UNIVERSITÀ DEL SALENTO
DIPARTIMENTO DI INGEGNERIA DELL'INNOVAZIONE

Centro Ricerca Energia e Ambiente
Dipartimento di Ingegneria dell'Innovazione
Università del Salento

Le prospettive future dei motori a combustione interna

GIORNATA DI STUDIO "GIORGIO MINELLI" SUI MCI - BOLOGNA 20 APRILE 2018

Sviluppi futuri per una combustione più pulita ed efficiente nei MCI

P. Carlucci, M. G. De Giorgi, T. Donateo, A. Ficarella
Università del Salento – Centro Ricerche Energia e Ambiente (CREA)

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Dipartimento di Ingegneria dell'Innovazione
Università del Salento

2 Full professors

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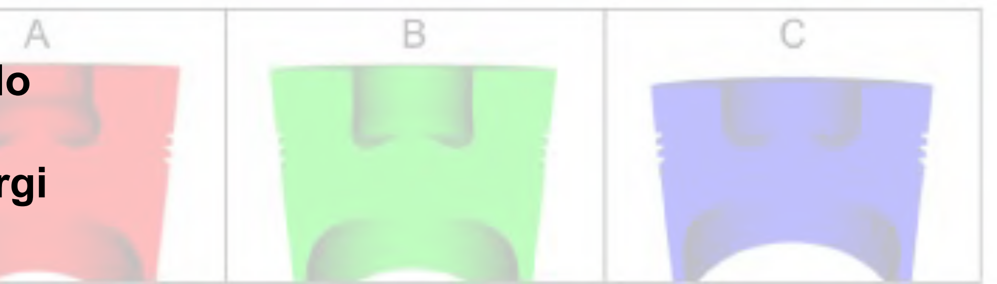
Antonio Ficarella

3 Associate professors

Arturo de Risi
A. Paolo Carlucci
Teresa Donateo

5 Assistant professors

Gianpiero Colangelo
Paolo M. Congedo
Mariagrazia de Giorgi
Marco Milanese
Giuseppe Starace



12 Research fellows
20 Ph.D. Students

Centro Ricerca Energia e Ambiente

Dipartimento di Ingegneria dell'Innovazione
Università del Salento

ICE/mobility research project

GREENING THE PROPULSION
Sviluppo di uno strumento di simulazione e valutazione tecnologica per un sistema propulsivo aeronautico ibrido (PON2007-2013)

MALET
Sviluppo di tecnologie per la propulsione ad alta quota e lunga autonomia di velivoli non abitati (PON2007-2013)

SEB
Ricerca e sviluppo di sistemi per la produzione efficiente, la gestione e l'accumulo di energia elettrica e termica, integrati e interconnessi in un virtual power plant (PON2007-2013)

SUNLIFE
Prototipo VEUS (Veicolo Elettrico Urbano Solare) (Progetto Interreg III/A Italia-Grecia)

MEA
Gestione ibrida dell'energia per applicazioni aeronautiche (PON2007-2013)

ICE/mobility research project

PRIME
Progetto di ricarica intelligente per la mobilità elettrica

CSEEM
Center for Sustainable Energy, Environment and Mobility

TACOM
Sistema di propulsione ibrido per un veicolo MSV (Maneuver Sustainment Vehicle)

Collaborations - Academy

Center for Automotive Research

CAR

The von Karman Institute for Fluid Dynamics

ILLINOIS
1867
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Università di Roma Tor Vergata

THE TECHNICAL UNIVERSITY of CLUJ-NAPOCA

PRINCETON UNIVERSITY

Politecnico di Bari

Tarbiat Modares University-International

THINK GREEN, LIVE GREEN!
BRTeam
BIOFUEL RESEARCH TEAM
Agricultural Biotechnology Research Institute of Iran (ABRII)
Fahmideh Blvd.
Karaj, Alborz
Iran

UTM
UNIVERSITI TEKNOLOGI MALAYSIA

Collaborations - Companies

CMD

Mercedes-Benz

Das Auto.

clean energy ahead
TURBODEN
A PRATT & WHITNEY POWER SYSTEMS COMPANY

ENEA
Ambiente Energia Innovazione

Nardò Technical Center
Porsche Engineering

BOSCH

ALSTOM

CEI CIVES

Enel

Thermocold

SOCOGES
GALANTO GROUP

CENTRO
RICERCHE
FIAT

Avio

G.E. Nuovo Pignone

Facilities

ICE1 Lab

2 AVL eddy-current engine test bench
(160 kW, 400 Nm, 10000 rpm;
240 kW, 600 Nm, 10000 rpm)

PEMS

Average fuel consumption (AVL 733 Fuel Balance) and emissions (AVL AMA i60, AVL smoke meter, microsoot sensor)

Facilities

ICE2 Lab

Constant-volume vessel for high pressure spray imaging and granulometric characterization (w and w/o combustion)

AVL single cylinder Diesel engine with optical accesses on Zollner test bench, with engine videoscope; it can be fueled with biodiesel, CNG, H_2, LPG, gaseous mixtures of CO, CO_2, H_2, CH_4, N_2 in variable %

Average fuel consumption (AVL 733 Fuel Balance) and emissions (AVL AMA i60, AVL smoke meter, microsoot sensor)

Outline

- Electrification
- Control oriented modeling
- Alternative fuels
- Dual-fuel combustion
- Photo-thermal ignition

Outline

- Electrification
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- Alternative fuels for CI engines
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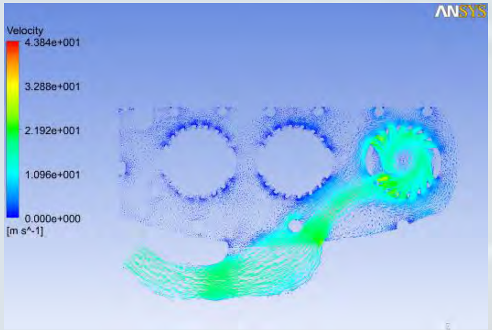
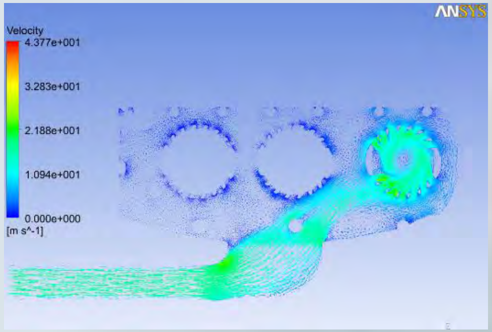
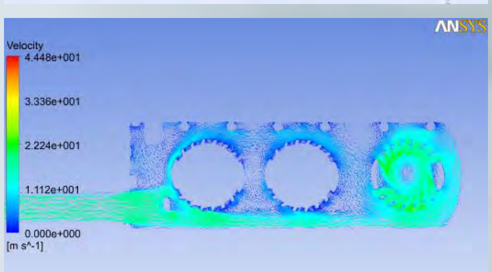
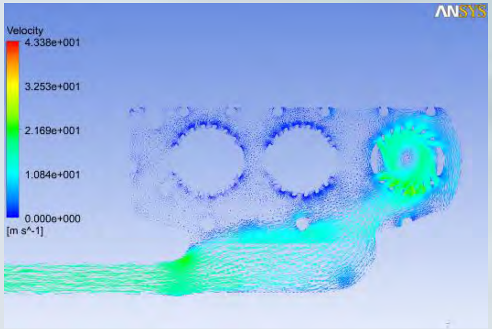
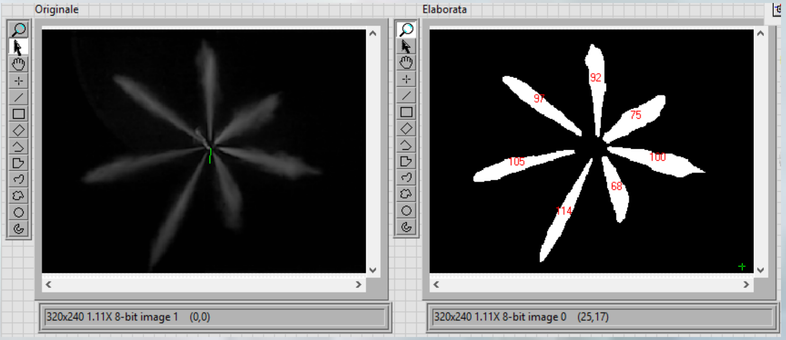
MALET project - GF56

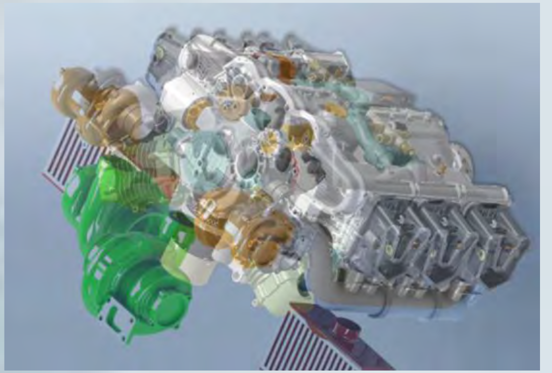


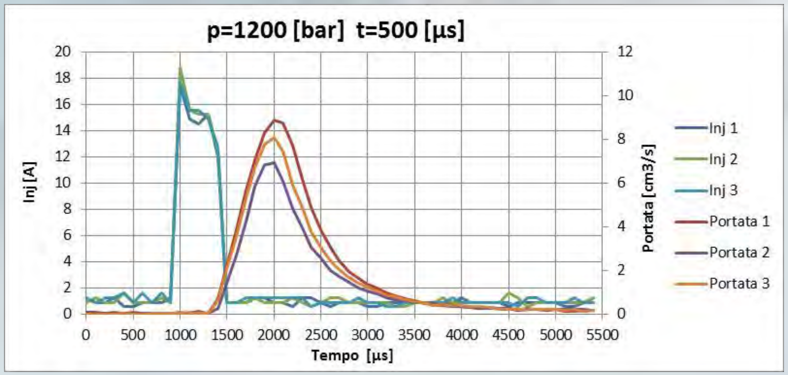


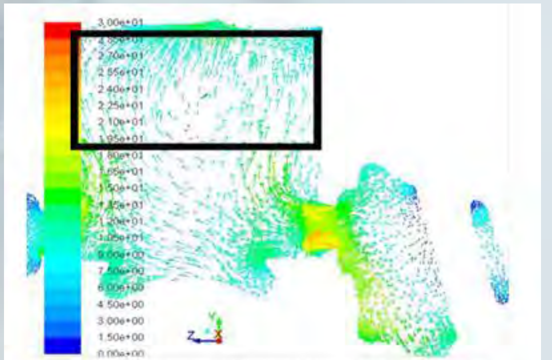




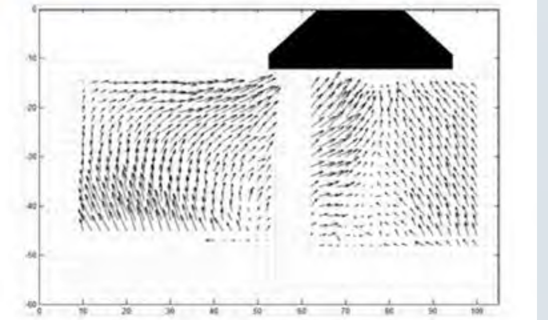






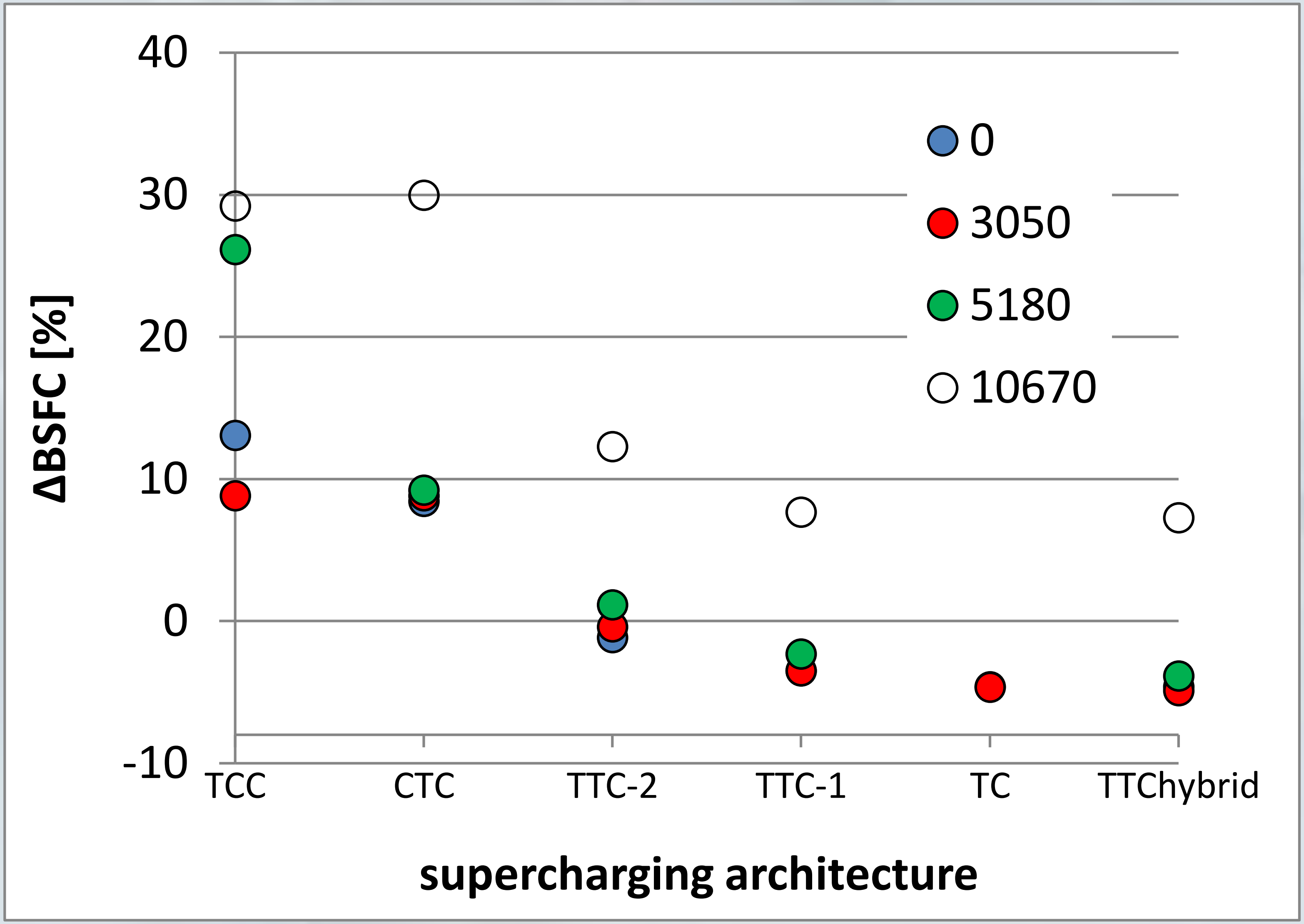


Simulazioni CFD Flussaggio (portata 0,13 kg/s@2,58 kg/mc) - POV



Campo di moto PIV (portata 0,06 kg/s @ 1,2 kg/mc) - POV

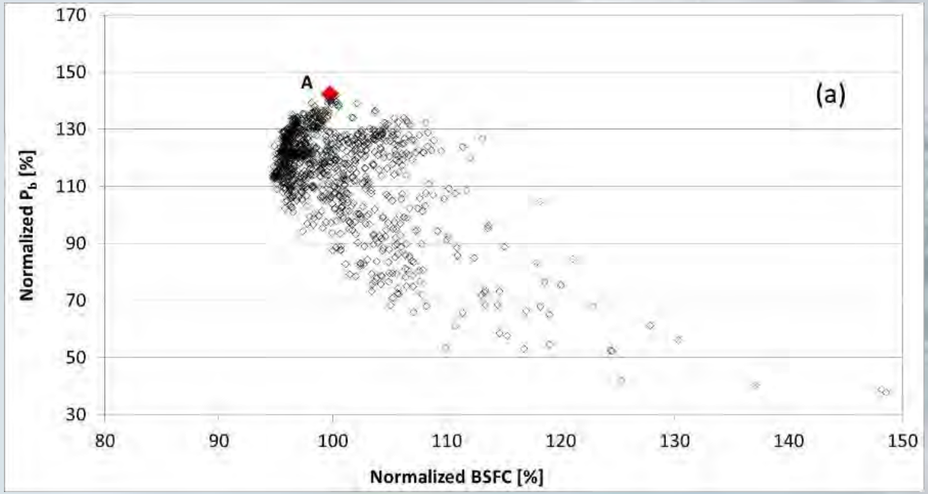
Comparative study of different supercharging architectures

