

European  
**Hydrogen**  
Week

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RESEARCH DAYS

15-16 NOVEMBER



Clean Hydrogen  
Partnership



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# End-uses: Transport

Luca Feola

Lionel Boillot

Pietro Caloprisco

Clean Hydrogen Partnership



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# Sessions on end-uses: transport

16<sup>th</sup> Nov. 9:30-11:00



End-Uses: Transport

Luca Feola

16<sup>th</sup> Nov. 11:30-13:00



Building Blocks for Transport Applications

Pietro Caloprisco

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# Decarbonizing transport: portfolio overview

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## Building blocks

FC stack components, BoP

Hydrogen tanks

Hydrogen infrastructure

Hydrogen transport

## Transport modes



Cars



Buses



Urban Lorries & Trucks



Maritime



Train



Aviation

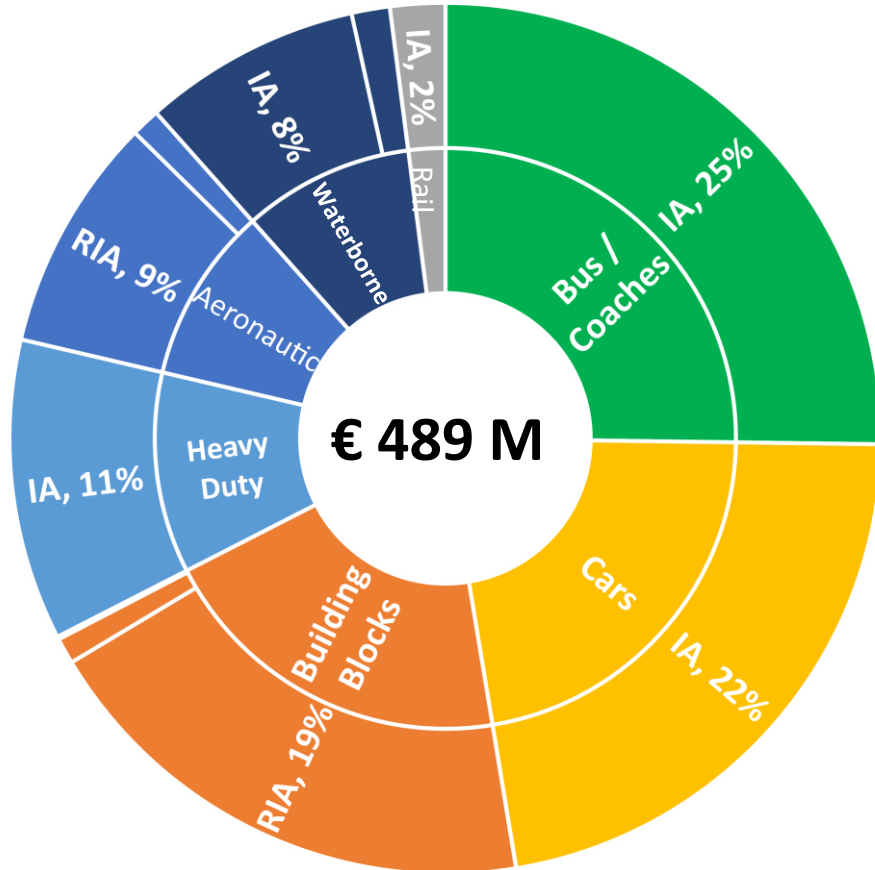


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# Decarbonizing transport: portfolio overview

Allocation of funds into different transport modes

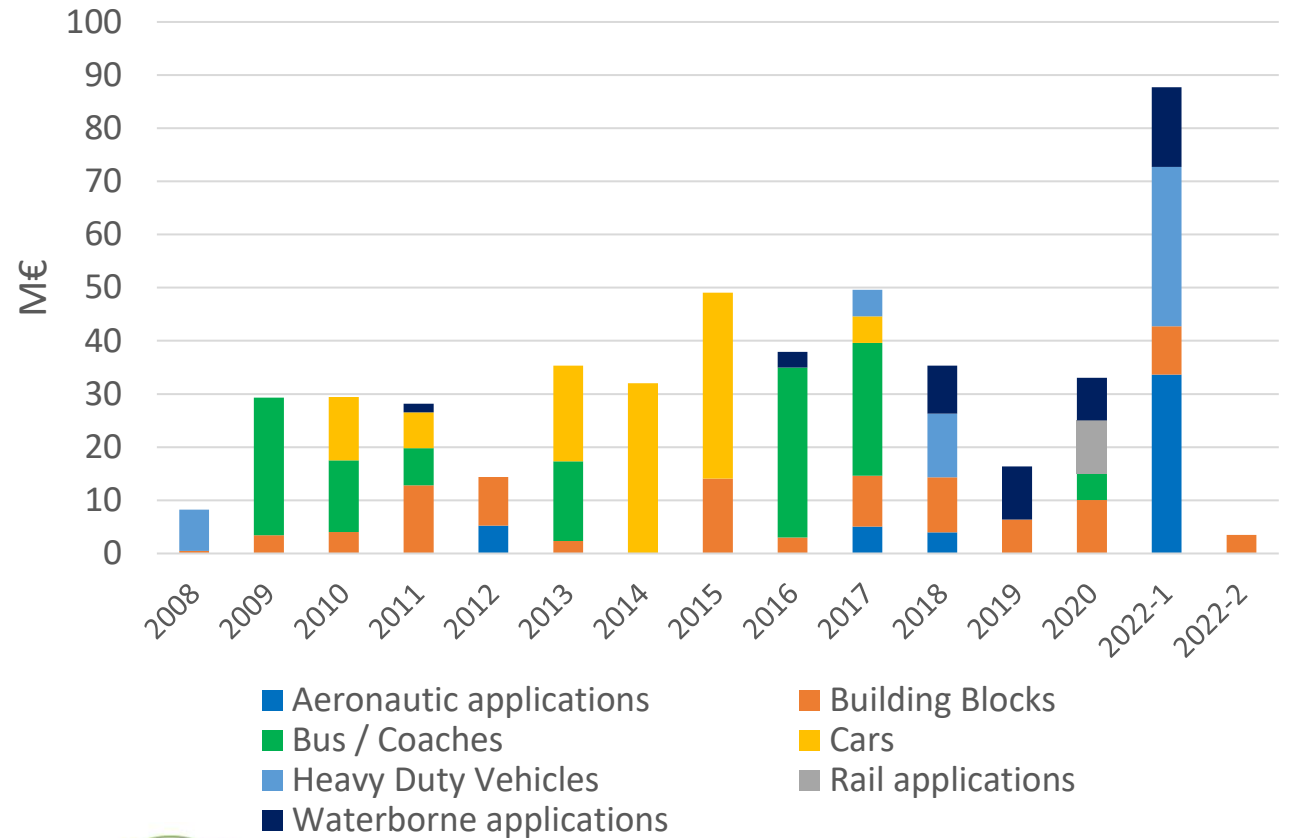
Transport: Clean H<sub>2</sub> JU support



