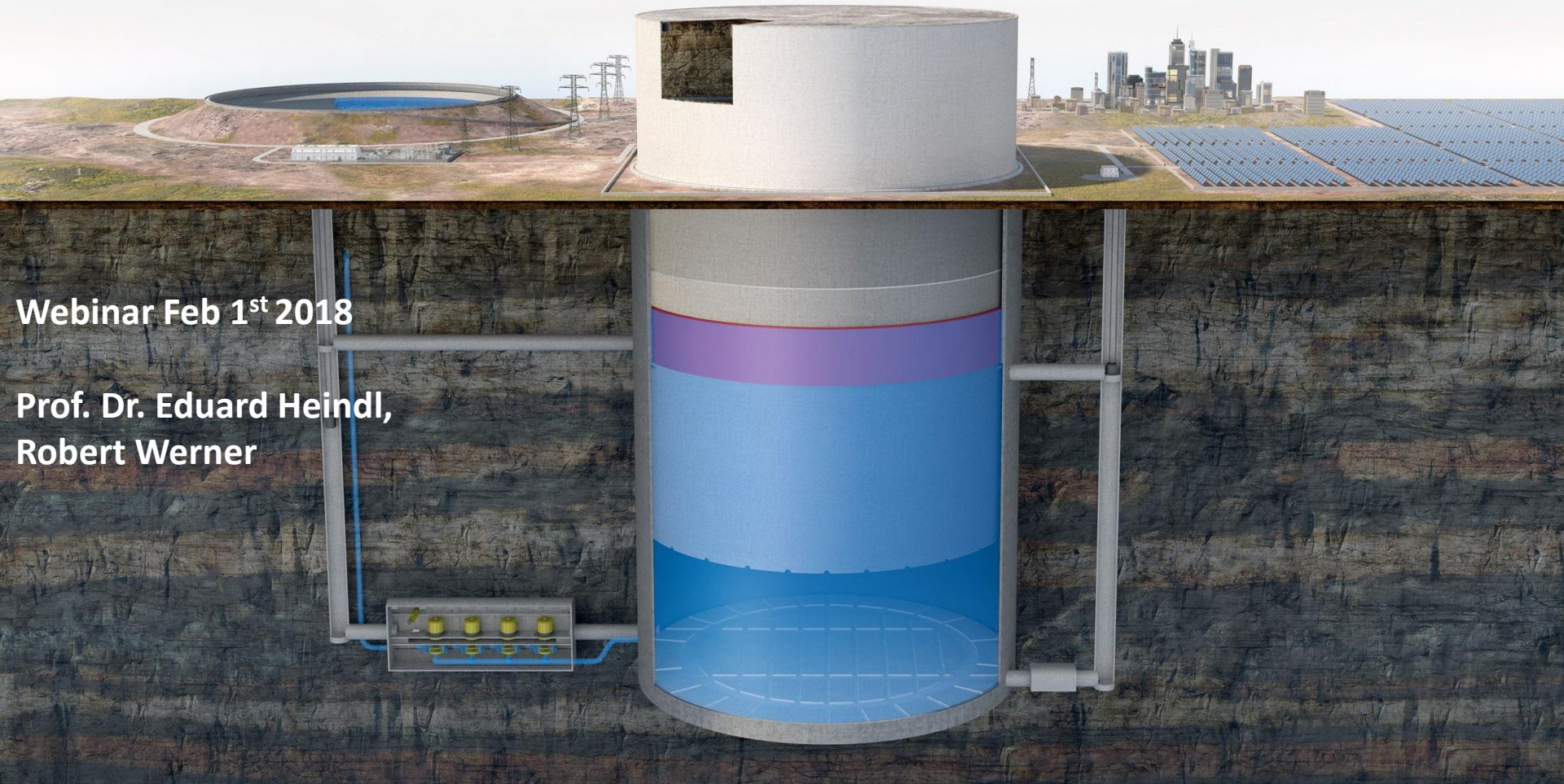


Gravity Storage

An Efficient System for Large-Scale Energy Storage



Webinar Feb 1st 2018

Prof. Dr. Eduard Heindl,
Robert Werner

➤ The Problem:

There is currently **no large scale storage solution** that concurrently addresses affordability, investment cost, environmental impact and ubiquity, to respond to the pressing macrotrends of general renewable spread and grid balancing challenges.

➤ The Answer:

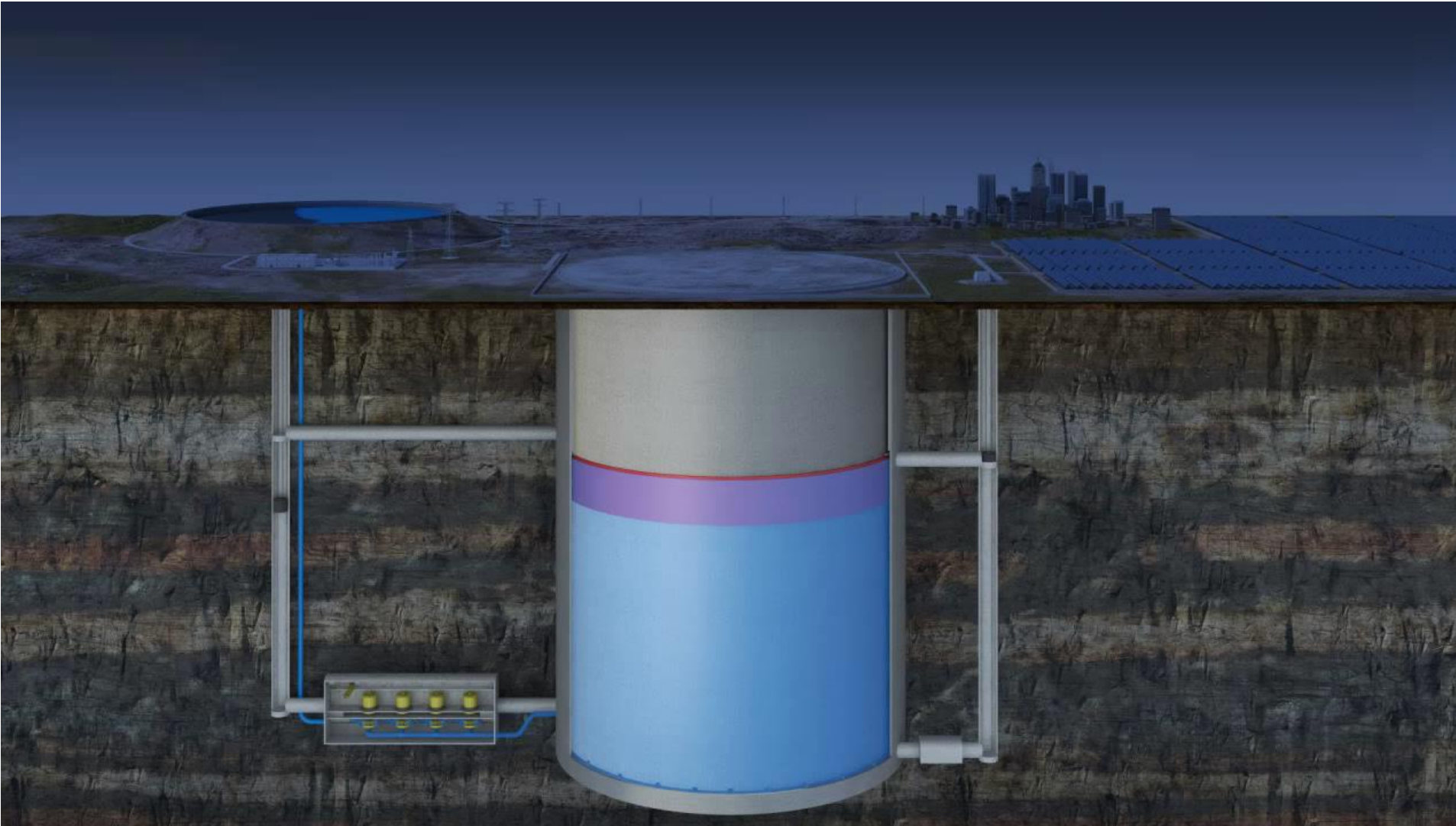
Gravity Storage solves this challenge with a unique sustainable large scale storage solution with:

- Unrivalled economic efficiency
- Lifetime: 60 years and more,
- lower CAPEX and LCoS than any other bulk storage
- Minimal environmental impact (max energy/sqm, limited water use)

How Gravity Storage works

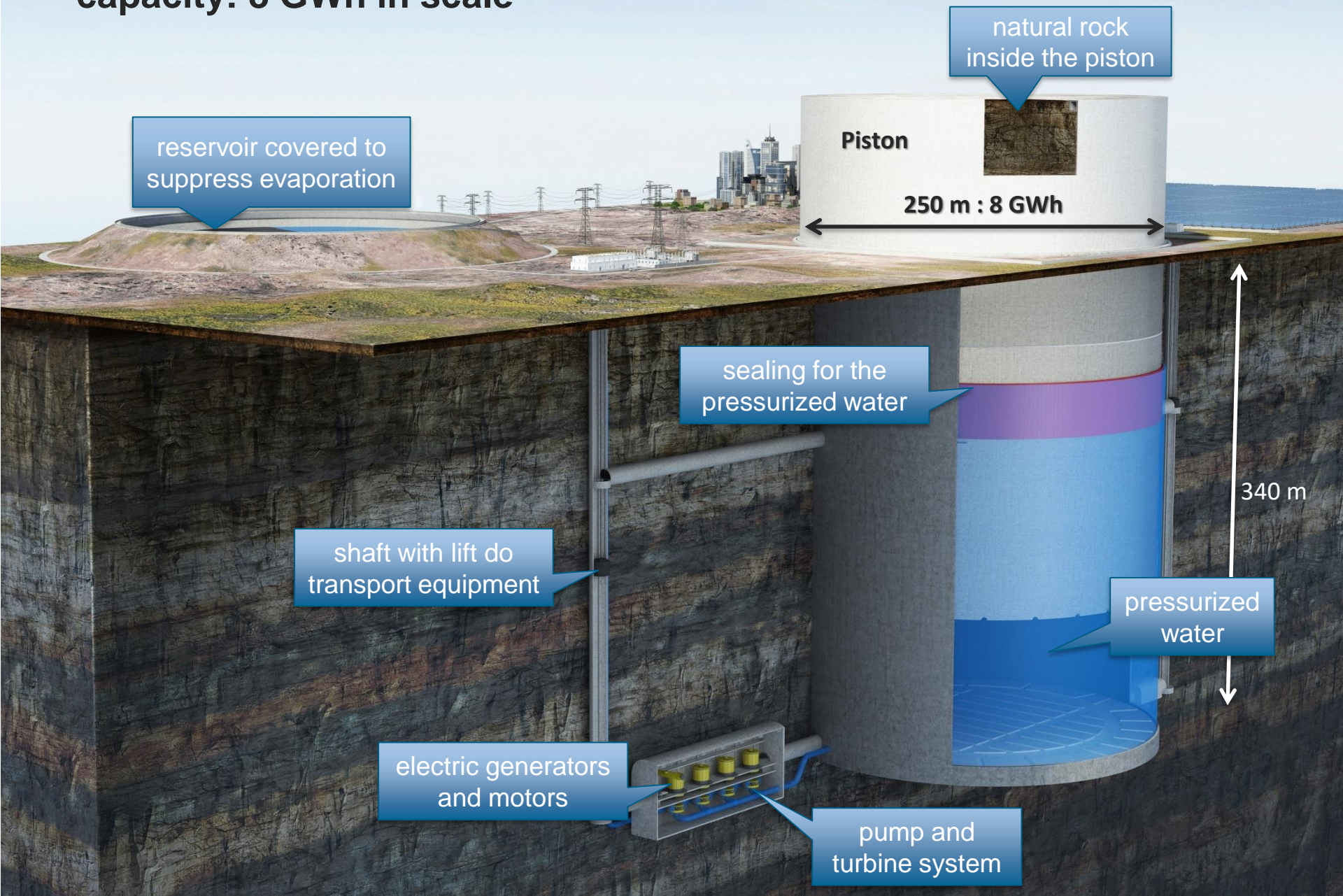
One storage cycle, animation <https://vimeo.com/242084551>

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Basic elements of a Gravity Storage

