

ENNOH H₂ Emissions Workshop

13 October, 10h30 – 15h10



01 Opening remarks



Abel Enríquez
Director

Hydrogen Leak Detection, Monitoring and Reduction

Directive (EU) 2024/1788:

- Article 50.1 (g) and 50.1 (h) for Operators
- Article 9.6 for the European Commission

Regulation (EU) 2024/1789

- Article 59.1 (l) for ENNOH
 - **ENNOH's regulatory mandate:** Develop and promote best practices for hydrogen leak detection, monitoring and reduction





Practical details for the day:

- **Workshop recording:** A recording of the workshop will be shared with all participants after the session;
- **Presentation slides:** The workshop slides will also be shared afterwards;
- **On-site Q&A:** If you would like to ask a question during the workshop, simply raise your hand and a member of our team will come over to hear your question.



Join the conversation in Slido!

- **Scan** the QR code below;
- **Enter** the password;
- **Submit your question**, indicating which speaker it is addressed to.



Password:
hydrogenforgood



02 Introduction



Daniel Bonnici
Head of System Operation & Transparency

Monitoring H₂ emissions

- ☐ ENNOH role
- ☐ Why such a monitoring?
- ☐ Assessing impacts
- ☐ Where are we now?
- ☐ No amalgamation/confusion with CH₄



JRC TECHNICAL REPORT

Hydrogen emissions from a hydrogen economy
and their potential global warming impact

Summary report of the Clean Hydrogen
Joint Undertaking Expert Workshop on
the Environmental Impacts of Hydrogen

Arrigoni, A., Bravo Diaz, L.

2022



10:30 – 10:35

Opening remarks

- Abel Enriquez, [ENNOH](#)

10:35 – 10:45

Introduction

- Daniel Bonnici, [ENNOH](#)

10:45 – 12:00

Panel Discussion: Hydrogen emissions and their associated impacts

- Tobias van Almsick, [FNB Gas](#)
- Anna Lóránt, [EDF](#)
- Guy de Reals, [Air Liquide](#)
- Mirela Atanasiu, [Clean Hydrogen Joint Undertaking](#)
- **Moderator:** Ruta Baltause, [European Commission](#)

12:00 – 12:30

Presentation: Designing compression infrastructure for Europe's hydrogen backbone

- Simon Stoverink, [Siemens Energy](#)

12:30 – 12:45

Presentation: Reducing hydrogen emissions from compression systems: available solutions and future technologies

- Clemens Förster (Baker Hughes), [EU Turbines](#)

12:45 – 13:45

Lunch break

13:45 – 15:00

Panel discussion: Detection, monitoring, and reduction of hydrogen emissions

- Alessandro Arrigoni, **Joint Research Centre**
- Cristina Lopez, **NaTran**
- Mures Zarea, **GERG**
- David Merbecks, **DVGW**
- Armin Wisthaler, **University of Oslo / Advanced Monitoring Solutions**
- David Granger, **Equinor**
- **Moderator:** Rod Robinson, **National Physical Laboratory**

15:00 – 15:10

Closing remarks

- Daniel Bonnici, **ENNOH**

End of the workshop

03 Panel discussion



Hydrogen emissions and their associated impacts



Ruta Baltause
European
Commission



Guy de Reals
Air Liquide



Mirela Atanasiu
Clean Hydrogen
Joint Undertaking



**Tobias van
Almsick**
OGE



Anna Lóránt
EDF

Hydrogen emission assessment – where were we in 2022 – 2024 and where do we stand today?!



2022: JRC summary report of the CH-JU Expert Workshop on the Environmental Impacts of Hydrogen:

- **High level of uncertainty:** lack of monitoring- and industry data, knowledge gaps
- **Potential climate impact of hydrogen losses:** GWP_{100} : 5-11; GWP_{20} : 12-33 kg CO₂eq/kg H₂
- **Prevention and monitoring of hydrogen losses:** Monitoring techniques at lab scale exist but further development is needed to demonstrate effectiveness in situ industrial/larger scales

2024: Directive (EU) 2024/ 1788 – internal market rules for renewable gas, natural gas and hydrogen, Article 9(6):

European Commission:

Where appropriate: to evaluate **hydrogen leakage**, including environmental and climate risks, technical specificities and adequate maximum hydrogen leakage rates

Where appropriate: to propose **measures** that minimise possible risks of hydrogen leakage, set maximum leakage rates and establish compliance mechanisms



Funded by the
European Union

1 January 2024 – 31 December 2026:



Inventory of Hydrogen Releases from hydrogen value chain and climate impact assessment

1 November 2023 - 31 October 2027



Leakage monitoring tool, assessment of climate impacts of a hydrogen economy

1 September 2024 – 31 August 31,2028



CLIMATE IMPACTS OF
A HYDROGEN ECONOMY:
The pathway to knowledge

Emission inventories, assessment of the climate and environmental risks and co-benefits of a hydrogen economy

Hydrogen emissions and their associated impacts



Ruta Baltause
European
Commission



Guy de Reals
Air Liquide



Mirela Atanasiu
Clean Hydrogen
Joint Undertaking



**Tobias van
Almsick**
OGE



Anna Lóránt
EDF

Climate impact of future hydrogen pipeline transport

ENNOH Workshop on Hydrogen Emissions

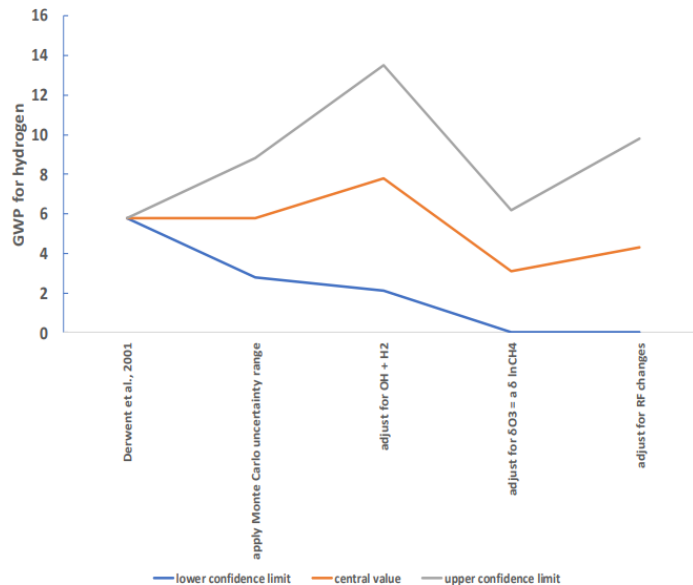
Tobias van Almsick

13.10.2026



Development of the GWP 100 of hydrogen

For the exact estimation of the GWP100 of hydrogen, the technical literature is still little unclear.



GWP₁₀₀ [kg CO₂e/kg H₂]

5,8 Derwent et al., 2000 [3]

5 ± 1 Derwent et al., 2020 [4]

11 ± 5 Paulot et al., 2021 [5]

11 ± 5 Warwick et al., 2021[6]

Newer determination methods from 2020

For comparison, methane:

- GWP100: 28 (5th IPCC Report)
- GWP100: 33 (5th IPCC report, taking into account interaction with aerosols)

Building on the approach of Derwent et al.

Material properties Natural gas – methane – hydrogen

- Relative flow rates hydrogen vs. methane (related to CO₂-eq.):

— H_2 : 5.8 CH_4 : 28 $\Rightarrow$ Quotient: 0.21

- | | |
|--------------------------------------|--|
| — Kiwa 2019: | 0.03 - 0.08 t CO ₂ -eq. H ₂ /t CO ₂ -eq. CH ₄ (calculated) |
| — "Hydrogen in the NTS" 2019: | 0.03 - 0.08 t CO ₂ -eq. H ₂ /t CO ₂ -eq. CH ₄ (calculated) |
| — OGE 2021 | 0.06 – 0.07 t CO ₂ -eq. H ₂ /t CO ₂ -eq. CH ₄ (calculated) |
| — H21 Phase 1 Technical Report 2021: | 0.03 – 0.07 t CO ₂ -eq. H ₂ /t CO ₂ -eq. CH ₄ (calculated) |
| | 0.03 – 0.06 t CO ₂ -eq. H ₂ /t CO ₂ -eq. CH ₄ (measured) |

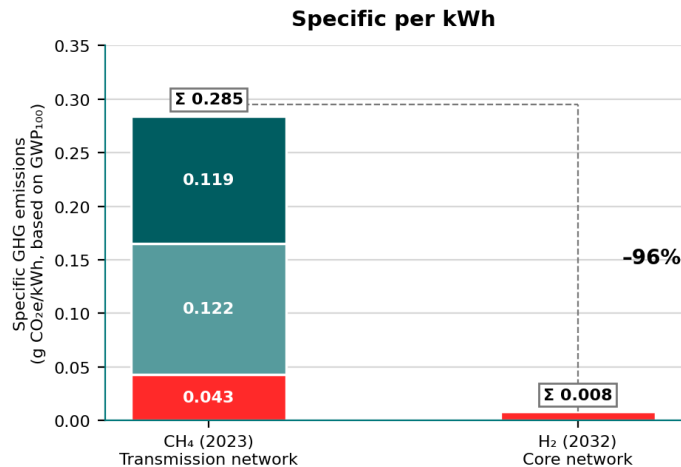
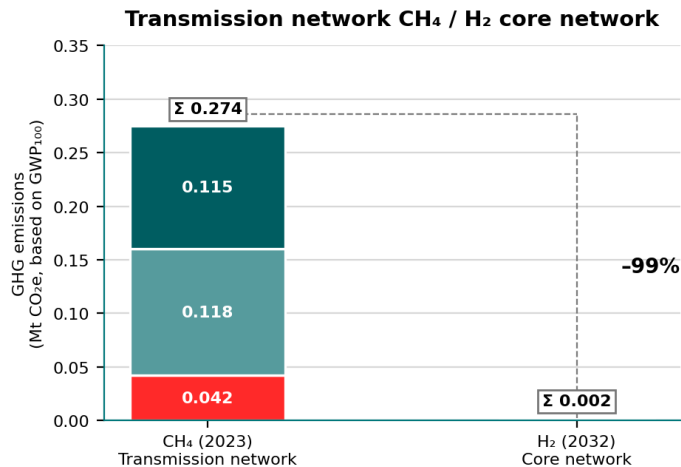
Mean: 0.05 t CO₂-eq. H₂/t CO₂-eq. CH₄

This results in:

One and the same leakage is about 20 times less harmful to the climate for hydrogen than for methane!

Hydrogen network: Emissions from network operation

- Assumption: Amount of energy transported 963 TWh CH₄ vs. 239 TWh H₂ Climate impact of gas losses decreases sharply with conversion to H₂ (-99% absolute and -96% specific)
- Due to the fact that GWP is a mass-related metric and due to the low density of H₂, the climate impact of gas losses during energy carrier change to H₂ decreases very significantly



Key messages of the study

- (Indirect) **climate effect of H₂** over 100 years is about **11.6*** (GWP100). Thus, between CO₂ (1) and CH₄ (29.8). CH₄ with 2.6 times the climate effect of H₂ is basically more potent greenhouse gas.
- **Grid emissions** from the future H₂ transmission line transport within Germany cause only around **1.8 %** of the total emissions from H₂ use. Of these grid emissions, approx. 98 % are electricity-related indirect compressor emissions and only approx. 2 % are gas losses (operational and fugitive emissions)
- In the future H₂ core network in 2032, the climate impact of **gas losses will be reduced by 99%** in absolute terms compared to the current natural gas transmission network and specifically (per kWh of energy transported) by **96%**.
- **Life cycle analysis:** Planned change of energy source to H₂ associated with considerable reductions in climate impact (specifically **-90 %** in the BV under consideration). Description of H₂ as a "climate killer" clearly exaggerated.
- **TSOs' levers** to reduce the climate impact of future H₂ provision:
 1. Demand a reduction in upstream chain emissions
 2. Climate-friendly operation of compressors
 3. Avoid H₂ emissions in grid operation

**We enable energy supply. Today and
in the energy mix of the future.**



Hydrogen emissions and their associated impacts



Ruta Baltause
European
Commission



Guy de Reals
Air Liquide



Mirela Atanasiu
Clean Hydrogen
Joint Undertaking



**Tobias van
Almsick**
OGE



Anna Lóránt
EDF



Hydrogen Energy

Building a sustainable,
low-carbon society

ENNOH's hydrogen emissions workshop - October 13, 2026

Hydrogen Energy

Key figures highlighting our hydrogen track record

2025 figures

60+

years of expertise

1.2 Mt

annual production

€2.2bn

annual sales

~500

hydrogen patent families

~1,000

employees in hydrogen

260+

refueling stations delivered
(as of December 2025)

Our targets by 2035

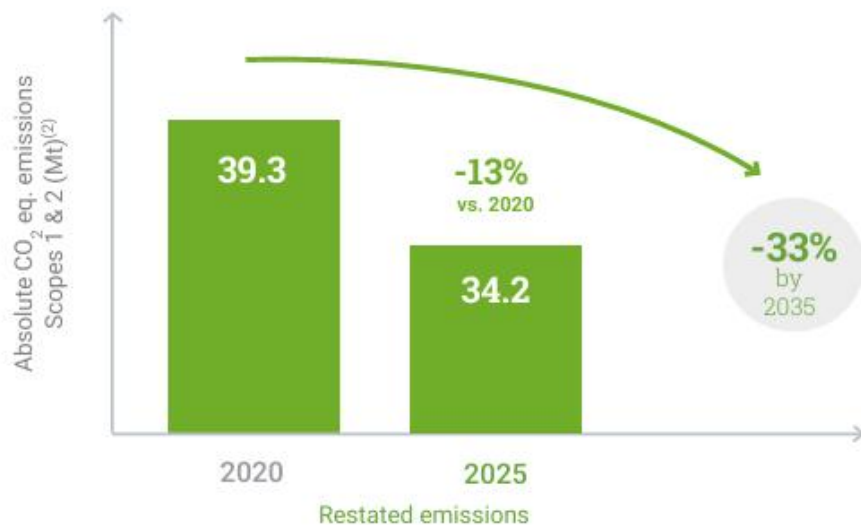
CO₂ Emissions reduction



By 2035, a **-33% reduction in absolute Scopes 1 and 2⁽¹⁾** CO₂ emissions vs. 2020, with an inflection point around 2025.

Decarbonization well engaged

Inflection objective achieved one year in advance ✓



H₂ objectives

~€8bn

investment decisions
in the low-carbon
hydrogen supply chain

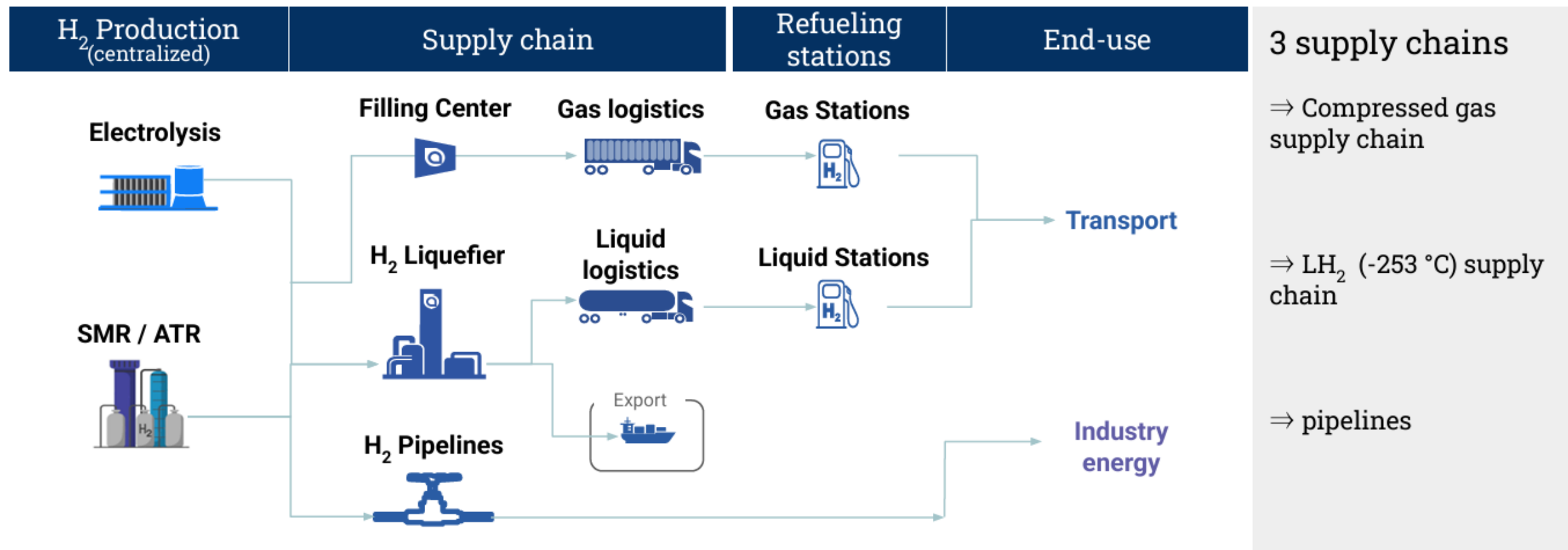
x3

sales

(1) Scope 1: direct emissions generated by all emission sources owned or controlled by the Group. Scope 2: indirect emissions from the production of electricity or steam purchased outside the Group.

