EC-LB-Topic VI

Introduction to Homogeneous Charge Compression Ignition (HCCI) Engines

Why Do We Need much more Advanced ICEs, such as Homogeneous Charge Compression Ignition (HCCI) Engines ?

The answer is mainly associated with:

☞ *Effectuation of the Kyoto protocol on February 16, 2005*

- *CAFE*
- *CO_2 emission trading*
- *Mileage CO_2 emission rate*

☞ *Inadequate state-of-the-art catalytic control technologies*

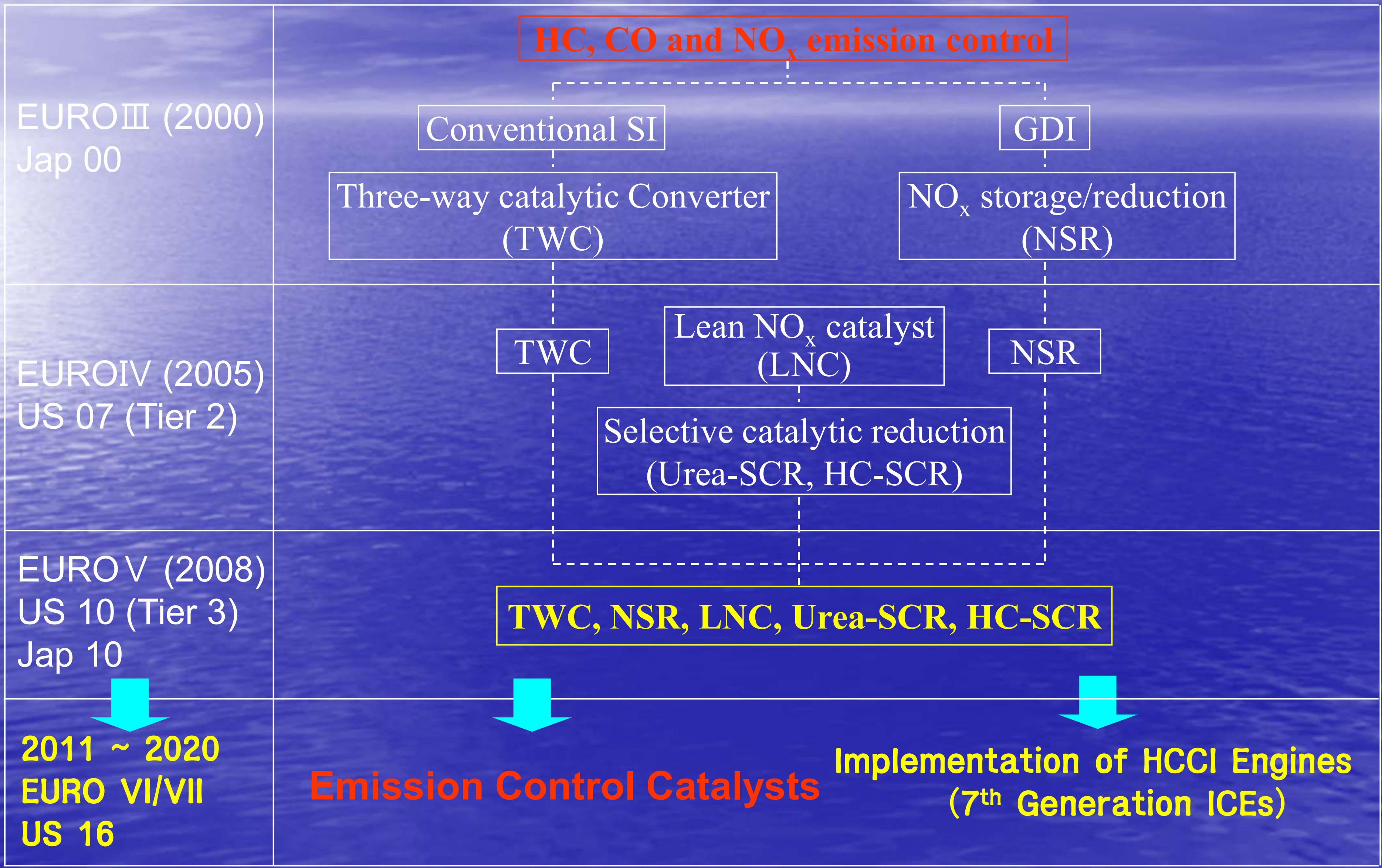
- *EURO VI/VII and (US14) US16*

☞ *Mandatory on-board diagnostic (OBD) systems*

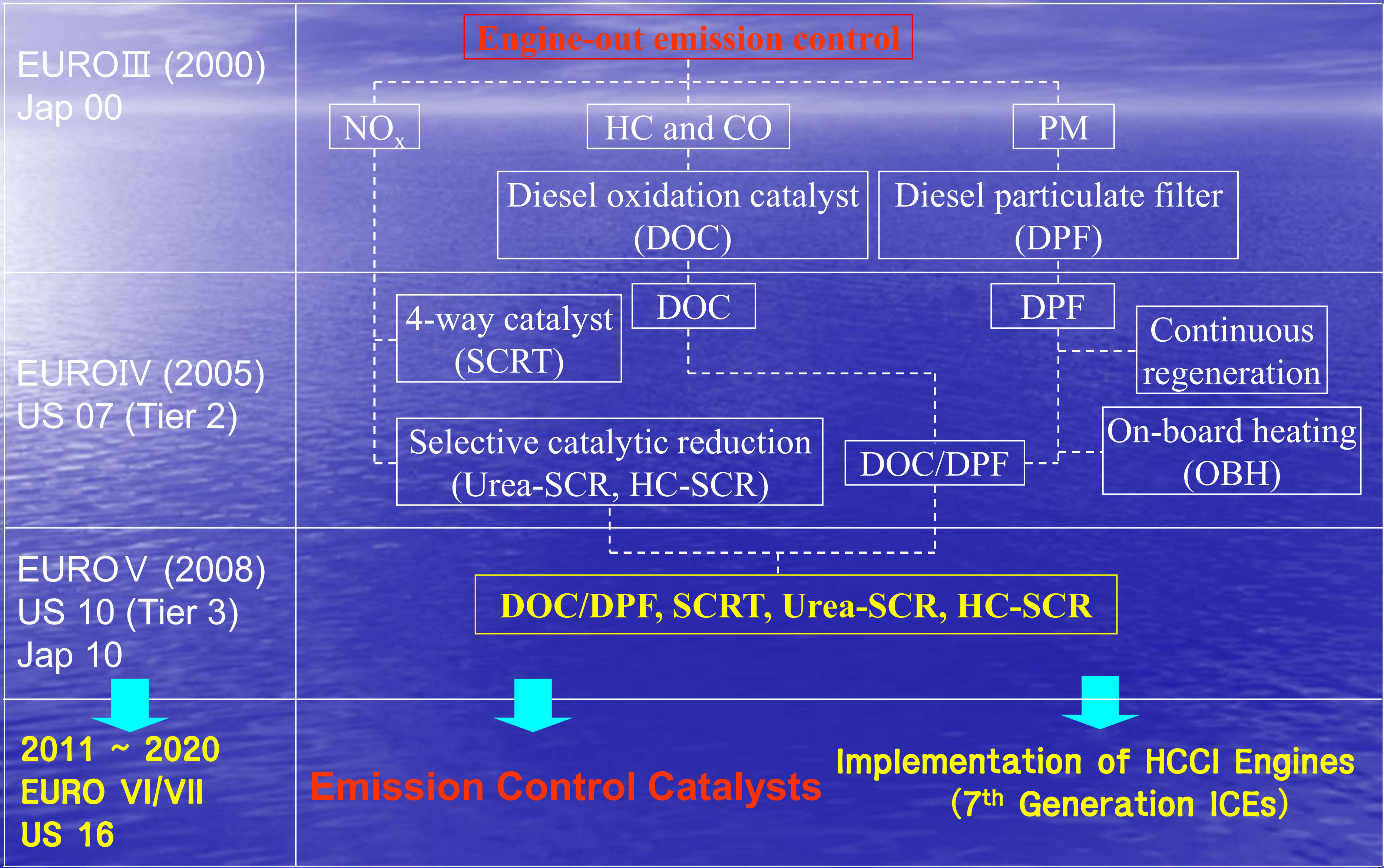
☞ *Global energy transition*

- *Bio-fuels, NG and H_2: 20% of road transport fuels by 2020*

Catalytic Technology for Gasoline Engine-out Emissions Control



Catalytic Technologies for Diesel Engine-out Emissions Control



