Giornata di studio

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

Hydrogen powertrains and innovative storage systems

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Università di Genova

UNIVERSITA' DEGLI STUDI DI NAPOLI PARTHENOPE

AIMSEA Associazione Italiana delle Macchine a fluido e dei Sistemi per l'Energia e l'Ambiente

People & projects

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Ivan Arsie, Full Professor
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Emmanuele Frasci, Post-doctoral Researcher
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Elio Simeoni, PhD candidate
Andrea Altomonte, PhD candidate
Gianluca Nacci, PhD candidate
Fabiana Romano, PhD candidate

6 EU projects, 3 projects funded by Regione Campania, 3 PRIN, MOST, contract agreements

PRIN 2020 - H2ICE
PRIN 2022 - ALPHA
PRIN 2022 PNRR - HyREFI

MOST – CENTRO NAZIONALE PER LA MOBILITÀ SOSTENIBILE

H2RESTORE *MHyMOST* *BEST*

H2 PORTS – *Implementing Fuel Cells and Hydrogen Technologies in Ports*

Ecosystemic knowledge in Standards for Hydrogen Implementation on Passenger Ship – eSHyIPS ON THE WAVE OF HYDROGEN

FUELSOME – *Multifuel SOFC system with Maritime Energy vectors*

Tubular proton conducting ceramic stacks for pressurised hydrogen production – protostack

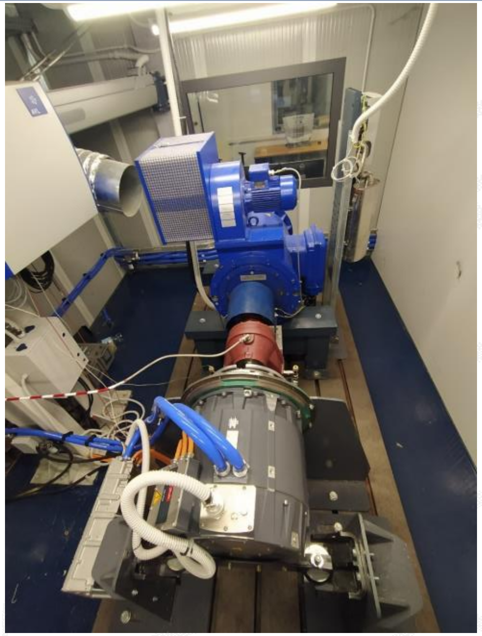
H2EXCELLENCE – *Fuel Cells and Green Hydrogen Centers of Vocational Excellence towards affordable, secure, and sustainable energy for Europe*

Airport-level demonstration of ground refuelling of liquid hydrogen for aviation – ALRIGH2T

Main research interests and activities

- H2 storage systems based on metal hydrides
- Design, development and testing of fuel cell/battery hybrid powertrains
- Development of energy management strategies for hybrid powertrains
- Hydrogen refueling stations & refueling processes for GH2 storage systems
- ICEs with alternative fuels and aftertreatment systems
- Integrated renewable multi-energy systems
- Regulations for H2 as fuel in maritime applications

uniParthenope facilities @ ATENA



H2 storage in metal hydrides

Aim: development of advanced solid-state hydrogen storage systems based on metal hydrides

Applications: road transport; maritime; stationary systems, i.e. refueling stations

Achieved and work-in-progress outcome:

- On-board *hybrid* energy storage system (battery+metal hydride tanks) for lightweight fuel cell vehicles
- High capacity metal hydride storage system (250 kg of H2) for maritime or stationary applications
- Metal hydride storage system (3-5 kg of H2) for road vehicles with fast refueling capabilities

❖ Focus:
  - Research on optimal design layouts
  - Development of integrated thermal management systems
  - Scalable and modular design methodology

❖ Main advantages:
  - Low operating pressure (< 50 bar) at near-room temperature conditions
  - Safety
  - Enhanced storage energy density
  - Significant reduction of compression-related costs

