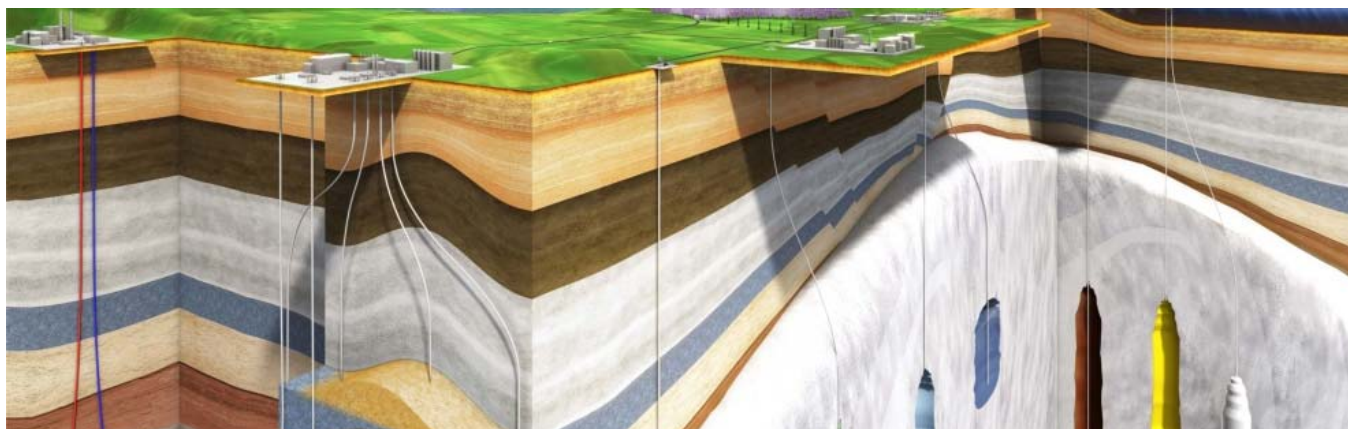




Conversion of gas storage caverns to hydrogen storage

RENE SCHNEIDER

HYDROGEN STORAGE IN CAVERNS 2022
London, 14 March 2022



DEEP.KBB

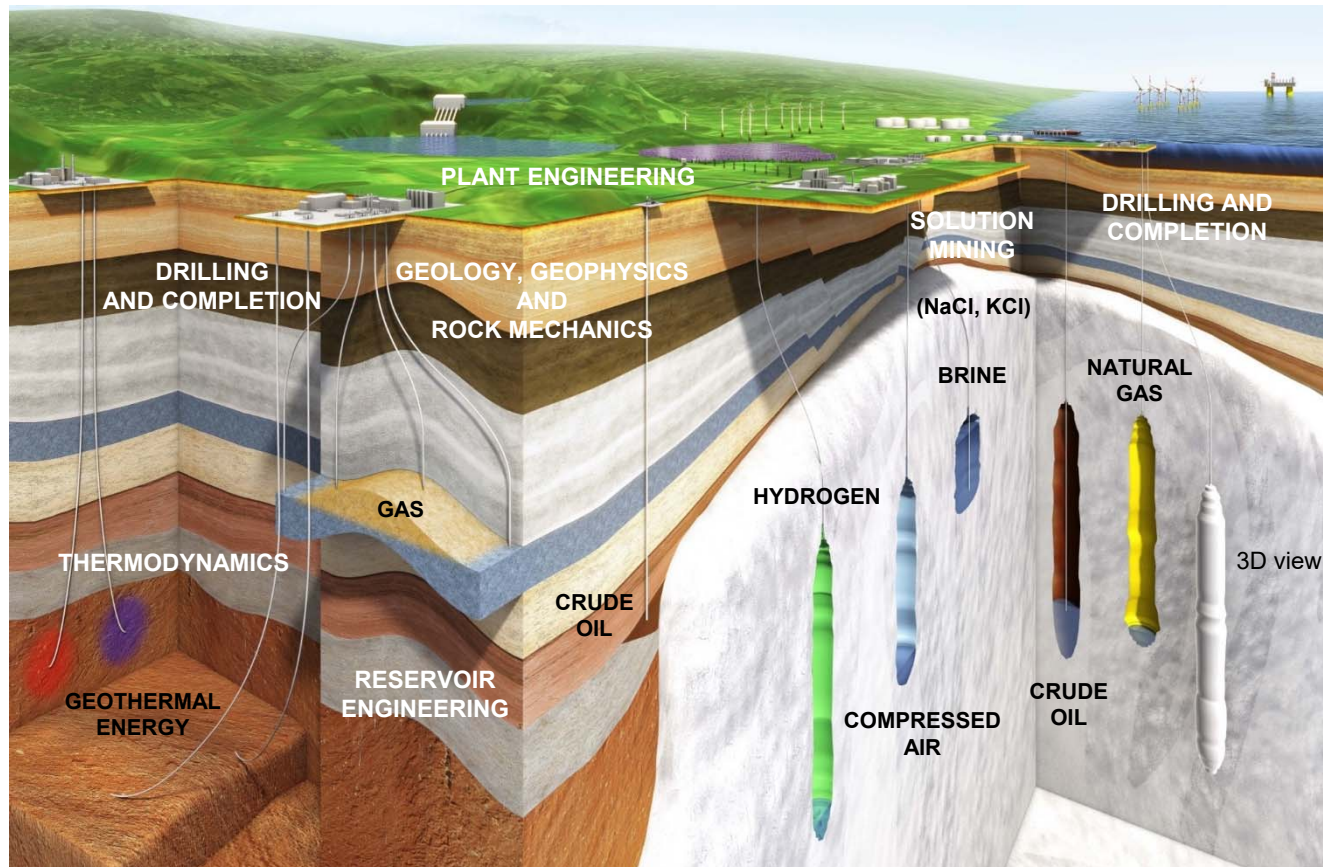
DEEP. KBB

Company Introduction

- DEEP.KBB GmbH is an engineering company specialised in subsurface technologies.
- Planning and construction of underground storage facilities for gas, crude oil and crude oil products worldwide.
- More than 50 years of experience in subsurface storage and brine production.
- Teams consisting of professional engineers, geologists and technicians, in total ~100 employees.
- Membership in relevant professional organizations.
- Certified acc. to DIN EN ISO 9001:2015 Quality, DIN EN ISO 14001:2015 Environment and SCC** (Version2011) Job Safety.



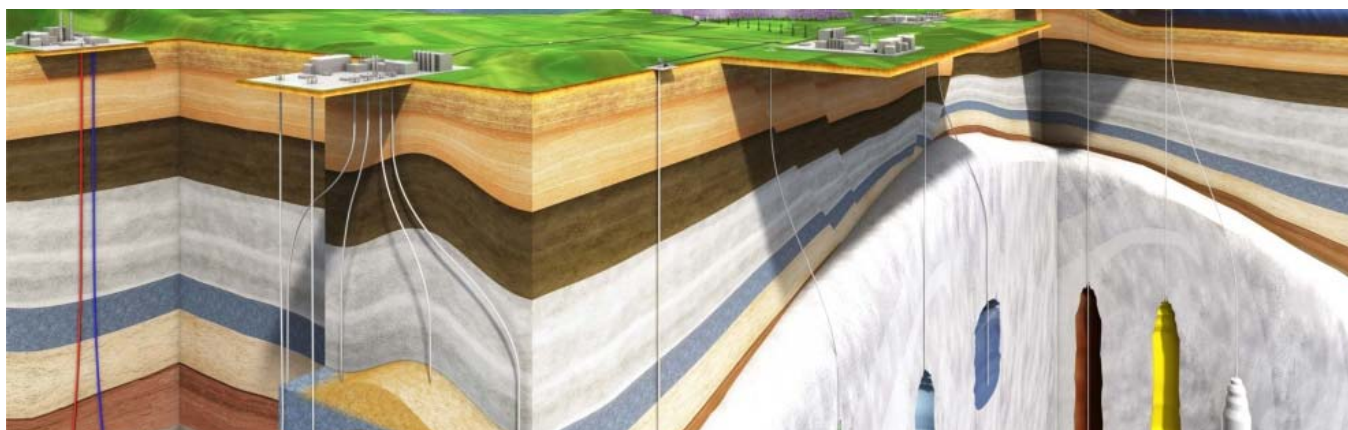
DEEP. KBB Portfolio



Content



1. Introduction
2. Natural gas storage in caverns
3. Hydrogen storage in caverns
4. Conversion of gas storage caverns to hydrogen storage
5. Hydrogen Projects
6. Summary

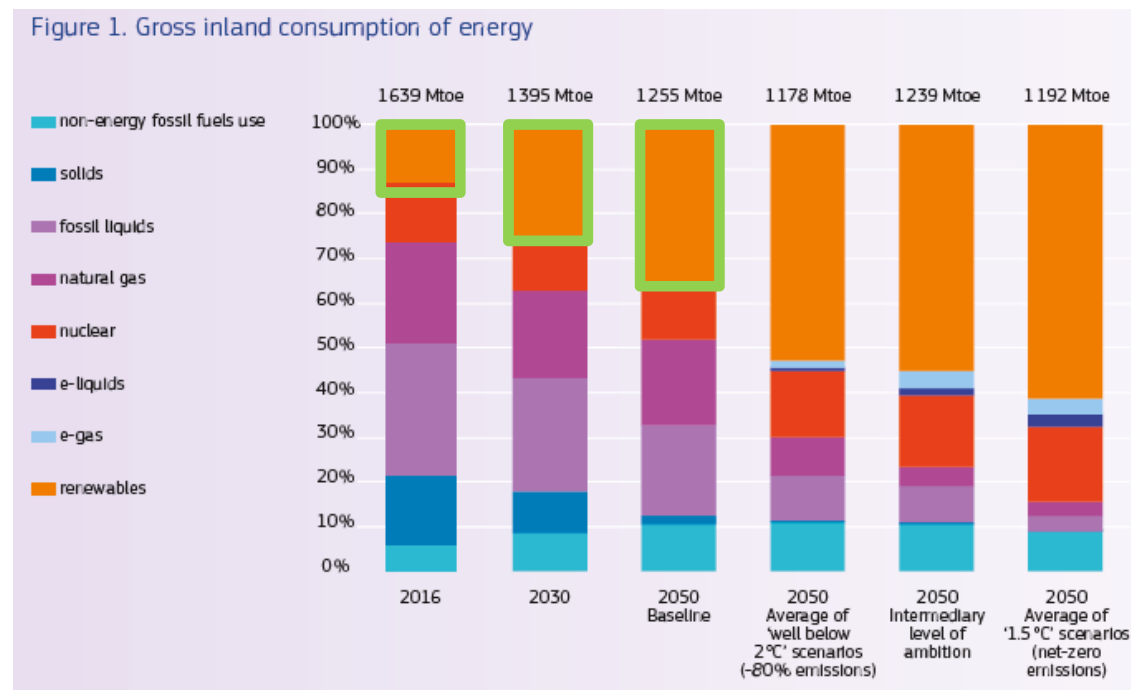


Introduction

Climate Protection: Reducing Emissions via Increase of Renewable Energy



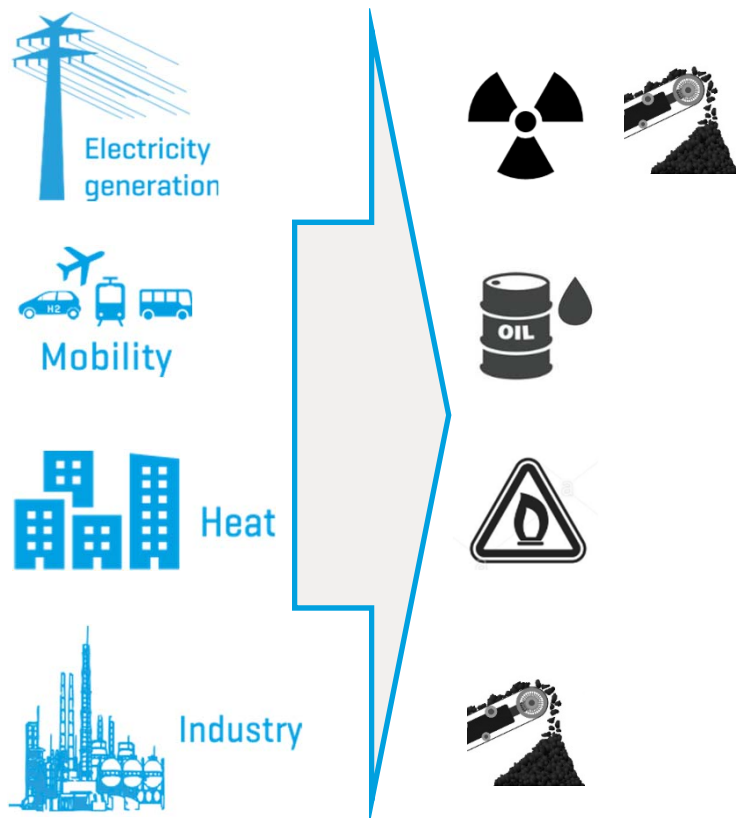
Figure 1. Gross inland consumption of energy



EU Policy:
Target to substantially reduce the share of fossils in energy production and consumption