Challenges of Gasoline and Diesel Emission Controls

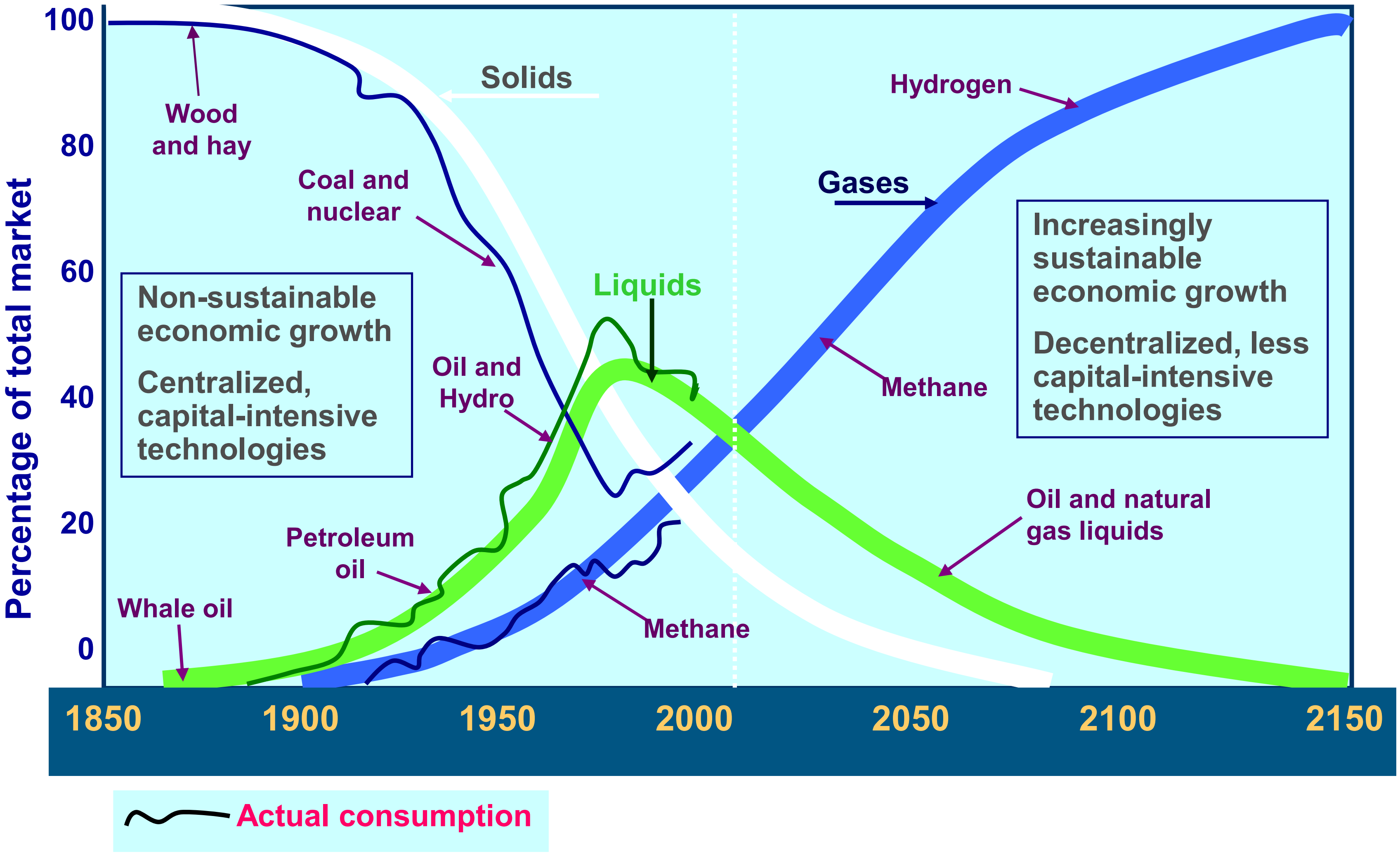
Aftertreatment systems	Efficiency	Limitations and/or requirements
TWC	> 90%	• Not working under lean burn conditions
LNC	20 ~ 40%	• Low catalytic efficiency • Production of N_2O with significant amounts • Post injection • High thermal stability • High sulfur tolerance
NSR	60 ~ 80%	• Very weak sulfur tolerance • Continuous or periodical regeneration • Post injection
SCR	70 ~ 90%	• Use of reductants • Subsequent infrastructures • Very complicated system • High volume of SCR catalysts • No way of PM reduction
DOC	HC and CO: 50 ~ 70% PM: ~20%	• Low catalytic efficiency • No way of NO reduction
DOC/DPF	HC and CO: 60 ~ 80% PM: 50 ~ 70%	• Continuous or periodical regeneration • Post injection • Weak sulfur tolerance • No way of NO reduction