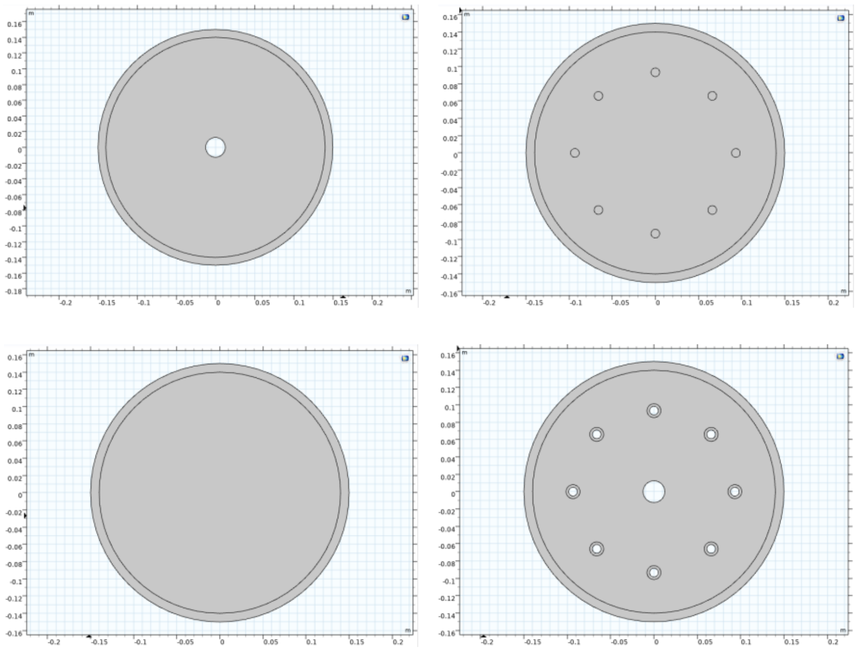
H2 storage in metal hydrides

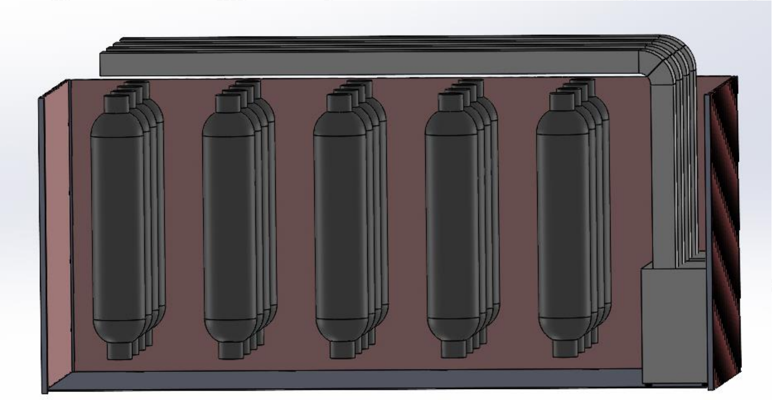
High capacity metal hydride storage system

Modular architecture – system made of a set of cylindrical elements whose height has been fixed (design constraint)

Parametric analysis to find an optimal configuration (thermal management & energy density):

- Internal/external heat transfer
- Different types of refrigerant (water, air, others)
- Natural/forced convection; conduction by means of aluminum rods
- Addition of graphite powder into the metal hydride to enhance conductivity
- Number of internal channels; different channel radius and locations
- Variation of external radius for each module (i.e. variation of number of modules)





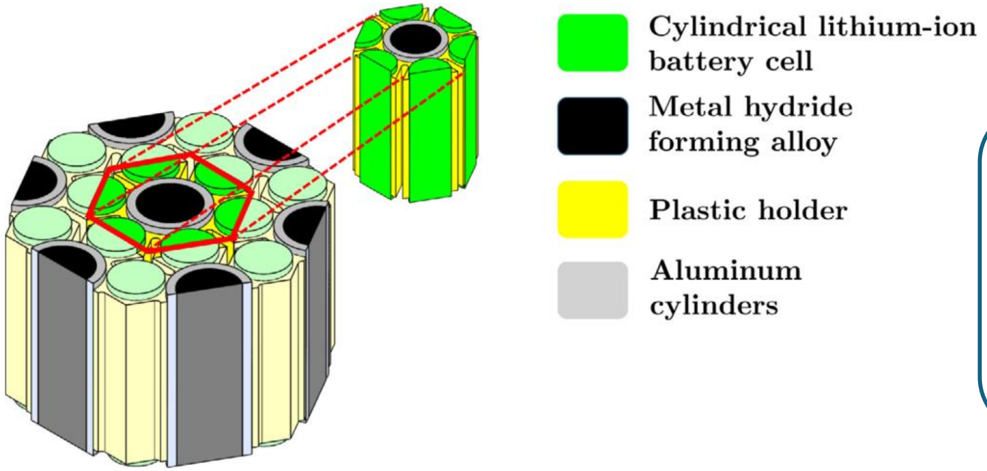
Performance:

- ➢ H_2 capacity: 250 kg
- ➢ Emptying of the storage system in 12 hours
- ➢ 36 refueling @ 7 kg/10 min
- ➢ Energy consumption related to thermal management system: around 6% H_2 equivalent

The hybrid energy storage system concept

The HESS is based on the integration between a battery pack and a hydrogen storage system made of a set of MH tanks, into a single, compact, component.

The rationale behind this solution is to use the exothermic absorption and endothermic desorption processes of hydrogen in metal hydrides for heating and cooling the battery pack, respectively, thus ensuring an optimal thermal management control.



- high gravimetric and volumetric energy densities w.r.t. state-of-the-art batteries
- no use of either a heat exchanger and a heat transfer media
- optimal thermal management of both metal hydrides and batteries
- no parasitic energy consumption for thermal management
- homogeneous temperature distribution within the battery pack
- low pressure hydrogen storage

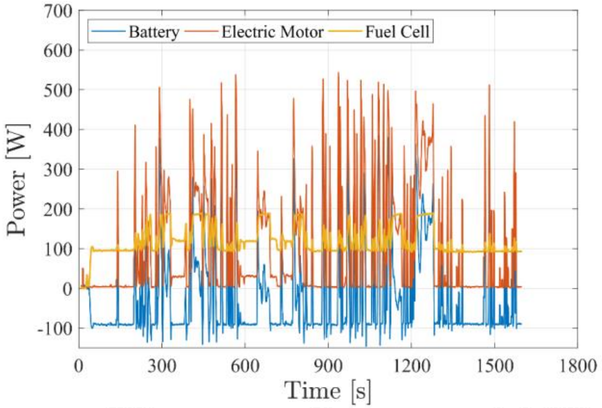
Hybrid power unit & HESS - HyBike

- Development of plug-in fuel cell electric bicycle & scooter prototypes
- Implementation of Hybrid Energy Storage System (HESS)
- Bench-testing of the power units
- Development of control strategies
- Experimental and numerical assessment of the thermal management capabilities of HESS
- On-road testing

