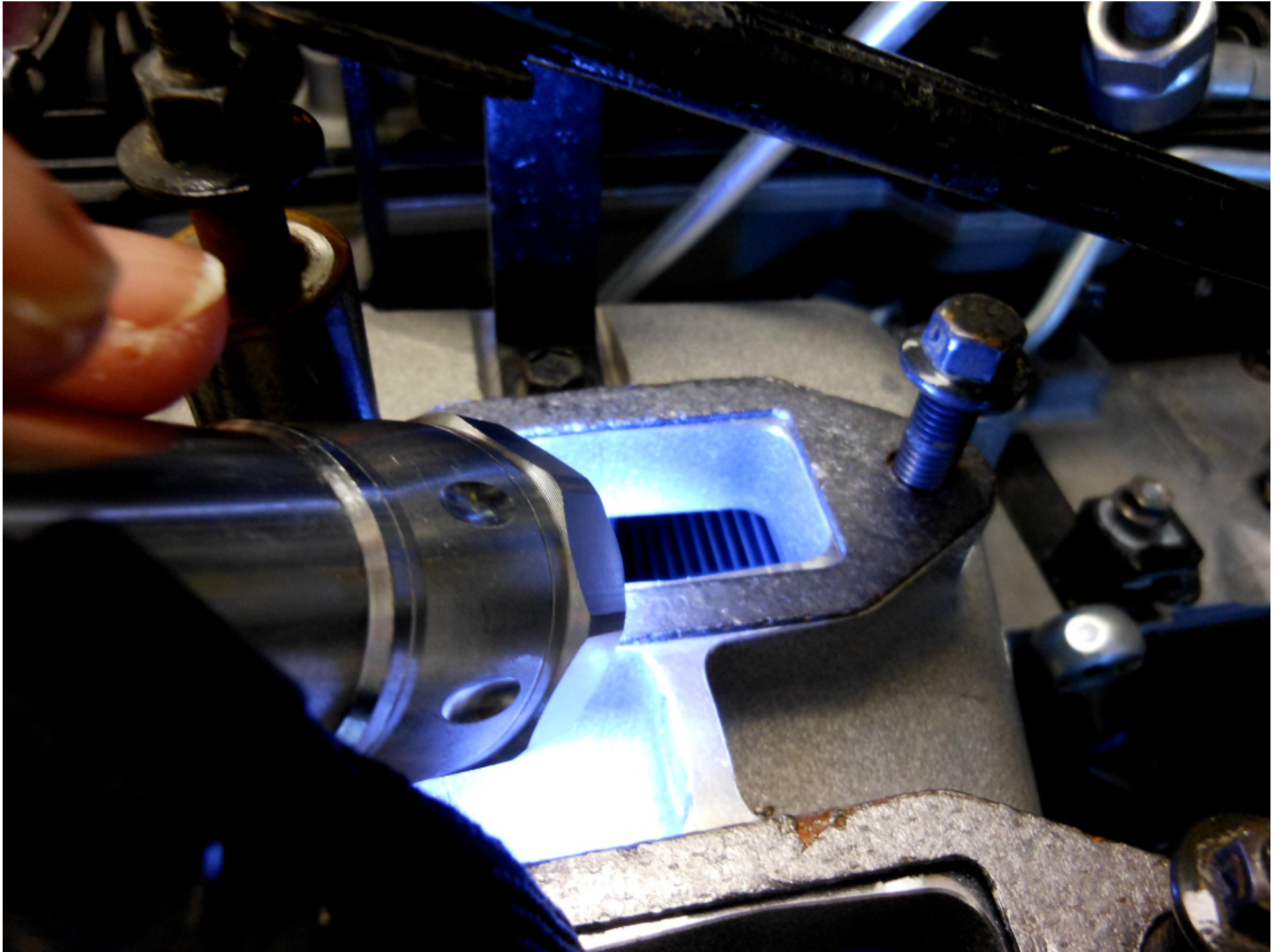
6.7L DIESEL



The fusible links  
come as a pair



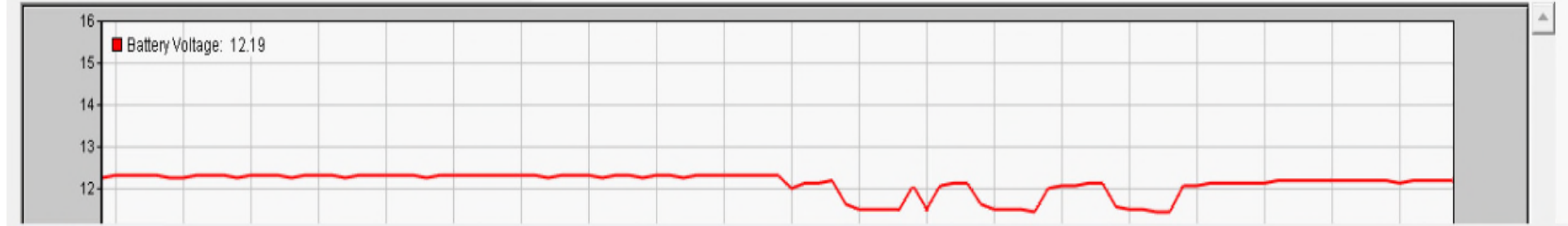






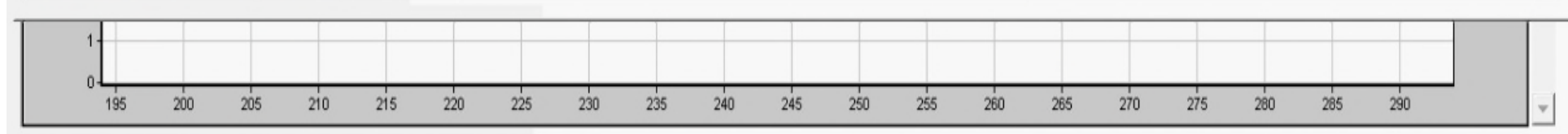
Battery Voltage Off

Off Off



**Actuation** x

Command Name	Comman...	Units	Instructions/Notes
<input type="checkbox"/> Cylinder 4 Cutout	Enable		The number assigned to the cylinder does not correspond to the actual firing orde...
<input type="checkbox"/> Cylinder 5 Cutout	Enable		The number assigned to the cylinder does not correspond to the actual firing orde...
<input type="checkbox"/> Cylinder 6 Cutout	Enable		The number assigned to the cylinder does not correspond to the actual firing orde...
Fuel Control	Actuate		Engine must not be running. Pulse-width modulated fuel pump pressure regulator ...
<input type="checkbox"/> Generator Field Test	Enable		Engine must be running to perform actuation
Intake Heater #1	Actuate		Engine must not be running. Intake manifold heater #1 toggled 'ON/OFF' approxi...
<input checked="" type="checkbox"/> Intake Heater #2	Actuate		Engine must not be running. Intake manifold heater #2 toggled 'ON/OFF' approxi...
<input type="checkbox"/> PWM Radiator Fan	Actuate		This actuation test will only change the radiator fan PWM Duty Cycle and will not p...
SetEngine Speed	900		



# Start engine correctly

Cycling the ignition on and off too frequently can damage the fuel and air intake heaters



