Emission optimized combustion of H_2-containing reformer gas in Internal Combustion Engines

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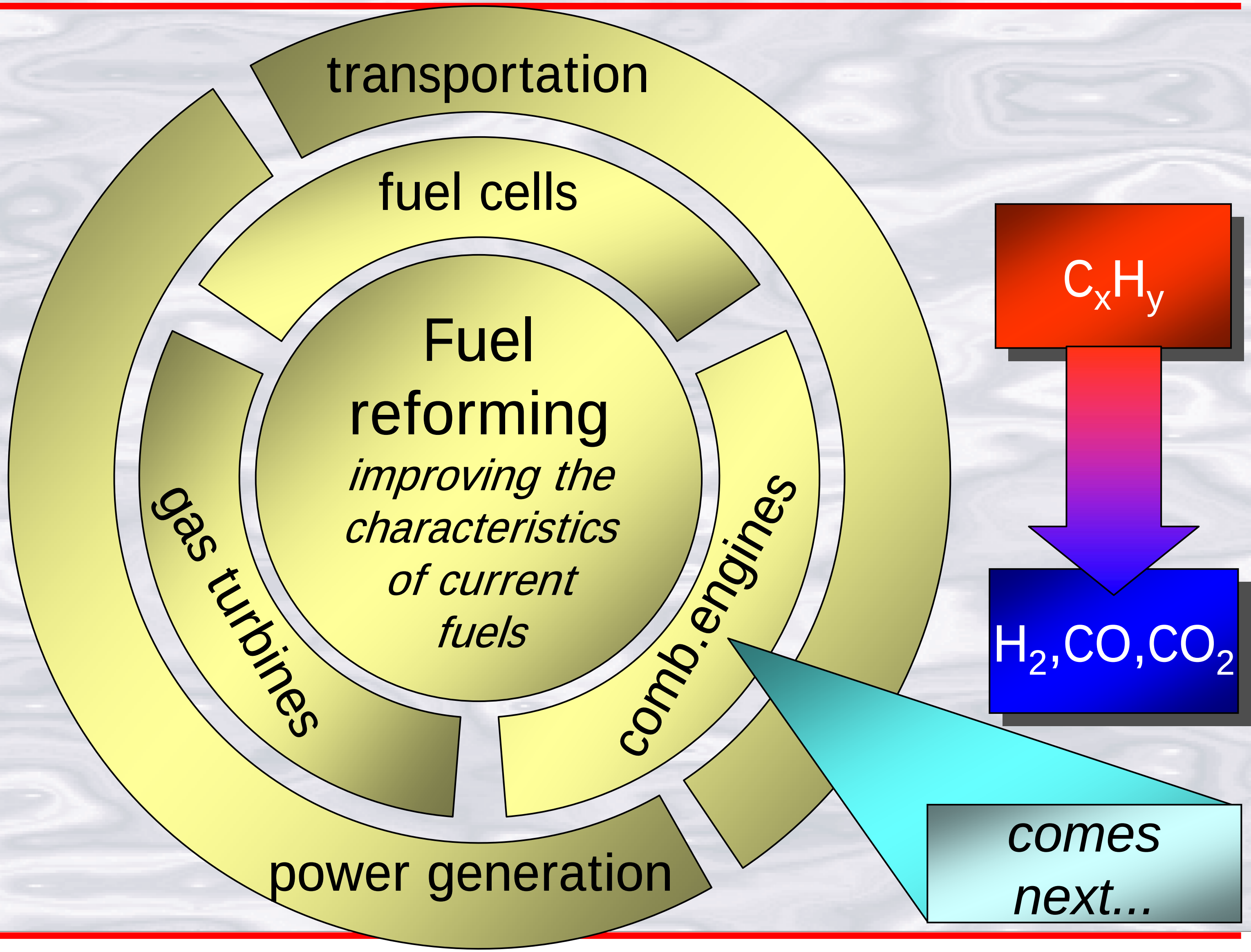
Applications of fuel reforming



Use of hydrogen in IC engines: why?

H_2
- Low density and A/F
- High reactivity

Phys./Chem. Effect
- Extension of flammability limits
- Activation of exhaust gas catalyst

Effect on Engine Operation
- Dethrottling
- Ultra-lean operation
- Ultra-high EGR rate
- Enhanced engine stability
- Injection in exhaust stream for catalyst warm-up

Results
- Improved engine efficiency
- Near-zero engine-out emissions
- Zero tail-pipe emissions

NOx emission control strategies in IC engines

$$NOx \approx \exp(T)$$

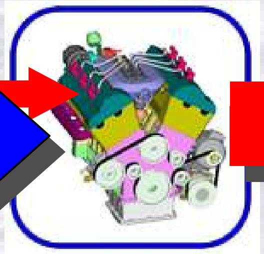
$$\Delta T = \frac{Q_{comb}}{mc}$$

lean operation

$\lambda > 1$

more air than what is stoichiometrically needed

exhaust gas recirculation (EGR)



