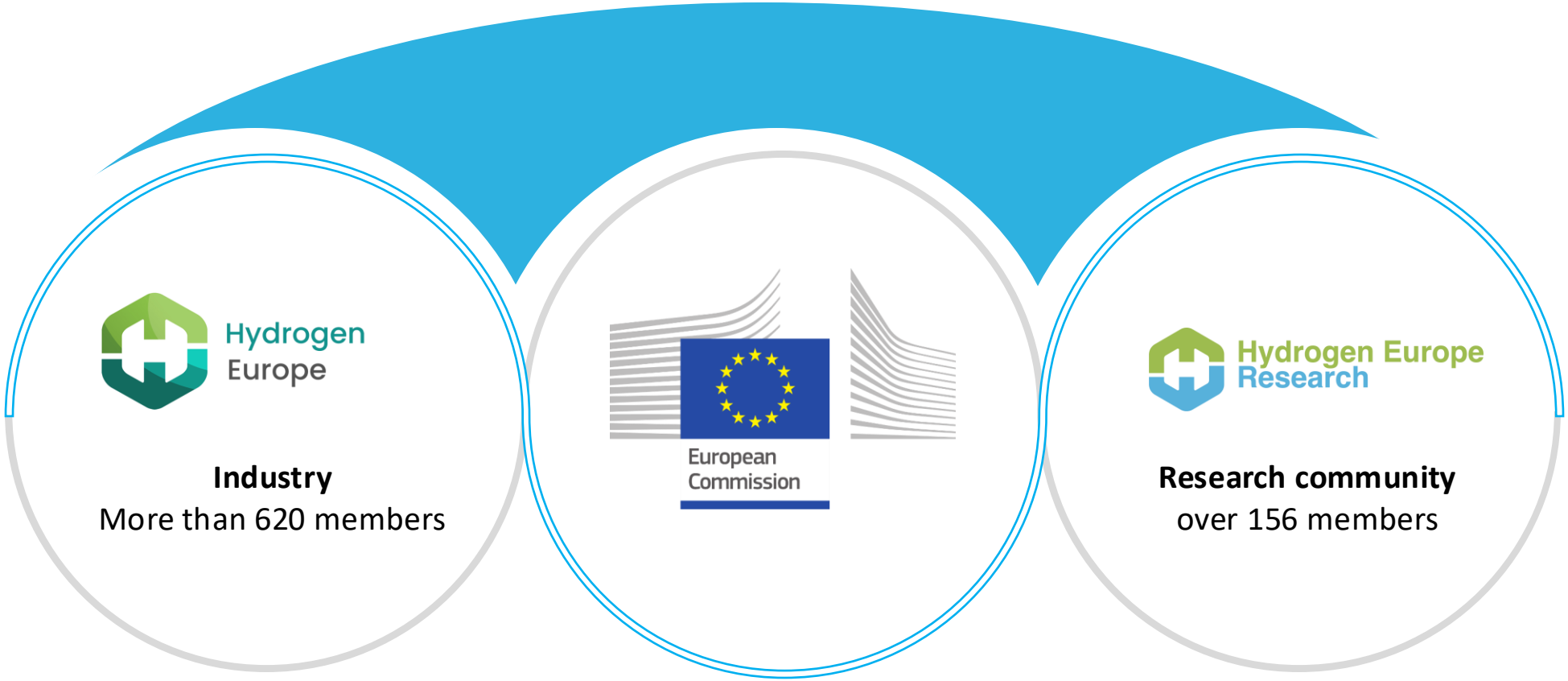
The state-of-the-art within hydrogen from the Clean Hydrogen Joint Undertaking's perspective

Mirela Atanasiu – Head of Unit Operations and Communication

Co-funded by the European Union

EU Institutional Public-Private Partnership (IPPP) 2021-2031



1 billion EURO from Horizon Europe* to implement R&I activities and facilitate the transition to a greener EU society through the development of hydrogen technologies

**** additional 200 million EURO for Hydrogen valleys (under RePowerEU)***

Co-funded by the European Union

Clean Hydrogen JU Objectives

General

- Support the implementation of the Commission's Hydrogen Strategy
- Stimulate research and innovation on clean hydrogen production, distribution, storage and end use applications
- Strengthen the competitiveness of the EU clean hydrogen value chain
- Contribute to the EU ambitious 2030 and 2050 climate ambition incl Green Deal

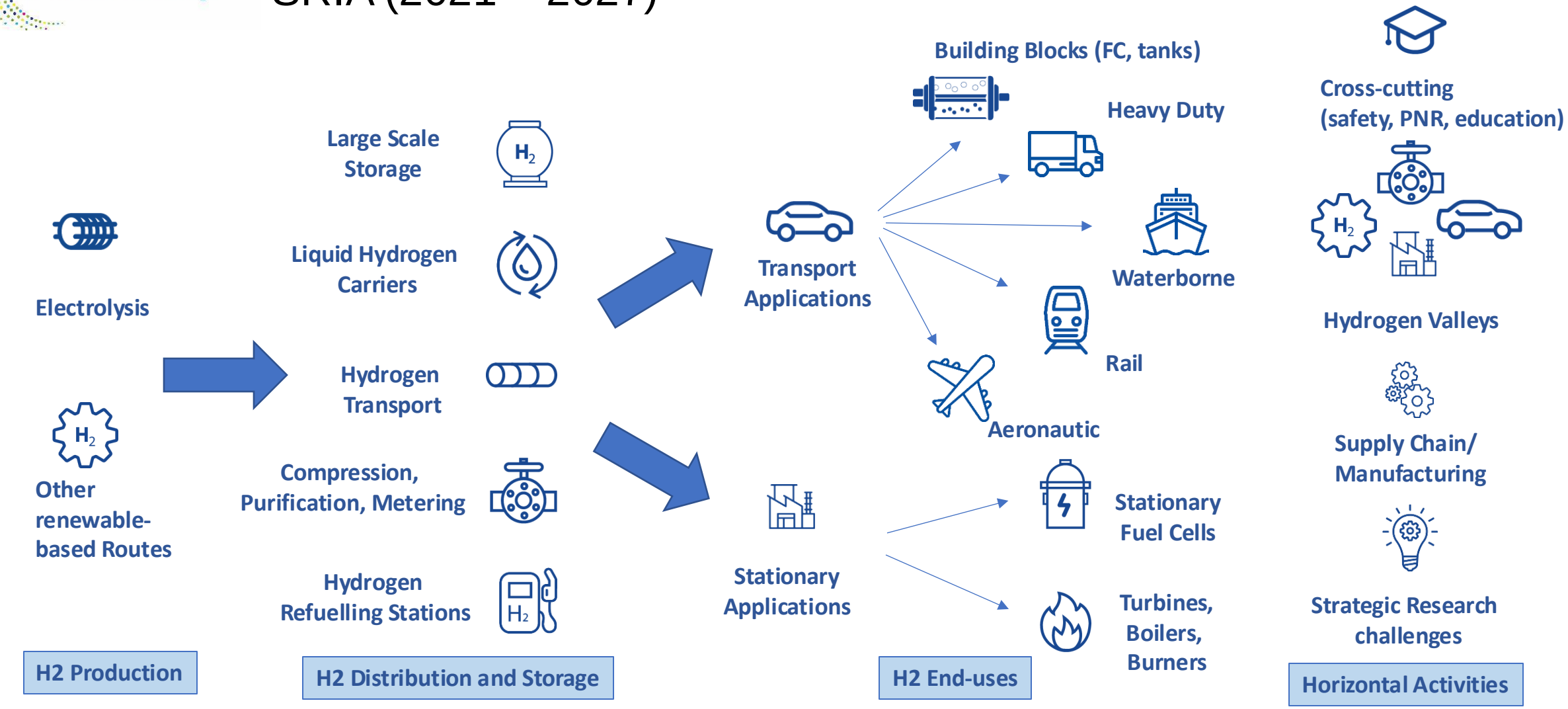
Specific

- Improve the cost-effectiveness, efficiency, reliability, quantity and quality of clean hydrogen solutions across entire value chain
- Strengthen the knowledge/capacity of scientific and industrial actors along the Union's hydrogen value chain while supporting the uptake of skills
- Demonstrations of clean hydrogen solutions with a view to local, regional and Union-wide deployment, aiming to involve stakeholders in all Member States and across entire value chain
- Increase public and private awareness, acceptance and uptake of clean hydrogen solutions

