CHARGE and CHASE

The UK FORESIGHT VEHICLE Research on Extending HCCI Engine Operating Boundaries

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SAE Homogeneous Charge Compression Ignition Symposium
19 -20 September 2005

ACKNOWLEDGEMENTS

Contribution to the current research

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Birmingham University - Thanos Megaritis, Daniel Yap, and Roy Lehrle

Johnson Matthey – David James and Sylvain Peucheret

UK DTI and EPSRC sponsorship through Foresight Vehicle LINK Projects CHARGE and CHASE

Presentation Outline

- Objectives
- Project outline
- Current status
- Future prospective

What is FORESIGHT VEHICLE

FORESIGHT VEHICLE is the UK's prime knowledge transfer network for the automotive industry involving collaboration between industry, academia and Government.

The R&D programme aims to promote technology and stimulate suppliers to develop market driven enabling technologies for motor vehicles.

The research within the programme is to ensure that future products and technologies meet social, economic and environmental goals, satisfying requirements for mobility, safety, performance, cost and desirability.

UK FORESIGHT projects on HCCI

CHARGE (**C**ontrolled **H**omogeneous **A**uto-ignition **R**eformed **G**as **E**ngine),

2 years (2002-2004)

Total funding = **£840K** (50% industrial contribution)

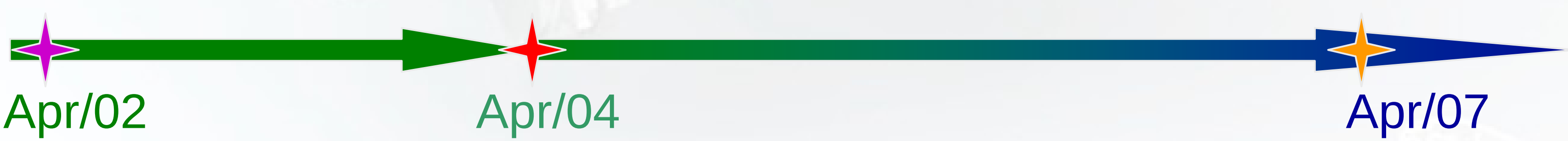
- Facilitate **natural gas** HCCI using fuel reforming

CHASE (**C**ontrolled **H**omogeneous **A**uto-ignition **S**upercharged **E**ngine)

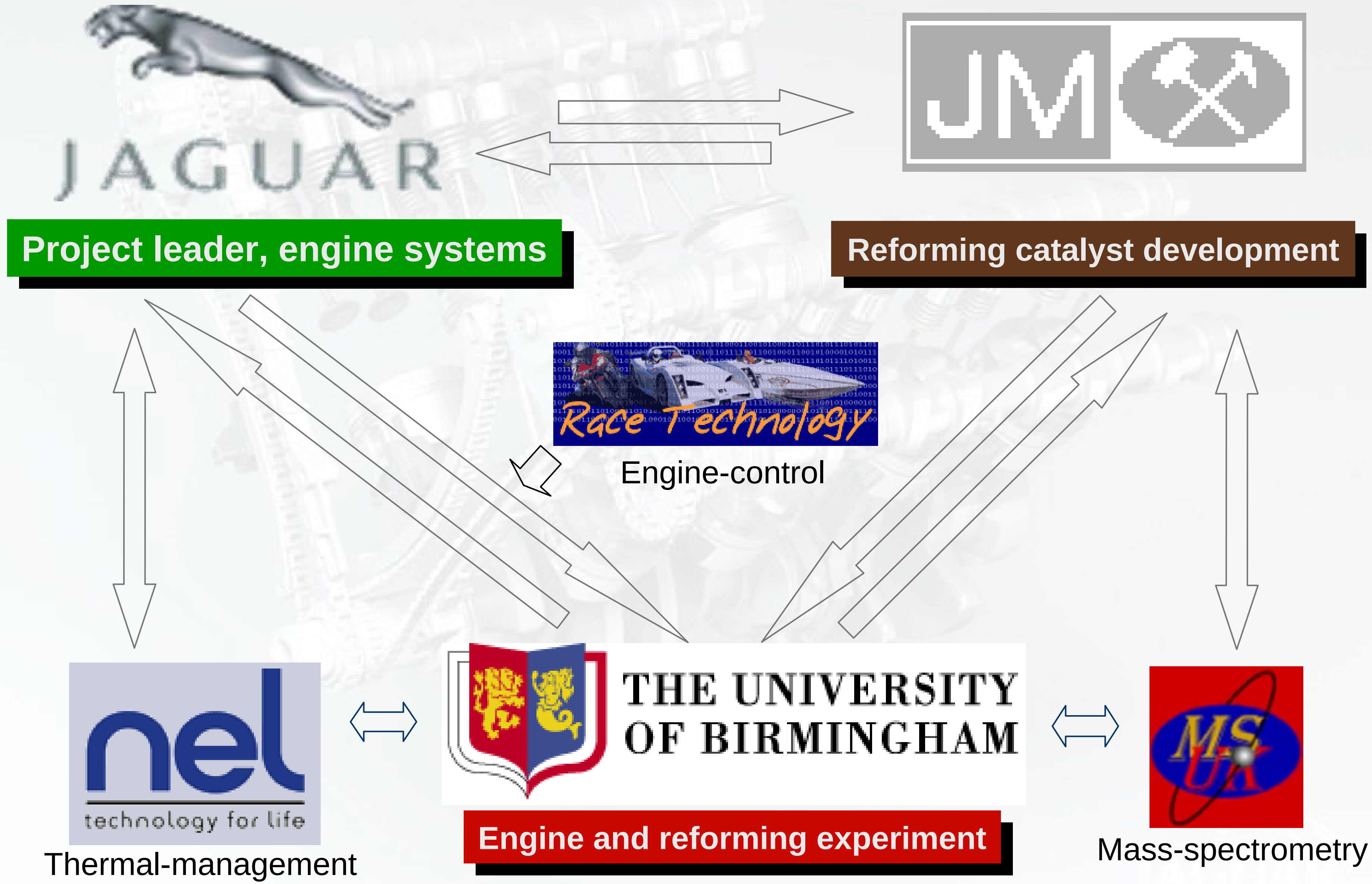
3 years (2004-2007)

Total funding = **£1,539K** (50% industrial contribution)

- Expand **gasoline** HCCI window

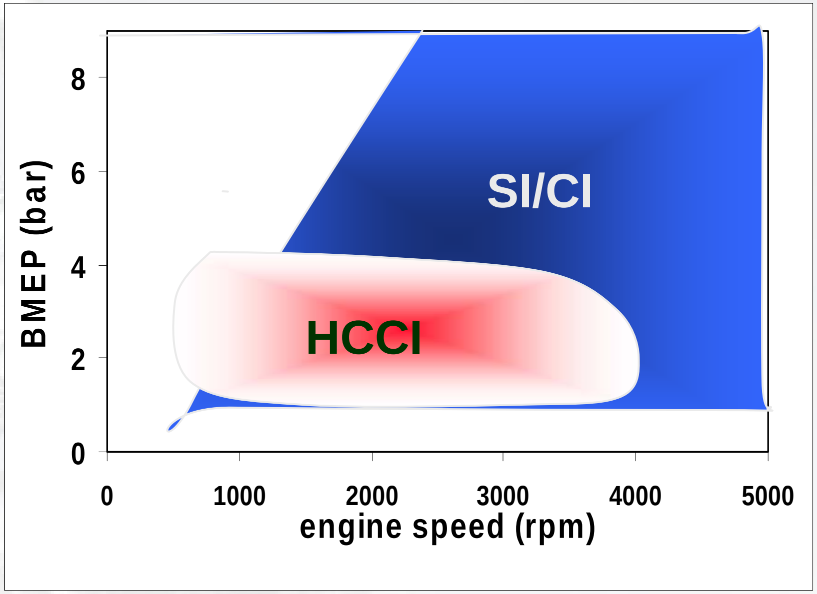


CHAREG/CHASE Project Consortium



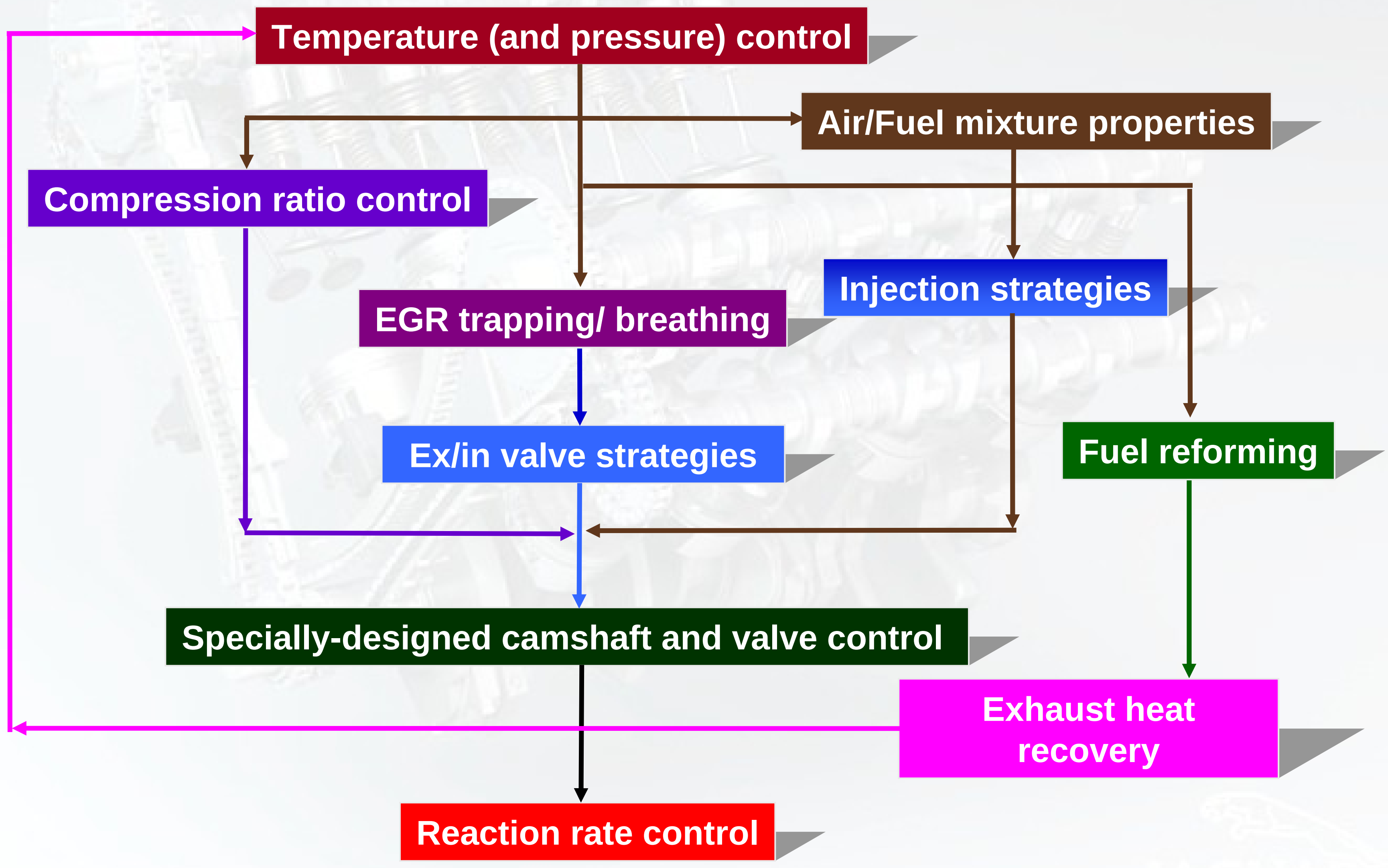
What are the outstanding issues?