(2) Scopes 1 & 2 CO₂ emissions: Scope 2 "market-based" restated emissions to take into account the full lifecycle of the purchased electricity or steam, including the emissions of the assets which can result in changes in scope and which have a significant impact (upwards and downwards) on CO₂ emissions.

We master the whole hydrogen supply chain.



H2 releases to the atmosphere - 2022 evaluations still stands

Clean Hydrogen JU Expert Workshop on Environmental impact of Hydrogen
Guy de Reals - April 1st 2022



0.2% → 0.03% loss

Electrolysis



0% loss

SMR / ATR



1% loss
Filling center



Gas logistics



3% → 2% loss
Gas Stations



10% → 2% loss

H₂ liquefier



Liquid
logistics



8.5% → 2% loss
Liquid stations



Transport

H₂ pipelines



Export



1% → 0.7% loss

Industry
energy

Relevant for Air Liquide operated private pipelines
dedicated to the supply of Hydrogen as a feedstock
to industries. Smaller and different characteristics
than future H2 backbone

3 supply chains

→ Compressed gas
Today ~4.2%
⇒ 3% (2030)

→ LH₂
Today ~10-20%
⇒ 4-5% (2030)

→ Pipelines
Today ~1.2%
⇒ <1% (2030)

H2 release infrastructure

- Releases = Sum of **Vented emissions** AND **Fugitive emissions**
- Vented:
 - “intentional” H₂ emission during operation and maintenance
 - **purging, boil-off, safety protocols...**
 - **actions:** localize, quantify, reduce... thanks to design and operation optimization, and innovation!
- Fugitive:
 - **unintentional** and **uncontrolled** H₂ emission
 - **connections**, piping, equipment...
 - due to **tightening, improper** assembly/equipment, permeation...
 - **actions:** be able to detect and repair
- **Vented emissions** are predominant versus **Fugitive emissions**



Venting is heavily dependent on site specific design and operation strategies

Transporting Energy by pipeline - GWP from leaks

- 1 kg H₂ = 120 MJ
- Indirect GWP H₂ = 11,5 kg_{CO₂}/kg_{H₂}
- 1% leak = 10g_{H₂}/kg_{H₂}
- Indirect GWP of H₂ released
 $11,5 \times 10 / 120 = 0,96 \text{ g}_{\text{CO}_2} / \text{MJ}$

- 1 kg CH₄ = 50 MJ
- GWP CH₄ = 31 kg_{CO₂}/kg_{CH₄}
- 1% leak = 10g_{CH₄}/kg_{CH₄}
- GWP of CH₄ released
 $31 \times 10 / 50 = 6.2 \text{ g}_{\text{CO}_2} / \text{MJ}$

Pipeline transport
H₂ Indirect GWP 6.5x lower than Natural Gas Direct GWP

Reminder: H₂ climate benefits

1% Leak indirect GWP: 0.12 kg_{CO₂}/kg_{H₂}

H₂ GHG savings potential: 10 kg_{CO₂}/kg_{H₂}



Thank you

Hydrogen emissions and their associated impacts



Ruta Baltause
European
Commission



Guy de Reals
Air Liquide



Mirela Atanasiu
Clean Hydrogen
Joint Undertaking



**Tobias van
Almsick**
OGE



Anna Lóránt
EDF

Activities incl projects on H2 Releases

ENNOH's hydrogen emissions workshop
13th of October 2026

Mirela Atanasiu - Head of Unit Operations and Communications

EUROPEAN PARTNERSHIP



Clean Hydrogen Joint Undertaking

EU Institutional Public-Private Partnership (IPPP)

Advisory:
Stakeholder Group
incl all H2 supply chain
stakeholders, associations

Advisory:
States Representative
Group incl 36 countries represent.
(all EU and Associated Countries)



**Industry
Association**
more than 600
members



**Research
community**
more than 150
members

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)**

First worldwide Expert workshop in 2022

Clean Hydrogen Joint Undertaking Expert workshop on Environmental Impacts of H₂

2-day workshop in **March 2022** – Co-organised with the US DoE, with the support of EC, HE, HER, IPHE, Hydrogen Council



Gain a better understanding and knowledge of the environmental impacts of hydrogen and hydrogen releases

Specific Objectives

1. Review the current knowledge on the global warming impact of hydrogen;
2. Share information on human-made hydrogen emissions (sources, quantities, etc.);
3. Reach a better understanding of the climate impact of hydrogen and **assess the need for action**

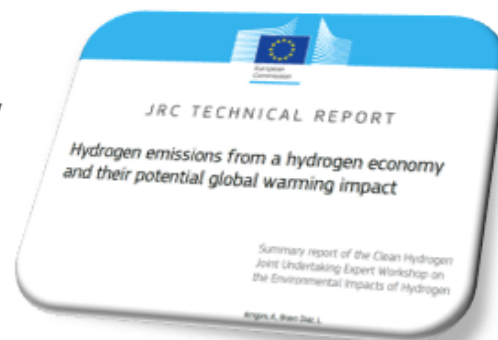
Clean Hydrogen JU Expert Workshop on Environmental Impacts of Hydrogen			
AGENDA			
Day 1 - Environmental Impacts of Hydrogen			
12:45	Login, registration		
13:00	Opening, organizational remarks	Clean Hydrogen JU	
13:05	Welcome remarks	Clean Hydrogen JU	
Session 1: Environmental Impacts of Hydrogen			
13:15	Behaviour of hydrogen in the atmosphere		
13:30	Behaviour of hydrogen in the atmosphere		
13:45	Behaviour of hydrogen in the atmosphere		
14:00	Q&A/ Panel discussion - moderated		
14:15	Break/ contingency time		
14:25	Behaviour of hydrogen in the atmosphere		
14:40	Behaviour of hydrogen in the atmosphere		
14:55	Environmental impacts of hydrogen		
15:10	Environmental impacts of hydrogen		
15:25	Q&A/ Panel discussion - moderated		
15:40	Break/ contingency time		

Clean Hydrogen JU Expert Workshop on Environmental Impacts of Hydrogen			
AGENDA			
Day 2 - Hydrogen Release			
12:45	Login, registration		
13:00	Opening, organizational remarks	Clean Hydrogen JU	
13:05	Welcome remarks	Clean Hydrogen JU	U.S. Department of Energy
Session 1: Hydrogen Release			
13:15	Hydrogen release	Stephen Bradley	European Industrial Gases Association (EIGA)
13:30	Hydrogen release	Guy de Real	Air Liquide
13:45	Hydrogen release	Pere Hargalef	SAH
14:00	Q&A/ Panel discussion - moderated by Clean Hydrogen JU	David Scrochi	
14:15	Break/ contingency time		
14:25	Hydrogen release	Bill Butler/ Kevin Hartmann	National Renewable Energy Laboratory (NREL)
14:40	Hydrogen release	Austin Glover/ Ethan Hecht	Sandia National Laboratories
14:55	Hydrogen release	Didier Jamsil/ Christophe Proust	Hydrolysis project, French National Institute for Industrial Environment and Risks (Ineris)
15:10	Hydrogen release	Rod Robinson	National Physical Laboratory (NPL), European Association of National Metrology Institutes (EURAMET)
15:25	Q&A/ Panel discussion - moderated by Clean Hydrogen JU		
15:40	Break/ contingency time		

Summary and conclusions publicly available (JRC report)

<https://publications.jrc.ec.europa.eu/repository/handle/JRC130362>

Follow-up actions? See next slides



Activities on H2 Emissions – JU Project

Project/Grant awarded from call in 2023 on pre-Normative Research on Hydrogen Releases Assessment

Mapping hydrogen emissions for a sustainable future

Specific Objectives

- Delivering validated methodologies and techniques for measuring or calculating H3 releases
- Creating a universally accepted and open-access inventory of the H2 releases to serve as a reference for the scientific and industrial community
- Improving the quantification capability of small and large releases
- Identifying and prioritising effective mitigation actions



Project Information

NHyRA
Grant agreement ID: 101137770

DOI 
[10.3030/101137770](https://doi.org/10.3030/101137770) 

EC signature date
17 December 2023

Start date
1 January 2024

End date
31 December 2026

Funded under
Climate, Energy and Mobility

Total cost 
€ 2 086 683,75

EU contribution 
€ 2 086 683,75

Investment in EU policy priorities 

Digital agenda ☐ Clean air ☒

Artificial Intelligence ☐ Climate action ☒

Biodiversity ☐

Coordinated by
SNAM SPA
Italy

WP1

H2 RELEASES INVENTORY

WP2

METHODOLOGY DEVELOPMENT FOR H2 RELEASES' QUANTIFICATION

WP3

METHODOLOGY VALIDATION AND FIELD TESTS ASSESSMENT

WP4

H2 RELEASES FROM SUPPLY CHAINS

WP5

HYDROGEN RELEASE SCENARIOS

WP6

DISSEMINATION, COMMUNICATION AND EXPLOITATION



Co-funded by the European Union

Activities on H2 Emissions – other EU Projects



Complementary grants/projects from Horizon Europe calls in 2023 on Climate impacts of a hydrogen economy



PROJECT

HYDRA HYDROGEN ECONOMY BENEFITS AND RISKS: TOOLS DEVELOPMENT AND POLICIES IMPLEMENTATION TO MITIGATE POSSIBLE CLIMATE IMPACTS

ID: 101137758

From: 1 November 2023 to: 31 October 2027

Hydrogen is undoubtedly the most talked-about carbon-free energy vector. However, policymakers and citizens that are supporting hydrogen large-scale penetration in the energy sector should not only be aware of the evident benefits but also of potential safety and climatic risks...

Coordinated in: Belgium

Programme: [Climate, Energy and Mobility](#) , [Climate Science and Solutions](#)

Last update: 10 September 2026



HYDrogen economy benefits and Risks:
tools development and policies implementation to
mitigate possible climAte impacts

Project Information

HYDRA
Grant agreement ID: 101137758

DOI 
[10.26203/101137758](https://doi.org/10.26203/101137758)

EC signature date
24 October 2023

Start date 1 November 2023 End date 31 October 2027

Funded under
Climate, Energy and Mobility

Total cost 
€ 3 847 500,00

EU contribution 
€ 3 847 500,00

Investment in EU policy priorities 

Digital agenda ☐ Clean air ☐
Artificial Intelligence ☐ Climate action ☒
Biodiversity ☐

Coordinated by
BEHARISANT
Belgium

<https://www.hydraproject.eu/>


PROJECT

HYWAY Climate impacts of a HYdrogen Economy – the pathWAY to knowledge

ID: 101137582

From: 1 September 2024 to: 31 August 2028

The HYway project will be the most comprehensive study on environmental effects of large-scale hydrogen usage to date. HYway is led by a team of experienced scientists who have already conducted extensive research on the climate effects of hydrogen. To fully understand the...

Coordinated in: Norway

Programme: [Climate, Energy and Mobility](#) , [Climate Science and Solutions](#)

Last update: 30 April 2026

Project Information

HYWAY
Grant agreement ID: 101137582

DOI 
[10.26203/101137582](https://doi.org/10.26203/101137582)

EC signature date
28 May 2024

Start date 1 September 2024 End date 31 August 2028

Funded under
Climate, Energy and Mobility

Total cost 
€ 3 949 103,75

EU contribution 
€ 3 949 103,75

Investment in EU policy priorities 

Digital agenda ☐ Clean air ☒
Artificial Intelligence ☐ Climate action ☒
Biodiversity ☐

Coordinated by
CICERO CENTER FOR KLIMAFORSKNING
Norway

<https://www.hywayhorizon.eu/>


**CLIMATE IMPACTS OF
A HYDROGEN ECONOMY:**
The pathway to knowledge

Hydrogen emissions and their associated impacts



Ruta Baltause
European
Commission



Guy de Reals
Air Liquide



Mirela Atanasiu
Clean Hydrogen
Joint Undertaking



**Tobias van
Almsick**
OGE



Anna Lóránt
EDF

Hydrogen Emissions Measurement for



Anna Lóránt
Environmental Defense Fund Europe

Current scientific understanding of hydrogen emissions' warming impact



Central estimates of H₂'s indirect GWP values:
GWP100 ~12, GWP20 ~38
(new review Sand et al. 2026)

- Long-standing topic with recent progress in quantification



H₂'s warming impact should be considered in the decarbonization context

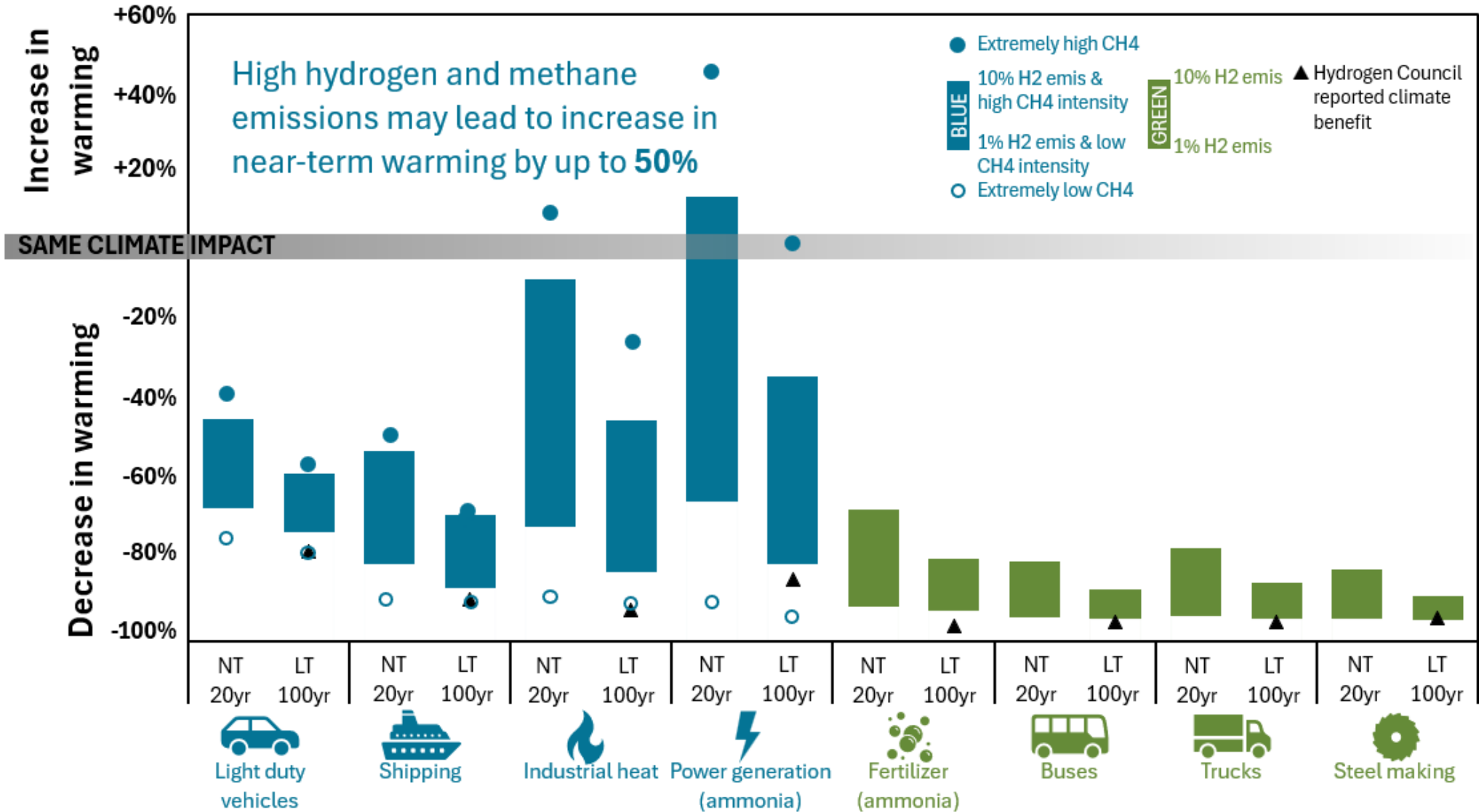
- GWP used mainly in two ways: clean/low-carbon H₂ definition, and lifecycle climate benefit against conventional fossil fuel
- Studies show non-negligible impact from H₂ emissions, magnitude can vary due to uncertain emission rates and various end use applications