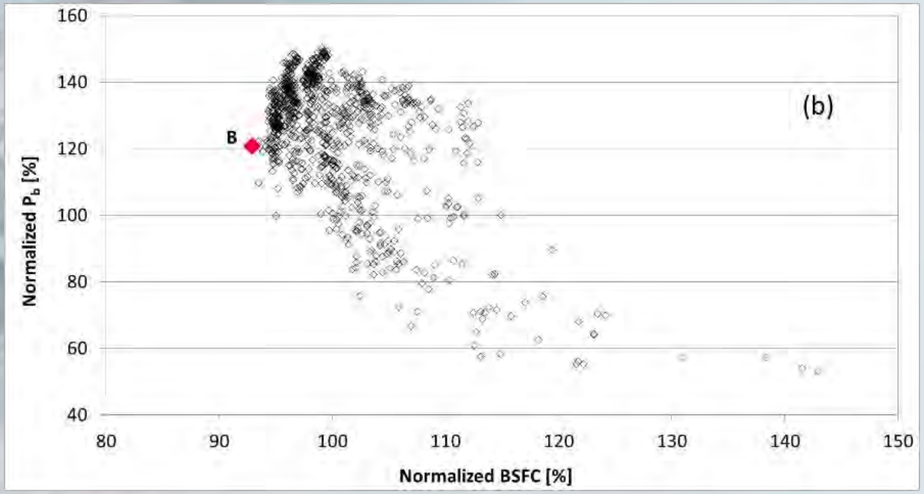


A.P. Carlucci, , A. Ficarella, D. Laforgia, A. Renna; *"Supercharging system behavior for high altitude operation of an aircraft 2-stroke Diesel engine"*, **Energy Conversion and Management** 101 (2015) 470-480

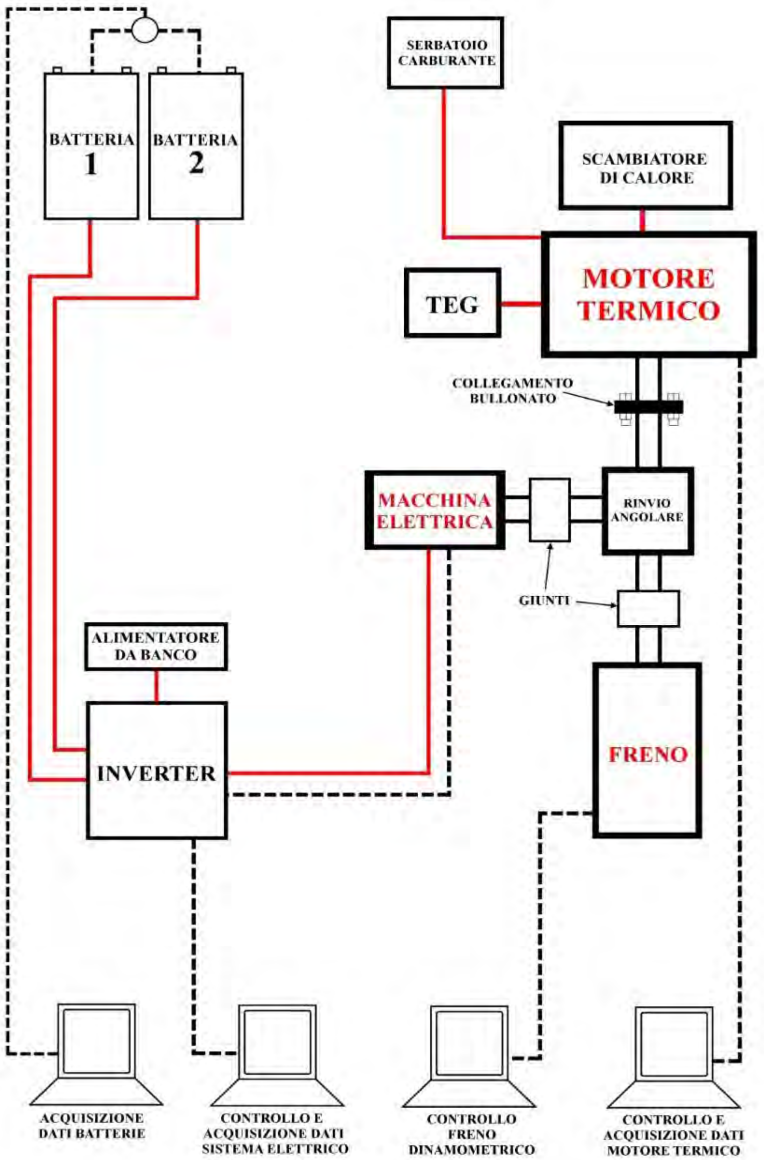
GF56 optimization

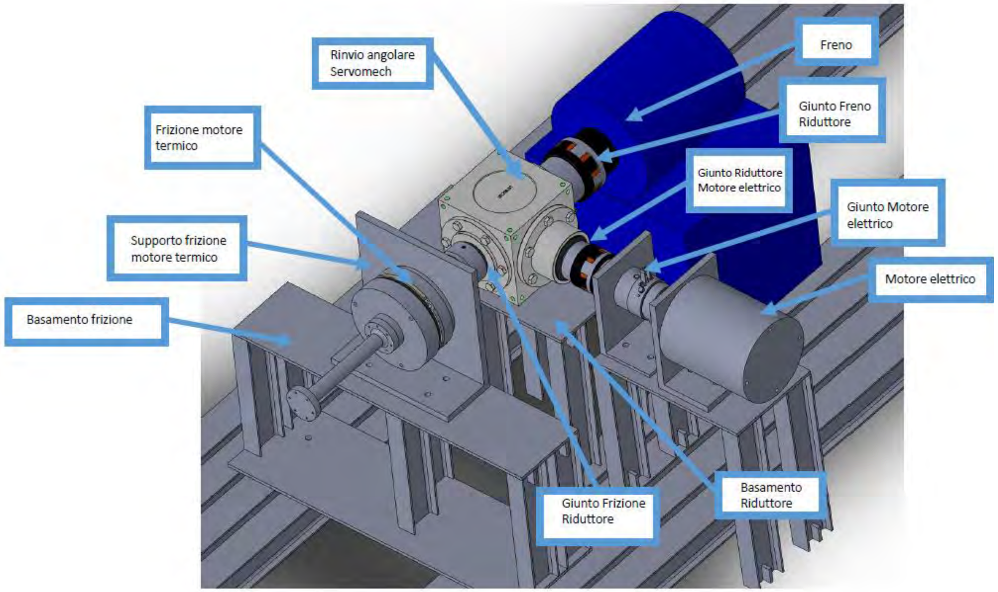
Flight level	P_b [%]	BSFC	A	AFR	CR	EVC	EVO	HBI	IPO	HEV	PR_{LP}	PR_{HP}	n	TE	SE
SL	142	99.75	240	17	16	270	110	1	115	10.5	1.7	2.1	10	0.92	0.69
CC	121	92.92	225	18.5	18	240	95	2	122.5	11	2.7	2.7	17	0.89	0.75

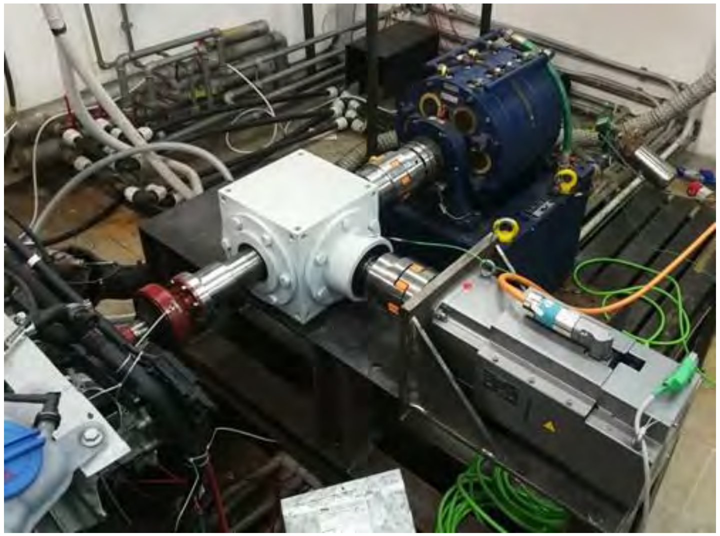




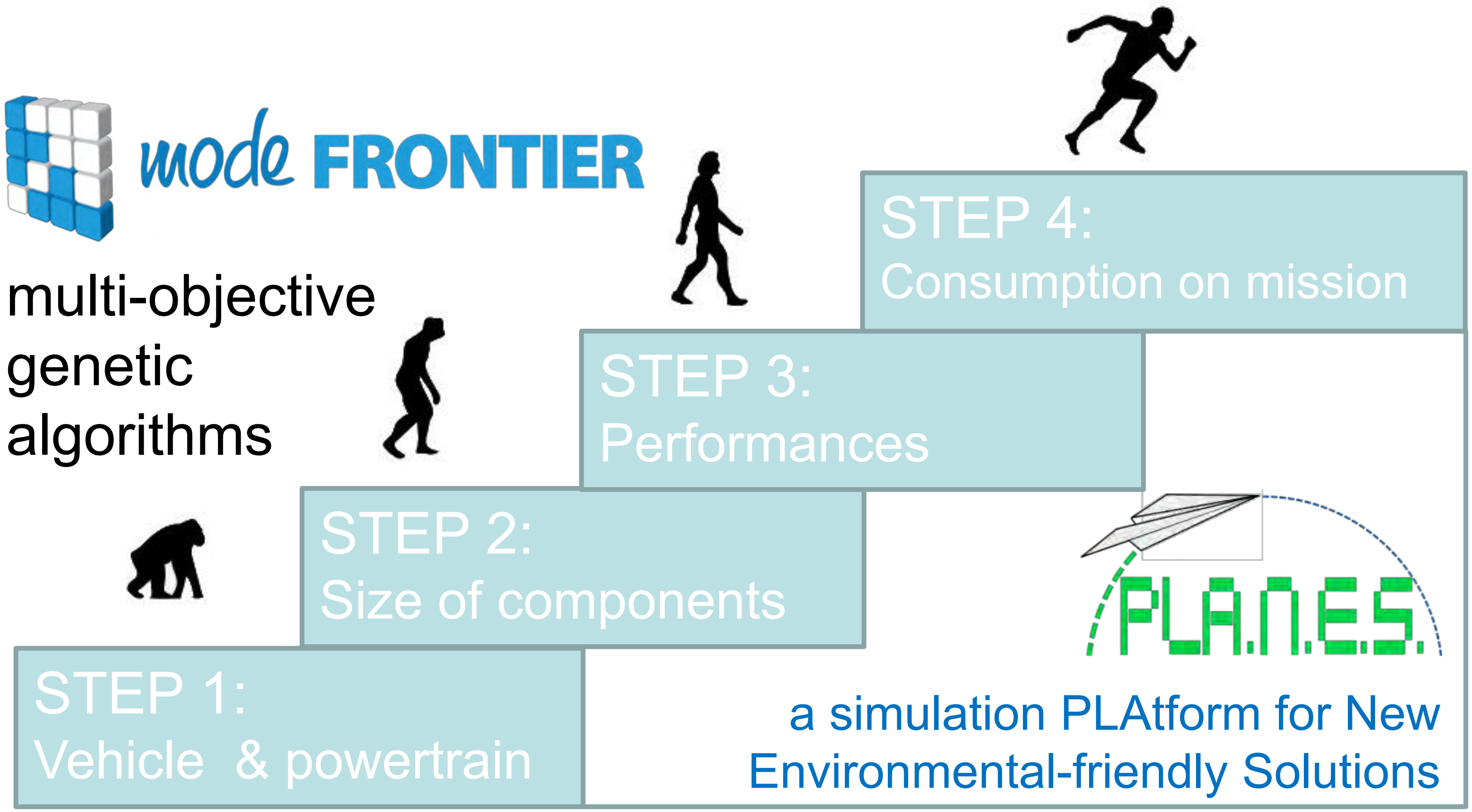
A.P. Carlucci, , A. Ficarella, G. Trullo; *"Performance optimization of a Two-Stroke supercharged diesel engine for aircraft propulsion"*, **Energy Conversion and Management** 122 (2016) 279-289


SERBATOIO CARBURANTE
BATTERIA 1
BATTERIA 2
SCAMBIATORE DI CALORE
TEG
MOTORE TERMICO
COLLEGAMENTO BULLONATO
MACCHINA ELETTRICA
RINVIO ANGOLARE
GIUNTI
ALIMENTATORE DA BANCO
INVERTER
FRENO
ACQUISIZIONE DATI BATTERIE
CONTROLLO E ACQUISIZIONE DATI SISTEMA ELETTRICO
CONTROLLO FRENO DINAMOMETRICO
CONTROLLO E ACQUISIZIONE DATI MOTORE TERMICO