RIA: Research & Innovations Actions  
IA: Innovation Actions (Demo)



JU funding per transport mode

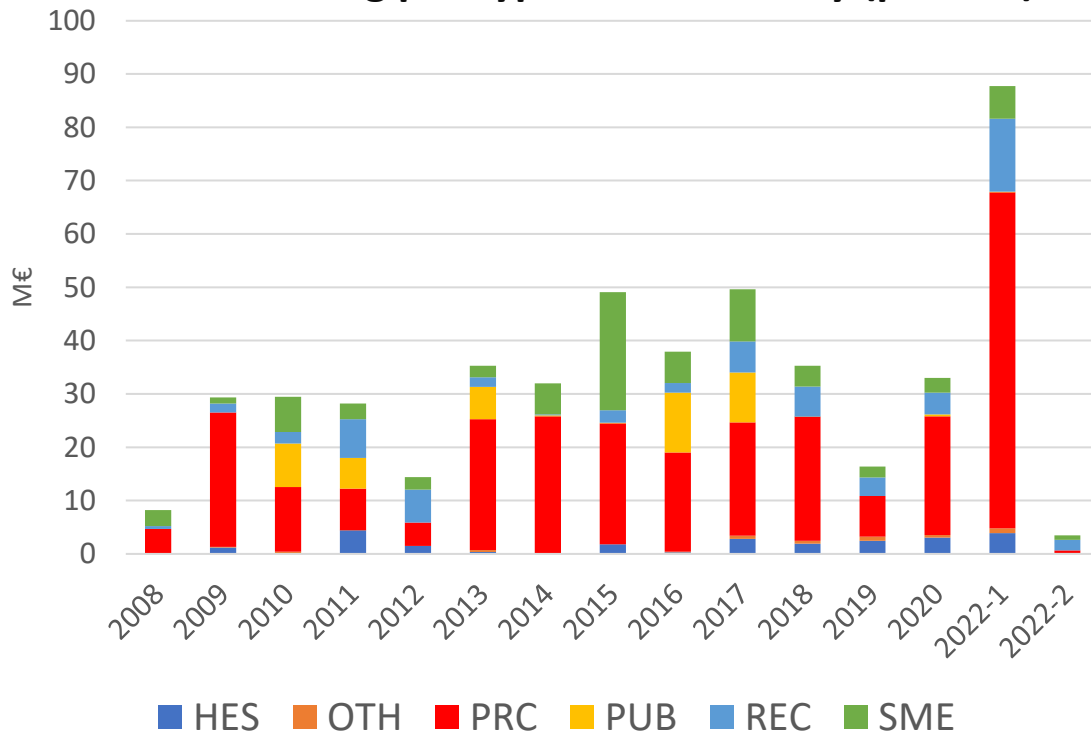




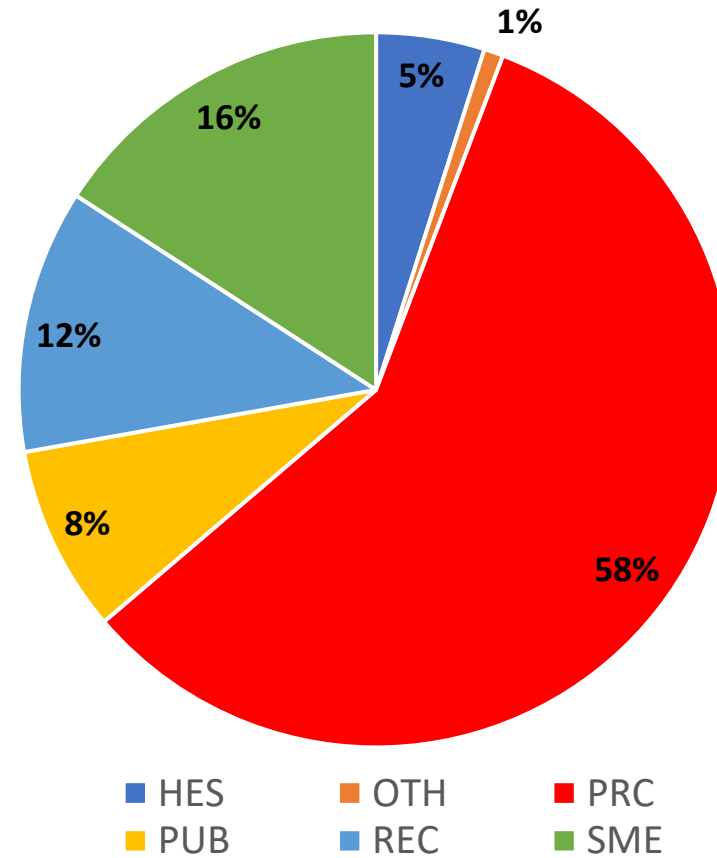
# Decarbonizing transport: portfolio overview

