HCCI fuel activities in Lund

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Lund University

Outline

- Why fuel research?
- Fuels for the future
- Introduction to Lund University and the HCCI activities
- HCCI fuel results
- Summary

Rationale for fuel research

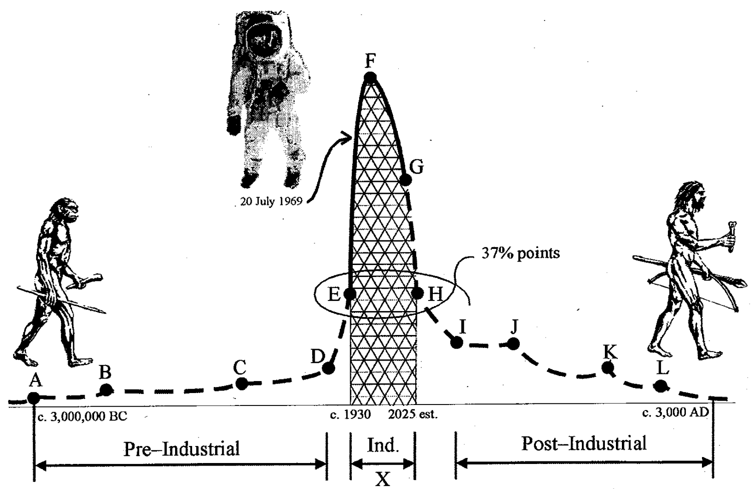
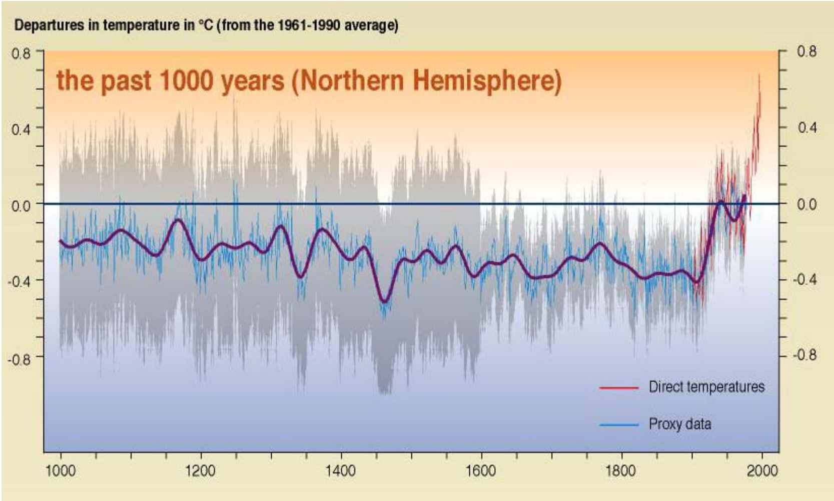
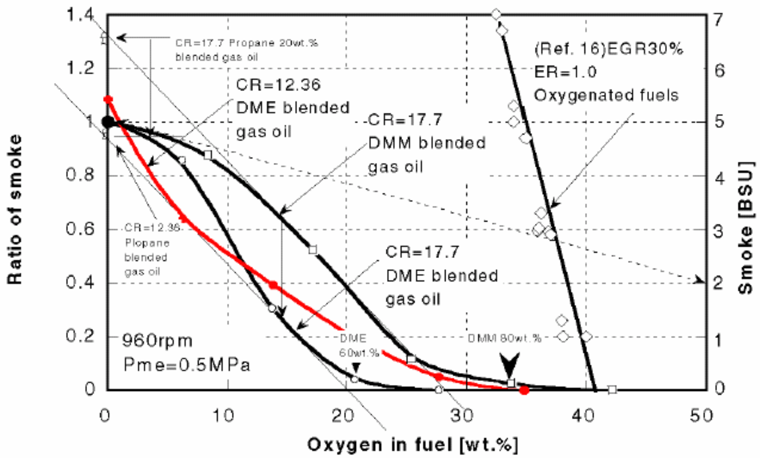
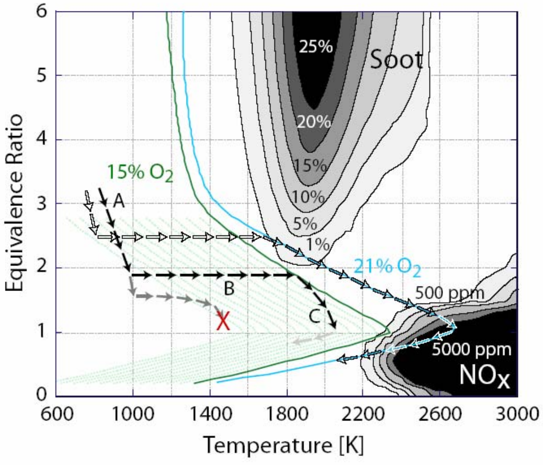


Fig. 8-15. The short span of Industrial Civilization.



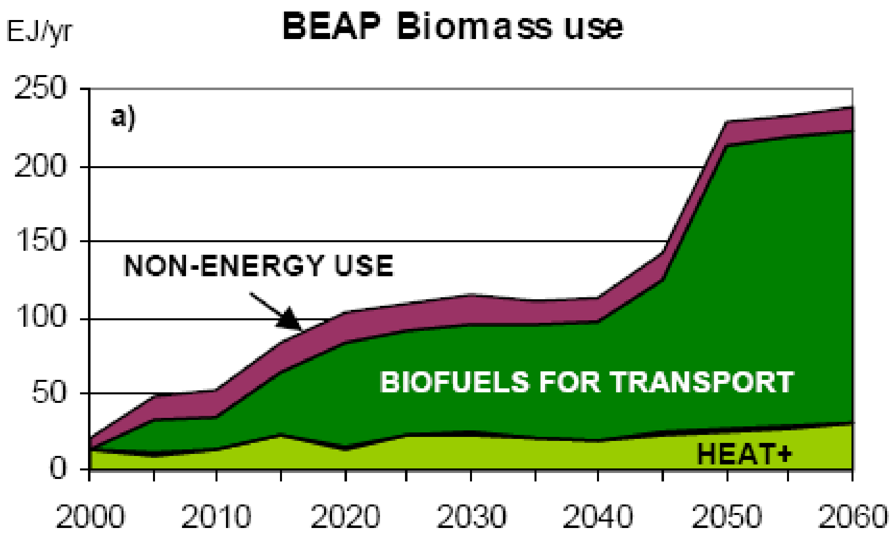


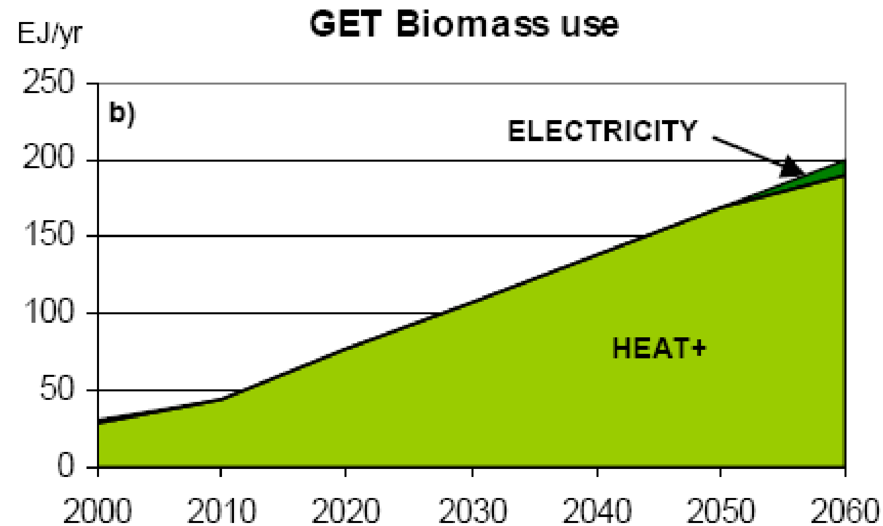


Forecast 1

BIOMASS FOR HEAT OR AS TRANSPORTATION FUEL?
A COMPARISON BETWEEN TWO MODEL BASED STUDIES

Maria Grahn[a], Christian Azar[a], Kristian Lindgren[a], Göran Berndes[a], Dolf Gielen[b]
a) Physical Resource Theory, Energy and Environment, Chalmers University of Technology, 412 96 Goteborg, Sweden. E-mail: maria.grahn@chalmers.se
b) International Energy Agency, 75739 Paris Cedex 15, France.





[4] Gielen D J, J Fujino, S Hashimoto and Y Moriguchi. Biomass strategies for climate policies?, Climate Policy 2(4), p.319-333 (2002).

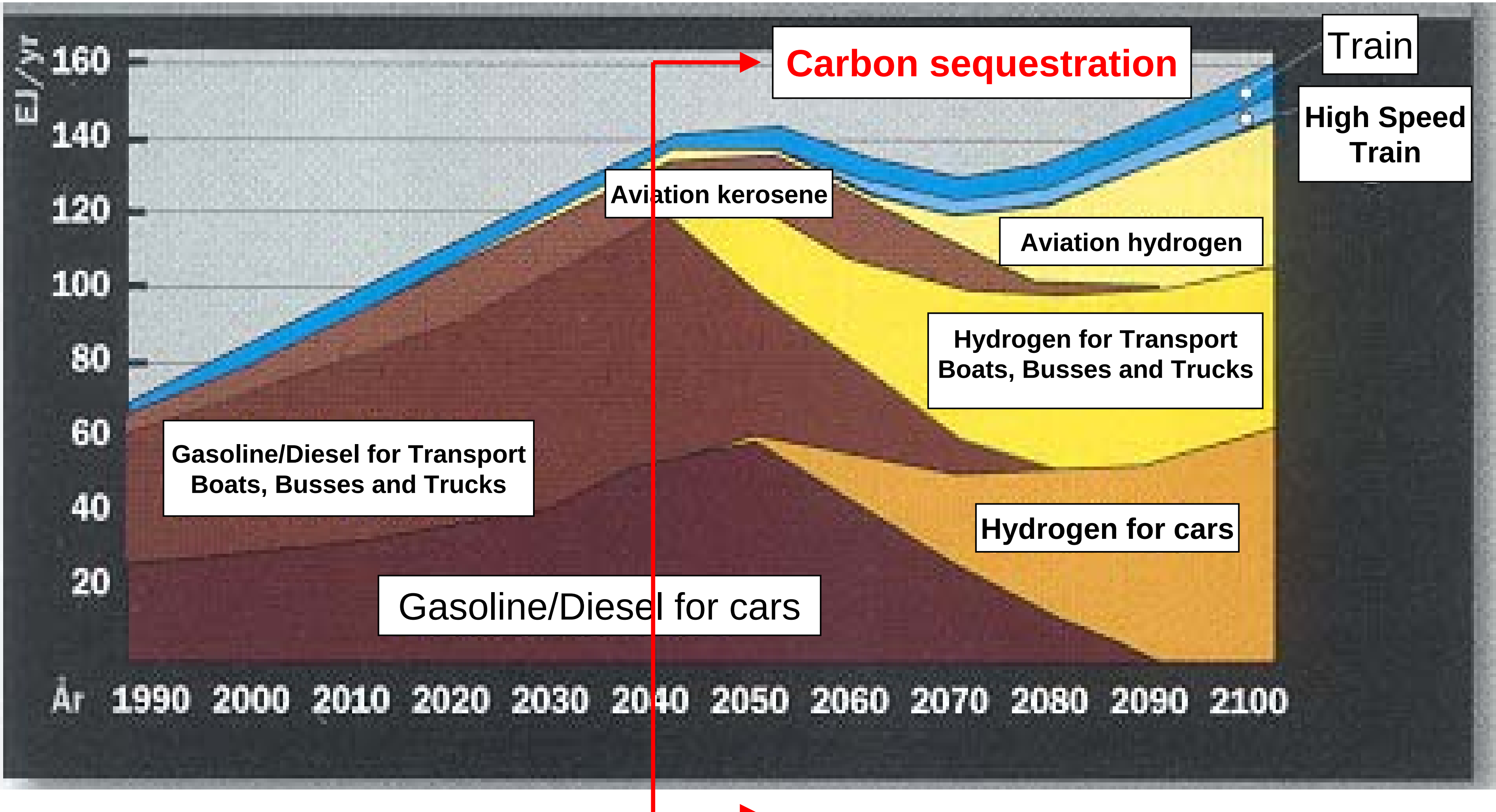
[5] Gielen D J, J Fujino, S Hashimoto and Y Moriguchi. Modeling of global biomass policies, Biomass & Bioenergy 25(2), p.177-195 (2003).

[1] Azar C. Emerging scarcities - Bioenergy-food competition in a carbon constrained world, (Eds) Simpson, D., Toman, M., and Ayres, R., Scarcity and growth in the new millennium. Resources for the future Inc. John Hopkins University Press (forthcoming, 2005)

[3] Azar C, K Lindgren, B A Andersson. Global energy scenarios meeting stringent CO_2 constraints - cost-effective fuel choices in the transportation sector, Energy Policy 31(10), 961–976 (2003).

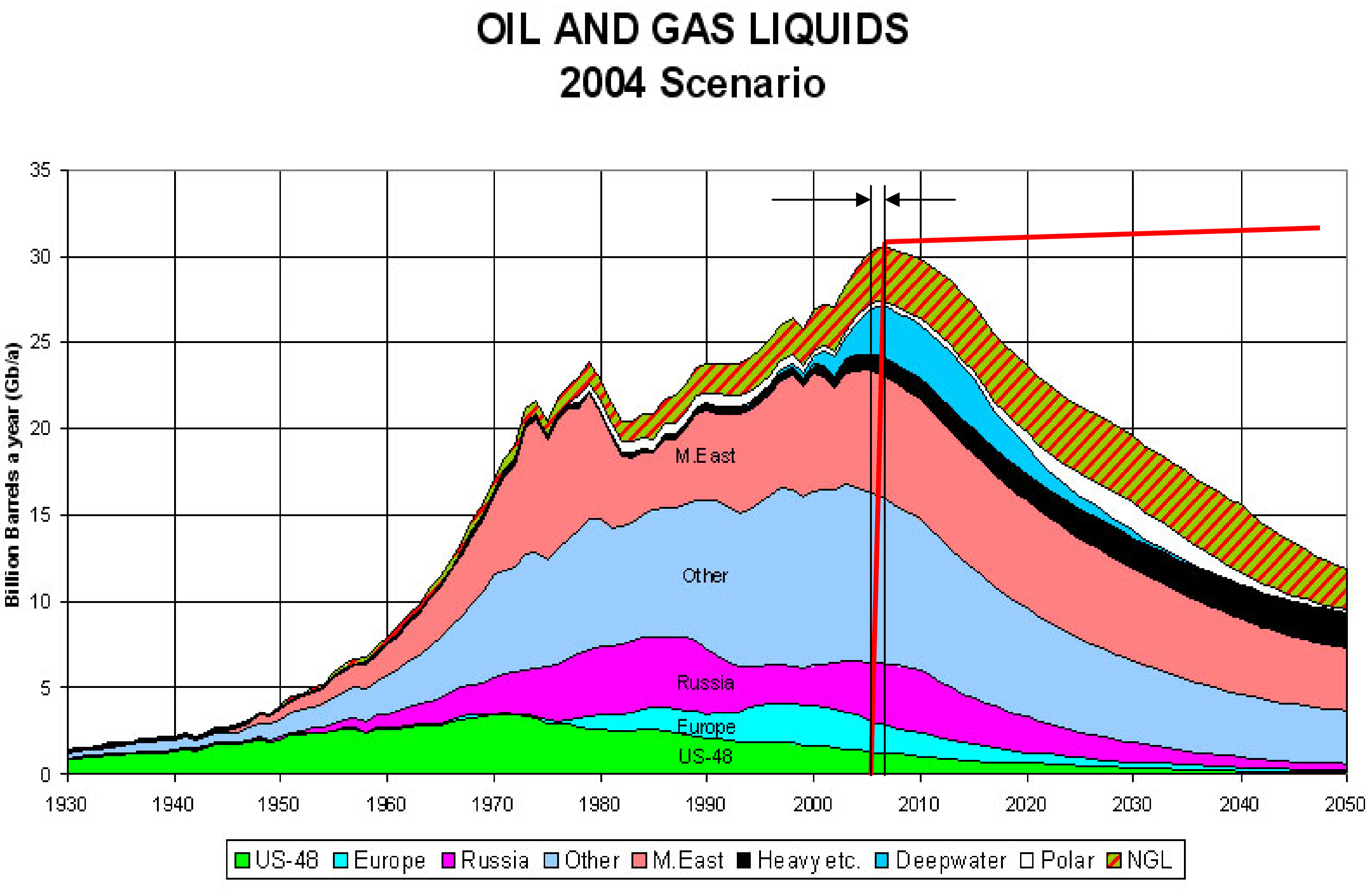
[8] Azar C, K Lindgren, B A Andersson. Hydrogen or methanol in the transportation sector?, Department of Physical Resource Theory, Chalmers University of Technology, Göteborg, Sweden (2000).

Forecast 2



This figure is copied from: Azar, C. "Ökad levnadsstandard och minskade utsläpp – En omöjlig kombination?". Det Naturliga Steget Nr 4-00/1-01. Translations made by Rolf Egnell

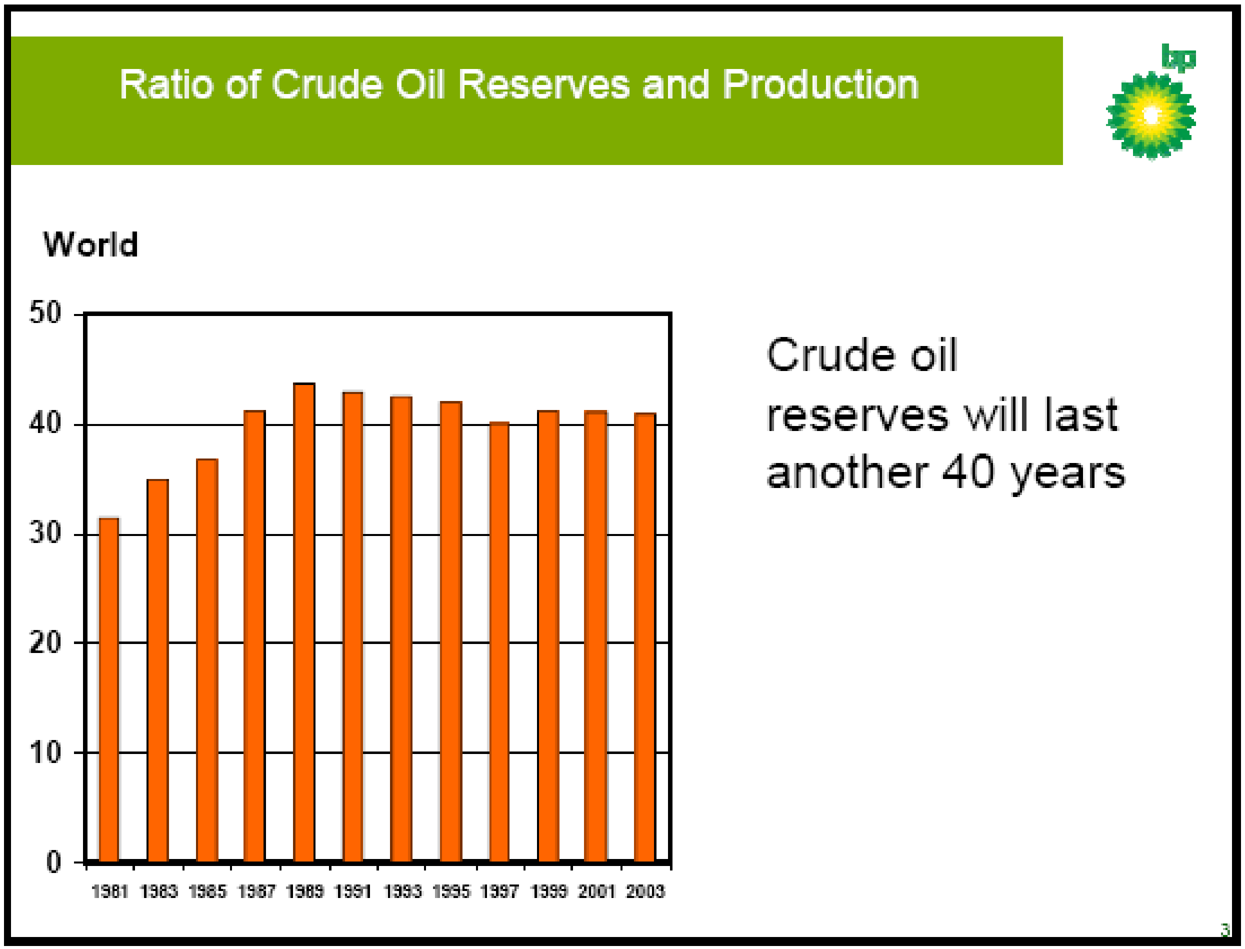
Forecast 3



But coal lasts for at least another 200 years!

