Giornata di studio:

«IDROGENO E TECNOLOGIE PER LA GENERAZIONE ENERGETICA E LA PROPULSIONE NEI TRASPORTI GREEN»

Genova 25 Gennaio 2024

Il ruolo della simulazione fluidodinamica nello sviluppo delle tecnologie legate all'idrogeno per la mobilità sostenibile.

Le attività di ricerca dell'Università di Modena e Reggio Emilia.

Massimo Borghi, Alessandro d'Adamo, Stefano Fontanesi, Enrico Mattarelli, Carlo Alberto Rinaldini, Fabio Berni, Sebastiano Breda

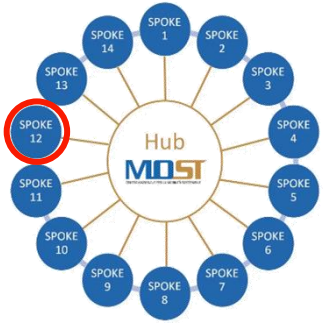
UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Dipartimento di Ingegneria "Enzo Ferrari"

SPOKE 12

«Innovative Propulsion Systems»

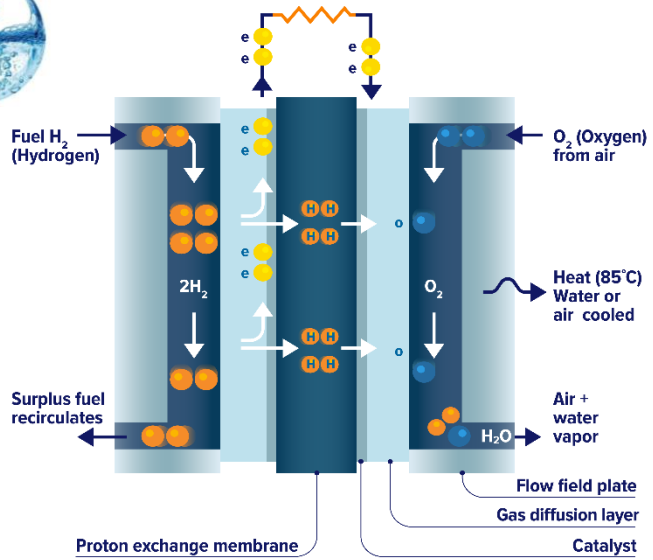
WP5: Virtual/Integration/LCA



- modelling and simulation to gain a better understanding on component-level complex phenomena, for the identification of strengths and weaknesses.
- modelling and simulation at system-level, to investigate the complex interplay of systems and sub-systems.
- digital twins of the most promising solutions to be delivered to the industrial partners at much lower cost and with much shorter times than the experimental practice would do.
- impact of the proposed propulsion technologies on sustainability and life-cycle based effectiveness.

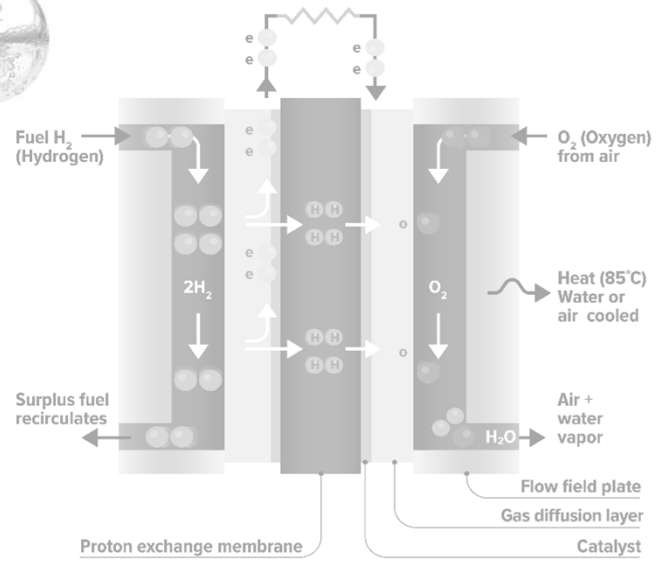
Internal combustion engines

Fuel cells



Internal combustion engines

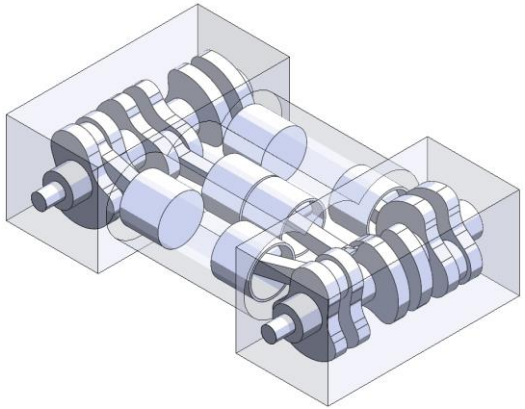
Fuel cells

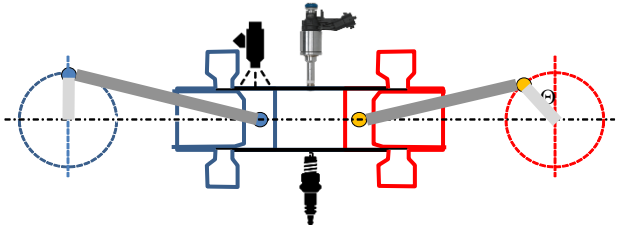


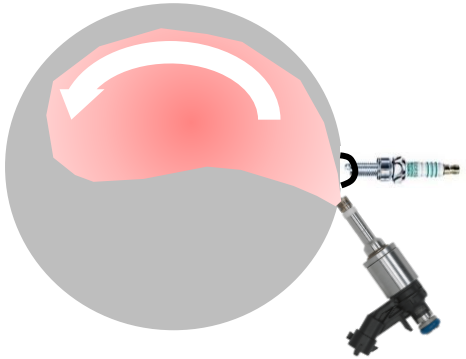
Development of a high-performance H2 fueled engine:

- Overall/Specific Target Power > 1000 Cv / 150 Cv/l
- Reduced Overall Engine size (limited space for H2 storage)

Two stroke, Opposed piston Engine





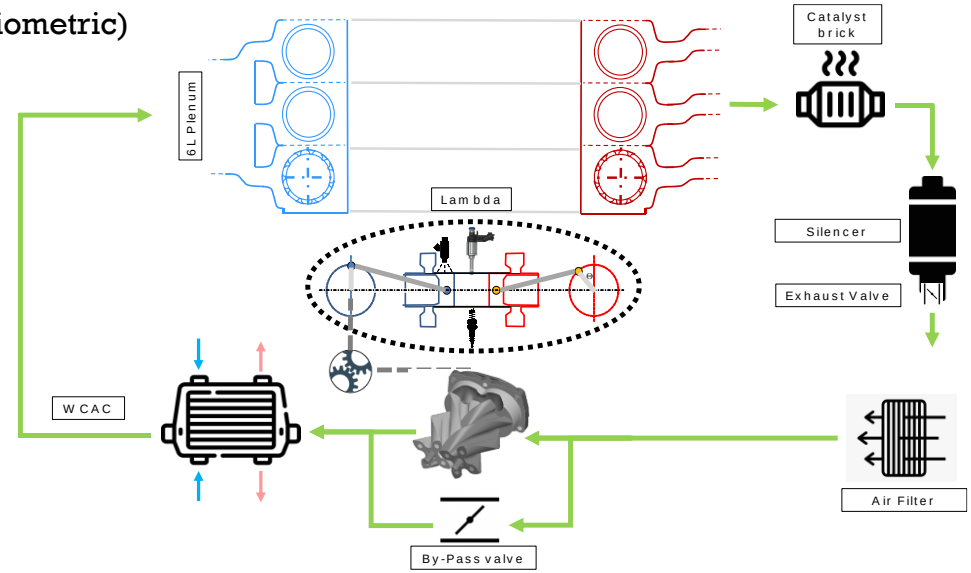


Digital Twin

Development of a high-performance H2 fueled engine:

1D Engine modelling

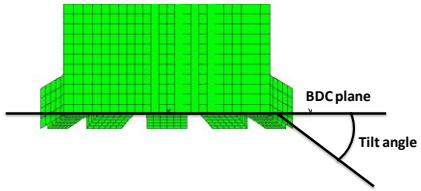
- Approximate engine sizing for target performance
- Engine Layout definition (turbocharging, supercharging)
- Definition of Operating conditions (Ultra-Lean Vs Stoichiometric)
- Water injection definition
- Estimation of Fuel/Water consumption
- Engine control strategy at part load operations

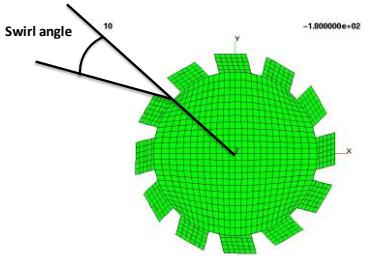


Volza, A., Scrignoli, F., Caprioli, S., Mattarelli, E. et al., "Exploring the Potential of Hydrogen Opposed Piston Engines for Single- Cylinder Electric Generators: A Computational Study," SAE Technical Paper, 2023

Development of a high-performance H2 fueled engine:

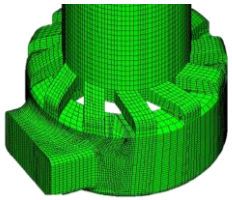
Scavenging Characterization and Port Geometry optimization





ANALISI LAVAGGIO

Workflow



GAMMA TECHNOLOGIES

Boundary conditions dal modello 1D-CFD (offset 0° tra gli alberi)

Definizione della matrice DoE
Tilt Angle: [0-30] deg ogni 5°
Swirl Angle: [0-30] deg ogni 5°

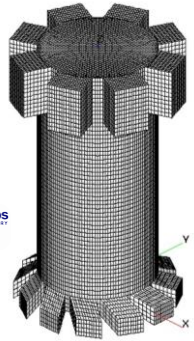
Creazione di uno script in KIVA-3V per la generazione di differenti mesh al variare di Swirl & Titl angle

Los Alamos NATIONAL LABORATORY
KIVA-3V

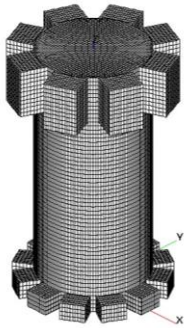
Calcoli e check sulle masse intrappolate nel cilindro modificando le BC's

Profili di scavenging aggiornati

Creazione di uno script in MATLAB per l'analisi dei risultati



Tilt Angle = 30°
Swirl Angle = 30°



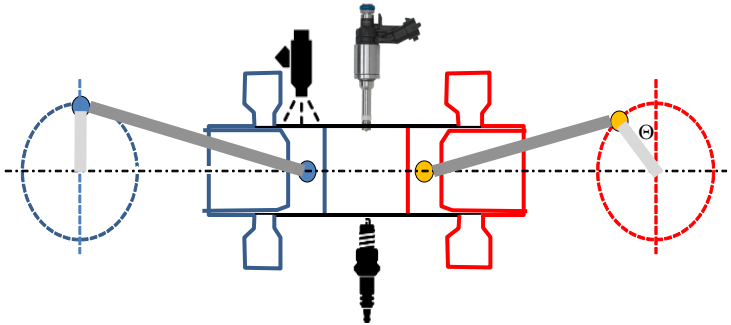
Tilt Angle = 0°
Swirl Angle = 0°

MATLAB

Development of a high-performance H2 fueled engine:

3D CFD Engine modelling: Ongoing

- Detailed characterization of scavenging process
- H2 Injection and mixing optimization
- Combustion simulations and performance analysis
- Abnormal combustion and pre-ignition prediction
- Water injection definition and optimization



Model validation is mandatory for the realization of a reliable Opposed piston Engine digital Twin

Development and Validation of CFD models and methodologies for H2 ICEs

Identify an accurate numerical framework for the analysis of high-pressure H_2 jets and their spatial/temporal evolution.