Metal hydride tank

Battery pack

- 8 aluminium cylinders
- Type of alloy: Hydralloy C5
- Amount of alloy: ~2.75 kg
- Max H_2 capacity: 50 g
- Tank weight: ~6.80 kg



	Original e-bike	HyBike
Hydrogen capacity	-	50 g
Battery pack capacity	10 Ah (360 Wh)	6.4 Ah (230 Wh)
Riding range	**40 km**	**115 km**

Hybrid power unit & HESS - HyScooter

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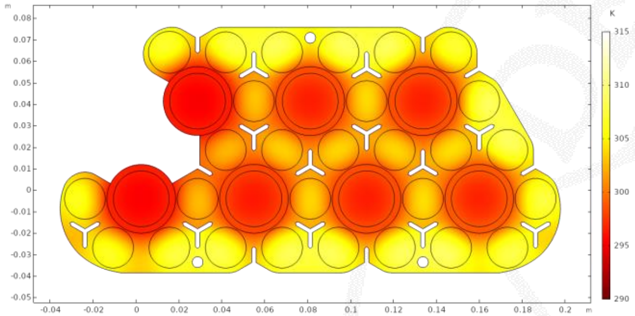
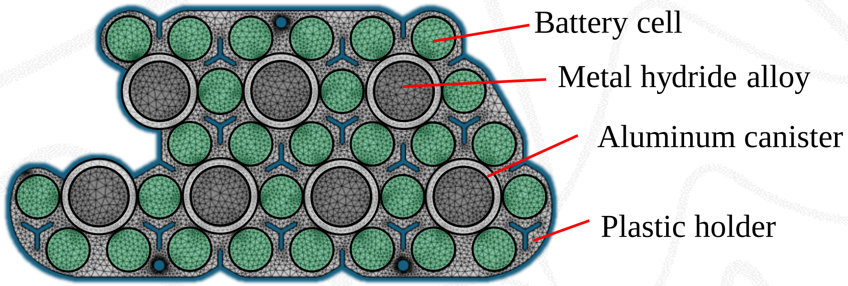
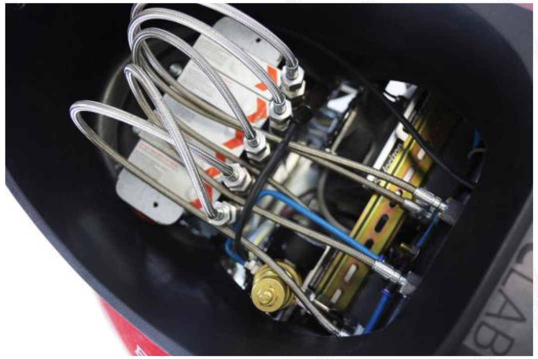
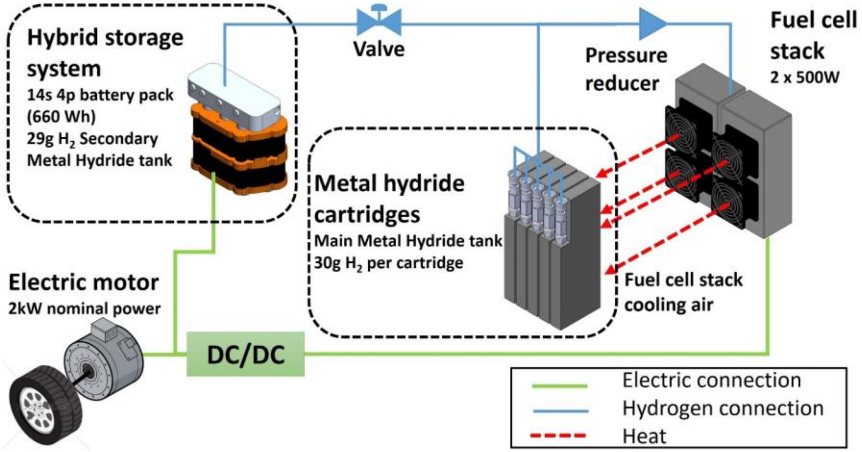








Improvement of performance - new driving range: 100 km vs 50 km for the original BEV

Energy Management Systems of hybrid powertrains

Development of Energy Management Systems of hybrid powertrain with H2 ICEs and Fuel Cells