Source: Aspo http://www.peakoil.net/

Forecast 4

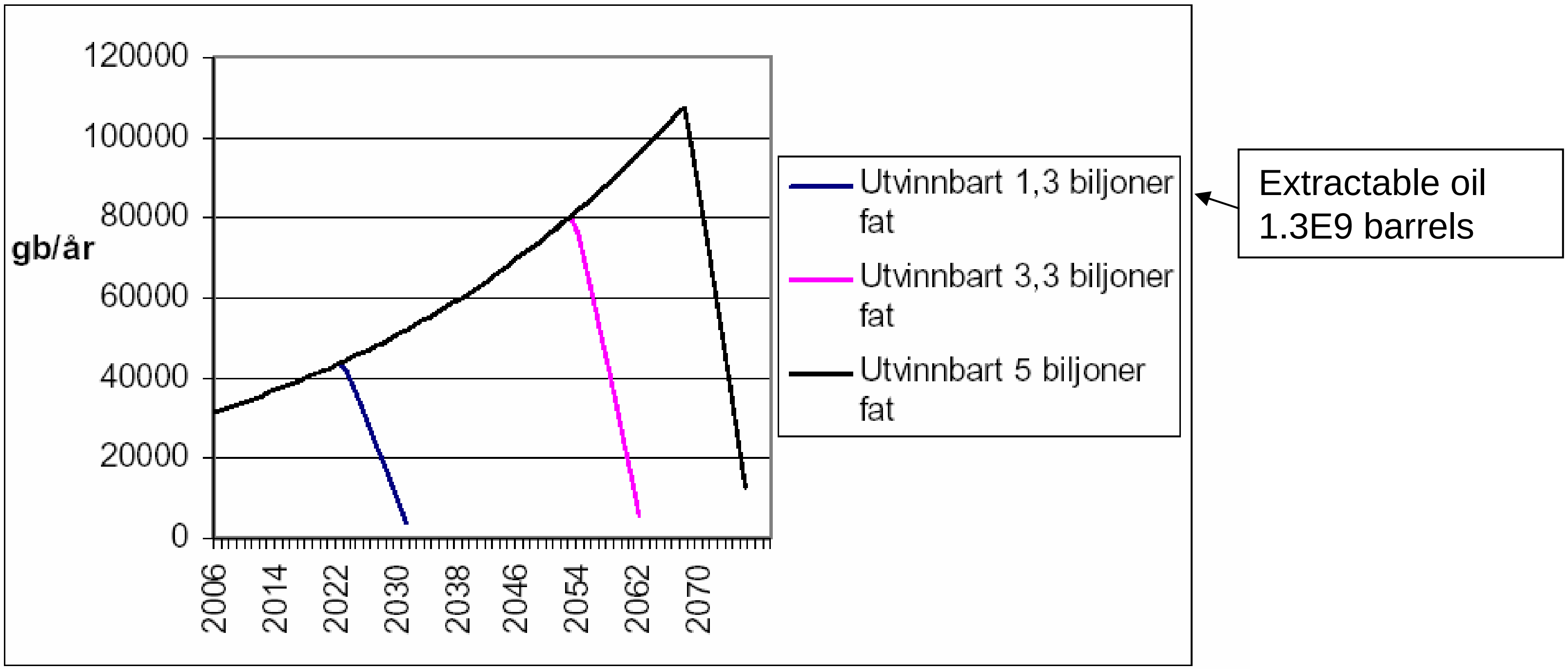


Ratio of Crude Oil Reserves and Production
World
50
40
30
20
10
0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003
Crude oil reserves will last another 40 years
3

Swedish Energy Administration

Source: Oljans ändlighet – ett rörligt mål. ER 2006:21

Figur 8 Uthålligheten med 2 % årlig ökning i efterfrågan

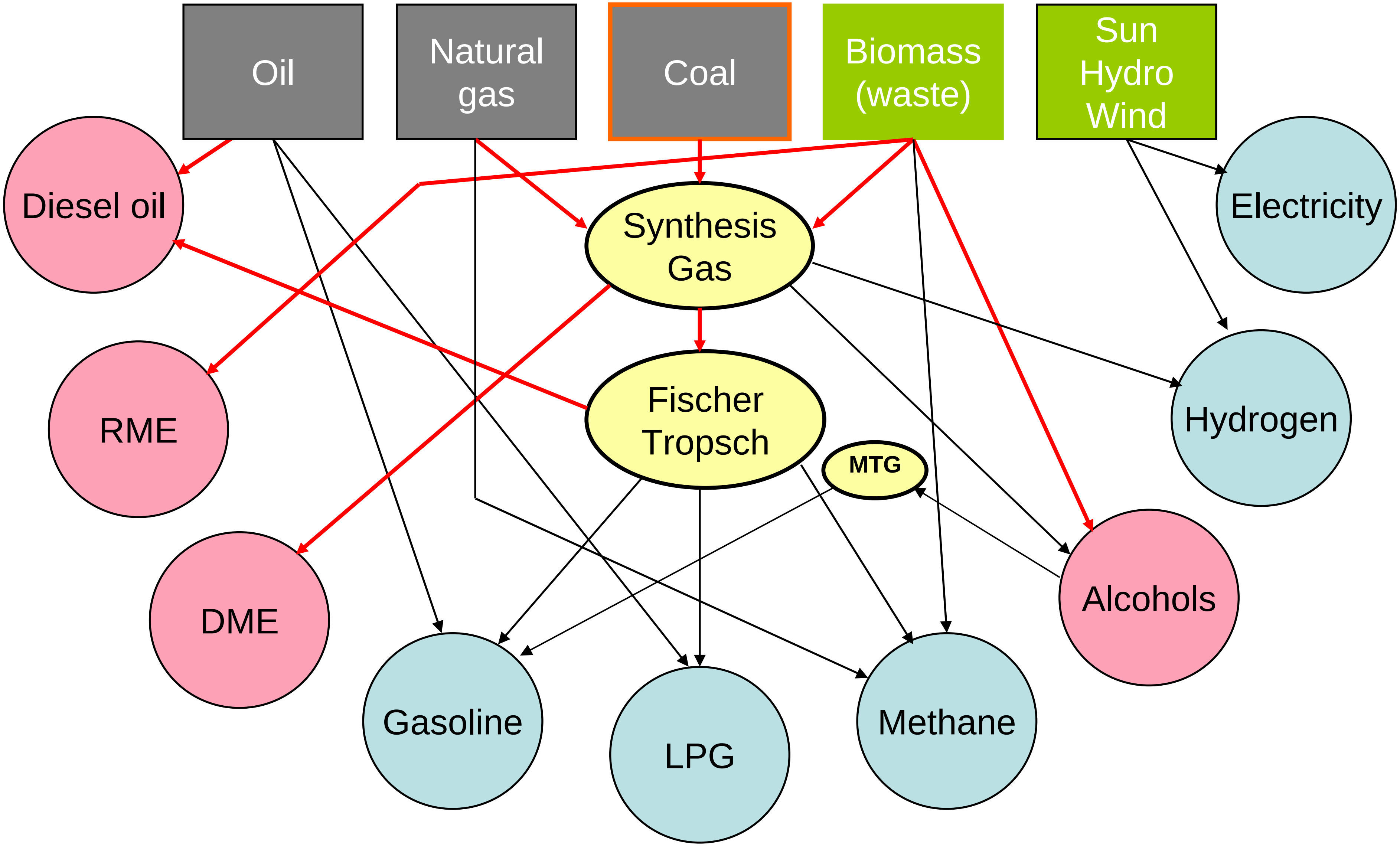


Oljan som fysisk resurs utgör knappast den gränssättande faktorn inom överskådlig tid.

Predictable future

- There will be new fuels on the market ➔ adaptation
- Fuel prices will increase ➔ low fuel consumption
- Concern of the climate ➔ CO_2 neutral feedstock (bio mass and fossil plus carbon sequestration
- Maintained or sharpened emission standards ➔ Further developed combustion processes and exhaust after treatment

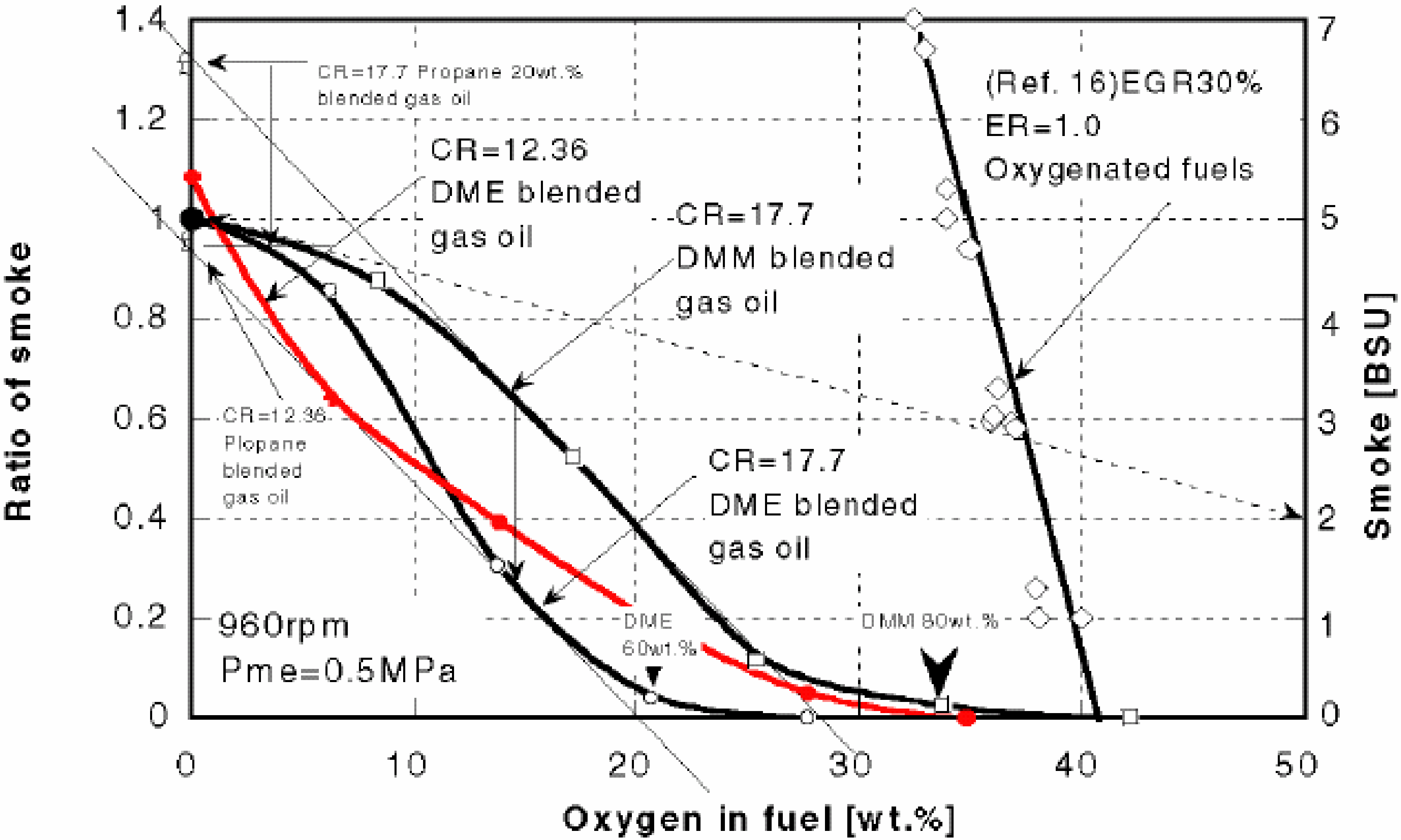
Production of fuels from different feedstock



The impact of fuel

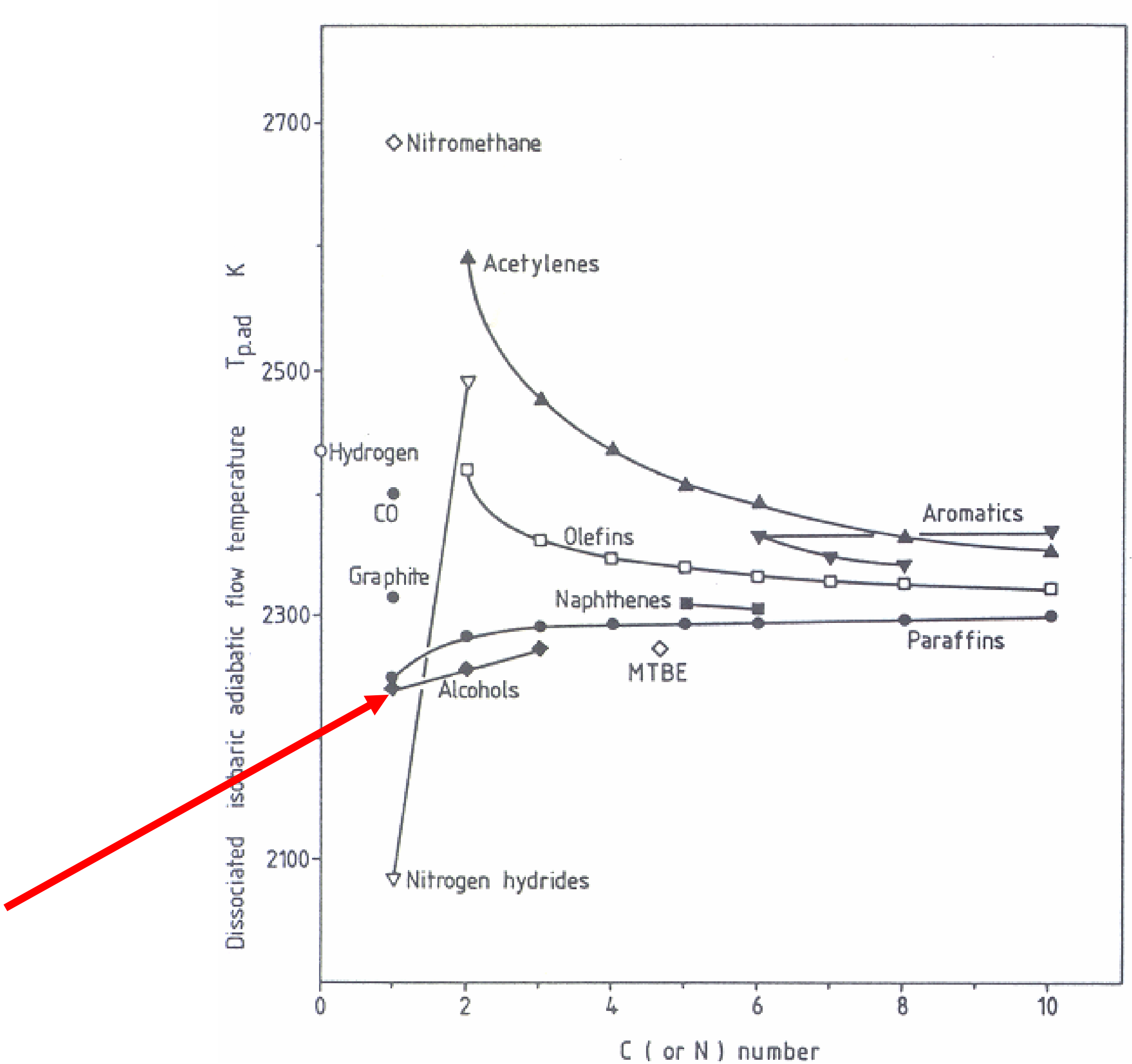
Oxygenates

Oxygenated diesel fuels and soot



Source: “DME fuel blends for low-emission, direct-injection diesel engines” SAE-paper 2000-01-2004

Adiabatic flame temperture



Dimethylether – DME

(?)

ECE R49 [g/kWh] ESC from Euro IV	Project results	Euro III	Euro IV	Euro V
NOx	2.99	5.0	3.5	2.0
HC	0.12	0.66	0.46	0.46
CO	0.25	2.1	1.5	1.5
PM	<0.02	0.1	0.02	0.02

Source: Hansen, K. F. et al ”Demonstration of a DME (Dimethyl Ether Fuelled) City Bus”. SAE Paper 2000-01-2005. 2000.

Ethanol with ignition improvers

Diesel engines

Scania

[g/kWh]	Ethanol w/o EGR	Ethanol with EGR	Euro IV	Euro V
NOx	3.5	1.73	3.5	2.0
CO	0.10	0.16	1.5	1.5
HC	0.10	0.16	0.46	0.46

Volvo

[g/kWh]	w/o Catalyst	With Catalyst
NOx	3.80	3.30
CO	1.68	0.196
HC	0.73	0.158

Volvo

Unregulated emissions	[g/kWh]
Formaldehyde	0.020
Acetaldehyde	0.031
Ethanol	0.870
Methanol	0.0002
Acetic acid	0.008

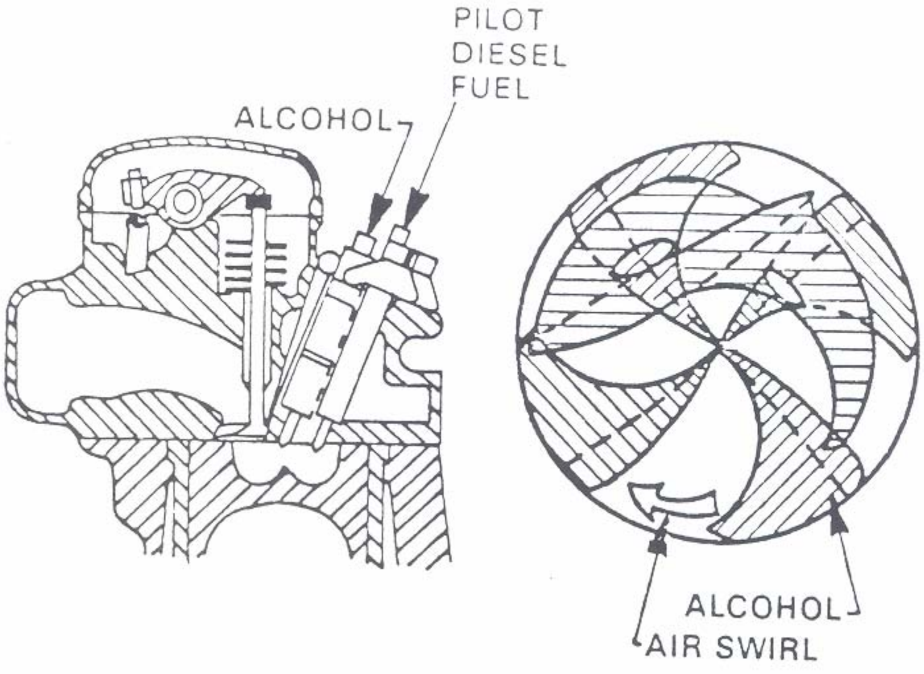
Adaptation and optimization of diesel engines for bio fuels (oxygenates) using HCCI experience and knowledge

Diffusive combustion

Memories from the 80th

Diesel engines

- Ignition improvers
- Pilot injection
- Spark or glow plugs
- Residual gas ignition



Recidual gas ignition
DDA two-stroke diesel engine

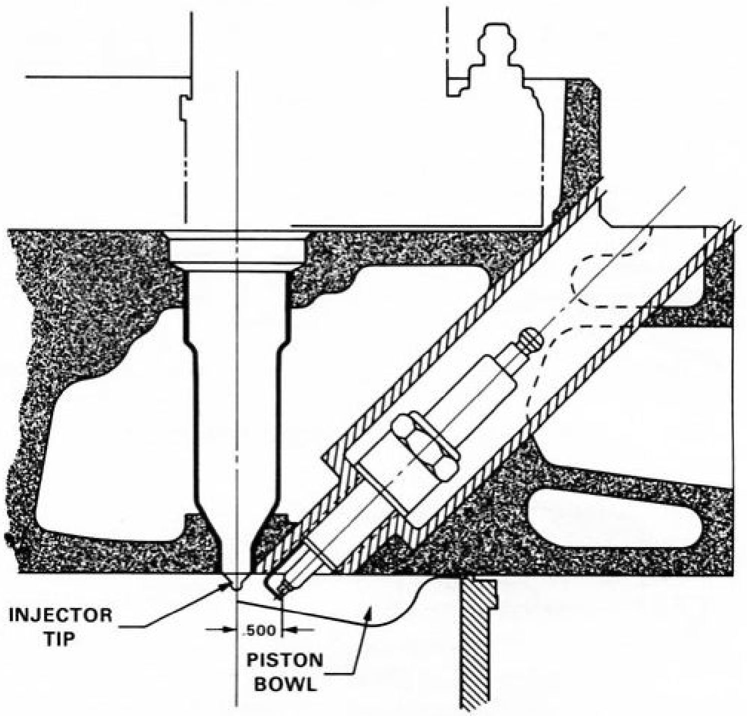


Fig. 12–Cross-Section of Final Single-Cylinder Engine Ignition Source Location.