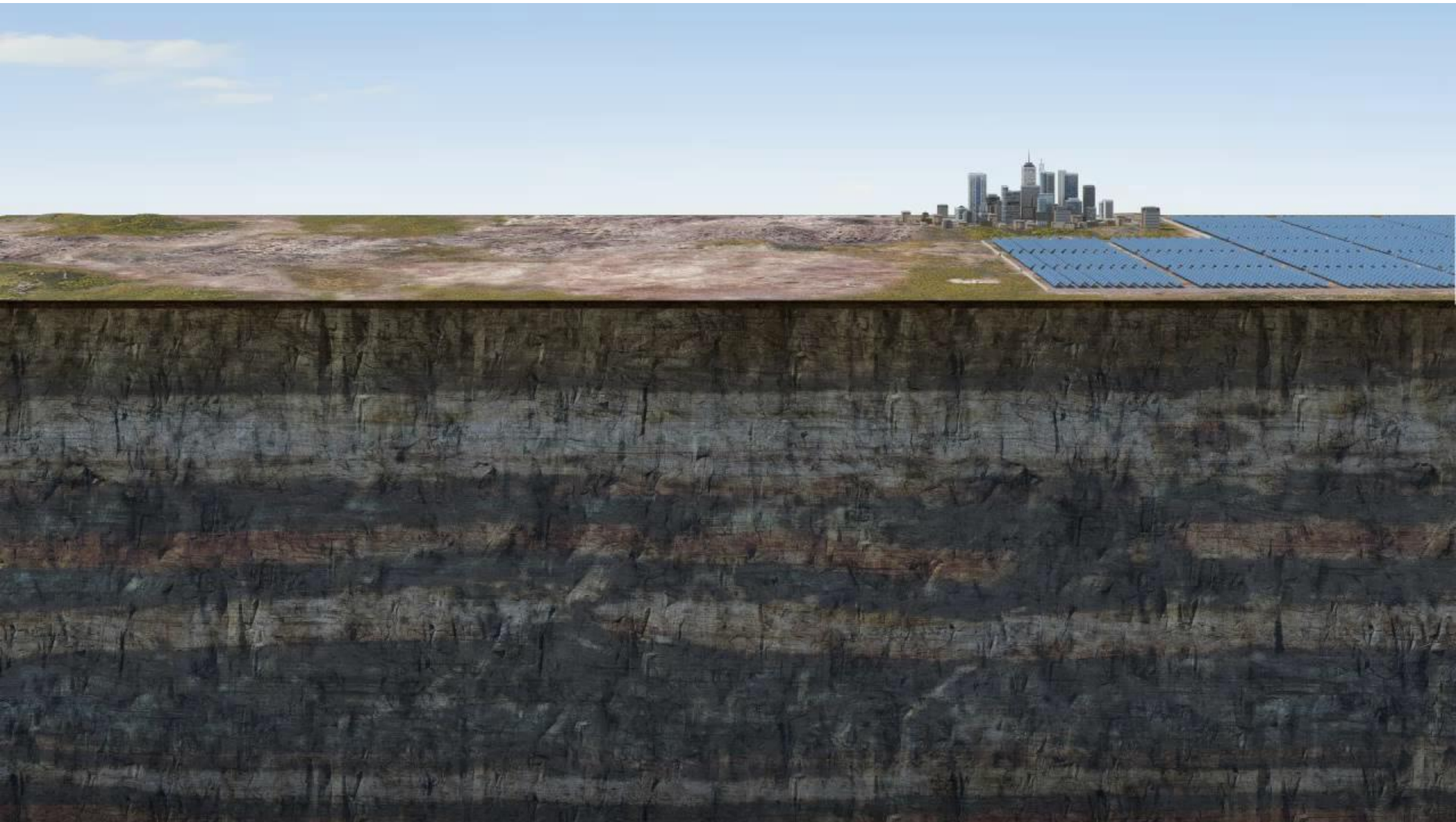
capacity: 8 GWh in scale



Construction of a Gravity Storage

Main steps, animation <https://vimeo.com/242082867>

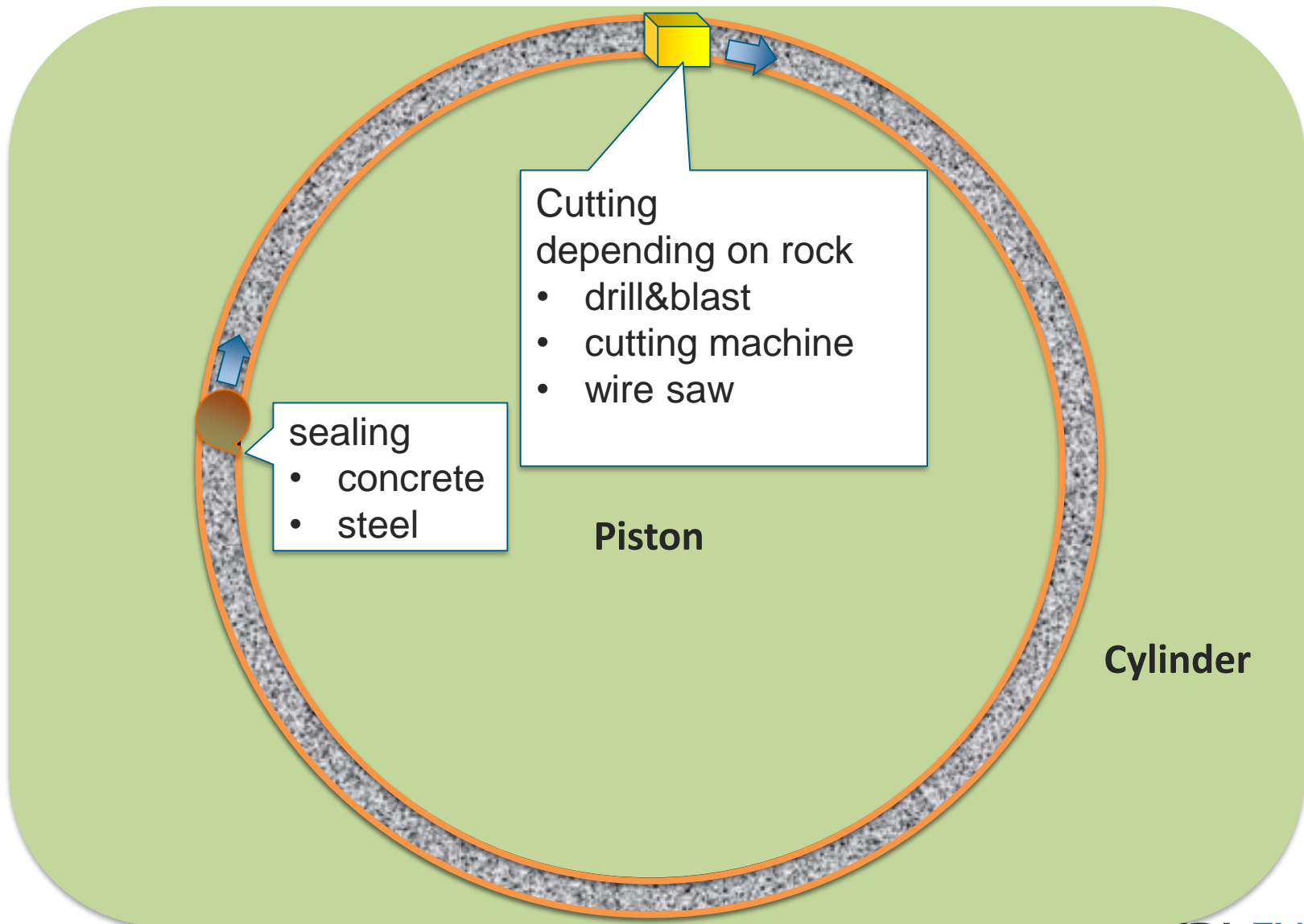
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Excavation of Annulus