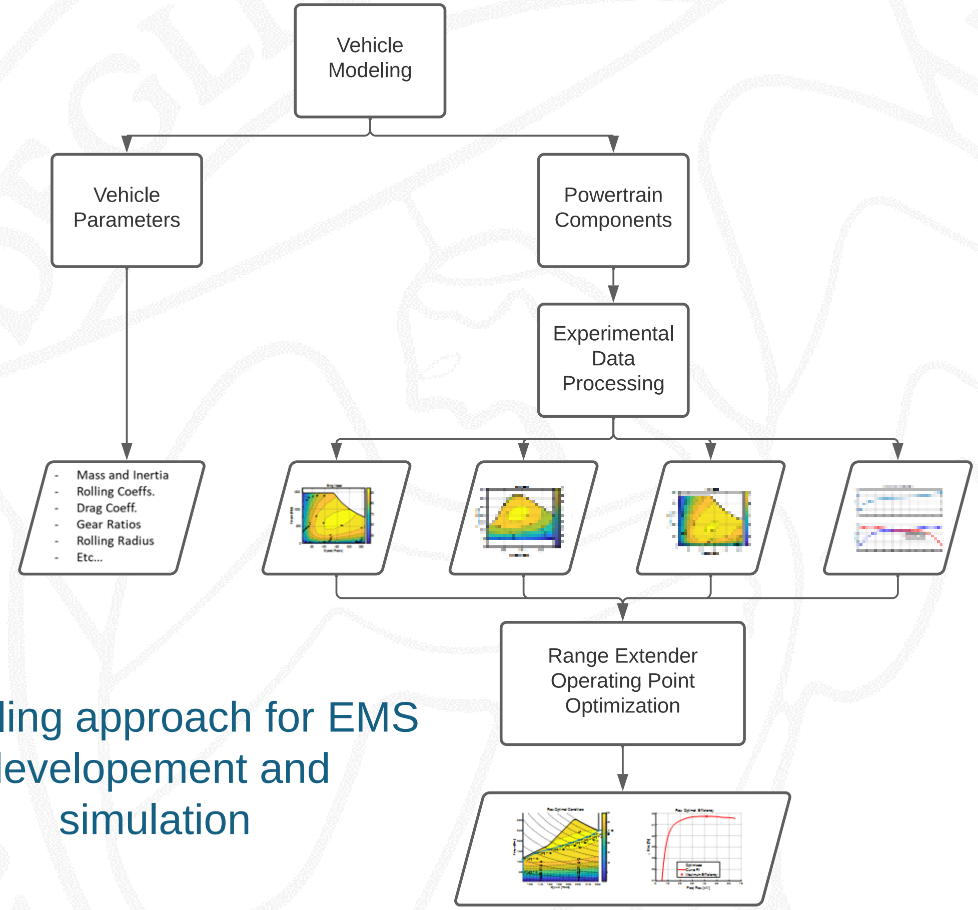
- to reduce fuel consumption and tail pipe NOx (i.e. suitable SCR operation)
- optimize powertrain components operation
- enhance liftime of critical components (e.g. fuel cell, batteries)

Different approaches of energy management strategies:

- Rule Based
- Dynamic Programming
- ECMS – PMP

Simulators:

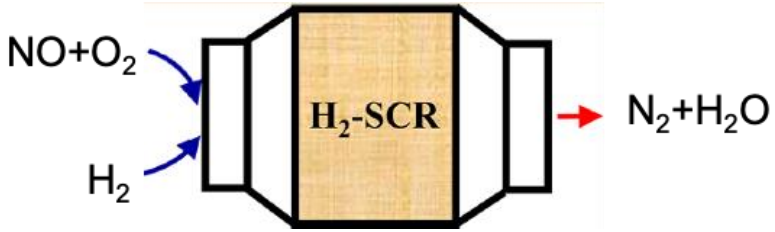
- Quasi-static backward-looking & dynamic forward-looking



Modeling approach for EMS developement and simulation

PRIN 2020 – H2ICE, Hydrogen fueled hybrid powertrain for urban buses

Development of a Selective Catalytic Reduction system of NOx using hydrogen as reducing agent



Advantages:

- Simplification of injection/storage systems of the reducing agent
- Lower optimal temperatures of SCR operation

Activity - Preparation of the catalytic systems

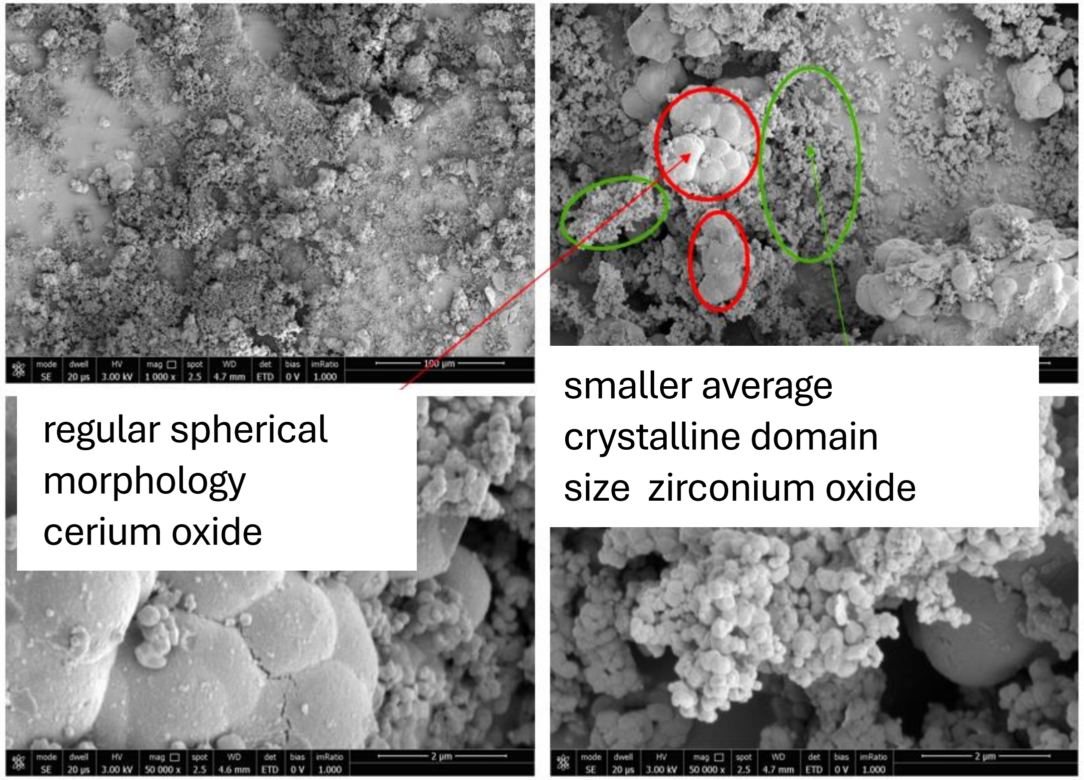
Materials:

- Palladium (Pd) as active phase
- CeO2 - ZrO2 as porous carriers (PCZ)
- Cordierite as monolithic substrate

Processes:

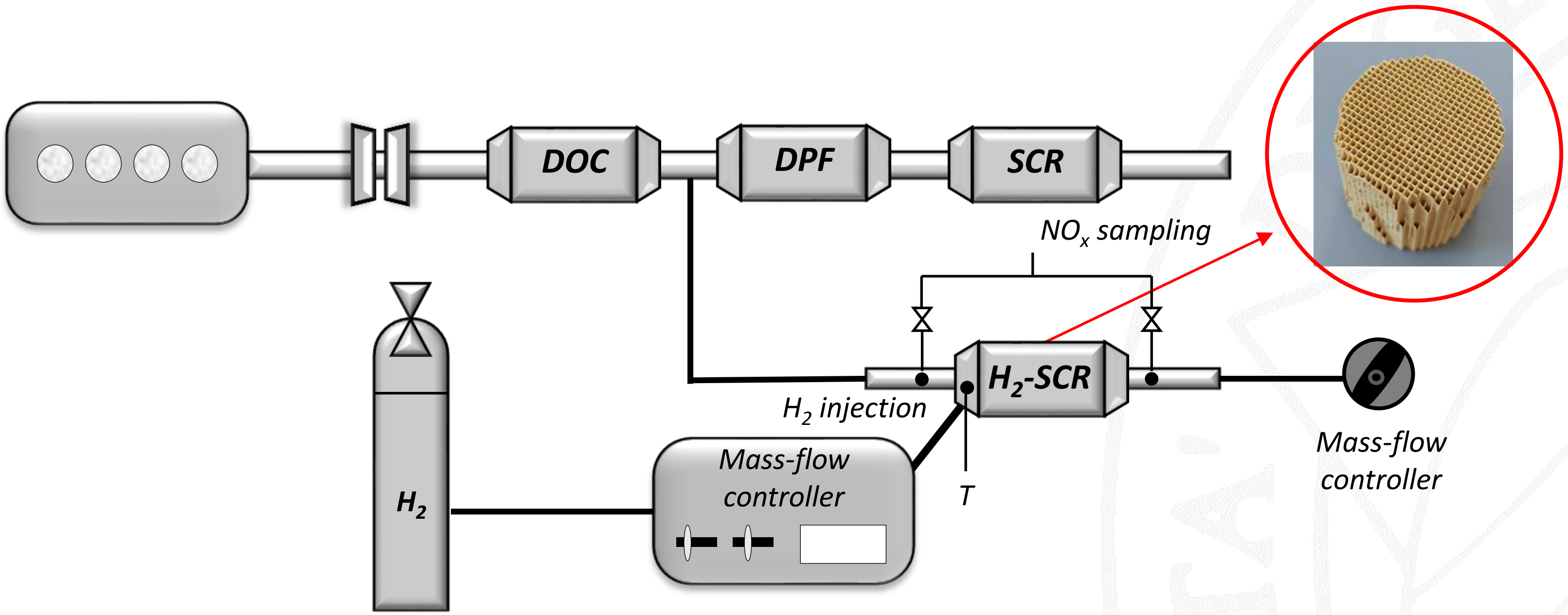
- coating suspension, washcoating, drying, calcination and reduction

