



Energy and Propulsion Laboratory

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Fisciano (SA) – www.eprolab.unisa.it

eProLab overview

Gianfranco Rizzo, Full Professor
Cesare Pianese, Full Professor
Ivan Arsie, Associate Professor
Marco Sorrentino, Assistant Professor
Andrea Cricchio, Research Fellow
Rocco Di Leo, Research Fellow
Dario Marra, Research Fellow
Massimo Naddeo, Research Fellow
Pierpaolo Polverino, Research Fellow

Gina Scorziello, Secretary & Administr.
Gianpaolo Noschese, Technician

Fabrizio Donatantonio, Ph.D. Student
Antonio D'Amato, Ph. D student
Mauro Grandone, Post Grad. Fellow
Bruno Rossomando, Post Grad. Fellow
Luigi Russo, Post Grad. Fellow

Main current partners...



■ 50% - EU
■ 35% - Private
■ 15% - Public

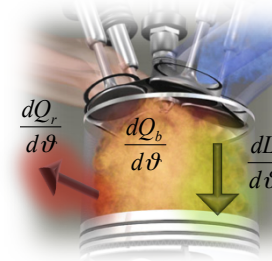


Research fields

- Engines, hybrid powertrains
- Non-conventional energy technologies (Fuel Cells)
- Simulation models for control, diagnosis, design and optimization



Adapted from <http://ralph-dte.eu>



ICE Modeling & Control

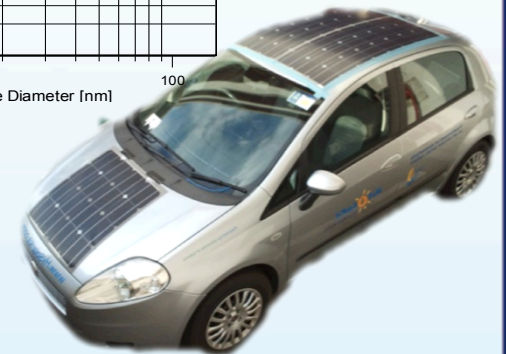
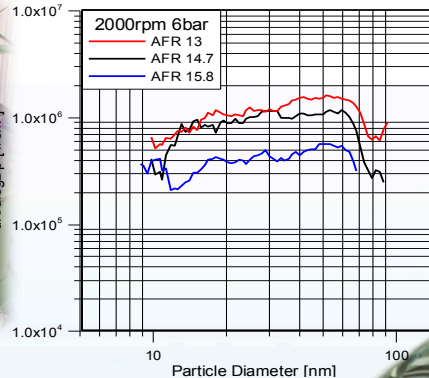
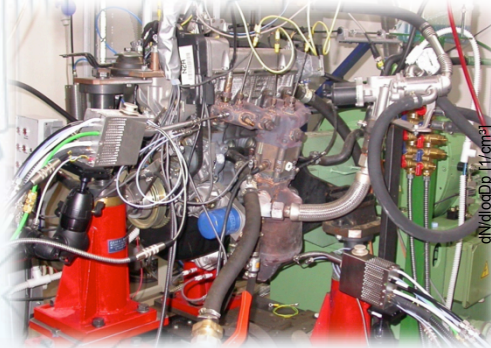
- CI/SI combustion/emissions modeling
- Dynamic modeling of vehicle/powertrains
- Emissions' virtual sensors
- Pressure based control/diagnosis

Eco-Innovation Technologies

- Hybrid and hybrid solar vehicles
- WHR technologies (TEG, E-turbo, ORC)
- Vehicle ibridization

Facilities

- Fully equipped engine test bench
- Indicating equipment
- Emissions analyzers (HC, CO_x, NO_x)
- Combustion fast NO_x analyzer
- Smoke meter
- SMPS system for nano-particulate
- dSpace MicroAutobox & Etas INCA
- Two solar hybrid vehicle prototypes
- Two Fuel-Cells test benches

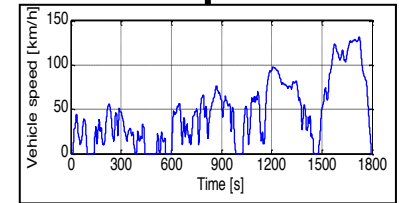
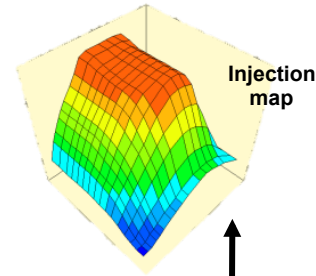


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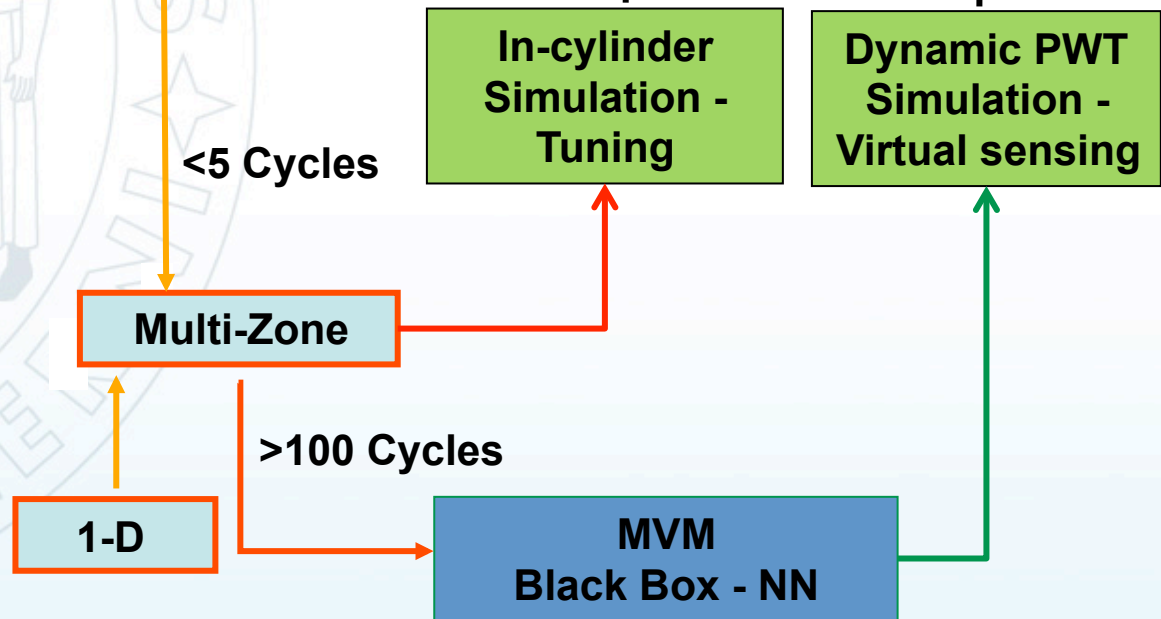
Control Oriented Modeling

Methodological Approach



- Suited methodologies to meet the trade-off between computational burden, experimental efforts and model accuracy.

- Different modeling approaches depending on the final purpose.



Presented Topics



- Model based Combustion Control
- Pressure based Modeling / Control
- Virtual Sensing of O_2 and NO_x
- Eco-Innovation Technologies

Funded by

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Model based Combustion Control

Model based Combustion Control

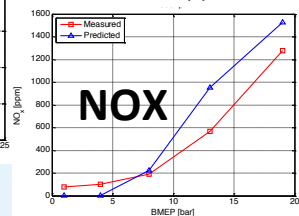
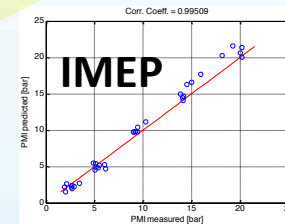
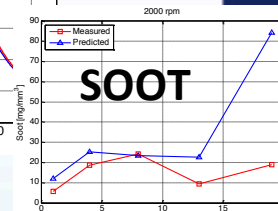
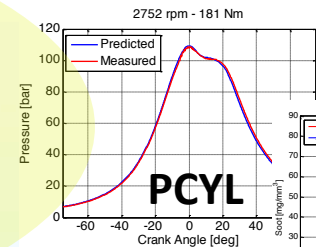
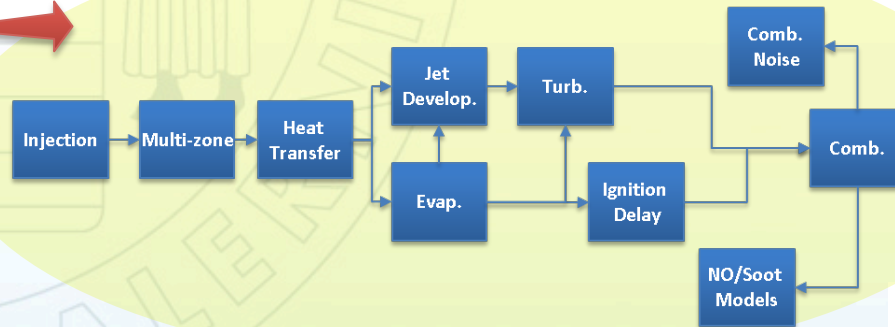


1. Meet stringent emissions standards, retain fuel economy benefits of Diesel engines, efficient operation of after-treatment devices (DPF, LNT/SCR);
2. Find optimal combination(s) of control variables for given Driver request (Speed and Torque);
3. Reduce the experimental effort for control strategies development to limit time and costs.

