Unabhängige Unternehmensgruppe des DVGW

DBI Gruppe

www.dbi-gruppe.de

9th HIPS-NET Workshop

Underground Hydrogen Storage

Nazika Moeininia, Cindy Kleinickel, Hagen Bültemeier

DBI Gas- und Umwelttechnik GmbH

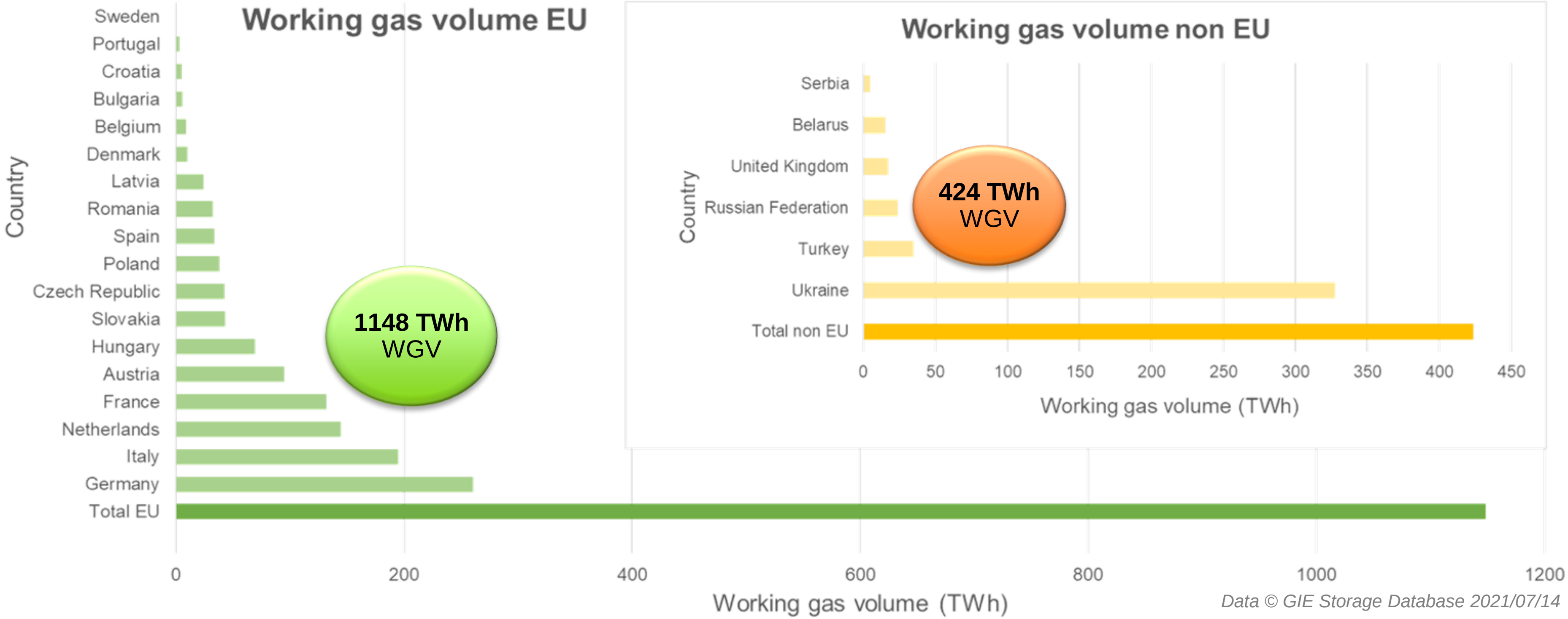
9th HIPS-NET Workshop, Web Conference

Agenda

DBI Gruppe

Hydogen – Energy Carrier of the Future

Underground Gas Storage Europe – Overview



Data © GIE Storage Database 2021/07/14

→ TOTAL working gas volume of natural gas in EUROPE **1572 TWh**

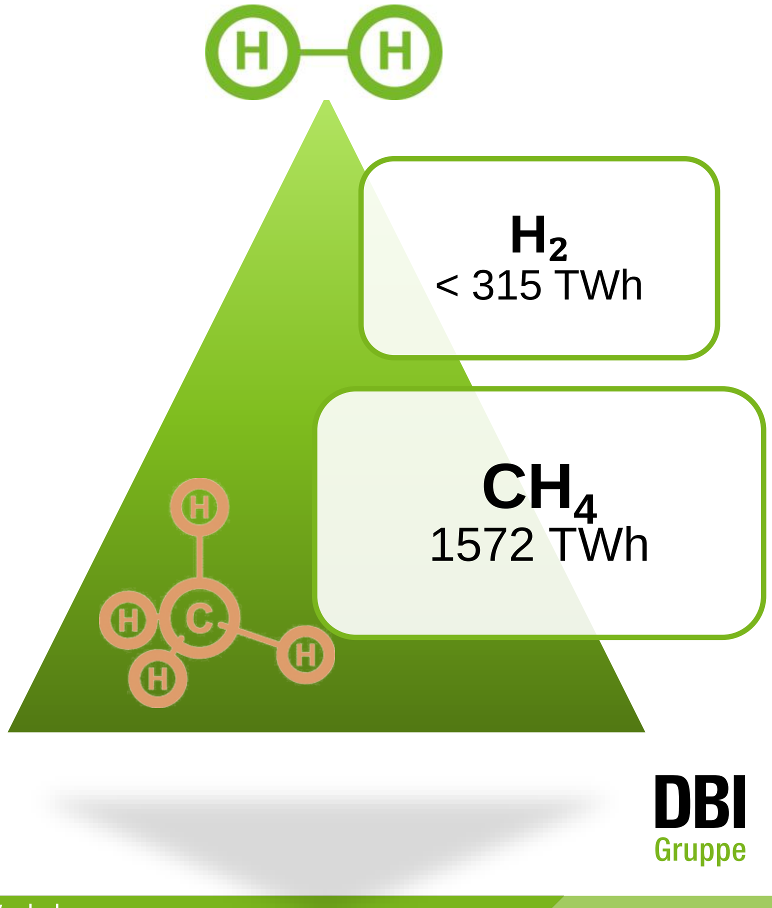
DBI Gruppe

Gas Storage Europe – Overview

Capacities by Type (Total Europe)

Type/Status	Operational	
	TWh	**No.**
Aquifer	88,7	27
Depleted field	761,7	87
Rock Cavern	0,1	2
Salt cavern	203,4	61
VGS - multiple types	518,4	
Europe total	**1572,2**	**177**