Rinvio angolare Servomech
Freno
Giunto Freno Riduttore
Frizione motore termico
Giunto Riduttore Motore elettrico
Giunto Motore elettrico
Supporto frizione motore termico
Motore elettrico
Basamento frizione
Basamento Riduttore
Giunto Frizione Riduttore



Hybrid electric power systems: optimization & analysis



Hybrid electric power systems: scalable models

Energy conversion

A library of fuels and engines (**piston**, turbine, rotary)

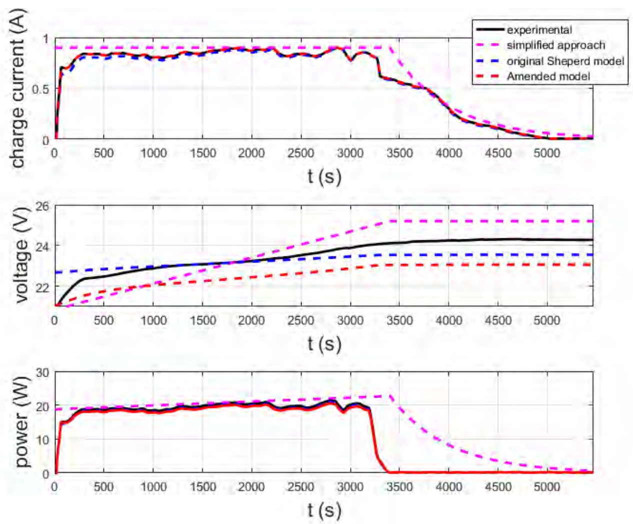
A library of electric machines

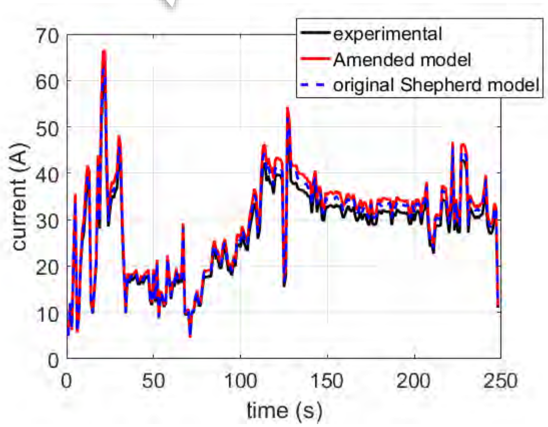
PEM and advanced fuel cells

Quasi-stationary models

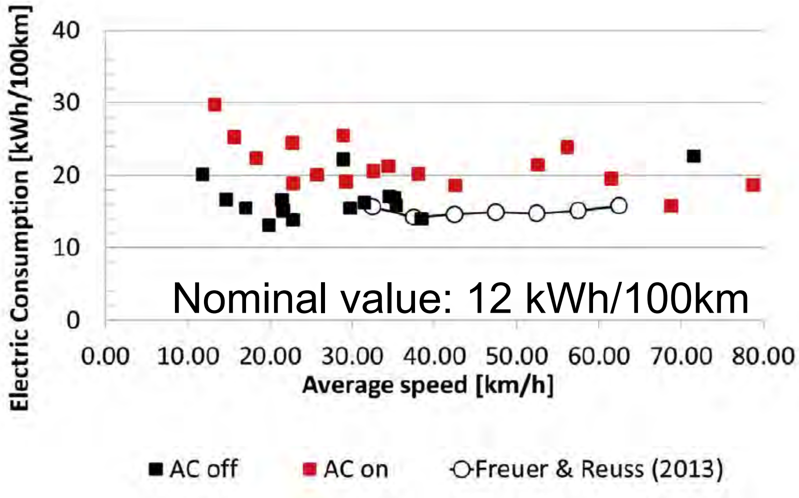
Energy storage

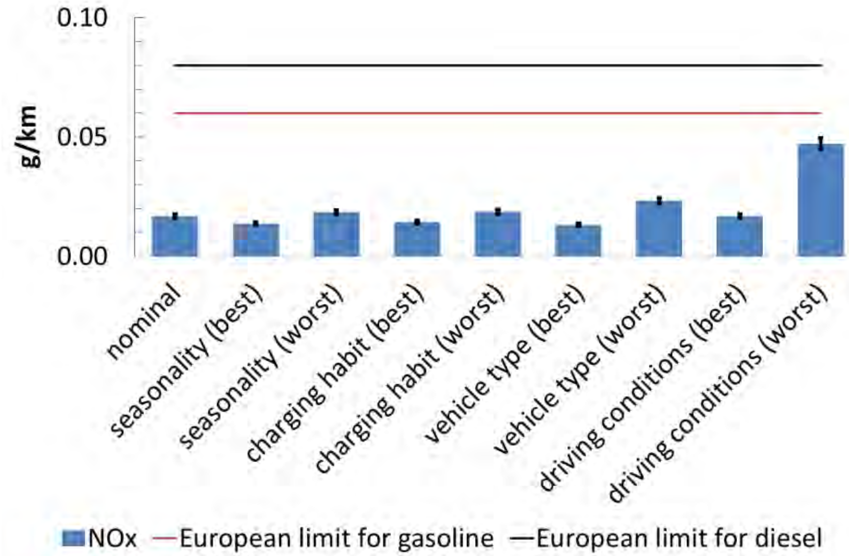
A modified version of the Shepherd model, extensively validated against experimental data of Lithium-polymer and Zebra batteries in charging and discharge.

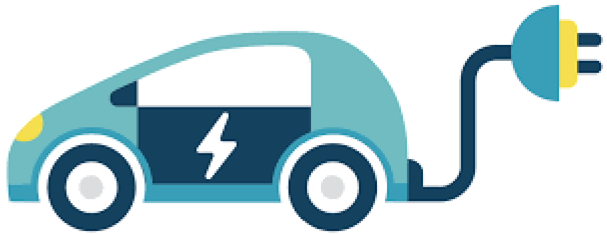


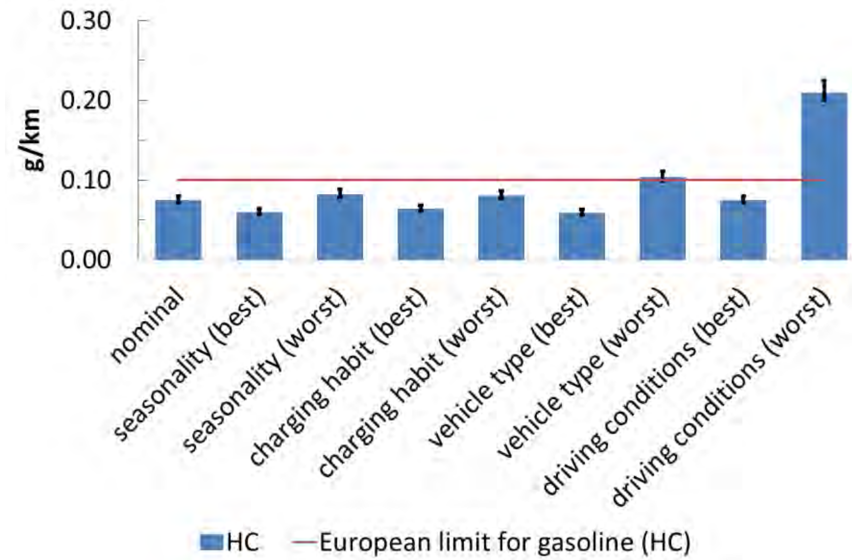


Real world consumption & emissions: Electric cars

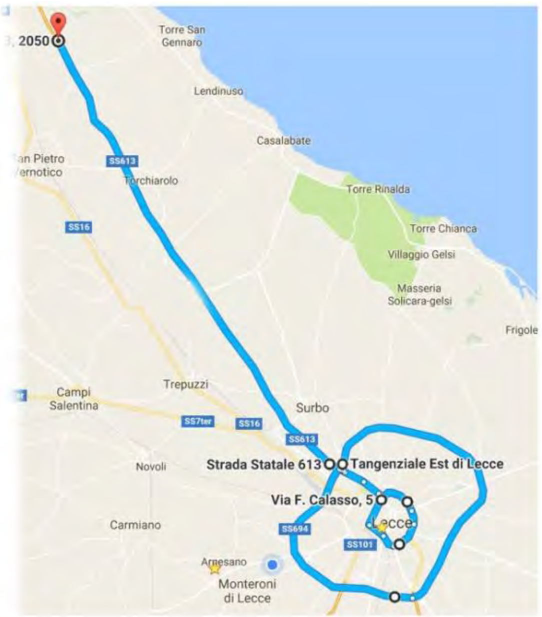


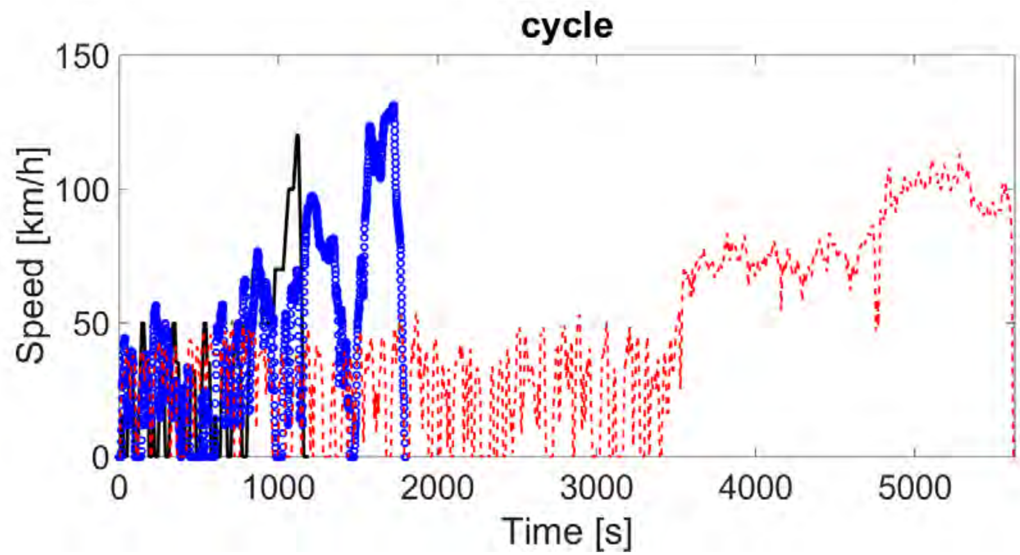




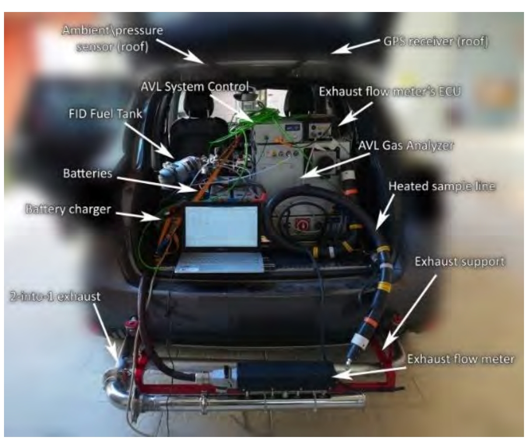


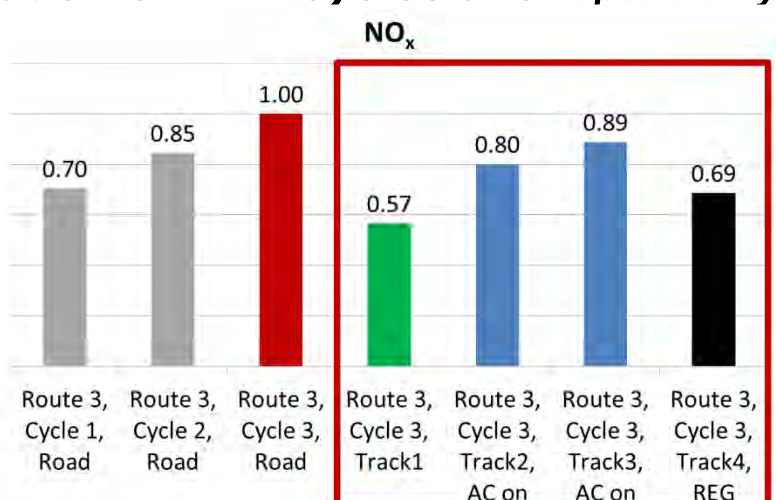
Real world consumption & emissions: Diesel cars





Execution of RDE cycles and repeatability on track





Outline

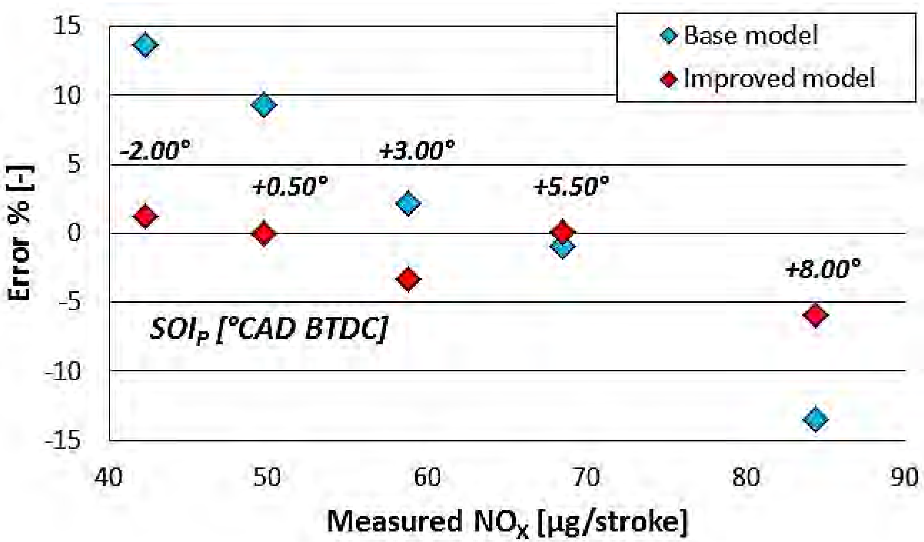
- Electrification
- Control oriented modeling
- Alternative fuels for CI engines
- Dual-fuel combustion
- Photo-thermal ignition

"Combustion features estimation for Diesel engines, based on cylinder pressure signal and speed oscillations"

- inner torque estimation model able to detect combustion changes (related to fuel injection quantity variations) affecting inner torque curves and IMEPH;
- exploitation of crankshaft speed and one in-cylinder pressure sensor;
- rigid body model of the crankshaft.

