RICAS2020 - Design Study for Advanced Adiabatic Compressed Air Energy Storage

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Innovative Energy Storage Systems for Green Energy Supply

Barcelona, 8th May 2018

RICAS
- 2020 -

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Participant No *	Participant organisation name	Country
1 (Coordinator)	Montanuniversität Leoben (hereinafter MUL)	Austria
2	SINTEF (hereinafter SINTEF)	Norway
3	Eidgenössische Technische Hochschule Zürich (hereinafter ETH)	Switzerland
4	HBI Haerter GmbH (hereinafter HBI)	Germany
5	Bayerisches Laserzentrum GmbH (hereinafter BLZ)	Germany
6	ALSTOM (Schweiz) AG (hereinafter ALSTOM)	Switzerland
7	Acondicionamiento Tarrasense Associacion (hereinafter LEITAT)	Spain

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SINTEF

ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

blz Bayerisches Laserzentrum

LEITAT managing your technologies | Technological Center member of TECNIO

ALSTOM

HBI

PROJECT VISION and OVERALL GOALS

- In 2009, the European Union adopted a ‘climate and energy package’ including that **at least 20% of EU gross final energy consumption and at least 10 % of transport final energy consumption** have to come from **renewable energy sources** and a **reduction in primary energy use** until 2020.
- As a consequence, the demand for **technologies** and resources for providing and **storing** adequate, **sustainable**, cost-efficient and affordable forms of energy is consequently increasing.
- The development of renewable energy, namely Biomass, Geothermal, Hydro, Ocean and **especially Solar and Wind energy**, requires highly applicable **energy storage technologies**.

PROJECT VISION and OVERALL GOALS

- **Compressed Air Energy Storage (CAES)**, where compressed air is stored in underground caverns, is a well-known option of energy storage and the only currently feasible **large-scale energy storage** technology apart from pumped hydrostorage.

- CAES has got **increasing attention** in the recent years due to constantly increasing renewable generation, but its application has been always **limited to a few specific cases** and is **currently only applicable in salt domes**.

- The only **2 worldwide existing CAES plants** - **Huntorf (DE)** and **McInthosh (US)** - are **diabatic** ones, where **fuel is added in the discharging phase**.

- The **Adiabatic CAES**, where **no fuel is added** in the process has been studied as pure **green storage alternative** to the diabatic ones and has some very interesting advantages.

PROJECT VISION and OVERALL GOALS

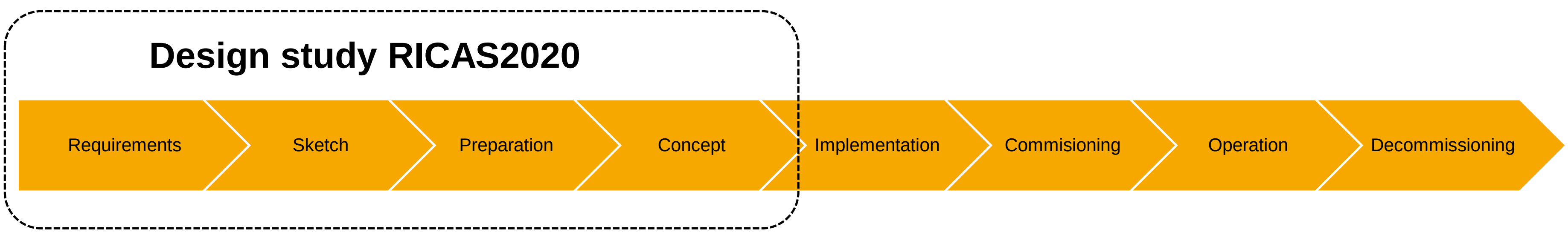
- The Adiabatic CAES Method or **Advanced Adiabatic Compressed Air Energy Storage (AA-CAES)** is designed to deliver higher efficiencies via a **zero-carbon process** to an **efficiency of about 70%**.
- Nevertheless, research on this method contends with difficulties like the **geological restriction to salt domes**.

- **RICAS2020 will provide an Underground Research Infrastructure to develop technologies by which the storage of very high amounts of green energy will be able to be done independently from the encountered geological conditions. As a result energy will be able to be stored at all places where high demands are existing.**

PROJECT VISION and OVERALL GOALS

The Design Study RICAS2020 was aiming to create an underground research infrastructure for AA-CAES and focused on the technical, legal, approval, institutional and financial requirements of such a research facility.

SCOPE OF THE STUDY



PROJECT VISION and OVERALL GOALS

- Research regarding the thermal **interaction between the surrounding rock** or soil, the **lining materials** behaviour and the **pressure of the stored compressed air**.
- Research on completely new resource-efficient environmental friendly excavation and cutting technologies for rock and soil, to be able **to build large underground storage caverns even close to highly populated areas without producing noise and vibration**.
- Research on dimensioning large underground storage caverns in various ground types using powerful **3D-numerical simulation tools which should be evaluated with underground 1:1 scale tests** in a next stage.

PROJECT VISION and OVERALL GOALS

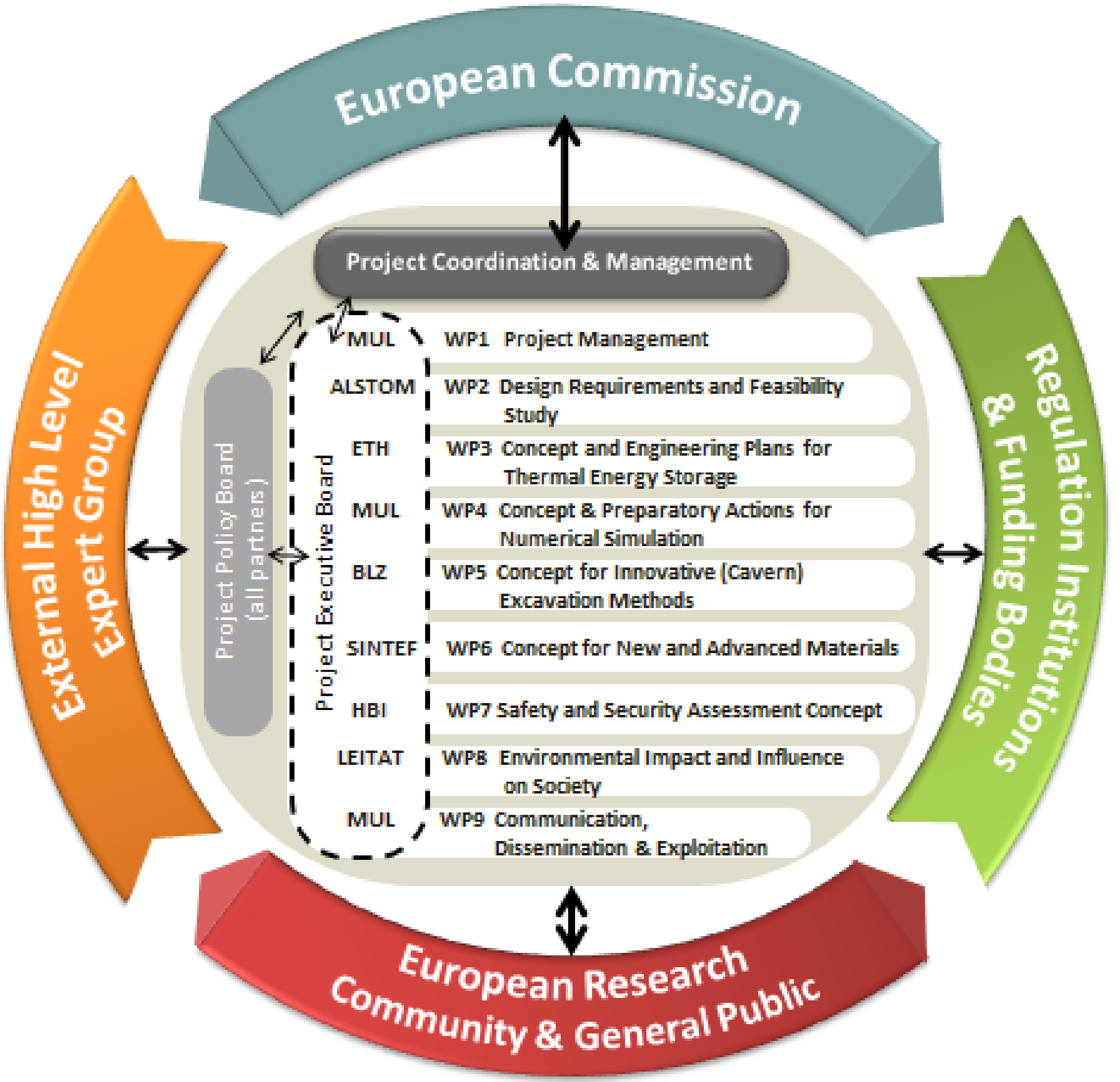
- Research on new economical **advanced materials resistant to the extraordinary high pressure and high temperature conditions**.
- Research regarding **operational safety aspects** for high-pressure storage of inert gases in underground structures.
- Research on **Modelling of compressed air flows**.
- Research on System integration.

Benefits of AA-CAES:

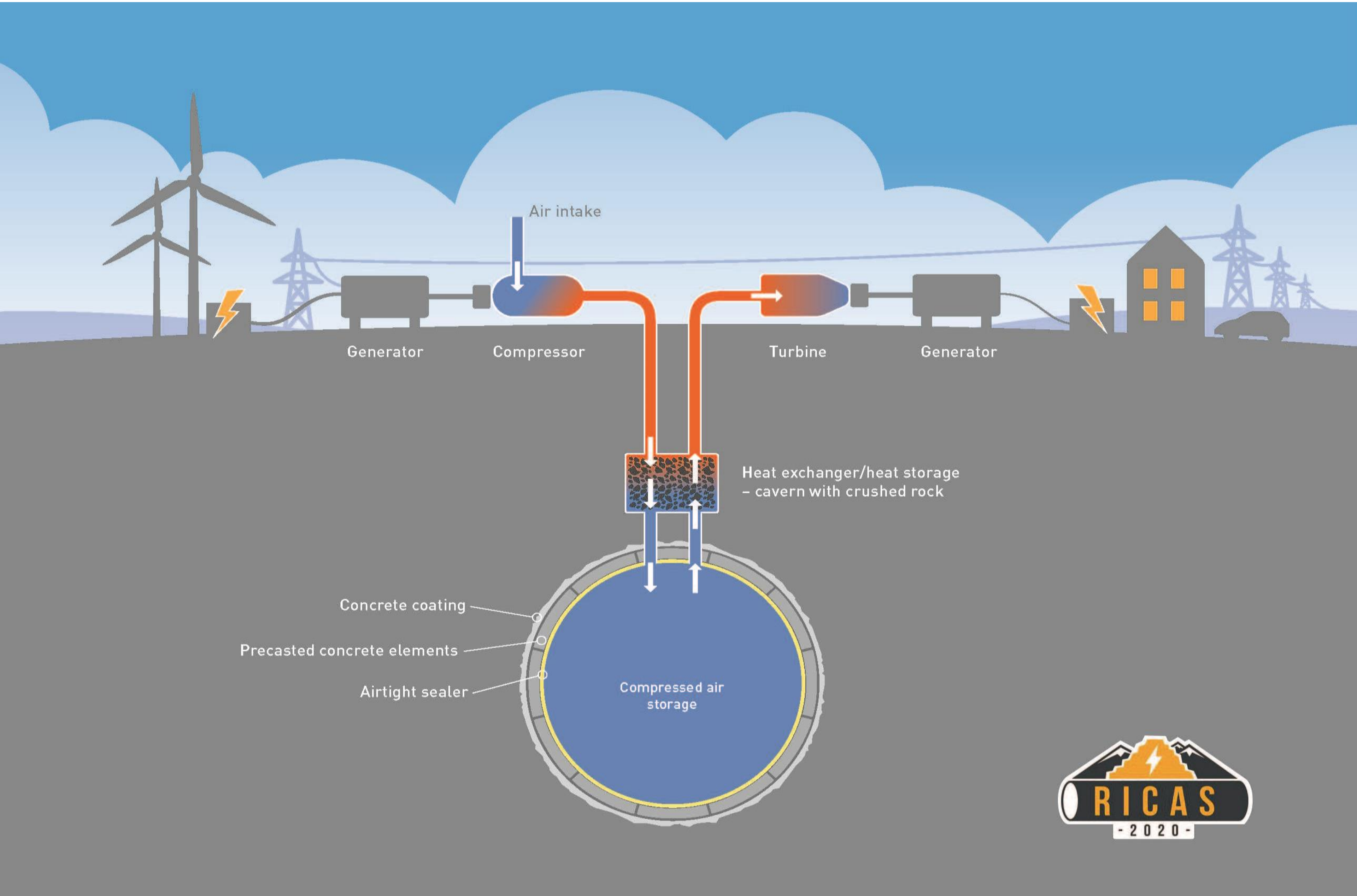
- no CO_2 emission,
- it does not use any fuel for heating the air in the expansion process,
- efficiency is higher compared to conventional CAES (up to 70%),
- reduced temperature and pressure fluctuations in the storage cavern.

