European Workshop on Underground Energy Storage

November 7th-8th 2019,
Quartier latin, Paris, France

Underground Pumped Hydro Storage

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SCOPE

- Pumped Hydro Storage Power Plants in General – Mode of Operation, Typical Applications, Limitations

- Underground Pumped Hydro Storage (UPHS) – Overview
  - Why to Go Underground
  - Basic Concepts in Mines
    - abandoned mines
    - active mines
    - virgin rock
  - UPHS in Salt Caverns

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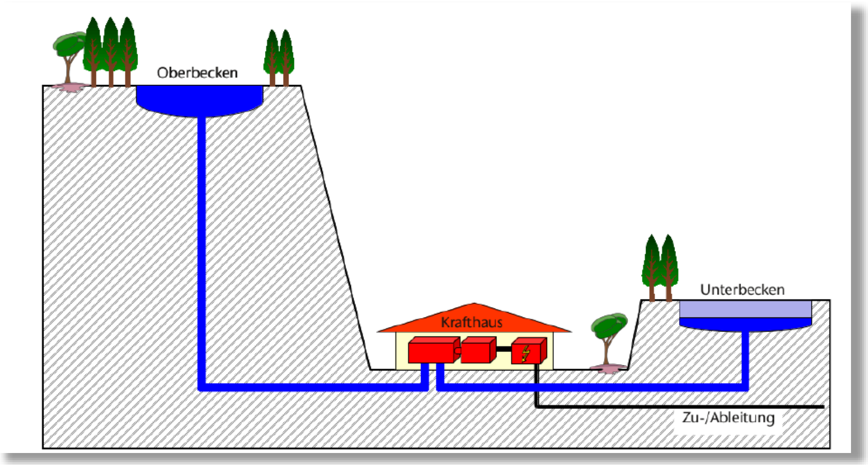
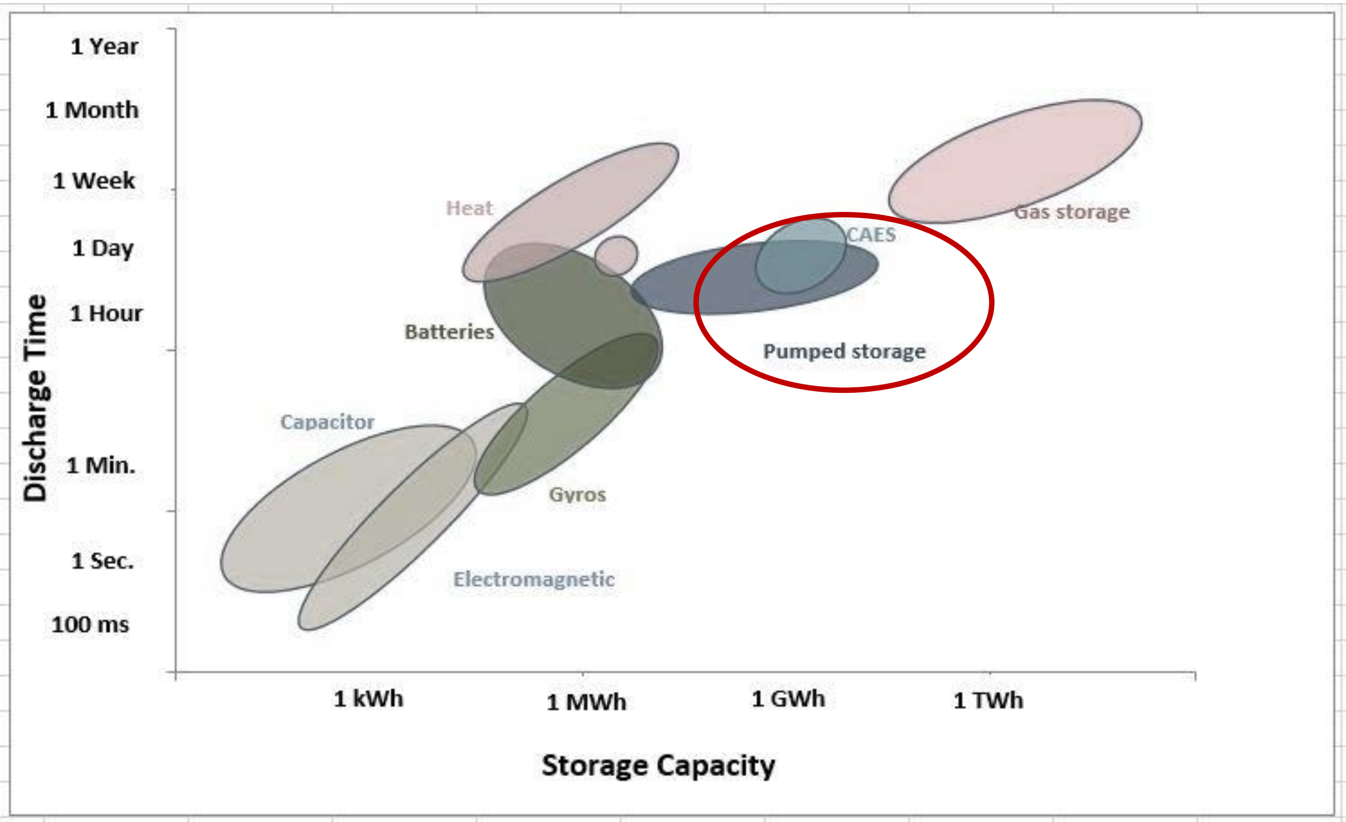
Pumped Hydro Storage



