Solar Energy International
Biodiesel Workshop

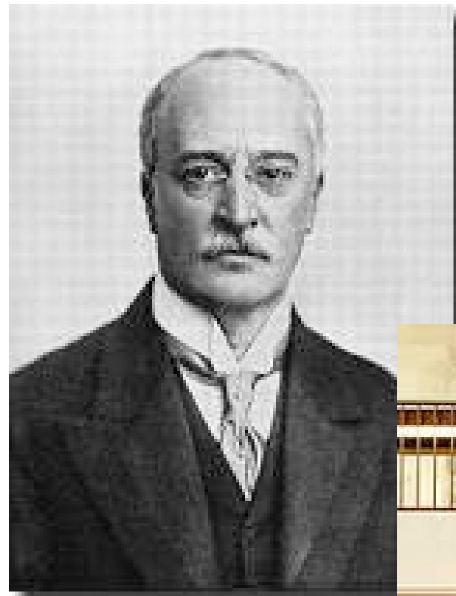
Introduction to the Diesel Engine

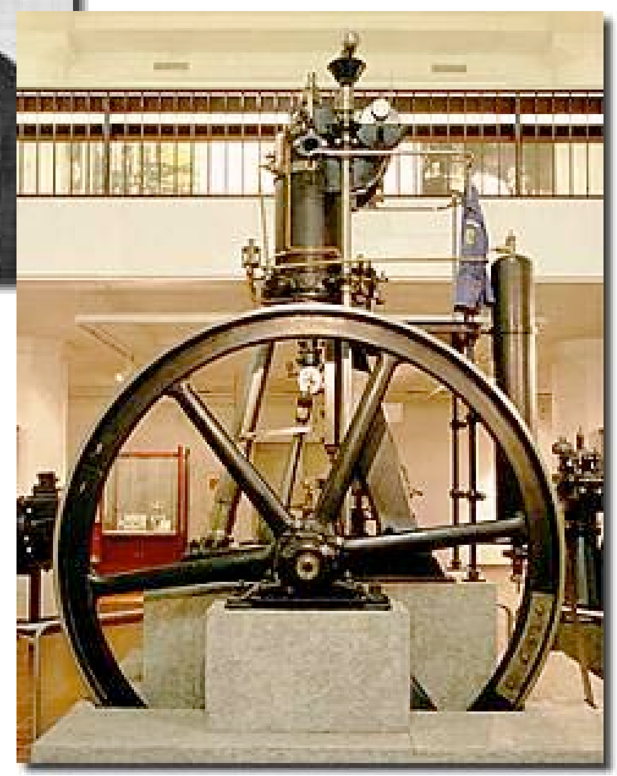
Diesel Vocabulary

- Aftercooling / Intercooling
- Turbocharging
- Cetane Number
- Cloud Point (CP)
- Flash Point
- Cold Filter Plugging Point (CFPP)
- Pour Point
- Compression Ignition (CI)
- Direct Injection (DI)
- In-Direct Injection (IDI)
- In-Line Injection Pump
- Nitrogen Oxides (NO_x)
- Pump-Line-Nozzle Fuel System
- Rotary Injection Pump
- Unit Injector
- Common Rail Injection

What is a Diesel Engine?

- **Rudolf Diesel** developed the idea for the diesel engine and obtained the German patent for it in 1892.
- His goal was to create an engine with **high efficiency**.
- Gasoline engines had been invented in 1876 and, especially at that time, were not very efficient
- Both the gasoline and diesel engine utilize the process of internal combustion for power





What is Internal Combustion?

Four stroke cycle

- **Intake stroke**: intake valve opens while the piston moves down from its highest position in the cylinder to its lowest position, drawing air into the cylinder in the process.
- **Compression stroke:** intake valve closes and the piston moves back up the cylinder.

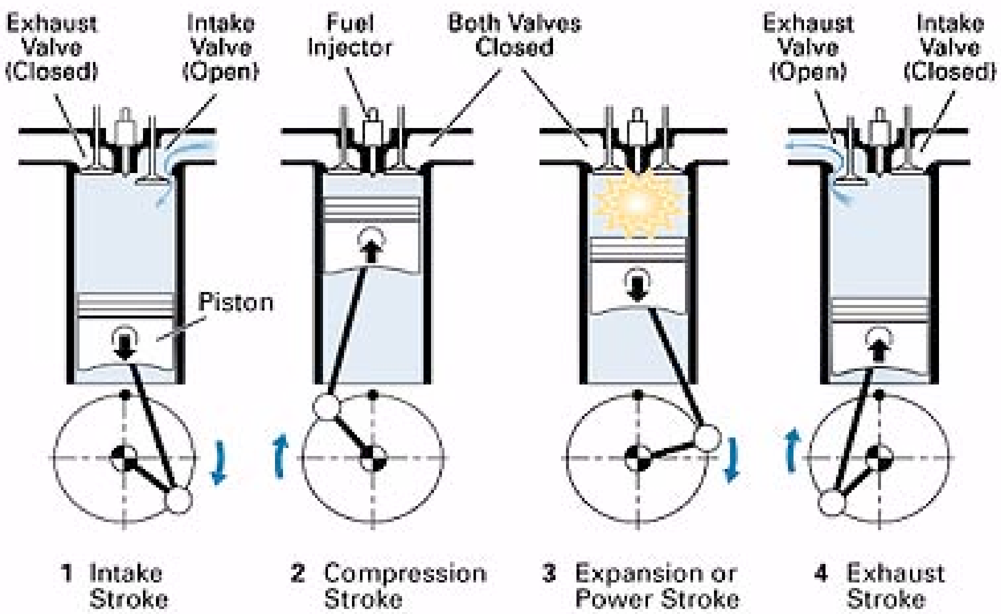
  This compresses the air & therefore heats it to a high temperature, typically in excess of 1000°F (540°C).

