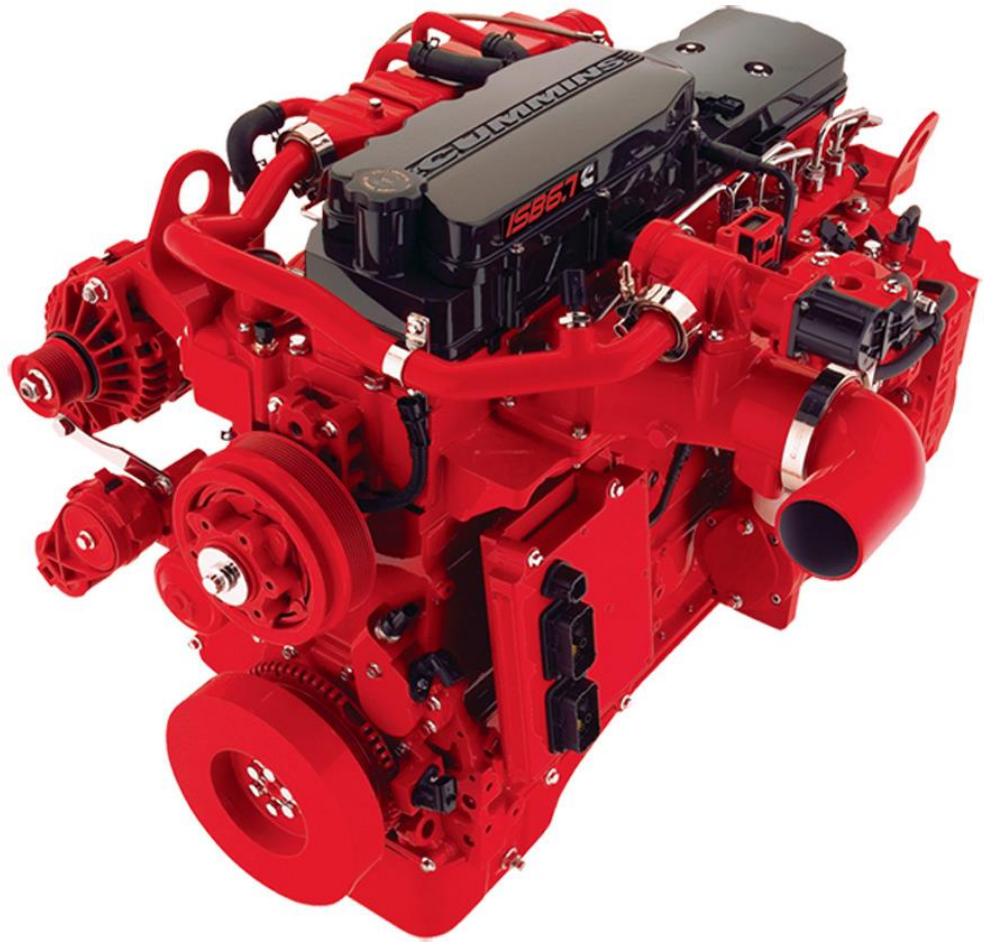
Basic Diesel Engine Operation



Basic Diesel Operation

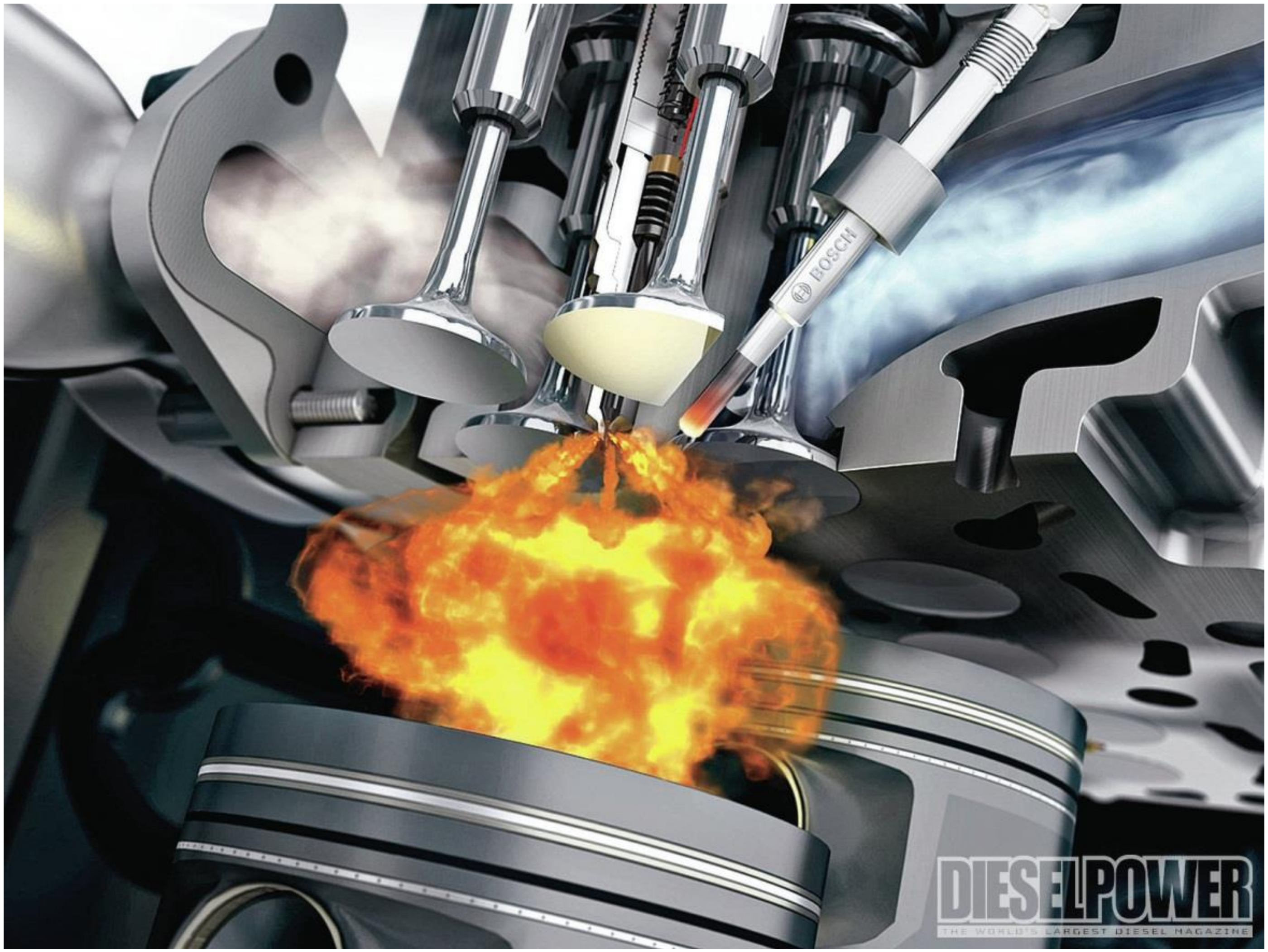
- The diesel engine will take in more air than a comparable size gasoline engine:
  - Intake manifold vacuum is very low due to minimal inlet restriction (low pressure differential)
  - The intake vacuum may increase significantly if there is a intake restriction
  - Pumping more air allows the engine to run leaner and cooler under all conditions
  - Diesel adjust only fuel injection to maintain engine speed under varying load conditions

Basic Diesel Operation

- Gasoline engines limit power by controlling the volume of fuel ***AND*** air:
  - Throttle plates reduce overall engine efficiency
  - Pumping losses due to inlet restriction
  - Air/Fuel ratios adjusted in the intake manifold

- The unregulated Diesel engine air intake system improves:
  - Volumetric efficiency
  - Thermal efficiency
  - Mechanical efficiency
  - No throttle plate restriction

Diesel Engine Combustion



Diesel Engine Combustion

- Air/Fuel Ratios
  - Power and speed is regulated by controlling only the amount of fuel injected
  - Diesels operate on a wide range of air/fuel ratios (unlike gasoline engines)
  - **More Fuel = More Power and RPM**