Ring shaped space between piston and cylinder

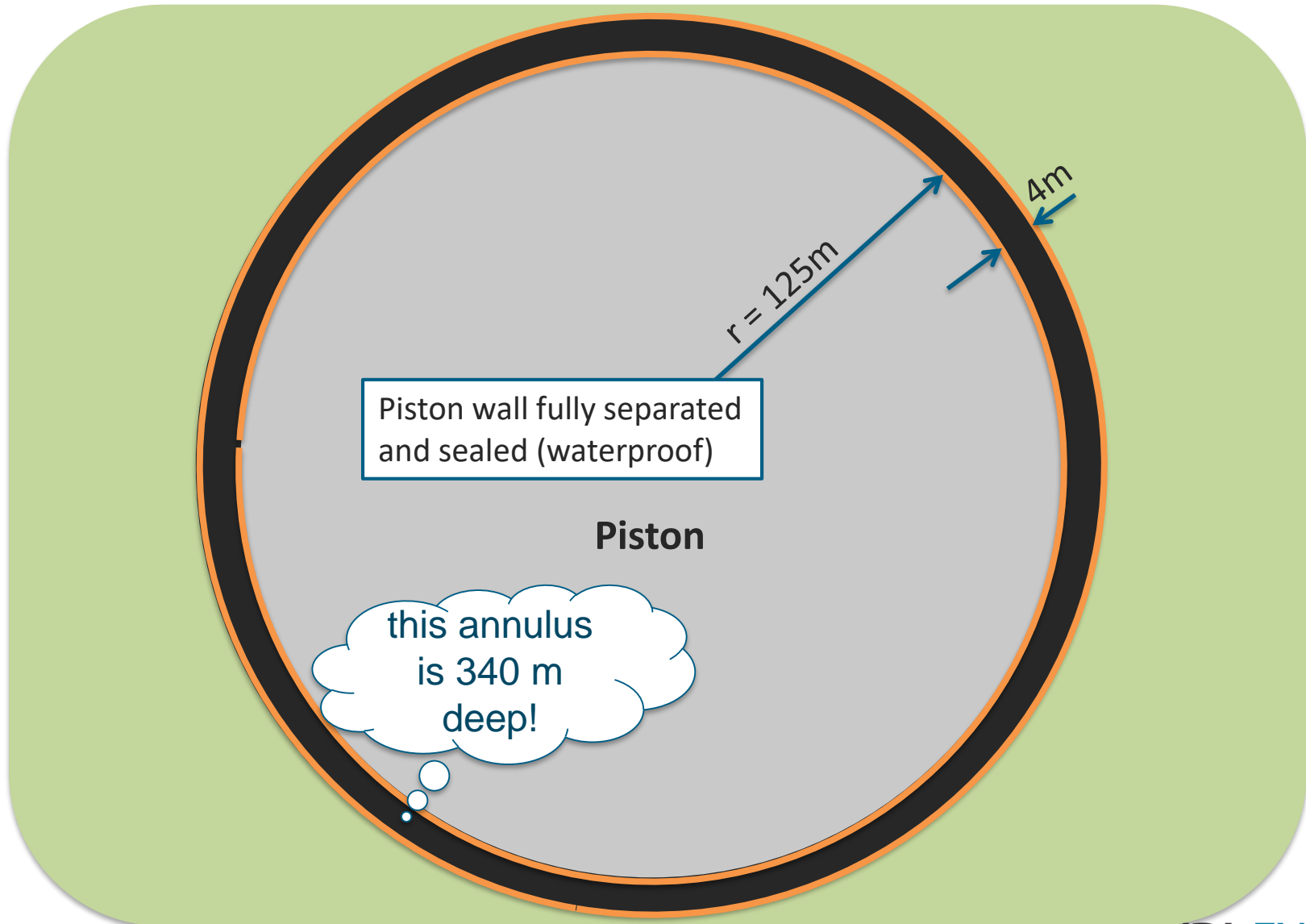
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Excavation of Annulus

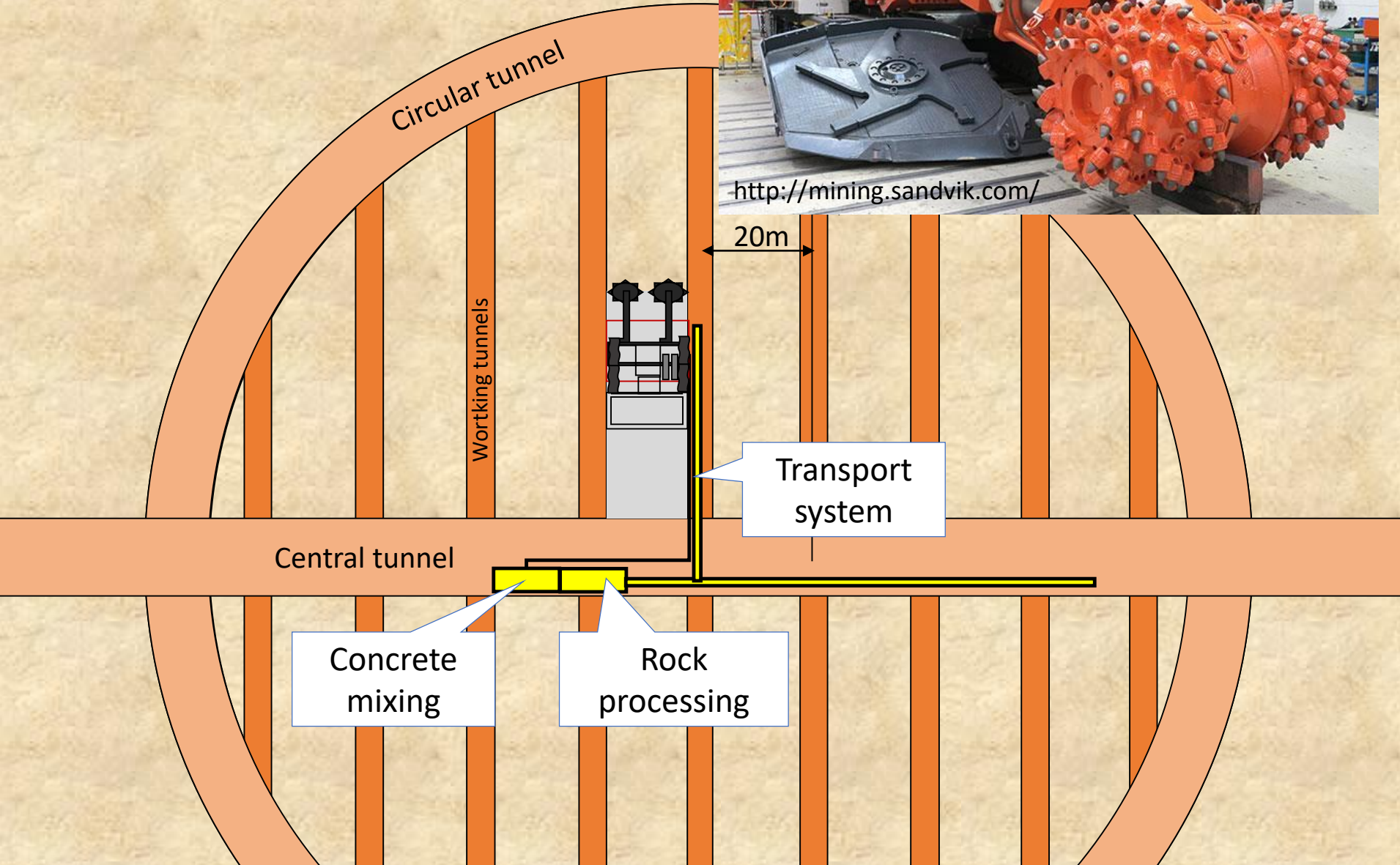
Ring shaped space between piston and cylinder