- Size of HCCI operation envelopes
- Fuel economy at vehicle level
- Driver transparent transitions between HCCI and SI
- NVH and robustness (Customer interest)
- Cost - engineering (engine upgrade)
  material (e.g. special valve-train and control)
  manufacturing



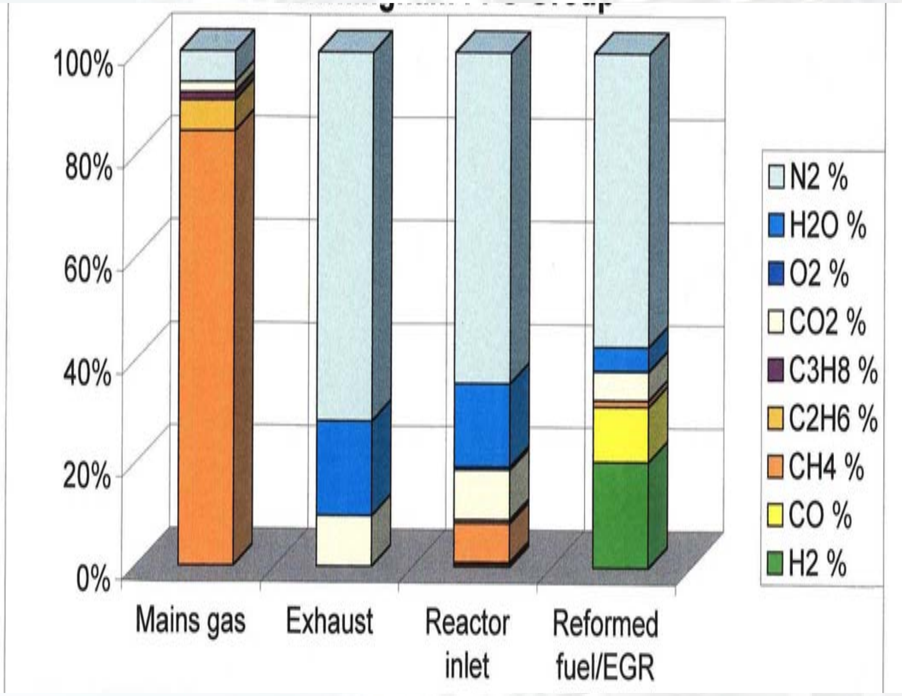
Schematic illustration of HCCI envelope for a vehicle application

Strategies to enable HCCI

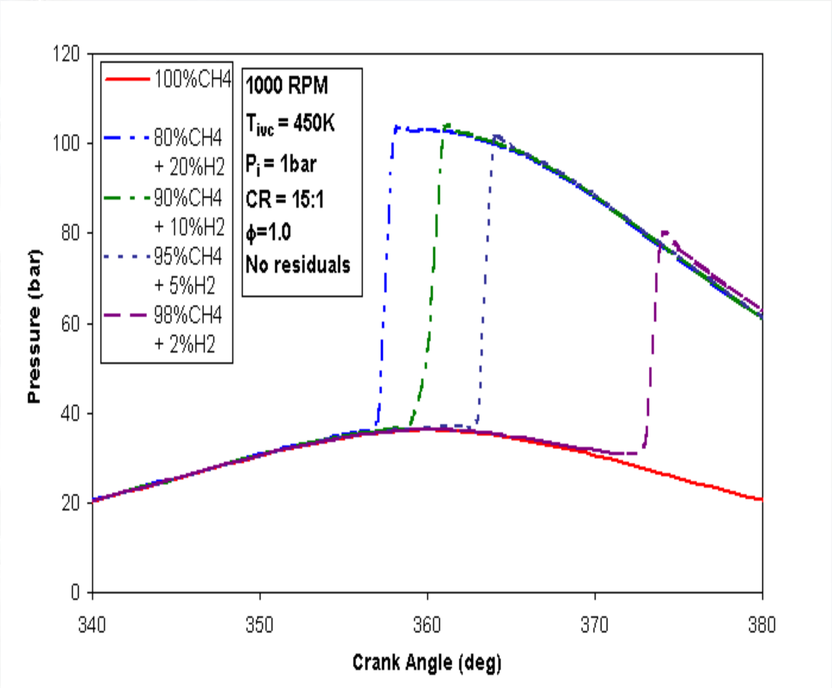


CHARGE Project Concept

Reformed natural gas (test data)

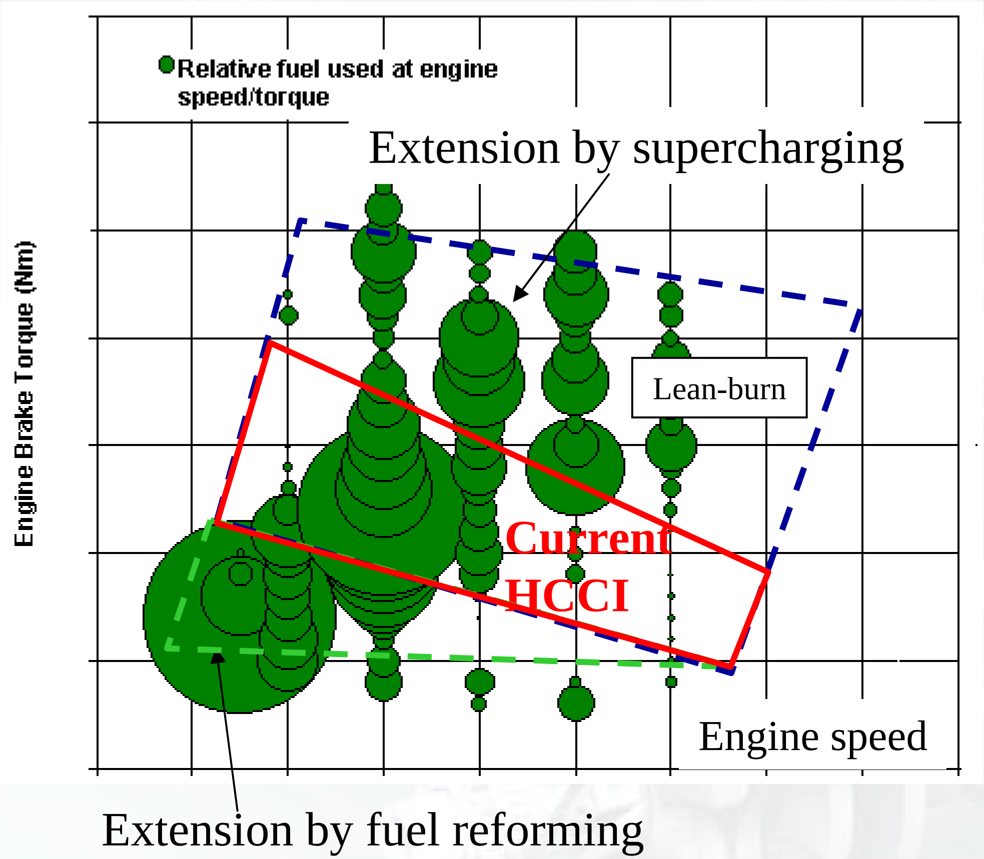


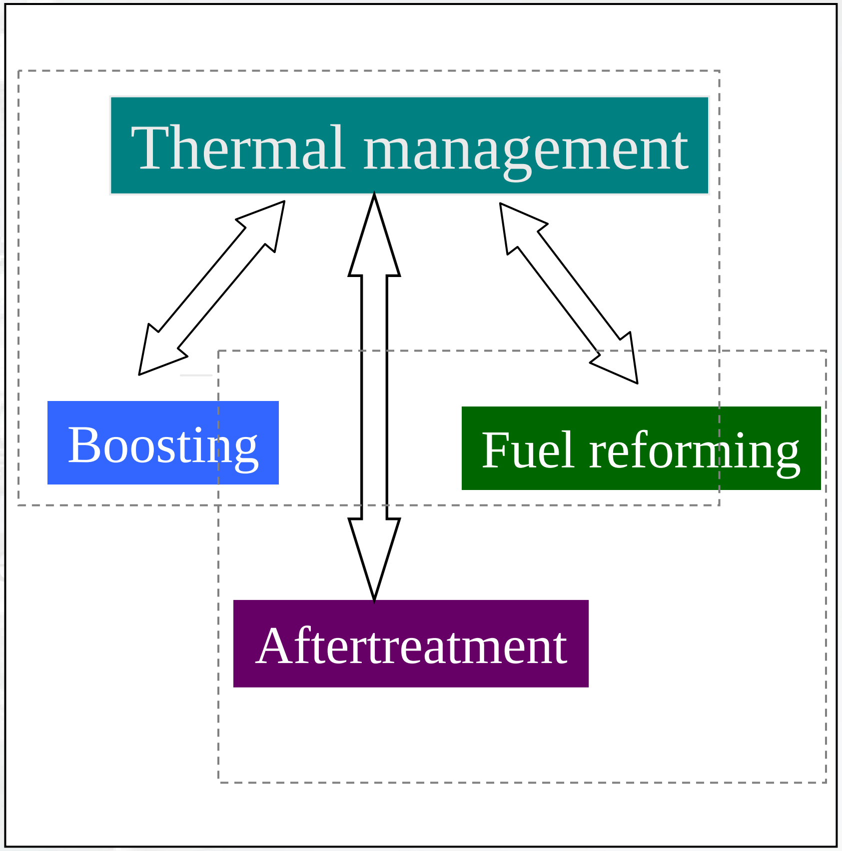
Modelling of the effect of H2 addition



Evaluate the effect of fuel composition and control of engine parameters on the auto-ignition process of natural gas in automotive engines with on-board fuel reforming

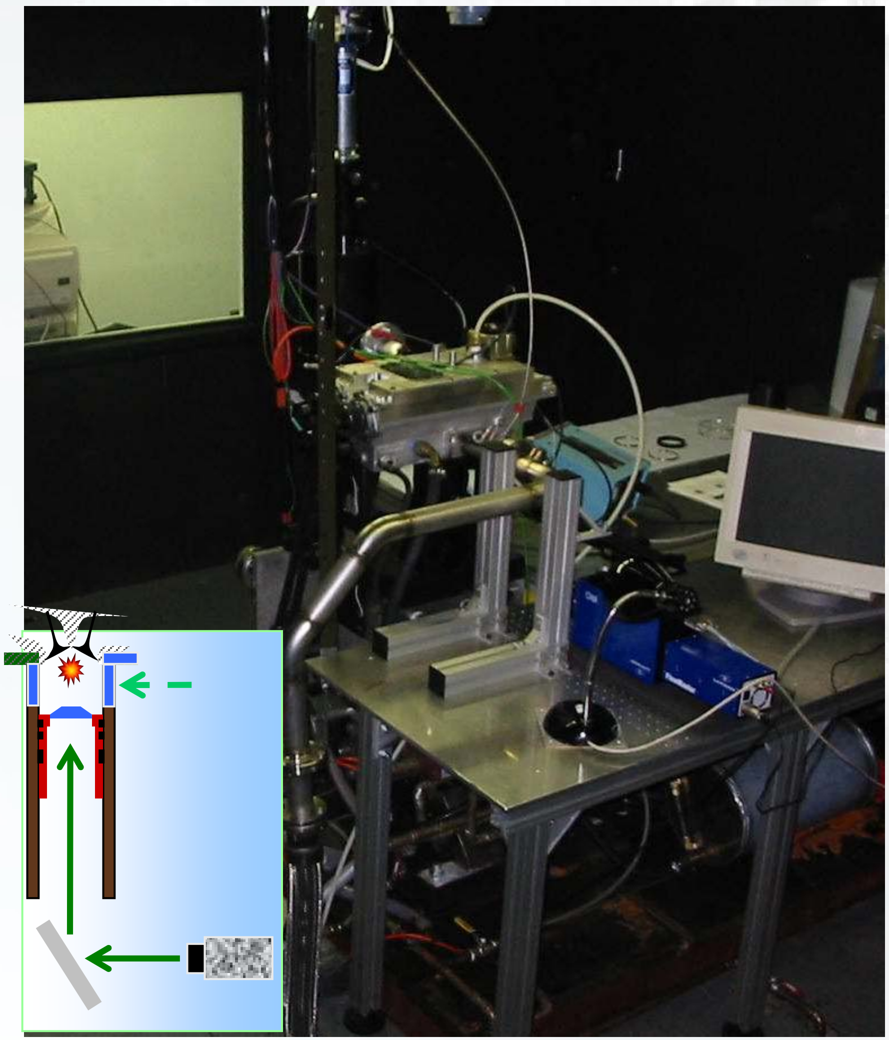
CHASE Project Concept





Extend the operating window of HCCI using combination of boosting, exhaust gas fuel reforming, and total thermal management.

CHARGE/CHASE Research Engines (1)



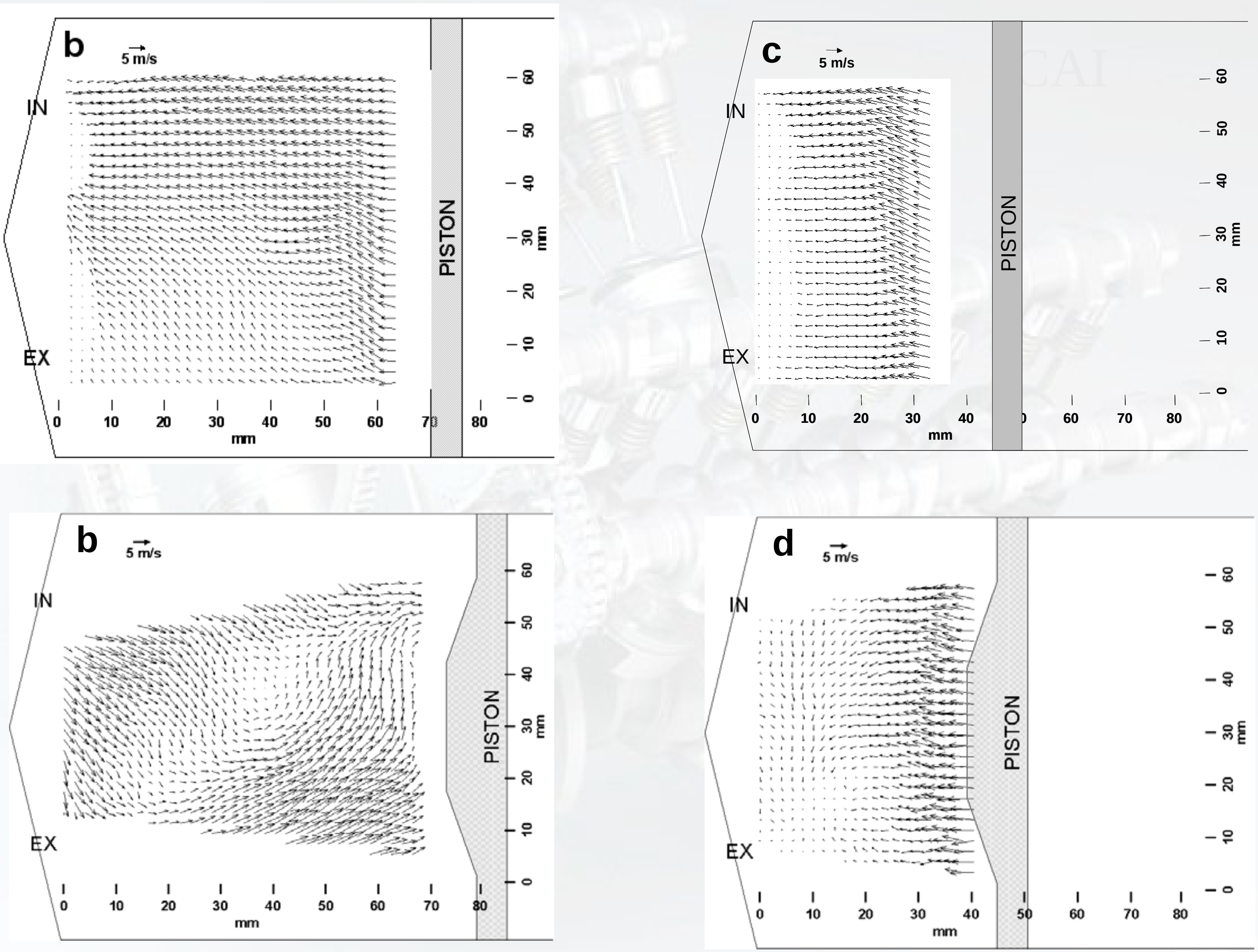
Jaguar Optical engine

Engine Type	4V, Jaguar V6/V8
Bore	82.5 mm
Stroke	79.5 mm
Compression Ratio	10.5, 11.3 or 14
Fuel system (1)	Liquid – DI or Port injection
Fuel system (2)	Gaseous – Manifold injection
Fuel reformer	Open loop
Intake heating	Electrical, up to 3kw

