Federal Ministry
for Economic Affairs
and Climate Action

MITTELSTAND
GLOBAL
ENERGY SOLUTIONS
MADE IN GERMANY

How to Build Up an Efficient Hydrogen Infrastructure in Germany: Current Status and Challenges

Tom Smolinka / Fraunhofer ISE

IDA Conference, Copenhagen

April 16, 2024

AHK Dansk-Tysk Handelskammer Deutsch-Dänische Handelskammer

Facilitator

eclareon

Fraunhofer Institute for Solar Energy Systems ISE in Freiburg / Germany

Division Hydrogen Technologies: Defossilization of Transport, Chemicals, and Industrial Processes

Electrolysis & H_2 Infrastructure

Membrane water electrolysis as basic technology for renewable energy carriers

Sustainable Mobility

Membrane fuel cells, sustainable fuel internal combustion engines, and fuel infrastructure

Sustainable Synthesis Products

Catalyst & process development including life cycle and techno-economic assessment

30 years H_2 experience | **170 employees** | **20 Mio € annual budget**

Outline of the Talk

1. Introduction to Fraunhofer ✓
2. Today's Hydrogen Infrastructure in Germany
3. Global Power-to-X Supply Chains
4. European Backbone & German Core Network
5. Hydrogen Storage in Bulk
6. Technical Challenges
7. Conclusion and Summary

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Hydrogen Infrastructure in Germany

What infrastructure already exists today?

Local industrial hydrogen networks

- Marl - Castrop-Rauxel - Leverkusen : 240 km (Air Liquide)
- Bitterfeld - Skopau – Leuna: : 150 km (Linde)
- Refinery Heide – Brunsbüttel : 30 km (Refinery Heide)

Marl Chemical Park in the Ruhr area

Road transportation via trailer

- CGH2 @ 200/300 bar → limited capacitiy → FCEV refuelling stations
- LH2 @ - 253 °C → high energy demand → large FC power units

LH2 trailer at a HRS

Hydrogen bleeding to the NG grid

- Up to 10% permitted by law → limited in practise to 2% (CNG)
- Currently not commercially viable

Up to 20% H_2 bleeding in pilot region Fläming

https://www.chemietechnik.de/energie-utilities/wasserstoff/plaene-fuer-ein-nationales-wasserstoff-netz-in-deutschland-341.html

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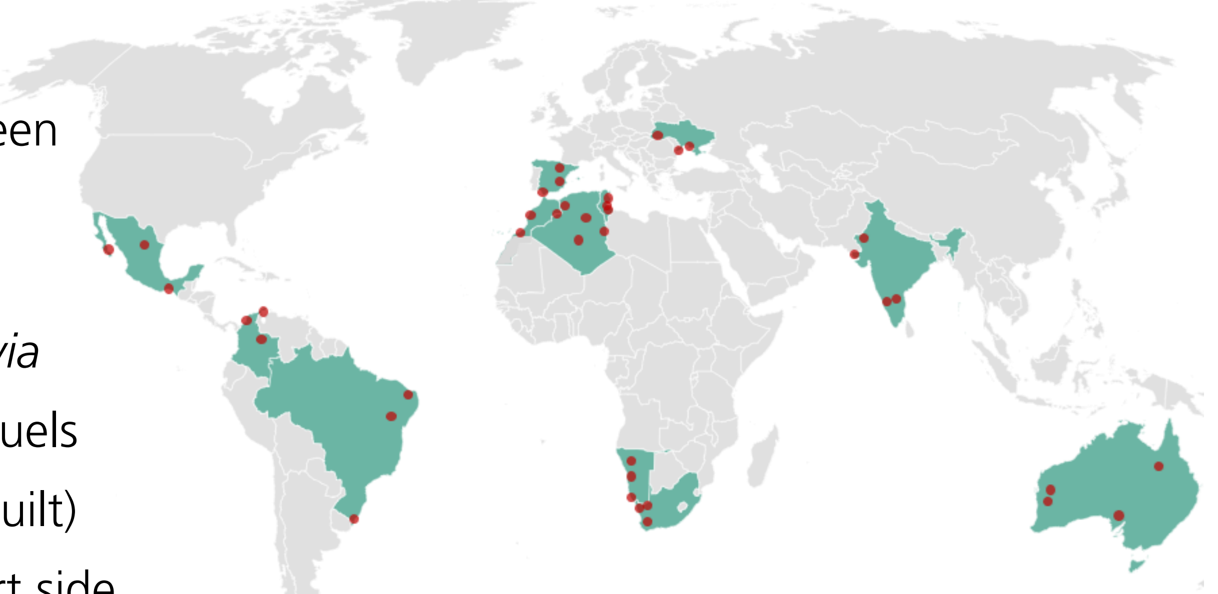
Global Power-to-X Supply Chains[1]