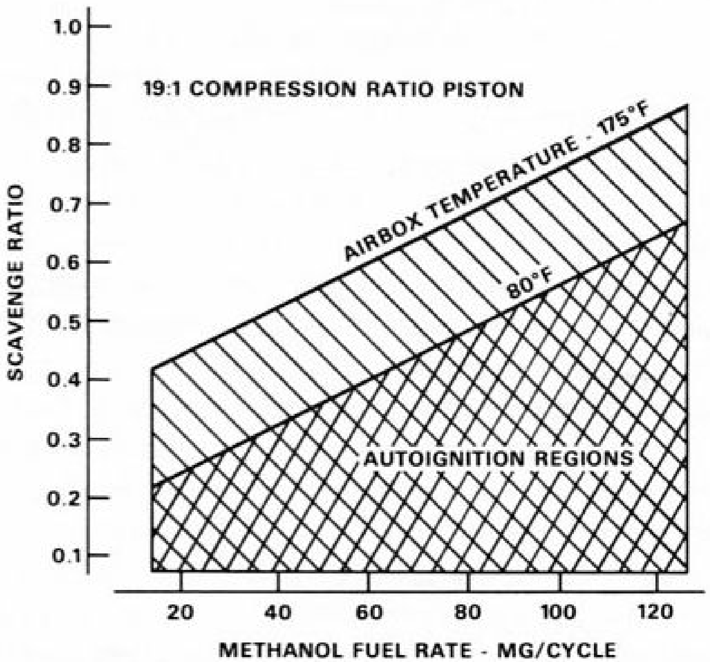
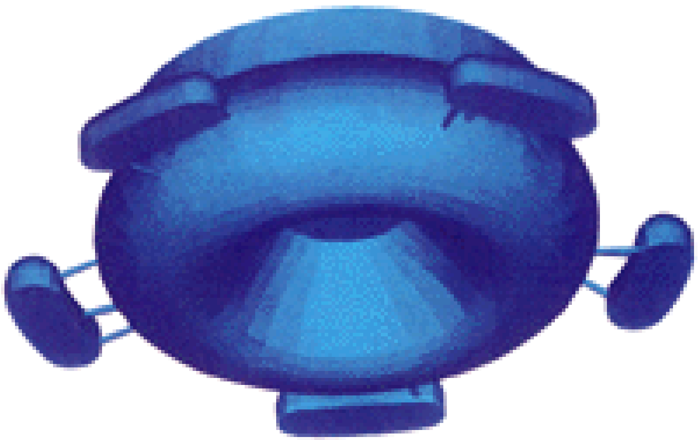
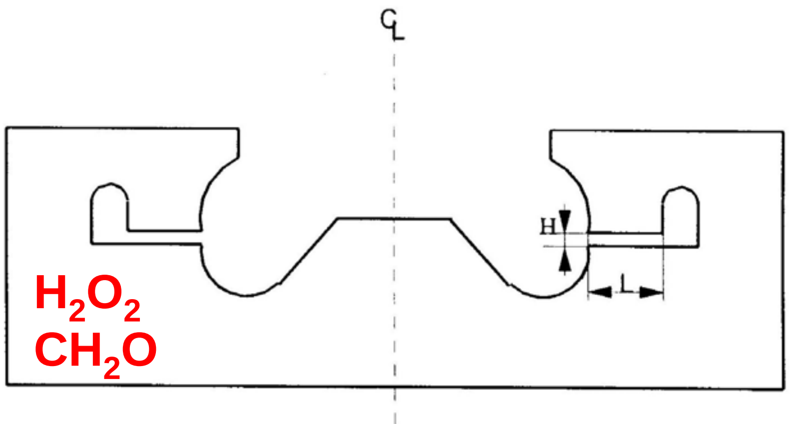


Fig. 10–Influence of Airbox Temperature on Autoignition Regime.

Sonex Ultra Clean Burn

- Standard Perkins DI diesel engine (CR=17:1)
- Neat Methanol (M100)
- No ignition improver
- No spark or glow plug (in cylinder)
- Misfire-free operation over the entire load and speed range.
- No smoke, lower NOx