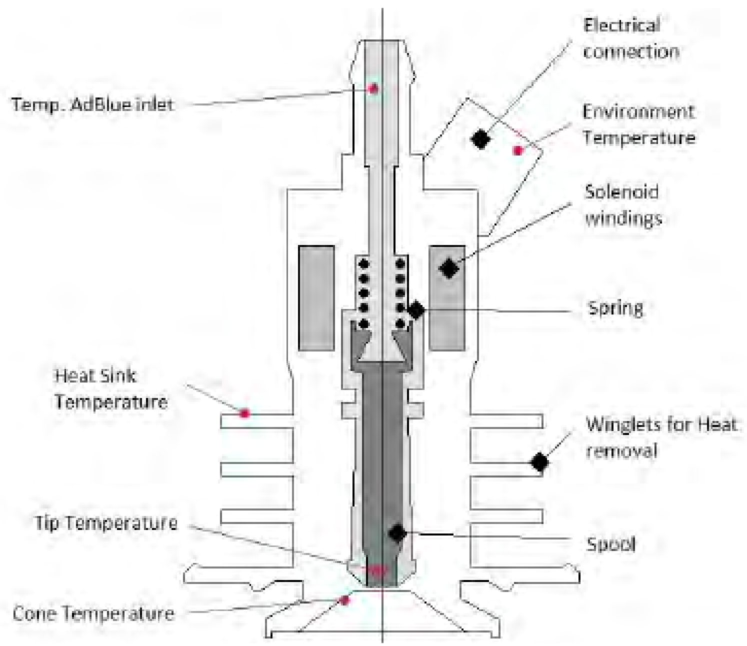
"Development of a semi-empirical in-cylinder pressure-based model predicting diesel engines NOx emission in dynamic conditions"

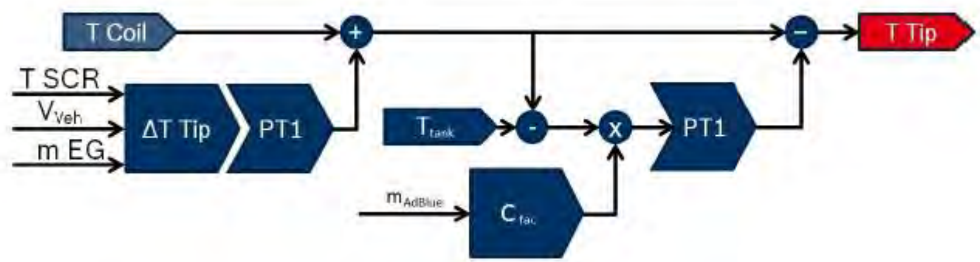
$$m_{NO_X,improved} = K_1 \cdot \left(\frac{n}{2000}\right)^{K_2} \cdot \int_\theta HRR(\theta) \cdot \boxed{\left(1 + \frac{\left|dV_{CYL}(\theta)\right|}{V_{CYL}(\theta)}\right)^{K_4}} \cdot \exp\left(\frac{K_3}{T_{AD}(\theta)}\right) \cdot d\theta$$

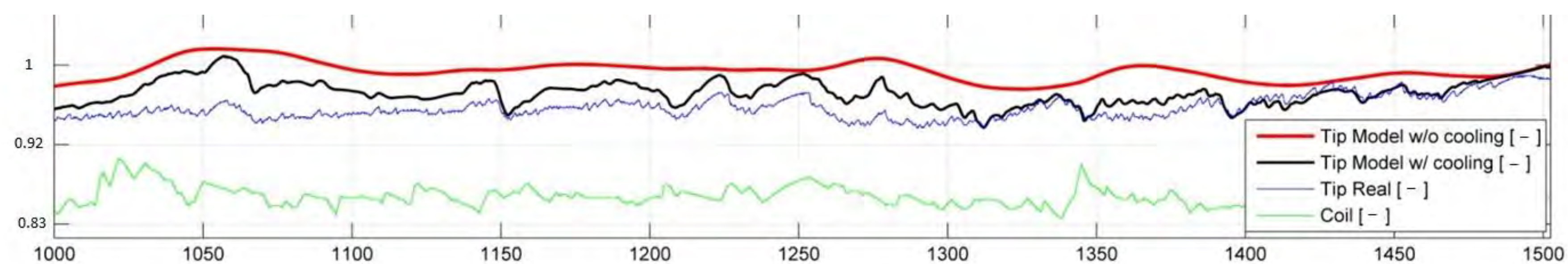


Parameter	Improved model		Base model	
	Trainin g	Testing	Training	Testing
RMSE [ppm]	37	39	70	90
RMSE [%]	18.8	18.3	24.8	28.6
R^2	0.97	0.97	0.91	0.86

"Diesel engine aftertreatment calibration: evaluation of potential in term of accuracy and efficiency of self-learning, remote controlled algorithms and physical modeling"

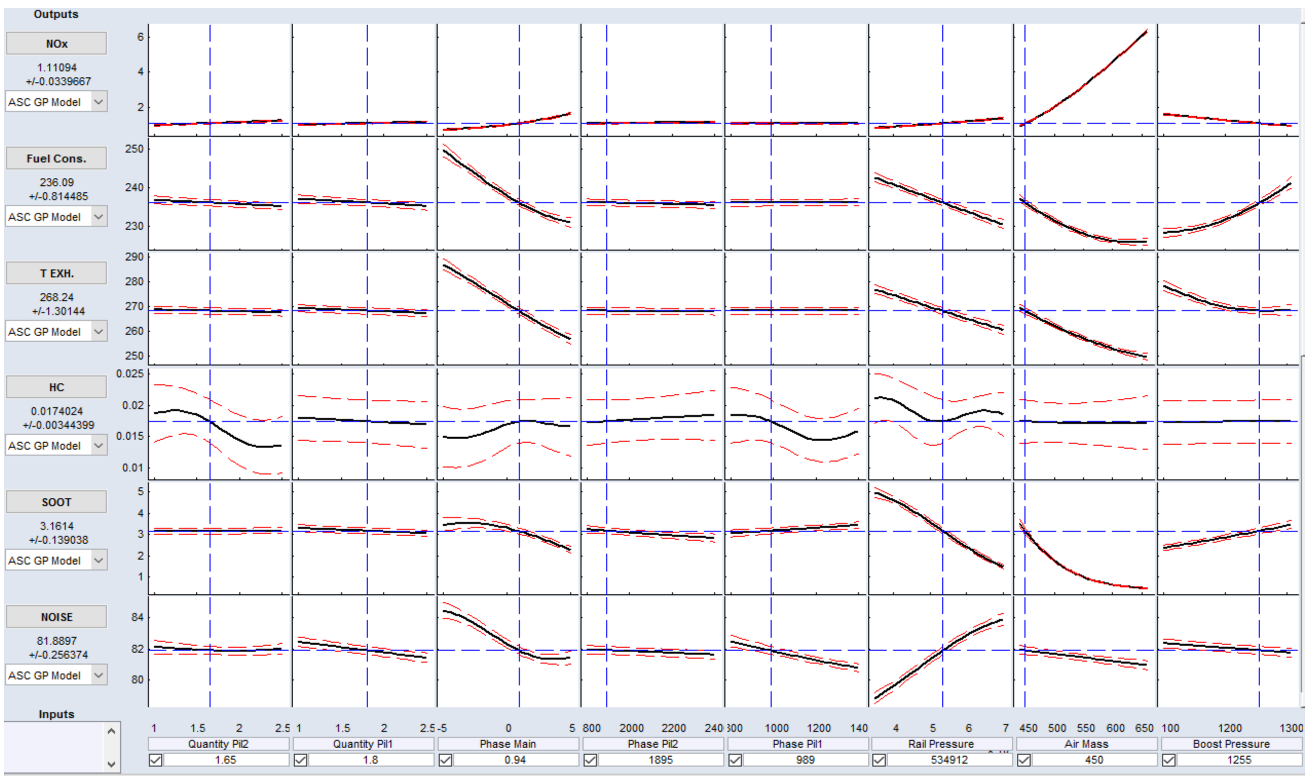


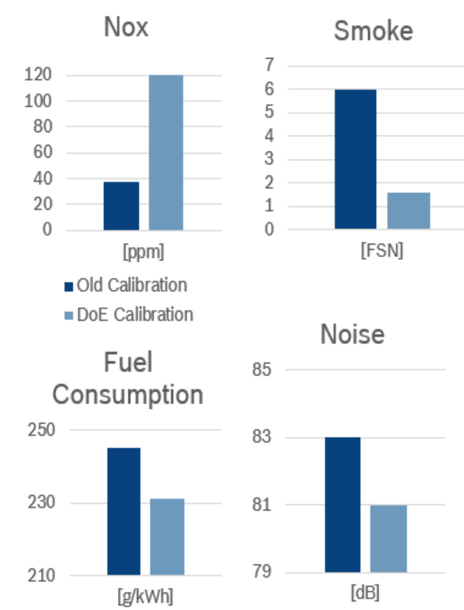




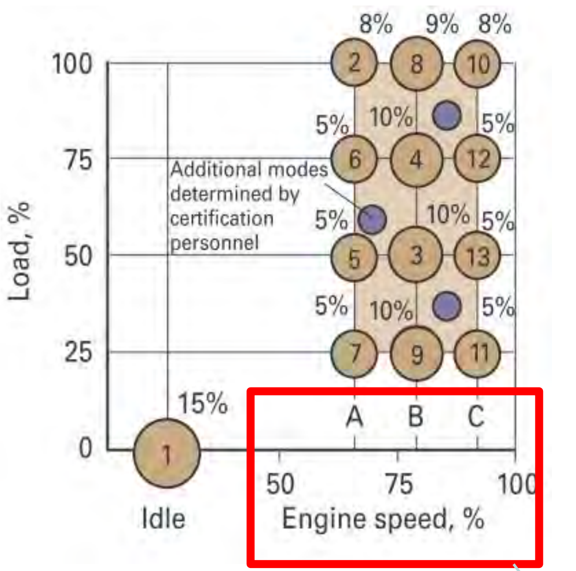
"Study of emissions and fuel consumption optimization strategies for RDE applications"

Effect of: Air mass; Rail pressure; Boost pressure; Main injection phase; pilot injections quantities and phases;
Outputs: Regulated emissions; Fuel consumption; Exhaust temperature; Combustion noise.

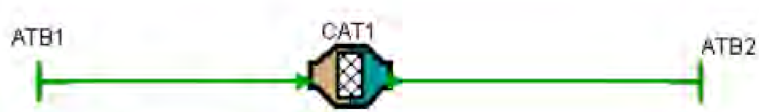


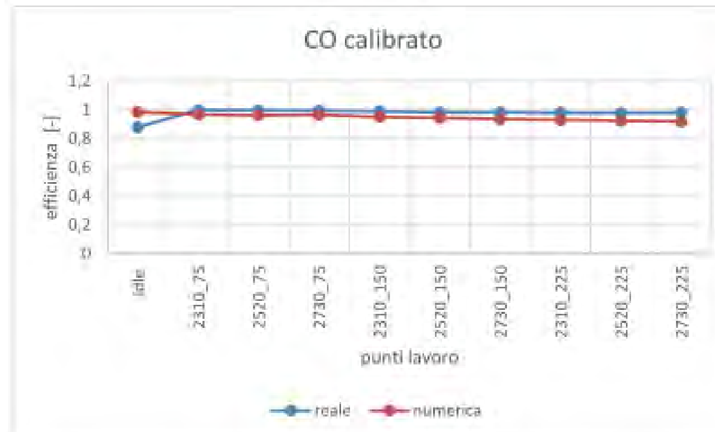


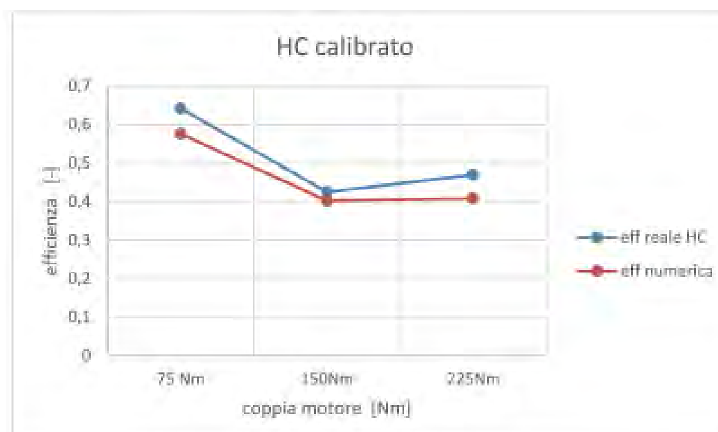
"Validazione sperimentale del modello numerico di un sistema di post trattamento per motori ad accensione per compressione"



Normativa 88/77/EC : ESC







"Analisi dati e creazione di modelli per la gestione dell'anticipo di accensione per motori con tecnologia VVA"

Scopo del modello proposto è quindi quello di cercare una relazione matematica che leghi l'anticipo di accensione alla massa complessivamente intrappolata e all'intake valve closing angle.

Outline

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Biodiesels in ICE

Consiglio Nazionale delle Ricerche ISPA ISTITUTO DI SCIENZE DELLE PRODUZIONI ALIMENTARI

Centro Ricerca Energia e Ambiente
Dipartimento di Ingegneria dell'Innovazione Università del Salento

Coffee grounds

8-10%

Cynara cardunculus var. altilis

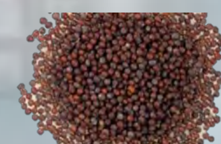
1300 kg/ha

25-30%


B)

Brassica carinata

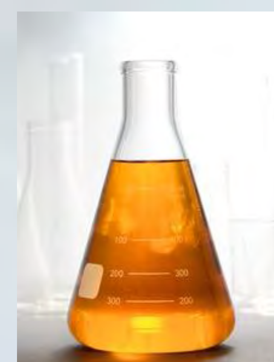
1100-1800 kg/ha

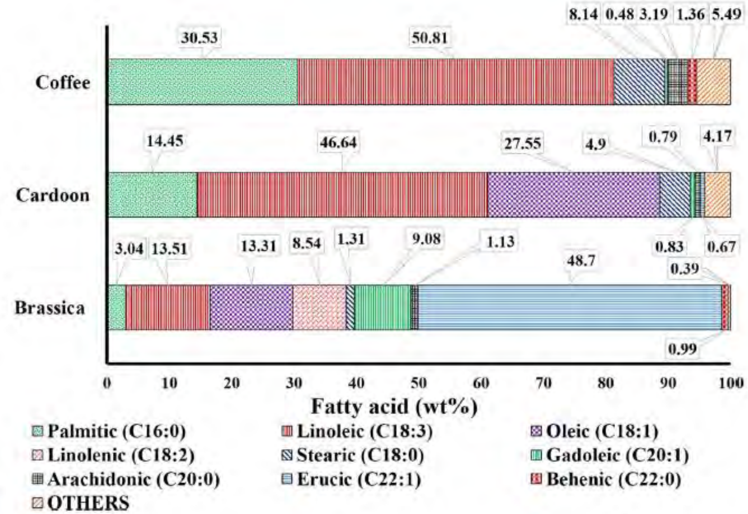


35-40%


A)

Waste oil





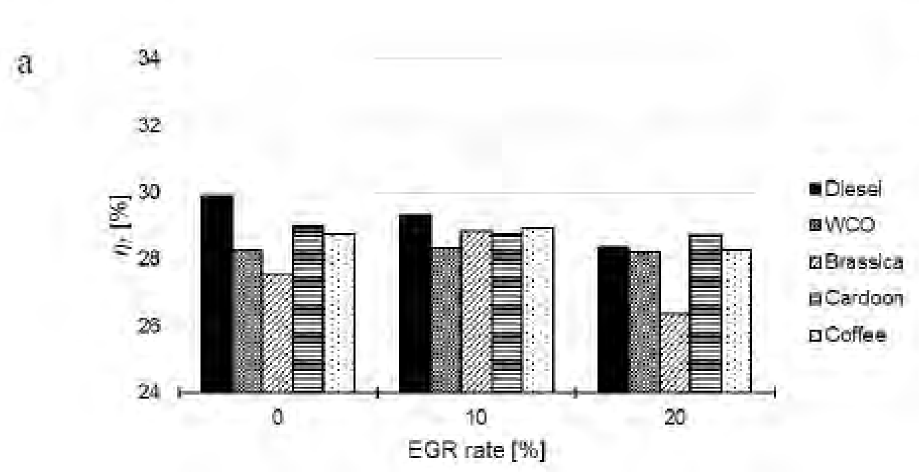
Characteristics of produced biodiesels.