Value chain emissions magnitude is still unknown

- New measurement technologies are becoming available, and measurement/quantification methods are being established
- **Data from EDF-coordinated measurement studies will be published in December**

Climate impacts of switching to hydrogen technologies from fossil fuel



Recently published new method for emissions measurement

Field testing at a fueling station



pubs.acs.org/estair

This article is licensed under [CC-BY 4.0](#)

Article

Development of a Hydrogen Full-Flow Sampling (H₂FFS) System to Quantify Hydrogen Leak and Loss Emissions

Derek Johnson,* Filiz Kazan, Christopher Ulishney, Christopher Loomis, David Childs, Scott Wayne, William Gillespie, David L. McKain, and Nigel N. Clark



Cite This: <https://doi.org/10.1021/acsestair.5c00517>



Read Online



Sometimes, **safety** and **climate** need similar approaches:

- Measurement teams conduct a leak check around the station first, using safety sensors
- Then each leak is flagged and quantified using the new H2FFS, ranging **0-2.2g/h**

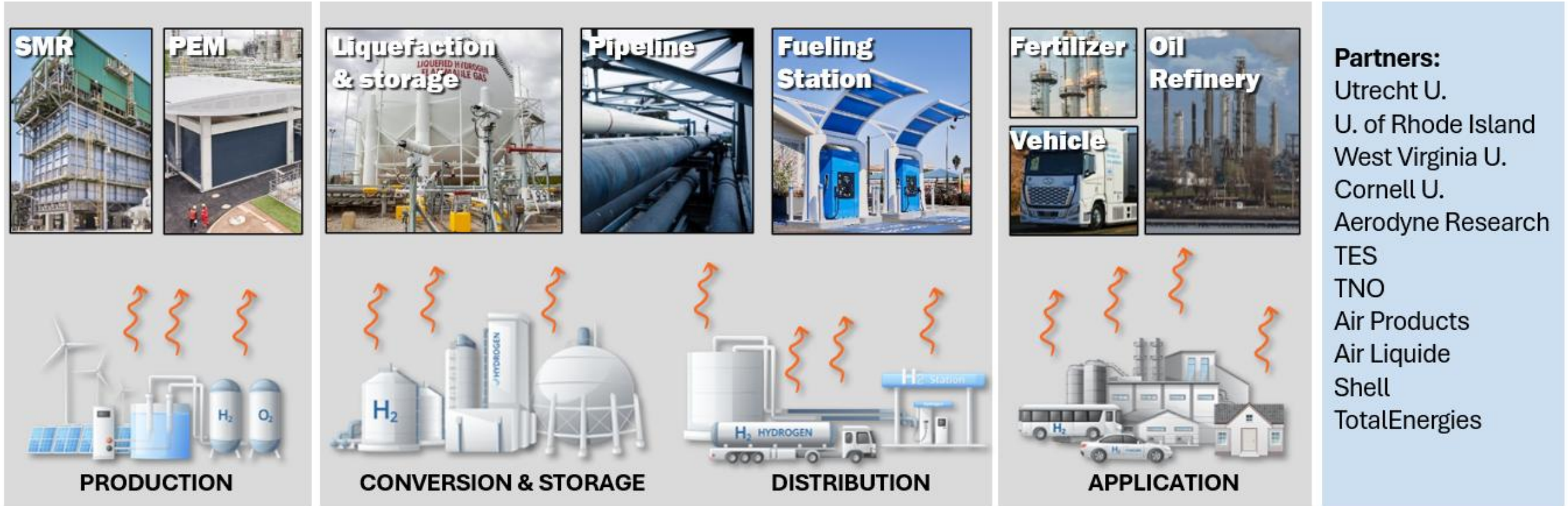
Sometimes, **safety** procedures can lead to **climate** emissions:

- One case of venting was also observed, it is an operational procedure to ensure safety, but vented amount was too large for H2FFS to fully quantify (**>4.3kg/h**)

We need complementary approaches to address **safety** AND **climate**.

Collaborative Hydrogen Emissions Measurement Campaign

Working with academic and industry partners to characterize emissions from operating facilities in NA and Europe





Thank you!

Contact: alorant@edf.org

04 Q&A



05 **Simon Stoverink**
Siemens Energy



Designing Compression Infrastructure for Europe's Hydrogen Backbone

Lessons from Pre-FEED and Feasibility Studies

ENNOH Hydrogen Emissions Workshop | Brussels, 13 October 2026
Simon Stoverink, Siemens Energy



Compression is a central building block of Europe's hydrogen backbone

Getting compression right is key to an economic hydrogen backbone

Network enabler

Compressor stations connect import corridors, storage and demand centers – they keep hydrogen flowing across Europe.

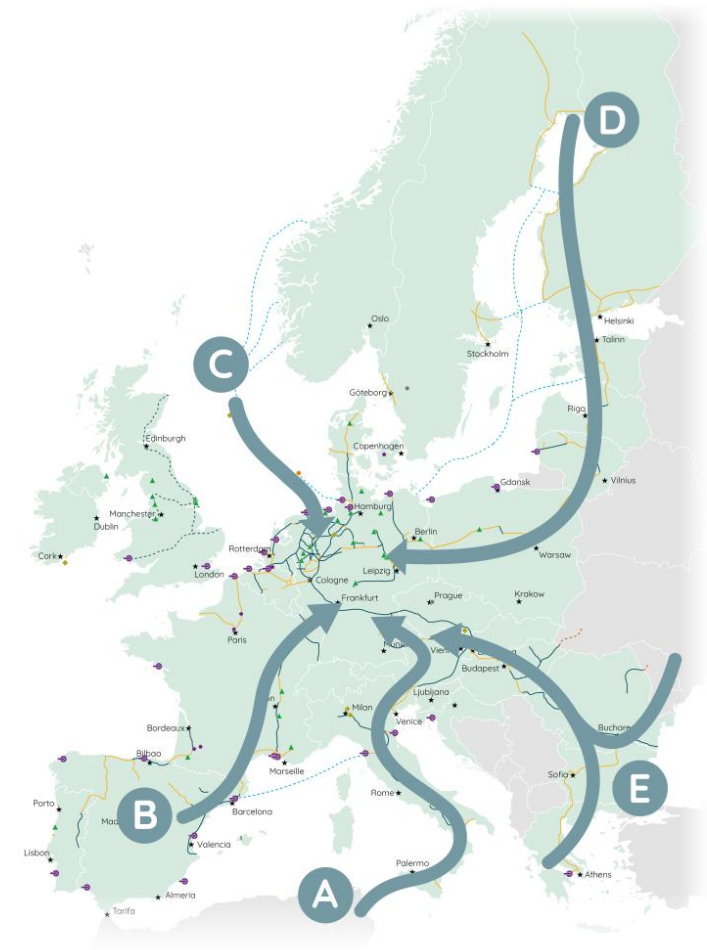
Hydrogen is different

Hydrogen's physical properties require advanced compression solutions – much higher compression speeds are required compared to natural gas.

Design drives cost

The right compression design has a significant impact on the overall station setup and the total cost of the backbone.

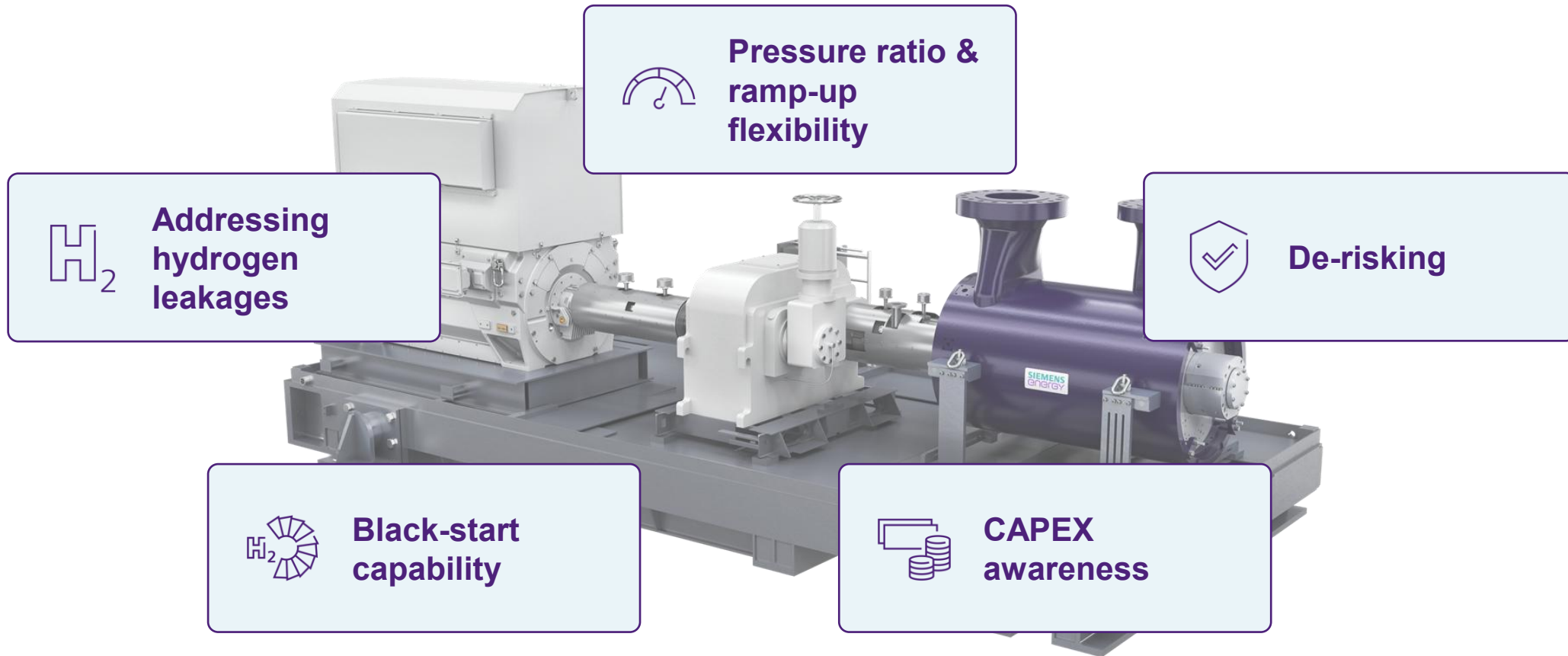
How we design compression today decides how economic, resilient and clean the backbone will be.



Source: ehb.eu/newsitems

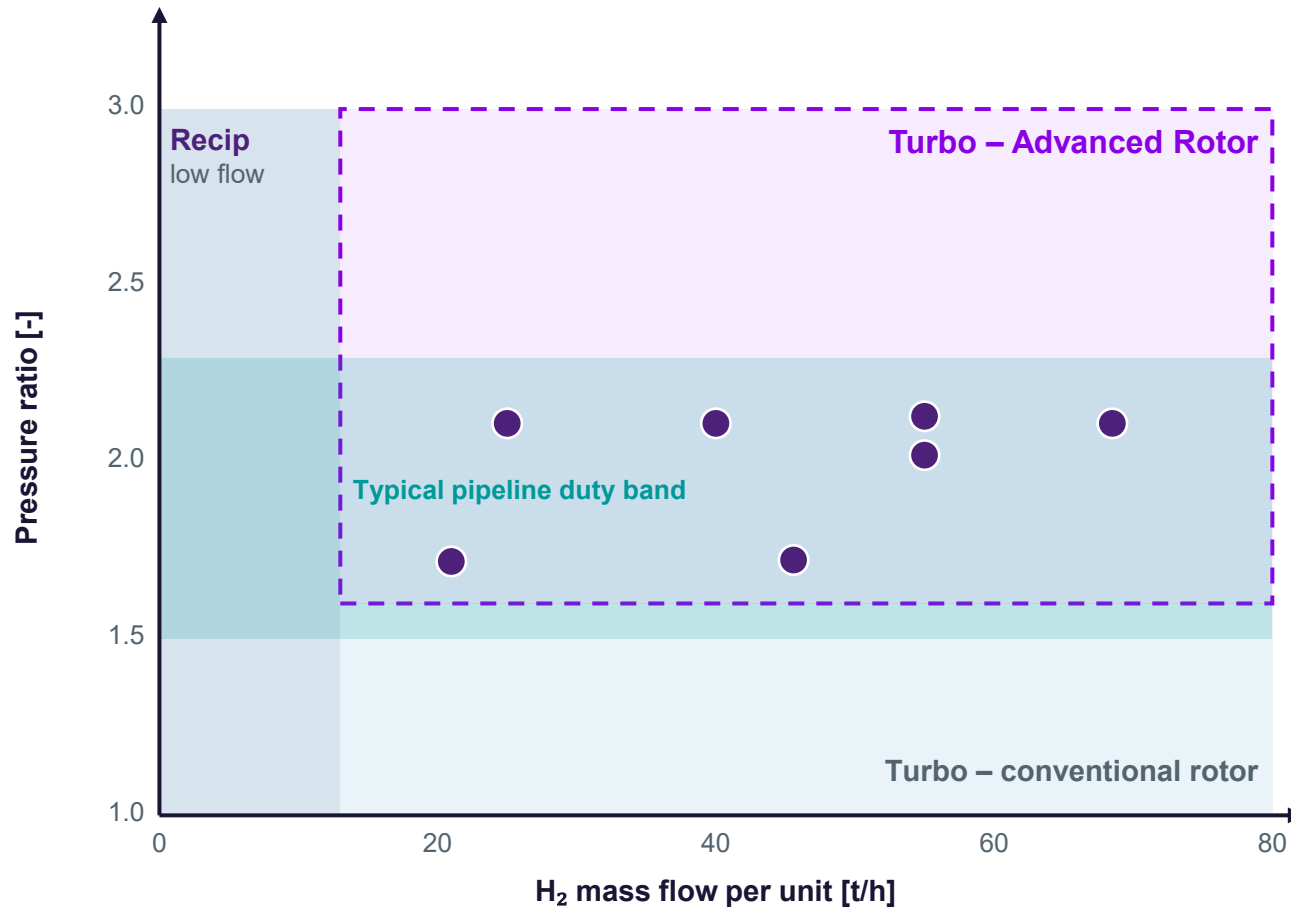
Five lessons from hydrogen backbone studies

Emissions are one of five equally important criteria

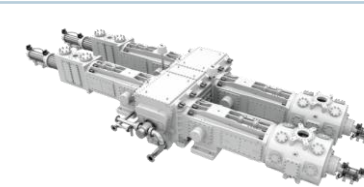


Flow and pressure ratio define the technology

Pipeline duties: high flow at PR ~1.5 – 2+



● Study cases (pre-FEED / Feasibility) Indicative; boundaries depend on suction pressure and duty



Reciprocating



Turbo (Advanced Rotor)

Key observations from the studies

- **Pressure ratio:** ~1.5 – 2+ per station
- **Flow:** up to 400+ t/h per station → multiple trains
- **Transmission:** uncertain how much flow & when
- **Distribution:** uncertain pressure ratio and timing
- **Ramp-up:** recip + turbo combined covers low flow without recycle