Source efzn

- By conventional Pumped Hydro Storage large amounts of Energy are stored with a high efficiency (η > 80%).
- PHS Goldisthal / Germany
  W = 8 500 MWh; P = 1 080 MW
  12 Mio. m^3 Water

Potential of PHS



after M. Sterner, I. Stadler: „Energiespeicher – Bedarf, Technologien, Integration“ , Springer Viehweg (2014) S. 605

Pumped hydro storage has the highest storage capacity, however below natural gas or hydrogen storage.

Produced Electricity by Pumped Hydro in GWh in Some Selected European Countries

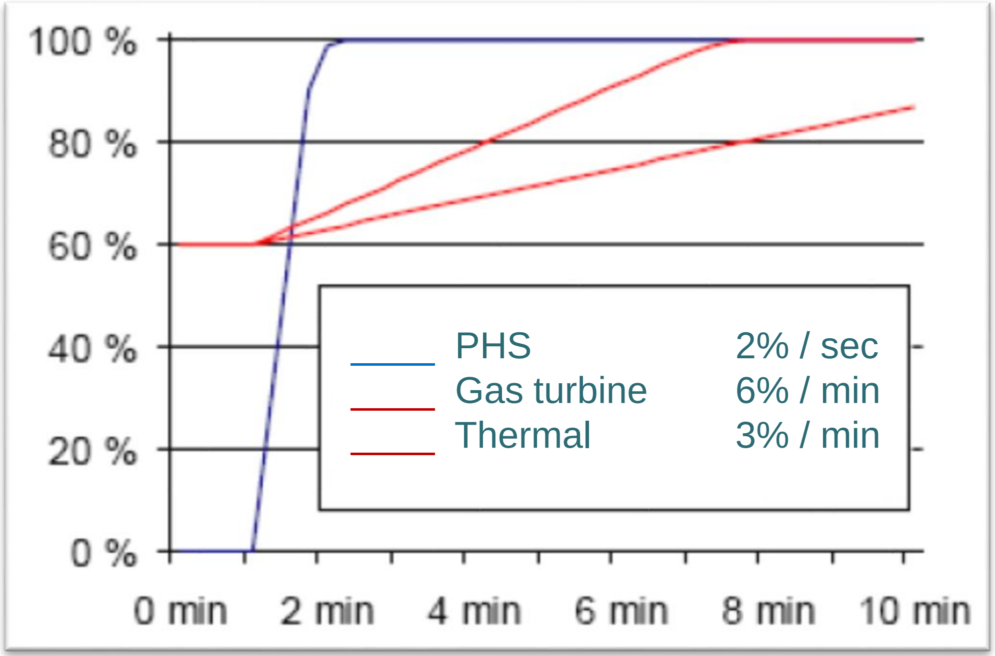
Country	1990	1995	2000	2005	2010
Belgium	624	889	1.237	1.307	1.348
Denmark	0	0	0	0	0
Germany	2.342	4.187	4.176	7.015	6.785
Estonia	0	0	0	0	0
Finland	0	0	0	0	0
France	3.459	2.961	4.621	4.659	4.812
Latvia	0	0	0	0	0
Luxemburg	746	743	737	777	1.353
Netherlands	0	0	0	0	0
Austria	988	1.037	1.369	2.319	3.163

