Underground Sun Storage

Seasonal Storage of Renewable Energy in depleted Gas Reservoirs

Latest Results of an in-situ Field Experiment

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RAG Austria - Company Profile

- Among leading Underground Gas Storage Operators in Europe
- State of the art and most innovative Storage Operator
- Storage capacity 66 TWh (6,0 bcm)

Our vision:

- Positioning RAG’s assets in a changing energy system

UNDERGROUND SUN.STORAGE

Electricity Storage ≠ Energy Storage

Electricity Generation
from renewable sources

H2, Methane

Gasgrid

Electricity Storage

≠

Gas Storage = Energy Storage

Grid Balancing

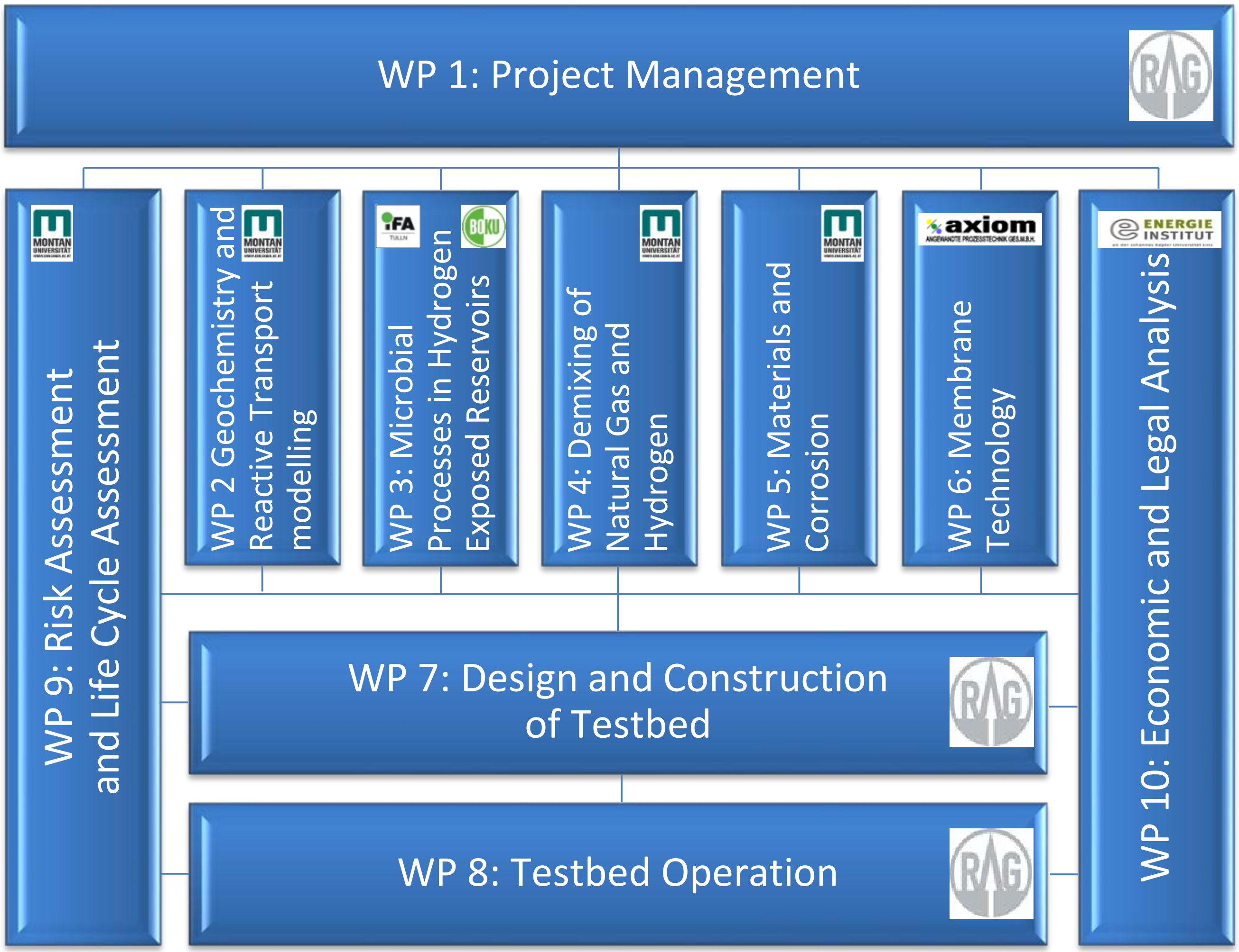
Day-Night Shift

20% Electricity	30% Mobility	50% Heating/Cooling Industry

Energy Demand

Development of the Underground Sun Storage Project

- Motivation
  - Gas Storage is Energy Storage
  - Gas Storage is ‘invisible‘ and ‘available on demand‘-Energy
  - Gas has an existing infrastructure in many regions of the world
  - Gas can be greened from 0-100% without changing the system
- Goals of the Project
  - Demonstration of Storability of renewable gases in Gas Storage facilities
  - Research on effects of 10% hydrogen admixtures in existing Gas Storage Facilities
- Partners