  Near the end of the compression stroke, fuel is injected into the cylinder. After a short delay, the fuel ignites spontaneously, a process called *auto ignition*.
- **Combustion stroke:** The hot gases produced by the combustion of the fuel further increase the pressure in the cylinder, forcing the piston down
- **Exhaust stroke:**

  exhaust valve opens when the piston is again near its lowest position, so that as the piston once more moves to its highest position, most of the burned gases are forced out of the cylinder.

Four stroke Cycle

Figure 6-1
Four-Stroke Cycle



Fuel injection begins shortly before the end of the compression stroke.

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Gasoline versus Diesel

- **Spark ignition:** Gasoline engines use spark plugs to ignite fuel/ air mixture
- **Compression ignition**:

  Diesel engines uses the heat of compressed air to ignite the fuel (intakes air, compresses it, then injects fuel)
- **Fuel injection**:

  -Gasoline uses port fuel injection or carburetion;

  -Diesel uses direct fuel injection or pre combustion chambers (indirect injection)
- **Glow plugs**:

  -electrically heated wire that helps heat pre combustion chambers fuel when the engine is cold

  - when a diesel engine is cold, compression may not raise air to temperature needed for fuel ignition

Compression Ratio

- **Compression ratio:**

  This is defined as the ratio of the volume of the cylinder at the beginning of the compression stroke (when the piston is at BDC) to the volume of the cylinder at the end of the compression stroke (when the piston is at TDC).

- The higher the compression ratio, the **higher the air temperature** in the cylinder at the end of the compression stroke.

- Higher compression ratios, to a point, lead to higher thermal efficiencies and **better fuel economies**.

- **Diesel engines need high compression ratios to generate the high temperatures required for fuel auto ignition.**
- In contrast, gasoline engines use lower compression ratios in order to avoid fuel auto ignition, which manifests itself as engine knock or pinging sound.

- Common spark ignition compression ratio: 8:1 to 12:1
- Common compression ignition ration: 14:1 to 25:1