Mandatory OBD Threshold Limits

Class	Reference weight (kg)	CO (g/km)		HC (g/km)		NO_x (g/km)		PM (g/km)
		SI	CI	SI	CI	SI	CI	CI
I	RW ≤1305	3.2	3.2	0.4	0.4	0.6	1.2	0.18
II	1305 < RW ≤1760	5.8	4.0	0.5	0.5	0.7	1.6	0.23
III	1760 < RW	7.3	4.8	0.6	0.6	0.8	1.9	0.28

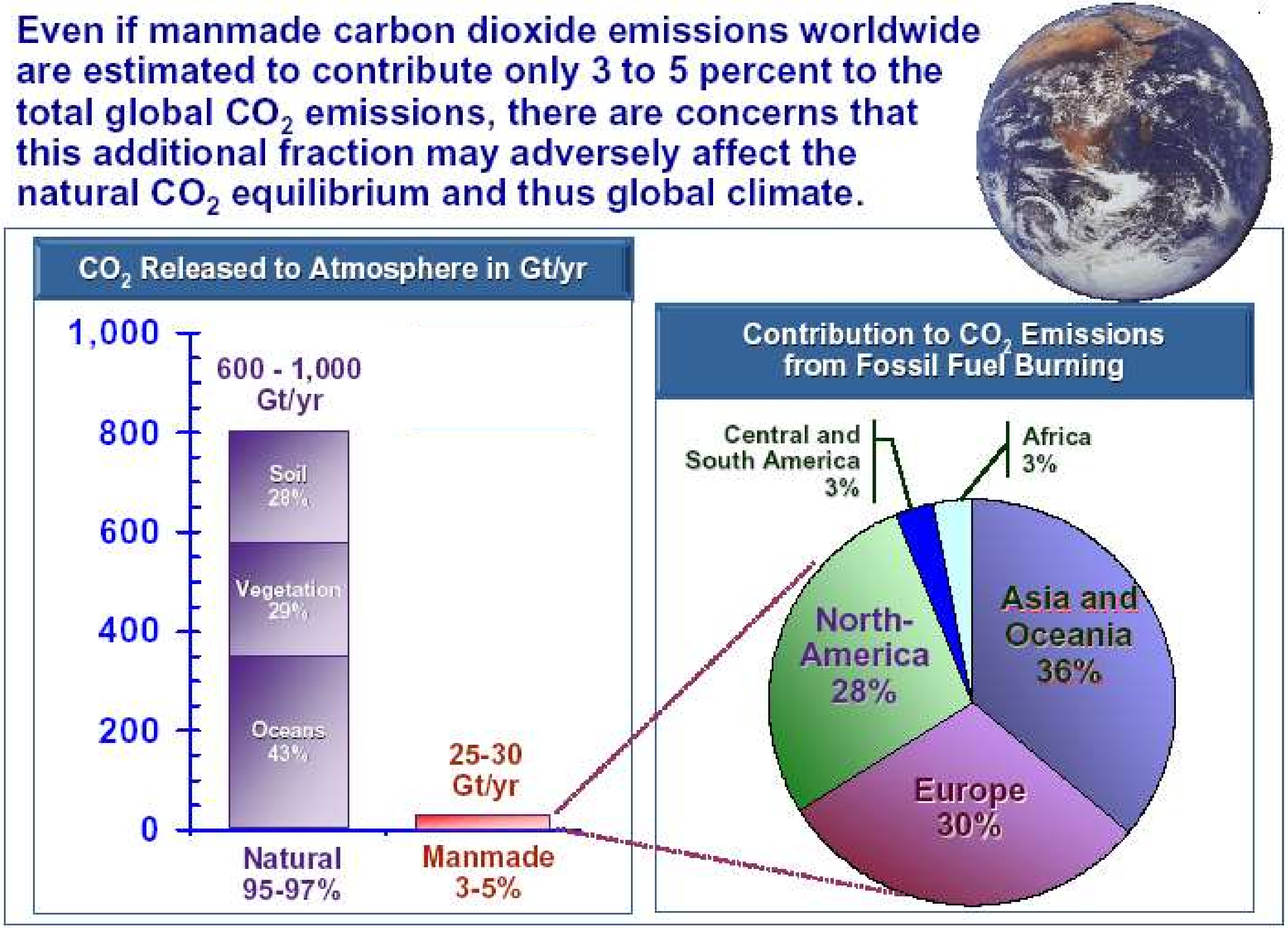
Gasoline and diesel passenger cars, except those designed to carry more that 6 persons including the driver and those of maximum mass exceeding 2,500 kg, must be fitted with an OBD system for engine-out emissions control.

