Developments in Internal Combustion Engine Technology

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- Pre-mixed combustion with direct injection (GDI)
- Low temperature combustion
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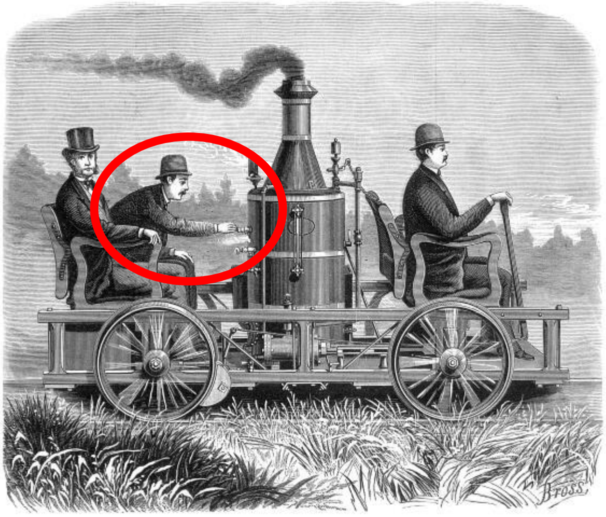
Conclusion

Steam Engine

Chauffeur
(stoker)

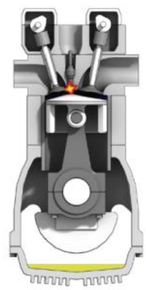


Early IC Engines

First principles of IC engine
Hautefeuille (1676)
Papin (1695)

Modern engines :
Lenoir (1860)
Rochas (1862)
Otto (1876)
Diesel (1892)

Limitations for SI Engines



Compression and Combustion

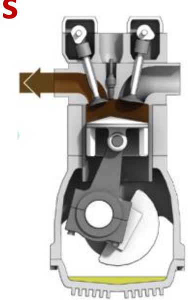
Friction Loss
Heat Loss

Incomplete oxidation
Slow burning
Knock limit
Efficiency limited by CR

Gas Exchange Process

Heat Loss
Pumping Losses
Waste heat out Exhaust

Inefficient valve timing at varying speeds



(Source : Morey, 2011)

Requirements for Sustainable Environment

«The machine that changed the World»

Controlling both the **emissions resulting from combustion process** and the **fuel consumption**

- Developments in engine and vehicle technology
- Utilization of some alternative fuels
- Electrification of the vehicle powertrain

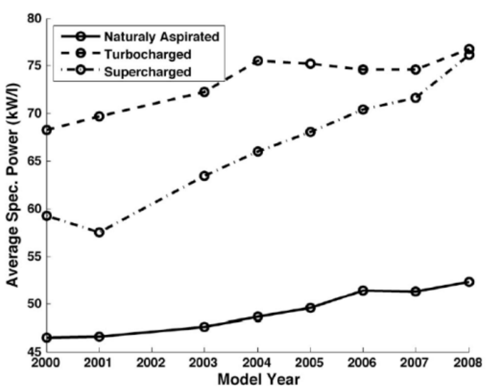
Developments in Engine Technology

Loss reduction (pumping, heat, frictional losses)
Combustion process improvement (quality and speed of burning)
Efficiency increase

some examples;

- Boosting
- Variable valve timing
- Variably reduced number of cylinders
- Start / Stop system etc

Developments in Engine Technology



(Source : Heywood, SAE 2009-01-1892, 2009)

Spark Ignition Engines

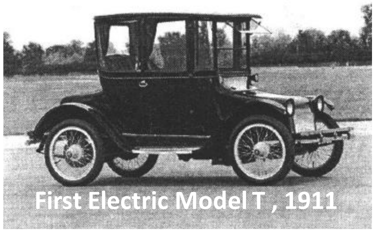
Increase in BMEF (2000 - 2008)

NA	1.4 % yearly
TC	1.5

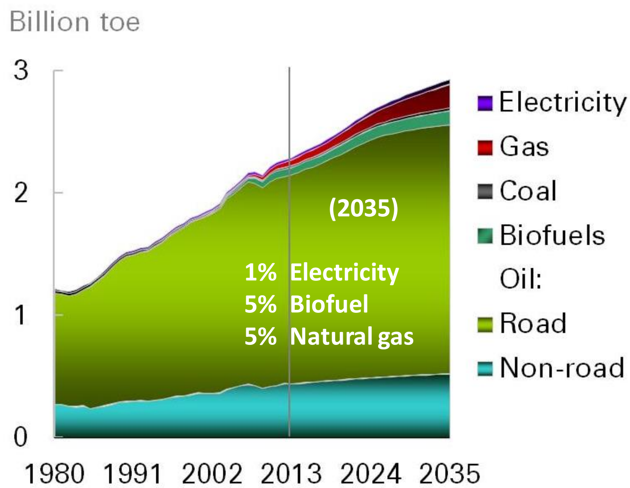
North America (2008 model year)