WP: Work Package

WP 2: Geochemistry and Reactive Transportmodelling

- Hydrogen induced geochemical alteration of rocks and fluids, deviation in transport mechanisms?
  - Laboratory experiments on cap rock permeability
  - Laboratory experiments on reservoir alteration
  - Laboratory experiments on H2 transport in reservoirs
  - Geochemical modelling

WP 2: Selected results

- Water saturated clay cap rock has no increased H_2 - permeability even @ 100%, 100 bar hydrogen

		Permebilität [m²]	
Formation	**Kern-Nr.**	**Methan**	**Wasserstoff**
Nussdorf P202 C2	2	$2{,}1\ 10^{-18}$	$2{,}3\ 10^{-18}$
	3	$2{,}5\ 10^{-18}$	$2{,}7\ 10^{-18}$
Wegscheid W-003	1	$8{,}5\ 10^{-19}$	$8{,}2\ 10^{-19}$
	3	$3{,}2\ 10^{-18}$	$1{,}9\ 10^{-18}$

- No significant reservoir alteration after 1 year @ 25% Hydrogen, 100 bar

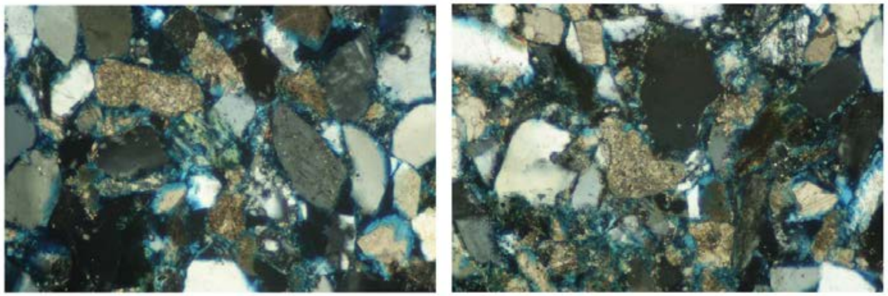
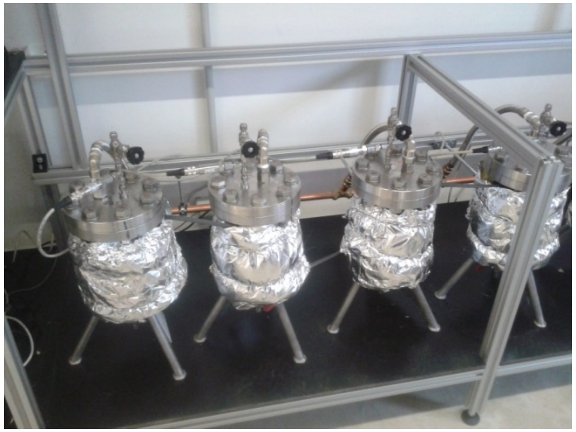


Abbildung A 23: Kern Nr. 10.1, Bamberg 1 C1, Teufe: 1310.94 m, (links: vor Einlagerung, rechts: nach Einlagerung für 12 Monate), gekreuzte Polarisatoren; Bildausschnitt: 900 µm x 600 µm

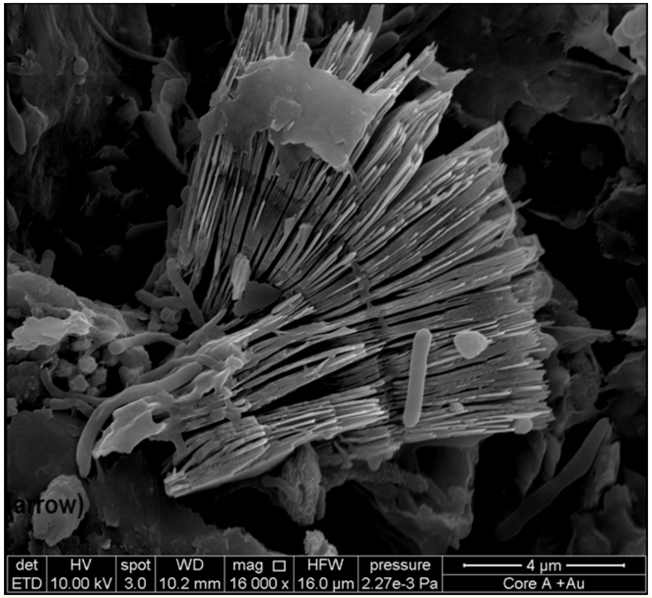
WP 3: Microbial Processes in Hydrogen Exposed Reservoirs