WP 1 Project Management … MUL	**WP5 Concept for Innovative (Cavern) Excavation Methods** **… BLZ**
WP2 Design Requirements and Feasibility Study (from system engineering, science related, operational and financial point of view) **… MUL with contribution of SINTEF, ETH, HBI, BLZ, ALSTOM and LEITAT**	**WP6 Concept for New and Advanced Materials** **… SINTEF**
WP3 Concept and Engineering Plans for Thermal Energy Storage **… ETH with contribution of MUL, HBI, ALSTOM and LEITAT**	**WP7 Safety and Security Assessment Concept** **… HBI**
WP4 Concept & Preparatory Actions for Numerical Simulation **… MUL**	**WP8 Environmental Impact and Influence on Society** **… LEITAT**
	WP9 Communication, Dissemination & Exploitation **… MUL & all Partners**

Project Organisation

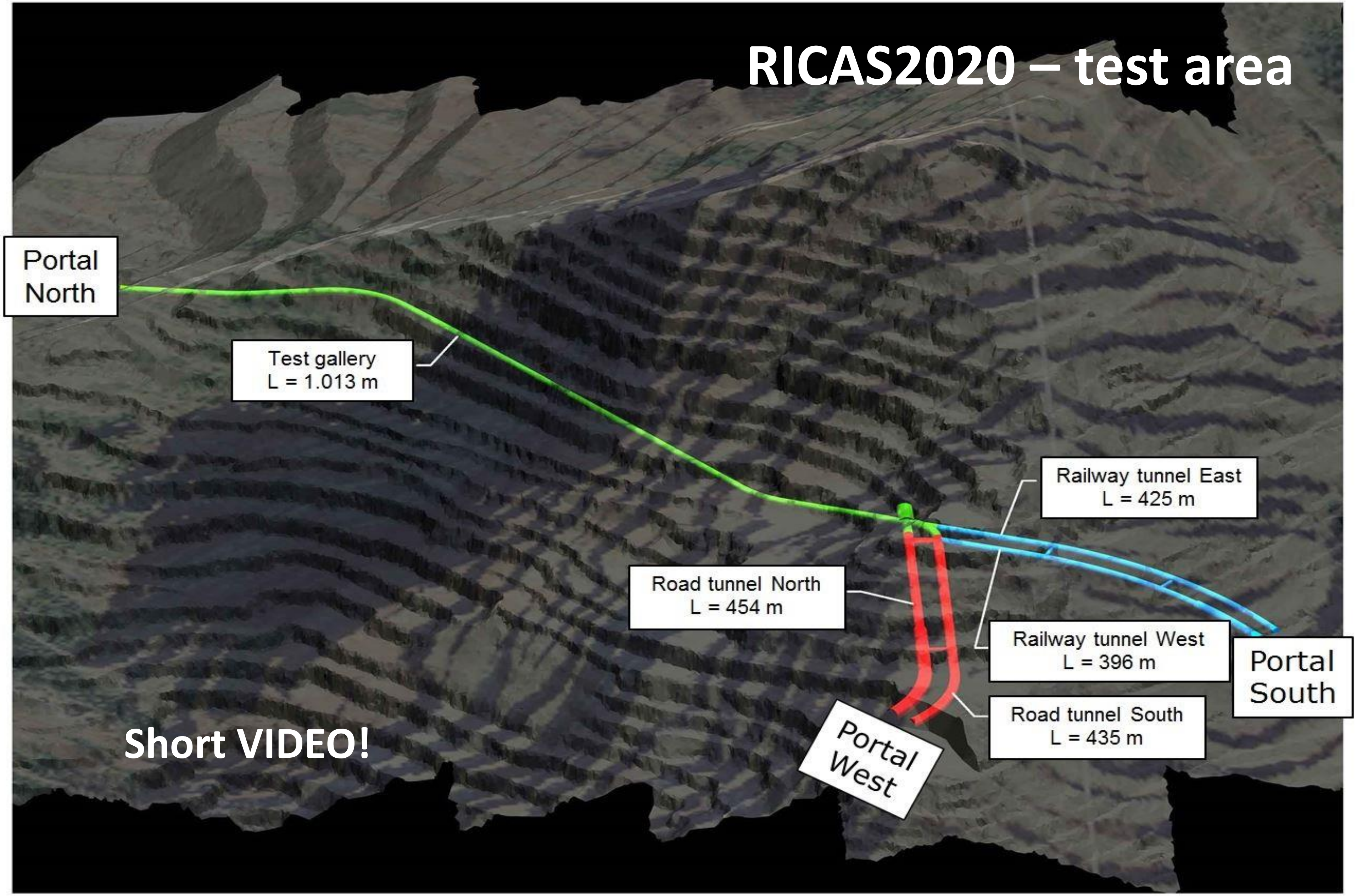


General Design Concept



Research infrastructure “Research@ZaB” in Eisenerz, Austria

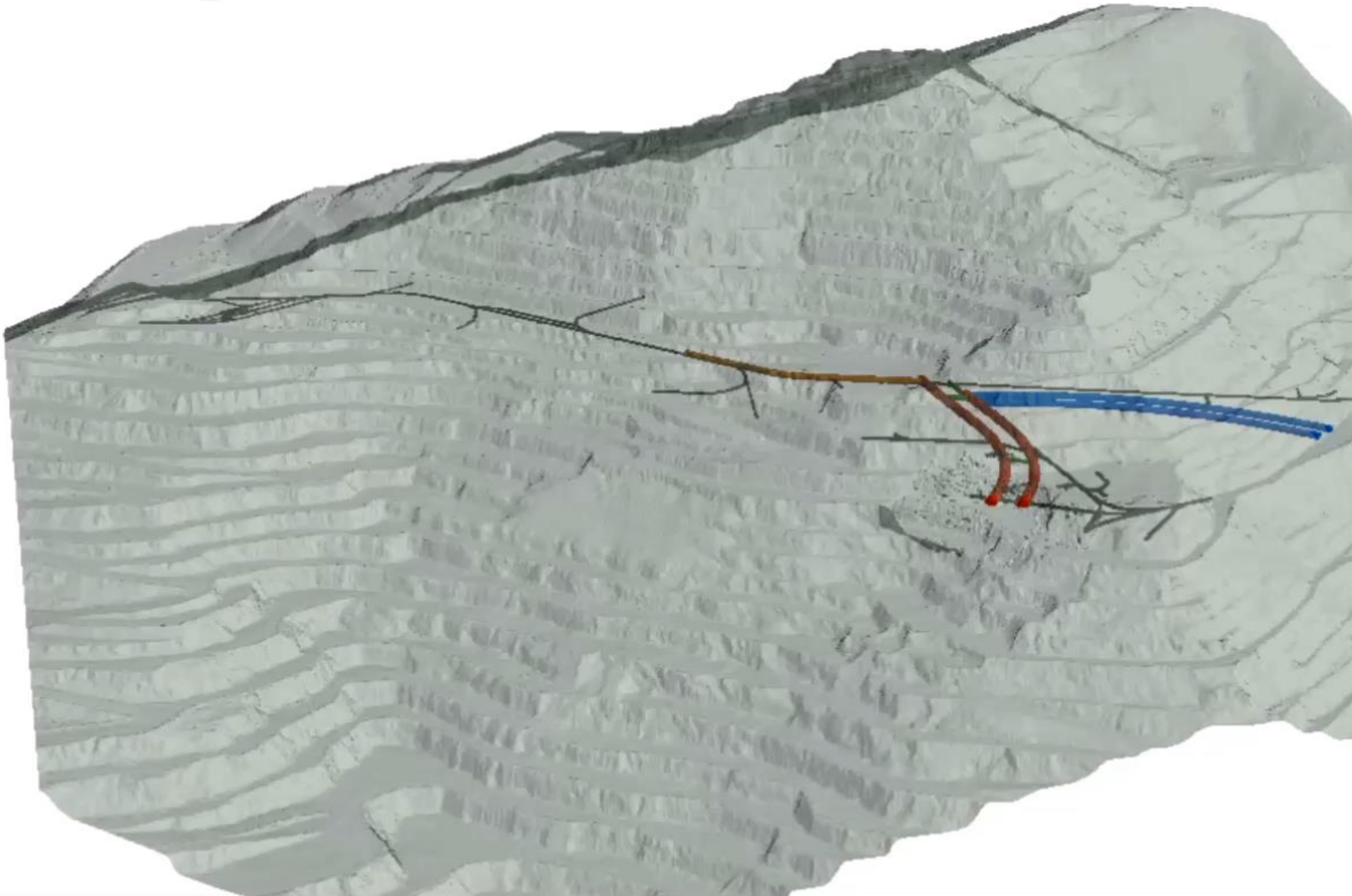
RICAS2020 – test area



Short VIDEO!

