Consiglio Nazionale delle Ricerche

Study of Advanced Combustion Mechanisms for Clean Engines at Istituto Motori

Felice E. Corcione

Istituto Motori – CNR

Naples - Italy

IEA 31th TLM – Collaborative Task on HCCI

Lake Louise - Canada, Sept. 20 - 24, 2009

Outlines

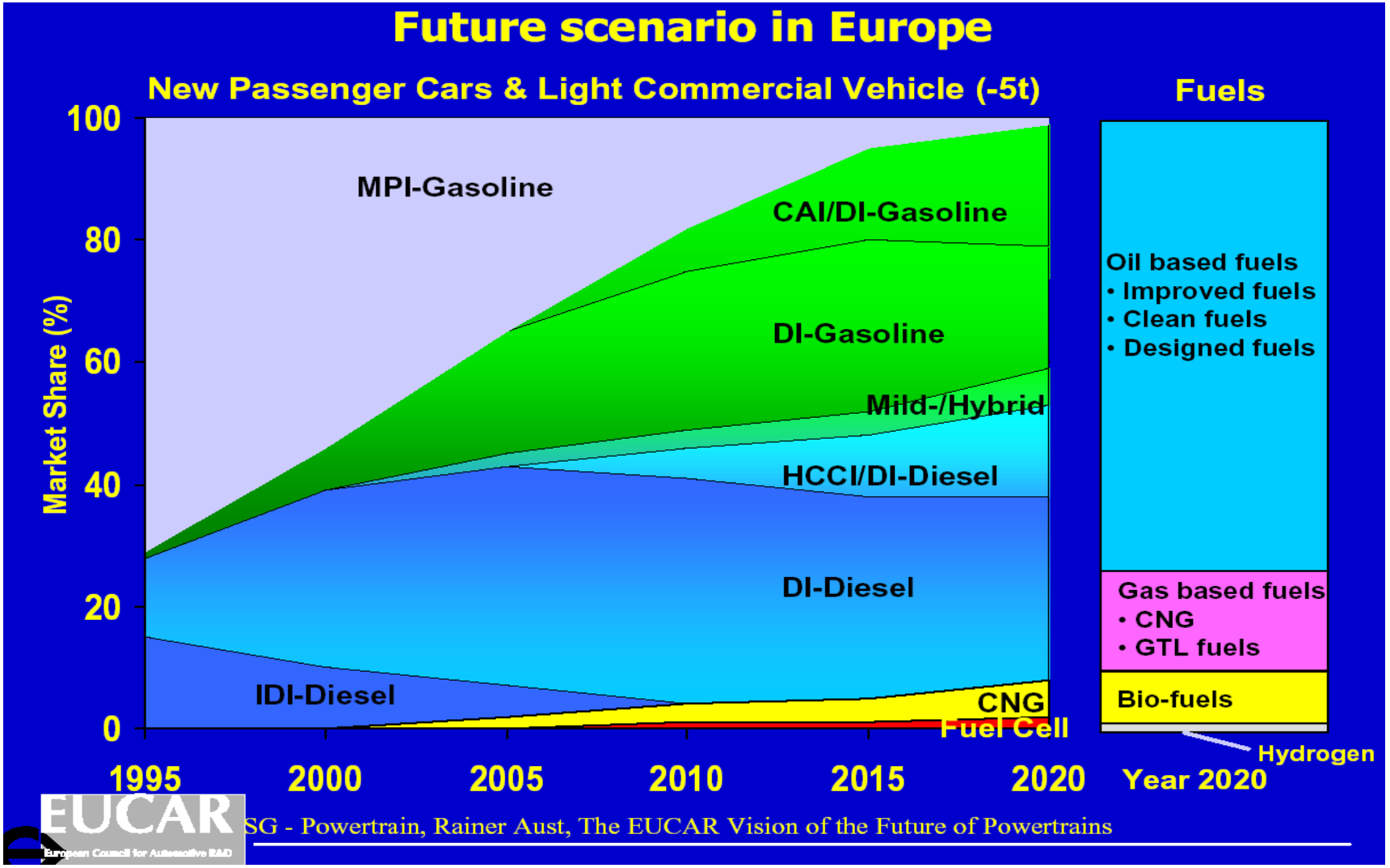
- Introduction & Background
- Advanced Combustion Mechanisms
- Low Temperature Premixed Combustion
- Optical Engines & Investigation Techniques
- Fuel for Advanced Combustion Mechanisms
- Conclusion

Introduction-Background
Engine Exhaust Emission

Introduction-Background

Engine Technology Road Map

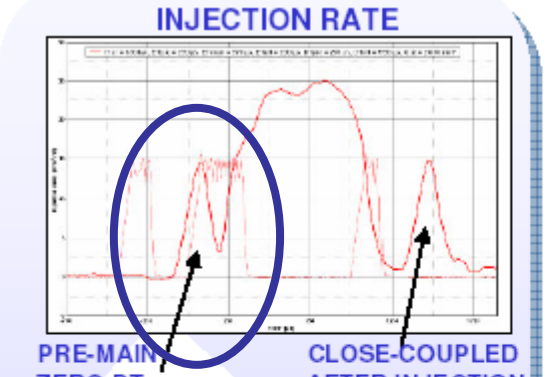
Future Vehicle Scenario in Europe



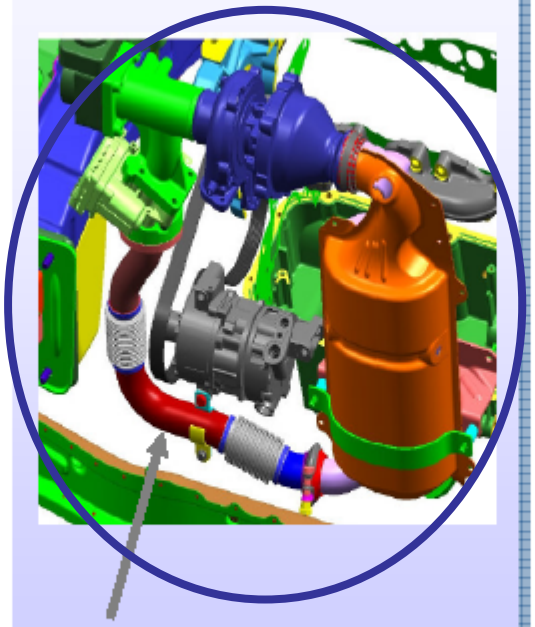
Introduction-Background

Drivers of the Powertrain Technology in the Next Decade 2010 - 2020

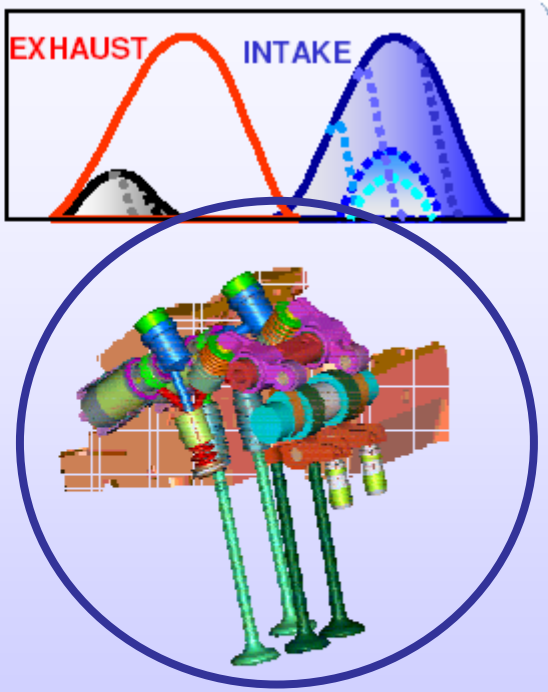
Who Will Drive the Powertrain Technology in



New Common Rail Technology for Modular Injection



Ultracooled & Clean EGR (Low Pressure EGR)



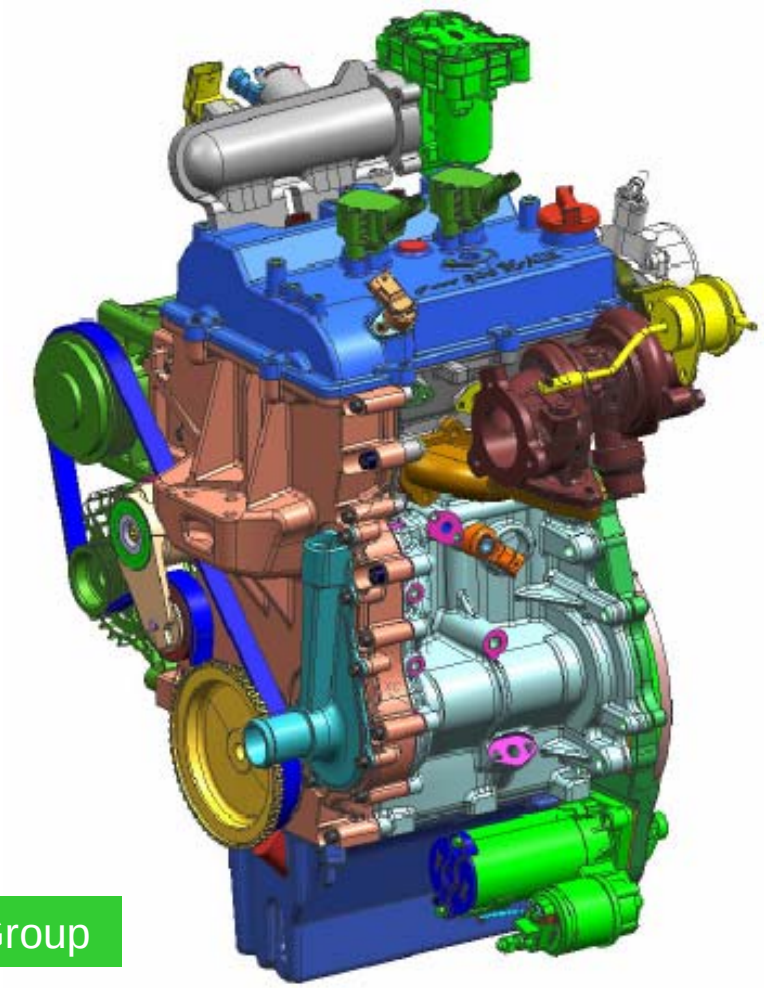
Electronic VVA for Transient EGR Control

Source FIAT Group

Introduction-Background

Drivers of the Powertrain Technology in the Next Decade 2010 - 2020

And:



ing

0.9 liter Twin-Cylinder
Multiair Turbo Engine

Power 78 kW
Torque max 155 Nm
CO2 Emission - 20%

Source FIAT Group

Introduction-Background

Drivers of the Powertrain Technology in the Next Decade 2010 - 2020

New Mechanism of Combustion

And

New Fuels

Advanced
Combustion Mechanisms

+Clean with 3-way Catalyst
-Poor low & part load efficiency

+ High efficiency
- Emissions of NO_x and soot

Spark Ignition (SI) engine (Gasoline, Otto)

Compression Ignition (CI) engine (Diesel)

+ High efficiency
+ Ultra low NO_x

Homogeneous Charge Compression Ignition (HCCI)

- Combustion control
- Power density

HCCI?