Validate the methodology against vessel experiments.

SENSITIVITY ANALYSIS

Impact of grid size, time step, EoS, physical properties, numerics, injector design, injector operation

⇩

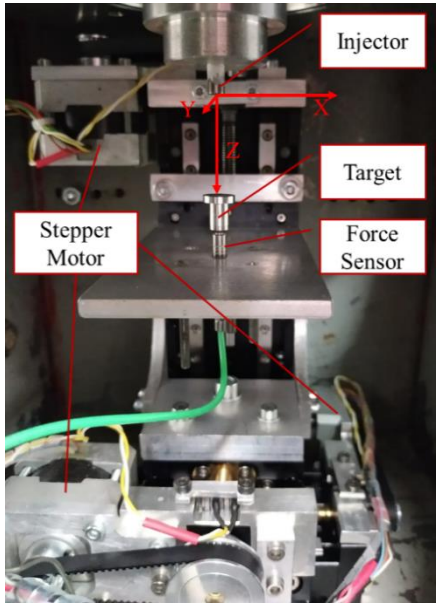
VALIDATION

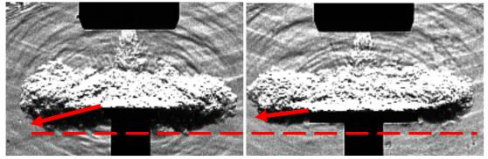
Identification of available measurements

⇩

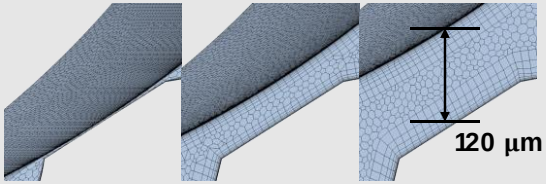
GAPS

Identification of current gaps/roadblocks

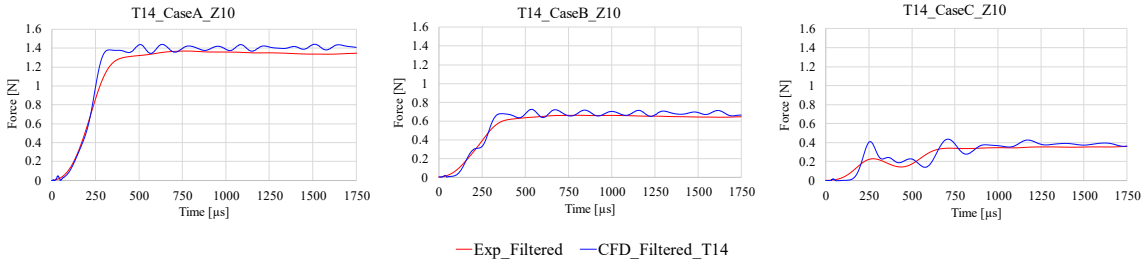




Target Diameter [mm]:	7; 8; 9; 10; 12; 14; 20				
Z Distance (injector tip-target) [mm]:				10	
Test	P_{inj} [bar,a]	T_{inj} [K]	P_{vessel} [bar,a]	P_{inj}/P_{vessel}	ET [ms]
A	40	298	1	40	5
B	20	298	1	20	5
C	20	298	10	2	5



Detailed meshing of the needle geometry to correctly capture the injector opening transient: Well predicted transient force signal



Postrioti L., Martino M., Fontanesi S., Breda S., Magnani M., "Experimental and Numerical Momentum Flux Analysis of Jets from a Hydrogen Injector". Accepted: WCX 2024 Detroit

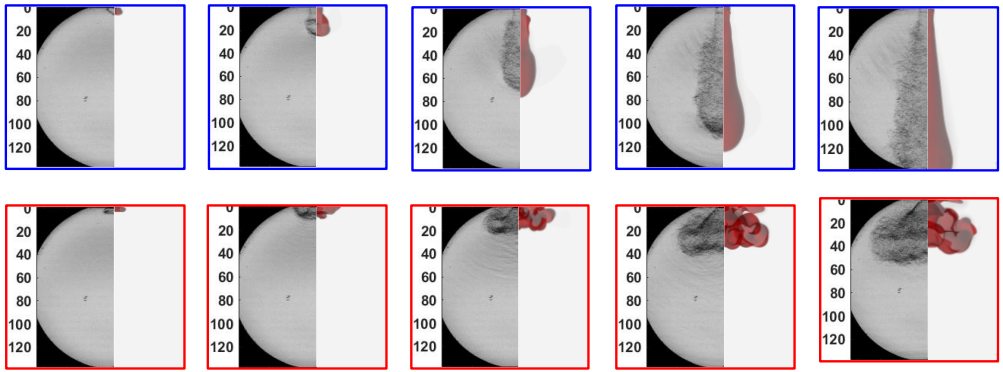
Development and Validation of CFD models and methodologies for H2 ICEs