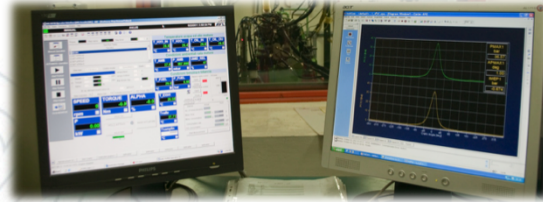
Control Variables

- Injection pattern
 - Rail pressure
 - # of injections
 - SOI
 - Pulse widths
- EGR (H/L pressure)
- Turbocharger(s)

CONTROL DESIGN VIA MULTI-ZONE MODEL

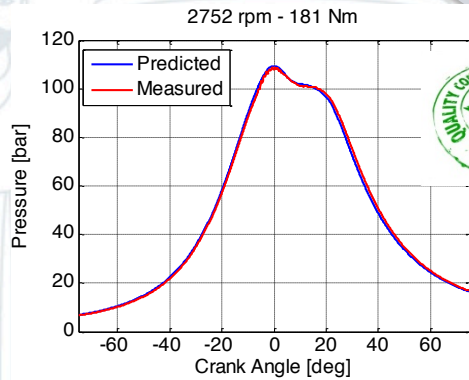


Results / Applications



Experimental Measurements

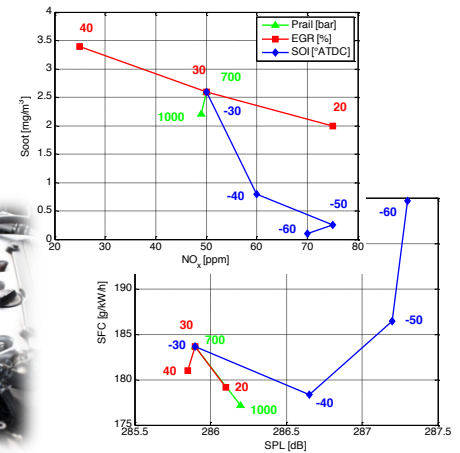
Model Identification



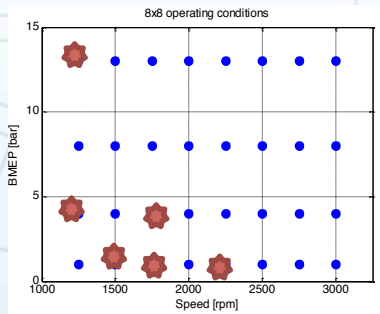
Model validation



Sensitivity Analysis



Optimal tuning of control variables 'u'



$$\min_{\underline{u}} (SFC, NO_x, soot, SPL, T_{exh})$$

$$\underline{u} = [SOI, Q_{inj}, DT, P_{rail}, VGT, EGR]$$



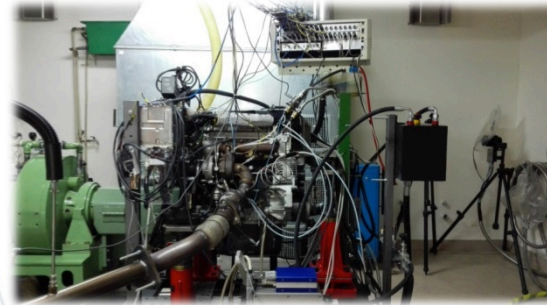
Experimental testing



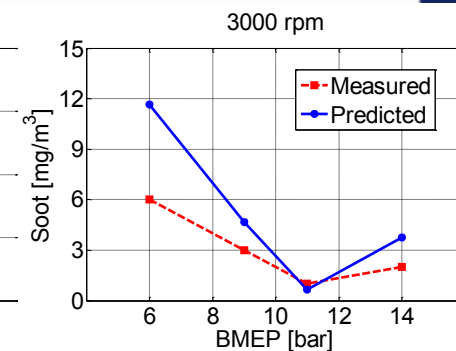
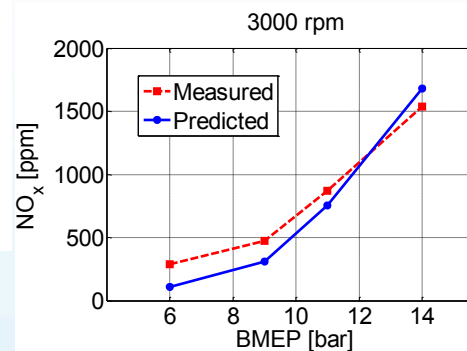
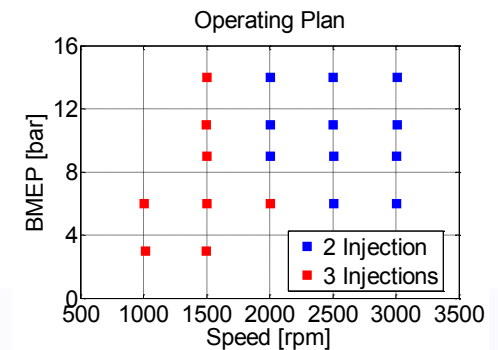
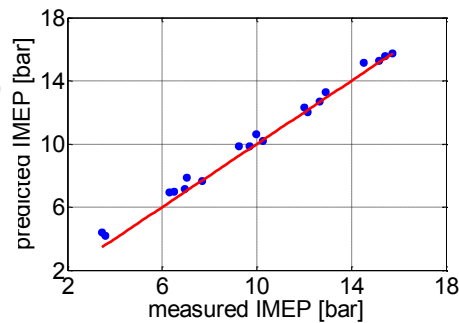
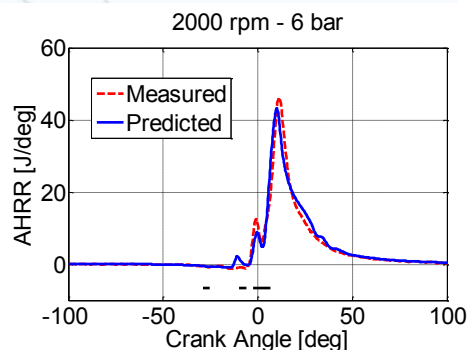
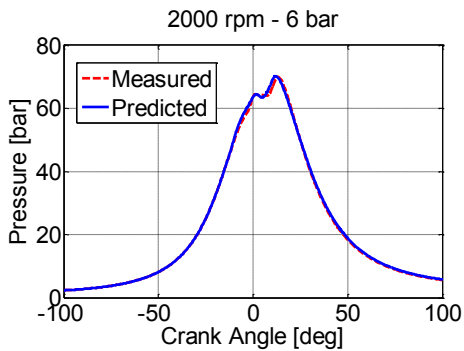
Experimental Validation



Diesel Common-Rail EGR/HP - VGT	
Max Power [kW]	107 @ 3600 rpm
Max Torque [Nm]	350 @ 1500 rpm
Nr. Cylinders	4
Displacement [cm ³]	2287
Volumetric compression ratio	16.2



Performance and Emissions Validation

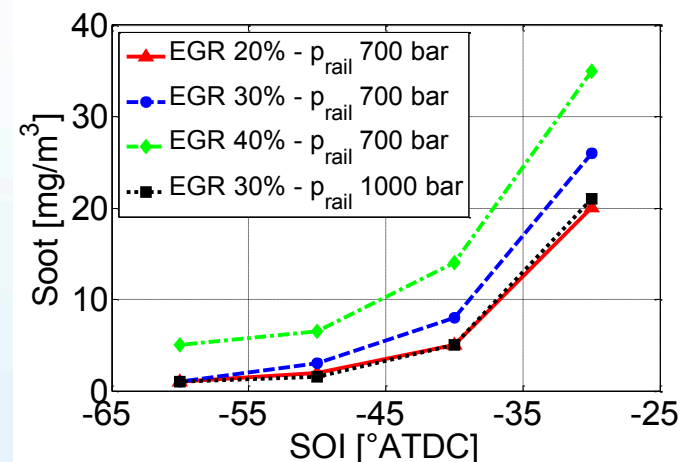
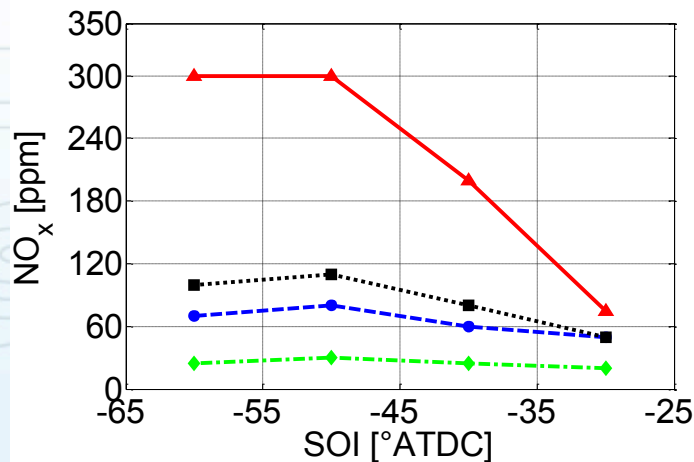
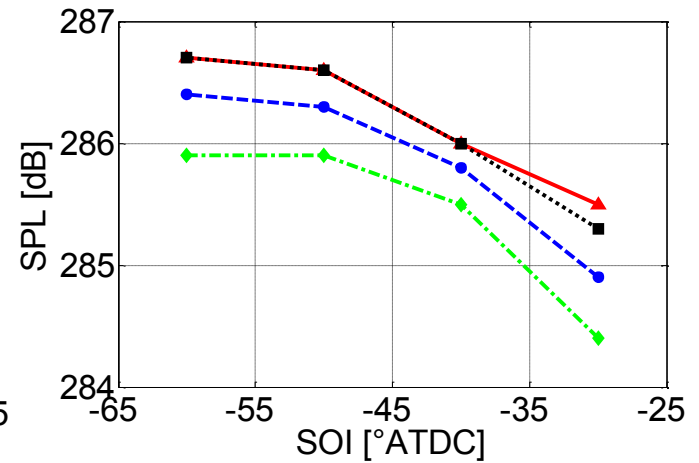
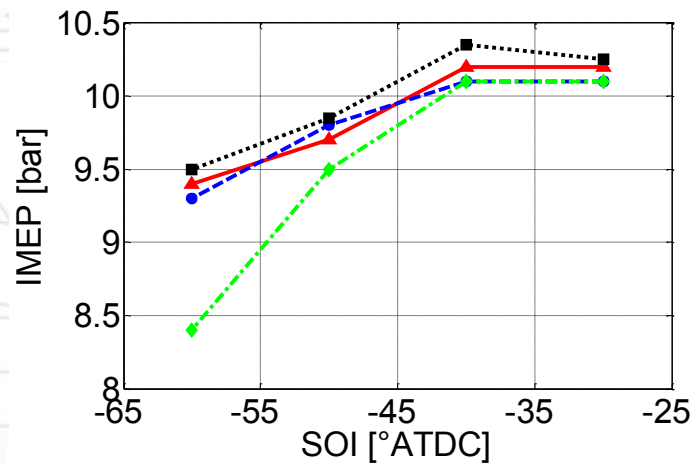