Co-funded by the European Union

Strategic Research & Innovation Agenda

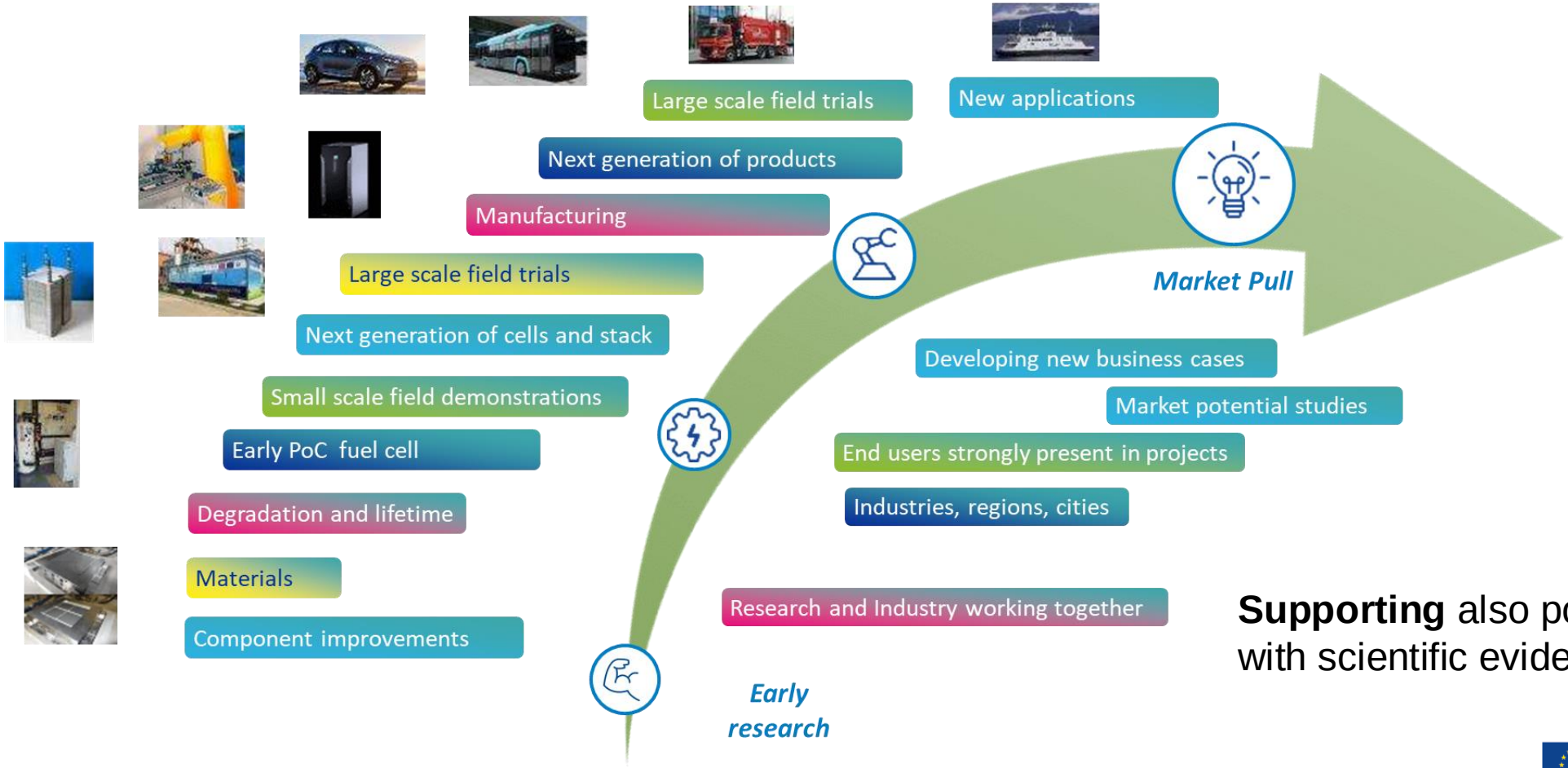
SRIA (2021 – 2027)



Co-funded by the European Union

16 years journey of the Joint Undertaking

From research to delivering hydrogen solutions/innovations in the market, continuing the work of predecessor FCH JU…

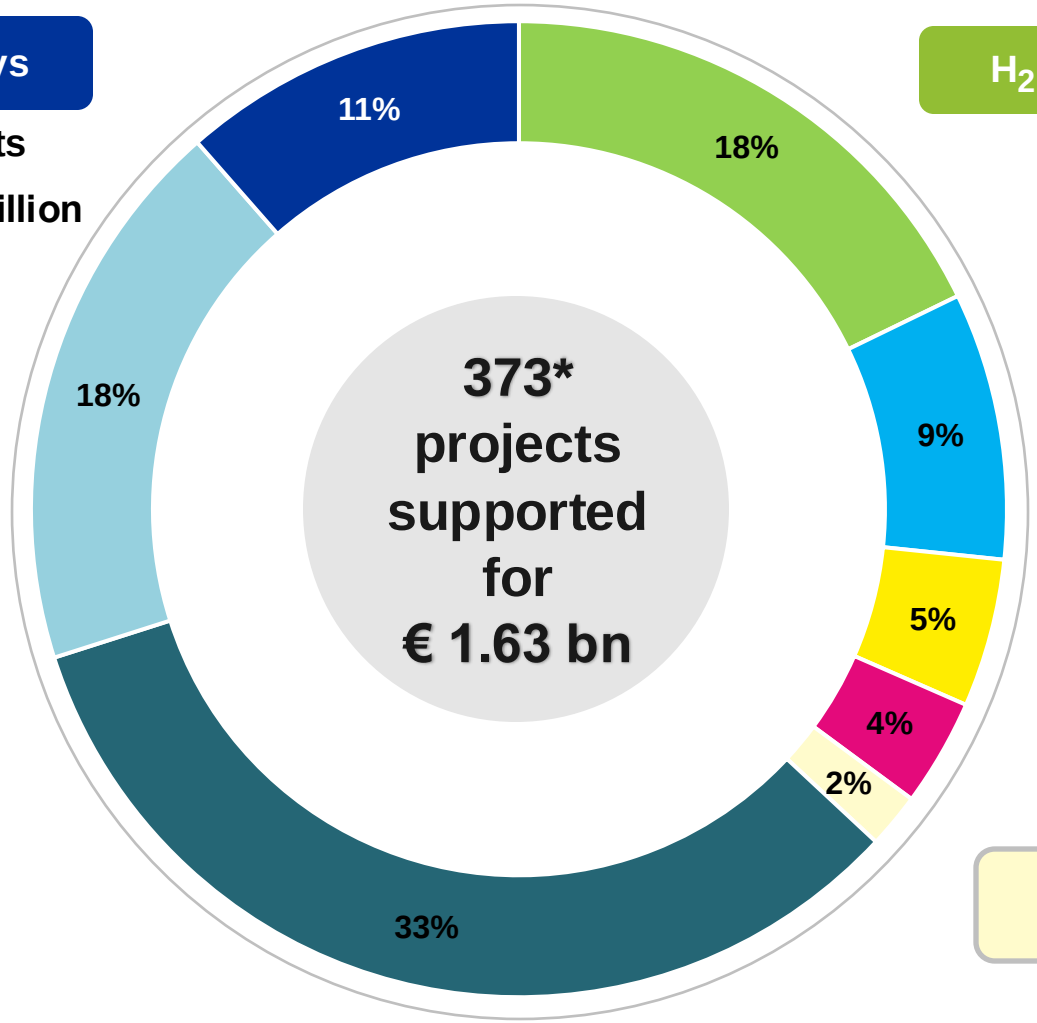


Supporting also policy with scientific evidence!