Turbo with Advanced Rotor covers the pipeline duty band in a single casing

Advanced Rotor: our answer to high-flow, high-pressure-ratio H₂ duties

Conventional Rotor

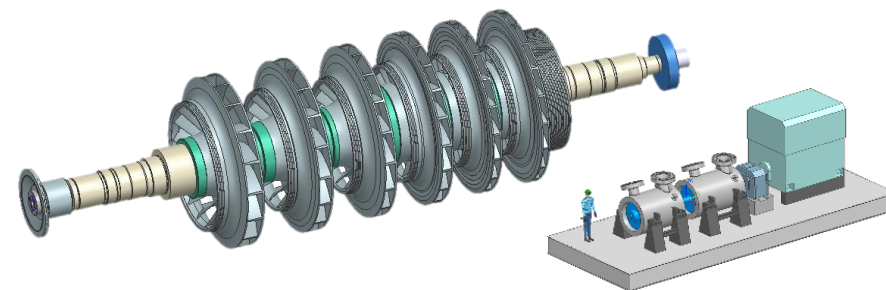
Impeller Tip Speed limit	<350 m/s
Pressure ratio per casing (H ₂)	~1.6

Advanced Rotor

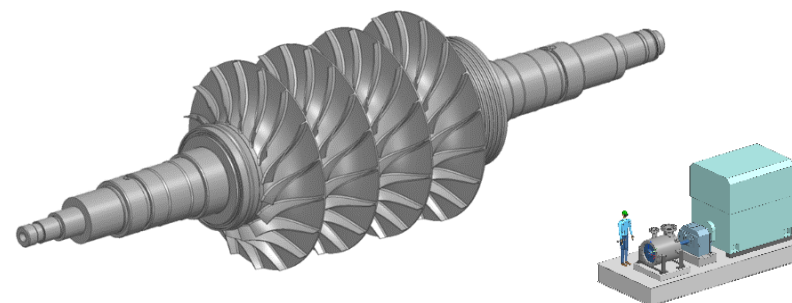
Impeller Tip Speed limit	up to 600 m/s
Pressure ratio per casing (H ₂)	up to 3



Example Conventional Rotor



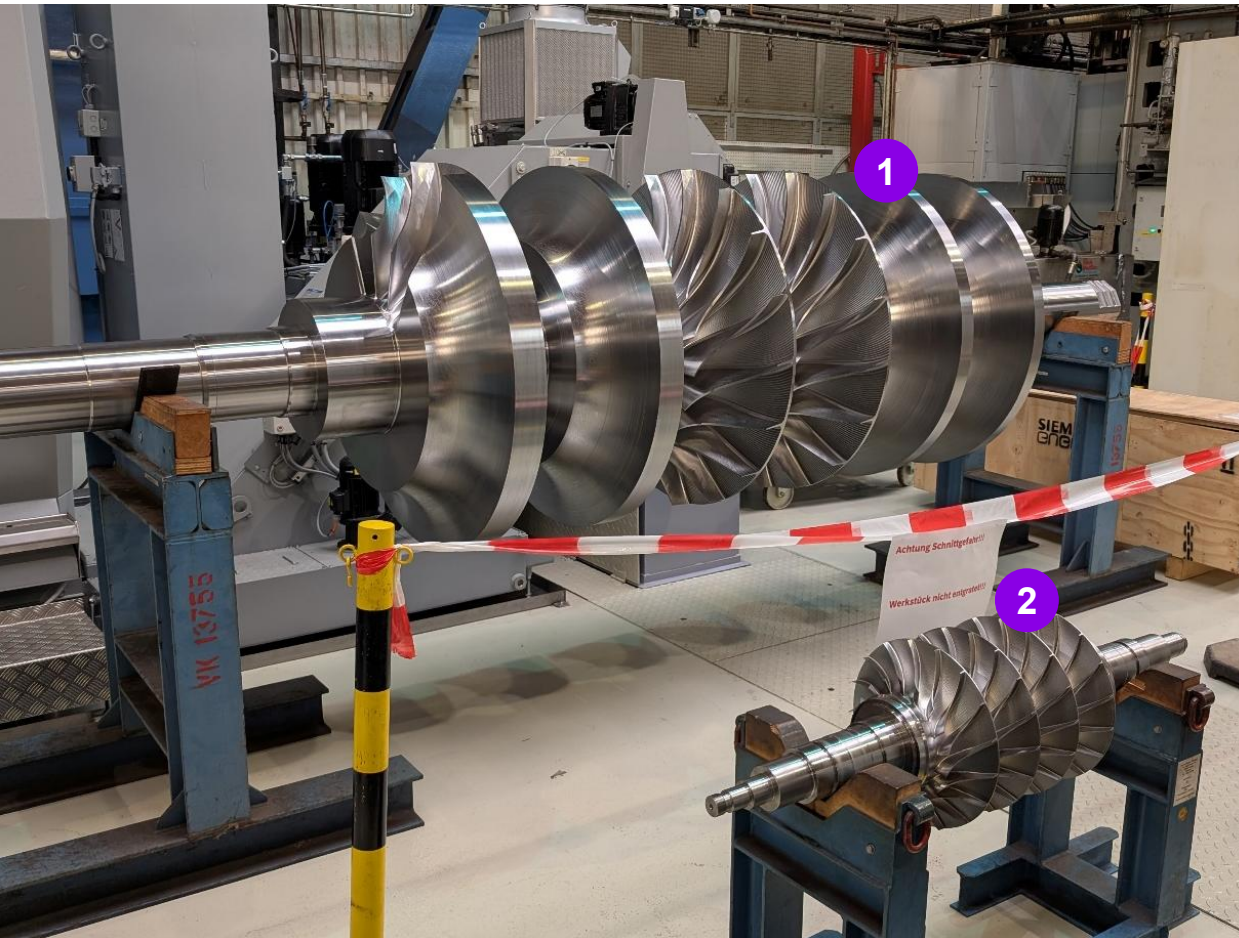
Example Advanced Rotor



Significant footprint reduction,
fewer casings → lower leakages

Advanced Rotor – Advancement of Manufacturing

AR scalable to cover entire SVm framesize range (06 – 17)



1 Manufacturing Qualification

- Length: >4.0 m
- Diameter: 1.05m

2 AR1.0 Prototype

- Length: ~1.4m
- Diameter: ~360mm

Siemens Energy has developed a new rotor structural design and manufacturing approach that enables **impeller tip speeds of up to 600 m/s**



Newly Built Laboratory in Redmond, USA to Support Turbomachinery Based Decarbonization Technologies



Closed loop testing for mechanical and aerodynamic validation

- Helium testing successfully completed in October 2023
- Hydrogen testing successfully completed in March 2025

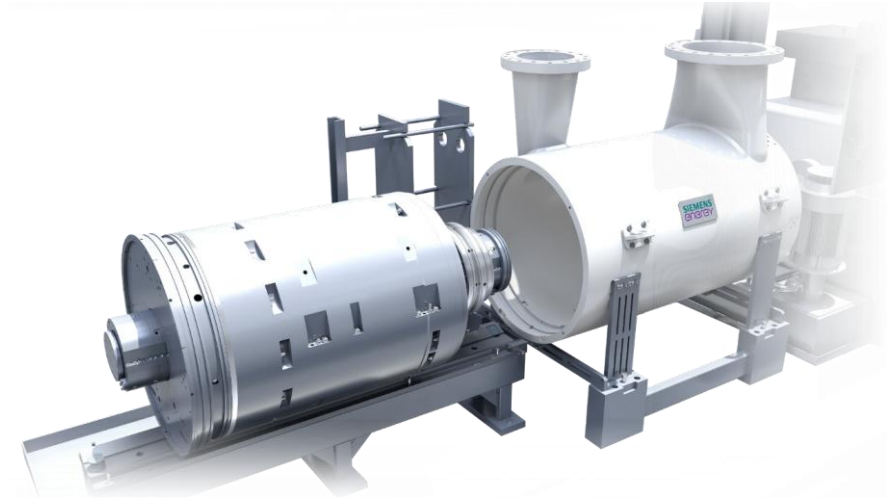
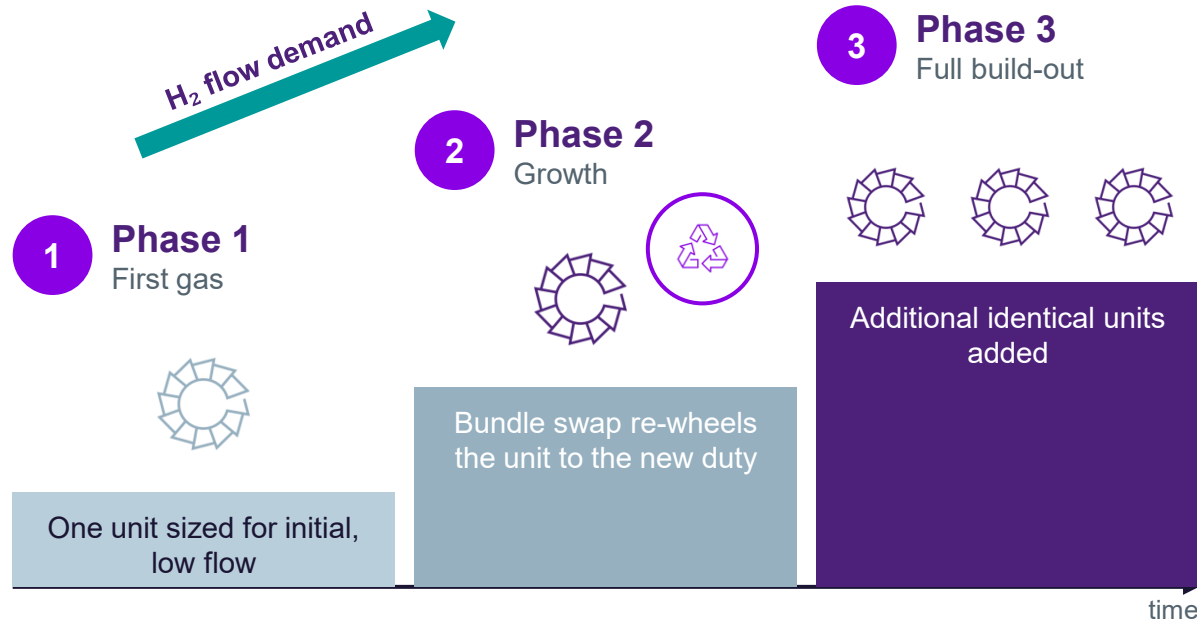


Compression must grow with the network

Bundle swap adapts to new duties



Growth plan of a compressor station (illustrative)

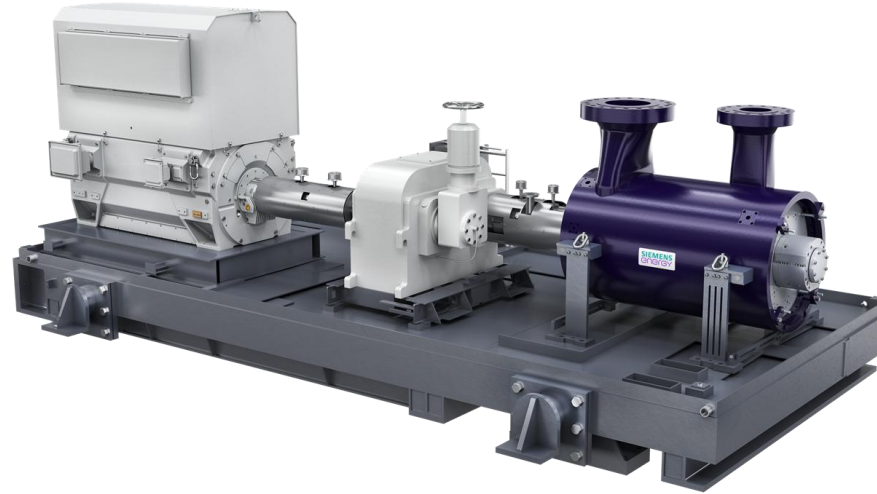


Siemens Energy turbo compressors allow an easy bundle swap

- Cartridge contains rotor, stationaries, heads, bearings and seals
- Re-wheel to a new duty without new casing or foundation
- Fully tested before installation, short outage
- Speed range adjustment (after bundle swap) possible with exchange of gear internals.

Emission link The seal system is part of the tested cartridge – the sealing concept stays proven through every duty change

Advanced Rotor: H₂ compression with standard, proven technology



Compressor

Advanced Rotor capable of running at the high speeds required for H₂ compression

Motor & VFD

Standard technology – not limited in motor size or motor speed. Powers in excess of 20 MW are possible

Gearbox

Standard technology – driver and driven equipment operate at optimum speed

Compression train

Built from referenced components – lower execution and operating risk

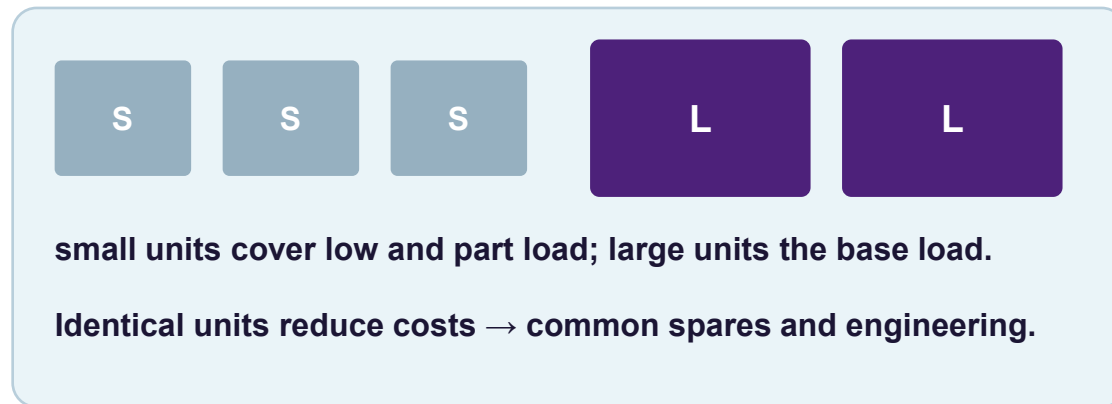
Compressor can run at its optimum speed (best efficiency) and does not depend on high speed motor power & speed capabilities of direct coupled solutions – No Performance Compromise Required.

Lower capital expenditures are key enabler for scaling

Advanced rotor technology reduces number of trains compared to conventional solutions



Flexible station layout: X identical small + Y identical large units



Same station duty – number of trains



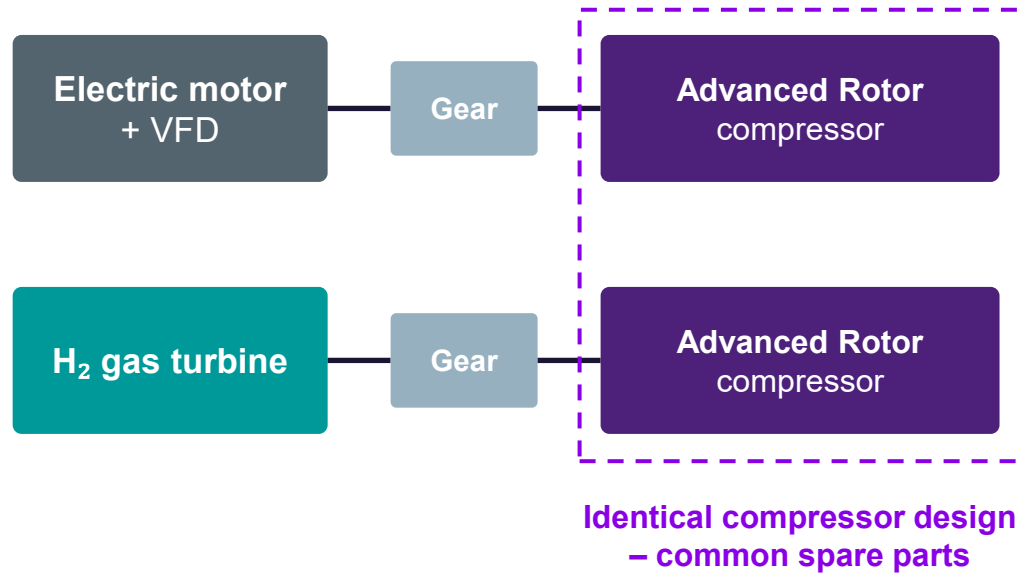
Cost levers

-  **Fewer trains per station**
Higher pressure ratio per casing → lower total CAPEX and lower transmission costs
-  **Identical units**
Standardized trains reduce engineering and spare-parts cost
-  **Bundle swap for future upgrades**
Adapt to new duties without new compressors – invest as demand materializes

Affordable hydrogen is the foundation of a scalable hydrogen economy.