Additional benefits

Lower heat losses

Dethrottling

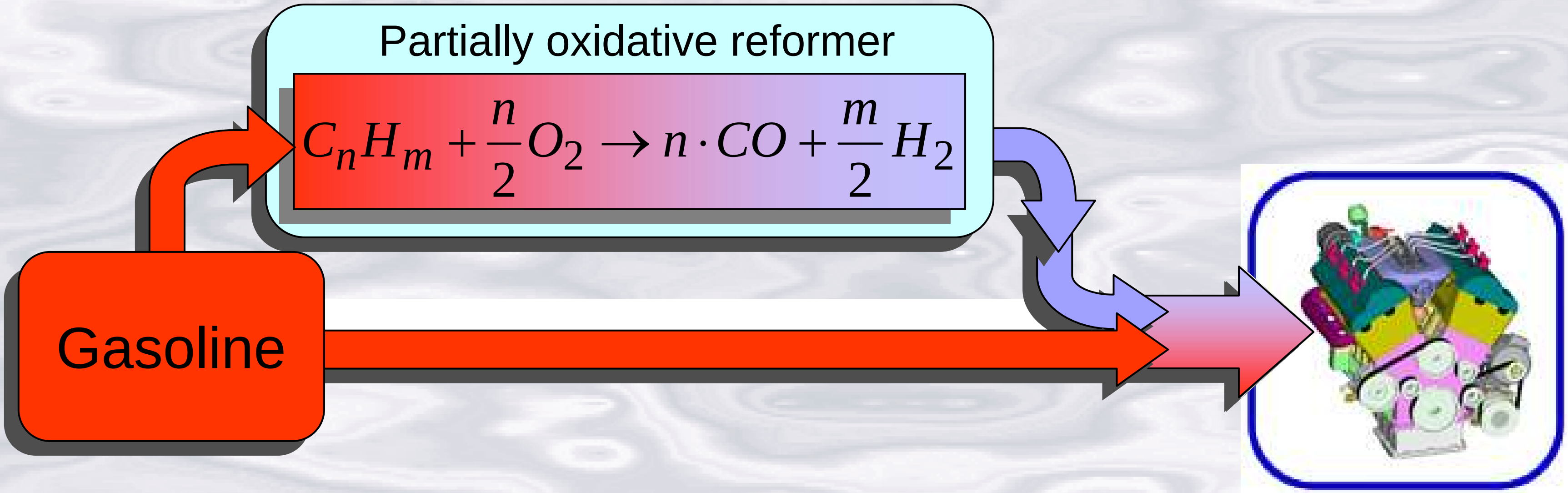
Improved engine efficiency

Limitations

λ or EGR rate can be increased only to a limited extent, as they cause the combustion process to deteriorate

UHC emissions

Use of hydrogen (now) in IC engines: how?



- 21% H_2
- 24% CO
- 55% N_2

- Water-shift reaction (to increase H_2 content and complete oxidation of CO to CO_2) does not give additional advantage in IC engine applications

Properties of RefGas

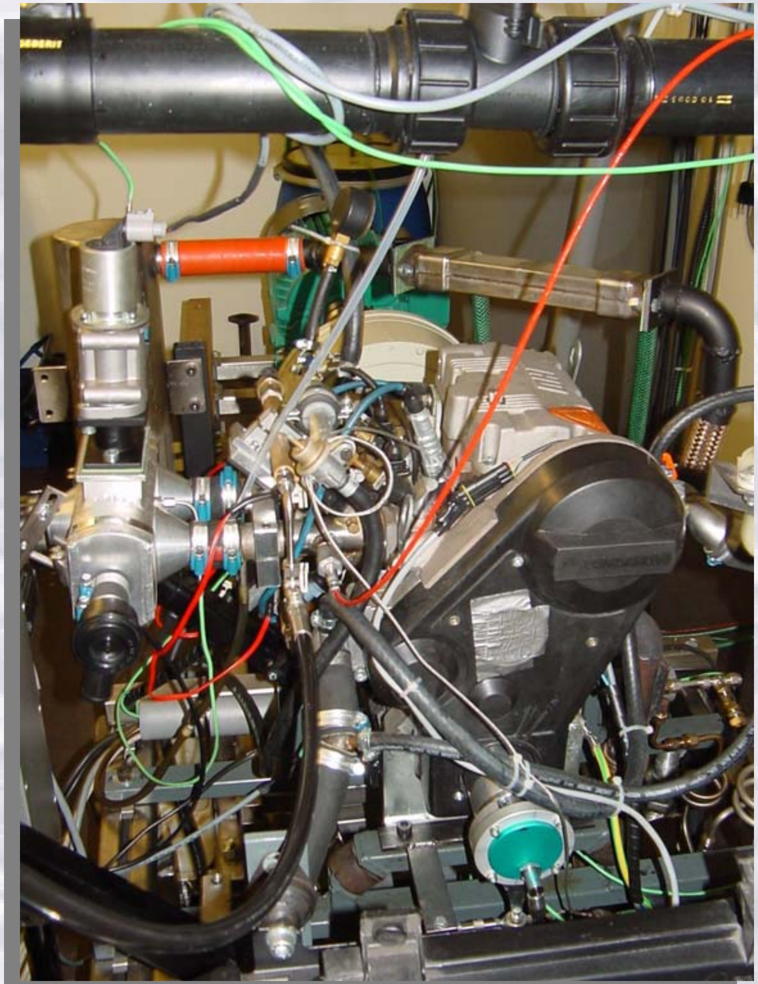
➔ Ideal partial oxidation of Isooctane:

$$C_8H_{18} + 4O_2 + 4\cdot\frac{79}{21}N_2 \Rightarrow 9H_2 + 8CO + 4\cdot\frac{79}{21}N_2 \qquad \lambda=0.32$$

	C_8H_{18}	O_2	N_2	TOT. Reactants	H_2	CO	N_2	TOT. Products
Vol.	1	4	15.05	20.05	9	8	15.05	32.05
Vol%	0.04988	0.19950	0.75062	1	0.28081	0.24961	0.46958	1
Mass(g)	114	128	421.33	663.33	18	224	421.33	663.33
Mass(%)	0.17186	0.19297	0.63517	1	0.02714	0.33769	0.63517	1
LHV(MJ/kg)	44.5	-	-	44.5	119.972	10.107	-	130.079
Energy(MJ)	7.64777	-	-	7.64777	3.25604	3.41303	-	6.66907

-13%

Experimental set up



Fuel
- Bottled blend of H_2, CO, N_2 to simulate a likely Reformer output

Engine
- Lombardini 4-stroke, 2 cylinder, 2 valve, 0.5 litre
- Port-injection of gasoline and RefGas, electronically controlled
- Water-cooled EGR line with water trap