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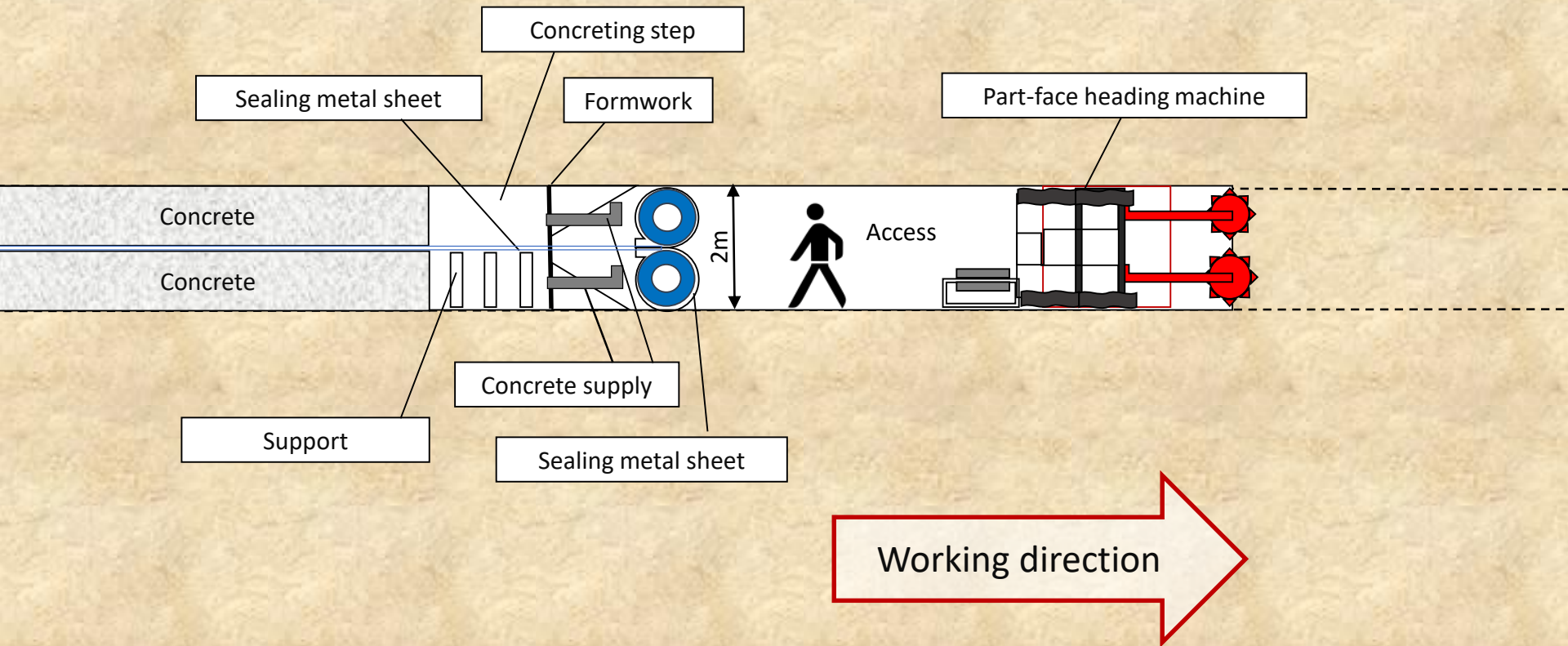
Separation of Piston Base