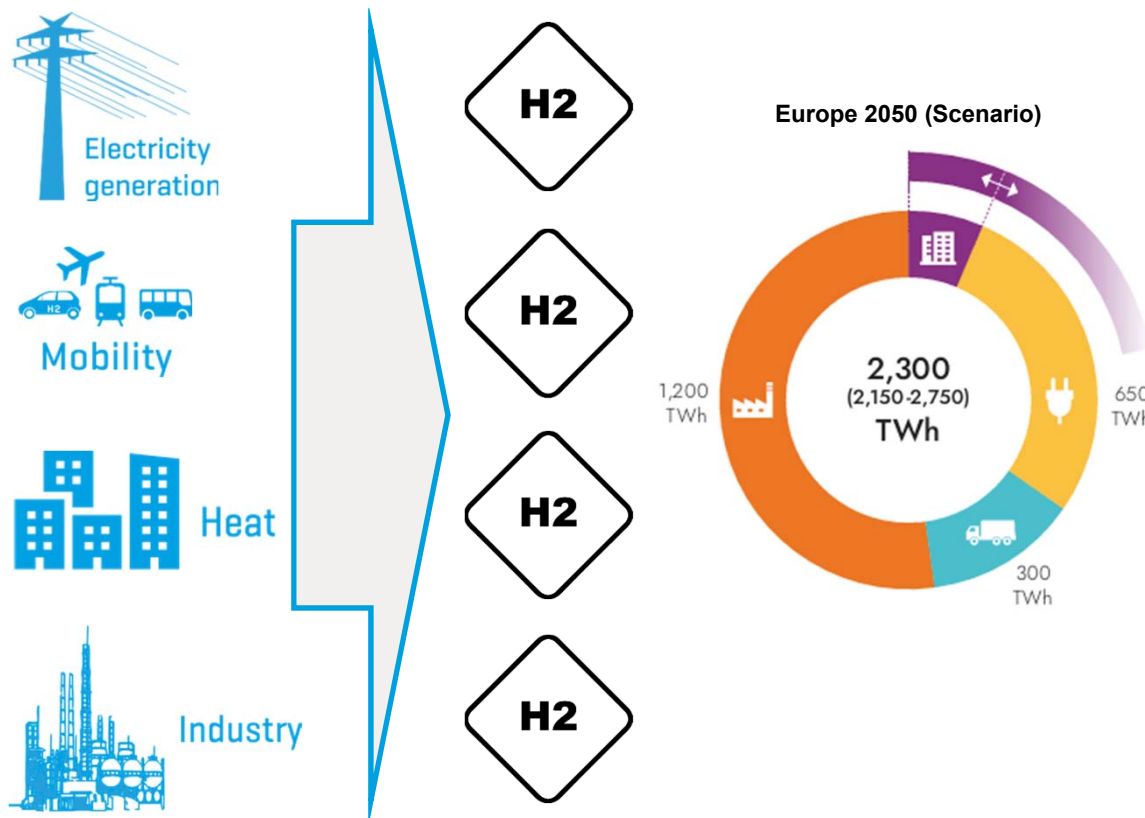
Source: European Commission, Going Climate Neutral by 2050. A strategic long-term vision for a prosperous, modern, competitive, and climate neutral EU economy, 2019; https://ec.europa.eu/clima/policies/strategies/2030_en

Change of Energy System Different Sectors



- Use of **various energy** carriers to **different industry sectors**, mostly **independent** of each other
- Conventional energy carriers are responsible for **90% of CO2 emissions**
- Legal requirements for CO2 reduction
- Decrease of conventional energy carrier leads to a **need for a replacement**
- **Hydrogen** as new energy carrier

Hydrogen Use(r) Different Sectors

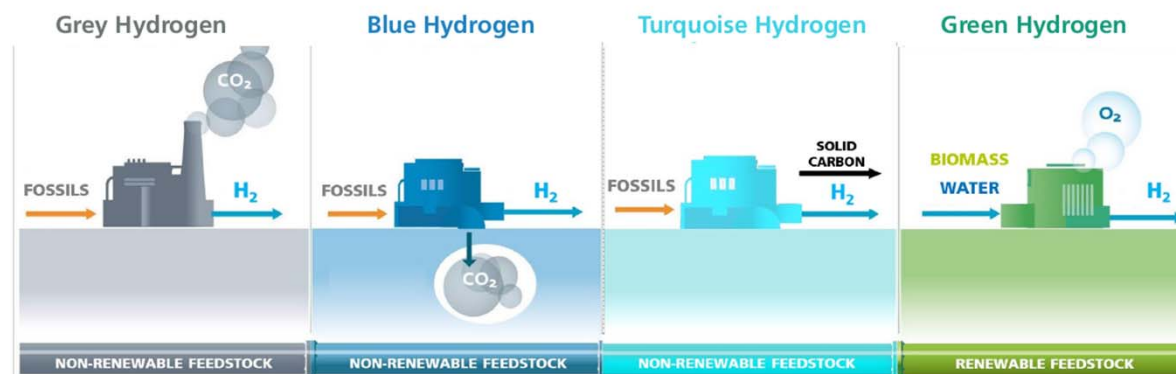


- Use of **hydrogen** as **one energy carrier**
- **Interdependencies** to be expected due to sector coupling
- **High demand** for hydrogen

Source: European Hydrogen Backbone, Analysing future demand, supply, and transport of hydrogen, June 2021

Hydrogen Production and Demand

Categorization of different production methods:



Input from:



Output to:



Industry



Electricity generation



Mobility



Heat

Varying volatility in production and demand

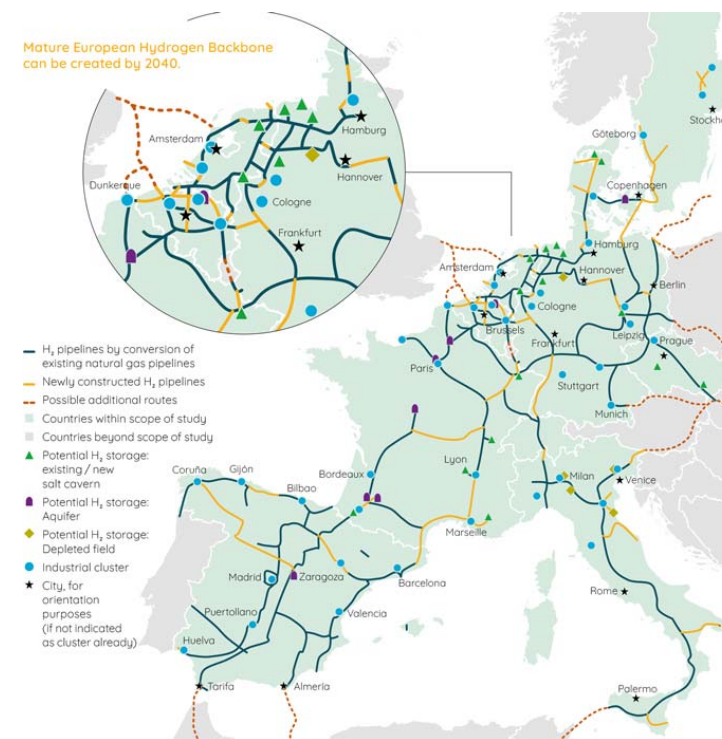
Hydrogen Storage and Distribution

- Production, storage, distribution and use of hydrogen
- Volatility requires grids and storage

Country	Hydrogen demand 2030 ⁶²	Hydrogen demand 2050	Hydrogen storage need 2030 ⁶³	Hydrogen storage need 2050	Potential hydrogen storage capacity-salt caverns	Potential hydrogen storage capacity-all types
Germany	66.9	470.0	15.9	111.4	39.5	61.4
Netherlands	26.6	133.4	6.3	31.6	0.9	34.6
UK	29.1	244.2	6.9	57.9	3.7	4.8
Total	304.5	1,968.1	72.2	466.4	50.0	264.7

Reference: gie, June 2021, in TWh

- Expected storage needs require large-scale energy storage
- Hydrogen storage in the geological underground?



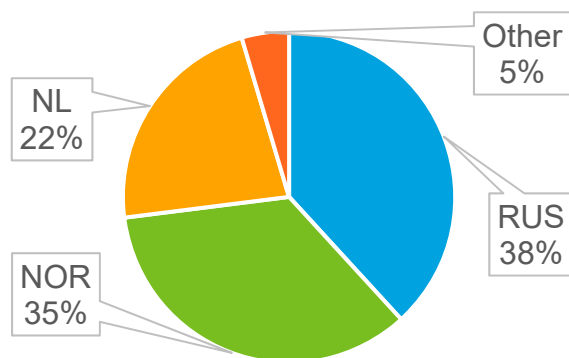
Source: European Hydrogen Backbone, July 2020

Unstable political situation vs. natural gas deliveries

Natural Gas Supply in Germany

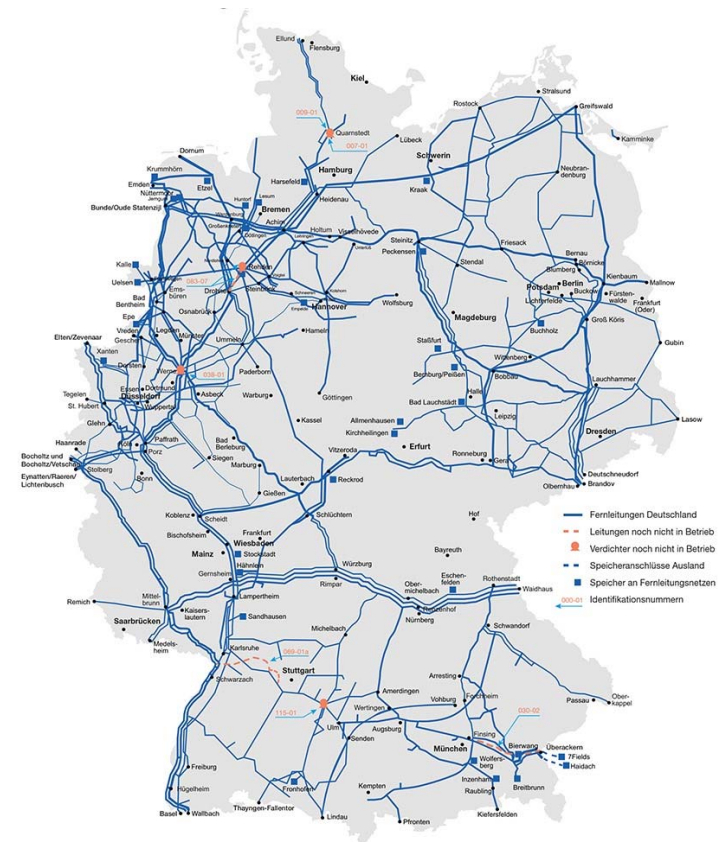


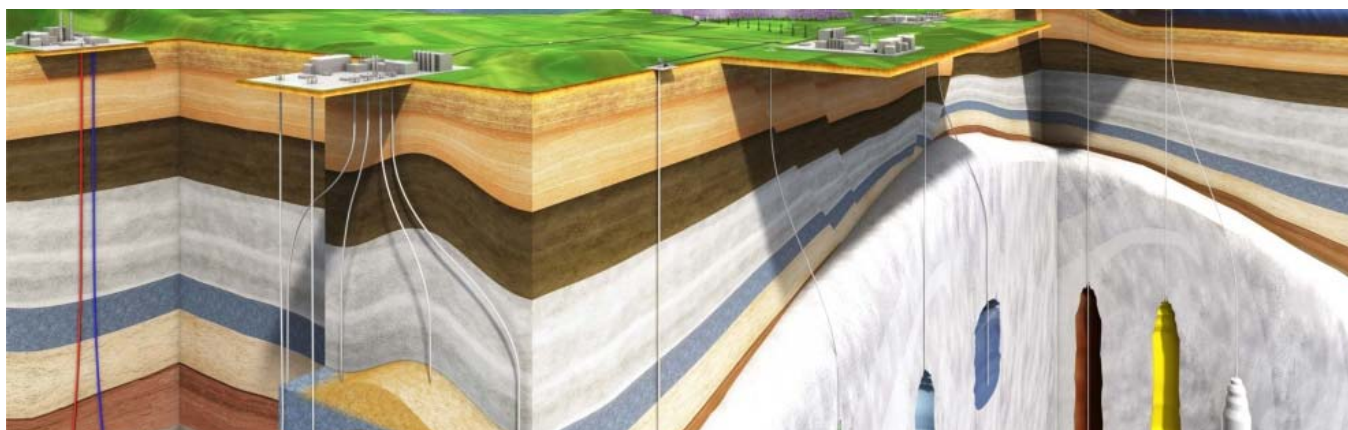
- 90% dependent on imports via pipeline
- Imports from 3 main suppliers (Russia, Norway, Netherlands)



- No strategic gas reserve, but now in discussion due to war in Ukraine
- Additional driver for change to alternative and renewable energy sources

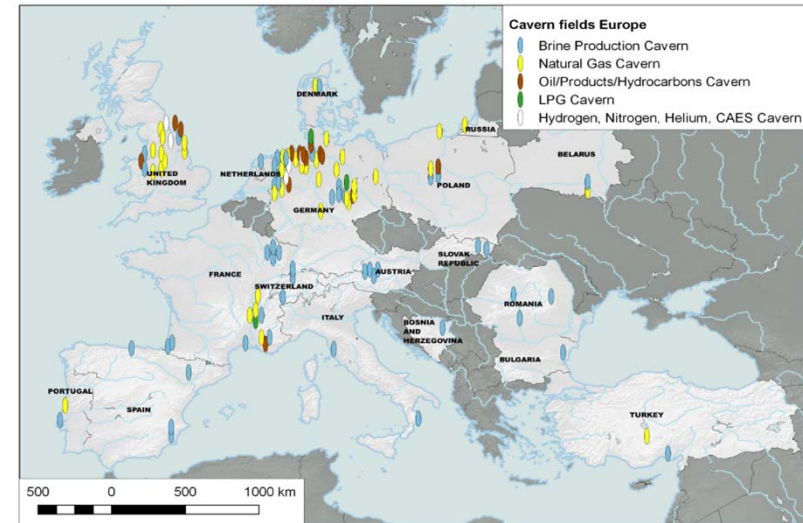
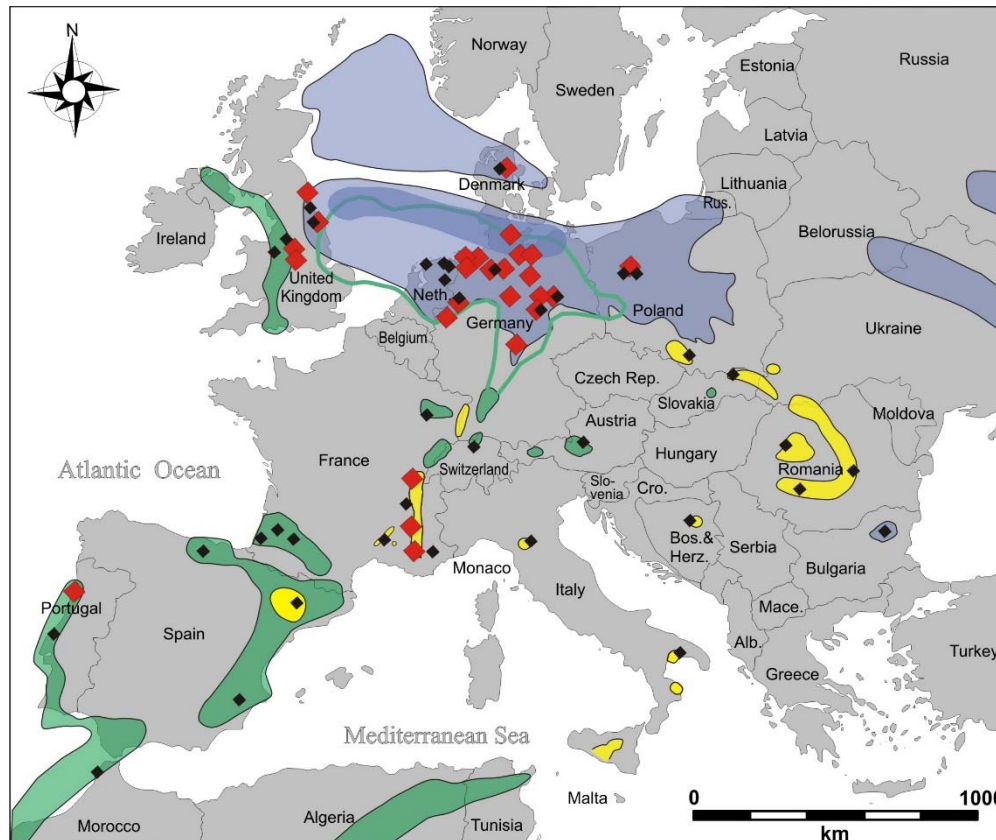
Quellen: Bundesregierung 2021, <https://www.bundesregierung.de/breg-de/themen/gasversorgung-abhaengigkeiten-verringern-441270?view=renderNewsletterHtml>, <https://www.bmwi.de/Redaktion/DE/Bilder/Energie/gas-fernleitungsnetz-im-ueberblick.html>