Co-funded by the European Union

Programme/projects portfolio

including legacy of FCH JU



H_2 Valleys

16 Projects

€ 186.8 million

H_2 Production

79 Projects

€ 290.3 million

H_2 End Use: Clean Heat and Power

87 Projects

€ 301.1 million

H_2 Storage & Distribution

38 Projects

€ 144.4 million

Cross-cutting

54 Projects

€ 80.1 million

H_2 End Use: Transport

78 Projects

€ 540.5 million

Supply Chain

18 Projects

€ 58 million

Strategic Research Challenge

3 Projects

€ 29.6 million

**Additional 29 grants under preparation (from 2024 call budget)*

Co-funded by the European Union

Solid EU Hydrogen Strategy & Support Schemes Leading to ambitious targets…

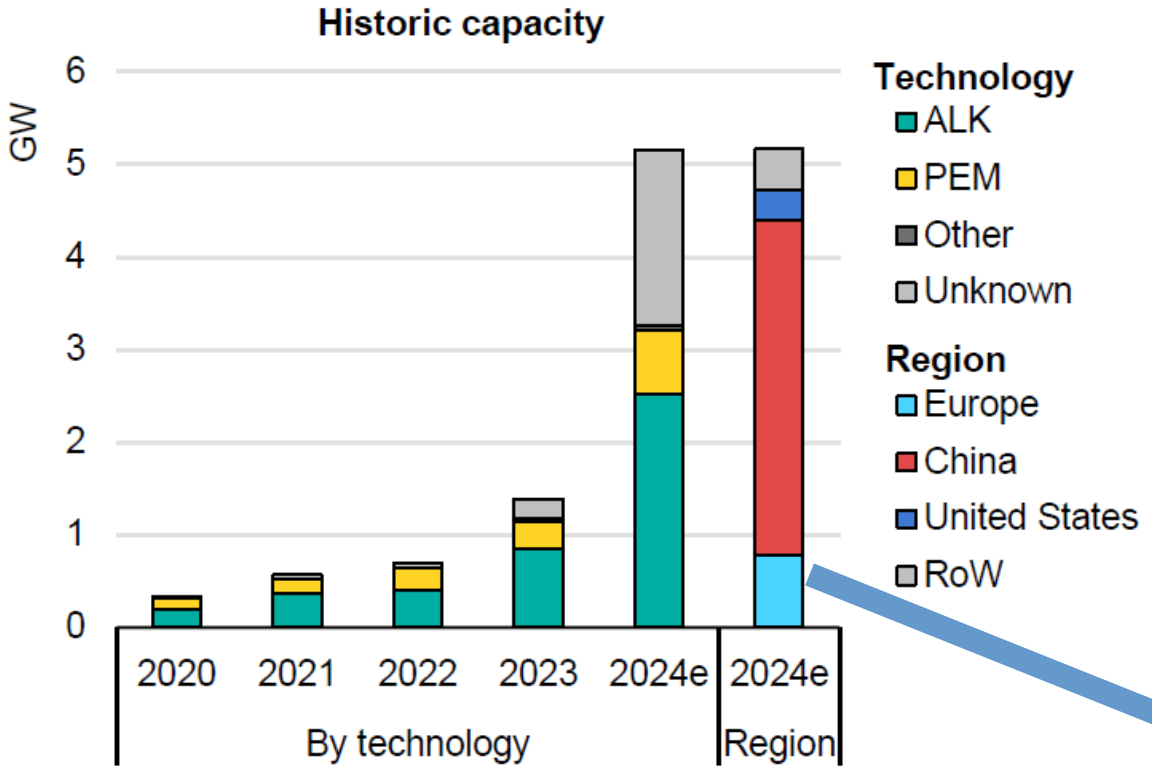
- 2020 EU Hydrogen Strategy
- 2021 Fit-for-55 package
- 2022 REPowerEU plan & Hydrogen Bank
- 2023 Two Delegated Acts on Renewable H2 and RFNBOs
- RRF: 2022 and 2024 IPCEIS on Hydrogen: Hy2Tech, Hy2Use, Hy2Infra, Hy2Move

to install at least 6 GW of renewable hydrogen electrolysers by 2024 and 40 GW by 2030 in the EU.

to produce 10 million tonnes and import 10 million tonnes of renewable hydrogen in the EU by 2030.

… that constitute major challenges

Installed electrolyser capacity increased from 1.4GW in 2023 to 5GW in 2024



700MW in Europe

out of which the Clean Hydrogen JU projects:

- **Installed 43 MW**
- **Planned 400 MW**

Low Temp Electrolysis Demonstration projects

In 12 years electrolyser capacity increased 200× and funding per MW installed reduced 100×

All facilities continue to operate after completion of each project

Project: **Don Quichote**
Place: Belgium
Date: **2011**
Electrolyser: Hydrogenics
Funding: 5.0 m€

0.15 MW

Project: **Hybalance**
Place: Denmark
Date: 2014
Electrolyser: Hydrogenics
Funding: 8.0 m€

1.2 MW

Project: **Haeolus**
Place: Norway
Date: **2017**
Electrolyser: Hydrogenics
Funding: 5.0 m€

2.5 MW

Project: **Demo4grid**
Place: Austria
Date: **2016**
Electrolyser: IHT
Funding: 2.9 m€

3.2 MW

Project: **H2future**
Place: Austria
Date: **2016**
Electrolyser: Siemens
Funding: 12 m€

6.0 MW

Project: **Refhyne**
Place: Germany
Date: **2017**
Electrolyser: ITM
Funding: 10 m€

10 MW

Project: **Djewels**
Place: The Netherlands
Date: **2018**
Electrolyser: McPhy
Funding: 11 m€

Djewels → HEAVENN

20 MW

Project: **EPHYRA**
Place: Greece
Date: **2023**
Electrolyser: TBA
Funding: 17.7 m€

Ephyra → TRIERES

30 MW

PEMEL

AEL

Till 2017 largest electrolyser projects globally

EUROPEAN PARTNERSHIP

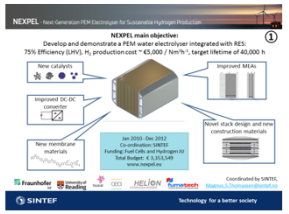
Co-funded by the European Union

Low Temp Electrolysis success

14 years of development from materials to 100MW plant

PEM Electrolyser technology

Five SINTEF-coordinated electrolyser EU funded projects (2010 → now)
Materials development → Up-scaling → Market implementation