Sensitivity Analysis



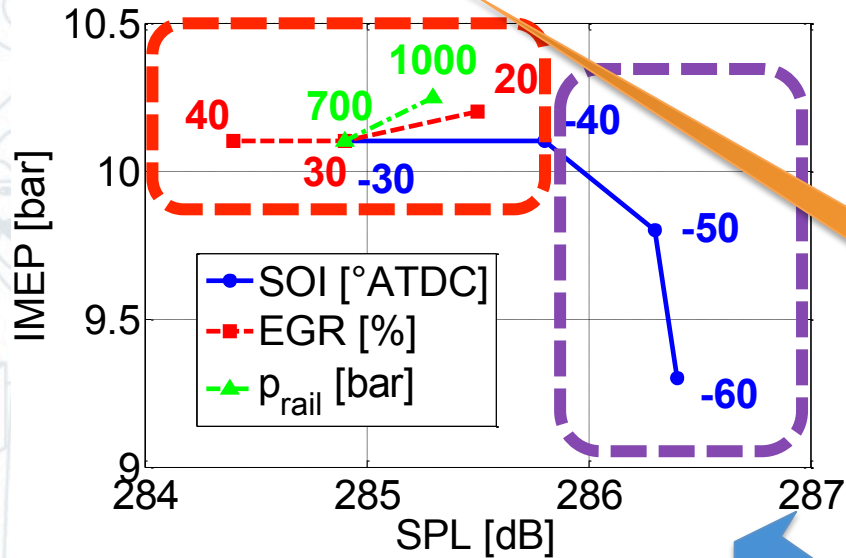
The optimization algorithm could explore engine operating conditions far from the conventional ones. It is worth checking the effective behaviour of the model.

Speed [rpm]	2000
BMEP [bar]	8
p_{rail} [bar]	700
V_{inj} [mm ³ /str]	35
SOI [°BTDC]	30
EGR [%]	30



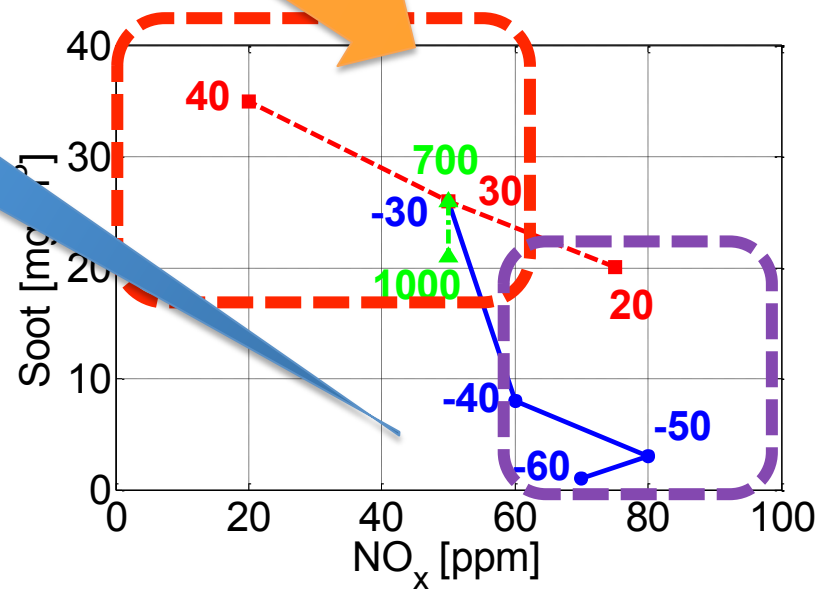
p_{rail} [bar]	700/1000
SOI [°BTDC]	30/40/50/60
EGR [%]	20/30/40

Combustion Tuning



EXHAUST GAS POST-TREATMENT

- FAP
- DPF
- SCR
- LNT



NOISE PASSIVE CONTROL

- Deadening materials (glass fibre, rock wool etc.)
- Mufflers
- Innovative materials

Optimal Combustion Tuning



Objective function:
Specific Fuel Consumption

✗ Optimization point

$$\min_{Q_{ref}, SOI, p_{rail}, EGR} ISFC$$

$$\Delta IMEP \leq 1\%$$

$$\Delta Soot \leq 5\%$$

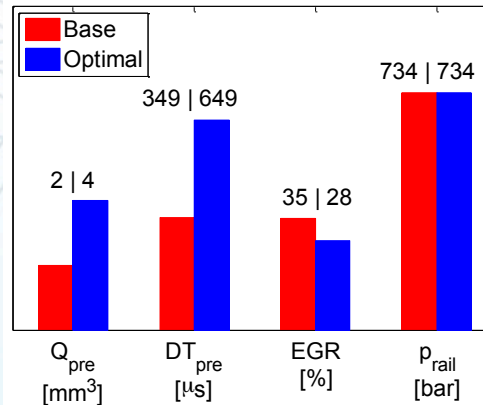
$$\Delta NO_x \leq 70\%$$

$$\Delta SPL \leq 0.21 dB$$

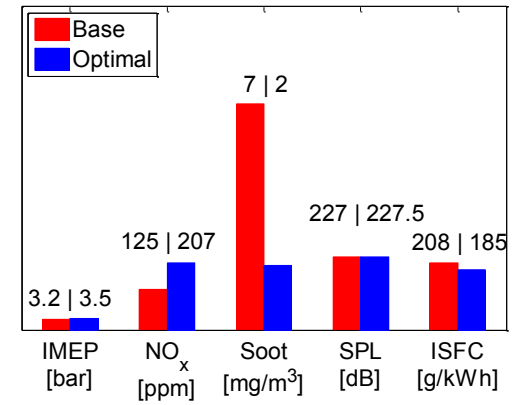
SCR system integration

5% Power

Engine Variables (Num. Data)



Emissions & Performance (Exp. Data)