One compressor design for motor and GT drive

Common design across compression stations independent of drives type



Same compressor, different driver

- Motor or gas turbine driver connected through a gearbox – compressor design unchanged

Mixed stations

- Electric and gas-turbine-driven units combined on one site, e.g. one GT driven unit for black start

Common spare-parts strategy

- Identical compressors keep spares, maintenance and training standardized



Siemens Energy is on track with its roadmap to 100 % H₂-fired gas turbines

- Portfolio development towards 100 % H₂ for mechanical drives
- SGT-400 industrial gas turbine operated with 100 % renewable hydrogen in the HYFLEXPOWER demonstrator

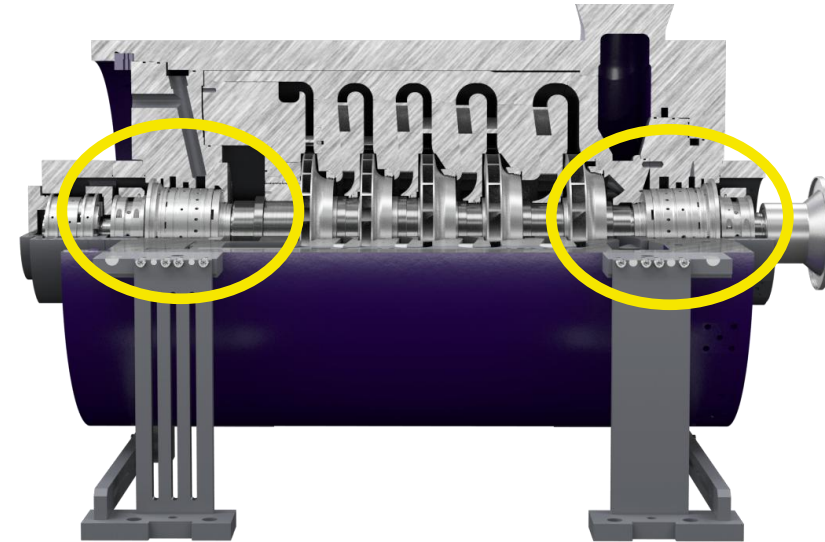
Leakages can be handled – requirements need to be clear

Different Dry Gas Seal architectures are available for the advanced rotor compressor



Use case: typical H₂ pipeline compressor

Parameter	Value
Compressor	STC-SVm (10-7-s)
Mass flow	55.000 kg/h
Suction / discharge pressure	50 / 100 bara
Pressure ratio	~2.0
Casings	1



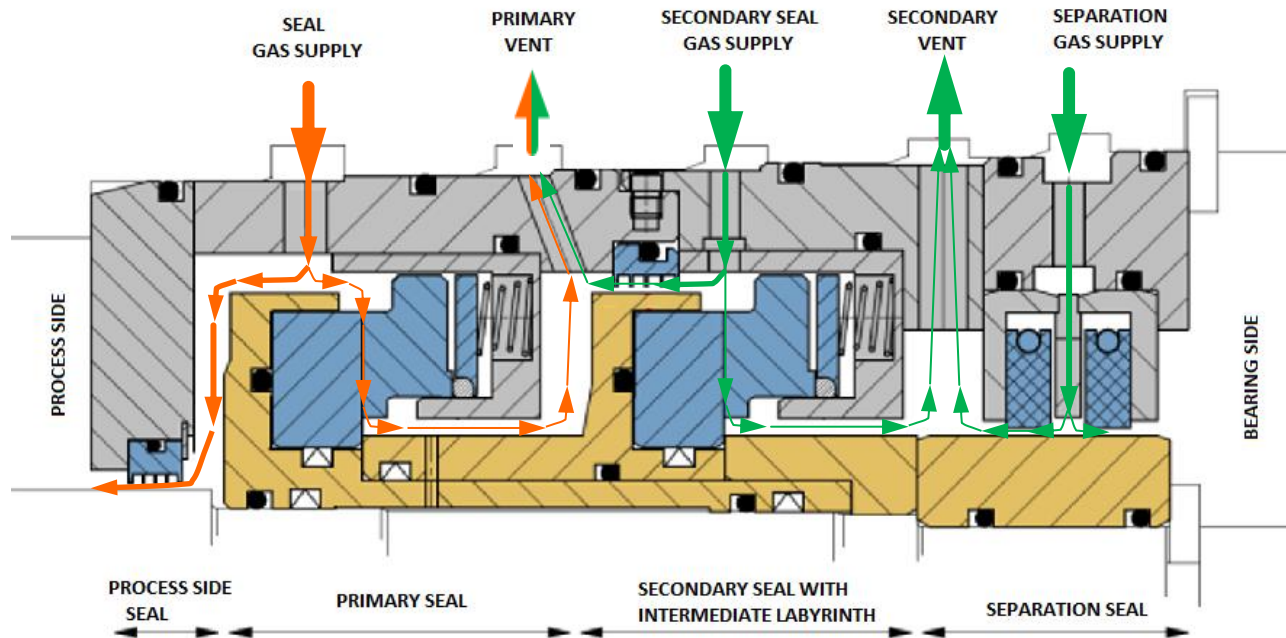
Why leakage occurs during operation

- Dry gas seals run contact-free on a thin gas film – a small, controlled leakage is part of the design

Open questions: (1) emission limits – how much H₂ may go to atmosphere? (2) H₂ purity specification – how much N₂ may enter the network?

Option 1: Tandem dry gas seals

Proven standard, small H_2 flow to vent



Legend

- Orange arrow: H_2 (process / buffer gas)
- Green arrow: N_2 (seal / separation gas)

Gas configuration

Seal gas supply	H_2
Secondary Seal gas	N_2
Separation gas	N_2
Primary vent	$H_2 + N_2$
Secondary vent	N_2

How it works

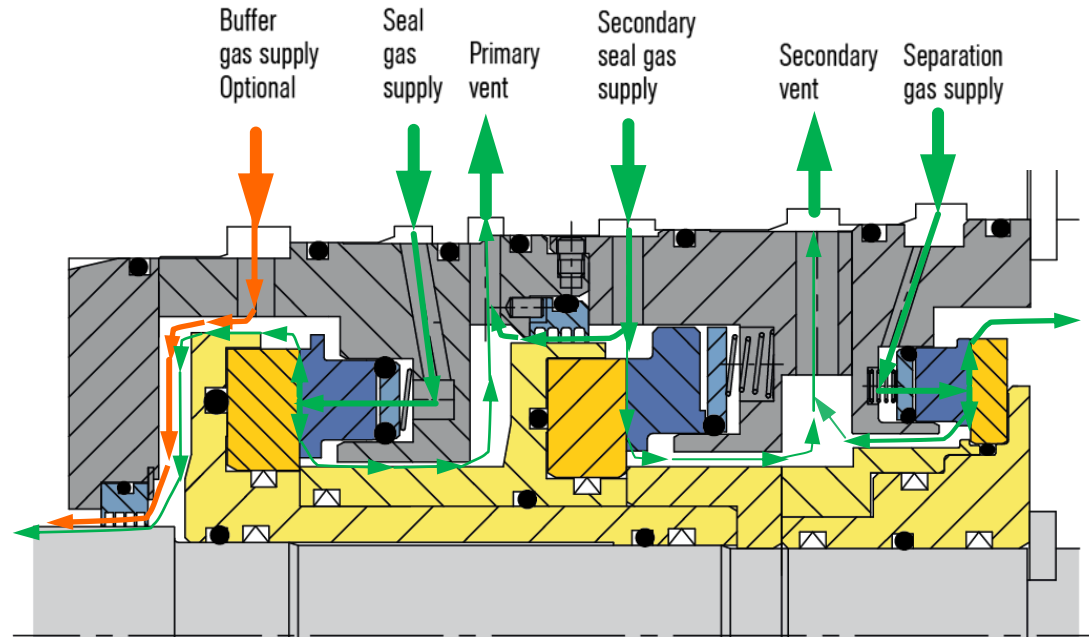
- Filtered H_2 process gas as buffer gas; a small H_2 leakage passes the primary seal to the vent
- N_2 seal gas keeps the vent mixture non-explosive and separates it from the bearing area

Assessment

- + Proven, widely referenced
- + No N_2 into the process gas
- Small continuous H_2 flow to the primary vent

Option 2: CobaSeal as Primary Seal

No H₂ to the outside – small N₂ ingress



Legend

- H₂ (process / buffer gas)
- N₂ (seal / separation gas)

Gas configuration

Buffer gas (optional)	H ₂
Seal gas (incl. secondary)	N ₂
Separation gas	N ₂
Primary vent	N ₂
Secondary vent	N ₂



EagleBurgmann
a member of **EKK** and **FREUDENBERG**

Courtesy of EagleBurgmann

How it works

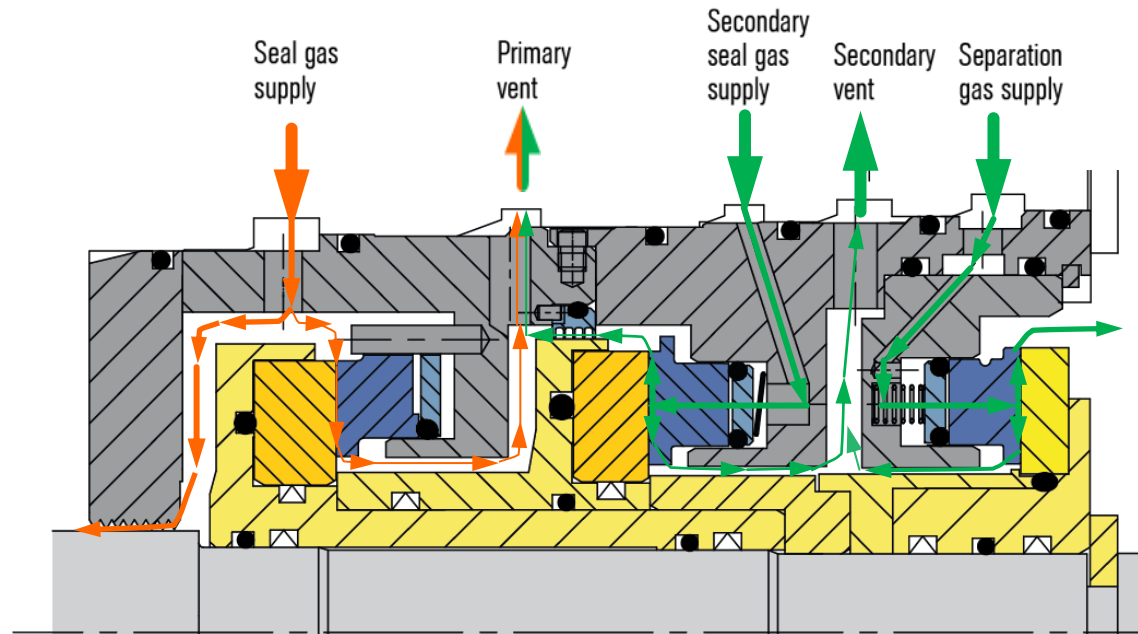
- Filtered H₂ process gas as buffer gas (Optional).
- High-pressure N₂ seal gas injected into the face of the primary seal
- A small portion of the N₂ flows into the process gas, and the rest into the primary vent – no H₂ reaches the DGS vents

Assessment

- + No H₂ to atmosphere
- Small N₂ ingress into the H₂ stream
- High-pressure N₂ supply required
- 100 % H₂ version in development

Option 3: CobaSeal as Secondary Seal

Reduced H₂ leakage to the primary vent



Legend

- H₂ (process / buffer gas)
→ N₂ (seal / separation gas)

Gas configuration

Seal gas supply	H ₂
Secondary seal gas	N ₂
Separation gas	N ₂
Primary vent	H ₂ + N ₂
Secondary vent	N ₂



EagleBurgmann
a member of **EKK** and **FREUDENBERG**

Courtesy of EagleBurgmann

How it works

- Standard primary dry gas seal on the inboard side.
- Filtered H₂ process gas as primary seal gas – small H₂ leakage to the primary vent
- CobaDGS as outboard (secondary) seal with low-pressure N₂ supply
- N₂ secondary seal gas keeps H₂ contained in primary vent with extremely low N₂ consumption

Assessment

- + Reduced H₂ to primary vent
- + No N₂ into the process gas
- + Low N₂ content in primary vent
- Small H₂ flow to vent remains
- DGS compatible with process and seal gas

Clear requirements are the key to economic low-emission compression solutions

Aligned requirements

Consider the interaction between emission limits and the H₂ purity specification

Performance-based and technology-neutral

Specify measurable outcomes rather than prescribing designs

Harmonised measurement

Common methods to quantify and report vent emissions across operators

The best emission concept is the one that still meets all other design requirements: duty, proven technology, cost and resilience.





Simon Stoverink

Business Development Director

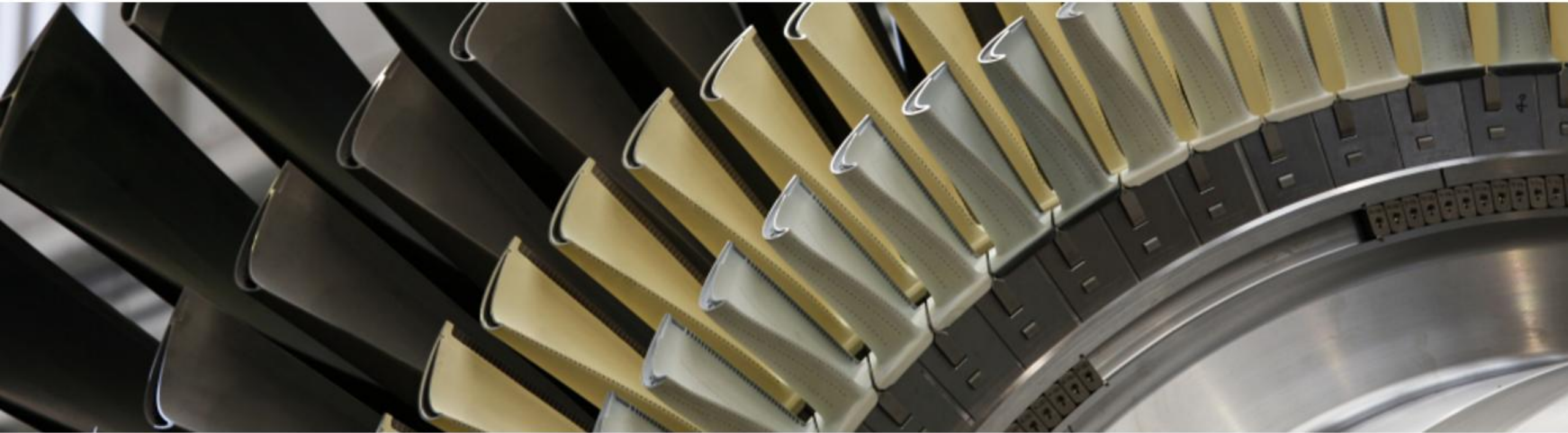
Decarbonization

06 Q&A



07 Clemens Foerster
EU Turbines





**Reducing hydrogen emissions from
compression systems:
available solutions and future technologies**

ENNOH's hydrogen emissions workshop

October 2026

Clemens Foerster, Baker Hughes



- 1. Compressor leakages: challenges and solutions**
- 2. Leakage recovery system**
- 3. Compressor internal leakages**
- 4. Zero-leakage compressor**
- 5. Q&A and contact**



CHALLENGE

- Compressors vent product gas through seals and packings during operation + additional emissions during depressurization
- Vented gases are often captured and flared, increasing site emissions and destroying product gas value

SOLUTION

- **Leakage recovery system**

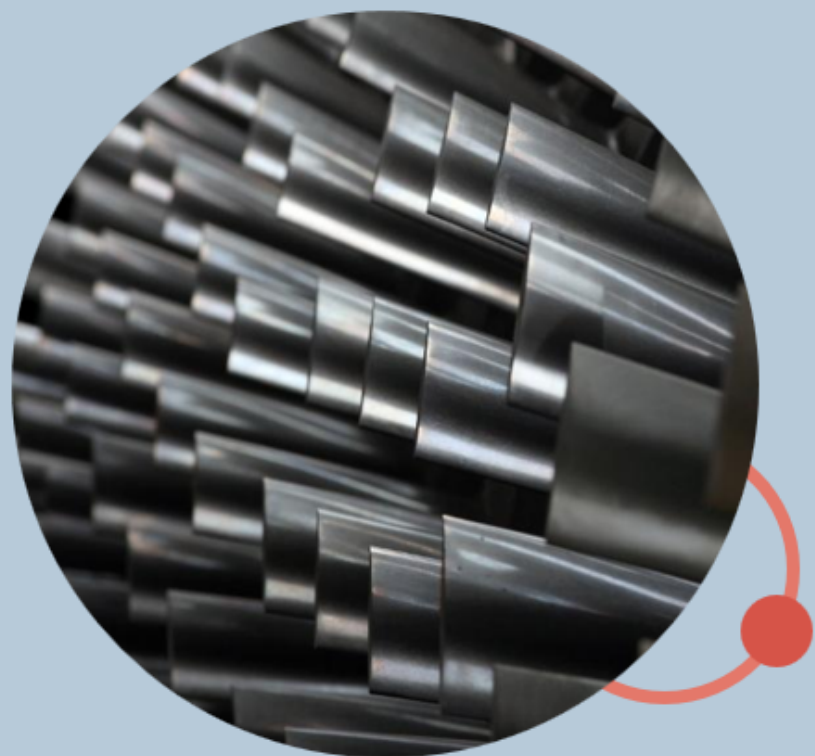
Leakage can be collected and routed back to compressor suction or used elsewhere in the plant

- **Zero-leakage compressor**

Driver and driven equipment contained in a single casing, rotating on magnetic bearings.