ZAB – Zentrum am Berg

RICAS2020 – test area

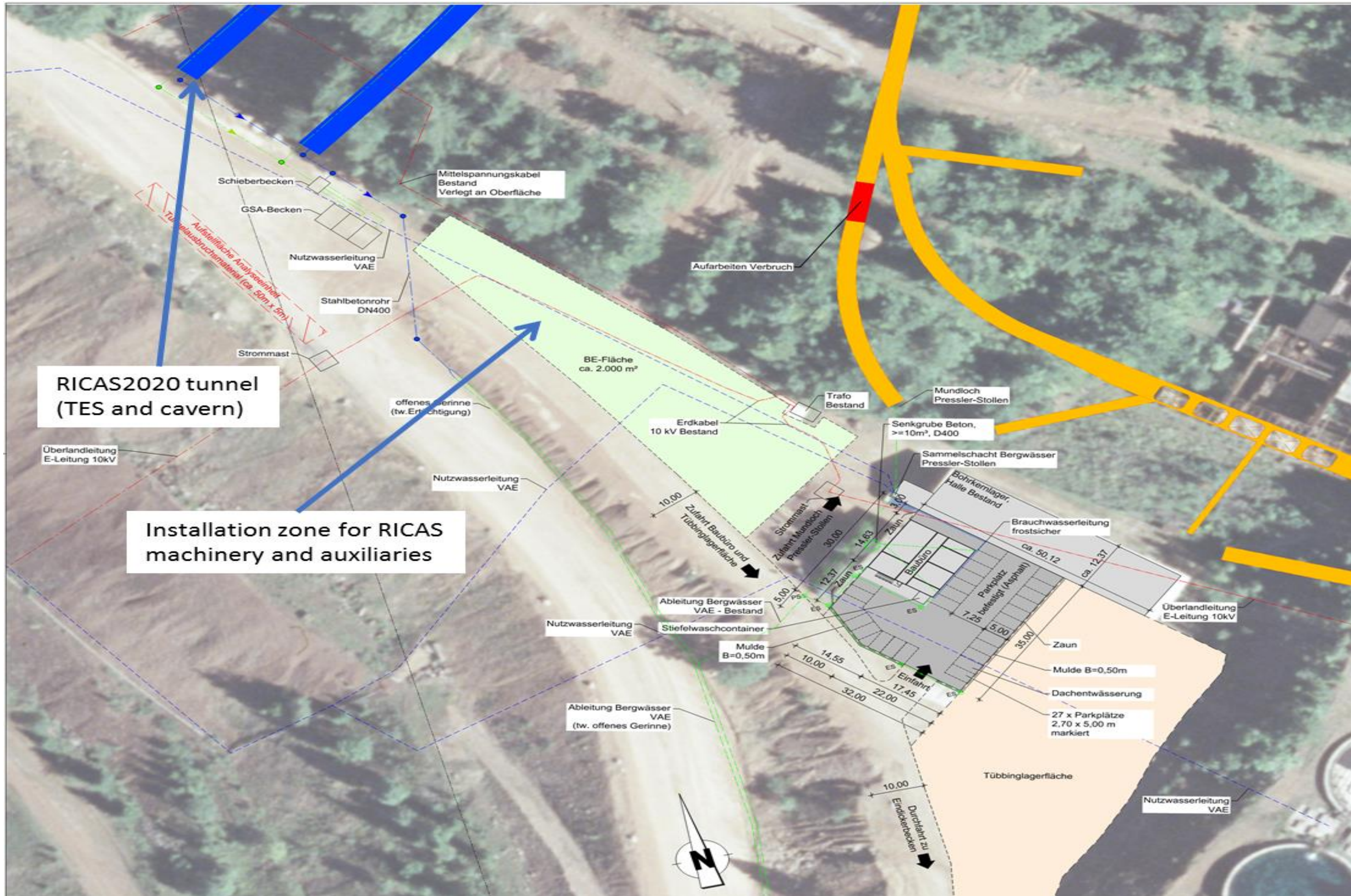


RICAS2020 operating equipment

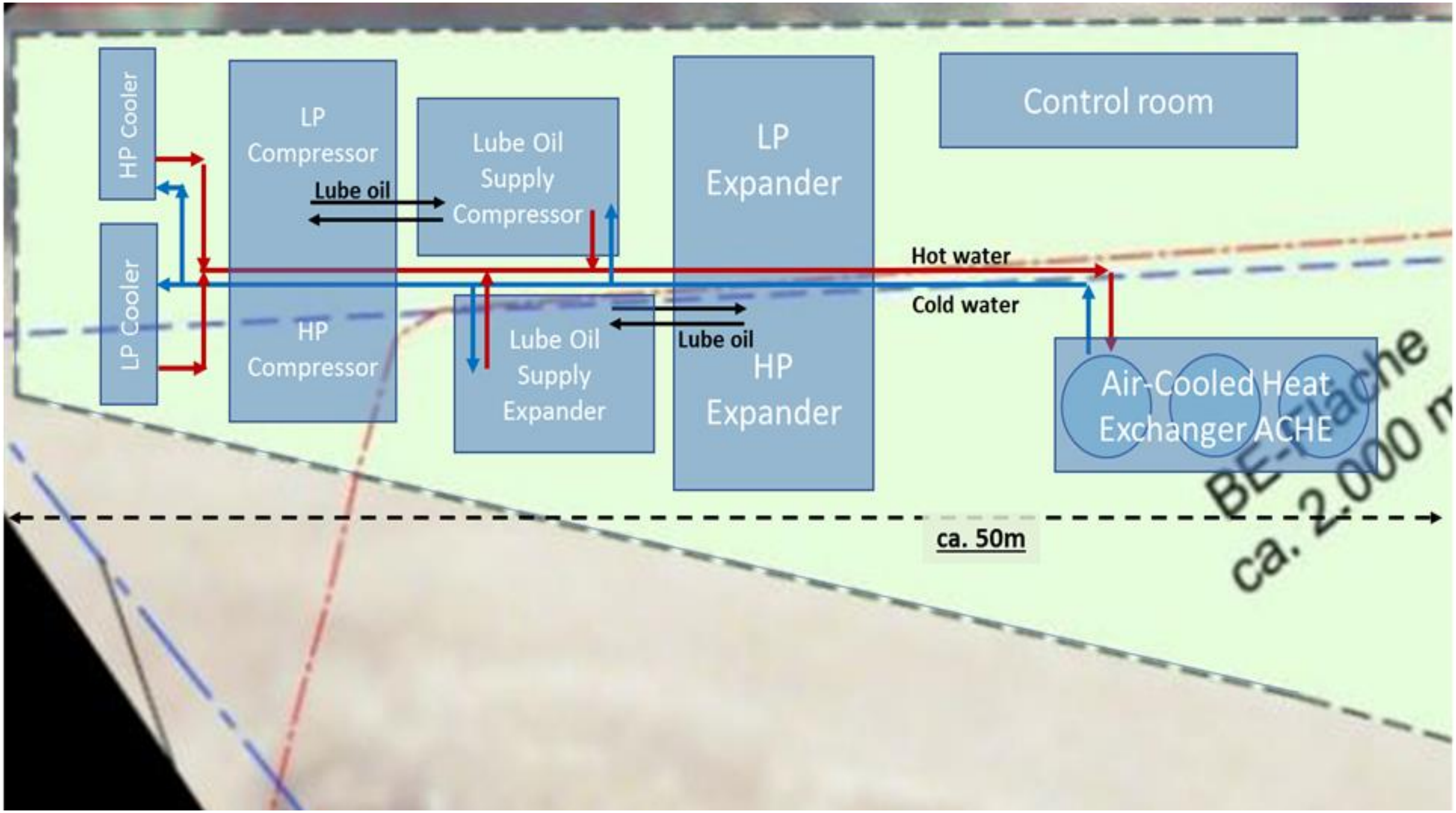
The air handling equipment comprises the **following components**:

- LP and HP **compressor**
- Lube oil supply and **oil cooler for both compressors**
- LP and HP **expander**
- Lube oil supply and **oil cooler for both expanders**
- LP and HP **air cooler**
- Air-cooled **heat exchanger** for **cooling of the cooling water**
- Eight **control valves** for switching between charging and discharging mode
- **Control room**

Location of the test facility



Air handling equipment



The space requirement of the equipment and the arrangement on the site.

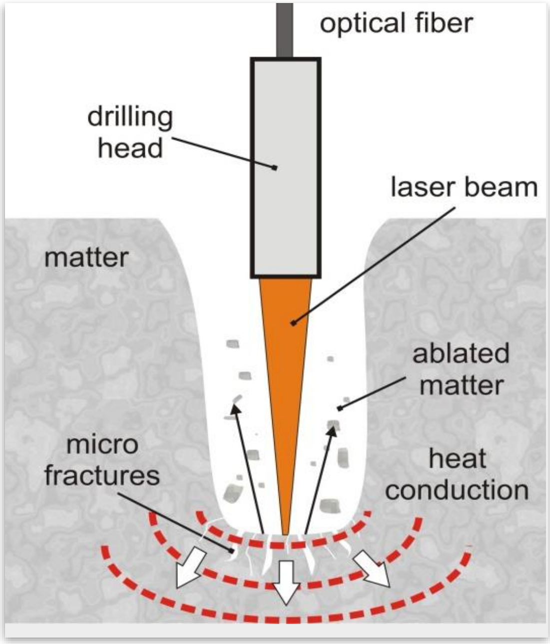
Concept for innovative excavation solutions

- With the given design requirements it is fixed that no tunnel boring machine (TBM) would be used for the excavation of the caverns for the prototype test facility since it is only cost effective to use TBM for longer tunnels

- Alternative excavation methods have to be considered. Basically there are two possible options:

  - **Conventional excavation (drill and blast, roadheaders, etc.),**
  - **Laser cutting excavation.**

Concept for innovative excavation solutions



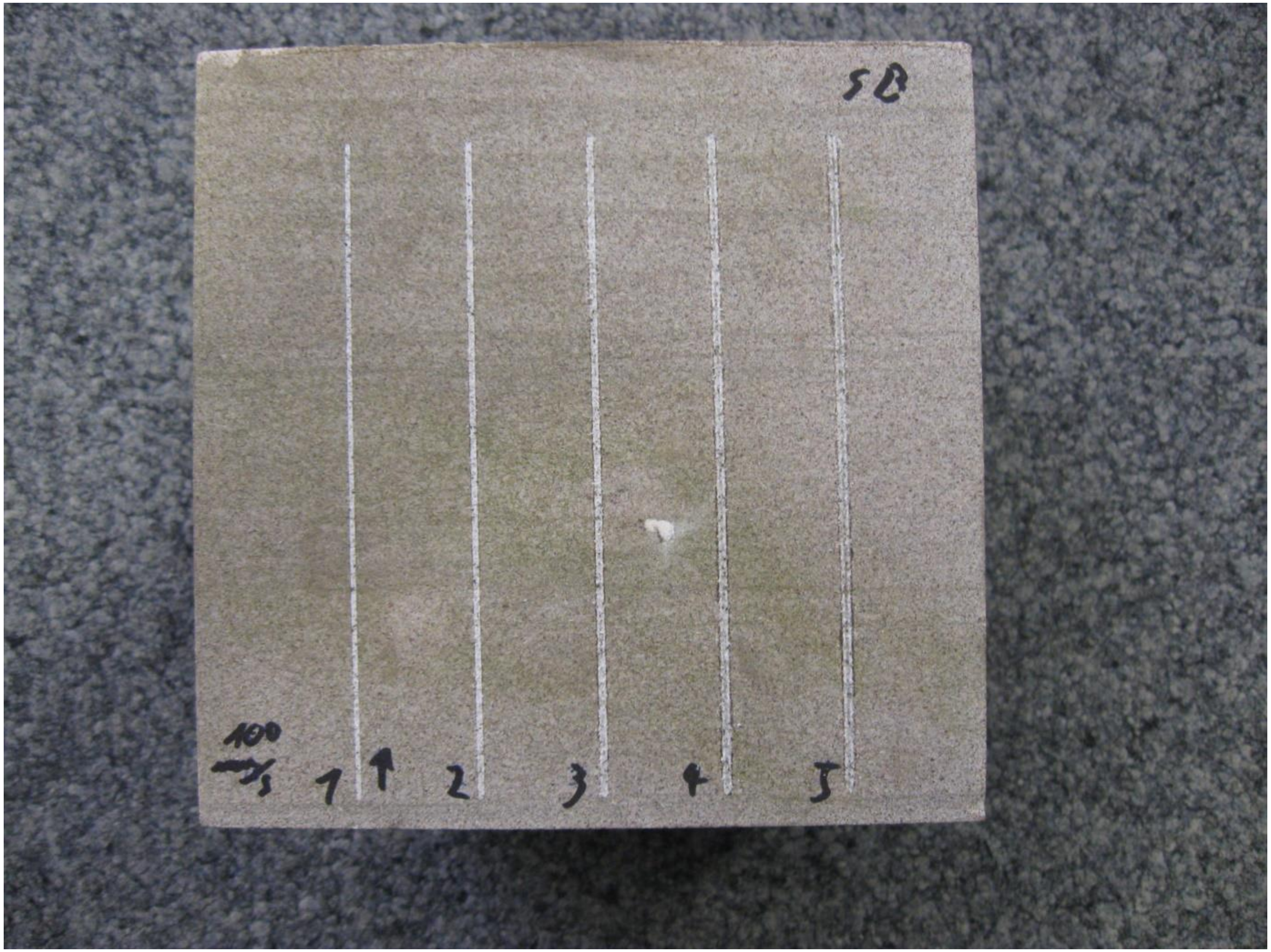
laser beam - material interaction

The principal interacting mechanism for a **high power laser beam** incident on a stone surface.

High intensities lead to a **melting** and **evaporation of rock**.

Laser rock spalling, a process utilizing laser induced thermal stress to fracture the rock, is the most efficient mechanism.

Sandstone



Constant speed: 100 mm/s

1: 500 W

2: 1 kW

3: 2 kW

4: 3 kW

5: 4 kW

RICAS2020: Safety and security hazards

During the state-of-the-art approach **similar projects were reviewed**.

- CAES power plants: Huntorf (GE)
  McIntosh (USA)
  ADELE (GE)

- High pressure natural gas storage rock caverns;
- Large-scale heat storage of process industry.

Huntorf CAES plant

Location:	Bremen, Germany
Completion date:	1978
Power	290 MW
Duration at full power	3 hours
Depth of cavern	650-800 m
Caverns	Two underground salt caverns with total of 310,000 m^3
Operation pressures	48 - 66 bar
Expanders	Stage 1: 46 to 11 bar Stage 2: 11 bar to 1 bar

McIntosh

Location:	Alabama, USA
Completion date:	1991
Power	110 MW
Duration at full power	26 hours
Depth of cavern	305 m
Caverns	single salt cavern total volume of 540,000 m^3
Operation pressures	45 - 74 bar

Adele (proposed)

Location:	Sachsen-Anhalt, Germany
Power	360 MW
Duration at full power	5 hours
Caverns	salt cavern
Year	2014

- Design based on **A-CAES** system aiming to a total **cycle efficiency higher that 70%** using a large heat storage and salt cavern

- The project is currently on hold due to the low energy price

STORAGE CAVERN for the compressed air

RICAS2020 could be **located** wherever required with **no geological limitations**.

Development of an A-CAES plant of **limited size** that can be **located in the proximity of the energy production plants**, like wind farm and large photovoltaic installations.

RICAS can be used for **storing the surplus energy** during the peak production and give it back during the electric peak demand (generally not happening at the same time).

STORAGE CAVERN for the compressed air

The **small scale A-CAES** is foreseen as a pilot plant to **evaluate the feasibility** of the developed solution

This testing facility is foreseen to present a total power output of **5kWh for 3h**.

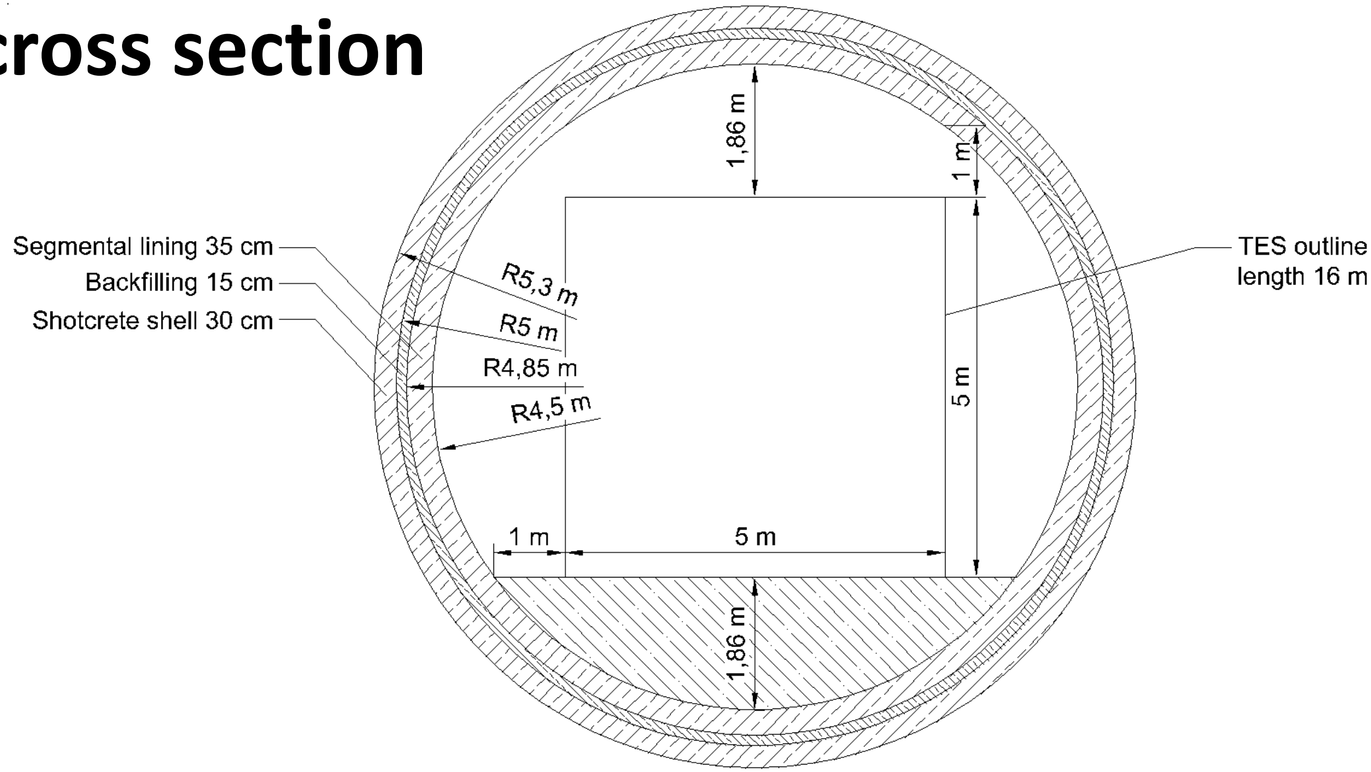
The planned **pressure range** will be from **30 to 36 bar**.