Spark Assisted Compression Ignition (SACI) Gasoline HCCI

Partially premixed combustion (PPC) Diesel HCCI

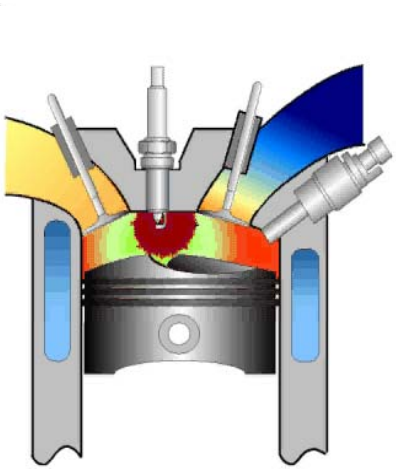
+ Injection controlled
- Less emissions advantage

Advanced Combustion Mechanisms

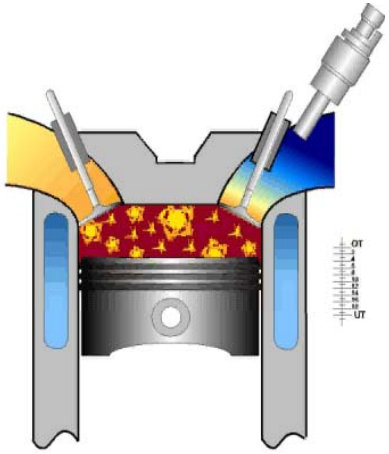
HCCI, CAI, PCCI, pHCCI, PPC, LTC…?

- HCCI is normally a set-up with port fuel injection and high compression ratio.
- CAI is normally a set-up with low compression ratio and high residual gas concentration with negative valve overlap
- PCCI is normally a set-up with early direct injection forming a rather homogeneous charge
- PPC, partially premixed combustion is an bit less homogeneous than PCCI i.e. later injection
- LTC is any combustion process giving low NOx due to low temperature combustion.

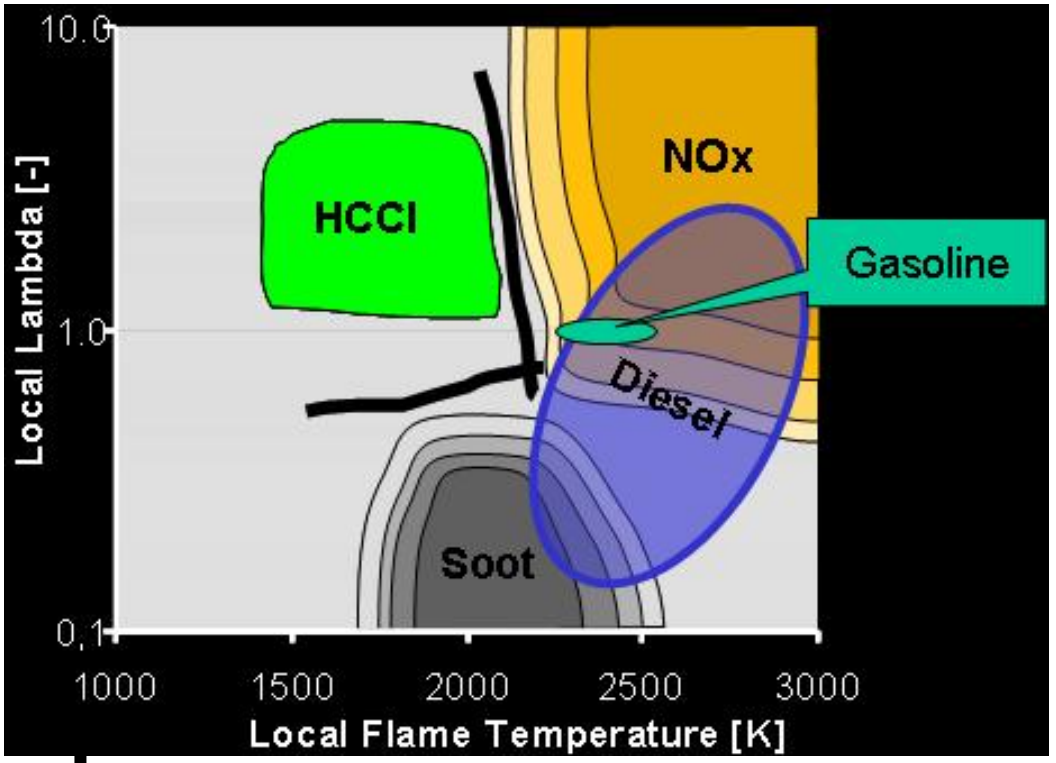
Advanced Combustion Mechanisms



Conventional DI



Advanced HCCI / CAI



The HCCI basic requirements:

- Flame temperature below 2000 °K
- Lambda above 0.8

The conflicts:

- ignition
- combustion of whole mixture
- combustion rate
- power density
- stationary and transient control

Advanced Combustion Mechanisms
Low Temperature Premixed Combustion (LTPC)

From many Authors:

The Low Temperature Premixed Combustion (LTPC) is one of the advanced concepts that is studied from many researchers. It can be seen as an in-cylinder combustion mechanism that allows a simultaneously reduction of soot and NOx emissions. This can occur if high level of EGR and retarded start of injection (at or after TDC) are realized.

In fact, the exhaust gas recirculation contributes to reduce the in-cylinder oxygen concentration and consequently the flame temperature. However, this reduction can result in a higher smoke production. To solve this problem, can be strategic to start the combustion after a long ignition delay because the mixing of fuel and oxygen is strongly improved.

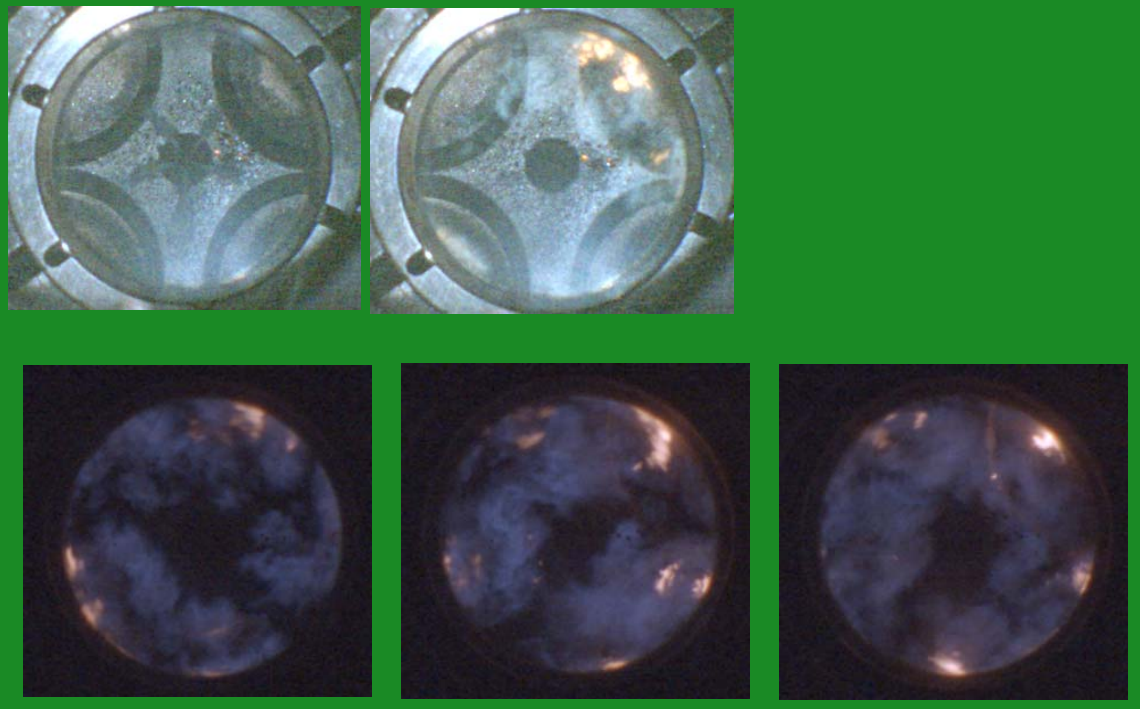
This is currently under investigation at Istituto Motori both on light and heavy duty diesel engines. The fuel is injected around or after the TDC in a toroidal combustion chamber for promoting the dispersion of the fuel outside the piston bowl.

Combustion investigations, performed in optical engines operating under the same in-cylinder thermo fluid dynamics conditions of the real one, have shown how the LTPC proceeds along the crank angle.

