UNDERGROUND ENERGY STORAGE TECHNOLOGIES

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HYDROGEN STORAGE IN DEPLETED GAS FIELDS

Big scale storage for seasonal demand

2nd Life for Depleted Gas Fields

Used for underground storage of gas

Gas Storage Operations in Austria

Natural Gas UGS

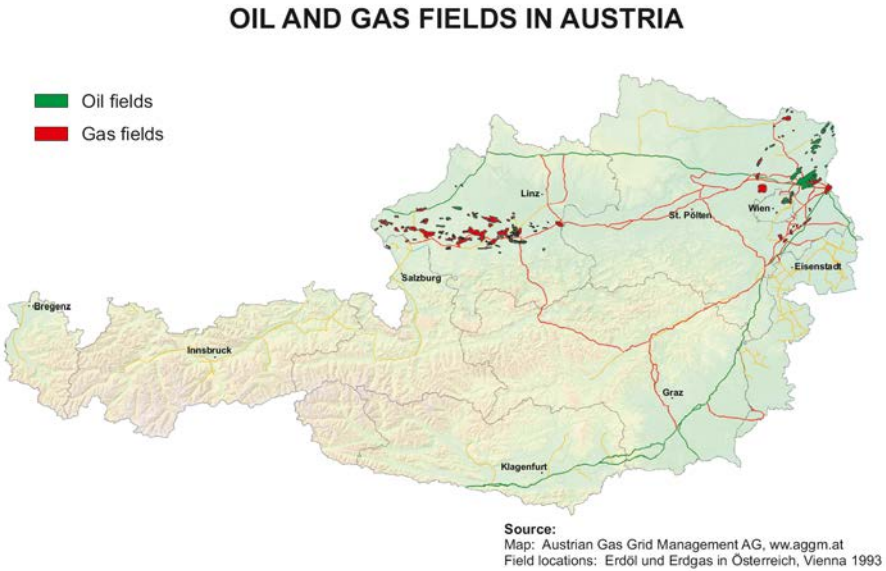
for more than 50 years

Hydrogen UHS

pilots in place

CO2 CCS

advisory for operators worldwide



50+ Years of UGS Operations in Austria: Commenced 1969

Strong Dependency on Imported Gas and Storage Capacity