Allocation of funds toward entity types and type of actions

JU Funding per type of Beneficiary (per call)



JU Funding per type of beneficiary



PRC: Private Companies  
REC: Research Centres  
HES: Higher Education Schools  
PUB: Public Bodies  
SME: Small Medium Enterprises  
OTH: Others

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# Decarbonizing transport: from building blocks into prototypes

Prototype tests ongoing for all transport modes

## Transport modes

### Hydrogen transport



**Cars:** Demo projects concluded: sharing lessons learned



**Buses:** FC technology reliable, HRS to be improved



**Urban Lorries & Trucks:** Tests ongoing or planned



**Maritime:** vessels construction delayed



**Train:** test on public rail



**Aviation:** first flight of liquid H<sub>2</sub> powered aircraft



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# Light duty vehicle demonstration

Demo projects concluded: lessons learned shared

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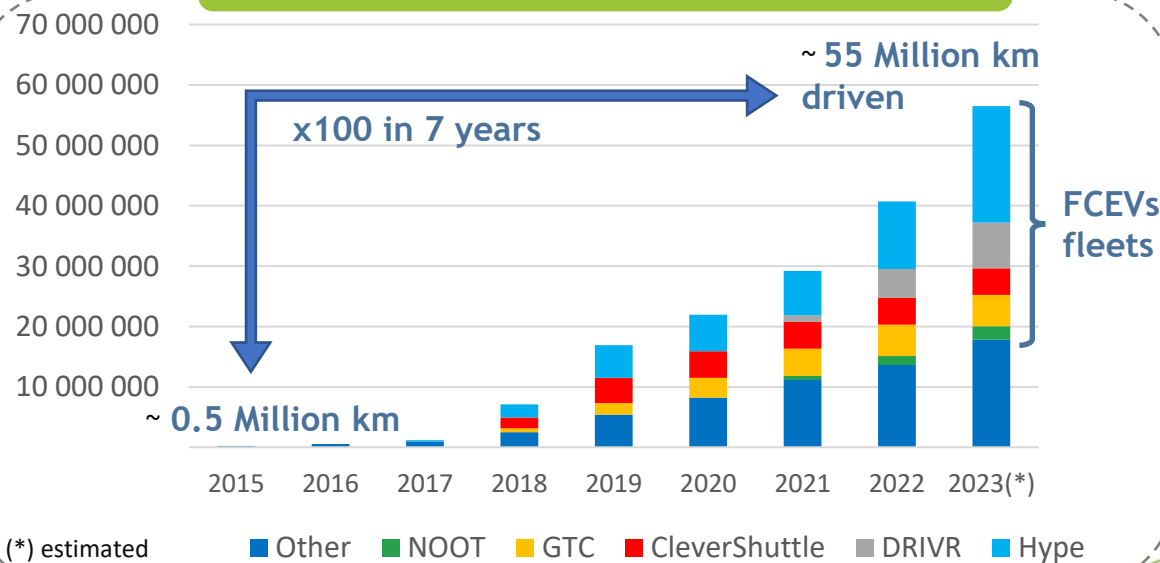
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## Achievements (H2ME/ZEFER)

- ~20% of all FC vehicles and ~20% of all HRSs in EU funded through these projects (1.740 cars and 46 HRSs)
- 245 tons of H<sub>2</sub> dispensed in 2022
- 1,4 million h of operation/ 1.400 tons CO<sub>2</sub> avoided

## FCEVs cumulative distance driven



## Fleet business models

- Spreading to other ZE cities
- Infrastructure + vehicles deployment at same time
- Increasing size of fleet, widening the applications (Hype taxi in Paris)



## Lessons learnt from cars projects

- (+) Fuel Cell technology reliable for mass deployment
- (+) FCEV refuel time remains advantageous versus EVs
- HRS infrastructure to be further improved:
- (-) low availability of HRS due to technical issues
- (-) low redundancy of HRS on the territory
- (-) decreased performance if HRS is underutilised