Global Energy System Transition



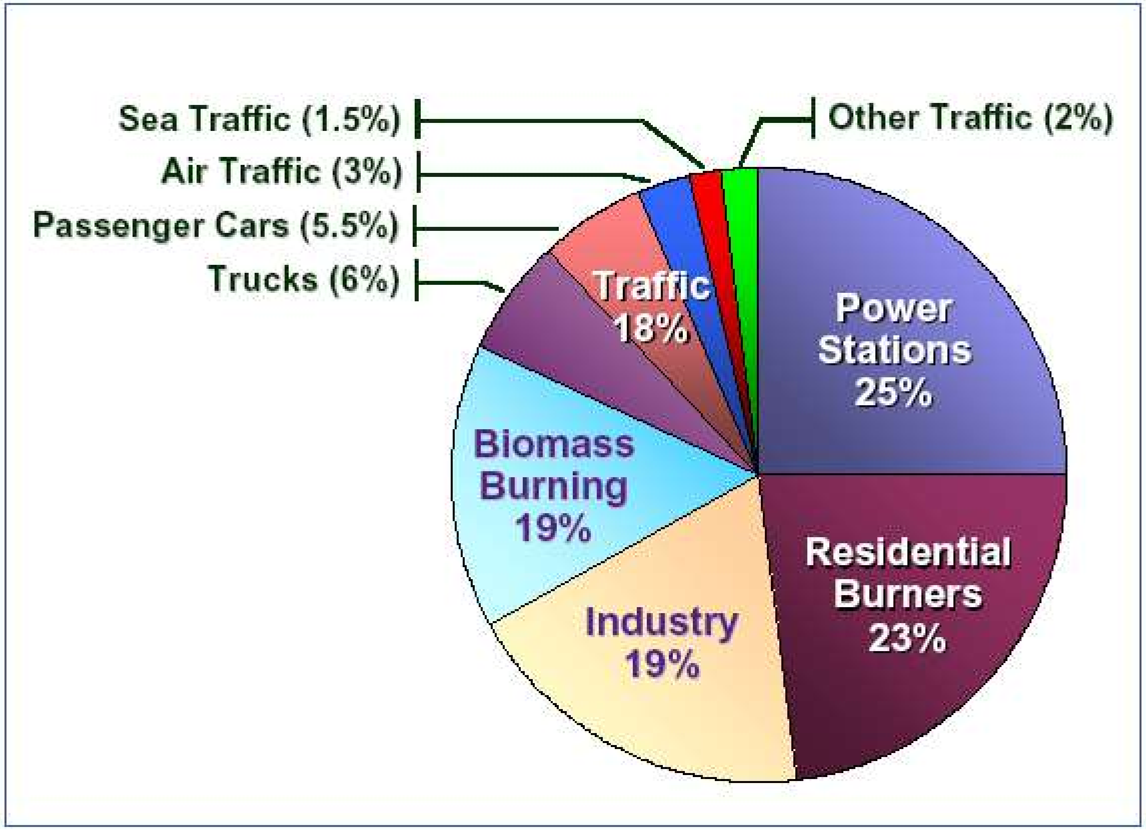
Global CO_2 Emissions

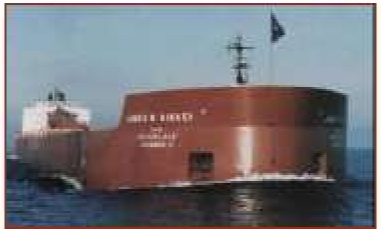
Even if manmade carbon dioxide emissions worldwide are estimated to contribute only 3 to 5 percent to the total global CO_2 emissions, there are concerns that this additional fraction may adversely affect the natural CO_2 equilibrium and thus global climate.



CO_2 Emission Estimates by End-Use Sectors

The transportation sector, representing one fifth of all manmade CO_2 emissions, consequently can expect to face mounting pressure to raise fuel efficiency in the wake of the Kyoto agreement to cut emissions of greenhouse gases back to 1990 levels by 2008–2012.





Systematic Integration of Gasoline and Diesel ICEs to HCCI Engines

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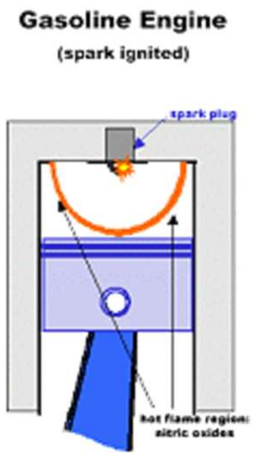
<td>
</td>
<td>TWC</td>
<td>High power density</td>
<td></td>
<td rowspan="2">