Advanced Combustion Mechanisms
Low Temperature Premixed Combustion

From Istituto Motori Investigation:

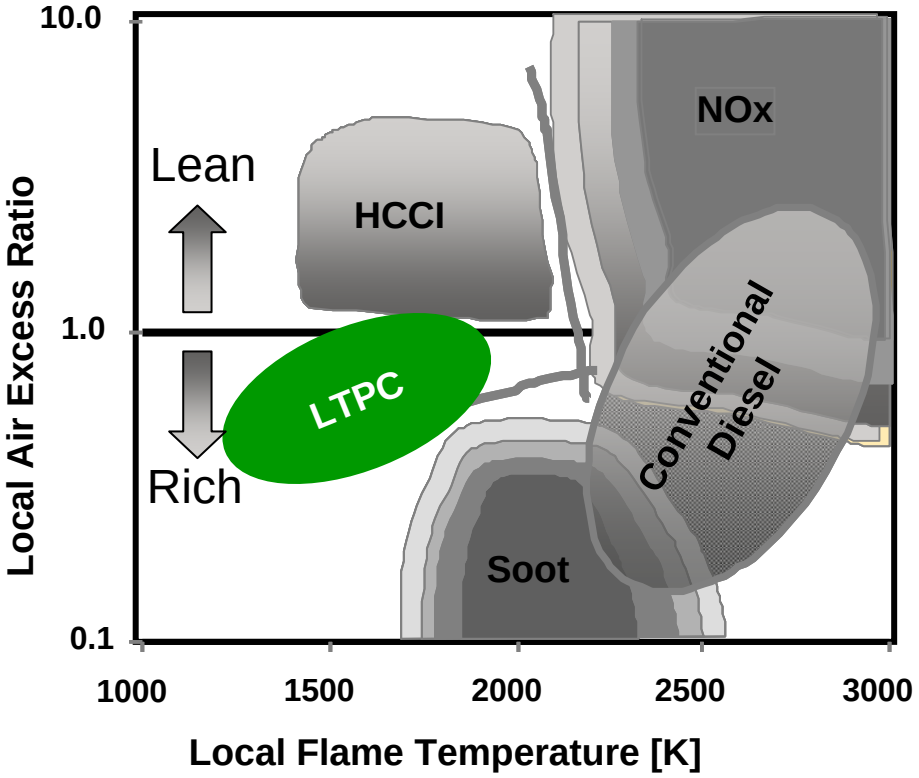
In the smokeless fuel richer combustion zone, *the luminous flame emitted from the soot particles disappears, and only a blue flame is observed.*



Crank Angle

Advanced Combustion Mechanisms
Low Temperature Premixed Combustion

From many Authors:



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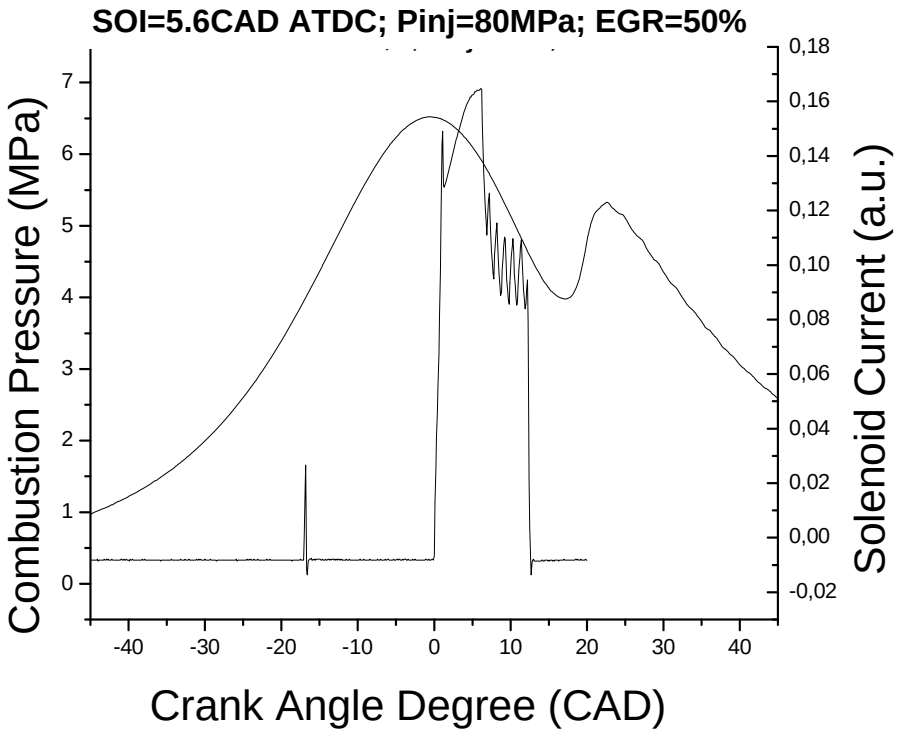

Advanced Combustion Mechanisms
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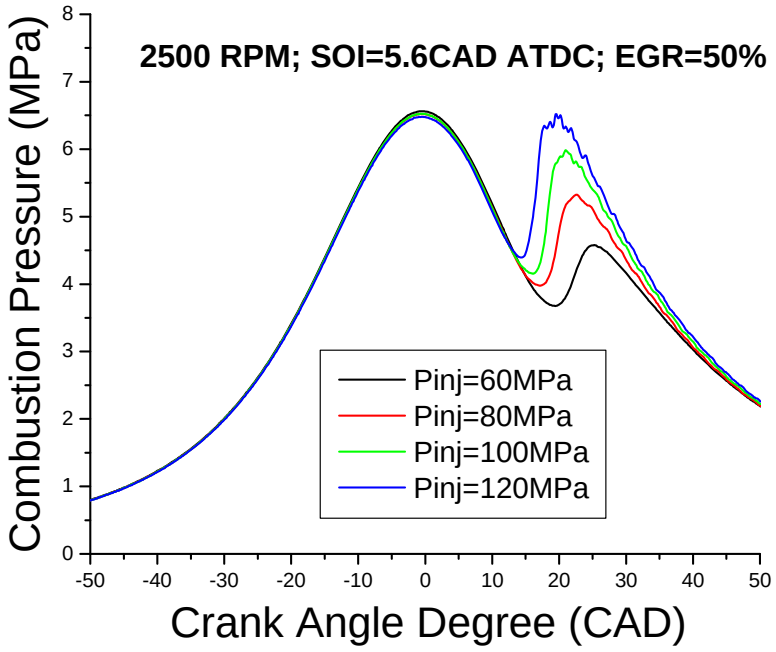
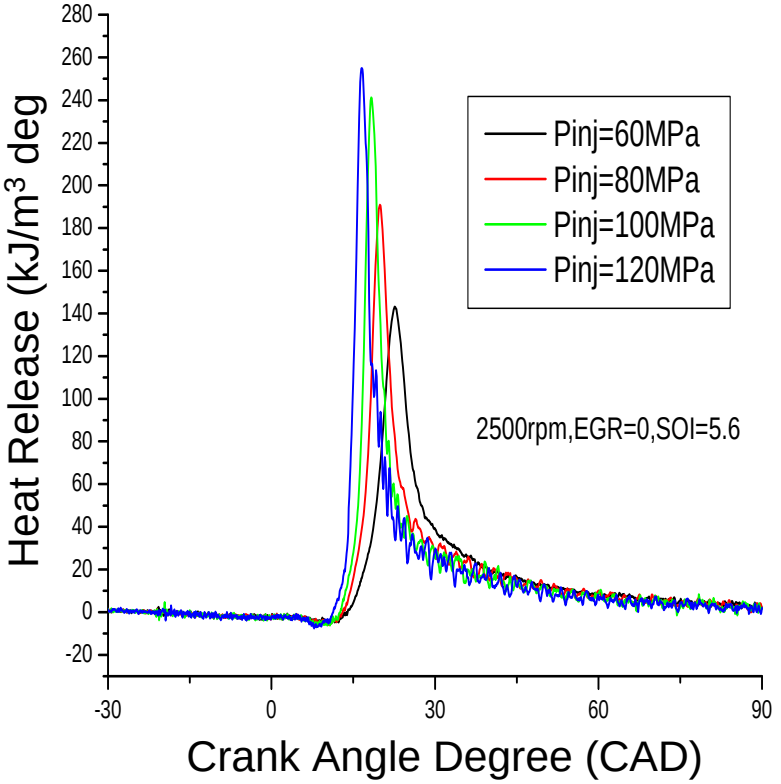


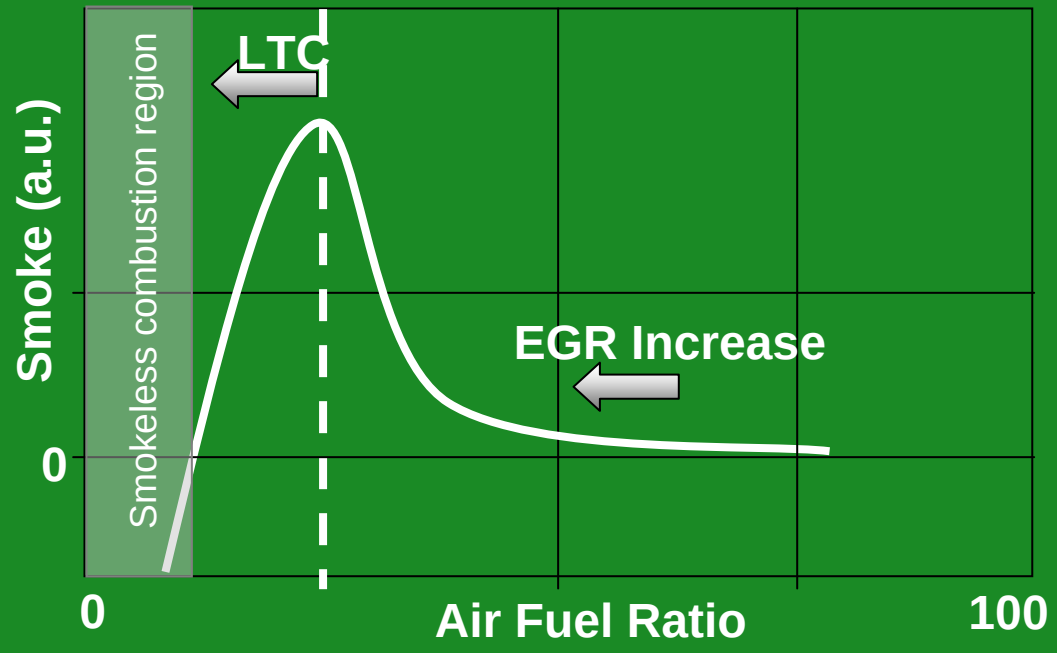


Advanced Combustion Mechanisms
Low Temperature Premixed Combustion

From Istituto Motori investigation:

