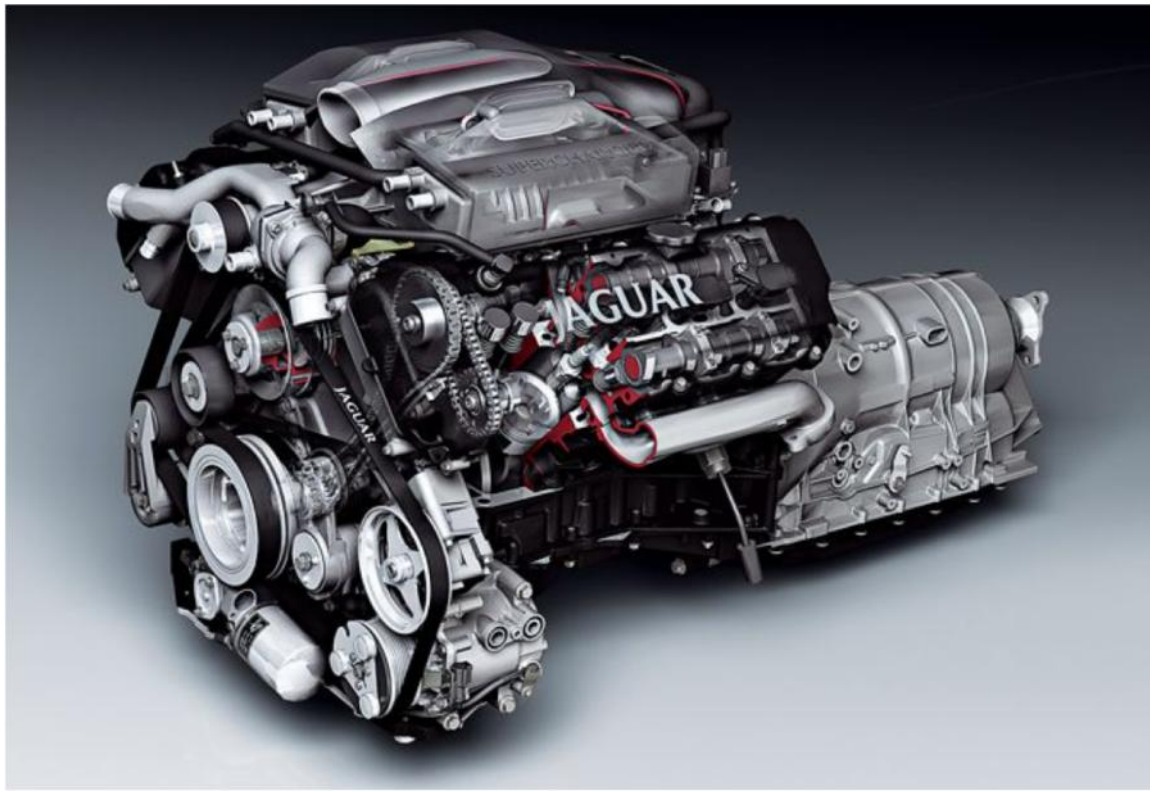
Internal Combustion Engine (ICE)



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Hello!

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References:

1. Willard Pulkrabek, “Engineering Fundamentals of the Internal Combustion Engines”
2. John Heywood, “Internal Combustion Engine Fundamentals”
3. Rolf Isermann, “Engine Modeling and Control”

Final Mark:

- ✓ Final Exam : %50
- ✓ Assignments : %20
- ✓ Project : %30

Course Outline:

- Introduction
- Operating Characteristics
- Engine Cycles
- Thermochemistry
- Air & Fuel Induction
- Fluid Motion
- Combustion
- Exhaust & Emission
- Heat Transfer in ICE
- ICE Modeling & Control

Introduction

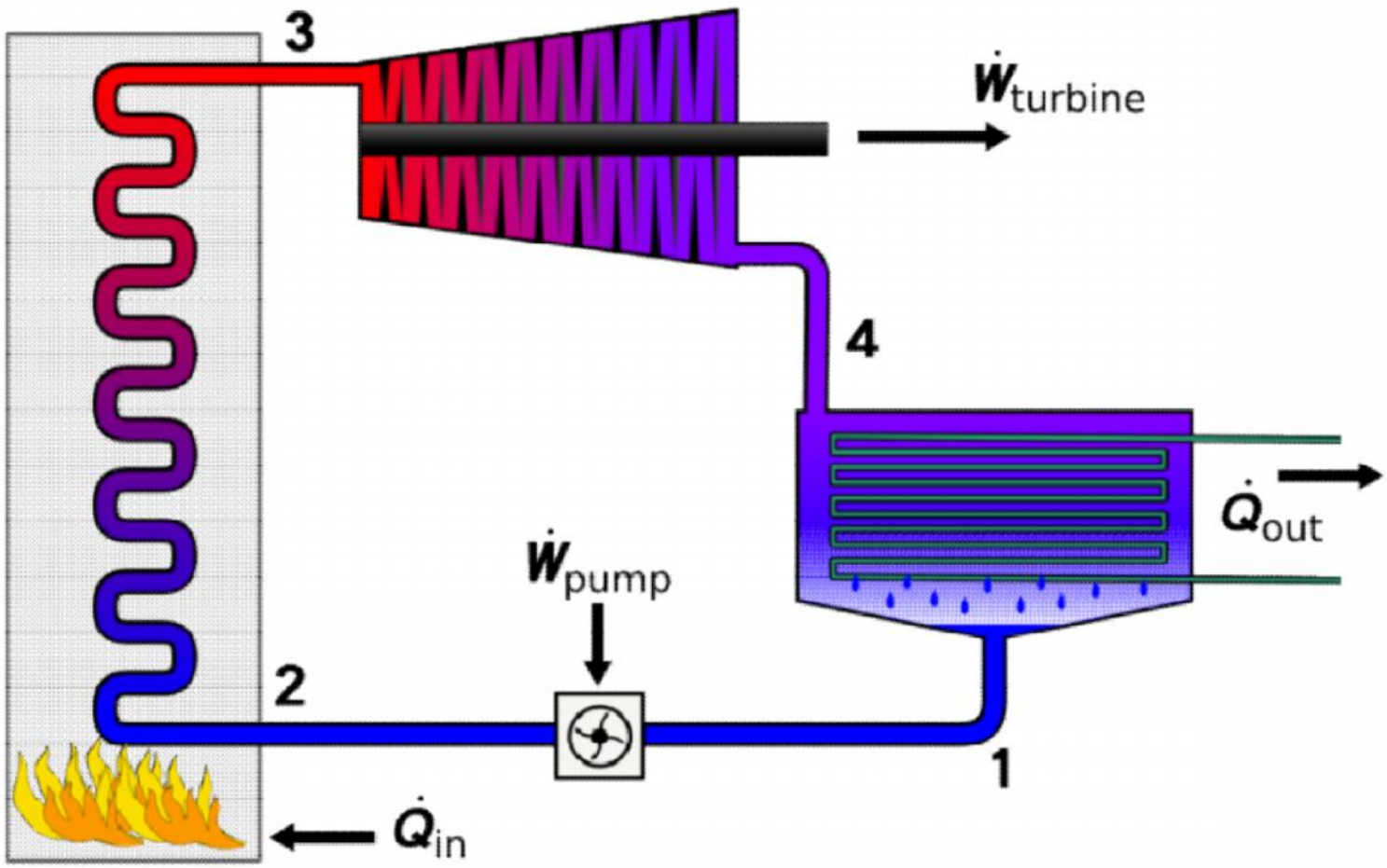
Device to convert the chemical energy in the fuel to mechanical energy (work)

Chemical energy to thermal energy (combustion)
Thermal energy to mechanical energy (expansion)

"Internal" : both processes are in the same chamber.
Examples: car engine, rocket engine, jet engine

"External" : the processes are in different chambers.
Examples: steam engine, steam power plant

External Combustion: Steam Power Plant (Rankine Cycle)



(Wikipedia)

- ✓ **Size:** 1 *cc* to 1 (displacement volume)
- ✓ **Power:** 10 W – 10 MW based on the displacement volume
- ✓ **Applications:** Automotive, marine, power generation, mechanical devices

- 1860 – Lenoir Engine (Jean J. Lenoir)
- 1867 – Otto-Langen Atmospheric Engine
- 1876 – First 4 stroke engine (Nicolaus Otto)
- 1878 – First 2 stroke engine (Dougald Clerk)
- 1892 – First 4 stroke compression ignition engine (Rudolf Diesel)
- 1920s – ICE dominates the market, multi-cylinder compression Engines
- 1960s – Vehicle emissions become an issue
- 1980s – 3 way catalytic converters to reduce CO, Hydrocarbons and NOx by an order of magnitude, unleaded gasoline
- 1990s – Recognition of importance of greenhouse gases
- 2000s – Towards sustainable transportation / advance mechatronics technologies