Background info:

- Centrifugal compressors and reciprocating compressors have process gas leakages (mechanical compression with moving parts).
- Dry gas seals and piston rod packing are used to reduce/control leakages.
- Leakage volume is typically negligible compared to process gas flow ($\ll 0.1\%$)
- **Hydrogen is an indirect GHG and costly to produce – it should not be vented to atmosphere!**

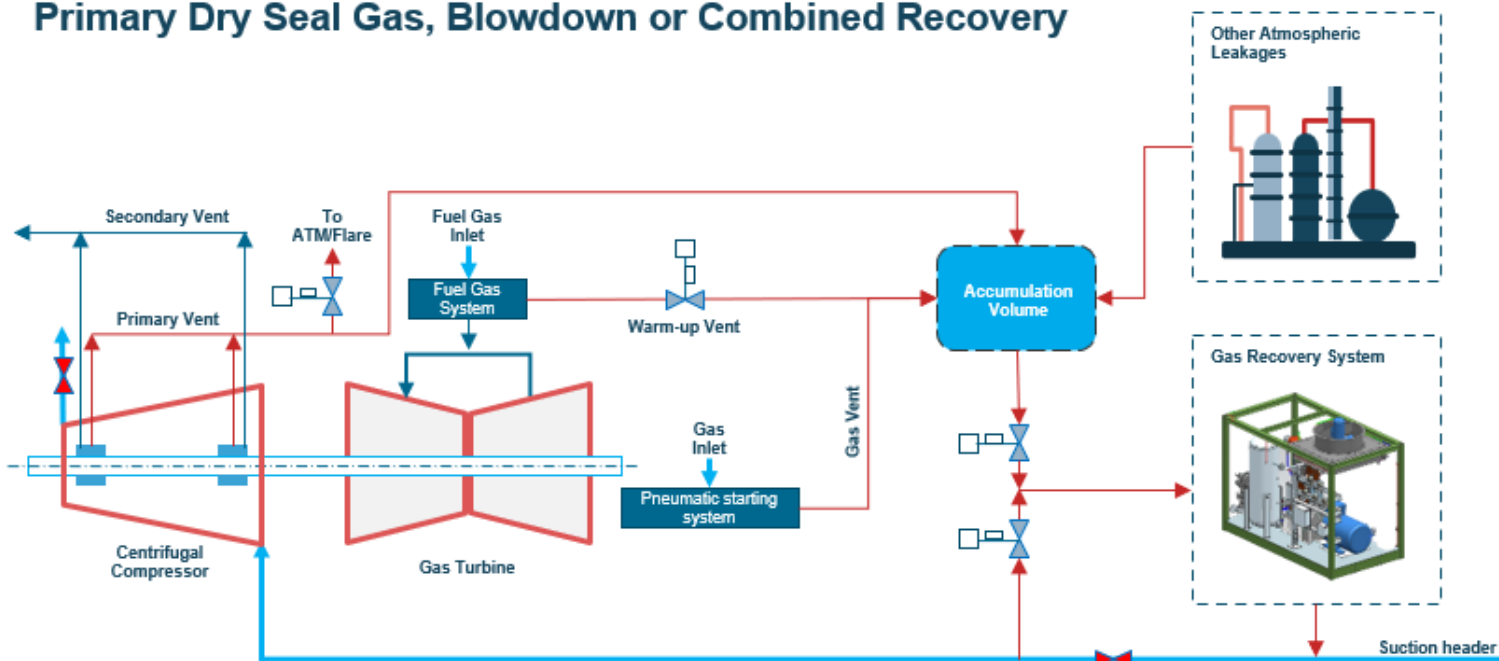


Leakage recovery system



Compressor leakage recovery system

**One skid can serve multiple streams at the same time...
Primary Dry Seal Gas, Blowdown or Combined Recovery**

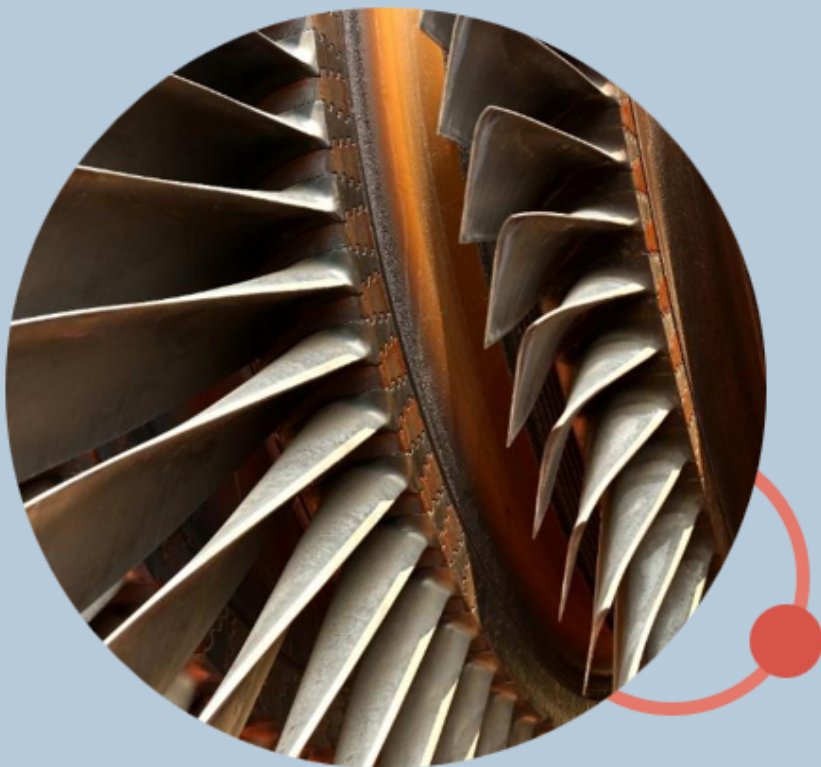


- Compact, plug & play skid, suitable for greenfield & brownfield
- Configuration based on proven technology
- Full control and process integration with the existing compression units
- Applicable to centrifugal and reciprocating compressor units.

✓ More than 99% of primary vent gas recovered – practically eliminating dry gas seal (DGS) emissions



- Primary vents and process gas loop are collected through a booster compressor unit and injected into the suction header or other valuable application
- The sizing of gas booster is driven by process gas recovery
- Electric motor size <75 kW and logic integration with unit control panel (UCP) and Distributed Control System on plant level (DCS).



Compressor internal leakage

**Example:
HPRC product line from
Baker Hughes**



Internal leakage: closed vs. open impellers

- Centrifugal compressors are subject to internal leakage across impellers and balance drum due to differential pressures.
- Internal leakage is not harmful to the environment, since it is confined within the compressor casing. It does, however, reduce compression efficiency. The lighter the gas, the greater the impact.

SOLUTION

- Seals are installed at the front and back of the impeller to reduce leakage. Special sealing / abradable types can be applied to close the gap between rotating and stationary parts to minimize leakage.
- Closed impellers significantly reduce internal leakage compared with open impellers.



Open Impeller



Closed Impeller



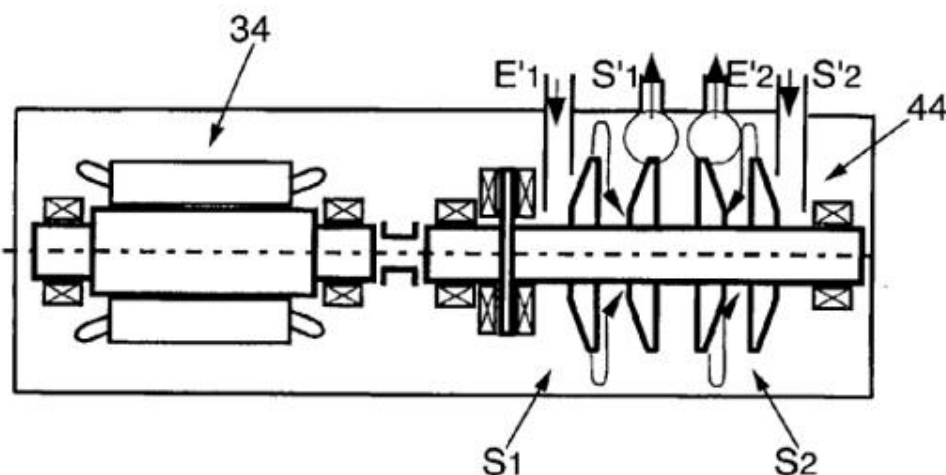
Zero-leakage compressor

**Example:
ICL product line from
Baker Hughes**

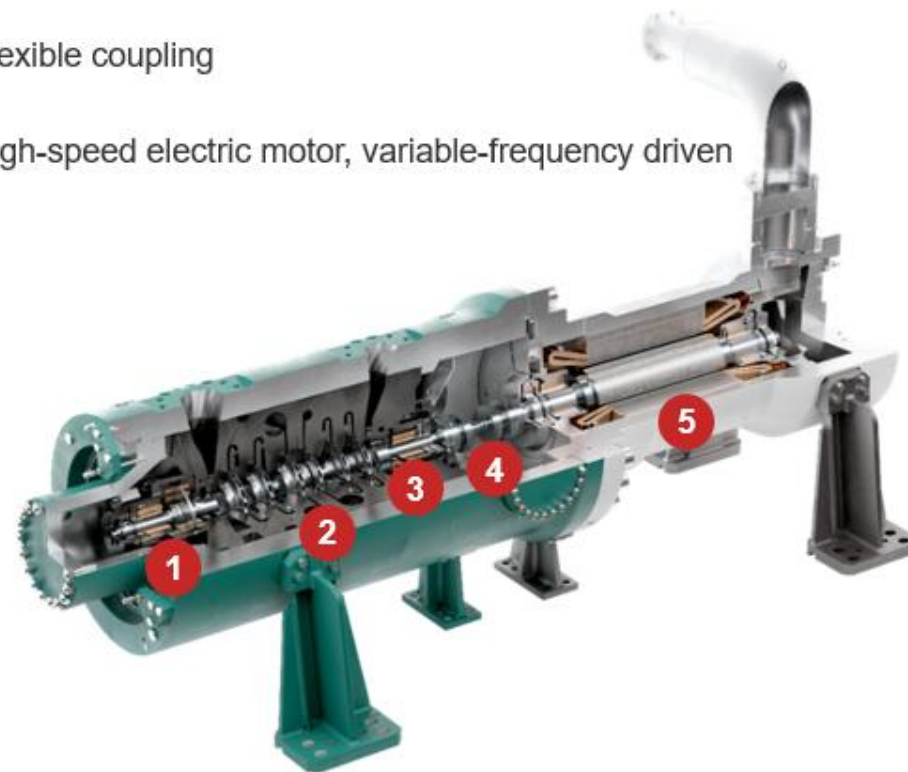


- Compressor rotor up to 9 impellers
- No gearbox
- No lube oil system
- No external motor cooling system
- No seal gas system

Simple shaft line architecture



- 1 Axial & radial Active Magnetic Bearings
- 2 Compressor stages
- 3 Radial Active Magnetic Bearing
- 4 Flexible coupling
- 5 High-speed electric motor, variable-frequency driven





ICL key advantages



Compact

Footprint & weight reduced by ~50% vs. conventional
No lube oil system, no dry gas seal & no gearbox

Zero Emission*

Hermetic, inherently safe without seal gas system
Zero CO₂, zero NO_x & no gas emissions at all

Oil Free

Enabled by Active Magnetic Bearing technology
No oil consumption and no risk of oil spills

- **Field-proven solution for natural gas applications**
- **Qualification ongoing for 100% H₂ applications:**
 - material compatibility for H₂ environment
 - electric components ATEX certification compliance for H₂

** Scope 1, during operation & standby*

Low Noise

Typical reduction of -3 dB(A) (-50% sound power)

Superior Operational Flexibility

Wider operating range (30–105% speed)
Efficiency remaining high across full operating range
Unlimited pressurized standstill: no flaring, no nitrogen required
Always ready to start, 5 minutes max warm-up time
Solution ready for unmanned operation
Low start-up current (low friction + variable-frequency drive) reduces stress on the station's electrical system





Clemens Foerster

Senior Sales and Business Development Manager
Climate Technology Solutions
Industrial & Energy Technology
Baker Hughes

Questions & Answers

Thank you for your attention

Contact

Clemens Foerster

Senior Sales and Business Development Manager
clemens.foerster@bakerhughes.com

08 Q&A



09 Lunch break
12:55 – 13:45



10 Panel discussion



Detection, monitoring, and reduction of hydrogen emissions



Rod Robinson
National Physical
Laboratory



Armin Wisthaler
University of Oslo



Cristina Lopez
NaTran



Alessandro Arrigoni
Joint Research
Centre



David Granger
Equinor



Mures Zarea
GERG



David Merbecks
DVGW

EISMEA H2Qual Net

in the context of EISMEA call SMP-STAND-2024-ESOS-01-
IBA Topic 10 Hydrogen quality in dedicated gaseous grids,
May 2024/approved July 2024

