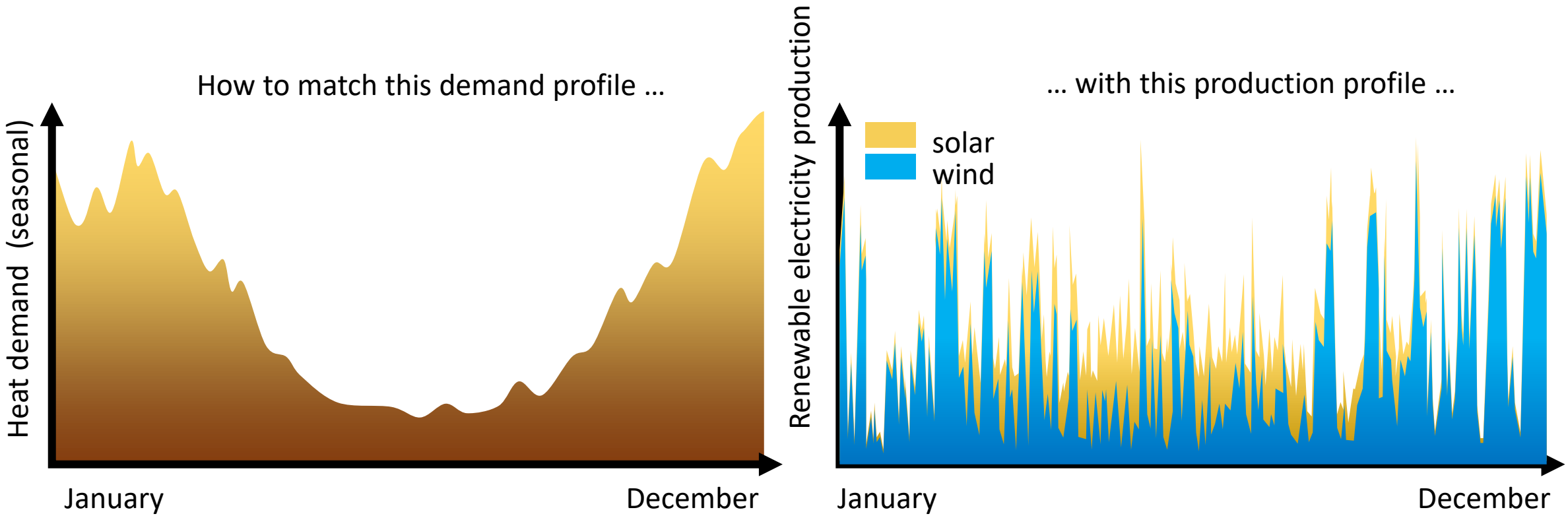
BULK STORAGE OF HYDROGEN EU PERSPECTIVE

SERGE VAN GESSEL, TNO

Bulk Storage of Gaseous Hydrogen 10 February 2022

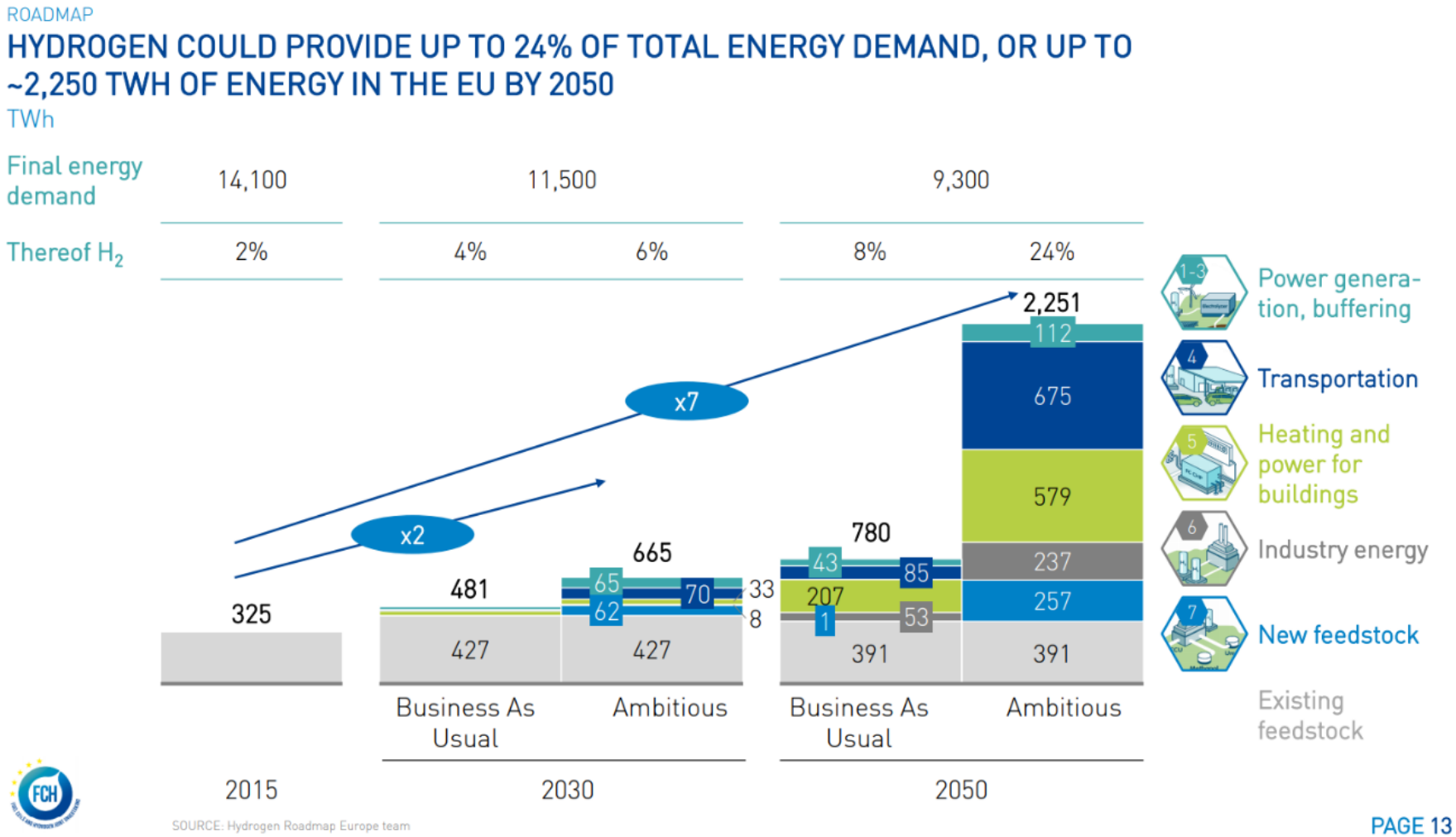
CHALLENGE OF THE FUTURE ENERGY SYSTEM …



… without fossil fuels?