According to the main goal of RICAS2020, this will be **located** in an already available set of tunnels **in a test facility** available in Austria.

Design requirements for the 5 MW facility

Tunnel pressure	P	max. 36	bar
Temperature	T	max. 65	°C
Charging time	Tch	3	h
Discharging time	Td	3-6	h
Tunnel volume	V	20410	m3
Tunnel diameter	d	10	m
Tunnel length	L	272	m

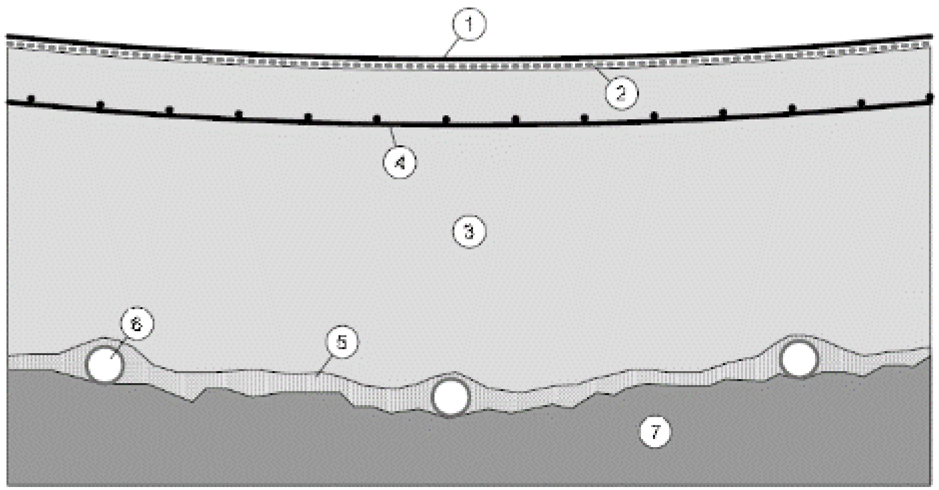
Cavern cross section



Double support system:

- outer lining – 30 cm thick shotcrete shell;
- inner lining – 35 cm segmental lining;
- backfill – 15 cm layer of rubber material (conveyer belt)

Existing liner solutions for gas storage



1. **Steel liner** (carbon steel): gas tightness; no pressure absorbing function. It is able to bridge minor cracks
2. **Sliding layer**: placed between the steel liner and the concrete to reduce friction during the sliding and as corrosion protection
3. **Concrete lining**: transfer the gas pressure force to the surrounding rocks
4. **Welded mesh reinforcement** in the concrete lining to distribute the tangential strain in many small cracks
5. **Low strength permeable concrete**: protect the drainage system
6. **Drainage system**: perforated drainpipes (to reduce pressure to the vessel in case of low internal pressure)
7. **Rock mass**: support the gas pressure force acting as load carrying elements

Existing liner solutions for gas storage

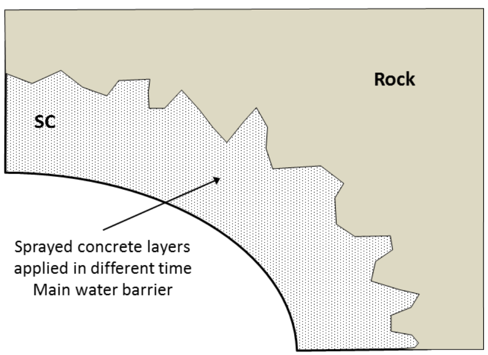
This lining solution has **proven feasible** for **demanding conditions** with pressure higher than the usual experienced in the CAES system (**≈200Bar** compared to the maximum ≈70Bar of a classic CAES).

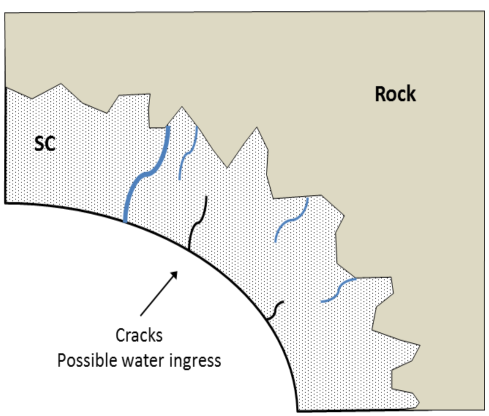
However, this solution presents two **main limitations**: **construction costs** and **fatigue damage**.

This is **not** a real **problem** for a **gas storage** system, where the typical **charging/discharging cycle** is **one or maximum twice per year**.

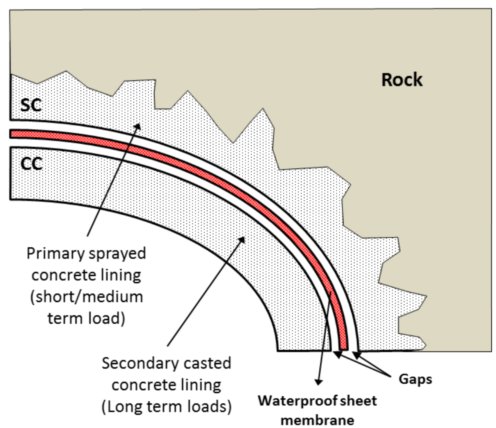
Common lining solutions from tunnelling applications