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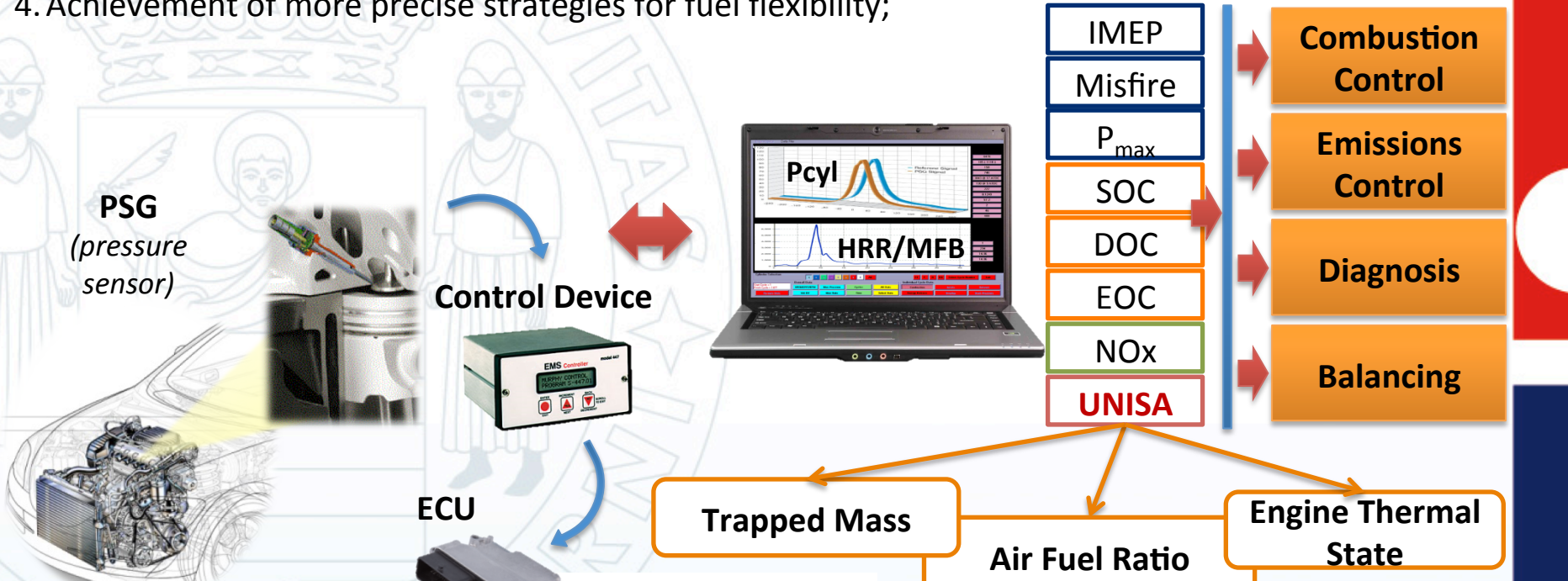


Pressure based Control

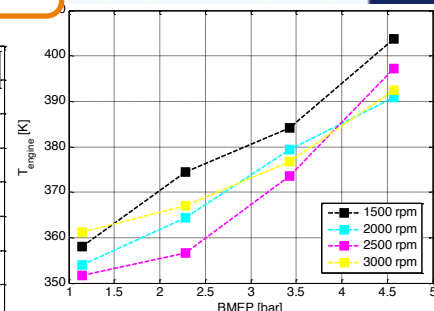
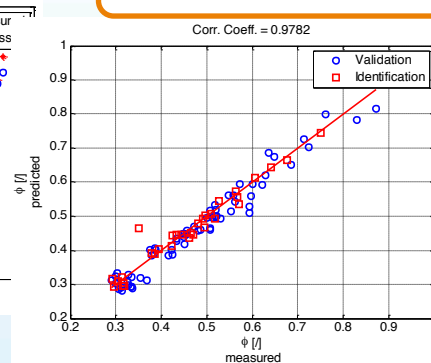
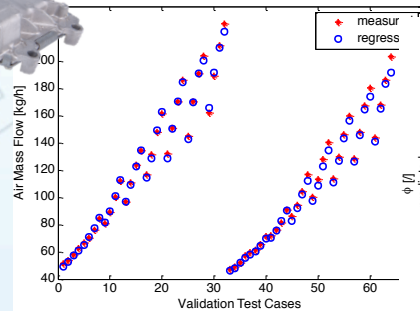
Pressure based Control



1. Improvement of feedback control by reducing time delays;
2. Implementation of tighter cylinder-by-cylinder control;
3. Development of more reliable observers for emissions;
4. Achievement of more precise strategies for fuel flexibility;



Existing sensors can be replaced by **virtual sensors based on in-cylinder pressure trace**, which may be the primary feedback variable for engine control and diagnosis.

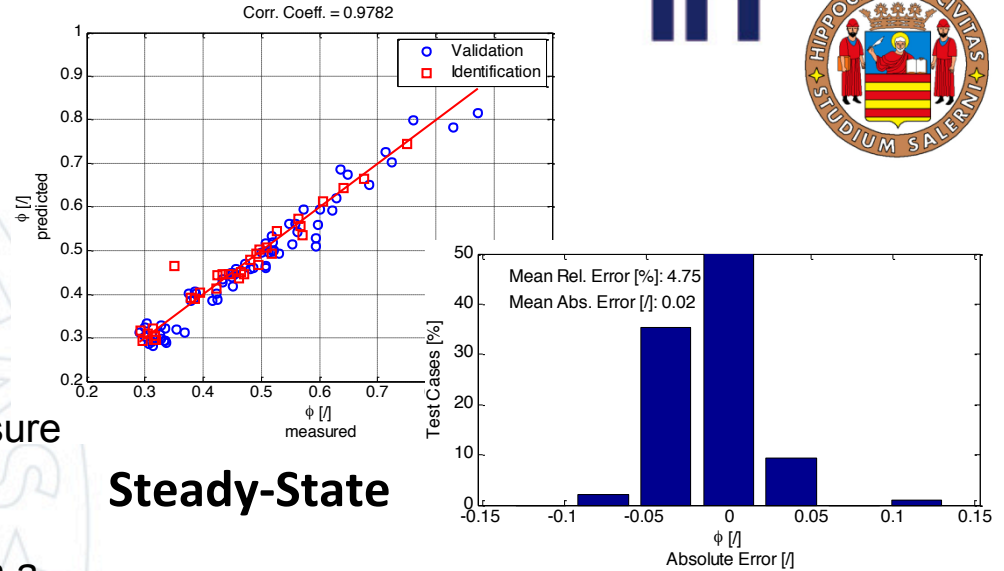


Air-Fuel Ratio Estimation

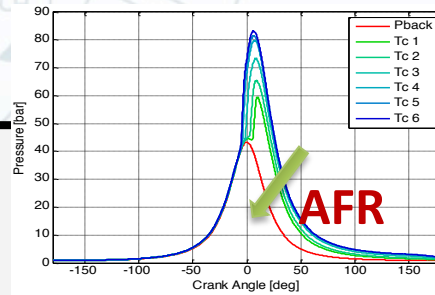


- AFR is fundamental to operate suitable control of fuel injection and air path.
- AFR is measured by a UEGO sensor located in the exhaust manifold.
- Some **limitations** arise, especially during transients, due to UEGO sensor management and time delay.

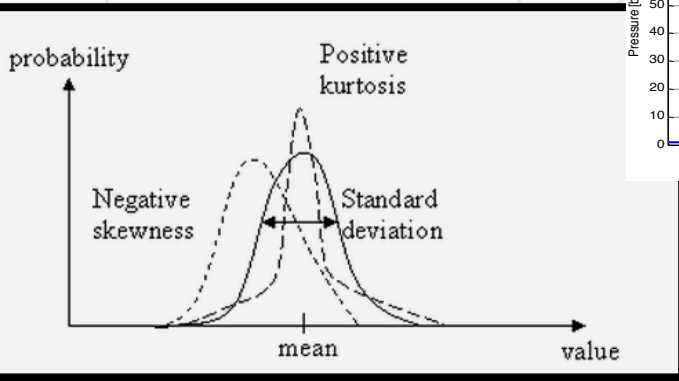
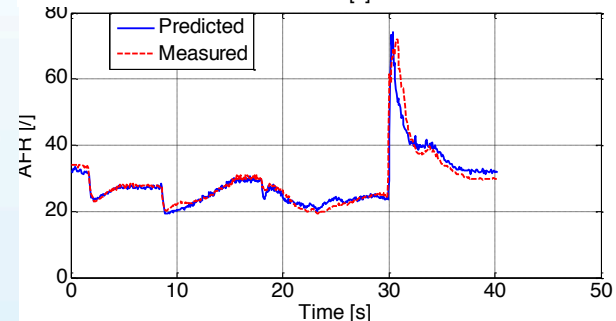
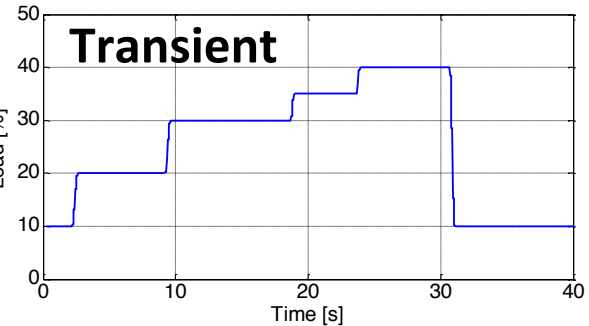
Statistical Approach, The in-cylinder pressure cycle is considered as a general **distribution signal**: a variation of AFR results in different value and position of the pressure peak with a change of its distribution with respect to its centroid.



