Benefits and drawbacks of compression ratio reduction in PCCI combustion application in an advanced LD diesel engine

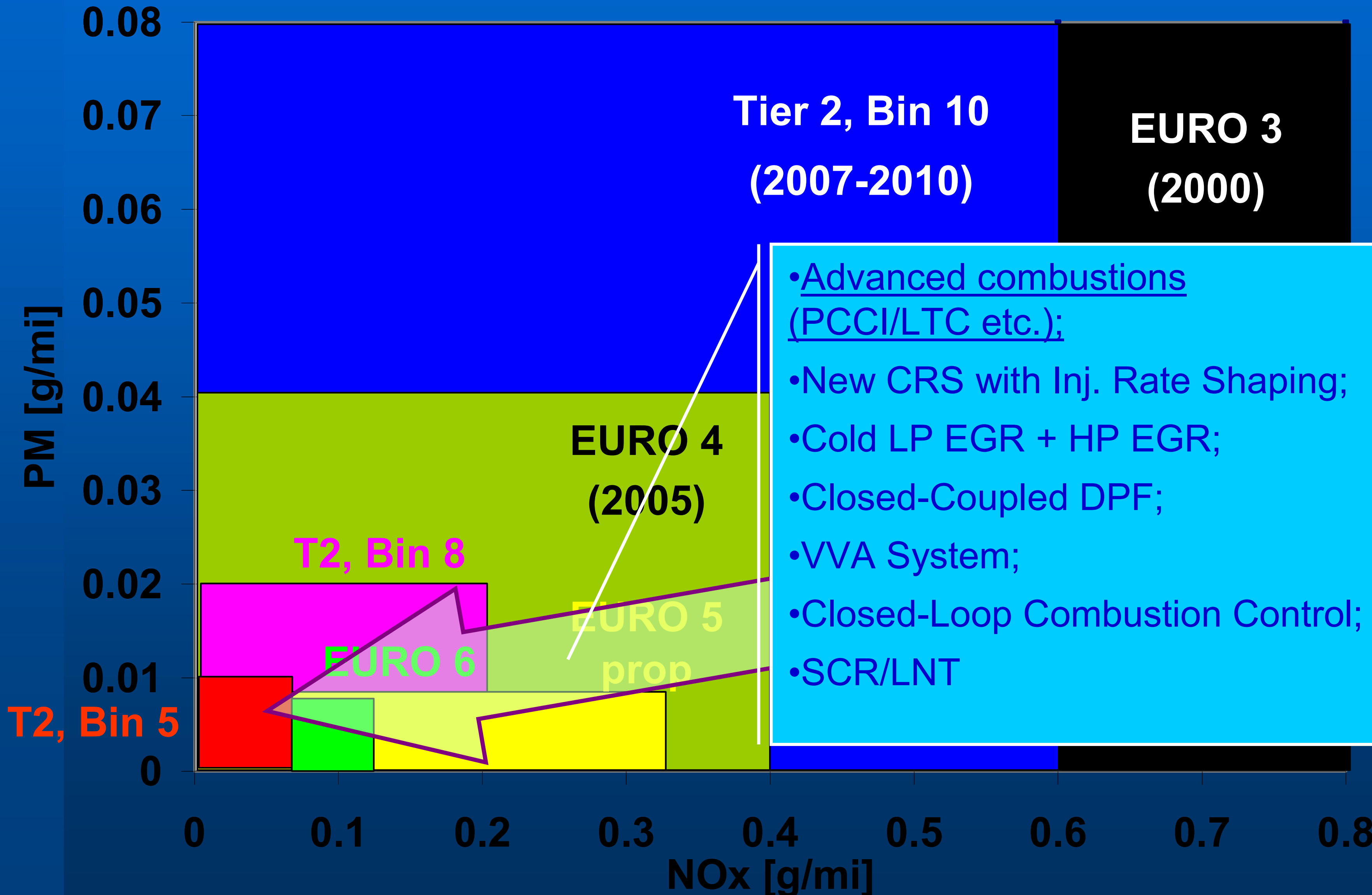
Carlo Beatrice and Chiara Guido

Istituto Motori, Consiglio Nazionale delle Ricerche
Naples , ITALY

Contacts: c.beatrice@im.cnr.it

c.guido@im.cnr.it

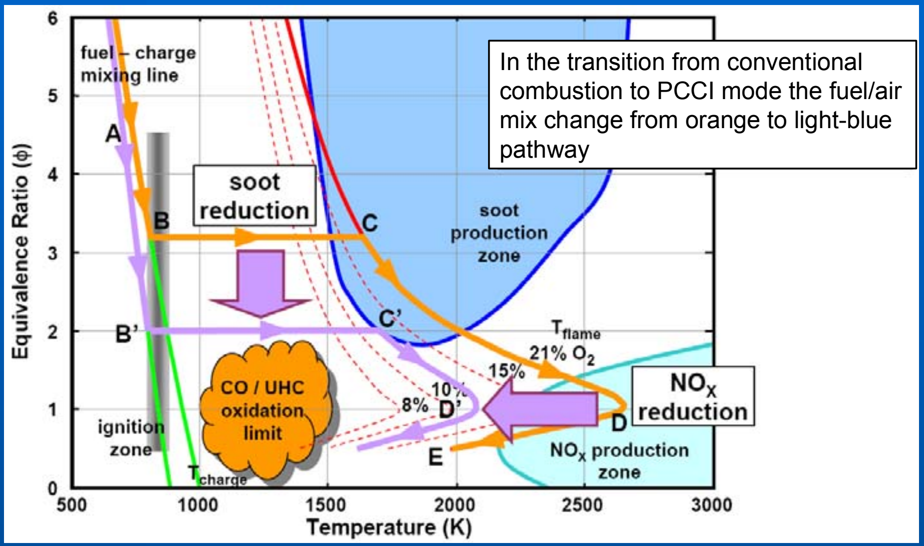
Future Targets and Technology Pathways for PC Diesel Engines



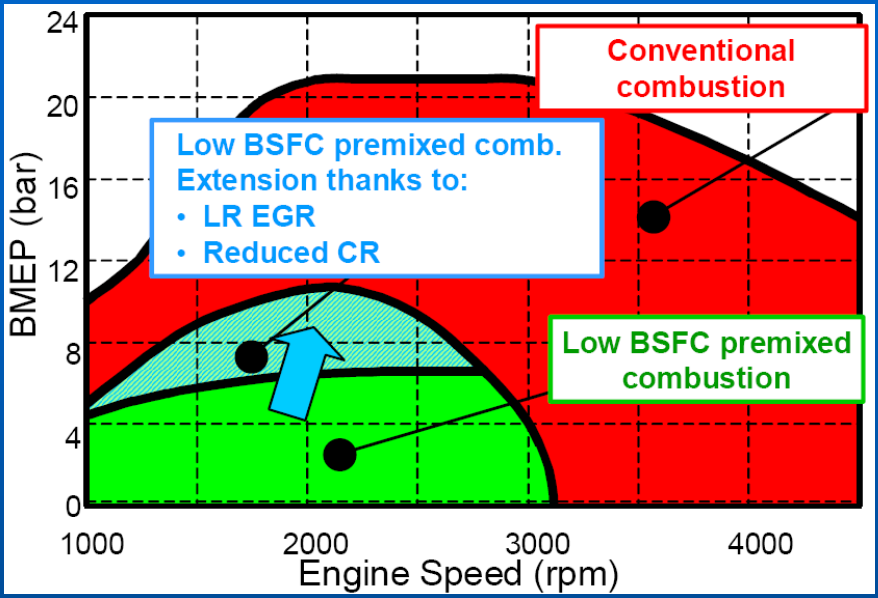
- Advanced combustions (PCCI/LTC etc.);
- New CRS with Inj. Rate Shaping;
- Cold LP EGR + HP EGR;
- Closed-Coupled DPF;
- VVA System;
- Closed-Loop Combustion Control;
- SCR/LNT