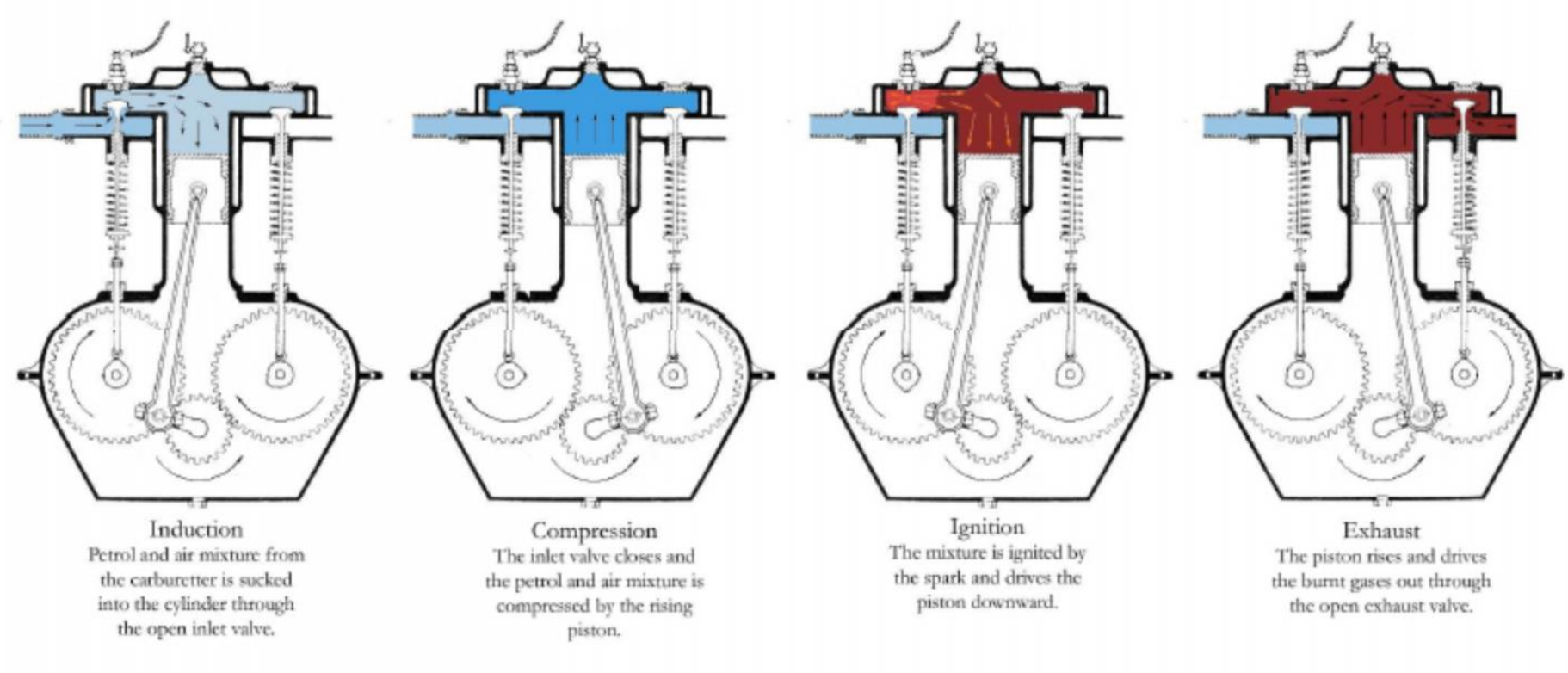
1880 – SI Engine Mass Production

1920 – CI Engine Mass Production

Otto-Langen Engine (1867) (Power House Museum Australia)

(http://www.powerhousemuseum.com/)

Otto Four-Stroke Engine



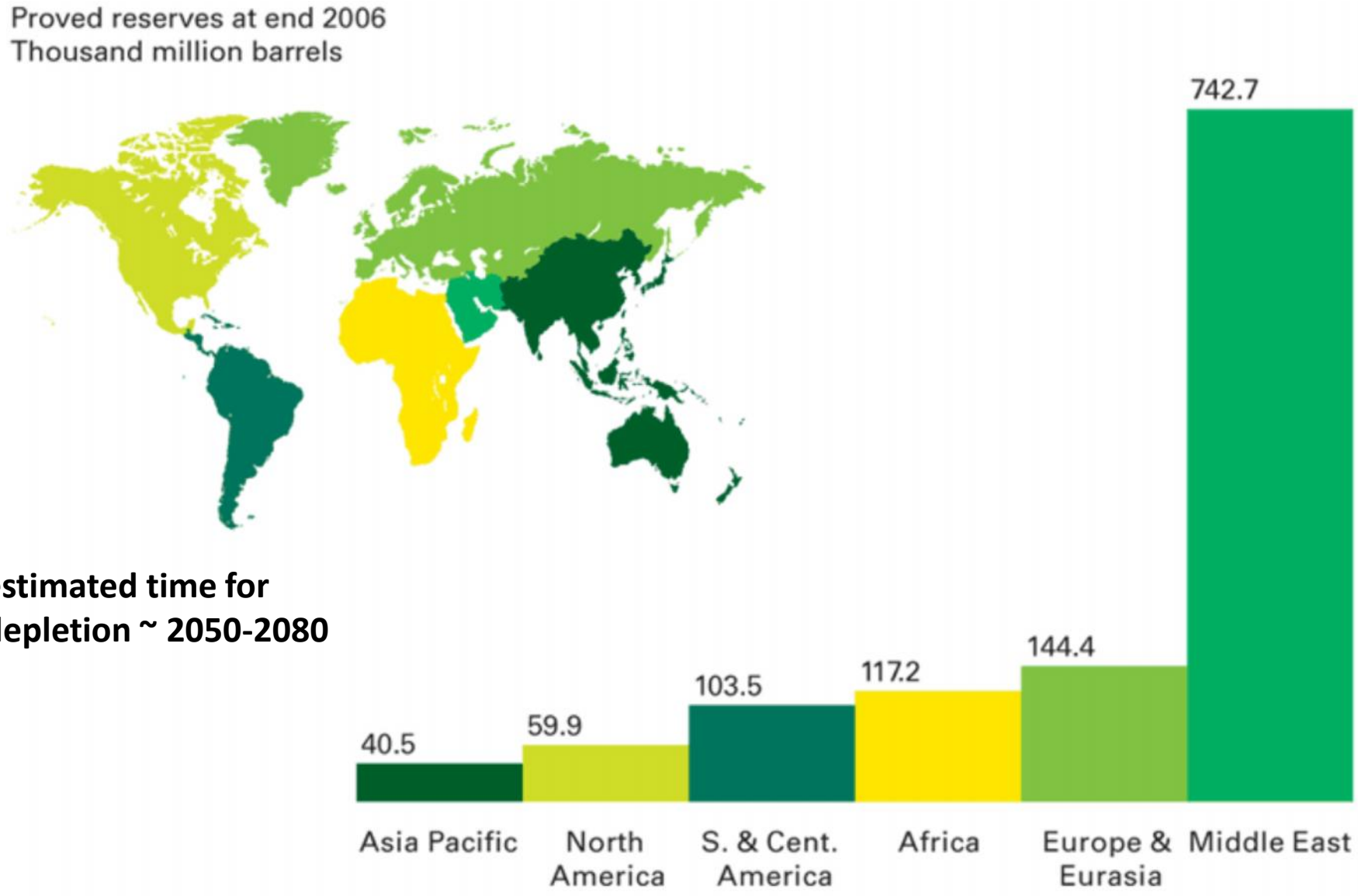
(http://www.rrec.org.uk/Cars/How_A_Car_Works.php)

TABLE 1.1
Comparison of Otto four-stroke cycle and Otto-Langen engines[2]

	Otto and Langen	Otto four-stroke
Brake horsepower	2	2
Weight, lb, approx.	4000	1250
Piston displacement, in^3	4900	310
Power strokes per min	28	80
Shaft speed, rev/min	90	160
Mechanical efficiency, %	68	84
Overall efficiency, %	11	14
Expansion ratio	10	2.5

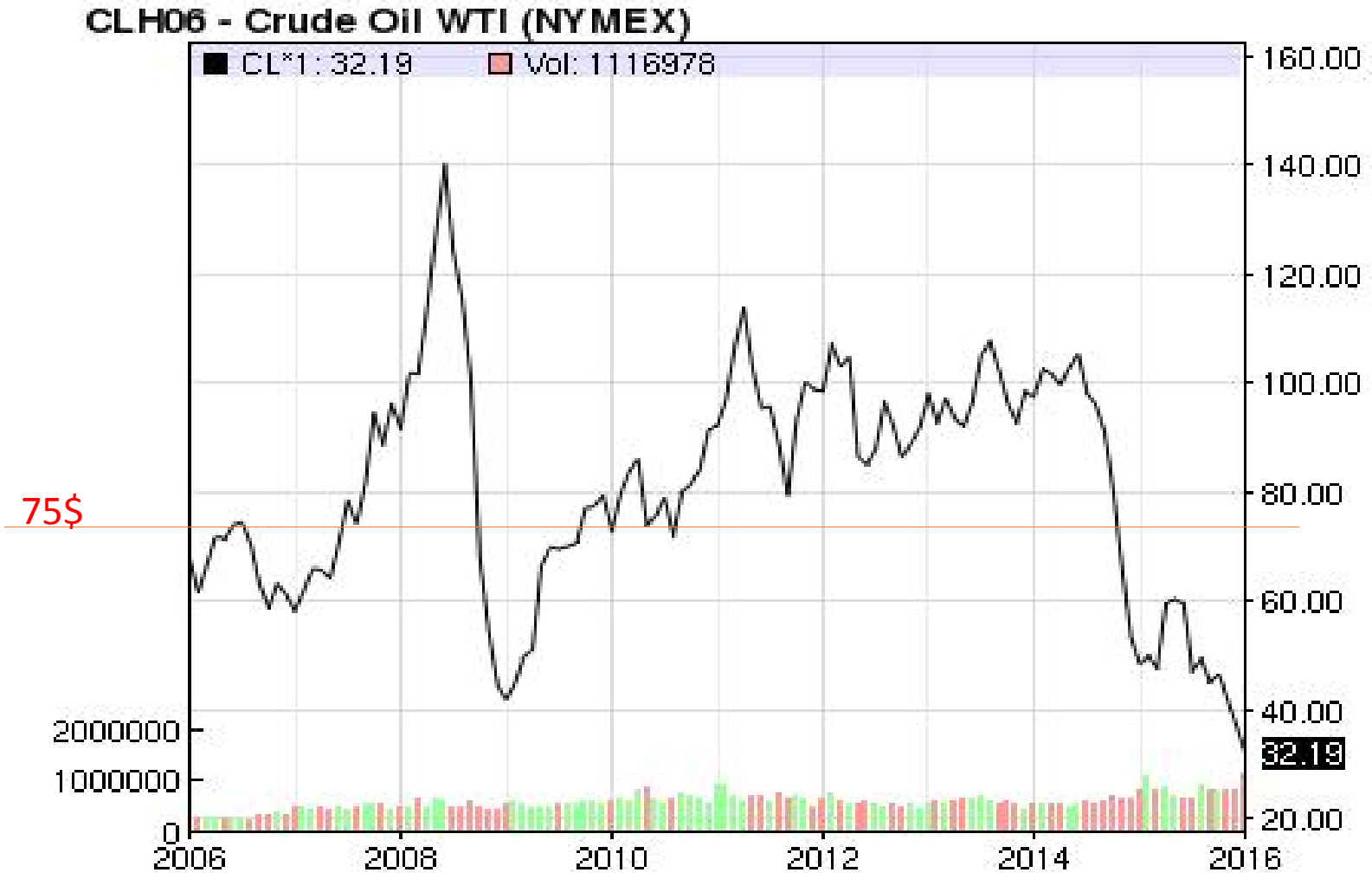
(Heywood)