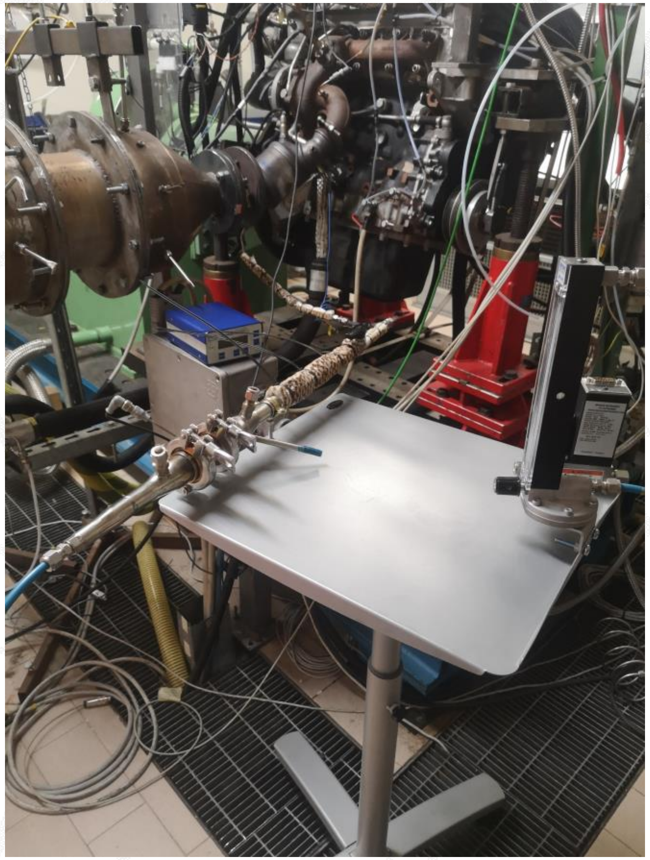
SEM Micrographs at various magnifications of the PCZ catalytic system



PRIN 2020 – H2ICE, Hydrogen fueled hybrid powertrain for urban buses

Small scale prototypes of coated cordierite substrate will be tested with real currents emitted by a **Diesel engine at the test bed of University of Salerno.** The reagent mixture is spilled by the **exhaust gases** downstream of the DOC. The **hydrogen** is injected upstream of the H2-SCR.

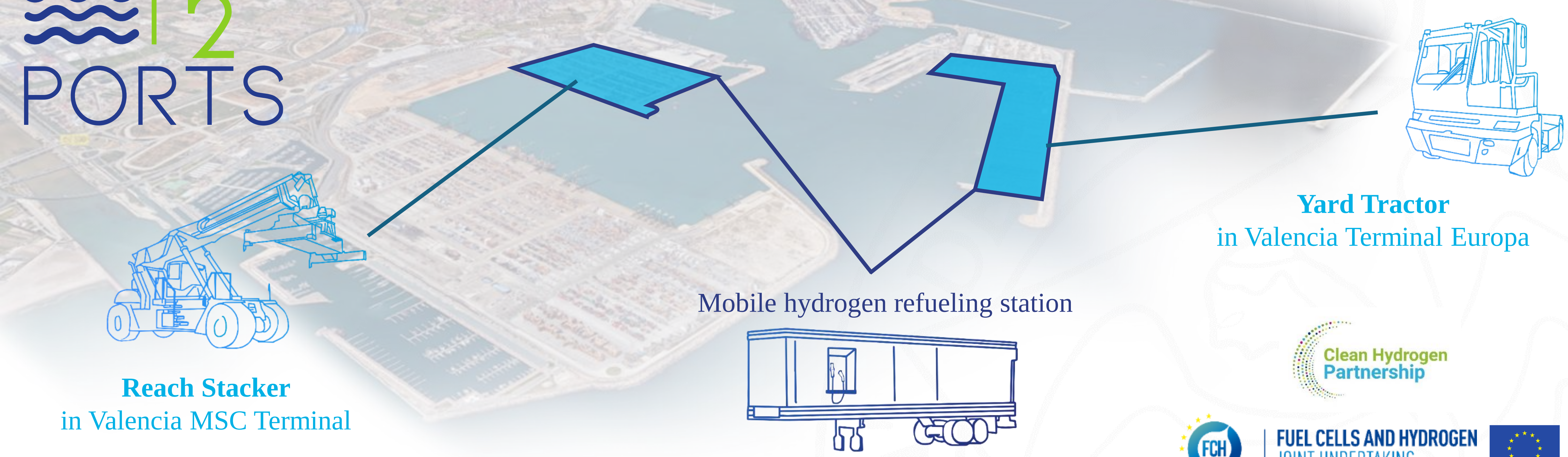




Different engine operating conditions and H2 flow rates will be tested to investigate a wide range of H2-SCR temperature, spatial velocity, reactants ratio.

The H2Ports project

"Implementing Fuel Cells and Hydrogen Technologies in Ports"



The first application of hydrogen technologies in port handling equipment in Europe.

The H2Ports project – Fuel cell hybrid yard tractor

- Development of a H_2 fuel cell/battery hybrid heavy-duty vehicle
- Derived from a Terberg RT223 YT - 4x4 heavy-duty yard tractor
- Application: RoRo operations of trailers on ships

Challenges:

- Power demanding and energy intensive activities
- All-day lasting operation, characterized by a wide variability of operating conditions and tasks