Flow characterisation with PVO and NVO

Positive Valve Overlap

Negative Valve Overlap



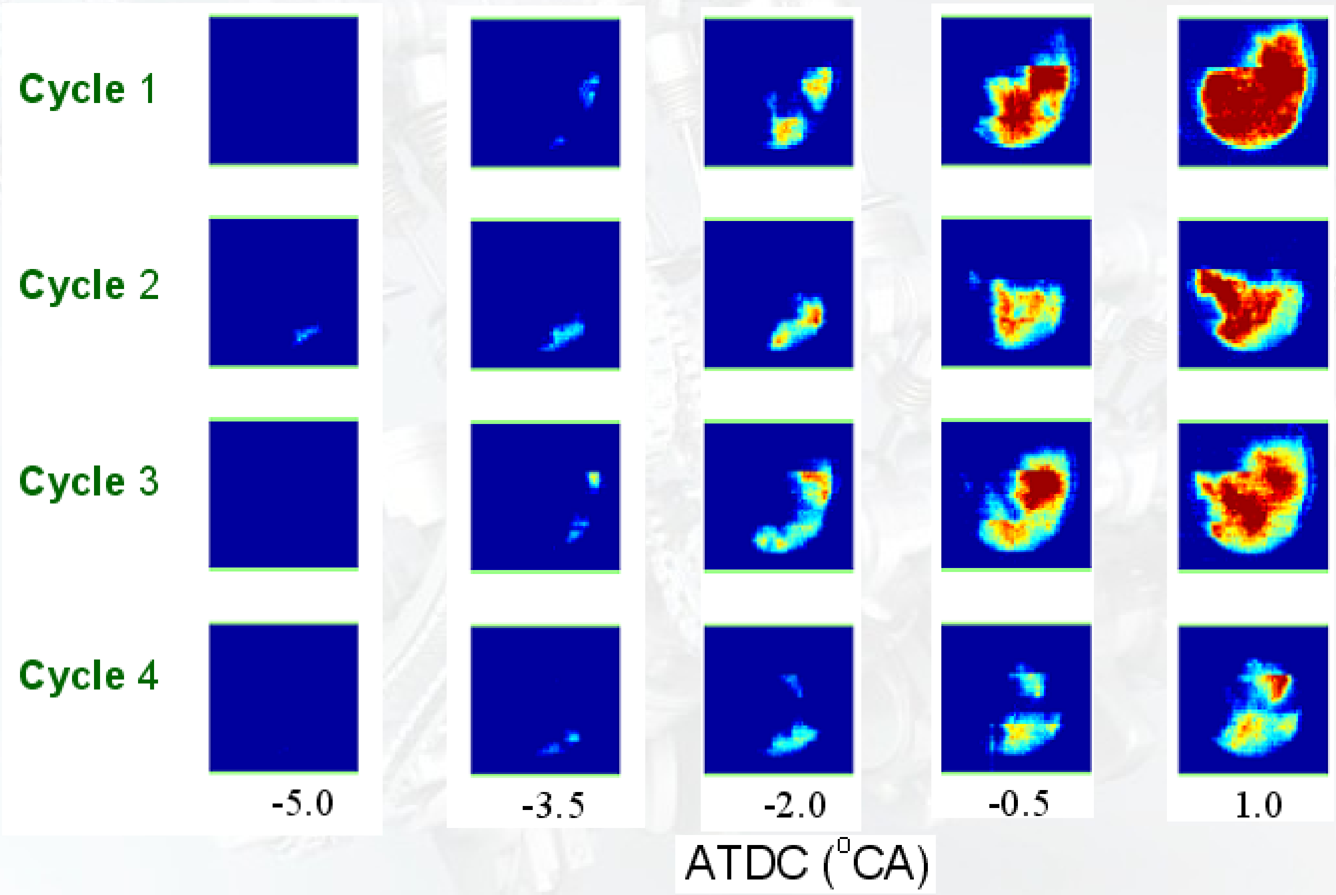
BDC

1000rpm

225 CAD

Wilson et al, 2005

Flame Propagation?

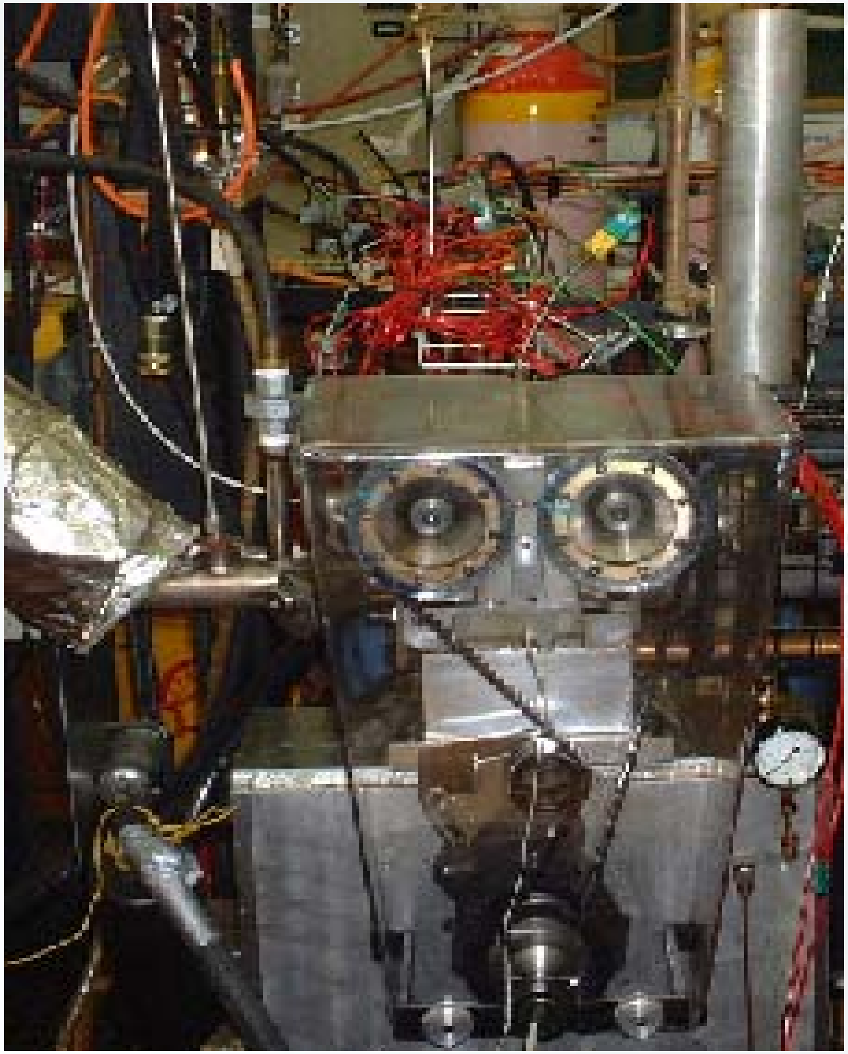


High speed imaging of gasoline HCCI combustion development

- Kodac EM high-speed, 240x50 intensified camera, 4000 fps.

Wilson et al, 2005

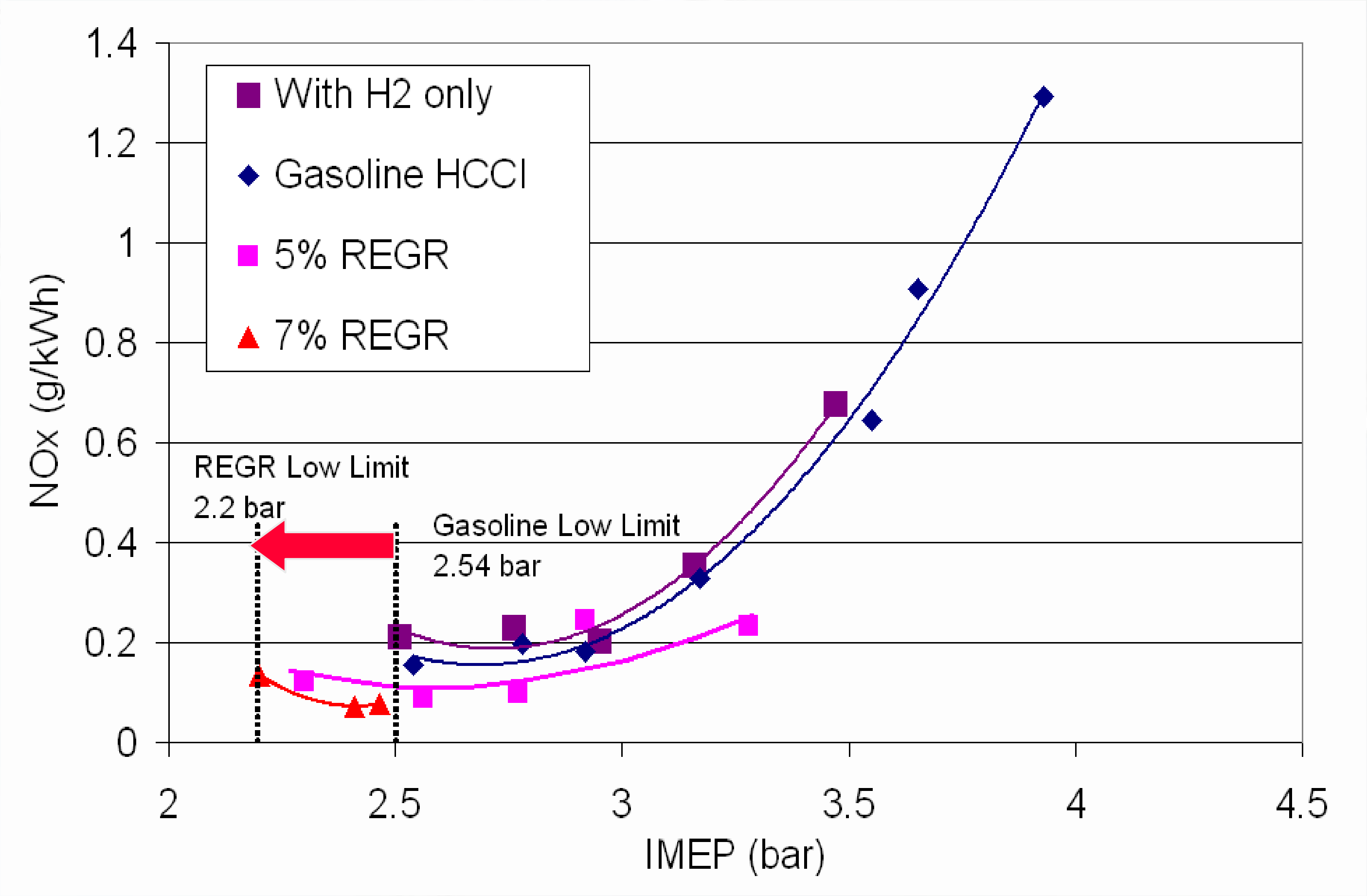
CHARGE/CHASE Engines (2)



Single cylinder Thermal engine

Engine Type	Medusa 4V
Bore	80 mm
Stroke	88.9 mm
Compression Ratio	10.5, 12.5 or 13.3
Fuel system (1)	Liquid – Port injected
Fuel system (2)	Gaseous – Manifold injection
Fuel reformer	Closed loop
Intake heating	Electrical, up to 3kw