BP Statistical Review of World Energy (2007)

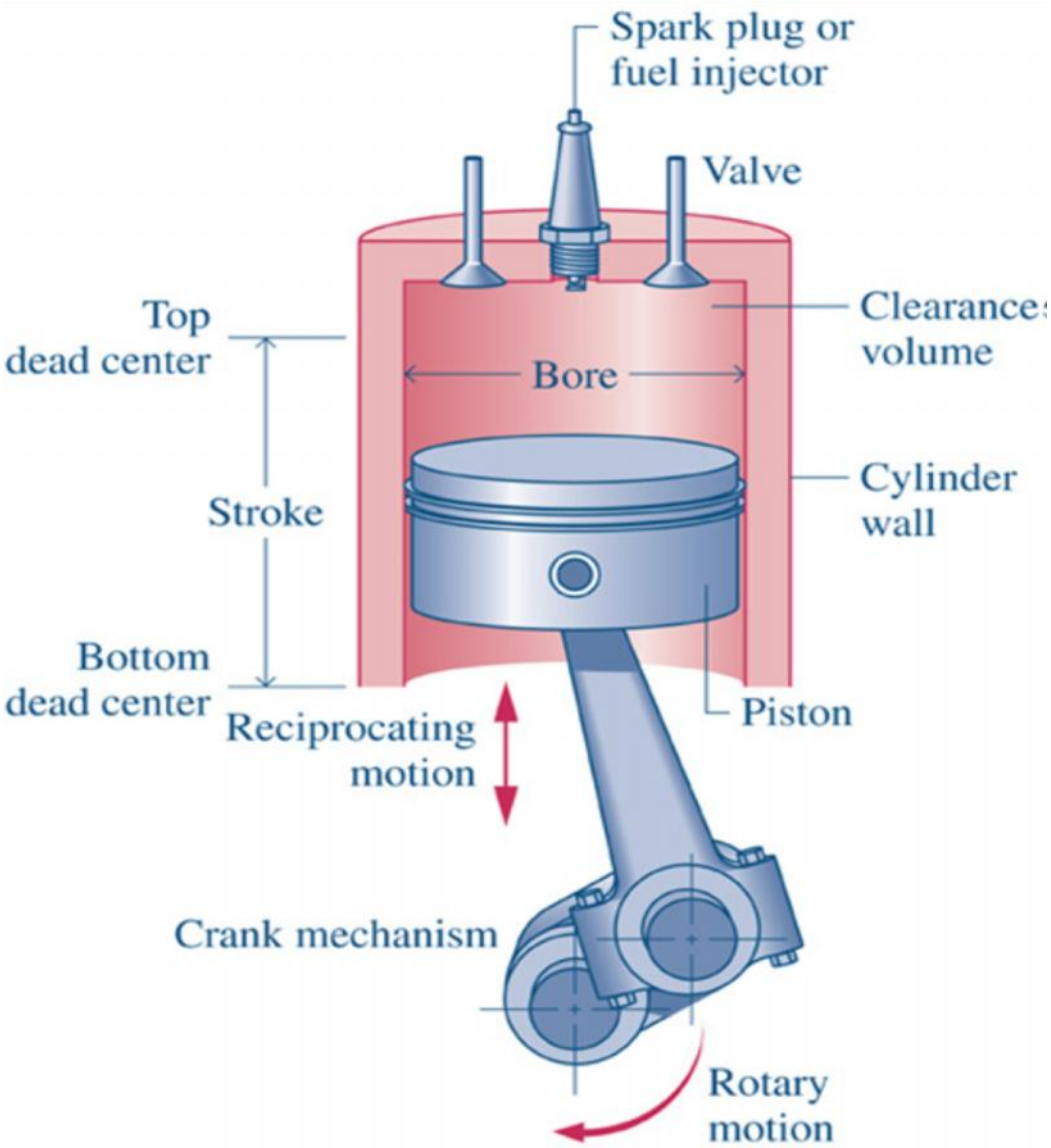


estimated time for depletion ~ 2050-2080

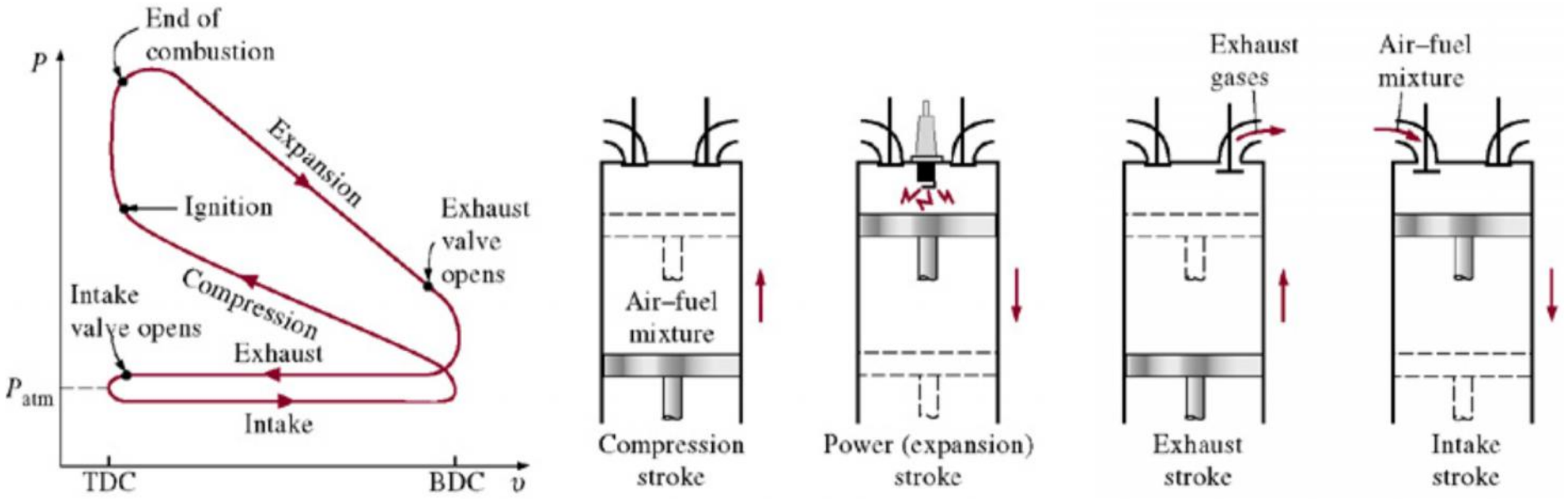
Cost of Crude Oil per Barrel (1 Barrel ~ 159 Liter)



(http://www.nasdaq.com/markets/crude-oil)


Spark plug or
fuel injector
Valve
Top
dead center
Clearance
volume
Bore
Cylinder
wall
Stroke
Bottom
dead center
Reciprocating
motion
Piston
Crank mechanism
Rotary
motion

Four-Stroke Spark Ignition Engine (Naturally Aspirated)



- **Spark Ignition Engines**
  - Good combustion efficiency
  - Improving emissions characteristics

- **Diesel Engines**
  - Better overall efficiency
  - NOx and particulate emissions are significant

[1Introduction-SI vs Diesel Engine]

- **Types of Ignition**
  - Spark Ignition
  - Compression Ignition
- **Types of Charge (air-fuel mixture)**
  - Homogeneous charge
  - Inhomogeneous charge
- **Engine Cycle**
  - 4 stroke
  - 2 stroke
- **Number of cylinders**
  - Single
  - Multi
- **Air introduction**
  - Naturally aspirated
  - Supercharged
  - Turbocharged
- **Cylinder Arrangement**
  - Inline
  - V
  - W
  - Radial
- **Fuel Introduction**
  - Carburetors
  - Fuel Injection
    - Throttle body injection
    - Manifold Injection
    - Port Injection
    - Direct Injection