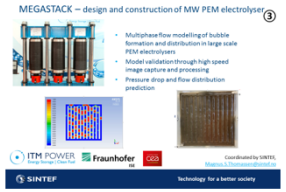


NEXPEL

https://www.sintef.no/projectweb/nexpel/

NOVEL

https://www.sintef.no/projectweb/novel/



MEGASTACK

https://www.sintef.no/Projectweb/megastack/

REFHYNE 1 & 2
10 – 100 MW PEM-electrolyser

REFHYNE

REFHYNE 2

https://refhyne.eu/

SINTEF is/has been partner in more than 38 EU/FCHJU/CHP funded H2 projects

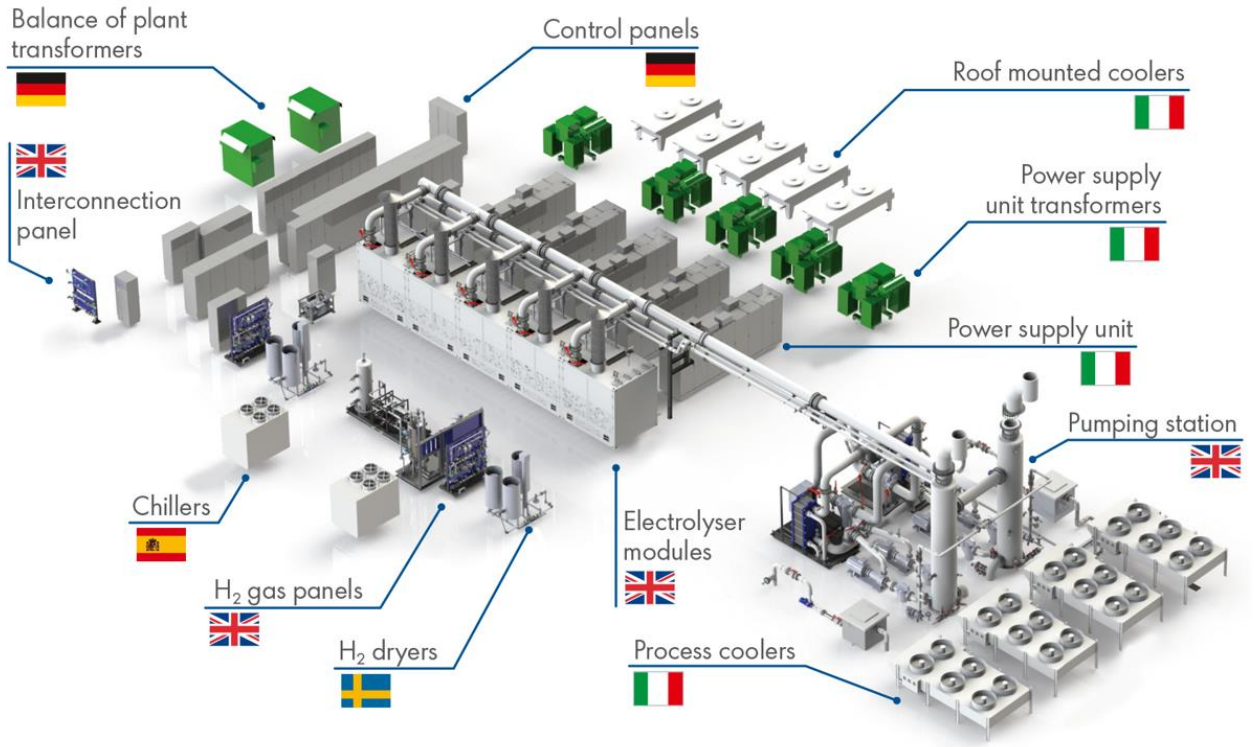
Low Temp Electrolysis Demonstration projects

100% EU-made components in 2017 REFHYNE project

Building Europe's largest PEM-Electrolyser

REFHYNE
CLEAN REFINERY HYDROGEN FOR EUROPE

- 10 MW
- Up to 1,300 tons production capacity
- The first large-scale water electrolyser integrated in a refinery
- Stepping stone and reference for the 100MW class



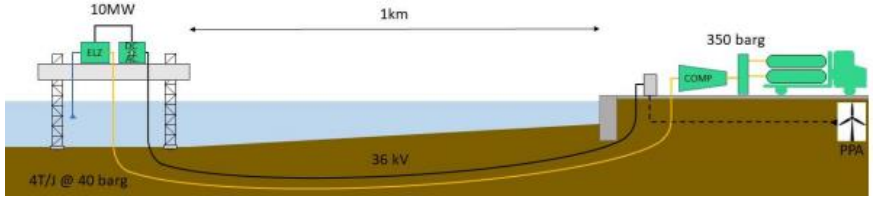
LT Electrolysis projects – Going off-shore

New electrolyser OEMs / players to JU frameworks

2020: OYSTER project

- Marinisation of 3MW AEL - Stiesdal (DK)
- Near-shore operation
- Denmark
- Integrated desalination

2022: HOPE project



- Marinisation of 10MW PEMEL - Frames Energy / Plug (NL)
- Off-shore operation
- Oostende (B)
- Recycled jack-up barge

High Temp Electrolysis Demonstration projects

HTELs finding their place in the industrial courtyards, facilitating strategic partnerships

2015

Salzgitter Iron and Steel Works
150kW

GrInHy
Green Industrial Hydrogen

2018

PAUL WURTH BECOMES NEW LEAD INVESTOR AND TECHNOLOGY PARTNER OF SUNFIRE

GrInHy2.0
Green Industrial Hydrogen

Salzgitter Iron and Steel Works
720kW – 200 Nm³/h – η 84.6%
Availability 84%
Valuable open access data

2019

MULTIPLHY

NESTE INVESTS IN SUNFIRE

Rotterdam Neste Biorefinery
2.4MW in commissioning

Electrolyser current (NEW) R&I emphasis

- Improvements in materials, components, BoP, control (Digital Twin)
- Seawater electrolysis
- Removing PFAS
- Recycling
- Improved/direct Coupling with renewables
- EU competitiveness – electrolyser design for safety

Underground Hydrogen Storage

Covering Salt Caverns and depleted gas fields

Depleted Gas Fields

TRL

- Building on the results of the Underground Sun Storage 2030 and HyUSPRe
- Rubensdorf, Austria site → fully functional and integrated hydrogen storage system (100 tonnes H_2)
- 4 testing cycles foreseen spanning 4 years
- Replication in 5 sites across the EU.

- Mapping H2 storage site and characteristics of reservoirs
- Extensive sampling and microbiological lab experiments
- Ranking of sites based on “suitability mark” and LCOS

Salt Caverns

CAPACITY

- 2024-2026: Conducting analyses for the Manosque demonstrator 2026-2027: Construction phase
- 2027-2029: 100 Injections/Withdrawals
- 2029 onwards: Commercial 6,000 tonnes H_2 capacity

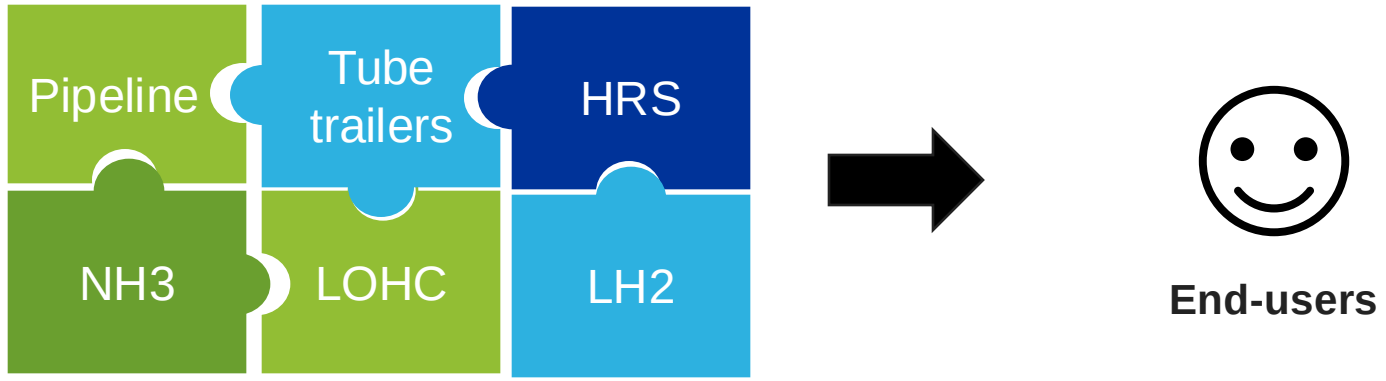
- Completed all cavern tightness tests
- About to start pressure cycling test with H_2
- 3 tonnes H_2 stored

EUROPEAN PARTNERSHIP
Co-funded by the European Union

The hydrogen distribution mosaic

By 2030:

- **EU Production of 10 million tonnes H_2**
- **Import of 10 million tonnes H_2**



Optimal distribution choice will depend on end-user requirements, distance, amount etc

Co-funded by the European Union

Gaseous Hydrogen Transport

Pipeline

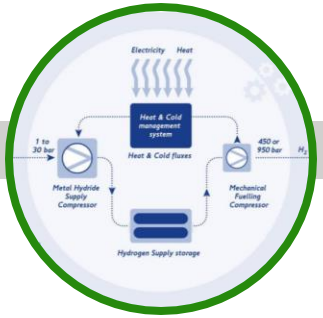
- Material Compatibility
- Leak Detection
- Network Management