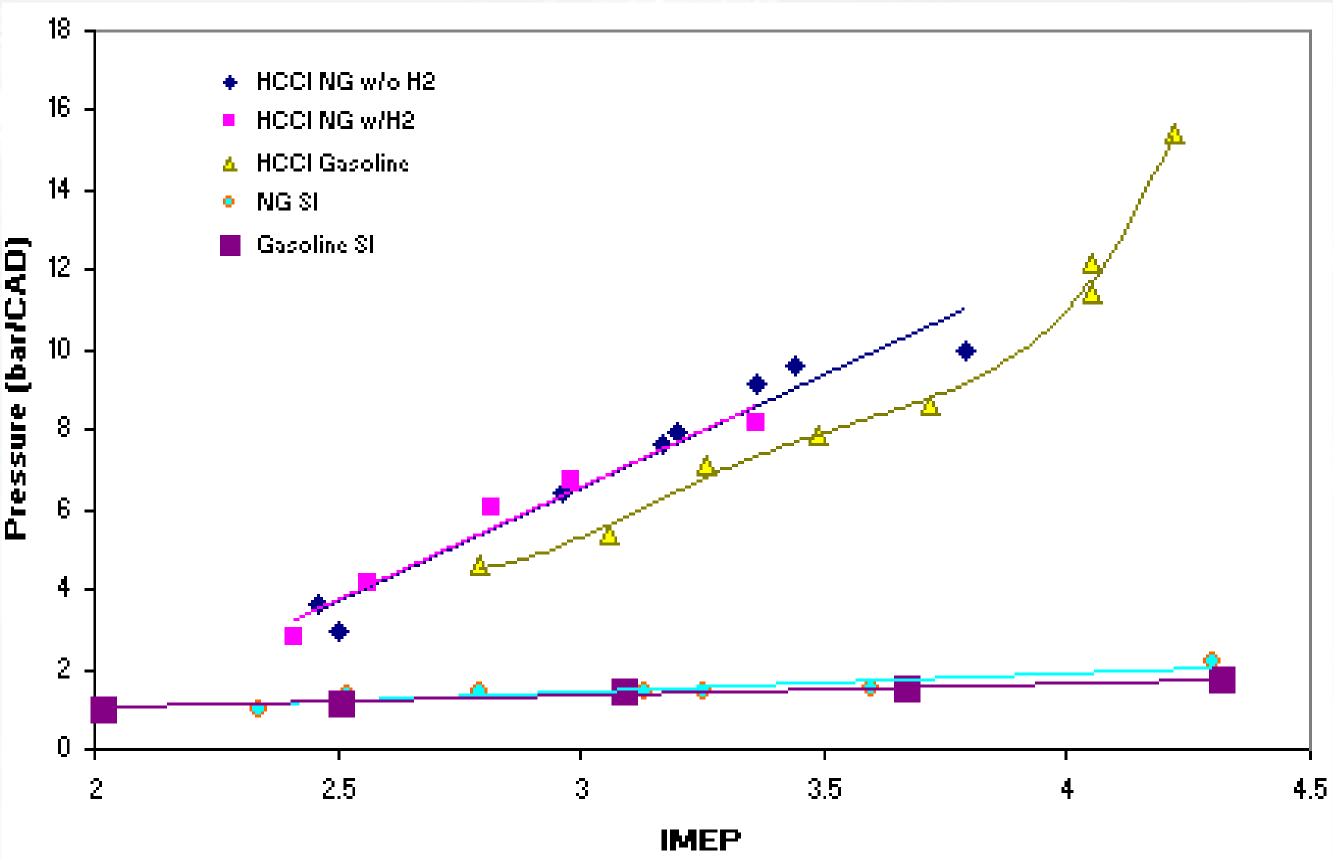
Fuel Reforming (1) - NOx emissions for gasoline HCCI



Fuel reforming could extend the low load limit by over 10%

Xu et al, 2005

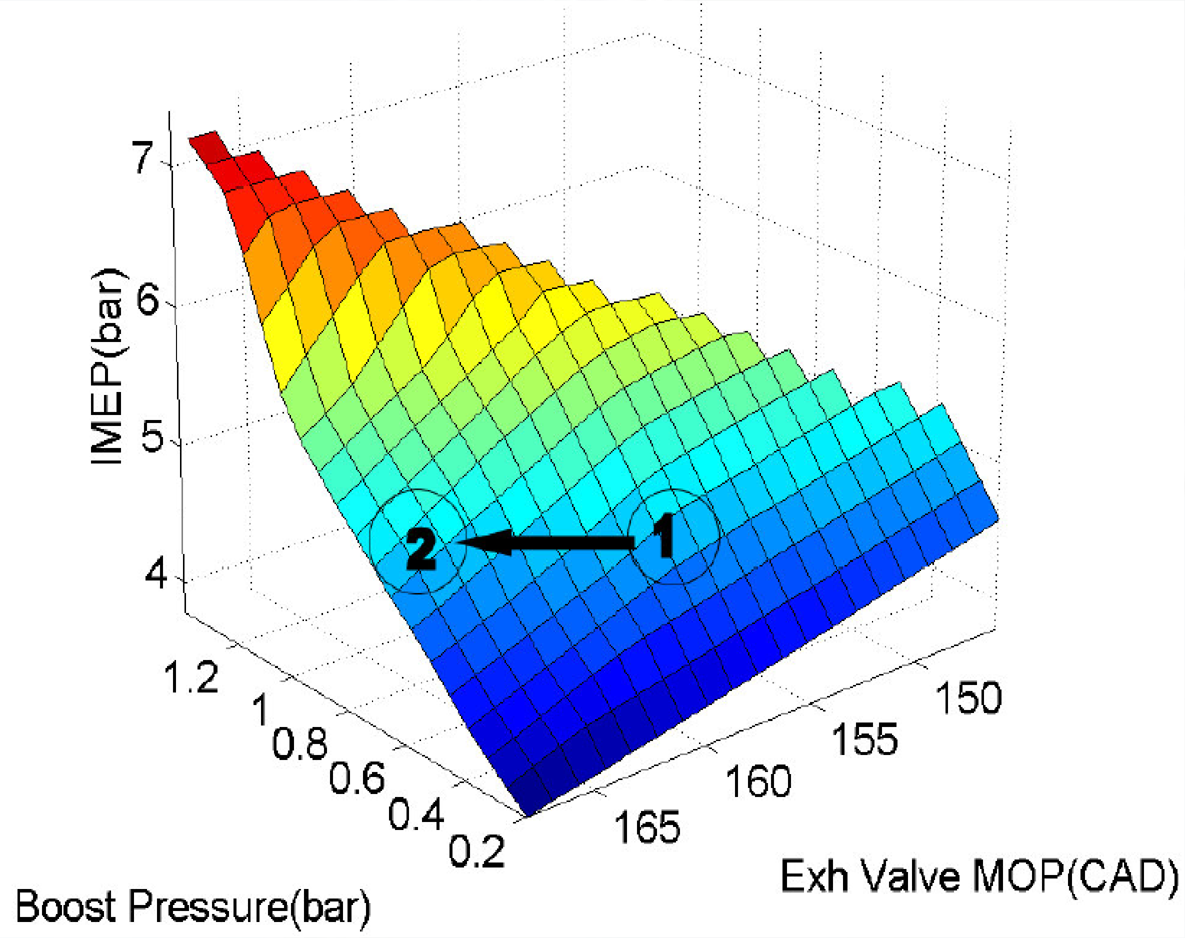
Fuel Reforming (2) – Pressure rise rate with H2 addition



Natural gas HCCI has a higher rate of pressure rise than gasoline HCCI because of the mixing features of the gaseous fuel with EGR and additional effect from intake heating.

Yap et al, 2004

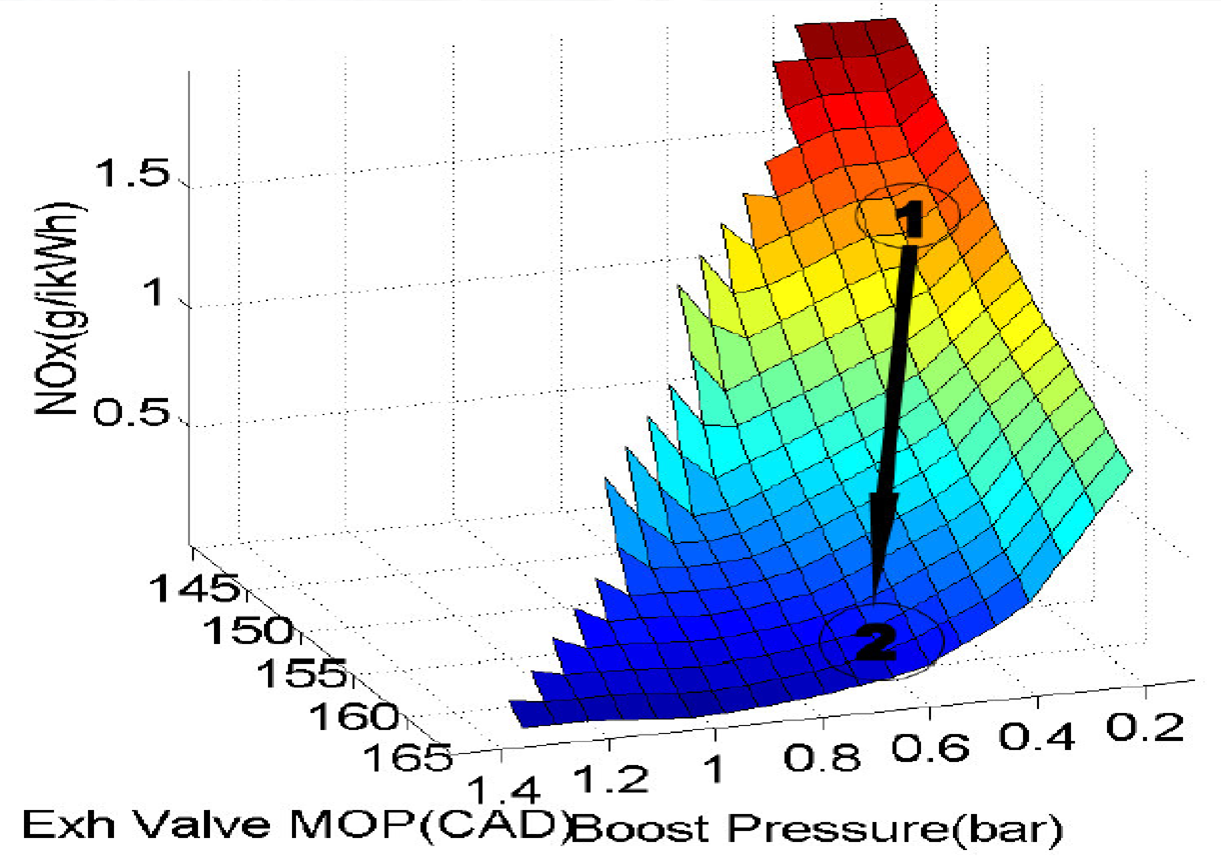
Boosting(1) - Valve strategy for minimum NOx emissions



Boosting and EGR selection strategy ‘1’ and ‘2 have the same engine load but any difference in NOX and fuel economy?

Yap et al, 2005

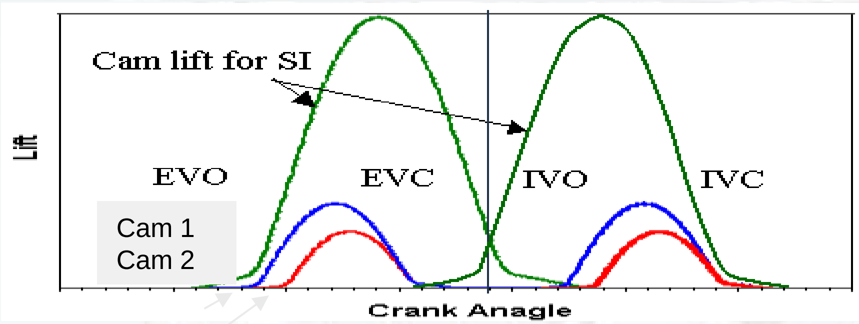
Boosting (2) - NOx reduction with diluted combustion

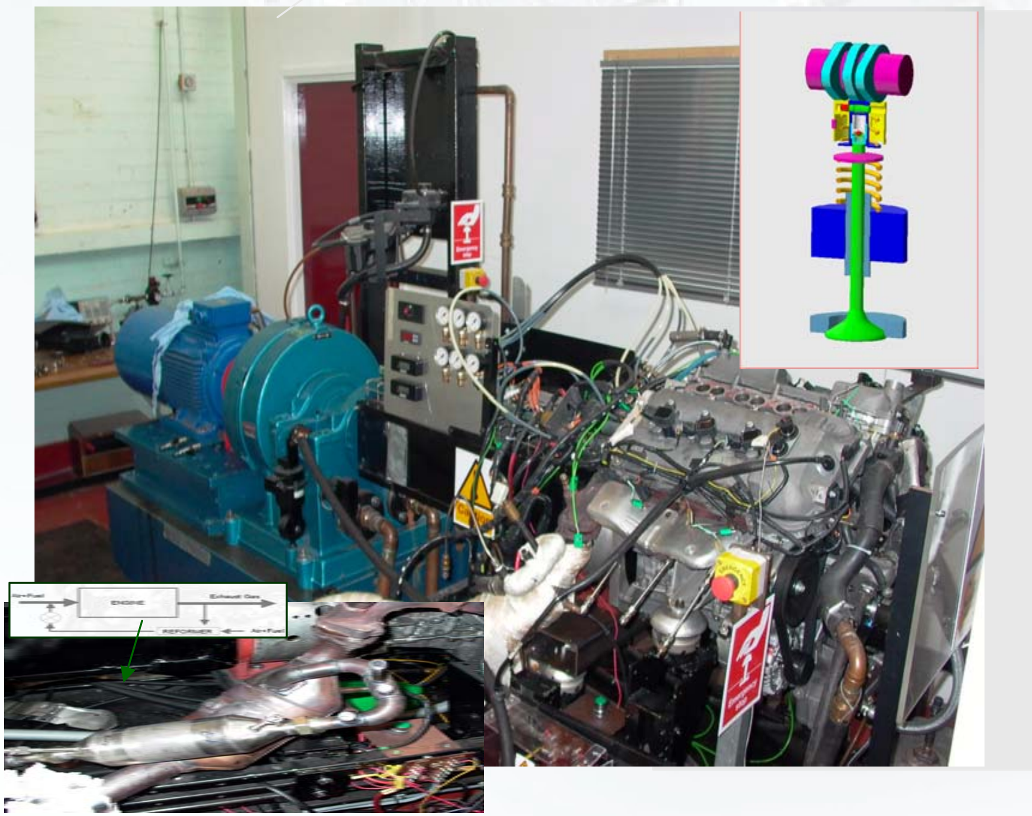


Advance exhaust valve closing and increase boosting pressure allow a significant reduction in NOx emissions with a very little penalty in FC