HCCI-Diesel hybrid vehicles in Europe has been sold by Nissan Motors in 2004.</td>
<td rowspan="2">High power density and high fuel economy
+
Very low CO_2 emissions</td>
<td rowspan="2">Unsolved problems:
• Ultra precise control for combustion
• Engine-out emissions control</td>
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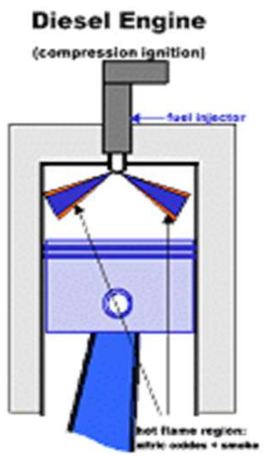
<td>
</td>
<td>DOC
+
DPF</td>
<td>High fuel economy</td>
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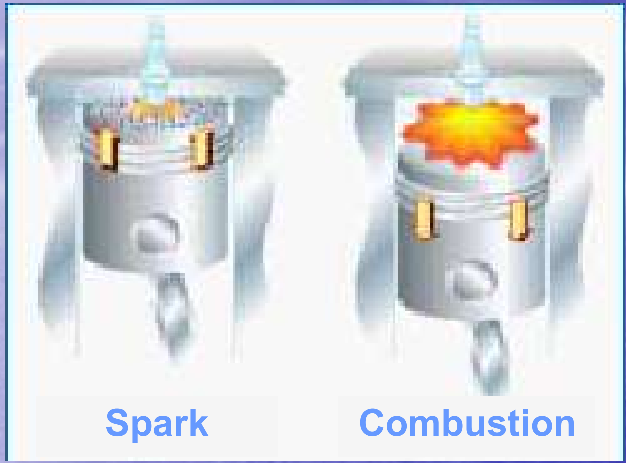
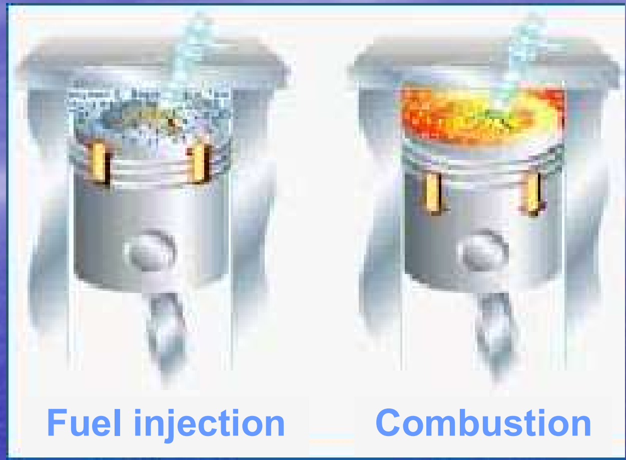
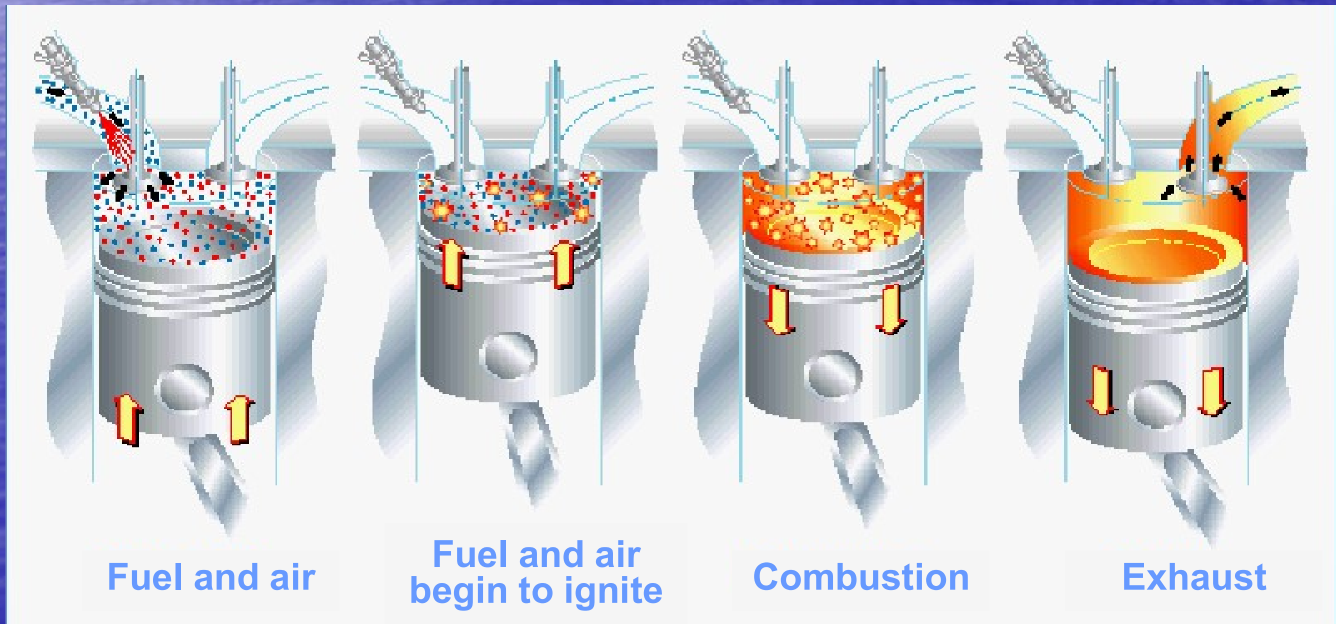
Toolbox Modes of Combustion