# Using The Tester



fig.2

Return Pipe

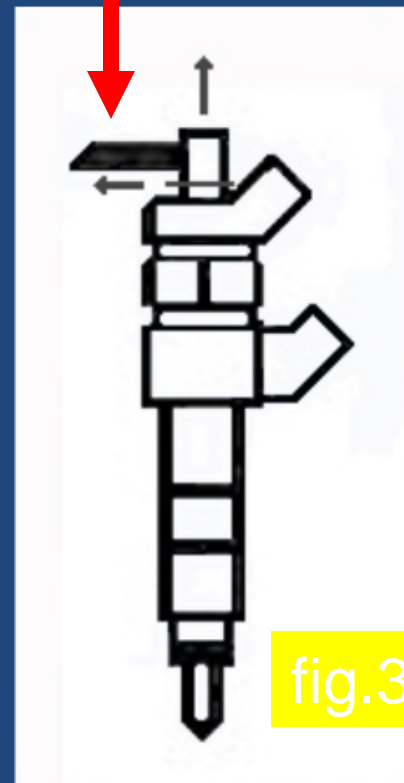


fig.3

# Using The Tester

Measurement Tube or Flexible Pipe

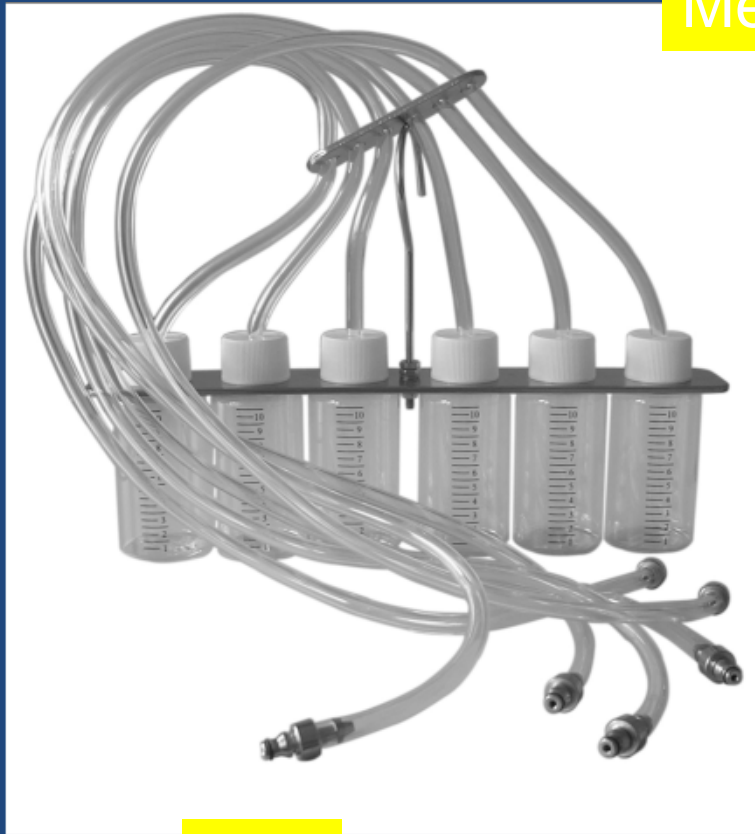


fig.2

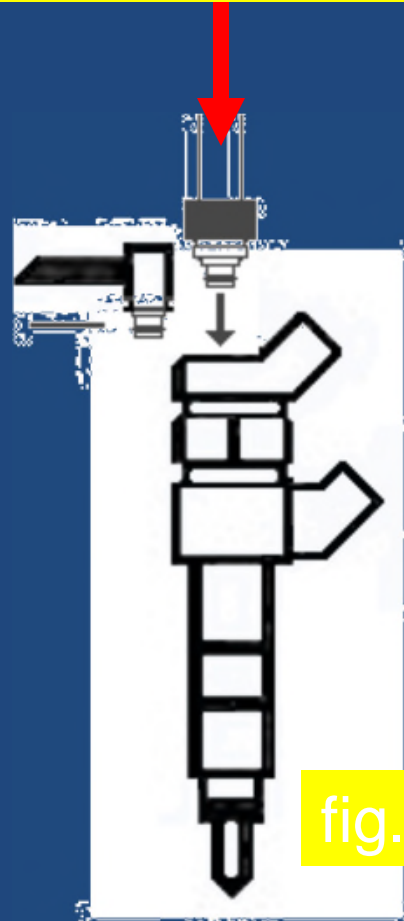


fig.4

# AST6070 Tester



Injector Back Leakage Test Kit offers a larger kit for testing Common Rail Diesel Engines.