Data © GIE Storage Database 2021/07/14

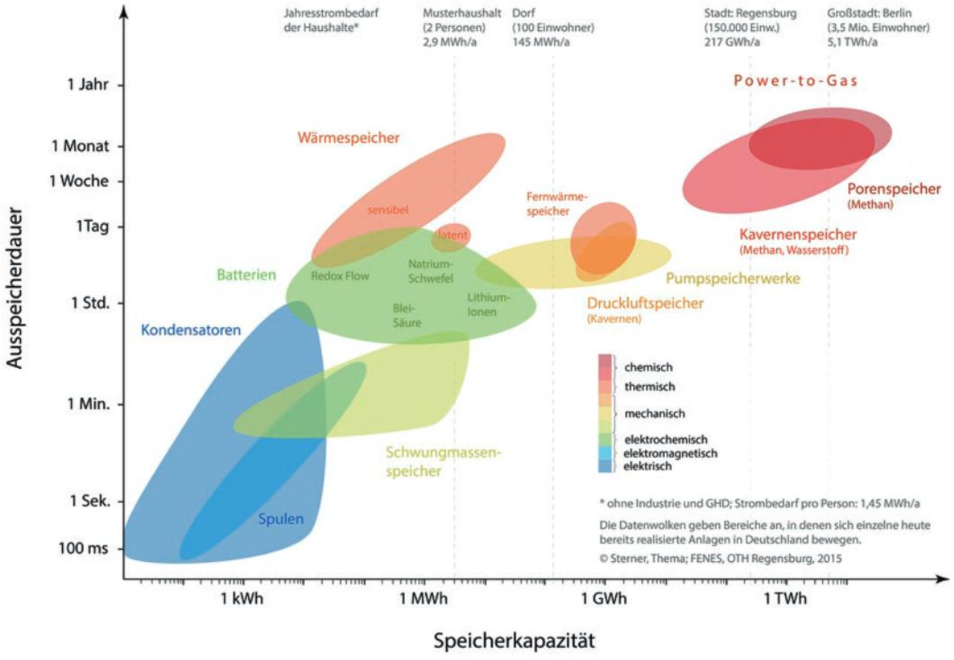


Hydrogen Storage Potential (Theoretical)

- Factor 1.6 lower in terms of volume then natural gas
- Factor 3.5 lower in terms of energy then natural gas

DBI Gruppe

Why (Underground-) Hydrogen Storage?



Michael Sterner et al (2017): Energiespeicher, Springer Vieweg

- **Short-term storage**
  - Capacitors, coils (electric)
  - Flywheel mass storage
  - Batteries (electrochemical)
  - Latent heat accumulators
  - Compressed air storage
  - Pumped storage plants (most of them)
- **Long-term storage**
  - Cavern storage
  - Pore storage
  - some thermal storages
  - some pumped storage plants

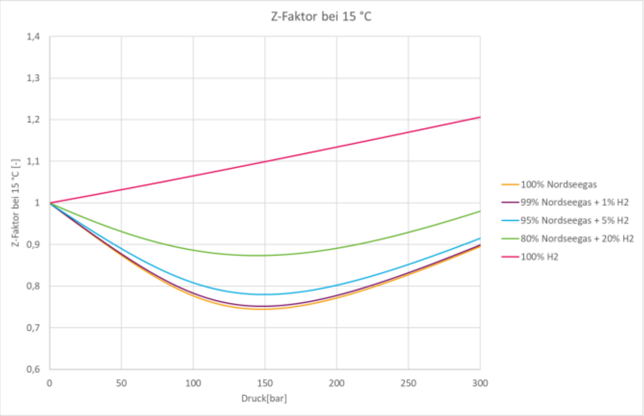
→ Chemical energy storage systems are in the required order of magnitude with required ranges

DBI Gruppe

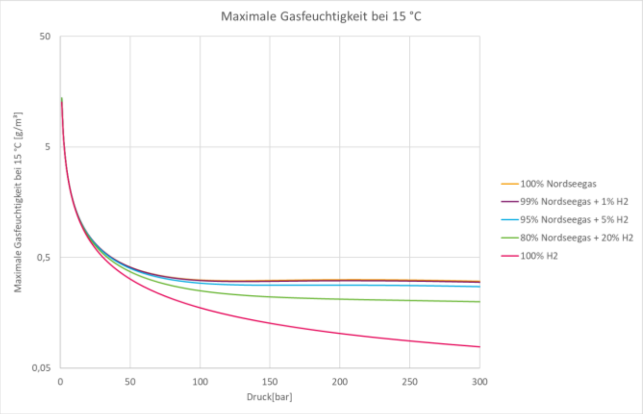
Hydrogen Underground Storage – Status quo

Hydrogen underground storage – status quo

- **Aspects affecting the underground storage of hydrogen (UGS)**
  - **Gas properties**
    - » Hydrogen is smallest gas molecule
    - » Highly diffusible
    - » Lower density, compressibility and energy content by volume compared to natural gas
  - **Working gas volume (WGV) and stored energy**
    - » Depending on gas density, compressibility and operating pressure range of UGS
  - **Operation**
    - » Pressures in the wellbore
    - » Flow velocities
  - **Material and functionality of equipment**
  - **Quality demands: affected by**
    - » hydrogen production process
    - » storage type (The storage of gases in geological formations leads to quality changes depending on the type of UGS and previous use)
    - » as well as the transport of the hydrogen (pipeline)



© ESK GmbH, Z-Factor of Hydrogen (-blends)



© ESK GmbH, Maximum water content of Hydrogen (-blends)

Hydrogen underground storage – status quo
WGV and stored energy, example numbers for Germany

- **Basis**
  - $p \cdot V = m \cdot R_i \cdot T \cdot Z(p,T)$
  - $V_N = V_{(p,T)} \cdot \frac{p_{res}}{p_N} \cdot \frac{T_N}{T_{res}} \cdot \frac{1}{Z(p,T)}$
  - $WGV_{H_2} \cdot \frac{p_N}{p_{Res}} \cdot \frac{T_{Res}}{T_N} \cdot Z(p,T)_{H_2} = WGV_{NG} \cdot \frac{p_N}{p_{Res}} \cdot \frac{T_{Res}}{T_N} \cdot Z(p,T)_{NG}$

- **Conversion**

$$WGV_{H_2} = WGV_{Natural\ Gas} \cdot \frac{Z(p,T)_{Natural\ Gas}}{Z(p,T)_{H_2}}$$

Types of UGS	Cumulative storage capacity of existing UGS in Germany			
	Natural gas WGV	Natural gas WGV	H_2-WGV	H_2-WGV
	Mio. m^3 i.N.	TWh	Mio. m^3 i.N.	TWh
Pore UGS	8.615	92.671	5.952	18
Cavern UGS	15.087	162.106	10.244	31
Total	**23.702**	**254.777**	**16.196**	**49**

$\boldsymbol{p}$: pressure, $\boldsymbol{V}$: Volume, $\boldsymbol{R_i}$: special gas constant, $\boldsymbol{T}$: Temperature, $\boldsymbol{Z}$: Z – Factor, $\boldsymbol{WGV}$: *Working gas volume*

→ The amount of energy stored depends on the calorific value (approx. 3.5 x lower than natural gas)