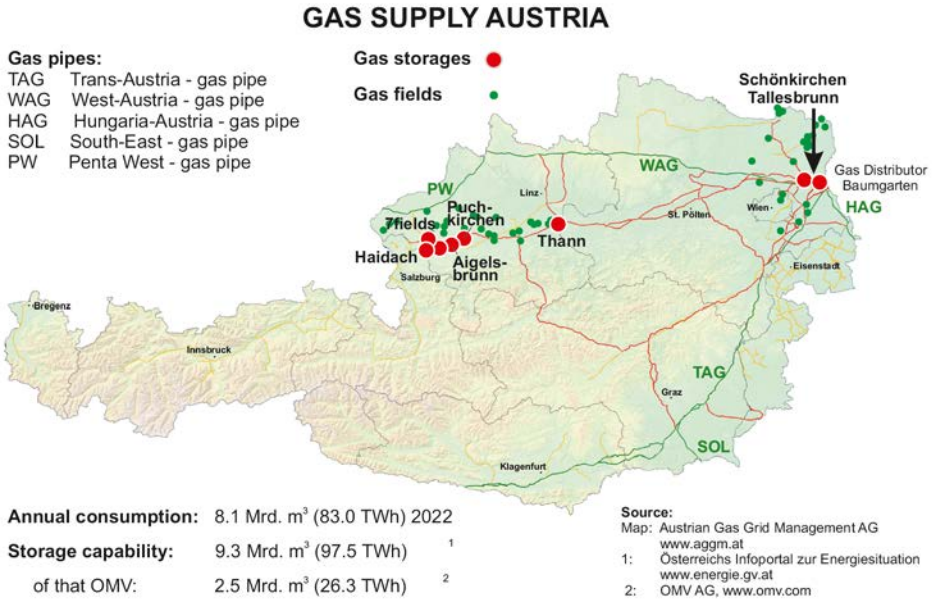
Unique Situation

Storage capacity exceeds annual demand

Large strategic reserve

Successful economic business

Continuous technology and operations upgrades



Conversion to Gas Storage Not Trivial

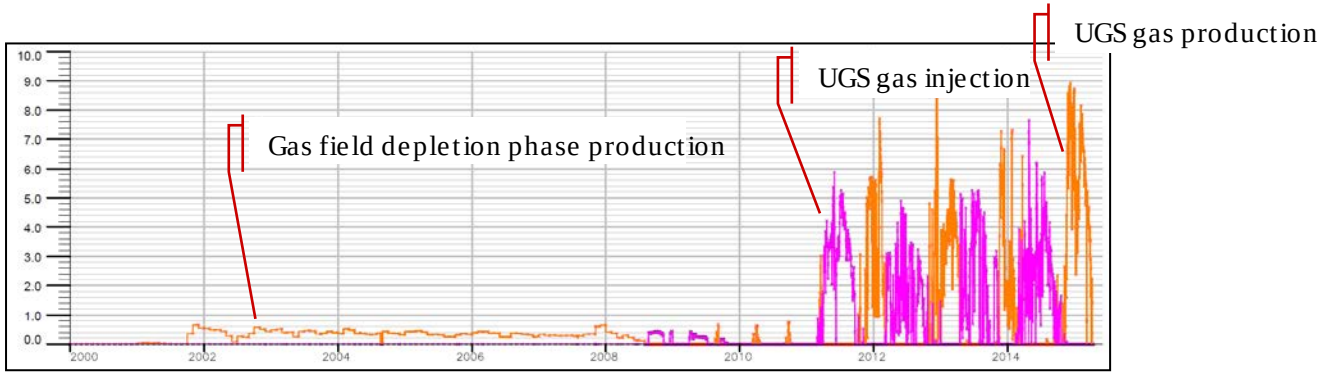
Challenges often underestimated

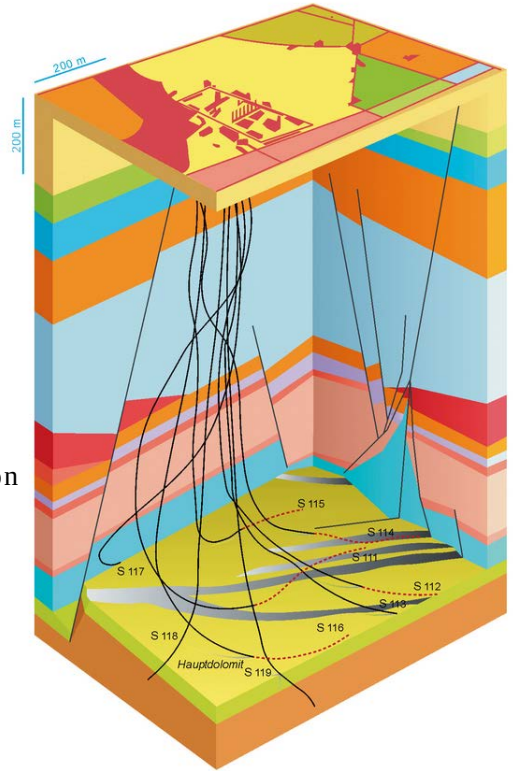
Physics Change

Pore space needs to be made accessible again

Required storage rates are typically at least an order of magnitude higher compared to depletion phase.