Cylinder Arrangements [Pulkrabek]

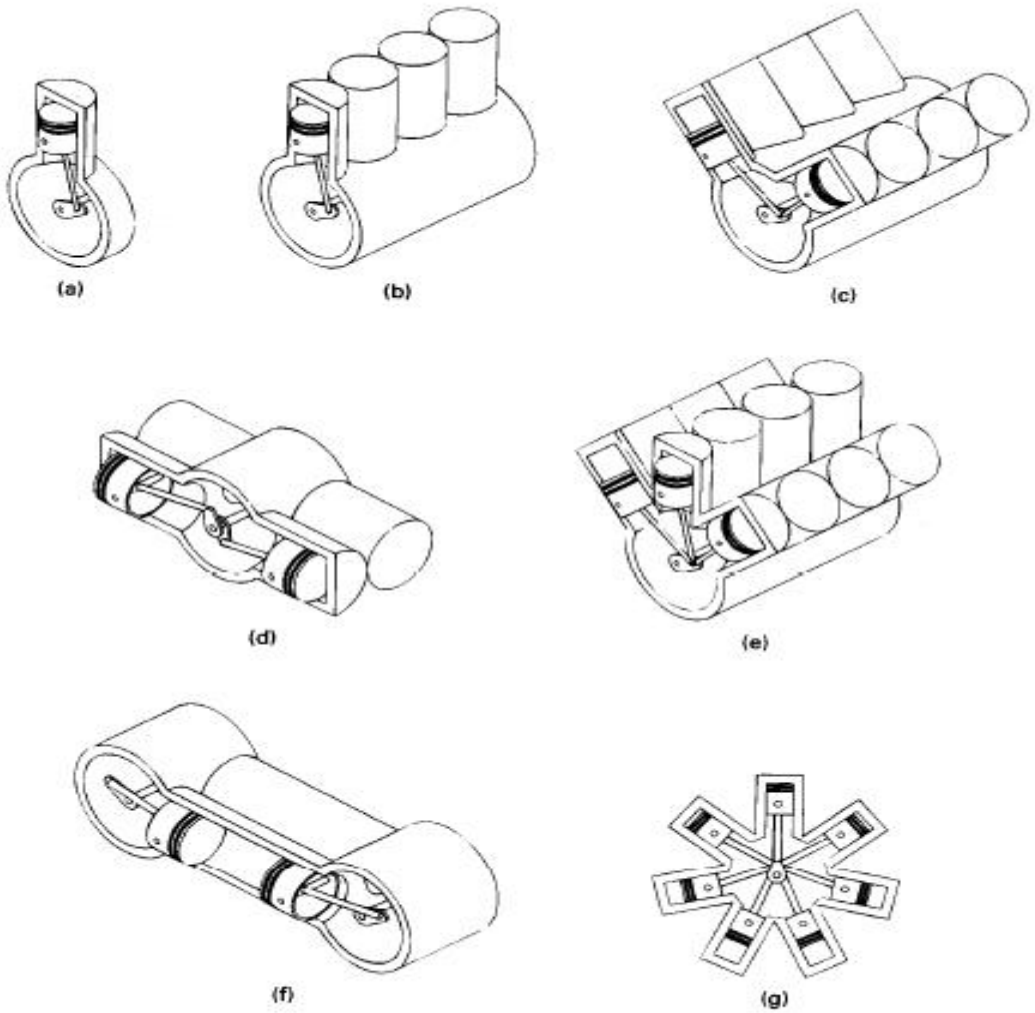


Figure 1-7 Engine Classification by Cylinder Arrangement. **(a)** Single cylinder. **(b)** In-line, or straight. **(c)** V engine. **(d)** Opposed cylinder. **(e)** W engine. **(f)** Opposed piston. **(g)** Radial.

[1Introduction-Rotary Engine]

- ✓ **Induction**, **Compression**, **Power (Expansion)** and **Exhaust** processes take place in 2 strokes of the piston.
- ✓ 2 strokes = 1 revolution of the crankshaft. There is 1 power process (stroke) for every revolution of the crankshaft.
- ✓ Used in motorcycles, chainsaws, lawn movers
- ✓ Can be SI or CI

➢ Advantages

– **Cost:** Simpler design (no valves, camshafts)

– **Higher power-to-weight ratio** (1 power stroke for every revolution, theoretically has twice the power density compared to 4 stroke, in practice the value is 1.4 due to incomplete scavenging).

➢ Disadvantages

– **Lower combustion efficiency:** Poor gas exchange (intake/exhaust). Scavenging is not perfect. Fresh charge may directly flow out of the cylinder.

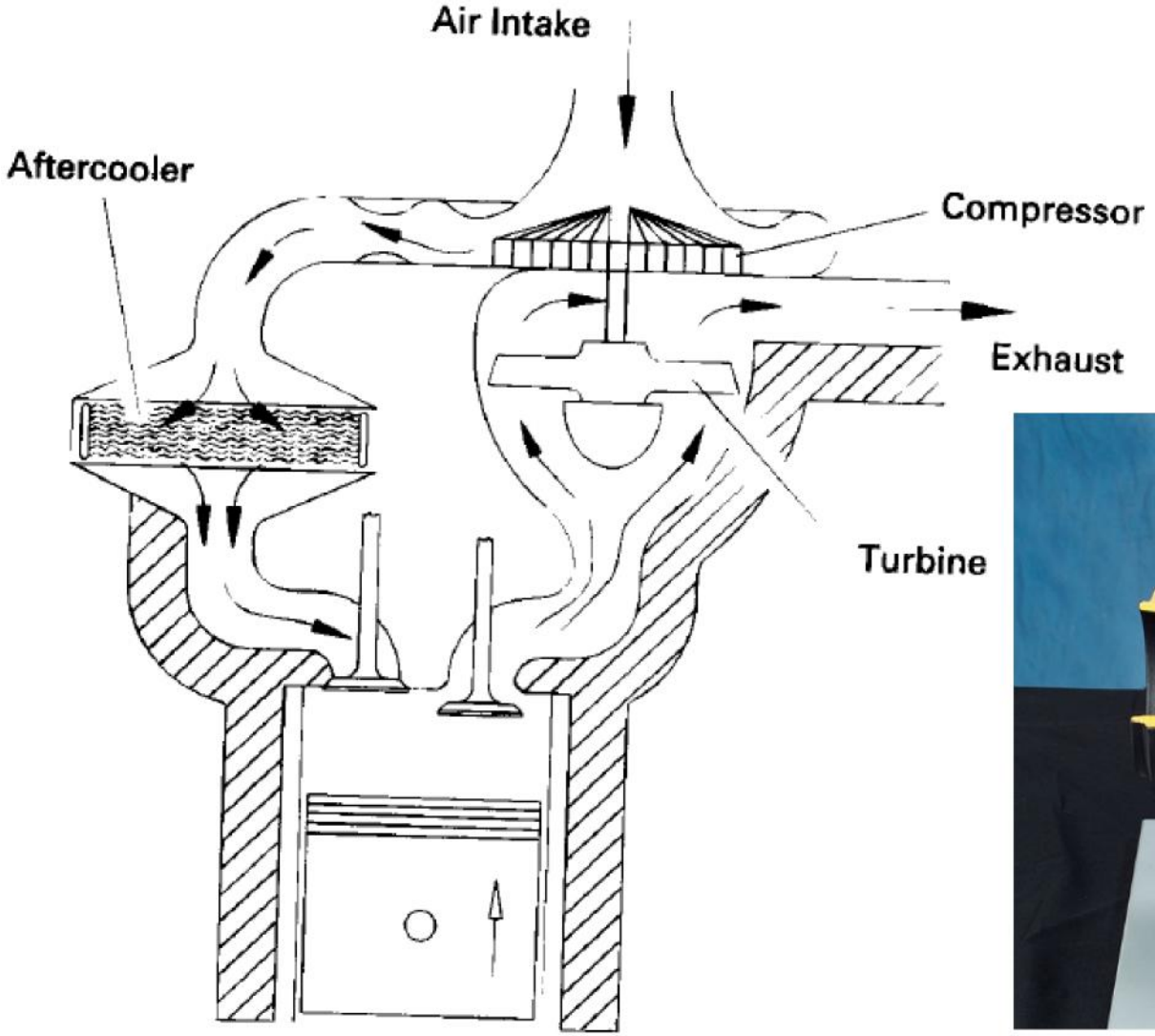
– **Higher Hydrocarbon emissions**

- Incomplete combustion due to poor scavenging
- Fuel is mixed with oil and may be partially burned.