Air + Fuel + Ignition =

Power

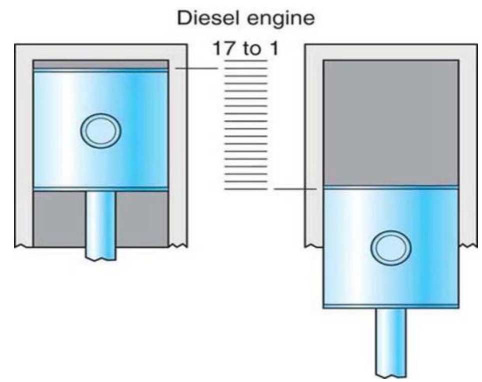
Diesel Combustion

- Diesel engines produce more power and better fuel economy because:
  - Diesel fuel contains more heat energy than does gasoline
  - Diesel fuel releases more energy but at a slower rate
  - Peak output is produced at lower speed and within a smaller RPM range
  - Higher compression and combustion* pressures improve engine output efficiency

*Combustion – Rapid oxidation of fuel producing heat

High Compression Ratios

- Diesel engines need to have very high compression ratios:
  - The compression ratio of a typical turbocharged truck engine is approx. 17:1



- Referred to as compression ignition engine
- High compression of air creates the heat needed for fuel ignition
- Minimum air temperature in the cylinder is approx. 750 degF (4000 degC) to ignite the fuel and start the combustion process

Diesel Starting Aids

- Outside air temperature affects the internal cylinder temperature
- Colder temperatures may require some type of starting aid
  - Glow Plugs
  - Intake pre-heater
  - Ether injection
  - Engine coolant or lube oil heaters
  - Auxiliary Power Units (APU)

Fuel Injection

- High fuel injection pressures are needed:
  - Injection pressure may exceed 25,000 psi in some applications
  - This is needed to overcome high internal cylinder pressures
  - Use only OEM methods when identifying the source of high pressure fuel leaks

Horsepower and Torque

- The amount of fuel injected determines the amount of combustion pressure
  - Limited by the amount of available oxygen
  - Fuel continues to be injected after the combustion process begins in the cylinder
  - This greatly improves torque and horsepower at lower engine speeds
  - Fuel injection is precisely controlled by the engine ECM governor
  - The engine ECM instantly adjusts the fuel injection to the load placed on the engine