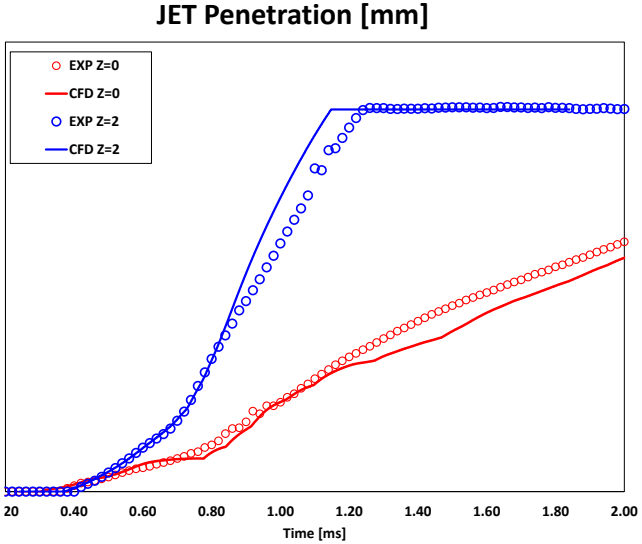
Identify an accurate numerical framework for the analysis of high-pressure H_2 jets and their spatial/temporal evolution.

Validate the methodology against vessel experiments.

Pintle H2 injector

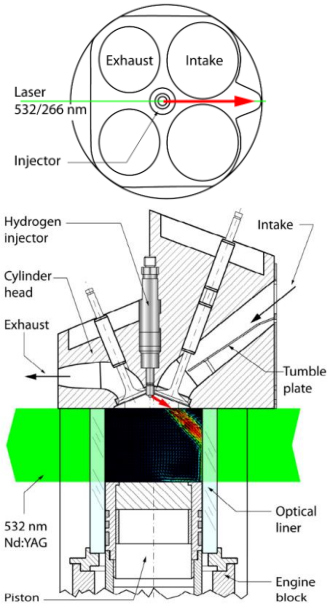
Different axial locations



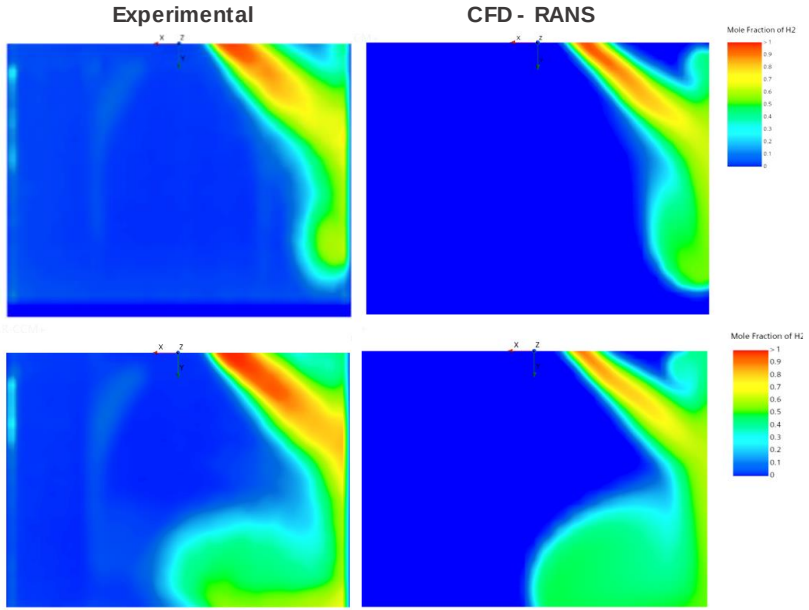


Development and Validation of CFD models and methodologies for H2 ICEs

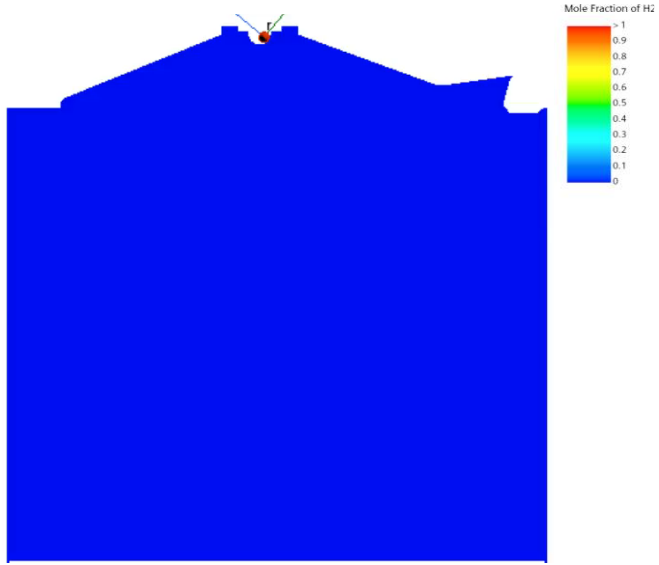
CFD/EXP correlation of **Air/hydrogen mixing** in RANS and LES framework: **SOpHy Engine** from SANDIA National Laboratories



RANS



Ongoing: simulation of several consecutive cycles using LES turbulece models

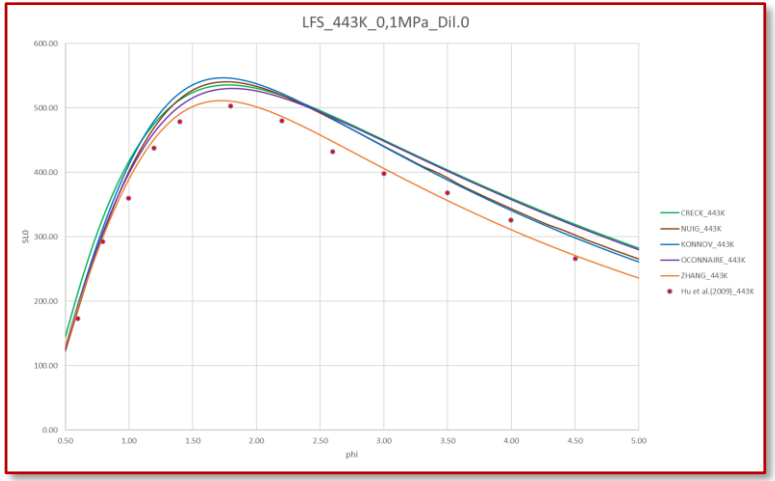


Development and Validation of CFD models and methodologies for H2 ICEs

SCOPE: Identify chemical kinetics mechanisms for the definition of unstretched laminar flame speed of H2/air mixtures at typical ICE operating conditions.