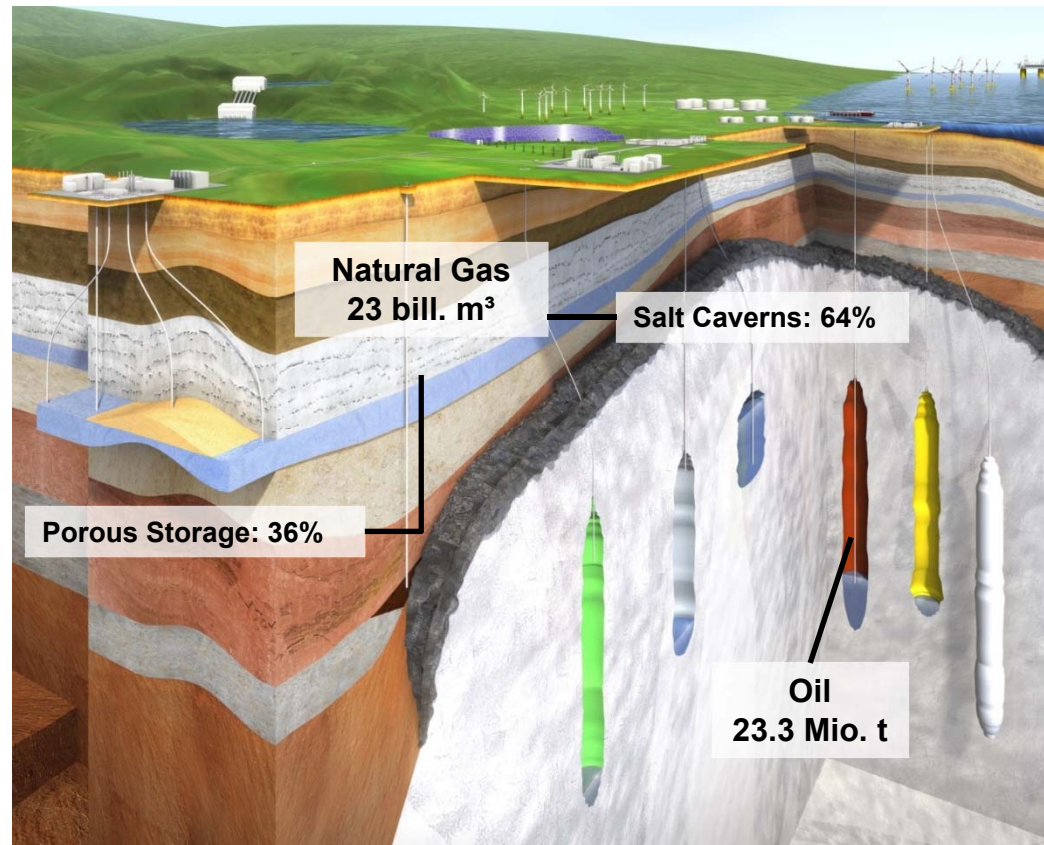
Natural gas storage in caverns

Salt Caverns in Europe



- Paleozoic salt deposit (Permian), Zechstein
- Paleozoic salt deposit (Permian), Rotliegend below Zechstein
- Tertiary salt deposit
- Mesozoic salt deposit

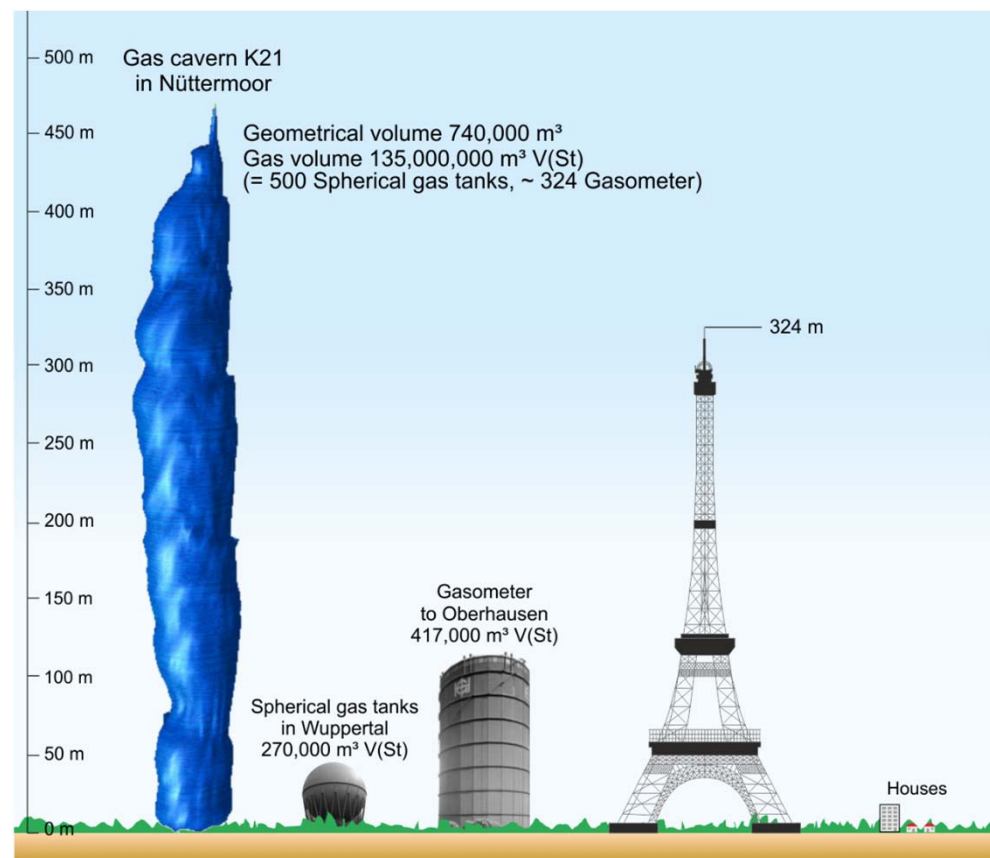
Fossil energy storage in Germany



- About 25% of annual gas consumption in Germany stored in underground gas storages
- Gas stored: ~ 23 bill. m³ (about 228 TWh)
- Oil stored: ~ 23.3 mill. T
- Distribution of gas storages worldwide:
 - 90% in porous storages
 - 10% in caverns

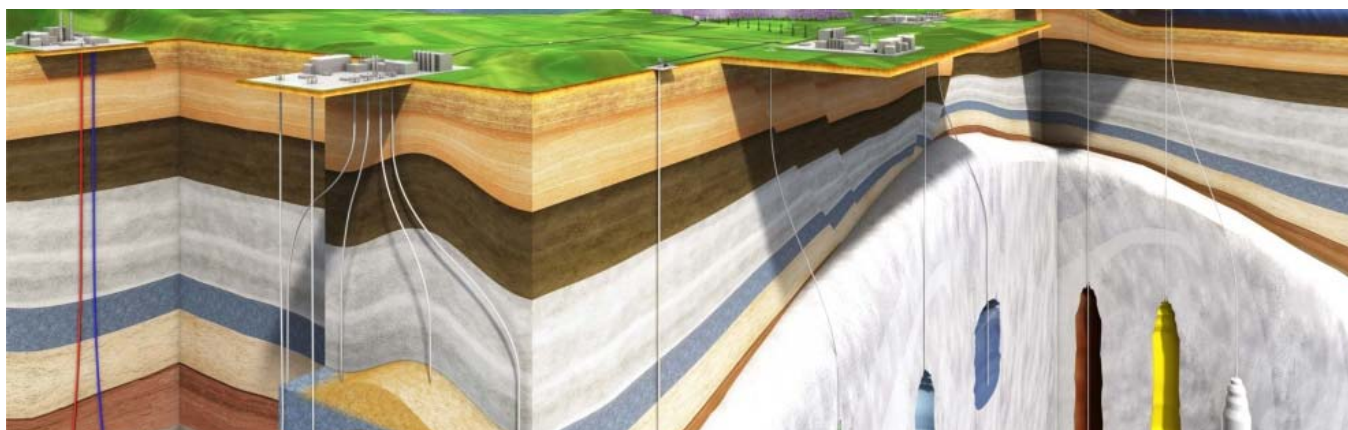
Source: Landesamt für Bergbau, Energie und Geologie. Erdöl und Erdgas in der Bundesrepublik Deutschland 2020

Advantages Underground Gas Storage



- Extremely large storage volumes
- Low land consumption
- Low specific investment costs per m³
- Safety aspects:
 - large distance to the biosphere and hydrosphere
 - caverns are extremely tight
 - insensitive to external influences

• Underground storage of 10 mill. m³ oil = 100 tanks above ground on 8 km²

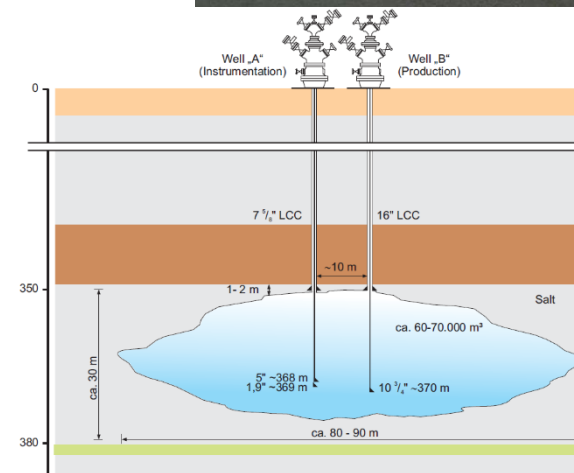


Hydrogen storage in caverns

Existing Hydrogen Storage in Caverns Teesside / UK



- Commissioned in the 1970s
- 3 caverns, each: 75,000 m³ (geom.)
- Depth approx. 370 m
- Operated by constant pressure (ca. 50 bar) and brine injection/withdrawal
- Operator: SABIC
- Hydrogen supply for chemical industry



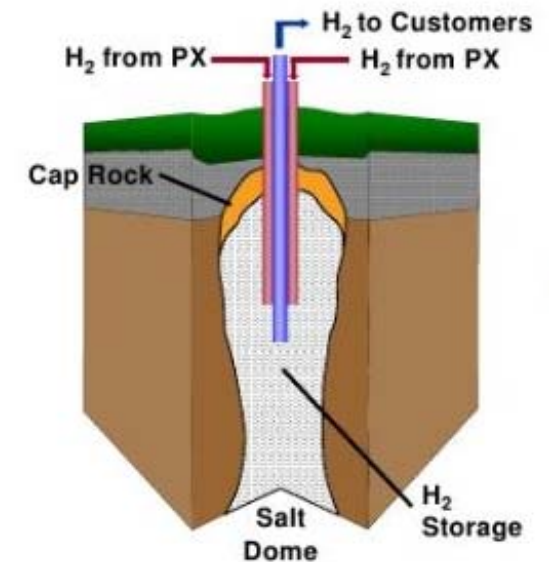
Source: DEEP.KBB, S.Donadei, G.-S. Schneider (2017): Wasserstoffspeicherung in Salzkavernen, in: Johannes Töpler, Jochen Lehmann (Hrsg.), Wasserstoff und Brennstoffzellen. Technologien und Marktperspektiven, 2. Auflage, Springer Verlag, S.315-325

Existing Hydrogen Storage in Caverns

Moss Bluff, TX, USA



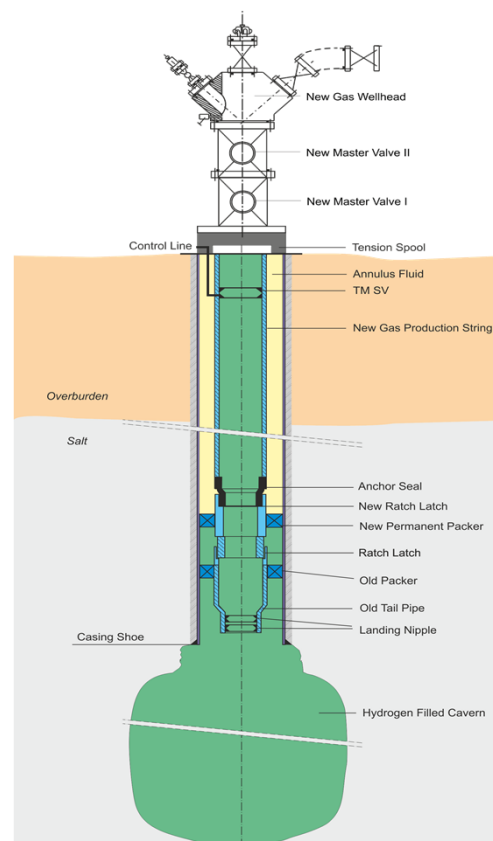
- Commissioned in 2007
- 1 cavern: 560,000 m³ (geom.)
- Pressure range: 55 – 150 bar
- Working gas capacity: ~40 million m³
- Operator: Praxair
- Hydrogen supply for chemical industry
- 2 other hydrogen caverns in Texas
 - 1 cavern (Air Liquide), 1 cavern (ConocoPhillips)



Source: www.praxair.com

Hydrogen Storage in Caverns

Operation principle and completion (analogy to gas storage)



- Example: typical gas cavern in Europe
 - Tightness tests
 - Long term operation, minimal intervention during operation
 - Use of a SSSV (Limit for production string)
 - Pressure driven operation



Check of applicability of existing/available standards and procedures



Changes and modifications, if required

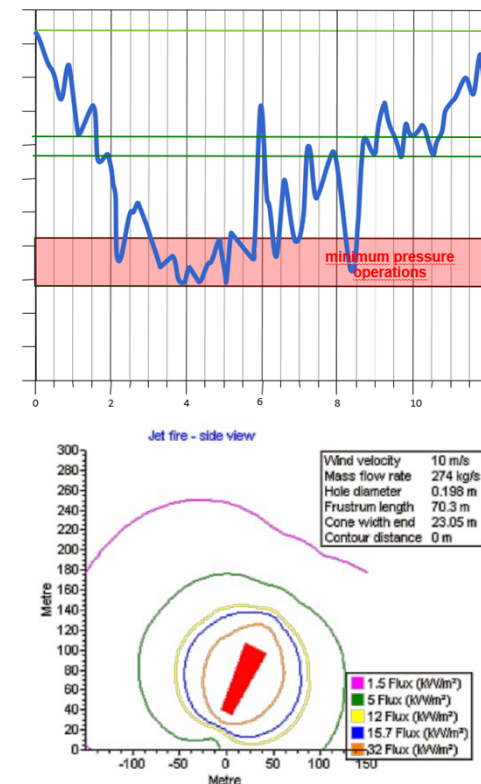
Hydrogen Storage in Salt Caverns

Specific Aspects regarding Conversion of existing Caverns



Rock mechanics & Thermodynamics

- Operation (multi / high cycling)
 - Requirements for feed-in/withdrawal rates will change in the future due to hydrogen production and demand from fluctuating energy sources (wind, solar)
 - Rapidly changing phases of a) high production and storage and b) demand and withdrawal from storage
- Blow out scenario
 - e.g. difference to natural gas; relevant for existing salt caverns with regard to the minimum distance to objects such as buildings, roads...