Bench
- Pressures, Temperatures, Gas analysis

Analysis
- 2-zone Heat release
- 1D / 3D Engine simulation

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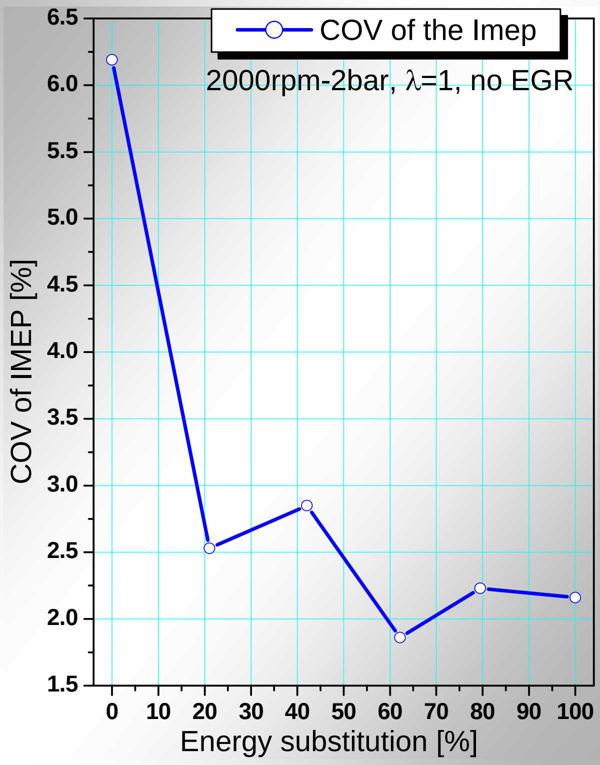
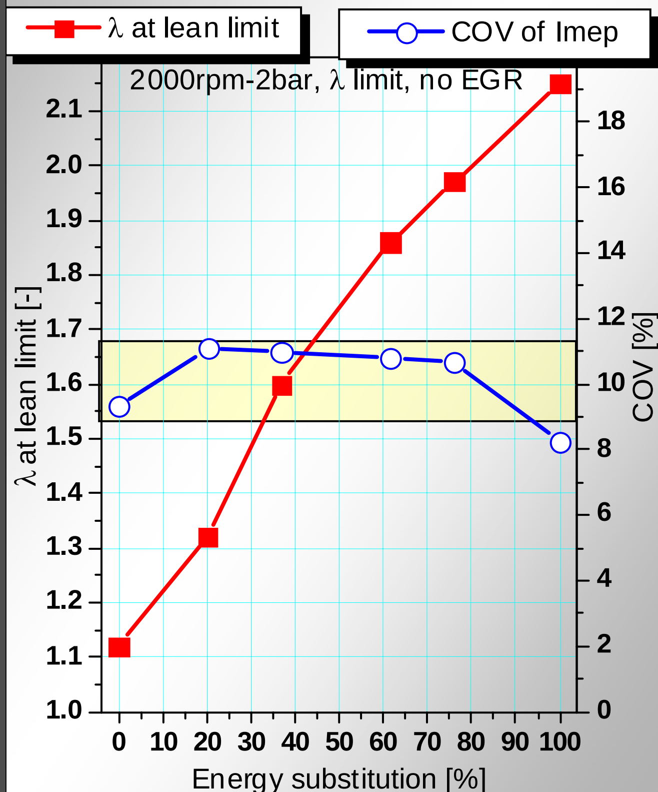
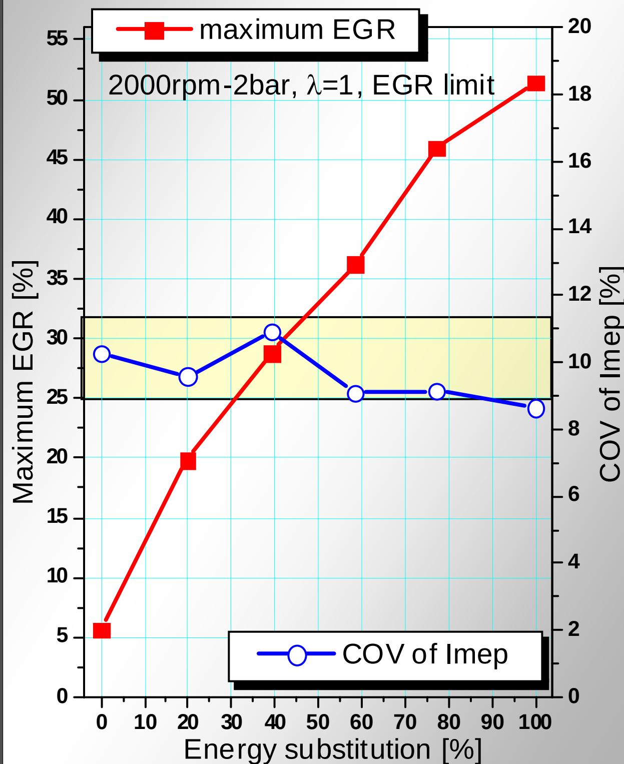
Engine behaviour

▪ $\lambda=1$ – no EGR	λ limit – no EGR	$\lambda=1$ – EGR limit
▪ Enhanced stability	▪ lean up to $\lambda=2.15$	▪ EGR up to 52 %