HYDROGEN ROADMAP 2030-2050

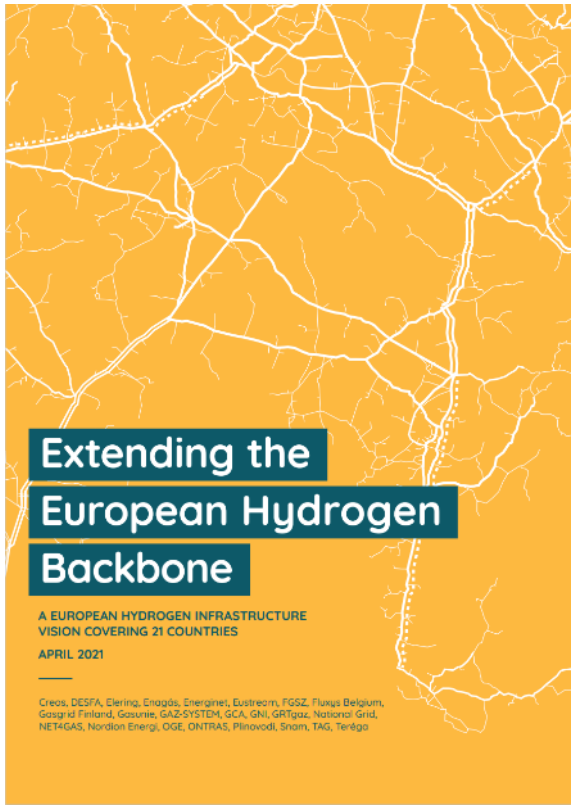
Without hydrogen at large scale, the EU would miss its decarbonization objective.



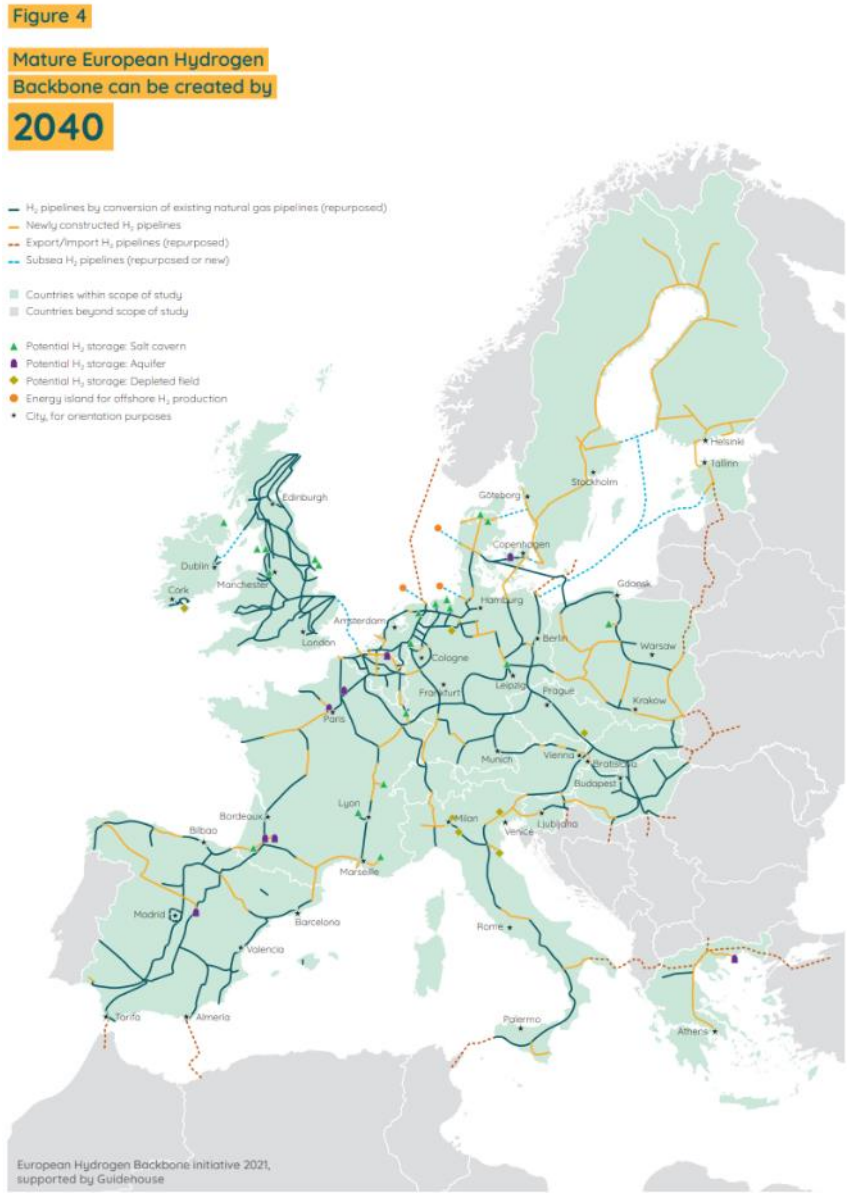
https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