SYSTEMATIC LITERATURE REVIEW Identify, select, evaluate, and compare available mechanisms

VALIDATION: Identification of available measurements



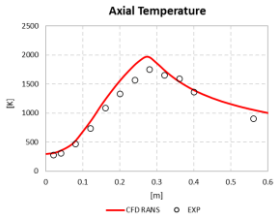
SCOPE: Characterization of H2 flame characteristics to improve reliability of 3D CFD combustion simulations in both RANS and LES framework

Flame H3

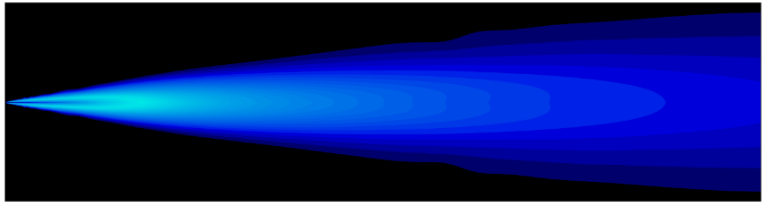
Fuel: H2

Exp. Data from SANDIA National Laboratories

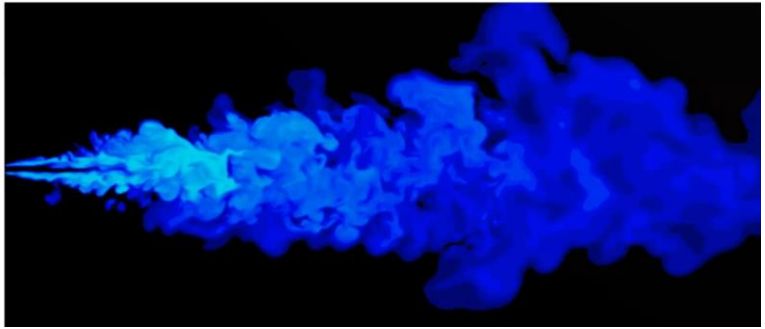
Validation of chemical mechanisms



RANS

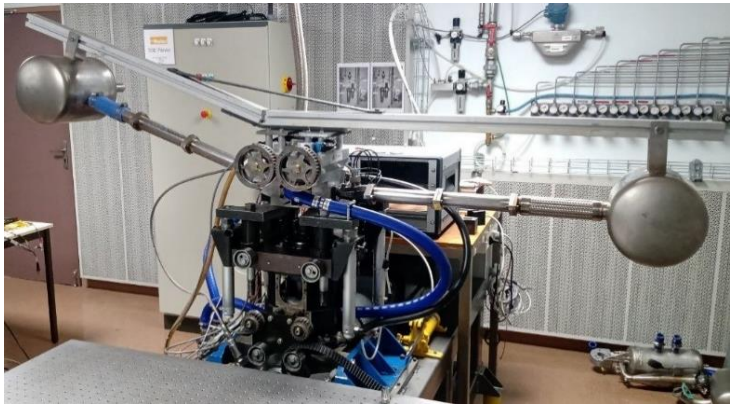


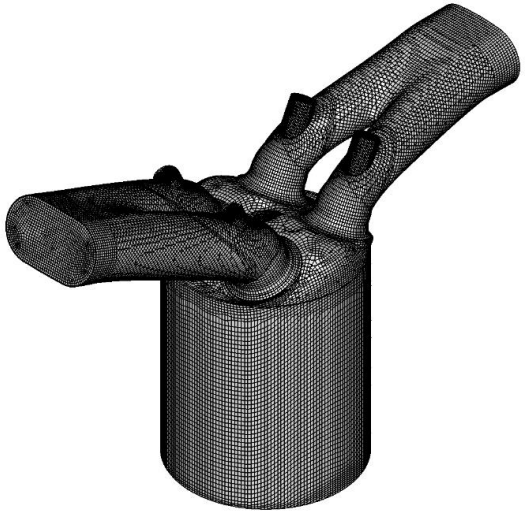
LES



Development and Validation of CFD models and methodologies for H2 ICEs

Validation of Engine combustion simulations in an optical engine operated with **fully premixed Air/H2 mixture** up to very lean operations





Φ	Ignition [CA BTDC]	Intake temperature [K]	Exhaust temperature [K]	Average intake pressure [bar]	rpm	CoV IMEP [%]
0.3	-15	295.65	595.99	0.7	1500	4.875
0.35	-15	295.65	608.57	0.7	1500	2.144
0.4	-15	295.75	623.66	0.7	1500	1.37
0.45	-15	295.85	634.97	0.7	1500	0.966
0.5	-15	295.95	658.40	0.7	1500	1.174
0.55	-15	295.95	666.15	0.7	1500	1.508