Main requirements

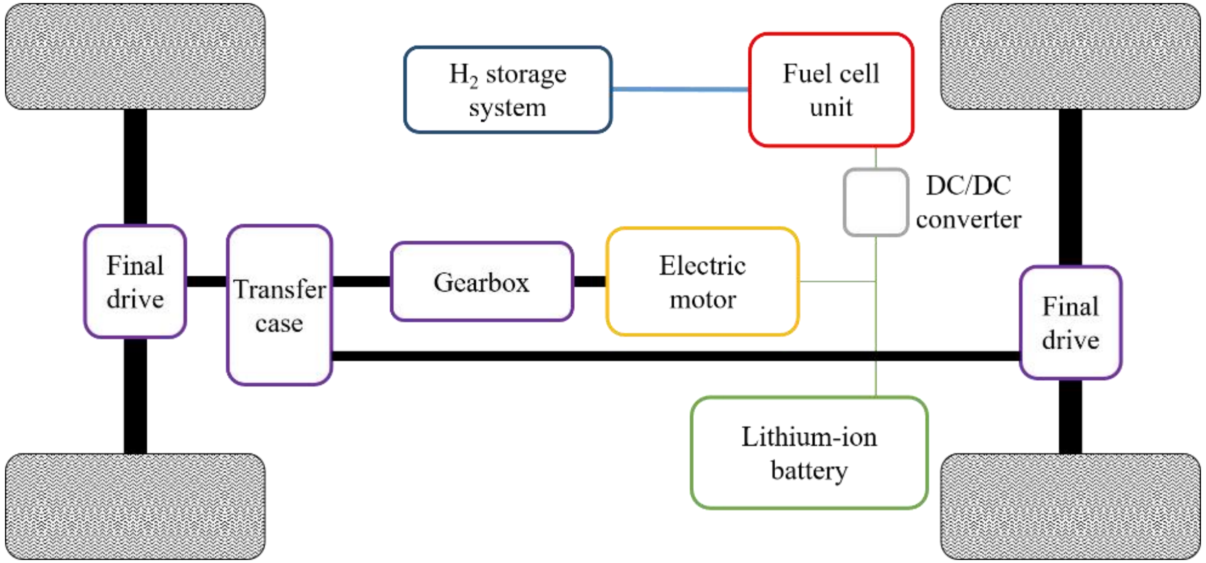
The hydrogen-powered vehicle has to accomplish the same tasks as the Diesel vehicle:

- same power/torque at wheels as the ICE vehicle
- 6 hours of continuous operation before refueling

The H2Ports project – Fuel cell hybrid yard tractor

- The **FC stack** has to provide the requested mean power in order to avoid the battery SoC depletion under continuous vehicle operation.

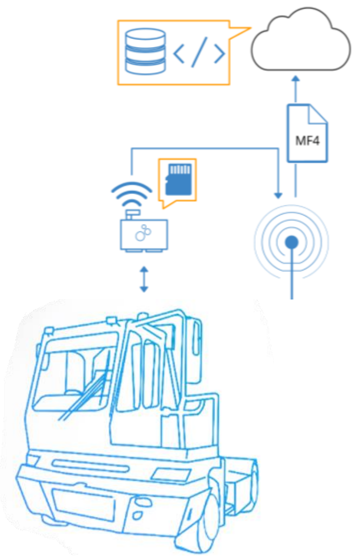
- The **battery pack** has to:
  - deal with transient operations
  - recover kinetic energy during braking;
  - ensure an adequate AER

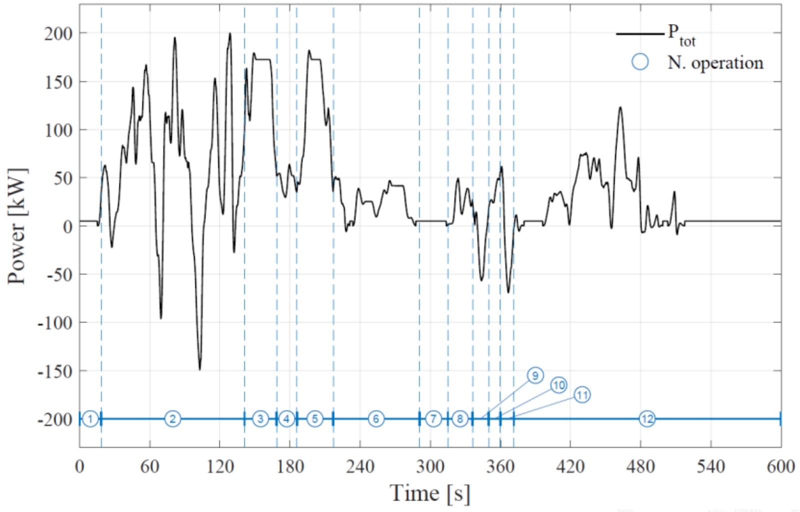


Electric Motor	Max. Continuous Torque	938 Nm
	Rated Torque (with one 350A inverter)	1300 Nm @ 1900 rpm
	Nominal Efficiency	96 %
Fuel Cell	Rated Power	70 kW
	Peak Efficiency	57 %
Battery pack	Nominal Voltage	25.6 V
	Nominal capacity	40 Ah
	N. of modules	24
	Battery Overall Energy Capacity	25 kWh
CHSS	Number of tanks	4
	H2 capacity	12.7 kg