Techno-economic cost assessments for green PtX products and their transport in 2030

PtX analyses for H2Global Foundation: 39 regions in 12 preselected countries

- Evaluation of **CGH2, LH2, ammonia, methanol and jet fuels**
- **Advanced system simulation**: Impact of fluctuating RES and hydrogen production on downstream syntheses and the resulting demand for buffer storage
- **100% green**: Solely dedicated Wind and PV plants for green H_2 production (1 GW_{el} electrolysis)
- **Water supply**: in arid regions via seawater desalination
- **Transport**: from export destination to Port of Rotterdam *via*
  - **Ships** for liquid hydrogen, ammonia, methanol and jet fuels
  - **Pipelines** for gaseous hydrogen (refurbished and new-built)
- No further reforming/regasification/transport on the import side



Countries were preselected by the H2Global Foundation

[1]: Christoph Hank, Marius Holst, Connor Thelen, Christoph Kost, Sven Längle Achim Schaadt, Tom Smolinka, *Site-specific, comparative analysis for suitable Power-to-X pathways and products in developing and emerging countries*, Fraunhofer ISE, 2023, commissioned by H2Global Foundation in cooperation with Gesellschaft für internationale Zusammenarbeit (GIZ). It was financed by the Federal Ministry for Economic Cooperation and Development (BMZ) → Link

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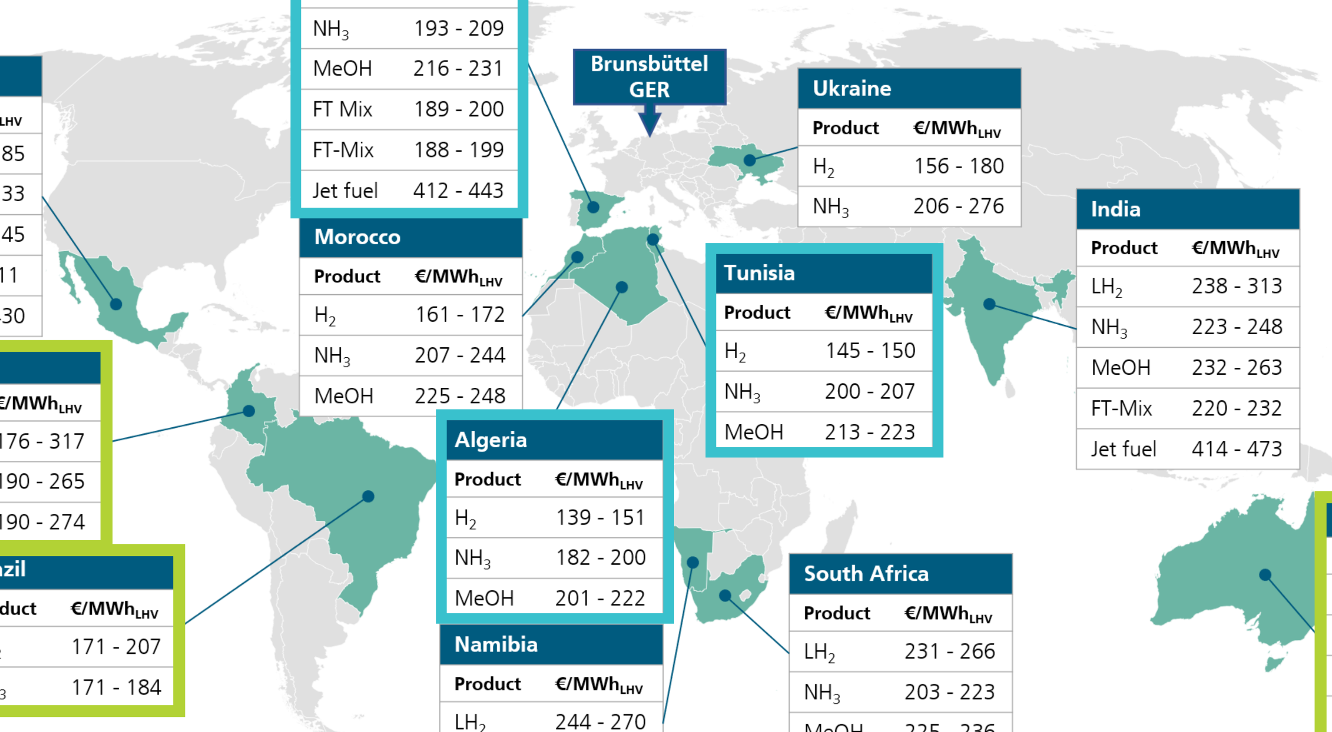
Global Power-to-X Supply Chains[1]

Lowest PtX cost achieved for countries with combined high solar and wind full load hours

- Total product **transport distance** can have a decisive influence but is not a **knock-out criterion** (e.g. Australia)
- **Gaseous H2: Spain and North Africa** will become major players in the export of gaseous hydrogen once a European Hydrogen Pipeline (EHP) network is partially developed.
- **H2 derivatives: Brazil, Australia and parts of Colombia** have emerged as favourites despite the long transport routes.