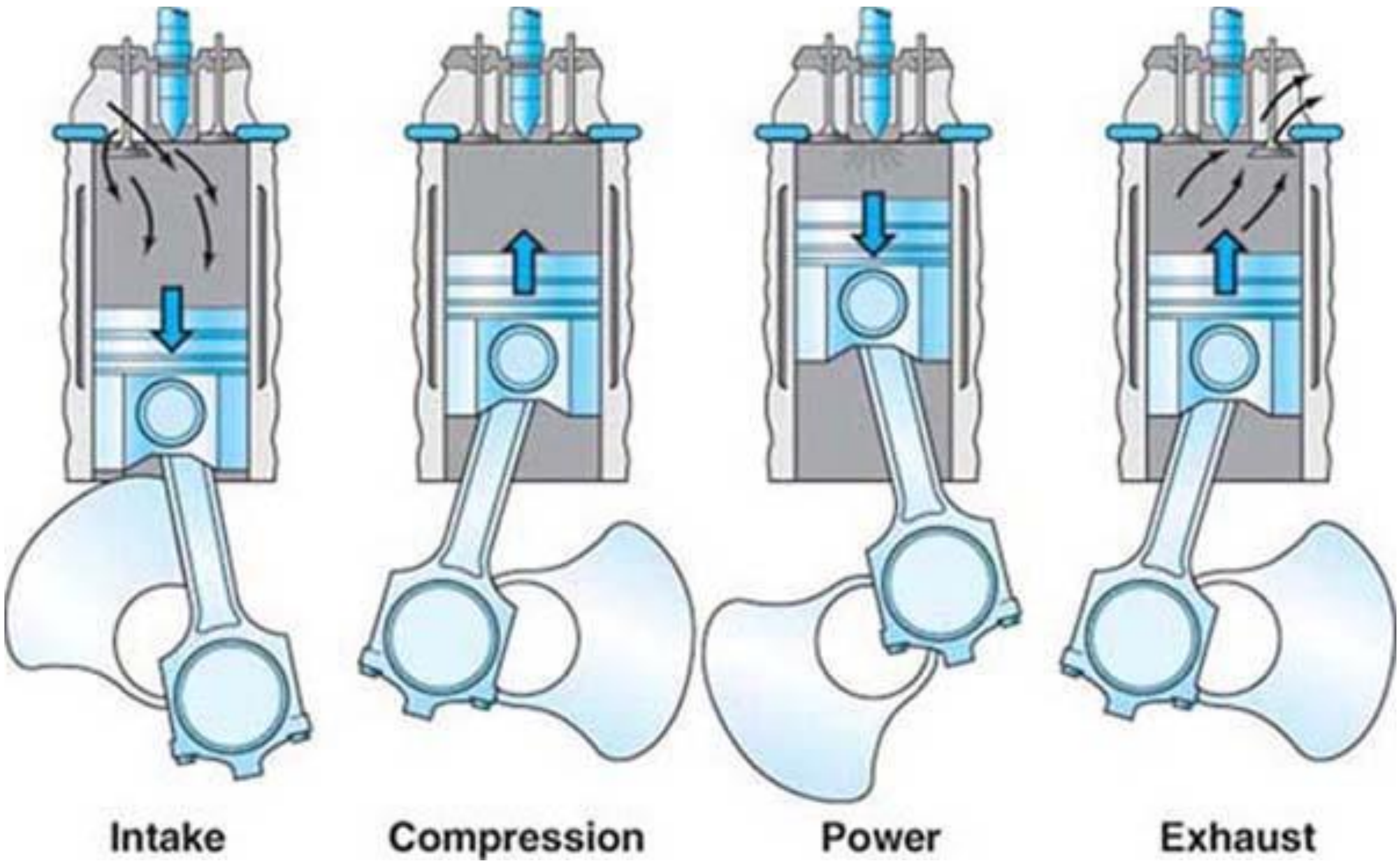
Diesel Combustion

- High pressure fuel injection is required
  - Precise fuel injection occurring at the correct time
  - Injection timing is critical to optimize engine power and fuel economy
    - Prevent engine damage
    - Control engine emissions
    - Prevent lube oil dilution from unburned fuel
  - There is a delay period after fuel is injected to when it begins to burn (lag)
  - This delay period determines the "Effective Timing"

Diesel fuel injection and combustion facts:

- Only the intake air charge is compressed in the cylinder
- Diesel fuel is injected into this compressed air charge
- Diesel fuel starts to combust rapidly upon mixing with the hot air
- Fuel continues to be injected mixing with hot combustion gases
- Diesel Combustion
- Diesel Combustion Process

The Four Stroke Cycle



Four Stroke Cycle (cont.)

- An engine cycle describes one operation, from start to finish
- A stroke is one event in the 4-stroke cycle
- The specific stroke is determined by the camshaft
- All reciprocating piston engines have four events which must take place
  - Intake
  - Compression
  - Power
  - Exhaust

Four Stroke Cycle (cont.)

- Completion of all four needed events constitutes one cycle:
  - The events must occur in the proper sequence
  - One stroke is the movement of the piston from Top Dead Center (TDC) to Bottom Dead Center (BDC) or vice versa
  - One stroke requires 180˚ of crankshaft rotation
  - Intake and exhaust strokes can overlap to help expel exhaust gasses

Four Stroke Cycle (cont.)

- All modern diesel truck engines are 4-stroke designs:
  - The crankshaft must turn two revolutions (720˚) in order to complete the 4-stroke cycle
  - All diesel truck engines will complete the 4-stroke cycle in 720˚
- The once popular Detroit Diesel Corp 2-stroke engine is no longer used in modern truck applications

Four Stroke Cycle (cont.)

- Valves can only be open during two of the four strokes – intake and exhaust
  - The camshaft must turn half as fast as the crankshaft
  - This is typically accomplished by gear or chain
  - The camshaft will turn one revolution (360˚) to complete the four-stroke cycle
  - The camshaft actuates the engine valvetrain
  - Valve Overlap will occur as the exhaust valve is closing and the intake valve is opening
  - Scavenging occurs during Valve Overlap

Four Stroke Cycle (cont.)