Yap et al, 2005

World 1st dual cam profile switching for HCCI



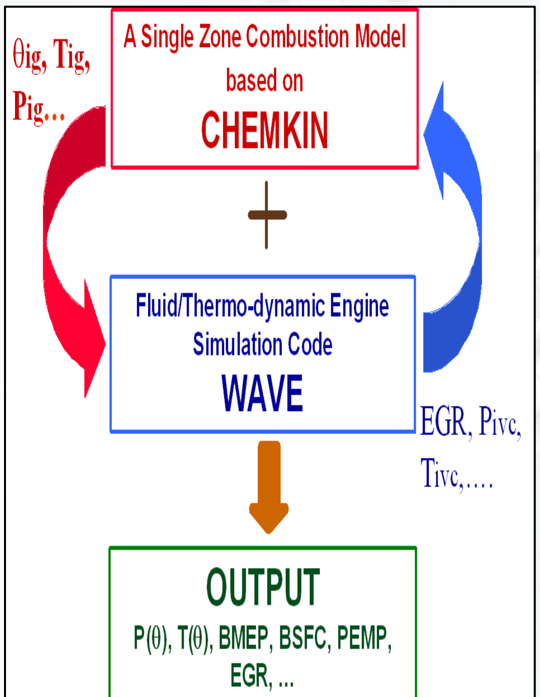


Engine Type	AJV6 – CHARGE (AJV8 - CHASE)
Bore	82.5 (86)mm
Stroke	79.5 (86) mm
Compression Ratio	(9) 11.3 or 13
Fuel system (1)	Liquid – GDI or Port injection
Fuel system (2)	Gaseous – Manifold injection
Fuel reformer	Closed loop
Intake heating	available
Variable Valve Timing	Intake and exhaust

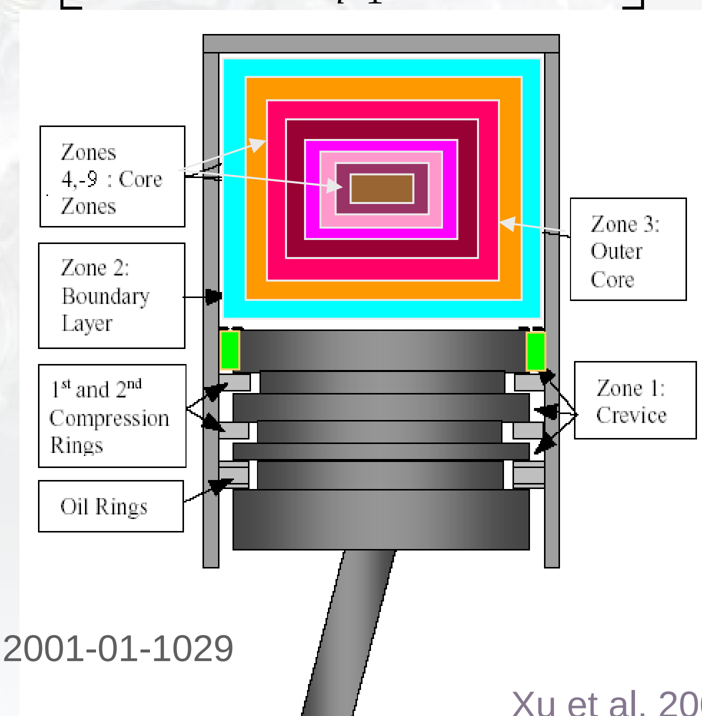
Modelling HCCI engine combustion and operation

Governing equations (similar as in a single-zone model):

$$\bar{c}_{p,i}\frac{dT_i}{dt} = -\frac{1}{\rho_i}\sum_{j=1}^{K} u_j\,\dot{\omega}_j\,M_j - \frac{\dot{Q}_{hli}}{m_i} - \bar{R}_i T_i\left[\frac{1}{V}\frac{dV}{dt} - \frac{\sum_{i=1}^{n} m_i \bar{R}_i \frac{dT_i}{dt}}{\sum_{i=1}^{n} m_i \bar{R}_i T_i}\right]$$



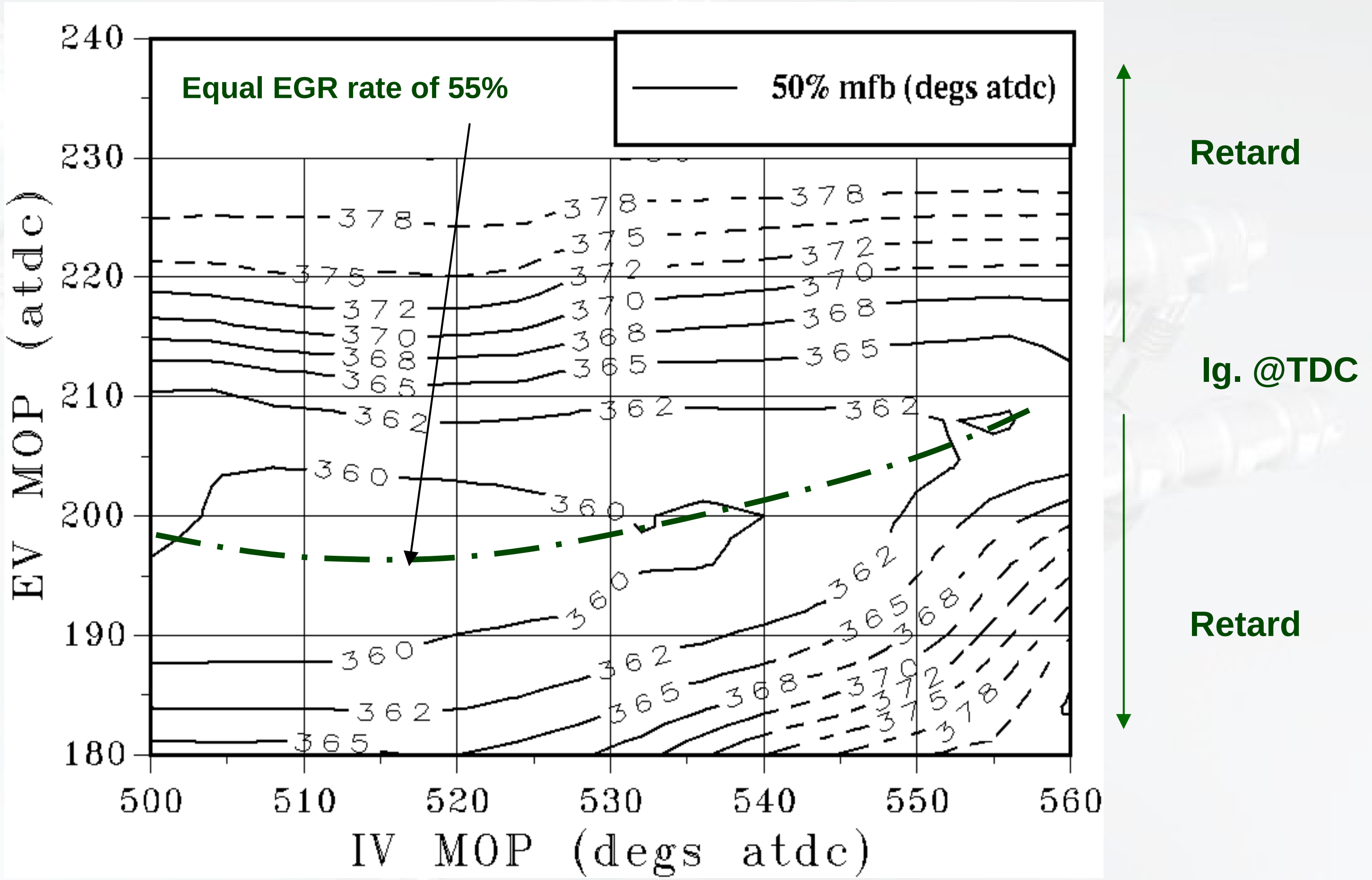
$$P = \frac{\sum_{i=1}^{n} m_i \bar{R}_i T_i}{V}$$



Ref: SAE 2001-01-1029

Xu et al, 2005

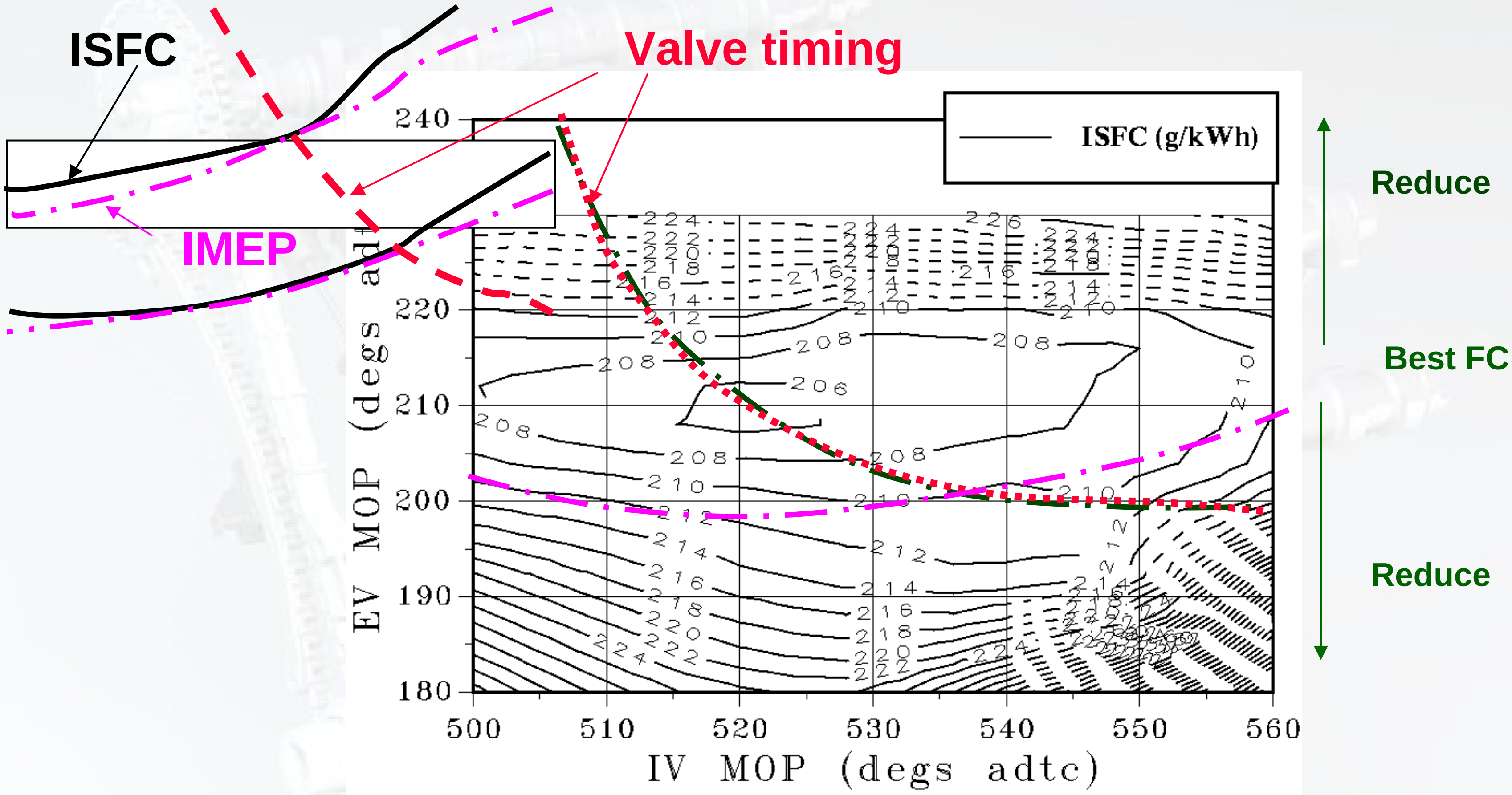
EGR as combustion phase control



• 55% EGR rate presents the earliest ignition, fastest burning rate and minimum FC line