2251 TWh ~ 24% of total EU energy demand

INFRASTRUCTURE: EUROPEAN HYDROGEN BACKBONE



https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf



Connecting industrial clusters to an emerging infrastructure in 2030

Growing network by 2035 covers more countries and enables imports

Mature infrastructure stretching towards all directions by 2040

Ca. 39.700 km in 2040
Including large-scale storage

HYDROGEN STORAGE DEMAND IN EUROPE (ESTIMATES)

Natural Gas Storage

Typical drivers for storage

- Heating (seasonal demand)
- Back-up power generation (peak demand)
- Arbitrage,
- Strategic (e.g. import dependency)

Global:

- 2019 gas demand: ~3.986 bcm[1]
- 2019 gas storage market size: ~483 bcm[2]
- Ca. 10% of demand in storage

Europe:

- 2020 gas demand: ~5411 TWh[3]
- 2021 gas storage capacity: ~1572 TWh[4] (~105 bcm)
- 2019 storage levels: ~90%[5]
- Ca. 20-30% of demand in storage

Large-scale underground storage of hydrogen widely acknowledged as an essential technology for security of supply and system resilience

Hydrogen Roadmap 2030/2050

Key drivers for storage

- Variable production renewable vs demand (peak)
- Heating (seasonal demand)?
- Arbitrage, Import dependency?

EU 2030[6]:

- Hydrogen demand 481 – 665 TWh
- Assumption 10 - 20% storage: ca. 16 bcm – 44 bcm

EU 2050[6]:

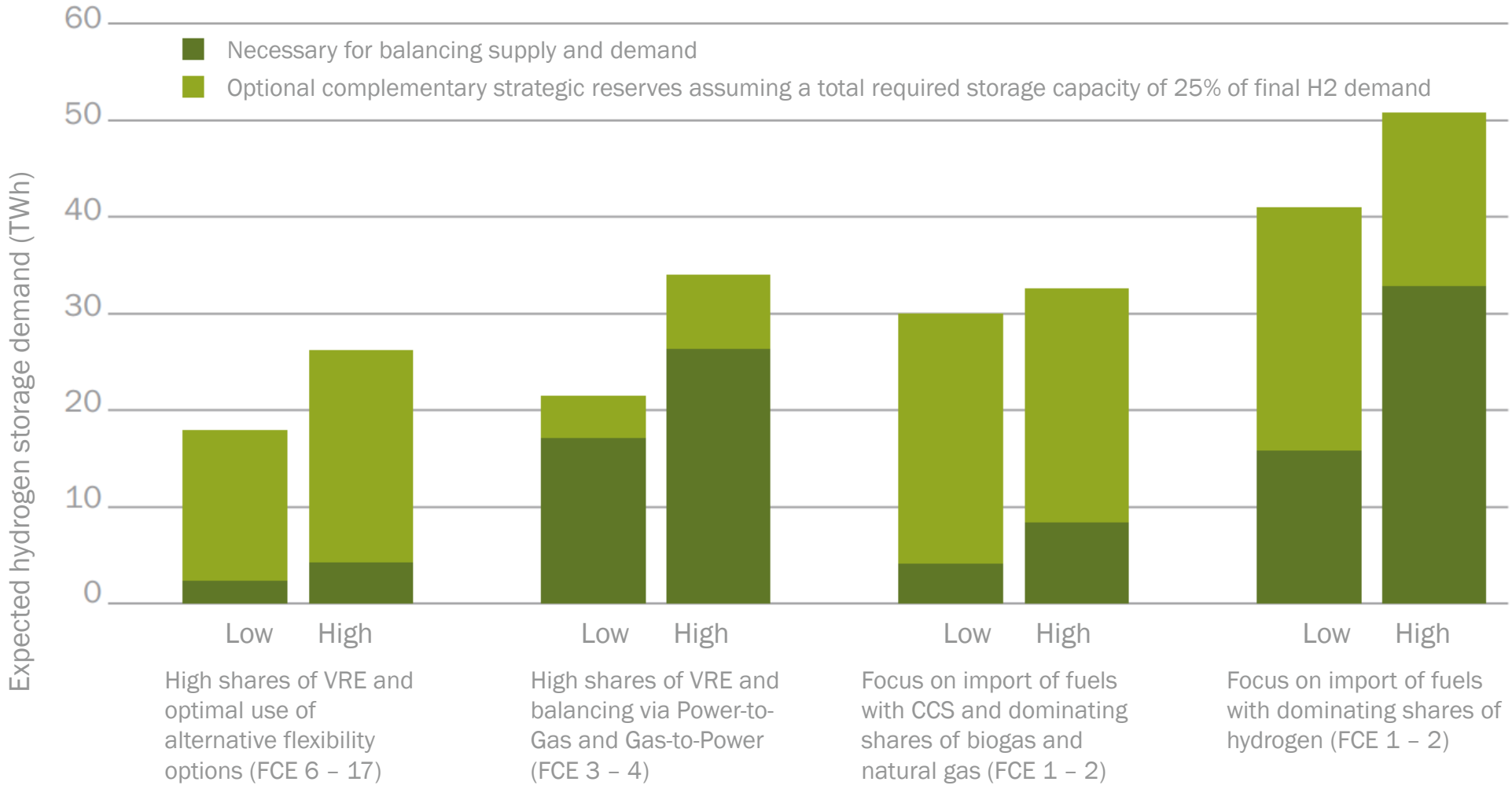
- Hydrogen demand 780 – 2.251 TWh
- Assumption 24% storage[7]: ca. 63 bcm – 180 bcm