Direct Injection vs. Indirect Injection

Figure 6-2
Direct-Injection (DI) Process

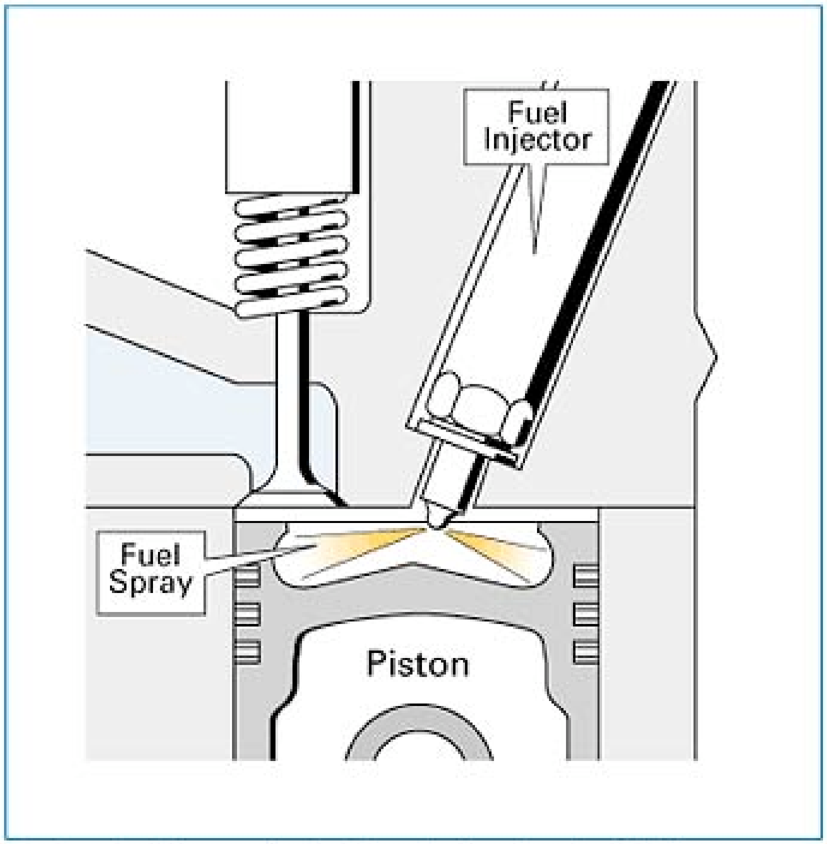

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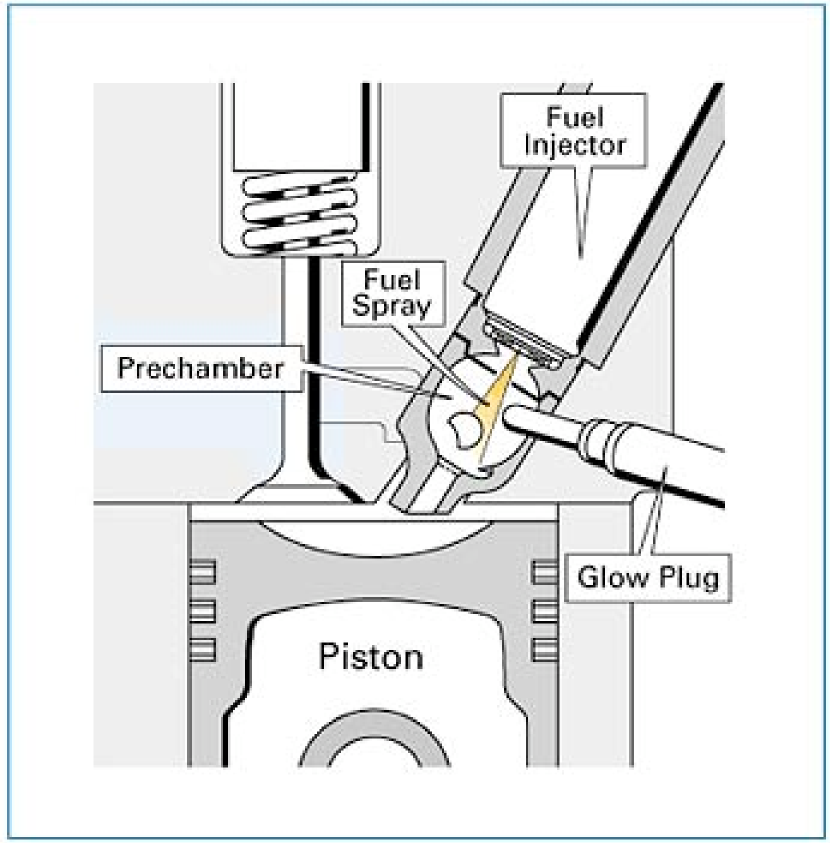
Figure 6-3
Indirect-Injection (IDI) Process



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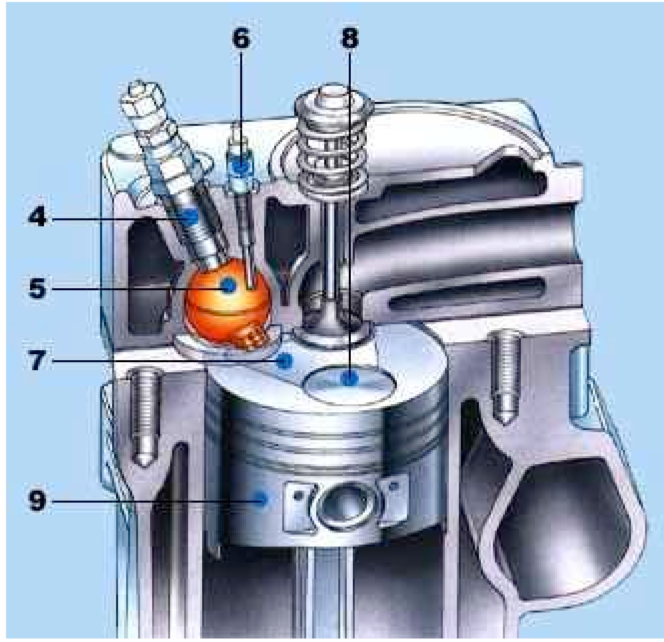
Direct Injection

- **Direct-Injection (DI) or Open Chamber Engine**: In this design, the fuel is injected directly into the cylinder chamber.

Direct injection engines have two design philosophies:
-**High-swirl design**, which have a **deep bowl** in the piston, a **low number of holes** in the injector and moderate injection pressures.
-**Low-swirl or quiescent engines** are characterized by having a **shallow bowl** in the piston, a **large number of holes** in the injector and higher injection pressures.

- Smaller engines tend to be of the high-swirl type, while bigger engines tend to be of the quiescent type
- All newer diesel engines use direct fuel injection
- Much **higher fuel pressure** then indirect fuel injection (example TDI)
- Injection/Injector Timing is critical
- Equipped with in-line pumps, distributor pumps, rail injection systems, or pump injector units



Indirect-Injection Engine (IDI):

In this design, the fuel is injected into a small pre-chamber attached to the main cylinder chamber.

The combination of rapidly swirling air in the prechamber and the jet-like expansion of combustion gases from the prechamber into the cylinder enhances the mixing and combustion of the fuel and air.