Steady-State



$$\varphi = f(M_2, M_3, M_4)$$



In-Cylinder trapped Mass



Motivations for PBC:

- The in-cylinder trapped mass allows estimating the EGR effective mass by using the air-flow meter with improvements for:
 - Combustion control
 - After-treatment management

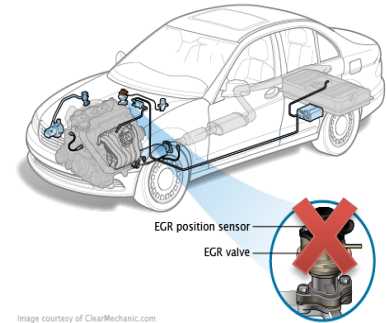
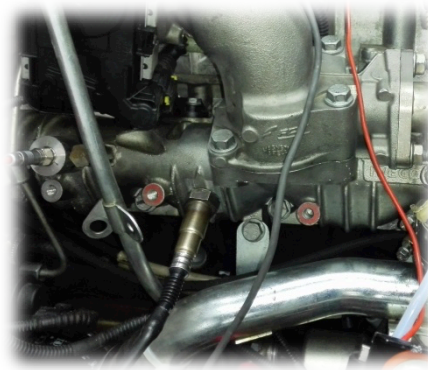


Image courtesy of ClearMechanic.com

$$m_{EGR} = m_{IVC} - m_{air}$$

The Δp method

Ideal gas law

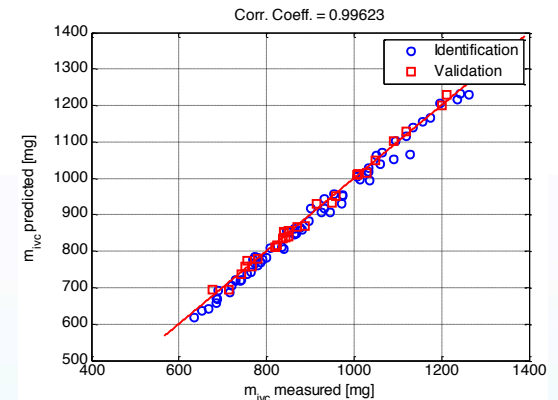
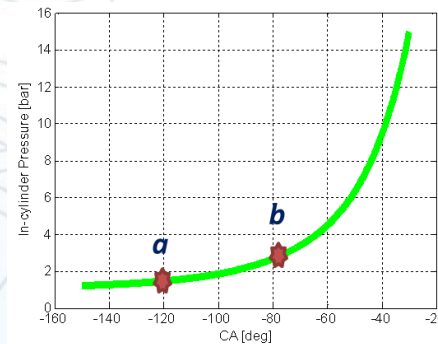
$$p_a V_a = m_{IVC} R T_a$$

$$p_b V_b = m_{IVC} R T_b$$

Polytropic compression

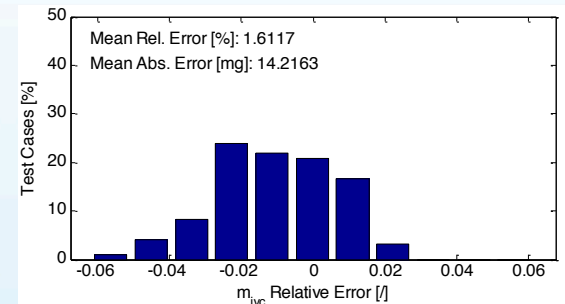
$$p_a V_a^m = p_b V_b^m$$

$$T_a V_a^{m-1} = T_b V_b^{m-1}$$



$$m_{IVC} = \frac{\Delta p \cdot V_a}{R \cdot T_a} \left\{ \left(\frac{V_a}{V_b} \right)^m - 1 \right\}^{-1}$$

$$T_a = f(\text{speed}, Q_{fuel})$$



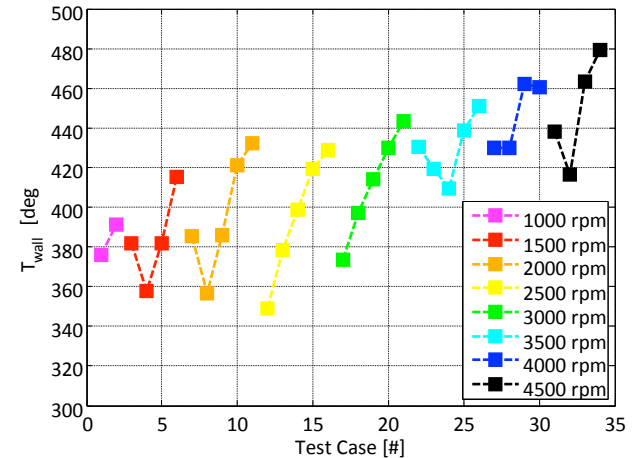
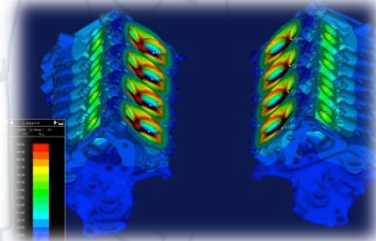
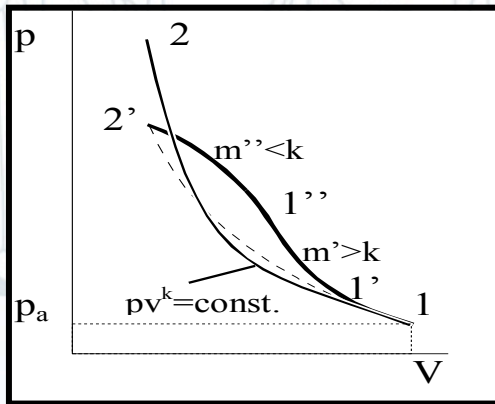
Engine Thermal State



The in-cylinder wall temperature (T_{wall}) affects the engine heat flow, efficiency and emissions.

Motivations for PBC:

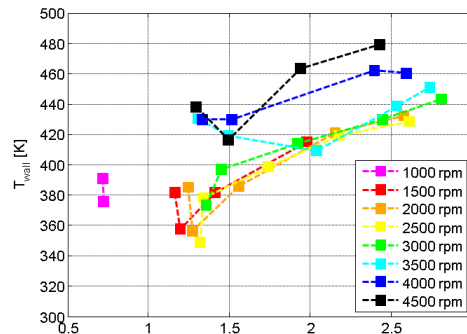
- High inertia of cooling system
- Complexity of direct measurement
- Problems with spatial temperature distribution



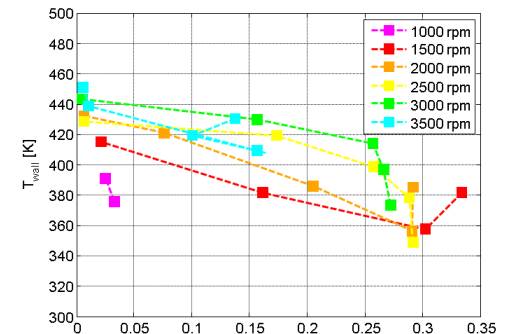
Adiabatic conditions

$$m(\vartheta) = k = c_p / c_v$$

In-cylinder gas temperature value is assumed equal to T_{wall} .



PMAN [bar]



EGR [/]

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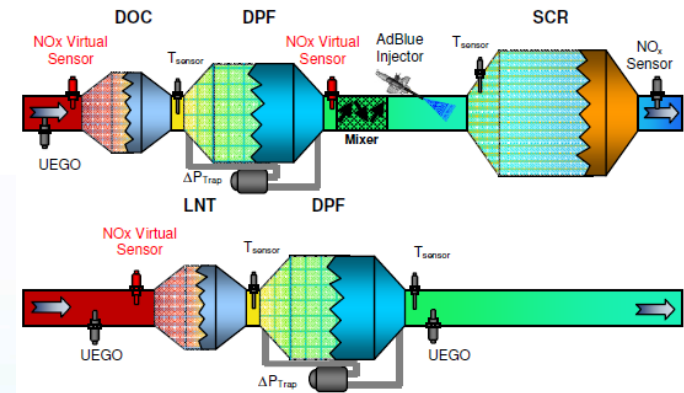
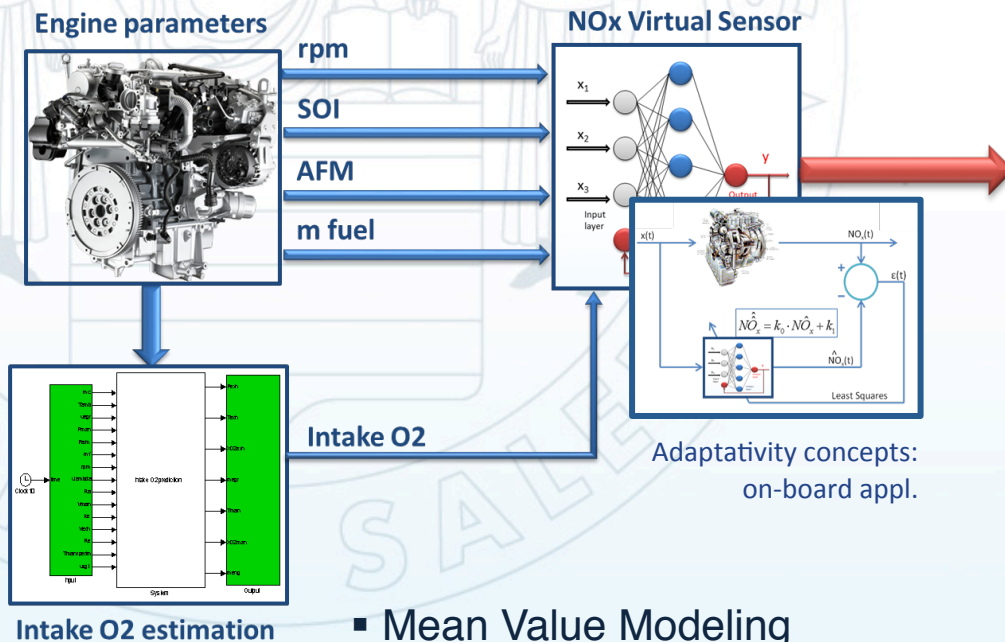
Virtual Sensing



Intake O₂ and NOx Virtual Sensor



- Estimation of effective EGR ratio
- Enhancement of conventional and advanced combustion control (PCCI, HCCI, LTC)
- Improvement of NOx prediction during engine transients, suitable for both dynamic adjustments of EMS strategies and management of after-treatment devices.