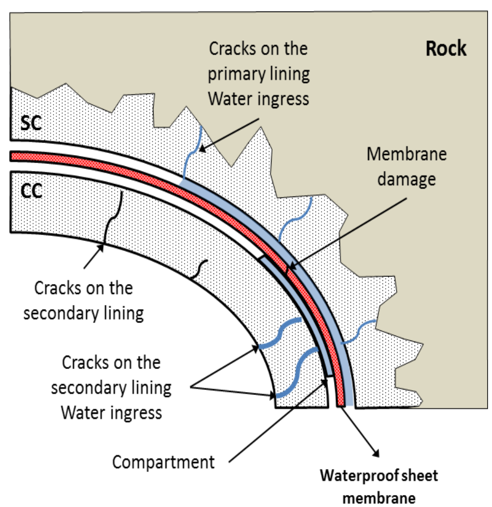
SSL – Single Shell Lining



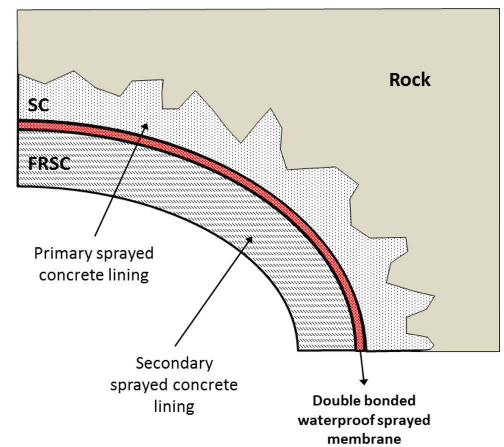


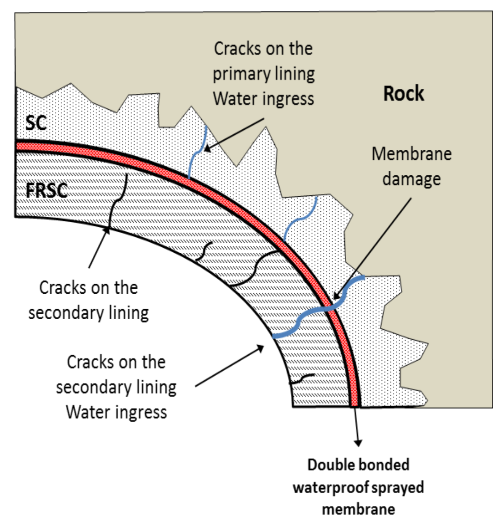
DSL – Double Shell Lining



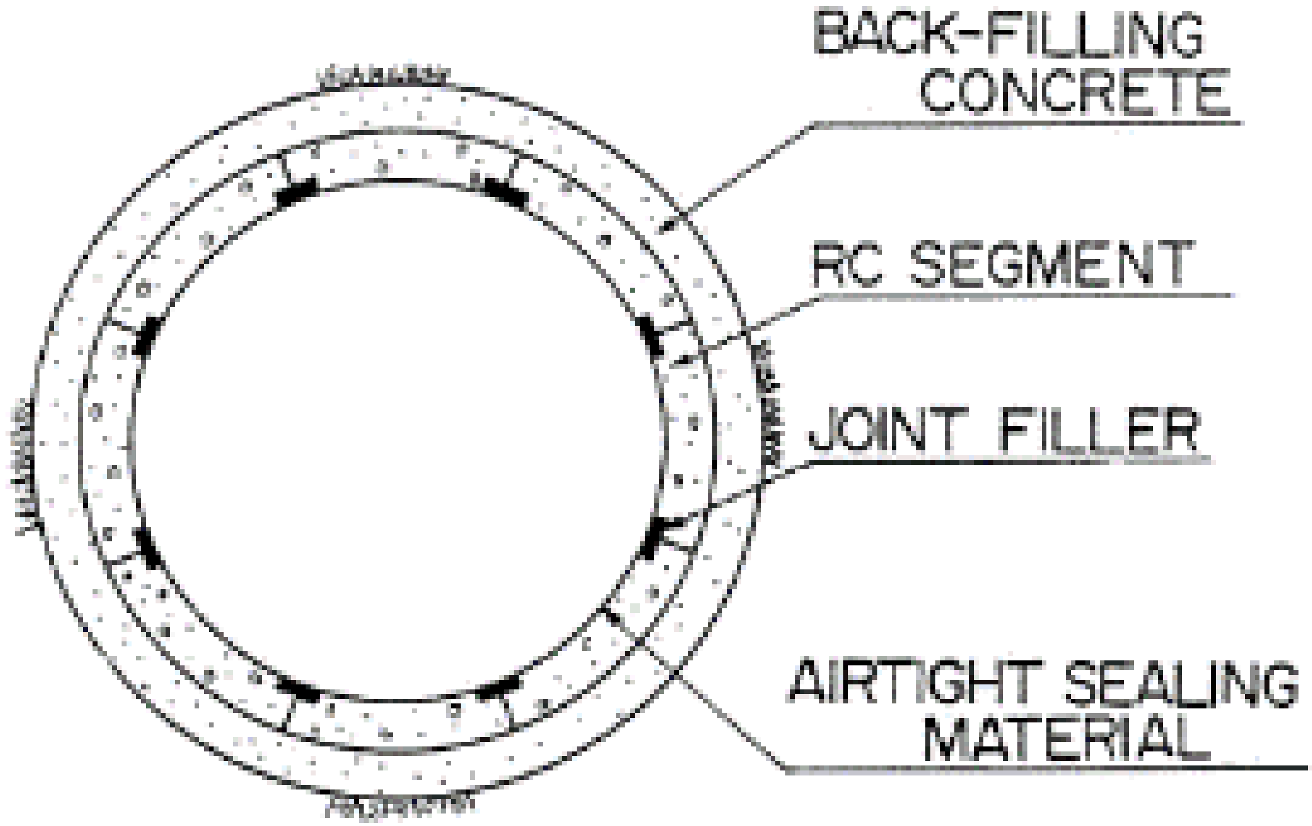


CSL –Composite Shell Lining

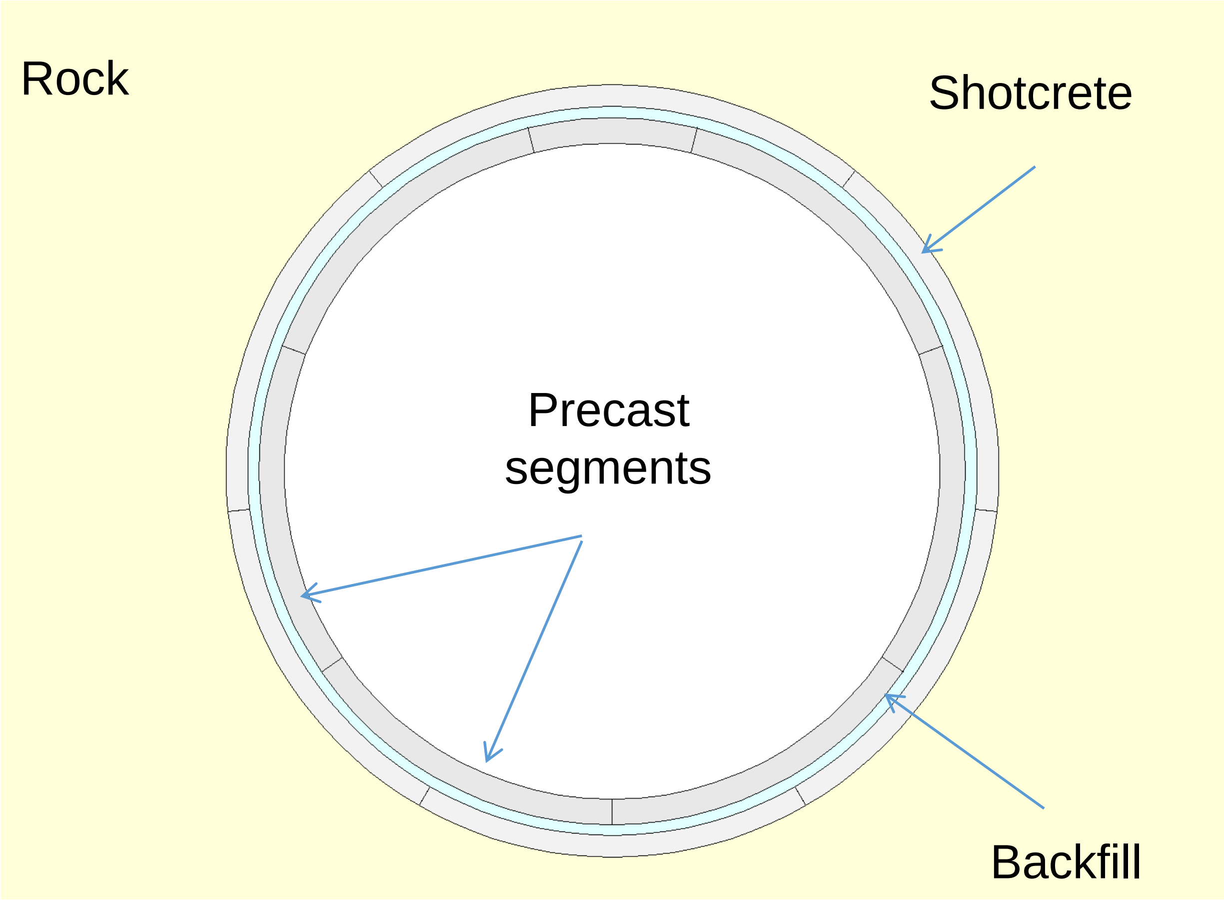




Segmented lining design

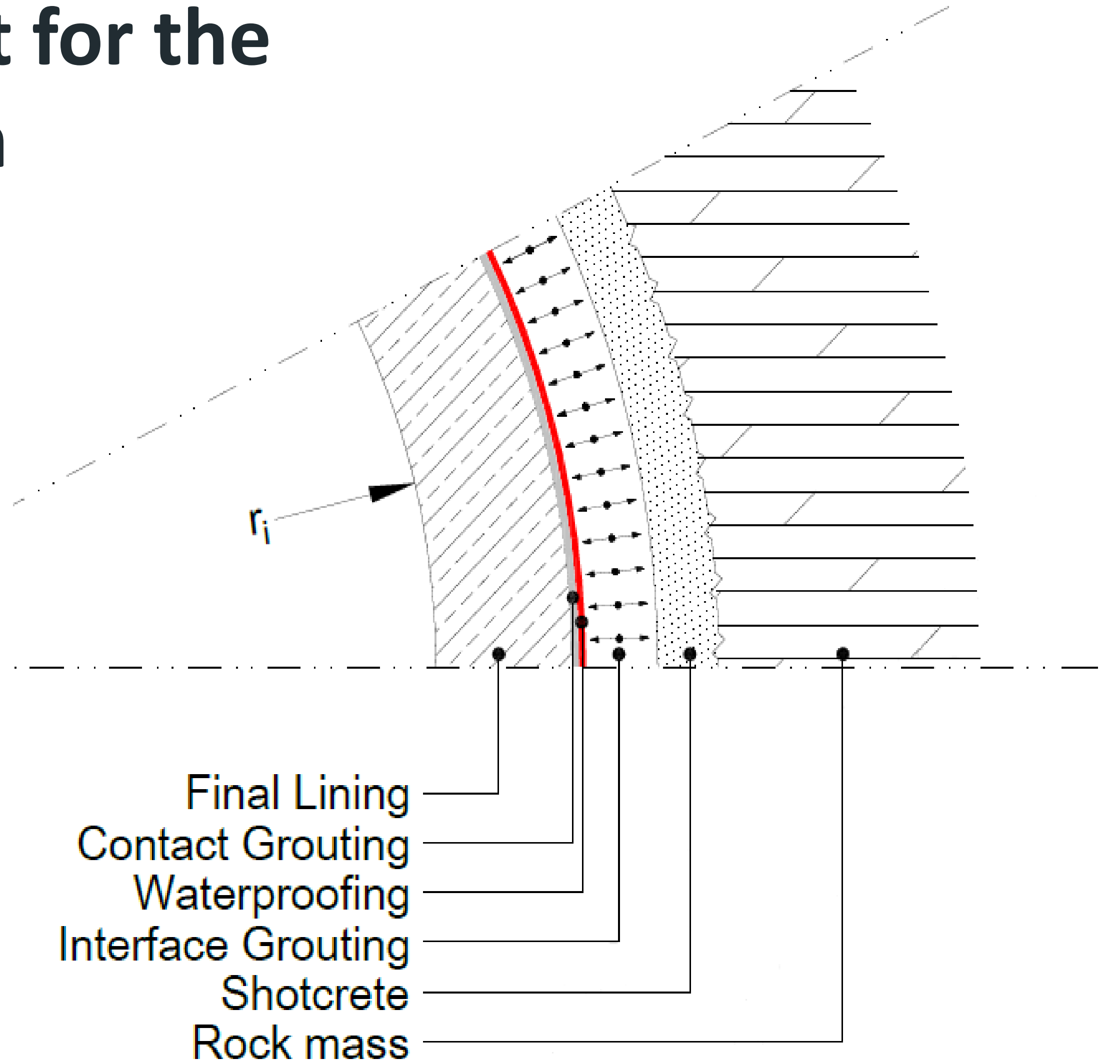


… and the follow up of the resulting lining structure



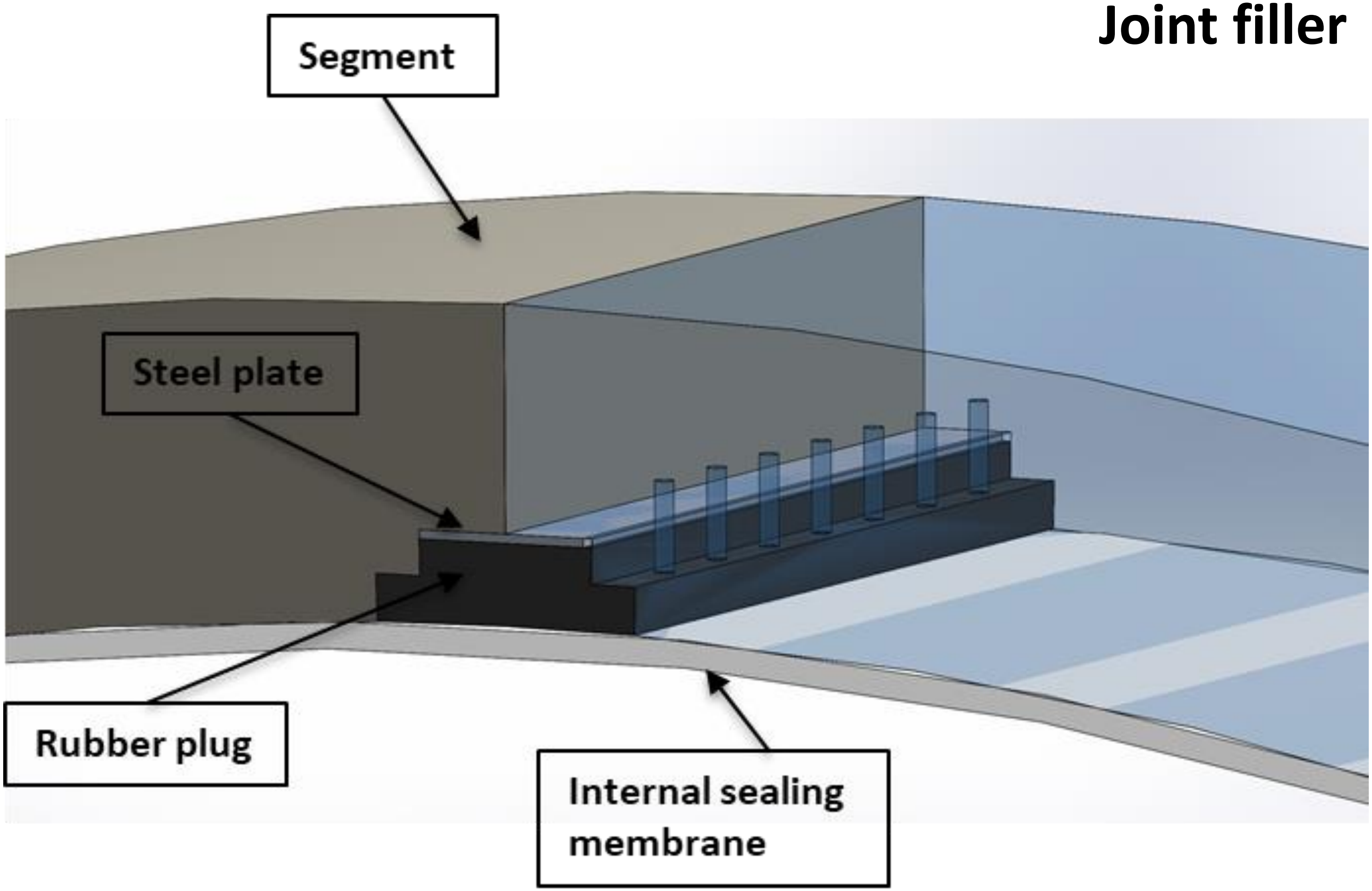
7 precast concrete segments; 6 slots in the outer shell