(bcm = billion cubic metres)

1) IEA 2020: Natural Gas Information: Overview
2) Grand View Research 2020: Natural Gas Storage Market Size, Share & Trends Analysis Report
3) BP statistical review of global energy (via www.ourworldindata.org)
4) GIE gas storage database (April 2021)
5) EC – DG Energy 2019: Quarterly Report Energy on European Gas Markets
6) FCH-JU 2019: Hydrogen Roadmap Europe
7) GIE 2021, Picturing the value of underground gas storage to the European hydrogen system

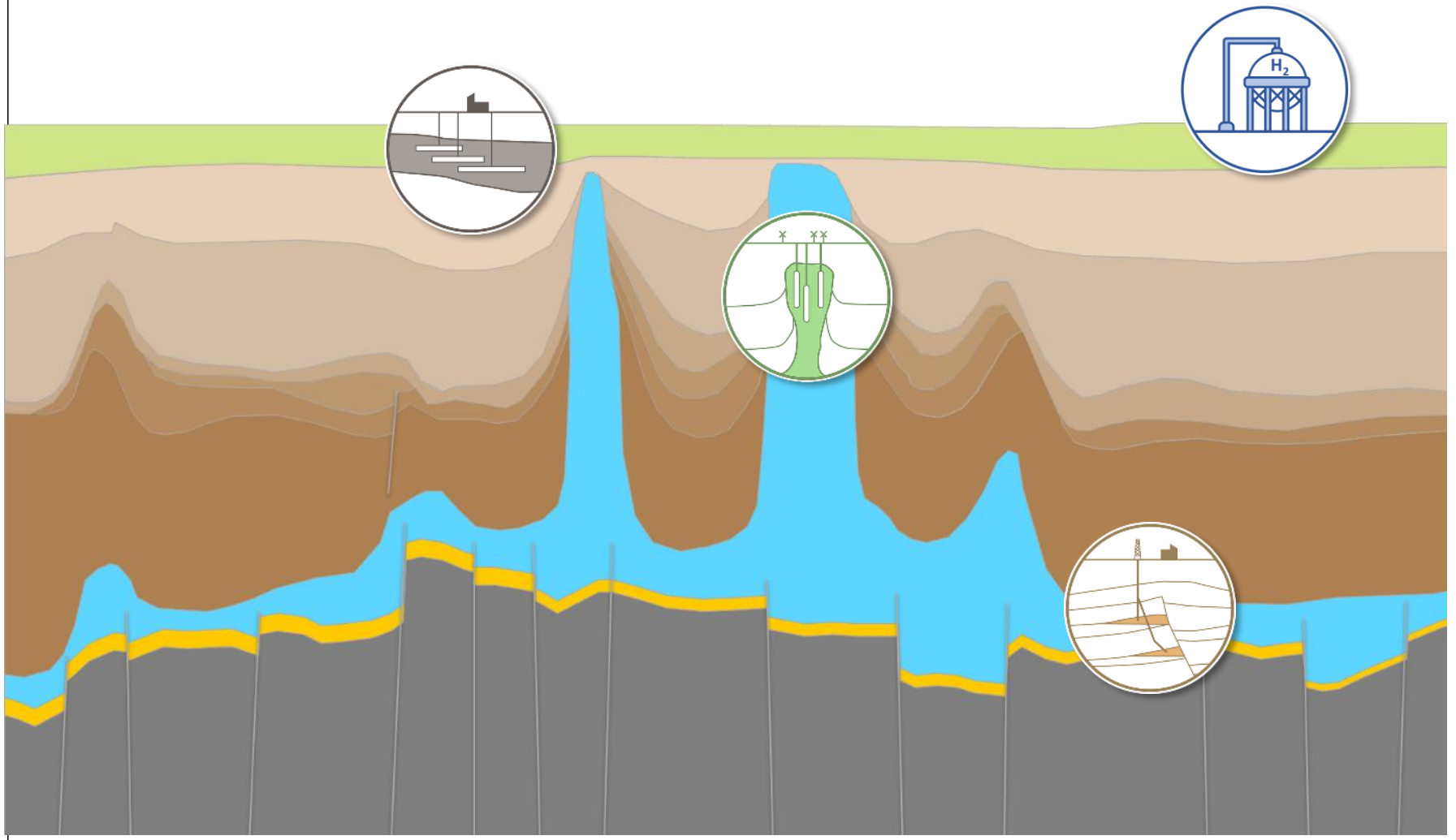
https://publications.tno.nl/publication/34638688/eEMR8K/TNO-2021-ondergrondse.pdf