- The camshaft will determine which of the two possible events occurs during a stroke:
  - The intake and exhaust strokes overlap
  - Intake always follows exhaust during the cycle
  - The exhaust valve will be closing as the intake valve is opening
  - This helps to purge exhaust gases from the cylinder (scavenging)
  - Observing this valve overlap action will determine the correct direction of rotation

Diesel Intake Stroke

- Only the intake air enters the cylinder:
  - **NOT** the air/fuel charge
  - The downward movement of the piston draws fresh air into the cylinder
  - The turbocharger can force in more air
  - The exhaust valve remains open at the beginning of the intake stroke
  - The intake valve closes as the piston reaches BDC

Diesel Compression Stroke

- Only the cylinder fresh intake air charge is compressed:
  - **NOT** the air/fuel charge
  - The upward movement of the piston squeezes the air charge creating heat
  - The combustion chamber is shaped to produce maximum air turbulence
  - Fuel is injected after the air charge is compressed
  - Thorough mixing of fuel and air is critical to proper combustion

Diesel Compression Stroke (cont.)

- Diesel truck engines typically produce compression pressures about 600 PSI
  - The low volatility and ignition qualities of Diesel fuel helps prevent pre-ignition
    - Proper injection timing also helps prevent pre-ignition
  - The higher compression pressure contributes to more heat developed in the cylinder
  - The high compression ratio also causes greater expansion of the burning gases
  - Resulting in higher cylinder combustion pressure deriving most of the available energy from the fuel

Diesel Power Stroke

- High pressure fuel is injected into the engine cylinder near TDC:
  - Near the end of the compression stroke
  - Fuel mixes with the compressed air charge
  - Heat of compression ignites the fuel
  - The quantity of fuel injected is determined by engine speed and load
  - The engine ECM governs the amount of fuel injected based on various inputs

Diesel Power Stroke (cont.)

- High cylinder pressure is maintained longer than in a gasoline engine:
  - This is called the diesel constant pressure power stroke (expansion stroke)
  - Takes advantage of existing cylinder pressure on a greater crank throw angle
  - Fuel continues to be injected causing the gas pressure to peak 5° - 20° ATDC
  - This provides more torque at lower RPM's

Diesel Exhaust Stroke

- The hot gases are expelled from the engine cylinder:
  - The exhaust valve opens when the piston is near BDC
  - Upward movement of the piston pushes the hot gases into the exhaust manifold
  - The intake valve opens near TDC drawing fresh, cool air into the cylinder
  - This provides additional cylinder cooling
  - Scavenging occurs when the intake air charge helps push the remaining exhaust out

Diesel Exhaust Stroke (cont.)

- The hot exhaust gas is used to drive the turbocharger:
  - Exhaust energy is captured by the turbine wheel of the turbocharger
  - The turbine wheel drives an impeller wheel compressing the intake air charge
  - Turbochargers capture exhaust energy
  - This action contributes to the volumetric and thermal efficiency of the diesel engine

Cylinder Compression Problems

Low Compression Pressure

- Low Compression could cause:
  - Hard starting
  - Rough idle
  - Low engine power
  - Poor engine performance
  - Poor engine fuel economy
  - Reduced engine power
  - Increased emissions/smoke
  - Cylinder misfire
  - Excessive crankcase pressure

Low Compression (cont.)

- Poor compression could be caused by:
  - Blown head gasket
  - Burnt valves/seats
  - Cracked cylinder head
  - Damaged compression seals
  - Cracked or worn piston rings
  - Burnt or damaged piston
  - Improper valve timing
  - Bent piston rod
- Internal combustion gas leaks usually occur with low compression problems
- Cylinder compression or leak-down tests can identify poor compression

Low Compression (cont.)

- Root causes of low compression:
  - Overall poor engine maintenance
  - Engine overheating issues
  - Poor quality lube oil
  - Lube system problems
  - Dirt entering air system
  - Cylinder misfire or detonation*
  - Fuel diluted engine oil
  - Improper use of starting fluids

**Violent, uncontrolled combustion that can cause internal engine damage*

Companion Cylinders and Engine Rotation

Companion Cylinders

- Engines usually have two pistons which move together on the same plane:
  - These are called "Companion Cylinders"
  - Piston travel from TDC to BDC can be either intake or power stroke
  - Piston travel from BDC to TDC can be either Compression or exhaust stroke
  - **Exception:** Engines with odd numbered cylinders do not have companion cylinders

  - Companion Cylinders

Companion Cylinders (cont.)