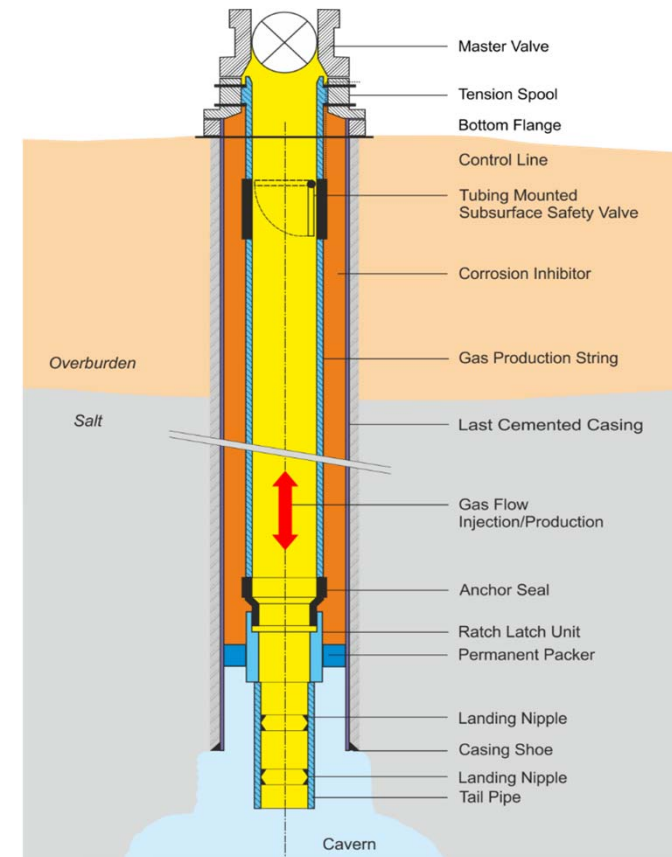
Hydrogen Storage in Salt Caverns

Specific Aspects regarding Conversion of existing Caverns



Subsurface equipment

- Compatibility of the materials (cement, steel, elastomers) & completion elements (e.g. SSSV) with regard to hydrogen and its properties
 - Relevance for retrofitting of existing salt caverns (feasibility?, recompletion?)
 - Relevance for the construction of new salt caverns for hydrogen (material selection)



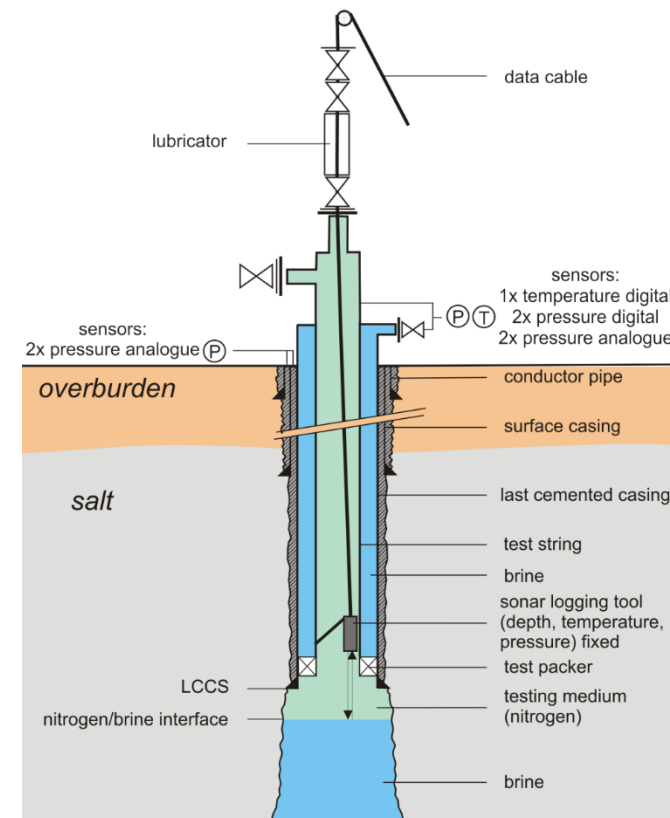
Hydrogen Storage in Salt Caverns

Specific Aspects regarding Conversion of existing Caverns



Integrity testing

- Mechanical Integrity Test (MIT) / Gas Tightness Test (GTT), e.g.
 - Adaptation of procedure
 - Selection of test medium
 - Determination of criteria
 - Adjustment of equipment



Hydrogen Storage in Salt Caverns

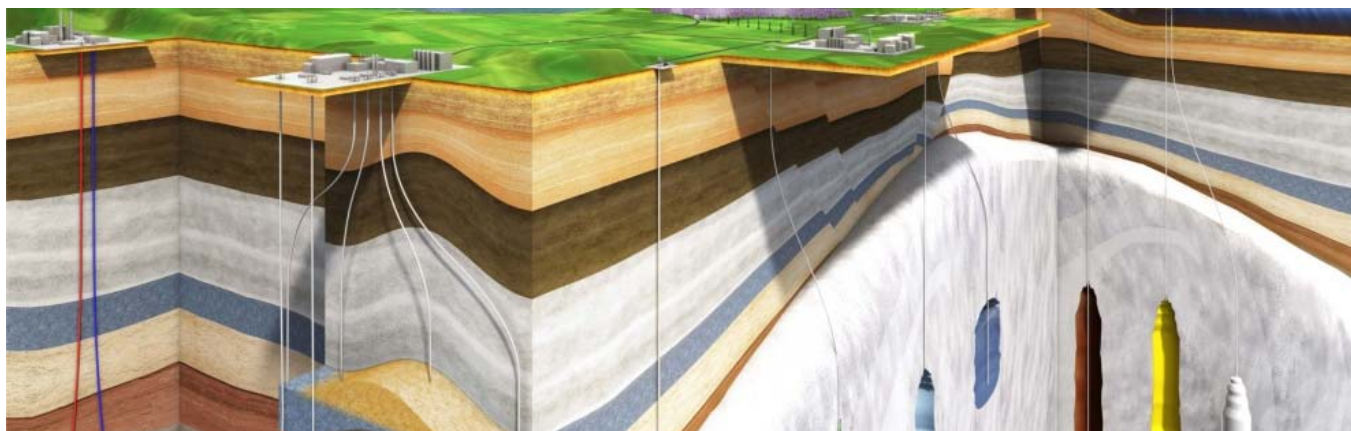
Specific Aspects regarding Conversion of existing Caverns



Purity of Hydrogen in Salt Caverns

- Depending on the use of the hydrogen, very high requirements are set for the purity of the hydrogen (e.g. fuel cells, industrial processes)
- No reaction with salt expected, but possible contamination by:
 - Water from the cavern sump
 - Gases trapped in the salt rock, such as methane (CH_4)
 - Reaction products of hydrogen connections with mineral components in rock salt such as anhydrite (CaSO_4)
 - Occurrence of hydrogen sulphide (H_2S) due to sulphate-reducing bacteria
 - Other relevant substances that may be present in caverns (e.g. hydrocarbons or blanket media such as diesel or oppanol)





Conversion of storage caverns to hydrogen storage

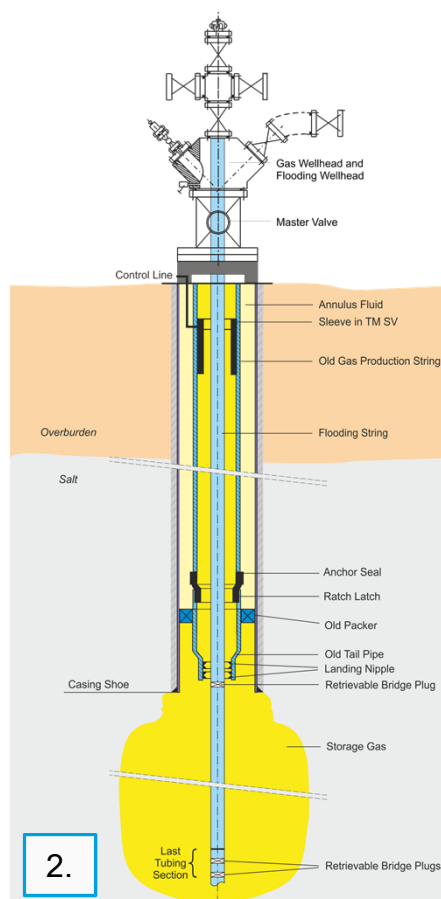
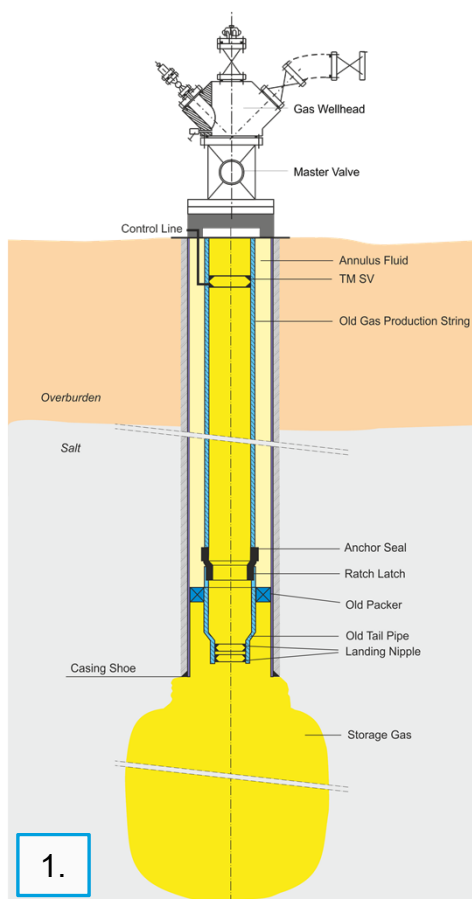
Conversion of natural gas storage caverns to hydrogen storage



General steps:

- Evaluation of suitability and design / engineering
(e.g. evaluation of procedures, programs, services, equipment, intended storage operation)
- Gas withdrawal / flooding of cavern
- Remove gas completion
- Tightness tests, evaluation of LCC/cementation condition
- Installation of H₂ gas completion
- (repeat MIT)
- Gas first fill
- Snubbing, installation of SSSV
- Commissioning of H₂ storage operation