RICAS concept for the lining solution



Concrete precast segments

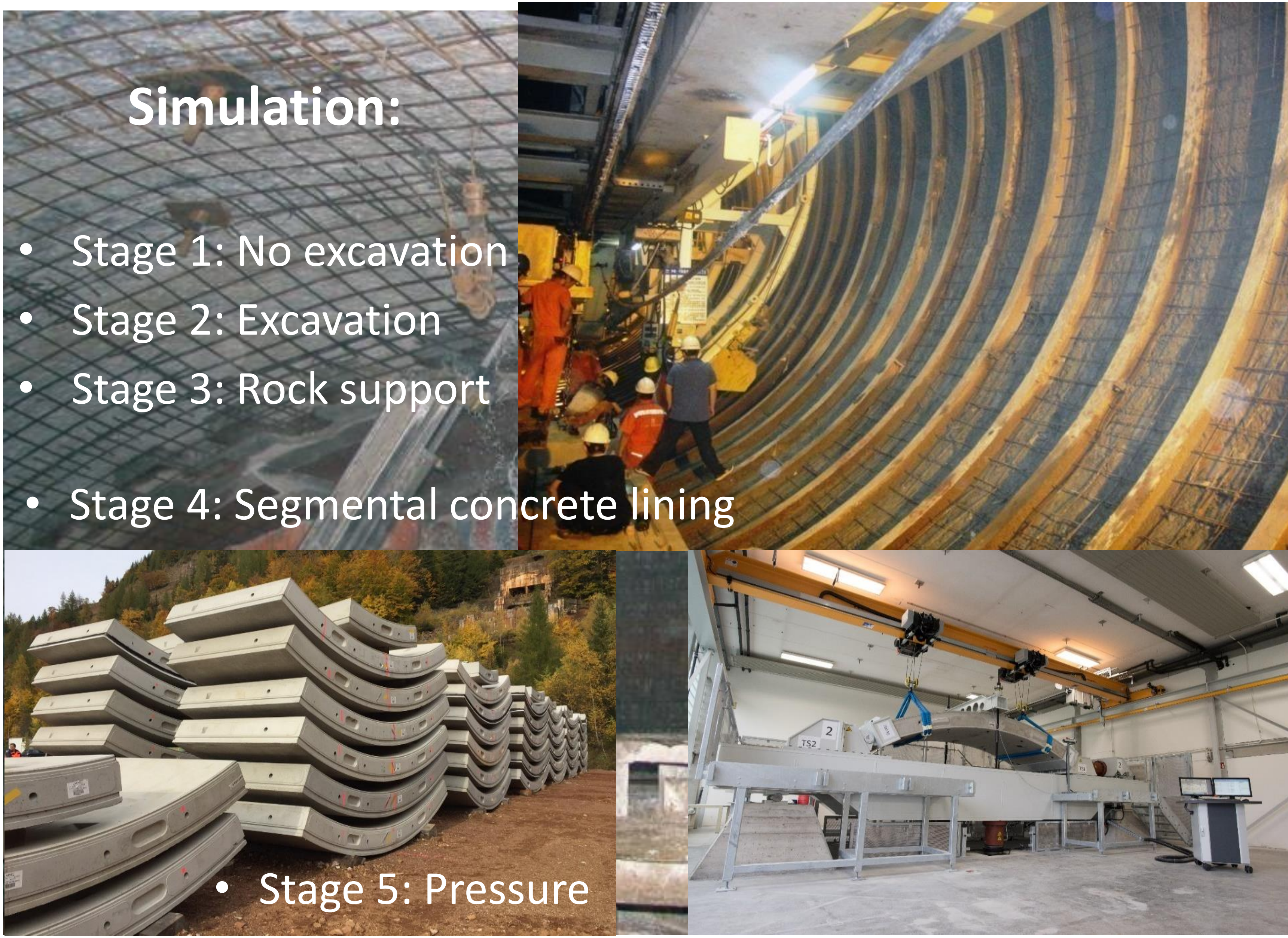
Joint filler

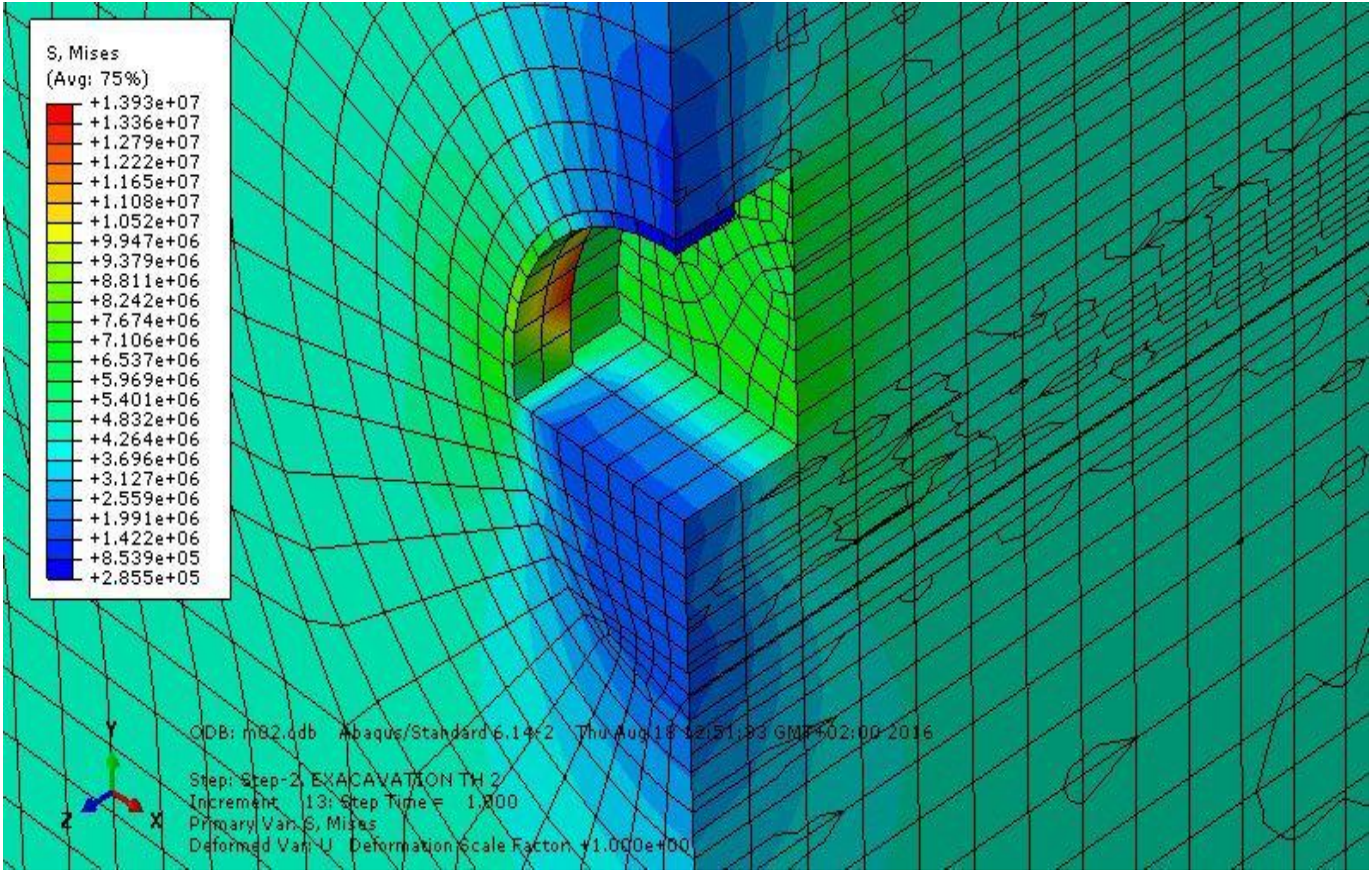


Sealing membrane

Simulation:

- Stage 1: No excavation
- Stage 2: Excavation
- Stage 3: Rock support
- Stage 4: Segmental concrete lining
- Stage 5: Pressure

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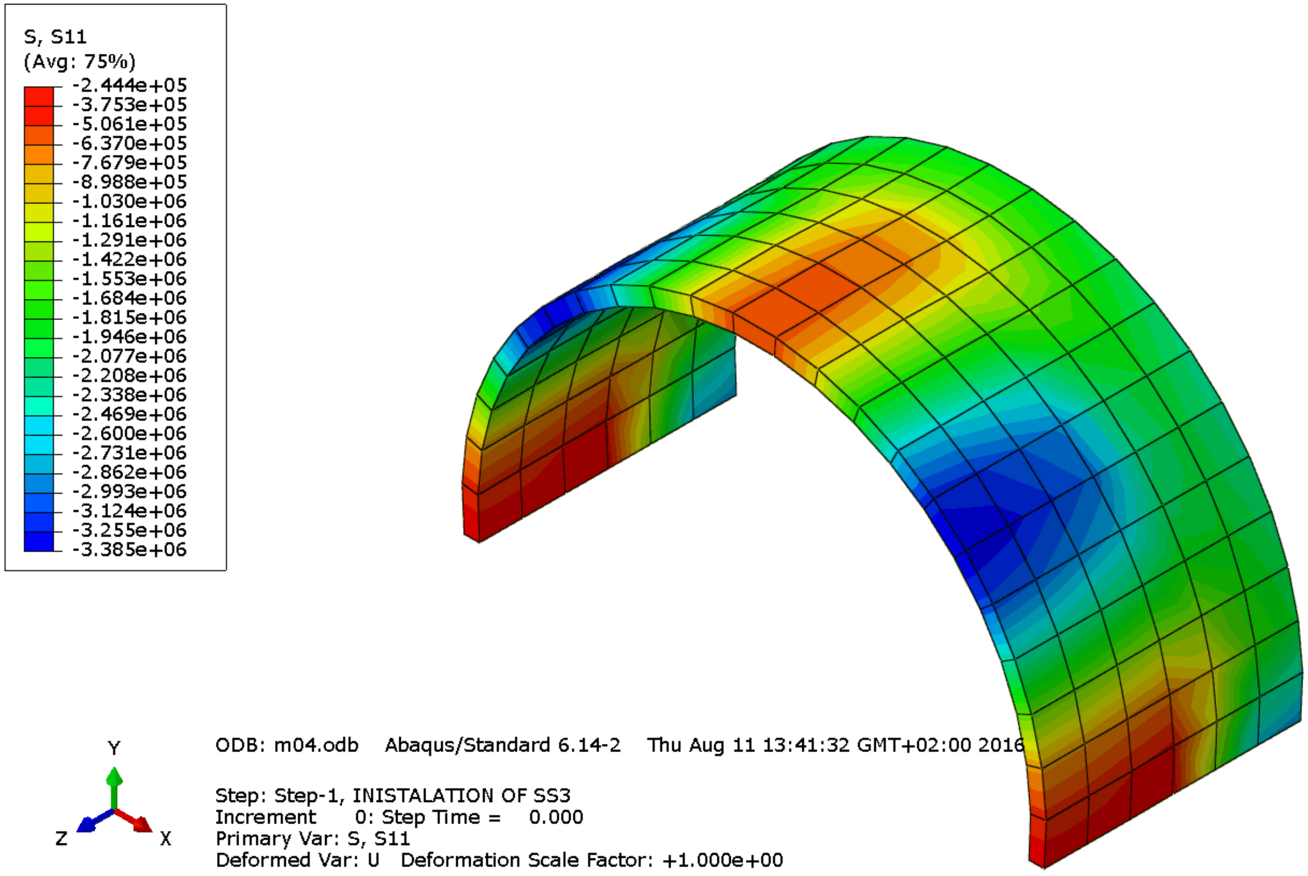
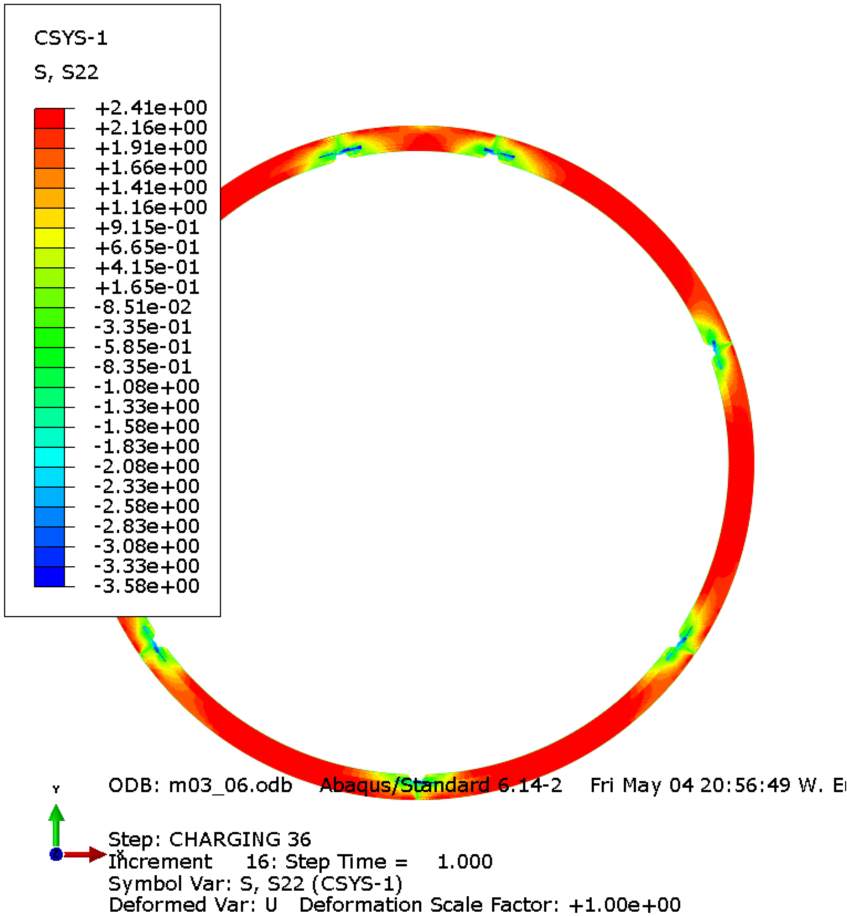
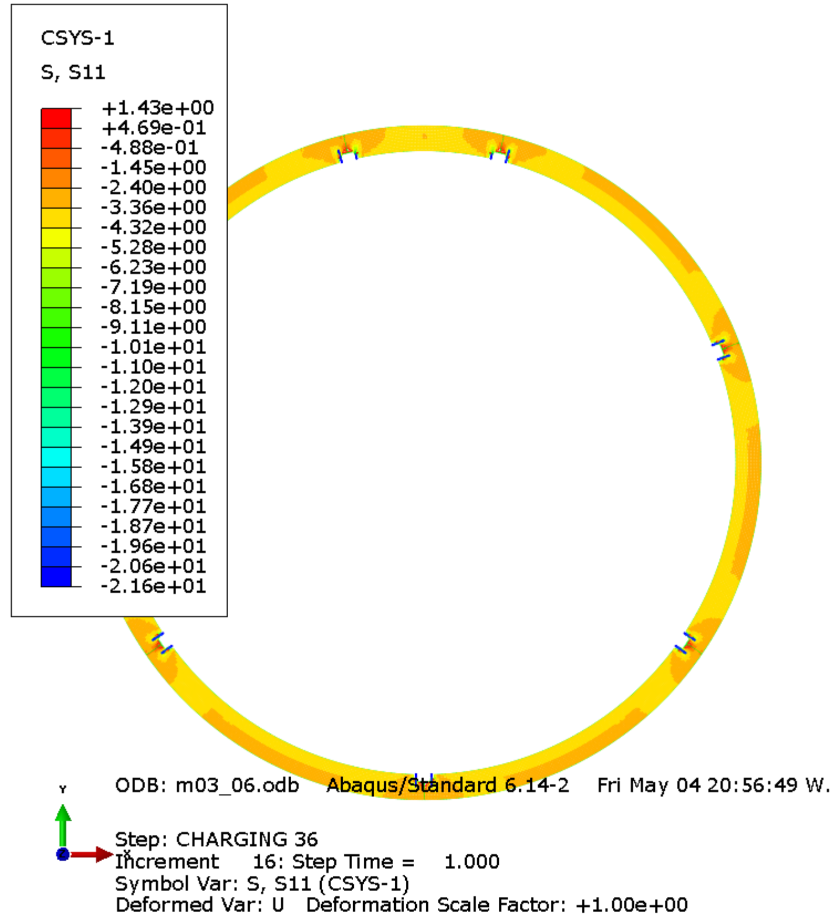
Deformed Var: U Deformation Scale Factor: +1.000e+00