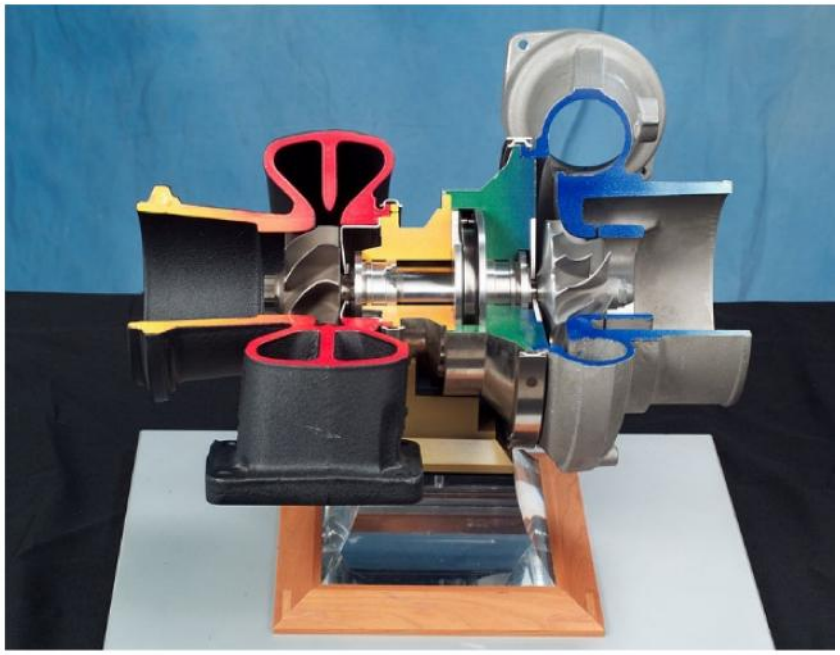
- **Naturally aspirated**
  - Intake air is not pressurized
- **Intake air is pressurized**
  - Turbocharging
  - Supercharging

Note that as increases, also increases.
More air gets into the engine. More fuel can be burned.

Turbocharger [Pulkrabek]

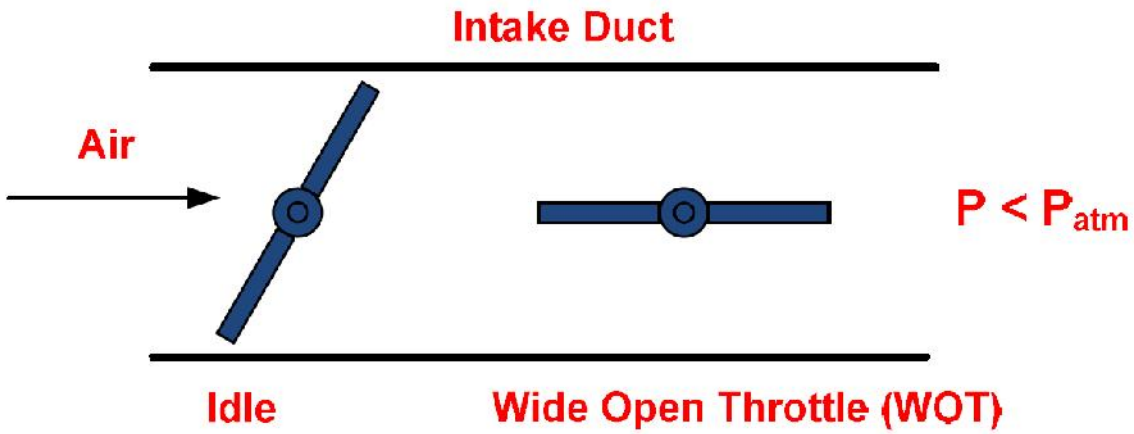


[1Introduction-Turbocharger]

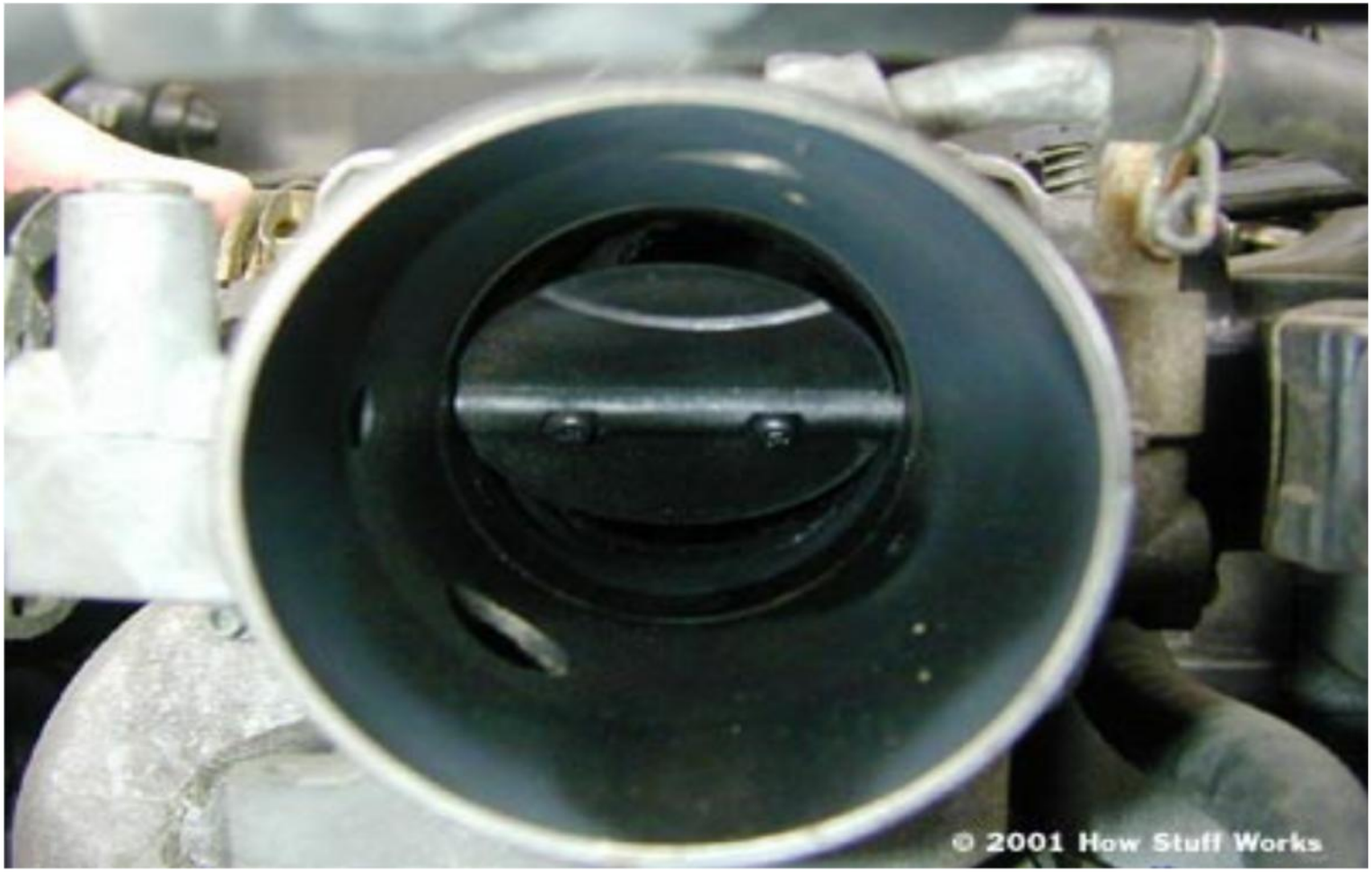


(Wikipedia)

- ✓ SI engines are **throttled**. **A throttle valve** is used to control the amount of air inducted.
- ✓ Air mass flow rate is simultaneously determined by an air mass flow meter in the intake duct, by a throttle position sensor and by measuring the intake manifold pressure.
- ✓ Fuel flow rate is metered by ECU (**E**ngine **C**ontrol **U**nit) such that air-to-fuel ratio, **A/F ~ 14-15 (6-7% fuel)**

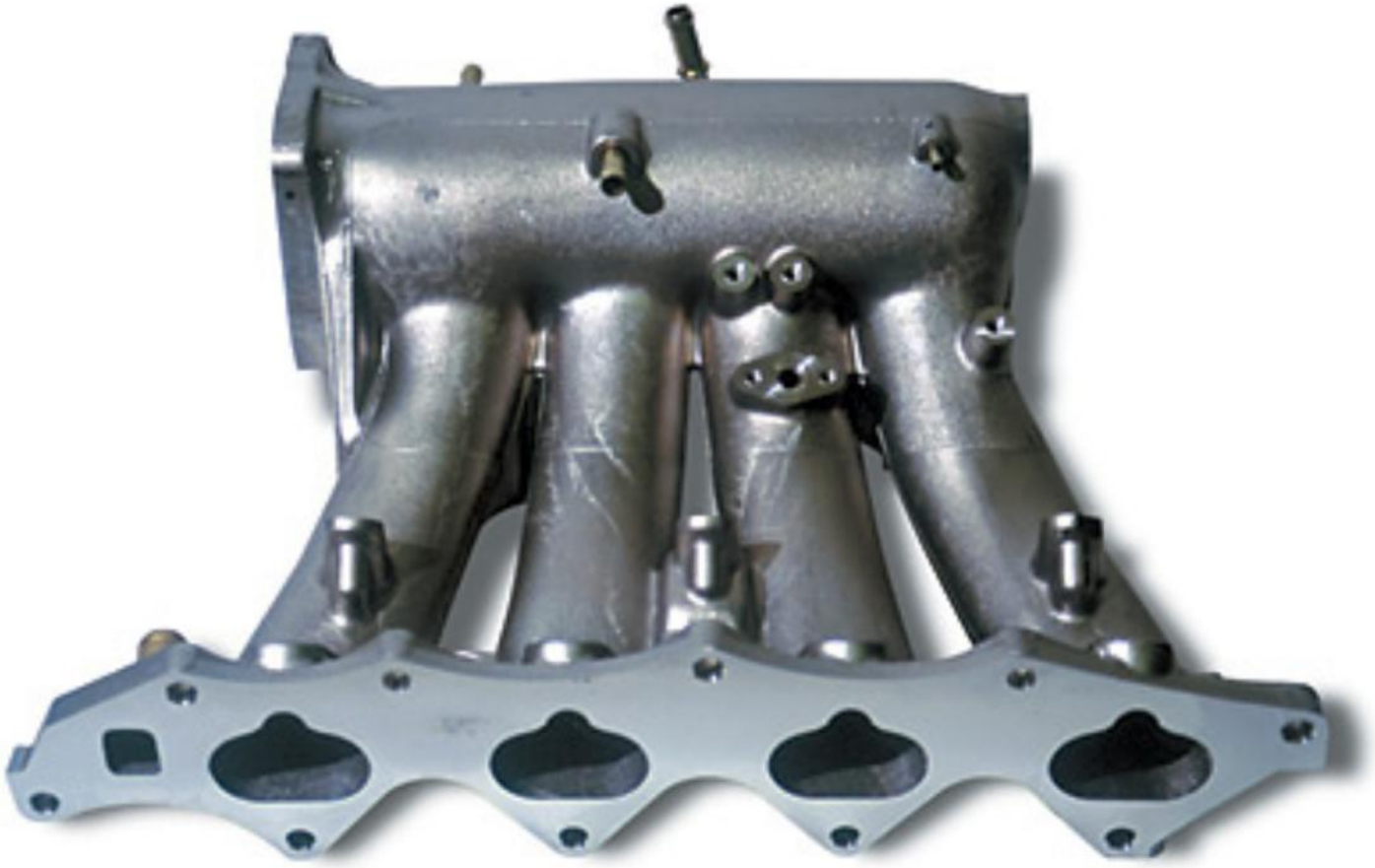


Throttle Valve (Partially Open)



