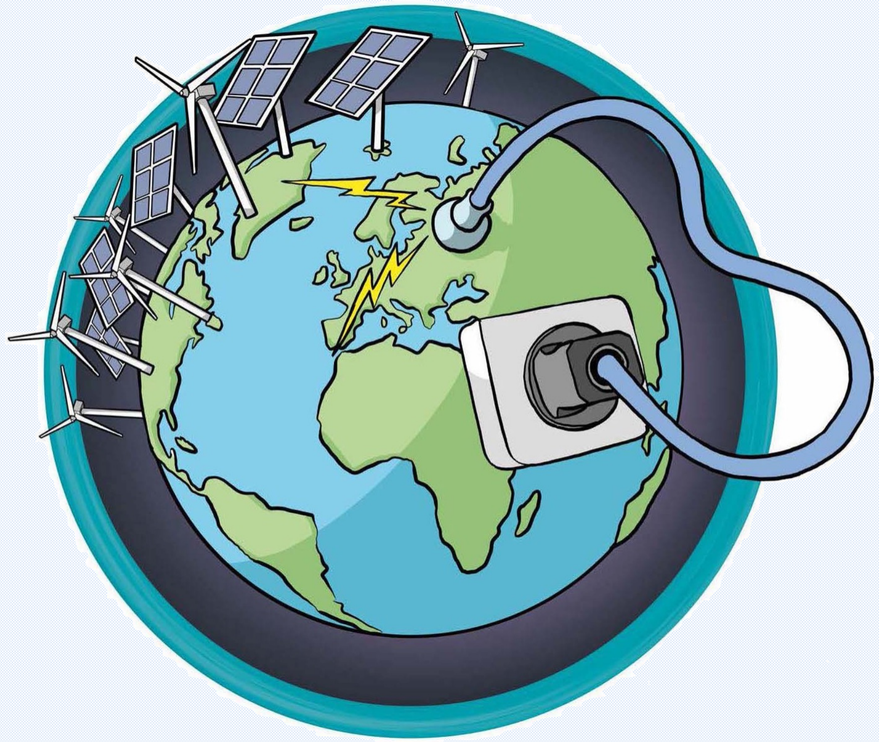

Underground Hydrogen Storage

Hadi Hajibeygi

27 Sep 2022, KAUST

How much energy do we consume?

Netherlands

~800 TWh

151 Mt of CO_2

USA

~30,000 TWh

4,921 Mt of CO_2

China

~37,000 TWh

9,528 Mt of CO_2

Brazil

~3,300 TWh

406 Mt of CO_2

Scaling up energy storage (TWh) technologies is as crucial as scaling up the production!