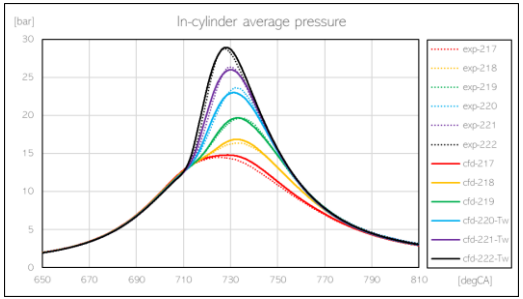
Activity in cooperation with

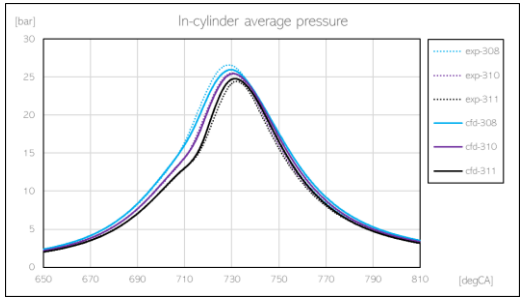
PSA GROUPE

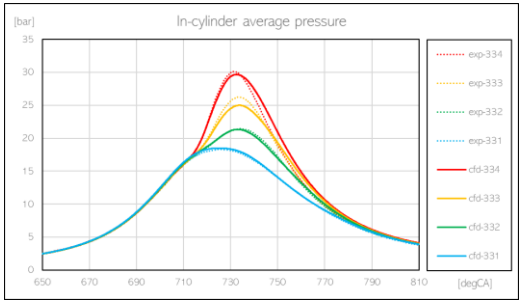
PRISME

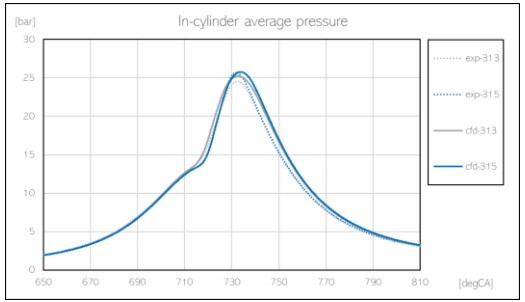
Development and Validation of CFD models and methodologies for H2 ICEs

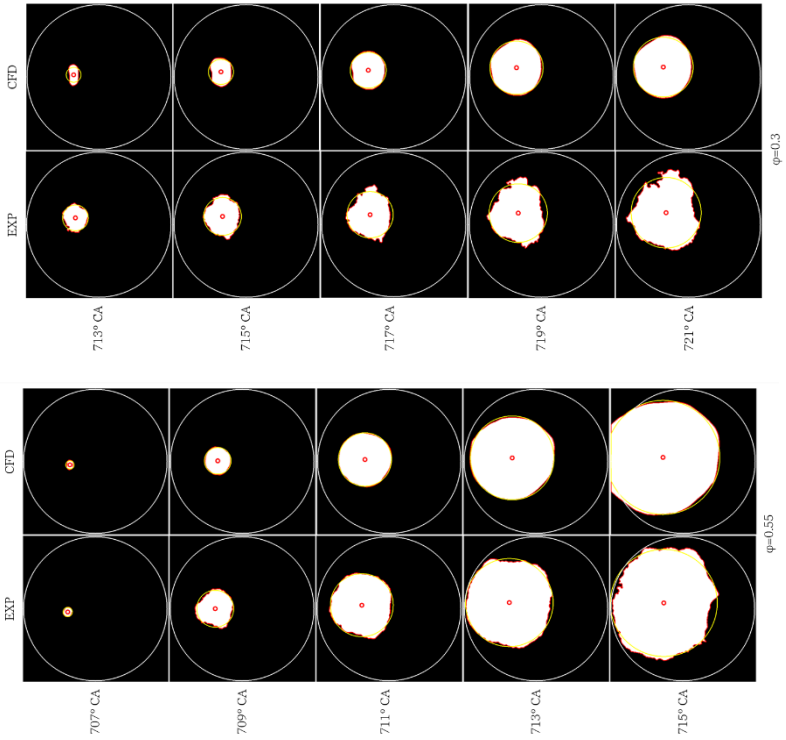
Validation of Engine combustion simulations in an optical engine operated with **fully premixed Air/H2 mixture** up to very lean operations









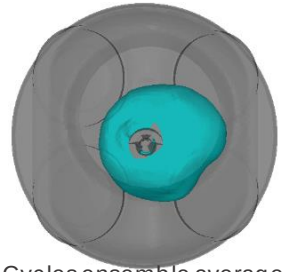


Sfriso S., Berni F., Breda S., Fontanesi S., Ramalho Leite C., Brequigny P., Foucher F., « Proposal and validation of 3D-CFD framework for ultra-lean hydrogen combustion in ICEs", Accepted: WCX 2024 Detroit

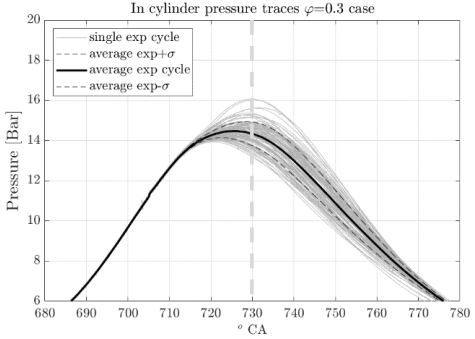
Development and Validation of CFD models and methodologies for H2 ICEs