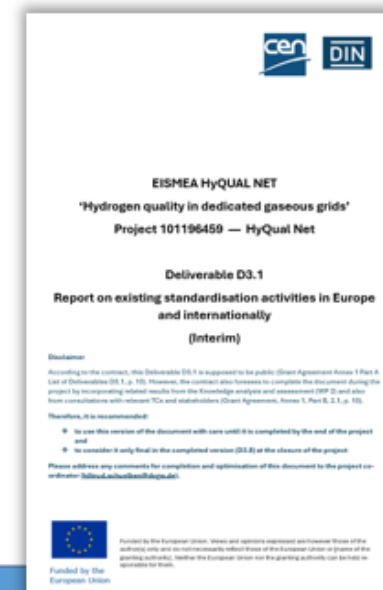
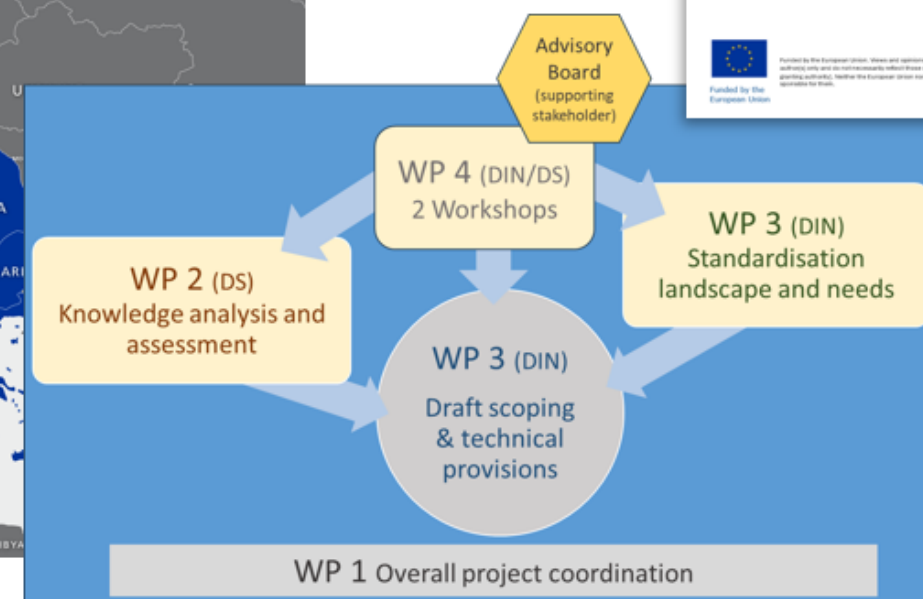
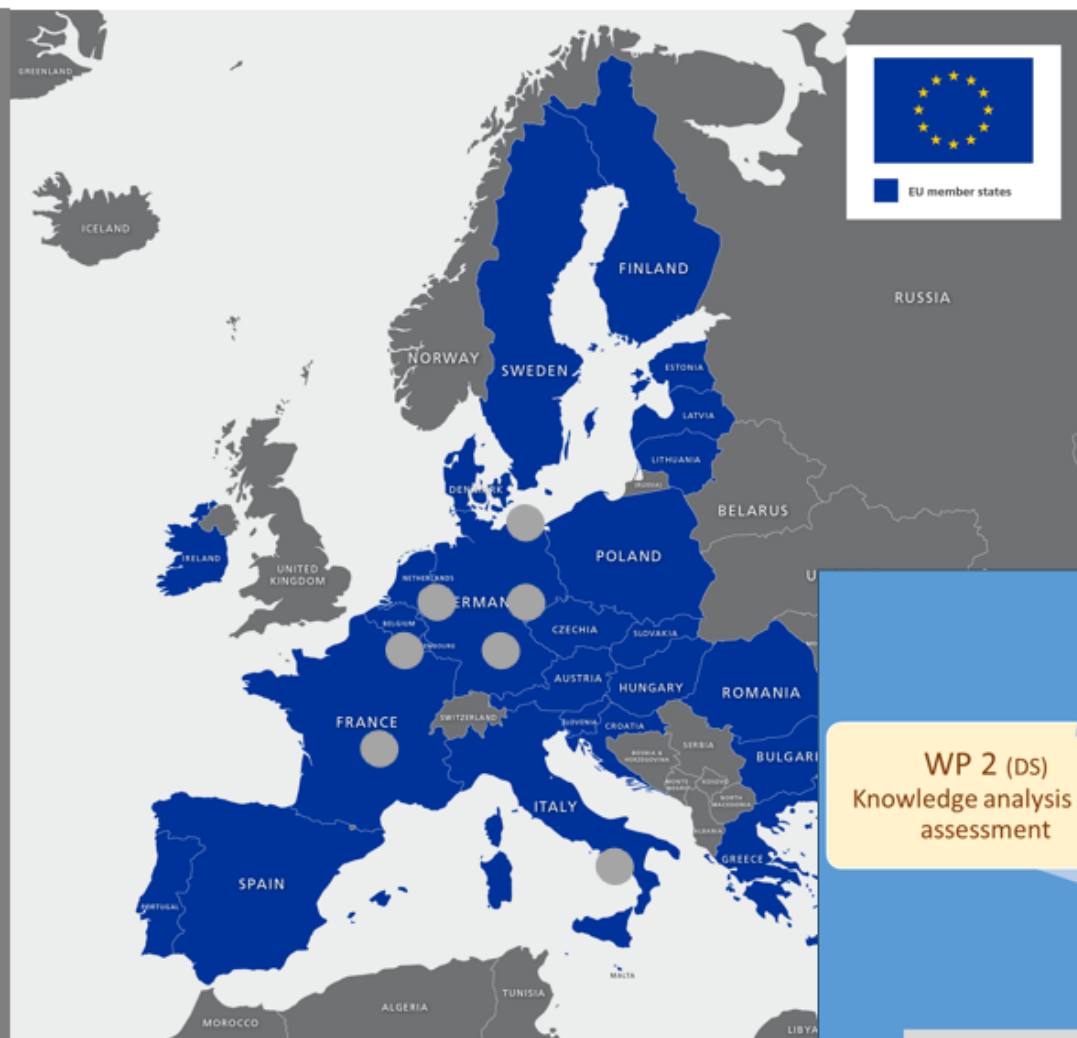
Joint project of DIN and Danish Standards (DS)

ENNOH Workshop:
“Detection, monitoring, and reduction of hydrogen emissions”
session Emissions

David A. Merbecks, DVGW
Brussels 13.10.2026

Project topics:

- (1) Leakage detection with/without odorisation (DVGW-EBI)
- (2) Leakage detection and monitoring (NATRAN R&I)
- (3) Odorants without sulfur (DBI)
- (4) Safety protocols and technical leakage/explosion prevention (KIWA)
- (5) Purification (DBI)
- (6) Hydrogen quality parameters (EVIDA)





Reflection on the project outcomes

- Leak detection and monitoring methane methodology is a usefull example but it isn't just a 1:1 blueprint for dedicated hydrogen infrastructure.
- We need integrated solutions in maintenance for safety and mitigation of emissions (leak detection and monitoring)
- Modern hydrogen grids with smart solutions regarding safety in operation already provide a high level of reliability and resilience.



EISMEA H2Qual Net – Hydrogen quality in dedicated gaseous grids

CONTACTS

Hiltrud Schülken

Project coordination + WP 3 lead

DIN NAGas

hiltrud.schuelken@dvgw.de

Mobile: + 49 172 7852138

Desk: + 228 9188 905

Sultan Wood

Project coordination + WP 2 lead

Danish Standards

sw@ds.dk

Mobile: + 45 5334 2313

Desk: +45 3996 6273

Jean Schweitzer

WP 2 Consortium lead

EVIDA

jeasc@evida.dk

Mobile: + 45 2913 3754

David Merbecks

DIN NAGas

david.merbecks@dvgw.de

Mobile: + 49 1511 2466280

Desk: + 228 9188 717

Ines Weller

Assistance/ WP 4 Workshop 2

DIN NAGas

ines.weller@dvgw.de

Desk: + 228 9188 689

Detection, monitoring, and reduction of hydrogen emissions



Rod Robinson
National Physical
Laboratory



Armin Wisthaler
University of Oslo



Cristina Lopez
NaTran



Alessandro Arrigoni
Joint Research
Centre



David Granger
Equinor



Mures Zarea
GERG



David Merbecks
DVGW

H₂ emissions monitoring

DRIVERS

- Addressing **climate change**
- Assessing the **life-cycle impact** of hydrogen technologies

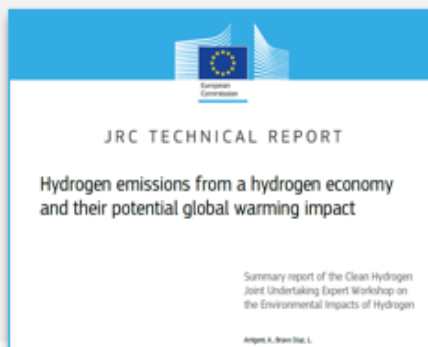


NEEDS

- **Primary data** from industrial applications
- Improved **tools for quantification**
- Standardised **monitoring protocols** and certification schemes
- **Reduce uncertainty** in the hydrogen budget
- **International consensus** on a global warming potential value for hydrogen, ideally through the IPCC
- Inclusion of hydrogen emissions in **policy** frameworks (e.g., DA RFNBO)

JRC activities on H₂ emissions

Monitor the state of knowledge
and synthesise it for the policymakers



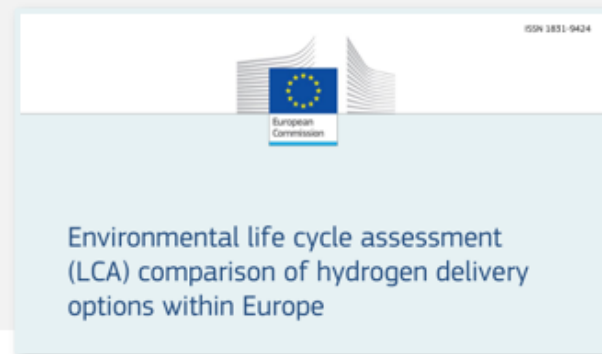
Take part in initiatives that **advance regulation**



Take part in initiatives that **advance scientific understanding**

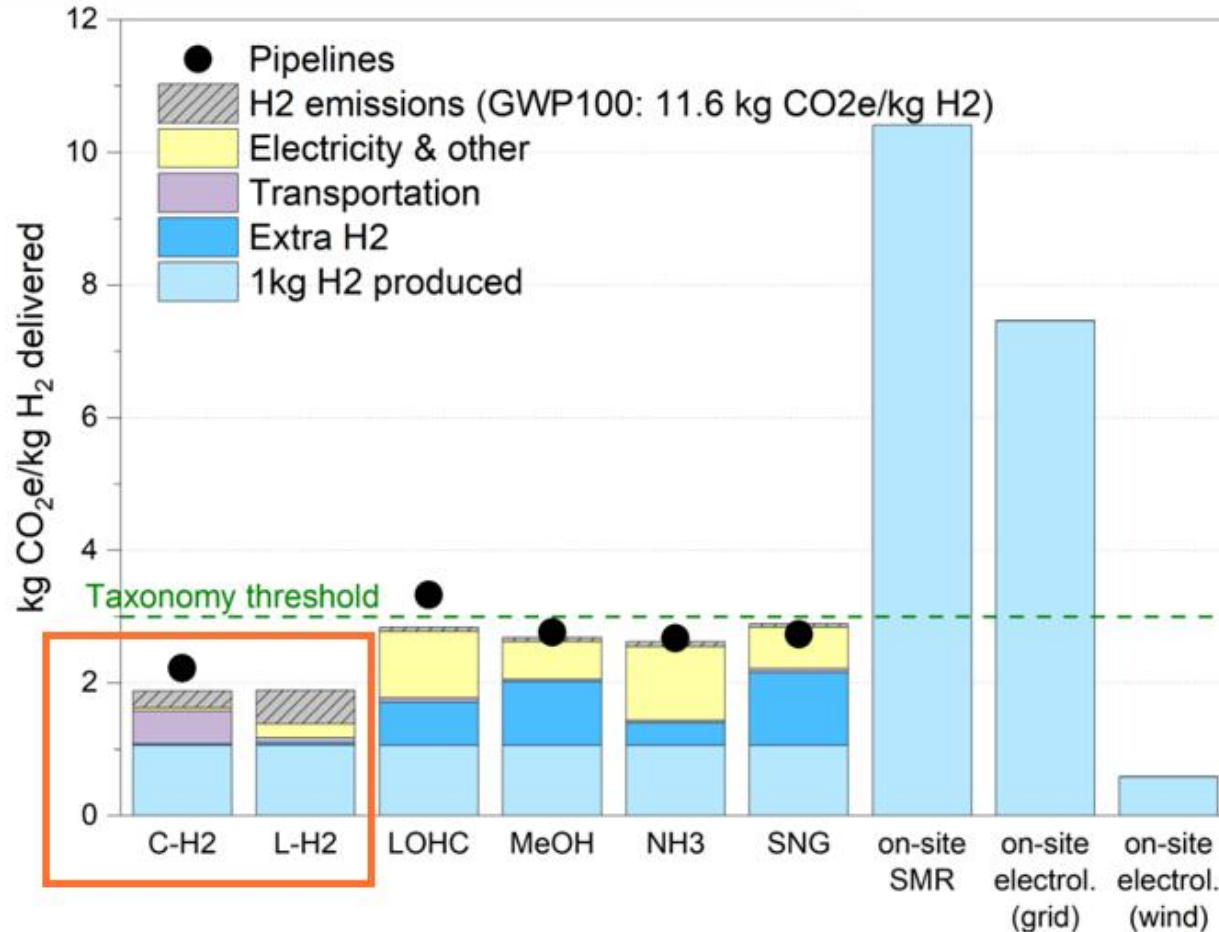


Conduct **in-house research**, including field measurements and LCAs



JRC research results

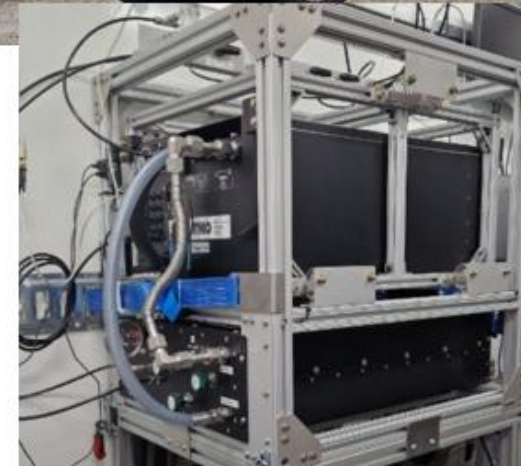
2024: LCA hydrogen delivery options



Compressed H₂: H₂ emissions responsible for **13%** of the overall impact

Liquefied H₂: H₂ emissions responsible for **27%** of the overall impact

2026: measurement campaign with TNO



**Aerodyne
H₂ analyser**

Detection, monitoring, and reduction of hydrogen emissions



Rod Robinson
National Physical
Laboratory



Armin Wisthaler
University of Oslo



Cristina Lopez
NaTran



Alessandro Arrigoni
Joint Research
Centre



David Granger
Equinor



Mures Zarea
GERG



David Merbecks
DVGW

OPHYCS aims to develop a new sensor technology that will lead to an increase in the safety level of H₂ applications, as well as minimize potential H₂ releases.

This project has received funding from the Clean Hydrogen Partnership under Grant Agreement No 101101415.

Three different use cases were considered for that technology.



Pipeline use case



Midstream sites

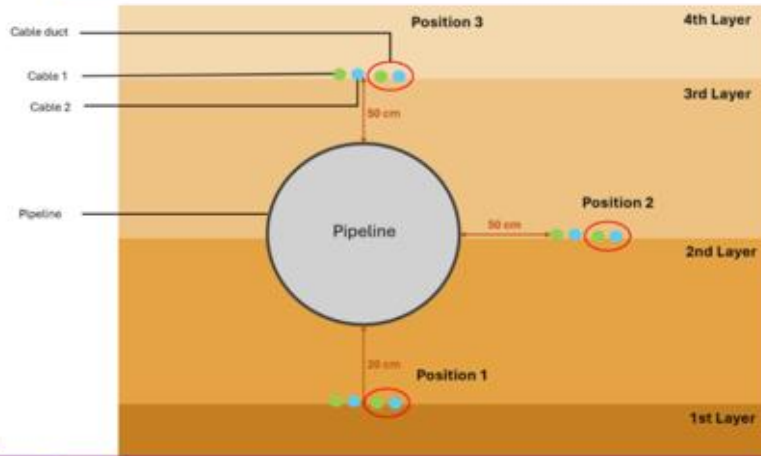


Hydrogen refueling station

Focus on pipeline use case



Aerial configuration : introduction of the test bench



Buried configuration – additional measurements with handheld sensors

Detection, monitoring, and reduction of hydrogen emissions



Rod Robinson
National Physical
Laboratory



Armin Wisthaler
University of Oslo



Cristina Lopez
NaTran



Alessandro Arrigoni
Joint Research
Centre



David Granger
Equinor



Mures Zarea
GERG



David Merbecks
DVGW

NPL Hydrogen Activities



- Development of test capabilities:
 - High flow sampling method: doi.org/10.1051/epiconf/202635201006
 - Hydrogen Controlled Release Facility: a traceable reference source
- Supporting a regulator in the UK to develop LDAR and MCERTS standards for Hydrogen.
- Test activities:
 - Performance testing using NPL's laboratory and controlled release facilities.
 - Field testing at various hydrogen test and research facilities and sites across the value chain (production to end use).
 - Gaining experience in use of various techniques to provide confidence and understand their scope and limitations.
 - Techniques such as acoustic cameras, sniffers, high flow and sensor networks. doi.org/10.1016/j.measene.2025.100069
- Research activities:
 - Development of Raman for remote sensing of hydrogen.
 - Investigate monitoring needs and emission scenarios for related areas: e.g. ammonia.
 - Development of sampling strategies (where and how to make measurements) for different techniques.