PCCI (or LTC/HCCI) potential for NOx & PM reduction

Source M. Lisbona, FPT, ATA2006

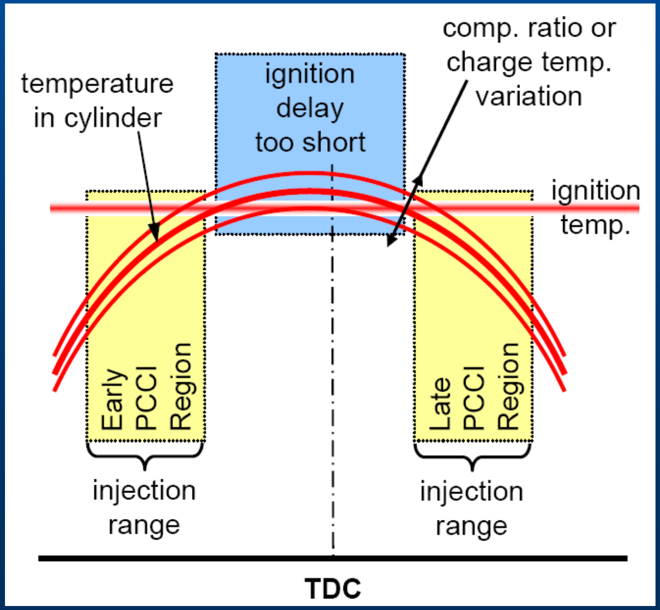


Source M. Potter, GM, DEER2006

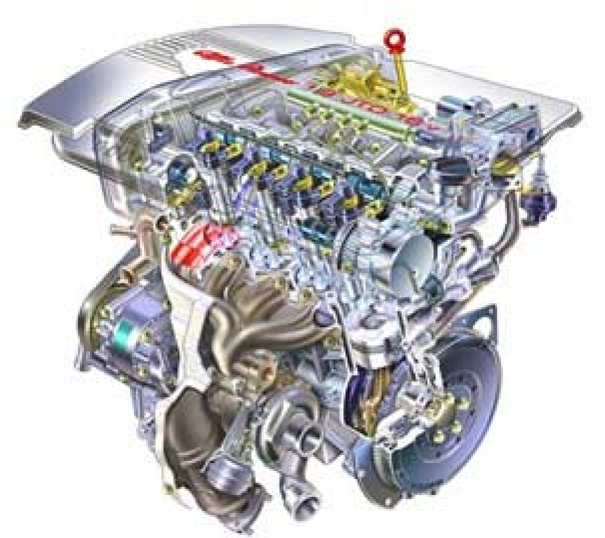


Compression Ratio appears a key parameter to improve PCCI combustion performance in partial load range

Source M. Potter, GM, DEER2006



IM-CRF Research Project on CR influence on PCCI performance



FIAT M741 *MultiJet* engine

Engine	4 cyl, 1.9L
Bore x Stroke [mm]	82 x 90
Stroke [mm]	90.0
Compr. Ratio	17.5
Turbo	VGT

Starting from an Eu4 Reference Engine (FIAT 1.9 *MultiJet*)

↓

An advanced low NOx calibration was applied
(PCCI calib. with single shot inj. and high EGR/pressure inj.)

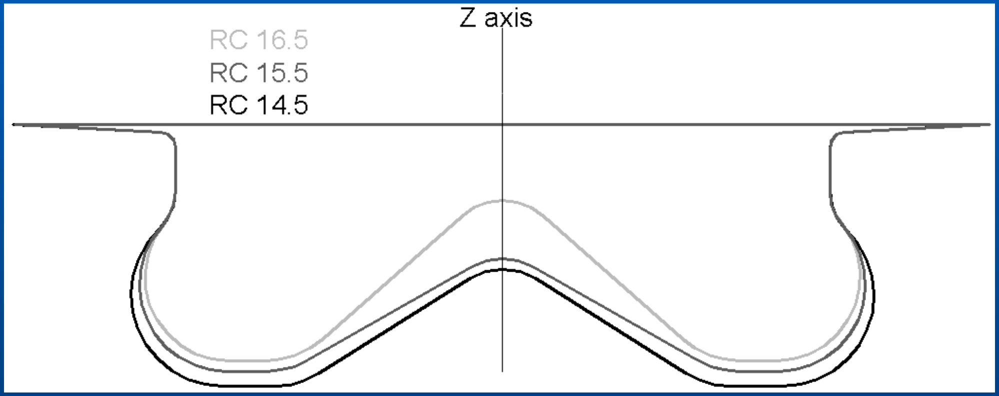
↓

Three CR values were selected for the tests (16.5:1 → 15.5:1 → 14.5:1)
The 3 engine configurations were run in several test points typical of NEDC engine operating area. Aim of the project was to characterize the influence of CR reduction on PCCI application in the largest NEDC area with NOx near Eu6 targets

CR selection and Piston Design

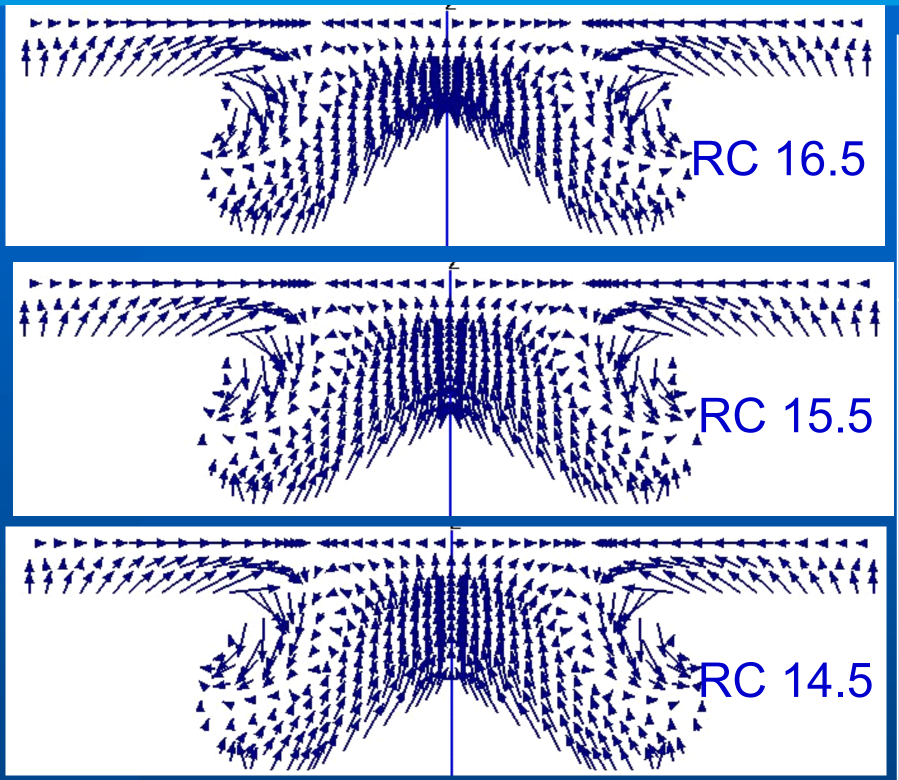
Starting from the commercial Eu4 piston geometry, 3 guidelines were followed:

- Same air flow structure at TDC (same swirl and turbulence charac. vs CR);
- Same squish height and internal lip diameter (similar squish flow in the bowl);
- Same lip profile of the bowl (same structural robustness at rated power).

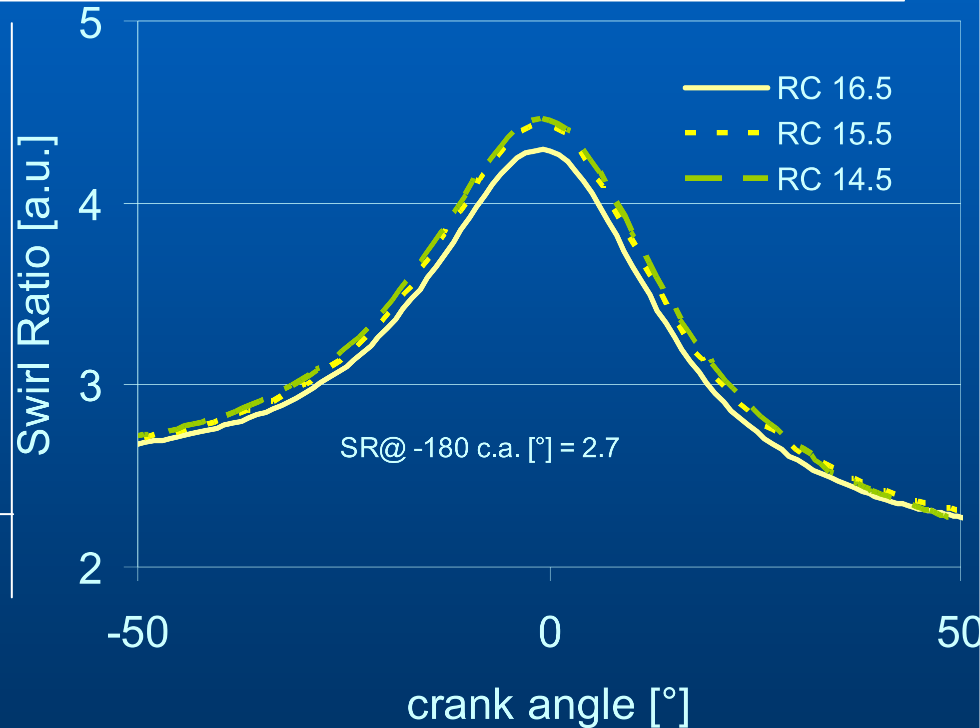


Parameter	Formula	CR 16.5	CR 15.5	CR 14.5
K-factor [%]	Bowl volume/Comb. chamber volume	75.2	76.8	78.4
Reentrant Ratio [%]	(Dext-Dint)/Dint	9.3	10.9	13.5
Aspect Ratio [%]	Hmax/Dext	33.0	34.0	35.2

In-bowl flow characteristics vs CR



•The main air flow patterns appear very similar;
•The main differences are in the central part of the bowl.

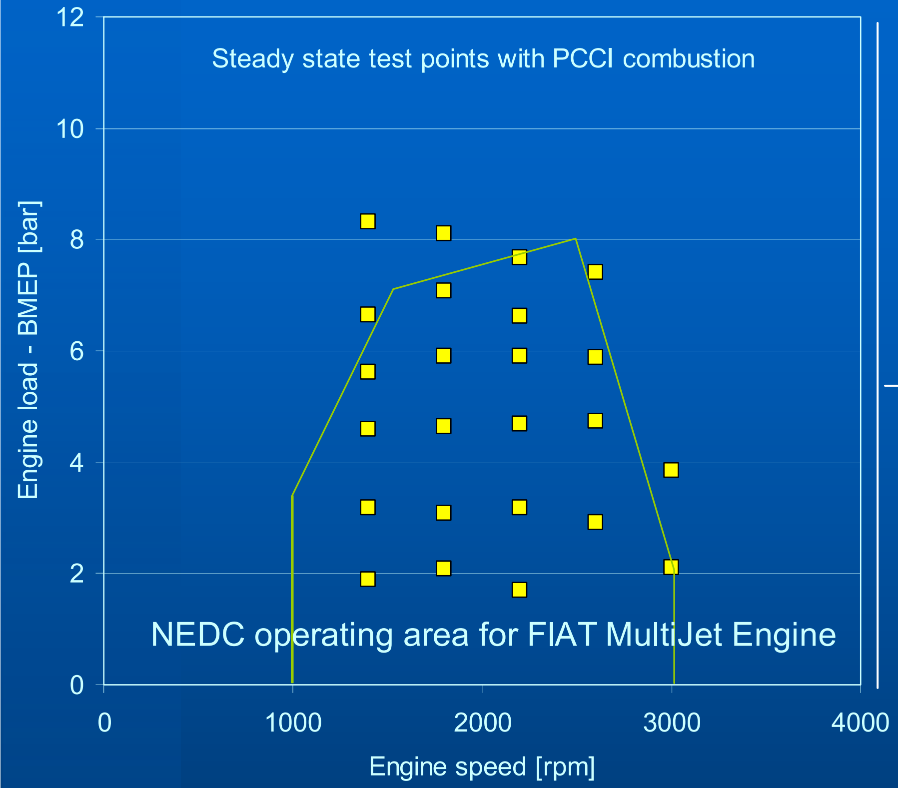


Slight increase of swirl ratio vs CR decrease

Friction loss reduction due to the surface/volume reduction and increment of moment of inertia

The CR influence on engine can be ascribed mainly to different fuel vaporization and thermodynamic effects