# Fleets of 5-50 buses in fifteen locations across EU

FC technology reliable for the end-use, HRS still to be improved



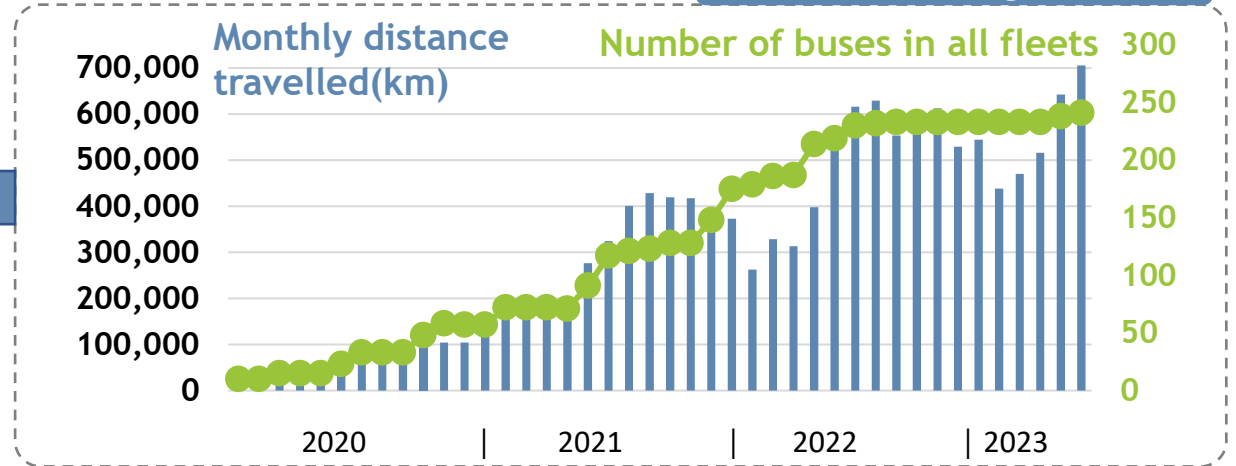
## Real operational data

- 252 FCB deployed (~65% of all FC buses in EU)
- Range similar to diesel bus (>350km)
- Excellent fuel efficiency 6-7kgH<sub>2</sub>/100km
- More than 13 million km driven
- Expected infancy issues cleared

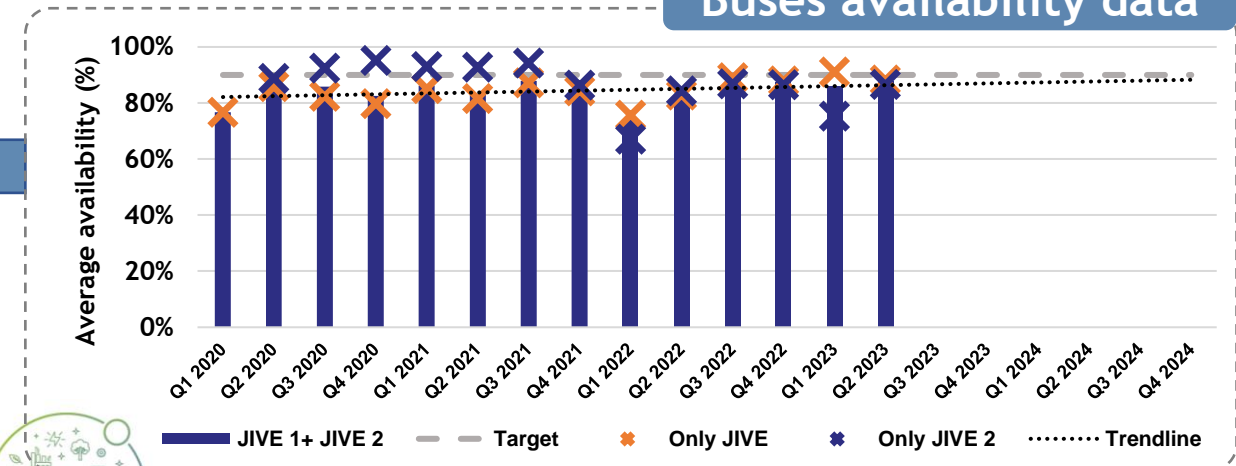
## Increasing buses availability, HRSs availability to be further improved

- Positive trend of FCB availability (target 90%)
- 85% of issues causing FCB unavailability are due to non-FC related components
- HRSs still face issues of unavailability due to technical issues (software, hardware, H<sub>2</sub> supply)

## Fleet mileage data



## Buses availability data



# FCB exploring new markets and increasing awareness

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## Increasing market and awareness

- Zero Emission Bus conference
- New bus OEMs entering the market
- Demand for coaches and 18m buses
- Best practices guide available: [www.fuelcellbuses.eu](http://www.fuelcellbuses.eu)



## JIVE2 Central and Eastern Europe Roadshow



- Display FCB and Mobile HRS in Central and Eastern Europe.
- Showcase the technology to the Public, Governments, PTO, PTA.
- Evaluate FCB performances in different environments.

## Key lessons learned from the Roadshow

- Preference of turnkey solution FCB/HRS/H<sub>2</sub>/maintenance for deploying FCB fleet by cities and operators.
- Need of synergies with funding programs (CEF, Cohesion fund, Modernisation funds, etc etc).
- Quick adoption (bus orders, commitment) following the roadshow (Estonia, Latvia, Hungary).



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# Urban heavy-duty applications

Operations started



2022

2024

Deployment 55%



Antwerp x2



Breda x 2



Helmond x 2



## Urban bin lorries configuration

Vehicle gross weight 27 t

Drivetrain 210 kW

FC Stack 45 kW

Max speed 90 km/h



Payload 9 t

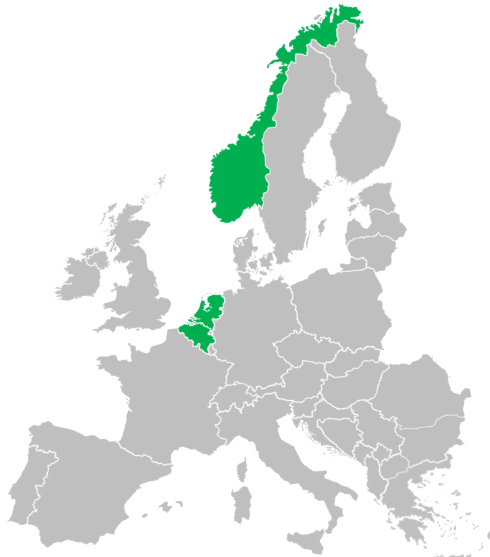
H<sub>2</sub>: 15 kg @ 350 bar

## Preliminary Data

Mileage (km)	22.837
Operating hours	1.670
H <sub>2</sub> consumed (kg)	3.208

Performance data not mature yet:  
Teething phase of newly deployed  
vehicles.