Parameter	Standard	Unit	Limits	Cardoon	Coffee	Brassica	Diesel
Flash point	ASTM D93	°C	93 min	309	292	296	78
Calcium	EN14538	mg/g	–	4.83	21.75	9.8	–
Magnesium	EN14538	mg/g	–	0.1	0.98	0.1	–
Calcium + Magnesium	EN14538	mg/g	0.005 max	4.93	22.73	9.9	–
Sodium	EN14538	mg/g	–	1.86	1.77	1.08	–
Potassium	EN14538	mg/g	–	1.54	0.58	0.84	–
Sodium + Potassium	EN14538	mg/g	0.005 max	3.4	2.35	1.92	–
Monoglycerides	ASTM D6584	% m/m	0.4 max	0.04	0.06	0.05	–
Methanol content	EN14110	% m/m	0.2 max	< 0.01	< 0.01	< 0.01	–
Water and sediment content	ASTM D2709	% v/v	0.05 max	< 0.01	< 0.01	< 0.01	–
Dynamic viscosity at 40C	ASTM D445	cSt	1.9–6.0	9.5	5.7	6	3.5
Sulfated Ash	ASTM D874	% m/m	0.02 max	< 0.02	< 0.02	< 0.02	–
Total sulfur	ASTM D5453	% m/m	0.015 max	< 0.001	< 0.001	< 0.001	–
Copper Strip Corrosion	D130	–	No. 3 max	Exceeded	Exceeded	Exceeded	–
Carbon Residue 100% sample*	D4530	% m/m	0.05 max	< 0.001	< 0.001	< 0.001	–
Acidity number	D664	mgKOH/g	0.5 max	0.3	0.7	0.6	–
Phosphorus Content	D4591	mg/g	0.001 max	1.58	4.93	0.86	–
Distillation	D1160	°C	360 max	> 300	> 300	> 300	–
Cetane number	ASTM D 613		47 min	57.44	56.11	56.44	48
oxidation stability	EN 15751	h	3 min	> 12	9	> 12	–
Visual aspect	ASTM D 4176	–	–	Clear yellow	Clear yellow	Clear yellow	–
Lower heating value	–	MJ/kg	–	40.69	39.18	40.10	–
Oxygen content	–	%	–	10.91	7.77	13.44	0
Surface tension	Drop shape method	mN/m	–	40.99	37.62	42.05	34.1

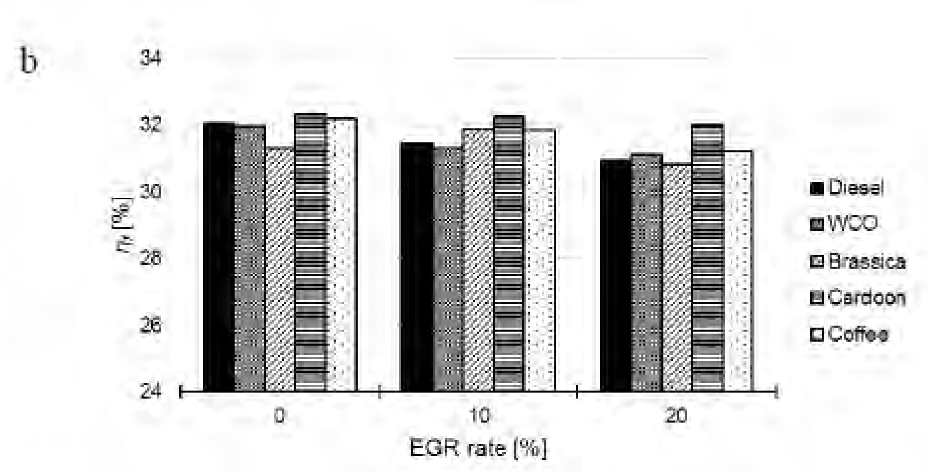
Biodiesels in ICE

Description	Abbreviation	Tested levels
Engine Speed	n	1500 [rpm]
Rail injection pressure	p_{rail}	500 [bar]
Injection timing	SOI	-6 [CAD ATDC]
Engine load	EL	7 / 14 [Nm]
Exhaust Gas Recirculated rate	EGR	0 / 10 / 20 [%]

Low load



Medium load



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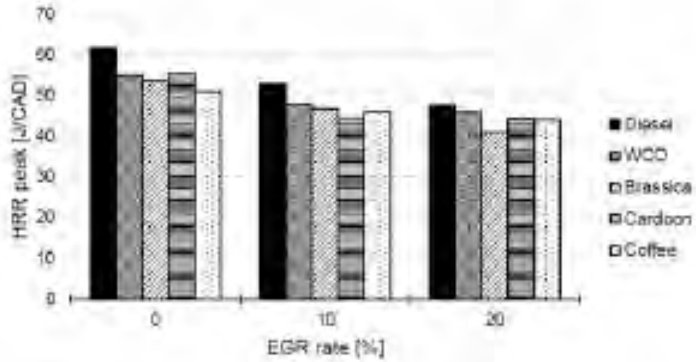
Low load

a



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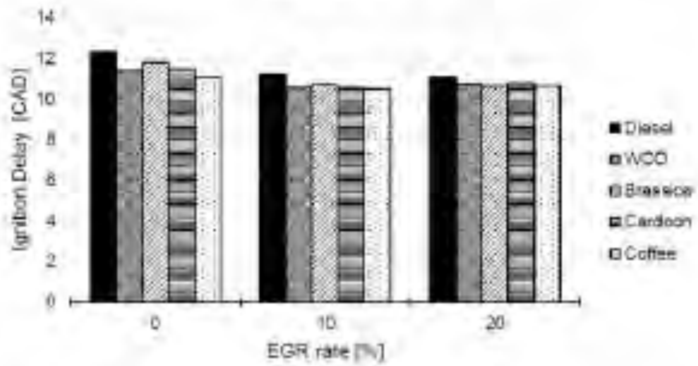

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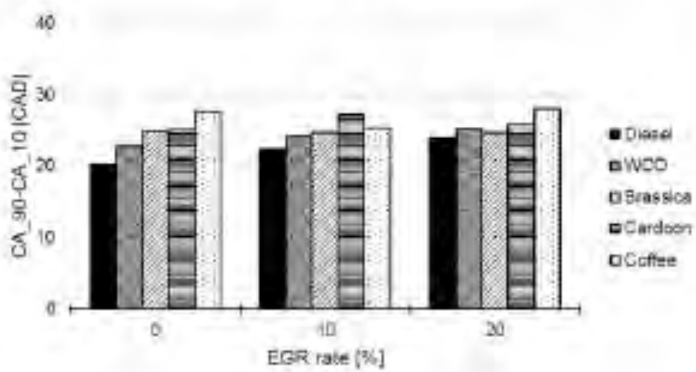
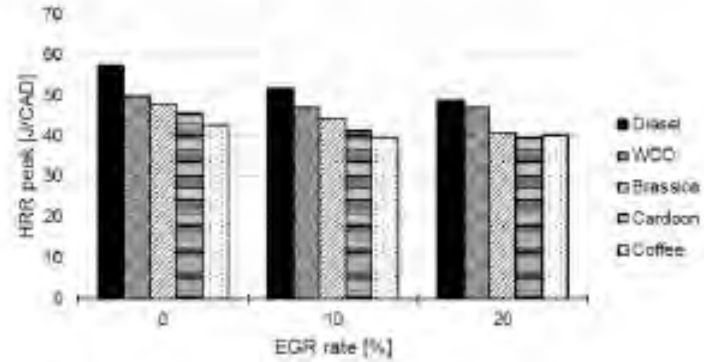


Medium load

b



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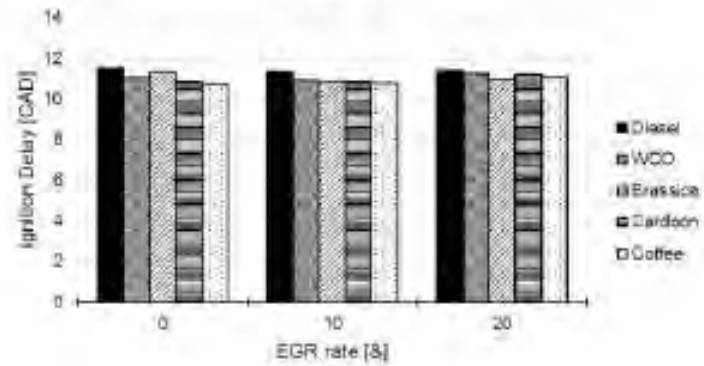

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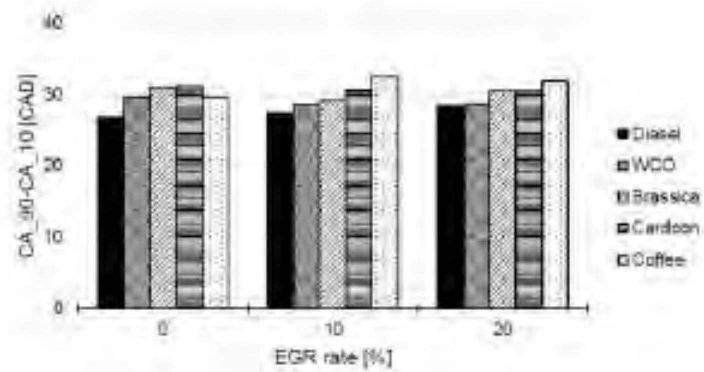

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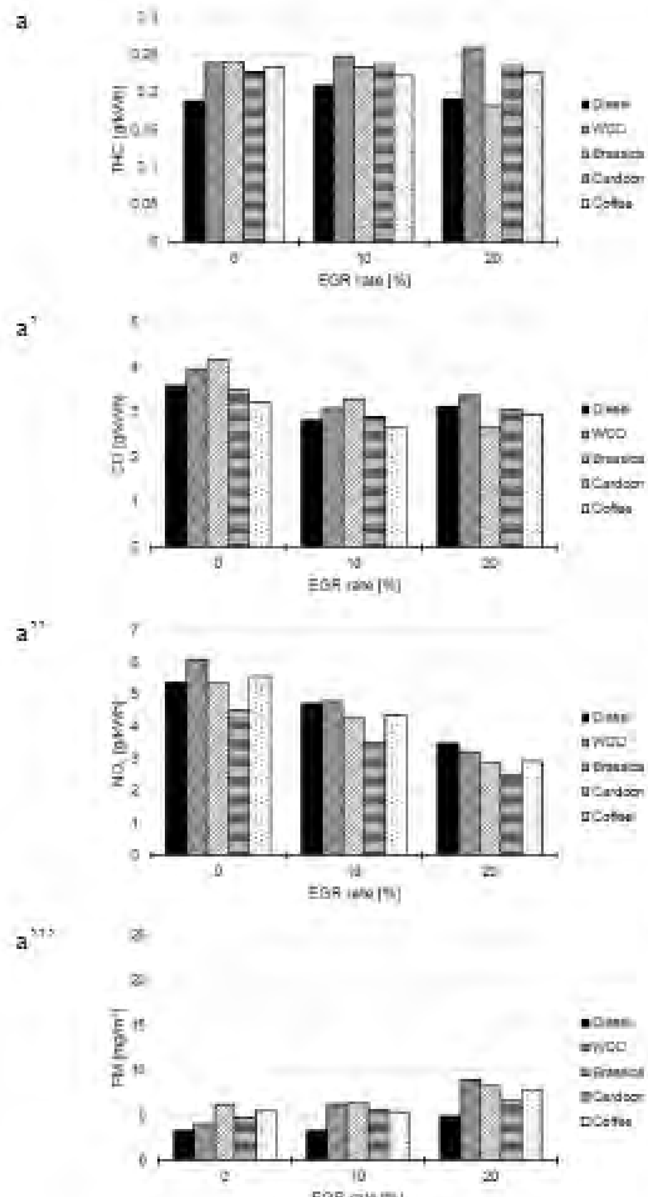
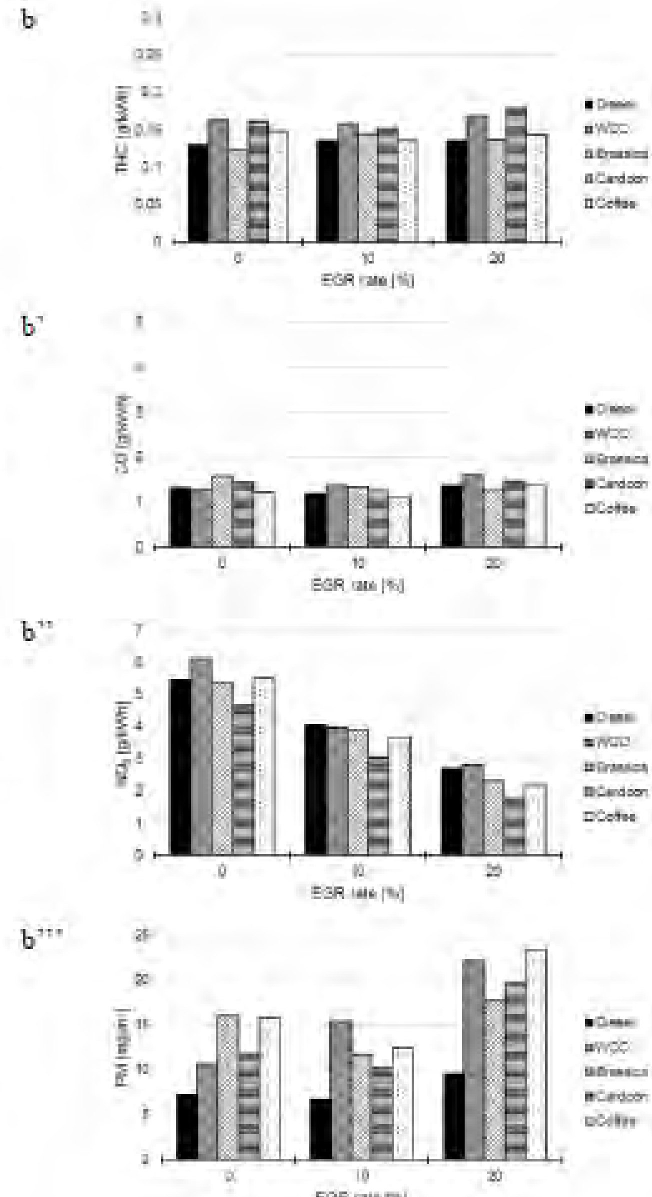
Low load



Medium load



Biodiesels in ICE

S. De Domenico, L. Strafella, L. D'Amico, M. Mastrorilli, A. Ficarella, A.P. Carlucci, A. Santino: "*Biodiesel production from Cynara cardunculus L. and Brassica carinata A. Braun seeds and their suitability as fuels in compression ignition engines*", **Italian Journal of Agronomy** 11-1 (2016) 47-56 (DOI: 10.4081/ija.2016.685) ISSN: eISSN 2039-6805.