- Potential hydrogen induces microbial metabolism in underground reservoirs
  - $4H_2 + SO_4^{2-} + 2H^+ \rightarrow H_2S + 4H_2O$ – sulfate reduction
  - $2CO_2 + 4H_2 \rightarrow CH_3COOH + 2H_2O$ - Acetogenesis
  - $4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ – hydrogenotrophic methanogenesis
- Design and operation of Laboratory Experiments
  - @ original drill cores
  - @ original reservoir fluids



WP3: Selected Results

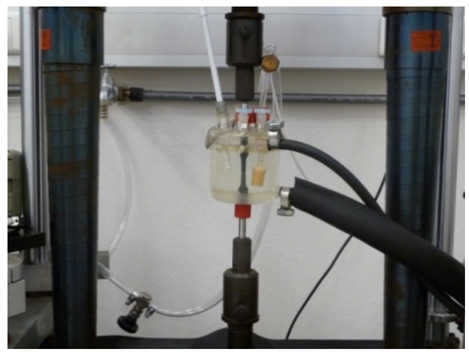
- Microbiological Metabolism of Hydrogen correlates with availability of **Electron -Acceptors** i.e. CO_2 or Sulfates
- No significant H_2S concentrations (<1 ppm) detectable
- Abiotic reactors did not deliver decline in hydrogen concentration



Kaolinit (clay mineral) and sulphate reduzers – rods (arrow)

WP 5: Materials and Corrosion

- Hydrogen induced corrosion (embrittlement) in wet gas systems?
  - Laboratory experiments testing typical steel alloys at RAG



Zugversuch in der Glaszelle (1 bar)

Zugversuch im Autoklaven (12 bar)

- Hydrogen induced alteration of cementation?
  - Laboratory experiments on cement plugs

WP 5: Selected results

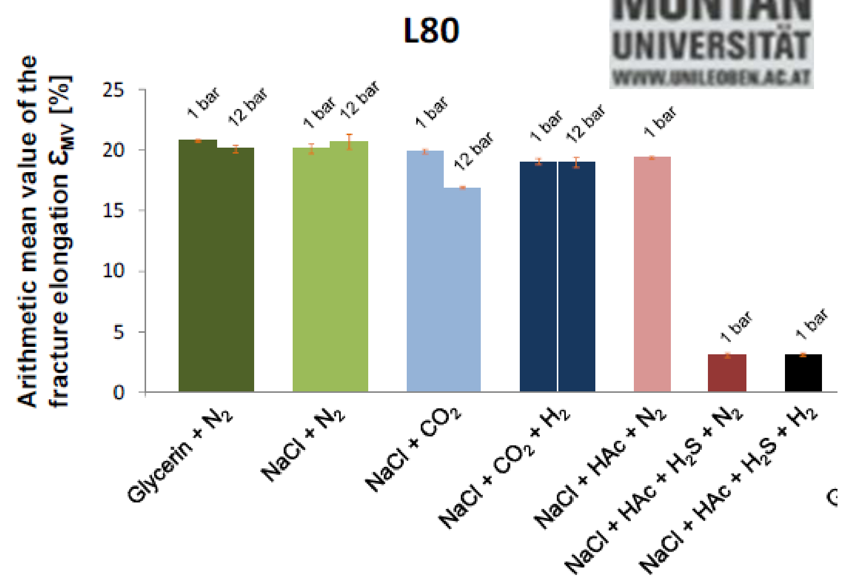
Tests under **inert conditions**: test condition 1

Effect of **NaCl, CO_2 and H_2**: test conditions 2–4

Effect of **Acetic Acid, H_2S and H_2**: test conditions 5–7

Test Condition [Nr.]	Media	Pressure p [bar]	Materials L80	Materials P110
1	Glycerin 100 vol.-% N_2	1	2 x	2 x
		12	2 x	2 x
2	5 wt.-% NaCl 100 vol.-% N_2	1	2 x	2 x
		12	2 x	2 x
3	5 wt.-% NaCl 100 vol.-% CO_2	1	2 x	2 x
		12	2 x	2 x
4	5 wt.-% NaCl, 17 vol.-% CO_2 83 vol.-% H_2	1	2 x	2 x
		12	2 x	2 x
5	5 wt.-% NaCl 0,5 vol.-% HAc 100 vol.-% N_2	1	2 x	2 x
6	5 wt.-% NaCl 0,5 vol.-% HAc 7 vol.-% H_2S 93 vol.-% N_2	1	2 x	2 x
7	5 wt.-% NaCl 0,5 vol.-% HAc 7 vol.-% H_2S 93 vol.-% H_2	1	2 x	2 x