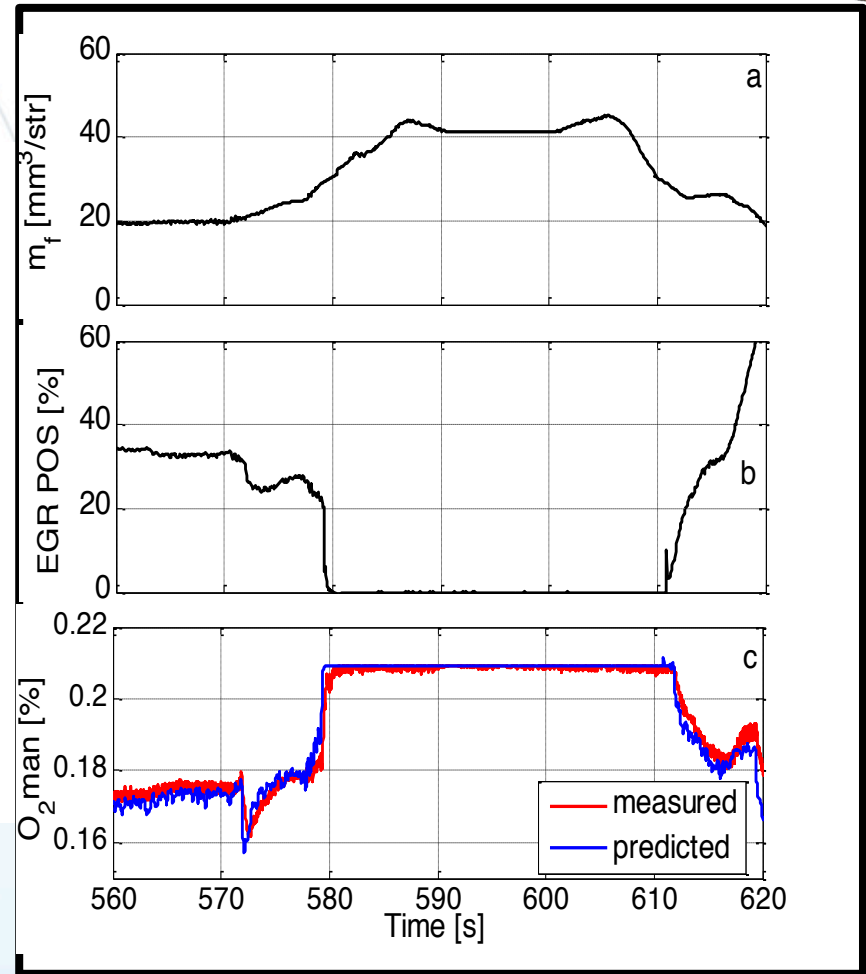
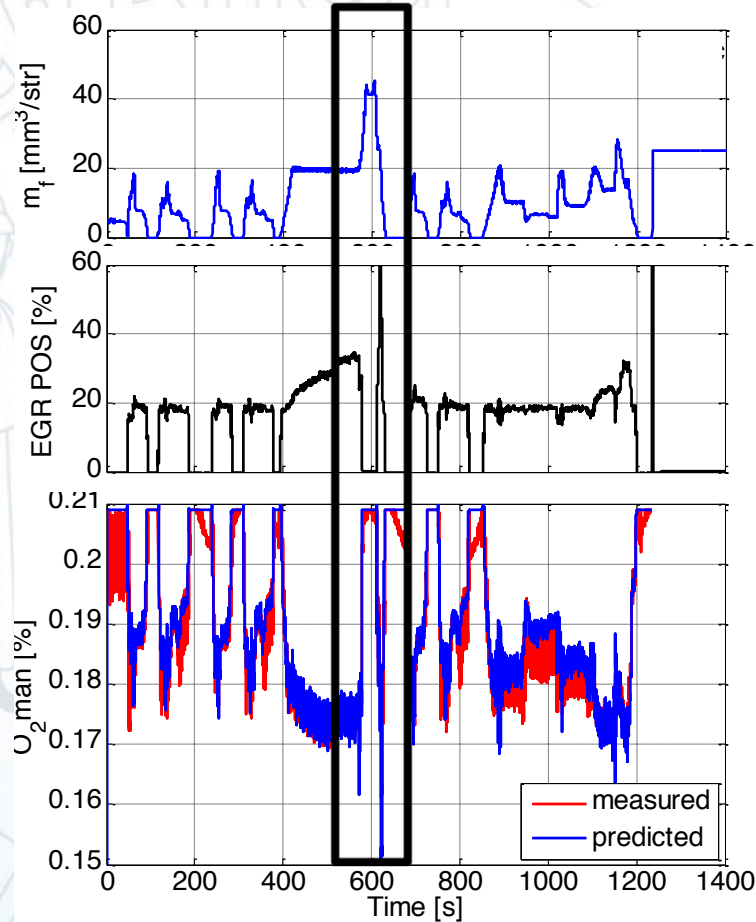