F. Jaliliantabar, B. Ghobadian, A.P. Carlucci, G. Najafi, A. Ficarella, L. Strafella, A. Santino, S. de Domenico: "*Comparative evaluation of performance, emission and combustion characteristics of brassica, cardoon and coffee based biodiesels as fuel in a compression-ignition engine*", **Fuel** 222 (2018) 156-174 (DOI: 10.1016/j.fuel.2018.02.145) ISSN: 00162361.

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Outline

- Electrification
- Control oriented modeling
- Alternative fuels for CI engines
- Dual-fuel combustion
- Photo-thermal ignition

Dual-fuel combustion

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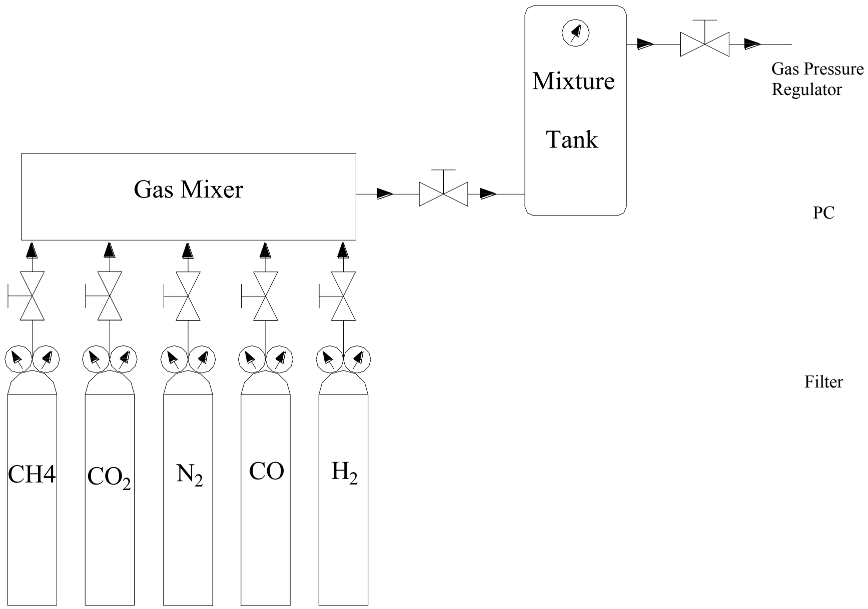

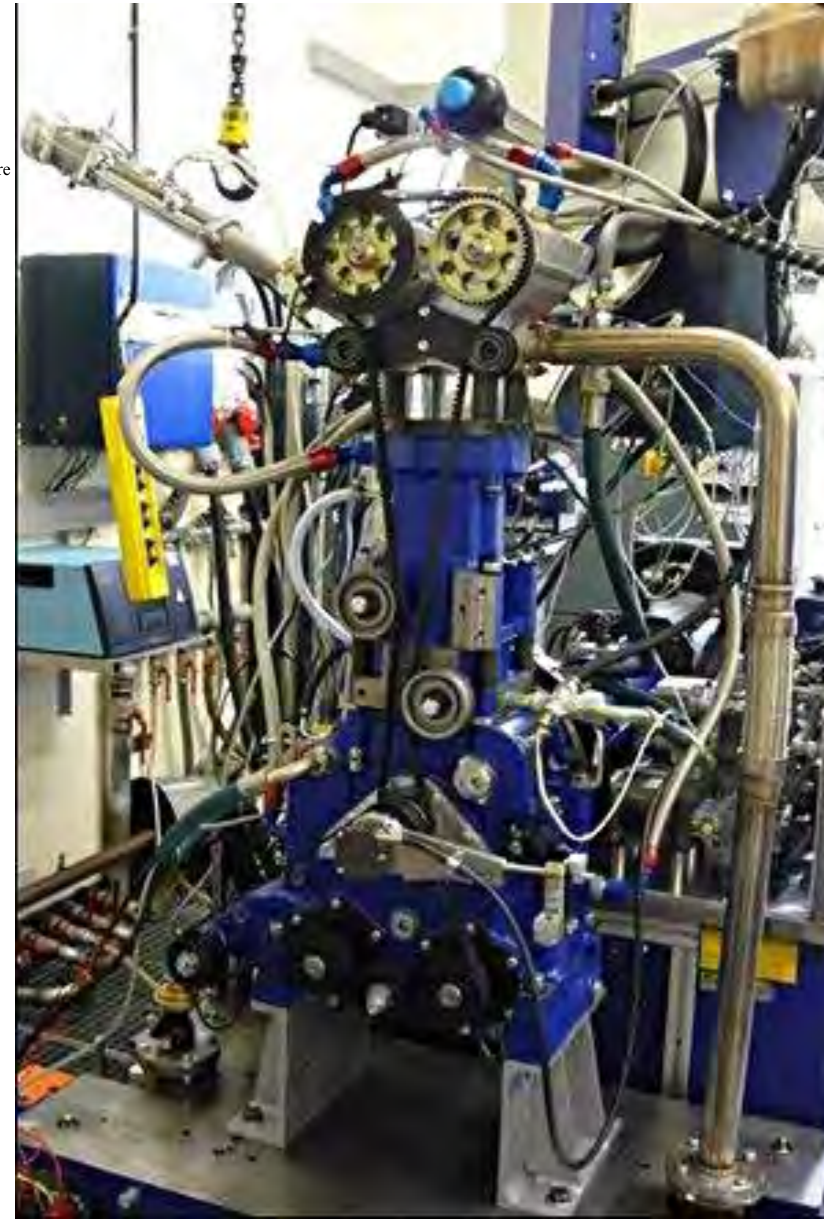

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Syngas DF – Splitting of diesel fuel injection

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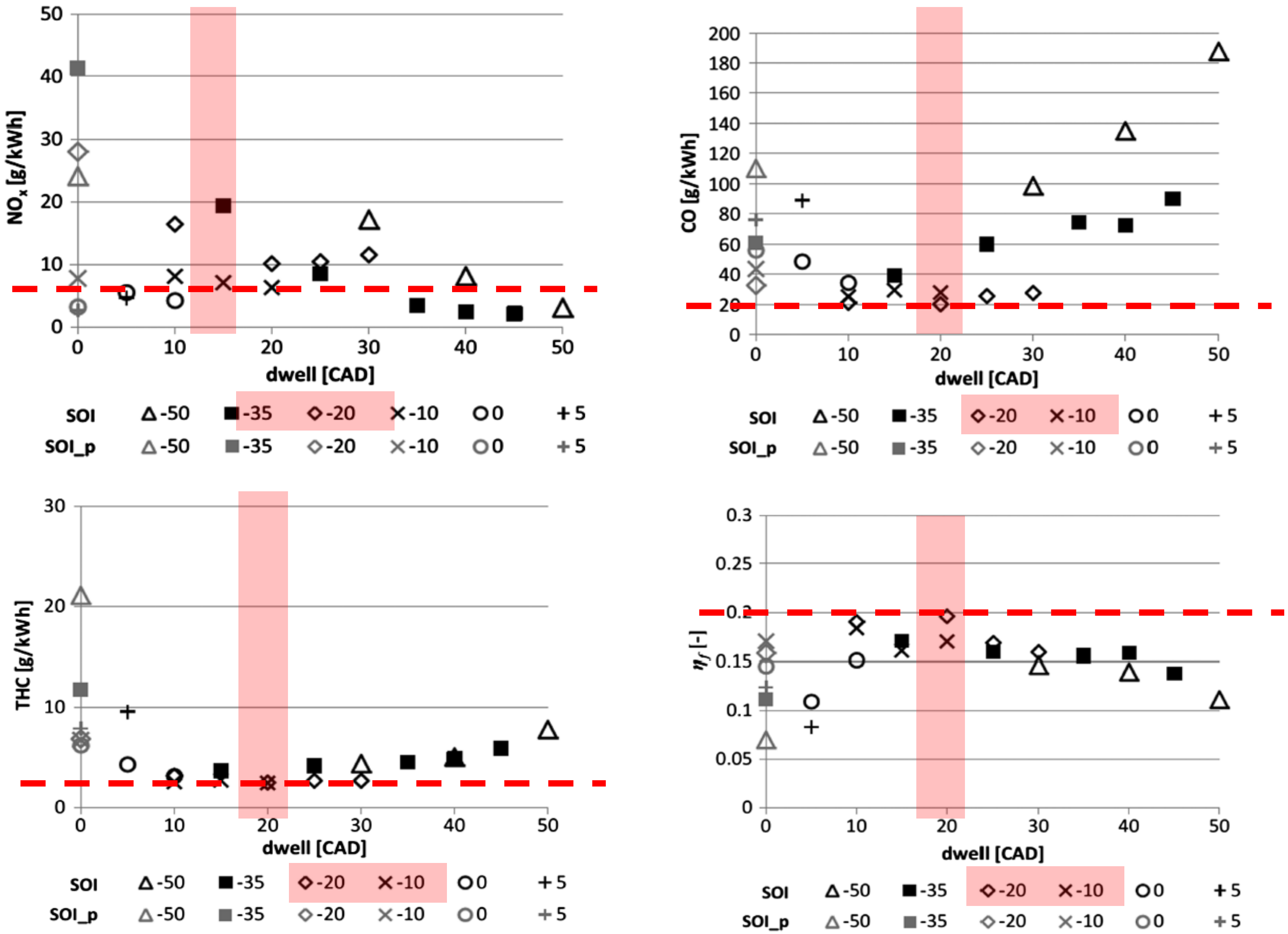

A.P. Carlucci, G. Colangelo, A. Ficarella, D. Laforgia, L. Strafella: "*Improvements in dual-fuel biodiesel-producer gas combustion at low load through pilot injection splitting*", **Journal of Energy Engineering** Volume 141, Issue 2 (2015)

P. Carlucci, D. Laforgia, A. Ficarella, L. Strafella: "*Improvement of a dual fuel biodiesel-producer gas engine performance acting on biodiesel injection parameters and strategy*", **Fuel** 209 (2017) 754-768

Methane DF – Splitting of diesel fuel injection

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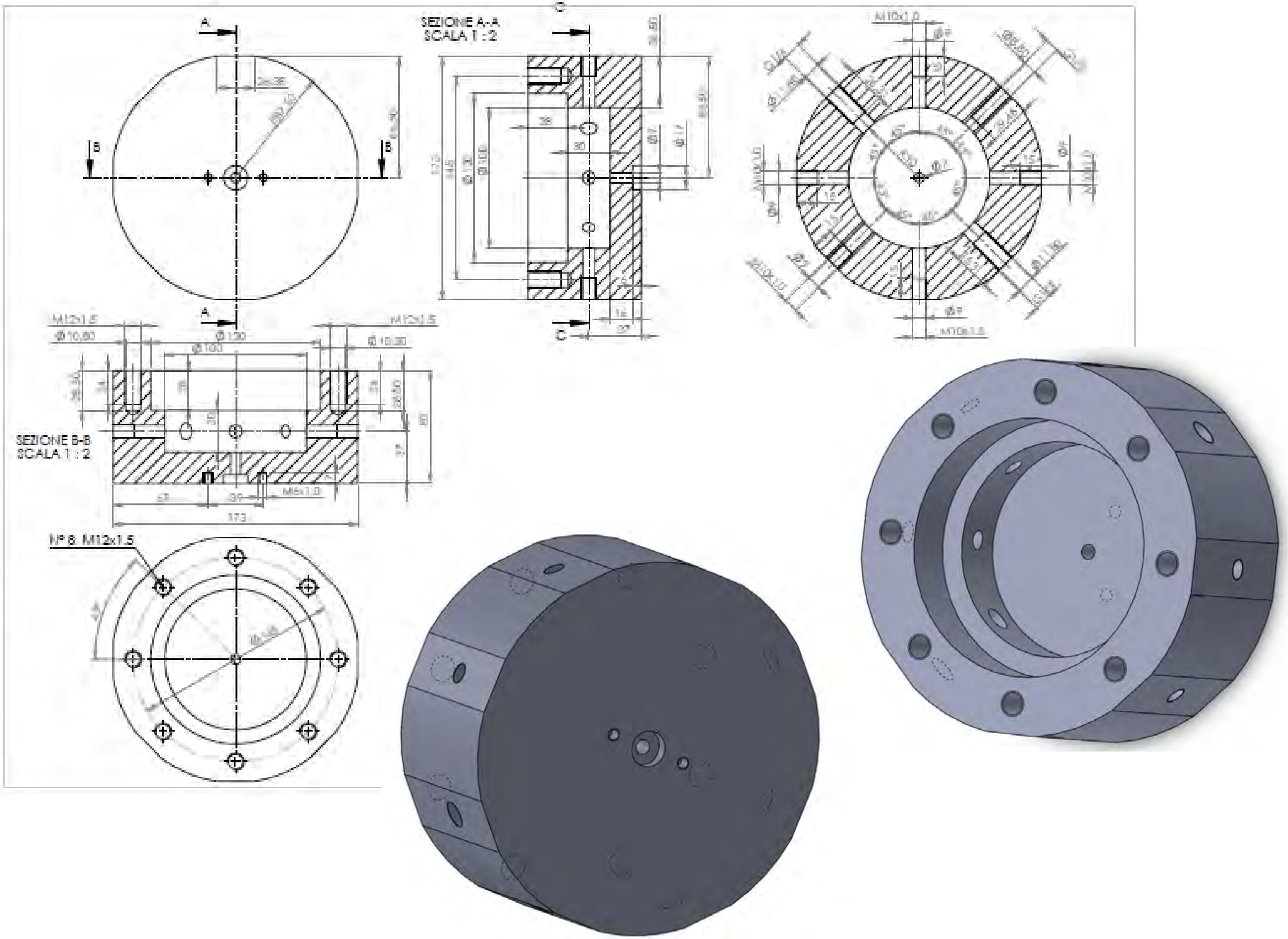