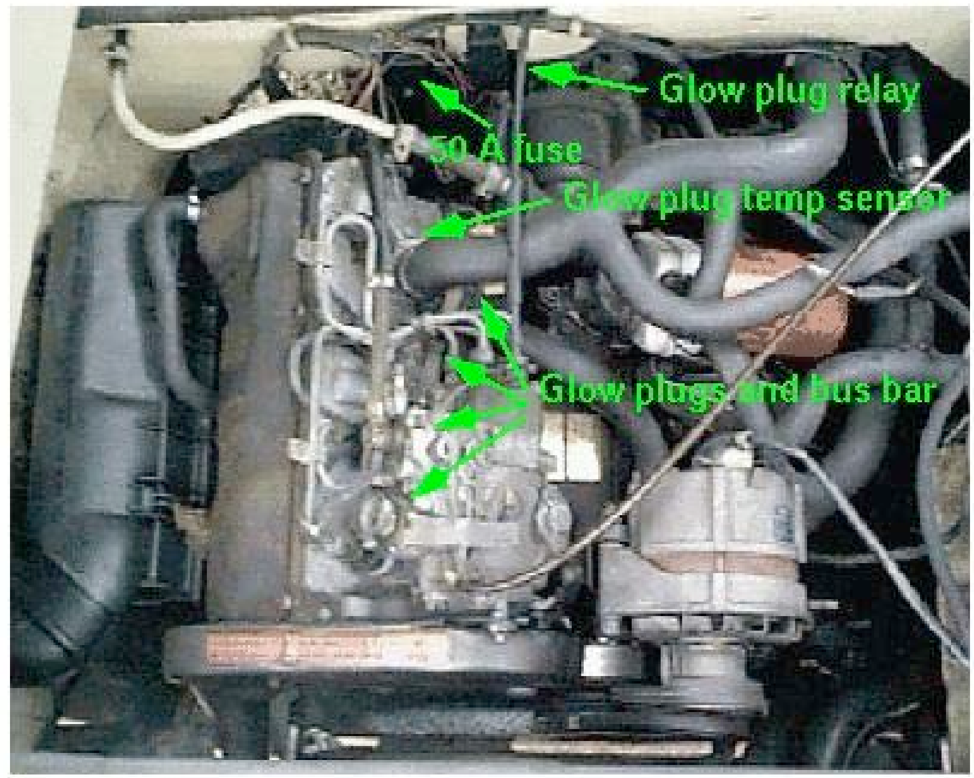
Starting is aided by a high compression ratio (24-27) and a glow plug mounted in the pre-chamber.

This design has the advantage of less noise and faster combustion,

but typically suffers from poorer fuel economy.

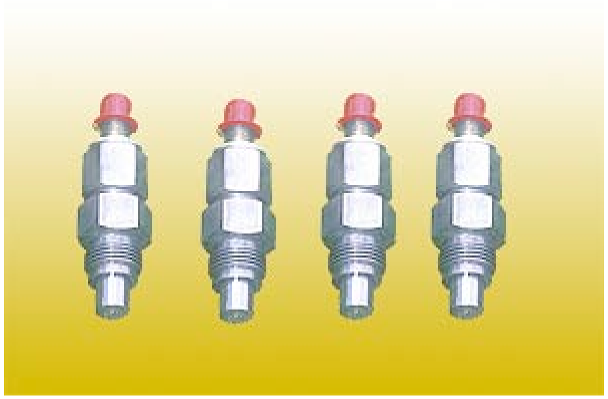
Diesel Ignition System

- Glow plug
- Glow plug relay
- Fusible Link
- Glow Plug Temp Sensor
- Heat Sink



Diesel Fuel System

- Fuel filter
- Fuel pumps : Injection pump and/ or Lift/Transfer pump
- Fuel Injectors



VE...F distributor pump with mechanical governor. Over 20 million such injection pumps have been produced.

Diesel Engine Fuel Requirements

- The Fuel Must Ignite in the Engine
- The Fuel Must Release Energy When It Burns
- The Fuel Must Provide A Large Amount of Energy Per Gallon
- The Fuel Must Not Limit The Operability of the Engine at Low Temperatures
- The Fuel Must Not Contribute to Corrosion
- The Fuel Must Not Contain Sediment that Could Plug Orifices or Cause Wear
- The Fuel Should Not Cause Excessive Pollution
- The Fuel Should Not Deviate from the Design Fuel
- The Fuel Should be Intrinsically Safe

Diesel Properties: Cetane

- One of the most important properties of a diesel fuel is its **readiness to auto-ignite** at the temperatures and pressures present in the cylinder when the fuel is injected.
- The **cetane** number is the standard measure of this property.
- Cetane – (ASTM D613) is tested by adjusting the fuel/air ratio and the compression ratio in a single cylinder, indirect injection diesel engine to produce a standard ignition delay (the period between the start of fuel injection and the start of combustion).
- *ASTM D6751 Biodiesel spec. has a minimum cetane number of 47*
- Cetane improvers are fuel additives that are designed to readily decompose to give precursors to combustion and thus enhance the rate at which auto-ignition occurs.
- Typical compounds used are alkyl nitrates, ether nitrates, dinitrates of polyethylene glycols, and certain peroxides. Due to low cost and ease of handling, alkyl nitrates are the most widely used cetane improvers.

Cetane Number

- Measures the readiness of a fuel to auto-ignite.
- High cetane means the fuel will ignite quickly at the conditions in the engine (does not mean the fuel is highly flammable or explosive).
- Most fuels have cetane numbers between 40 and 60.
- ASTM D 975 requires a minimum cetane number of 40 (so does EPA for on-highway fuel).

