



*University of Pisa*  
*DESTEC – Department of Energy, Systems, Territory*  
*and Construction Engineering*

# **Prospettive e criticità nell'uso dell'idrogeno come combustibile nei motori a combustione interna per il trasporto pesante**

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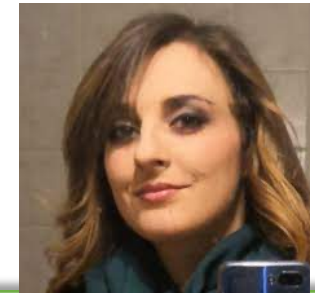
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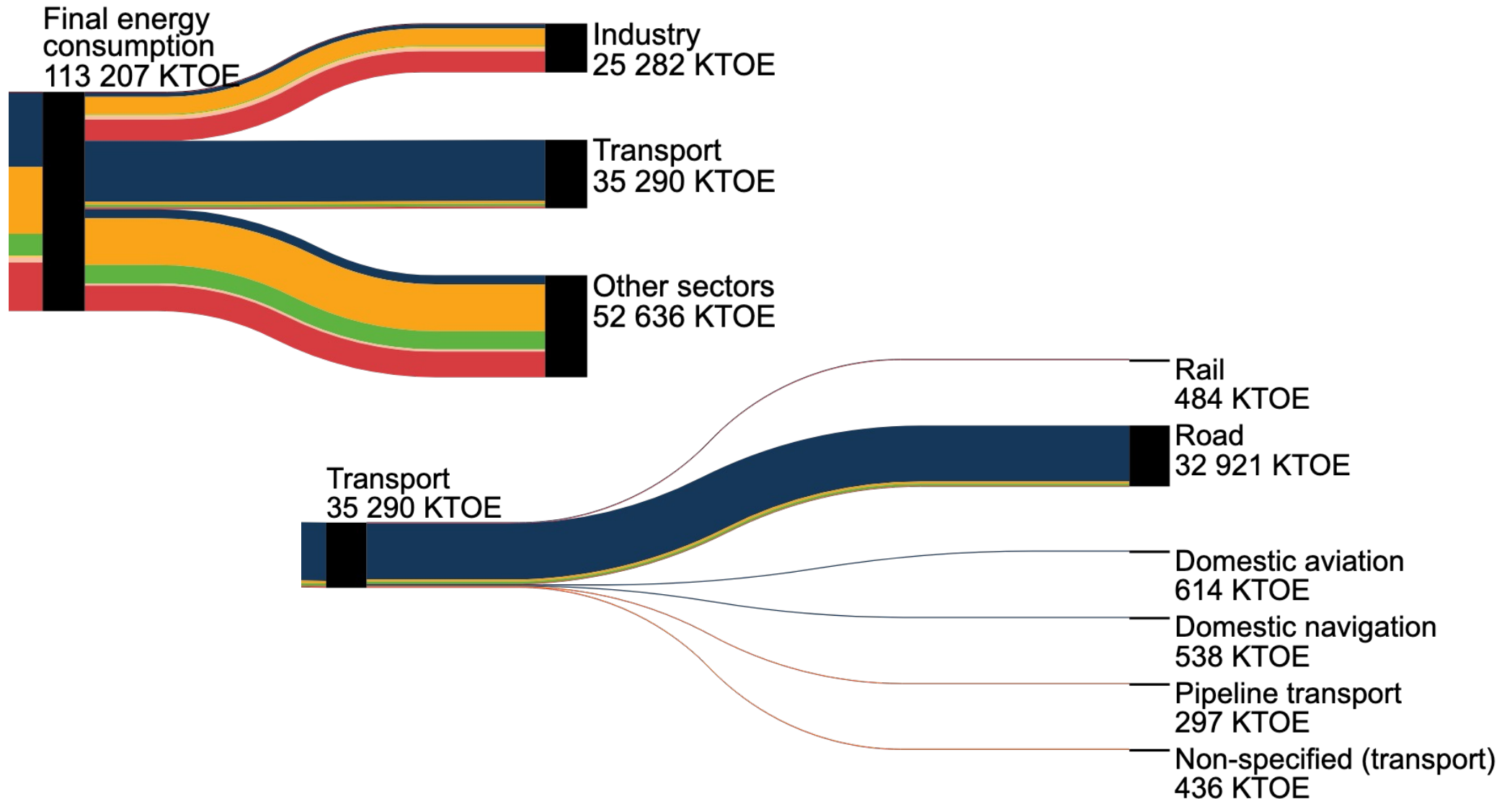


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# Inquadramento del problema

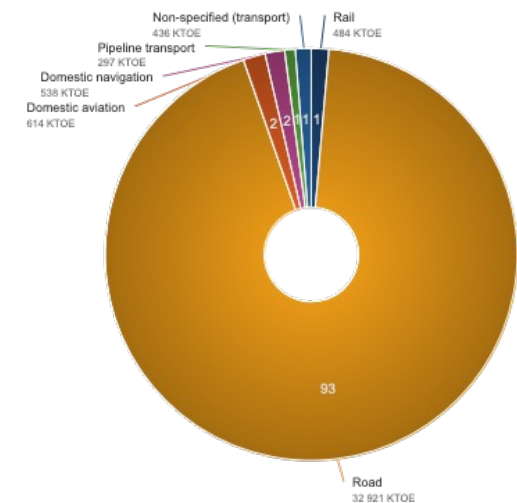


# Inquadramento del problema

- Il consumo di prodotti petroliferi per uso nel trasporto marittimo supera i 200.000 kTOE
- I consumi nel settore dei trasporti in kTOE, quasi interamente derivati dal petrolio, per alcuni paesi Europei sono :

	Italy	Netherlands	Germany	Greece	Sweden
Domestic Navigation	238	538	367	569	102
Rail	160	484	1400	15	231
Road	8783	32921	49785	4831	6446
Domestic Aviation	9	614	252	151	71
<b>Total transport</b>	<b>9190</b>	<b>34557</b>	<b>51804</b>	<b>5566</b>	<b>6850</b>