Ref. IEA.ORG/Countries

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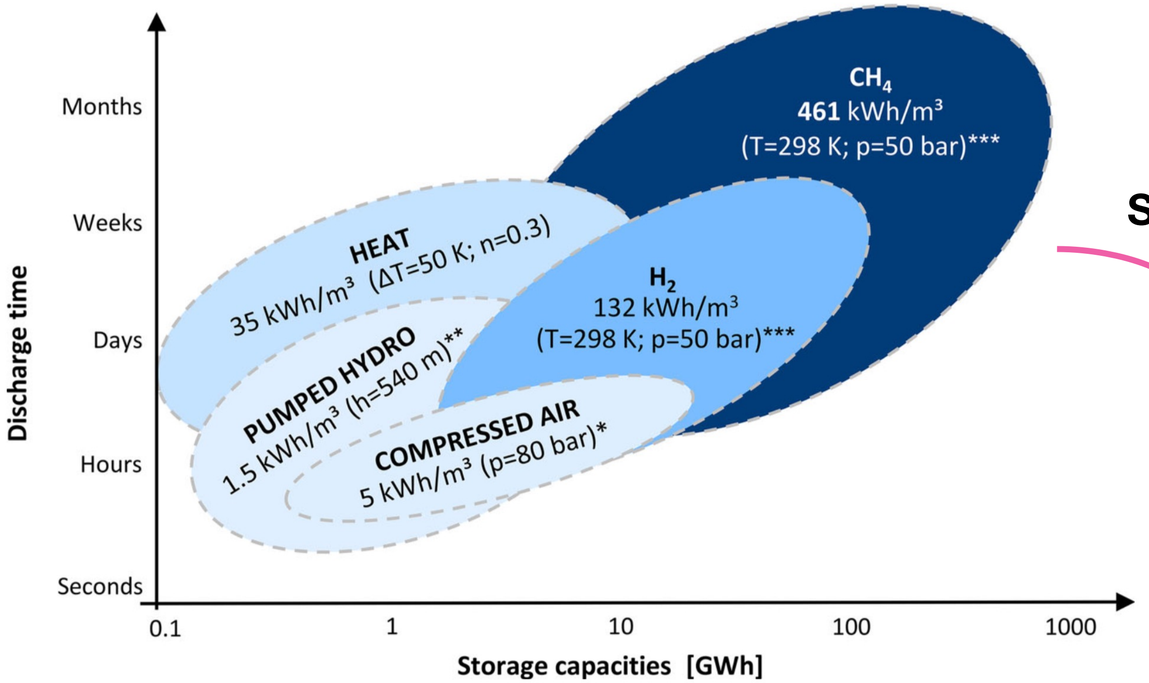
Scaling up energy storage (TWh) technologies is as crucial as scaling up the production!

✗ Electrification is not enough!
(transport & storage limited)

Ref. IEA.ORG/Countries

Large-Scale Energy Storage (TWh) is possible in the form of green gas!



ANGUS+ project, DOI 10.1007/s12665-016-6319-5

Store

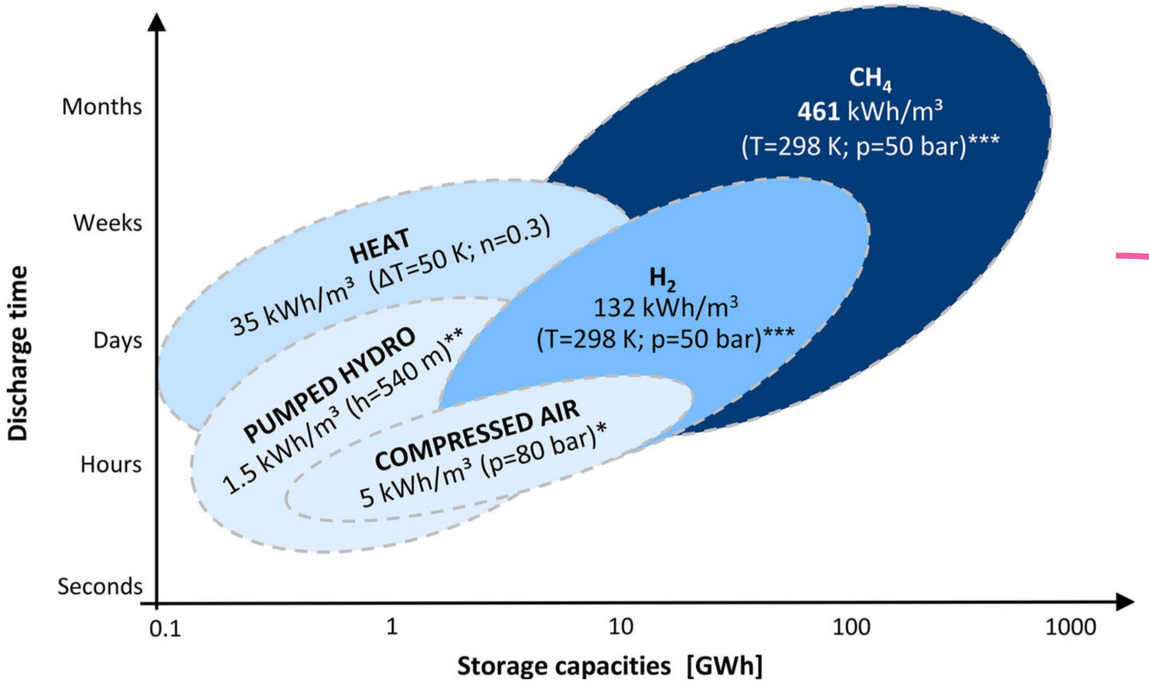
Japan's Largest Liquid Hydrogen Storage Tank