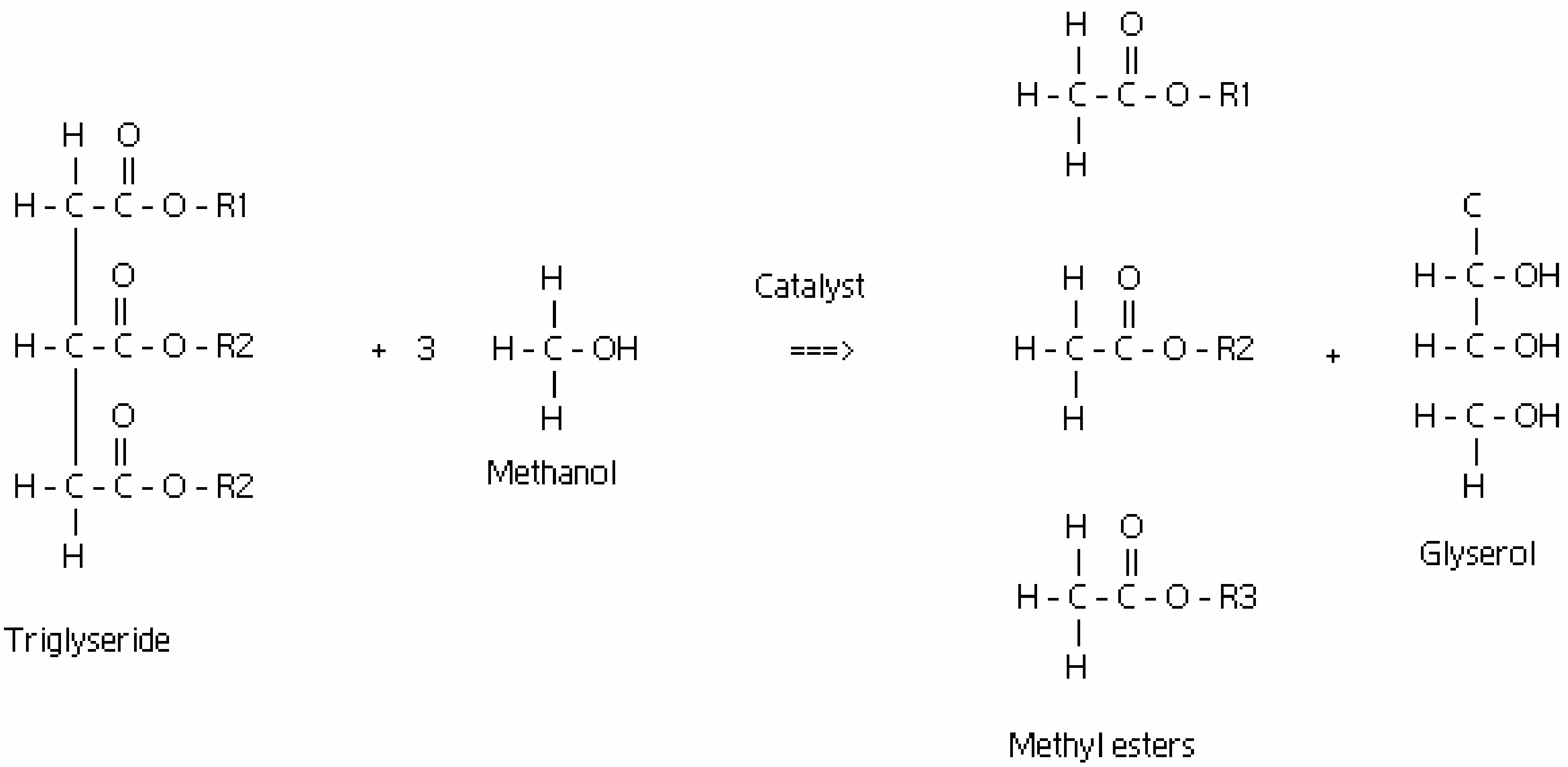




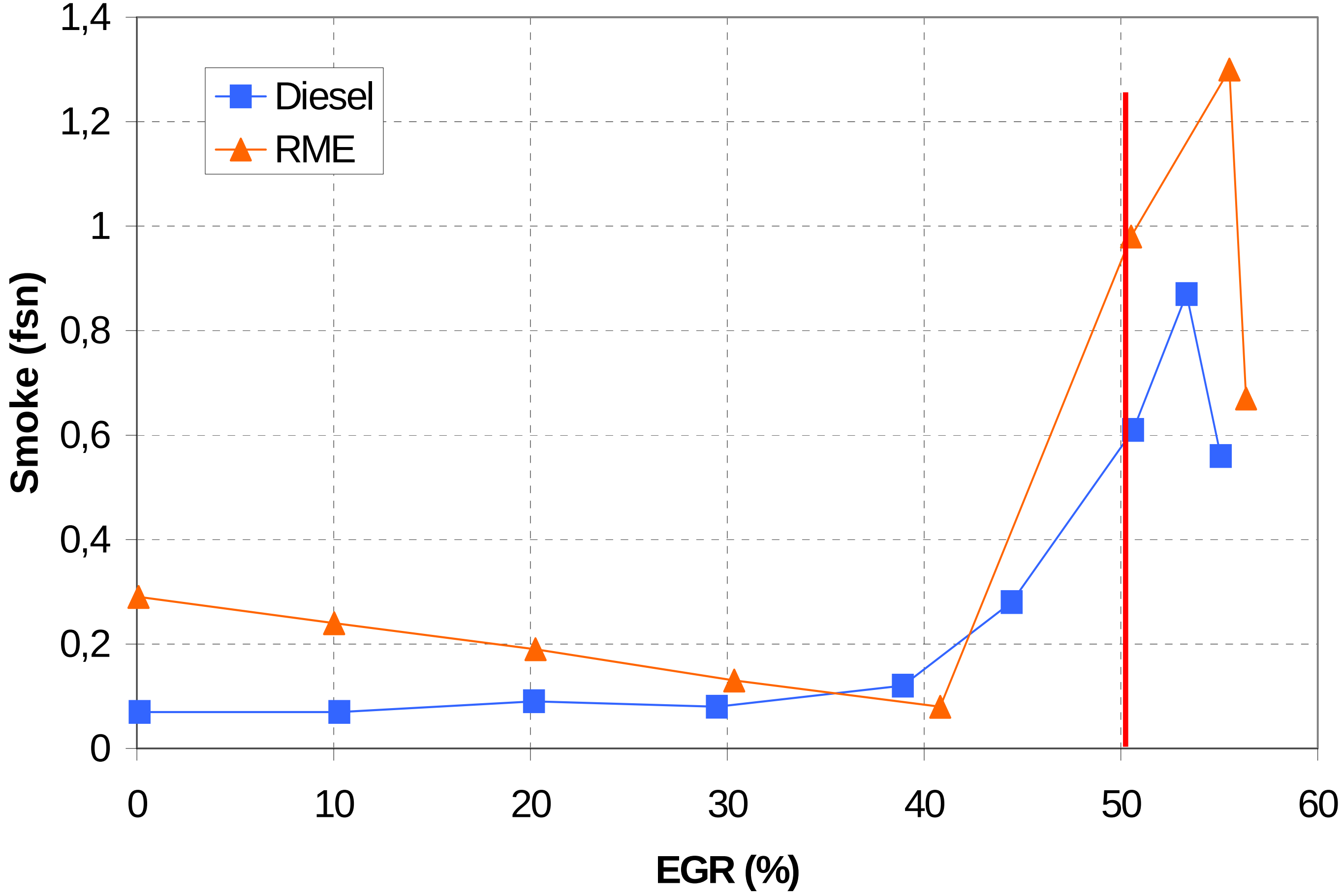
Chemical enhancement of ignition

Previous experience of DME

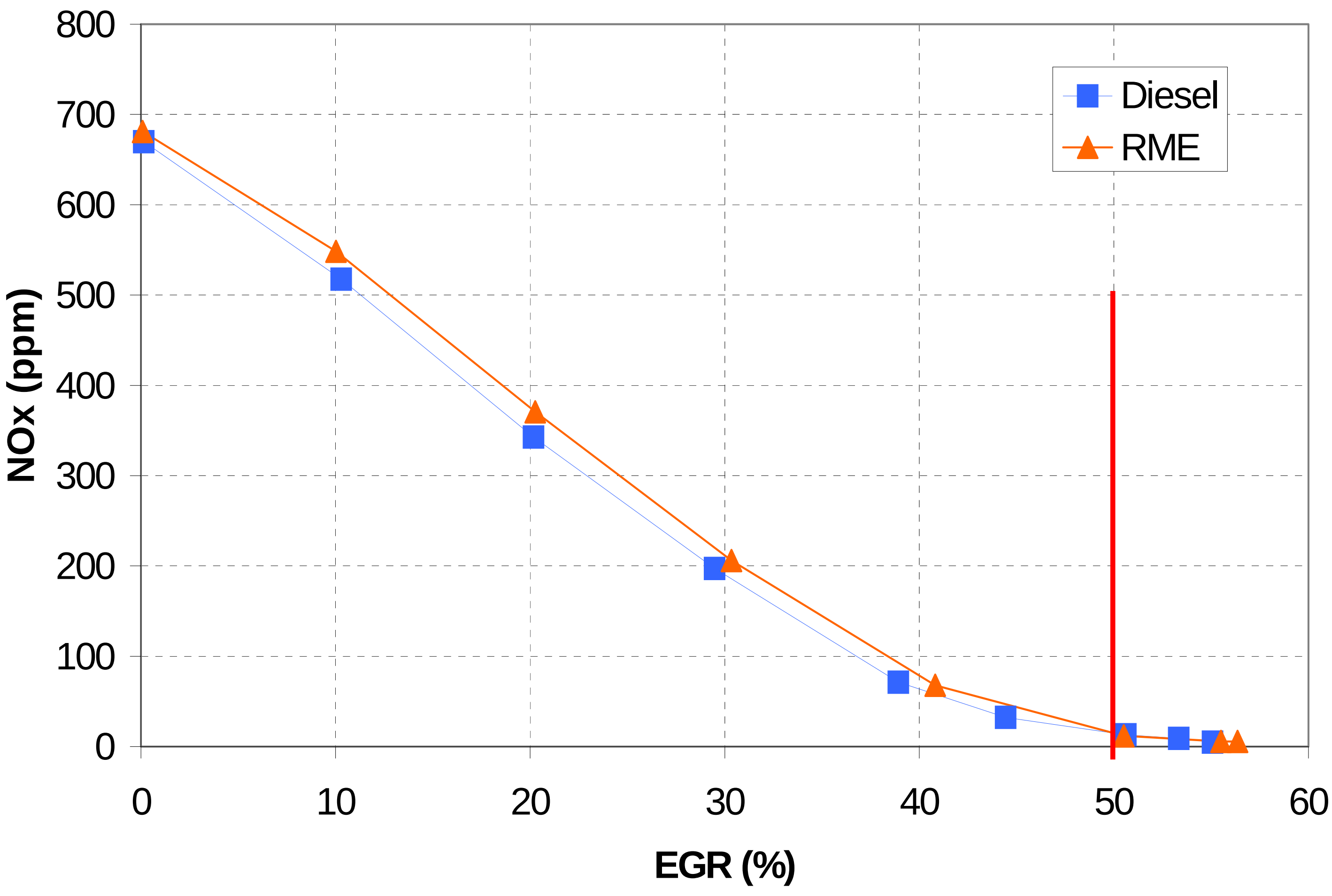
Bio Diesel - RME



Smoke trends: Diesel and RME

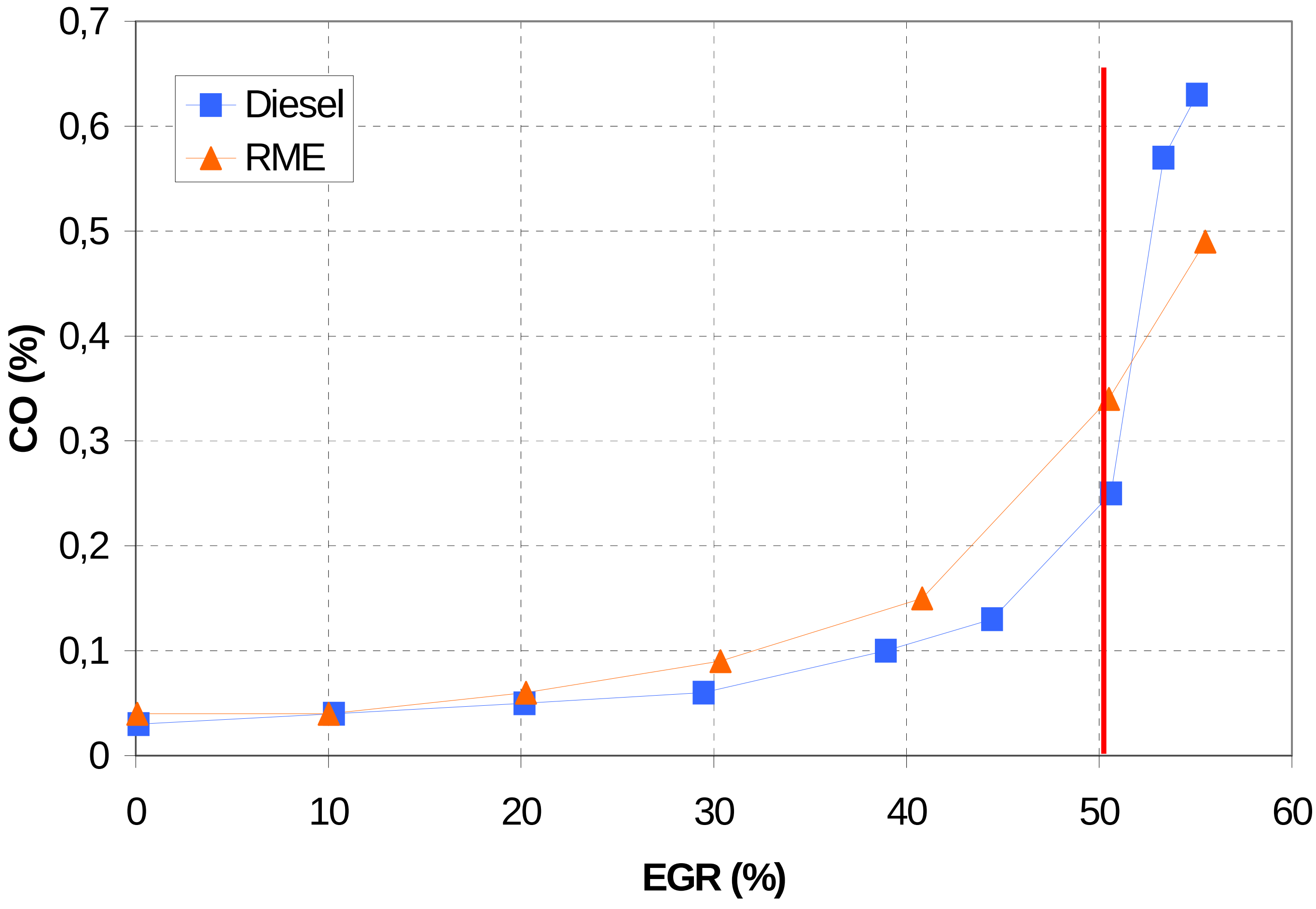


NOx trends

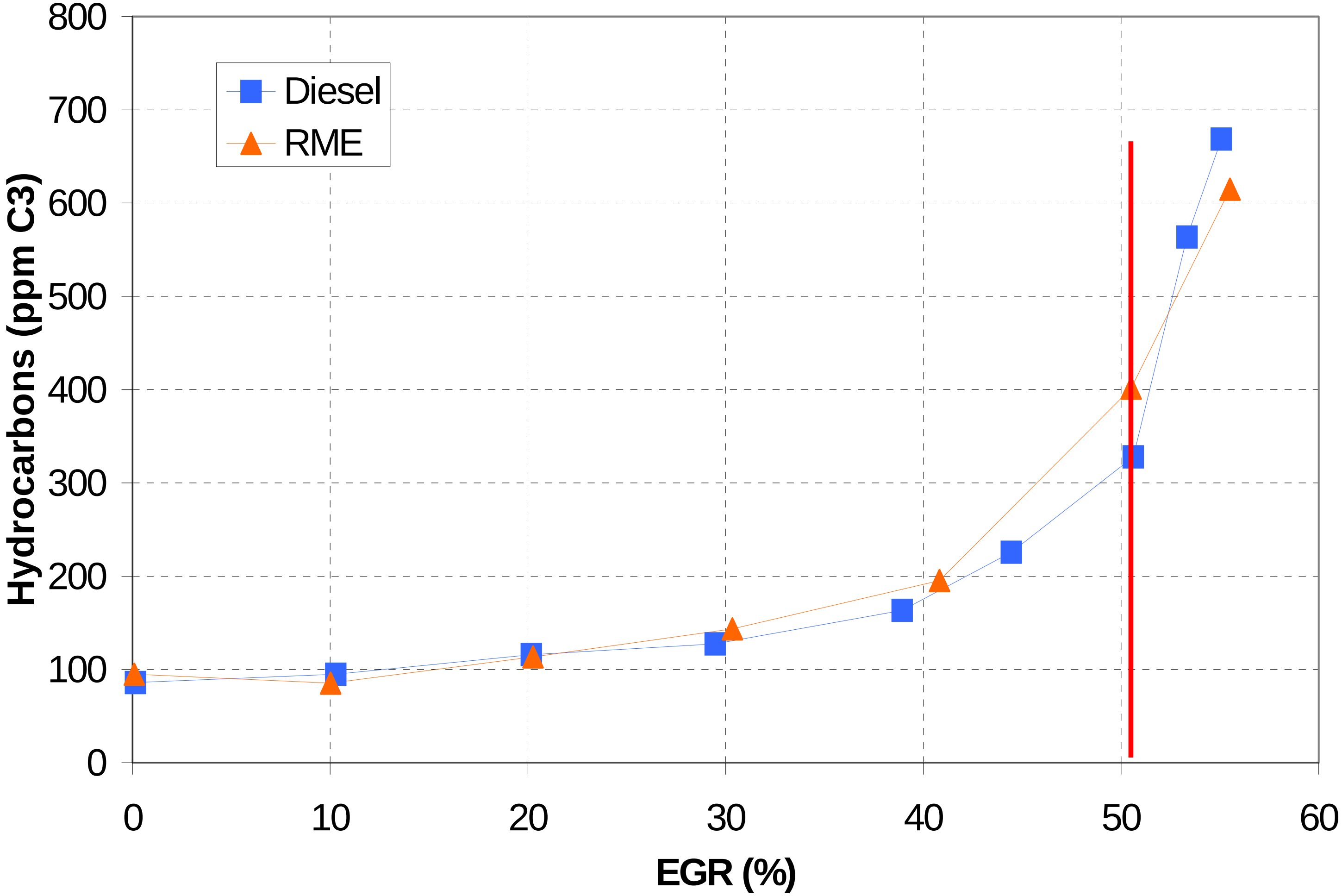


800
700
600
500
400
300
200
100
0
NOx (ppm)
0
10
20
30
40
50
60
EGR (%)
Diesel
RME

CO trends



Hydrocarbon trends



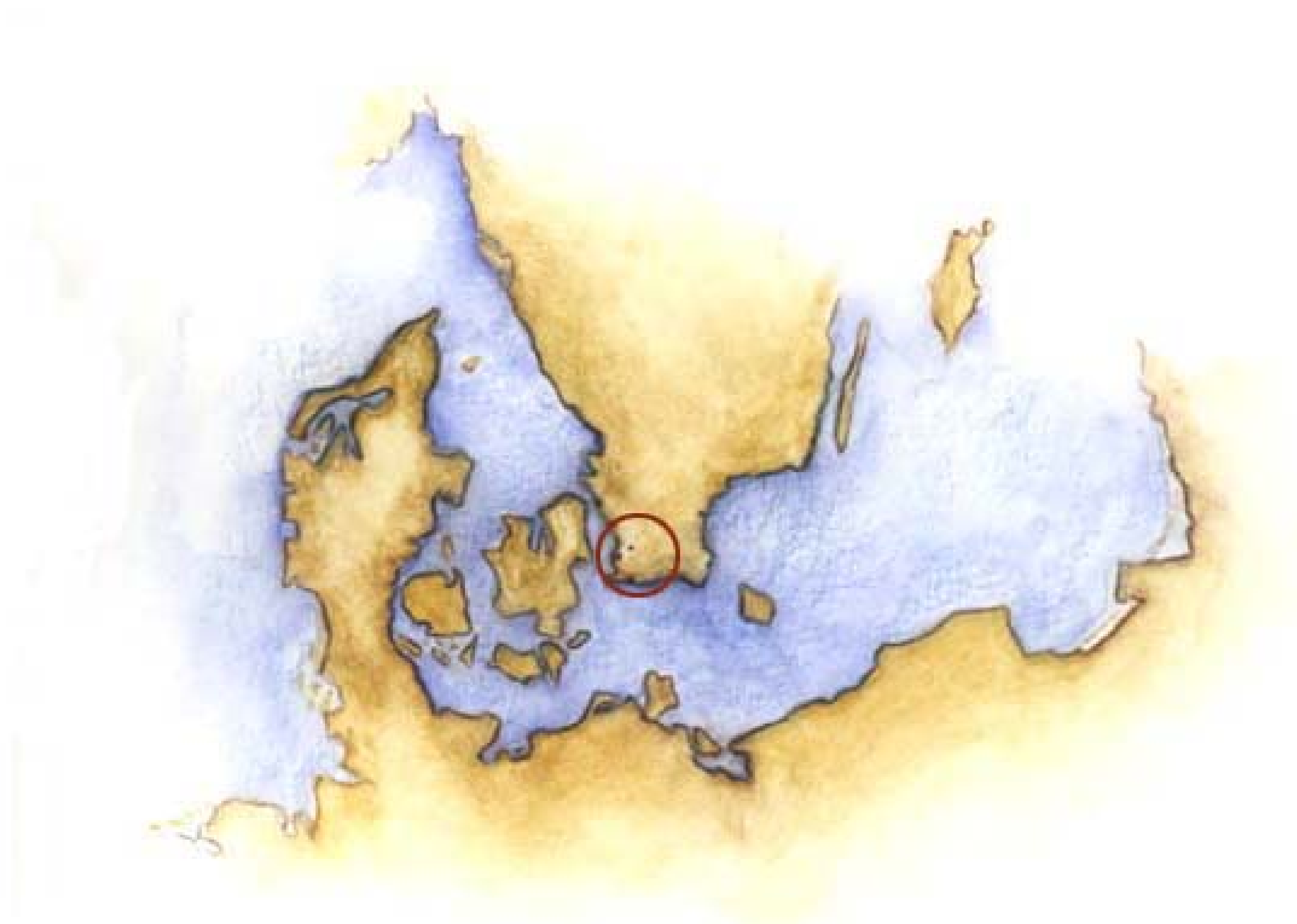
RME results

	NOx g/km	CO g/km	HC g/km	PM g/km	CO_2 g/km	CH_4 g/km	Σ PAH μg/km	Acet-aldehyde mg/km	Form-aldehyde mg/km	Benzene mg/km
RME	**16**	**4.5**	**0.05**	**0.3**	**1080**	**<0.01**	**80**	**10**	**<2**	**<2**
EC1	**12**	**6**	**0.7**	**0.3**	**1050**	**0.02**	**150**	**20**	**<10**	**<10**

Lund University and HCCI

Lund (?)

Lund



Lund University

Lund University

Lund University
(35000 students)

Lund Institute of Technology
(5000 students)

Department of Energy Sciences (former Heat and Power Engineering)
(Staff 80 persons)

Department of Engineering Physics

Division of **Energy economics and planning**
Prof.
L. Törnqvist

Division of **Fluid dynamics**

Prof.
Lazlo Fuchs

Division of **Heat transfer**

Prof.
Bengt Sundén

Division of **Thermal Power Engineering**
Prof.
Tord Torrison

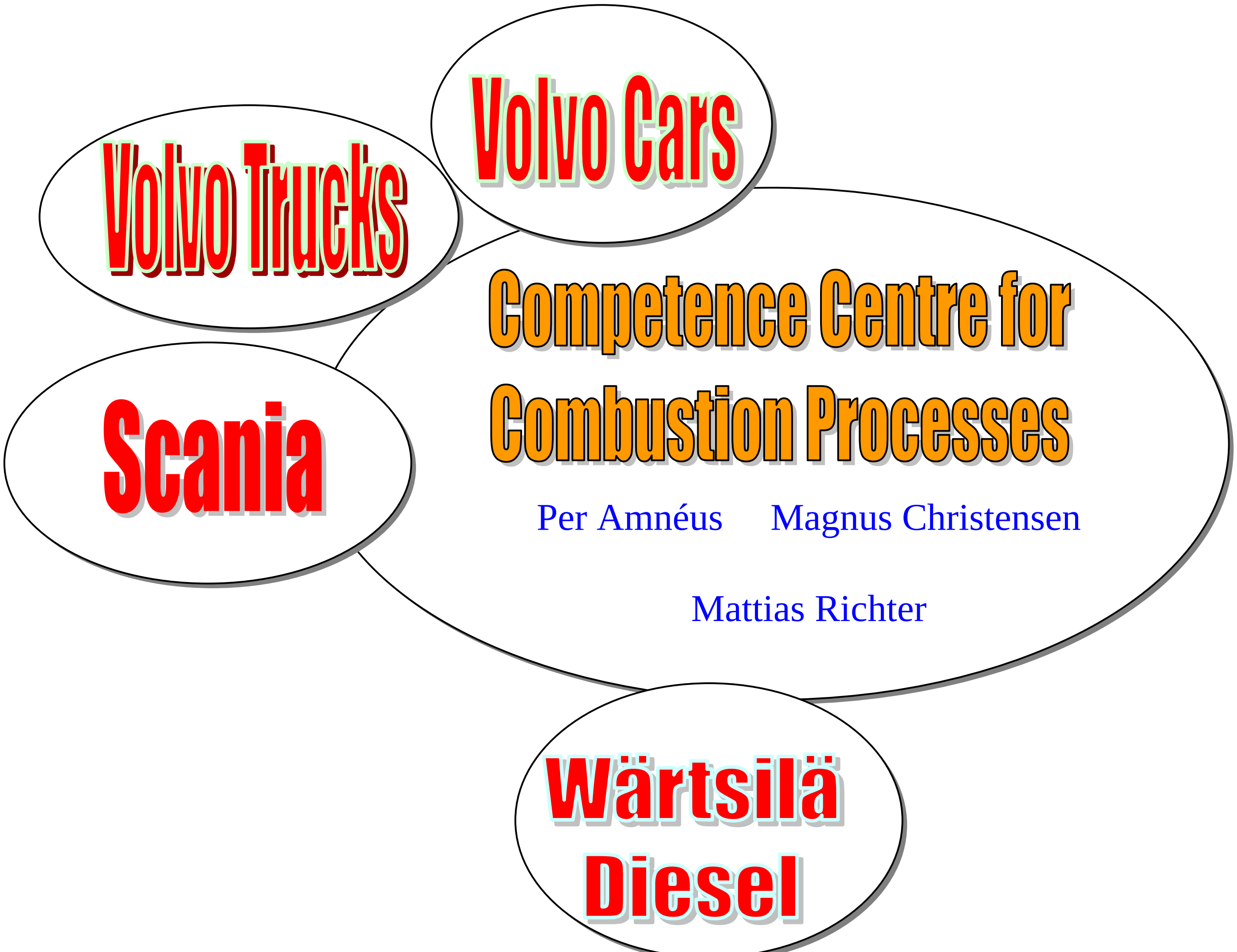
Division of **Combustion Engines**

Prof.
Bengt Johansson
(staff 25 persons)

Division of **Combustion Physics**

Prof.
Marcus Aldén
(staff 35 persons)

HCCI in Lund 1997



HCCI-Projects 2006

Cargine

PFF
Sasa Trajkovic

PFF
Kent Ekholm
Maria Karlsson

PFF
Hans Aulin
Thomas Johansson

Volvo Cars

SAAB

Volvo Trucks

Caterpillar

Competence Centre for Combustion Processes

Anders Hultqvist Martin Tunér Andreas Vressner
Per Tunestål Carl Wilhelmsson Håkan Persson
Mattias Richter **Xue-song Bai** Leif Hildingsson
Rolf Egnell Uwe Horn Mehrzad Kaiadi