HYDROGEN STORAGE DEMAND – NETHERLANDS 2050



Expected H2 storage demand: ca. 6 - 17 bcm
Present-day natural gas storage capacity ca. 12,5 bcm, (130 TWh)

UNDERGROUND HYDROGEN STORAGE OPTIONS



Surface tanks
Ca. 5 – 10 GWh

Lined rock caverns
Ca. 10 – 30 GWh

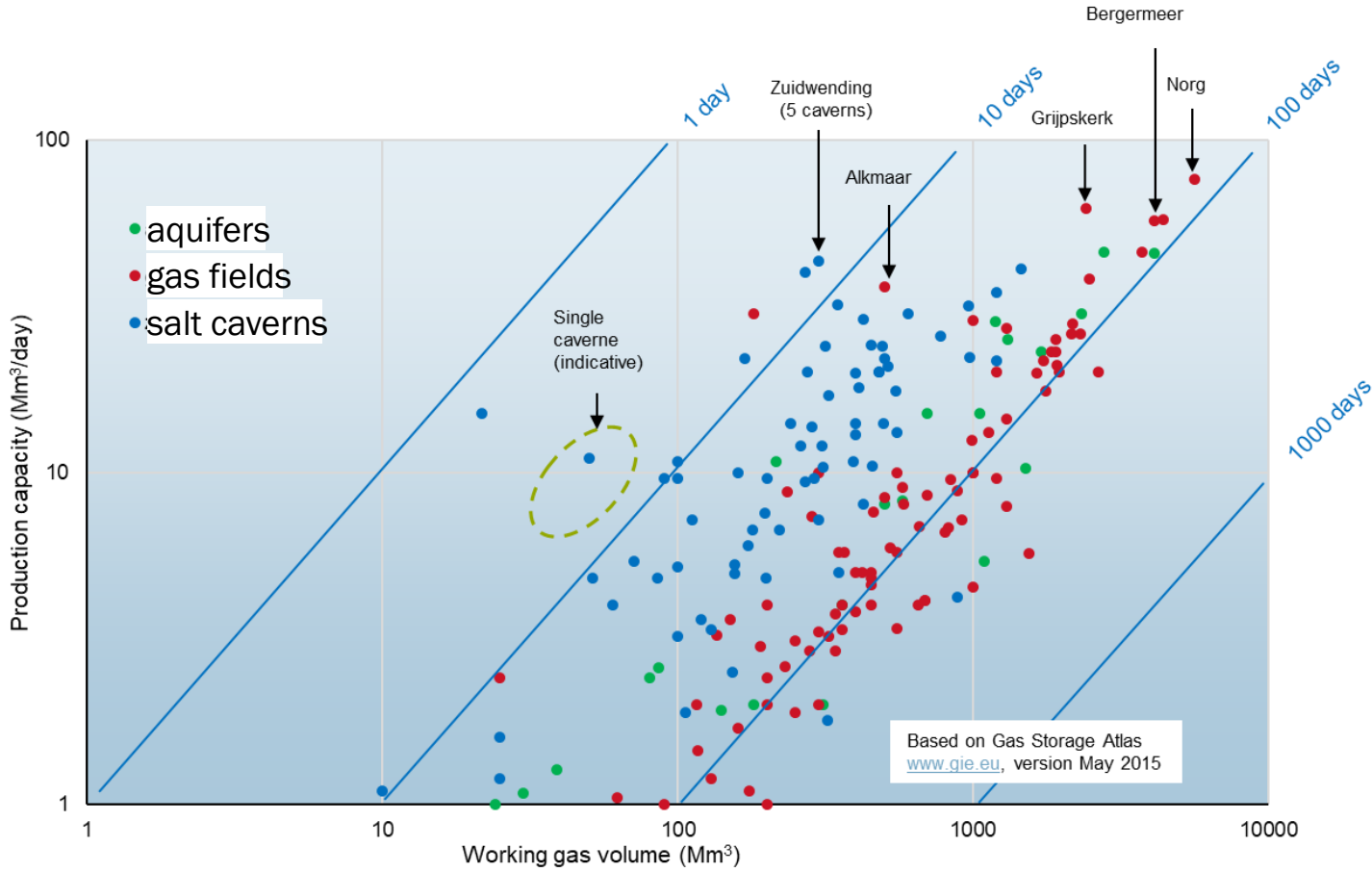
Salt caverns
Ca. 100 – 250 GWh

Gas fields & Aquifers
Ca. 100 – 20.000 GWh

REPURPOSING NATURAL GAS STORAGES EUROPE

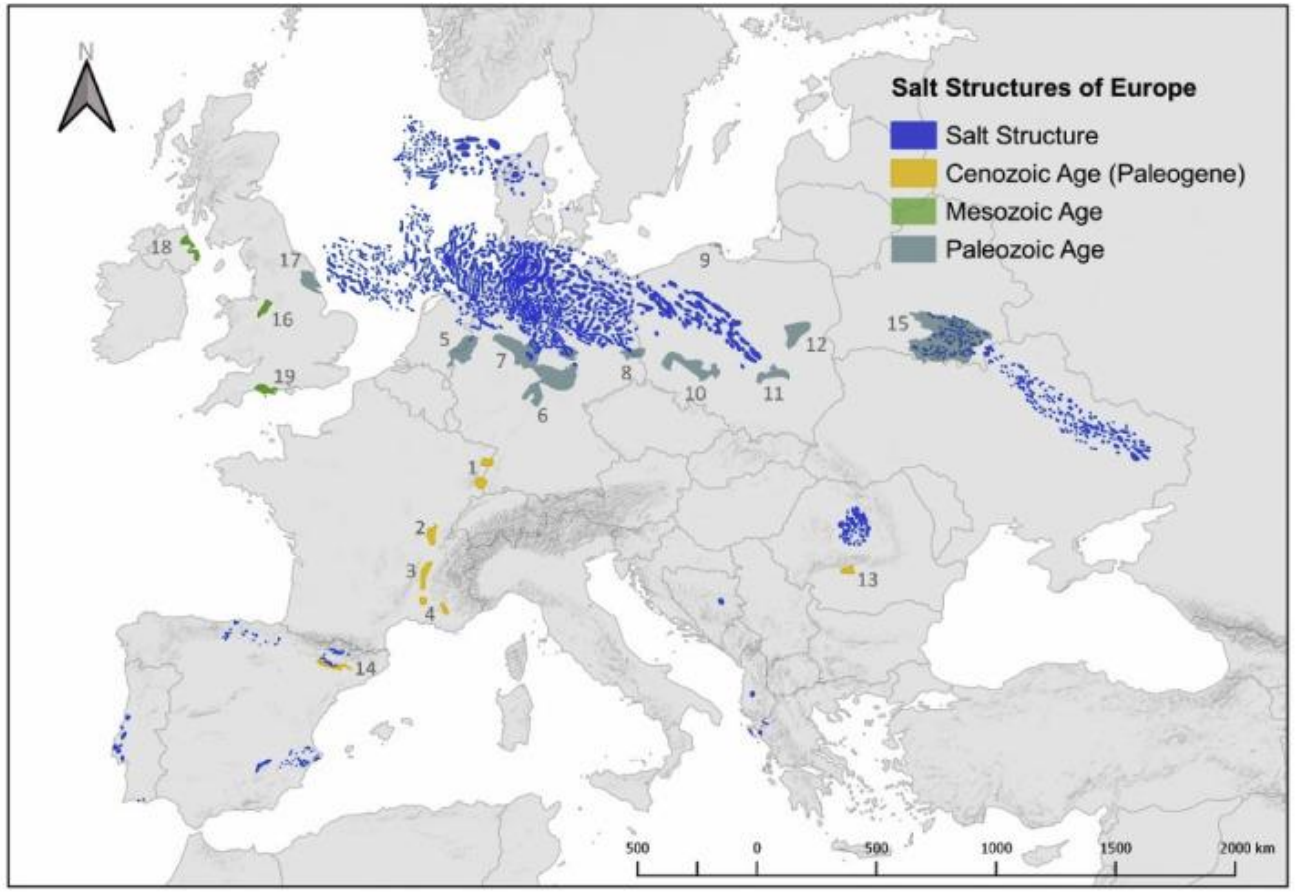
Europe natural gas storage capacity (GIE - 2021):
177 facilities, 1572 TWh

Map from ESTMAP (after GIE database 2015 – www.gie.eu): shows UGS locations in depleted gas fields, aquifers and salt caverns



Theoretically existing UGS sites in Europe could provide a technical working volume in the order of. 100 bcm when repurposed
There is a huge additional technical potential in other depleted gas fields, aquifers and rock salt formations which are not yet deployed for gas storage