volume, security, land, cost

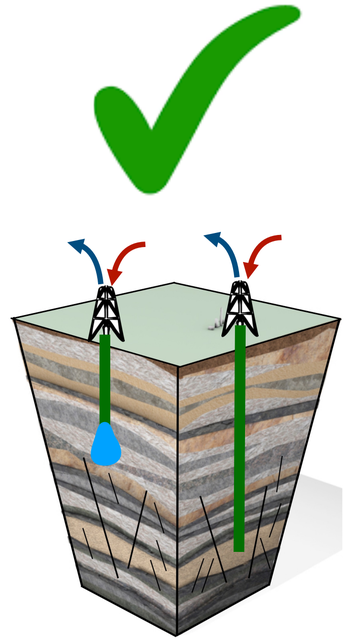
Liquid H2 at -253°C to power rockets to the space, built in 1987, operational since then!

https://global.kawasaki.com/en/stories/articles/vol39/

Large-Scale Energy Storage (TWh) is possible in the form of green gas!



Store

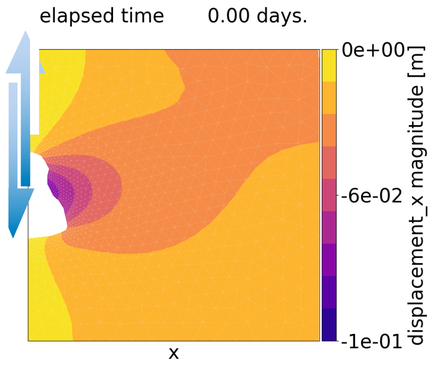


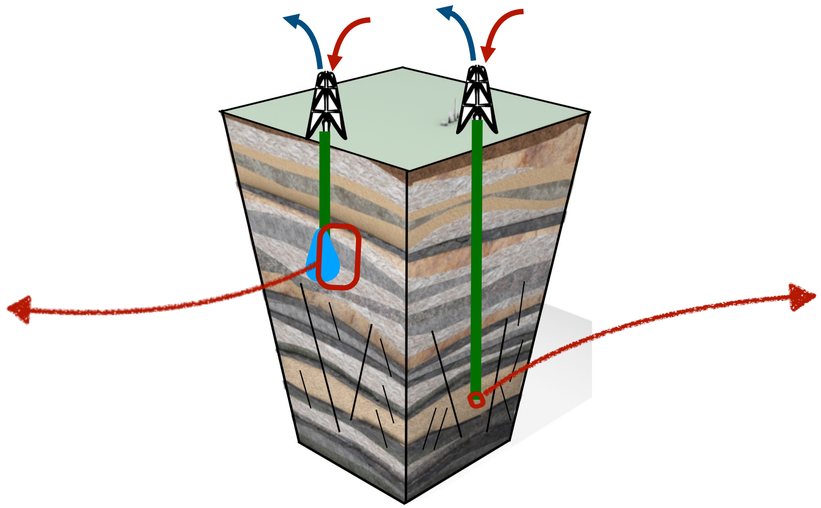
ANGUS+ project, DOI 10.1007/s12665-016-6319-5

4 Caverns operational (since 1971; 1 UK; 3 Texas/US), Few Porous Rocks
not much cyclic; not much public data!

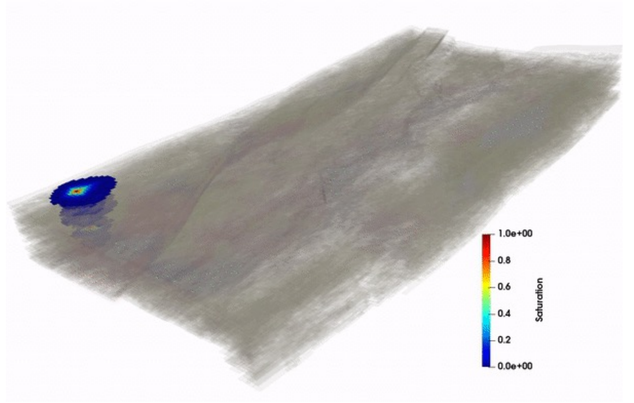
Ref. Hashemi, Blunt, Hajibeygi, Sci. Rep. https://doi.org/10.1038/s41598-021-87490-7