Flows going out from Transport  
Italy 2021



Source: Eurostat

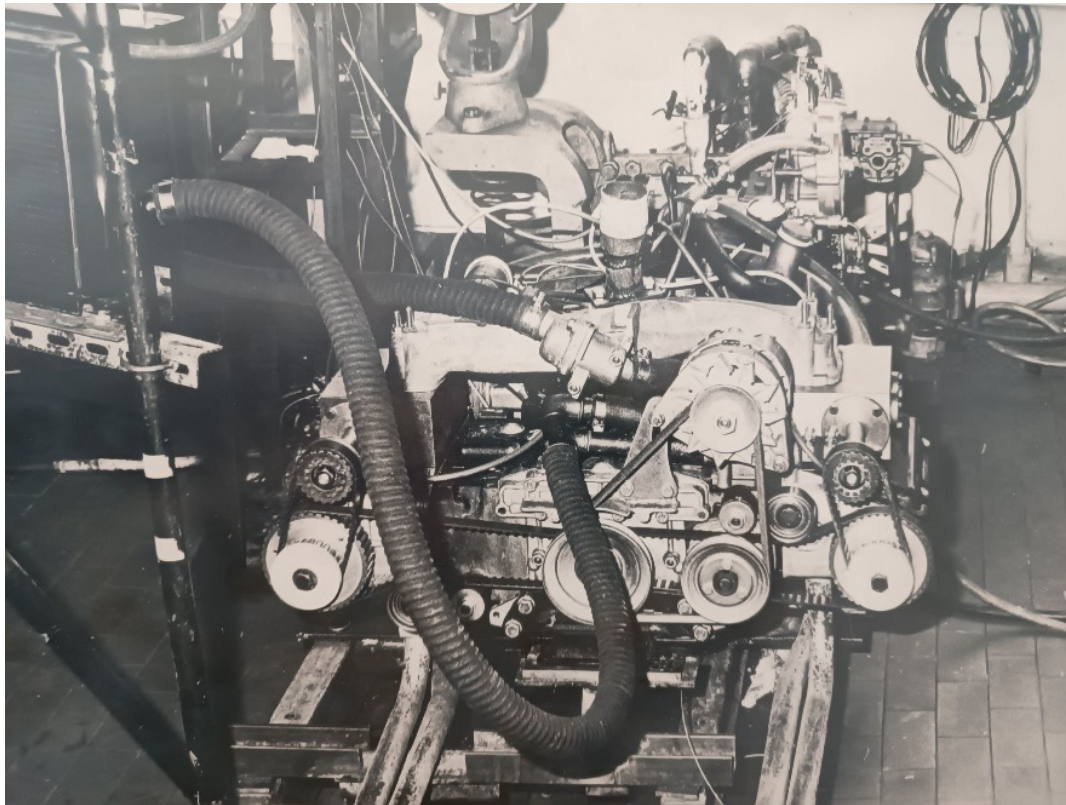
## Dubbi e domande

- Combustibili “verdi” hanno bisogno di energia “verde”: quanta ne serve? In Italia almeno 120 TWh
- Abbiamo davvero abbandonato l’idea di usare i biocombustibili?
- I motori saranno completamente sostituiti dalle celle a combustibile?
- Idrogeno e/o suoi derivati (Ammoniaca, Metanolo, ...?)
- Idrogeno accumulato in che forma? (Gas, Liquido, Stato Solido, LOHC, ...?)

Quanto costa e quanto dura la transizione?

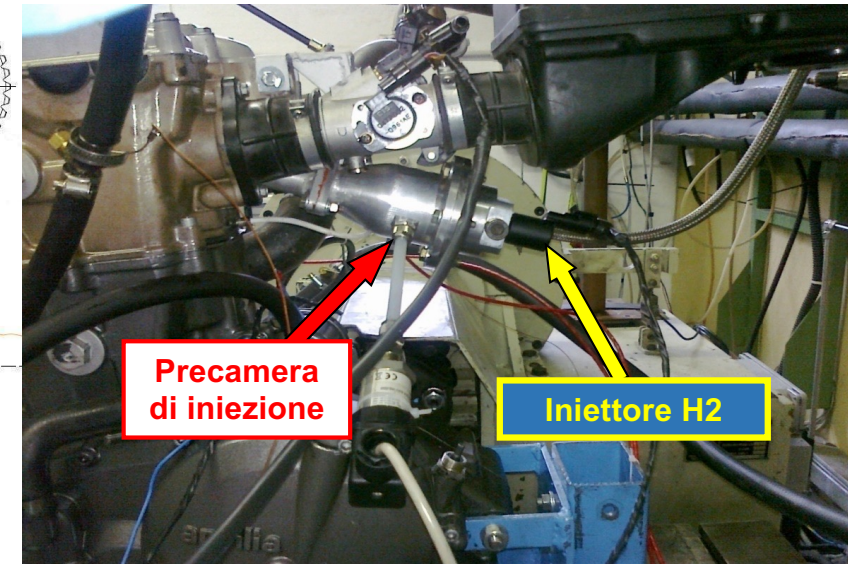
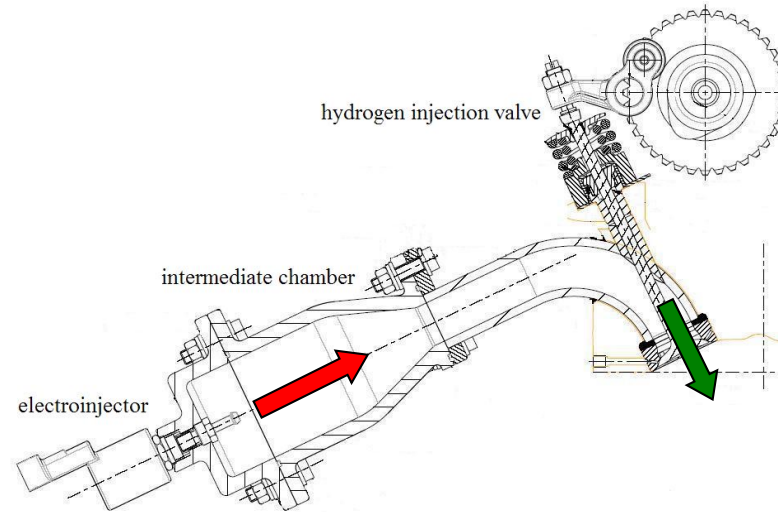
# Un po' di storia all'Università di Pisa

*A partire dalla fine degli anni ottanta la facoltà di Ingegneria di Pisa ha affrontato diversi progetti riguardanti l'utilizzo dell'idrogeno come combustibile per MCI*

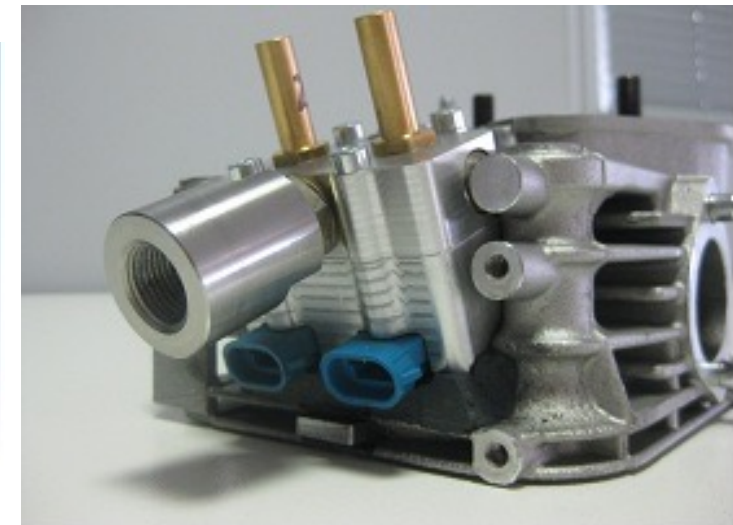
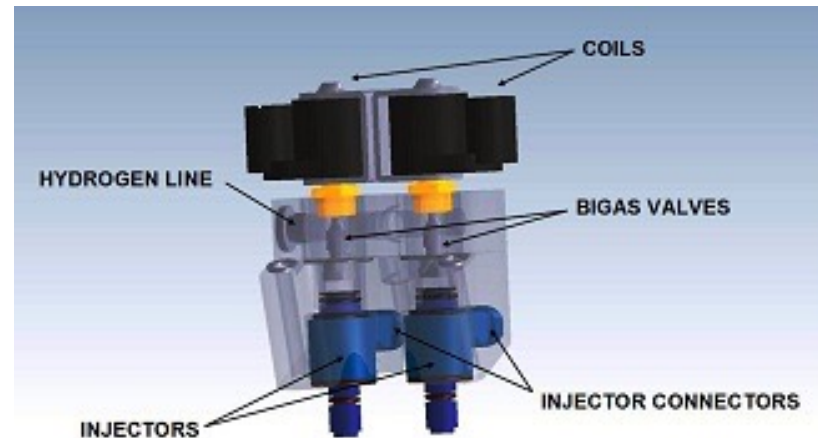