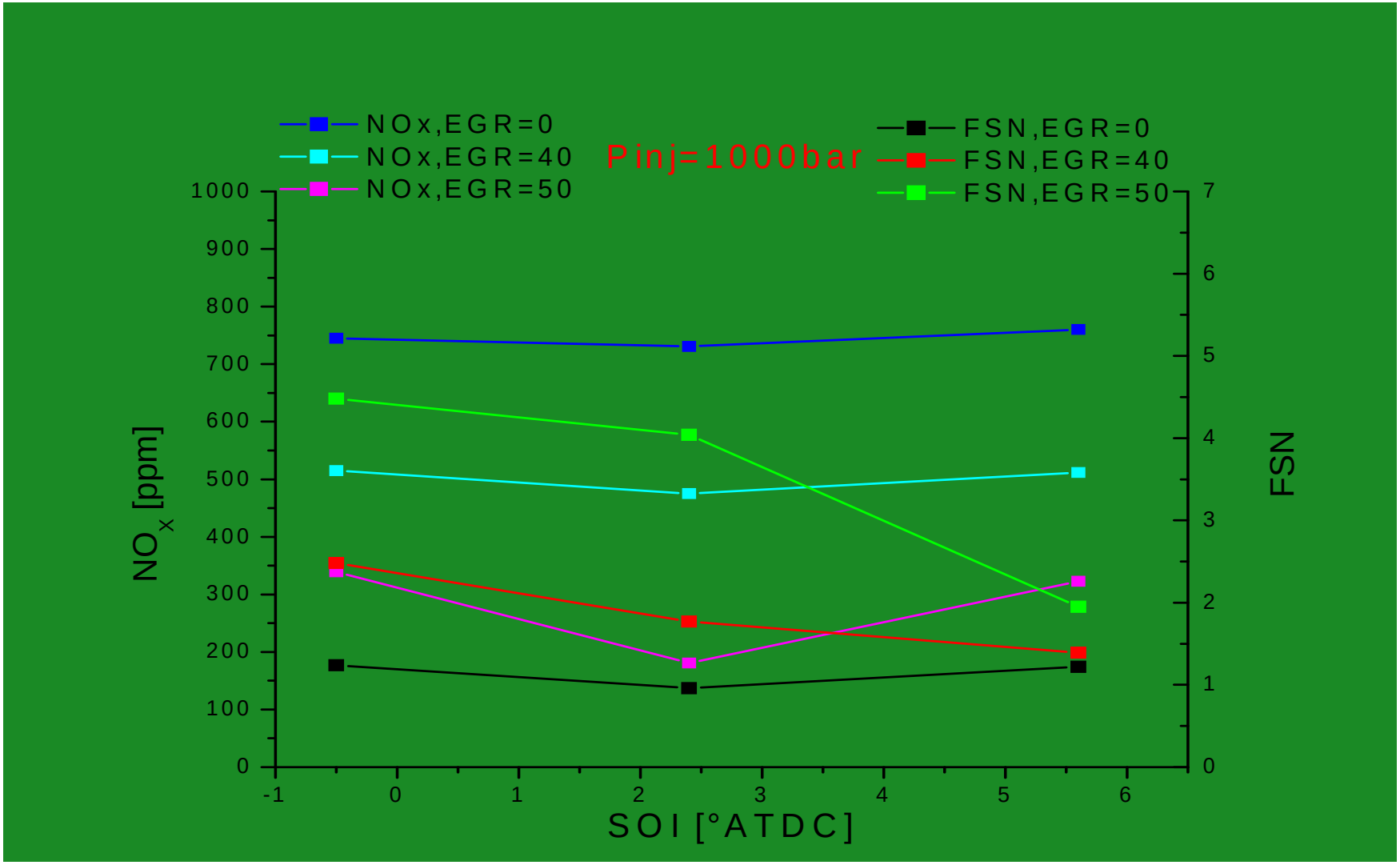
In order to explain how LTPC mechanism works, it can be useful to see the diagram of Figure. In order to change the air-fuel ratio, the EGR rate was varied from 0 to 50%.

Reading the diagram from right to left, at first it can be seen that the smoke increases as expected while decreasing air-fuel ratio. Then, when the EGR rate exceeds a critical point (dotted line), the smoke starts to sharply decrease denoting that the combustion starts in the fuel richer region. In such smokeless fuel richer combustion zone, *the luminous flame emitted from the soot particles disappears, and only a blue flame is observed.*



Advanced Combustion Mechanisms
Low Temperature Premixed Combustion

From Istituto Motori investigation:



Advanced Combustion Mechanisms
Low Temperature Premixed Combustion

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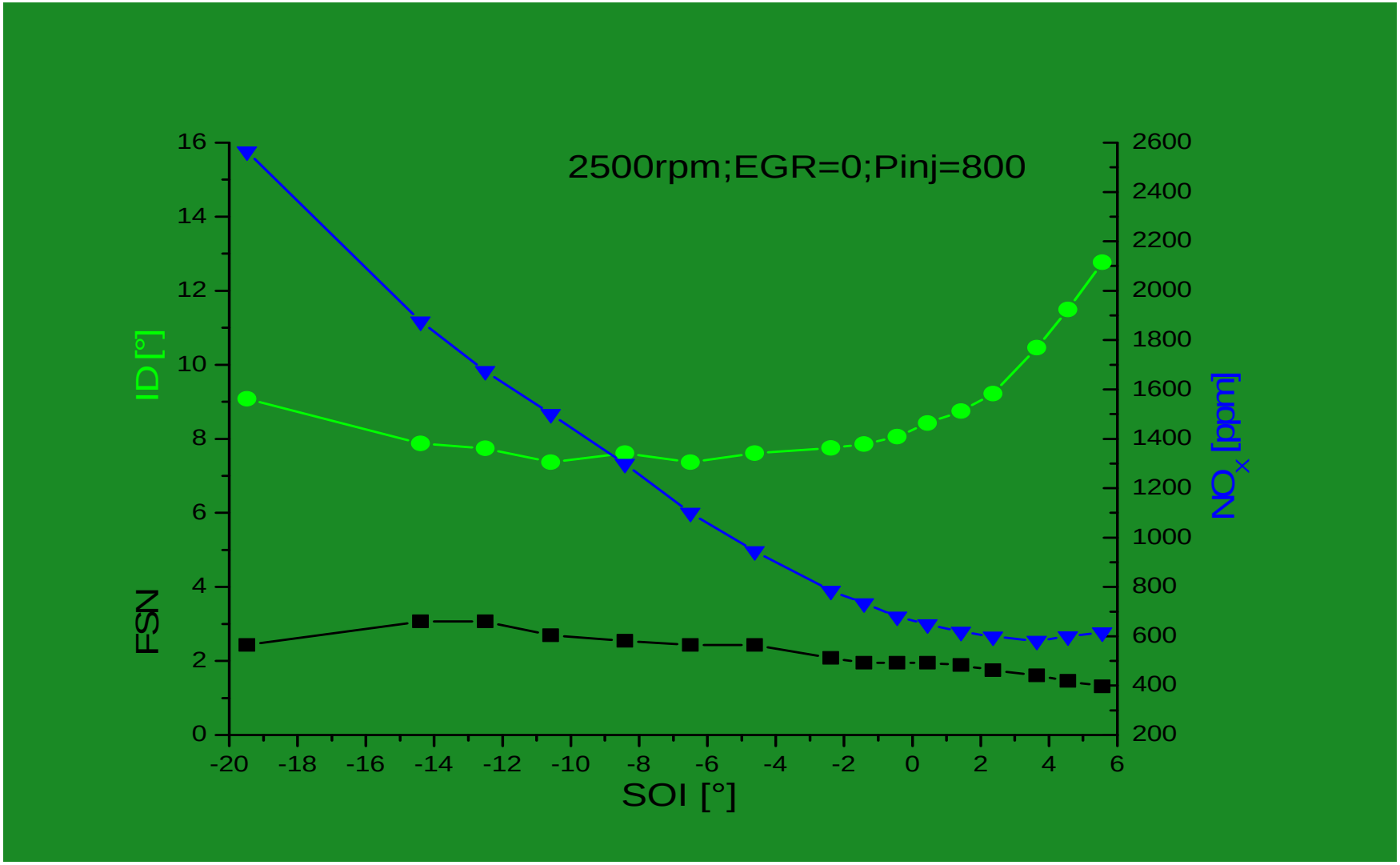
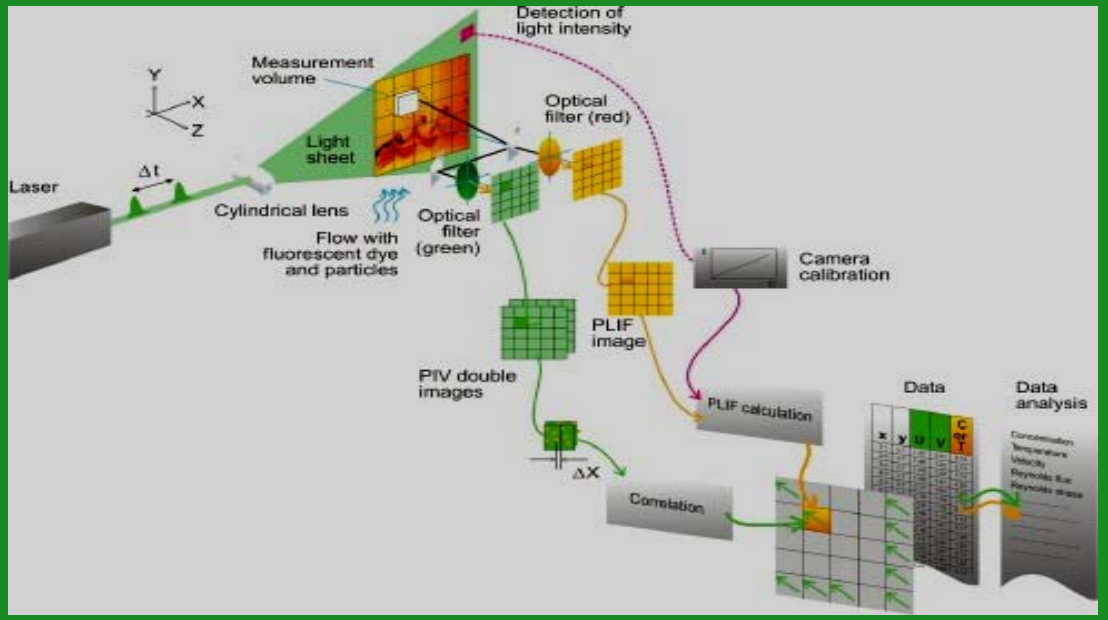


Advanced Combustion Mechanisms
Low Temperature Premixed Combustion

From many Authors:

Generally, LTPC combustion suffers from combustion efficiency penalties resulting from increased unburned hydrocarbon (UHC) and carbon monoxide (CO) emissions, particularly at low and moderate engine loads. To better understand the root causes of the emissions and efficiency deterioration, UHC and CO emissions sources are under examination in optically accessible engines. Laser Induced Fluorescence can give help to understand the HC and CO formation during combustion process.