This unit will check the following systems:

**BOSCH, DELPHI, DENSO, SIEMENS**

Injectors whose return fuel quantity has increased substantially can have the following affect on the engine:

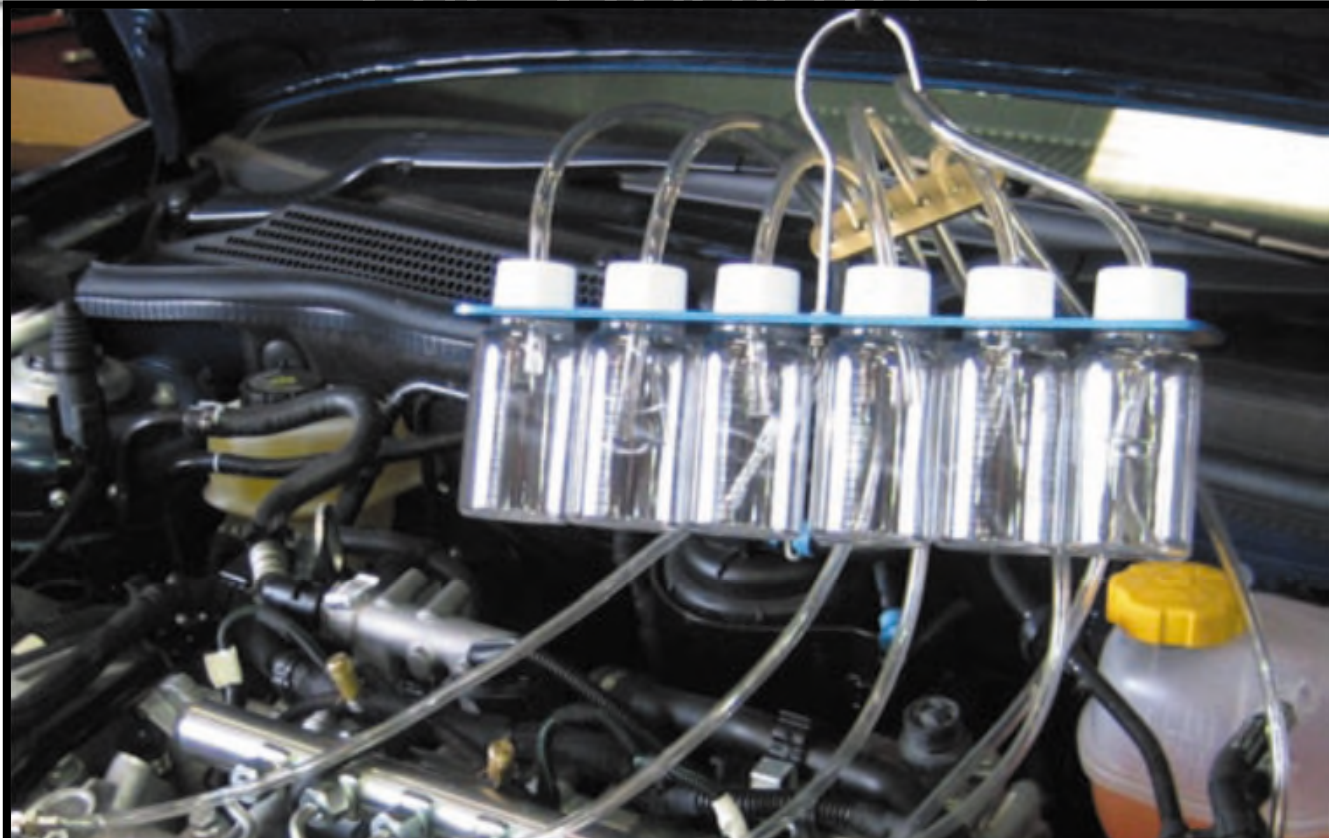
Poor starting performance

Engine no start

Engine cut out

Reduced power across all ranges