Conversion of Storage Caverns to Hydrogen

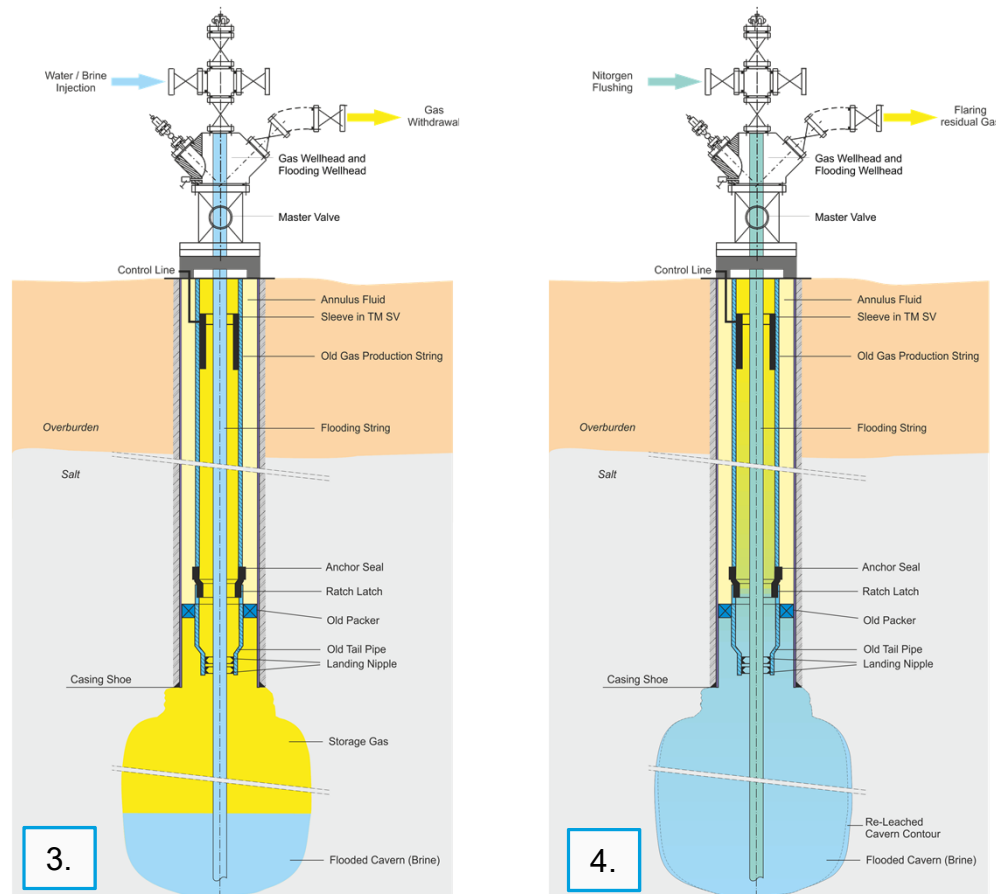


1. Gas storage cavern (initial state)
2. Deinstall SSSV, install Sleeve in SVLN

Snubbing in flooding string

Rig up flooding wellhead

Conversion of Storage Caverns to Hydrogen



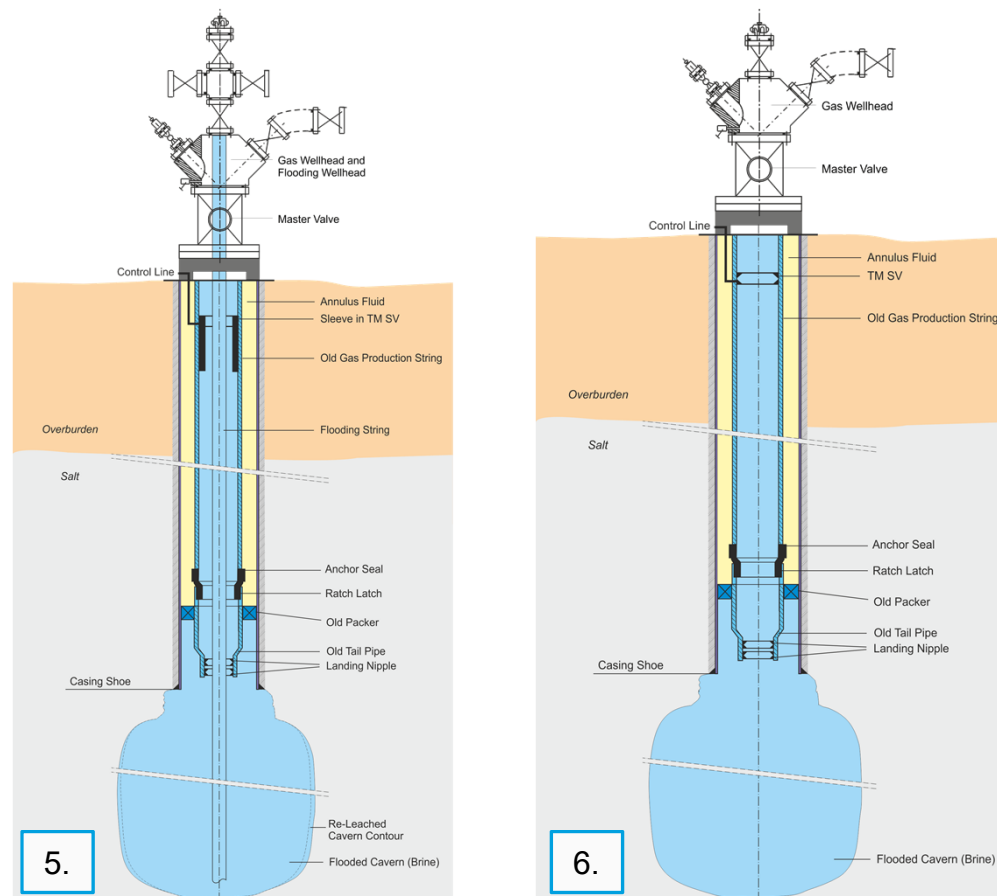
3. Flooding operation

4. Flooded cavern

Nitrogen flushing

Flaring of residual gas

Conversion of Storage Caverns to Hydrogen



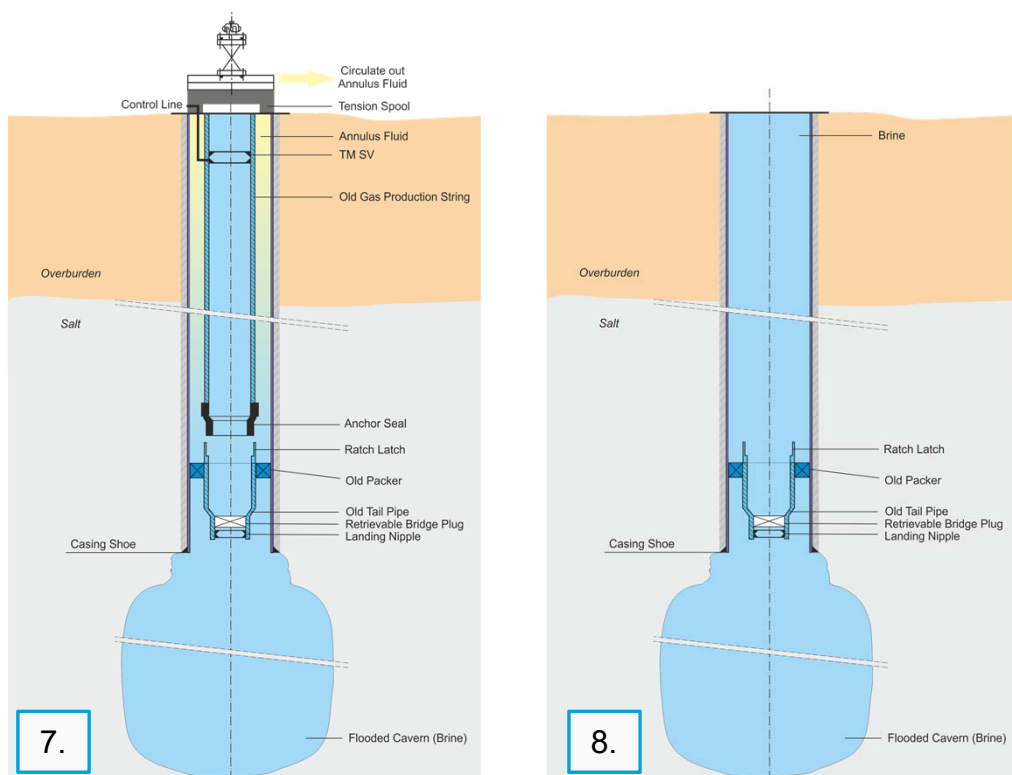
5. Pressure release and degassing

6. POOH flooding string

Remove flooding wellhead

Perform sonar survey

Conversion of Storage Caverns to Hydrogen



7. Set plug in tailpipe

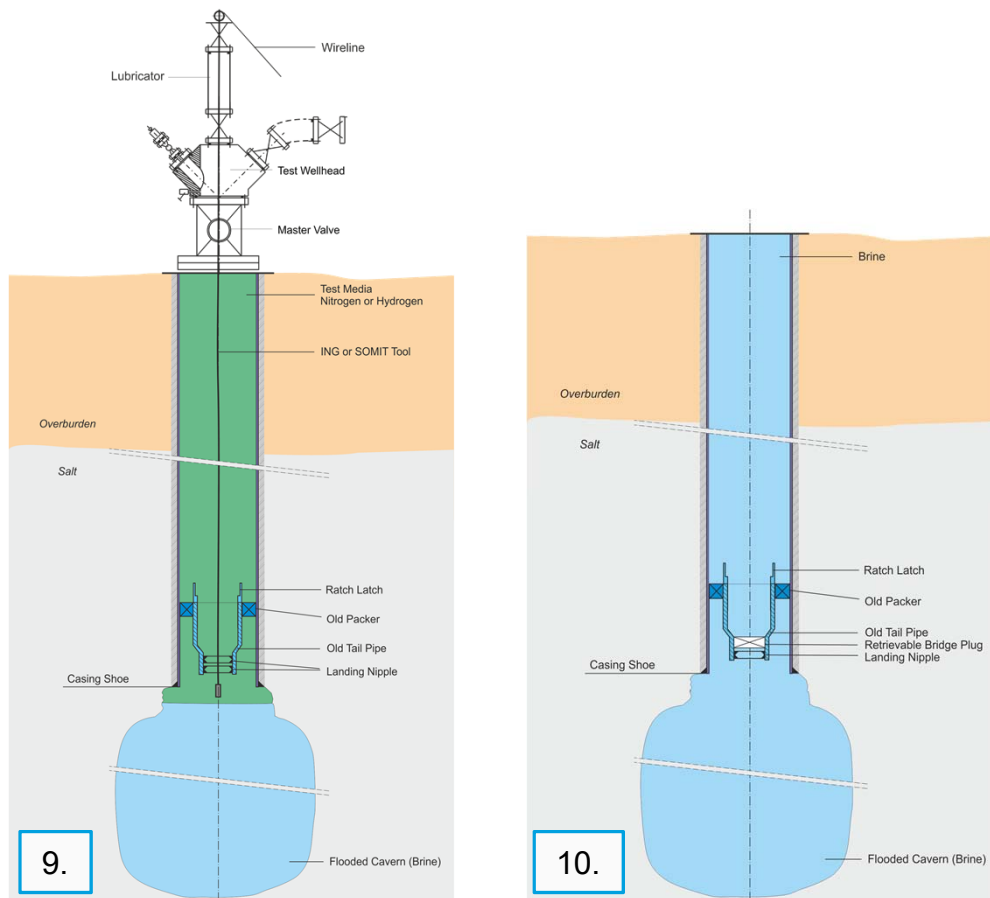
Disconnect gas production string from packer

Circulate out annulus fluid

8. POOH old gas production string

Remove gas wellhead

Conversion of Storage Caverns to Hydrogen



9. Rig up test wellhead and wireline service

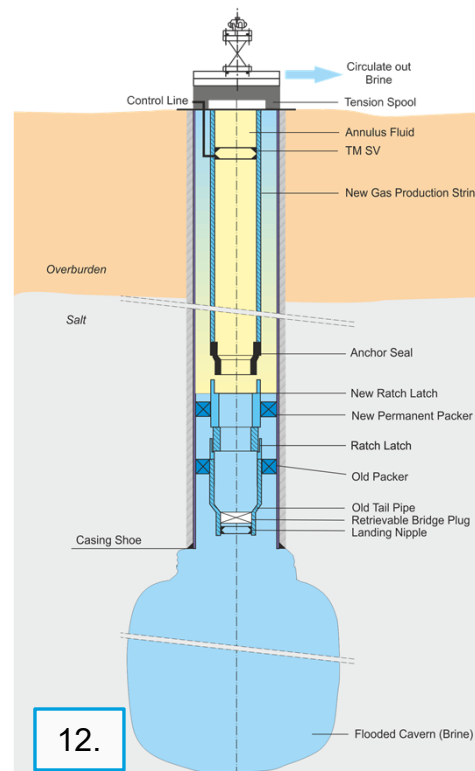
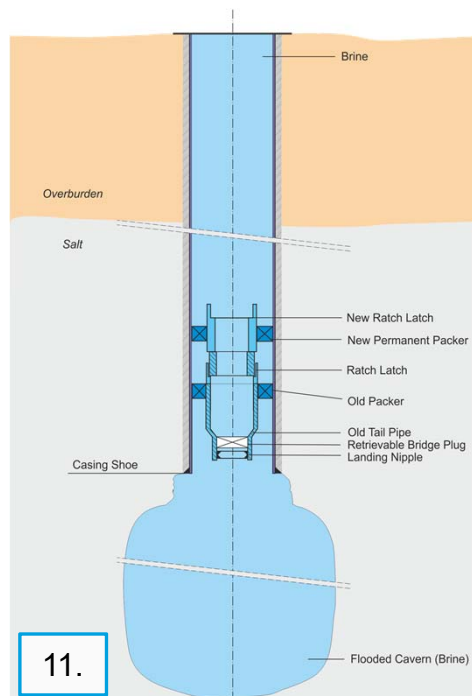
Inject test medium N_2

Perform MIT

Repeat test with H_2 (test packer)
10. Release test medium and pressure

Install plug in tailpipe

Conversion of Storage Caverns to Hydrogen



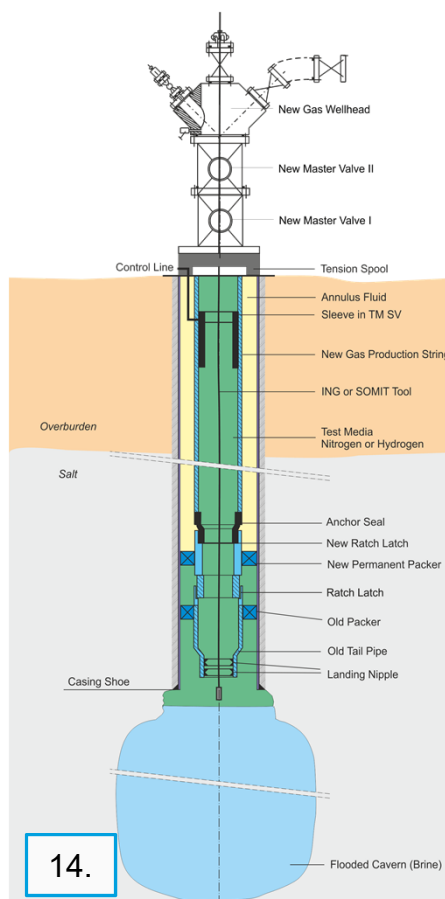
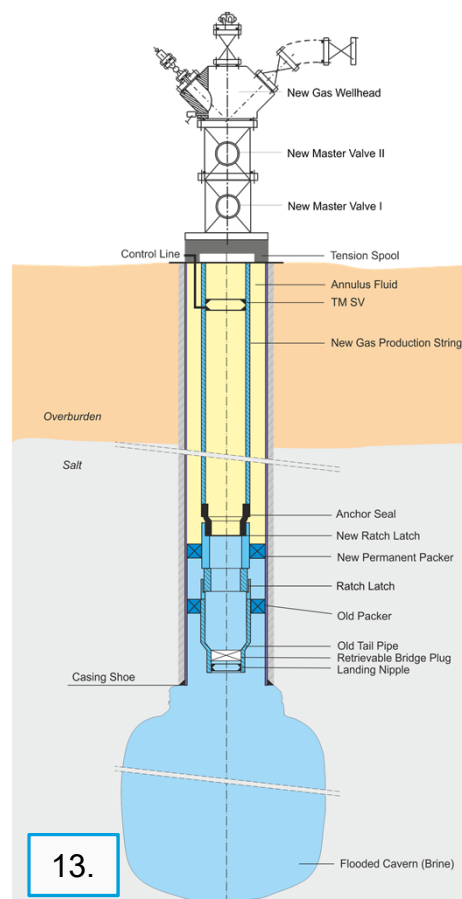
11. Clean borehole using scraper and brush