High- Pressure Supply Chain

- Improve system efficiency
- Increase tube trailer payload
- Increase capacity of filling center

HRS

- Deployed >105 HRS
- Priority now is to match the requirements of heavy-duty applications
- Component and protocol development for higher capacities and faster refueling times



Compressor

- Scaled-up novel prototypes from lab to demonstration.
- Higher availability and capacities remain as challenges

Co-funded by the European Union

Liquid Hydrogen Transport

Liquefaction

HyLICAL

- 8kWh/kgH_2 target
- 1€/kgH_2 cost target
- Prototype of 100kg/day

Storage

LH2 CRAFT

NICOLHy

- Novel insulation concepts
- On-shore and on-board designs
- Scaled-down prototypes ~10tH2

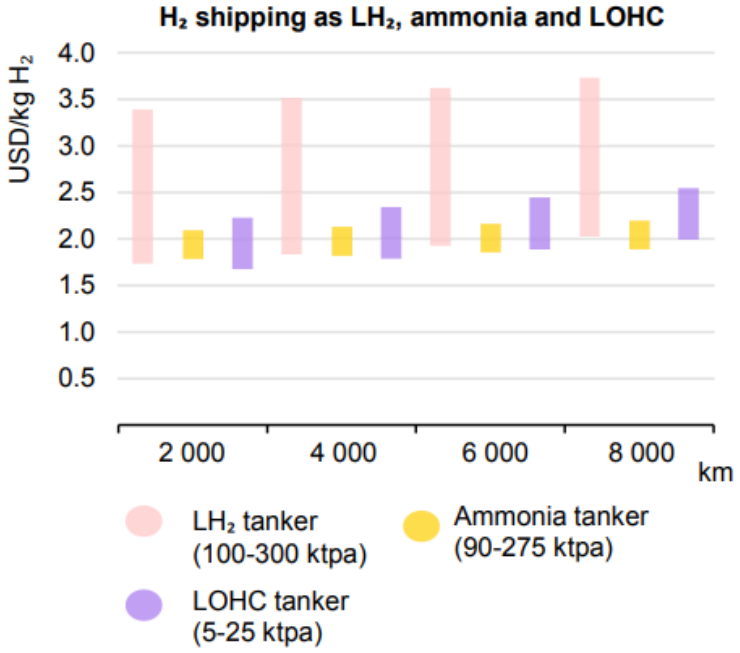
Delivery

DelHyVEHR

- High-flow rates> 5tH_2/hour
- Boil-off management
- Targeting Heavy-duty Transport applications

Hydrogen Carriers

Levelised Cost of shipping Hydrogen



Source: IEA Global Hydrogen Review 2024

LOHCs

- Full system has been demonstrated for storage and release 24kgH_2/day
- Subsequent projects focusing on PGM reduction and energy efficiency improvements with small-scale demonstrations

Ammonia

- Focus is solely on ammonia cracking
- Small-scale prototypes of 10kgH2/day

Co-funded by the European Union

Transport Policy framework and targets

Green Deal

- First **Climate-Neutral continent by 2050**
- At least 55% less GHGs emissions by 2030

Transport target

- **90% emissions reductions by 2050**

Road

New CO2 emission standards:

- 100% reduction as of 2035 for LDV
- 90% reduction as of 2040 for HDV

Waterborne

Fuel EU Maritime:

- GHGs intensity reduced by 80% by 2050
- Uptake of RFNBO

Aviation

Refuel EU

- 70% of SAF in EU airports as of 2050
- 35% of synthetic aviation fuels in EU airports as of 2050

AFIR/AFIF Calls

- Public electric and **H_2 infrastructure** (every 200km)
- Electricity, ammonia and methanol supply at **ports**
- Electricity and hydrogen supply at **airports**

Clean Hydrogen JU

- Entire value chain from H_2 production to end uses
- **Technology** building blocks
- Innovation **demonstration**

Co-funded by the European Union

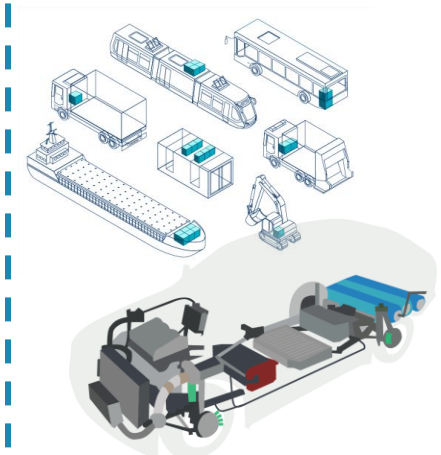
From technology building blocks to applications

Clean Hydrogen Partnership

Continuous loop of innovation

Components

Prototypes



Applications

Demo feedback for new generation products

Costs ↓ Performances ↑ Lifetime ↑ Competitiveness ↑

TRL

Co-funded by the European Union

Urban public and passengers' transport

Light duty vehicle (cars and vans)

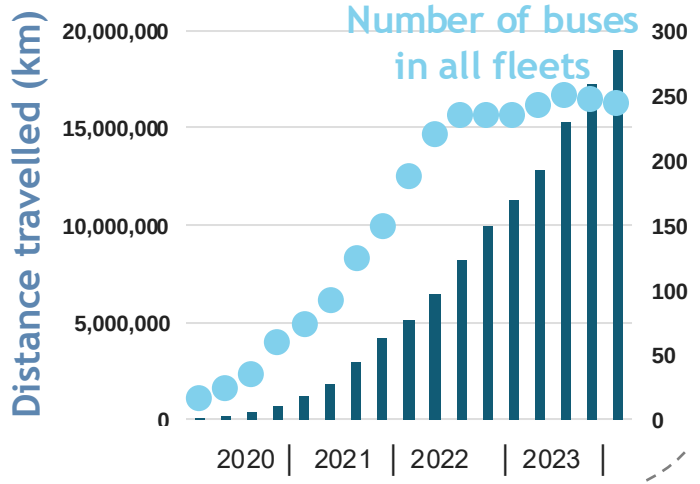
- 1/5th of all FC vehicles and HRSs in EU (**~1.740 cars and 50 HRSs**)
- 245 tons of H_2 dispensed in 2022
- 1,4 million hours of operation
- 1.400 tons CO_2 avoided

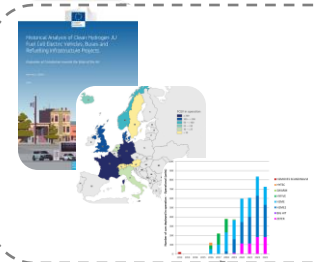
Fleet business models

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

Urban buses

- 2/3rd of all FC buses in EU (**~252 FCB**)
- Range >350km
- **Efficiency 6-7kgH_2/100km**
- Total reliability >600.000 FC hours





Historical Analysis of Clean Hydrogen JU Fuel Cell Electric Vehicles, Buses and Refuelling Infrastructure Projects - ***JRC***

Publication

HRS infrastructure projects - ***CINEA***

- H2F4P Hydrogen Fuel for Paris
- MEHRLIN
- H2BENELUX, …

Synergies

Co-funded by the European Union

Growing ambition on the road

Urban applications

REVIVE

- **11 trucks deployed**
- 20.000 km driven
- 3.000 hours of operations

100% deployed !