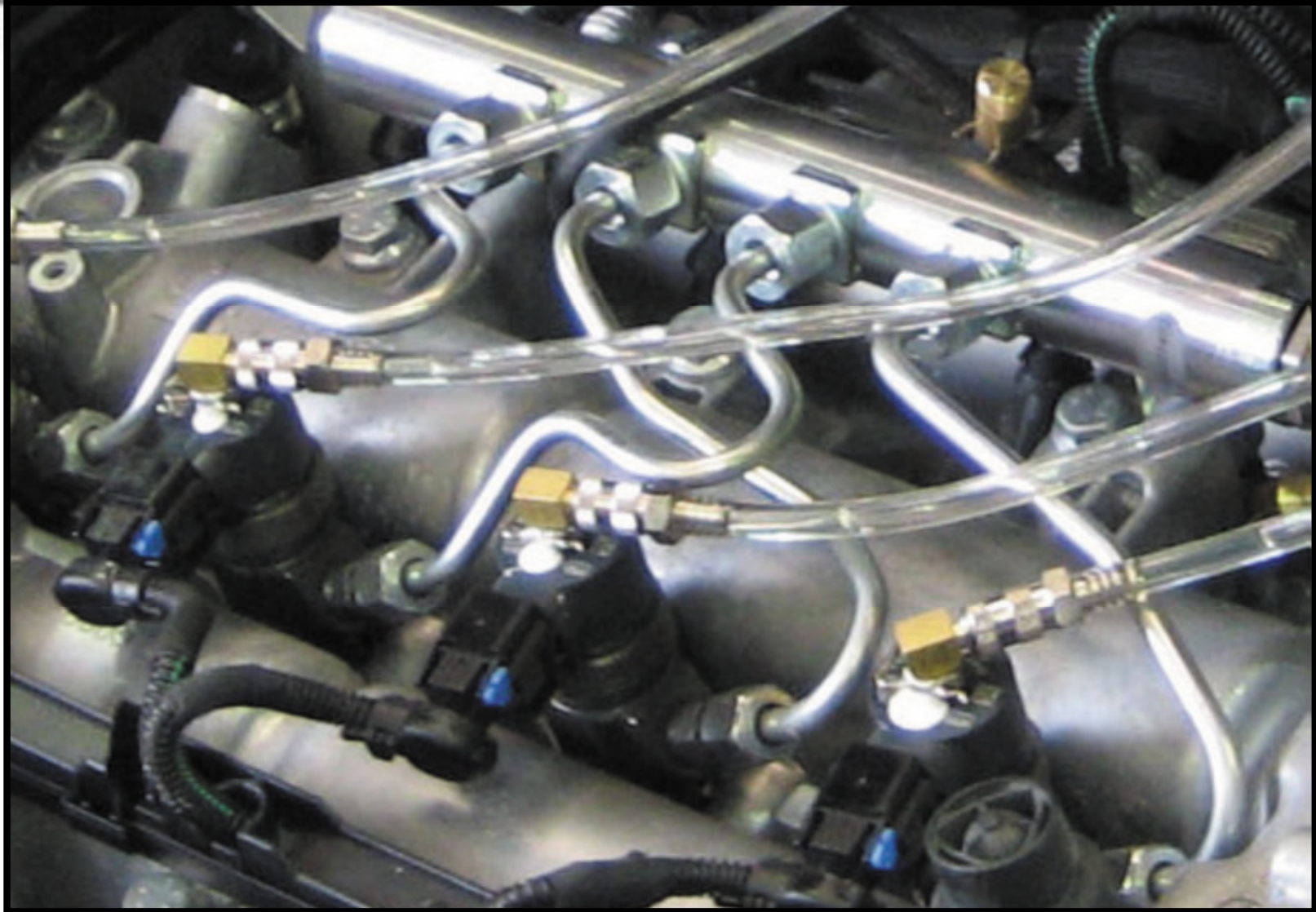
# The Hookup 1



The fuel measurement tool **HANGING RACK ASSEMBLY** can be suspended above the engine compartment. The fuel enters from the **TOP** of the Graduated Measuring Bottles, which should be hung as upright as possible to assist the reading of the fuel volumes.