NA DI	63 [kW/liter]
TC DI	87
NA PI	54
TC PI	75
TC Diesel	43

Transport Demand by Fuel


First Electric Model T , 1911

(Source : Schuetzle and Glaze, 1999)



(Source : Energy Outlook 2035, BP 2014)

Advanced Combustion Concepts

Compression Ignition (CI) engines have higher efficiency at part load operation, longer lifetime and relatively lower emissions of CO2, CO and unburned HC

Spark Ignition (SI) engines have higher power density and lower combustion noise.

In the history of engine design and development, there have been many attempts to combine the advantages of both CI and SI engines.

Gasoline Direct Injection Engines

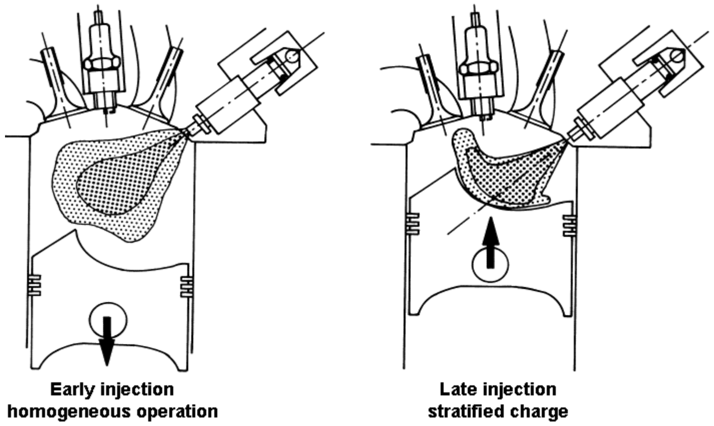
Conventional Spark Ignition Engines

pre-mixed combustion
homogeneous and stoichiometric mixture prepared in the manifold

GDI Engines

in-cylinder mixture formation
stratified charge with a globally lean mixture

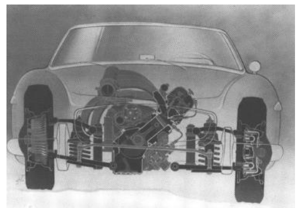
Gasoline Direct Injection Engines



Gasoline Direct Injection Engines

Spread of GDI engines in the market took a long time from 1970's to 1990

competitive cars	2 – 3 years
all vehicles	approx. 10 years



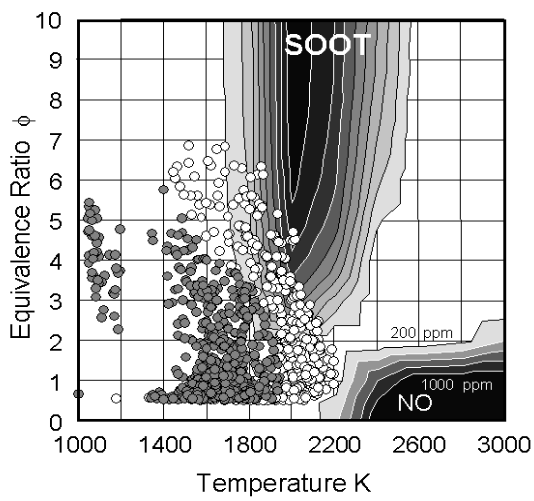
First application was in 1954
with Mercedes 300SL
(6-cylinder 2996 cc 215HP SI engine)

(Source : Eckermann, 2001)

Low Temperature Combustion

Diesel Engine
major pollutants are
NOx and PM

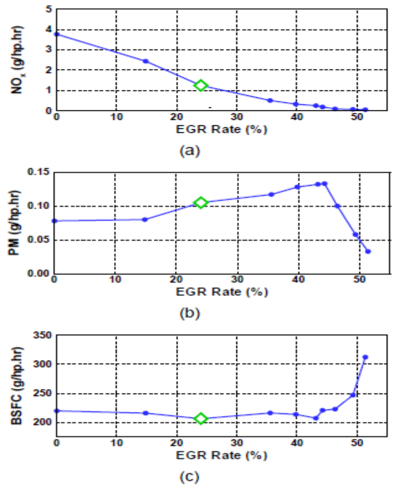
There is a trade – off
between these emissions