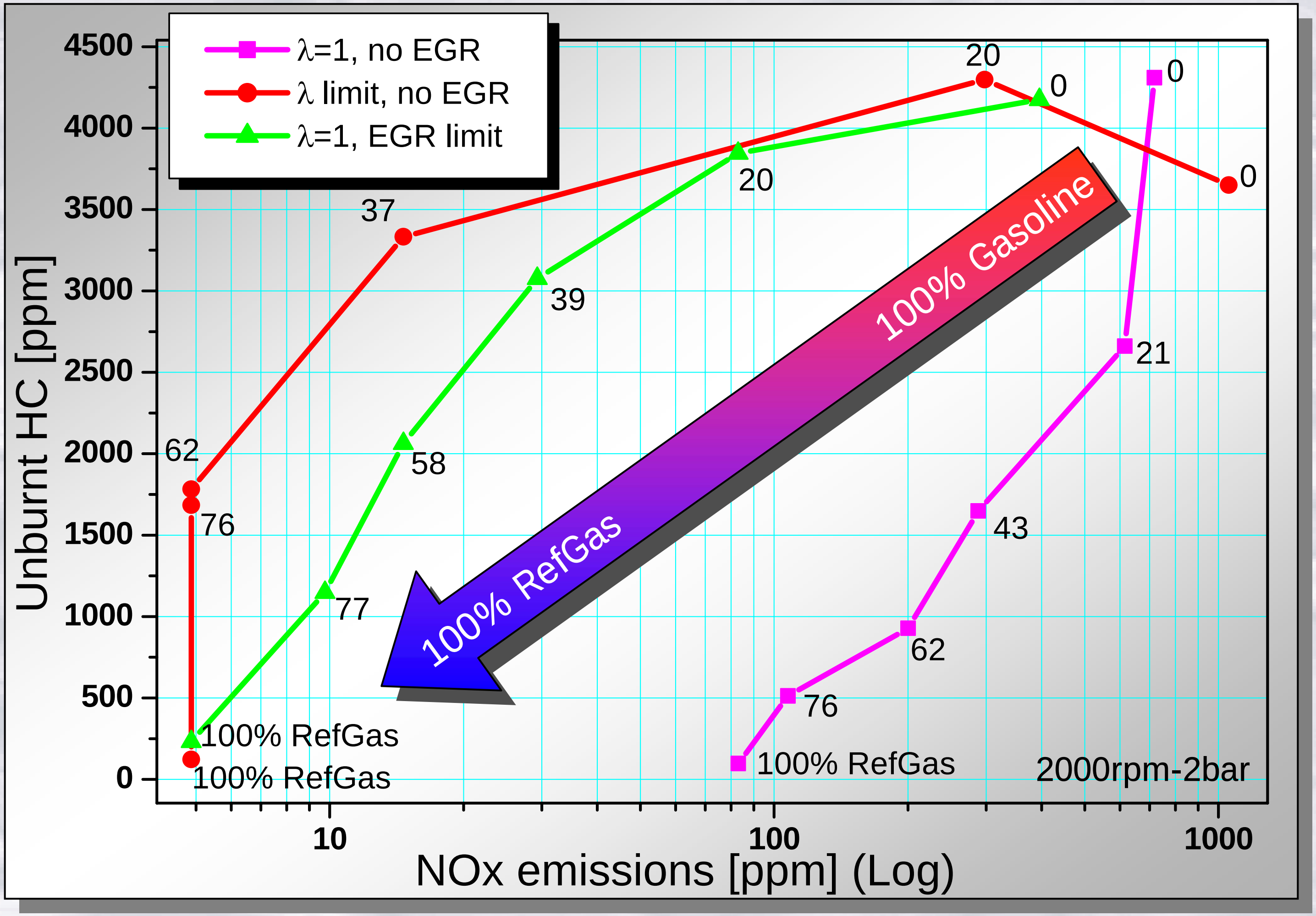




Emissions

Engine-out emissions:

- UHCs drop down to few tens of ppm (burning of lubricating oil, release of deposits)
- NOx's drop down below instrument sensitivity (5 ppm)
- Presumably only prompt-NOx survives



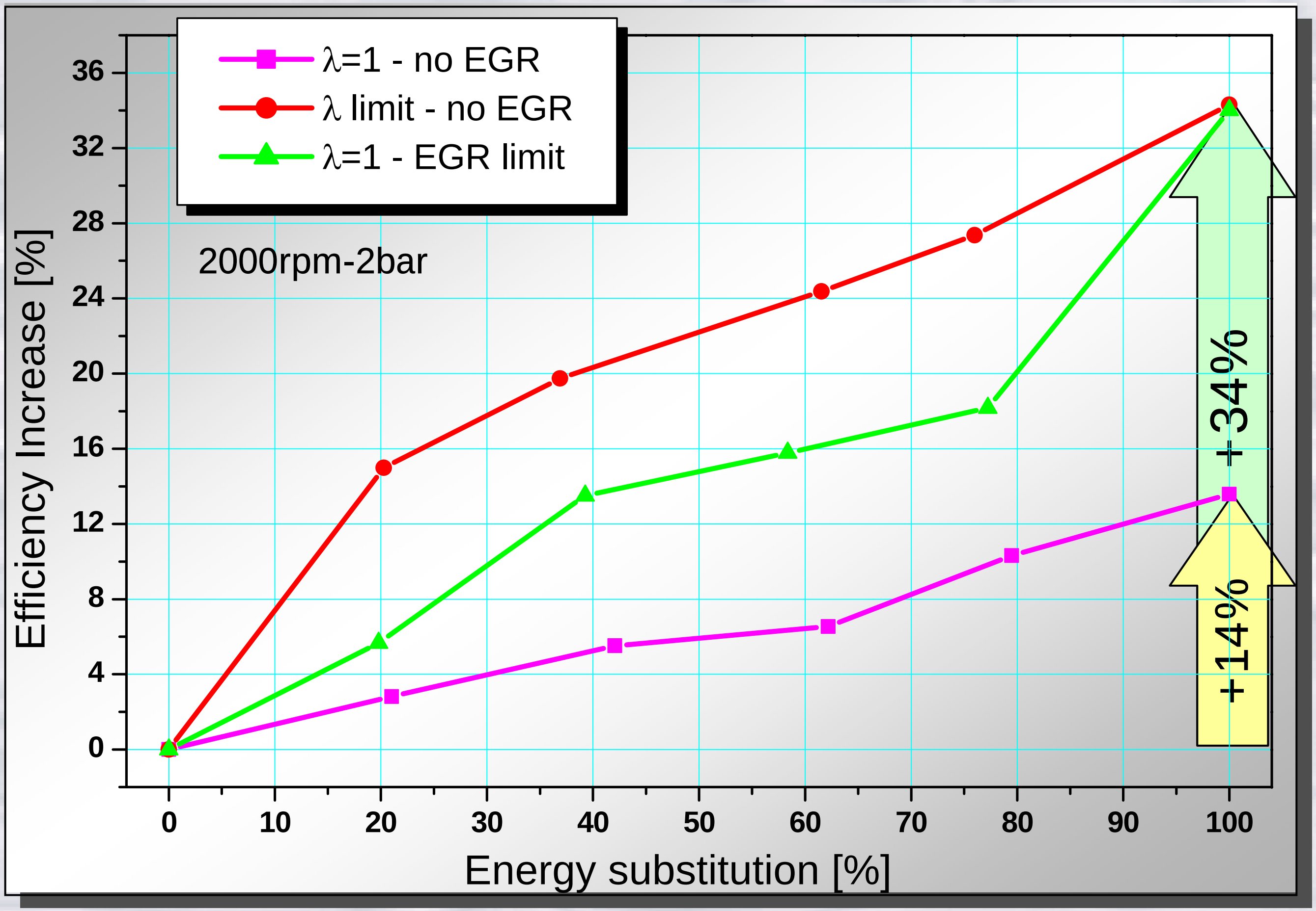
Engine Efficiency

λ=1 – no EGR

- dethrottling, faster combustion, combustion completeness, improve efficiency of +14%

λ limit
EGR limit

- Massive dethrottling, lower heat losses, combustion completeness, improve efficiency of +34%