# Adapter for Bosch





**Slide 560**

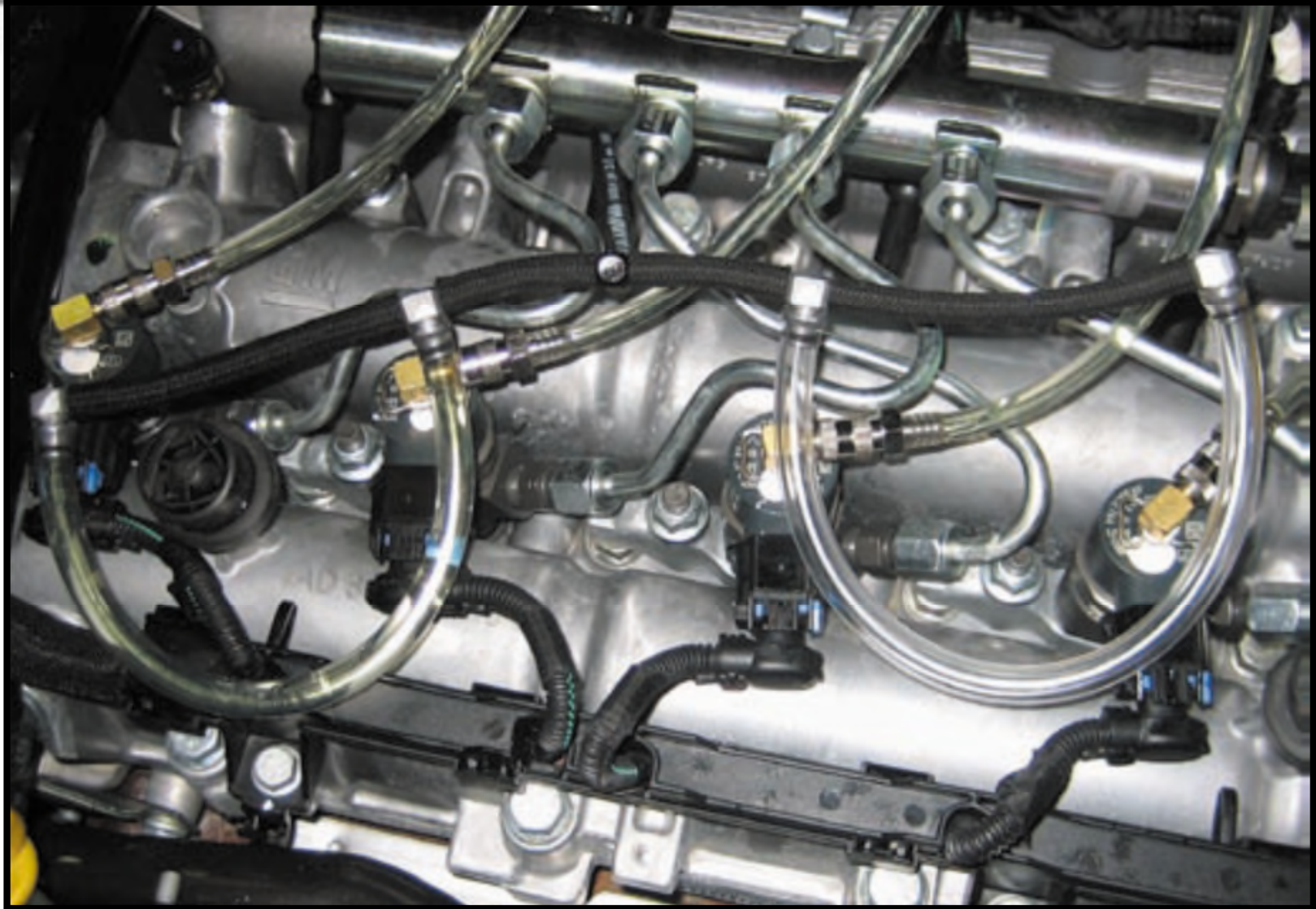
---

**G1**

What is 3? Step 3?