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Distributed ignition with nanotubes

with Dr. B. Chehroudi - Advanced Technology Consultants (www.AdvTechConsultants.com)

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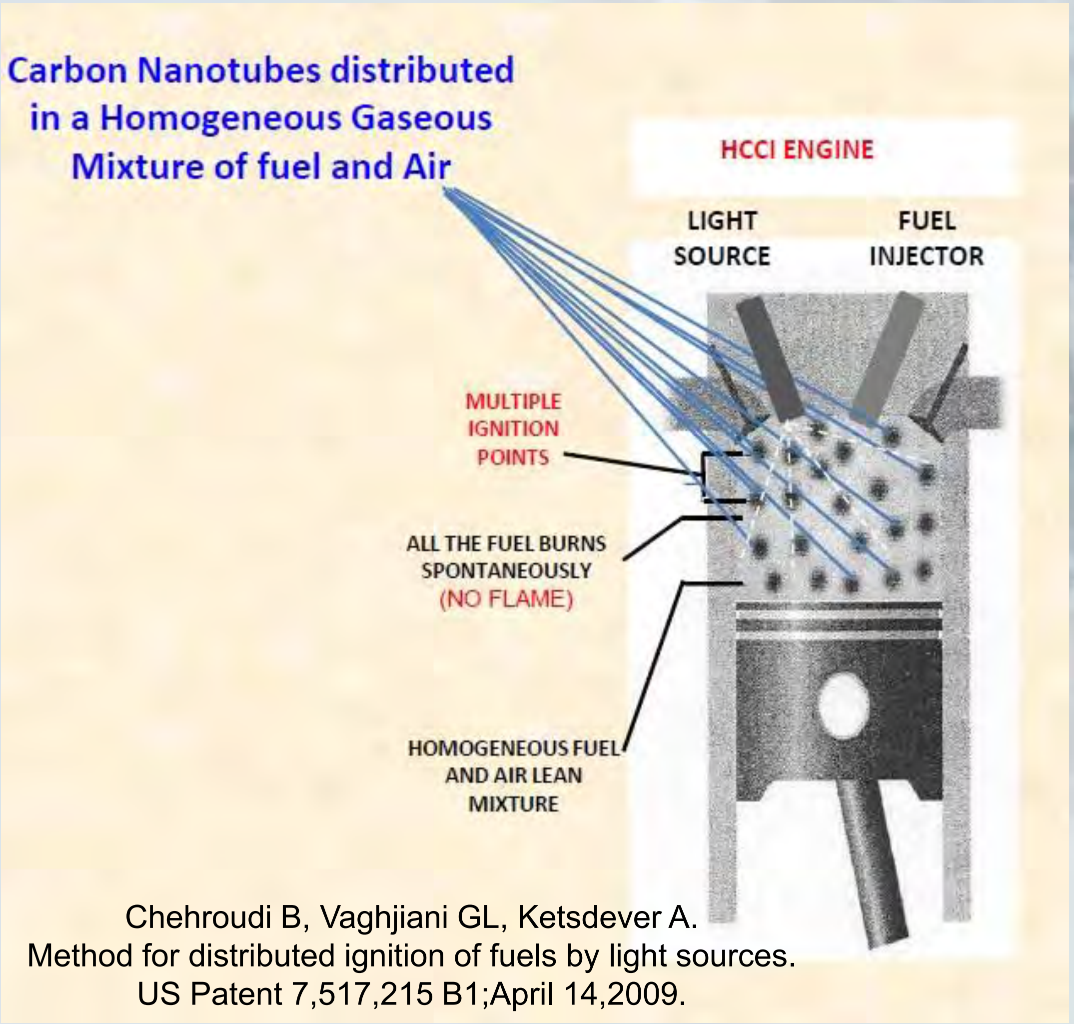
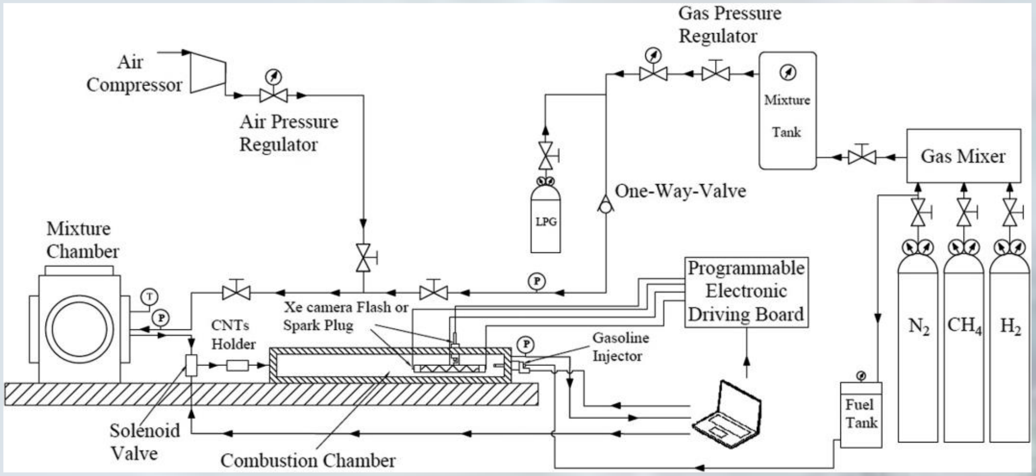
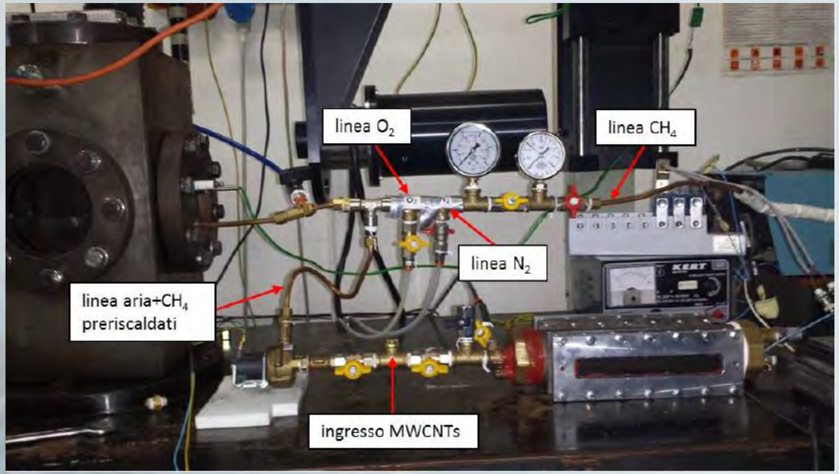


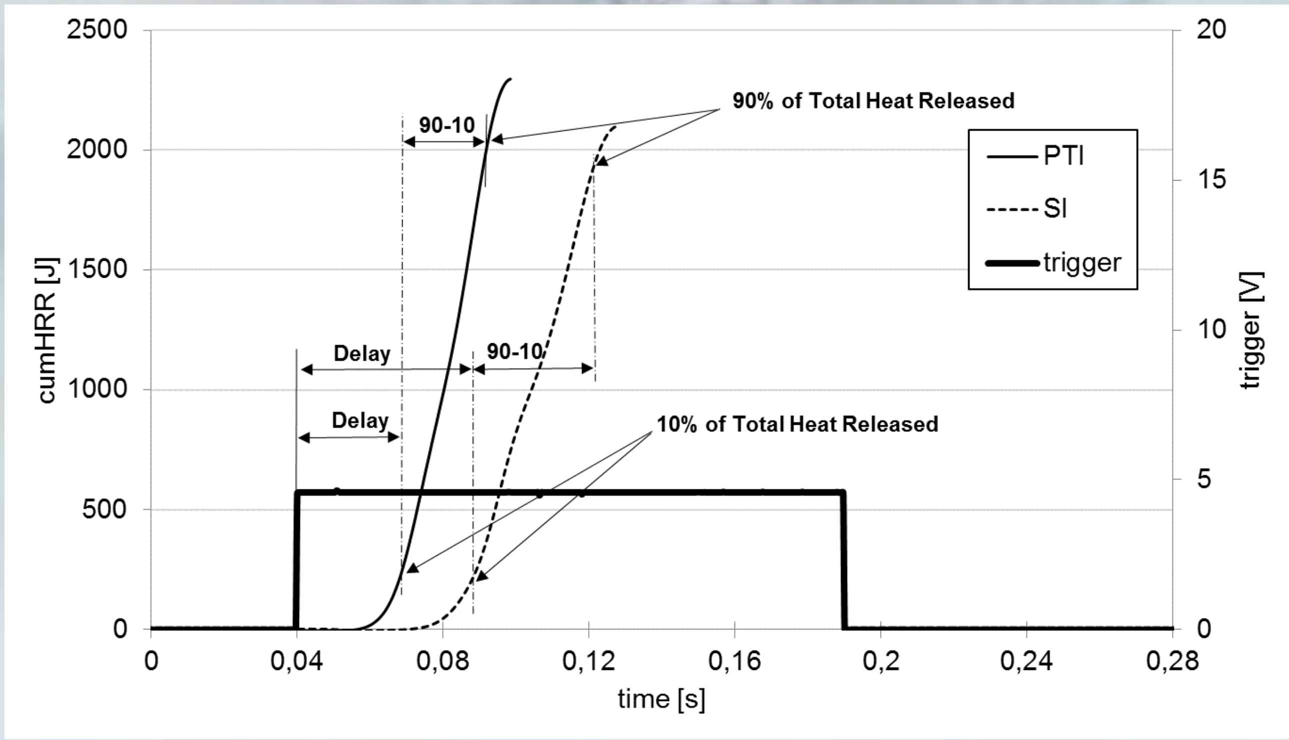
Chehroudi B, Vaghjiani GL, Ketsdever A.
Method for distributed ignition of fuels by light sources.
US Patent 7,517,215 B1;April 14,2009.

- Photo-ignition of CNT can be used to:
  - manages the HCCI combustion process
  - On-demand autoignition of homogeneous gaseouse air-fuel mixture
- **Photo-ignition of CNT is a new technology for a precise control/initiation of autoignition process in HCCI engines**
- **Other possible applications: DPF more uniform regeneration**