Stress situation in the shotcrete lining after each simulatio step

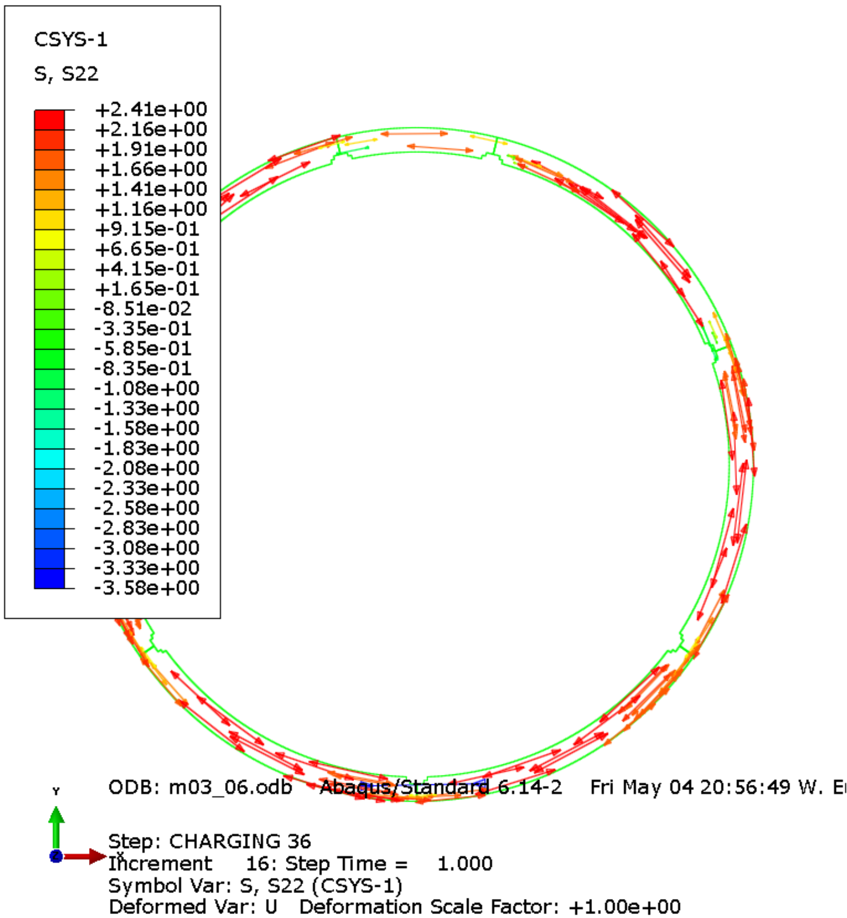


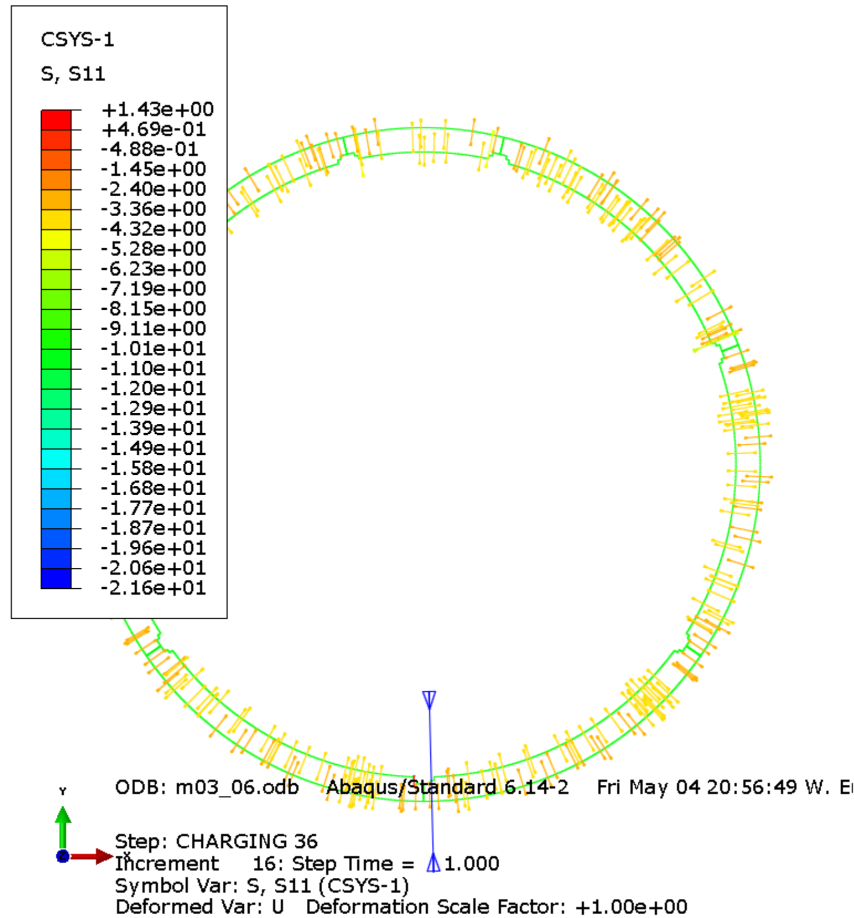
Stresses in the inner lining. Charging (3.6 MPa)



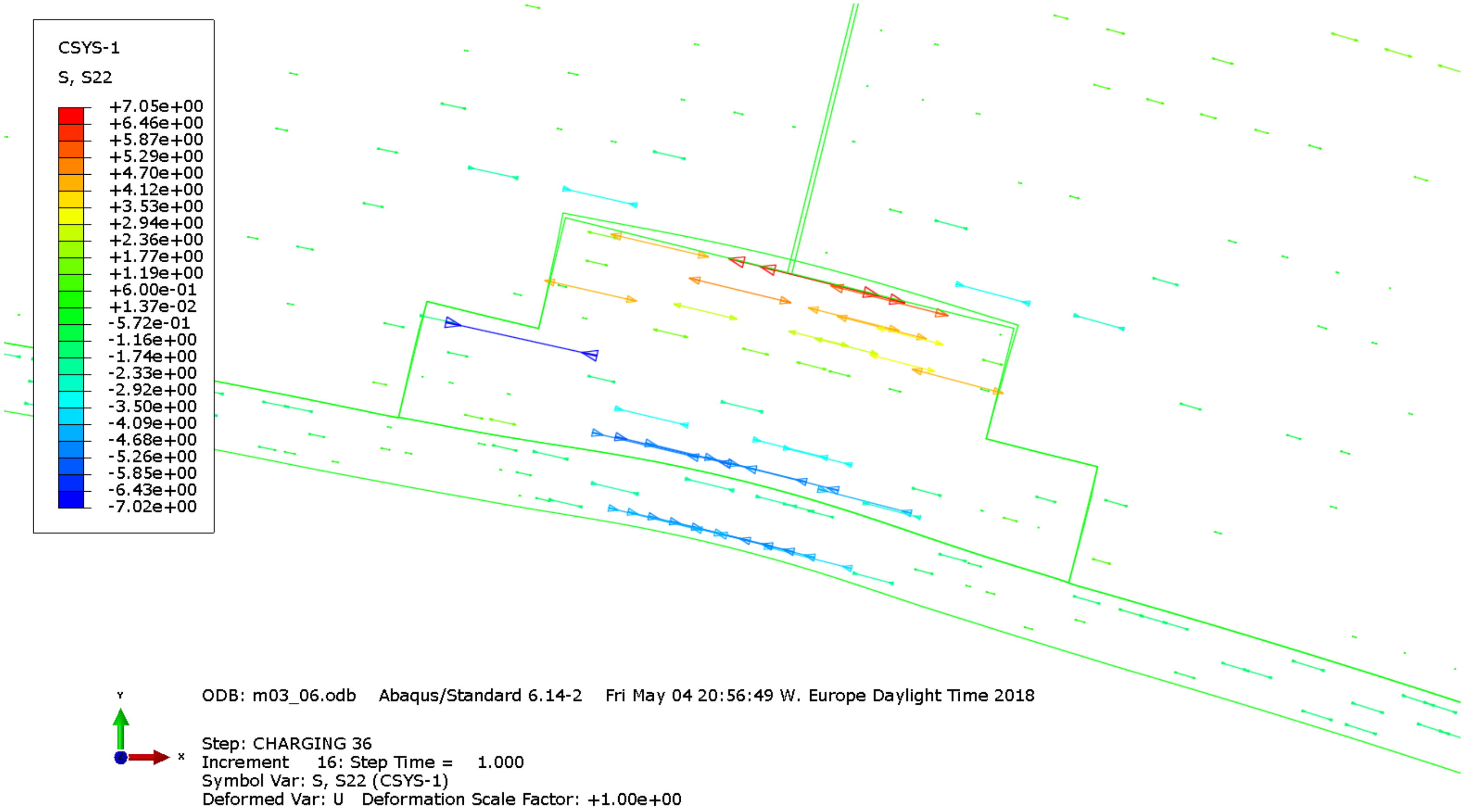


Stresses in the inner lining. Charging (3.6 MPa)

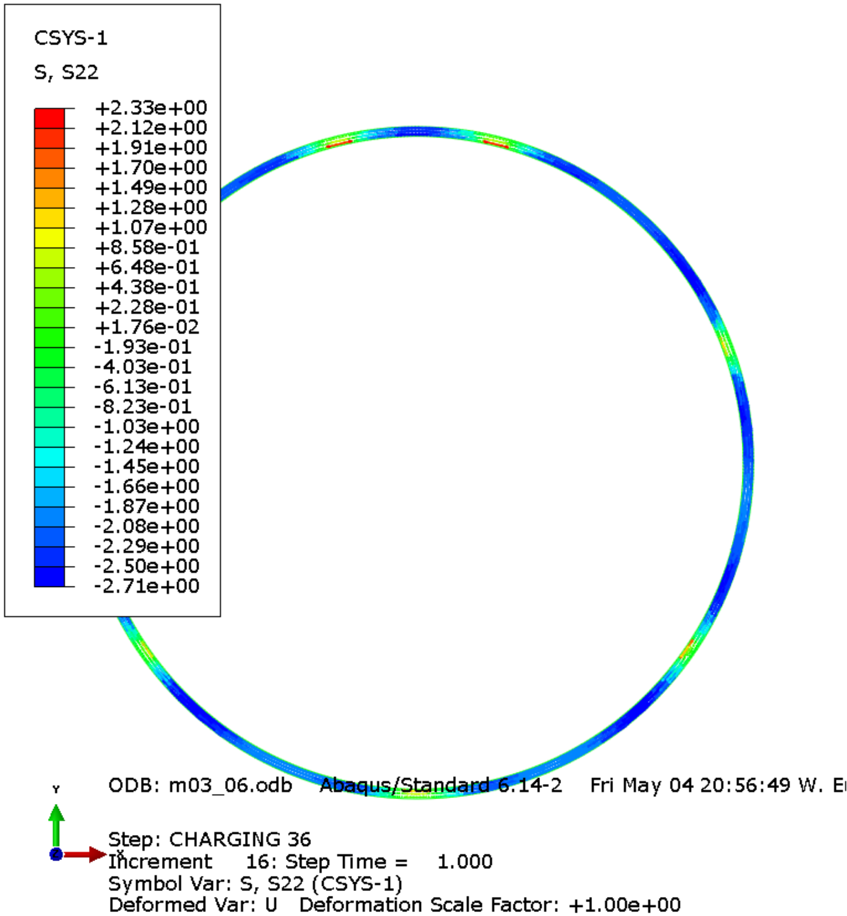


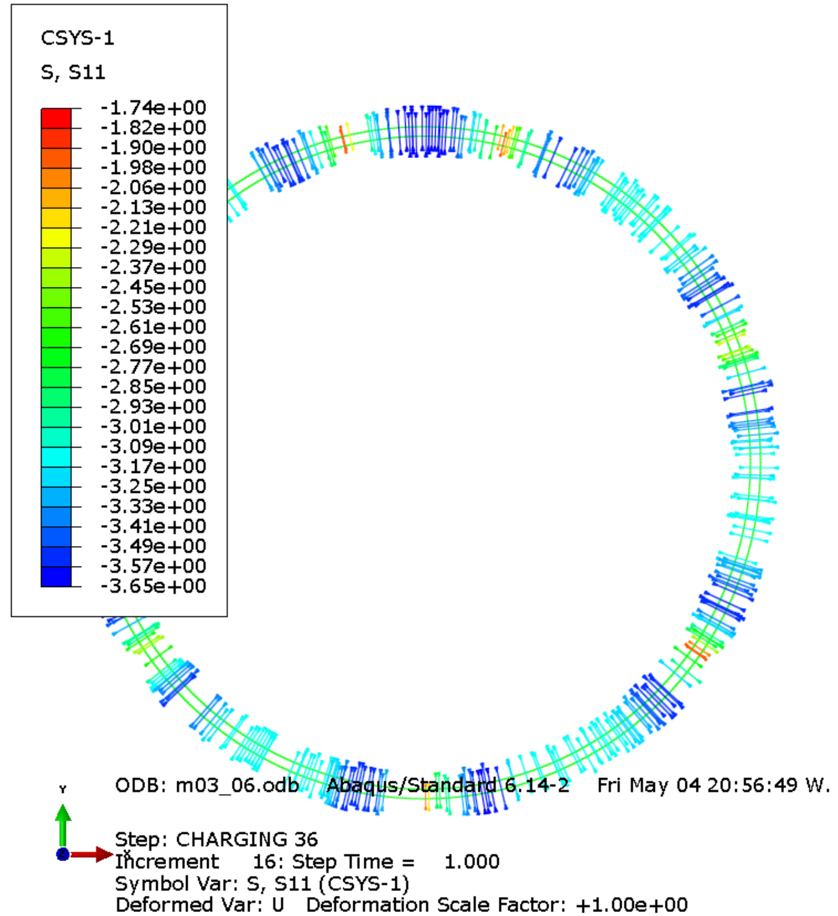


Stresses in the gap fill plug. Charging (3.6 MPa)