Salt Caverns





Porous Rocks



Objectives:

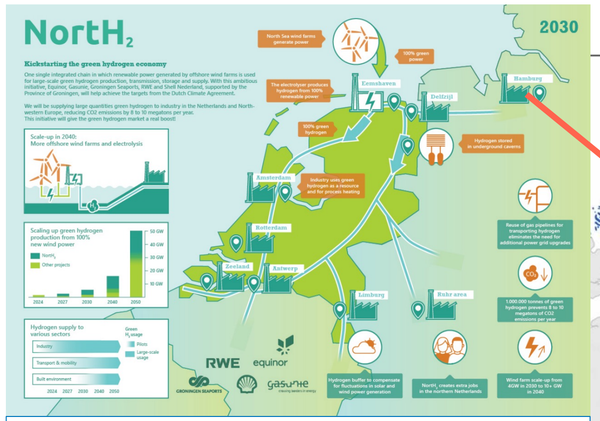
Cyclic

Store fully inside the reservoirs
Maintain purity
Below critical stress

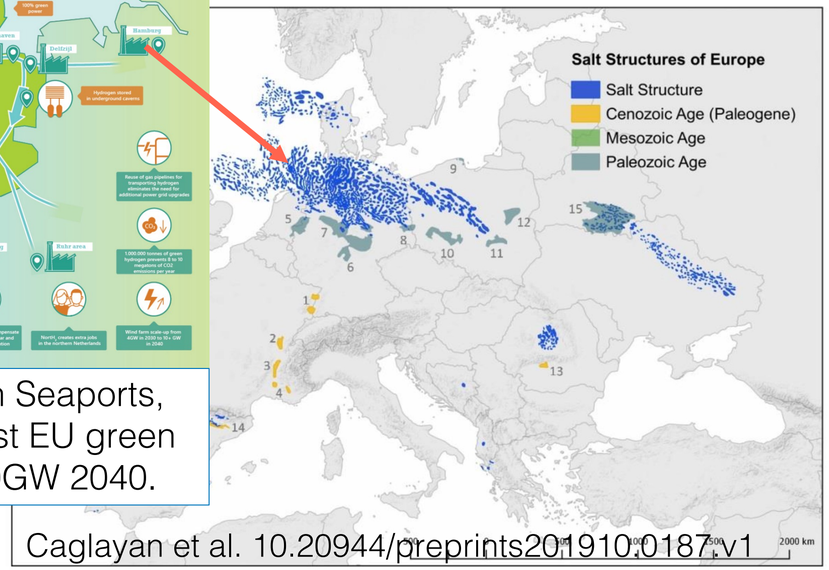
Similarities & dissimilarities with alternative storage systems: CCS & Gas Storage

Do we have suitable formations available?