@ SI Engine

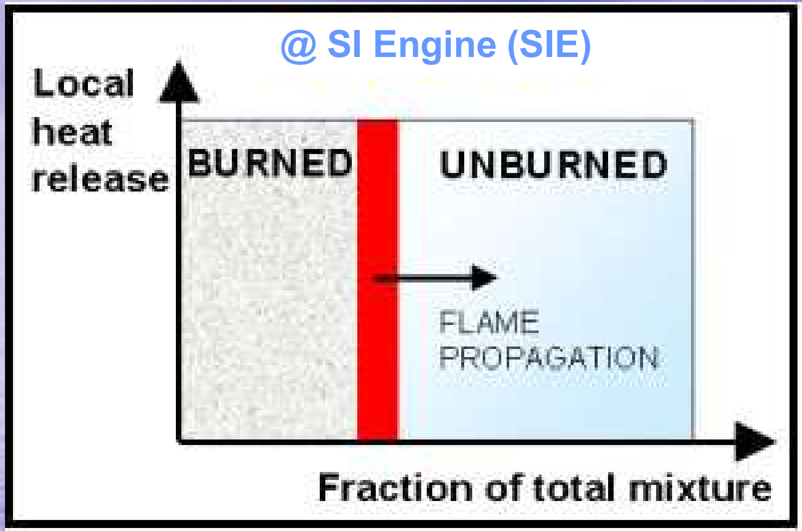


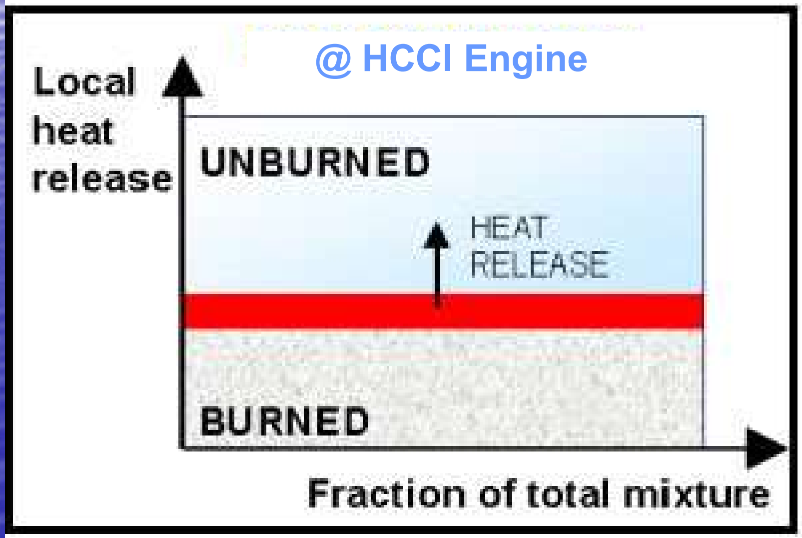
@ CI Engine



@ HCCI Engine

Combustion Mode of HCCI Engines





Homogeneous Charge Compression Ignition (HCCI) combustion is best regarded as an operating mode of internal combustion engines.

In SI engines, a flame is initiated by a electric discharge and propagates through a premixed charge of air and fuel.

In CI engines, the flame starts at multiple sites by autoignition in a heterogeneous mixture.

Under HCCI conditions a homogeneous mixture of fuel, air and residual gases from previous cycles are compressed until autoignition occurs. Combustion initiates at multiple sites throughout the combustion chamber.

Such HCCI engines have the potential to combine the advantages of both the CI and the SI engine, and offers excellent fuel economy, low noxious emissions and stable combustion. However, significant obstacles remain to implementation of HCCI engines in practical passenger cars.

Advantages of HCCI Engines

HCCI has been proposed as the ultimate lean burn concept because of the potential for high thermal efficiency and near-zero NOx emissions.

- ***As in Diesel engines, the fuel is exposed to a sufficiently high temperature for auto-ignition to occur (compression ignition).***
- ***However, in contrast to Diesel engines a homogeneous fuel/air mixture is used.***
- ***An important difference between spark ignition and HCCI engines is the lack of flame propagation in HCCI combustion and hence increased lean burn tolerance.***

Advantages	
Advantages	• High thermal efficiency (some studies have reported over 50%) associated with unthrottled, ultra-lean operation: - *Increased ratio of specific heats during expansion stroke* - *Lower dissociation losses* - *Reduced cooling losses* • Very low NO_x emissions (<10ppm, some studies have suggested that less than 1ppm may be attainable) resulting from ultra-lean operation ($\phi < 0.5$). • Next to zero emissions of particulate matter thanks to pre-mixed homogeneous charge operation • Compatible with fuels ranging from natural gas to Diesel.

These emissions characteristics could allow the technology to operate without NOx reduction exhaust aftertreatment. Oxidation catalysts would be required however as both CO and HC can exceed 10,000 ppm.

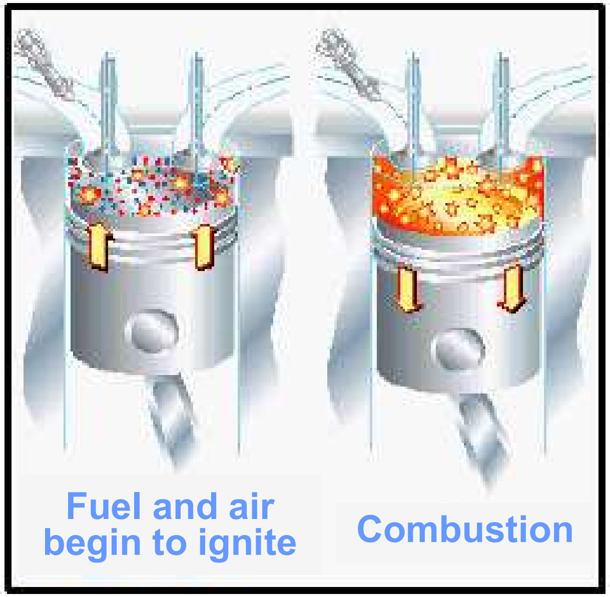
Challenges of HCCI Engines

A critical limitation of HCCI is that the engines are prone to misfire and knock unless maintained within a certain operating window which makes control over a range of operating conditions challenging.

Challenges
• Combustion phasing is hard to control over a range of load, resulting in problems with misfire and knock. • Very rapid combustion results in high pressure rise rates provoking audible noise. • High peak pressures. • The combustion of highly dilute mixtures in these engines results in relatively low power density (unless supercharged). • In addition, lean-burn exhaust composition is incompatible with the current state of the art NO_x reduction catalyst technology. Consequently, reaching very low levels of NOx emissions hinges on achieving stable controllable operation at ultra-lean conditions ($\phi < 0.5$).

Homogeneous Charge Compression Ignition (HCCI) Engines

The Holy Grail of Internal Combustion Engines…
But
Can We Tame the Beast?