Working/cushion gas volume needs to be optimised





Source: astora.de

Concession-Wide Reservoir Management

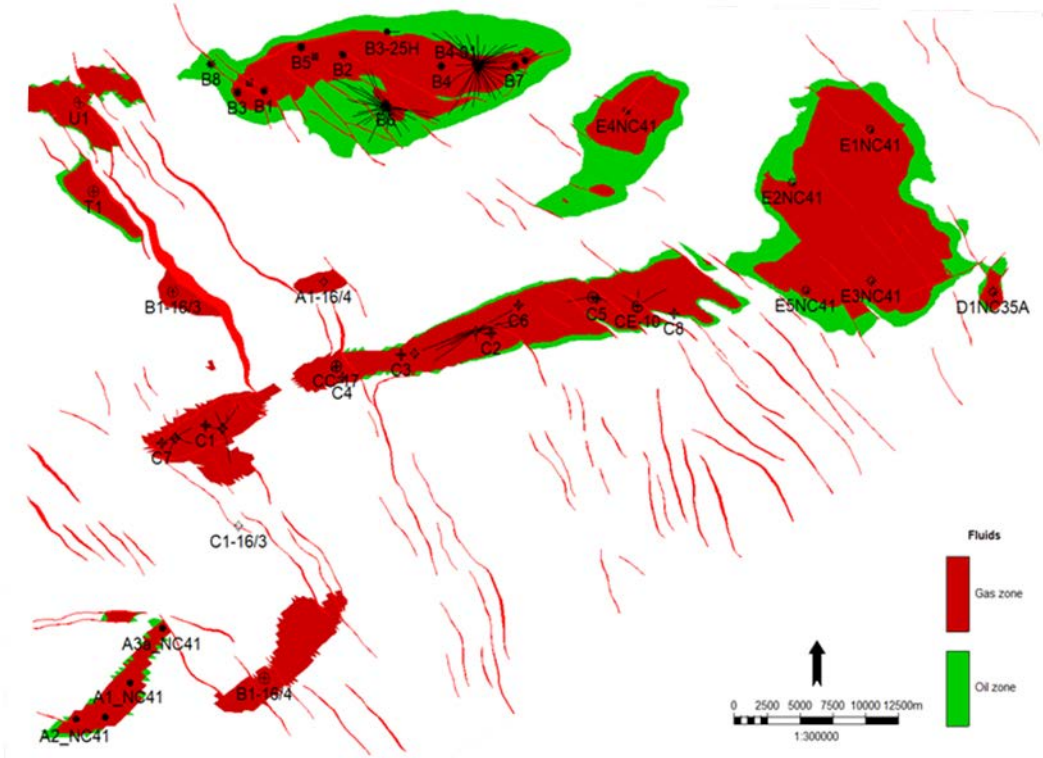
Sharing Common Aquifer

Interference with depletion operations must be considered

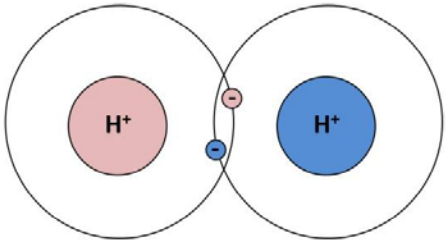
Aquifer effected by multiple operations

Might induce spill

Lower operating pressures



Conversion of Storage Specification to H2

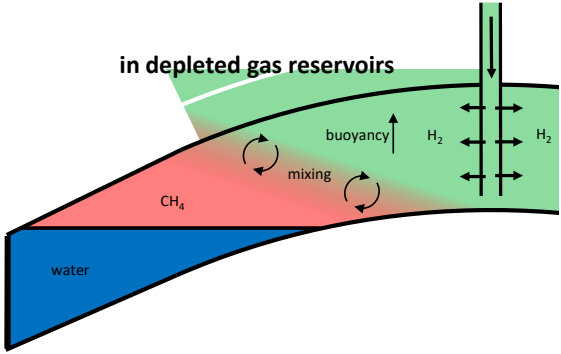


Four Times More Storage Needed

Comparison of energy content (gross calorific value)
11kWh/m³ for natural gas / 3,54kWh/m³ for hydrogen

And Hydrogen is less compressible

- Deviating physical and thermodynamic properties of H2
  - low viscosity and high diffusivity increases the potential for leakage
  - lower density than natural gas by a factor of ca. 8
  - mixing of initial and injected gas
  - gravity segregation and lateral spreading



Cushion gas becomes a significant economic factor

H2-Compatibility of Surface Facilities

Surplus load due to more dynamic operation and short-term change intervals

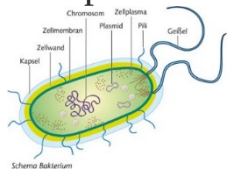
Compatibility of Materials

Hydrogen induced cracking

Hydrogen embrittlement

Increased Leakage Potential at Seals and Flanges

- Stimulation of microbiological activity
  - Loss of stored H2
  - Reduction of gas quality (e.g. generation of H2S by sulfate-reducing bacteria)
  - Decrease of injectivity and deliverability due to plugging of pore space by reaction products or biomass
  - Scaling by microbial reaction products (e.g. sulfur) or biomass
  - Microbial-induced corrosion
  - Highly corrosive conditions due to H2S or acetic acid



Source: www.bode-science-center.de

Underground Hydrogen Storage Projects

Austria is a technology leader in hydrogen storage in depleted gas fields

Underground Sun Storage

Green hydrogen storage pilot using a single well

First porous media hydrogen storage worldwide

Underground Sun Conversion

Injection of hydrogen-CO2-gas mixture, in-situ methanation and 'renewable' gas production