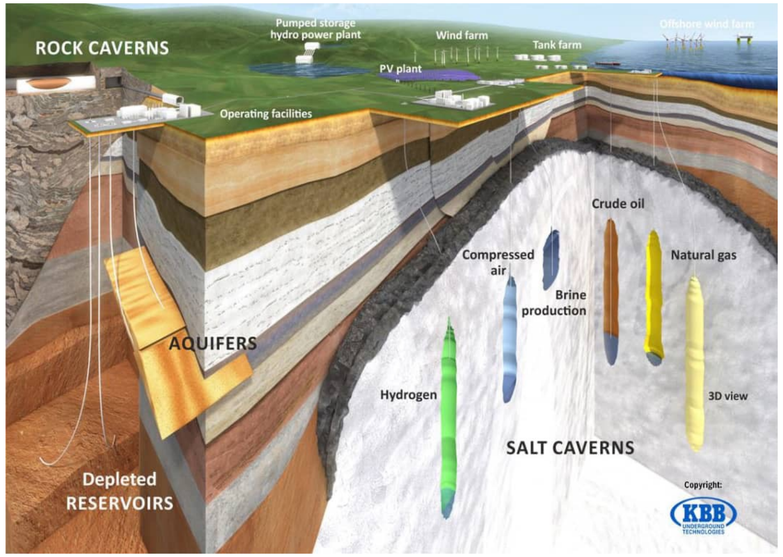
Salt Caverns



(Gasunie, Groningen Seaports, Shell, Equinoir), largest EU green H2 ~3GW 2030 & 10GW 2040.



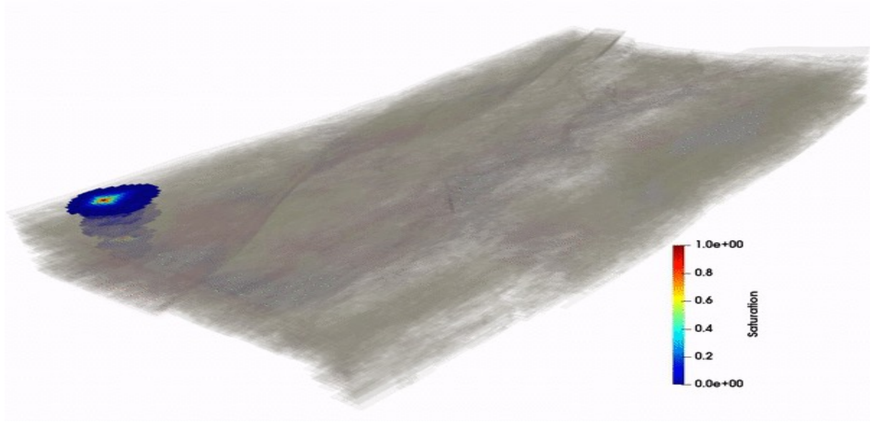
Caglayan et al. 10.20944/preprints201910.0187.v1

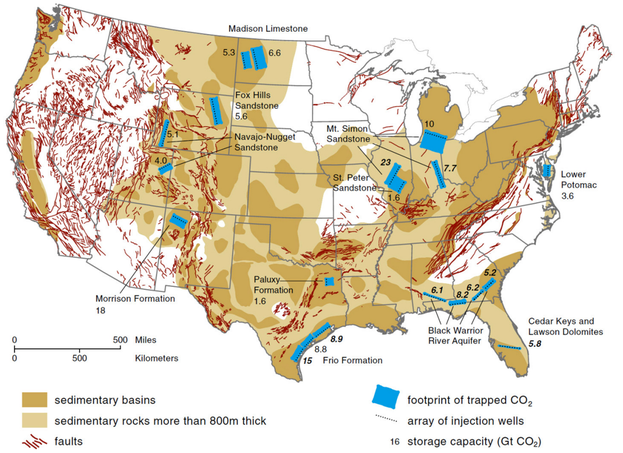


- Proven seals for H2 (4 operational, a few more pilots under development)
- Ongoing research:
    - Geomechanics (heterogeneous, cycling, system of caverns)
    - Microbiology (purity)
    - Monitoring

Do we have suitable formations available?

Salt Caverns | Depleted Reservoirs | Aquifers





Szulczewski et al., PNAS 2012, 10.1073/pnas.1115347109

- A few field trials (e.g., Austria by RAG)
- Compared with caverns: much bigger
- Less known, much research ongoing incl.:
  - Mechanics (cyclic loading, seismicity, …)
  - Hydro-thermodynamics (H2-reservoir/cushion gas)
  - Microbiology & Geo-chemistry (**purity**)
  - Monitoring