Scania

Wärtsilä

PFF
NN

EU-proj
Vittorio Manente

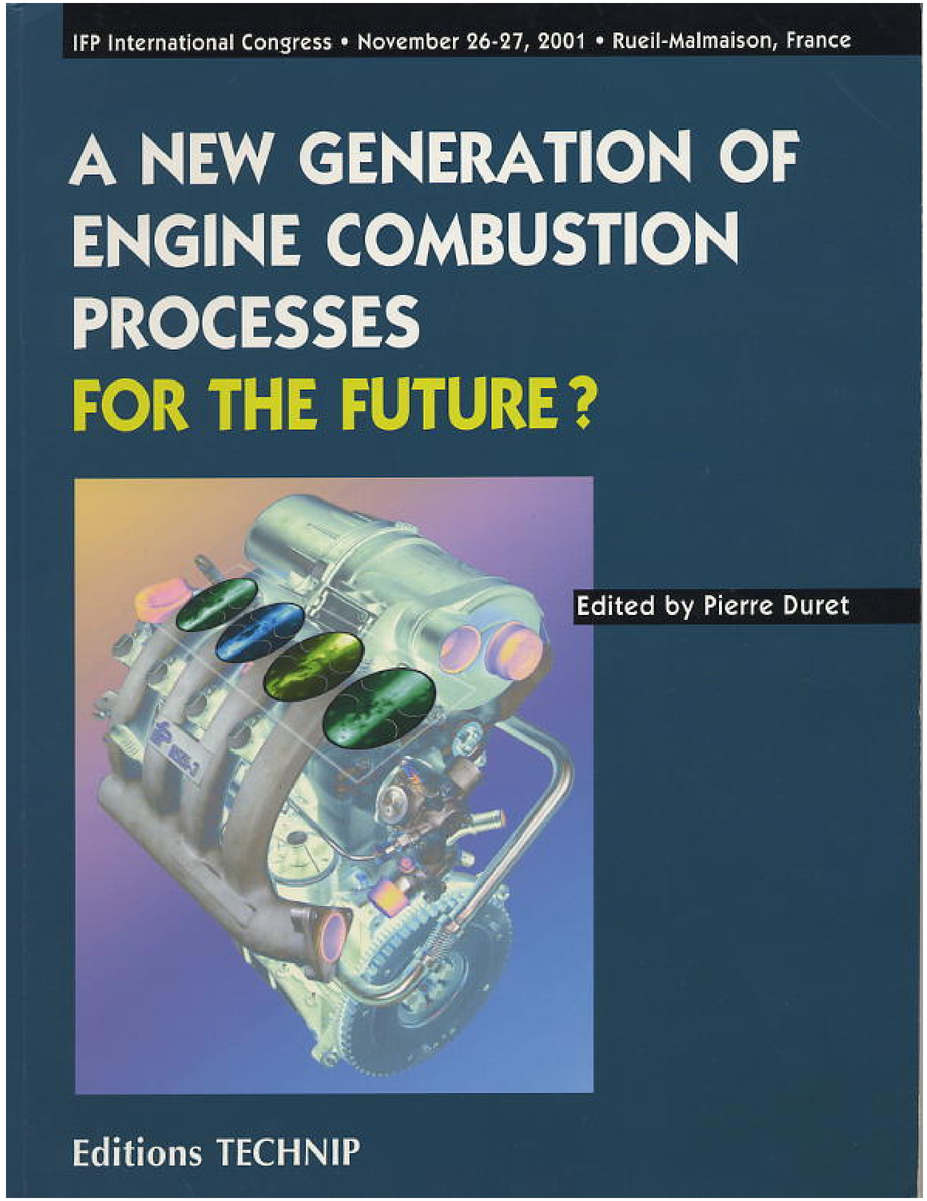
Toyota
Ryo Hasegawa

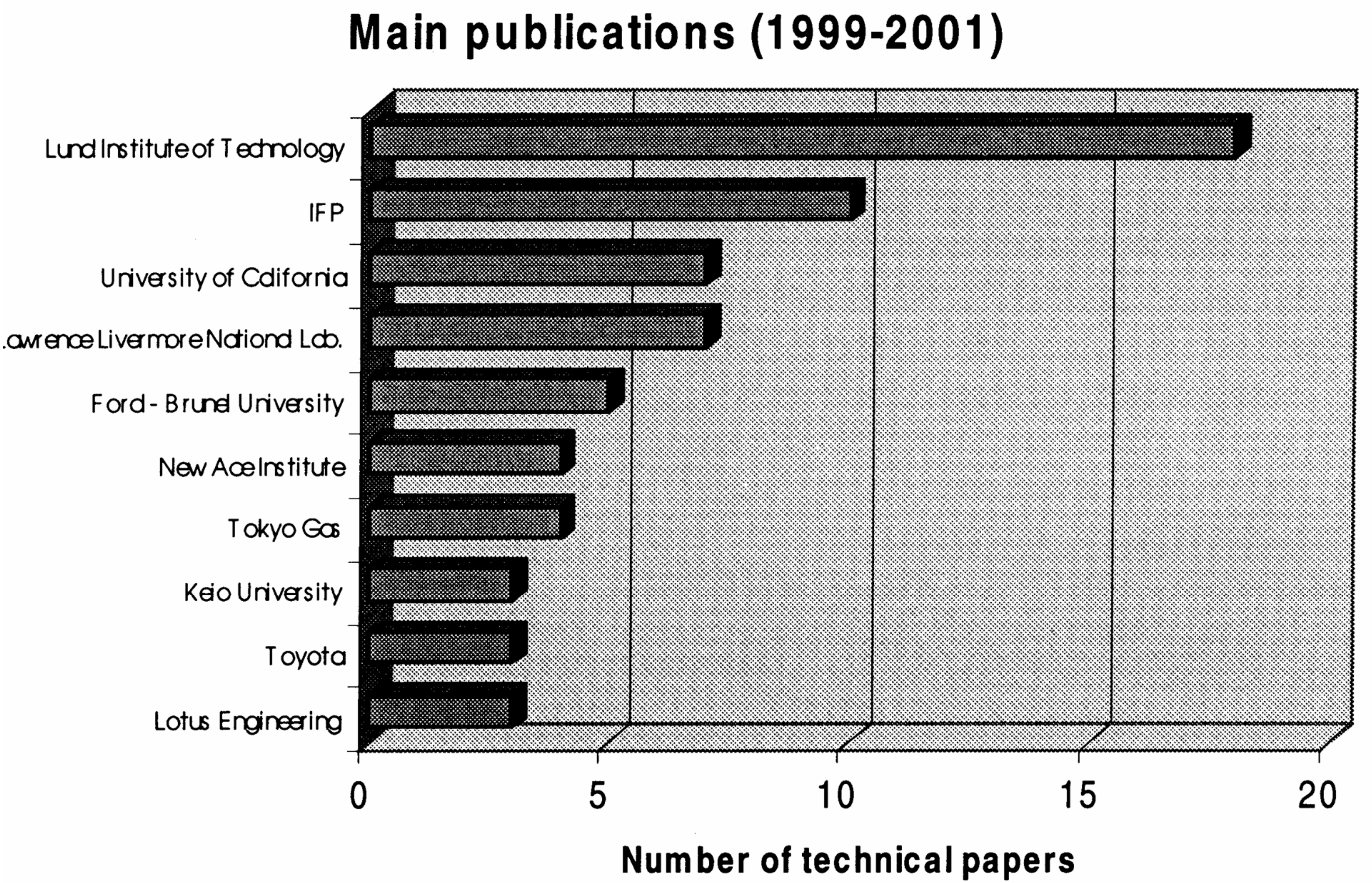
Nissan

SGC

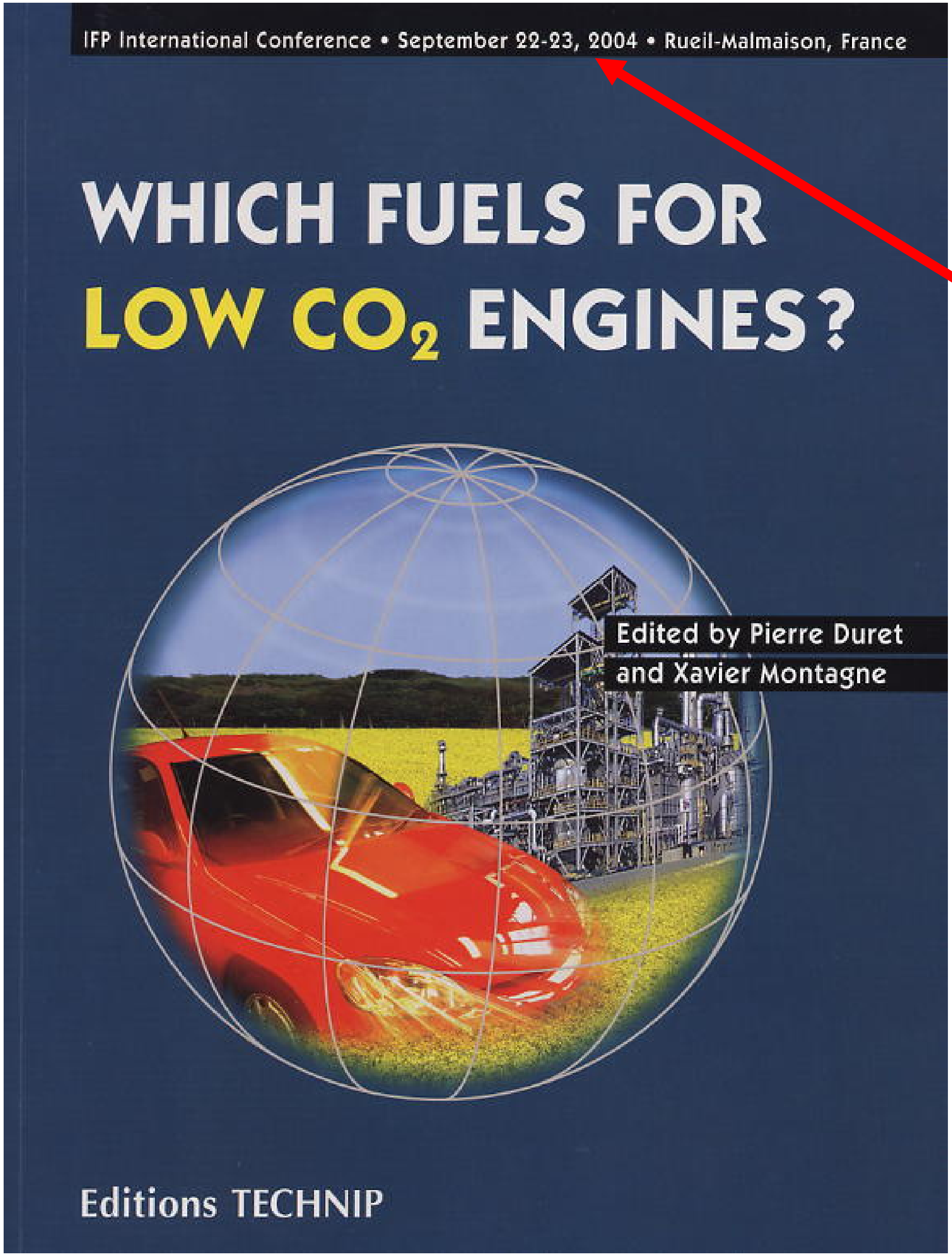
Finnveden

Publications on HCCI worldwide



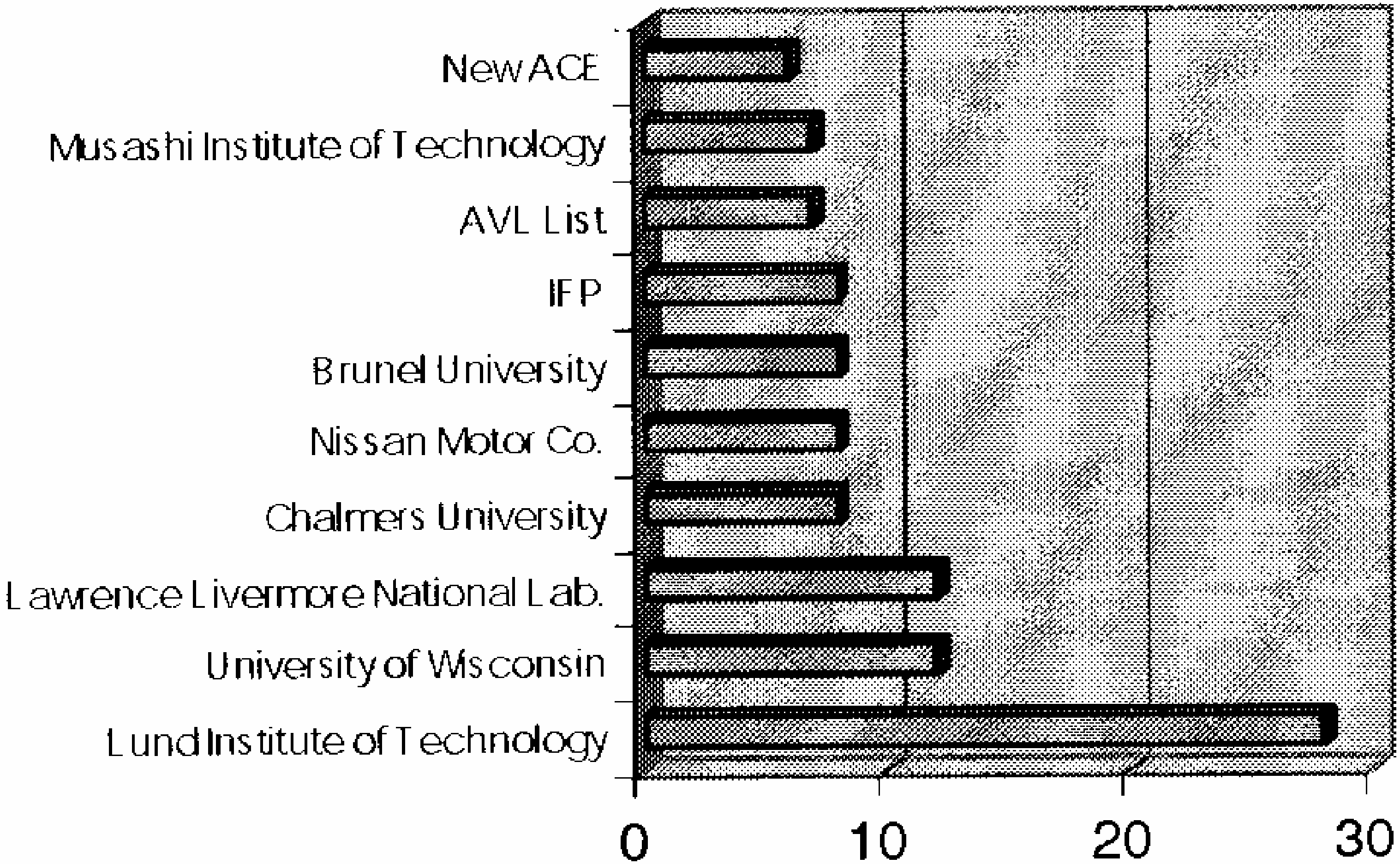


From keynote talk by Pierre Duret
at IFP International Congress Nov. 26-27 2001.


IFP International Conference • September 22-23, 2004 • Rueil-Malmaison, France
WHICH FUELS FOR
LOW CO_2 ENGINES?
Edited by Pierre Duret
and Xavier Montagne
Editions TECHNIP

More recent

Papers on HCCI the last 3.5 years



From keynote talk by Pierre Duret
at IFP International Congress Sept. 22-23 2004.

HCCI activities in Lund

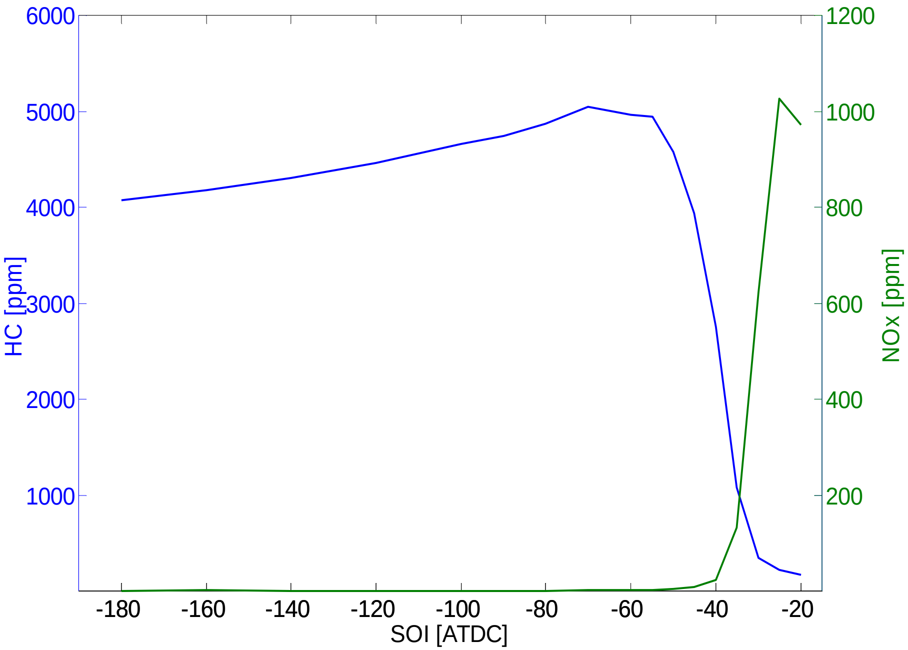
1. Basic engine studies
   Prof. Bengt Johansson
2. Laser diagnostics
   Prof. Marcus Aldén
3. Combustion modeling
   Prof. Xuesong Bai, (Prof. Fabian Mauss)
4. Closed loop combustion control
   Asc. Prof. Per Tunestål
5. Fuel Effect

   Asc. Prof. Rolf Egnell

HCCI, CAI, PCCI, pHCCI, PPC, LTC…?

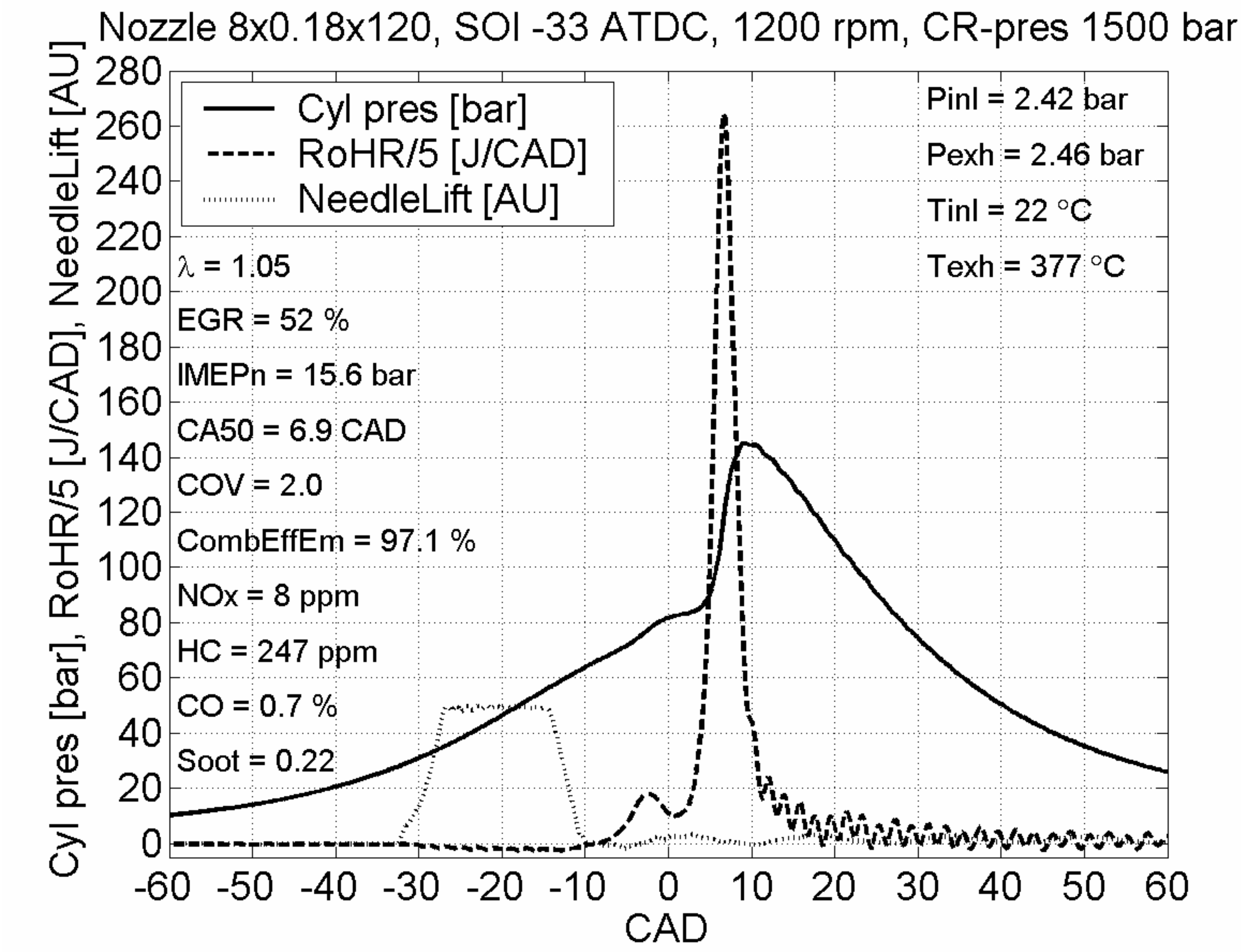
- HCCI is normally a concept with port fuel injection and high compression ratio.
- CAI is normally a concept with low compression ratio and high residual gas concentration with negative valve overlap
- PCCI is normally a concept with early direct injection forming a rather homogeneous charge
- pHCCI=PCCI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

Partially premixed combustion, PPC

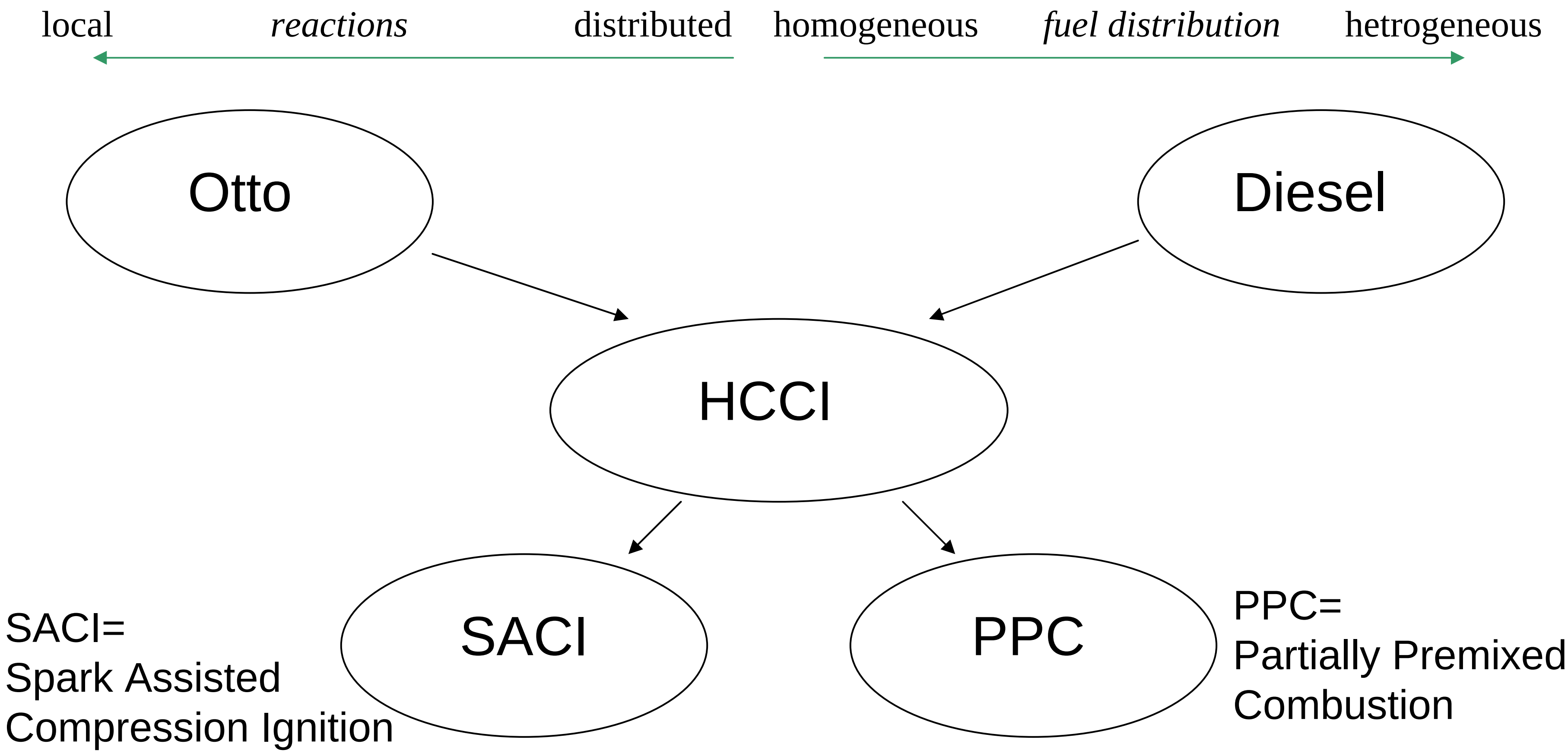


- Def: region between truly homogeneous combustion, HCCI, and diffusion controlled combustion, diesel
- Trade-off between NOx and HC, soot typical
- Combustion process not well known
- Soot the key feature

PPC potential



Evolution


local
reactions
distributed
homogeneous
fuel distribution
hetrogeneous
Otto
Diesel
HCCI
SACI
PPC
SACI=
Spark Assisted
Compression Ignition
PPC=
Partially Premixed
Combustion