*Dipartimento di Energetica - UNIPI  
Motore Alfa Romeo Boxer con alimentazione  
indiretta ad H<sub>2</sub> (1989)*

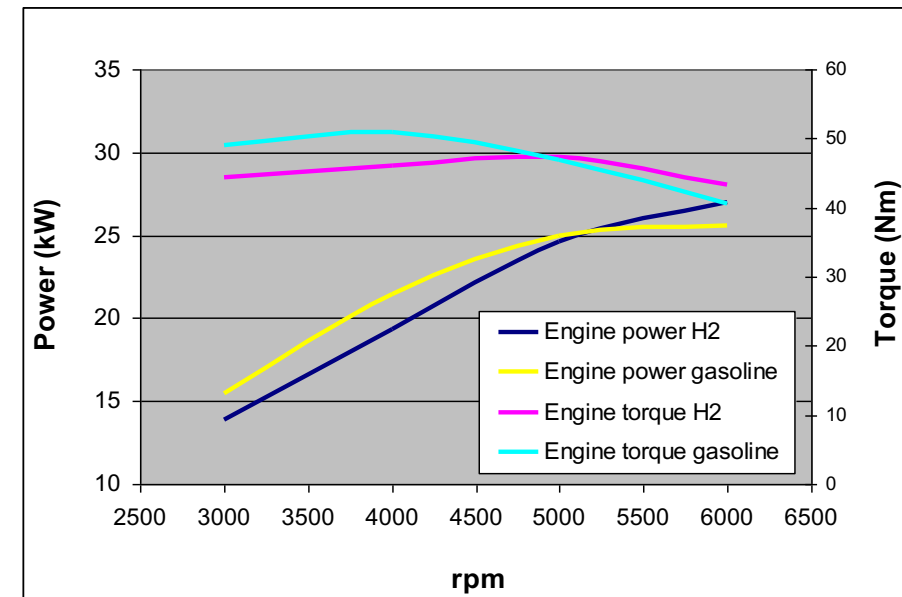
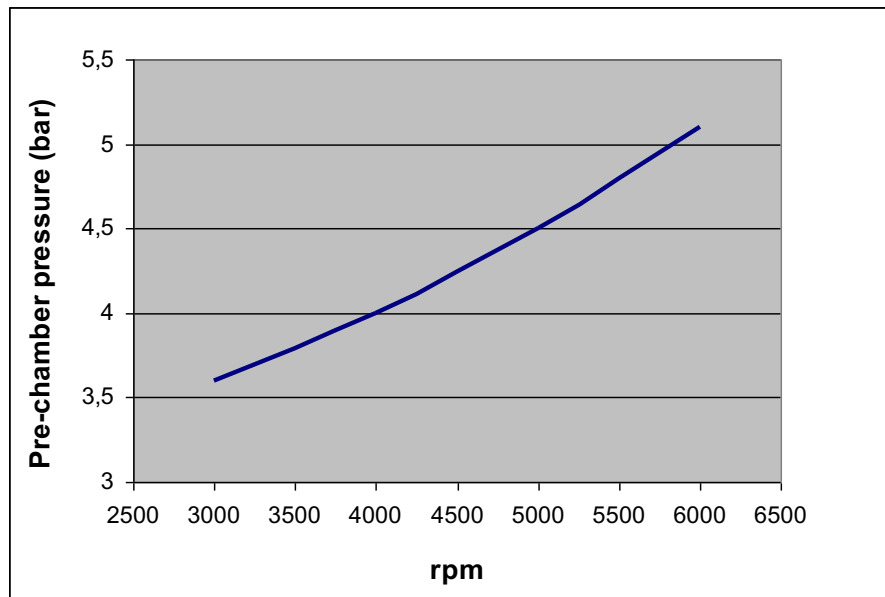
2008-2011  
SVILUPPO DI UN  
SISTEMA DI  
INIEZIONE DIRETTA  
IDROGENO IN DUE  
FASI