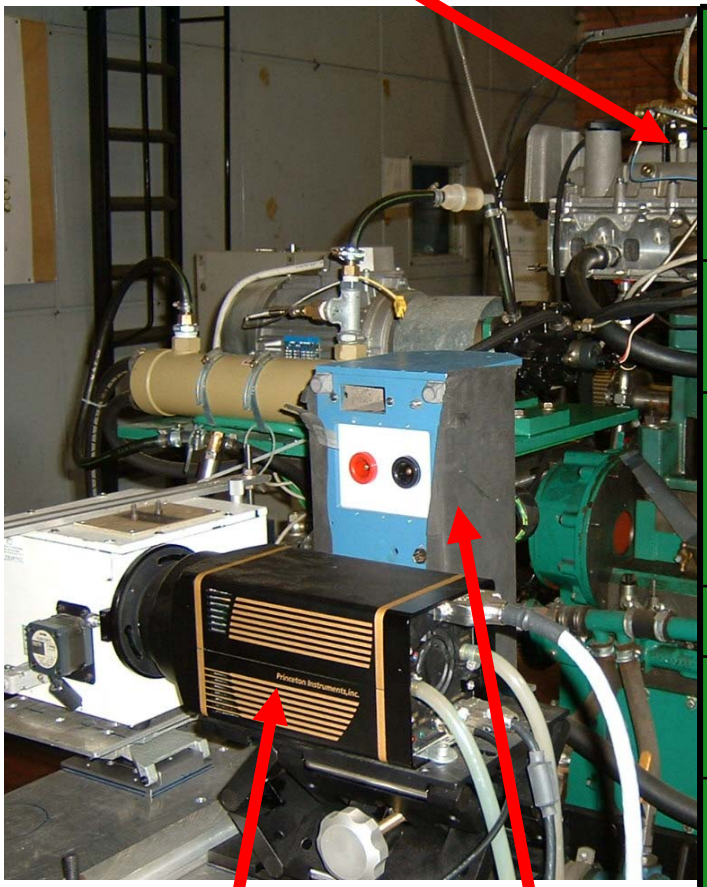


A typical PLIF setup consists a laser, an arrangement of lenses to form a sheet, fluorescent medium, collection optics and a detector. The light from the source, illuminates the medium, which then fluoresces. This signal is captured by the detector and can be related to the various properties of the medium.

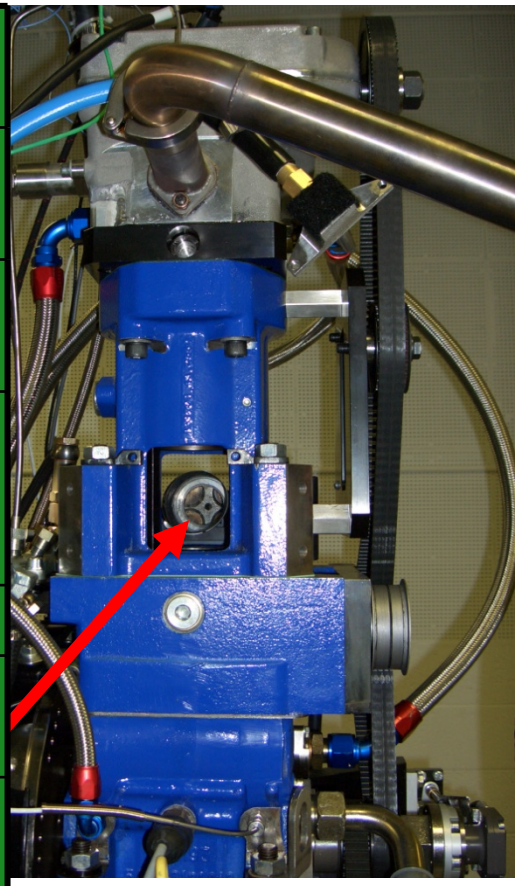
Optical Engines
DI CR AVL Engine

FIAT 1910 Engine head

Advanced common rail



DI-CR OPTICAL DIESEL ENGINE	
Displacement (cm3)	522
Bore (mm) Stroke (mm)	85.0 92.0
Cylindrical Comb. Bowl (mmxmm)	40x17
Swirl Ratio	2.0 - 4.5
Solenoid Injector	4/0.17/142
Compression Ratio	17.34:1

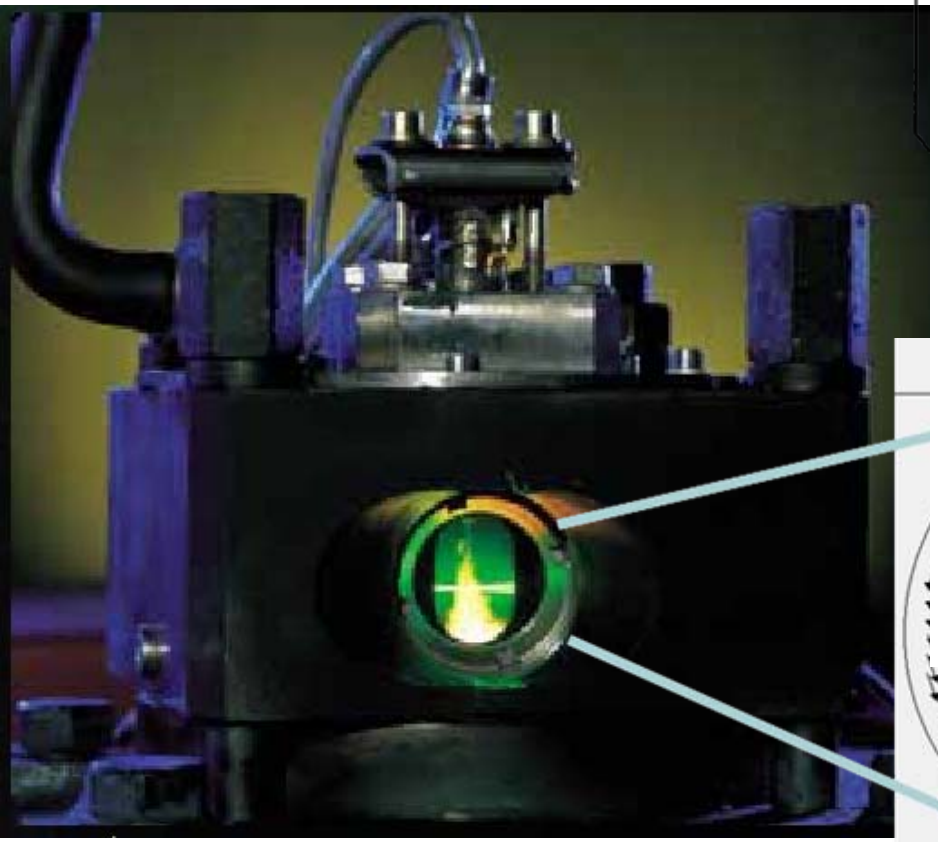


Intensified CCD Camera

Spectrometer

Optical access

Optical Engines
High Swirl Spray Engine



1.1 SPRAY RESEARCH ENGINE

Engine components:

Base engine: JW50

Manufacturer: Jenbacher Werke Austria

JW50 single cylinder,

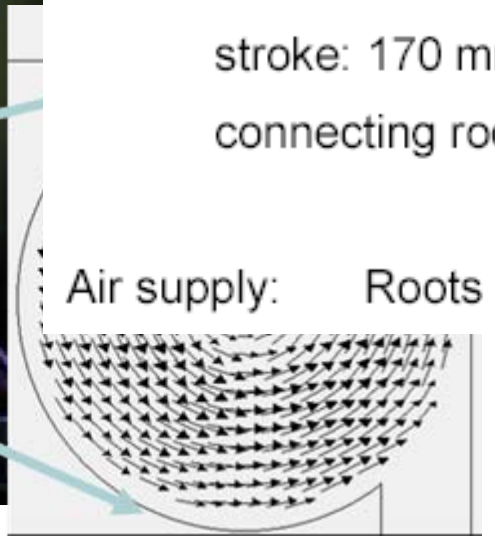
2-stroke, loop scavenged,

bore: 150 mm,

stroke: 170 mm,

connecting rod: 360 mm.

Air supply: Roots blower in engine,



Isotta Fraschini DI CR Diesel Engine for Marine Application 16 cyl – 2.8 MW

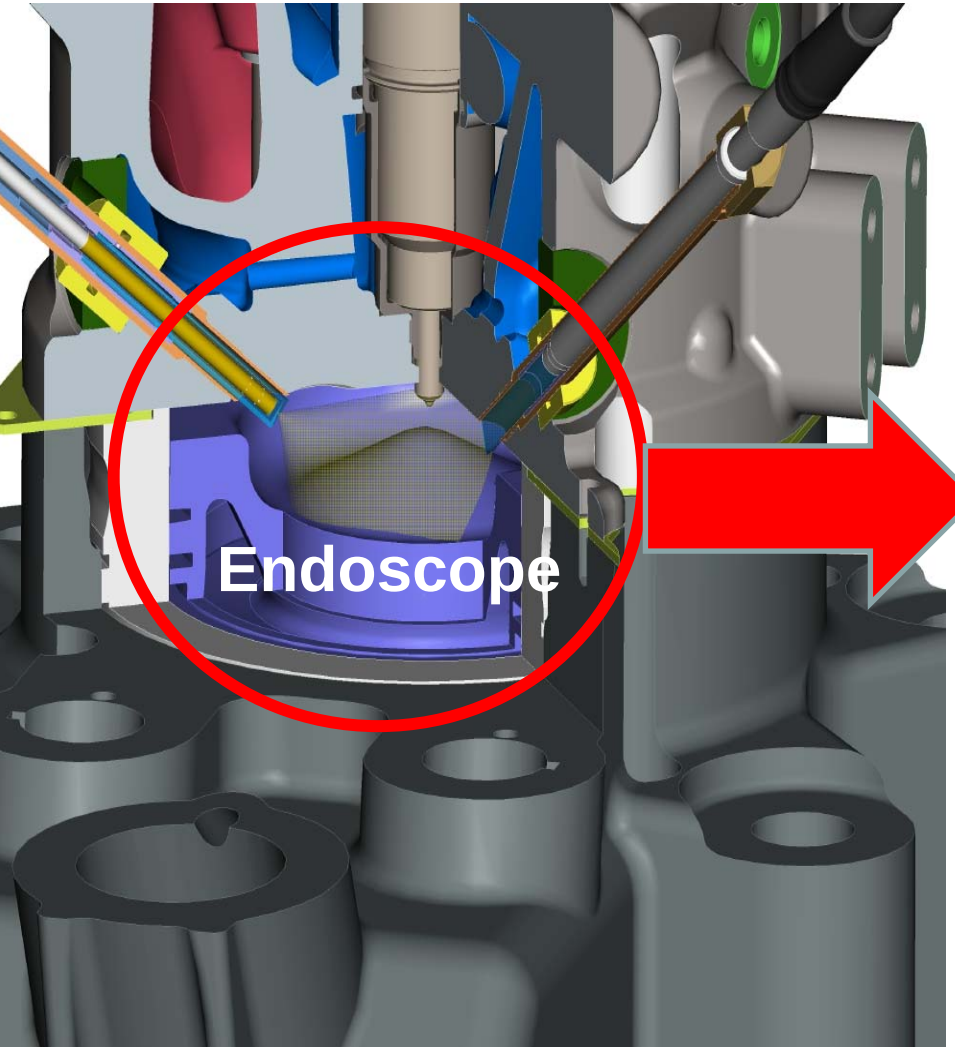
Engine Type	DI TCI Diesel
Application	Marine Propulsion
Emissions Norms	Tier-2
Engine Designation	
Cylinder configuratio	
Bore (mm)	
Stroke (mm)	
Swept volume per cy	
Total swept volume (	
Compression ratio	
Max. PFP (bar)	180**
Rating (MW/1/min)	2.8/2100
Rated BMEP (bar)	23.8