Flashpoint

- Measures the temperature at which the vapors above the liquid can be ignited.
- Primarily used to determine whether a liquid is flammable or combustible
- DOT and OSHA say that any liquid with a flash point below 100F is flammable.
- ASTM D 93 is most common test for diesel fuels.
- Can also be used to identify contamination (.i.e. methanol)
- No. 1 = 38°C (100F) No. 2 = 52°C (125F)
- Biodiesel's flashpoint is usually well above 130C

Viscosity

- A measurement of the resistance to flow of a liquid
- Thicker the liquid, higher the viscosity
- Water (lower viscosity) vs. Vegetable Oil (higher viscosity)
- Measured with ASTM D 445.
- #1 diesel fuel = 1.3 – 2.4 mm^2/s
- #2 diesel fuel = 1.9 – 4.1 mm^2/s
- Biodiesel = 4.0 – 6.2 mm^2/s, although most soybean based biodiesel will be between 4.0 and 4.5 mm^2/s.

Cloud Point

- Corresponds to the temperature at which fuel first starts to crystallize (forms a faint cloud in liquid) when cooled.
- No specific value is given in the standard. Requirements vary depending on location.

Producer reports cloud point at point of sale

- Pour Point: temperature at which fuel thickens and will not pour
- Cold Filter Plug Point (CFPP): The temperature at which fuel crystals have agglomerated in sufficient amounts to cause a test filter to plug.
- The CFPP is less conservative than the cloud point, and is considered by some to be a better indication of low temperature operability.

Fuel Stability

- Fuel will undergo chemical degradation if in contact with oxygen for long periods or at high temperatures.
- There is no method specified in ASTM D 975 for diesel fuels.
- ASTM D 2274 is most commonly referenced.
- FIE/OEM have a strong interest in stability

Lubricity

- The ability of a fluid to minimize friction between, and damage to, surfaces in relative motion under loaded conditions.
- Diesel fuel injection equipment relies on the lubricating properties of the fuel.
- Biodiesel has shown higher lubricity properties than petroleum diesel
- Lubricity is tested by 2 methods:

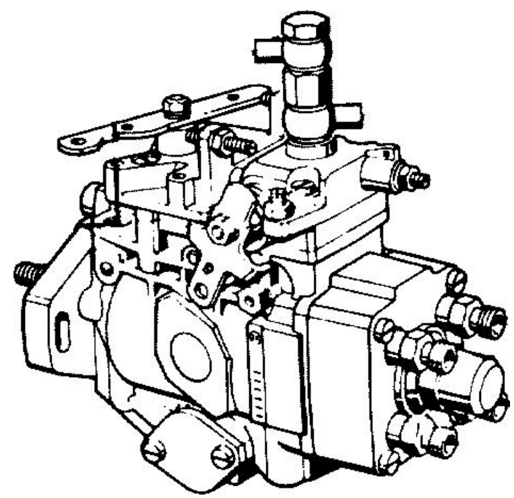
  -SLBOLCE (scuffing load ball on cylinder lubricity evaluator)
  - ASTM D 6078-99

  -HFRR (high frequency reciprocating rig)
  - ASTM D 6079-99

New research shows FFA or "contaminants give better lubricity than neat methyl esters" -Knothe

Injection Pumps

- A rotary type fuel injection pump is "round" in shape with the fuel fittings arranged around the pump.
- An in-line type fuel injection pump is more "rectangular" or square in shape with the fuel fittings arranged in a straight line.



In-Line Injection Pumps

- An injection pump with a separate cylinder and plunger for each engine cylinder.
- Each plunger is rotated by a rack to determine metering via ports in the body of the pump and helical cuts on the pump plungers.
- The plungers are driven off a camshaft, which usually incorporates a centrifugal or electronically controlled timing advance mechanism.

Rotary Injection Pump

A lower-cost injection pump used with pump-line-nozzle systems.

The pump has a central plunger system (usually consisting of two opposing plungers) that provides fuel to every cylinder during the required injection period.

A plate located near the top of the pump rotates, opening an appropriate orifice at the right time for distribution to each cylinder's injection nozzle through a separate line.

It is usually used with automotive or agricultural engines that have lower performance and durability requirements than the heavy-duty truck diesels.

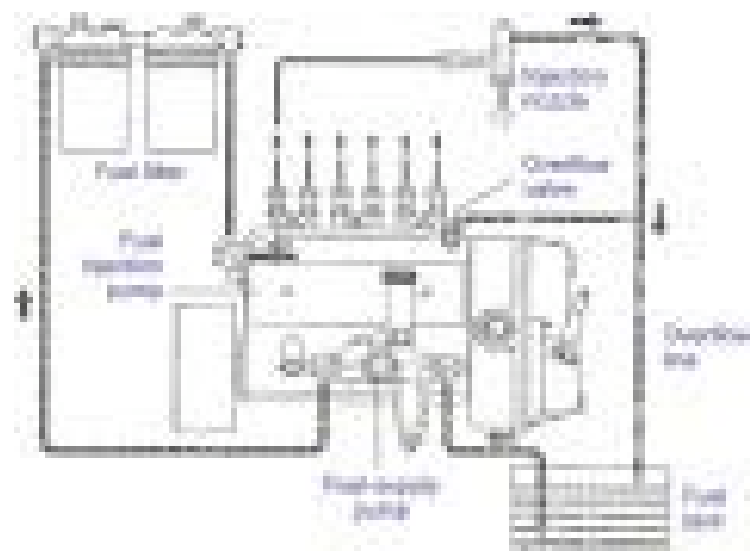
Pump-Line-Nozzle Fuel System

A fuel system using a single injection pump driven off the geartrain on the front of the engine that also drives the camshaft.