DBI Gruppe

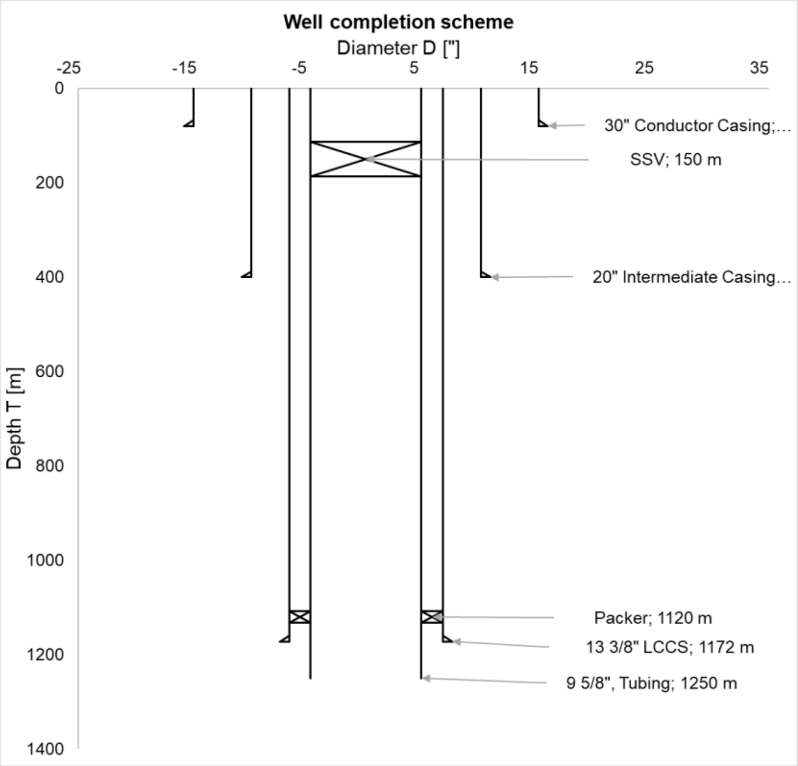
Operation:
Pressure development in boreholes and impact on compressors

Static

- $BHP = WHP \times e^{S}$

Example		
h	1200	m
dv	0,069561077	
Temperature at WH	10	°C
Temperature at BH	50	°C
WHP	175	bar
$Z_m = f(P_m, T_m)$	1,0716	
s	0,10185371	
BHP	**193,76**	**bar**

$\boldsymbol{BHP}$: Bottom Hole Pressure
$\boldsymbol{WHP}$: Well Head pressure
Hydrostatic Component: $\boldsymbol{s} = \frac{g \cdot h}{T_m \cdot R_i \cdot \boldsymbol{Z_m}}$



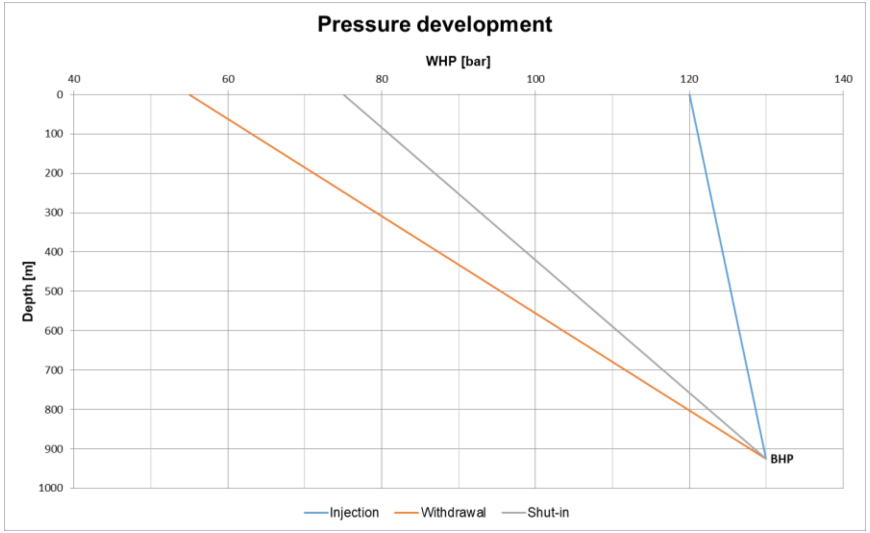
© DBI, example of well complition scheme

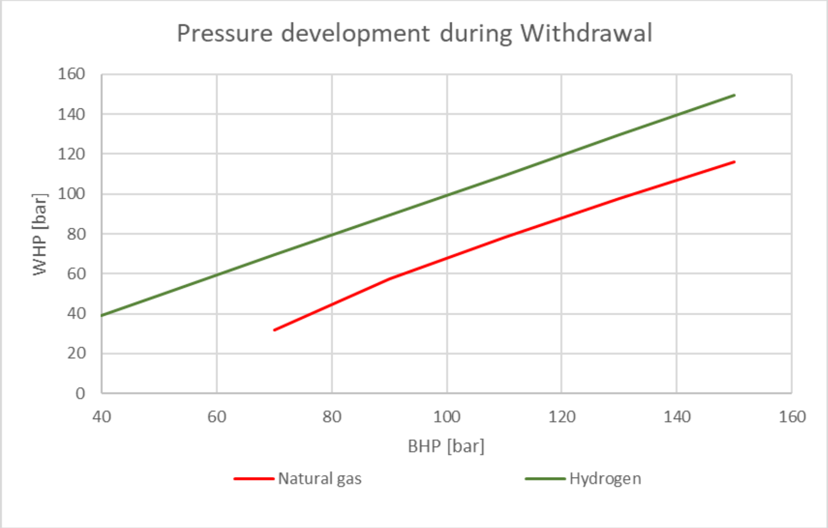
DBI Gruppe

Operation:
Pressure development in boreholes and impact on compressors

$$BHP^2 = WHP^2 \times e^{2S} \pm \theta \dot{V}_n^2 \dot{V}_n$$

Static component and **dynamic friction losses**: $\boldsymbol{\theta} = 1.137 \cdot 10^4 \cdot \frac{\lambda \cdot T_m^2 \cdot \boldsymbol{Z_m^2}(e^{2s}-1)}{d^5}$





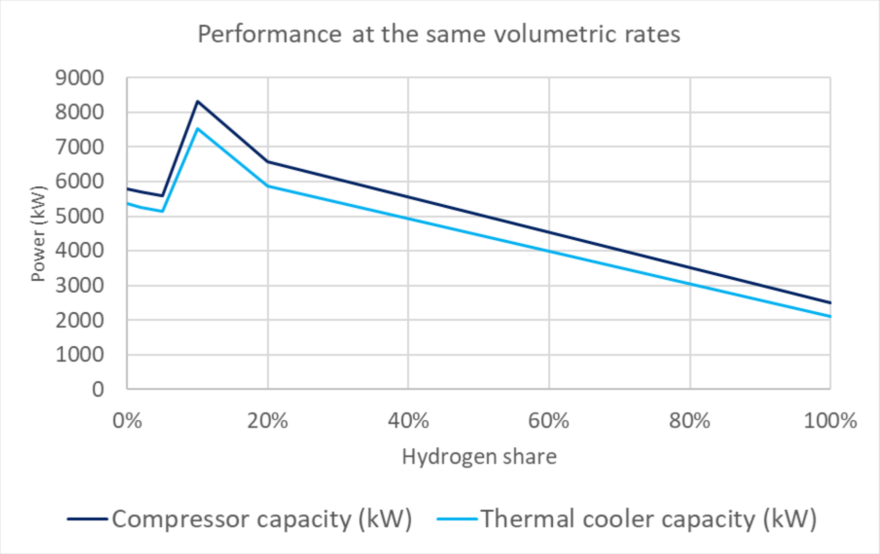
→ $BHP_{H_2} = BHP_{Natural\ gas} \rightarrow WHP \uparrow$ → Pressure on compressor increases