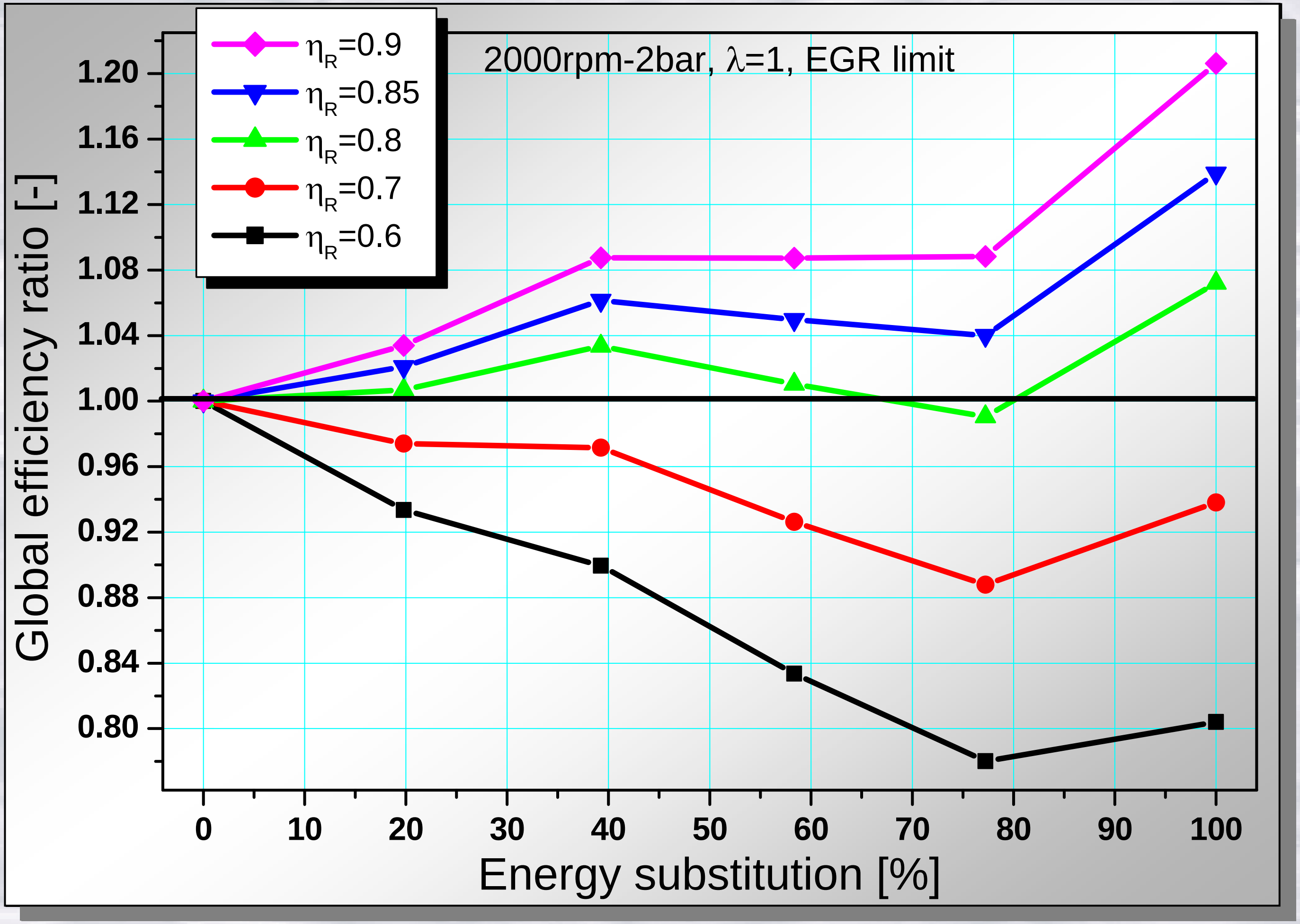


Engine+Reformer Efficiency

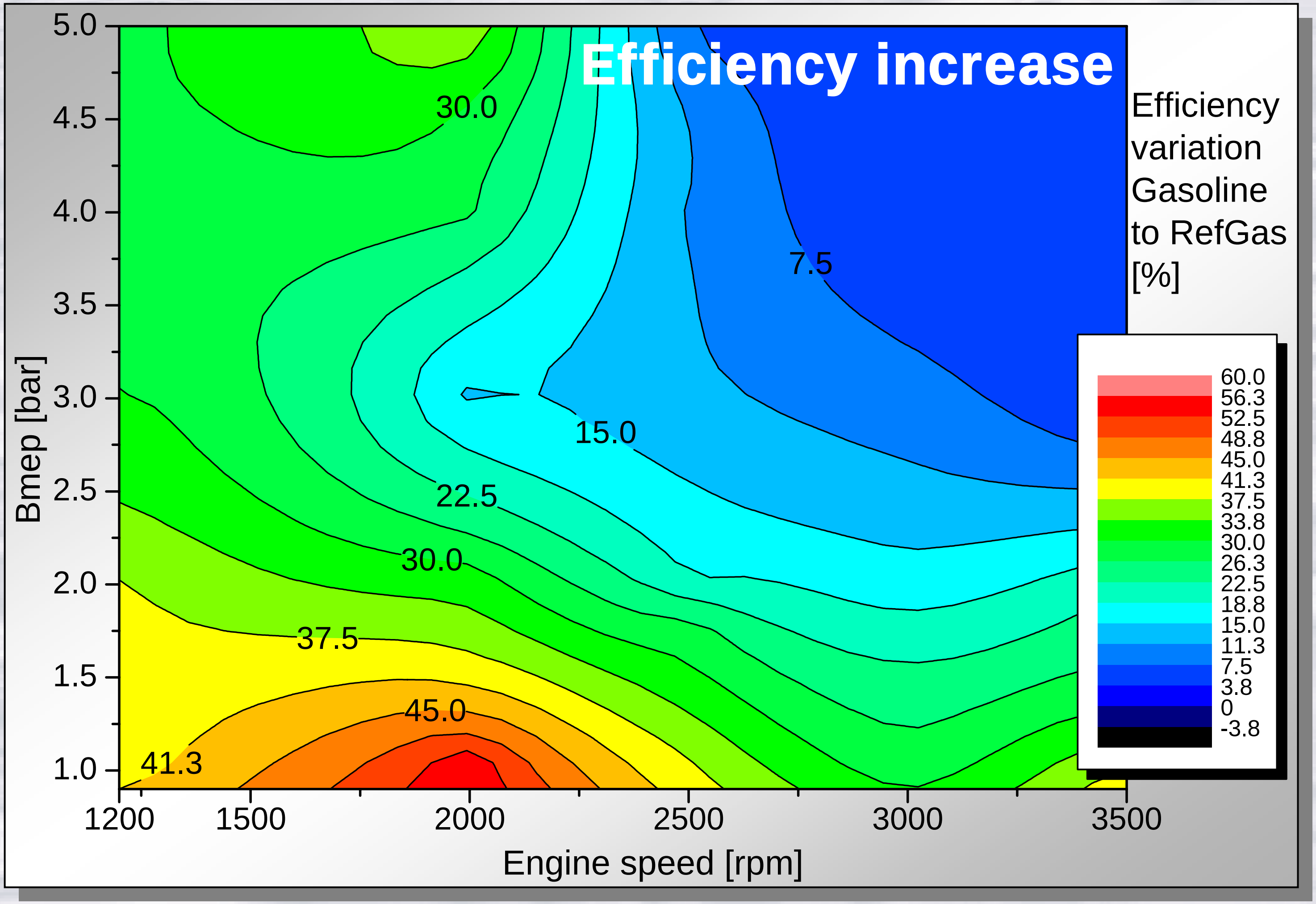
$$\frac{\eta_{tot}}{\eta_{E,x=0}} = \frac{\dfrac{\eta_E(x)}{1 - x + \dfrac{x}{\eta_R}}}{\eta_{E,x=0}}$$