2008-2011  
SVILUPPO DI UN  
SISTEMA DI  
INIEZIONE DIRETTA  
DI H<sub>2</sub> A SINGOLO  
STADIO CON  
ELETTROINIETTORI



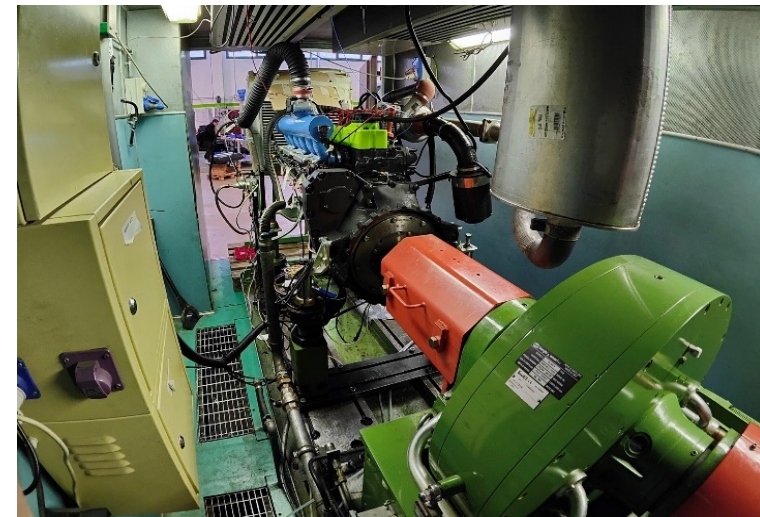
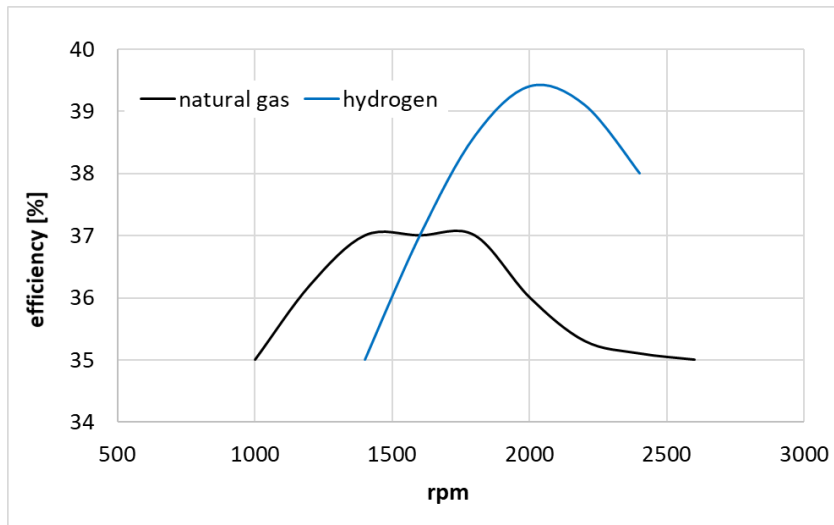
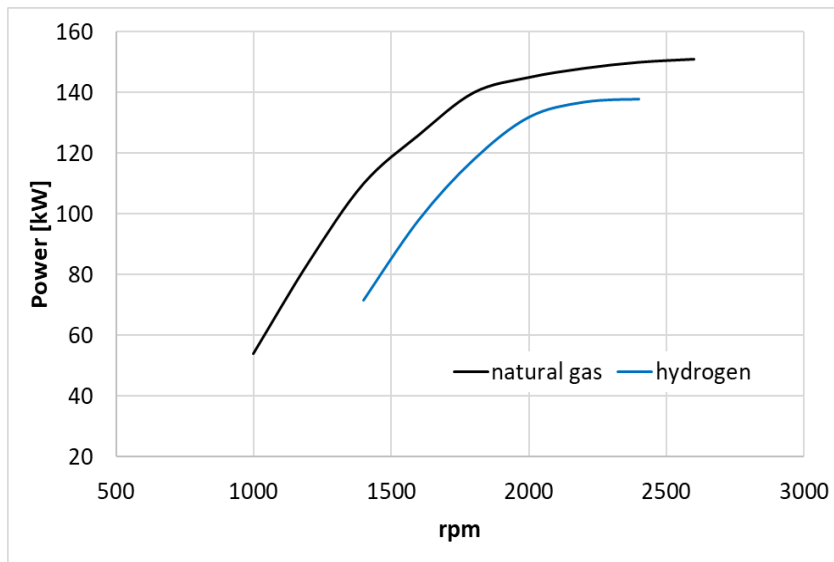
I primi risultati sperimentali hanno permesso di verificare che le prestazioni del motore alimentato ad H<sub>2</sub> non si discostano fondamentalmente da quelle del motore alimentato a benzina



**Pieno carico (stechiometrico)**

2022

## Sviluppo di un sistema di alimentazione idrogeno PFI per motori ad AC sovralimentati in collaborazione con la ditta Ecomotive Solutions (AL)



- ❑ Motore NEF 6 cilindri in linea da 5880 cm<sup>3</sup>, in origine alimentato a metano.
- ❑ L'utilizzo di miscele aria/H<sub>2</sub> molto diluite ( $\lambda \approx 2,5$ ) ha permesso di evitare back-fire e detonazione e in più di aumentare l'efficienza motore.
- ❑ Un'opportuna scelta del gruppo turbo-compressore (a geometria variabile) ha permesso di raggiungere alti rapporti di sovralimentazione (circa 2,5 bar) e di recuperare quasi totalmente l'originale potenza

# Idrogeno nel trasporto ferroviario - merci

- Presenza di raccordi ferroviari non elettrificati
- Scali merci privi di linea aerea
- Servizi terminali su linee o raccordi di non ridotta lunghezza
- Necessaria molta più energia rispetto al caso del trasporto passeggeri (massa rimorchiata!)
- Diffusione negli ultimi anni di locomotive bimodali pantografo + diesel («last mile»)
- **Campo applicativo interessante per idrogeno (decarbonizzazione ultimo miglio)**



## Caso studio

- Treno per il trasporto della pietra calcarea dalla cava di San Carlo allo stabilimento Solvay di Rosignano (LI)
- Doppia trazione simmetrica (loco diesel a una estremità, elettrica all'altra)
- Lunghezza percorsa sotto linea aerea 34 km
- Lunghezza del raccordo non elettrificato 5 km
- 1,4 Mt/y di carico trasportato
- 1700 treni/anno
- Composizione treno: 16 carri merci a 4 assi da circa 50 t ognuno
- Massa rimorchiata complessiva 800 t
- **Conversione della locomotiva diesel ad idrogeno per il tratto non elettrificato**



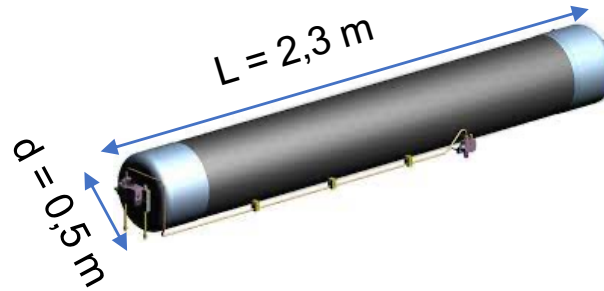
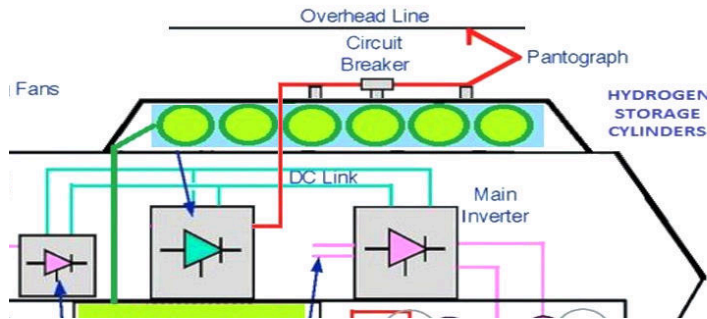
Rosignano  
Solvay

34 km

San  
Vincenzo

San Carlo  
(cava)

# Calcolo energetico conversione ad idrogeno



Contenuto in H<sub>2</sub> ≈ 8,4 kg  
 Massa bombola ≈ 110 kg  
 Bombe necessarie 9  
 Massa complessiva ≈ 1,1 t

## CON CELLA A COMBUSTIBILE

Max potenza (fase di recupero) ≈ 600 kW  
 Max Energia (fase di recupero) ≈ 50 kWh  
 Dimensionamento secondo max potenza – 600 kWh

## SOLO BATTERIA

Max potenza (fase di salita) ≈ 1500 kW  
 Energia (fase di salita) ≈ 170 kWh  
 Dimensionamento secondo max potenza – 1500 kWh

Resistenze al moto

Incremento di energia cinetica in accelerazione



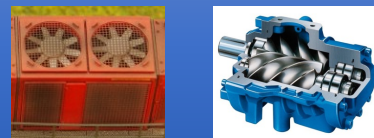
$$\eta_{fc} \approx 0,45$$



$$\eta_{azion} \approx 0,84$$



Ausiliari (≈100 kW medi)