Xu et al, 2003

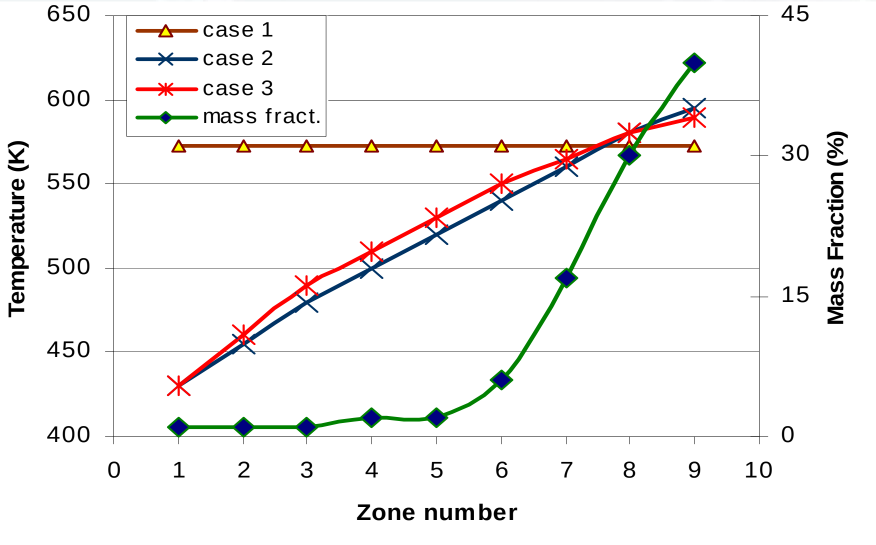
HCCI Engine modelling

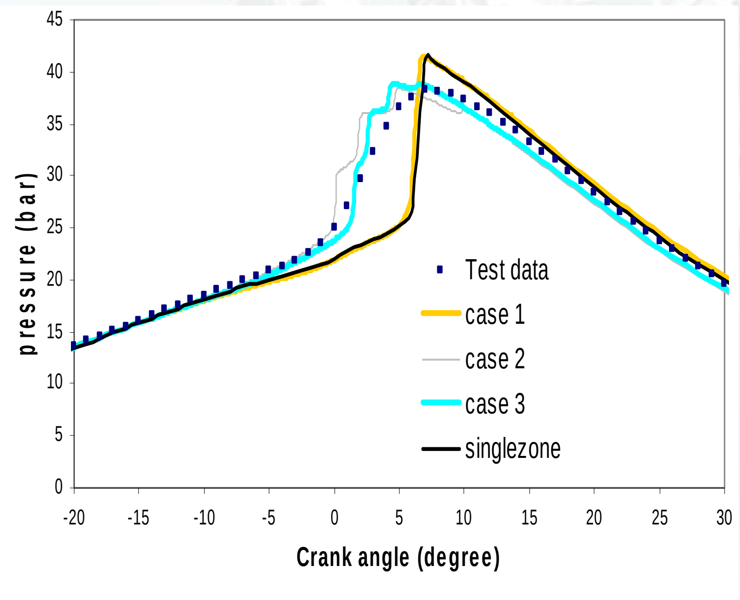


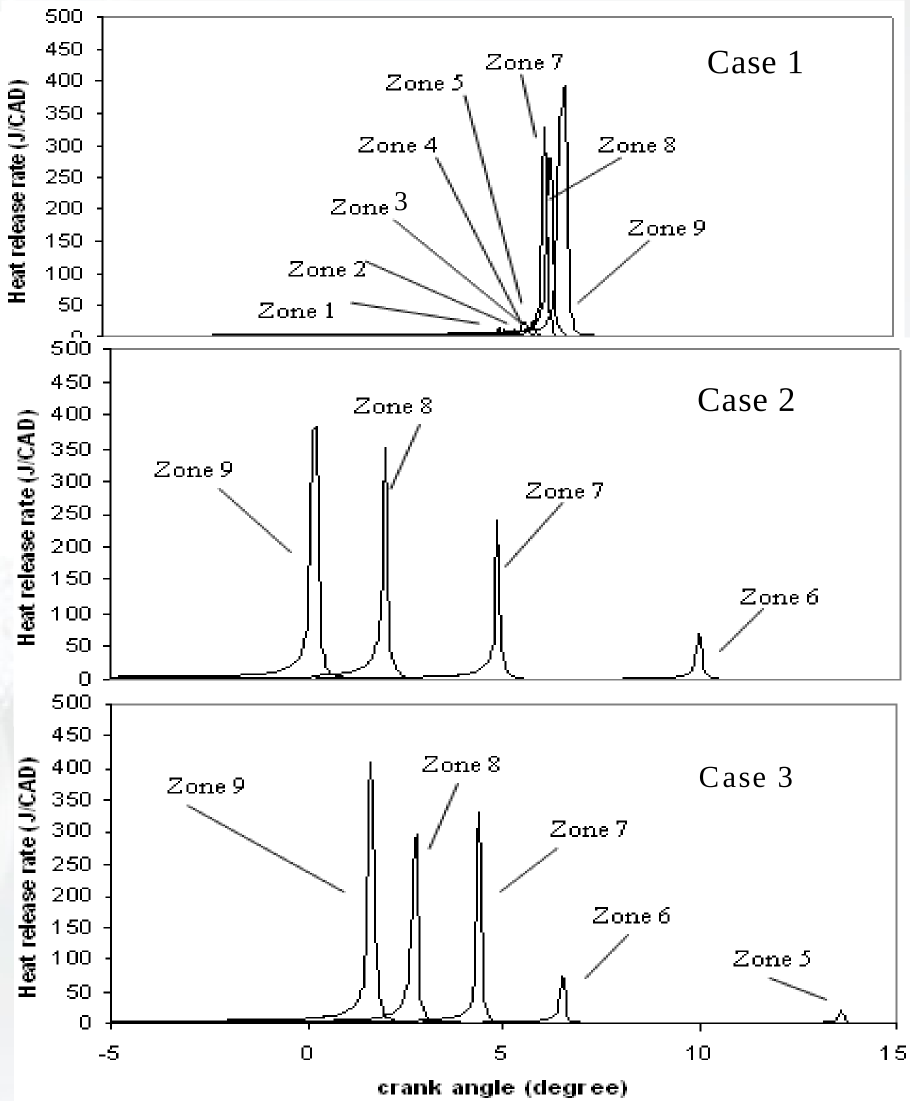
Valve strategy for the best fuel economy with HCCI