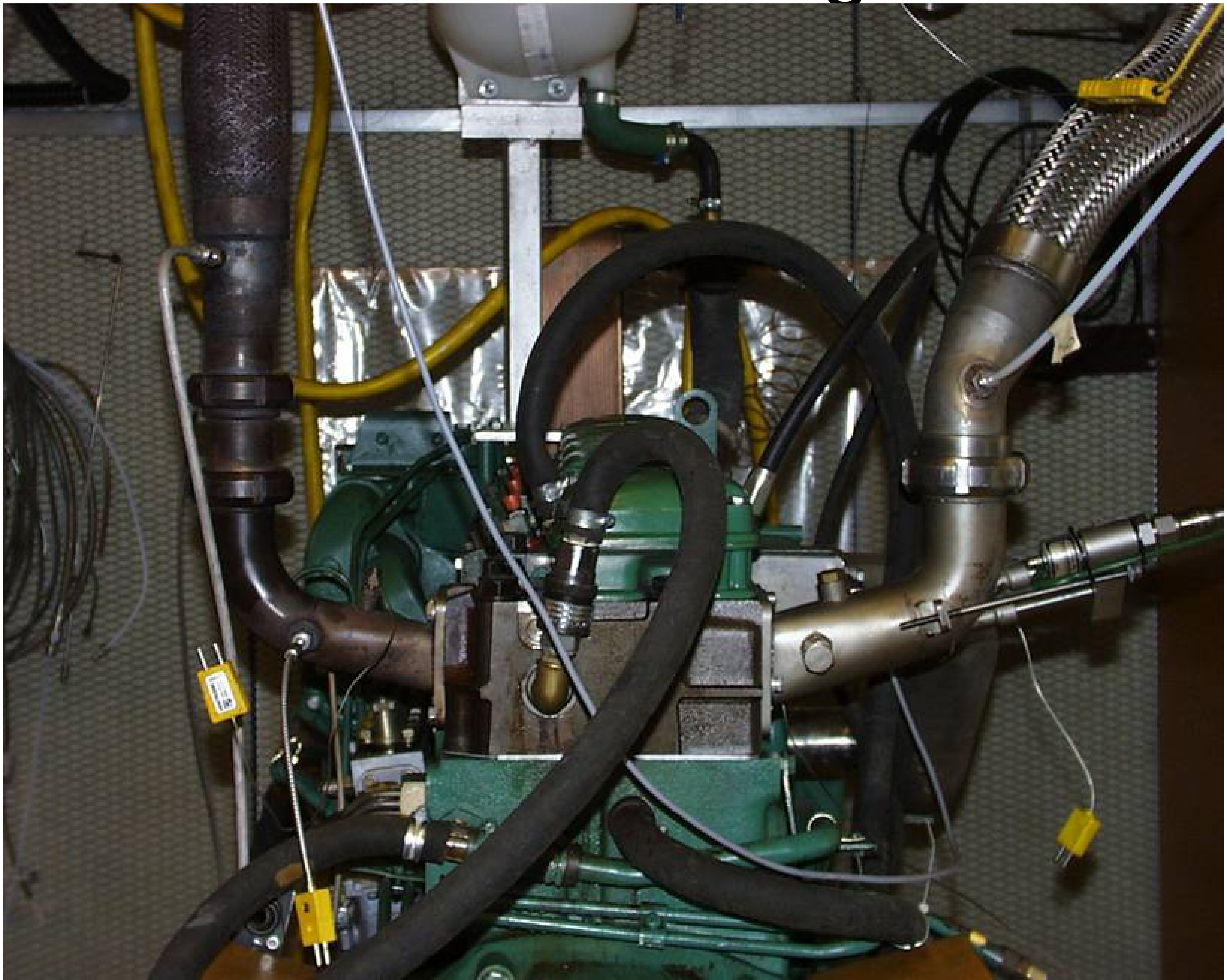
Fields of work 2006-2009

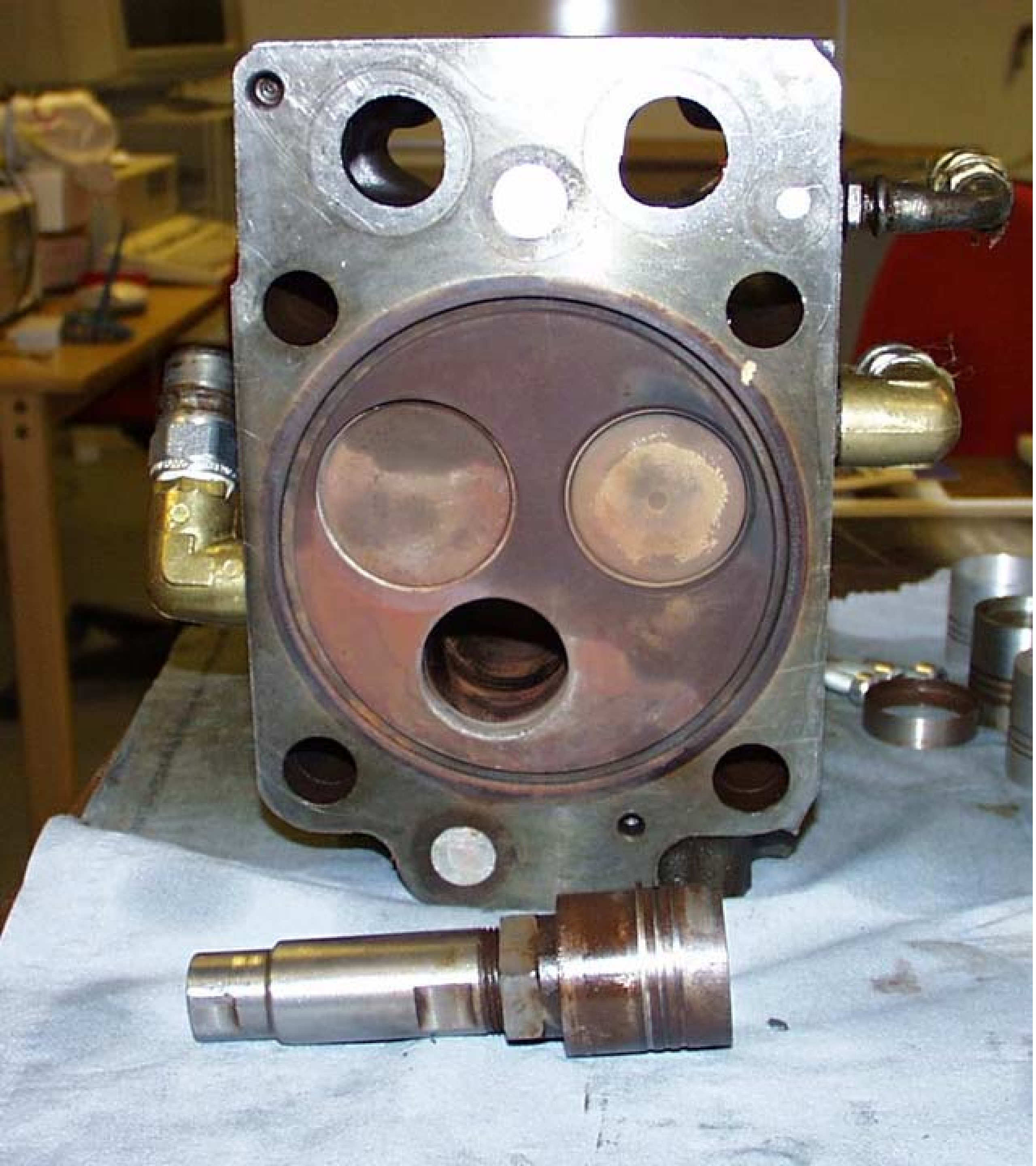
	Spark assisted compression ignition, SACI	Partially premixed combustion, PPC	Generic diesel research, GenDies
Engine experiments			
Laser diagnostics			
Modelling			
Combustion control			
Fuel effects			

HCCI activities in Lund

1. Basic engine studies
2. Laser diagnostics
3. Combustion modeling - Chemical kinetics
4. Closed loop combustion control
5. Fuel effect

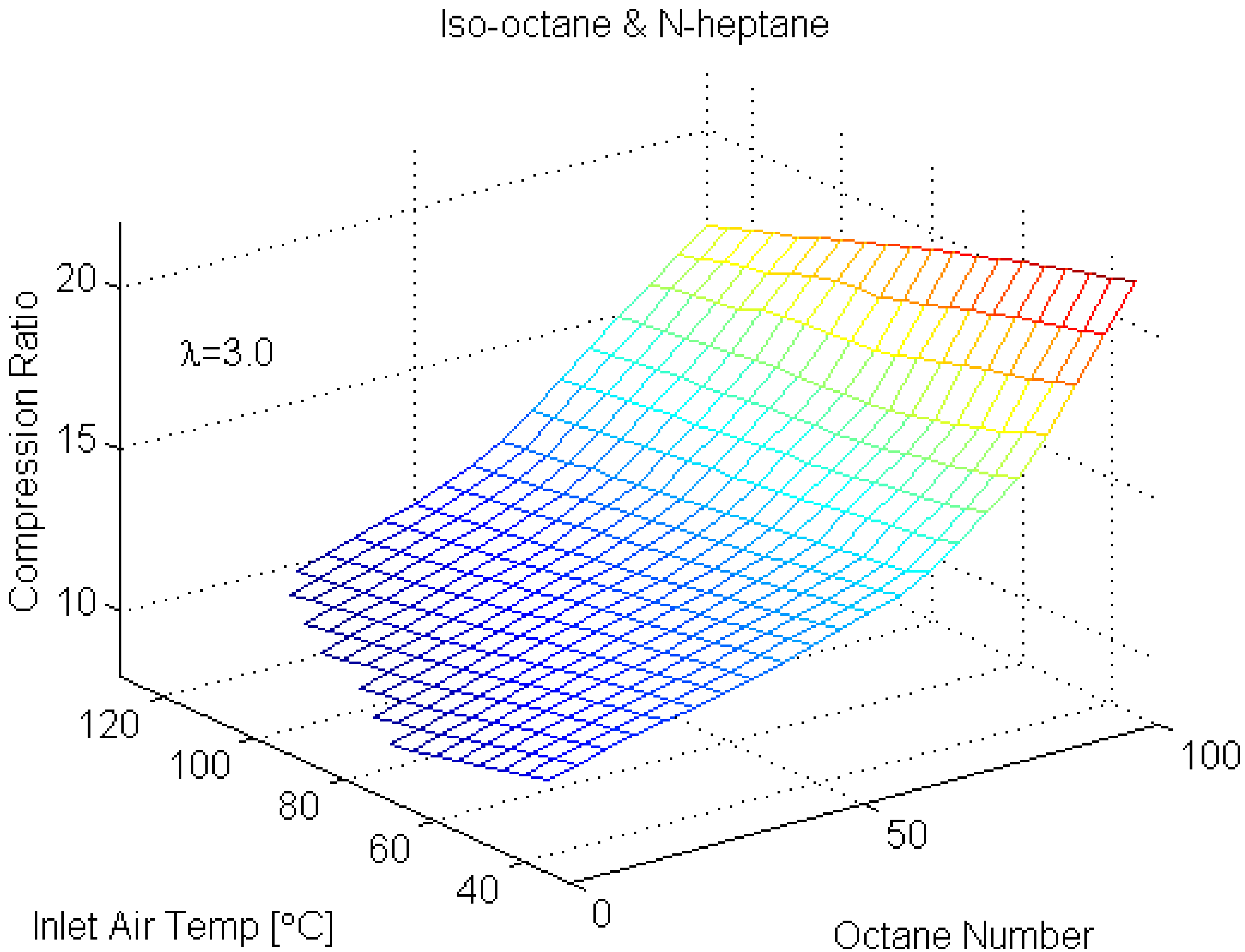
Volvo TD100 engine



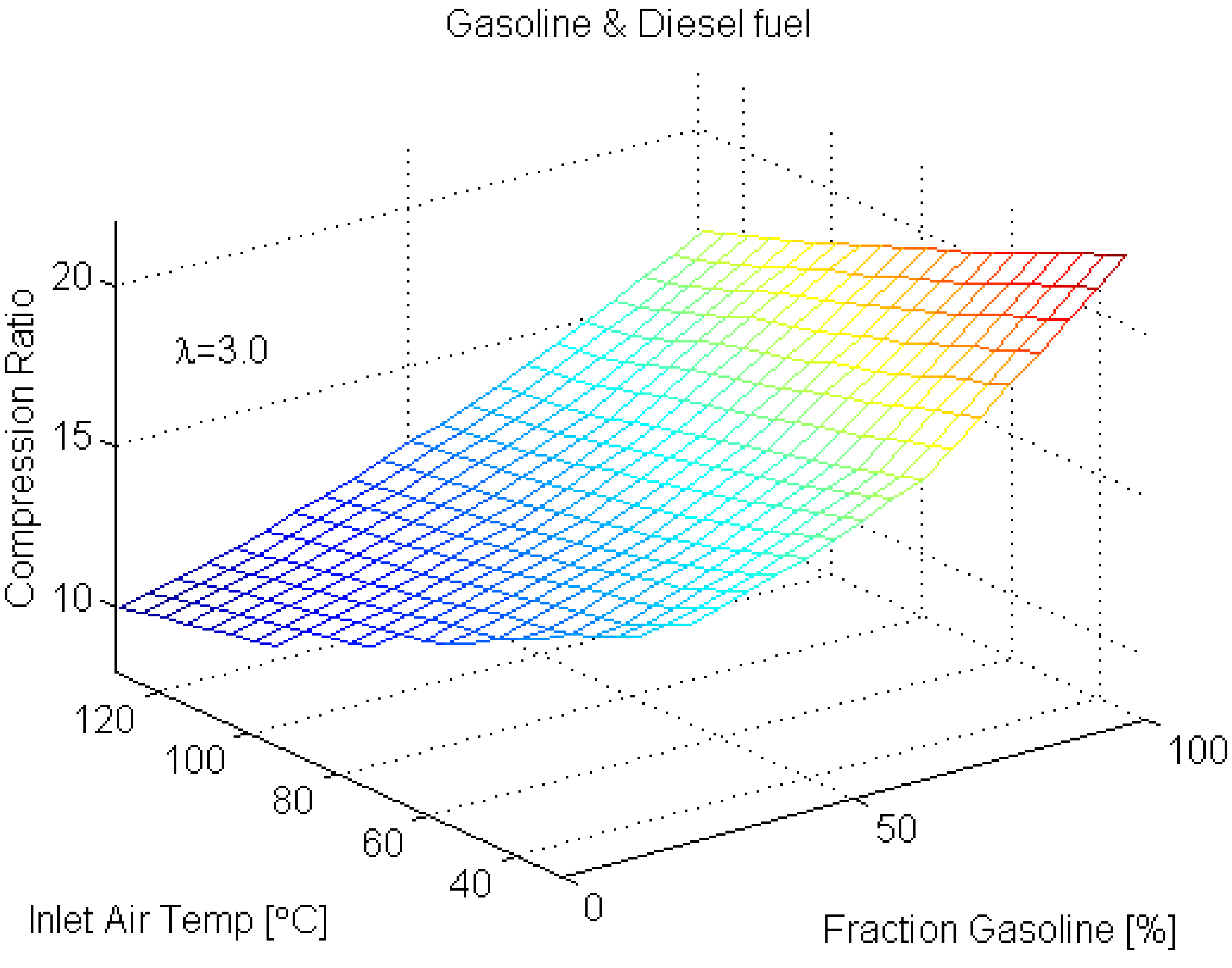


First
VCR
system

Multifuel capability



Multifuel capability

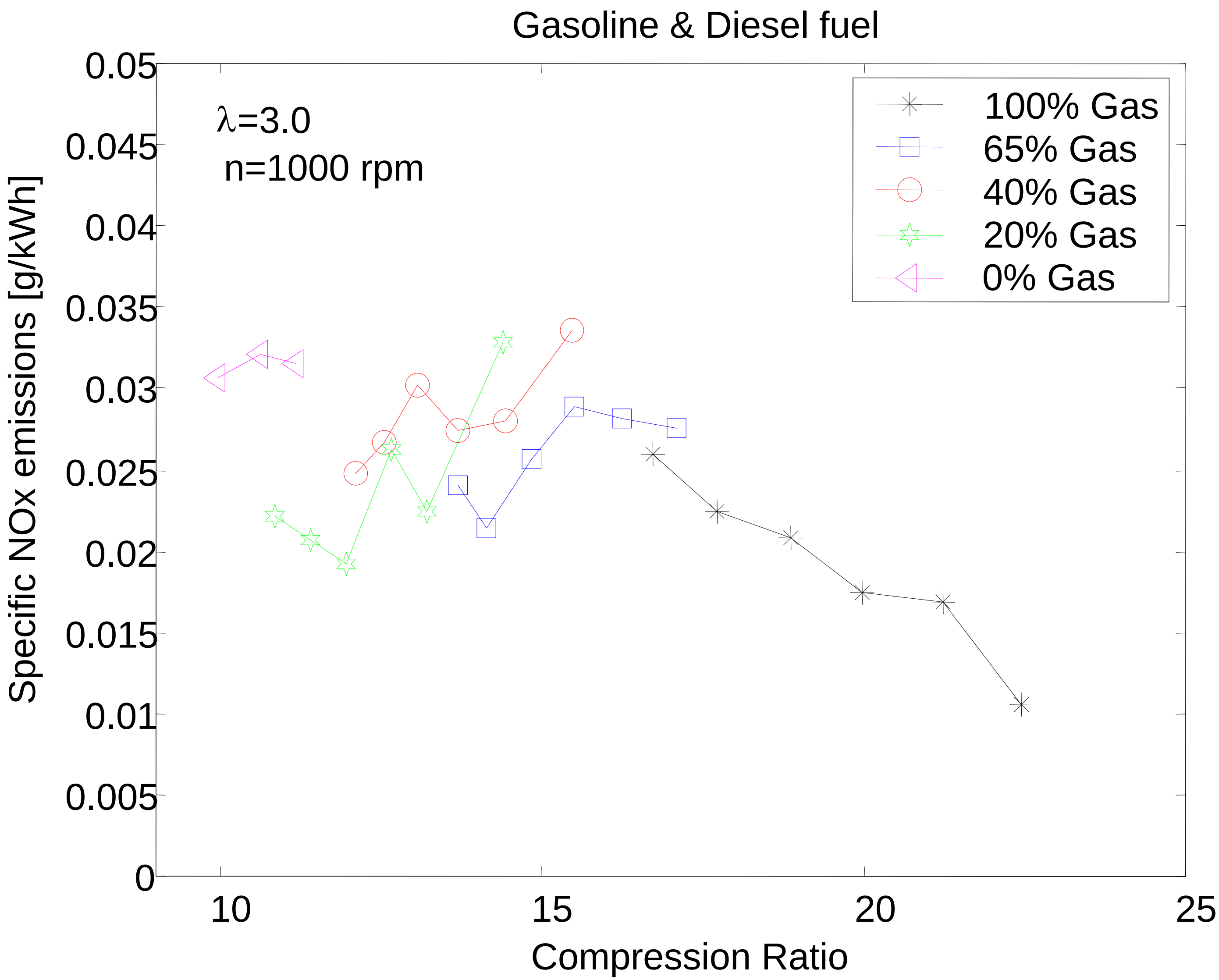


With
Variable Compression Ratio,
VCR,
the HCCI engine can use

ANY

liquid or gaseous fuel!

Low NOx from HCCI mode



Hydrogen?

Hydrogen HCCI

2004-01-1976

Hydrogen as Homogeneous Charge Compression Ignition Engine Fuel

Stenlåås, O., Christensen, M., Egnell, R. and Johansson, B.
Heat and Power Engineering Department, Lund Institute of Technology

Mauss, F.
Combustion Physics Department, Lund Institute of Technology

ABSTRACT

Hydrogen has been proposed as a possible fuel for automotive applications. This paper reports an experimental investigation of hydrogen as HCCI engine fuel. The aim of the experimental study is to investigate the possibility to run an HCCI engine on an extremely fast burning fuel such as hydrogen as well as to study the efficiency, the combustion phasing and the formation of emissions.

The experiments were conducted on a single-cylinder research engine with a displacement volume of 1.6 litres and pancake combustion chamber geometry. Variation of lambda, engine speed, compression ratio and intake temperature were parts of the experimental setting. The engine was operated in Homogenous Charge Compression Ignition (HCCI) mode and as comparison also in Spark Ignition (SI) mode.

Hydrogen was found to be a possible fuel for an HCCI engine. The heat release rate was extremely high and the interval of possible start of combustion crank angles was found to be narrow. The high rate of heat release limited the operating range to lean (λ>3) conditions. On the other hand operation on extremely lean mixtures (λ=6) was found possible. The possible operating range was investigated when intake gas temperature was used for control and also this control interval was found to be narrow, especially when richer cases were run.

The maximum load in HCCI mode was an IMEPn of 3.5 bar which is about half of the load possible in SI mode and about half the maximum load in HCCI mode with other fuels. For the loads where HCCI operation could be conducted indicated thermal efficiency for HCCI was superior to that of SI.

NOx emissions were, as expected, found to decrease when lambda was increased and the levels were very low in HCCI mode. High levels of hydrogen were found in the exhaust with HCCI.

When the engine was operated on low lambdas (i.e. λ=3) emissions of carbon monoxide and hydrocarbons were detected, probably originating from evaporated and partially oxidized lubrication oil.