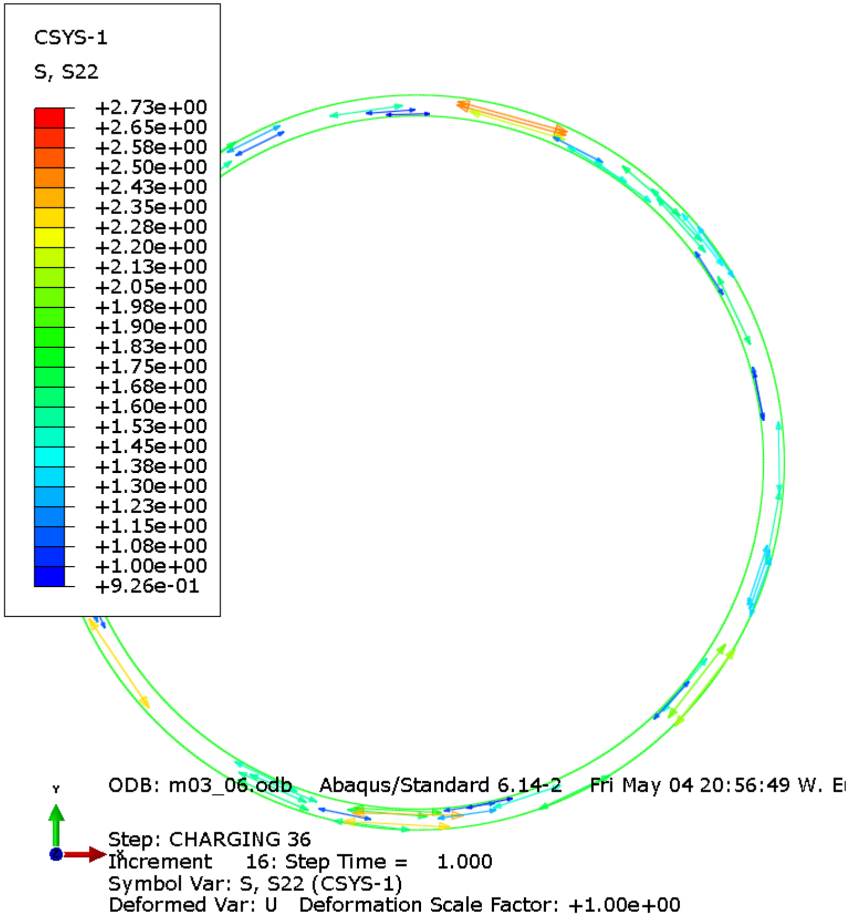


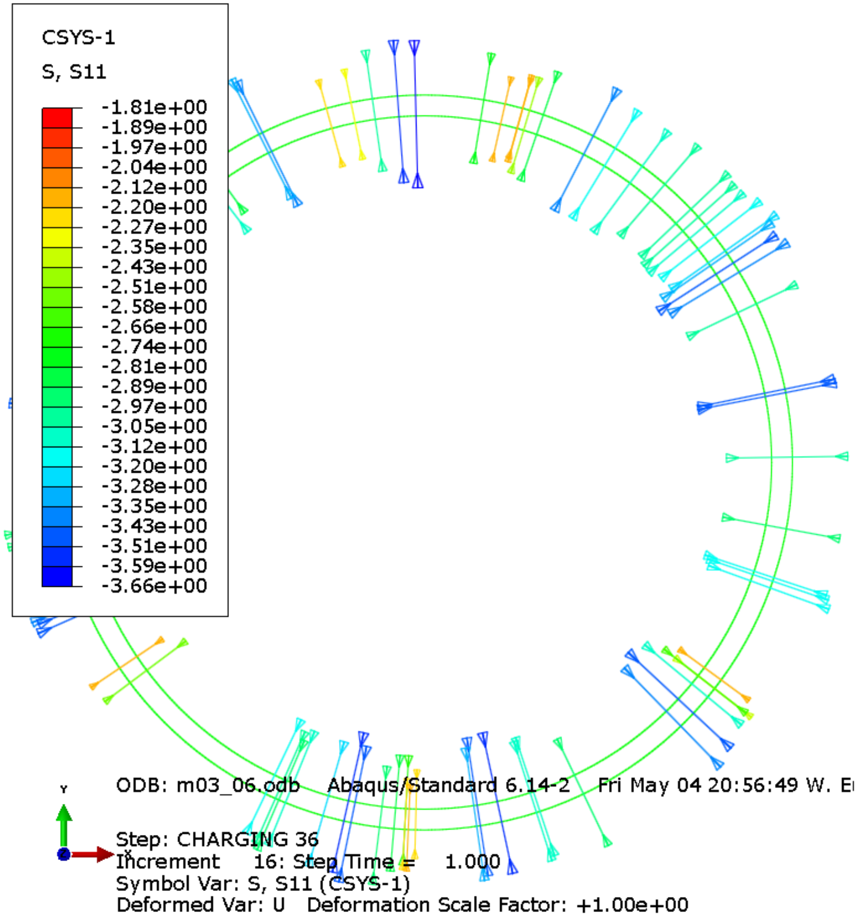
Stresses in the backfilling. Charging (3.6 MPa)



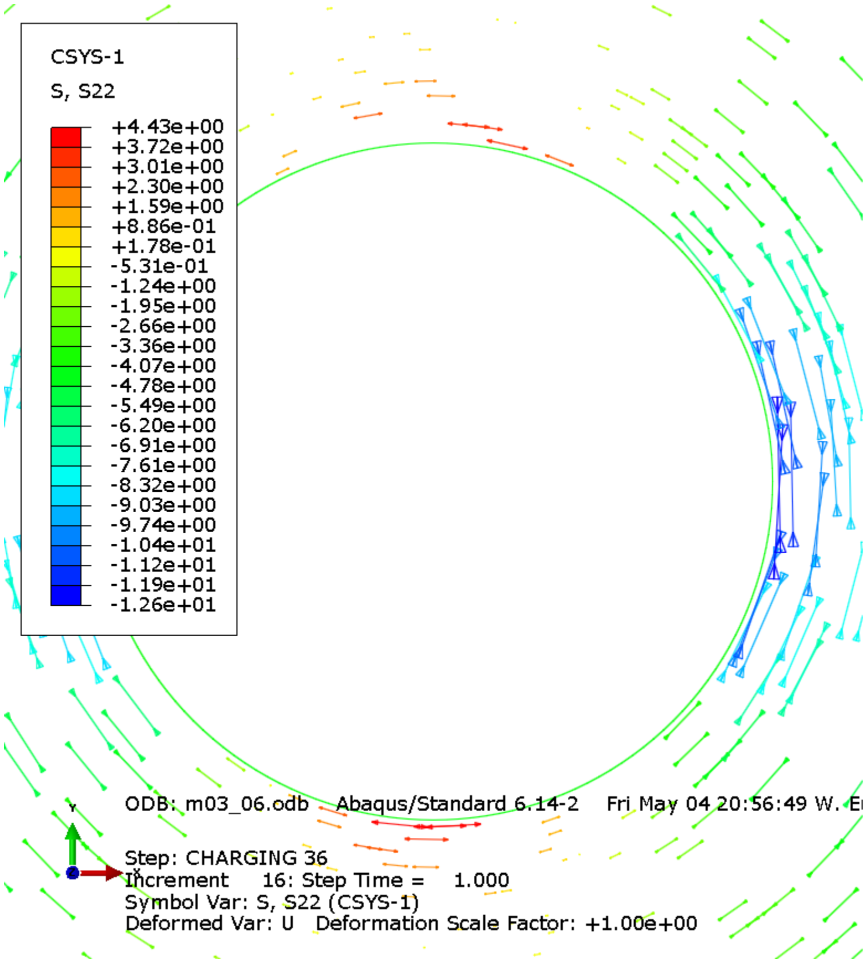


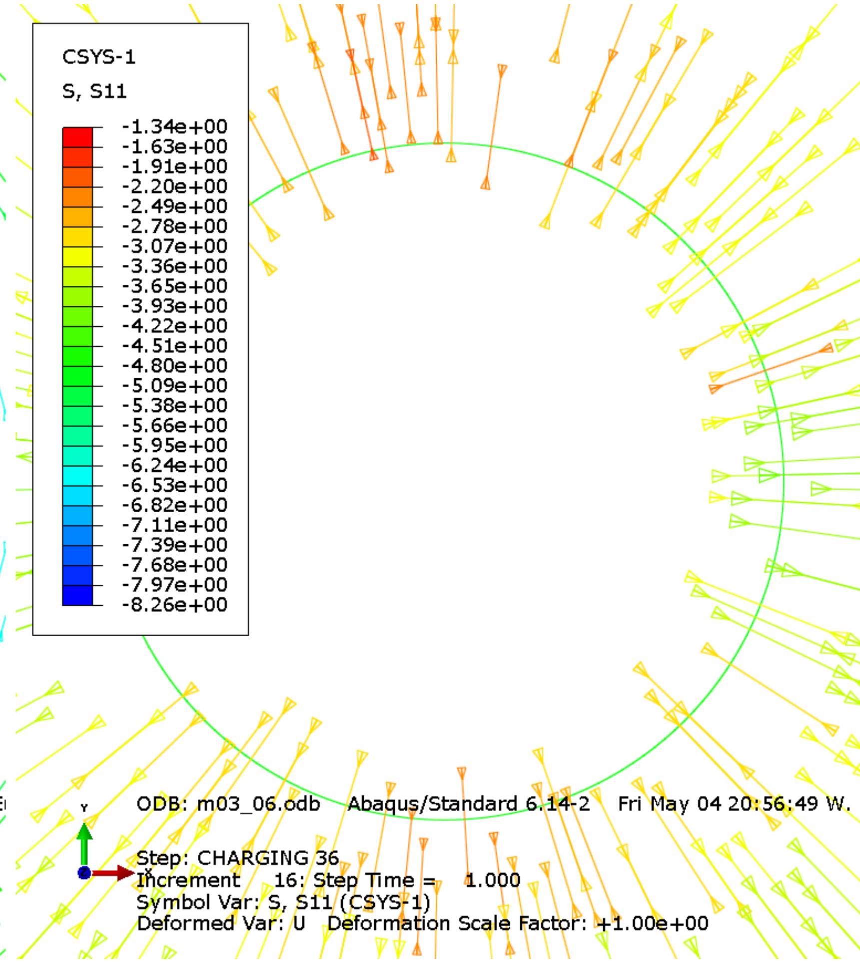
Stresses in the shotcrete shell. Charging (3.6 MPa)





Stresses in the rock. Charging (3.6 MPa)

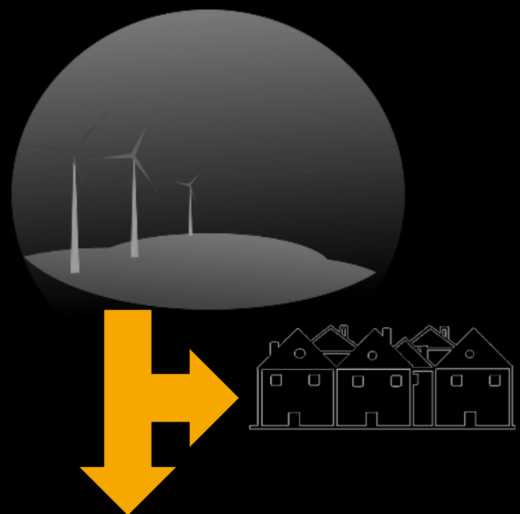




Costs for Energy Storage Options

Technology	Capital cost Capacity ($/kW)	Capital Cost Energy ($/kWh)
CAES (300MW)	580	1.75
PHS (1000MW)	600	37.5
Sodium Sulfur Battery (10MW)	1720-1860	180-210
Vanadiun Redox Battery (10MW)	2410-2550	240-340

Energy System without RICAS2020



Energy not consumed is lost

Energy System with RICAS2020

- Aligned with the energy policy framework
- Includes sustainable criteria for the design infrastructure
- Increases the energy efficiency
- Ensures the access to green energy
- Increases the sustainability of the region
- Guarantees the availability of renewable energy

- Research-, development and seminar centre for the construction and operation of underground facilities (tunnels, underground railways, underground mining, underground power plant facilities, deep drilling systems of the oil industry)
- Reasearch- and training centre for emergency organisations.
- Training- and education centre for the maintenance personell as well as for users of the road- and railway infrastructure.

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Das Land Steiermark

bmvit Bundesministerium für Verkehr, Innovation und Technologie

bmwfw Bundesministerium für Wissenschaft, Forschung und Wirtschaft