The H2Ports project – Fuel cell hybrid yard tractor

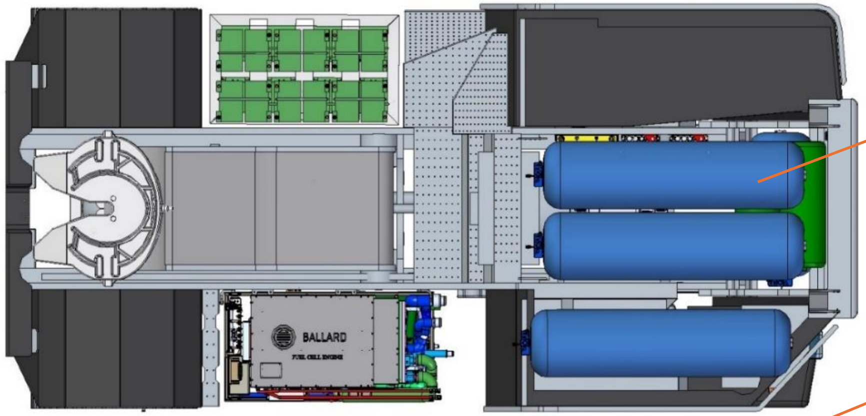
Duty Cycle Acquisition





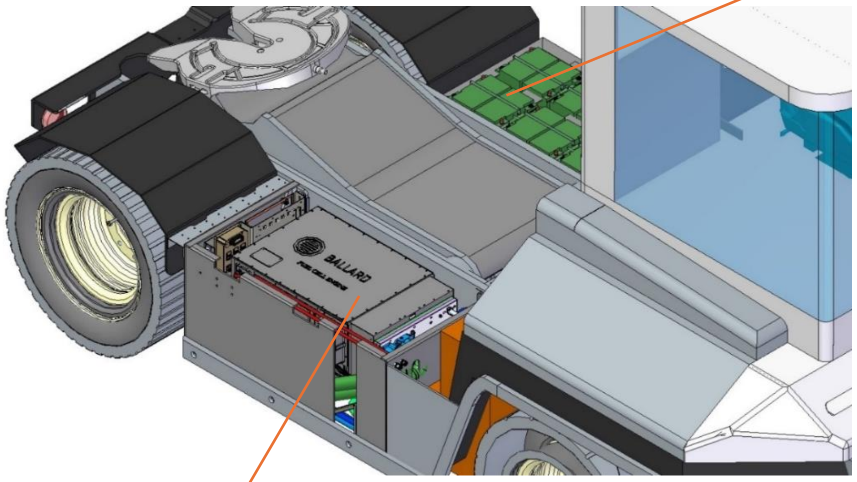
N.	YT Roll-on operations
1	lift of the trailer in the on-shore terminal area
2	carrying the trailer from the on-shore terminal into the ship
3	climbing ramp #1 to reach the first deck
4	driving inside the ship
5	climbing ramp #2 to reach the second deck
6	driving inside the ship
7	release of the trailer
8	driving inside the ship
9	climbing down ramp #2
10	driving inside the ship
11	climbing down ramp #1
12	return to the on-shore terminal area

The H2Ports project – Fuel cell hybrid yard tractor

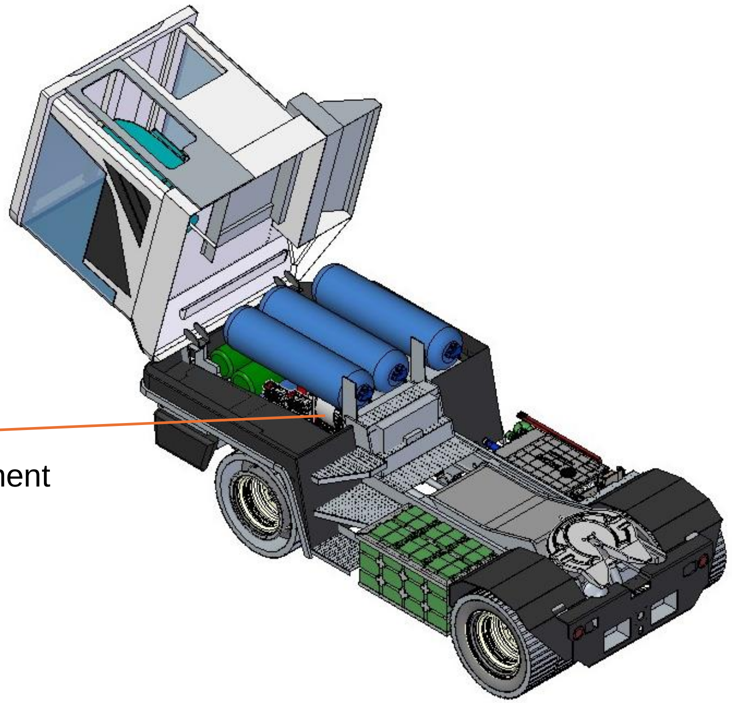


LUXFER G-Stor™ H2 – carbon composite Type 3 cylinders
Hydrogen storage system: CH2 @ 350 bar

LITHION P40-24 POWER MODULE
24-volt battery, built on Lithion Battery' patented Lithium Iron Phosphate chemistry platform.



Danfoss EM-PMI375-T800
Synchronous Reluctance assisted Permanent Magnet (SRPM) technology.



BALLARD FCmove™ HD70
Ballard's FCmove™-HD is the next-generation heavy duty fuel cell power module for use in zero-emission motive applications.

The H2Ports project – Fuel cell hybrid yard tractor

H2Ports Demo Day

Valencia, November 28th, 2023

Thank you!

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