The central injection pump feeds a separate injection nozzle located in the cylinder head above each cylinder.

Lines which must be of exactly equal length link each pump plunger with the associated nozzle.

Each nozzle incorporates a needle valve and the orifices which actually handle atomization.



Common Rail Injection

A diesel fuel injection system employing a common pressure accumulator, called the **rail**, which is mounted along the engine block.

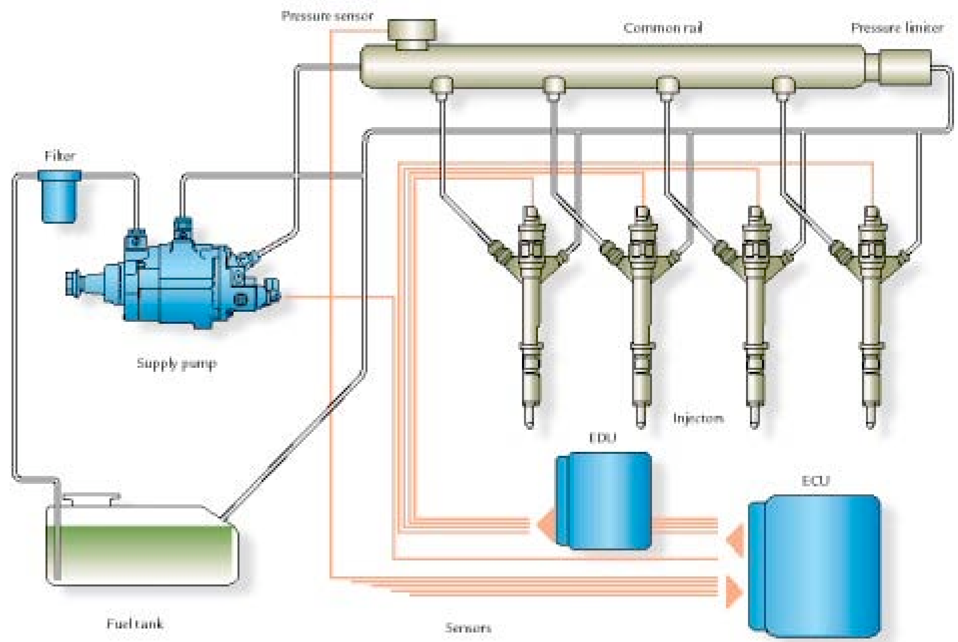
The rail is fed by a **high pressure fuel pump**.
The injectors, which are fed from the common rail, are activated by **solenoid valves**.
The solenoid valves and the fuel pump are electronically controlled.

In the common rail injection system the injection pressure is independent from engine speed and load.
Therefore, the injection parameters can be freely controlled.

Usually a pilot injection is introduced, which allows for **reductions in engine noise and NOx emissions.**

This system operates at 27,500 psi (1900 BAR). The injectors use a needle-and-seat-type valve to control fuel flow, and fuel pressure is fed to both the top and bottom of the needle valve. By bleeding some of the pressure off the top, the pressure on the bottom will push the needle off its seat and fuel will flow through the nozzle holes.