Set new packer above old packer

12. RIH new gas production string

Circulate in annulus fluid

Conversion of Storage Caverns to Hydrogen



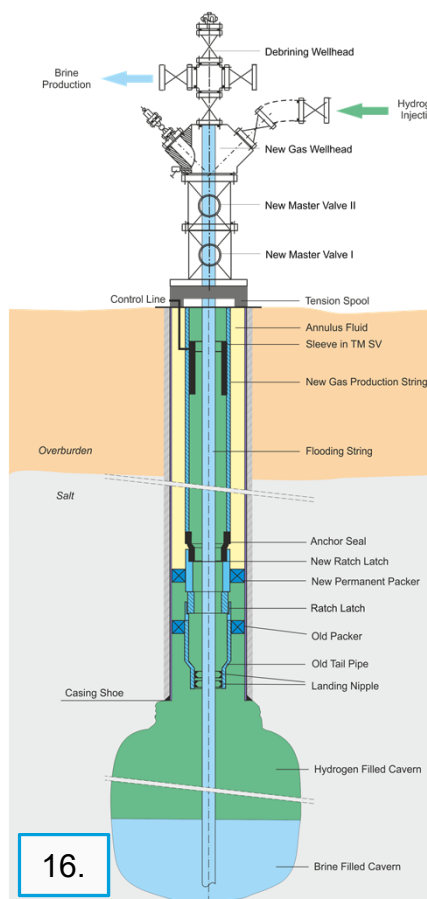
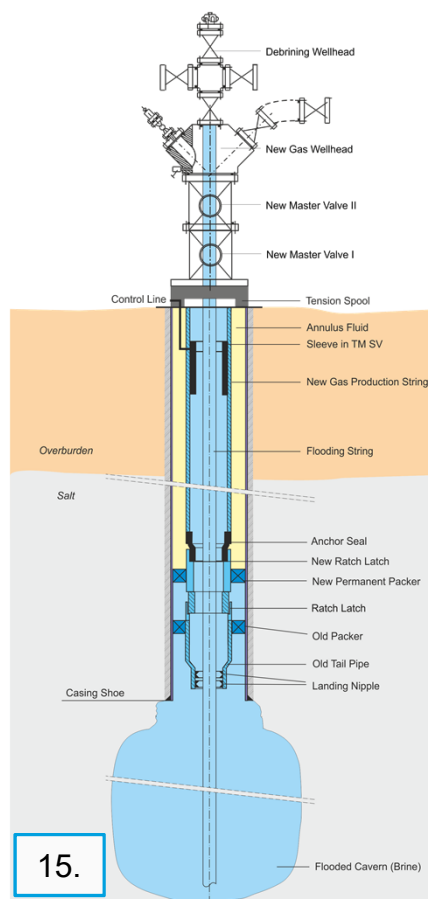
13. Connect anchor seal into ratch latch connection

Rig up new gas wellhead incl. additional master valve

14. Install sleeve in SVLN

Repeat MIT
(also possible after installation of
debrining string)

Conversion of Storage Caverns to Hydrogen



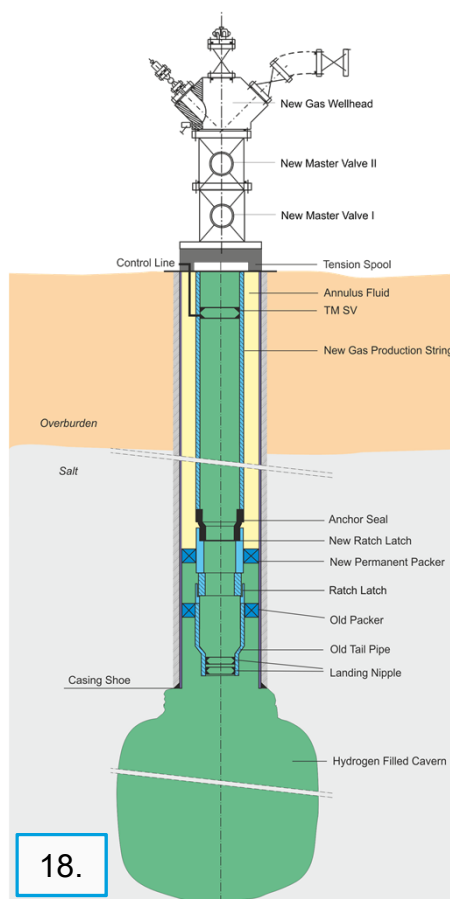
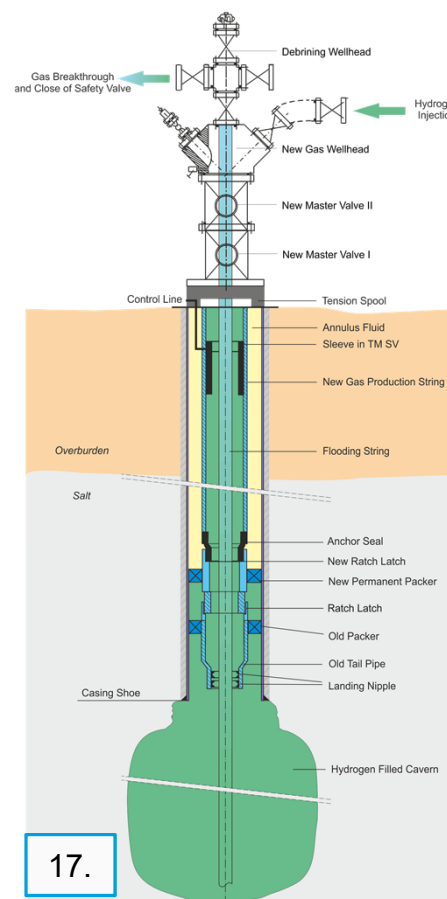
15. Release test medium and pressure

Install debrining string

Rig up brine wellhead

16. Gas fill operation with H_2

Conversion of Storage Caverns to Hydrogen



17. Gas breakthrough as cavern is completely filled

Close of safety shut off valves

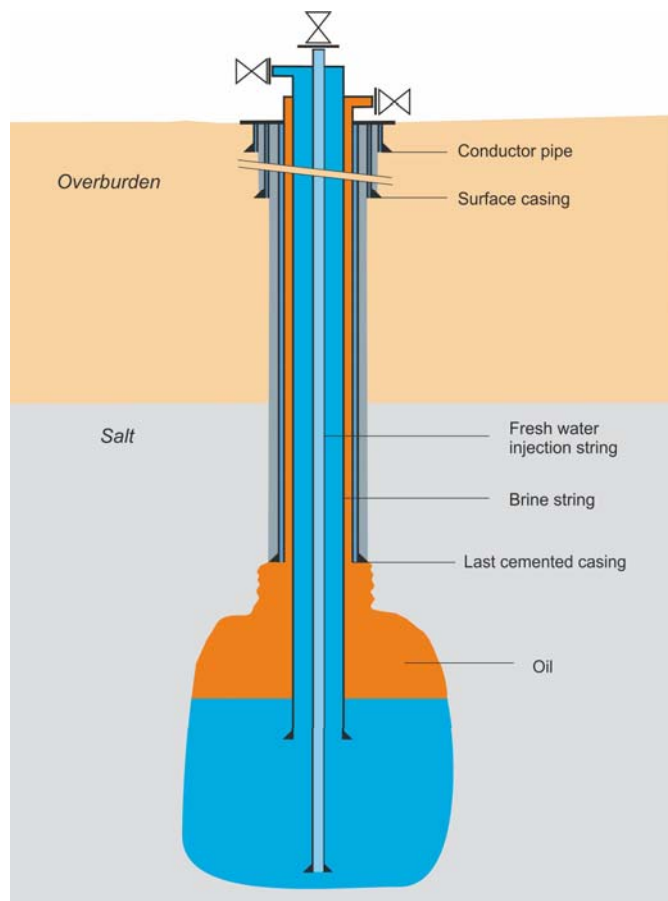
18. Snubbing out debrining string

Remove brine wellhead

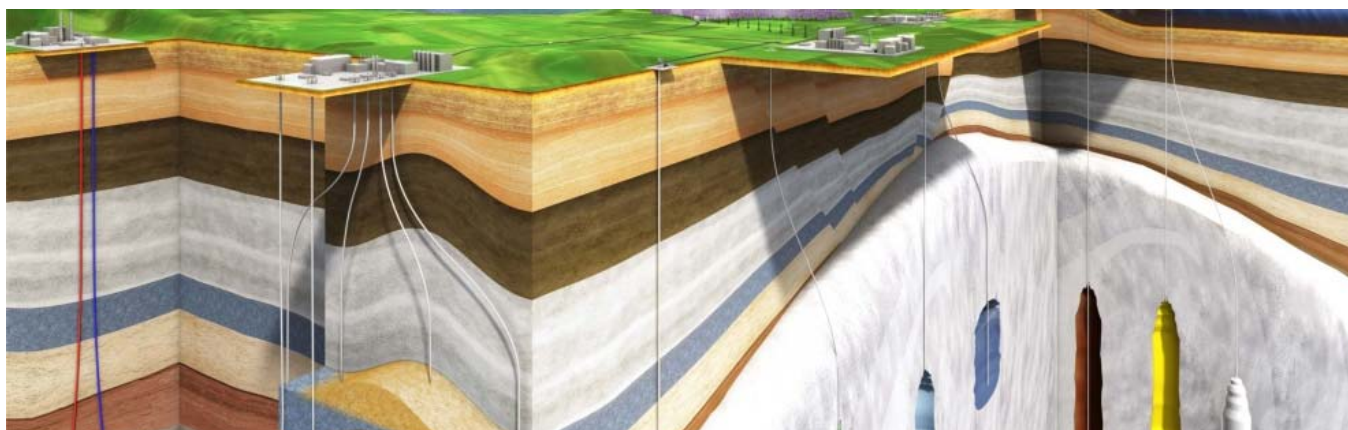
Pull sleeve in SVLN

Set SCSSV

Other cavern types for conversion to H2 storage



- Oil storage and brine production caverns
- Additional requirements:
 - Last cemented casing
 - H2 quality (oil/diesel residues, operations)
 - Rock mechanics, e.g. shape, distances etc.
- Conversion of oil storage caverns for natural gas storage was realised successfully several times.

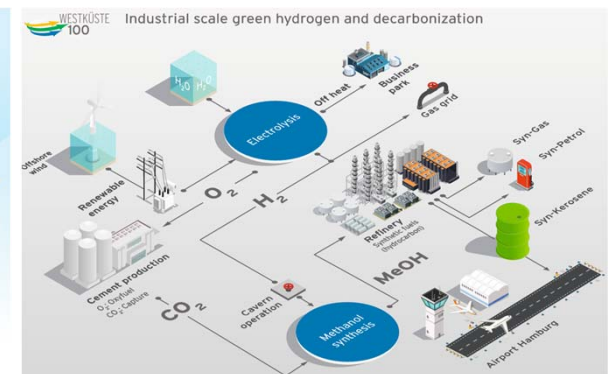
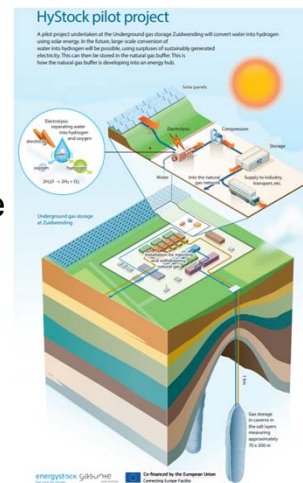


Hydrogen Projects

R&D projects on Hydrogen incl. Caverns

Recent Activities in Europe

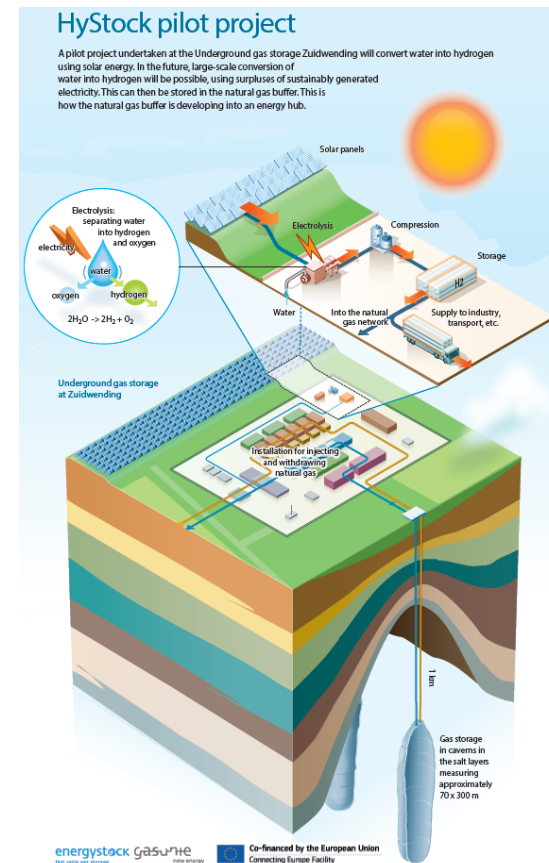
- EU-Policy: Continuous expansion of renewable energies for climate protection and decarbonization
- Integration of renewable energy (wind, solar) into the energy system via production of hydrogen
- Several national and international hydrogen R&D programs, plans and initiatives including large scale funding of research projects
- Projects in several countries started / in preparation including salt caverns:
 - The Netherlands: Zuidwending
 - Germany: Bad Lauchstädt, Heide, Rüdersdorf, Etzel
 - France: Etrez
 - UK, Denmark, Poland



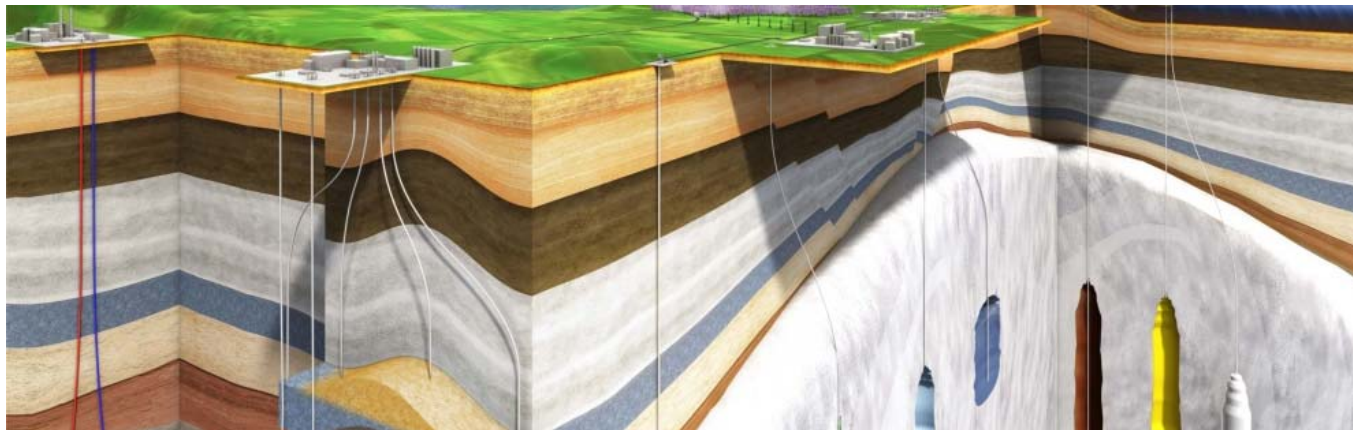
HyStock-Project



- Power-to-gas-facility & solar field (1 MW)
- Converting sustainable electricity into green hydrogen
- Salt cavern facility at Zuidwending, The Netherlands
- Status: since 2019 in operation
- Technical implementation of hydrogen storage in caverns
- Operator: energystock gasunie
fast cycle gas storage