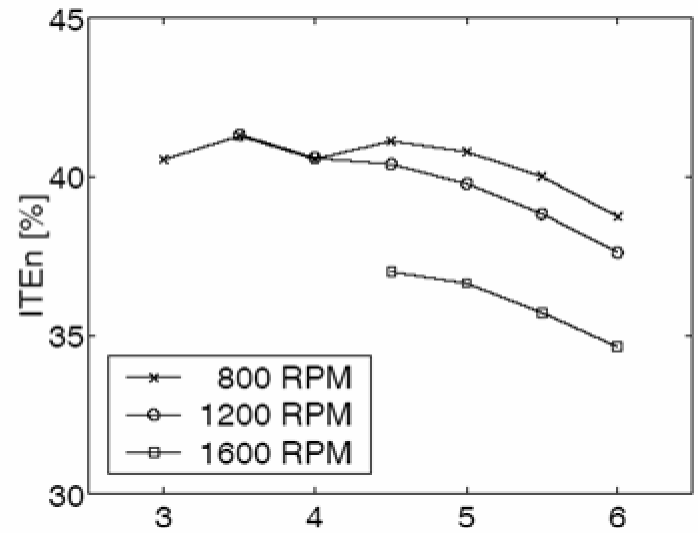
INTRODUCTION

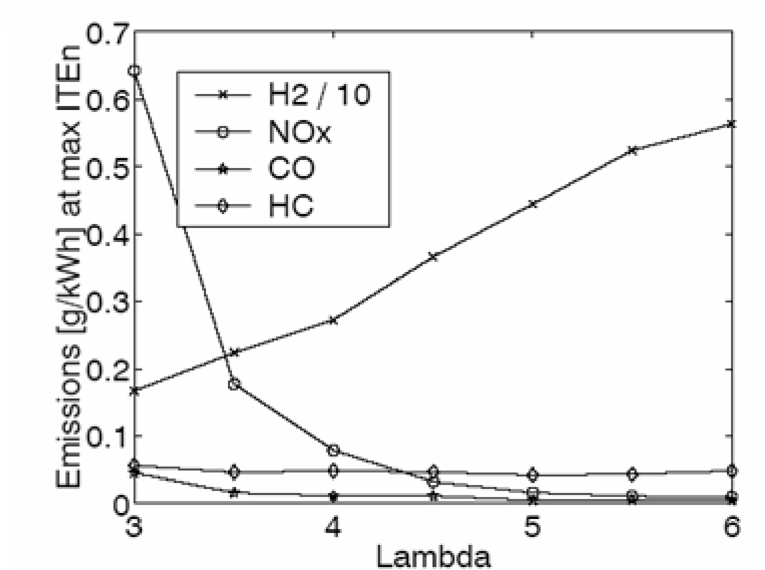
The engine manufacturers of today are challenged by the legislative demands of low emissions and by the need to decrease the dependency on non-renewable fuels, such as oil. Hydrogen (H_2) has been suggested as a possible supplement or replacer of the fuels used today [1]. Hydrogen can be produced by sustainable methods but it can also be produced from fossil fuels.

The advantages of using hydrogen as fuel for internal combustion engines are its high heating value and its lack of carbon content leading to the absence of hydrocarbon, carbon monoxide and carbon dioxide emissions. Problems still in need to be solved are the emissions of nitrogen oxides and the emissions from combusted lubrication oil as well as more practical problems regarding its storage and handling [1, 2].

Numerous studies [2-6] have been made on hydrogen as SI engine fuel both in premixed and direct injected engines. Problems associated with premixed SI operation is ignition in the intake due to hot valves and non optimal valve times as well as ignition in the tail pipe after a misfire. Other problems identified are increased heat loss and high combustion rate.

Recently the spark ignition, SI, and compression ignition, CI, engines have been accompanied by the homogeneous charge compression ignition, HCCI, engine. This engine type can be considered as a hybrid of the SI and CI engines as it uses a premixed charge as the SI engine but combustion is initiated by increased temperature originating from compression as in the CI engine. The major benefits of the HCCI engine compared to the CI engine are the low levels of NOx and PM since combustion is lean both globally and locally in





SAE paper 2004-01-1976, presented at SAE fuel and lubricants meeting Toulouse, France , June 2004

HCCI activities in Lund

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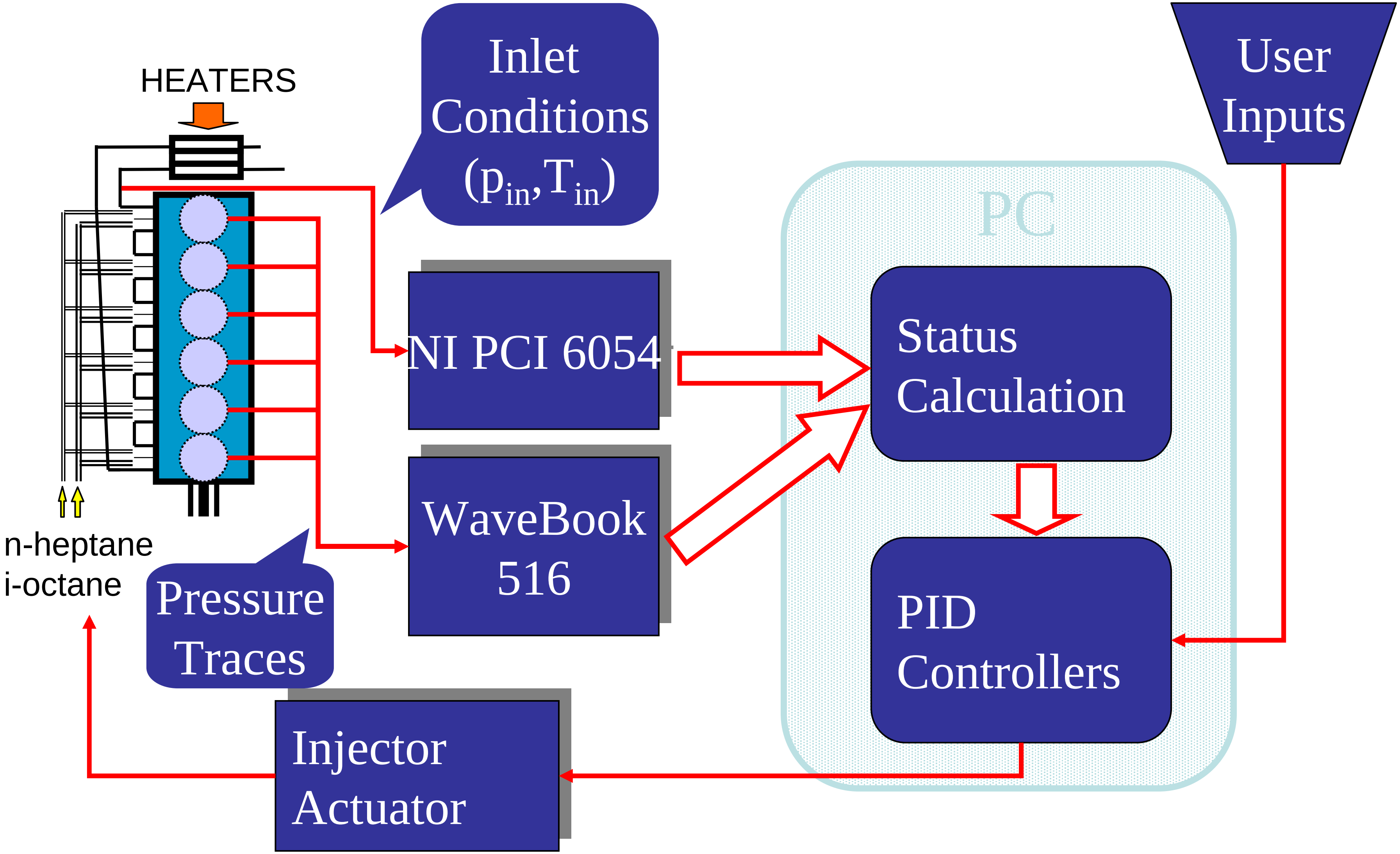
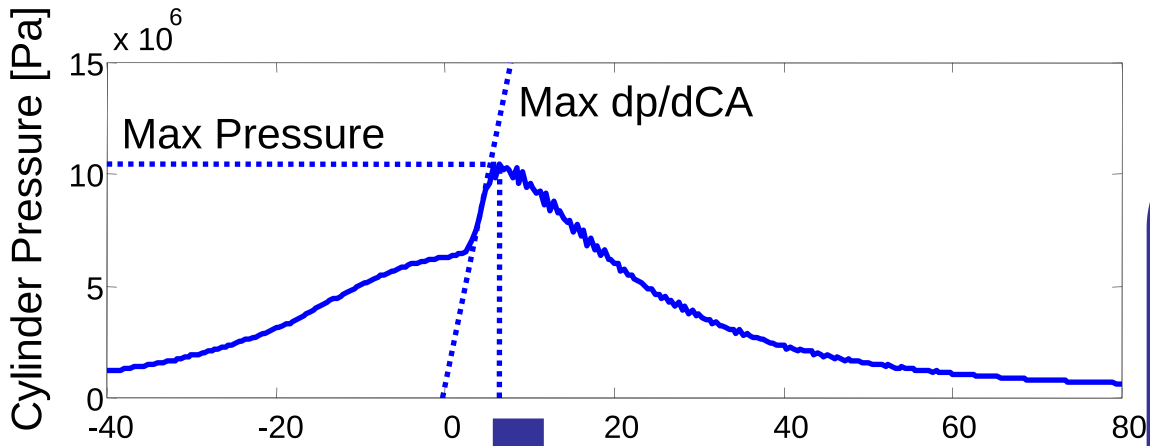
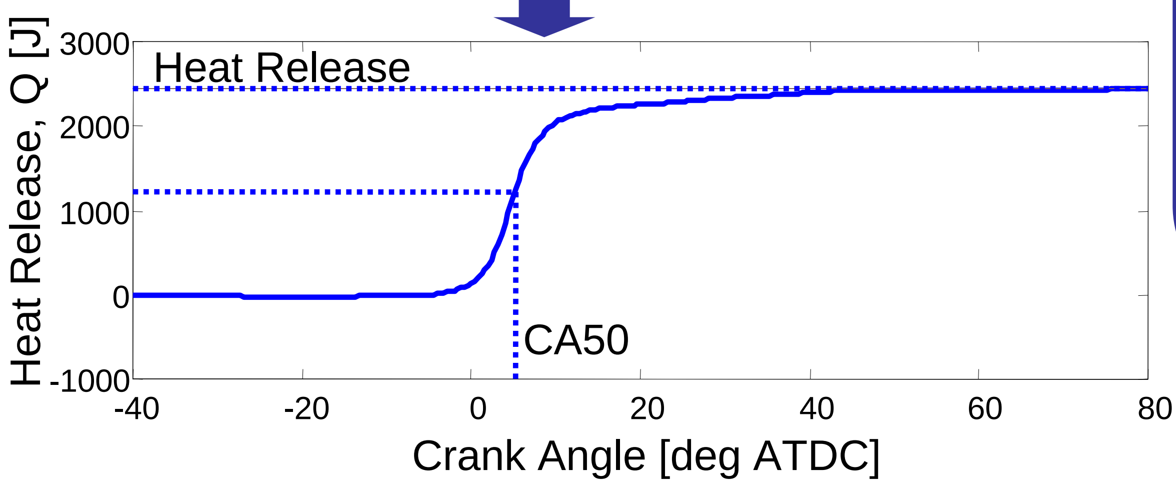
Closed loop combustion control, CLCC



Control Parameters



$$\frac{dQ}{dCA} = \frac{\gamma}{\gamma - 1} p \frac{dV}{dCA} + \frac{1}{\gamma - 1} V \frac{dp}{dCA}$$