→ $WHP_{H_2} = WHP_{Natural\ gas} \rightarrow max.BHP \downarrow$ → WGV is reduced further (lower operating range of UGS)

DBI Gruppe

Operation:
Pressure development in boreholes and impact on compressors

- $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\kappa-1}{\kappa}}$
- $P = \dot{m} \cdot c_p \cdot (T_2 - T_1)$
- $\dot{Q} = \dot{m} \cdot c_p \cdot (T_3 - T_2)$
- T_1 und P_1: $Compressor\ inlet\ temperature\ \&\ Pressure$
- T_2 und P_2: $Compressor\ outlet\ temperature\ \&\ Pressure$
- T_3: $Outlet\ temperature\ of\ cooler$
- $\dot{Q}$: $Cooling\ Power, \dot{m}$: $Mass\ flow\ rate\ \&\ P$: $Power$



© DBI, Compressor performance (Generic example)

→ Up to approx. 5 % by volume H_2: isentropic exponent changes only insignificantly ($\dot{m}\downarrow$)

→ Up to approx. 20 vol.% H_2: $\dot{m}$ decreases and isentropic exponent changes significantly

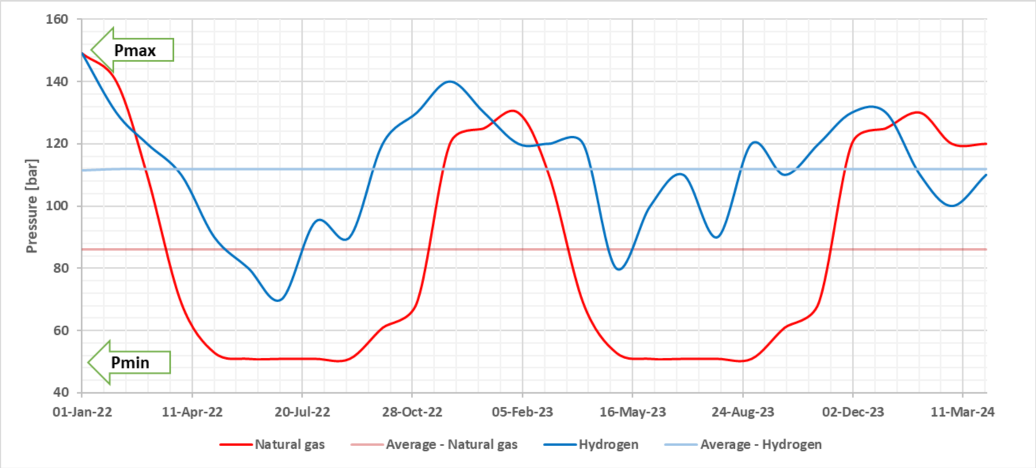
→ Up to 100 % H_2: Power decreases due to strongly decreased $\dot{m}$

DBI Gruppe

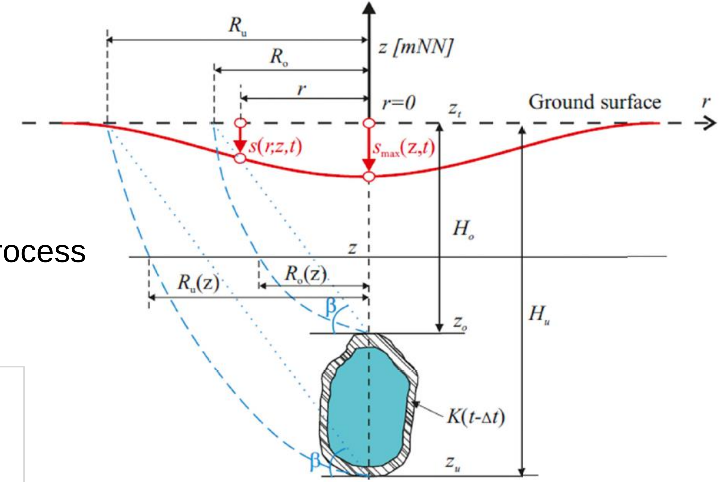
Operation: cycles and convergence (cavern-UGS)

Operation Cycles

- Multi-cyclic possible in H_2-operation
  - » Changed average cavern pressure
- Surface subsidence
  - » Change of P_{max}, P_{min}, P_{avg}, Temperature, cycles during withdrawal process
  - » Change of mechanical properties of salt - convergence
  - » WGV-Development



© DBI, Generic example



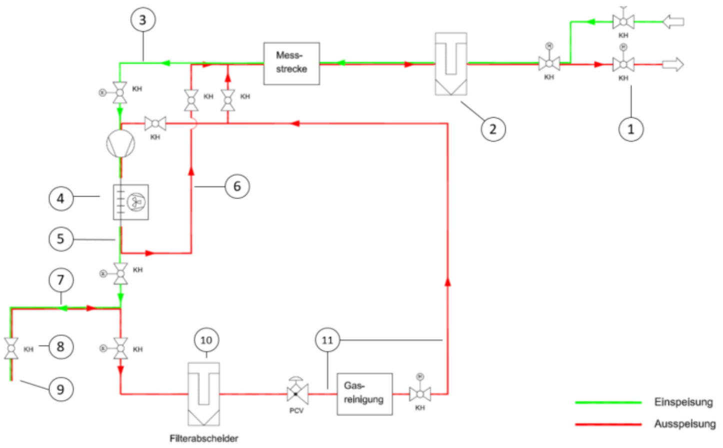
Scheme Subsidence as result of cavern convergence
© Sroka et. al, Freiberg, 2017

Average: $P_{Avg} = \sum P_i t_i \; and \; t_i = \frac{t}{365}$

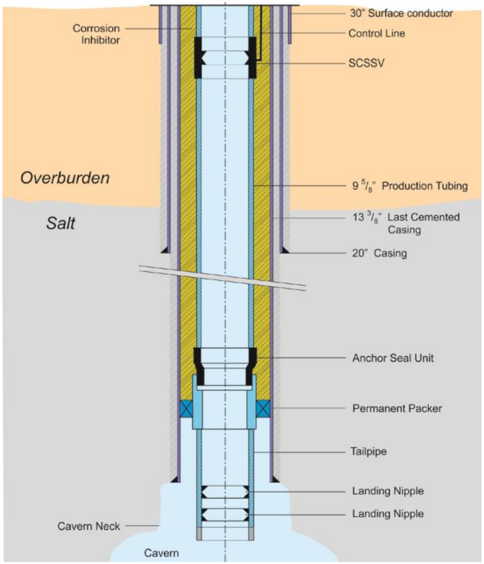
Material and functionality of equipment
Main components of a UGS