**pre-Normative Research on Hydrogen
Releases Assessment**



**Co-funded by
the European Union**



NHyRA: Pre-Normative Research on Hydrogen Release Assessment



Scope of the project

Hydrogen as an energy vector could play a crucial role in meeting the Green Deal target of climate neutrality by 2050. It is acknowledged that H_2 molecule can react with hydroxyl radicals present in the atmosphere, extending methane's lifetime thus acting as an **indirect greenhouse gas**. Furthermore, there is still uncertainty regarding the amount of the H_2 emissions expected along the future H_2 value chain. A **dedicated normative framework**, including testing methodologies for hydrogen emissions, **does not exist**. The project configures as a **pre-normative research** for supporting the **development of new and updated standards**, filling the existing normative gaps. Building on the experience gained in the NG sector and on the characterization of methane emissions, the project will assess the potential H_2 emissions of the future H_2 value chain.

Main Project objectives

- Objective 1 concerns the creation of an **inventory** for the anthropogenic H_2 emissions from the hydrogen value chains
- Objective 2 is related to the development and validation of **methodologies** for **detecting and quantifying the H_2 emissions**
- Objective 3 concerns the **H_2 emissions quantification and definition of scenarios** for different time horizons (e.g. 2030, 2050), with the assessment of **potential mitigation strategies**

Partners, Roles and Timeline



Project coordinator



WPs and activities	2024				2025				2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
WP1: H_2 release inventory												
WP2: Methodology development for H_2 releases quantification												
WP3: Methodology validation and field tests assessment												
WP4: H_2 releases from supply chains												
WP5: H_2 release scenarios												
WP6: Dissemination, Communication & Exploitation												
WP7: Coordination and Project Management												

HORIZON-JTI-CLEANH2-2023-05-03:

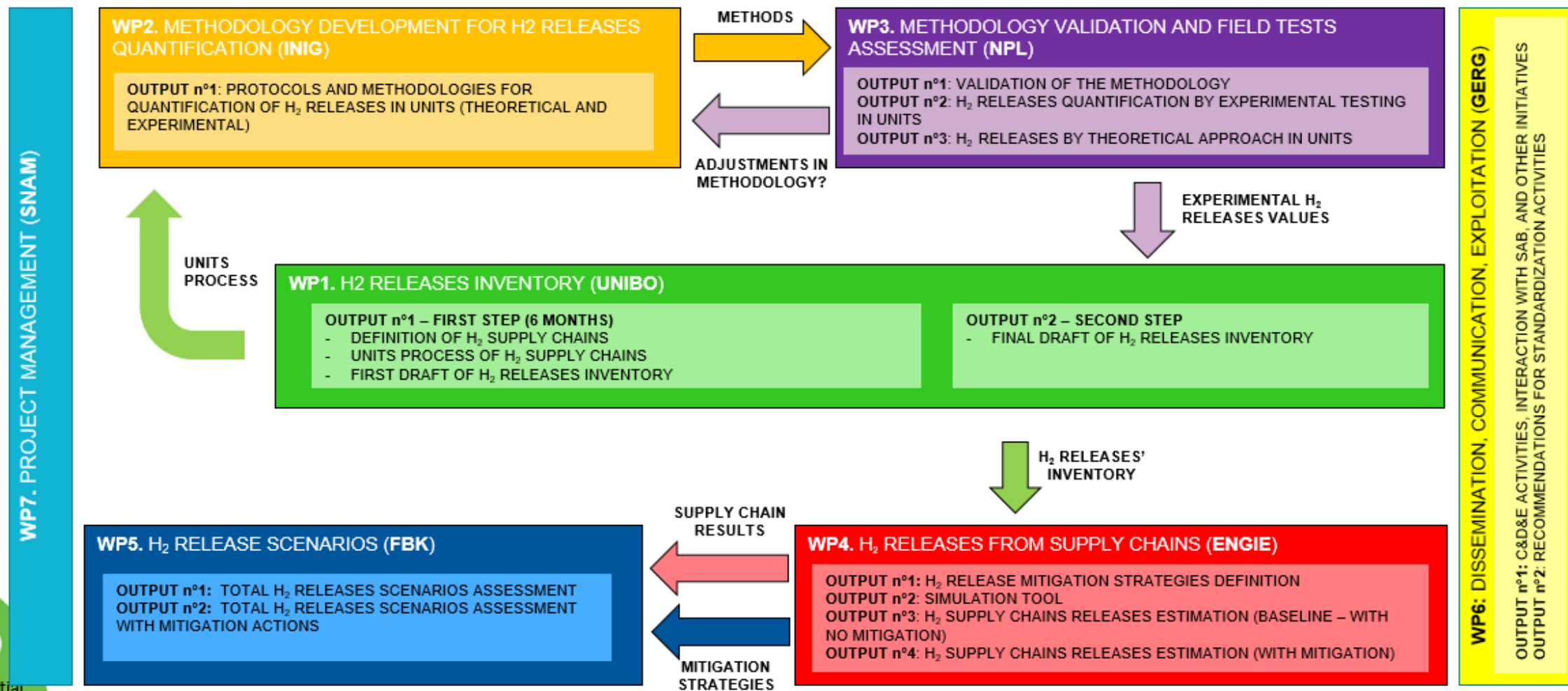
Pre-Normative Research on the determination of hydrogen releases from the hydrogen value chain



Co-funded by
the European Union



Project methodology



Detection, monitoring, and reduction of hydrogen emissions



Rod Robinson
National Physical
Laboratory



Armin Wisthaler
University of Oslo



Cristina Lopez
NaTran



Alessandro Arrigoni
Joint Research
Centre



David Granger
Equinor



Mures Zarea
GERG

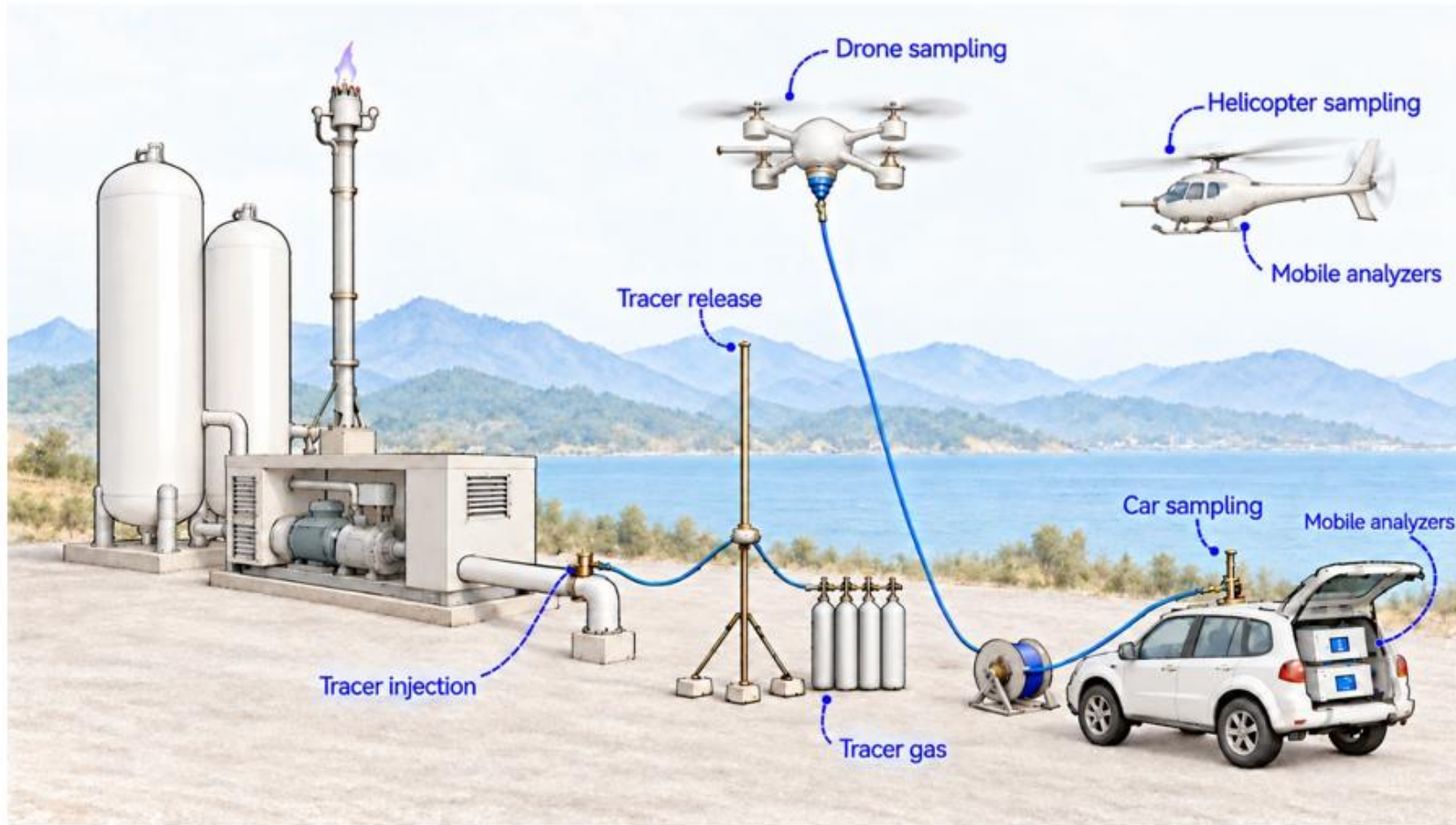


David Merbecks
DVGW

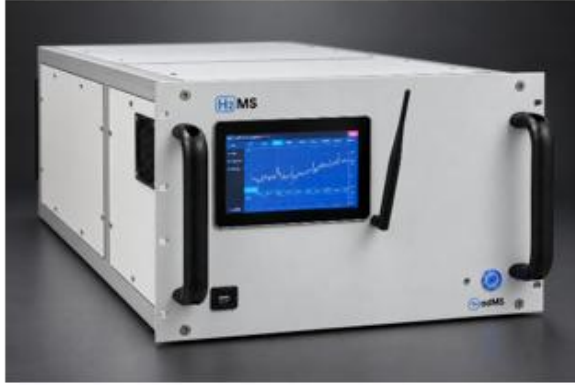
Hydrogen Emission Quantification (HEQ)

A joint project by Equinor and adMS to develop a comprehensive toolbox for accurate emission quantification of hydrogen, supporting effective emission management and the safe development of the hydrogen economy

The HEQ measurement toolbox



H₂ emission monitoring in practice



Mobile H₂ analyzer



Drone sampling



Car sampling



Helicopter sampling



Tracer release

Method validated for wide emission range



Controlled release (0.0075 kg/h)

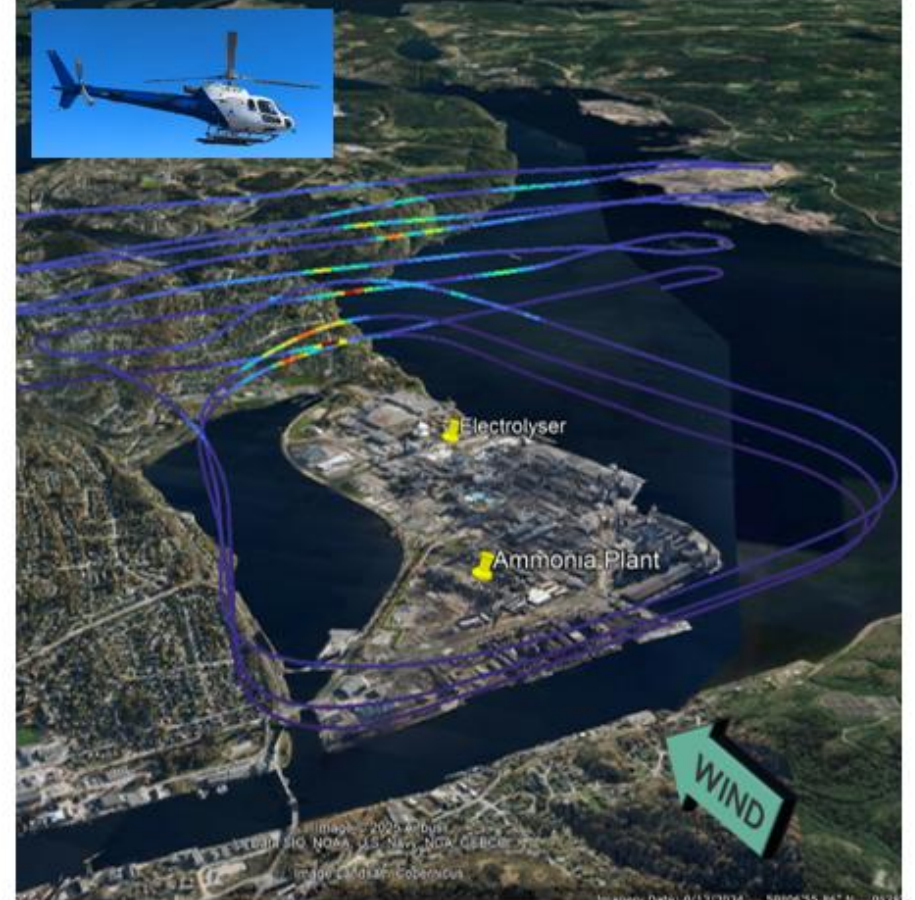


SMR (<5 kg/h)



Small electrolyzer (0.8 kg/h)

Vented production



Industrial site (≥ 90 kg/h)

Mostly vented production from test electrolyzer

Detection, monitoring, and reduction of hydrogen emissions



Rod Robinson
National Physical
Laboratory



Armin Wisthaler
University of Oslo



Cristina Lopez
NaTran



Alessandro Arrigoni
Joint Research
Centre



David Granger
Equinor



Mures Zarea
GERG

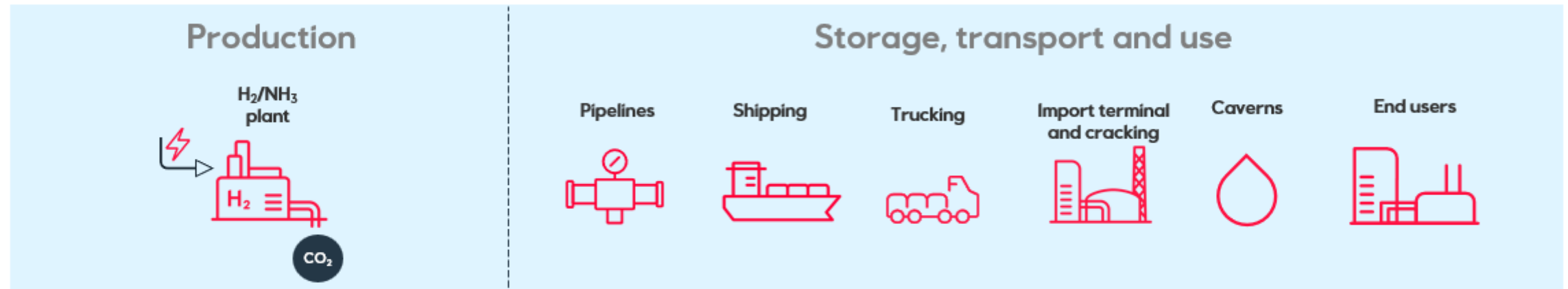


David Merbecks
DVGW



Hydrogen emissions may be included in the CI of clean hydrogen

...But not until the science is more settled



Potential H₂ emissions scope



Low Carbon Hydrogen Standard



RFNBO Delegated Act; Low carbon fuels Delegated Act

Detection, monitoring, and reduction of hydrogen emissions



Rod Robinson
National Physical
Laboratory



Armin Wisthaler
University of Oslo



Cristina Lopez
NaTran



Alessandro Arrigoni
Joint Research
Centre



David Granger
Equinor



Mures Zarea
GERG



David Merbecks
DVGW

11 Q&A



12 Closing remarks



Daniel Bonnici
Head of System Operation & Transparency



Thank you for your attention



info@ennoh.eu



[@ennoh](https://www.linkedin.com/company/ennoh)



[ennoh.eu](https://www.ennoh.eu)



[ENNOH Newsletter](#)