Test Methodology



Starting from a prototype "near NOx Euro6" engine calibration for a CR=16.5

All CRs were tested in different operating points typical of NEDC area

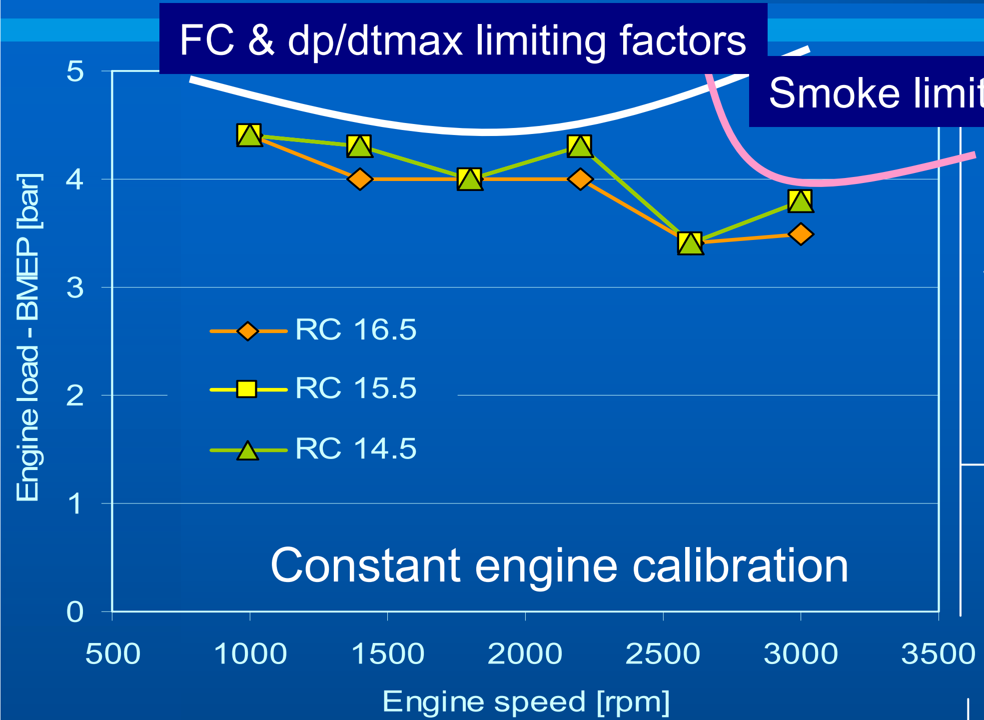
In the engine speed range, the load was increased until one of the following limits were reached:

- +5% of FC w resp to Eu4 calib.;
- 80 bar/ms of the dp/dtmax;
- 1.5 FSN of smoke as limit for DPF.

In this way all CRs can be compared with optimized combustion timing and intake airflow conditions

MBF50% and boost pressure were optimized vs CR varying SOI and VGT nozzle.
The fuel is a commercial Low Sulfur respecting the EN 590 standards

CR influence on max PCCI torque: max torque, FC & smoke

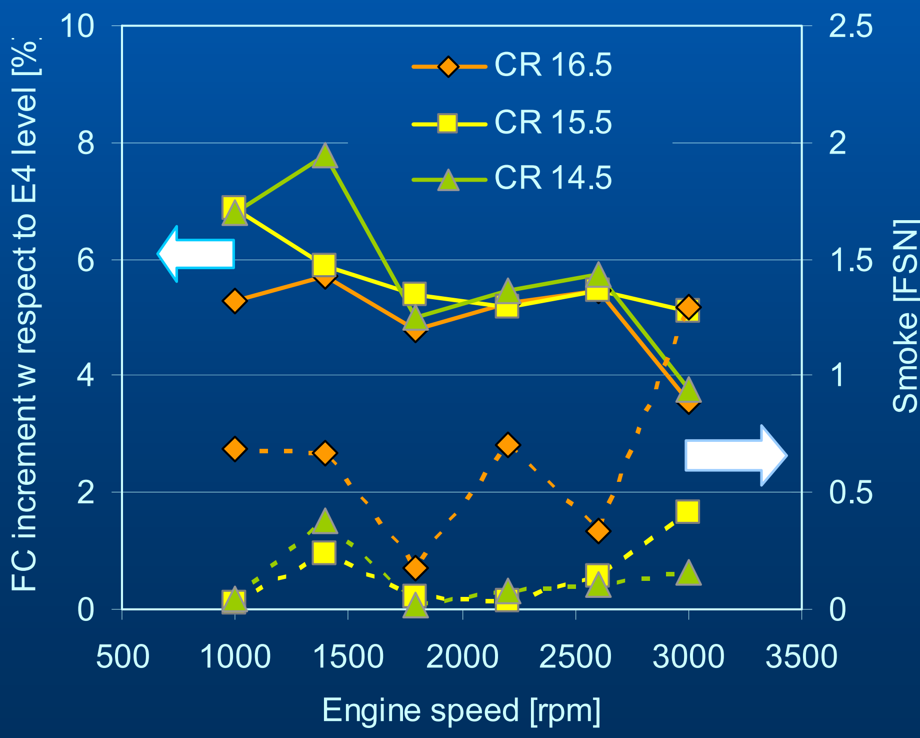


Reducing CR only small increments in maximum engine torque are possible within the limits and without changing the engine technology (Euro4)

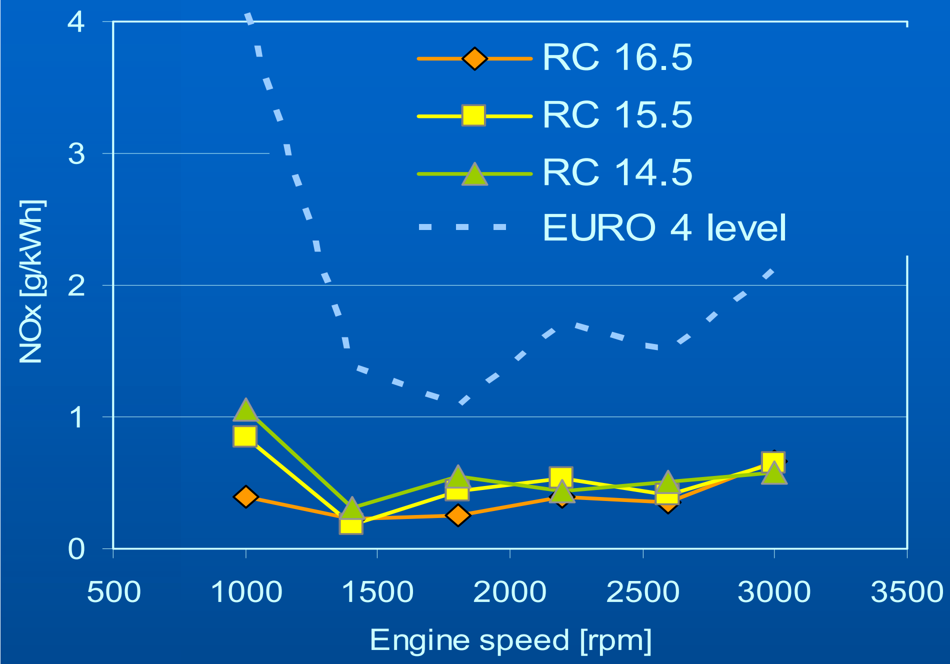
Reducing CR the τid increases lowering the smoke in the whole range.

dp/dtmax limits the MBF50% that controls the engine efficiency.