(http://www.howstuffworks.com)

Intake Manifold (Honda Civic)



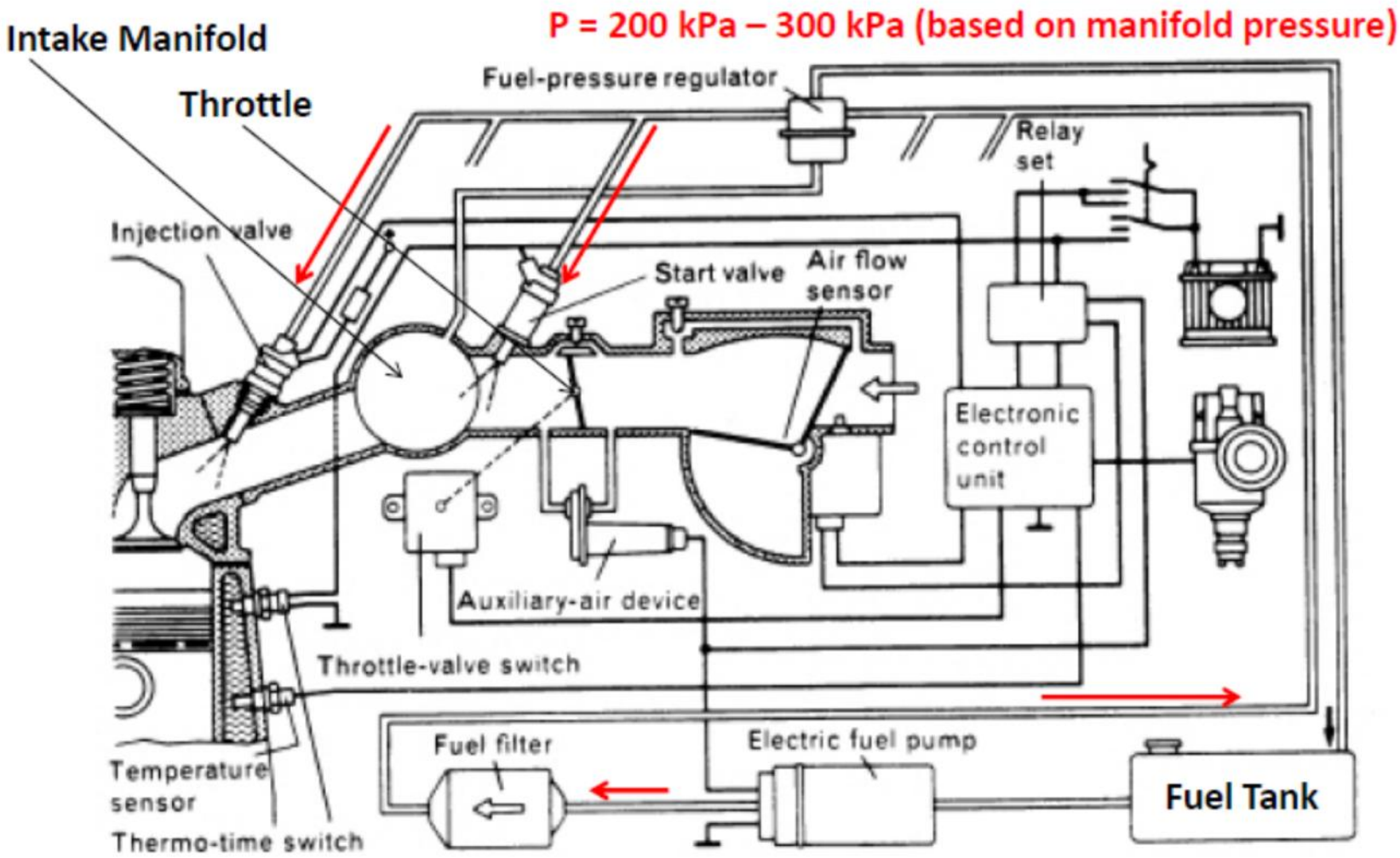
(http://www.slickcar.com/details/2250-intake-manifolds.asp)

In SI engines air and fuel are mixed together in the intake system prior to entry to the cylinder using a:

- **carburetor** (replaced by fuel injectors in 1980s)
- **fuel injection system**
  - Older systems: throttle body injection
  - 1980s: single injector injecting fuel into the manifold
  - 1990s: one injector per cylinder injecting fuel into the intake port (port injection)
  - 2000s: gasoline direct injection

✓ The temperature of the air entering the intake system is controlled by mixing the ambient air with air heated by contact with the exhaust manifold.

Port Fuel Injection [Heywood]

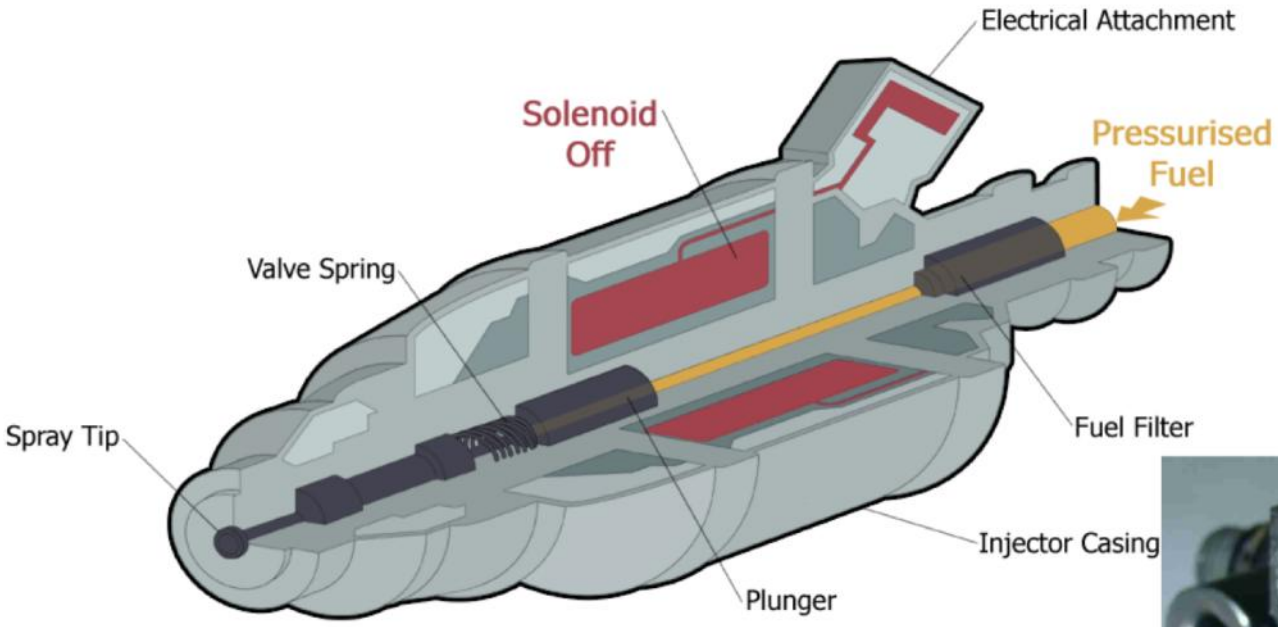


L-Jetronic port electronic fuel injection system (Bosch)

Advantages of Port Fuel Injection [Heywood]

- ✓ Increased power and torque due to increased volumetric efficiency.
- ✓ More uniform fuel distribution.
- ✓ More rapid engine response to changes in throttle position.
- ✓ More precise control of air-to-fuel ratio during cold start and engine warm-up.
- ✓ The amount of fuel injected per cycle for each cylinder can be varied in response to inputs from sensors which define the actual engine operating conditions.

Fuel Injector



(Siemens)

- ✓ CI engines are unthrottled. The engine speed and power are controlled by the amount of fuel injected.

- ✓ Fuel injection systems must operate at high pressures around **1000 – 2500 bar**.
  - The fuel pressure must be greater than the cylinder pressure near the end of the compression stroke (high due to high compression ratios in CI engines).
  - The fuel velocity must be high (**around 200 – 250 m/s**) since mass transfer (evaporation of the fuel) directly depends on the local flow velocity around the droplets.
  - Average droplet size decreases with increasing injection pressure. Small droplets will evaporate faster.