Long haul

H2HAUL

- **16 long haul trucks**
- Last teething issues being solved
- Full deployment by February 2025

Ready for deployment

Large fleets

H2A TRUCKS

- **150 HD long haul trucks**
- Range: over 600 km
- Deployment: 8 MS, 5 TEN-T corridors

Ground work

Challenges

- Further TCO reduction
- Infrastructure
- Standardisation
- Continuous R&I evolution

Co-funded by the European Union

Clean solutions for shipping and ports

Clean Hydrogen Partnership

H MARINE

Multi-MW stacks and **fuel cells** systems

LH2 CRAFT

NICOLHy

Tanks for hydrogen and derivatives fuels

Demonstration of short sea and fluvial vessels

MARANDA HEAVENN FLAGSHIPS HyShip SHIPFC RH2IWER

EUROPEAN PARTNERSHIP

Hydrogen **ports ecosystems**

NAHV BalticSeaH2 CONVEY TRIĒRĒS

Regulations, codes and standards

HyLAW e-SHyIPS ON THE WAVE OF HYDROGEN

Heavy machinery for container handling

H2 PORTS

Heat and **on-shore power** for ferry terminals

BIGHIT GREEN HYSLAND EVERYWH2ERE BalticSeaH2 amon

Challenges

- H_2 and FC supply chains
- Regulations

Co-funded by the European Union

Pilots of hydrogen trains and aircrafts

Retrofitted train

Key achievements

- **1.2MW FC** pack retrofitted
- Built and used mobile HRS for testing purposes
- **10.000km of tests** in public and private railways
- TCO assessment vs diesel trains ongoing
- Results validation with EU-Rail JU projects

Challenges

- Business case: TCO vs Electric train seems unfavorable (see low adoption in Germany)
- Infrastructure unavailability

Demo aircraft

- 4 tests flights completed using LH_2 only
- One flight over 3 hours
- **Flying range** doubled to **1.500km**

2022 Technology maturation → **2026** Ground and flight tests

Research for aviation

- FC from stack to full system (**MW**)
- Next-gen **high temperature** FC
- Composite conformal **LH_2 Tank**

Challenges

- LH_2 storage, infrastructure, LH_2 supply
- Safety measures, regulations and procedures for LH_2
- FC stack and components size up to 1.5MW

Co-funded by the European Union

Hydrogen Refuelling Stations as enabler for hydrogen mobility

- On board storage: 5 kg H_2
- Refuelling speed: 1 min / kg H_2

x 7

- On board storage: 70 kg H_2
- Refuelling speed: 1 min / 7 kg H_2

Passengers cars, small fleets → Bigger vehicles, larger fleets

Achievements

- **>1 million kgH_2** dispensed to buses (06/2023)
- **>600 kgH_2/day** dispensed to taxis on a single HRS
- **Sustained availability of 99.9% for best-in-class**
- Improved users experience

Protocols and standards

- LH_2 high-capacity delivery at 5tH_2/h
- Protocol for HD H_2 refuelling

DelHyVEHR

PRHYDE
Protocol for heavy-duty Hydrogen refuelling

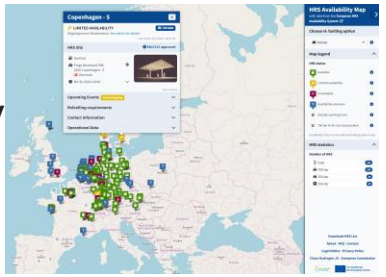
Challenges

- H_2 supply and MTBF
- Faster flow rates
- Back-to-back refuelling
- Deployment

E-HRS Availability system

- Free, real-time and quality data
- Supports AFIR and hydrogen mobility
- Future development for HD

https://h2-map.eu/



Co-funded by the European Union

Synergies at EU level

Several programmes are now active in hydrogen technology and deployment

Clean Hydrogen Partnership · Interreg Europe · Co-funded by the European Union · 2ZERO · Europe's Rail · CLEAN AVIATION · WATERBORNE · CINEA

Example of coordination

+

150 trucks, 8 countries

H2A TRUCKS

14 HRS, 4 countries

GREATER4H

...and others

End Uses: Clean Heat and Power

Residential, commercial buildings, service sector, industry

Research

- Lifetime & performance
- Monitoring & Diagnostics
- Component and System aspects
- Materials & Manufacturing

Proof of Concepts

Trials and Demonstrations

End use ready solution, new business models for market introduction

Next Generation Products

Fuel cells

O1: Reducing CAPEX and TCO of FCs
O2: Next generation 0-100% H2 and H2-rich fuels
O3: Improve flexibility with reversible fuel cells
O4: Reducing critical raw materials and recycling
O5: Mass manufacturing

Gas turbines + burners/furnaces

O1: 0-100% H2 (low NOx, high eff,, flexible op.)
O2: Demos (retrofitting) + safety and plan integration

Co-funded by the European Union

End Uses: Clean Heat and Power

… and the work continues

Fuel Cells

- Ammonia powered FC system
- Reversible SOC system and grid integration
- Innovative manufacturing processes for SOFC systems and FC components
- Impurity tolerant FC

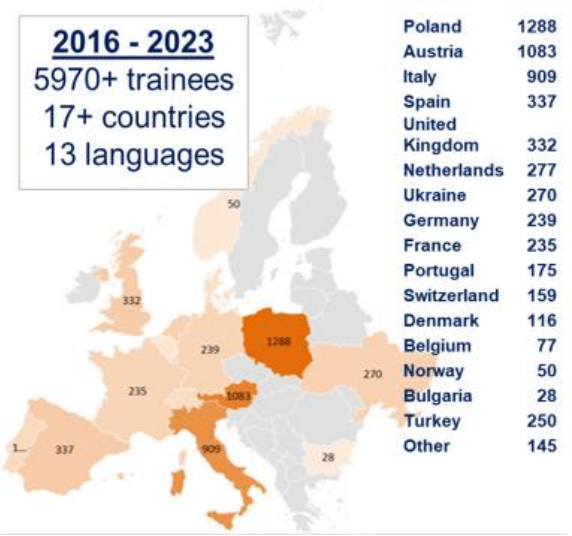
Gas turbines, boilers and burners

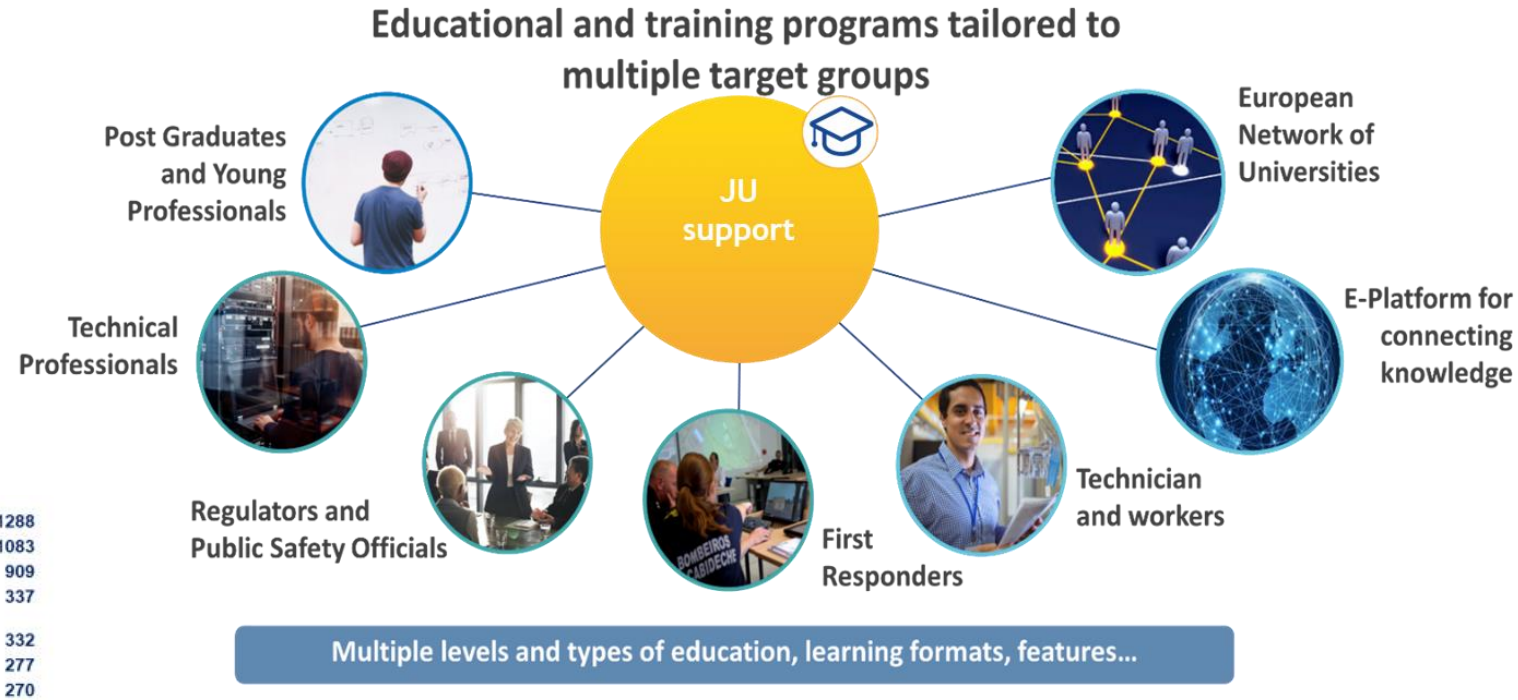
- Combustion of hydrogen-enriched fuels in gas turbines
- Fundamental combustion physics for H_2 and variable blends of H_2
- Retrofitting of gas turbines cogeneration systems for H_2 combustion
- Hydrogen for heat production for hard-to-abate industries