IEA – Task 42 - UHS

Hydrogen TCP

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

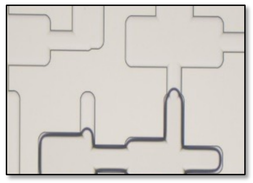
Estimation, ranking and optimization of H_2 injection, production and storage capacities

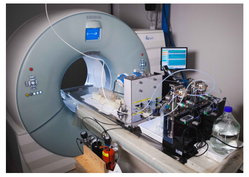
Planning, Regulation, Safety & Society

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

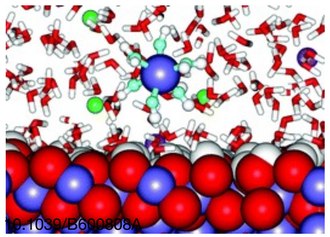
Project ADMIRE: porous rocks & salt caverns

Lab

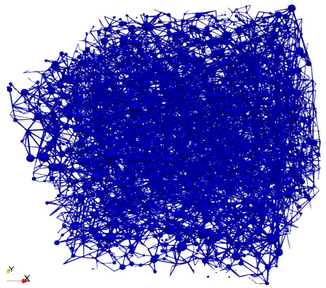




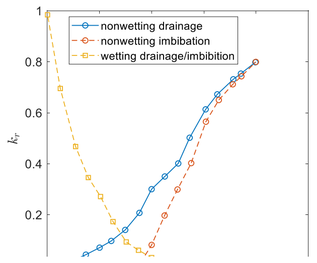
Molecular Dynamics



Pore-scale Sim

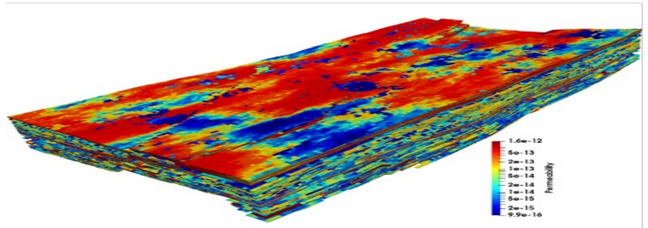


Upscaled Functions

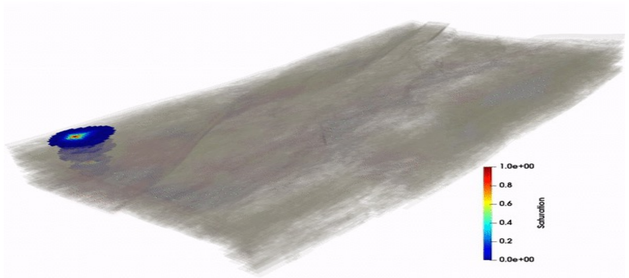


Kr, PC, Xij, D

Geo-Model (geology/geophysics)



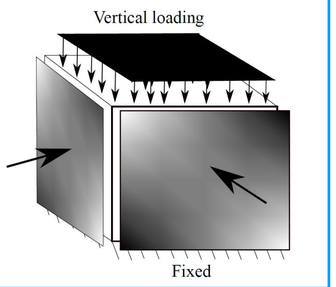
Multiscale Reservoir Simulation



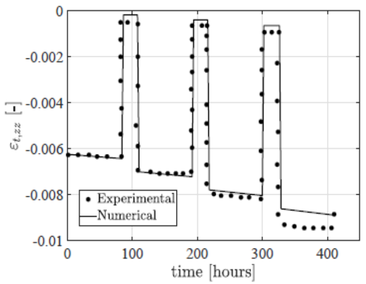
For the many refs, please visit my scholar page, with hydrogen keyword: https://scholar.google.nl/citations?user=T9q3vYQAAAAJ&hl=en