Part face heading machine

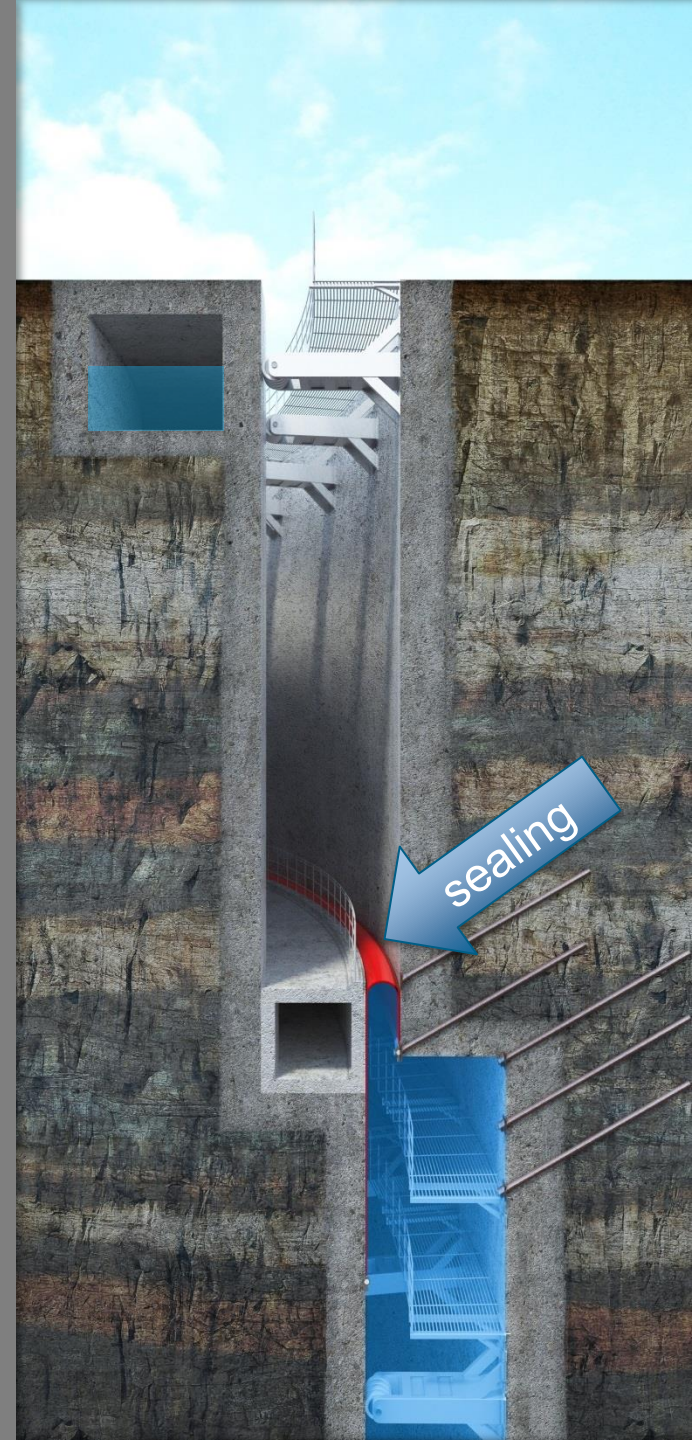


Separation of Piston Base

Part-face heading machine and lining setup



Rolling membrane seal

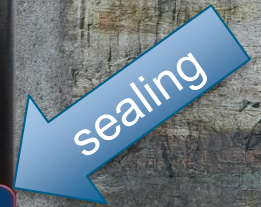


Rolling membrane seal



Rolling membrane seal

- Typical pressure regime: 70 bar
- Forces will be taken up by steel wires
- Flexible against imprecisions
- Self centering
- Constructed out of conveyor belts out of mining industry



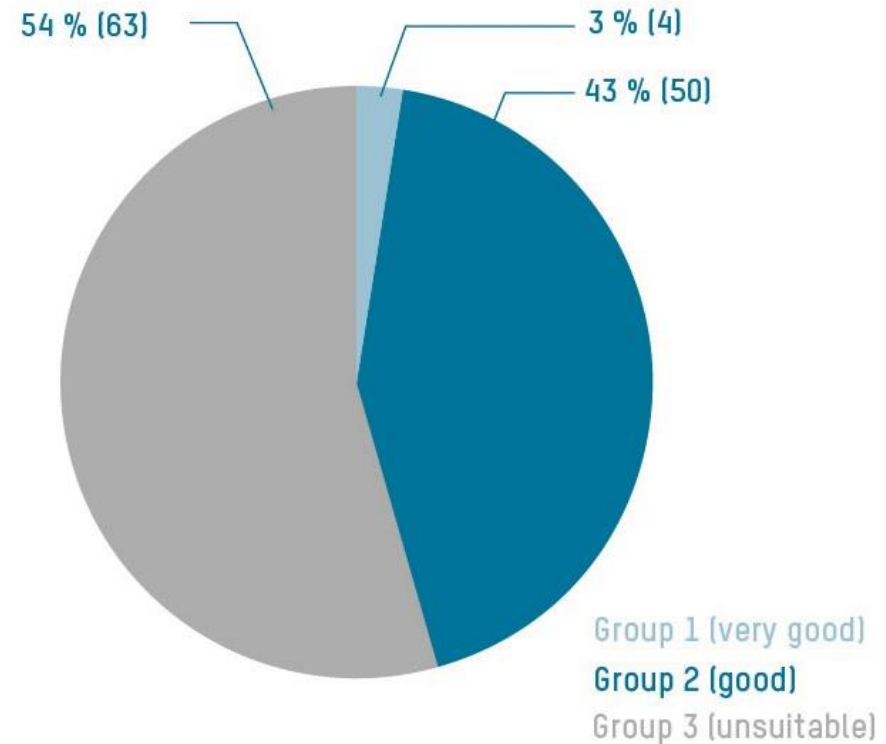
Geology

The most favorable sites have stable, **little-faulted rock such as granite** or compact layers of otherwise solid rock material.



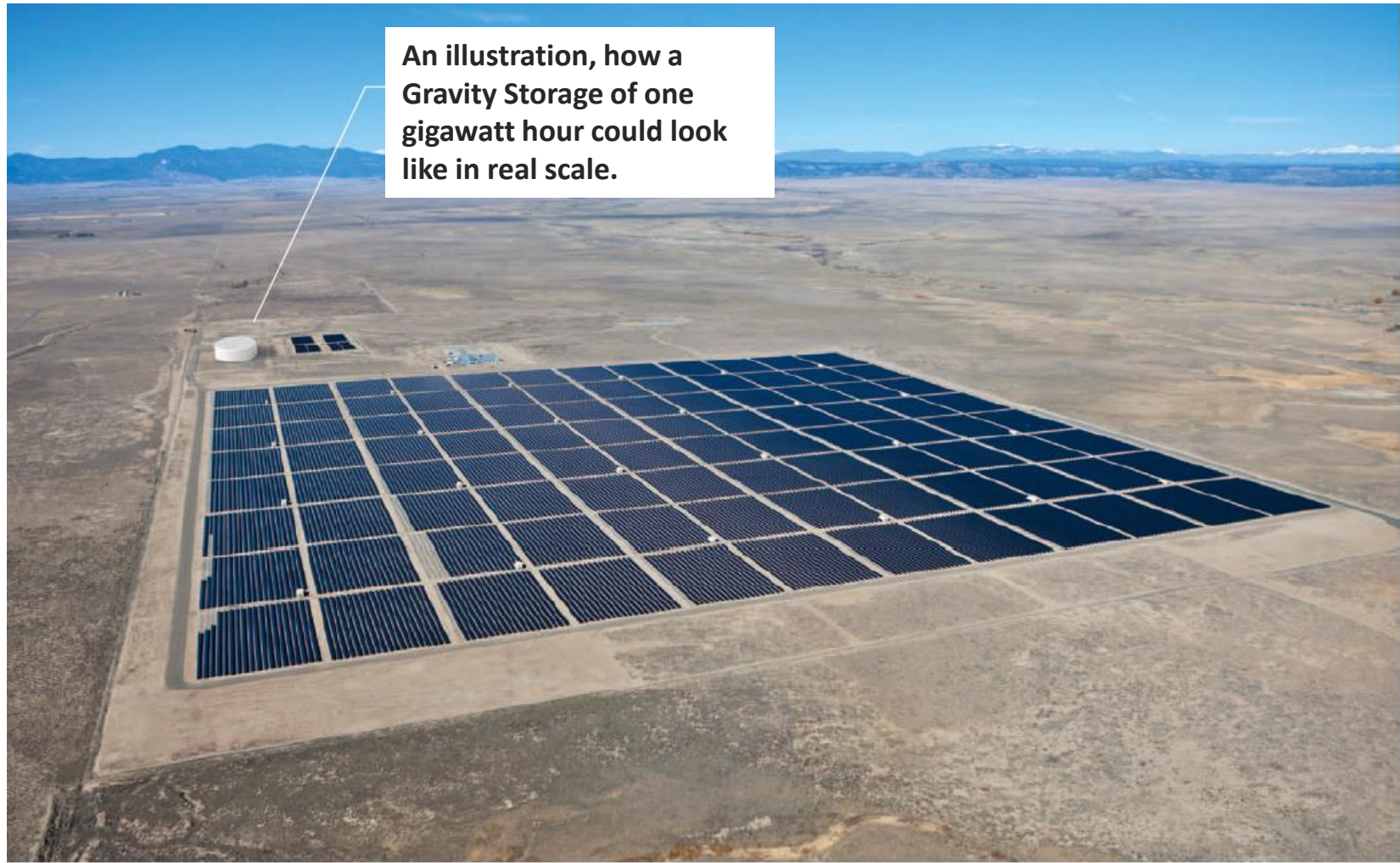
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How widespread are suitable geological conditions for Gravity Storage?