Hydrogen has special thermodynamic, fluid dynamic, energetic, and corrosive properties that affect storage, operation, and equipment

- **Surface facility**
  - » Compressor
  - » Gas treatment
- **Well equipment**
  - » Tubing
  - » Packer
  - » SSV
- **Storage formation**
  - » Microbial and geochemical processes,
    relevant for pore storage



Stylized P&ID surface facility © DBI-Gruppe

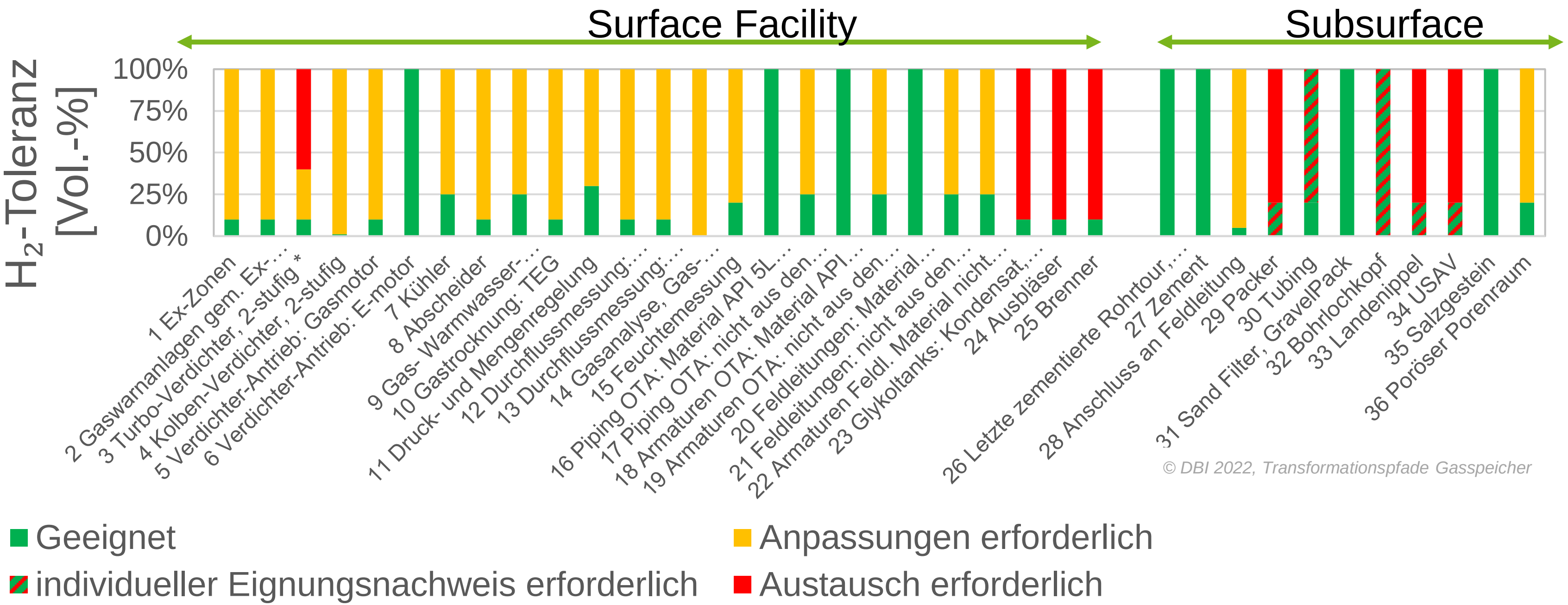


© DEEP.KBB GmbH: sample completion, cavern well

DBI Gruppe

Material and Functionality of Equipment

Actual Tolerance of equipment: results project „Transformation paths UGS“



→ Cavern Storage: Evaluate material and function

→ Pore Storage: additional evaluation processes in the geological porous formation

DBI Gruppe

Further Research demand

Further Research demand: materials for subsurface well completion

Material assessment according to EIGA-guideline, no specific knowledge for API-steels. Some practical short – mid-term experience was gathered in projects.

- » Austenitic metal grids
- » Carbon equivalent less than 0.35 %
- » Yield strength below 830 MPa
- » Phosphorus content ≤ 0.015 %and sulfur content ≤ 0.025%, etc.

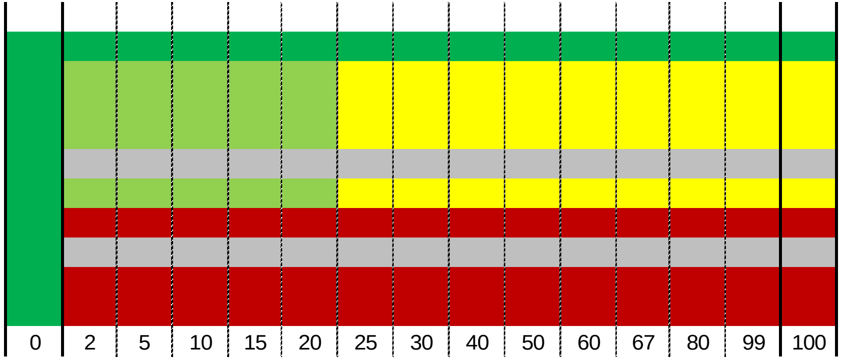
Well completion		Material	C-content	Mn-content	Mo-content	Cr-content	V-content	Ni-content	Cu-content	C.E	Max. Sulfur content	Max. Phosphorus content	Yield strength	HRC	HB	Suitability
			[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[Mpa]	[-]	[-]	
Casing	Section 1, 32"									0						Does not come into contact with the storage medium
	Section 2, 18 5/8"	**N80**								0	**0,03**	**0,03**	**758**			
	Section 3, 18 5/8"	**K55**								0	**0,03**	**0,03**	**552**			
	Section, 13 3/8"	**N80**								0	**0,03**	**0,03**	**758**			
	Section 5, 13 3/8"	**N80**								0	**0,03**	**0,03**	**758**			
	Section 6, 13 3/8"	**N80**									**0,03**	**0,03**	**758**			
	Section 7, 13 3/8"	**N80**								0	**0,03**	**0,03**	**758**			
Tubing	Steel pipe	**C75**	0,75	0,7	0,01	0,4	0	0,4	0	0,96166667	0,025	0,025	880		241	Not suitable
	Thread	**C75**	0,75	0,7	0,01	0,4	0	0,4	0	0,96166667	0,025	0,025	880		241	Not suitable
	Tubing Hanger	**F6NM**	0,05	1,5	0,5	13	0	4	0	2,81666667	0,015	0,04	520		245 - 309	suitable
	transition	**AISI 4140**	0,405	0,875	0,2	0,95	0	0	0	0,7425	0,04	0,04	655	22		Not suitable
Flow coupling	9 5/8"	**AISI 4130**	0,305	0,5	0,2	0,95	0	0	0	0,58	0,04	0,04	655	23		Not suitable
	7"	**AISI 4140**	0,405	0,875	0,2	0,95	0	0	0	0,7425	0,04	0,04	655	22		suitable

© DBI: Material evaluation according to EIGA-guideline and ISO/TR 15916, 2015; example of a cavern well

Further Research demand: materials for subsurface well completion

For subsurface well completion materials, suitability of many components unclear yet. Some practical experiences exist.