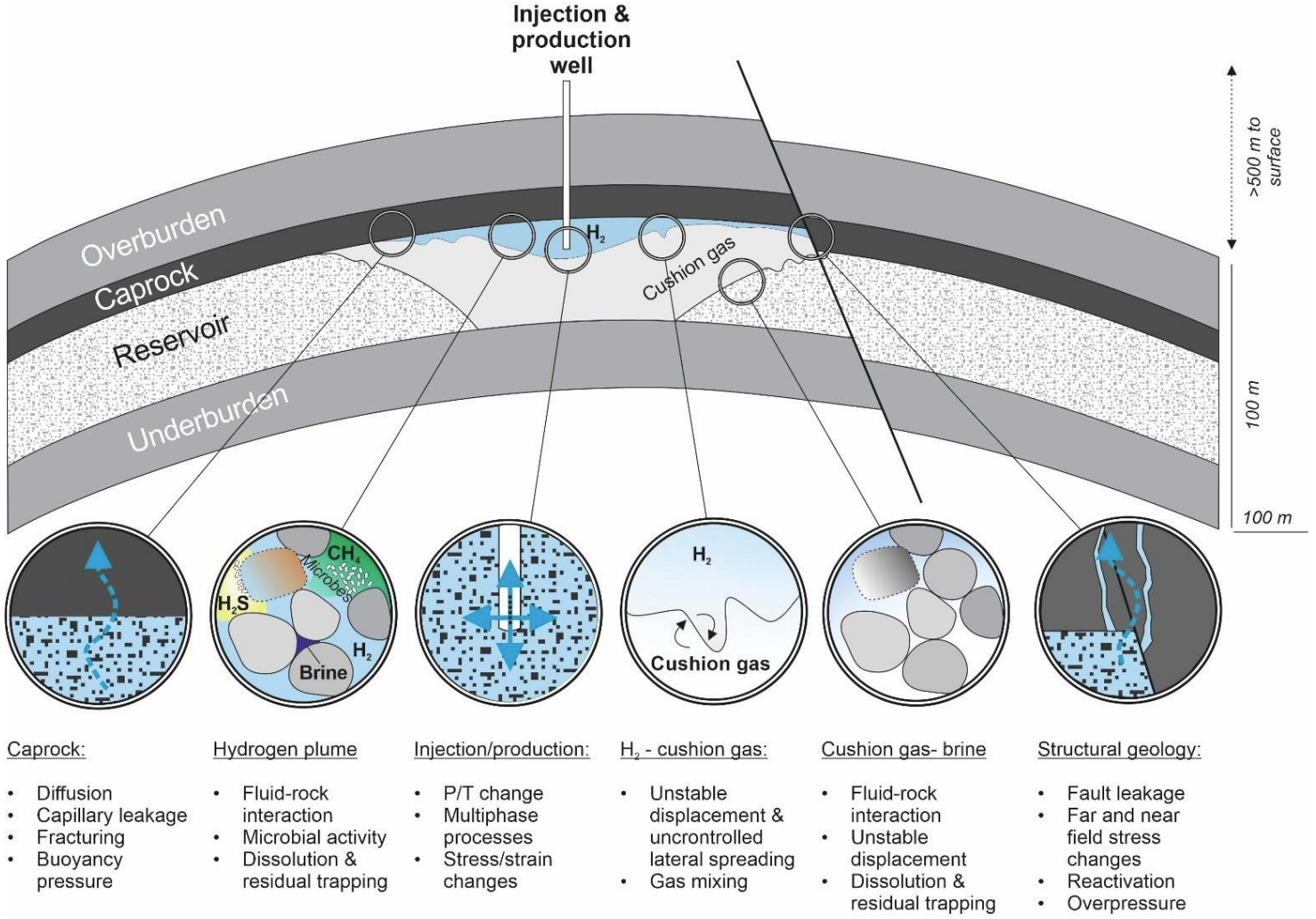
UNDERGROUND HYDROGEN STORAGE: SALT CAVERNS



D.C. Caglayan, et. Al. 2020, Technical potential of salt caverns for hydrogen storage in Europe, International Journal of Hydrogen Energy, Volume 45, Issue 11. https://doi.org/10.1016/j.ijhydene.2019.12.161.

- Overall technical readiness level: proven, pilot/demonstration
- Large technical concentrated in specific areas
- Operational challenges: System integration (fast-cyclic operation, hydrogen purity)
- Practical issues for large-scale cavern development (e.g. brine disposal, subsidence, lead time)
- Several pilots next to existing UK / US
  - https://www.hystock.nl/ (Netherlands)
  - https://h2cast.com/ (Germany)
  - https://hypster-project.eu/ Etrez-France)
  - https://greenhydrogenhub.dk/ (Denmark)

UNDERGROUND HYDROGEN STORAGE: POROUS RESERVOIRS



Technical
- Microbial and geochemical conversions
- Geomechanical effects (faults, seismicity)
- Sealing and integrity (reservoir/well)
- Flow, Performance, Mixing, Recovery
- Subsidence (salt caverns)
- Monitoring

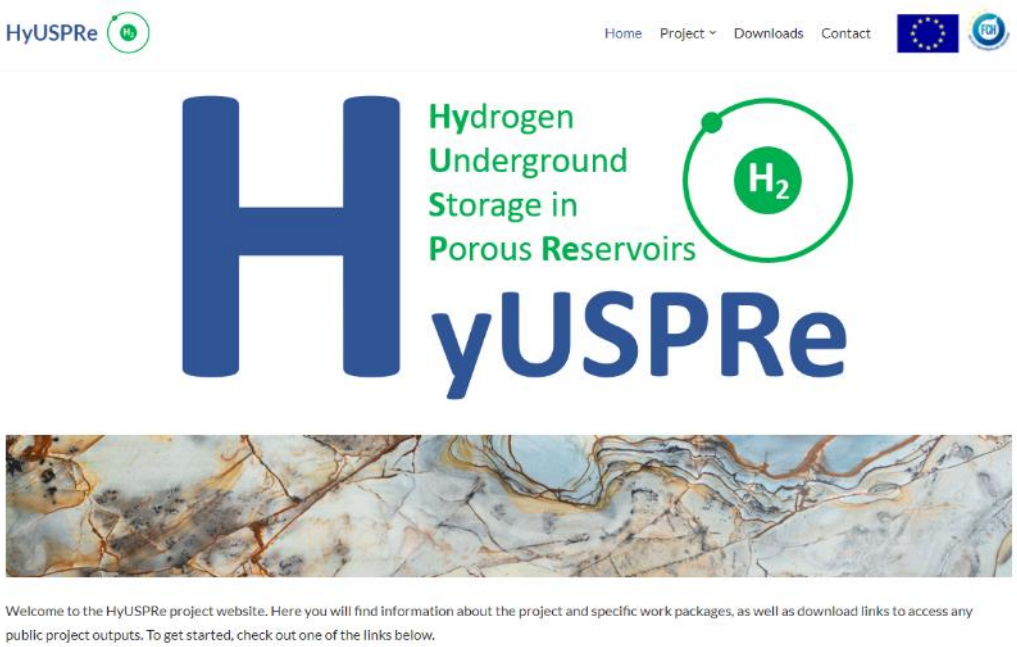
Economical
- Business models, market
- Cushion gas, operations
- System integration
- International developments

Political / societal
- Safety
- Spatial planning
- Licensing, supervision
- Alternatives
- Synergies, competition
- Societal acceptance