- ✓ Part of the fuel can be sprayed against hot cylinder walls to speed up evaporation.

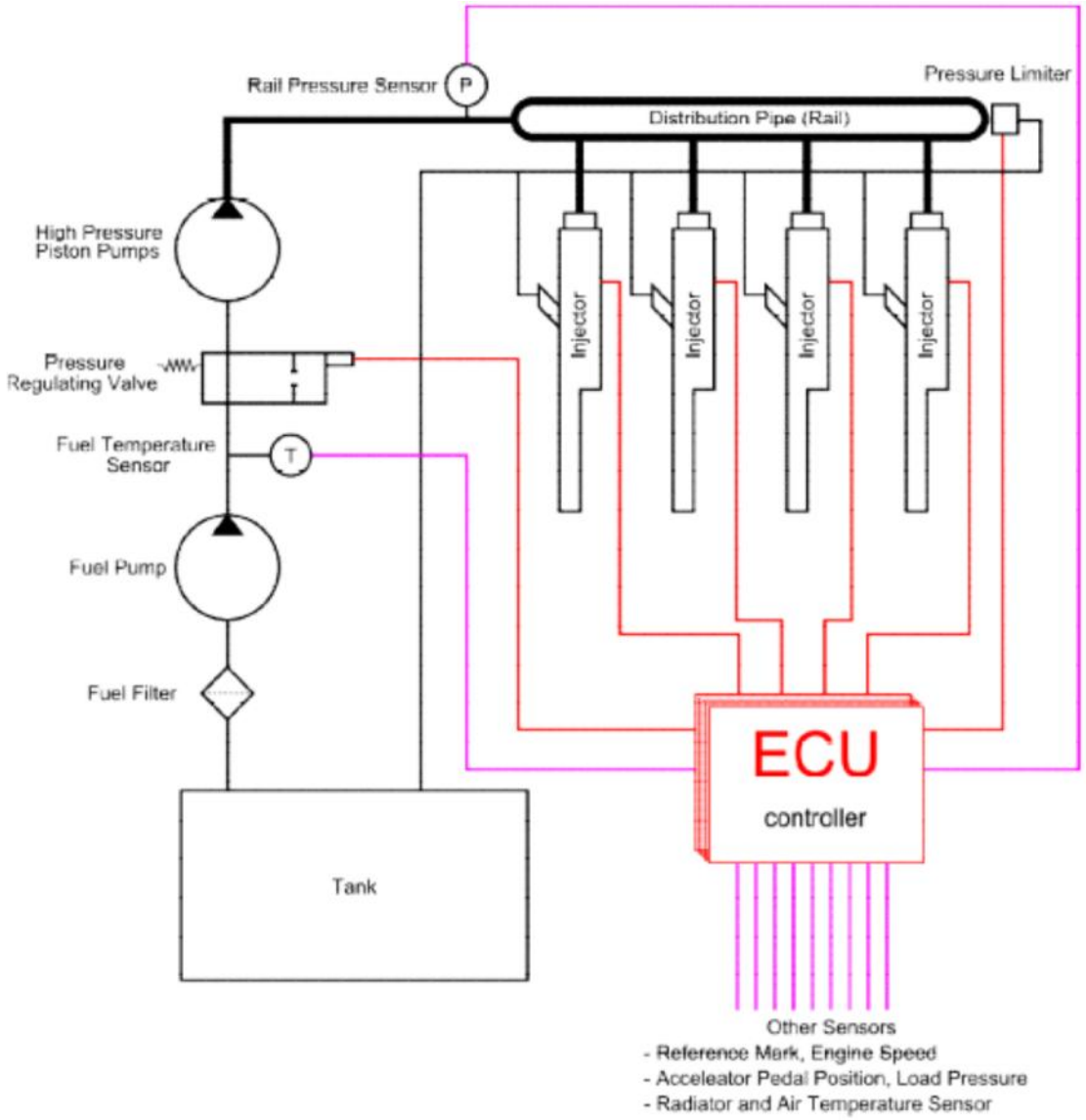
- **Unit Injection systems**

– There is a fuel pump for each cylinder with the pump built in as a single unit with the injector. High pressure is created in the injector (used by Volvo, Land Rover and Volkswagen group).

- **Common Rail Injection Systems (CRDi, DCi)**

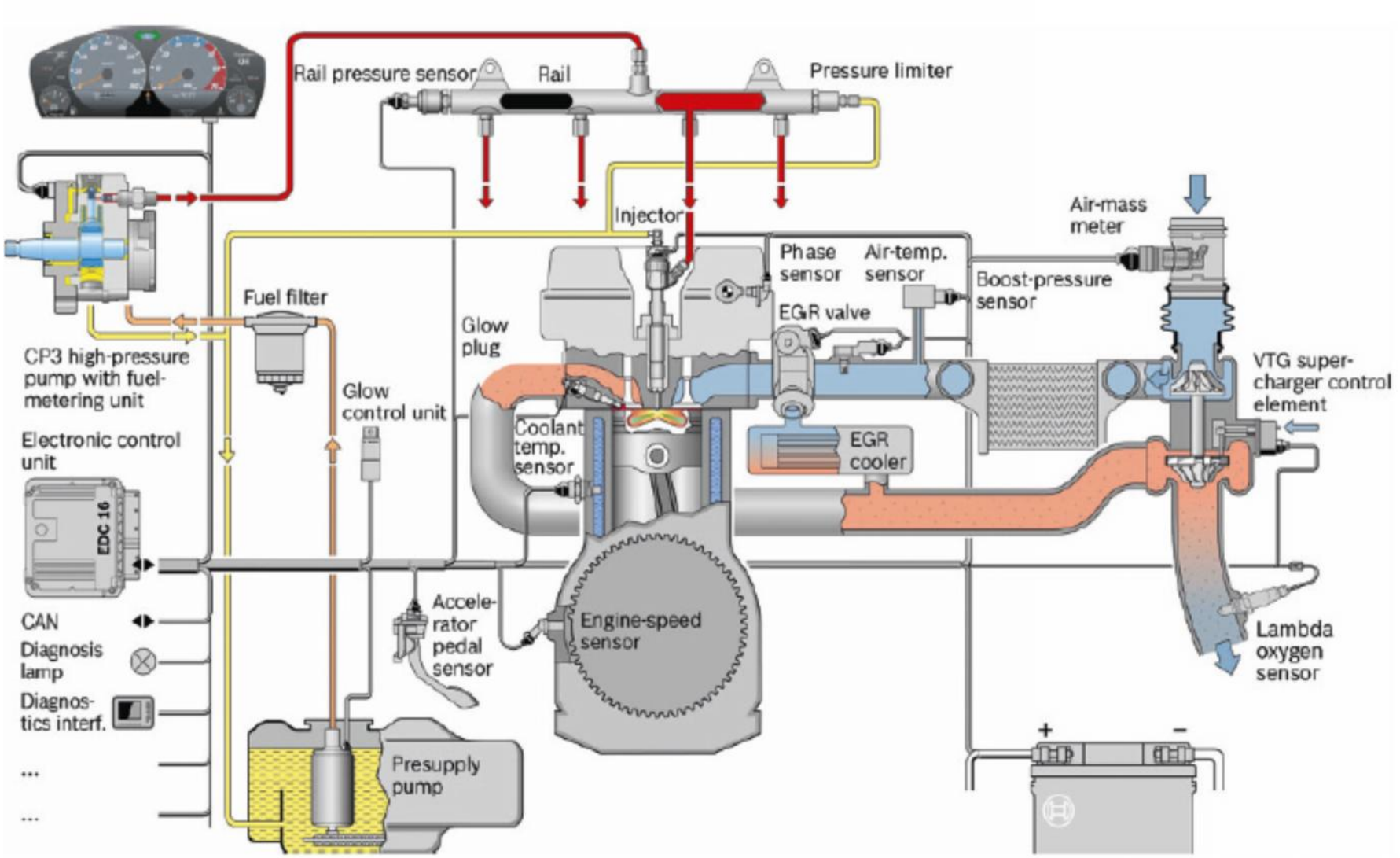
– There is a single fuel pump. The term "common rail" refers to the fact that all of the fuel injectors are supplied by a common fuel rail which is nothing more than a pressure accumulator where the fuel is stored at high pressure.
– High injection pressures and good spray preparation are possible even at low engine speeds and loads.
– Reduced emissions.