"Pumped-hydro energy storage: potential for transformation from single dams", European Commission, EUR 25239 EN - 2012

- Pumped hydro storage is restricted by the geodetic conditions.
- Suitable geodetic conditions for PHS are limited and in some countries not present at all.
- Therefore underground-PHS in abandoned mines or similar locations is an option to store electricity from renewable energy.

Pros & Cons

Pros	Cons
Standard practice since …. years	Major environmental impact
High efficiency (>90%)	Low volumetric energy density
High reliability	Low acceptance for additional PHSs
Short ramp up time of sec..min	



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- *UPHS in Salt Caverns*

Motivation for UPHS Going Underground

- Possible locations for conventional PHS often in mountainous, touristic areas.
- Significant impact on the landscape.
- Underground UPHS can also be built in flat landscapes.
- Existing mines can provide already existing reservoirs.
- Minor impact on the landscape above ground.

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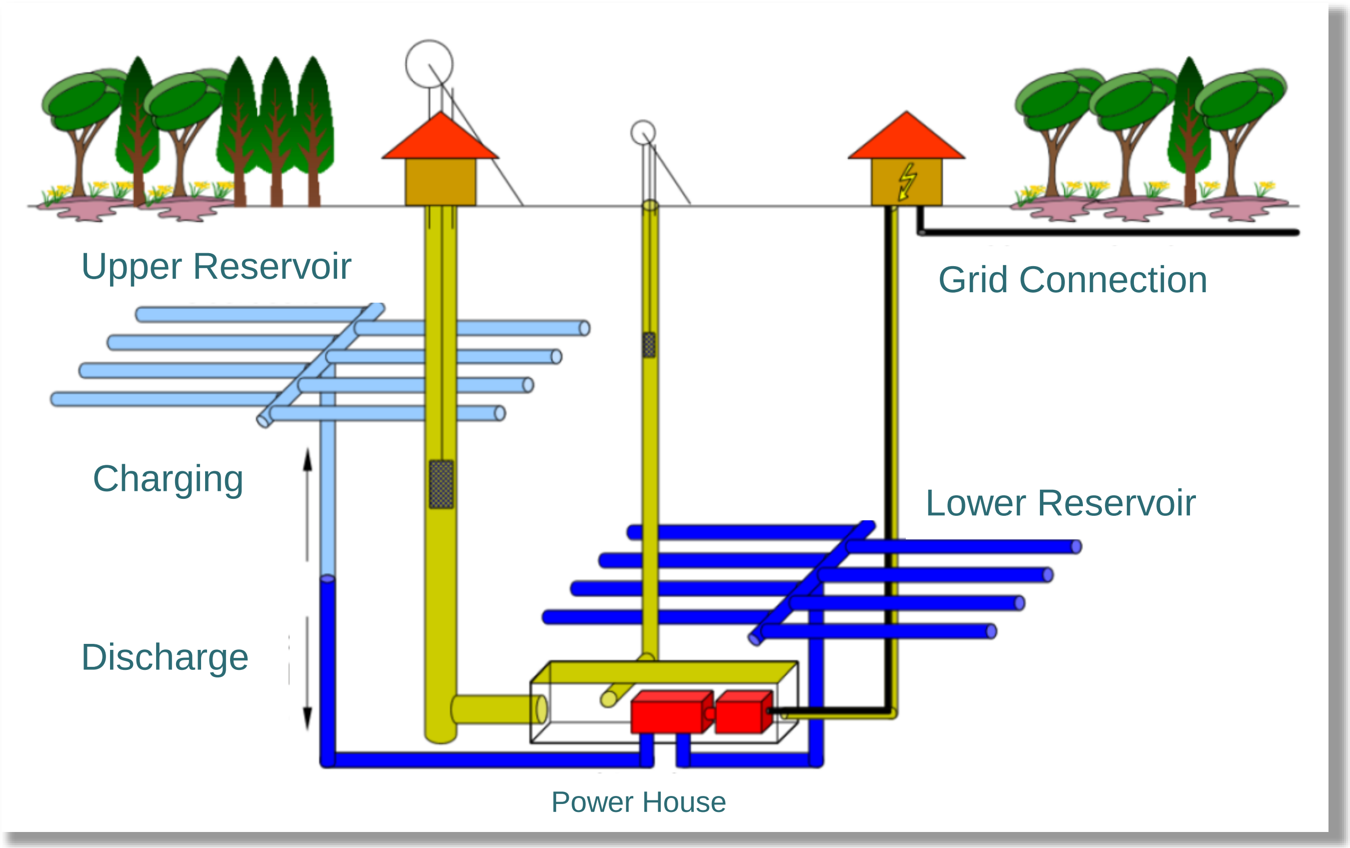
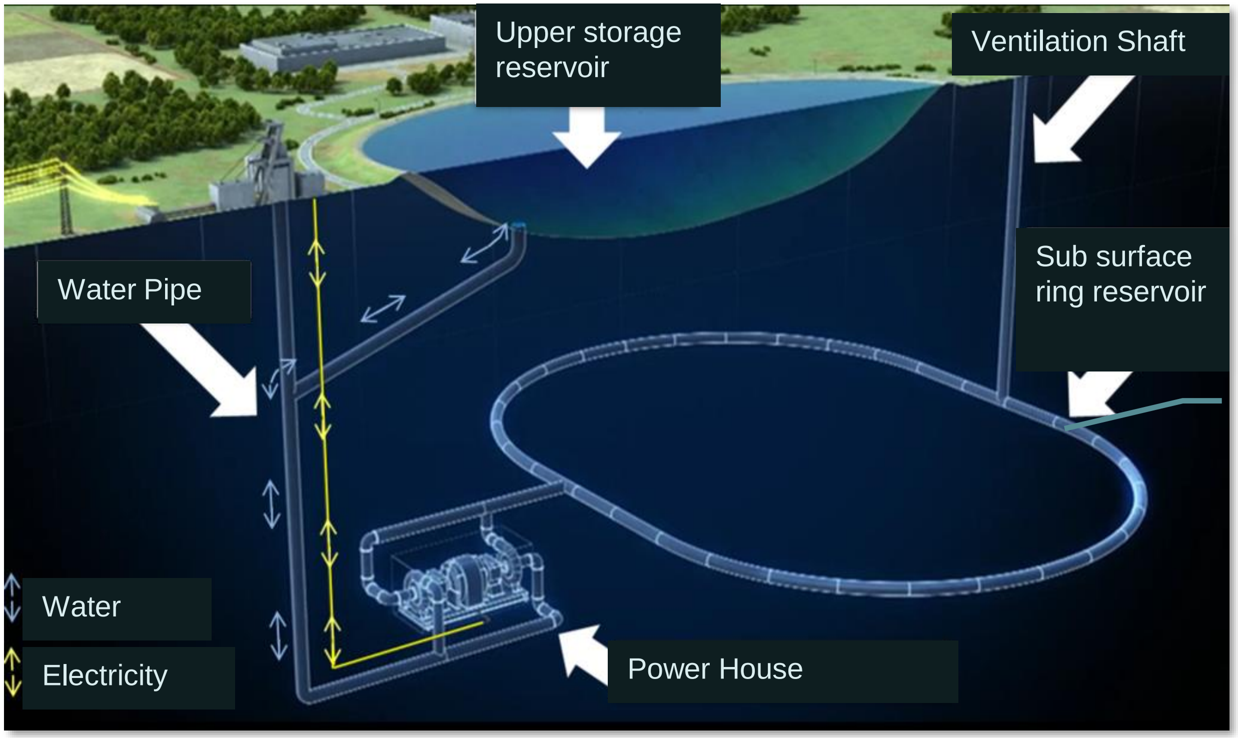
Principle of UPHS in Mines