Aggressivity of test conditions

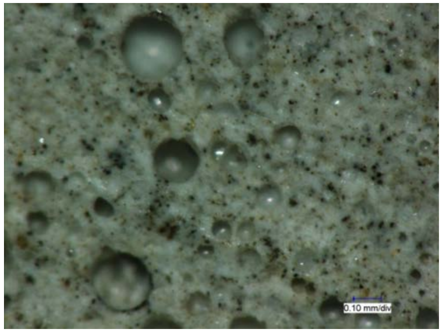


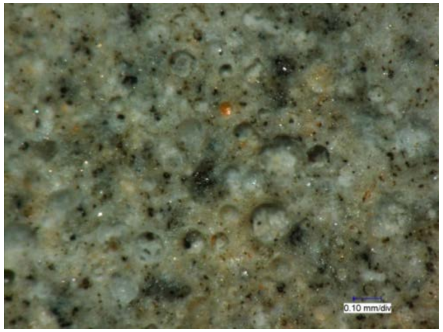
- Low alloyed steel qualities (tensile strength up to 1.100 N/mm²) are suitable for partial hydrogen pressure of up to 10 bars

WP 5: Selected Results

- No hydrogen related alteration of cementation detectable.

Einlagerungszeit [Monate]	Kern-Nr.	Pemeabilität [m²] vor Einlagerung	nach Einlagerung
2	6	$1.04\ 10^{-17}$	$1.73\ 10^{-17}$
	8	$2.10\ 10^{-17}$	$2.55\ 10^{-17}$
6	4	$1.78\ 10^{-17}$	$2.25\ 10^{-17}$
	3	$3.97\ 10^{-17}$	$4.88\ 10^{-17}$
12	9	$2.21\ 10^{-17}$	$1.97\ 10^{-17}$
14	2	$2.26\ 10^{-17}$	$9.21\ 10^{-17}$
	5	$2.74\ 10^{-17}$	$3.24\ 10^{-17}$