Mexico

Product	€/MWh_{LHV}
LH_2	242 - 285
NH_3	215 - 233
MeOH	238 - 245
FT-Mix	210 -211
Jet fuel	406 - 430

Colombia

Product	€/MWh_{LHV}
LH_2	176 - 317
NH_3	190 - 265
MeOH	190 - 274

Brazil

Product	€/MWh_{LHV}
LH_2	171 - 207
NH_3	171 - 184

Spain

Product	€/MWh_{LHV}
H_2	134 - 146
NH_3	193 - 209
MeOH	216 - 231
FT Mix	189 - 200
FT-Mix	188 - 199
Jet fuel	412 - 443

Morocco

Product	€/MWh_{LHV}
H_2	161 - 172
NH_3	207 - 244
MeOH	225 - 248

Algeria

Product	€/MWh_{LHV}
H_2	139 - 151
NH_3	182 - 200
MeOH	201 - 222

Namibia

Product	€/MWh_{LHV}
LH_2	244 - 270
NH_3	202 - 213
MeOH	222 - 240

Ukraine

Product	€/MWh_{LHV}
H_2	156 - 180
NH_3	206 - 276

Tunisia

Product	€/MWh_{LHV}
H_2	145 - 150
NH_3	200 - 207
MeOH	213 - 223

South Africa

Product	€/MWh_{LHV}
LH_2	231 - 266
NH_3	203 - 223
MeOH	225 - 236

India

Product	€/MWh_{LHV}
LH_2	238 - 313
NH_3	223 - 248
MeOH	232 - 263
FT-Mix	220 - 232
Jet fuel	414 - 473

Australia

Product	€/MWh_{LHV}
LH_2	217 - 233
NH_3	172 - 184
MeOH	192 - 200
FT-Mix	166 - 181
Jet fuel	298 - 333

[1]: Christoph Hank, Marius Holst, Connor Thelen, Christoph Kost, Sven Längle Achim Schaadt, Tom Smolinka, *Site-specific, comparative analysis for suitable Power-to-X pathways and products in developing and emerging countries*, Fraunhofer ISE, 2023, commissioned by H2Global Foundation in cooperation with Gesellschaft für internationale Zusammenarbeit (GIZ). It was financed by the Federal Ministry for Economic Cooperation and Development (BMZ) → Link