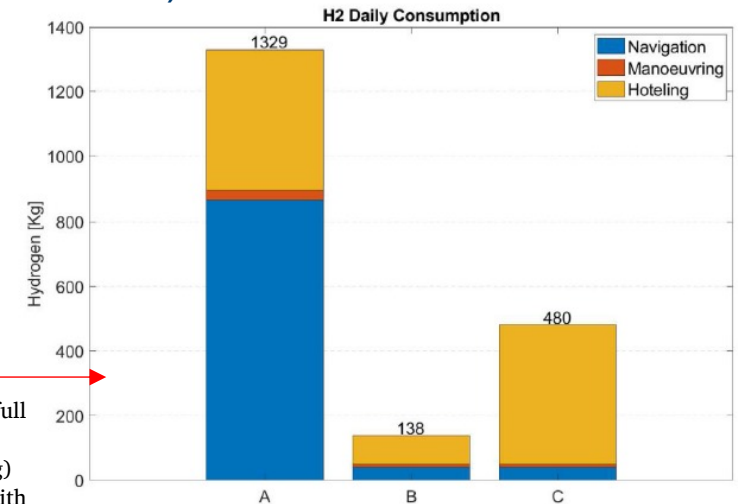


H<sub>2</sub> per 1 viaggio ≈ 8,7 kg  
 8 treni / giorno  
 H<sub>2</sub> per 1 giorno ≈ 70 kg

# Retrofitting of roll-on/roll-off short-sea vessels

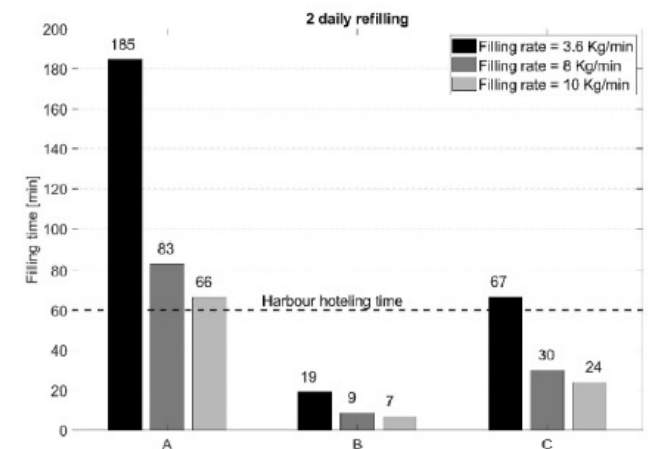
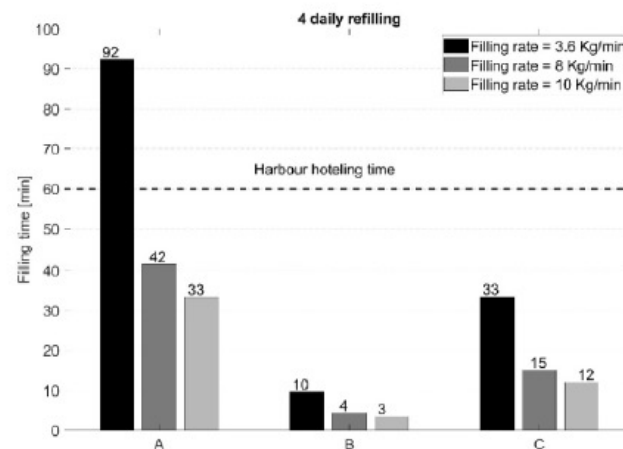
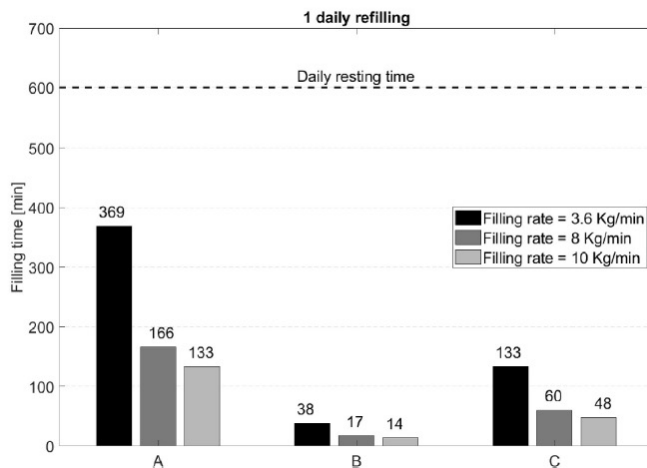
Amount of H<sub>2</sub>, the filling time and the energy needed for production, compression and pre-cooling of hydrogen calculated for the different scenarios (route Piombino – Elba Island)

#	Company	Name	Ruote	MAIN ENGINE POWER [kW]				AUX ENGINE POWER [kW]			
				Total P	Nav	Man	Hot	Total P	Nav	Man	Hot
Ro-Pax rowhead	TOREMAR	MARMORICA	L1	5560	4448	1112	1112	1200	360	600	480
		STELIO MONTOMOLI	L1	5692	4554	1138	1138	1910	573	955	764
		OGLASA	L1	5560	4448	1112	1112	1200	360	600	480
		RIO MARINA BELLA	L2	5420	4336	1084	1084	1200	360	600	480
5	MOBY LINES	GIOVANNI BELLINI	L2	3706	2965	741	741	486	146	243	194
6		SCHIOPPARELLO JET	L3	3476	2781	695	695	900	270	450	360
7		NIKI	L1	9415	7532	1883	1883	3123	937	1562	1249
8		KISS	L1	10880	8704	2176	2176	2115	635	1058	846
9		BABY TWO	L1	9856	7885	1971	1971	1589	477	795	636
10		ALE	L1	7415	5932	1483	1483	1640	492	820	656
11	BLUE NAVY	ACCIARELLO	L1	6620	5296	1324	1324	1200	360	600	480
12	CORSICA FERRIES	CORSICA EXPRESS III	L1	19308	15446	3862	3862	7646	2294	3823	3058