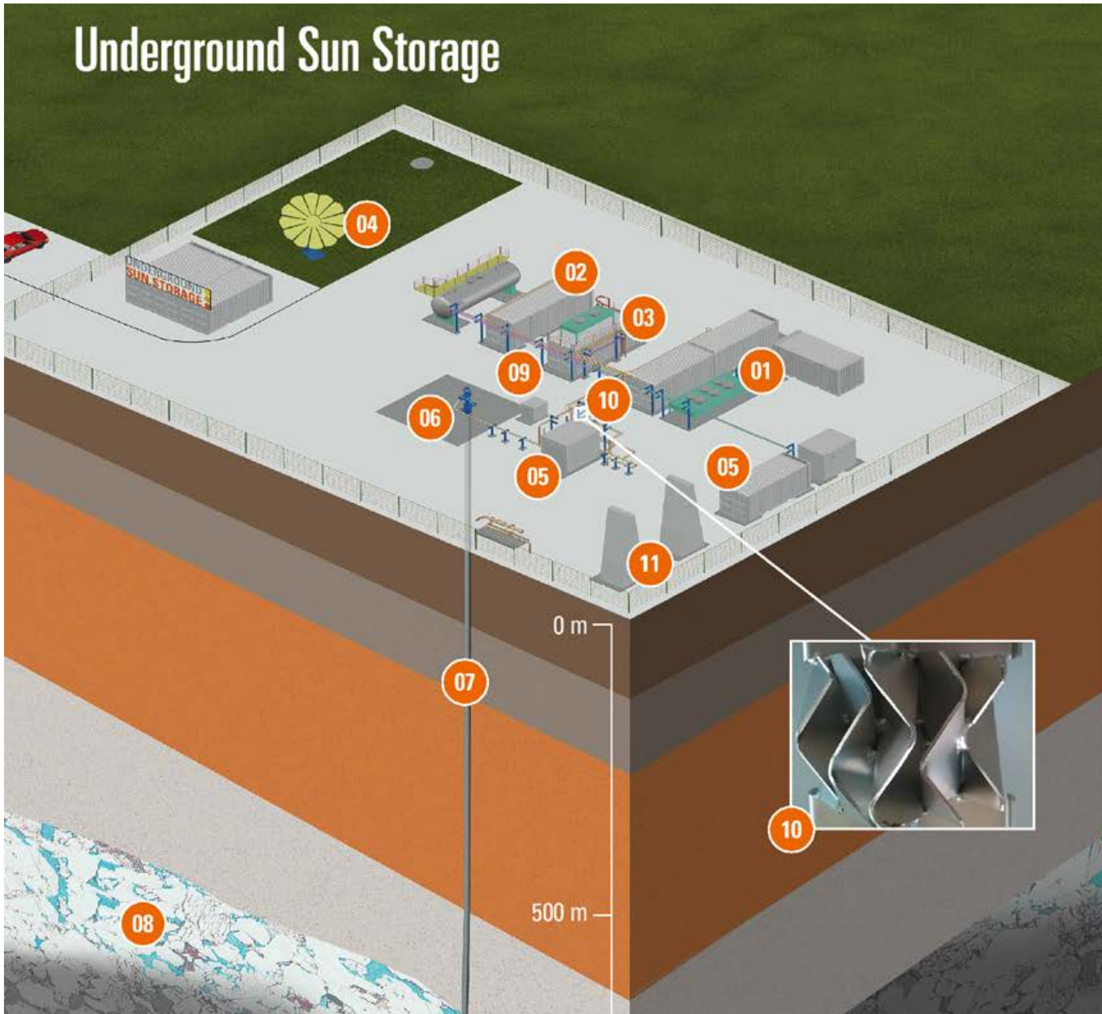


Zementkern vor und nach Einlagerung

WP 7 & 8: In-situ Field Experiment Construction and Operation

- Selection of Reservoir
  - Lehen-002 is very small and isolated
  - Field experiments at reasonable costs and risks
  - Conditions comparable to commercial RAG storage facilities
- Storage cycle with 10% Hydrogen admixture
- App. 1.2 Mio m³ injected
- Pressure range 30 – 78 bar
- Duration app. 10 months
- Material testing section

Schematic View – Underground Sun Storage



01 Elektrolyse | Electrolysis
Wasserstoffproduktion, 600 kW, 100 Nm^3/h
Hydrogen production unit, 600 kW, 100 Nm^3/h

02 Membranmodul | Membrane unit
Abtrennung H_2, Polymer-Hohlfasermembran
Separation of hydrogen, Polymer hollow fibre membrane

03 Verdichter | Compressor unit
3-stufiger Kolben-Verdichter mit Elektromotorantrieb, 130 kW
3-stage reciprocating compressor with electrical drive, 130 kW

04 Solar-Blume | „Smartflower“
Photovoltaik-Anlage, 2,3 kWp, 2-achsige Nachführung
Photovoltaics unit, 2,3 kWp, 2-axis autotracking