- The typical inline 6-cylinder diesel engine firing order is 1-5-3-6-2-4
- The inline 6-cylinder companion cylinders are 1-6, 2-5, 3-4
- Example: If cylinder #6 is on the exhaust stroke, cylinder #1 is at TDC Compression stroke
- Observing valve overlap can determine the position of two pistons at TDC

Engine Rotation

- Engine rotation is usually determined by observing the crankshaft from the front
- Right-hand (clockwise) rotation is standard on truck engines
  - Some OEM's list engine rotation by flywheel view (CAT)
  - Left-hand (counterclockwise) rotation for special applications

Service Tip: Observing valve overlap can be used to determine correct engine rotation

Engine Construction

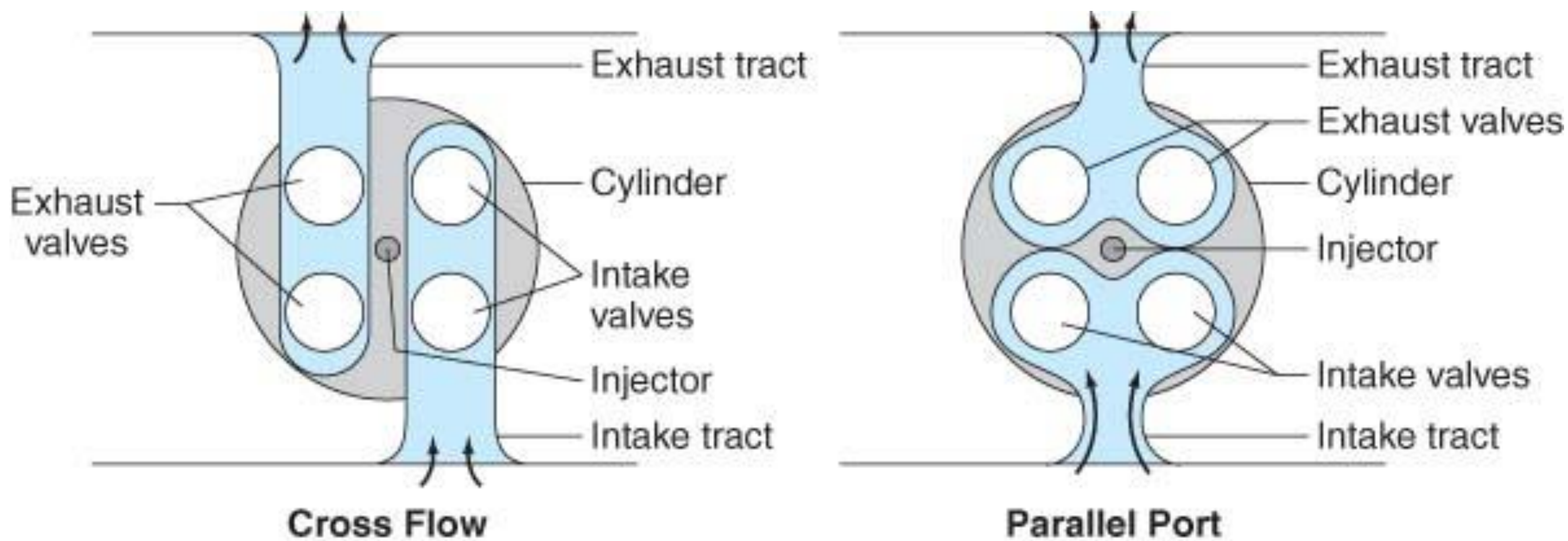
Diesel Engine Construction

- Diesel engines have stronger parts and more robust designs:
  - Necessary because of higher pressures and loads
  - May be designed for in-chassis overhauls and major component replacement
  - Allows longer intervals between repair and maintenance
  - Designed for optimum engine life

Diesel Engine Design

- Intake and exhaust efficiency are primary design factors:
  - 4-valve heads are used for higher volumetric efficiency
  - The cross flow design of air intake and exhaust ports in the cylinder head is common
  - Turbochargers are standard on all truck engines
  - Charge-Air-Cooling (CAC) is common in truck applications (may be called Air-To-Air Coolers)
  - The CAC lowers the temperature of the intake air charge improving overall engine efficiency