FC was similar for all CRs, no fuel penalty was evidenced reducing CR



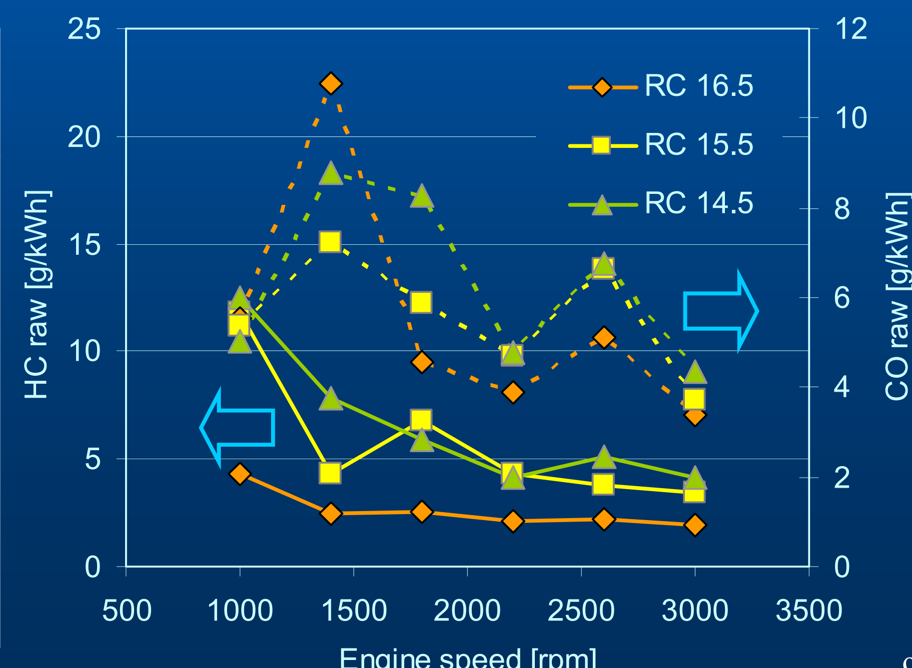
CR influence on max PCCI torque: NOx, HC & CO



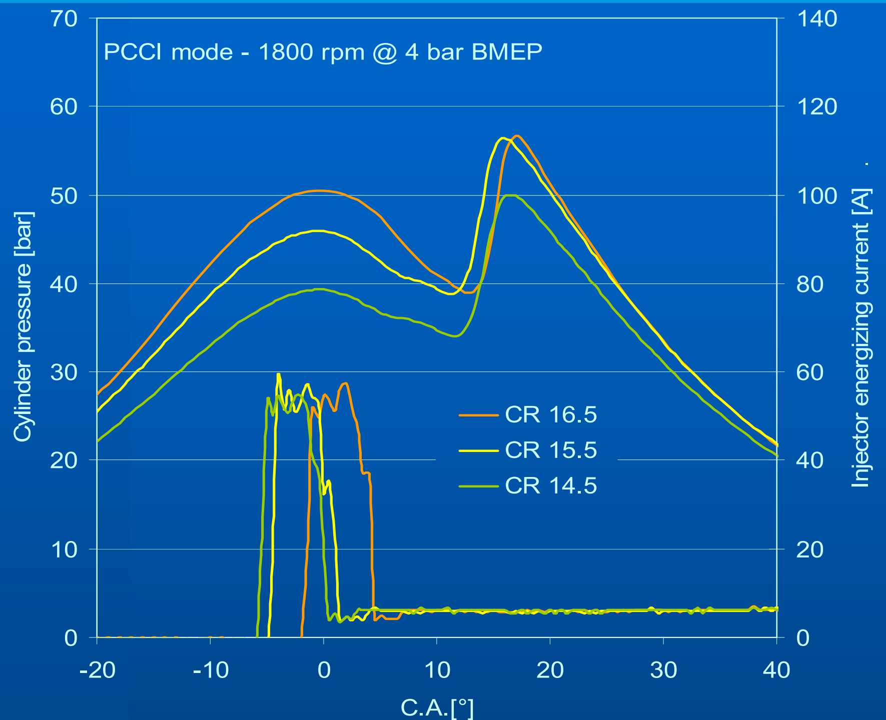
NOx emissions are mainly driven by EGR.
Under PCCI mode, the already very low NOx concentrations are poorly influenced by CR

HC & CO emissions tend to increase reducing CR.

Premixing time and spray wall interaction have effect on unburned compound emissions