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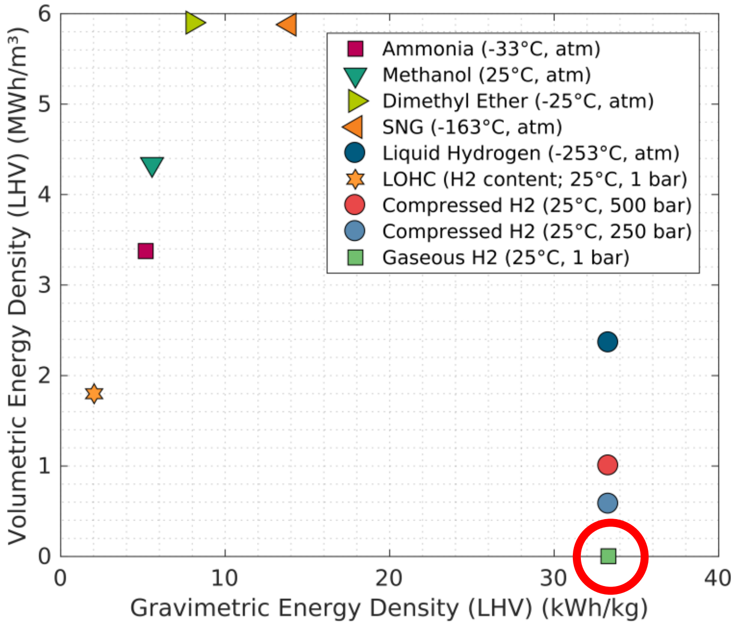
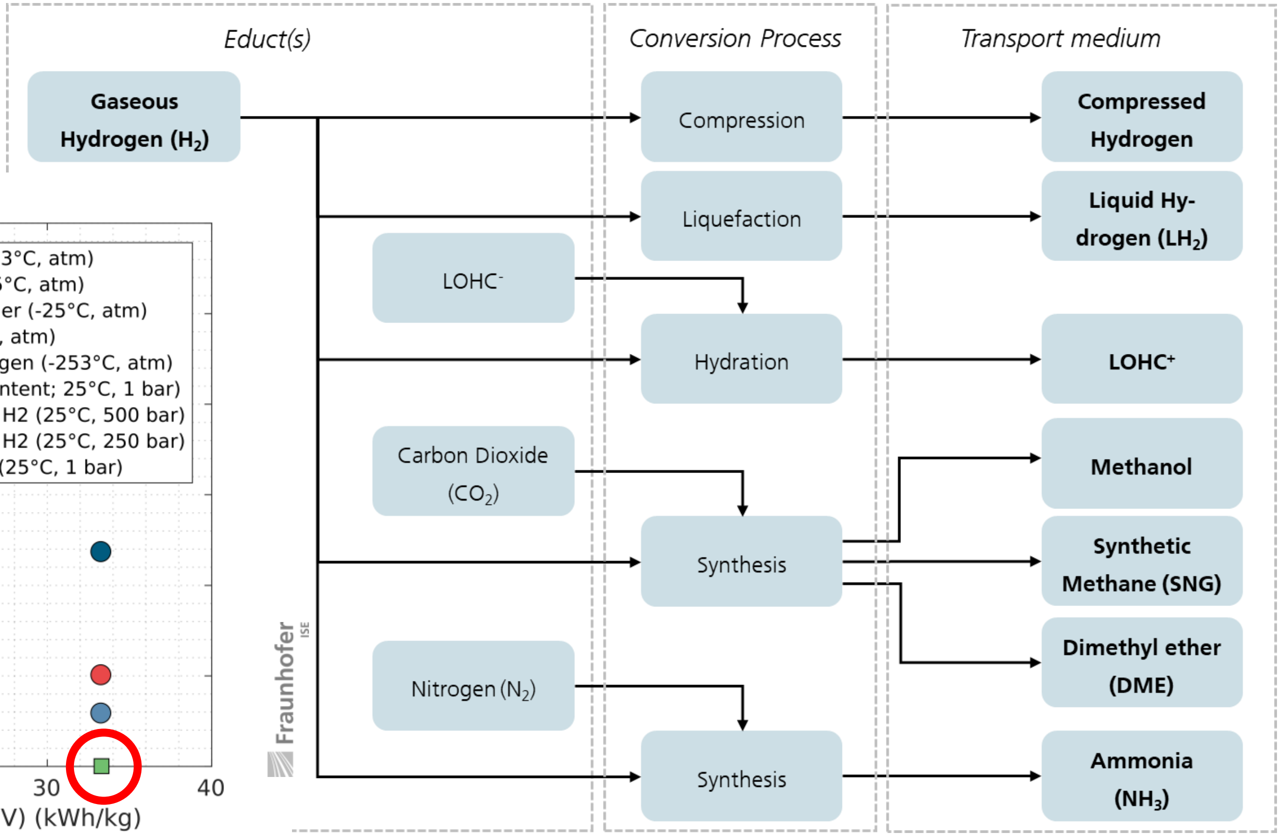
Infrastructure for Importing Hydrogen

Low volumetric energy density of gaseous H_2 makes transport and storage complex and expensive

- Physical storage at low temperature & high pressure is proven technology but has its limitations
- Material based storage via absorption/adsorption has no technical relevance for large quantities
- Conversion to derivatives enables transport with higher volumetric energy density, low pressure and moderate temperatures