>1 efficiency gain
<1 efficiency loss

- If the RefGas is provided by a well designed reactor (η_R>=0.8), the efficiency gain overcomes the losses in the reactor itself



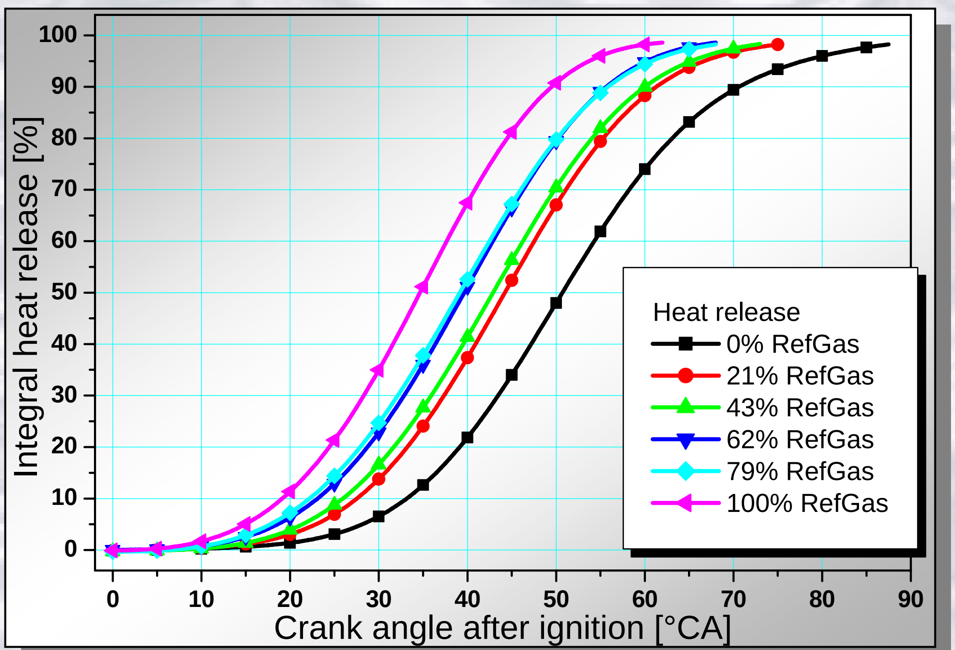
Engine efficiency at EGR limit - comparison

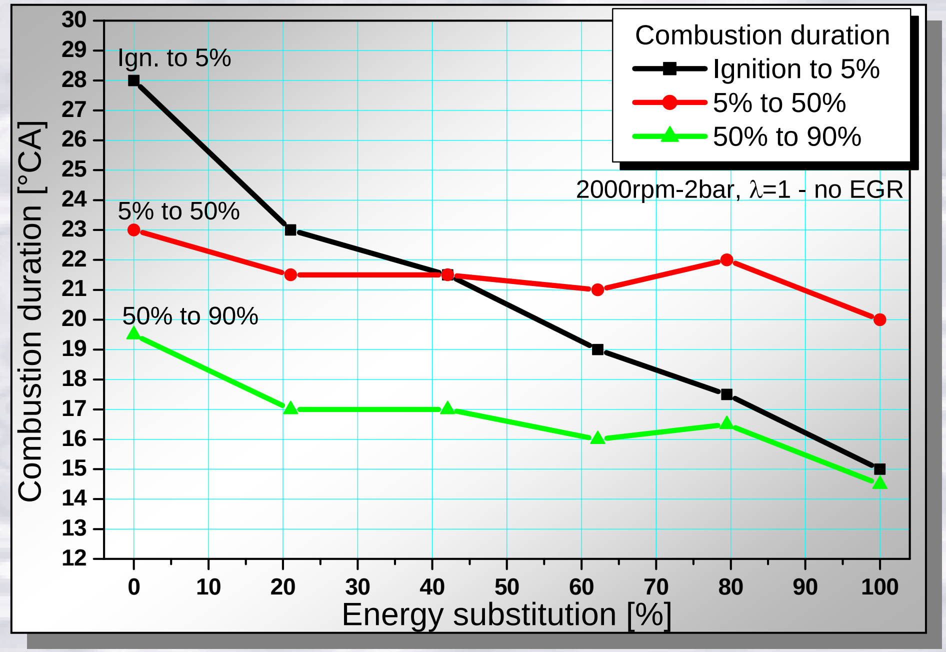


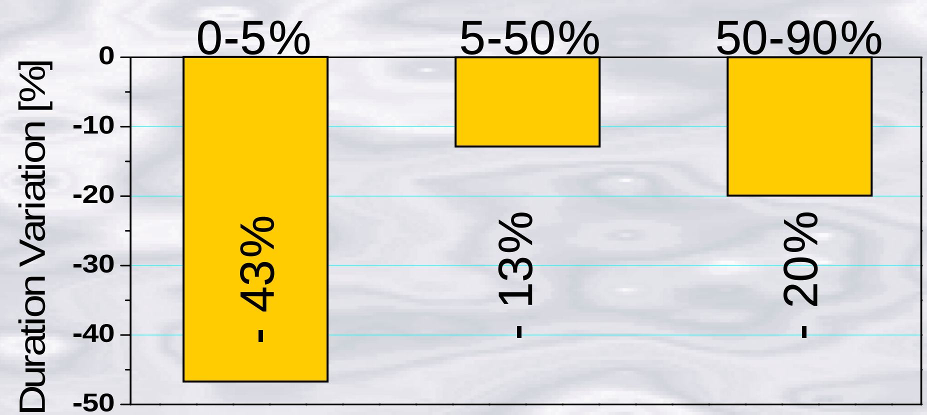
Combustion process

▪ λ=1 – no EGR

- The combustion process becomes progressively faster for increasing quantities of RefGas
- The RefGas has a stronger effect on the early phase of combustion