05 Steuerung/EMSR | Control system
Prozessüberwachung, Prozesssteuerung
Process monitoring system, Process control

06 Sonde | Well

07 Bohrung | Borehole

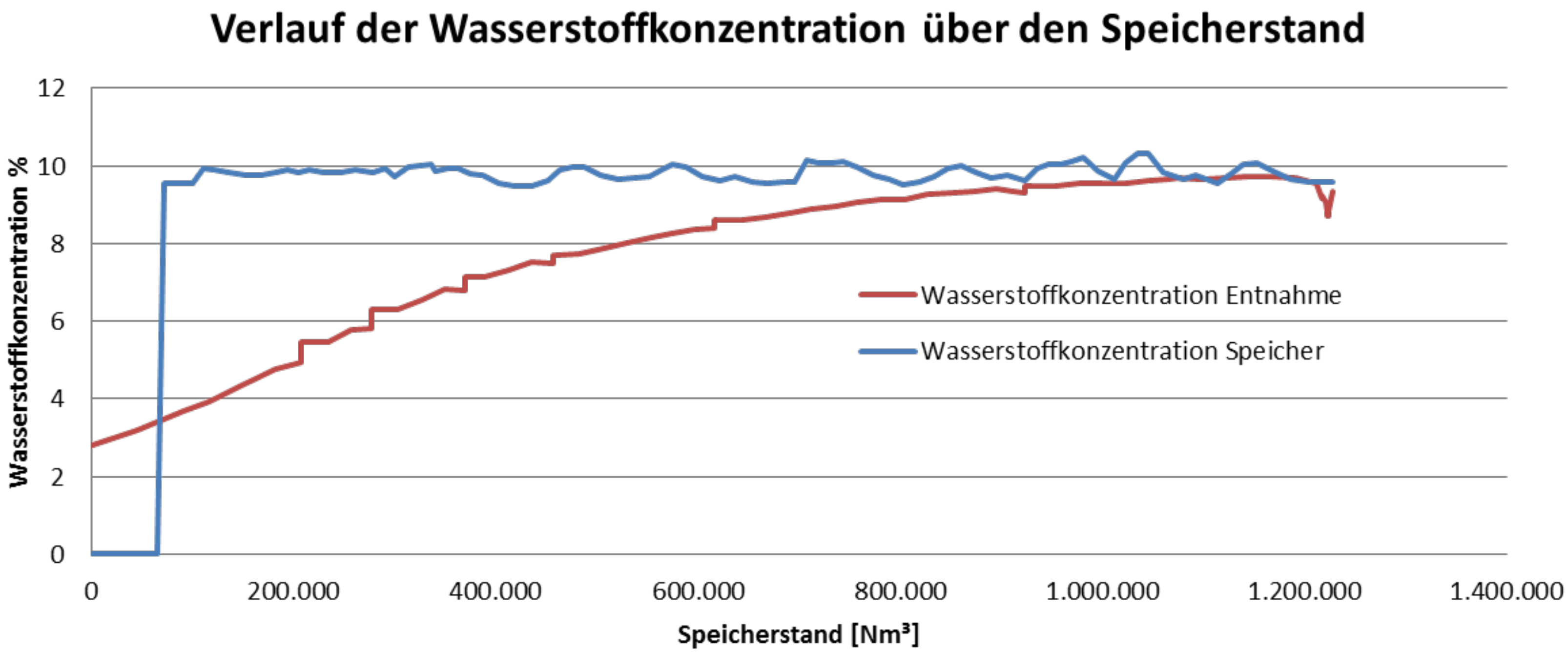
08 Lagerstätte | Reservoir

09 Gas Chromatograph | Gas chromatograph
Gasanalyse für Wasserstoff Bilanzierung
Gas analysis for hydrogen balancing

10 Statischer Mischer | Static mixer
3 Mischelemente, Länge 0,5 m
3 mixing stages, length 0,5 m

11 Stromversorgung | Power supply
30 kV Trafo, 1,1 MW Anschlussleistung
30 kV Transformer, 1,1 MW primary power supply

WP 8: Balancing of Hydrogen



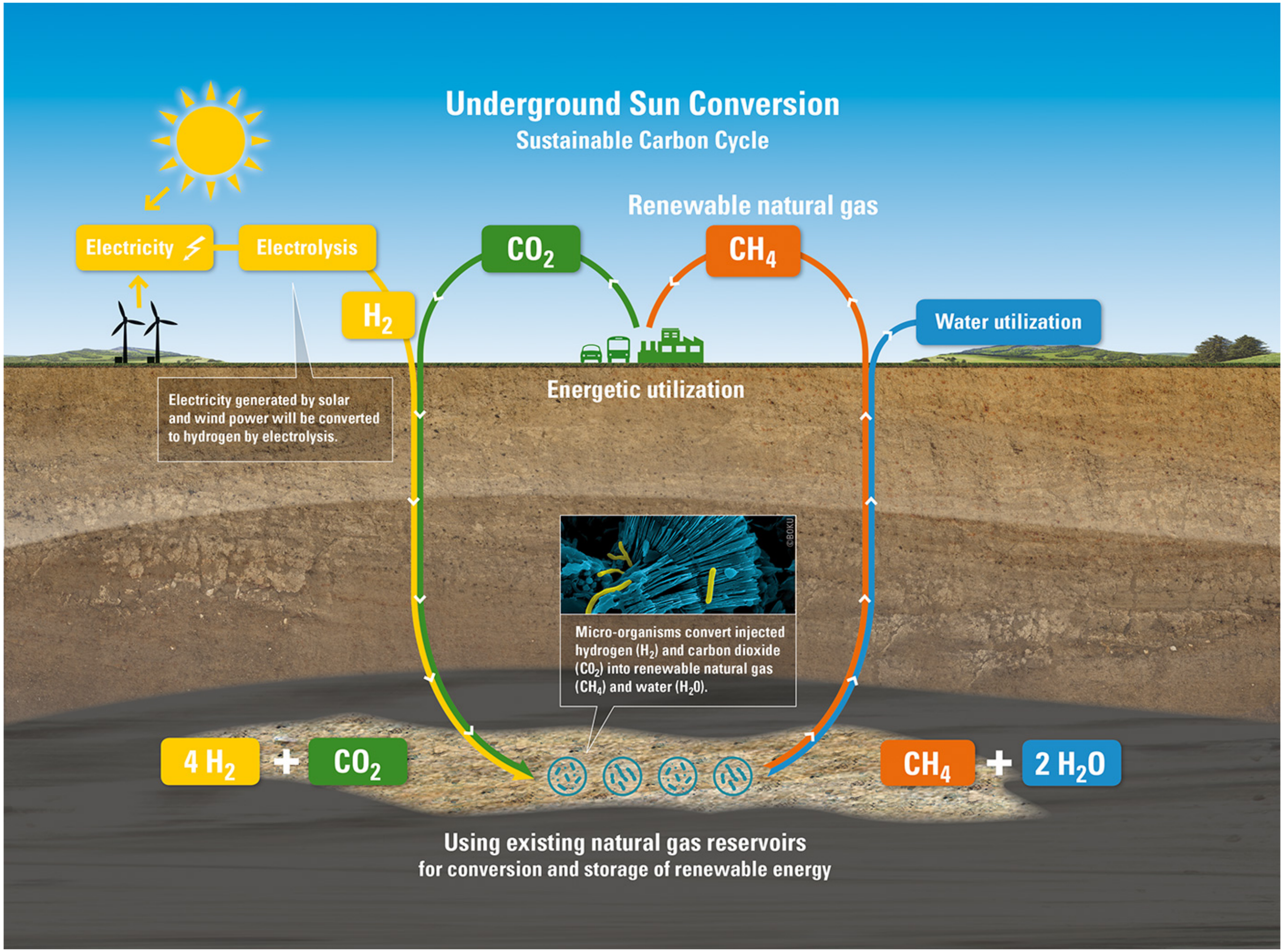
- 82% of H2 retrieved
- Rest has dissolved in reservoir fluids, migrated into cushion gas or was transformed to other gases by microbial metabolism
- => In total calculation models allow the balancing of hydrogen. Majority of balancing defizits arise for establishing a new equilibrium in the reservoir