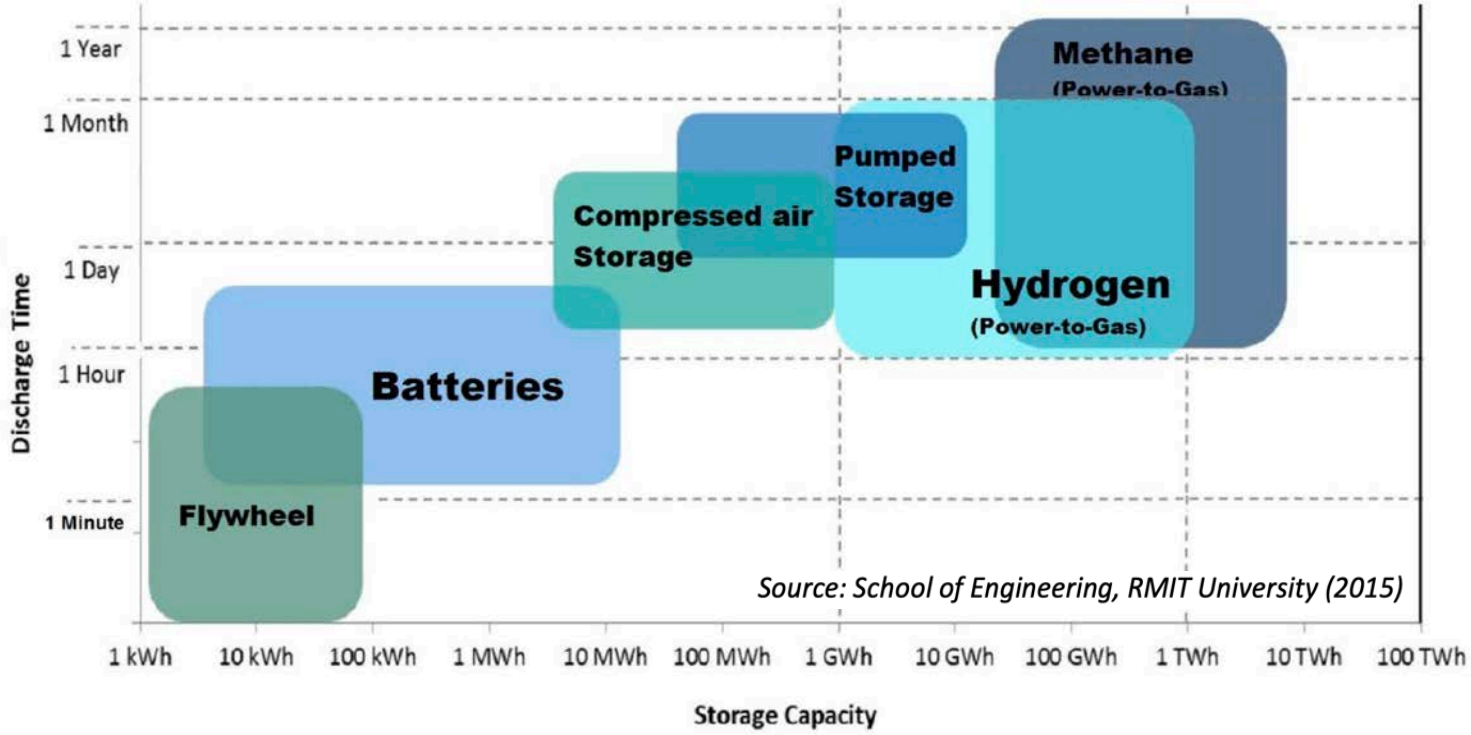
First hydrogen storage facility worldwide

100% hydrogen injection in depleted gas field

Courtesy: RAG Austria AG

Available Energy Storage Technologies

Big scale storage needed to compensate differences in seasonal demand



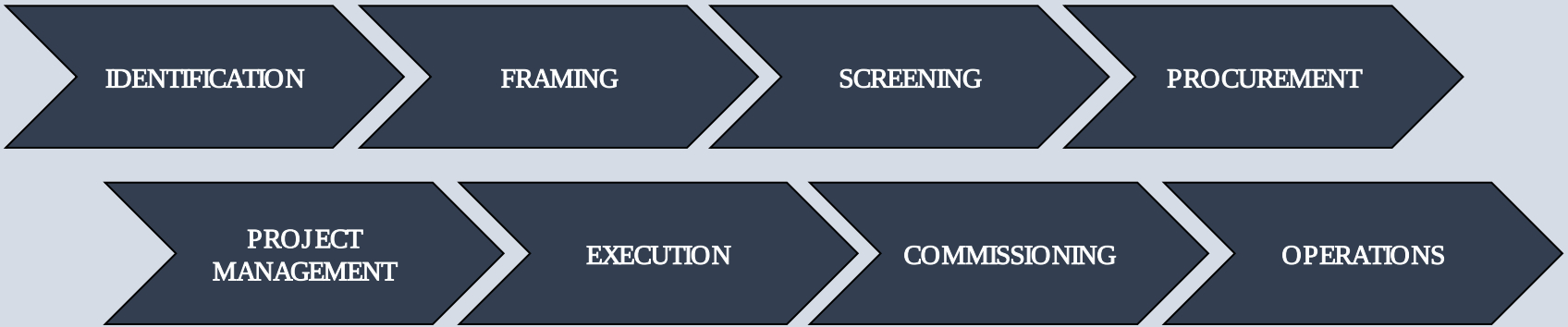
Source: School of Engineering, RMIT University (2015)

Austria has 50+Years of Gas Storage Experience

And many lessons learned …

Methodology, geological, technical, economic, legal, financial and regulatory

Throughout all project stages, from identification, framing, screening, procurement, project management, execution, commissioning and operations



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ENERGY, BUT WITH THE ENVIRONMENT IN MIND

UGS, CCU/CCS, Hydrogen, Geothermal

THANK YOU