Co-funded by the European Union

Educational Activities - Projects - Overview

- Promoting excellence in education and training and preparing the European workforce while increasing trust





Undergraduate *Vocational* *e-learning* *Serious games*
Graduate *Compulsory* *In person training* *Blended* *Virtual reality*
Mock-up installations

Co-funded by the European Union

Working with regions - Raising awareness, developing ideas and implementing hydrogen projects

Regions initiative (2016-2018)

To support cities and regions with an interest in FCH technologies

Engagement

- Business cases for FCH applications;
- Mapping of local assets;
- Identification of existing funding;

Report

- FCH applications: status and potential;
- FCH plans and ambitions;
- Way forward;

MOU

- 89 European Regions;
- 22 countries
- ¼ of Europe's population, surface & GDP;

Project Development Assistance (2021-onwards)

https://europa.eu/!McW9JP

From idea to project plan

JU Annual Work Plans

https://europa.eu/!WYcrhy

Support to investments: H2 projects including H2 Valleys

MI2.0 H2V Platform

https://h2v.eu

Global collaboration

Hydrogen Valley S3P Platform

Co-funded by the European Union

Working with regions - Raising awareness, developing ideas and implementing hydrogen projects

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MOU

- 89 European Regions;
- 22 countries
- ¼ of Europe's population, surface & GDP;

Project Dev… …ment Assis… (2021-…

JU Ann… …Work Plans

25 Regions supported
€ 1.4 bn CAPEX
500+ MW Electrolysers
30+ HRS

16 Hydrogen Valleys funded
€ 1,000 bn JU funding
(+6 grants in preparation)

~100 Hydrogen Valleys worldwide
(¾ yet to take FID)

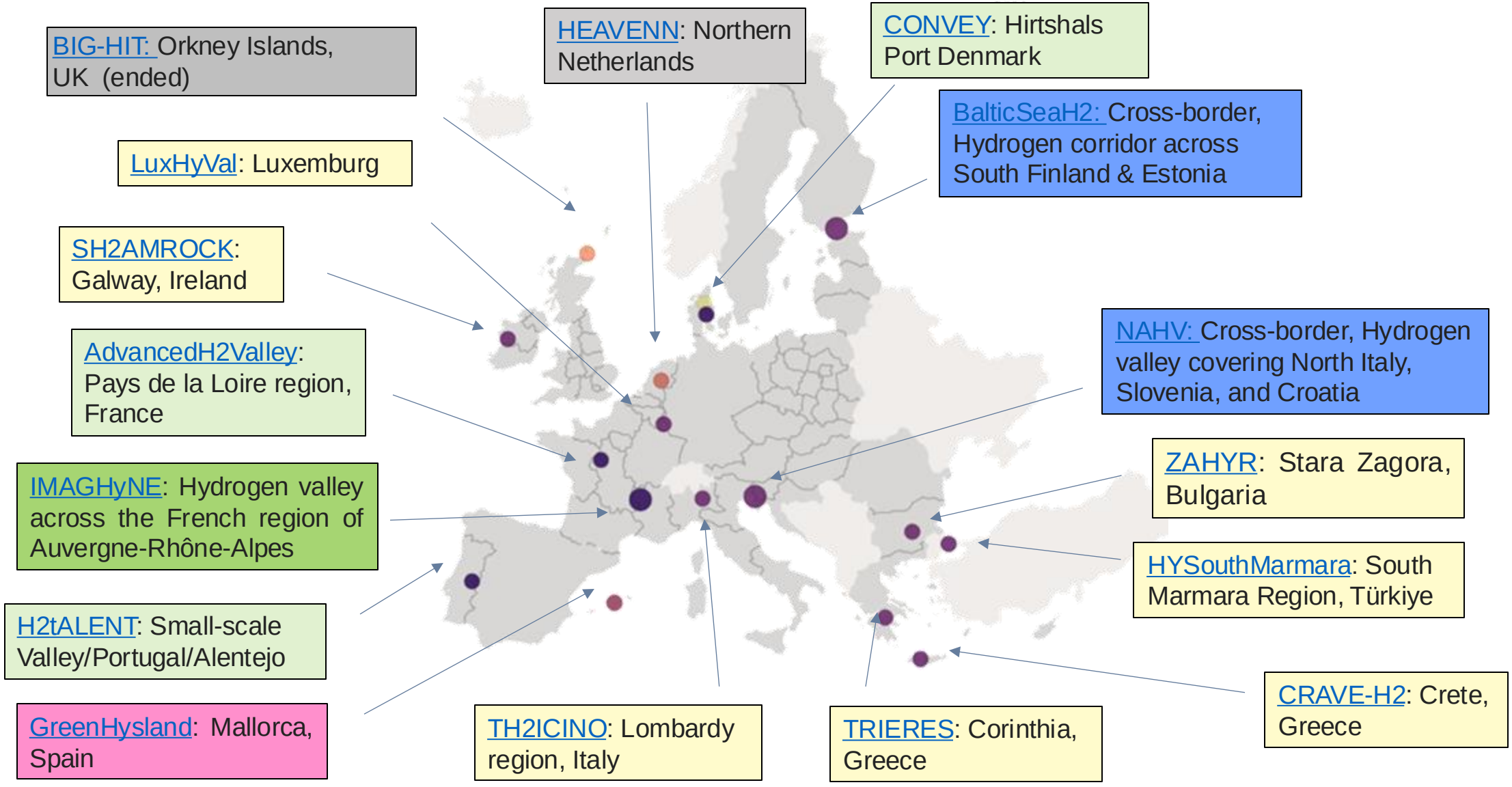
https://h2v.eu

Hydrogen Valley S3P Platform

Co-funded by the European Union

Hydrogen Valleys supported by the Clean Hydrogen Partnership

Different scales, hydrogen production mainly via electrolysis, diverse end- uses



Synergies with national and regional managing authorities

Identifying areas of collaboration between the Clean Hydrogen JU (EU level) and National and Regional Public Authorities