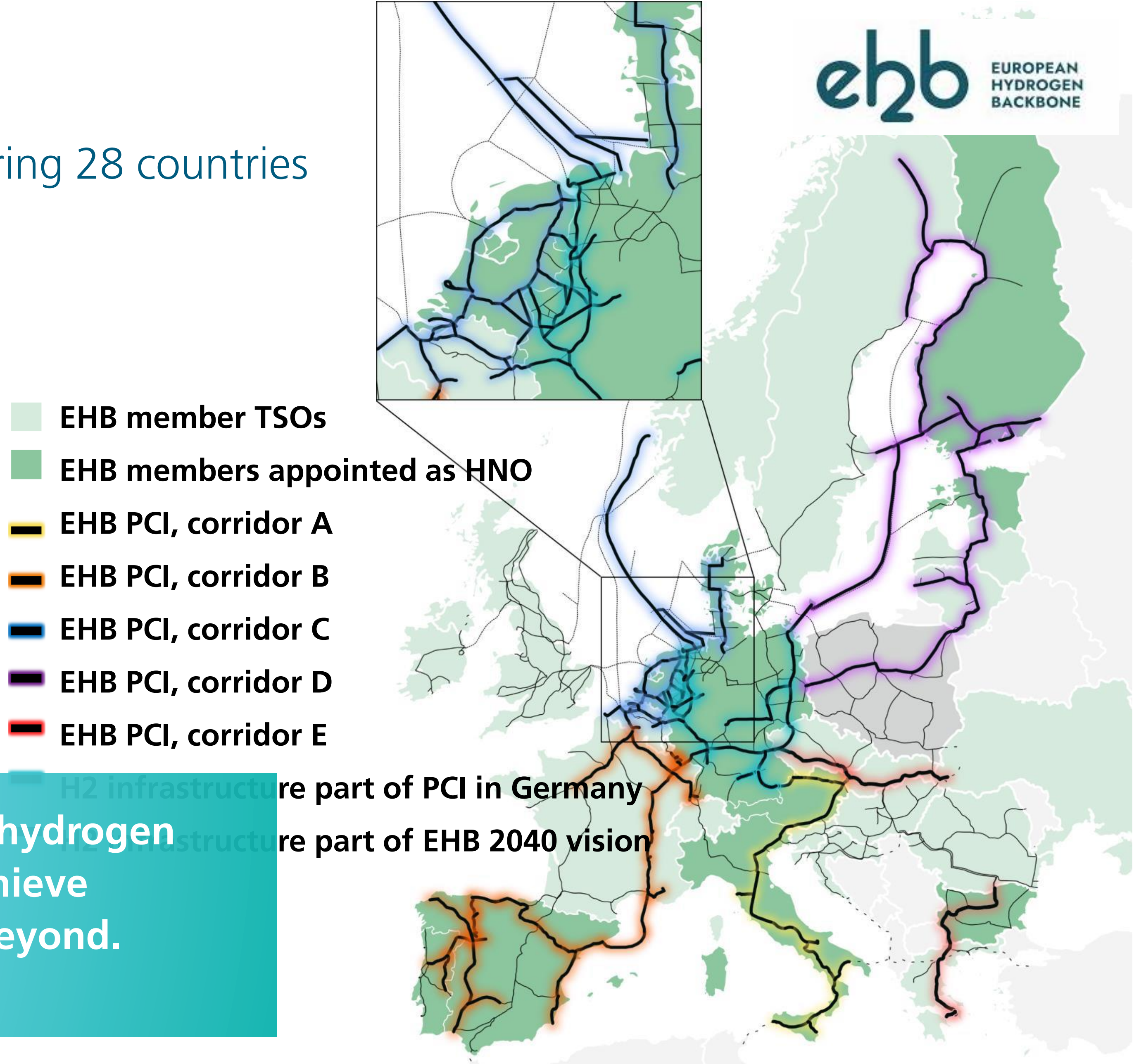


Hydrogen and its derivatives for transport and storage in bulk

European Hydrogen Backbone

A European hydrogen infrastructure vision covering 28 countries

- EHB initiative consists of a group of thirty-one energy infrastructure operators (TSOs)
- initiative aims to accelerate critical H_2 infra-structure – based on existing and new pipelines
- By 2040: 53,000 km EHB with estimated total investment of € 80 - 143 billion
- 60% of of the EHB are repurposed NG pipelines and 40% new pipeline stretches



The EHB is crucial for a successful rollout of the hydrogen economy in Europe and Germany and key to achieve Europe's decarbonisation targets by 2030 and beyond.

https://ehb.eu/files/downloads/1712733755_EHB-Implementation-Roadmap-Public-support-as-catalyst-for-hydrogen-infrastructure.pdf
https://ehb.eu/files/downloads/EHB-2023-20-Nov-FINAL-design.pdf