Source efzn

UPHS in Abandoned Coal Mine with Surface Upper Reservoir



lower reservoir purpose designed / lined tunnel

- In an abandoned coal mine in Germany (Prosper Haniel, Bottrop) a project is planned:
- $\Delta h = 500$ m $V = 600\,000$ m^3 200 MW 800 MWh

Storage with Underground Upper Reservoir and Above Ground Lower Reservoir

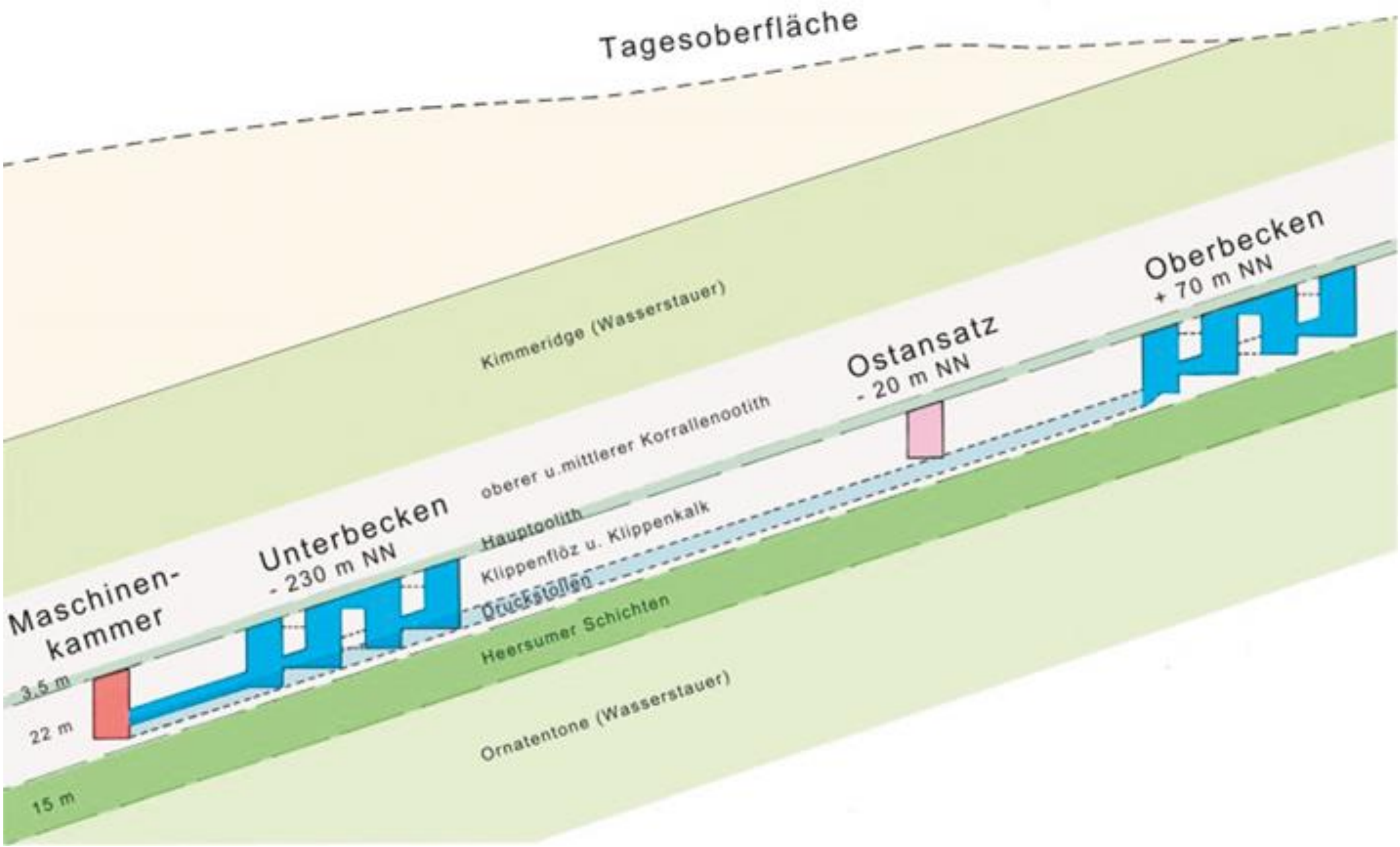
Project Pfaffenboden (Austria) by Wien Energy