Distributed ignition with nanotubes



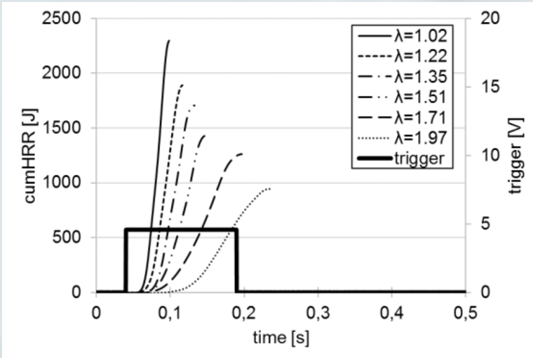


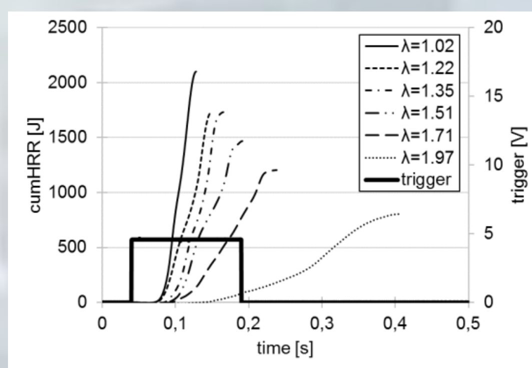


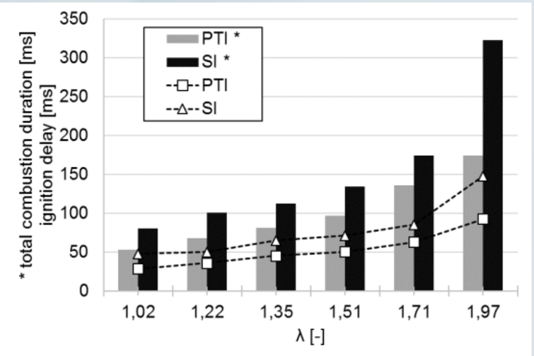
Distributed ignition with nanotubes

PTI | SI | Comparison

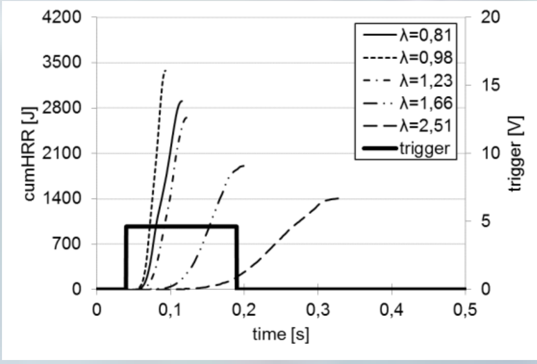
CH_4

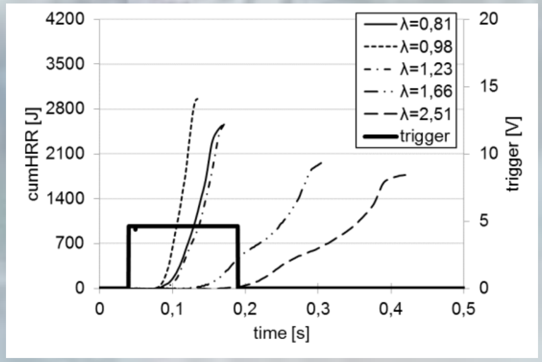


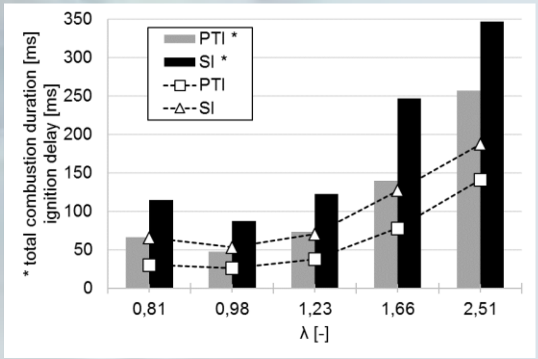




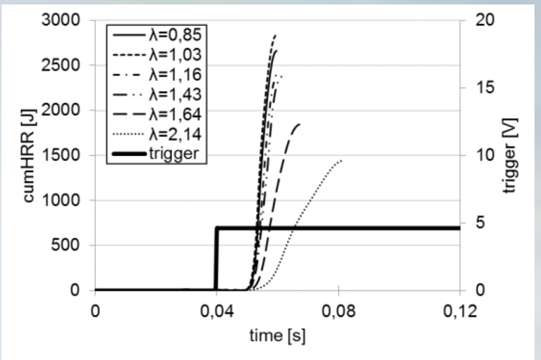
LPG

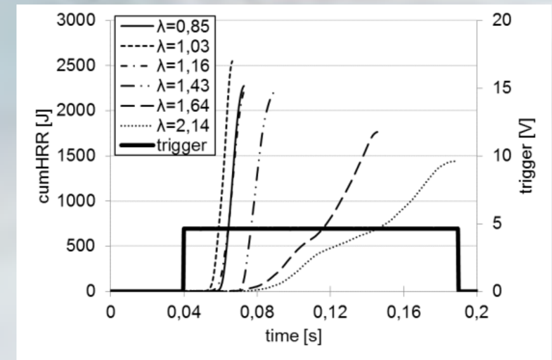


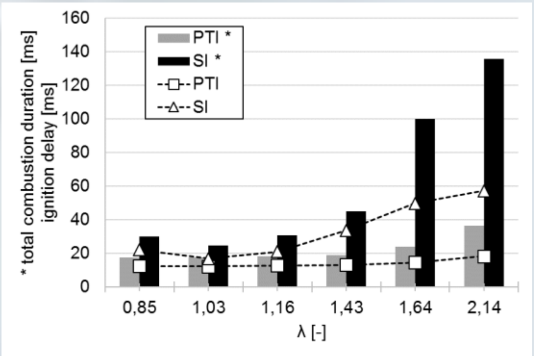




H_2







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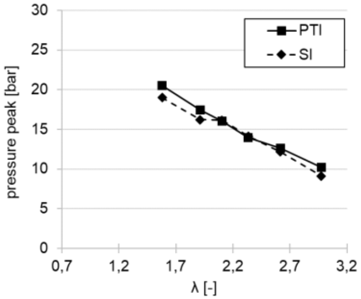
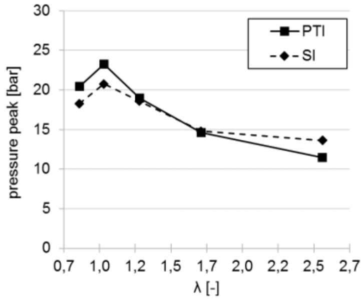
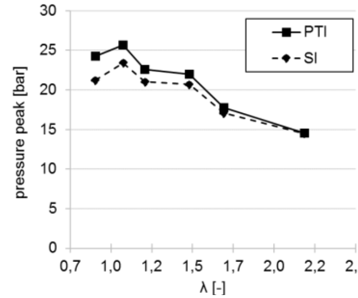
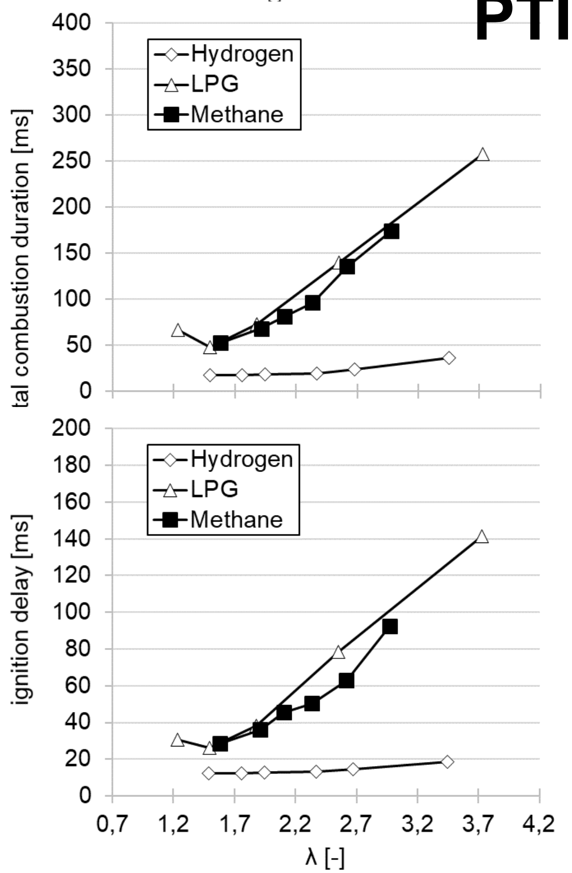
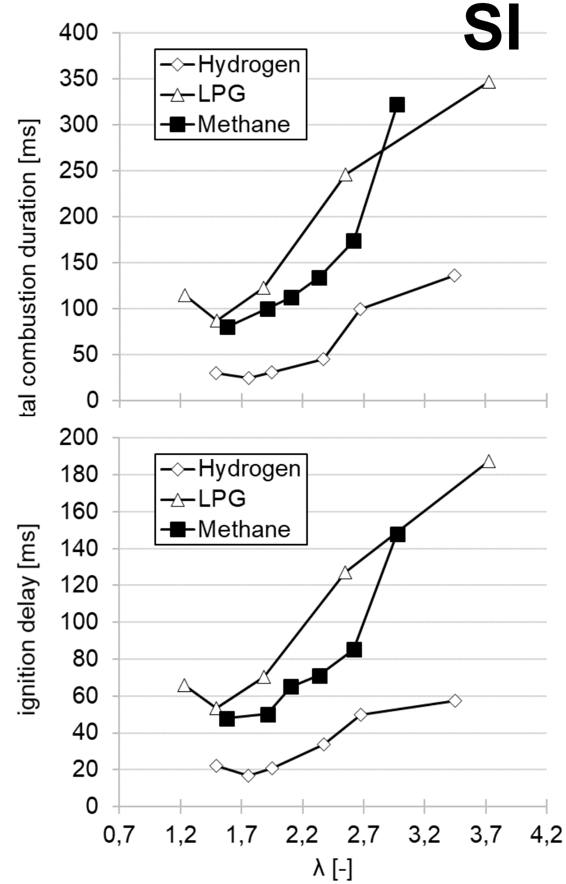
CH_4 LPG H_2


PTI
SI
pressure peak [bar]
λ [-]


PTI
SI
pressure peak [bar]
λ [-]


PTI
SI
pressure peak [bar]
λ [-]

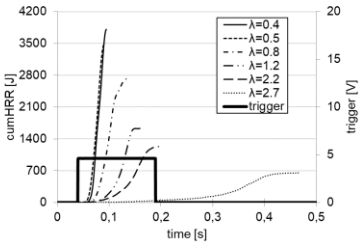

PTI
Hydrogen
LPG
Methane
tal combustion duration [ms]
ignition delay [ms]
λ [-]

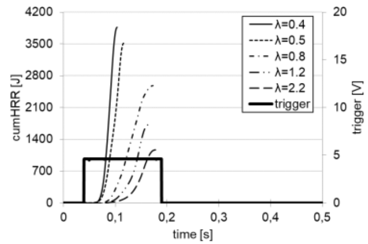

SI
Hydrogen
LPG
Methane
tal combustion duration [ms]
ignition delay [ms]
λ [-]

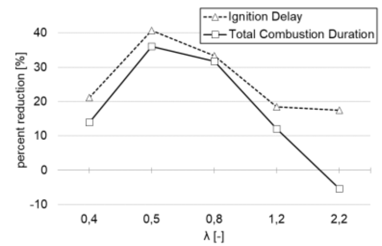
PTI

SI

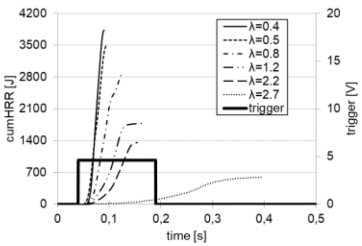
0 ms

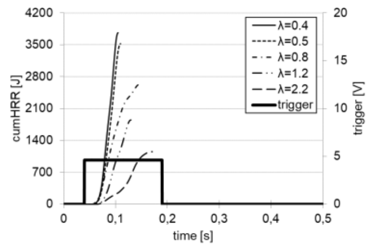


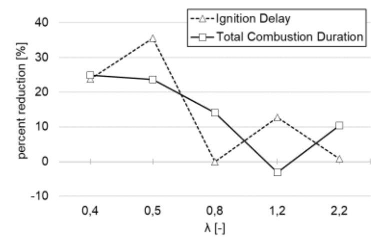


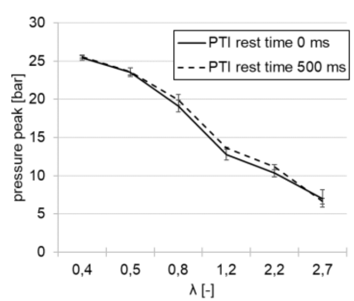


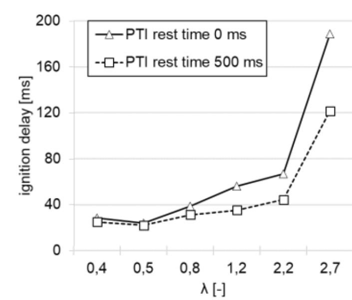
500 ms

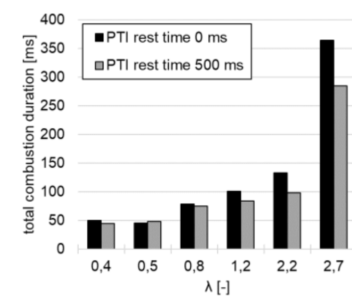


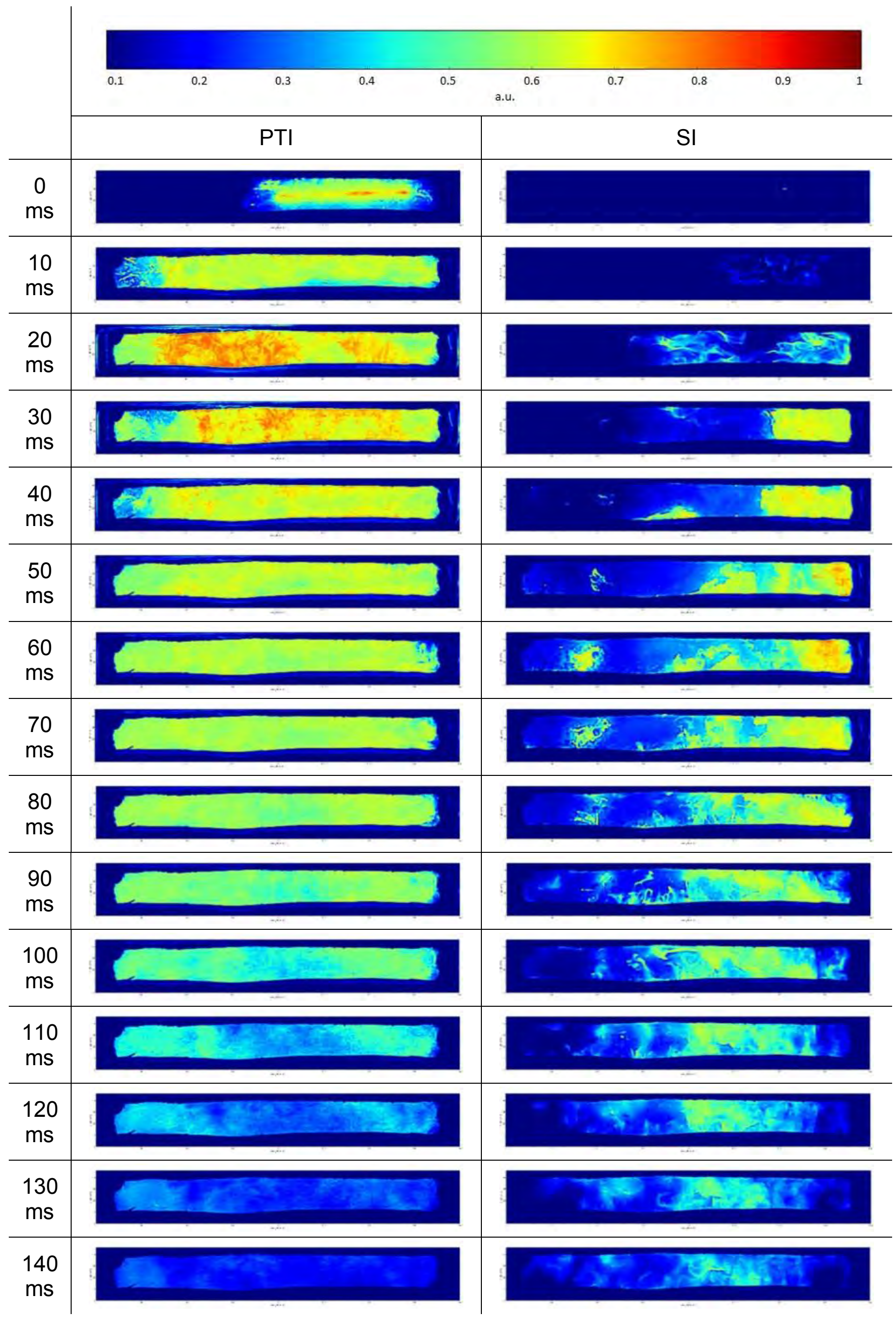











0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
a.u.
PTI
SI
0 ms
10 ms
20 ms
30 ms
40 ms
50 ms
60 ms
70 ms
80 ms
90 ms
100 ms
110 ms
120 ms
130 ms
140 ms

Carlucci, A.P., Visconti, P., Primiceri, P., Strafella, L., Ficarella, A., Laforgia, D.: "*Photo-Induced Ignition of Different Gaseous Fuels Using Carbon Nanotubes Mixed with Metal Nanoparticles as Ignitor Agents*", Combustion Science and Technology, 2017, Volume 189, Issue 6, pp. 937-953.

A.P. Carlucci, G. Ciccarella, L. Strafella: "*Multi-Walled Carbon Nanotubes (MWCNTs) as ignition agents for air/methane mixtures*", **IEEE Transactions on Nanotechnology** Volume 15, Issue 5, September 2016, Article number 7347419, Pages 699-704 (DOI: 10.1109/TNANO.2015.2505907) ISSN: 1536-125X.

A. Ficarella, A.P. Carlucci, B. Chehroudi, D. Laforgia, L. Strafella: "*Multi-Walled Carbon Nanotubes (MWCNTs) Bonded with Iron Particles as Ignition Agents for Air-Fuel Mixtures*", **Fuel** 208 (2017) 734-745

Carlucci, A.P., Visconti, P., Primiceri, P., Strafella, L., Ficarella, A., Laforgia, D.: "*Photo-Induced Ignition of Different Gaseous Fuels Using Carbon Nanotubes Mixed with Metal Nanoparticles as Ignitor Agents*", Combustion Science and Technology, 2017, Volume 189, Issue 6, pp. 937-953.

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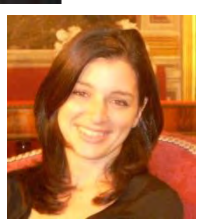

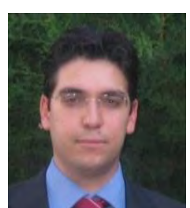

Grazie!

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