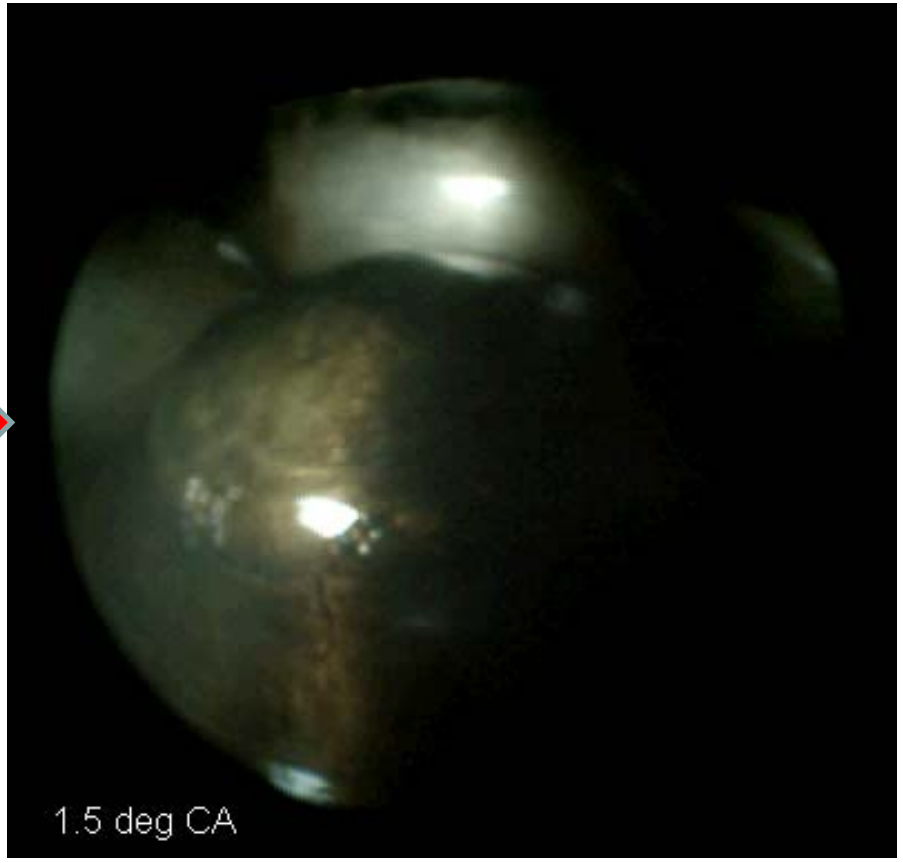
Exhaust Emissions Limitations

EPA TIER 2 (2004) for marine propulsion with:
1.2 <_ unit displacement <_ 2.5 dm^3

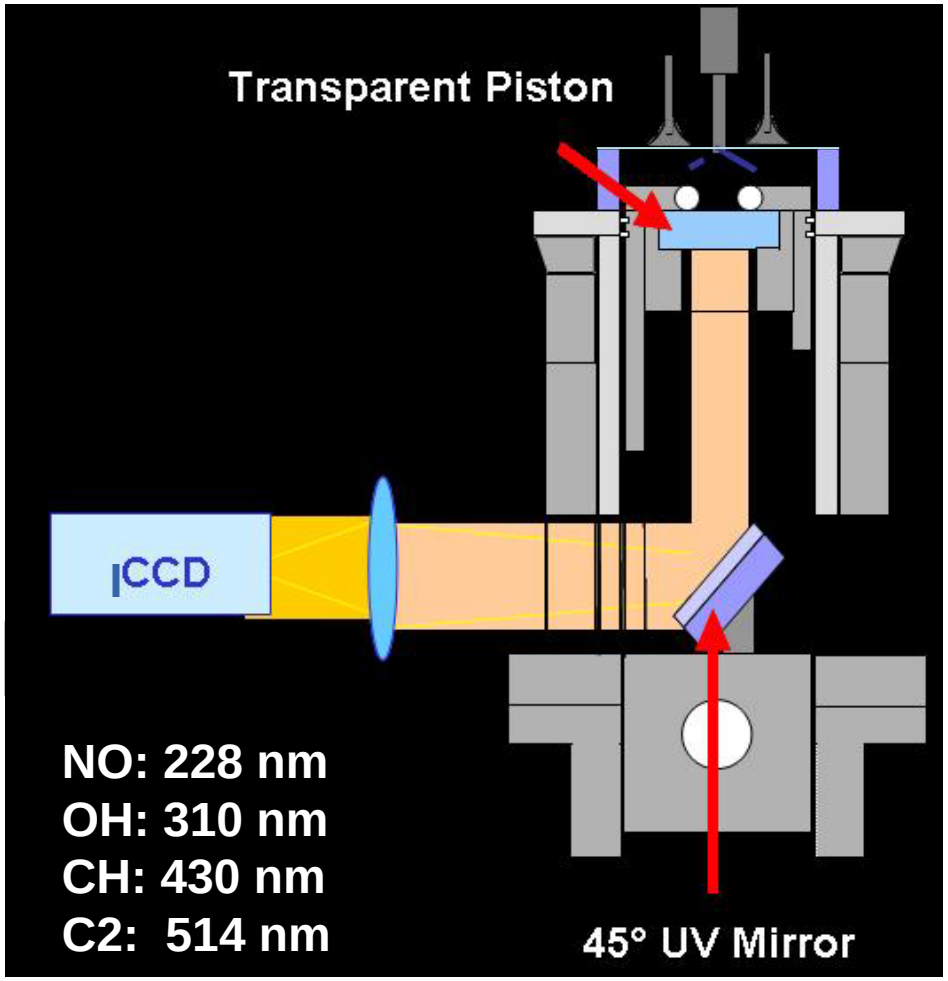
NOx+THC g/KWh	PM g/KWh	CO g/KWh
7.2	0.20	5.0

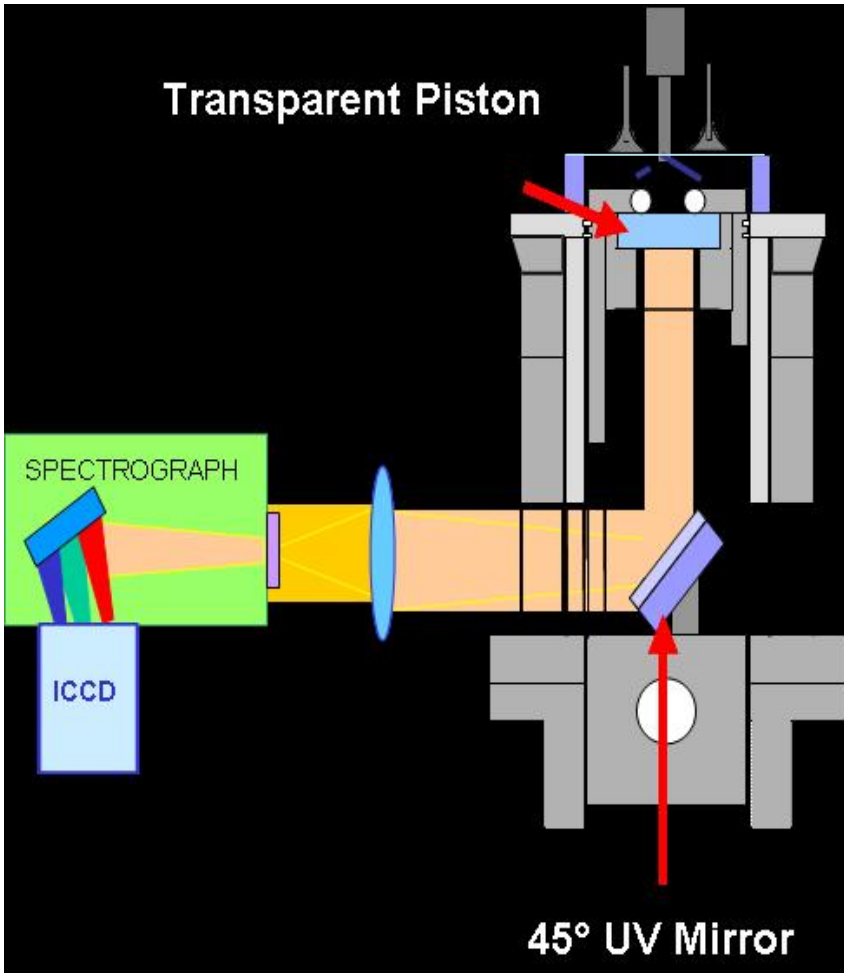
Optical Engines
Large Engine for Marine Applications