- 6 trucks deployed. 5 more to be deployed in Gothenburg, Groningen, Noordenveld



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# Long haul applications

HRS deployment started in synergy with CEF program



H2Accelerate



Targets: 16 HD trucks deployed in 4 EU Countries  
6 HRS stations deployed

## Partners and Locations



## Latest HRS deployment



- HRS Fos-sur-Mer operational
- 1ton H<sub>2</sub>/day
- 700 bar
- Pipeline supply

- Other 5 HRs in Belgium, France and Switzerland currently in operation being upgraded

## Truck configurations

Gross weight (tons)	42t	27t
Drive train power (kW)	480	210
Stack Power (kW)	132	50
Onboard H <sub>2</sub> (kg)	73	30
H <sub>2</sub> pressure (bar)	700	350
FC efficiency	55%	47%

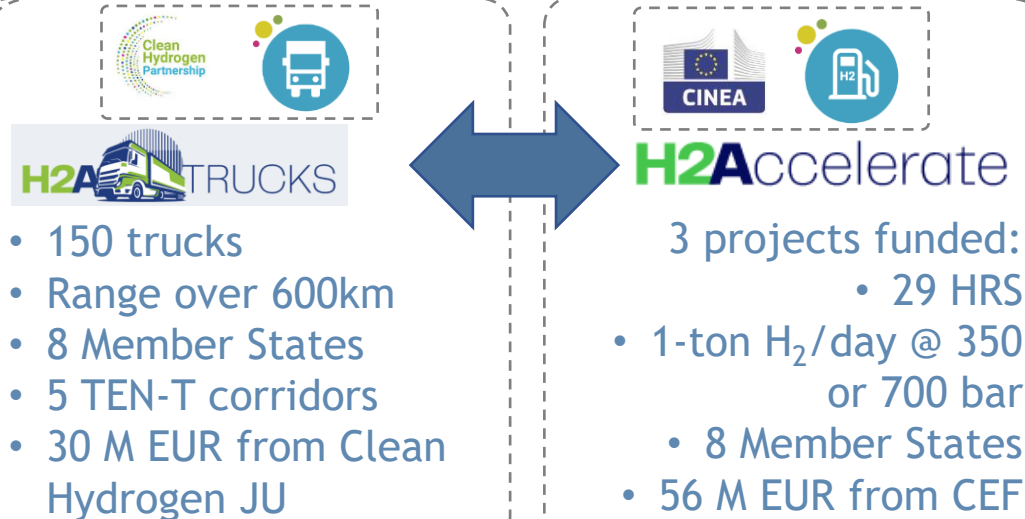
## Truck deployment



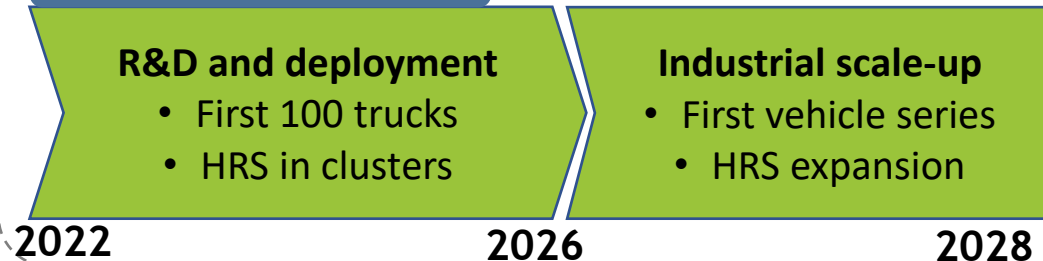
- Truck delivery delayed
- Final tests ongoing, first delivery expected in Q1 2024



## H2Accelerate: Synchronized approach between programs



## Timeline



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# Ships: towards larger vessels testing different fuels and FC

Building the pilots and experiments to speed up standards for waterborne applications

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Maritime

R&D vessel  
CH<sub>2</sub> PEM



MARANDA / 0,16 MW

Platform vessel  
NH<sub>3</sub> SOFC



SHIPFC / 2 MW

Ro-Ro vessel  
LH<sub>2</sub> PEM



HyShip / 3 MW



Fluvial

FLAGSHIPS > 1 MW



2 cargo vessels  
CH<sub>2</sub> PEM

HEAVENN / 0,38 MW



Barge vessel  
CH<sub>2</sub> PEM

RHEINER / 7.5MW

6 inland vessels  
CH<sub>2</sub> PEM

Pre-Normative  
Research

Hydrogen for passenger vessels

- Experimental data
- Guidelines for safe design for the new IGF chapter on hydrogen



Synergies



Challenges

- Delayed implementation
- H<sub>2</sub> supply issues
- Supply chain issues for large SOFC
- Lengthy authorisation process





# Ports as hydrogen «coastal hubs»

Pilots for clean port operations in container and ferry terminals

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## Heat and on-shore power for ferry terminals

- Port of Palma = 100kW
- Port of Orkney = 75 kW
- Port of Tenerife = 100kW
- Port of Helsinki = 600kW



## Heavy machinery for container handling



- Port of Valencia



## Studies and pilots on:

- Infrastructure for H<sub>2</sub>/NH<sub>3</sub> bunkering
- NH<sub>3</sub> and synthetic fuels for maritime
- Retrofit of port vessels fleet
- Passenger ferries



## Ports as hydrogen « coastal hubs »

- Creating / Serving H<sub>2</sub> demand locally for energy intensive industry (steel, chemicals, refineries, etc)
- Integration of renewable electricity
- International trading routes for H<sub>2</sub>
- Multimodal transport node



## Study on hydrogen in ports and industrial coastal areas

- European Hydrogen Ports Network
- [Report 1](#): Hydrogen demand & supply, business models
- [Report 2](#): R&I, safety and governance gaps