Conclusion – Field Experiment

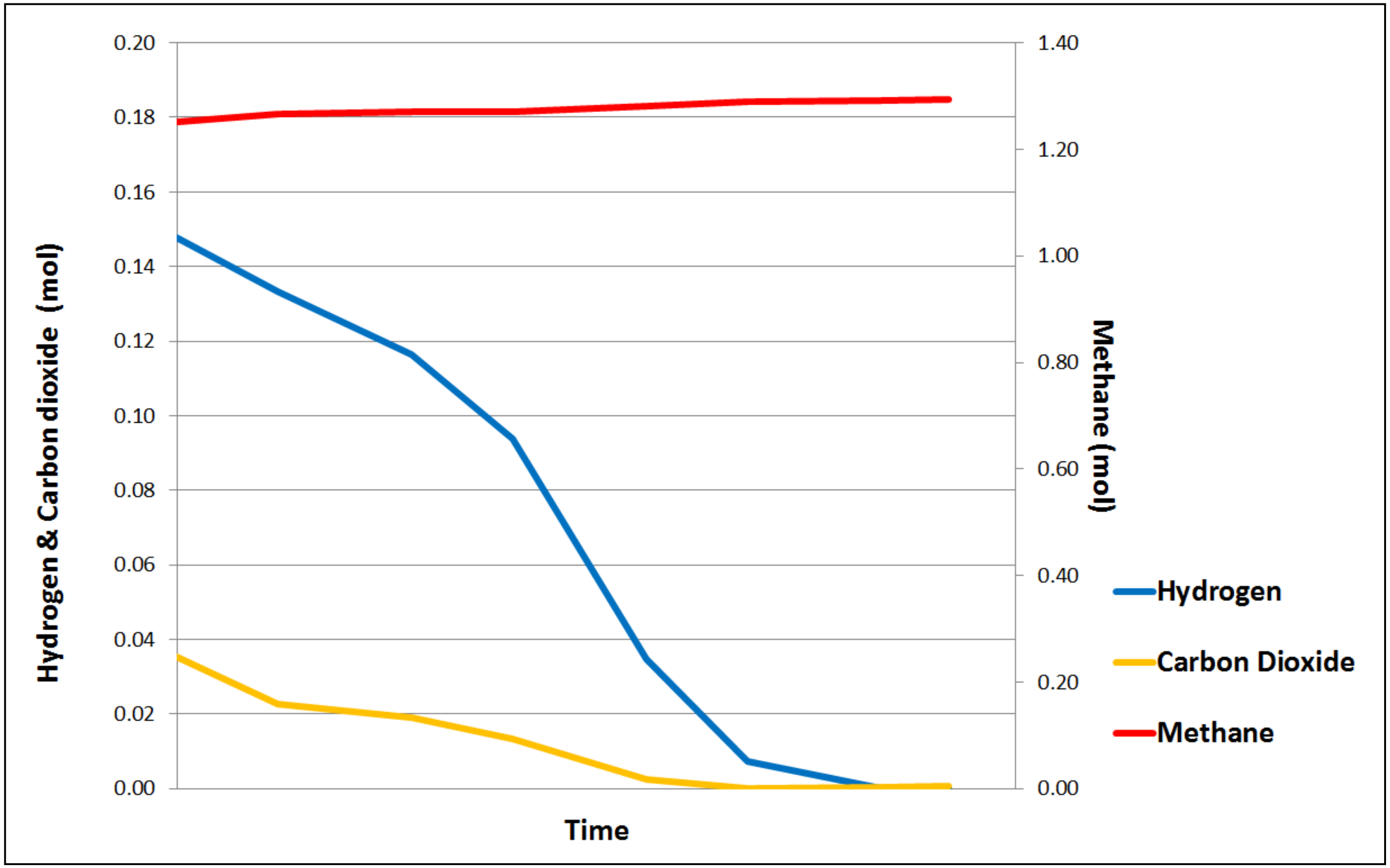
- No curtailment of storage integrity detected
- No H2S detected
- No decrease of permeability, no pore glogging
- Good analogy between lab-tests and field test
- Handling within the existing legal framework
- Open: operational and commercial effects
- Discovery of future potential