Ongoing: Study of H2 engine CCV in fully premixed condition trough LES

RANS



Cycles ensemble average



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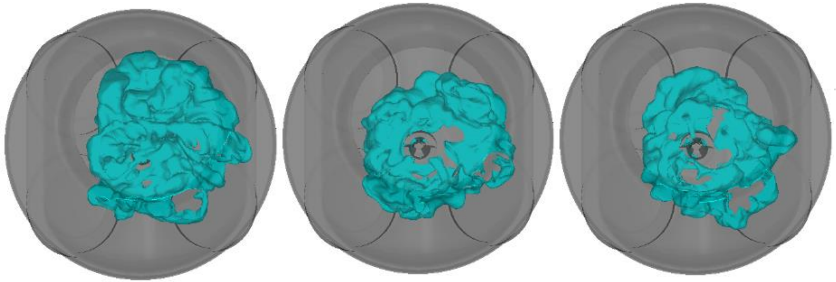
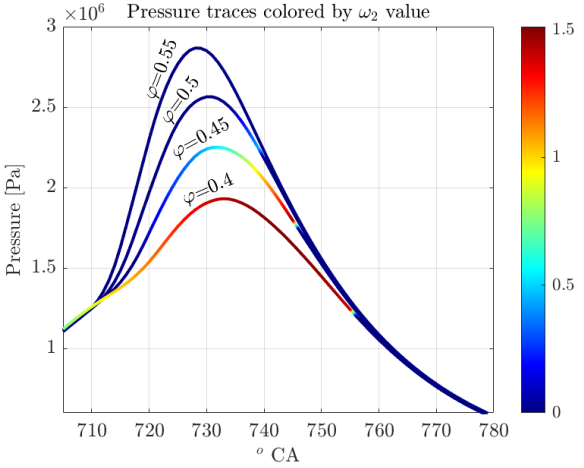
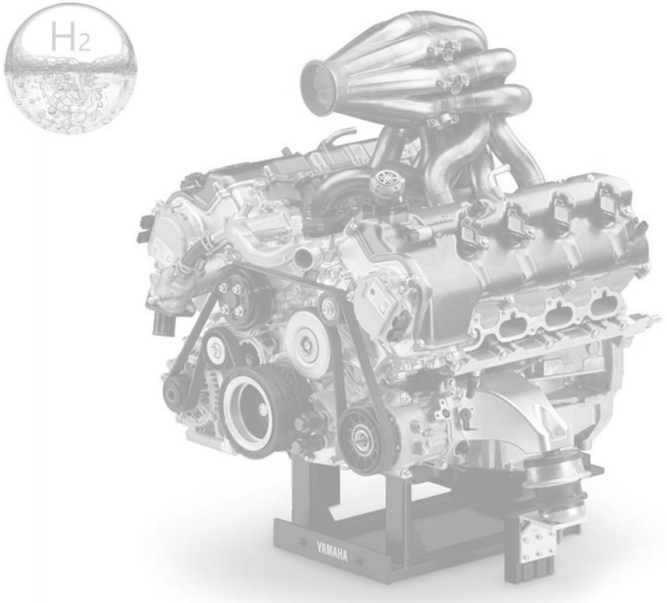


Ongoing: Development/Implementation of flame speed correction function accounting for flame acceleration in lean conditions due to flame instabilities

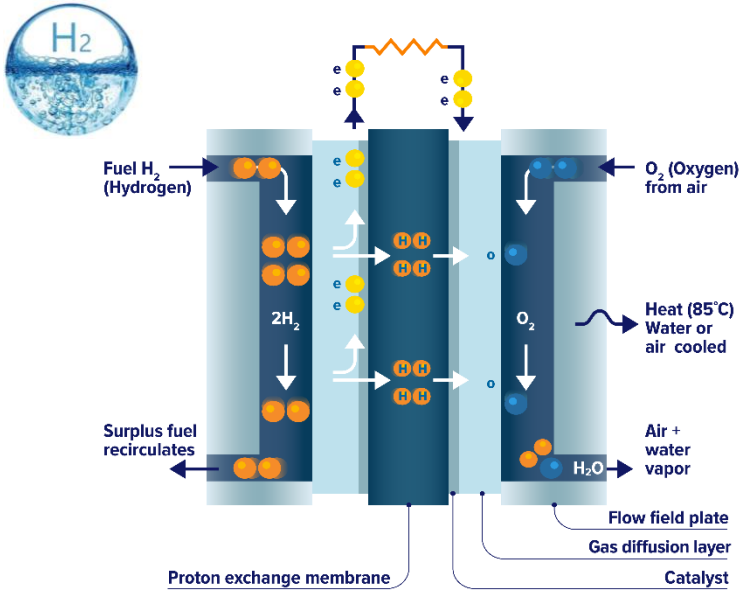


Sfriso S., Berni F., Breda S., Fontanesi S., Ramalho Leite C., Brequigny P., Foucher F., « Proposal and validation of 3D-CFD framework for ultra-lean hydrogen combustion in ICEs", Accepted: WCX 2024 Detroit