		Material specified by the company	Evaluated material
Casing	Section 7"	J55	J55
	Liner 5"	K55	K55
Tubing	Section 4 1/2 "	J55	J55
	Section 3 1/2"	K55	K55
	transition 4 1/2" x 3 1/2"		
	tubing 3 1/2"	K55	K55
	Flow Coupling	AISI 4140	42CrMo4
	Sliding Side Door		
	Overshot Tubing Seal Divider	42CrMo4	42CrMo4
	LN with wireline shoe	42CrMo4	42CrMo4



Legend: Possibilities of hydrogen admixture to natural gas

Suitable | Possible according to experience | Case-by-case consideration or adjustment required | Not Suitable | No statement possible at

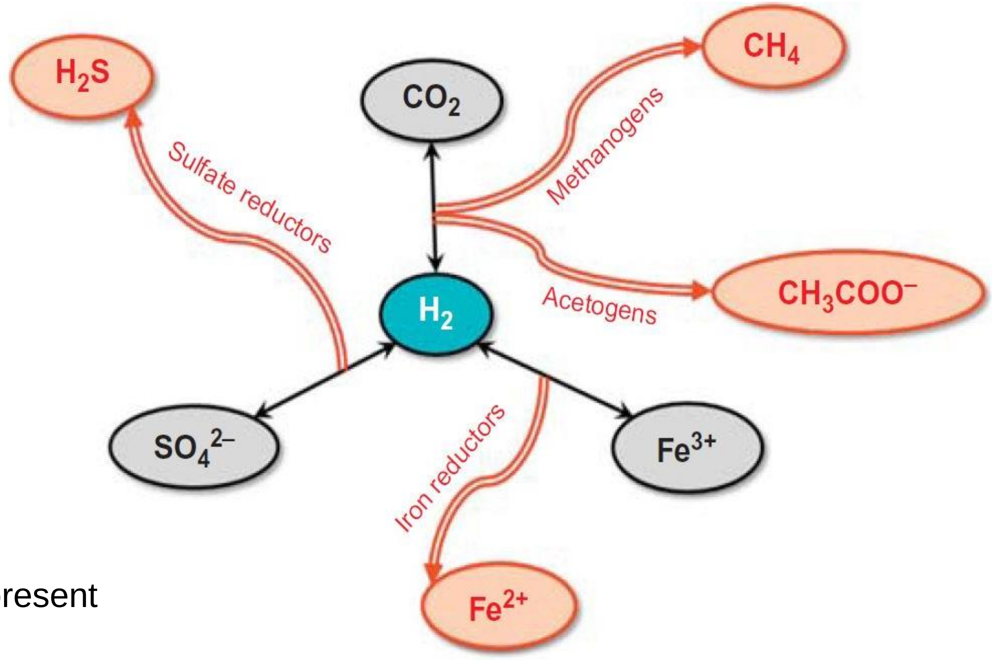
© DBI: Material evaluation according to EIGA-guideline and ISO/TR 15916, 2015; example of a cavern well

→ DVGW-UGS-Kompendium (G 202143): 1st May 2022 – 31st August 2023

→ Casing below Packer – Current discussion

Further Research demand:
suitability of porous UGS, processes in the reservoir

- **Heterogenity of the reservoirs**
  - Hysteresis
  - Gas mixing processes WGV – CGV
  - Dispersion
- **Microorganisms**
  - Present based on reservoir condition
- **Salinity**
  - Salinity↑ → H_2 solubility ↓
  - Hydrogen solubility in water
  - Gas loss
    - » Biomethanation possible, if CO_2 source present

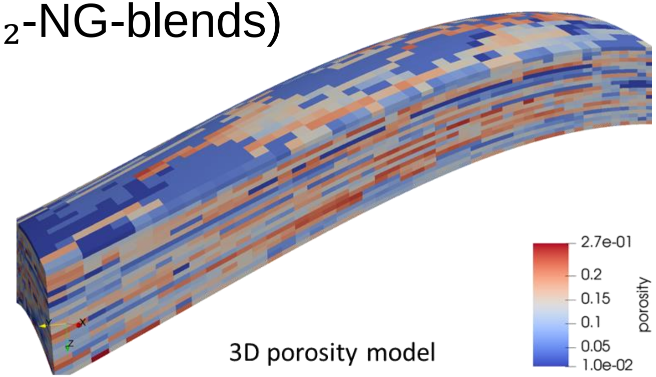


→ Pore UGS are also important to achieve climate protection goals and to provide the required H2-storage capacities (until 2045)

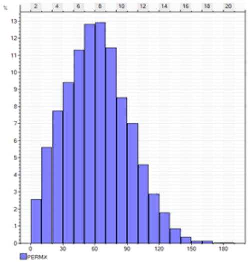
DBI Gruppe

Further Research demand: suitability of porous UGS, processes in the reservoir

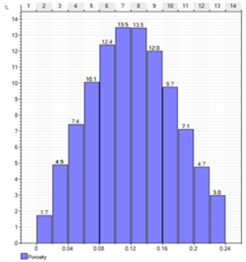
- Investigation of effects of gas properties (H_2 und H_2-NG-blends)
  - Large difference in density
  - Large difference in viscosity
  - Large difference in compressibility
  - (competitive) gas solubility in (saline) water
- Main questions
  - Gas mixing behaviour, WGV (H_2) – CGV (Natural Gas)
    - Structure of UGS, tilting angles, thickness, Aquifers,...
    - Pore structure
    - Well Locations and storage operation regime
  - Transmissivity
  - Diffusion, Dispersion



3D porosity model



Permeability of fluvial facies



Porosity of Aeolian facies

→ Clarification of Gas composition after withdrawal

→ required effort for treatment and purification

DBI Gruppe

Further Research demand:
suitability of porous UGS, processes in the reservoir

Special topics

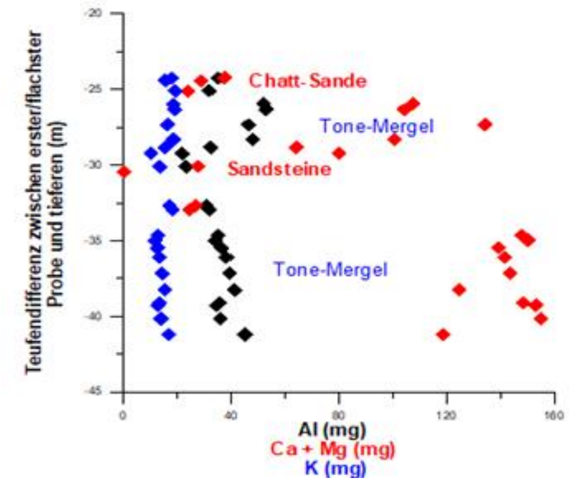
- Microbial gas conversion processes
- Microbial growth, Pore-Plugging (bio-film generation)
- Geo-chemical rock alteration