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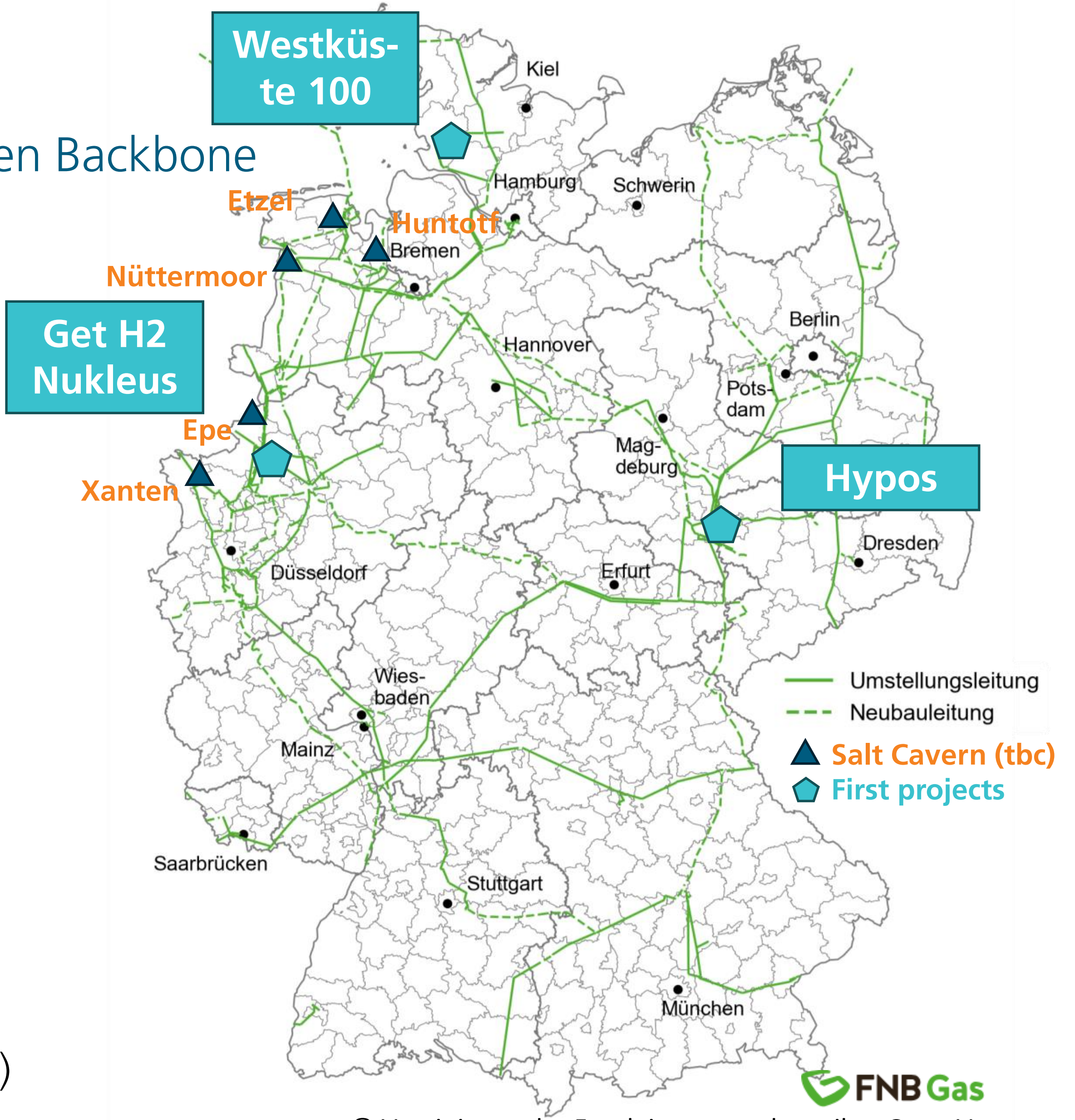
The German „Wasserstoff-Kernnetz“

Hydrogen core network as part of the European Hydrogen Backbone

- Amendment to the Energy Industry Act passed in 04/2024
  → § 28r EnWG: Hydrogen Core Network
- Draft application for the network plan submitted by FNB Gas to Federal Network Agency / BMWK in 11/2023 [1]
- Key figures [2]
  - Planned commissioning: 2025 – 2032
  - Total length: 9,700 km; 60% repurpose / 40 % new
  - Feed-in/out capacities: 100 GW / 87 GW
  - Feed-out volume 2032: 280 TWh_{th}; 160 TWh_{th} for CHP locations
  - Estimated investment: € 20 billion (supported grid fees)



[1] https://fnb-gas.de/wasserstoffnetz-wasserstoff-kernnetz/
[2] https://www.bmwk.de/Redaktion/DE/FAQ/Wasserstoff-Kernnetz/faq-wasserstoff-kernnetz.html

Hydrogen Bulk Underground Storage

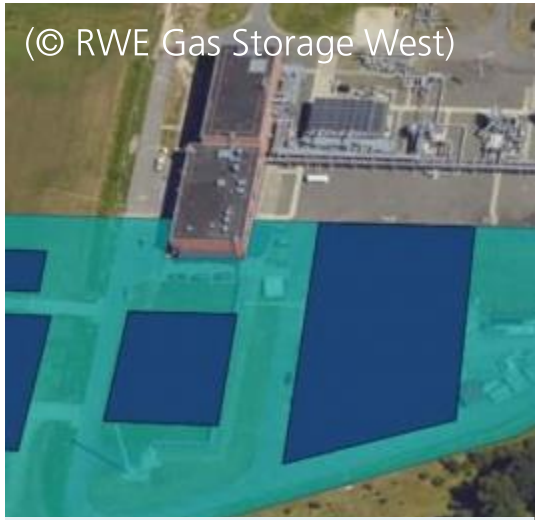
First salt cavern projects are set up to gather operating experience

Cavern Rüdersdorf

- EWE (HyCAVmobil)
- Capacity: 500 m³
- Depth: ~ 1000 m
- H_2 test operation

Cavern Krummhörn

- Uniper (Green WHV)
- > 200,000 m³
- 800 - 1200 m
- Commissioning 2024



Cavern Gronau Epe

- RWE (Get H2)
- Conversion NG cavern
- Planning approval decision (01/2024)