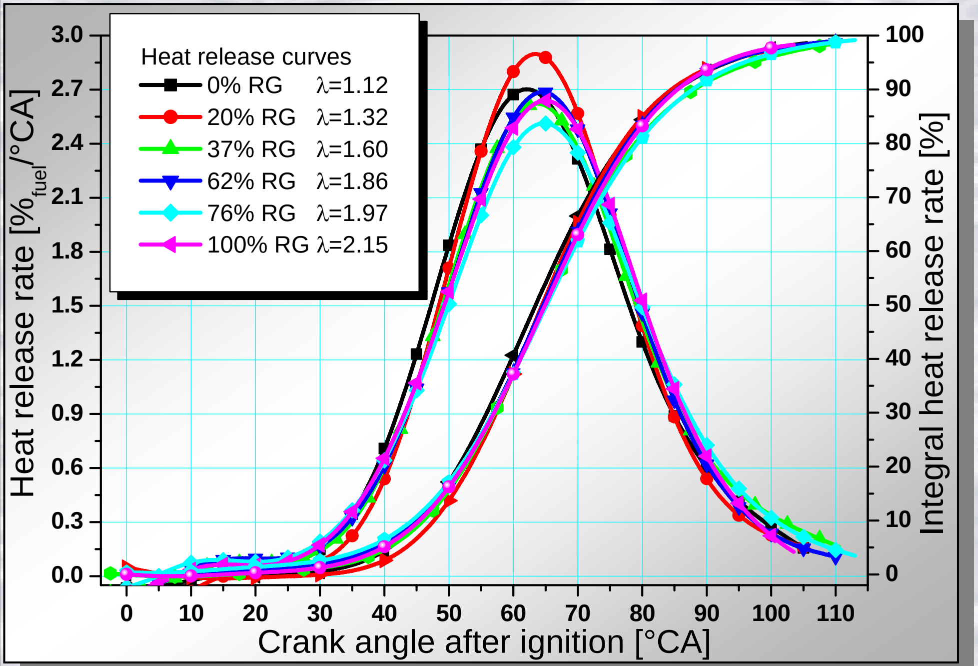


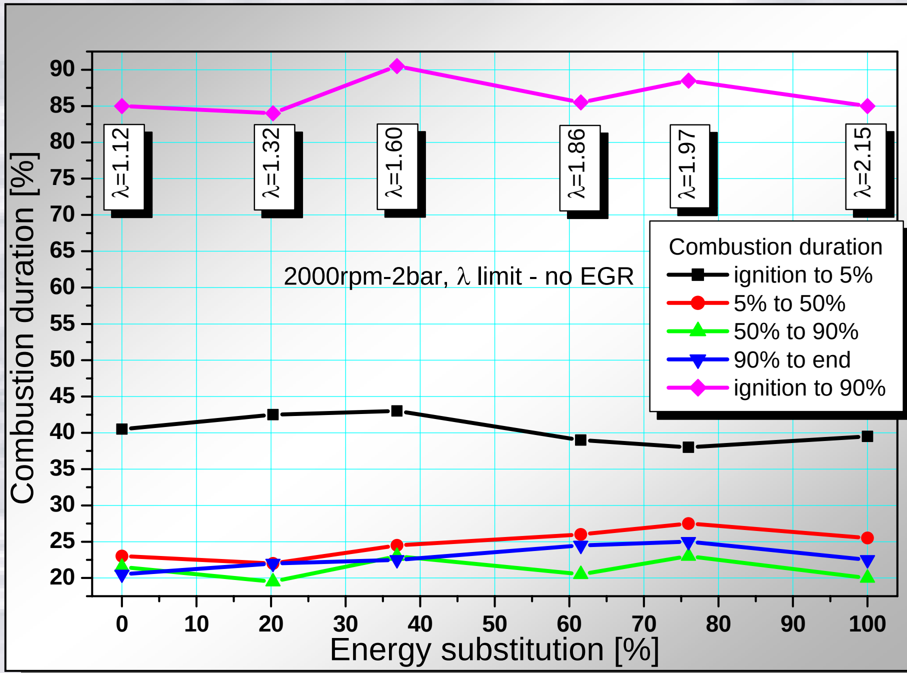


Combustion process

λ limit – no EGR

- When λ is increased to keep COV~10%, the combustion process takes place in the same way for increasing quantities of RefGas