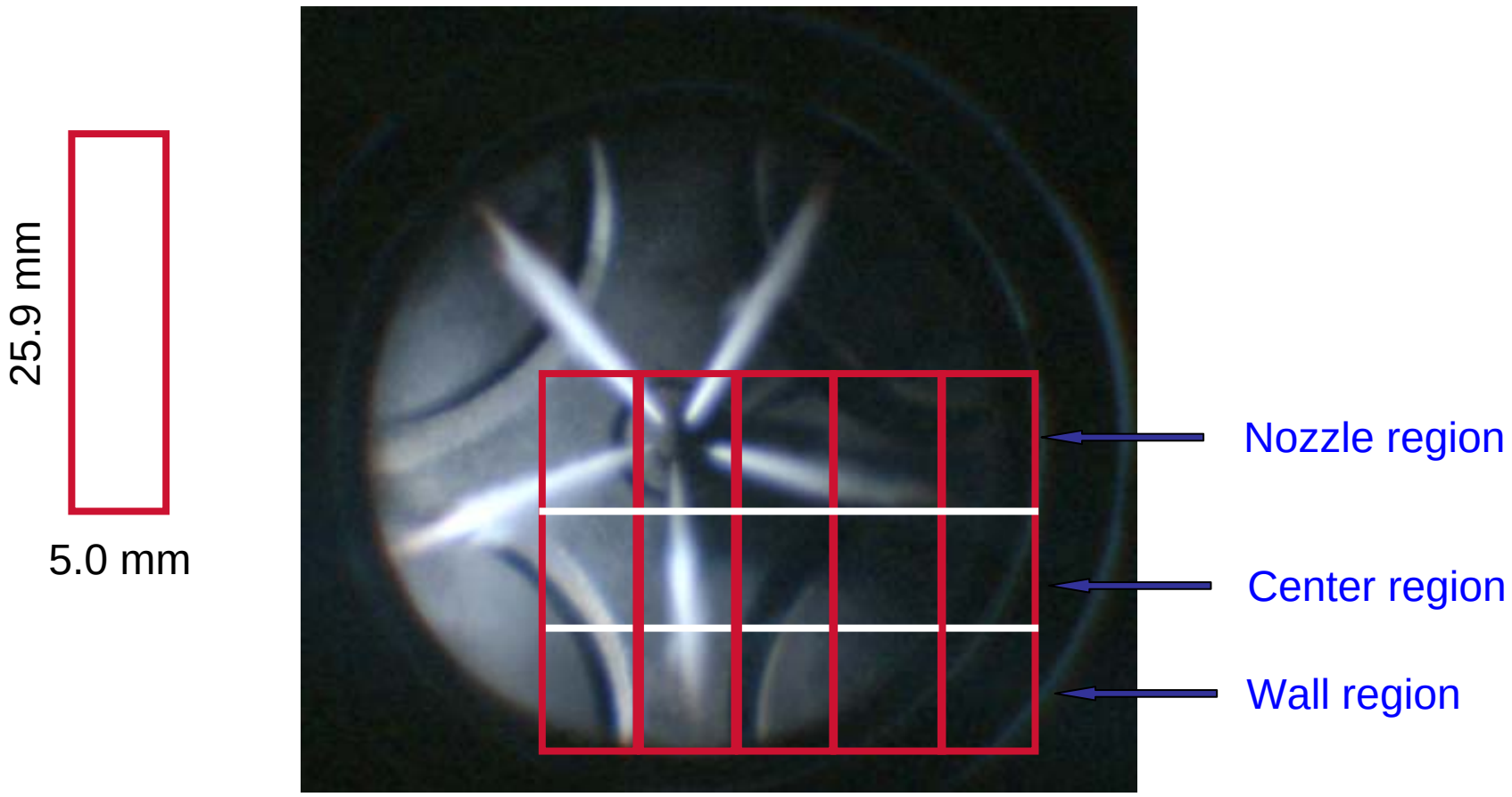


Optical Techniques
2D Imaging and Spectroscopy

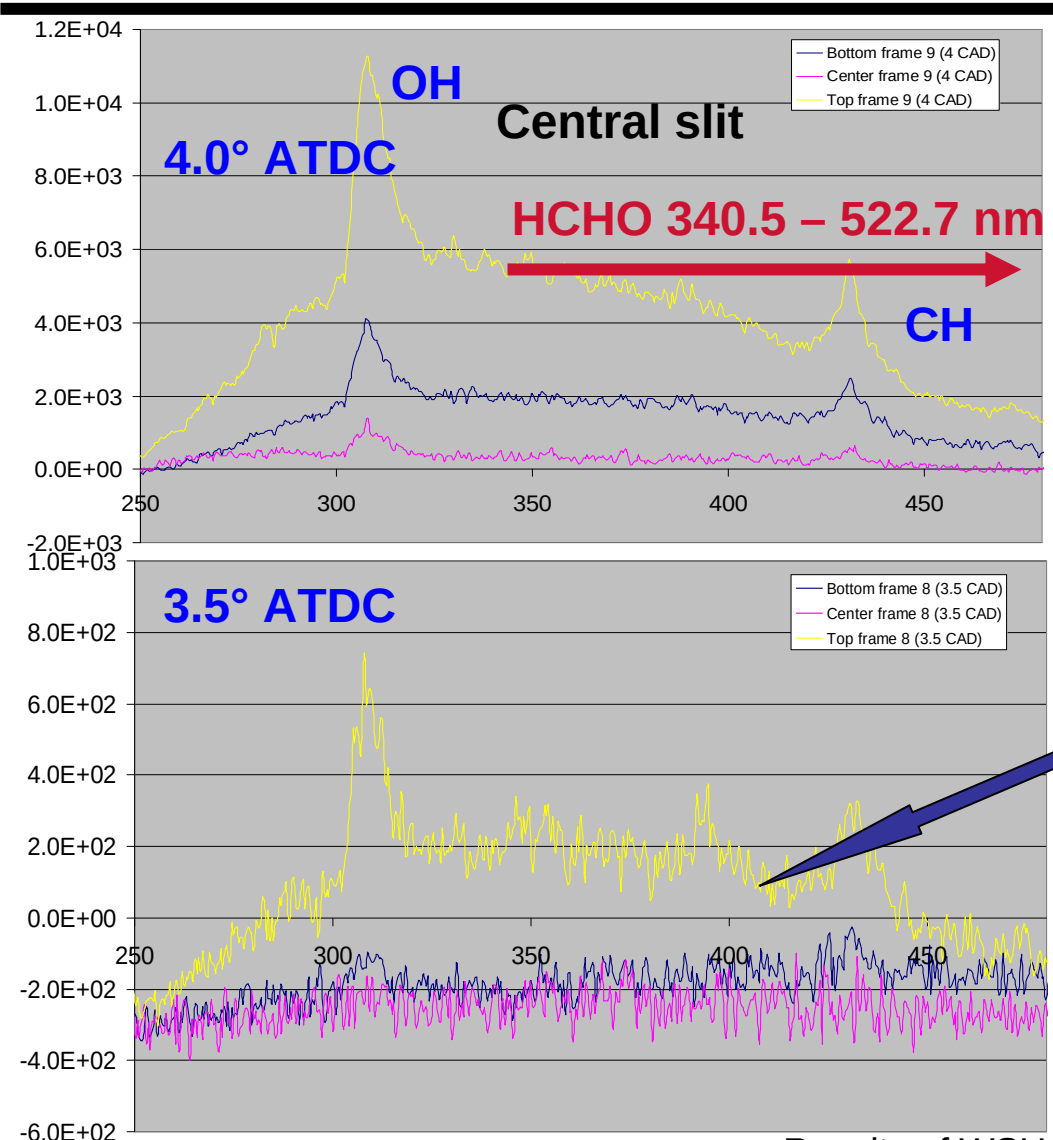


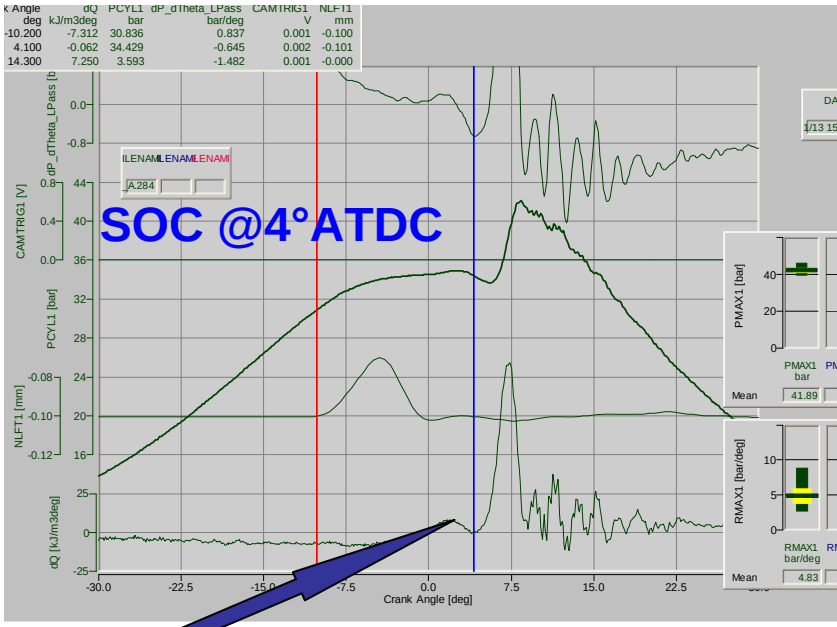


Optical Techniques
Chemiluminescence and Flame Emissions

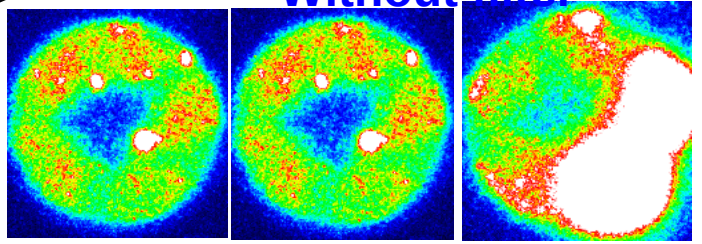


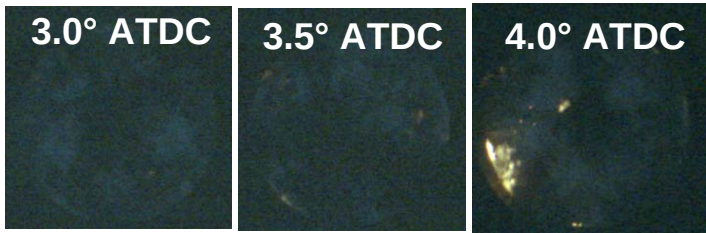
Spectroscopic Detection of HCHO @2000rpm; Pinj=800 bar; Qinj=8mg/st; sw=2; imep=0.72 bar