UNDERGROUND SUN.CONVERSION

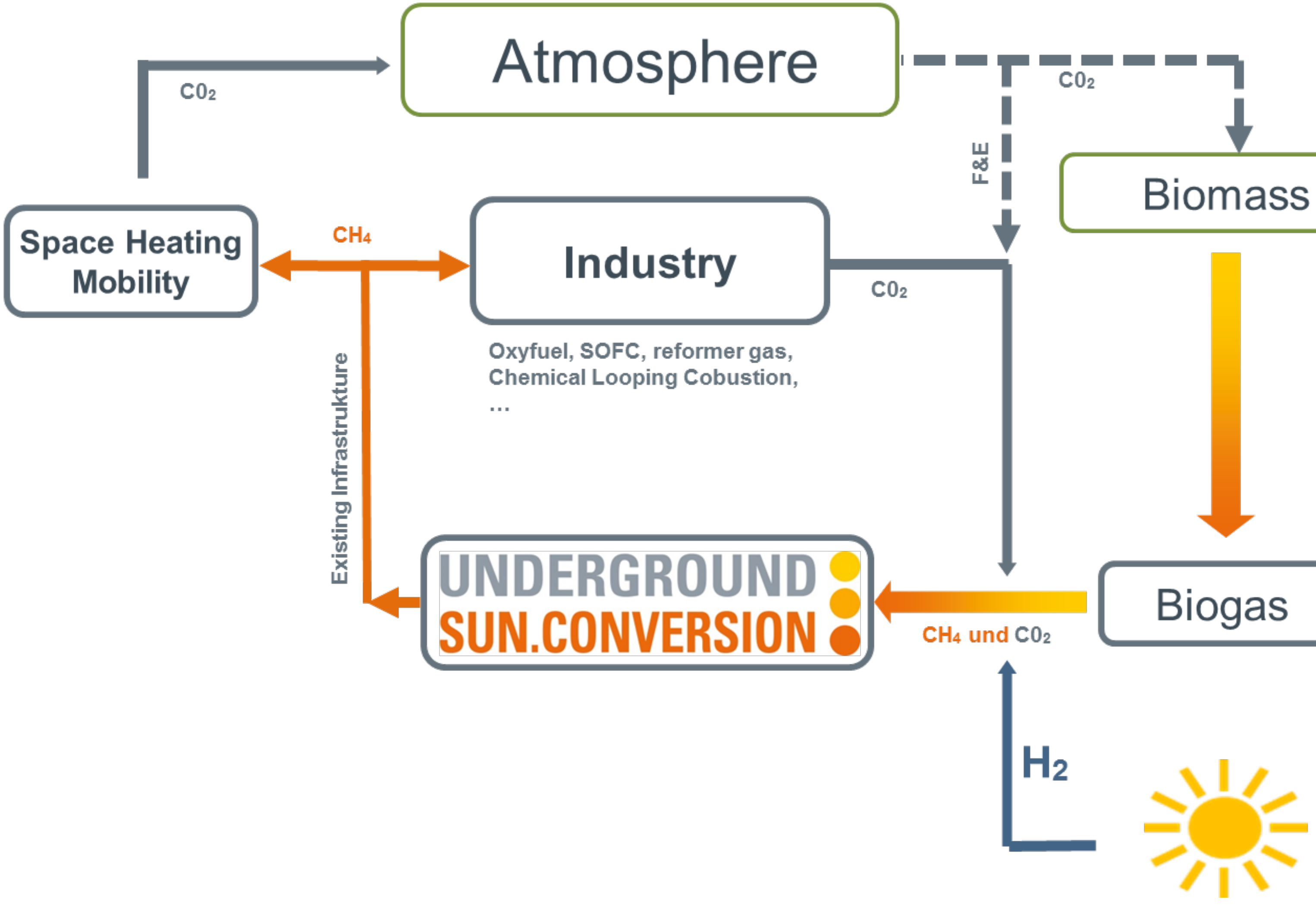
Follow up project 2017-2021



Changes in gas composition



Establishing a Sustainable Carbon Cycle



High potential for the future

- Establishing a **sustainable carbon cycle**
- **Seasonal storage** of renewable energy
- Future use for **existing infrastructure** (grids, storages, appliances)
- **Renewable gas** for heat market and mobility
- Import of renewable energy to Europe as gas
  - **Decarbonizing despite missing production potentials**

Underground Sun Conversion – Contact

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Thank you for your kind Attention!