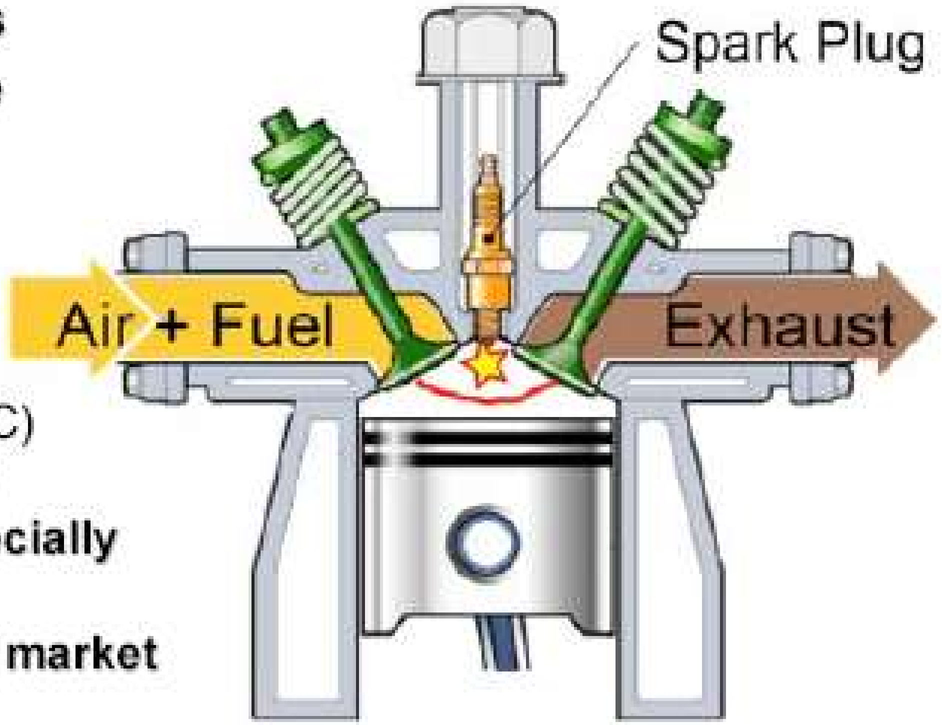


- Combustion phasing and control
- Proper air/fuel mixing
- Full road operation

- HCCI engine-out emissions control
  - [CO] ≥ 10,000 ppm
  - [HC] ≥ 10,000 ppm
  - $[NO_x]$ ≤ 10 ppm
  - Active radicals

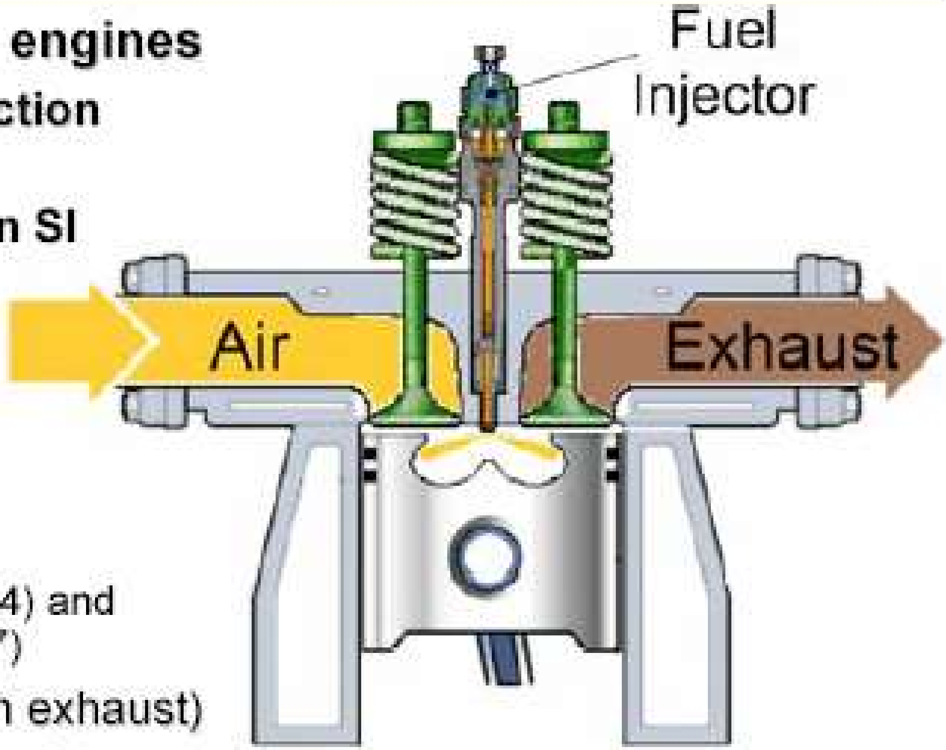
Current Engine Technologies: SI

- **Spark-ignition (SI) engines**
  - **Port fuel injected gasoline**
  - **Non-optimal efficiency**
    - Low compression ratio
    - Pumping losses
  - **Very low emissions**
    - Three-way catalyst (TWC) removes NO_x, UHC, CO
  - **Good power density, especially at high speed**
  - **Dominates light-duty (LD) market in US**
    - Low emissions
    - Lower peak cylinder pressure → cheap to manufacture