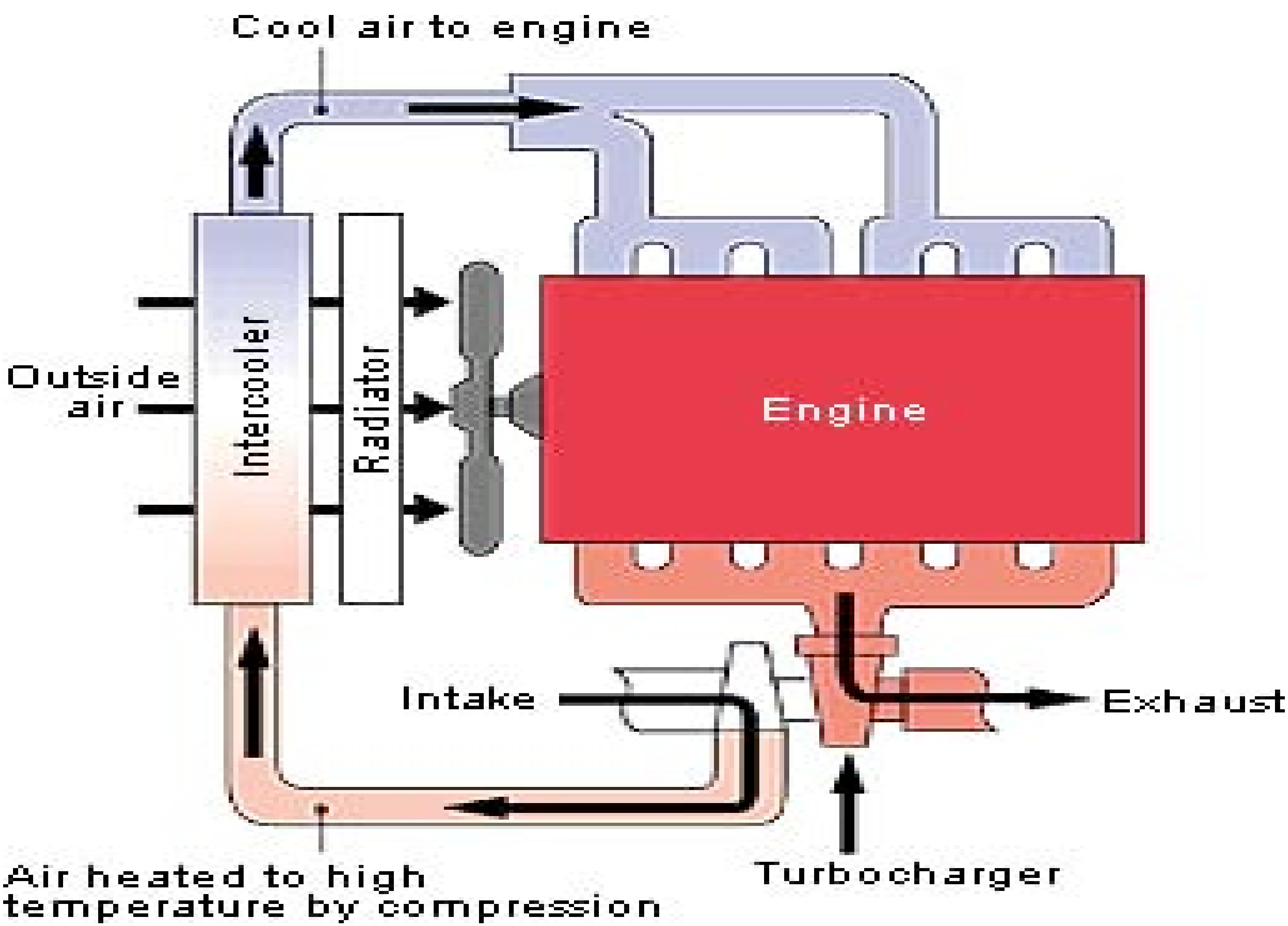
Common Rail Fuel Injection Schematic



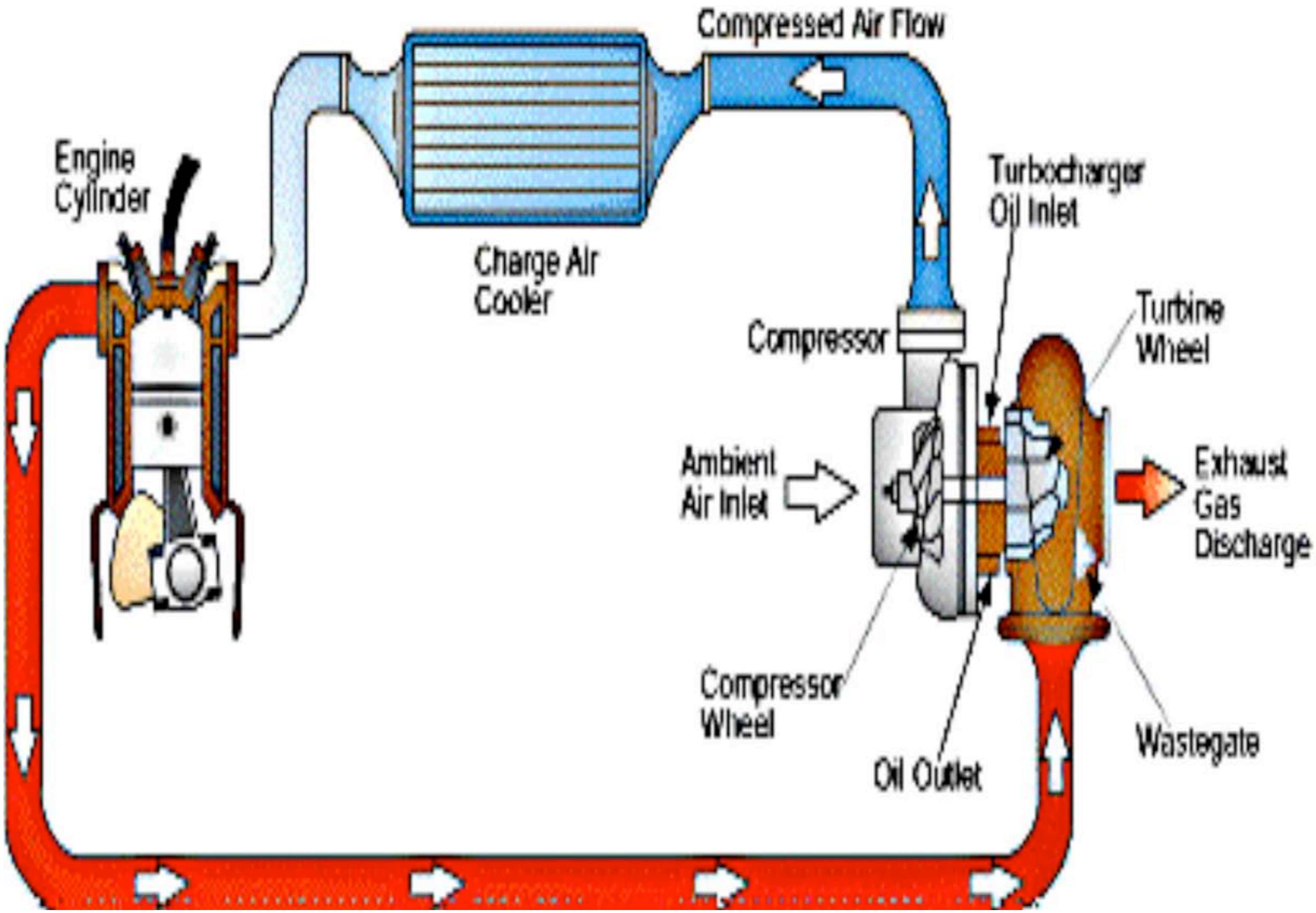
Common Rail Injection Vehicles

Turbochargers & Superchargers

- Increase or compress more air to be delivered to each engine cylinder
- Superchargers: mechanically driven from engine crankshaft
- Turbochargers: driven by waste exhaust gases
- increased air mass improves the engine's thermal efficiency (fuel economy) and emissions performance, depending on other factors.
- Turbochargers must operate at high temperatures and high rotational speeds.
- Variable Geometry Turbochargers



Cool air to engine
Outside air
Intercooler
Radiator
Engine
Intake
Exhaust
Air heated to high temperature by compression
Turbocharger


Compressed Air Flow
Engine
Cylinder
Charge Air
Cooler
Turbocharger
Oil Inlet
Turbine
Wheel
Compressor
Ambient
Air Inlet
Exhaust
Gas
Discharge
Compressor
Wheel
Wastegate
Oil Outlet

Intercoolers

- **Intercooler:** network of thin metal fins that cool air coming out of the turbocharger
- Both turbocharging & supercharging compress the intake air, they increase its temperature & its density.
- This temperature increase is counterproductive, because air density is inversely proportional to temperature; **the hotter the air, the less dense.**
- An additional increase in density can be achieved by cooling the hot compressed air before it enters the engine.
- *Intercooling*, passes the hot compressed air coming from the compressor over a heat exchanger (such as a radiator) to lower its temperature
- Inter-cooling can provide significant gains in **power output.** It also can **decrease NOx emissions**
- Dense air-->more oxygen--->more complete combustion--->more efficient engine

Besides Transportation, where else do we use diesel engines?

Power generation, Agricultural, marine…

Biodiesel: Energy, Power, & Torque

Conservative Studies:

Biodiesel has 12% less energy than diesel