Source: www.energystock.com/about-energystock/the-hydrogen-project-hystock



Project H2CAST

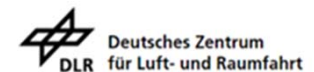
H₂CAST Etzel

Research project to investigate
hydrogen storage in salt caverns

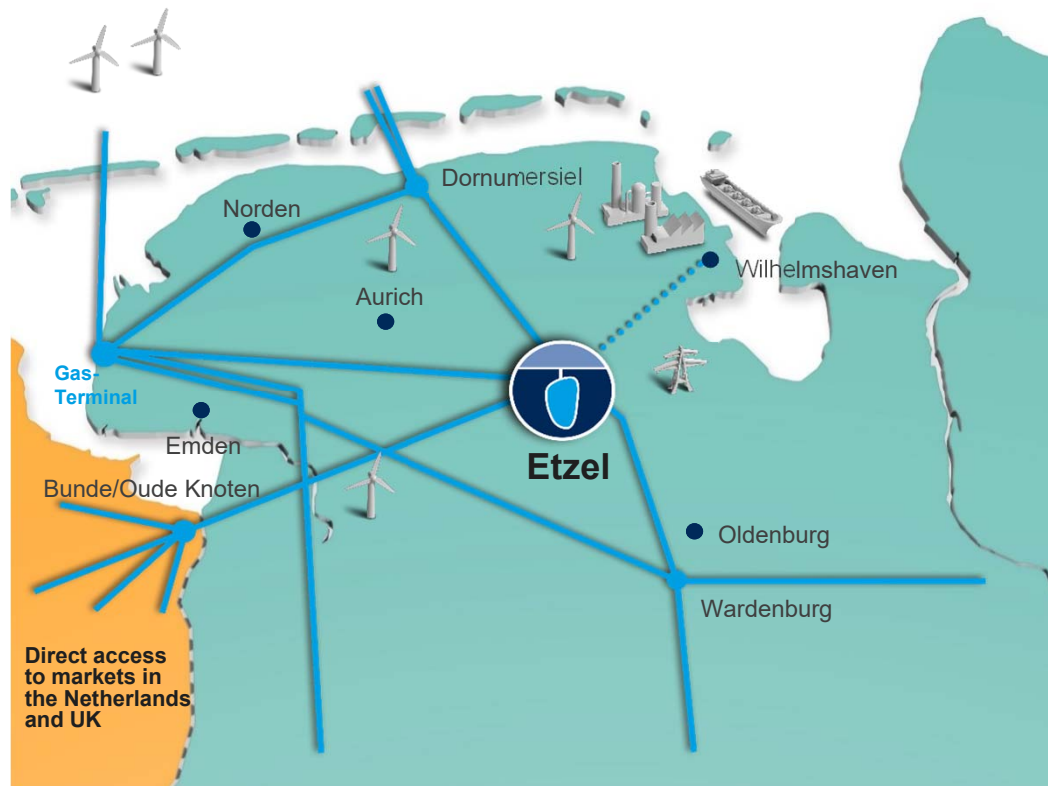


Division of project outlines

STORAG ETZEL
Energy Storage Solutions
Joint undertaking Coordinator



H₂CAST: Benefits of Etzel



- Optimal geographic location and connection to transnational gas pipelines
- With 99 approved cavern locations (75 already in operation), the Etzel site has the largest expansion potential in Germany (144+)
- Four large natural gas surface facilities of international consortia already present at the site
- Caverns suitable for research on transition to hydrogen storage already exist. A total of 25 TWh_{H₂} could be stored in the approved sites.¹
- **To achieve the H₂ development goals of the Federal Government and Lower Saxony, applied research project launched on an industrial scale.**

¹⁾ Up to 0.25 TWh of hydrogen can be stored in each cavern at the Etzel site

Source: STORAG Etzel

H₂CAST: Plan



- Division of project **into two project outlines** for funding application according to the Lower Saxony Hydrogen Directive (Aug. 26, 2020) and funding announcement of the 7th Energy Research Program "Innovations for the Energy Turnaround" (May 5, 2021)

State of Lower Saxony: H₂CAST I – H₂ ready

- Development, construction and operation of a **demonstration project for industrial research** with a development focus on Lower Saxony
 - Preparation of a guideline for the approval procedure according to the Nds. regulations (Mining)

H₂CAST II – Proving H₂ operation

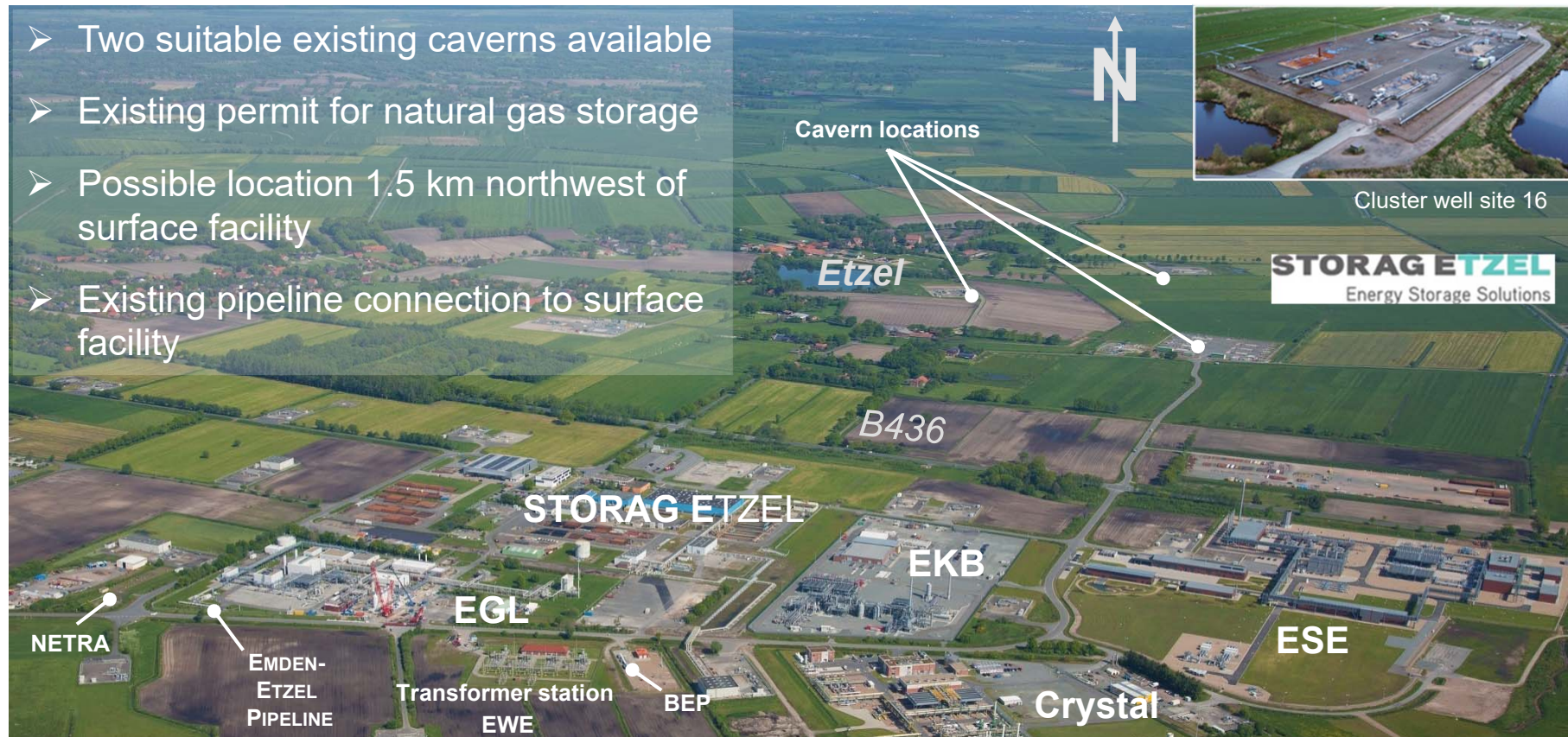
- Investigation of **novel operating modes** for salt caverns using **brine flows**
- R&D on conversion of existing oil and gas caverns to hydrogen storage and transferability to other sites
 - Testing hydrogen purification
 - Multicycle hydrogen operation

Project Start: 01/2022

Project End: 10/2026



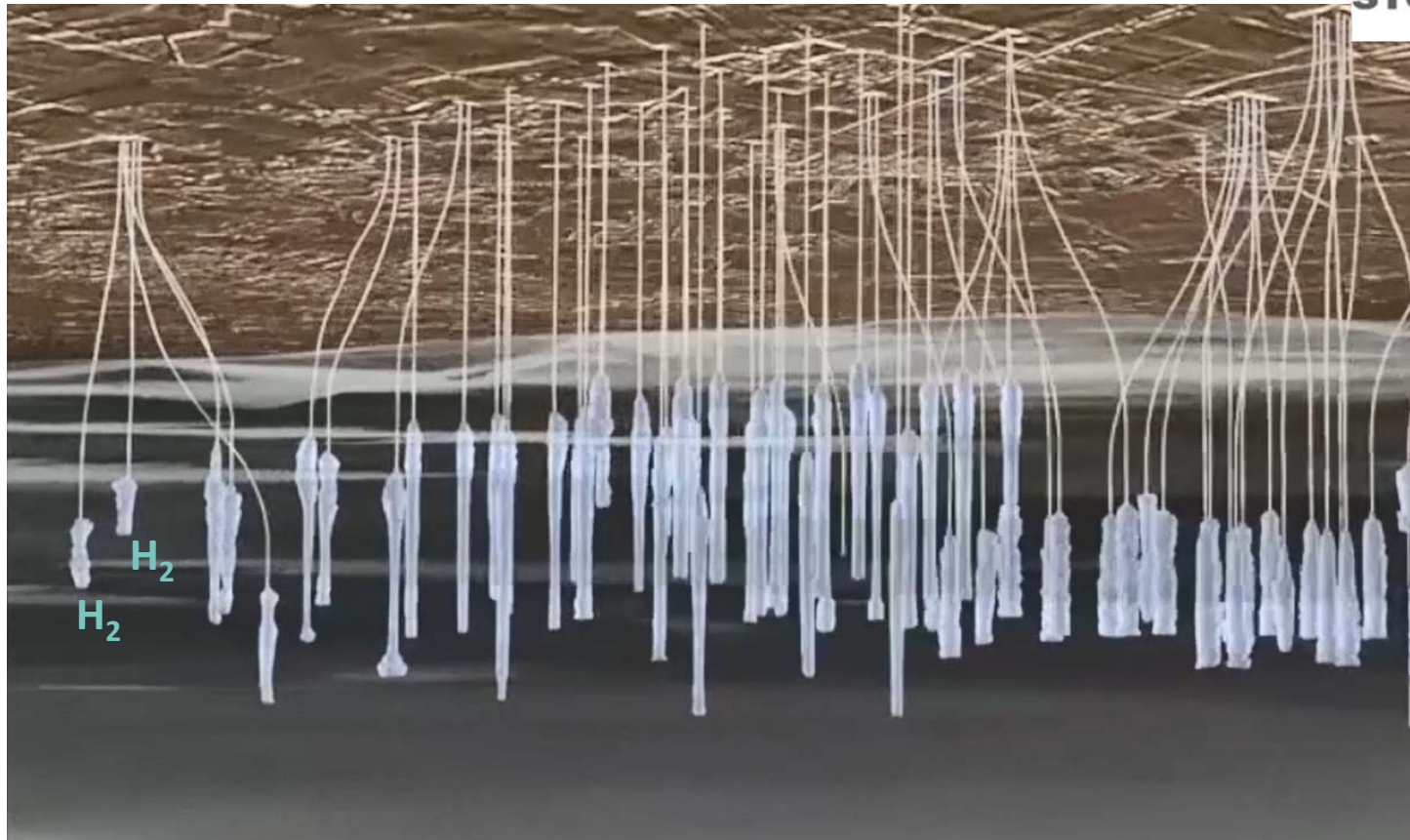
H₂CAST: STORAG Etzel cavern storage site