(Source: Akihama, SAE 2001-01-0655)

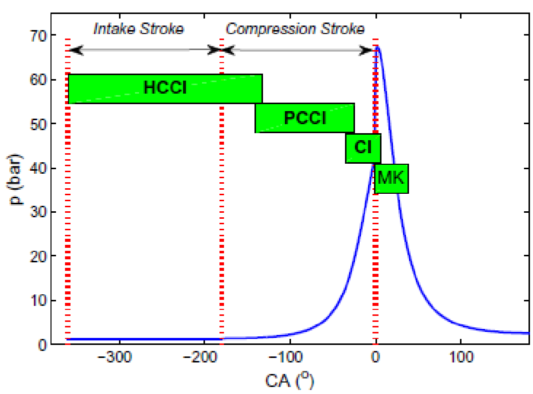
Low Temperature Combustion

Heavy EGR application



(Source : Wagner, SAE Paper No.2003-01-0262)

Advanced Combustion Concepts



(Source : Ulas, PhD Thesis, TU Eindhoven, 2013)

HCCI Engines

Homogeneous Charge Compression Ignition engines : lean and homogeneous mixture is compressed until p and T are high enough for autoignition to ocur

HCCI ignition is governed by **chemical kinetics** and **histories of cylinder pressure and temperature** (inlet air temperature, compression ratio, residual gas ratio and EGR, wall temperature). Combustion starts simultaneously all over the cylinder

Reaction rate is much lower than knock in SI engines due to a higher dilution of the fuel with air or residual gases (EGR)

HCCI Engines

High thermal efficiency due to high compression ratio, rapid heat release rate

Low specific fuel consumption with lean mixture

Low NOx emissions

Difficulties in controlling ignition and combustion over a wide range of engine operating conditions

PCCI Engines

Premixed charge compression ignition engines : mixture of the fuel with air is provided prior to the initiation of combustion due to early injection of the fuel into the cylinder at low pressure and temperature conditions for autoignition to take place.

Combustion is controlled by **chemical kinetics**. In cylinder temperature levels are controlled by applying heavy exhaust gas recirculation (EGR) rates to dominate ignition process, which also controls NOx and PM emissions.

PCCI Engines

Misfire especially at **low load conditions** is a potential problem

Rapid pressure rise at **high loads** and uncontrolled ignition timing are other issues which can cause low thermal efficieny and engine damage

Dual Fuel Combustion

Premixed Natural Gas induced into the cylinder during the intake stroke and ignited by **pilot injection of Diesel Fuel**

Lean operation is possible providing reduction in emissions and improvement in fuel consumption

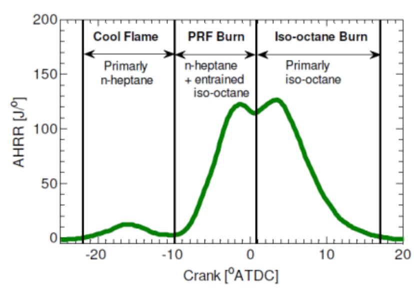
City Bus fleet in
Asian part of Istanbul
(1992)

RCCI Engines

Reactivity Controlled Compression Ignition engine : mixture is formed with early injection of the fuel into the cylinder

Low octane fuel injected earlier can be blended with high octane fuel with post injection

Fuel blend ratio and injection timing are the parameters for control



(Source : Reitz, 2011)

RCCI Engines

Varying the mixture ratio of fuel blends with different reactivity levels can provide considerably high thermal efficiencies.

Relatively low injection pressures, in comparison to fuel injection systems used in modern diesel engines, provide energy saving.

Low temperature combustion reduce NOx emissions while the level of uniformaty of the mixture reduce PM emissions.

Conclusion

Using pre-mixed combustion in compression ignition engines can combine the advantages of the present CI and SI engines in one system

Considerably high thermal efficiencies can be achieved by varying the reactivity levels of the fuel blends used

Clean and efficient operation of IC engines can be achieved with new combustion concepts

Thank you for your attention