# Supporting the uptake of clean rail

Taking the steps towards zero-emission rail



## Objective

- Develop a bi-mode fuel cell hybrid train to operate on catenary and on FC/battery propulsion
- Test, validate and carry out the homologation of the prototype

## Regulation, codes and standards

- Identify gaps normative framework
- Modifications of relevant standards and technical specifications for interoperability

## Tests on railway ongoing

- Tests completed on public railways from Zaragoza to Canfranc.
- Next tests will be on public line Zaragoza - Soria as of Nov. 2023
- Use of mobile HRS



## Next steps (2024)

- Track testing of demo in Portugal
- Build own HRS for demo purposes
- Assess competitiveness of H<sub>2</sub> vs diesel train

# Toward a clean aeronautic transport

From small planes to long range H<sub>2</sub> powered aircrafts

## From Auxiliary Power Unit to small aircraft propulsion

2023 - Flying demo with LH<sub>2</sub> tank achieved

- 4 tests flights completed
- One flight over 3 hours
- Flying range doubled from 750km to 1500km



2017 - FC for emergency operation



2012 - APU for secondary electrical system



## Moving to hydrogen powered regional aviation

- Synergy with Clean Aviation JU (CAJU)

Technology maturation (up to TRL 5/6)

2022



2026



2030

Ground and flight tests

- Dedicated Fuel cells for Aviation from stack to full system (MW)
- Disruptive next-gen high temperature fuel cells for future aviation



### Challenges

As outcome of the Workshop (April '23) with CAJU:

- LH<sub>2</sub> storage, infrastructure, LH<sub>2</sub> supply
- Safety measures, regulations and procedures for LH<sub>2</sub>
- FC stack and components size up to 1.5MW

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# Decarbonizing transport: from building blocks into prototypes

Addressing the main challenges of demanding transport modes

## Building blocks

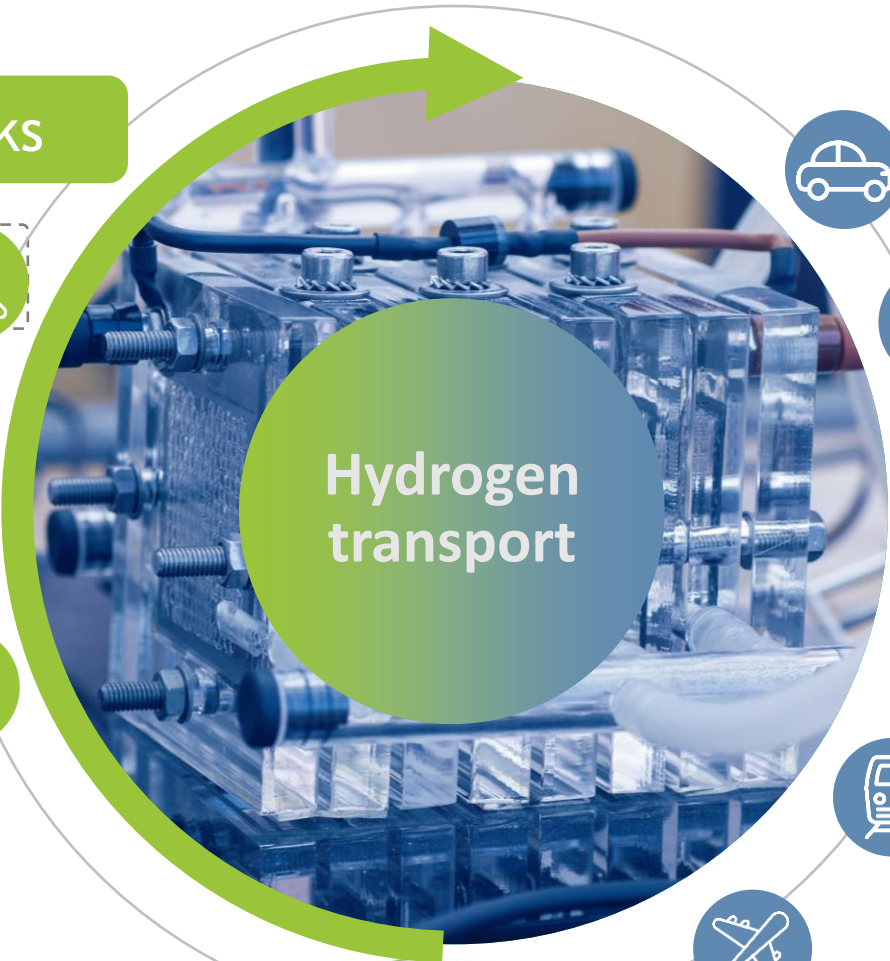
**FC stack components, BoP:**  
research on performance increase



**Hydrogen tanks:** optimising  
space with conformable tanks



**Hydrogen infrastructure:**  
increasing size, availability to be  
improved



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# Driving forward fuel cell technology for HD

Advancing fuel cell components toward performance and durability targets

## MEA/Stack development

- Focus on charge, mass and heat transports phenomena
- Light-weight and compact fuel cell stack (100kW) designs suitable for automotive applications.