- Mean Value Modeling
- Mass and energy equations to Intake/Exhaust manifolds

Experimental results



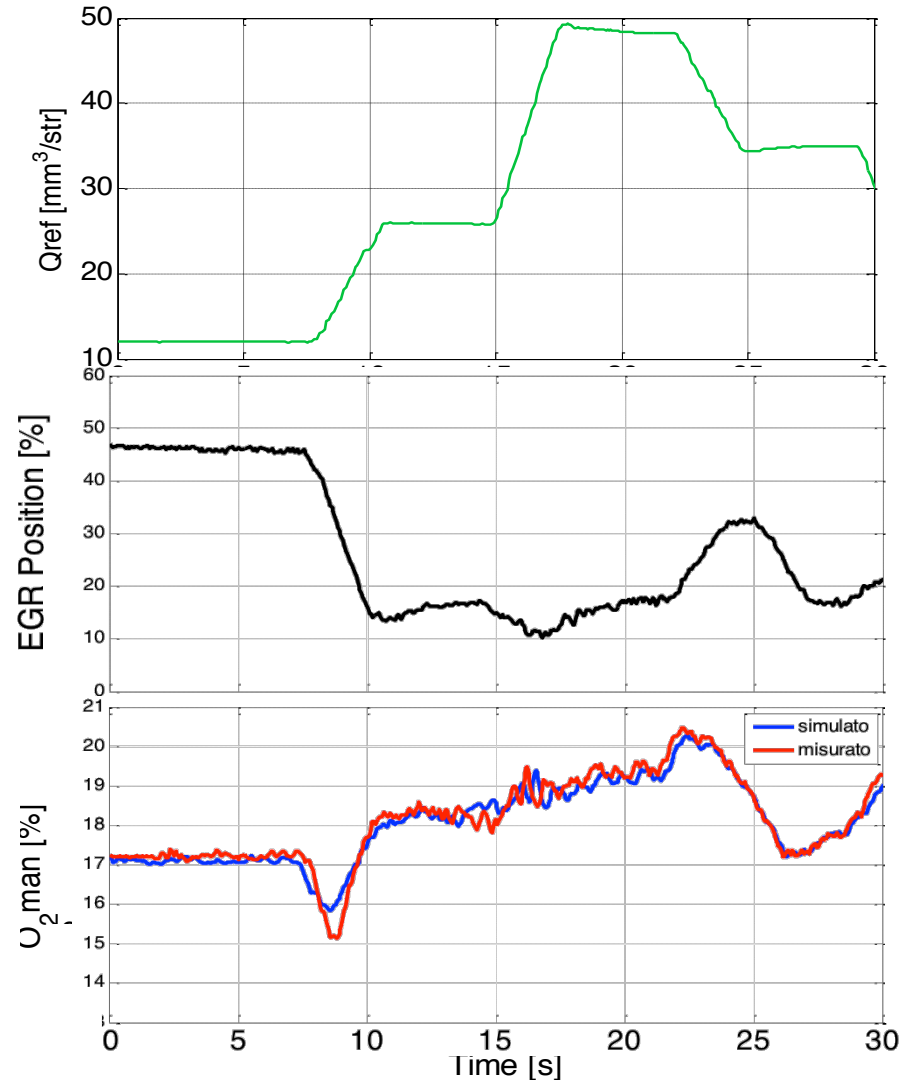
Common-Rail Diesel 1.3 – EGR/HP - VGT



Experimental results



Common-Rail Diesel 2.3 – EGR/HP - VGT

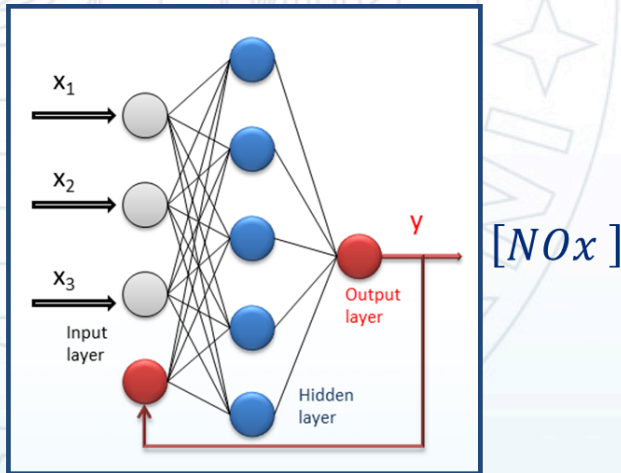


Modelling Approach /Results

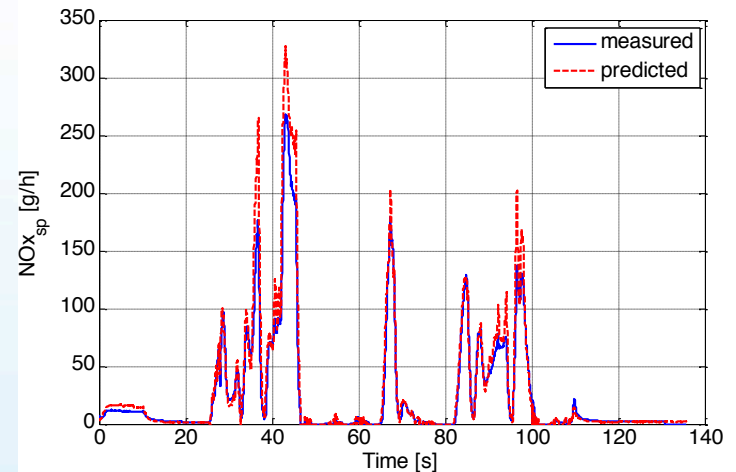
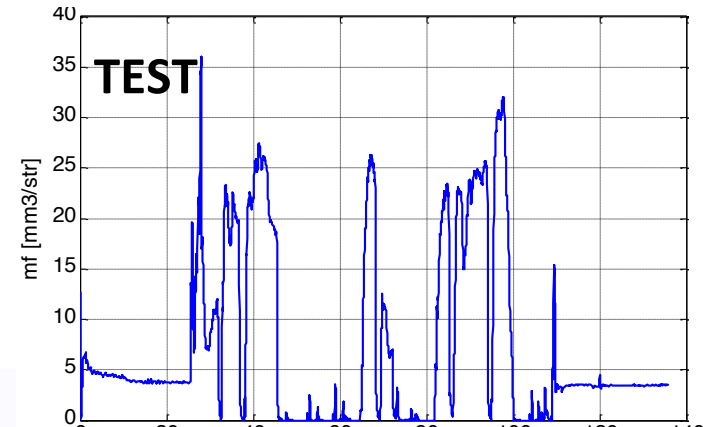
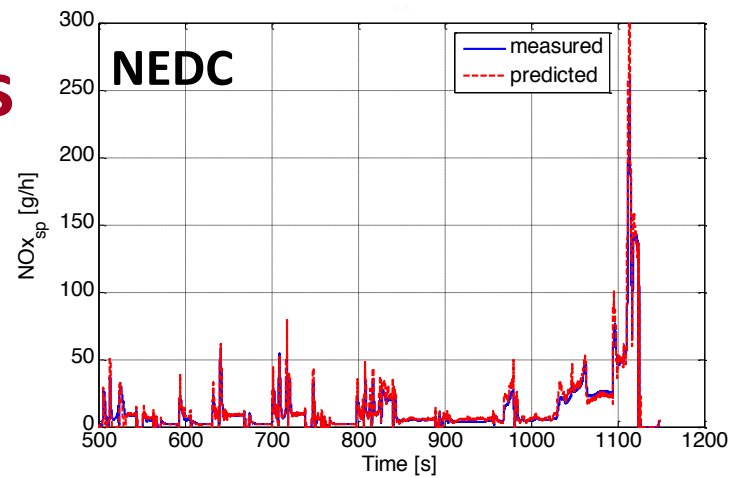
Recurrent Neural Network

- Delay removal from measured data;
- RNN identification/ training:
 - Parametric analysis and selection of the most suitable neural network structure;
 - Deterministic analysis to set RNN weights initial conditions;
 - RNN Pruning by means of the Optimal Brain Surgeon (OBS) algorithm.

$[\dot{m}_a]$
 $[m_f]$
 $[rpm]$
 $[O_{2man}]$
 $[SOI]$



	MSE	R2	ERR.INT
NEDC	16,14	0,9746	0,0909
TEST	90,21	0,9756	0,1707

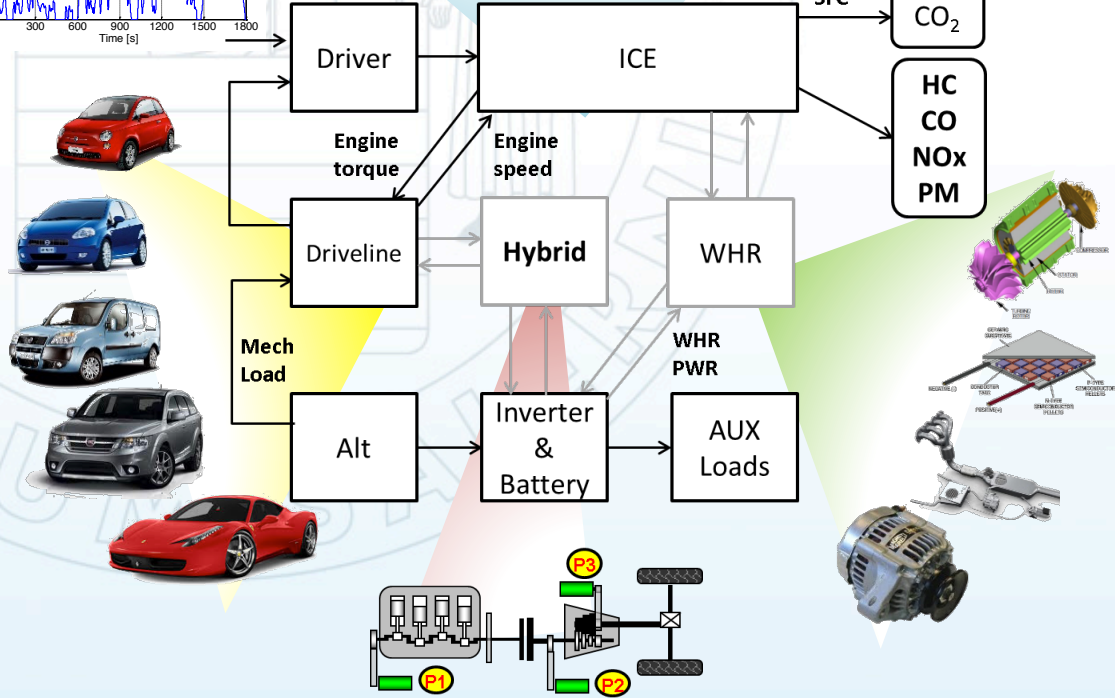
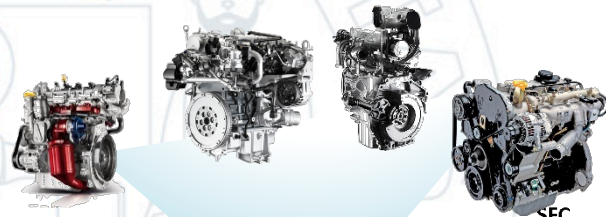
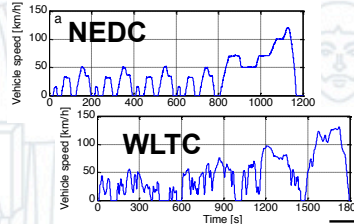


Eco-Innovation Technologies



Need to fulfil European CO₂ targets from innovative technologies: 'eco-innovations'.

Model Based Computational Framework to simulate different vehicles with different powertrain configurations along standard (NEDC, WLTC) or arbitrary driving cycles and evaluate the benefits achievable in reducing CO₂ emissions, depending on WHR/Hybrid technology, components sizing and system management.