Cavern Bad Lauchstädt

- VGS (HYPOS)
- 15+50 10^6 Nm³ H_2
- 765 – 925 m
- Commissioning 2026+

https://www.ewe.com/de/media-center/pressemitteilungen/2023/03/ wasserstoffkaverne-ist-fertiggestellt-ewe-ag
https://www.uniper.energy/de/hydrogen-pilot-cavern
https://www.rwe-gasstorage-west.com/wasserstoff/
https://www.vng-gasspeicher.de/de/gruener_wasserstoff

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Hydrogen Bulk Underground Storage

First salt cavern projects are set up to gather operating experience → Lessons to learn

Technical questions

- Material compatibility and duarability in 100 % H_2 atmosphere
- functionality of underground and above-ground components in H_2 storage operation
- Quality of the hydrogen after withdrawal

Operational and project issues

- Operational testing in a real 100 % environment (Safety concepts, commissioning, operating procedures)
- Understanding approval procedures and legal requirements

Business management issues

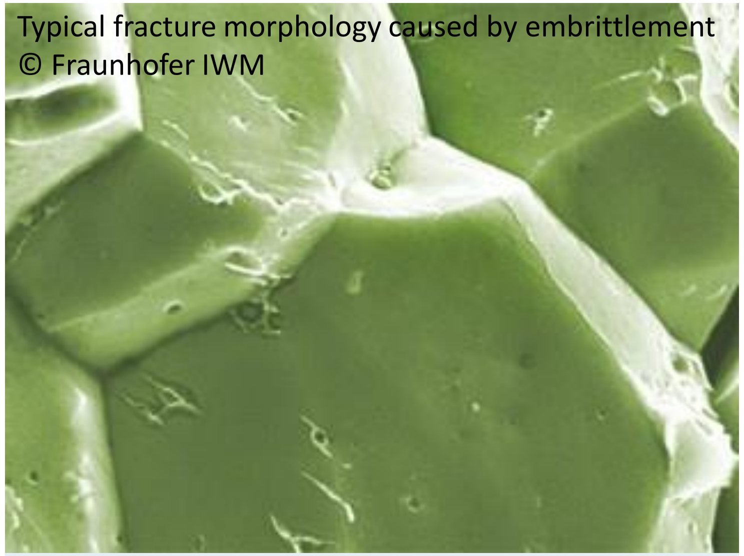
- Development of a storage solution for green hydrogen on a commercial scale → regulative framework and business models

(© VNG Gasspeicher GmbH)

https://www.vng.de/de/vng-gasspeicher-gmbh

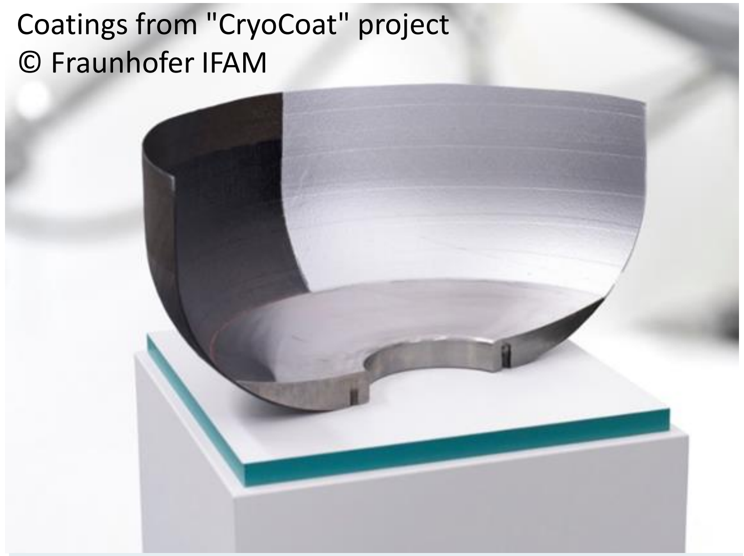
Technical Challenges for an Efficient Hydrogen Infrastructure

Hydrogen places high demands on the materials used and component design


Typical fracture morphology caused by embrittlement © Fraunhofer IWM

Hydrogen Embrittlement

- Understanding material properties under H_2 influence
- Predicting stress limits and life expectancy of component


Coatings from "CryoCoat" project © Fraunhofer IFAM

Hydrogen Permeation

- Hydrogen barrier coatings for tanks, pipelines, etc.
- Enabling lightweight and cost-effective materials as FRP


Creep test stand with cameras for optical strain detection © Fraunhofer LBF

Sustainable Materials

- Reliable design and reduced needs of critical materials
- Recyclable materials for a circular economy

Conclusion and Summary

Take home messages

For a rapid market ramp-up of hydrogen, Germany needs an efficient infrastructure that is designed to import a large proportion of the hydrogen.

1. Hydrogen can be imported either grid-based via the European Hydrogen Backbone or ship-based with hydrogen derivatives. The EHB is crucial for a successful early rollout of the hydrogen economy in Europe and Germany.

2. A core network with almost 10,000 kilometers of pipeline is to become the backbone of the German hydrogen supply until 2032. 60% of the network will consist of repurposed natural gas pipelines.