Xu et al, 2003

Multi-zone modelling of auto-ignition

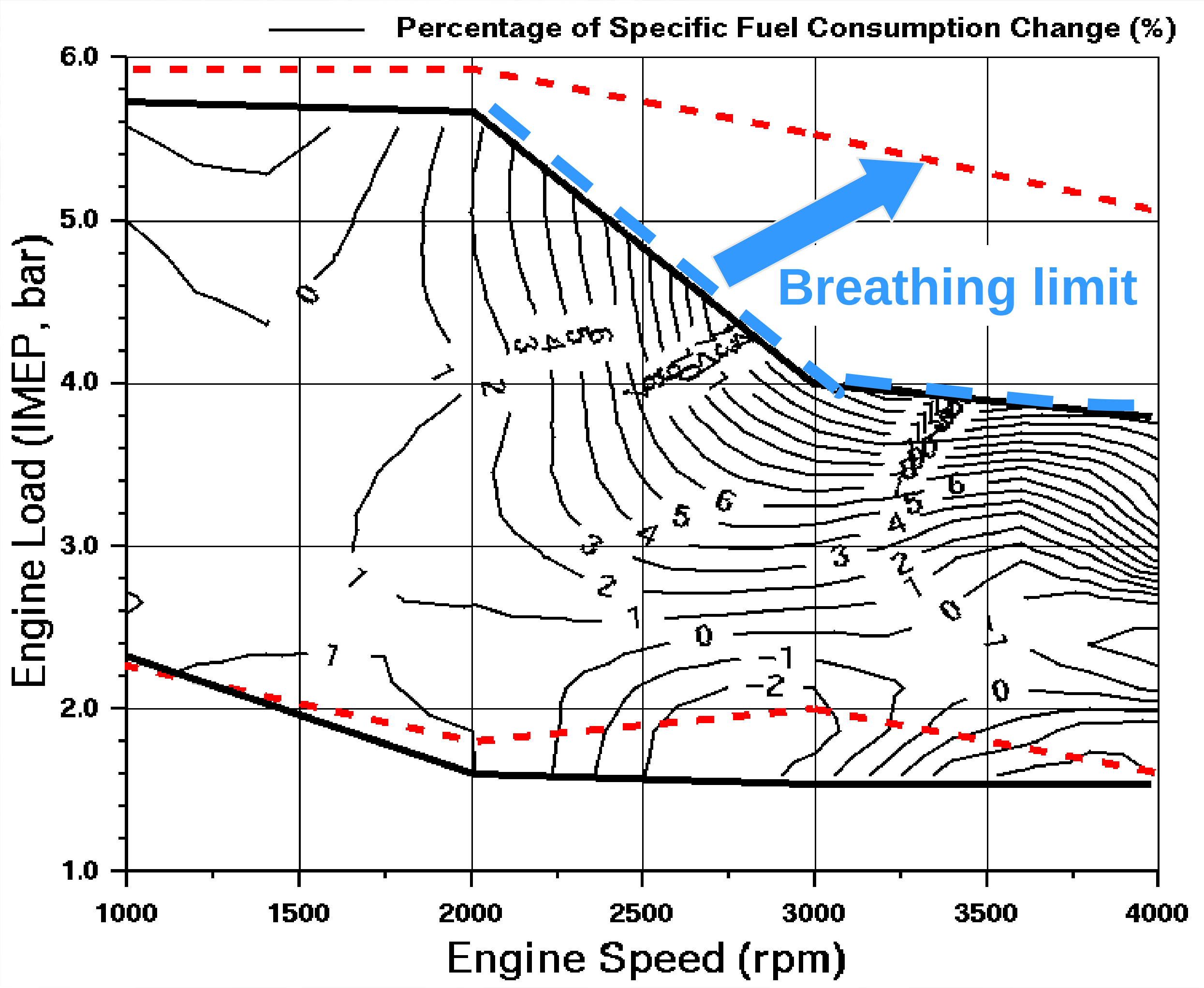






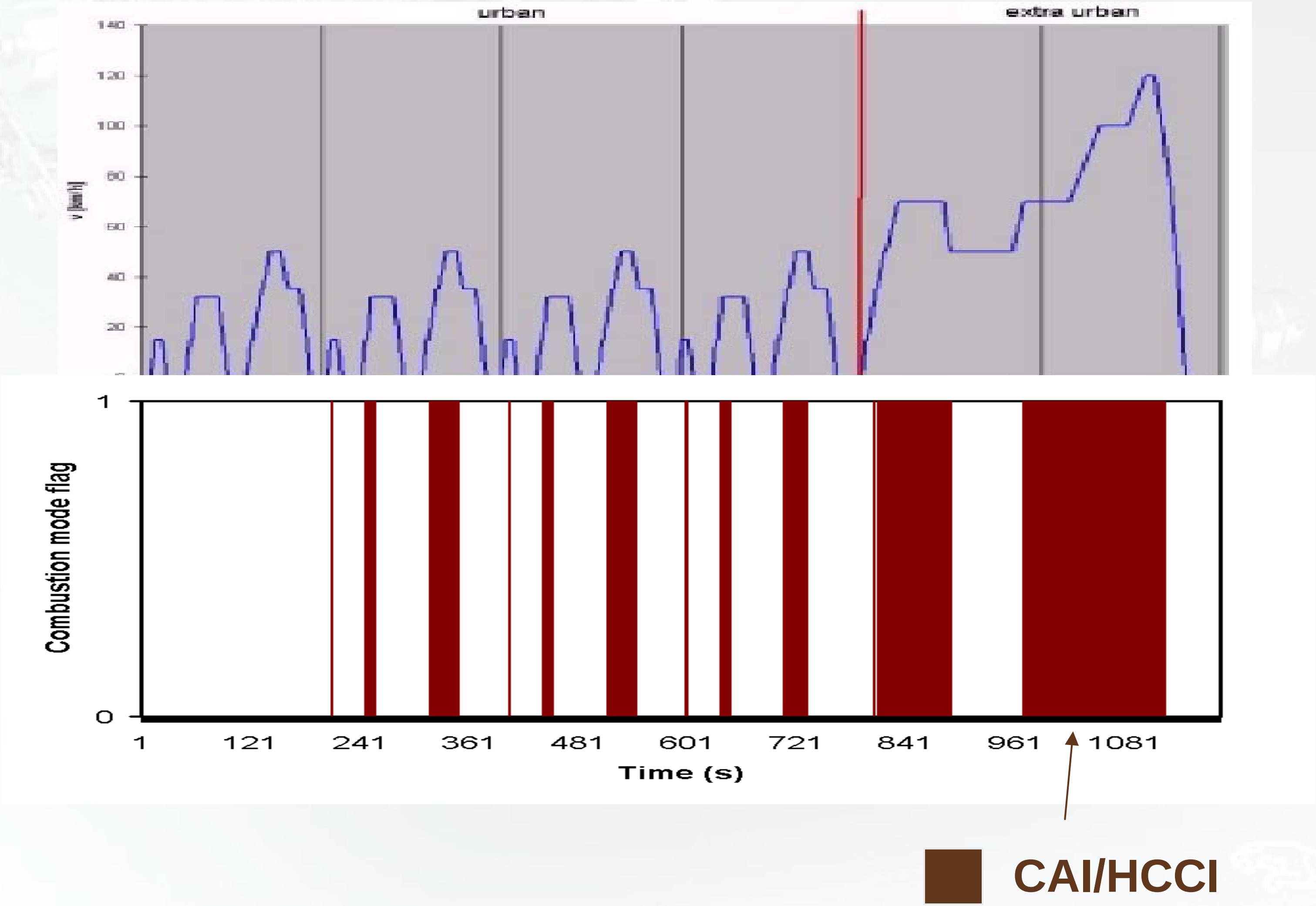
Xu et al, 2005

Optimisation of valve lift and duration

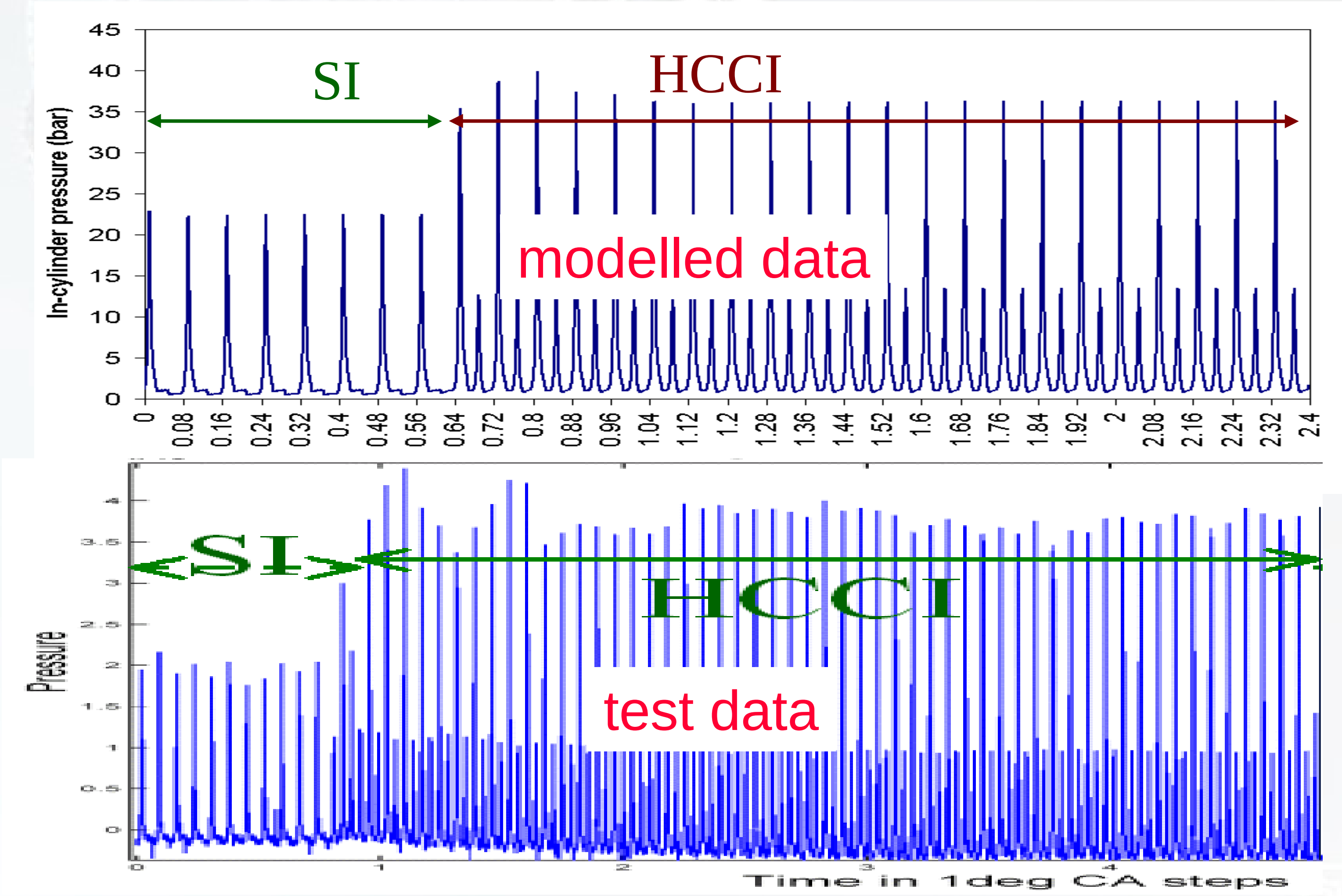


Xu et al, 2003

Transitions required for the Jaguar NA V6

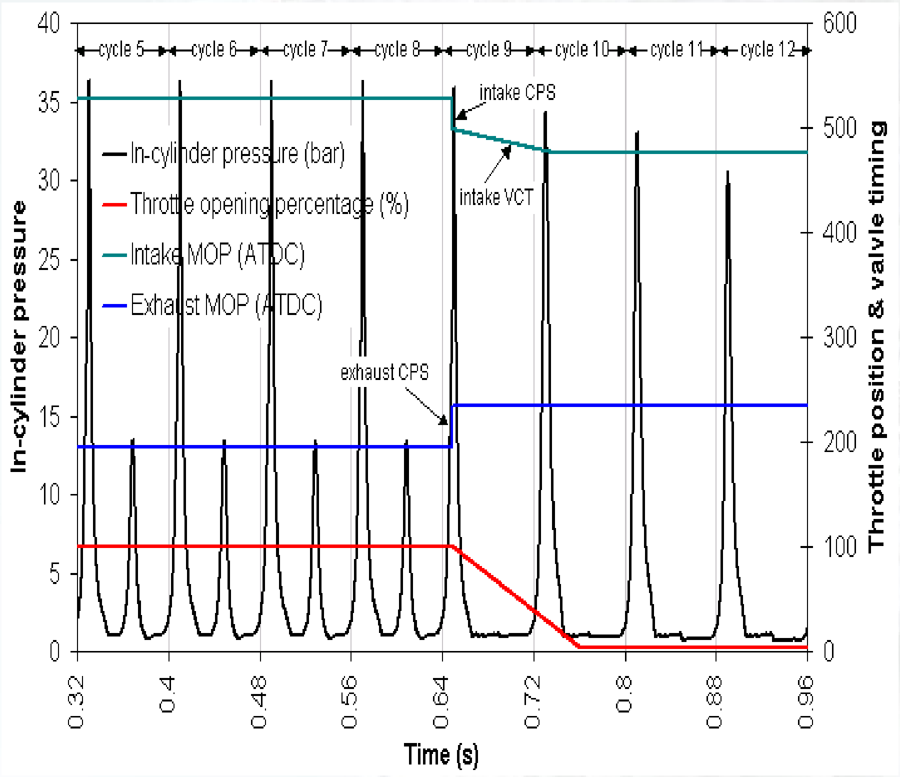


Combustion mode transition

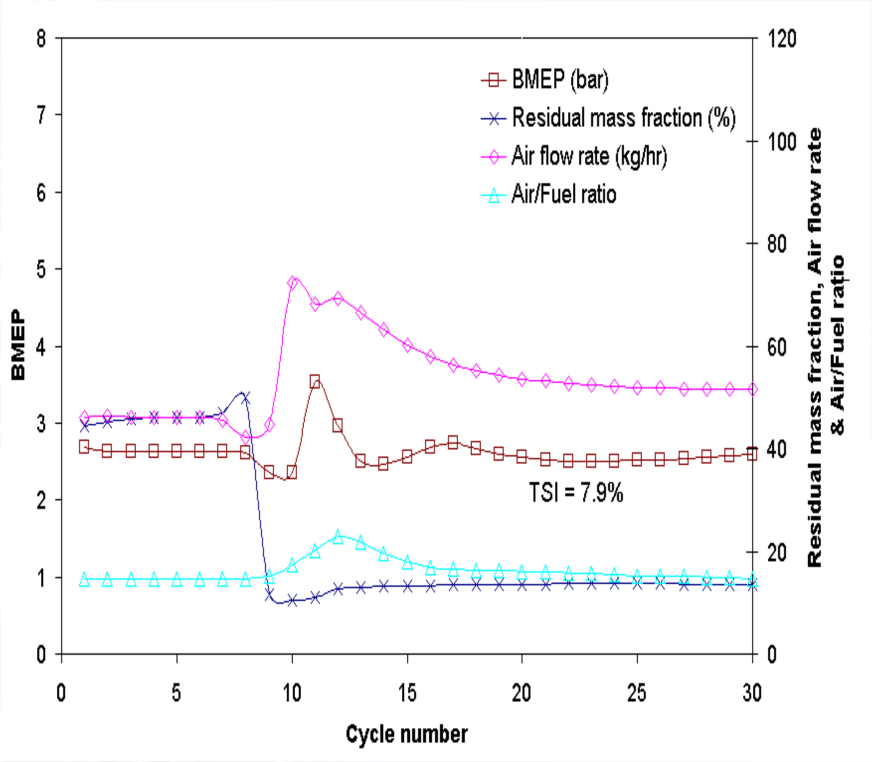


Xu et al, 2004

Transition optimisation modelling



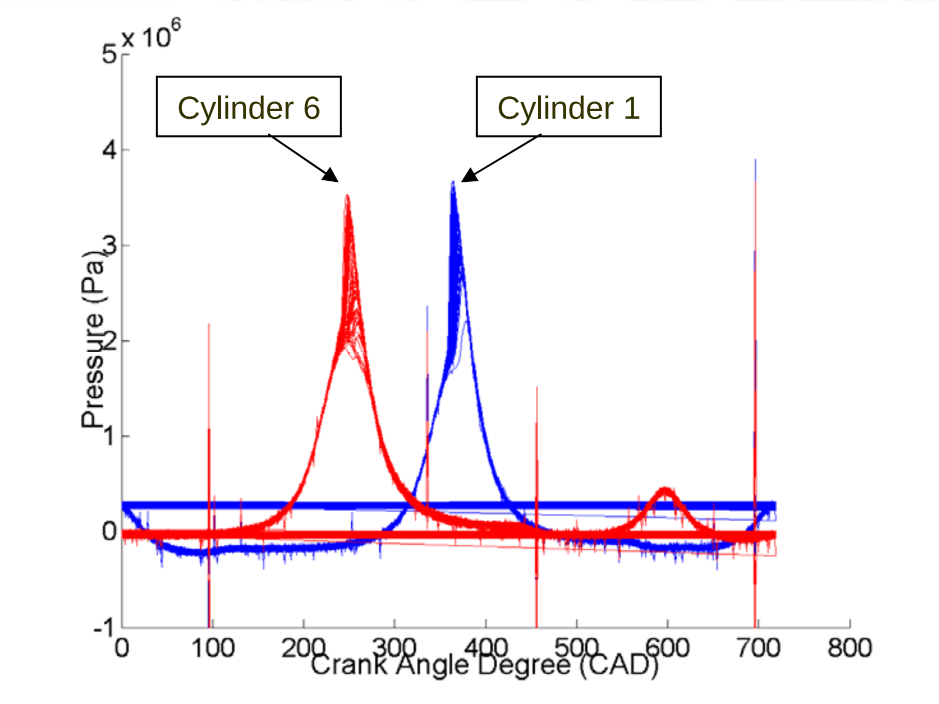
Transient response of throttle, intake and exhaust valves



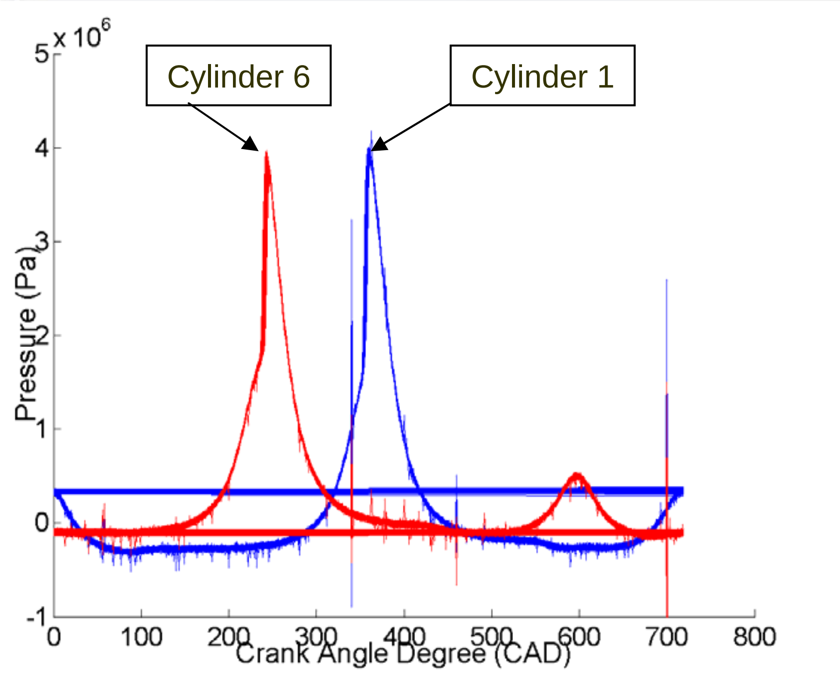
Variation of BMEP, airflow rate and residual mass fraction