Common Rail Injection

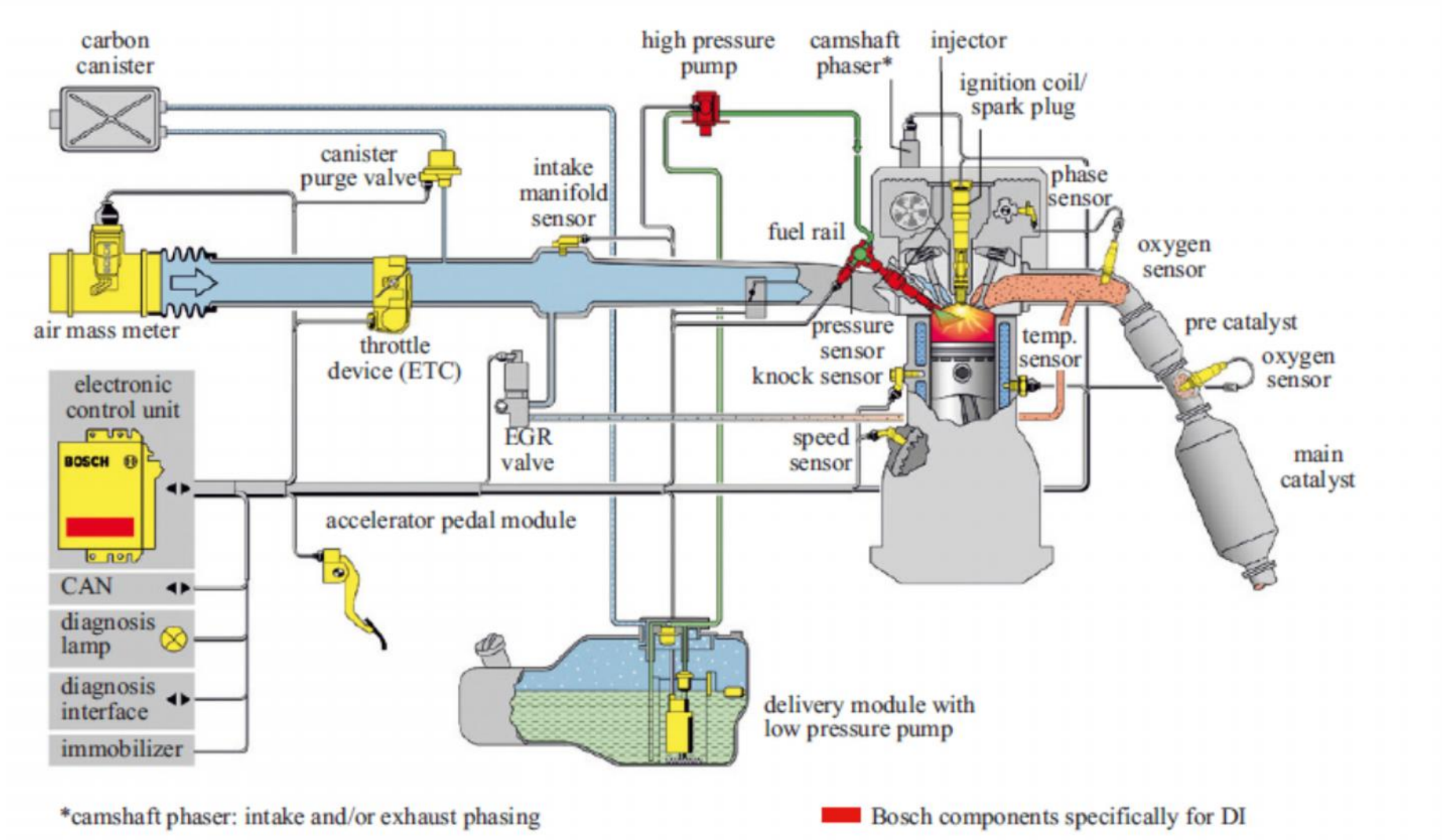


The rail is a thick walled tube designed to supply the full fueling without significant pressure drop. The volume of the rail varies from only a few cubic centimeters in passenger cars, to as much as 60 cm^3 in heavy-duty applications.

Schematic of Direct Injection (CI) [Isermann]

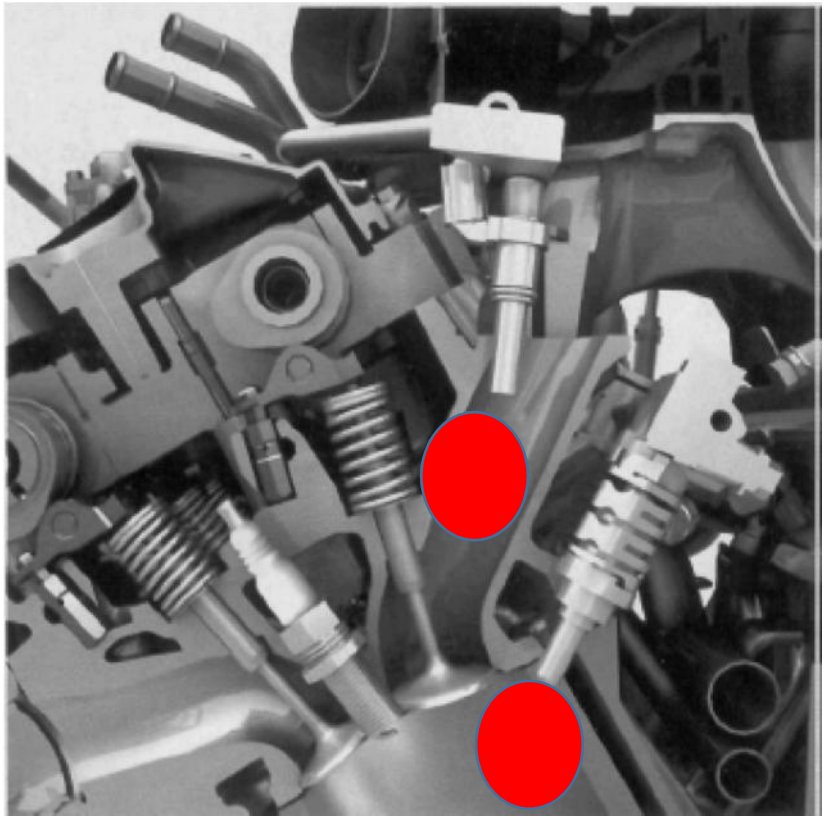


Schematic of Direct Injection (SI) [Isermann]

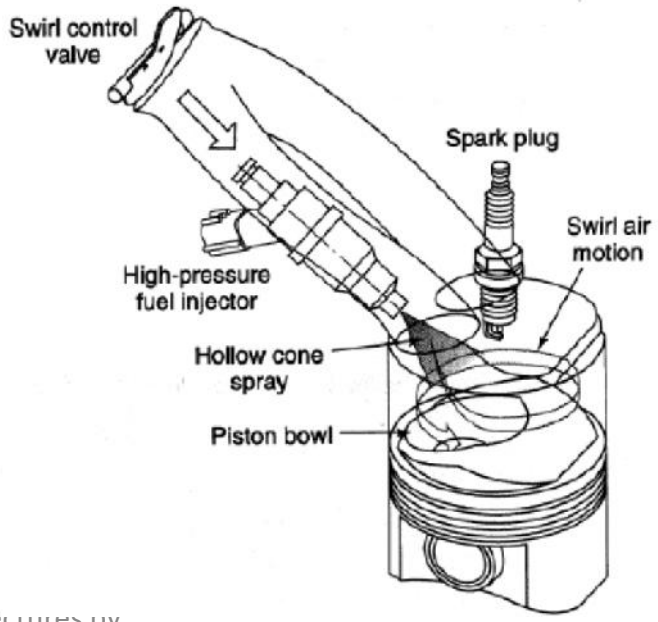


Gasoline Direct Injection (GDI)

(Lexus)

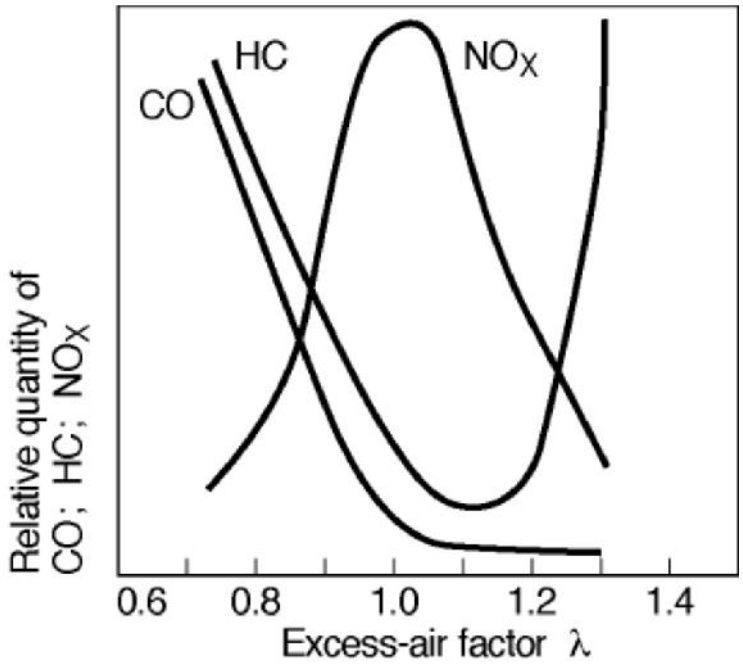


(BMW)



[1Introduction-gasoline direct injection]

- **Hydrocarbons (HC):** Fuel and lubricant gaseous products that did not get burned or partially burned.
- **Oxides of Nitrogen (NO, NO2):** Reactant in photochemical smog. NO2 is toxic.
- **Carbon monoxide (CO):** Toxic
- **Particulates (soot):** are tiny subdivisions of solid matter suspended in a gas. Reduces visibility, mutagenic.
- **Carbon dioxide (CO2):** Believed to be a greenhouse gas.
- **Others:** Aldehydes, Sulfur, Lead



- HCCI has the characteristics of SI and CI engines: Fuel is injected at least 40-50o CA bTDC, a homogeneous charge (lean) is formed and the mixture is compressed until the autoignition occurs as in the case of a CI engine.
- **Ignition occurs at several places at a time which makes the fuel/air mixture burn nearly simultaneously with lean mixture** lowering lower NOx emissions and giving better fuel efficiency.
- Higher compression ratios (14-16) compared to conventional SI engines can be used.
- Higher HC and CO emissions.
- Combustion is difficult to control.

Volkswagen plans to have this technology in Touran models soon!!