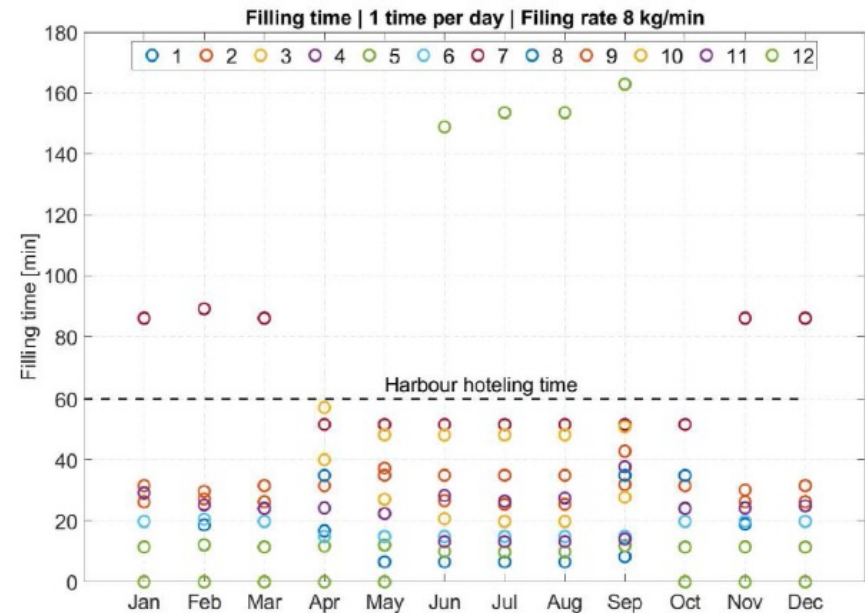
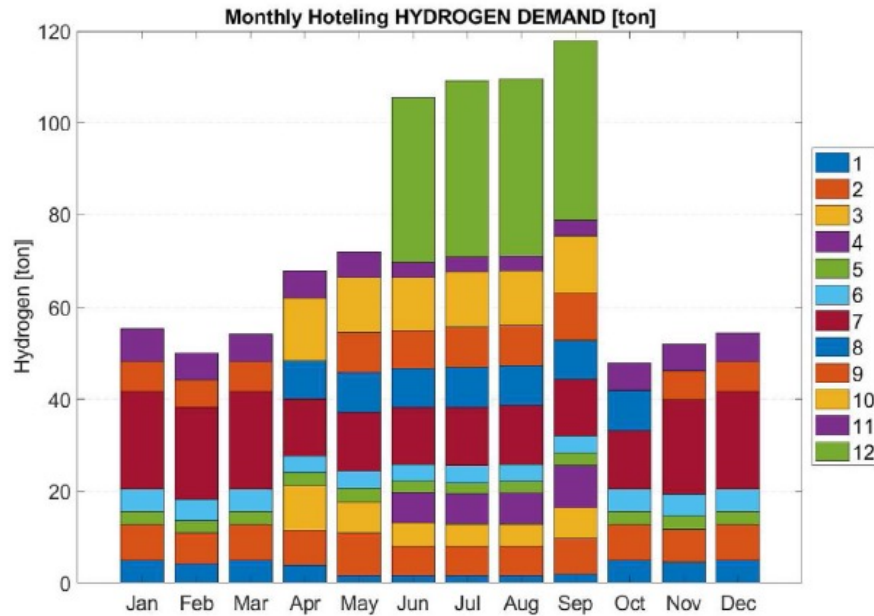
- A. Replacement of the main and auxiliary engines with FC (full retrofitting)
- B. Replacement of the auxiliary engines with FC (partial retrofitting)
- C. Replacement of the auxiliary engines with FC and hoteling only with auxiliary engines (partial retrofitting)

## Filling time with different filling rates

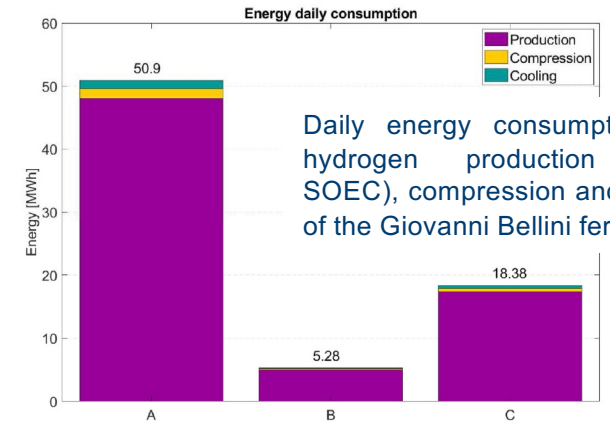
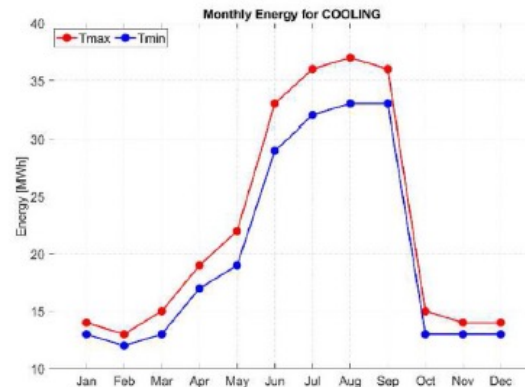
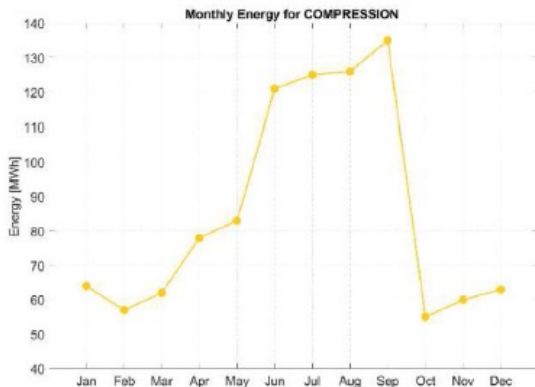


# Retrofitting of roll-on/roll-off short-sea vessels

Monthly hydrogen demand for hoteling (in ton) and filling time for all the vessels during the year

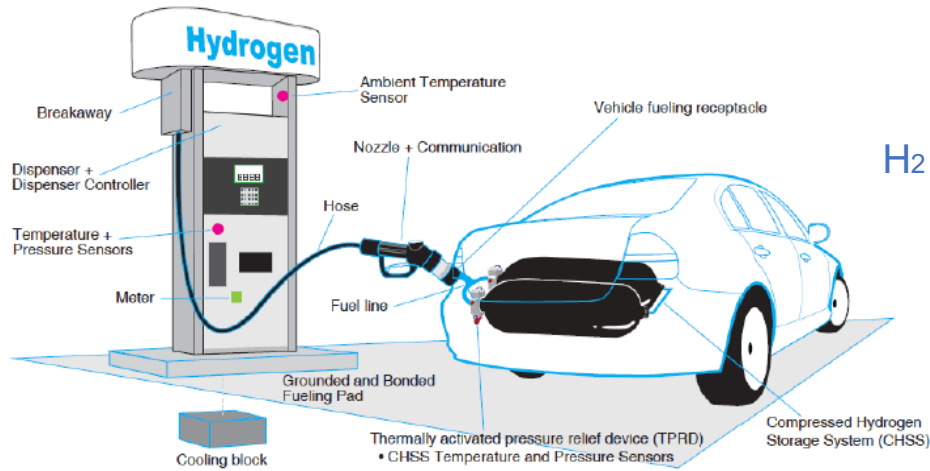


Monthly energy for compression and cooling for all the vessels during the year

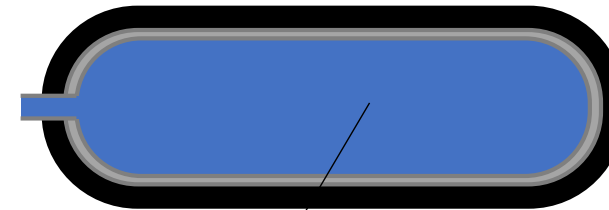
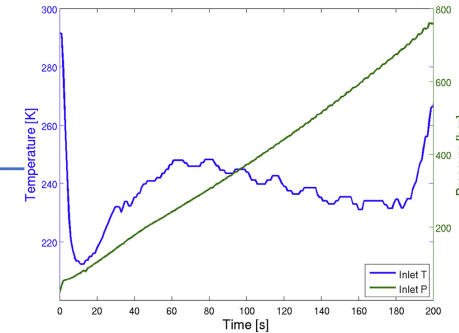