caMelot



## Focus on durability

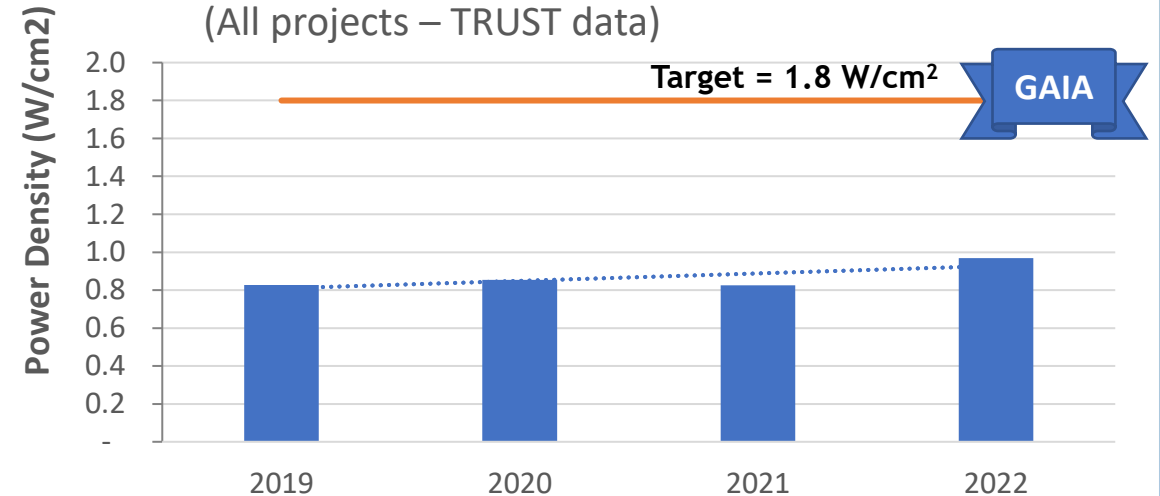
Development of durable and high-power density MEAs for trucks.  
Target = 30000h at system level.

IMMORTAL

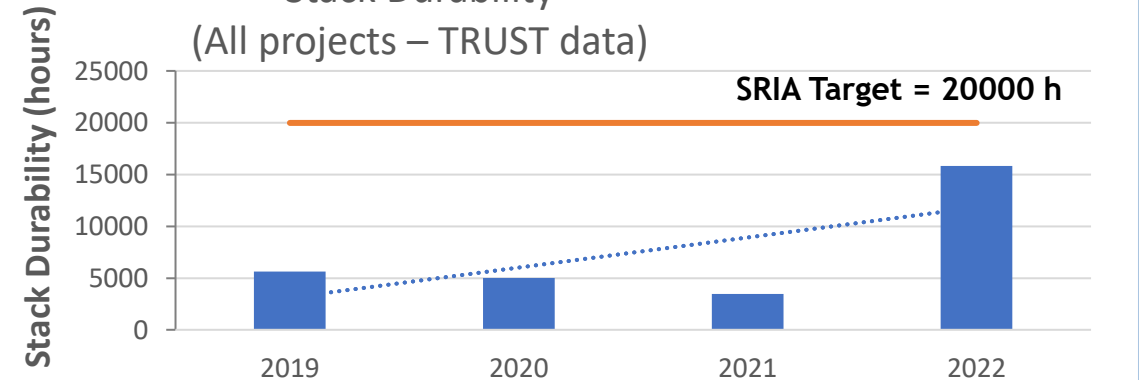
MORE LIFE



MEA - Areal Power Density  
(All projects – TRUST data)



Stack Durability  
(All projects – TRUST data)





# Driving forward fuel cell technology for HD

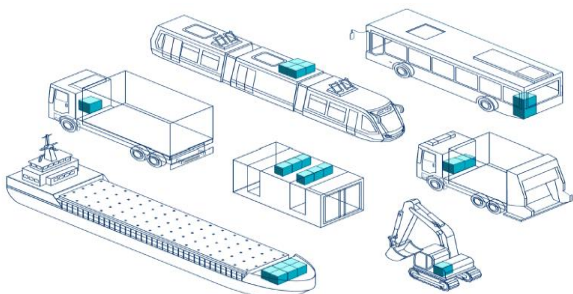
Advancing fuel cell components toward performance and durability targets

## Heavy Duty Specific projects



### Definition of the specifications

- Define dimensions
- Physical interface
- Application Program Interface



### Testing campaign

- Partners are building and testing the FC modules
- 50% of the modules built!



### Dissemination

- Exploitation workshop done (Sept 2022)
- European Hydrogen Week Side Event (22 Nov 2023)
- Public deliverables

- Optimisation of stacks for High Power Range Application
- Deliver a public open-design platform with high efficiency and durability under HD conditions.
- Started June 2023



**STASH**  
Towards a standardised fuel cell module

**PARTNERS**  
ALSTOM, AVL, BALLARD, CEA, CETENA, DAMEN, FEV, FREUDENBERG, FUTURE PROOF SHIPPING, INTELLIGENT ENERGY, NUVERA, PLASTIC OMNIUM, PROTON MOTOR, SINTEF, SOLARIS, TNO, TOYOTA, VDL ENERGY SYSTEMS, VDL, VOLVO, WATERSTOFNET

You are cordially invited to join:  
European Hydrogen Week - Side event

**Exploitation Workshop of StashH:  
Standard-Sized Heavy-duty Hydrogen**

World's first open standard for fuel cell modules

Looking forward meeting you at:  
Wednesday, 22.11.2023  
16:00 - 17:00 CET  
Hall 11, room 1124 (second floor)  
Michel Honselaar MSc : +32 488 471507

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# Hydrogen on-board storage and transport

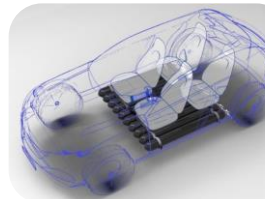
Developing solutions from gas to liquid hydrogen for all transport modes

Gas @ 700 bar

Liquid Hydrogen

## Automotive and Road Transport

- **High payload road transport: 1.5 tons @ 700 bar H<sub>2</sub> trailers with Type V cylinders**
- **New materials (type V): cost effective thermoplastic composite**
- **Conformable tanks: Fitting solutions for tight spaces**