H₂CAST: Subsurface view



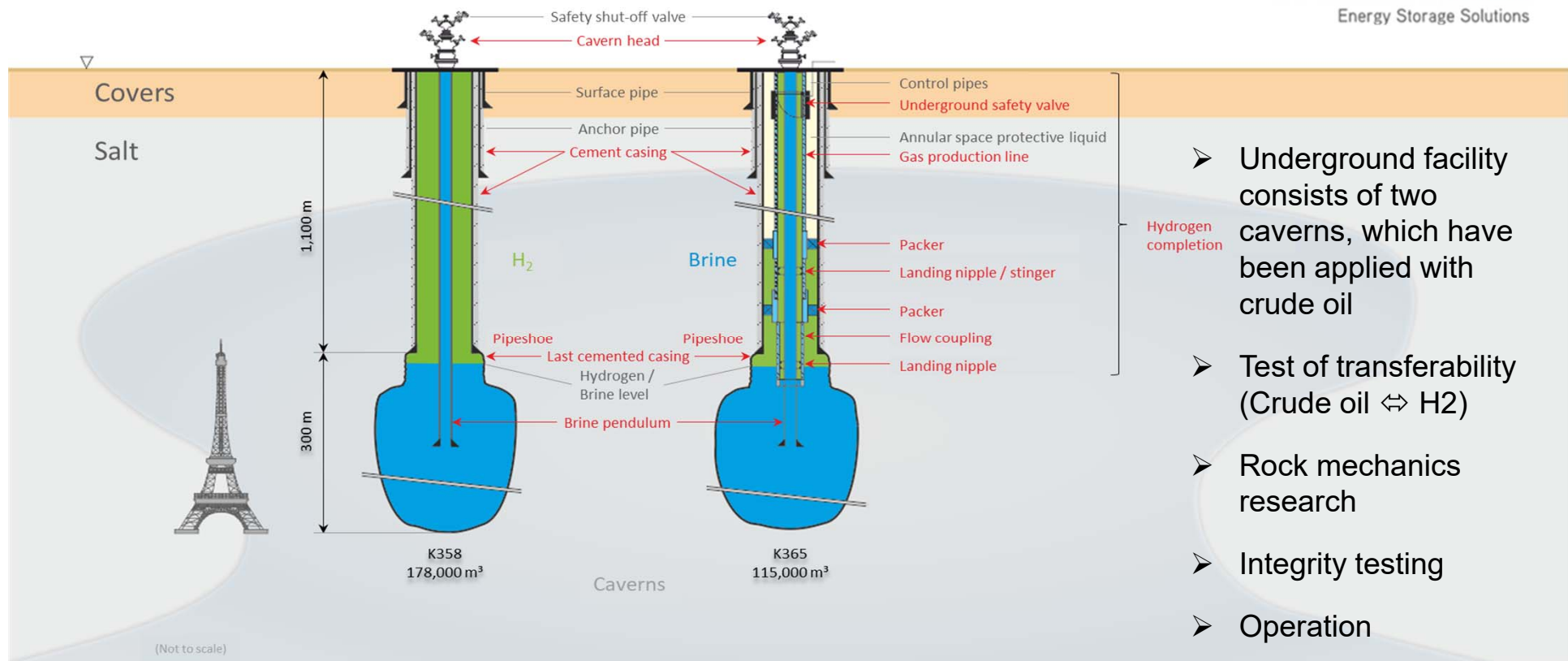
STORAG ETZEL
Energy Storage Solutions



H₂CAST: Two Caverns for H₂-Storage

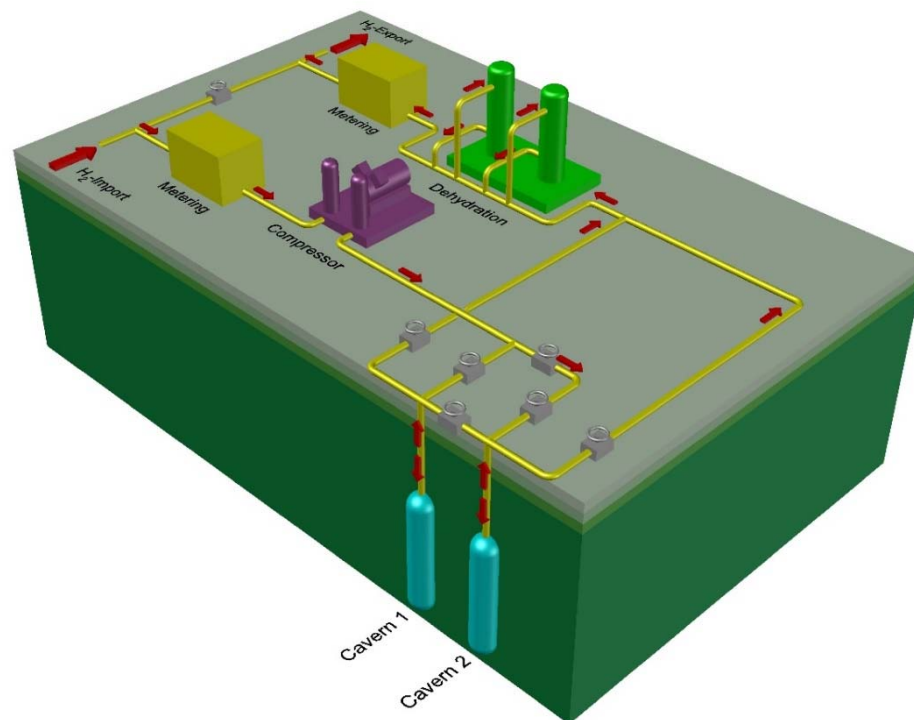


STORAG ETZEL
Energy Storage Solutions



- Underground facility consists of two caverns, which have been applied with crude oil
- Test of transferability (Crude oil ⇔ H₂)
- Rock mechanics research
- Integrity testing
- Operation

H₂CAST: Surface Plant H₂-Storage



- Construction of surface plant for demonstration and research purposes
 - Working pressure 50-180 bar, 5,000 – 10,000 Nm³/h
 - Multicycle feeds and discharges
 - Researching operations field
 - Gas cleaning (Adsorption)
 - Comparing quality and quantity with requirements
 - Safety engineering

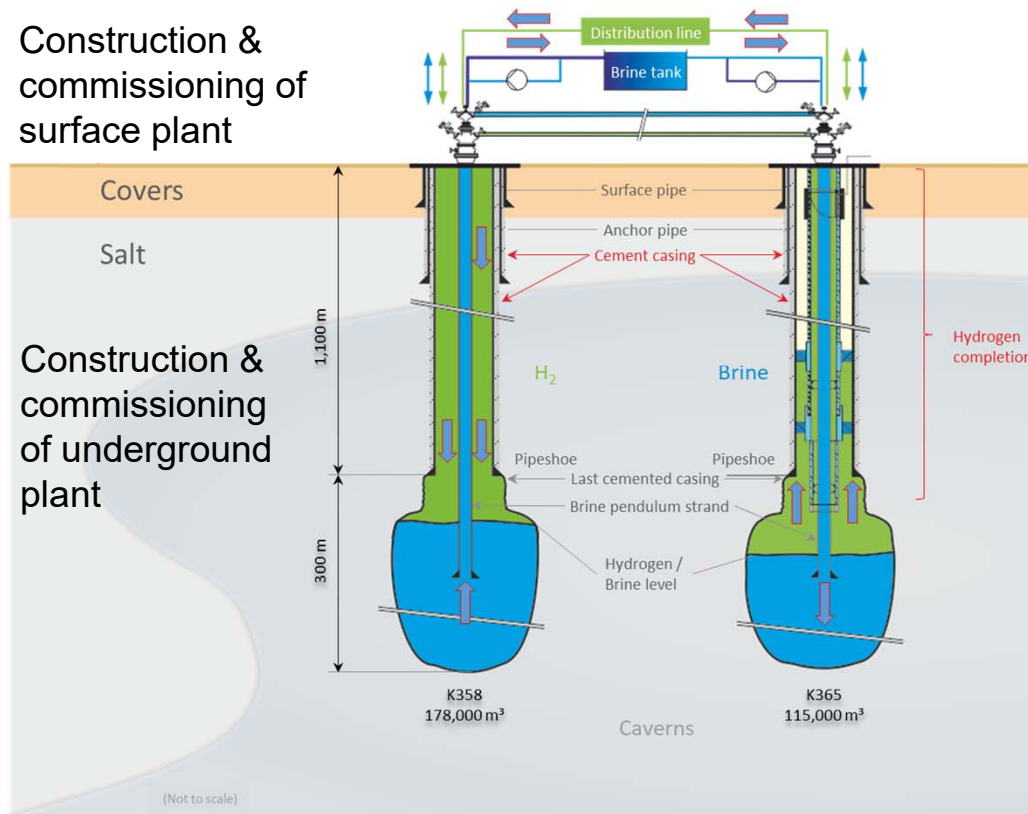
H₂CAST I: Technical Pre-Validation of H₂-Storage



STORAG ETZEL
Energy Storage Solutions

Construction & commissioning of surface plant

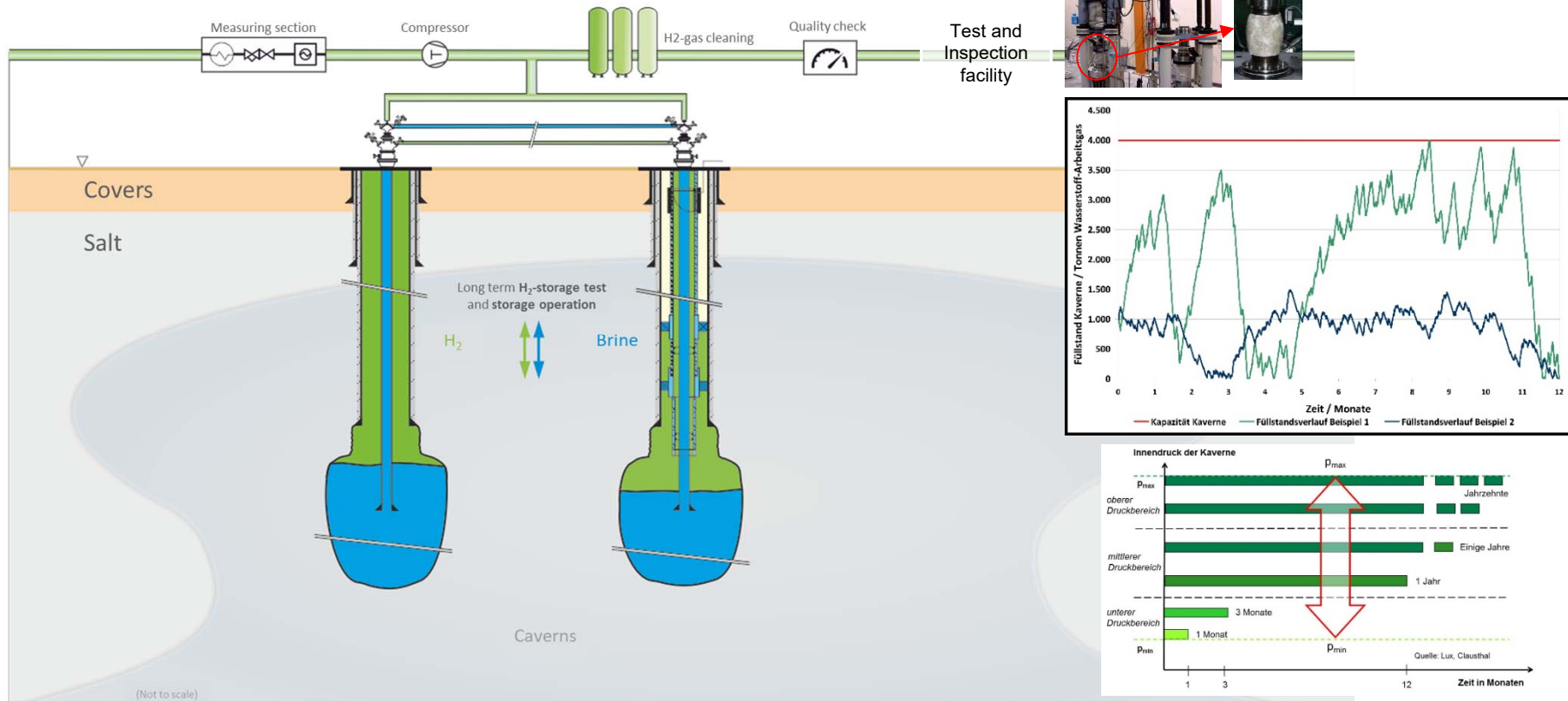
Construction & commissioning of underground plant



H₂CAST II: Long-term H₂-Storage Test



STORAG ETZEL
Energy Storage Solutions



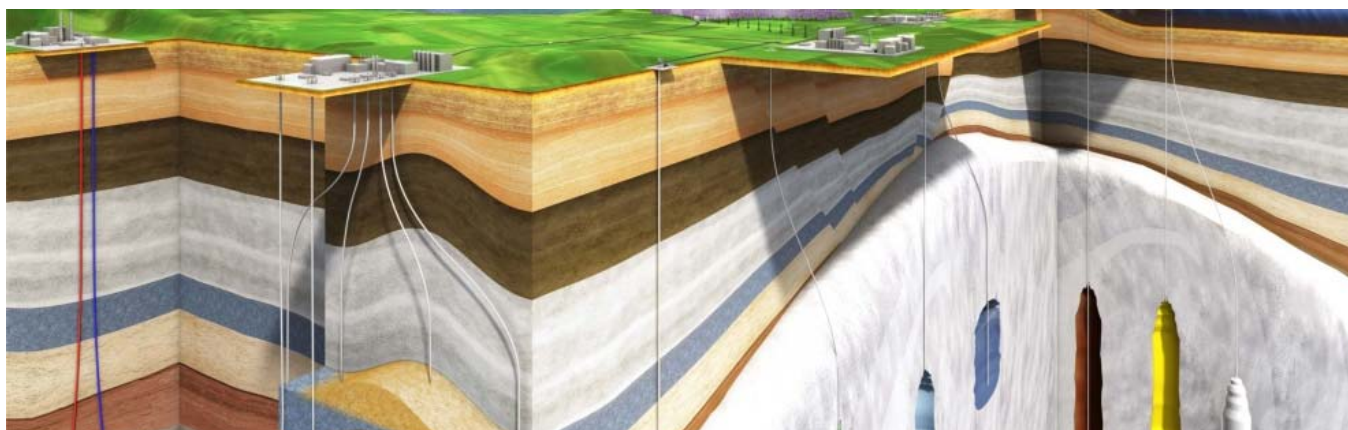
H₂CAST: Main Objectives

TRANSFORMATION

SCALABILITY

ACCEPTANCE

- Implementation of hydrogen in the future energy economy, especially infrastructure
- Demonstrate operational safety of hydrogen storage in salt caverns
 - Storage integrity and validation of equipment
 - Acceptance of operational safety and impacts of underground storage by the general public
- Explore operational fields and develop services for hydrogen cavern operations
- Development of storage facilities to ensure security of supply
 - Estimate storage needs for hydrogen and develop strategy for flexible, scalable repurposing of former oil and natural gas storage facilities in transition phase
- Interaction of underground storage with overground storage in transition from oil / natural gas to hydrogen.
- Diversity of research and (underground) storage
- Avoid environmental impact and increase of social acceptance



Summary

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- Underground storage of natural gas is a proven technology for decades
- The ongoing changes in the energy sector due to emissions reduction, decarbonization and increase of renewable energies force a transition towards alternatives for energy storage, in particular as hydrogen.
- Existing infrastructure and storage sites can be repurposed for storage of hydrogen. Available technologies, procedures, equipment have to be adapted for hydrogen storage.
- Several hydrogen research and development projects were initiated in different countries, in particular including storage caverns for hydrogen.
- According to recent studies (GIE, 2021) the conversion of existing caverns is a required element to meet the future demand for H₂ storage.

HYDROGEN STORAGE IN CAVERNS 2022

„Conversion of gas storage caverns to hydrogen storage“



Thank you for your attention.
Questions?

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