Daily energy consumptions for hydrogen production (using SOEC), compression and cooling of the Giovanni Bellini ferry

# 0D hydrogen tank filling validation



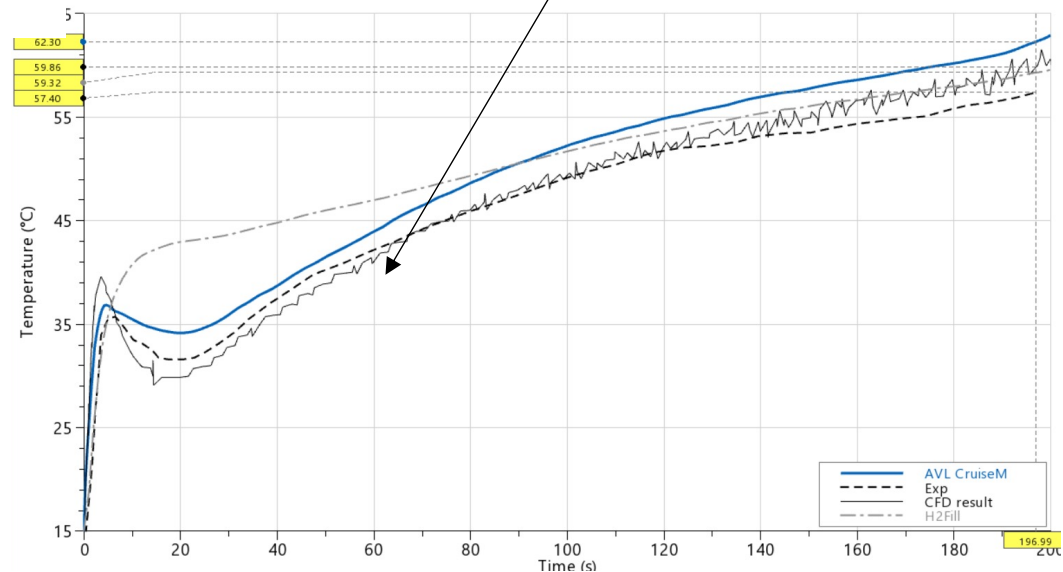
H<sub>2</sub> P and T inlet



## Three main targets:

- Short refuelling time (3 min)
- Long drive range (600-700 km)
- High safety and reliability

**T tank < 85° C (SAE J2579)**



# CFD analysis of hydrogen tanks during refilling

- CFD model validation a 2.5-litre hydrogen tank filling process in the presence of adsorbent materials
- Investigation of the impact of various factors, including inlet temperature, inlet pressure ramp rate, and initial tank temperature, on the quantity of hydrogen stored at the end of the filling process
- Tank design optimization

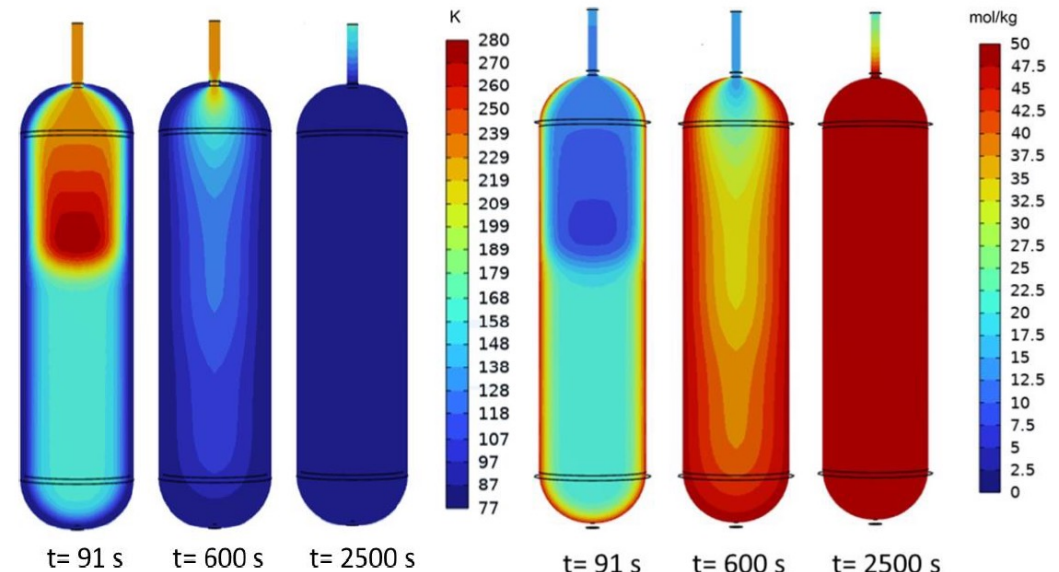
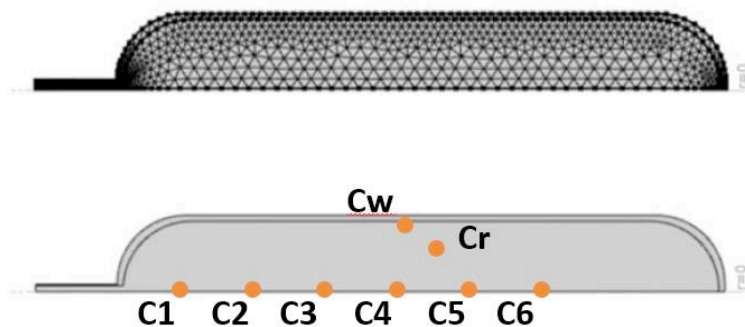
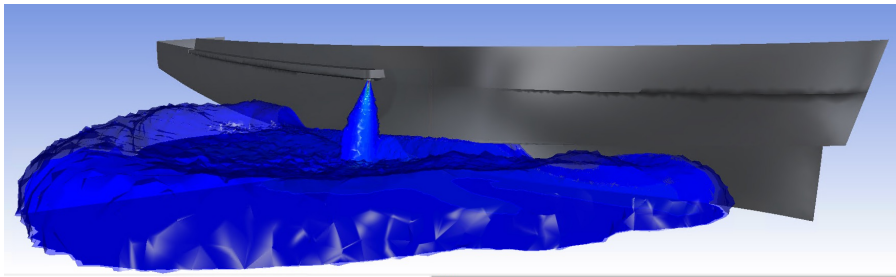