Project ADMIRE: porous rocks & salt caverns

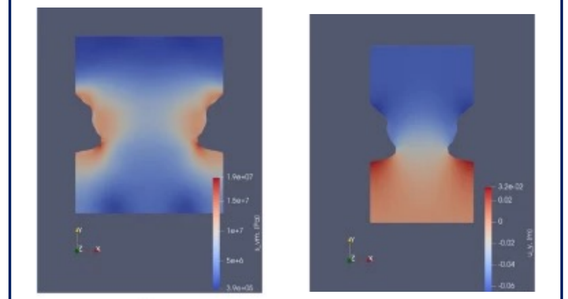
LAB



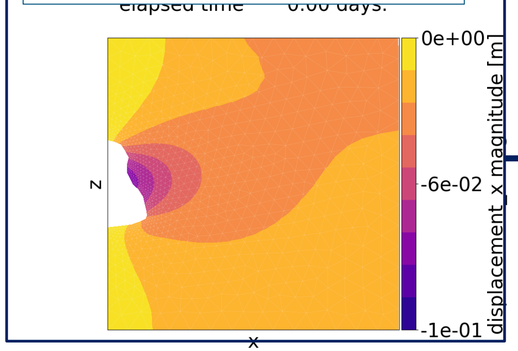
Validation



Heterogeneous Multi-Cavern System

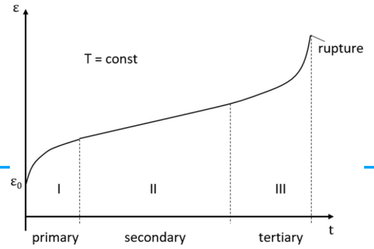


Heterogeneous Cavern



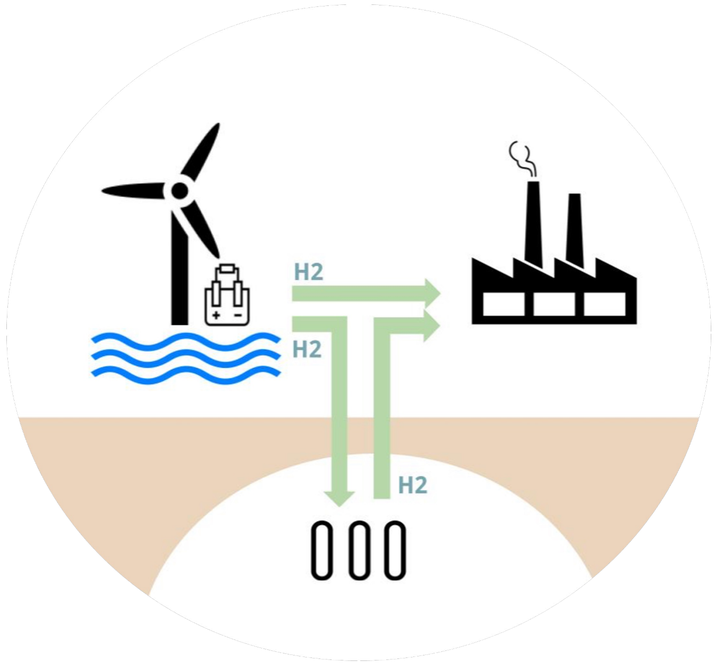
Constitutive Laws

$$\dot{\varepsilon}_{cr} = A \exp\left(\frac{-Q}{RT}\right)\sigma^n$$



For the many refs, please visit my scholar page, with hydrogen keyword: https://scholar.google.nl/citations?user=T9q3vYQAAAAJ&hl=en

Techno-Economics: H2 to run a steel factory



1 

What H2 production capacity & salt cavern storage capacity would be required for sufficient baseload H2 supply?

2 

Which locations in the North Sea would be suitable?

3 

What would be the costs of this storage system?

Deirdre Eradus, MSc thesis (together with Prof. Ad van Wijk & Prof. Zofia Lukszo):
Ref: http://resolver.tudelft.nl/uuid:8eb96cf8-2c91-4553-b0cb-a41458f61b5d

Thank you!

- H2 can be stored in giant underground reservoirs
- Some debatable (dis)similarities with CCS & UGS!
- Existing UHS: 4 active Salt Caverns & a few porous rocks!
- New sites under developments (Netherlands, France, …)
- Geoscience & Engineering developments are crucial for safety and efficiency (goal: few % of the total H2 cost)
- There is no big market for H2 today, all is for ’near’ future!