Internal combustion engines

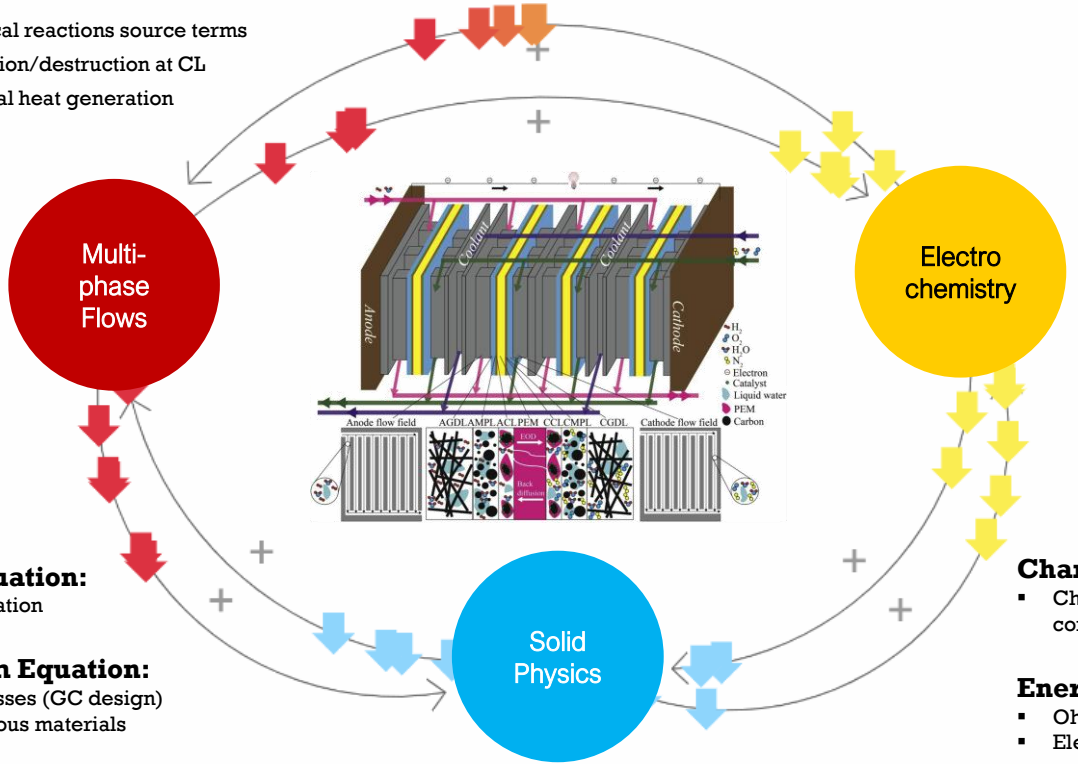


Fuel cells



Development and Validation of CFD models for detailed modelling of PEM fuel cells

Species Equation: Electro-chemical reactions source terms
Continuity Equation: Mass creation/destruction at CL
Energy Equation: Electro-chemical heat generation



Energy Equation:
- Heat dissipation

Momentum Equation:
- Pressure losses (GC design)
- Flow in porous materials

Charge Equation:
- Charge transport through conductive parts

Energy Equation:
- Ohmic heat generation
- Electro-chemical heat generation

Modelling of Fuel Cell Powertrain

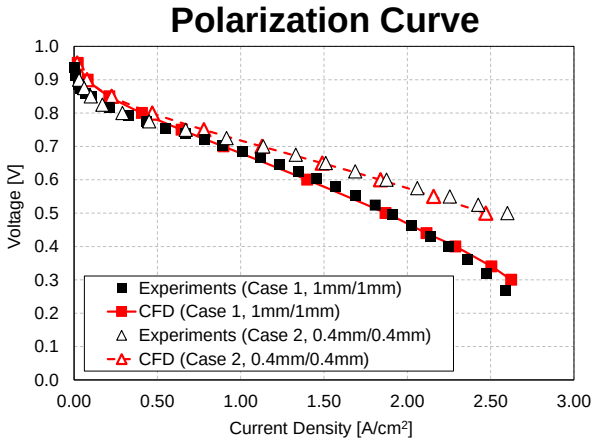
- PEM Fuel Cell
- Compressor
- Expander
- Cooling System
- Battery
- Drive Cycle

3D-CFD

- Flow field analysis
- Water transport modelling
- Design optimization techniques
- Cell thermal management

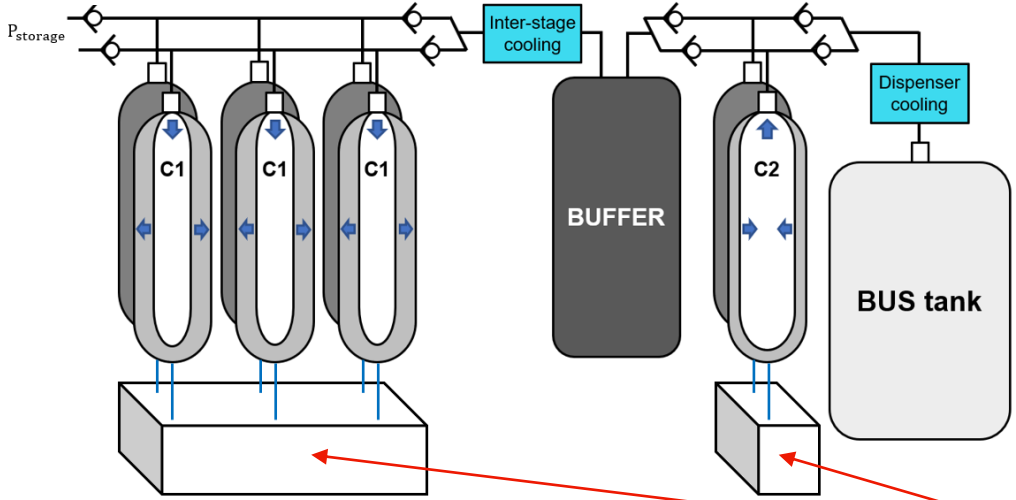
1D-CFD

- Pressure
- Temperature
- Stoichiometric Factor
- Relative Humidity
- Water balance for vehicle autonomy



H2REF-DEMO Project HE, HORIZON JU

Hydraulic compression for high-capacity Hydrogen refuelling Station Demonstration



NEW: Compression of H2 using hydro-pneumatic bladder accumulators.

TARGET: storage and refuelling at 350 bar (1,2 ton/day, 150 kg/h) for buses and trucks tanks

UNIMORE is designing and optimizing the hydraulic power groups that regulates the inlet and outlet oil flow rate towards the accumulators, to compress H2 and deliver it towards the final tank

Main References

1. Sfriso S., Berni F., Fontanesi S., d'Adamo A., Frigo S., Antonelli M., Borghi M., Proposal and validation of a numerical framework for 3D-CFD in-cylinder simulations of hydrogen spark-ignition internal combustion engines, International Journal of Hydrogen Energy, https://doi.org/10.1016/j.ijhydene.2023.12.027
2. Sfriso, S., Berni, F., Fontanesi, S., D'Adamo, A. et al., "A 3D-CFD Numerical Approach for Combustion Simulations of Spark Ignition Engines Fuelled with Hydrogen: A Preliminary Analysis," SAE Technical Paper 2023-01-0207, 2023,
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Contacts

Sebastiano Breda, PhD.
sebastiano.breda@unimore.it