Cross-Flow Cylinder Head



Valve Configuration

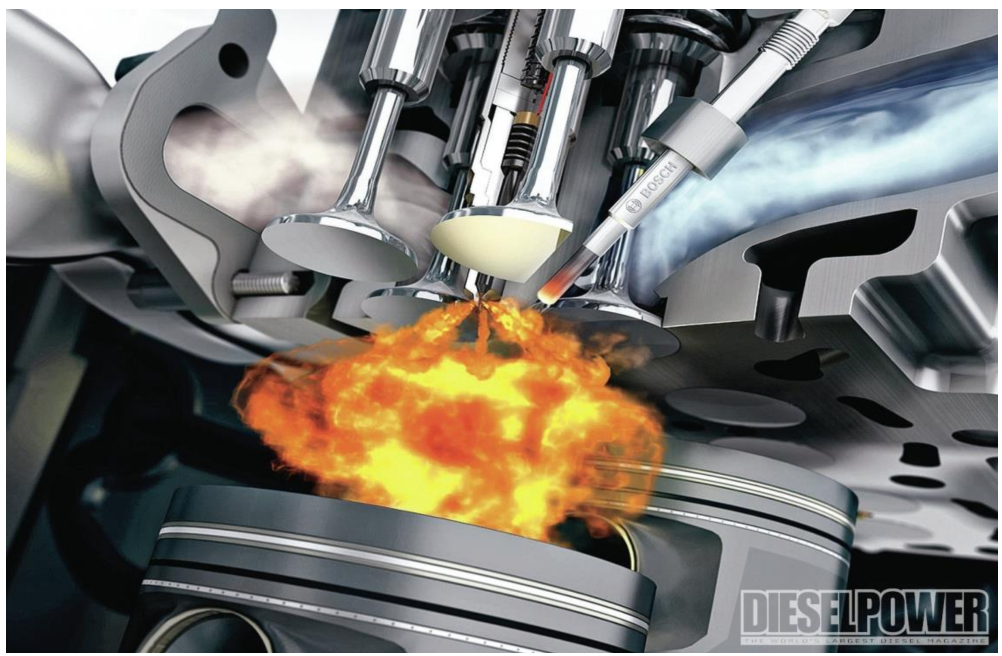
Diesel Combustion Chambers

Diesel Combustion Chambers

- Combustion Chambers
  - The combustion chamber is designed to develop maximum cylinder turbulence
  - This improves the mixing of the fuel with the intake air charge
  - Open Chambers – All of the cylinder volume is contained in a single space above or in the piston
  - Pre-combustion Chambers have an auxiliary chamber connected to the main chamber

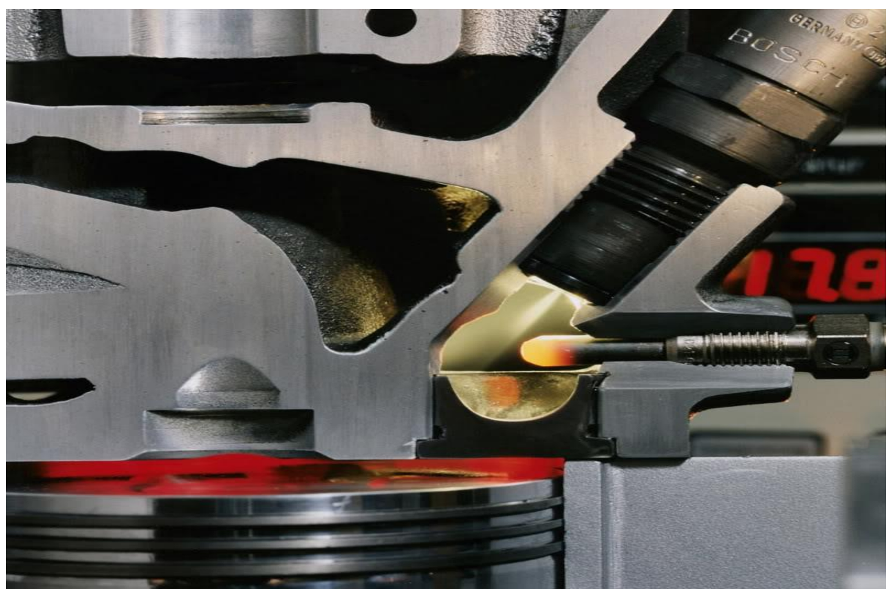
Diesel Combustion Chambers

- Open Chambers
  - Improved thermal & volumetric efficiency
  - Do not need glow plugs to start
  - Uses Direct Injection (DI)