Figure 9. Temperature contours at 91, 600 and 2500 seconds

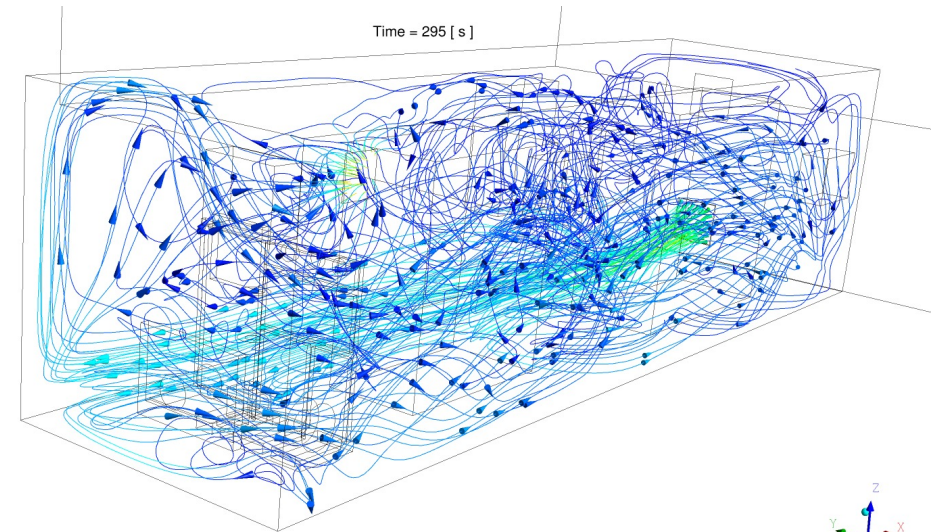
Figure 10. Absolute adsorption at 91, 600 and 2500 seconds

# Hydrogen release and dispersion

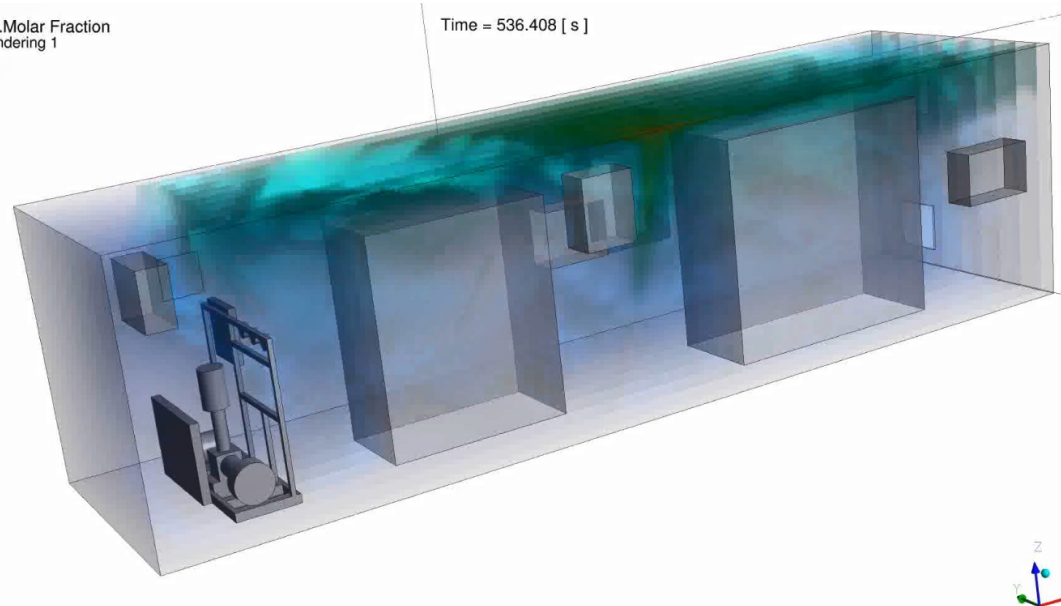
- CFD model validation of a hydrogen accidental release in confined space
- Methanol accidental release for maritime application



Velocity  
Streamline 1  
2.244  
1.684  
1.124  
0.564  
0.004  
[m s<sup>-1</sup>]



He at STP, Molar Fraction  
Volume Rendering 1  
0.008  
0.006  
0.004  
0.002  
0.000



# Ongoing projects

## **HyLICAL** HyLICAL - Development and validation of a new magnetocaloric high-performance hydrogen liquefier prototype (Horizon Europe)

HyLICAL will contribute to reaching an energy demand of 8 kWh/kg and a liquefaction cost of <1.5 €/kg as targeted in the call by validating an innovative and energy-efficient liquefier prototype for the cryogenic region (< 120 K) based on magnetic refrigeration.

## **PRIN2020: Technical, Environmental and Socio-Economic study of power-to-fuel solutions for a sustainable path towards a green future: achieving 80% renewable electric energy and 40% renewable primary energy supply within the next two decades (MUR)**

This proposal aims at defining the optimal renewable power generation and energy storage mix for grids with 80% renewable electricity share and 40% renewable primary energy share by 2040.

## **H2MOVE:Hydrogène pour une MObilité VERte et durable (Interreg IT/FR Marittimo)**

With the overall objective of supporting the climate neutrality of the cross-border maritime dimension, the partnership will collaborate in the definition of the macrostrategy for the development of H2 in ports and connected areas in order to provide a synergistic framework for ongoing (such as those foreseen in the Italian PNRR and France 2030) and future initiatives.

## **Analisi del ciclo di produzione dell'ammoniaca verde e del suo utilizzo come carrier dell'idrogeno (ENEA/PNRR)**

The overall objective of the project is the study of innovative pathways to produce green ammonia using different renewable energy sources and their combinations. The study will focus on performance (design and off-design), technical and economic feasibility

## TISMEN - *Tecnologie Innovative per lo Sviluppo di Motori ad Emissione di CO<sub>2</sub> Neutra (Accordo Prog.)*

- Il progetto ha come obiettivo lo sviluppo di metodologie di progettazione, tecnologie produttive e materiali per pistoni e parti calde di motori a combustione interna anche ad alte prestazioni che utilizzano idrogeno e altri e-fuels
- Il partner industriale è Assowerke, produttore di pistoni per motori ad alte prestazioni (Ducati, Ferrari, BMW moto, etc.)



## Development of new containment systems for alternative fuels in marine applications

- Studying the effectiveness of liquid hydrogen storage inside a predefined double wall tank, including the tank loading process and the transportation process.
- Studying the vacuum level effect between the inner and the outer tanks on the storage performance
- Studying the filling procedures and constraints

# Conclusioni

- Combustibili “verdi” hanno bisogno di energia “verde”: quanta ne serve? In Italia almeno 120 TWh
- Abbiamo davvero abbandonato l’idea di usare i biocombustibili?
- I motori saranno completamente sostituiti dalle celle a combustibile?
- Idrogeno o suoi derivati (Ammoniaca, Metanolo, ...?)
- Idrogeno in che forma ?

Quanto costa e quanto dura la transizione?

Grazie per l'attenzione

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