3. Large underground hydrogen storage facilities in salt caverns will form part of the core network and ensure a stable supply. Initial projects have been launched to gather operating experience.

4. Barriers to a rapid development of a H_2 infrastructure lie primarily in setting a legal framework that offers investment security and less in technical challenges.

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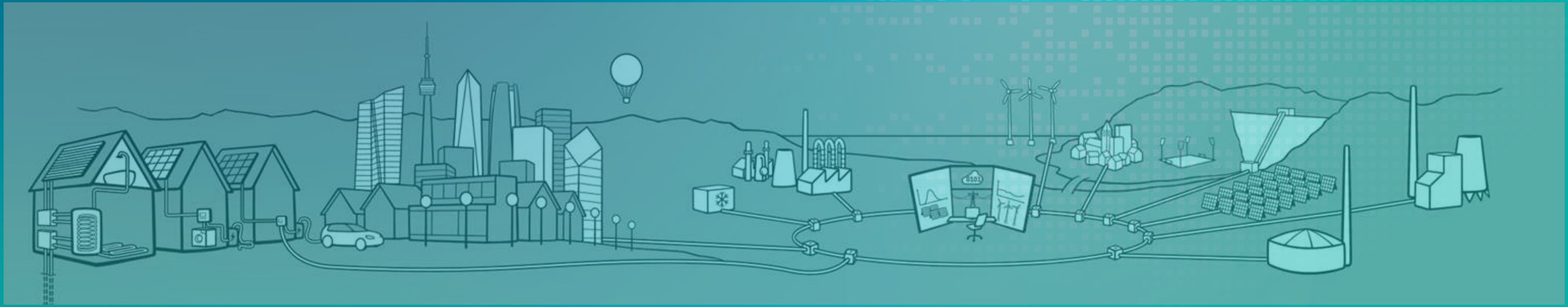
Thanks a lot for your kind attention!



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European Hydrogen Backbone

A European hydrogen infrastructure vision covering 28 countries

EUROPEAN HYDROGEN BACKBONE

Backup slide

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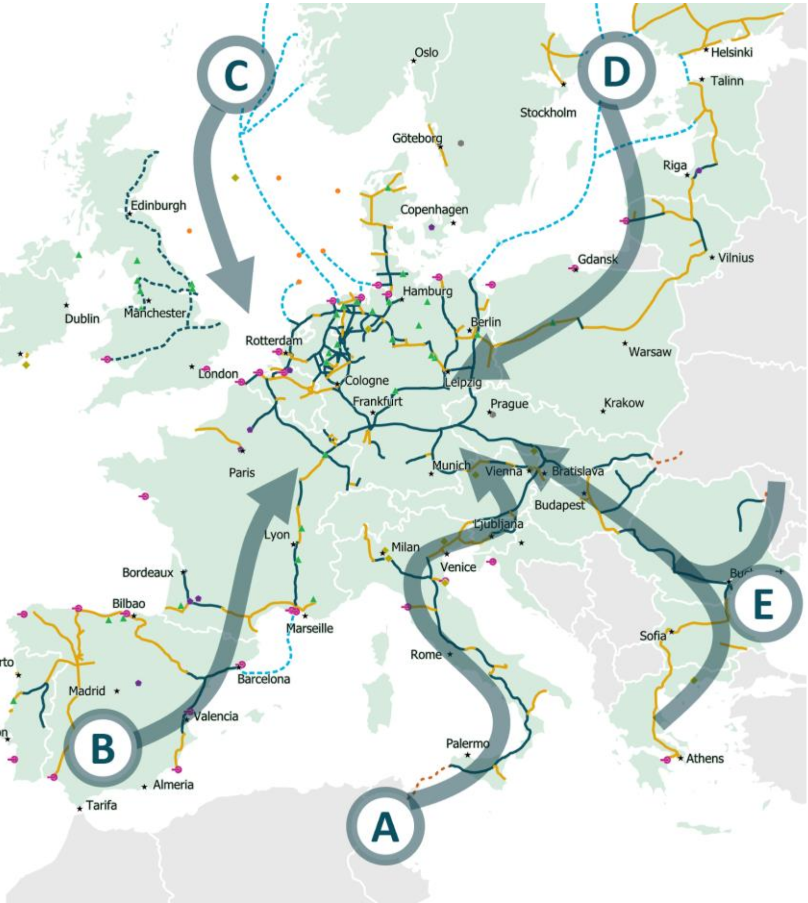

European Hydrogen Backbone in 2030 and in 2040

https://ehb.eu/files/downloads/1712733755_EHB-Implementation-Roadmap-Public-support-as-catalyst-for-hydrogen-infrastructure.pdf
https://ehb.eu/files/downloads/EHB-2023-20-Nov-FINAL-design.pdf