Tank cost target: 400€/kg of H<sub>2</sub>

## Aviation

- **Composite conformal LH<sub>2</sub> tank for aviation use**
- **57kg with >25% gravimetric efficiency**
- **Dormancy >24h, Boil-off < 2% day**
- **Vacuum insulated**
- **Started 2023 - Ending 2026**



## Maritime

- **Next generation of large LH<sub>2</sub> tanks for shipping on vessels**
- **Long-term storage and long-distance transport**
- **Material research**
- **180m<sup>3</sup> ⇔ 10t LH<sub>2</sub> demonstrator**
- **Started 2023 - Ending 2027**



# Witnessing the operation of the new generation HRS

Shifting towards tonnes of H<sub>2</sub> per month for large and solicited stations

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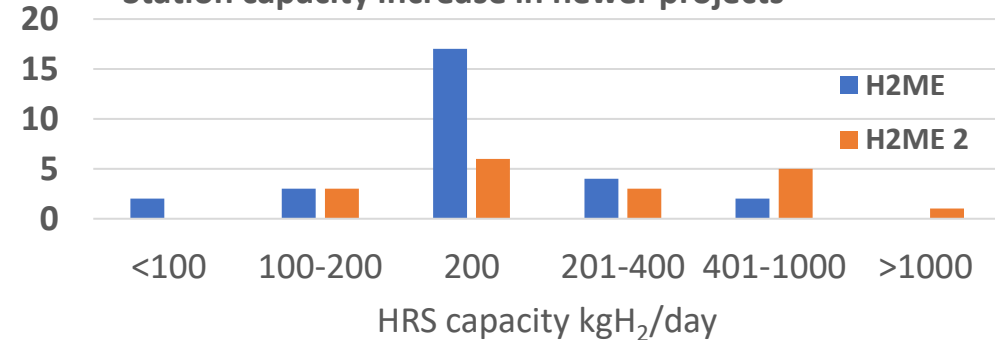
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## Robust HRS service

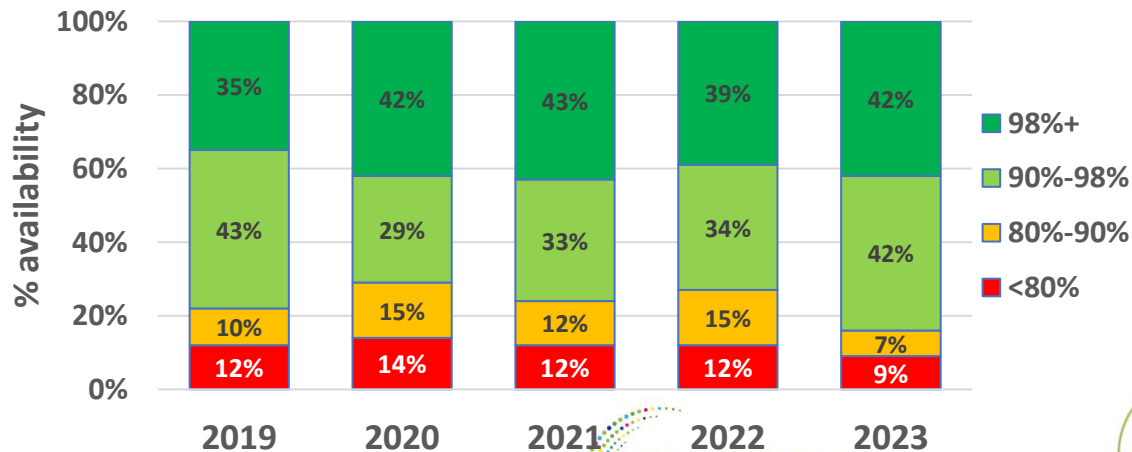
- Larger HRS sustaining fleets of buses or cars
- Operators handling a network of HRS
- Improved customers experience (payment system, back-to-back, multidispensers, etc.)

## HRS capacity (kgH<sub>2</sub>/day)

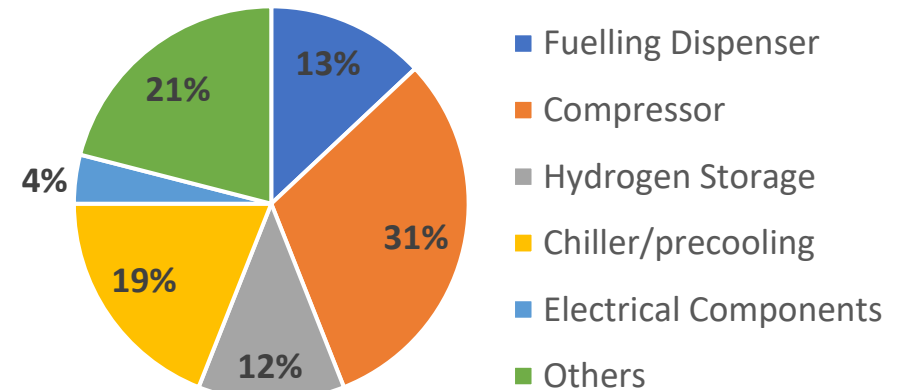
Station capacity increase in newer projects



## HRS availability to be further improved



## HRS downtime analysis H2ME & ZEFER (\*)



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(\*) H2ME2-D5.36-Public-FV-Report-3-technical-performance-...pdf

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## Conclusions



**Bus & Cars:** FC technology suitable for the end use. Disseminating best practises and lessons learnt at projects conclusion. Infrastructure to be further improved.



**Trucks:** First prototypes in preparation. Synergy for heavy duty applications infrastructure.



**Ships, aircrafts, trains and heavy machinery:** tests ongoing for the the commercial products in the heavy duty segment.



**R&D Building blocks:** keep improving performances. New materials and tank types on various end uses.