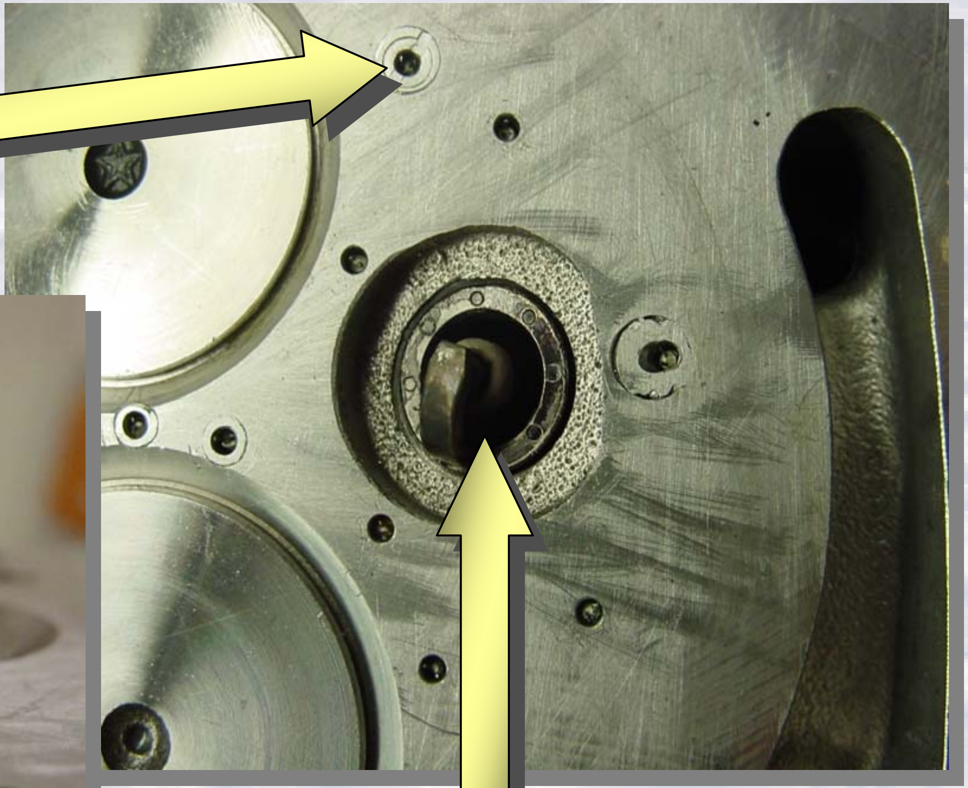




- The duration of the combustion phases remains practically constant
- A diluted (therefore less reactive) mixture is formed with an extremely reactive fuel: compensation of effects

Ion sensors and optical spark plug

- 16 ion sensors on the cylinder head surface, to investigate the flame propagation into the chamber



- 8 optical fibres around the spark plug, to investigate the onset of the combustion process

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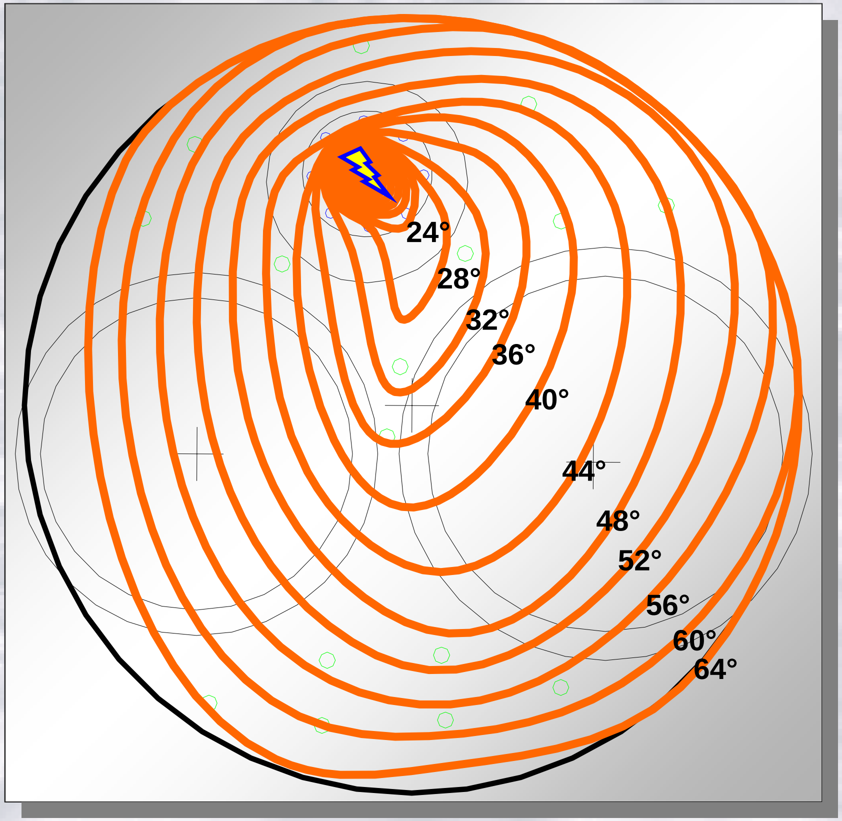
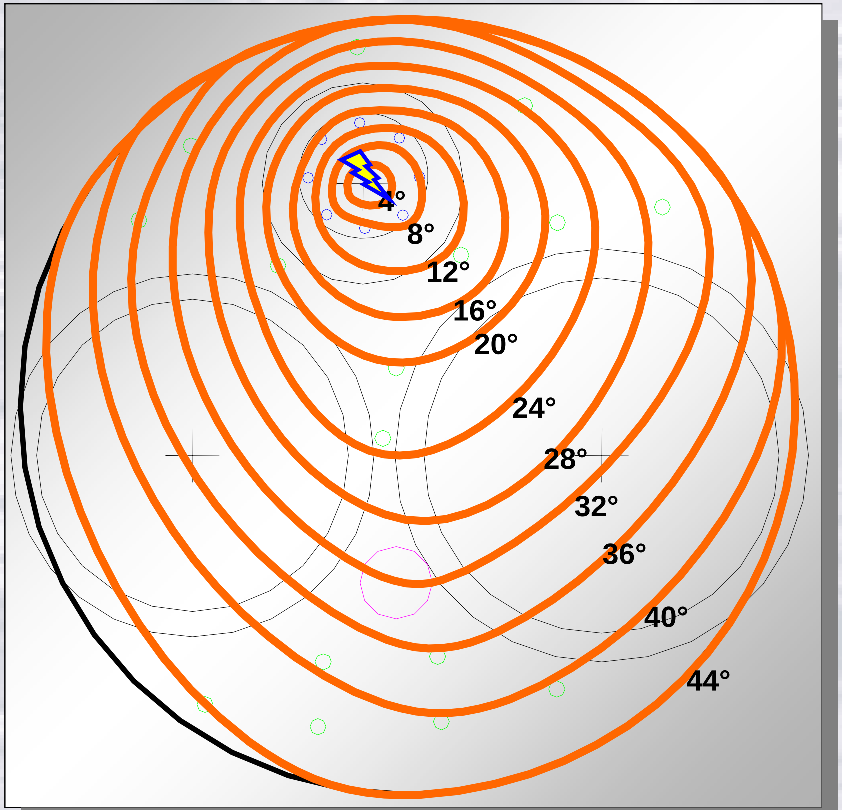
Flame front propagation

λ=1 – no EGR

100 % Gasoline
spark=-35°CA bTDC



100 % RefGas
spark=-27°CA bTDC



Partners

Financing

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