Diesel Combustion Chambers

- Pre-combustion Chambers
  - Needs glow plugs to start
  - Uses Indirect Injection (IDI)
  - Not typically used in modern Diesel Truck Engine applications



Glow Plugs

- Necessary to start engines equipped with pre-combustion chambers
- Electrical heating element that is inserted into the pre-combustion chamber
- Will shut-off shortly after the engine starts
- May cycle on/off during engine warm-up to improve performance & reduce smoke
- May be used in open chamber engines
  - Example: International/Ford Powerstroke
- Engine ECM controlled in most applications

Intake Pre-heaters

- Pre-heaters may be required to start engines in colder temperatures
- Heats the intake air
- An electrical grid placed in the intake manifold
- May be cycled on/off to improve engine performance & reduce smoke
- Controlled by engine electronics

Ether Injection

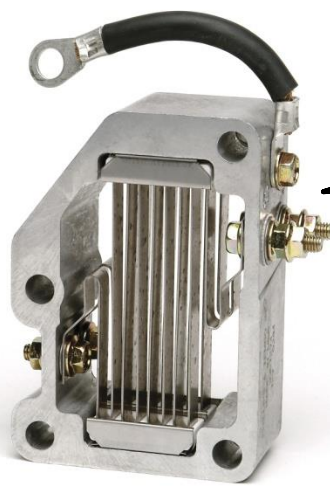
- A diesel engine may be equipped with an ether injection system
- Used to assist the starting of a diesel engine in cold weather
- Current ether injection systems are usually controlled by an ECM

Warning!! *Do not use ether starting fluids on Diesel engines equipped with glow plugs, intake air pre-heaters or Flamestart (CAT) starting aids*

Diesel Engine Starting Aids

Glow Plugs

Ether Injection



Intake Pre-heater

Diesel Advantages and Disadvantages

- The Diesel Advantage
  - In truck applications diesel engines have several advantages:
  - Superior fuel economy
  - Greater engine output @ lower RPM’s
  - Designed for serviceability
  - Major in-chassis repairs possible
  - Less routine maintenance
  - Less CO emissions
  - Diesel fuel is inherently safer to handle
  - Longer engine life

Diesel Advantages and Disadvantages (cont.)

- The Diesel Disadvantage:
  - Higher initial cost
  - Higher component replacement cost
  - Noise
  - Weight
  - Hard starting in cold weather
  - Two diesel emissions are difficult to control
    - Nitrogen Oxides – NOx
    - Particulate Matter – PM (soot)

Diesel Engine Usage

- Usage of diesel engines is widespread:
  - Trucks & Automobiles
  - Marine & Ocean Vessels
  - Mining
  - Logging
  - Oil Drilling
  - Utility companies
  - Military vehicles
  - Farming

Diesel Engine Usage (cont.)

- Electrical power generation
  - Hospitals
  - Shopping centers
  - Highway department
  - Large buildings
  - Railroad

Diesel & Gas Engine Comparison

- Popular Light Truck Gas Engines
  - Ford Triton V-10 6.8L
    - 310 HP @ 4250 RPM
    - 425 lb-ft of torque @ 3250 RPM
  - GM Vortec 8100 V8 8.1L
    - 330 HP @ 4200 RPM
    - 450 lb-ft of torque @ 3200 RPM
  - Dodge Magnum 5.7L Hemi
    - 345 HP @ 5400 RPM
    - 375 lb-ft of torque @ 4200 RPM

Diesel & Gas Engine Comparison (cont.)

- Popular Light Duty Diesel Engines
  - Cummins ISB Series (inline 6)
    - 325 HP @ 2900 RPM
    - 600 lb-ft of torque @ 1600 RPM
  - Ford (Int'l) Power Stroke 6.0L (V8)
    - 325 HP @ 3300 RPM
    - 560 lb-ft of torque @ 2000 RPM
  - Ford (International) 4.5L (V6)
    - 200 HP @ 3000 RPM
    - 440 lb-ft of torque @ 1850 RPM