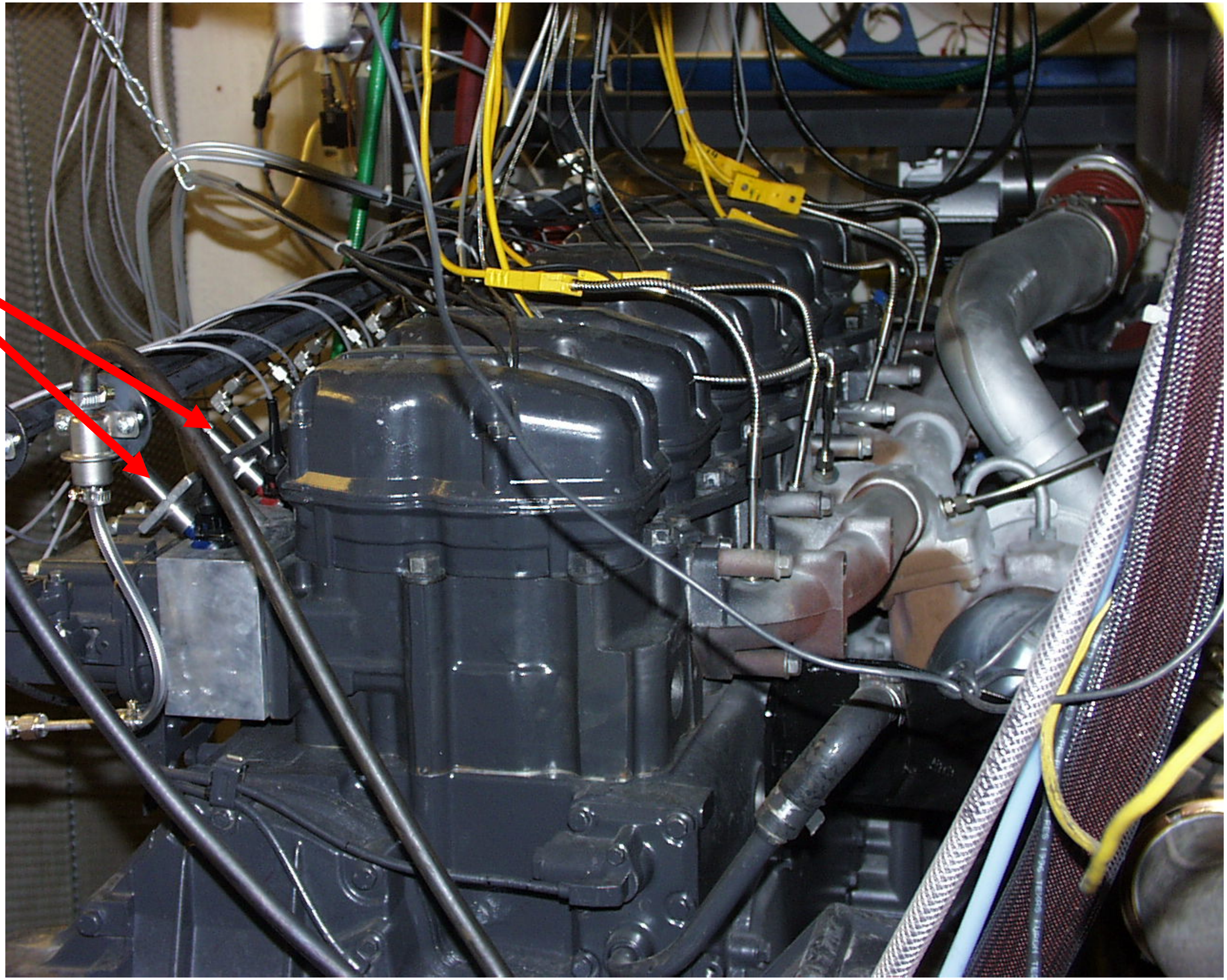
Controlled

- CA50
- Net IMEP:s

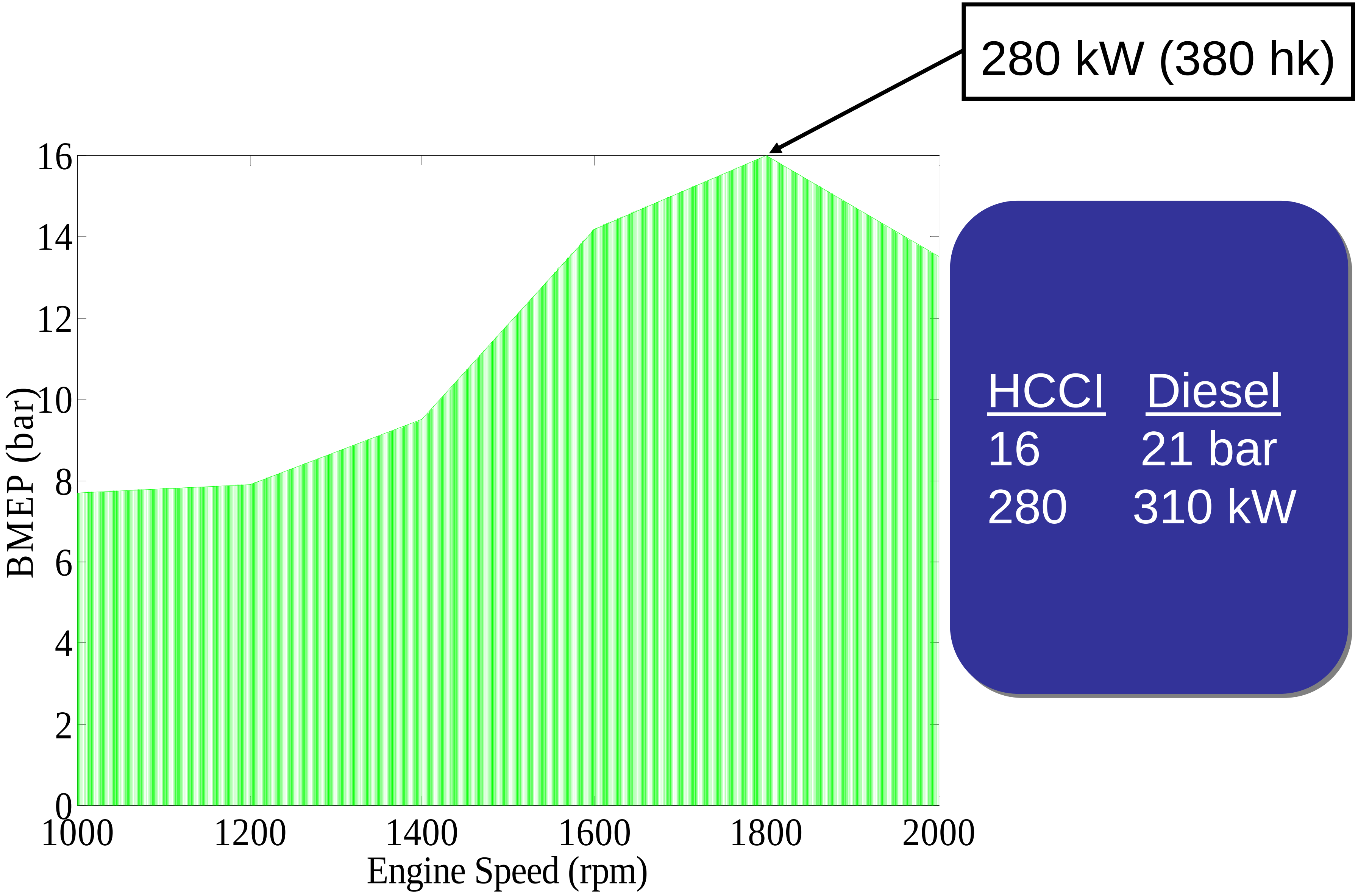
Constraints

- Peak pressure
- Peak dp/dCA
- Net heat release

6-cylinder HCCI Engine with dual fuel

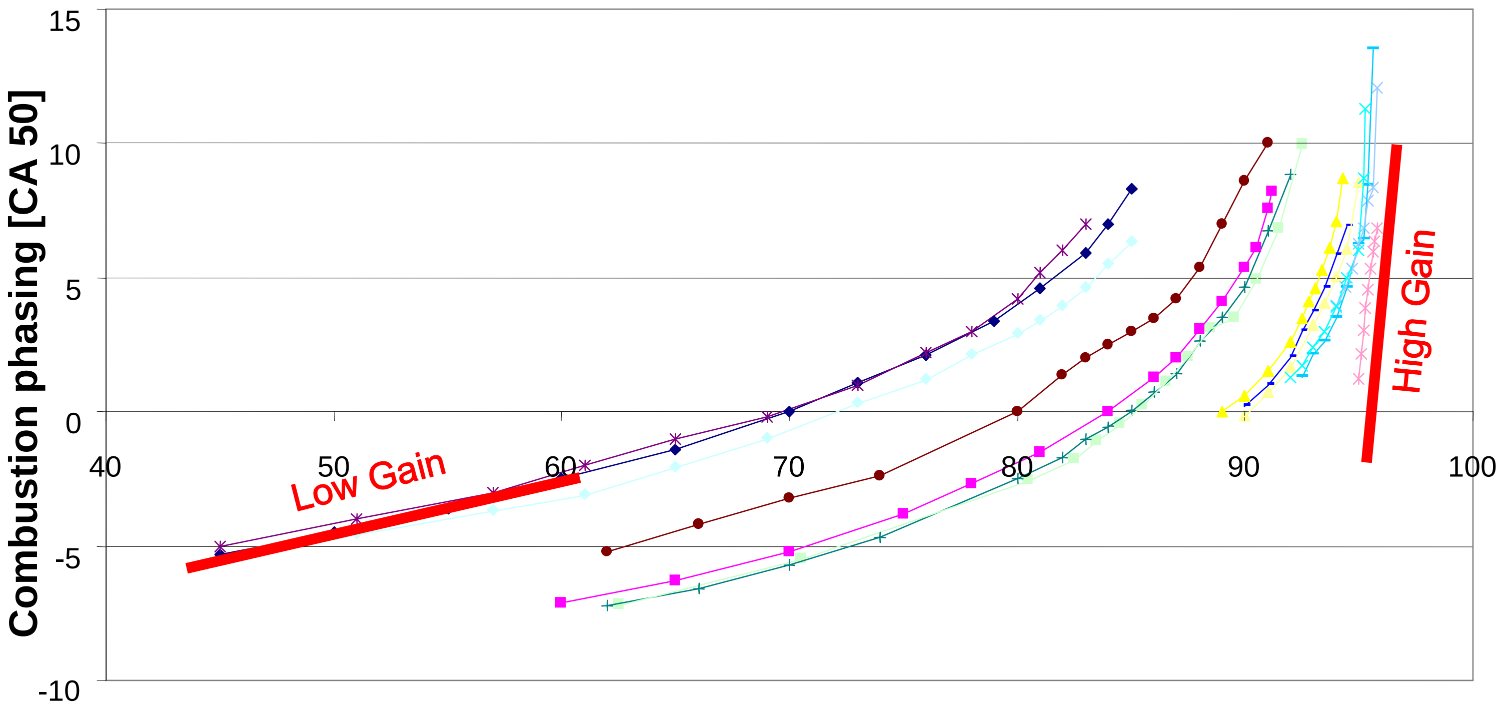


Operating range with CLCC



HCCI	Diesel
16	21 bar
280	310 kW

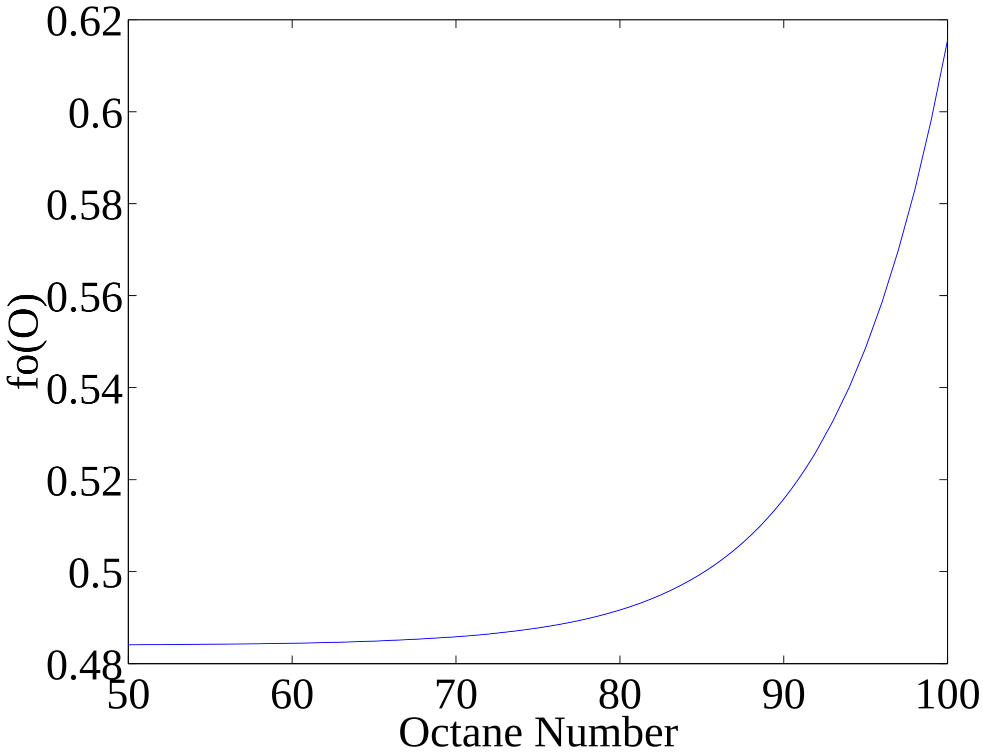
Combustion timing



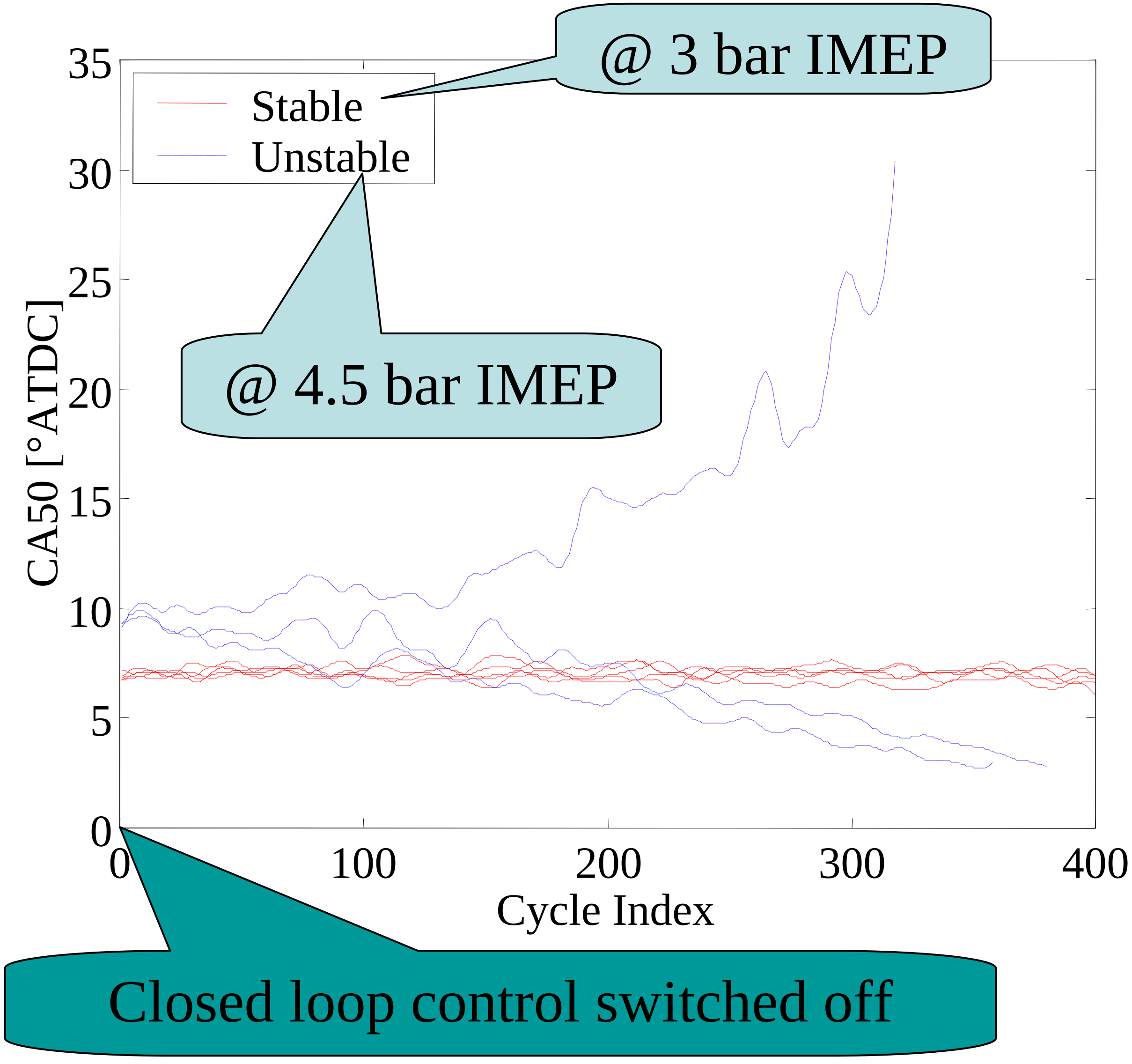
S = d(CA50%) / d(Octane Number)

Sensitivity Estimation

$$S = f_N(N) \cdot f_T(T_i) \cdot f_f(m_f) \cdot f_O(O) \cdot f_\theta(\theta_{50})$$



Unstable operation possible with CLCC



HCCI activities in Lund

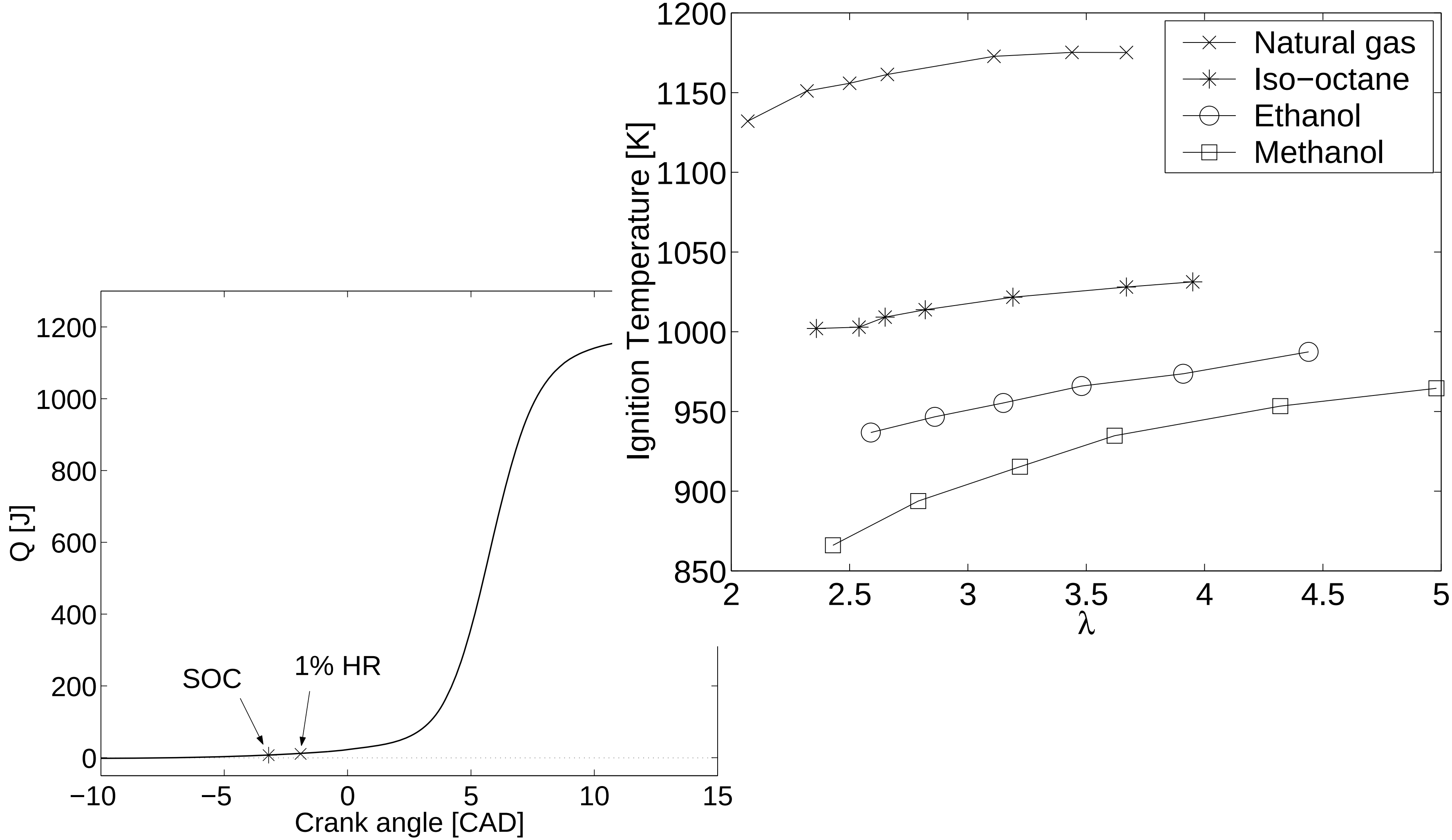
1. Basic engine studies
2. Laser diagnostics
3. Combustion modeling - Chemical kinetics
4. Closed loop combustion control
5. Fuel effect

HCCI-fuel

HCCI fuel index to be developed

- Diesel engine has cetane number CN
- SI engine has octane number, RON and MON
- But HCCI is a different process

Ignition Temperature



Ignition temperature

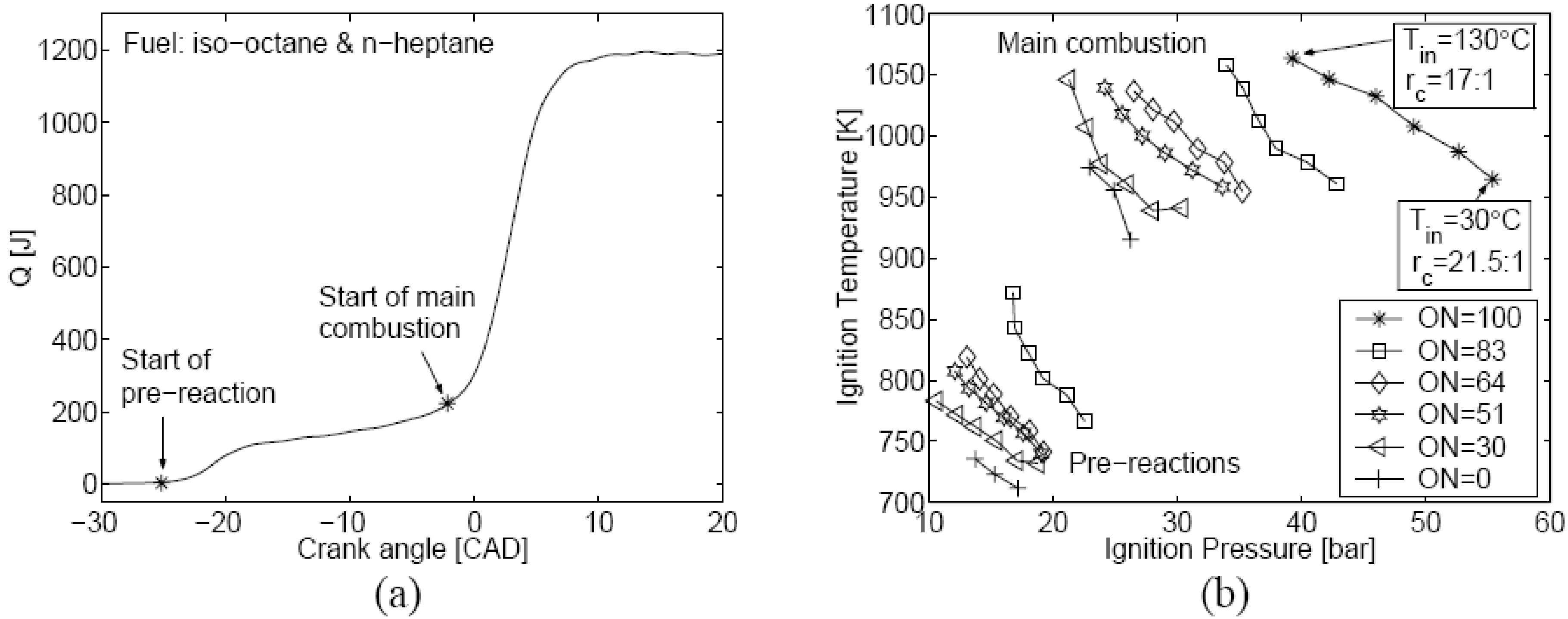
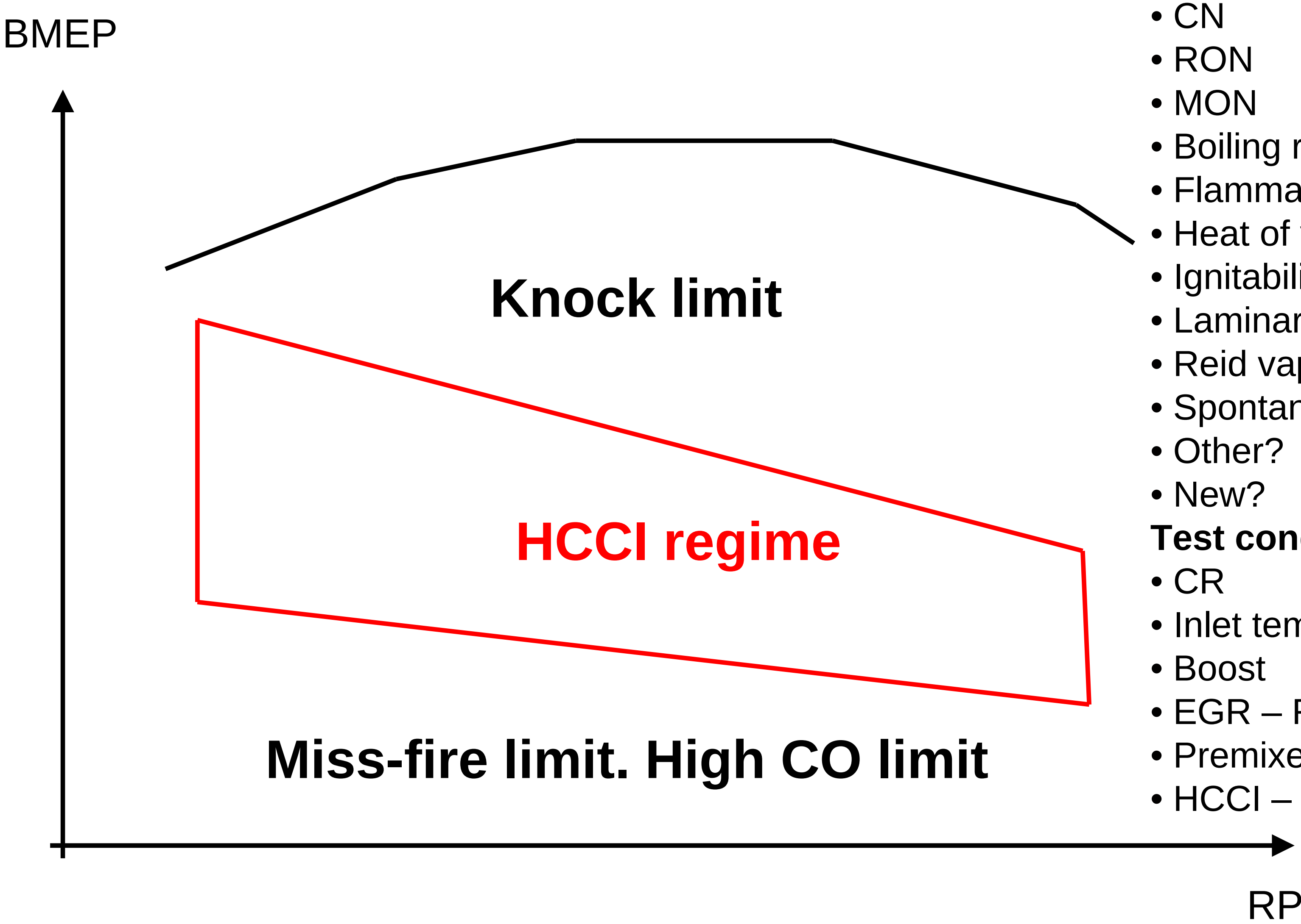


Figure 8.3. (a) Two-stage ignition process of iso-octane and n-heptane. (b) Evaluated ignition temperature versus ignition pressure for different mixtures of iso-octane and n-heptane. The legend states the octane number (ON). Engine speed = 1000 rpm and $\lambda = 3.0$.

HCCI fuel specification



Fuel parameters:
- CN
- RON
- MON
- Boiling range
- Flammability limits
- Heat of vaporization
- Ignitability
- Laminar flame speed
- Reid vapor pressure
- Spontaneous ign. temp.
- Other?
- New?

Test conditions:
- CR
- Inlet temperature
- Boost
- EGR – Residual gases
- Premixed – DI
- HCCI – CAI

Summary

- HCCI needs a fuel rating similar to Research Octane Number,RON, Motor Octane Number, MON and Cetane Number, CN
- Alternative fuels containing oxygen can reduce soot significant
- HCCI techniques can be used to improve normal diffusion combustion of alcohols

Thank you!