Same question for the next slides

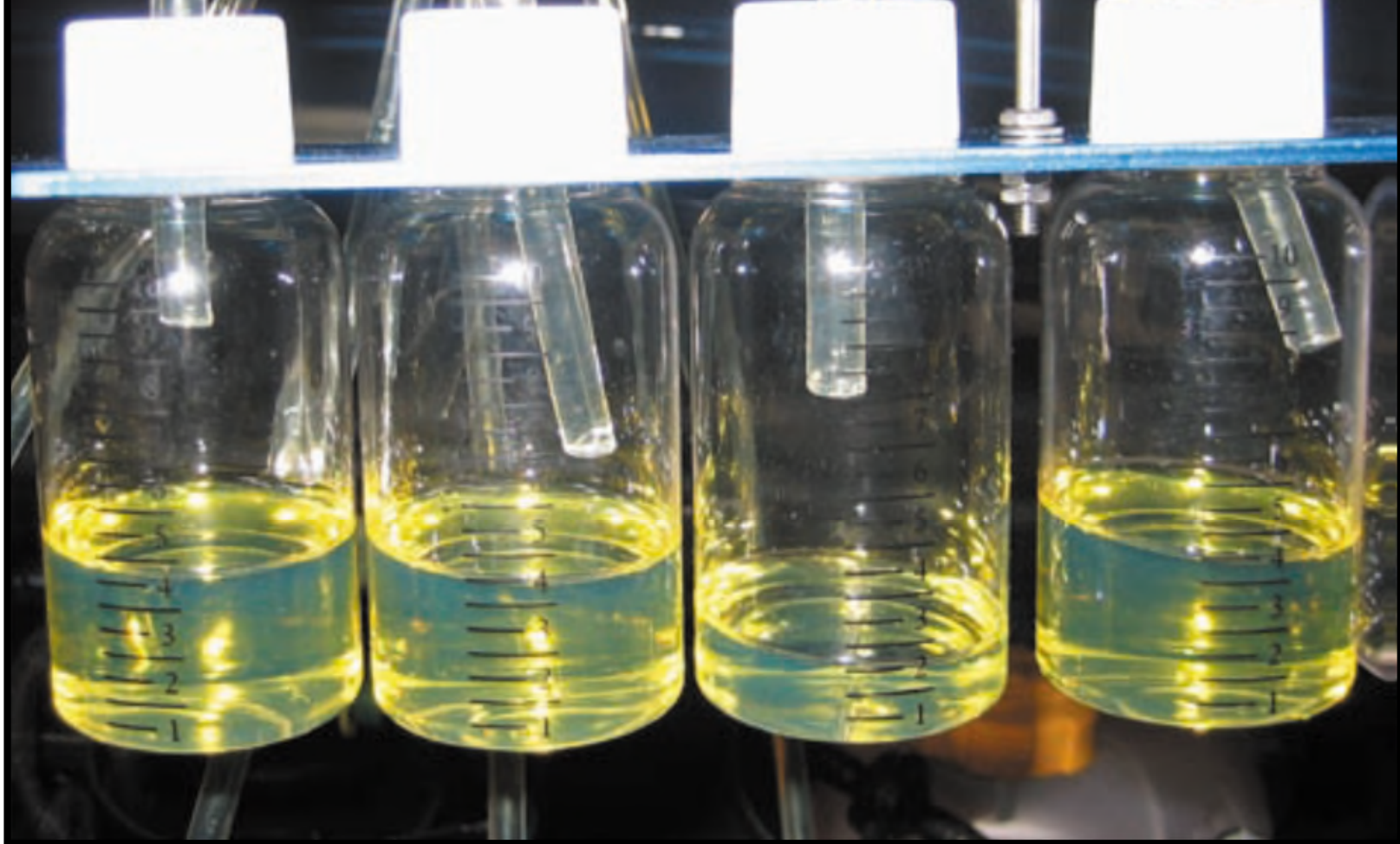
GPI, 3/8/2010

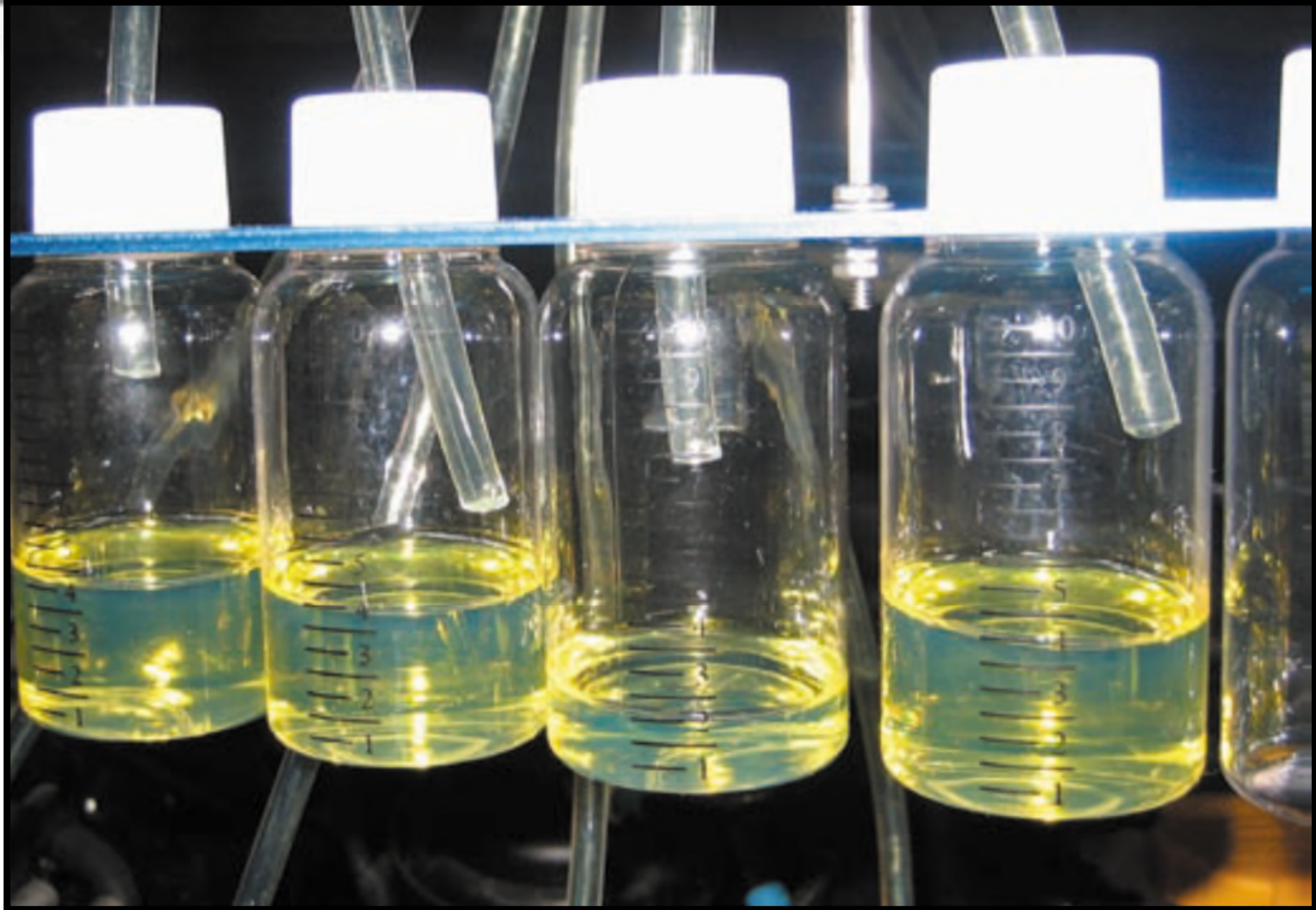






If fuel volume is **UNEVEN** or **VERY RAPID**, then this is an indication of problems with that injector. Good, efficient injectors will show a **STEADY, EVEN** amount of fuel entering each bottle.





# Volume Test



## **Volume Test: (EXAMPLE 1)**

Bottle No. 1 = Measurement 8

Bottle No. 2 = Measurement 8.5

**Bottle No. 3 = Measurement 10**

Bottle No. 4 = Measurement 9

# Injector Flowing Too Much Fuel



**Injector Number 1 is NO Good!**

# Bosch Fuel Measurement Tubes



# Fuel Measurement Tube