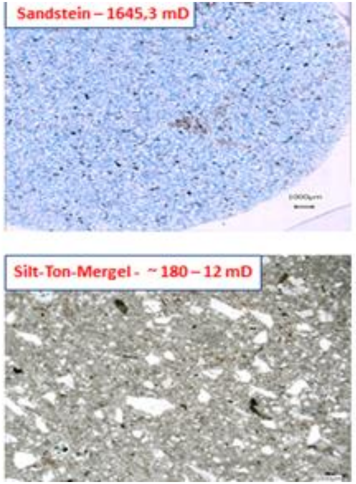
$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

$$2CO_2 + 4H_2 \longrightarrow CH_3COOH + 2H_2O$$

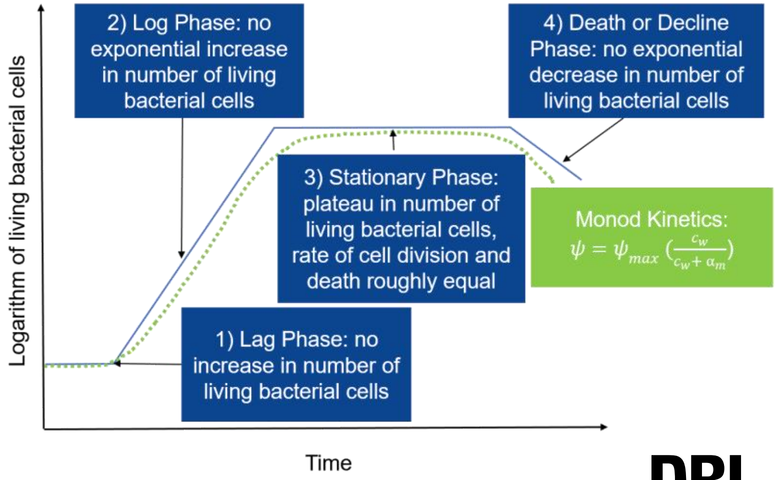
$$SO_4^{2-} + 5H_2 \longrightarrow H_2S + 4H_2O$$

$$3Fe_2^{III}O_3 + H_2 \longrightarrow 2Fe_3^{II}O_4 + H_2O$$





Heterogeneity rock minerals © FSU Jena



Overview microbial processes in reservoirs © Parker et. al, 2018

DBI Gruppe

Thank you very much for your attention!

Your contact

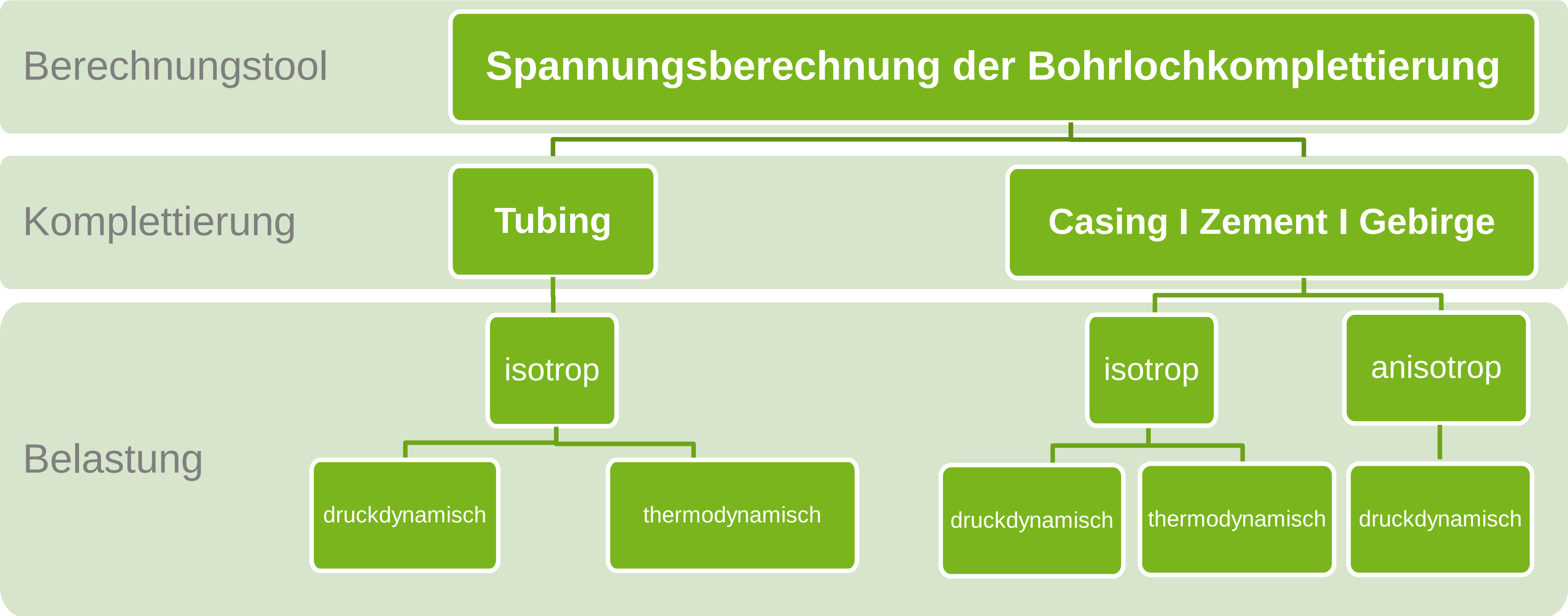
Nazika Moeininia
Project Manager/Reservoir Engineer