Xu et al, 2004

Cycle-by-cycle & cylinder-to-cylinder variations

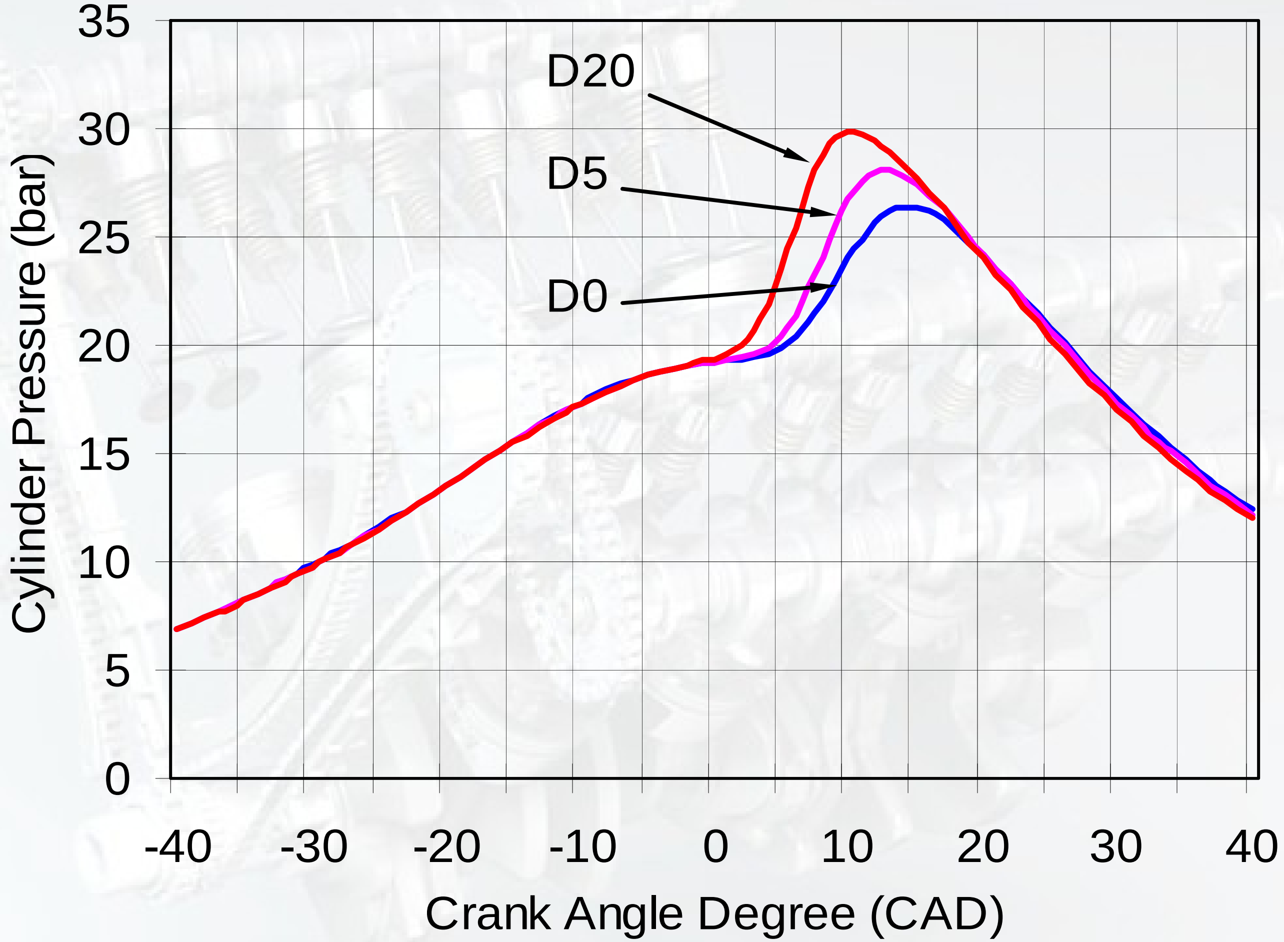


Without reformed gas



With reformed gas

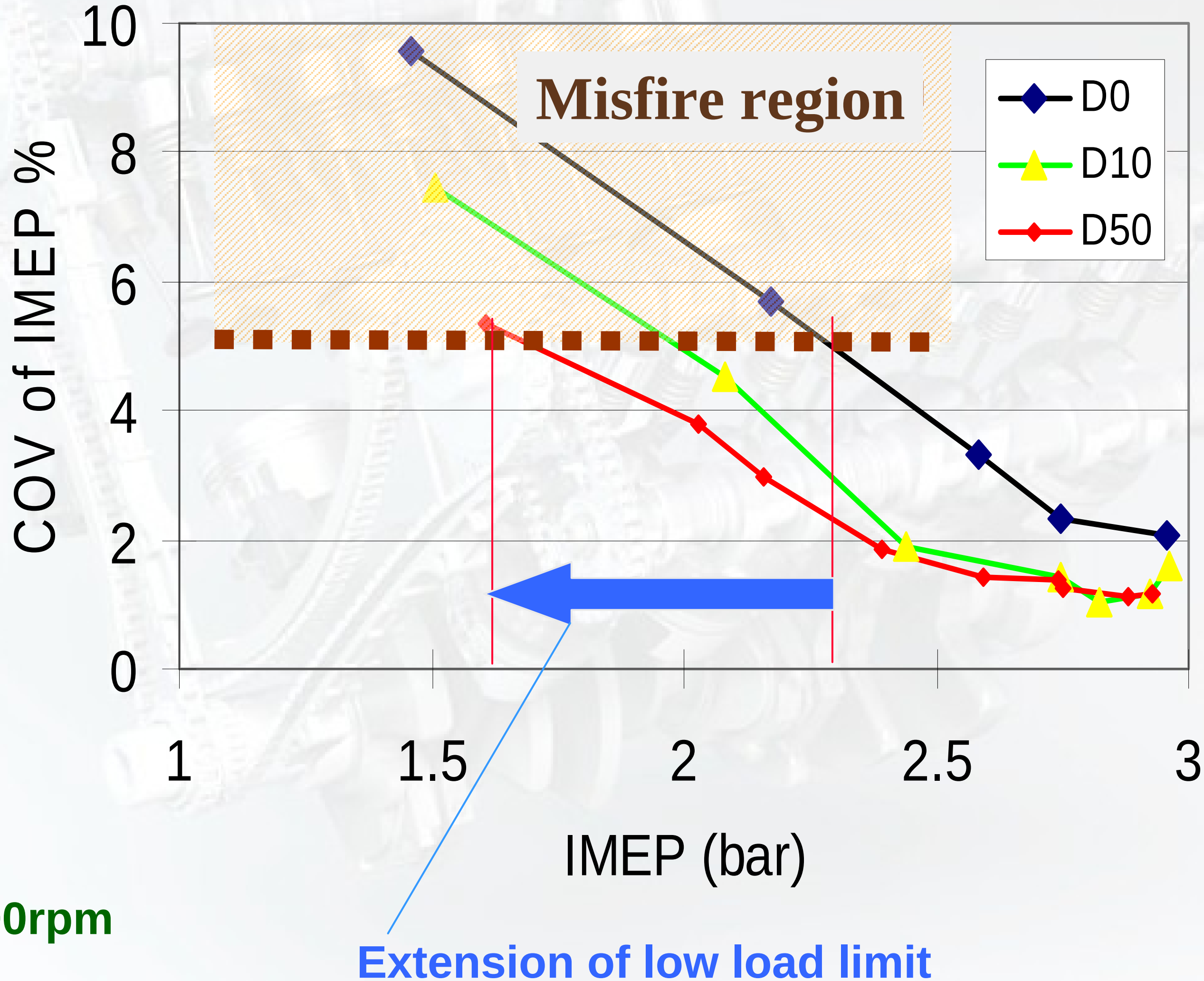
Gasoline and Diesel blending (1) – Ignition control



1500rpm, Dx=(100-x)%gasoline + x% diesel

Zhong et al, 2005

Gasoline and Diesel blending (2) – expanding HCCI window



1500rpm

Zhong et al, 2005

HCCI – what are we after?

Conventional Diesel

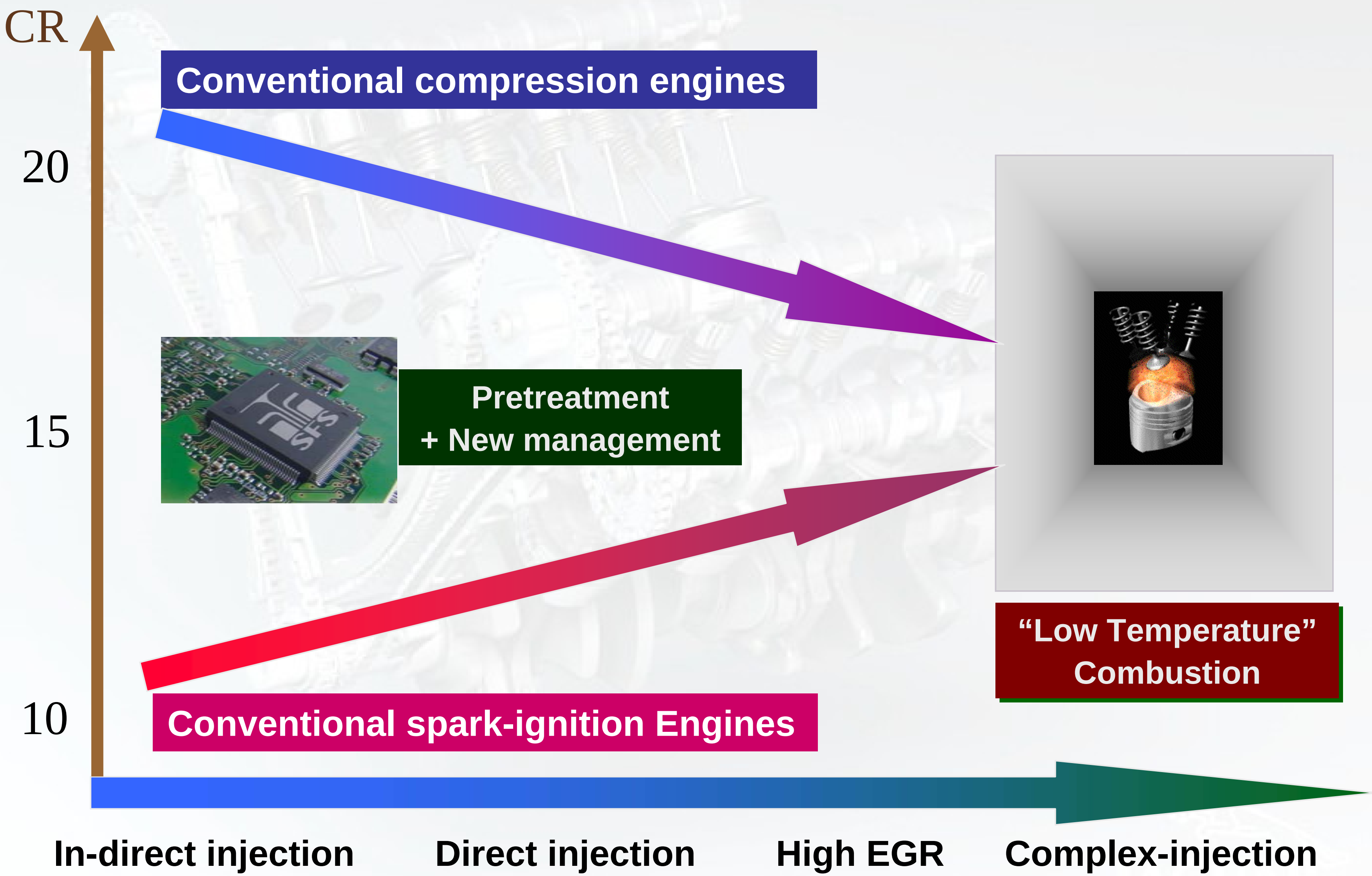
Comp-ignition
- Fuel with high T_{AI}
- Late fuelling
- Heterogeneous
- Diffusion flame
- Higher C/R
- Unthrottled
- Higher EGR
- Lean burn
- L-NOx
- Higher FE
- PM
- ...

Diesel
Or
Gasoline

Conventional SI

- Spark-ignition
- Fuel with low T_{AI}
- Early fuelling
- Homogeneous
- Premixed comb
- Lower C/R
- Throttled
- Lower EGR
- Stoichiometric
- No L-NOx
- Lower FE
- Little PM?
- .....

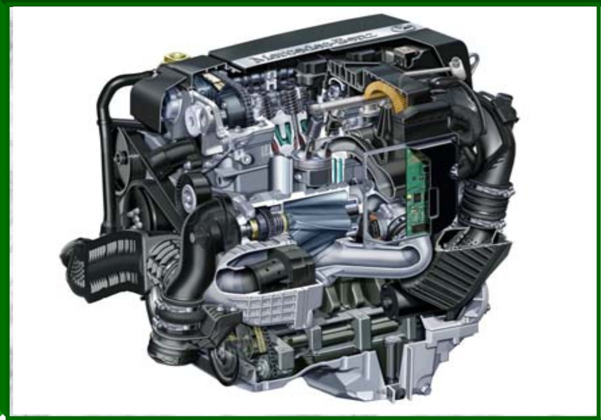
Gasoline and Diesel Engine Technologies are emerging



What could the future engine be like?

Spark-ignition or spark assisted CI at high speed and full load

Mixture pre-treated and boosted



Cycle resolved on line model assisted control

Multi-fuels management capability

Variable strokes and CR with flexible valvetrains

Boosted and stratified auto-ignition at low speeds

Multi point fuel supply in each cylinder

Conclusions (1)

- The use of HCCI engines with fuels having a high octane number (poor AI quality) employing EGR trapping alone to enable ‘controlled auto-ignition’ makes it very difficult to achieve cost-effective vehicle level benefits.
- HCCI engines will ideally require air boosting and possibly fuel pre-treatment (in one way or another). Thermal management (system- and in-cylinder resolved) is a very promising technology for expanding the HCCI operating window.
- A new concept of engine control system (e.g. interactive) may be required to handle mixture preparation, ignition and mode transition for the best vehicle performance.

Conclusions (2)

- The author envisages that gasoline and diesel technologies are merging, leading to a new engine system with a combination of “premixed and stratified” combustion.
- Current HCCI developments are to some extent preparing for the advent of other related engine technologies including fully flexible valve-train, variable compression ratio and on-line model based control.
- Future internal combustion engines will burn any combustible liquid and gaseous fuels with a fuel management system. A new type of fuel – ‘dieseline’ is likely to be required to suit the needs of the new combustion system.

Thank you for your attention

Questions?