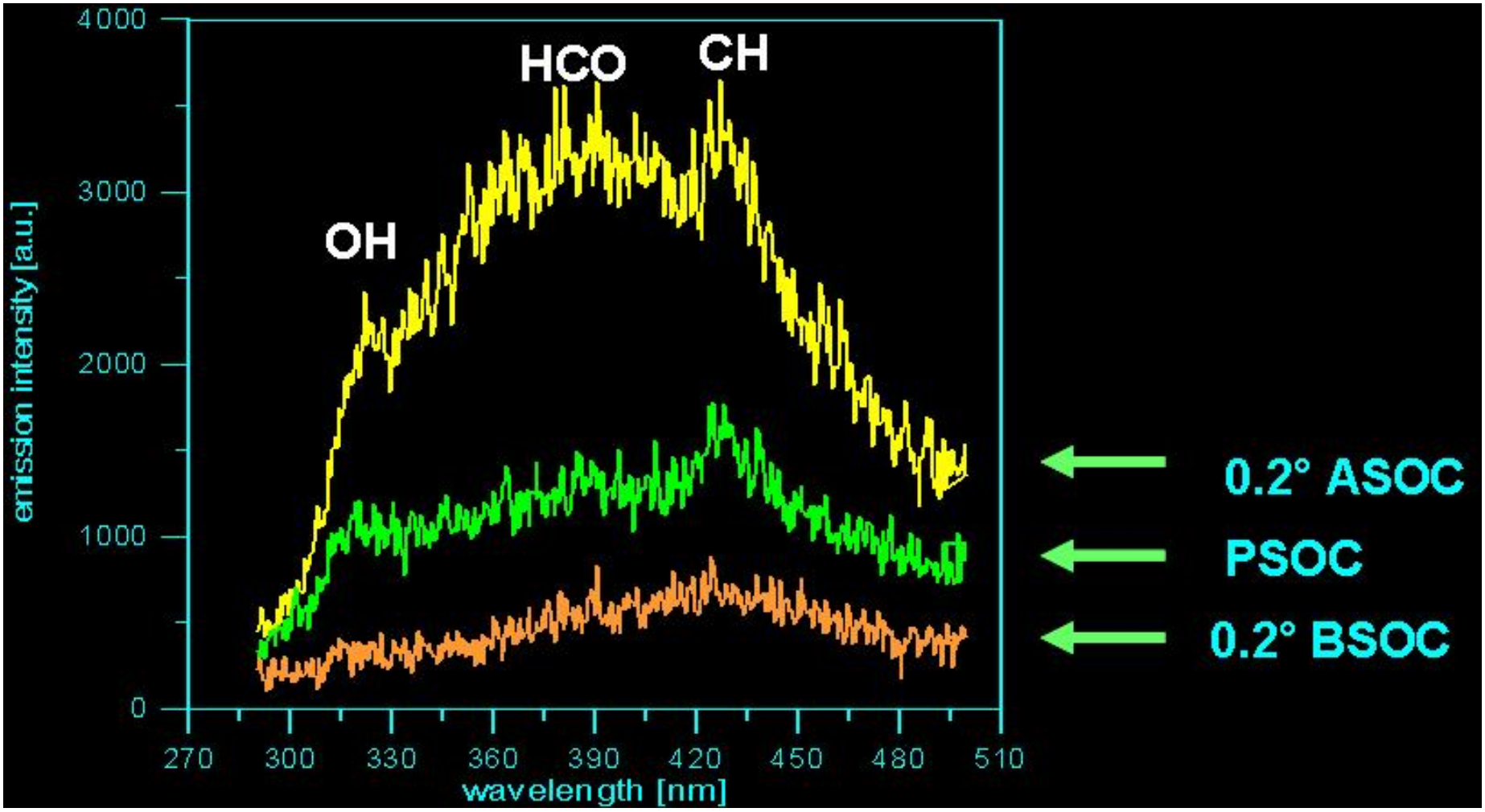
Without filter





Results of WSU

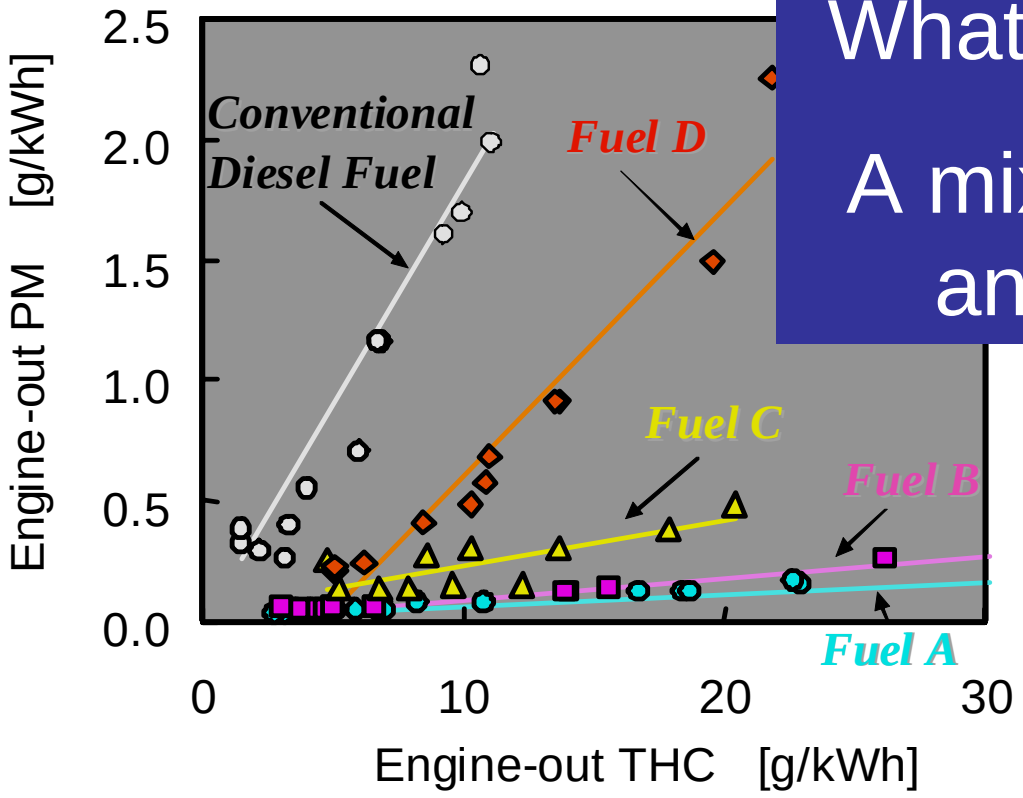
Optical Techniques
Chemiluminescence



What Fuel for Advanced Combustion Mechanisms?

From Yoshihiko Matsuda (Toyota), EF_Coference, Catania 2003

Lighter fuel (low boiling point, low aromatics) can restrain PM emissions in the pre-mixed charge Compression Ignition (PCCI) combustion.



What about Dieseline?

A mix between Diesel and gasoline fuel

		atics %)
		9
		3
Fuel C	150 - 261	13.8
Fuel D	177 - 362	11.9
Conv.Fuel	170 - 358	18.9

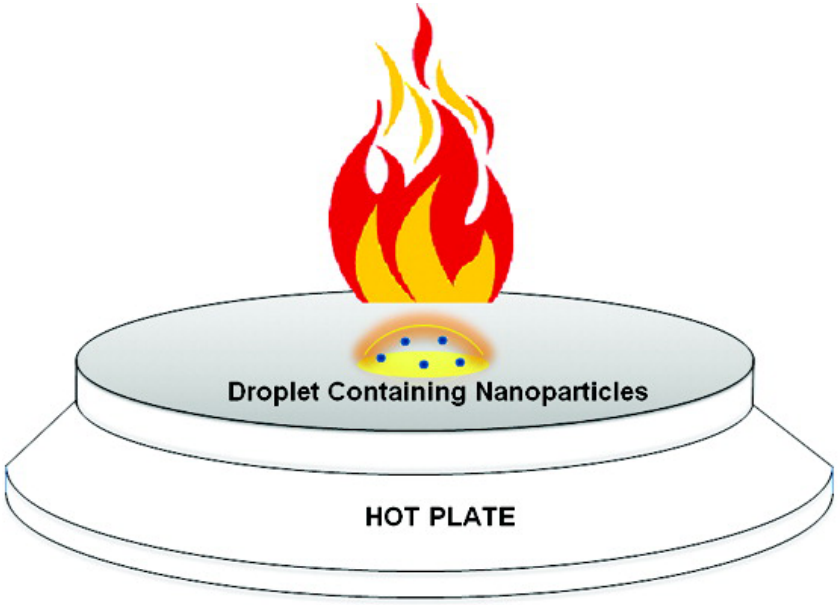
Cetane #	
Fuel A,B,C,D	40
Conv. Fuel	53

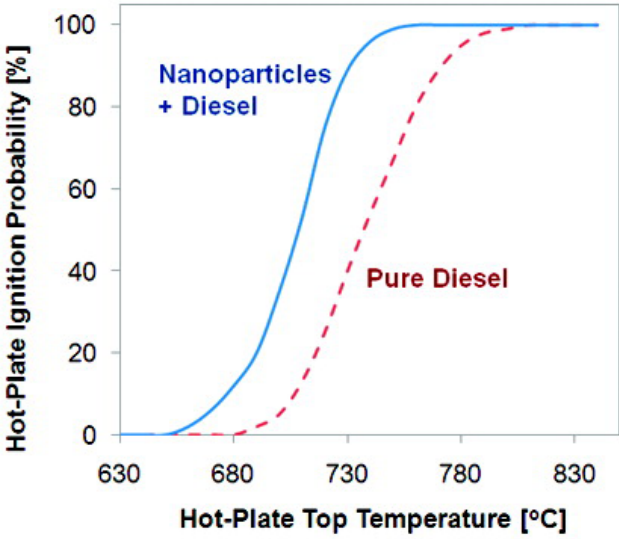
TEST ENGINE ; I4, 2L, TDI (Compression ratio 15:1)

TEST CONDITION ; 2000rpm, PCCI combustion (Smokeless operation)

What Fuel for Advanced Combustion Mechanisms?

What about Nanoparticle-Laden Diesel Fuel ?





Conclusion

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- Optical Engines & Investigation Techniques
- Fuel for Advanced Combustion Mechanisms

Thank you for your Attention