Large PV-plants in Combination with Gravity Storage

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✓ Applicability

- Gravity Storage requires no elevation
- It can be integrated easily in any transmission grid
- More than 40% of the Earth's continental surface is basically suitable for Gravity Storage

✓ Sustainability

- Minimal raw material requirement, "just rock and water"
- It needs substantially less water compared to Pumped Hydro Storage
- Small land footprint per kWh
- No chemicals

✓ Performance

- High energy round trip efficiency 80%
- Provides all types of system services: ancillary services, black start capability, rotating masses.
- Our discharging time can be tailored to the operators needs.

✓ Profitability

- Gravity Storage is economically superior
- Most competitive LCoS for Bulk Storage
- Low running costs

Path for size development

From R&D towards commercial application

Gravity Storage

Our partners/ experts:



SEMPERIT



Commercial size with 250 meter diameter, ~8 GWh capacity

First commercial size with 150 meter diameter, ~1 GWh capacity

Pilot project:
Ca. 80 x 120 meters, ~200 MWh capacity

- First commercial application
- Optimization of separating the bottom
- Strengthening of applications from proof of concept

Proof of Concept:
Demonstrator (2018/2019), 20x30 meter, 0,3 MWh

- Construction method in general, excavation of piston, separating the bottom.
- Sealing of surface, Sealing of the pressurized water.
- Pressure management, determining failure limits
- Proof of ability for permanent application
- Investigating rock stability

In depth **research** on construction and implementation of Rolling Membrane Sealing and geotechnical challenges concerning piston stability

- ✓ Scoping Study on the overall feasibility to build such a storage
- ✓ Study on geological requirements
- ✓ Assessment about global potential of geologically suitable locations
- ✓ Cost analyses of total costs of investment including pumps, turbines and E&M parts
- ✓ Expertise: environmental impact assessment
- ✓ Running project: Proof of Concept for manufacturing the Rolle Membrane Sealing.
- ✓ Running research: seismic resilience

2017

2018

2019

2020

2021

2022

2023

2024

Demonstrator project near Ar Ruwaidhah, Saudi Arabia

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Goal:

To **proof the concept** of Gravity Storage.

- Convincing potential operators of the commercial size of Gravity Storage
- Testing of materials and techniques required for the construction
- Gaining experience in the design of commercial-size gravity storage plants with a piston of up to 250 m diameter

Size: Diameter 20m, Height: 30m
=> 0,3 MWh (no commercial use)

Sealing:

Built in scale 1:1, as it will be in commercial size

Pressure test: beyond 70 bar

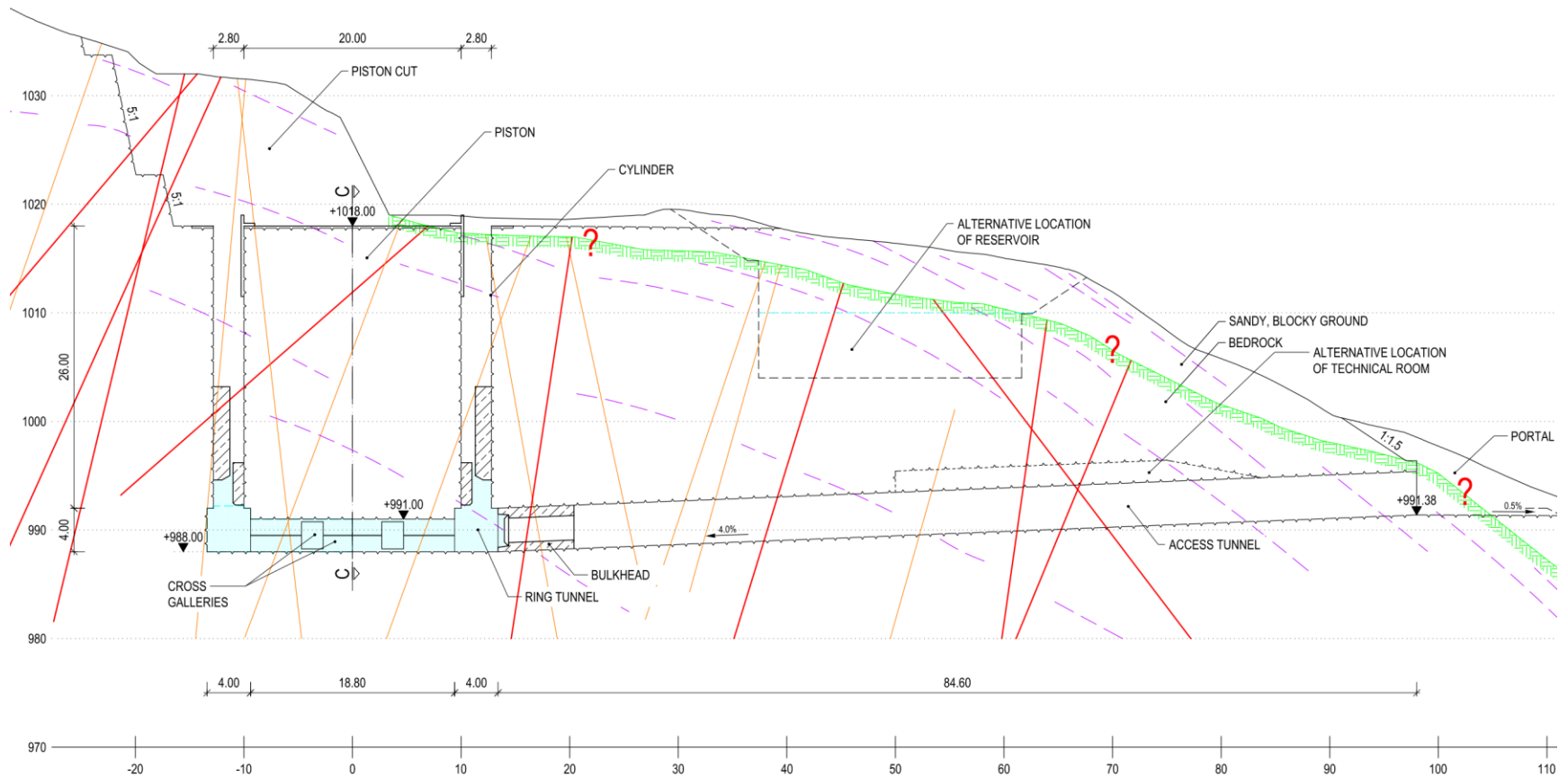
Scheduled start of operation: 2019



General Layout

Long Section incl. discontinuities

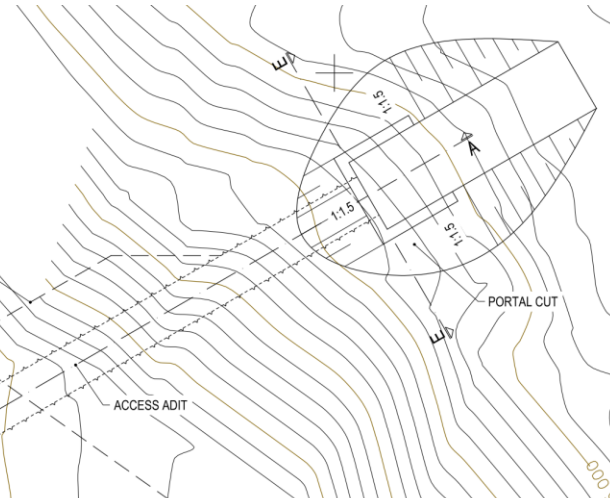
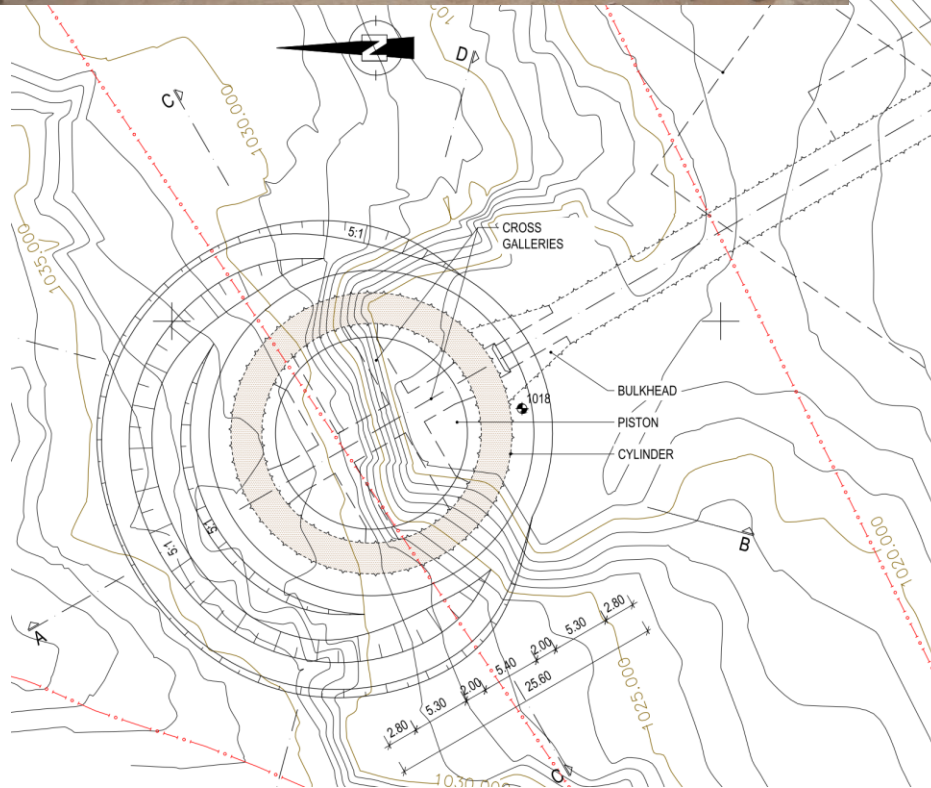
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Location, general layout

Plan demonstrator and access tunnel

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Gravity Storage's Revenue Models I

The future demand of energy storage will be manifold in terms of business cases and revenue streams. GS is perfect to combine these applications

Arbitrage Model & PPA's

Enabling renewables to perform 24 hours:

Combine generation and storage capabilities to deliver electricity for 24-hour at a fixed price.

This sort of supply requires daily storage capacity of 6-14 hours to **guarantee a 24-hour supply**.

Provision of ancillary services, such as

- frequency regulation,
- voltage support,
- black start capability and
- spinning reserve capacity.

These services require storage solutions for a few seconds up to a few hours. In this case, the return will come from specific service fees and grid charges.

Provision of balancing power,

when intermittent generation requires fast ramping capacities.

GS takes part in the markets for balancing power.

How utilities and IPP's benefit from Gravity Storage

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Gravity Storage provides a solid business case while making renewables available for 24 hours with steady margins for decades

Exemplary calculation for size of 8 GWh and a costs for charging power of 3 \$ct./kWh

	for 8 GWh size	remarks
capex	1,7 bn USD	calculated in EUR at German cost level
opex	<1% of capex	annually
Revenue per year	260mn USD	assuming 330 cycles a year
IRR (equity) p.a.	11%	without subsidies!
payback time	16 years	Lifetime 60 years

Gravity Storage:

- ✓ Capacity up to 8 GWh
- ✓ Efficiency > 80%
- ✓ Investment costs: ~200 USD/kWh
- ✓ Lifetime > 60 yrs.

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