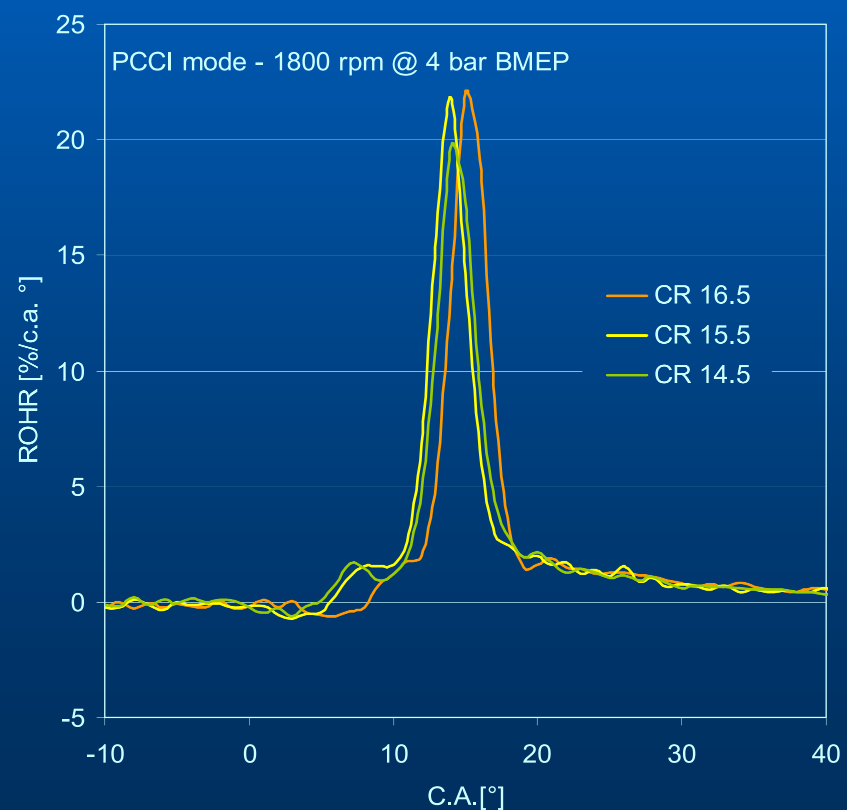


CR influence on max PCCI torque: Ind. engine cycle

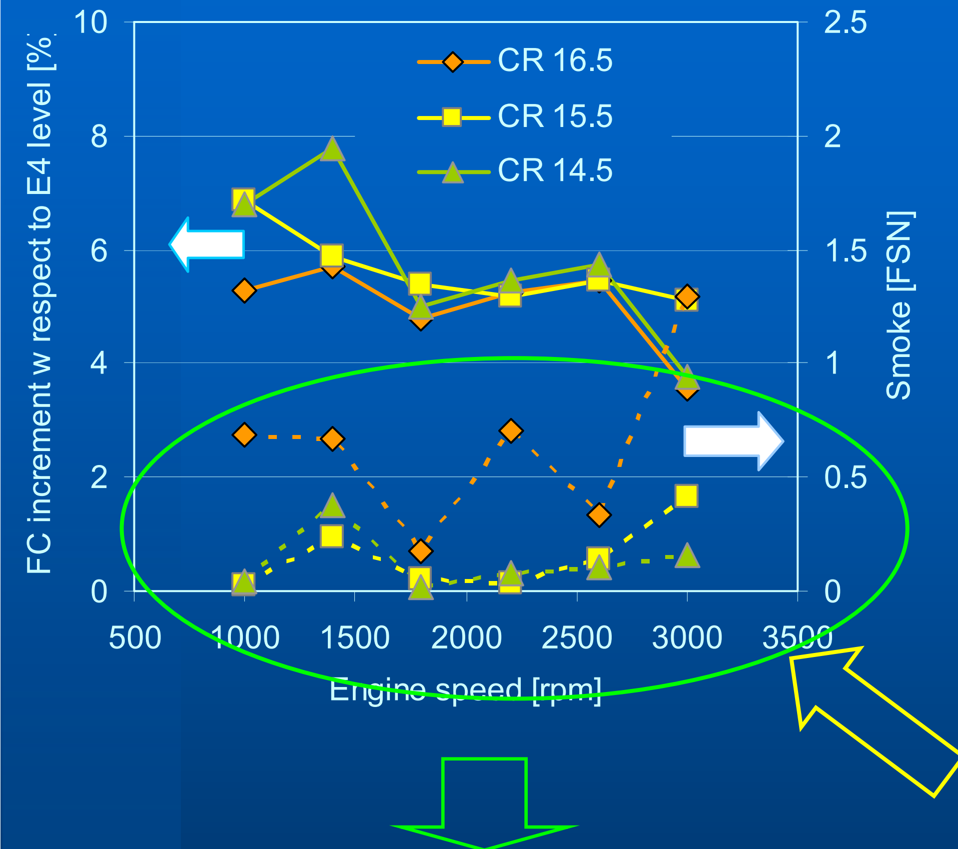


From CR 15.5 to 14.5 the τid increase was lower than from 16.5 to 15.5. Apart that τid is not linear with temp., possible cause is also the fall of τid in the NTC range (1050÷900K) in some conditions.

ROHR curves confirm that small changes were detected varying CR in terms of "thermodynamic" combustion evolution



Engine Optimization vs CR



EGR has to be kept quite constant in order to have same NOx.
Two ECU parameters affect in opposite way both engine efficiency and smoke:

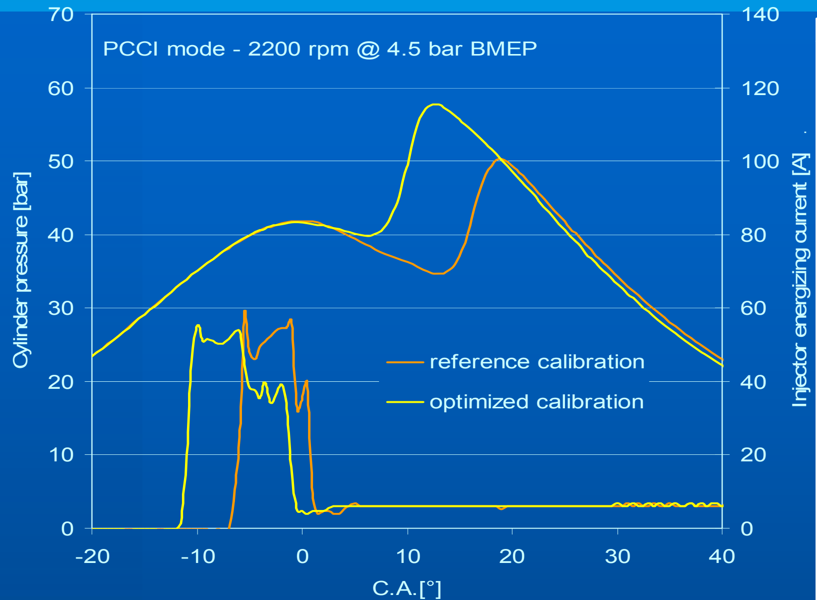
- Rail pressure (friction loss / atomization);
- Swirl valve position (pumping loss, intake valve permeability and heat loss / fuel premixing level);

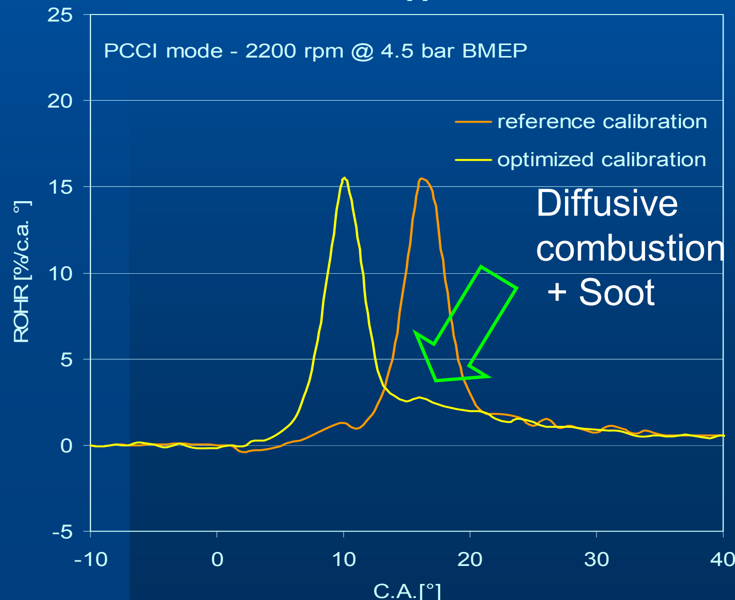
These parameters can be optimized in order to exploit the very low smoke of the lowest CRs.