- 7% average increase in combustion efficiency in biodiesel
- 5% average decrease in power, torque, & fuel efficiency
- Performance: Less energy can reduce engine power

"Biodiesel blends of 20% or less should not change the engine performance in a noticeable way"

- 2004 Biodiesel Handling and Use Guidelines.

Engine Warranties & Biodiesel

- Engine manufacturers & Fuel Injection Equip. Manufacturers warranty their products against defects of materials & workmanship, not fuel.
- If concerned on warranty, buy biodiesel from commercial manufacturer who will back an engine warranty
- Magnuson-Moss Act
- ASTM D-6751 fuel specifications
- Fuel quality and stability issues are what prevent approval of blending levels above 5% for most manufacturers
- See www.biodiesel.org for updated warranty info

- EMA Up to B5, must meet ASTM D6751.
- Caterpillar Many engines approved for B100, others limited to B5. Must meet ASTM D6751.
- Cummins All engines up to B5, must meet ASTM D6751.
- Detroit Diesel Approve up to B20. Must meet DDC specific diesel fuel specification.
- Ford B5, must meet both ASTM D6751 and EN 14214.
- General Motors All engines approved for up to B5, must meet ASTM D6751.
- International Approve up to B20, must meet ASTM D6751.
- John Deere All engines approved for B5, must meet ASTM D6751.

Fuel Injection Equipment:

- Bosch Up to 5% biodiesel, must meet EN 14214.
- Delphi Up to 5% biodiesel, must meet ASTM D6751.
- Stanadyne Up to 20% biodiesel, must meet ASTM D6751.

http://www.biodiesel.org/resources/fuelfactsheets/standards_and_warranties.shtm

Links

Some slides/material came from University of Iowa Biodiesel Production Course
At www.me.iastate.edu/biodiesel

- www.dieselveg.com
- http://www.journeytoforever.org
- http://www.dieselnet.com
- http://www.dieselpage.com
- http://www.howstuffworks.com/diesel.htm
- http://www.vw.com/engine
- www.biodiesel.org
- www.tdiclub.com
- http://www.difflock.com/diesel/troubleshooting.shtml