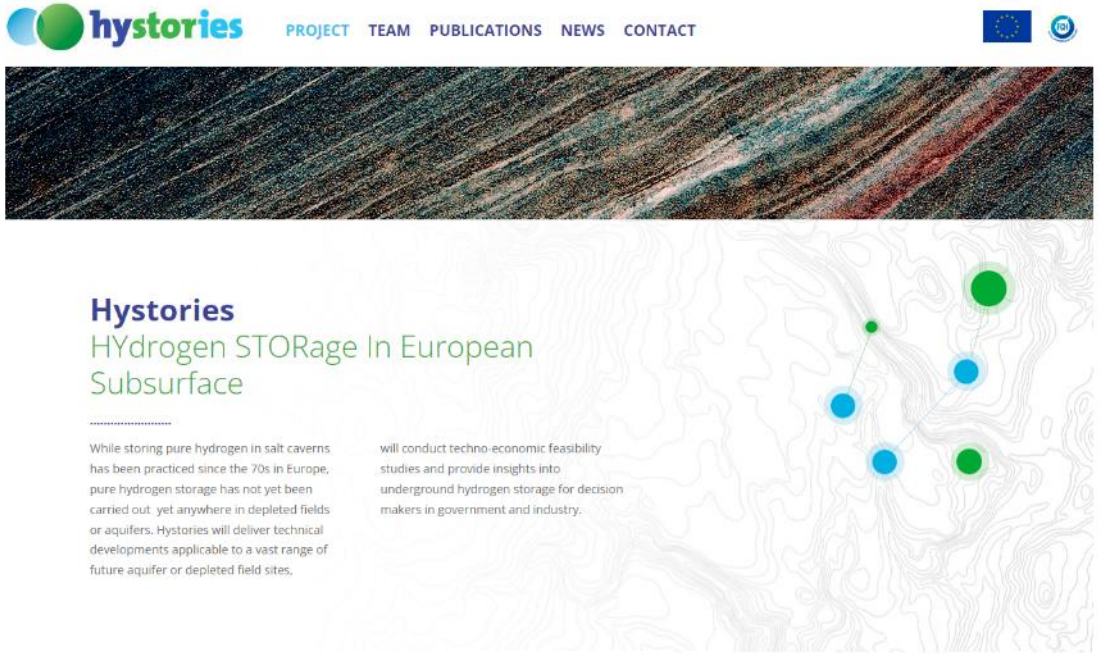
Pilots / Evaluations in Europe:
- www.underground-sun-storage.at (Austria)
- www.underground-sun-conversion.at (Austria)
- Potential repurposing of Rough UGS (UK)
- http://www.hychico.com.ar/eng/index.html (AR)

Heinemann, N., Alcalde, J., Miocic, J.M., Hangx, S.J.T., Kallmeyer, J., Ostertag-Henning, C., Hassanpouryouzband, A., Thaysen, E.M., Strobel, G.J., Schmidt-Hattenberger, C., Edlmann, K., Wilkinson, M., Bentham, M., Haszeldine, R.S., Carbonell, R., Rudloff, A., 2021: Enabling large-scale hydrogen storage in porous media – the scientific challenges. : Energy and Environmental Science., 2021, 14, 853

HORIZON EUROPE PROJECTS:



https://www.hyuspre.eu/



https://hystories.eu/

IEA – HYDROGEN TECHNOLOGY COLLABORATION PROGRAM

Hydrogen TCP - Task Underground H_2 Storage

H2 Conversion & Contamination

Impacts of reservoir and fluid processes on quality and recover-ability of stored H_2

Surface Facilities & Wells

Concepts, designs and materials for safe and effective storage of H_2

Storage Integrity

Integrity and stability of subsurface reservoirs and seals under H_2 storage operations

Economics & System Integration

General concepts for techno-economic integration and upscaling of H_2 storage in the future energy system

Storage Performance

Estimation, ranking and optimization of H_2 injection, production and storage capacities

Planning, Regulation, Safety & Society

Tools, guidelines and best practices for safe and responsible subsurface H_2 storage development and societal embedding

Hydrogen TCP

Technology Collaboration Programme
by IEA

https://www.ieahydrogen.org/task/task-42-underground-hydrogen-storage/

Task duration: 2022 - 2024

TNO innovation for life

CONCLUDING REMARKS

- Without hydrogen at large scale, the EU would miss its decarbonization objective. Hydrogen applications foreseen across all sectors. Ambitious scenario's expect H2 share in the order of 20 – 25% of total final energy demand

- Europe is in a good position to achieve a pan-European Hydrogen Backbone in a cost-effective manner (vision includes both new and repurposed pipelines). Connection with potential UHS sites

- Demand for UHS expected to be in the order of 25% of total H2 demand (similar to natural gas and oil)

- Different pathways envisioned with blended hydrogen (natural gas grid) and pure hydrogen storage. Seasonal heat demand and high shares of VRE are key drivers. Need for strategic reserves to be evaluated.

- Salt formations, gas fields and aquifers represent very large potential, yet many steps needed towards demonstration and upscaling. Consider long lead times (large-scale demand for UHS expected to emerge after 2030). Many projects started or emerging (private, national, EU)
    - Long-term durability and integrity of rocks and (well) materials (steel alloys, cement, elastomers, etc.)
    - Interactions of hydrogen with rocks, fluids and microbes in reservoirs and their effects on reservoir performance, quality and retrievability
    - Economics & system integration pathways
    - Societal embedding

- Existing UGS sites (depleted gas fields and salt caverns) may be fit for repurposing. Several pilots underway. It is likely that development in new locations (gas fields, aquifers, salt formations) is needed

THANK YOU FOR YOUR ATTENTION

SERGE VAN GESSEL, TNO

Bulk Storage of Gaseous Hydrogen 10 February 2022