Optimization work was done respecting the limits on max pressure rise, exhaust smoke and max FC increment

Injection strategy optimization was not considered in this project but it is another key factor

Engine Optimization vs CR: Ind. engine cycle





Reducing Rail Pressure:

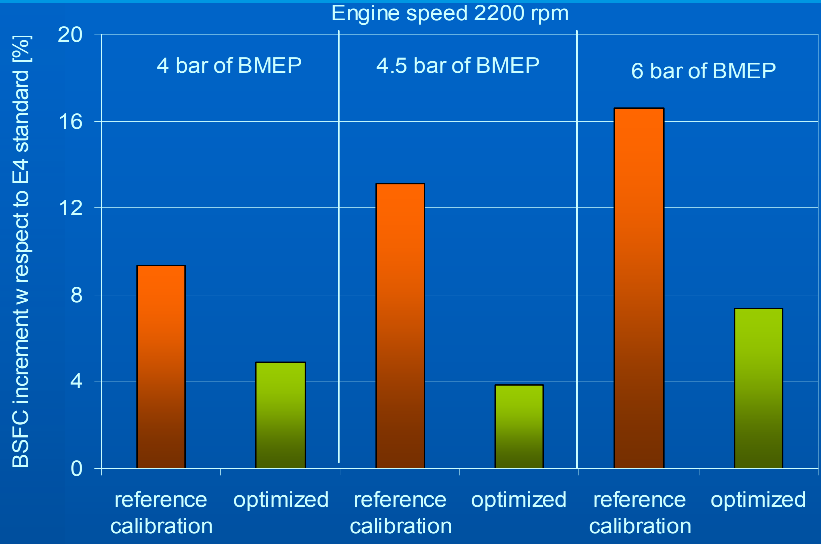
- Less parasitic and friction losses;
- Less premixed fuel→ Lower dp/dtmax→ Early SOImain→ MBF50% closer to TDC;
- Less HCs&CO → Higher ηcomb

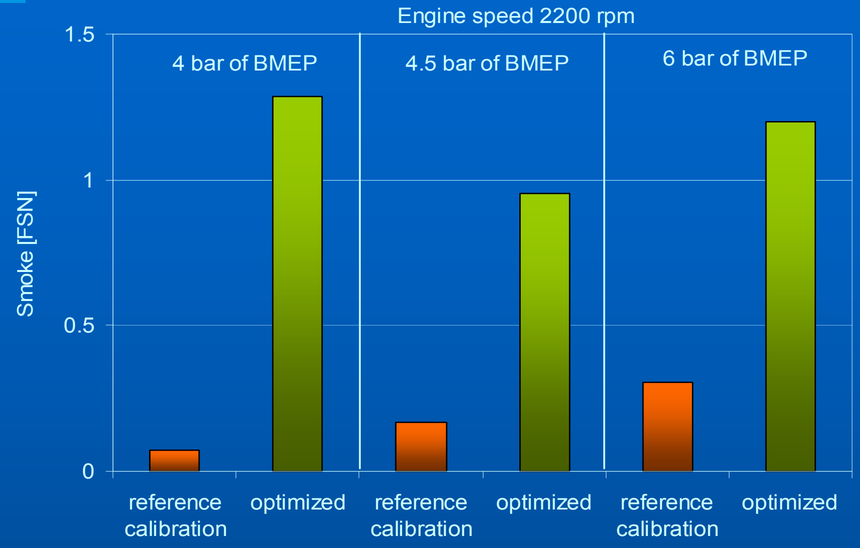
Particularly important at high speed and medium load (late combustion)

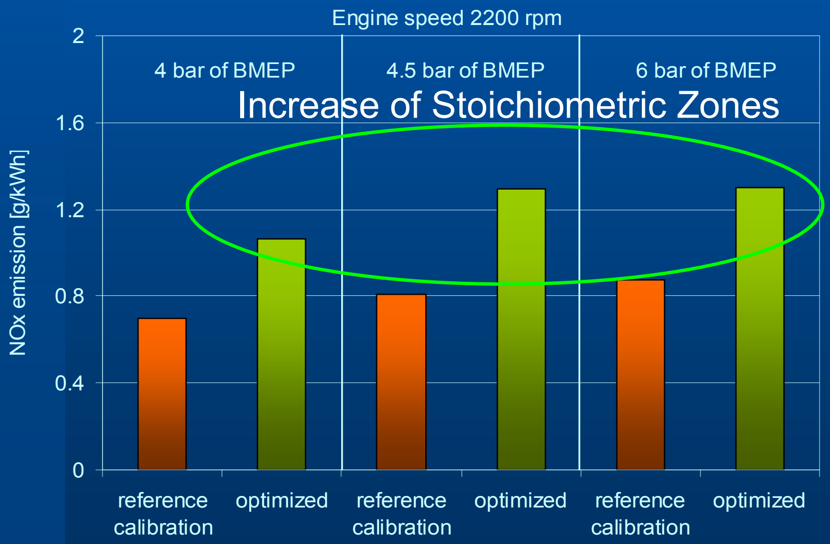
Reducing SW ratio:

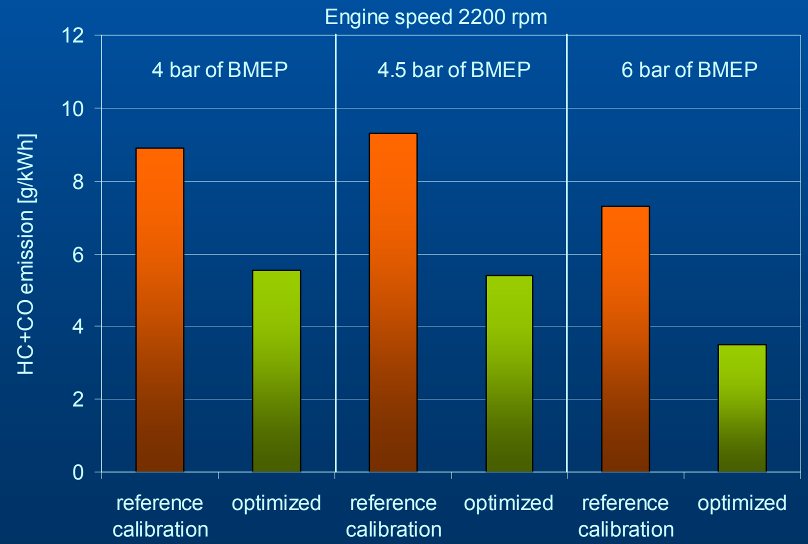
- Less pumping losses;
- Less premixed fuel→ etc…..;
- Higher valve permeability→Higher trapped gas mass ;
- Less heat losses;
- Less overleaning A/F zones→Less HCs & CO