State-of-Play

- Assess policy and identify gaps and potential

RESEARCH

Select Managing Authorities

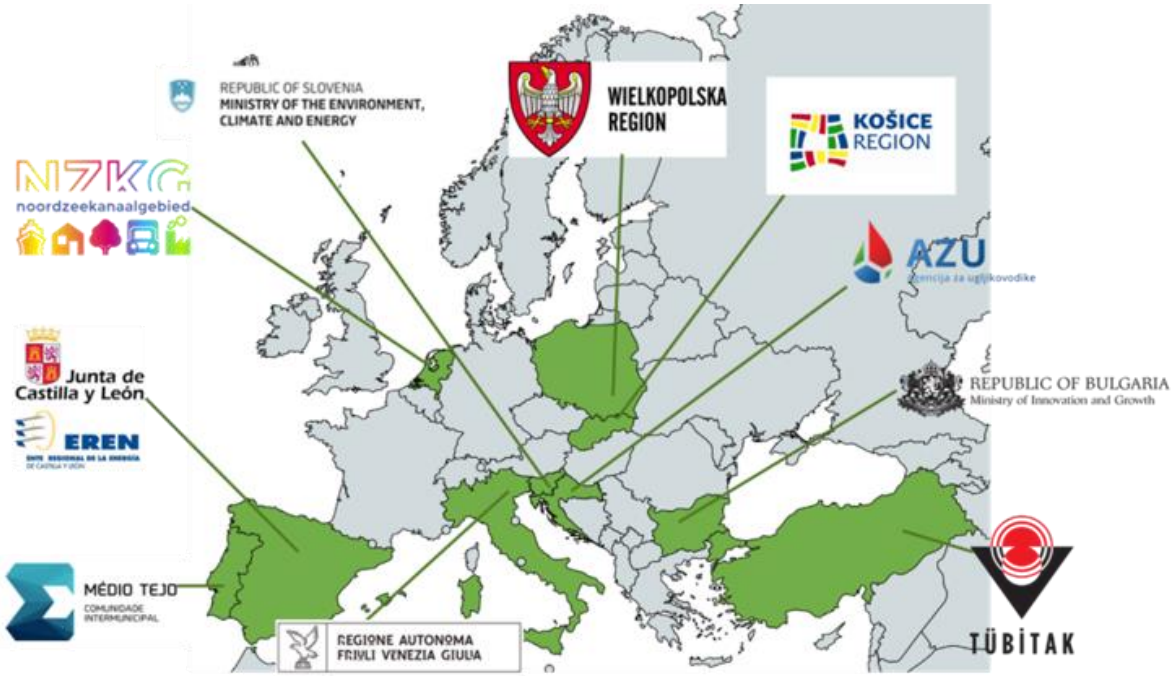
- Call of Expression of Interest (Jun/Jul 2023)
- **10 national and regional authorities selected**

ENGAGE

Memorandum of Cooperation

- Focusing on capacity building, knowledge management and funding
- **3 MoCs signed** in June 2024 (Bulgaria, Croatia and Italy)
- **6 MoCs** signed during the H2 week (18-22 November 2024) **1 MoC** to follow

OPERATIONALISE



Programme Office North Sea Canal Area (Netherlands)

Wielkopolska Region (Poland)

Friuli Venezia Giulia Region (Italy)

Kosice Region (Slovakia)

Intermunicipal Community of Medio Tejo (Portugal)

Regional Public Body of Energy – Castilla y Leon (Spain)

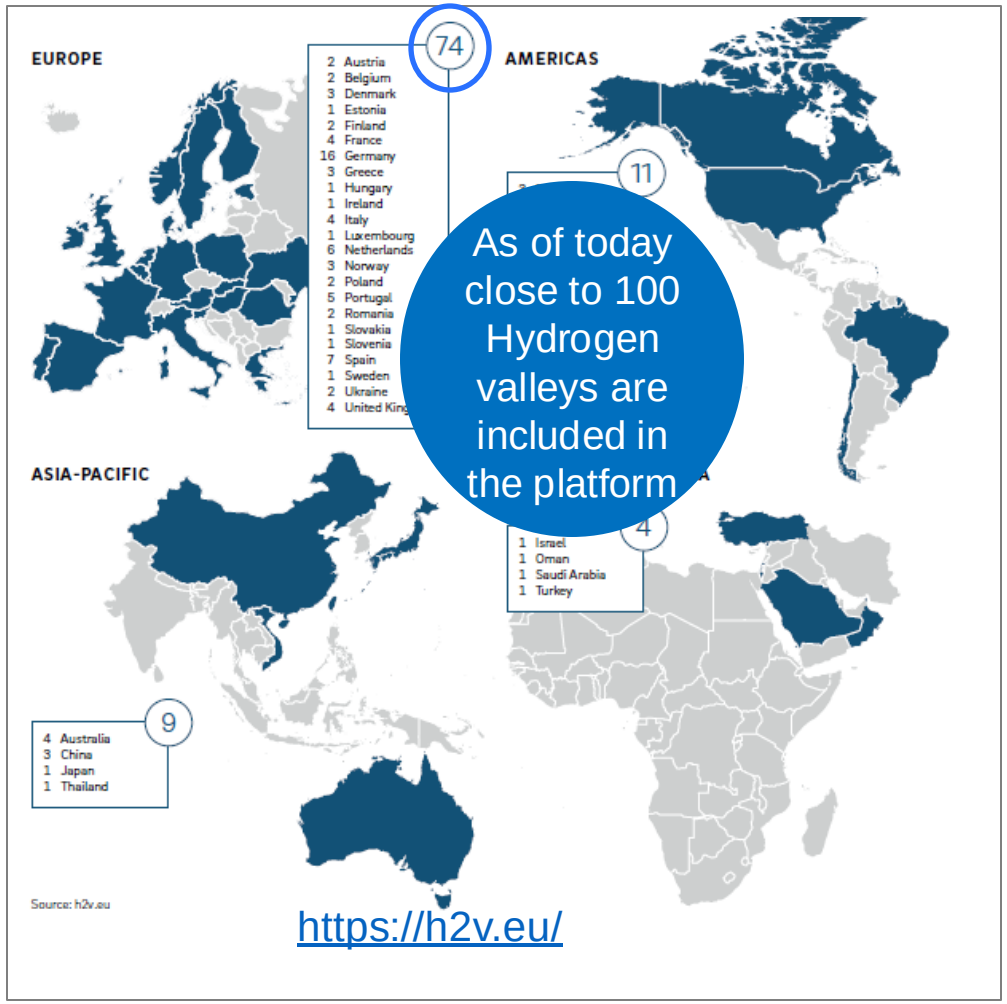
Scientific and Technological Research Council of Türkiye (Türkiye)

Slovenian Ministry of the Environment, Climate and Energy (Slovenia)

Croatian Hydrocarbon Agency (Croatia)

Bulgarian Ministry of Innovation and Growth (Bulgaria)

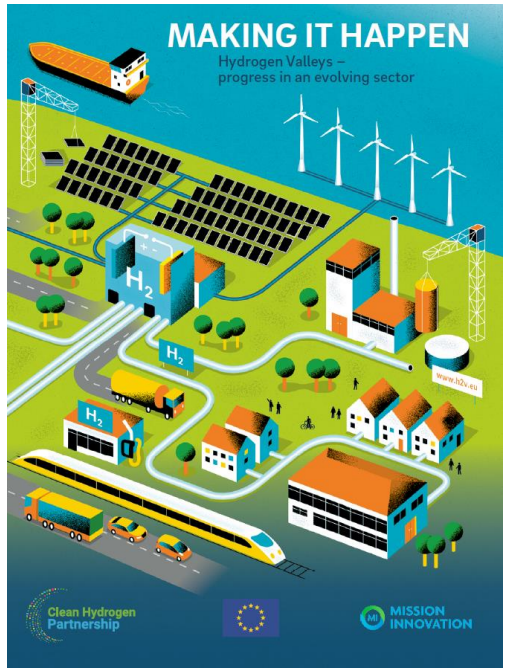
Hydrogen Valleys: concept developed in Europe and now global phenomenon…~ **about ¾ are yet to take a final investment decision**



https://h2v.eu/

Hydrogen Valleys Final Report [published]

- State of the clean hydrogen sector by analysing empirical evidence from Hydrogen Valleys globally over the last three years.
- Development of the Hydrogen Valley concept and community as well as the necessary framework conditions for its development
- Recent challenges faced by Hydrogen Valleys and the clean hydrogen sector as a whole and seeks to find forward looking solutions



Clean Hydrogen Partnership

Thank you!

For further information
www.clean-hydrogen.europa.eu

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