Tel.: +49 (0) 3731 4195 362
E-Mail: nazika.moeininia@dbi-gruppe.de

DBI Gas- und Umwelttechnik GmbH
Karl-Heine-Straße 109/111 · D-04229 Leipzig

www.dbi-gruppe.de

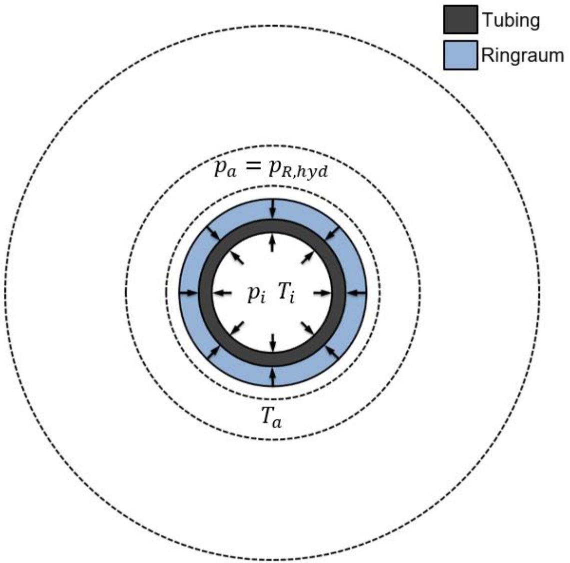
Well Integrity



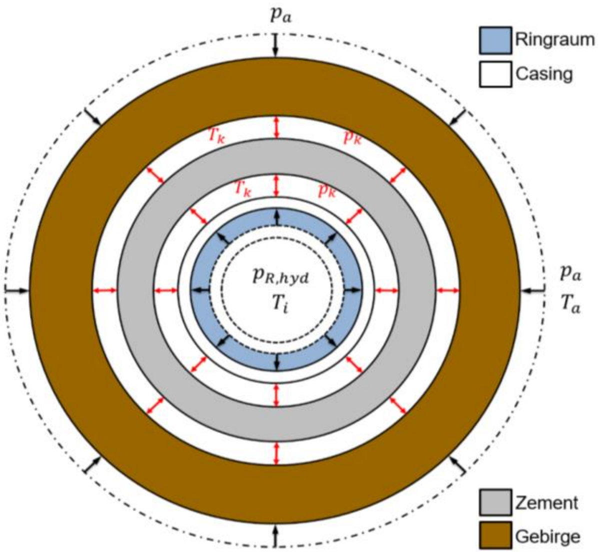
→ DBI eigenes Berechnungstool zur Spannungs- und Stabilitätsberechnung

DBI Gruppe

Well load - Tubing subsystem vs. Casing subsystem - Cement - Formation



© DBI, Well load in subsystem Tubing - Isotropic

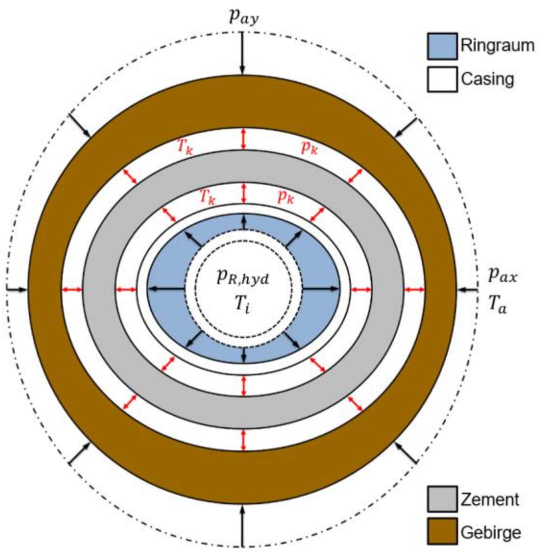


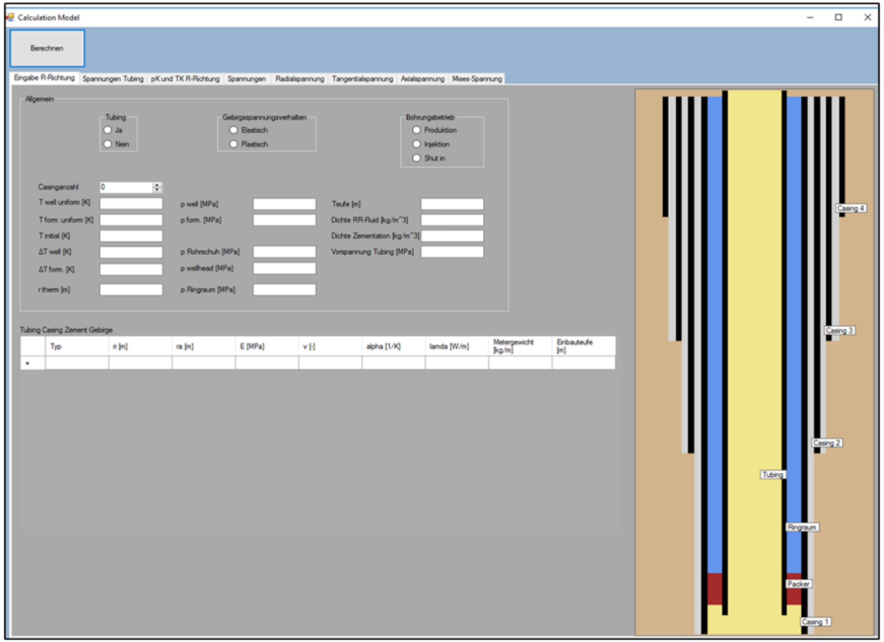
© DBI, Well load in subsystem Casing-cement-formation - Isotropic

→ Isotropic load in the tubing subsystem

Well Integrity

Stress calculation in borehole completions Casing - cement - formation subsystem

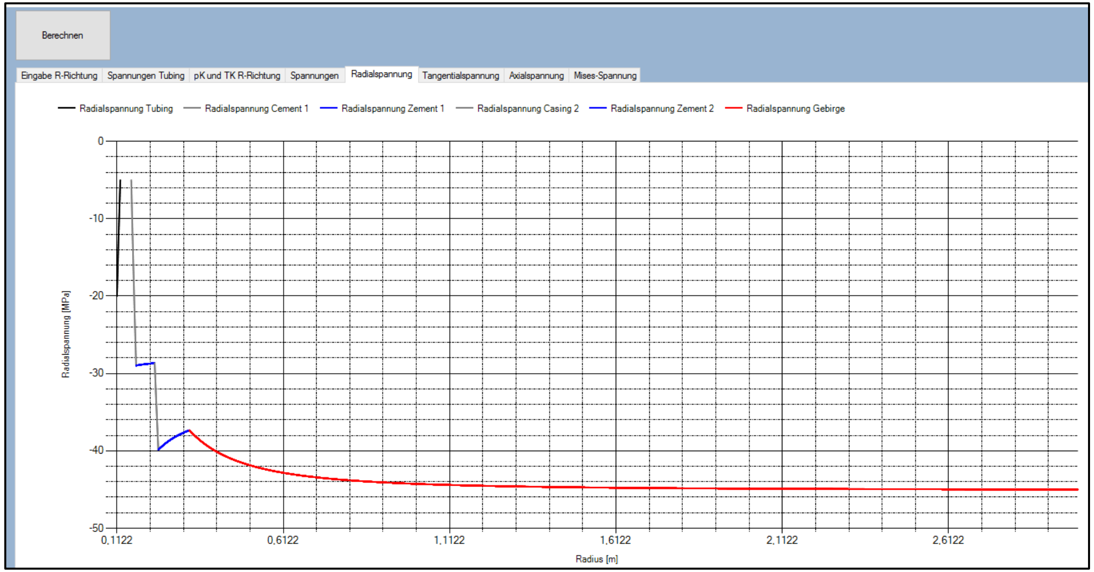




→ Contact pressure is difficult to calculate mathematically→ numerical simulation is necessary

→ Numerical calculation tool

Bohrungsintegrität (Beispiel)



Teufe [m]	Anfahren S_t [-]	Einspeichern S_t [-]	Ausspeichern S_t [-]
0	1,92	1,92	2,56
1230	2,95	2,72	4,07

Beispiel: Ergebnisse Integritätsberechnung Tubing

$$S = \frac{\sigma_R}{\sigma_{V,Mi}} \leq 1,25$$

→ Prüfung bestehender Casing-Komplettierung auf Standsicherheit für H_2-Betrieb

DBI Gruppe