Engine Optimization vs CR: FC & Emissions



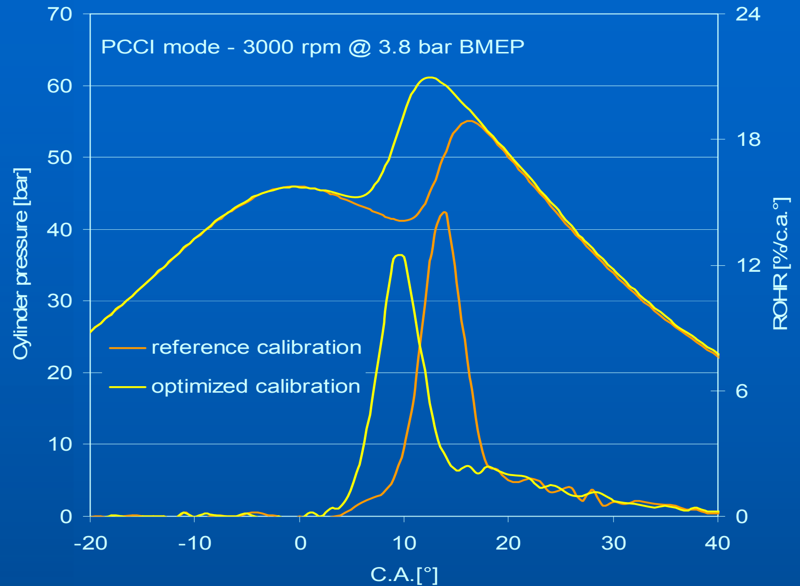


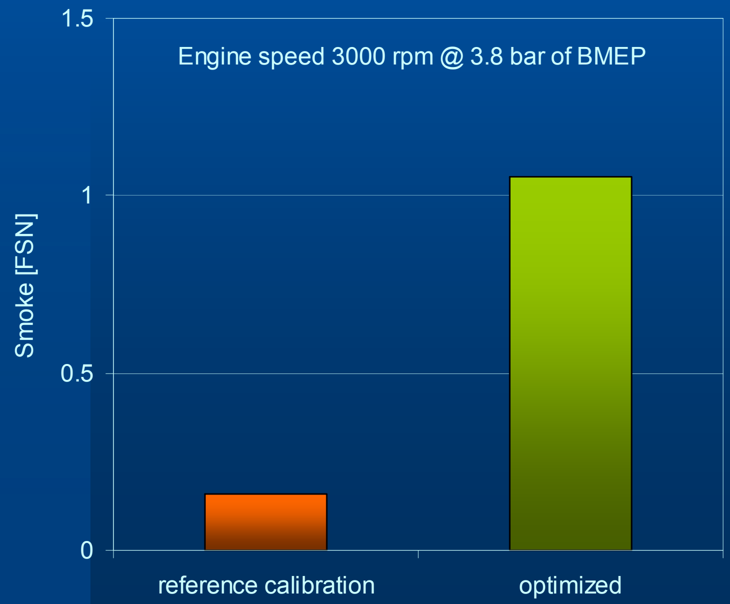




FC reduction at same dp/dtmax permits the increment of Torque limit

Engine Optimization vs CR: Conditions @ 3000 rpm





At high speed the available premixing time is low also at the lowest CR.

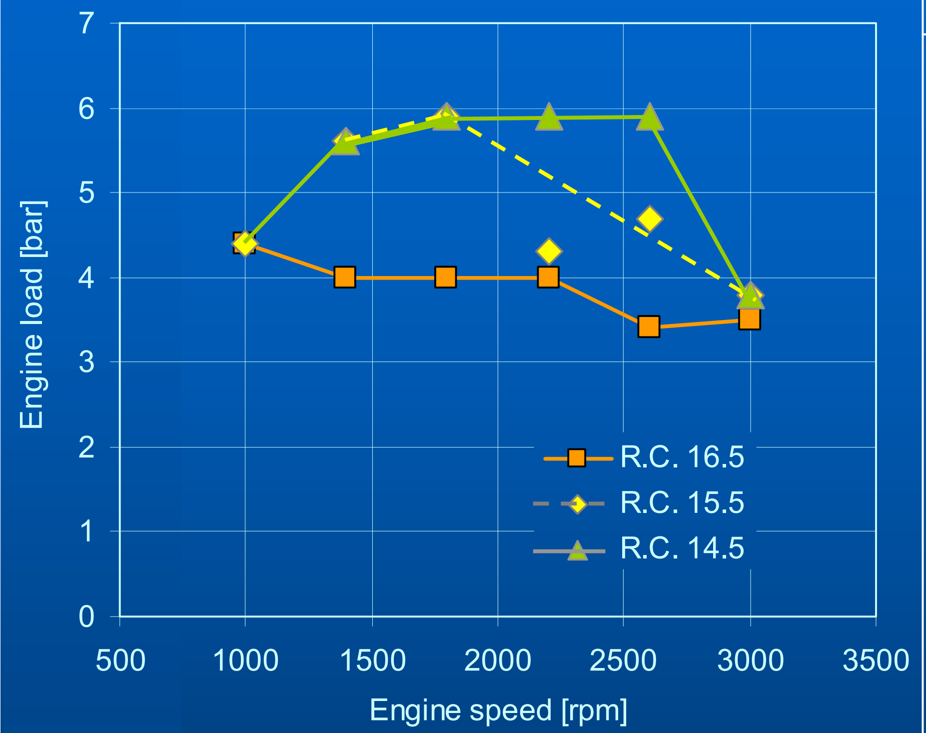
Smoke becomes the limiting factor.

The effectiveness of both Injection pressure and Swirl ratio reduction on FC improvement is strongly lowered.

Smoke emissions are strongly sensible to SW and Rail Pressure reduction.

However this engine speed level is less critical on NEDC engine performance.

Engine Optimization vs CR: Max Torque vs Speed



After engine optimization the maximum PCCI torque was increased from 4 to 6 bar of BMEP with CR 14.5.

For CR 16.5 the improvement was negligible due to smoke emission close to the limit.

CR 15.5 and 14.5 showed similar results in the low speed range, while CR 14.5 was more effective than CR 15.5 in the high speed range.

At highest engine speed, the CR reduction is less effective for PCCI improvement due to smoke limitation.

Conclusions

• FC penalty vs CR, in NEDC operating area, was small and mainly dependent on ηcomb reduction;

• Lowering the CR a marked drop in smoke and a drastic rise in HC and CO have to be expected. NOx remain EGR driven;

• CR reduction is able to increase the max PCCI torque only through engine re-optimization;

• Smoke drop can be exploited to improve the torque. Working only on the SW and Prail reduction, pumping and friction loss can be lowered and intake duct permeability increased. HCs&CO can be also lowered;

• In PCCI mode, combustion phase optimization and friction losses reduction do not cause the FC deterioration for low CR engines. NOx emission can be reduced well beyond the Eu5 and near Eu6 targets. From our results, a CR value around 15.5 appears the best compromise;

• HCs&CO remain the main issue lowering CR. They cannot be controlled by DOC during cold start. Startability can also becomes a problem.

General Outline

• It was pointed out that, independently from the DeNOx adoption, in order to drop the NOx emissions for Euro6/Tier2 Bin5 targets, the CR optimization (or the use of VCR) appears one of the key factors for PCCI application improvement.

• For a complete assessment of the CR reduction benefits, the preservation or the improvement of the current rated power target and the control of the high HCs&CO emissions during cold start remain open questions. Engine technology improvement could give adequate solutions for these problems (CLC-Comb., LP-EGR, VVA, new FIE, VCR, new TC, new DOC etc.)

Acknowledgments

Special thanks to Dr. Roberto Imarisio and Dr. Marco Tonetti of Centro Ricerche Fiat, for their support in the providing scientific cooperation, information and hardware.

Istituto Motori of National Research Council, ITALY

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