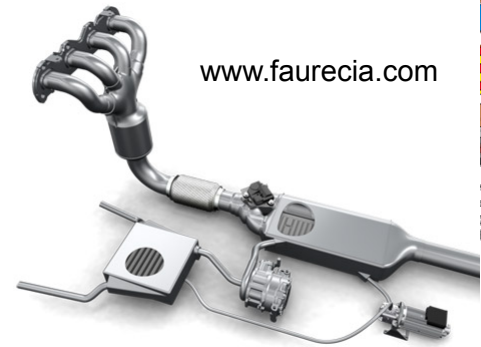


ECO-innovation technologies



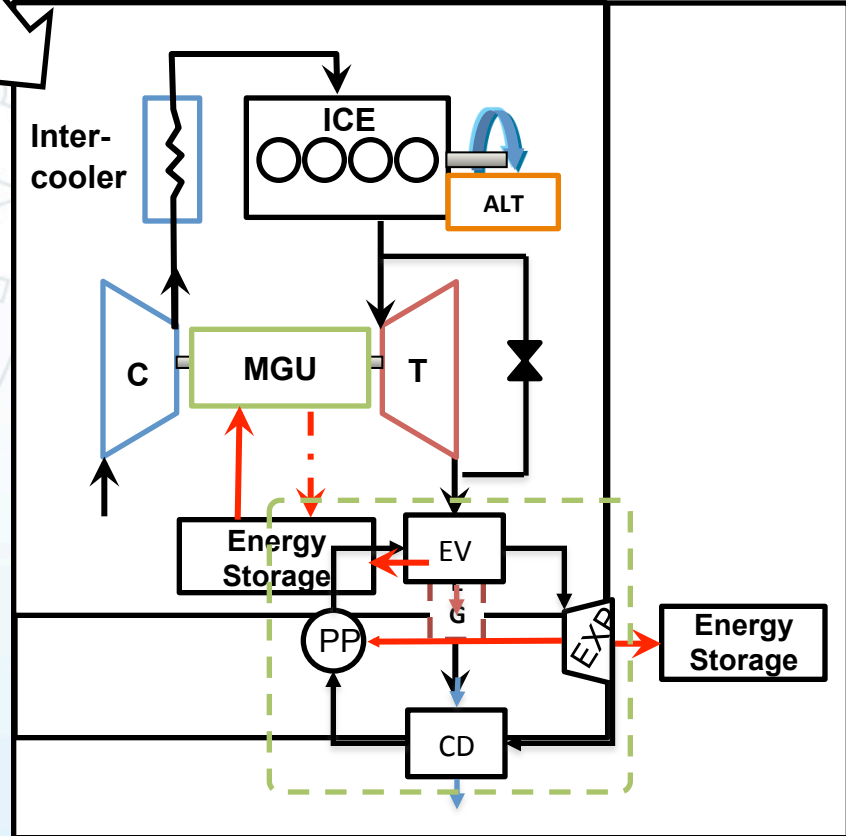
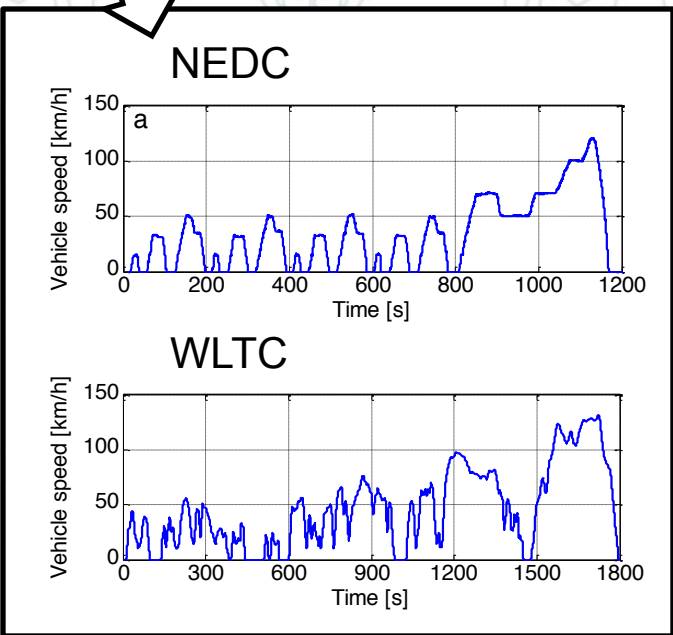
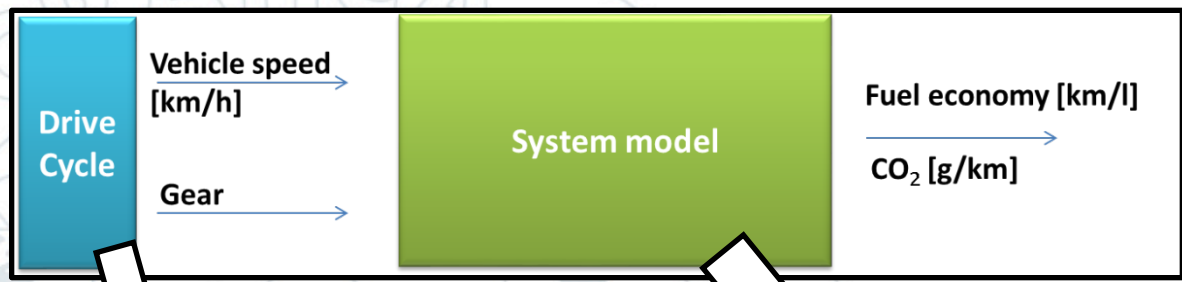
- WHR
- Hybrid
- ETC
- TEG
- ORC
- P1/P2/P3
- Fuel Cell

Waste Heat Recovery systems (WHRs)



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TYPE INDUCTION ELLETS



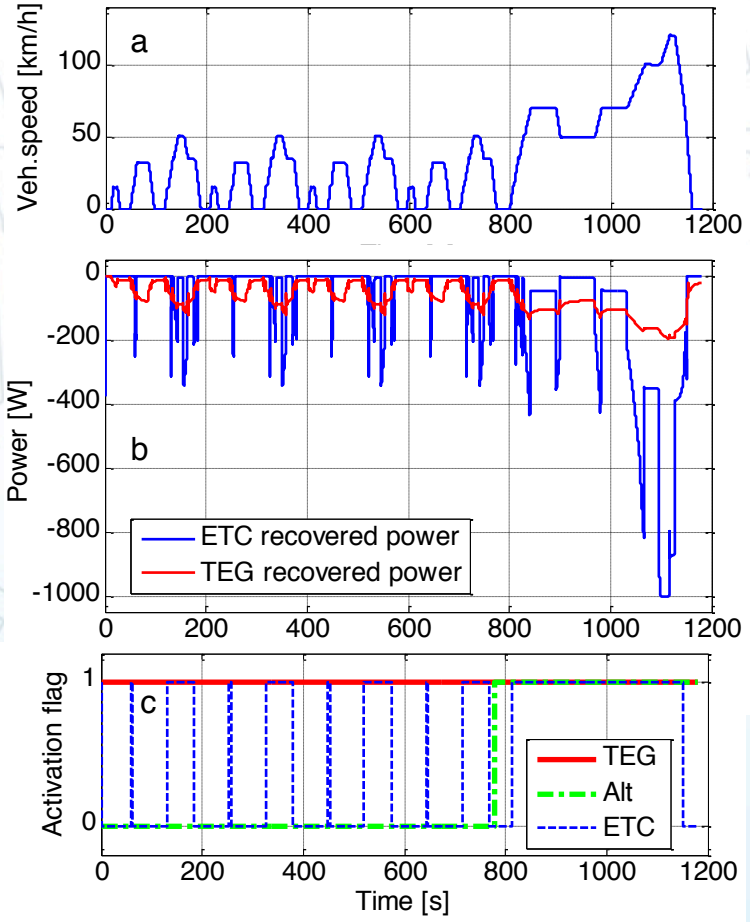
Results



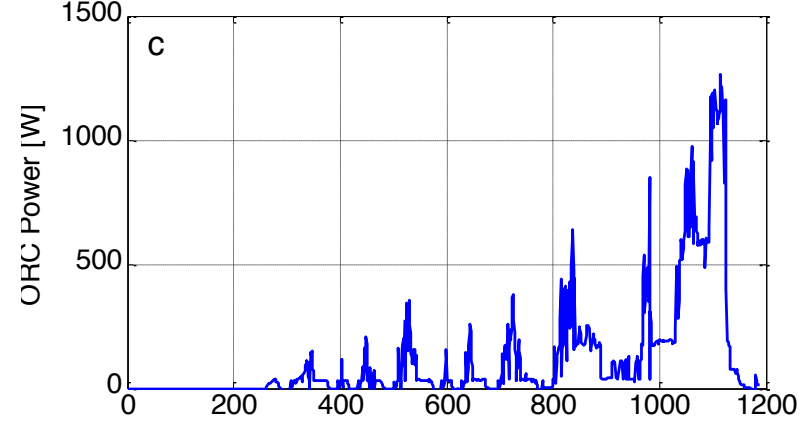
CO₂ reduction:

- ETC: 4,9 ÷ 5,3 %;
- TEG: 1,5 ÷ 1,9 %;
- ETC + TEG: 5,6 ÷ 6,6 %;
- ORC: 3,7 ÷ 4,0 %.

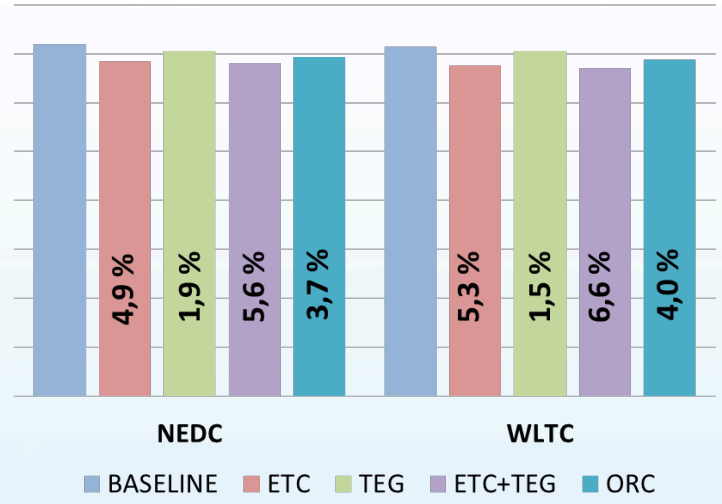
ETC + TEG



ORC



CO₂ reduction [%]





Thank You

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