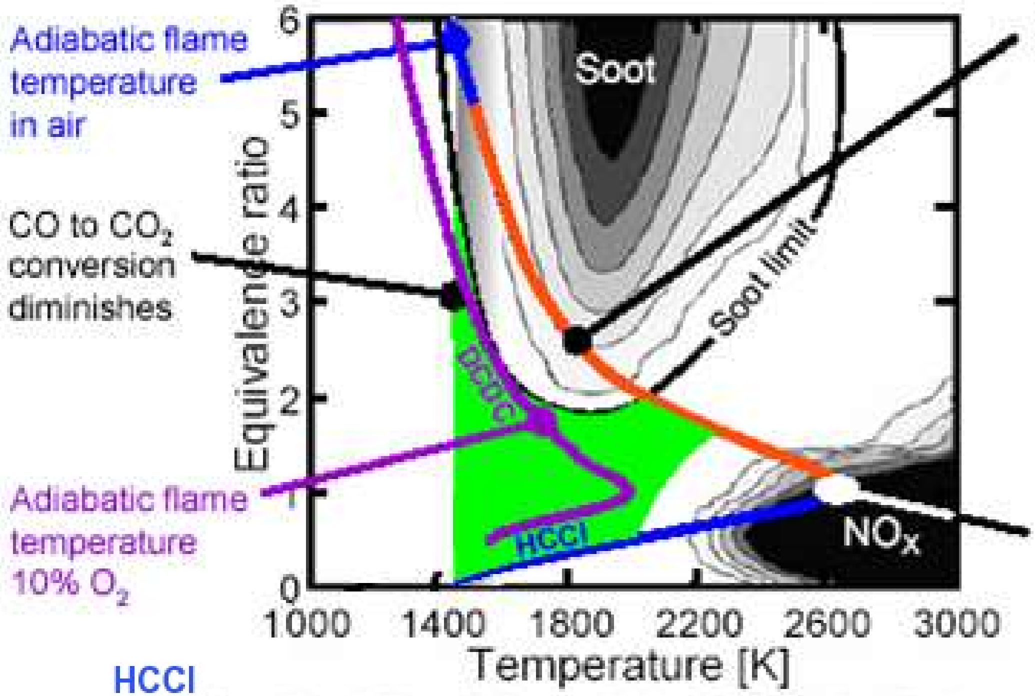
Current Engine Technologies: CI

- Compression-ignition (CI) engines
  - Turbocharged, direct injection of diesel fuel
  - 30-40% more efficient than SI
    - Higher compr. ratio
    - Load controlled by amount of fuel injected
  - Emissions
    - High NO_x and soot
      - LD fails CA LEV II (2004) and Fed. Tier II, Bin 5 (2007)
    - TWC doesn't work (O_2 in exhaust)
  - Better low-end torque than SI
  - Dominates heavy-duty market
    - Highly efficient and reliable



Graphical Summary of SI, CI and HCCI Engines

Akihama et al., SAE paper 2001-01-0655

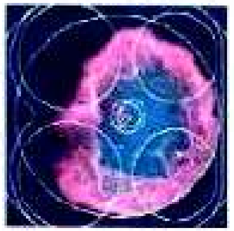


Diesel (CI) combustion

- controlled heat release (mixing)
- controlled combustion timing
- wide load range
- high efficiency (relative to SI)
- **NO_x and PM emissions**

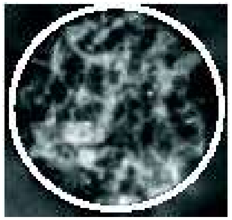
Spark ignition (SI) combustion

- controlled heat release (flame propagation)
- controlled combustion timing
- wide load range
- three-way catalyst
- **low efficiency** (relative to diesel)



HCCI

- offers diesel-like efficiency (high CR & no throttling)
- low NO_x and particulate emissions
- **load range?**
- **combustion timing?**
- **heat release rate?**
- **transient control?**
- **fuel?**

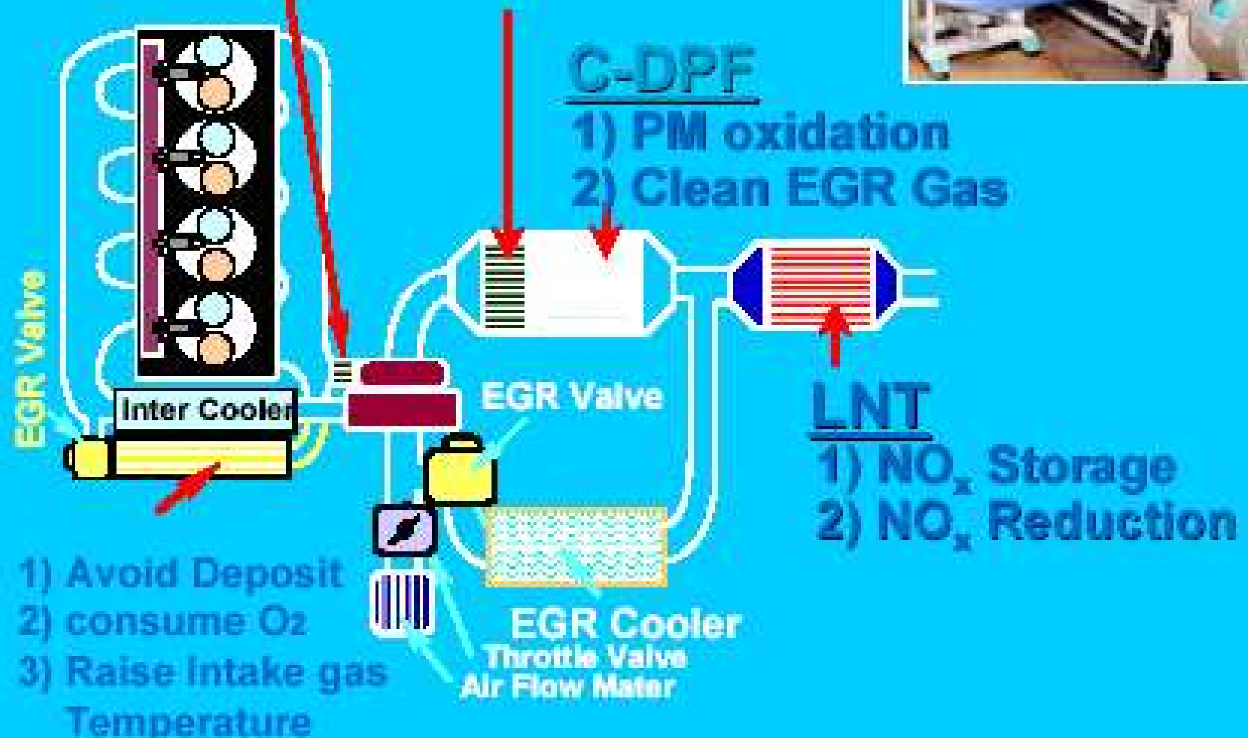


Advance Diesel Engine

Euro V / US Tier II
Combustion Strategies for
Light-Duty Diesel Engine

SwRI Internal Research

Project



Summary

Homogeneous Charge Compression Ignition (HCCI) engines are attracting significant attention as a clean and efficient power source

HCCI engines provide high efficiencies with dramatically improved emissions.

- ***Thermal efficiency reported: 50%***
- ***NOx < 10 ppm (compared to > 500 ppm for diesel engines)***
- ***PM < detection limit (comparable to gasoline engines)***

With conventional control technologies, misfire and knock limits the load following capabilities of HCCI engines to less than half of that required.

If the control issues are successfully addressed, HCCI could combine fuel economies comparable to the best diesel engines, with exhaust emissions comparable to the best spark-ignition engines.