UPHS in Abandoned Mines

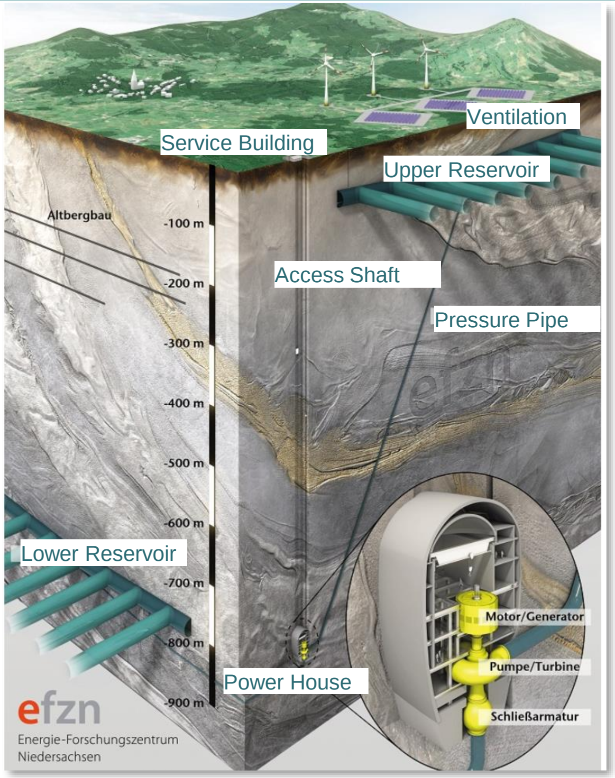
- Precondition are mines in stable host rock
- Existing large, unfilled openings like galleries are rather unsuitable as reservoirs, as long-term stability and tightness are questionable.
- Therefore rather new building of suitable, lined openings
- Construction of the upper reservoir above ground advantageous for cost reasons
- With a design for large electrical outputs as usual with conventional PHS, very large shaft diameter (costs!) is required for the large machines.

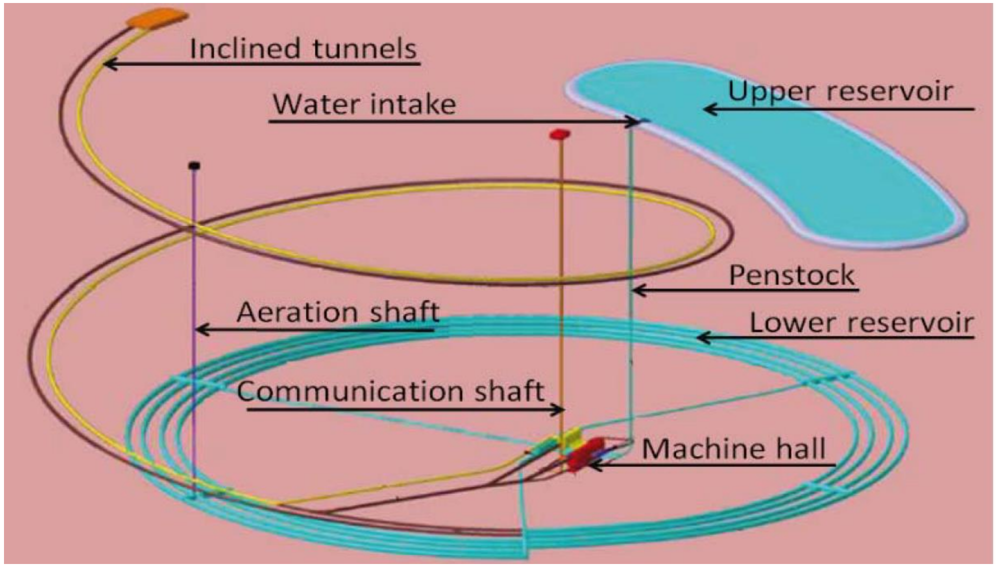
UPHS in an Operating mine

Schematic sketch of a pumped-storage power plant at Wohlverwahrt-Nammen mine (Germany).
Source/Quelle: Barbara Erzbergbau GmbH



UPHS In Virgine Rockmass

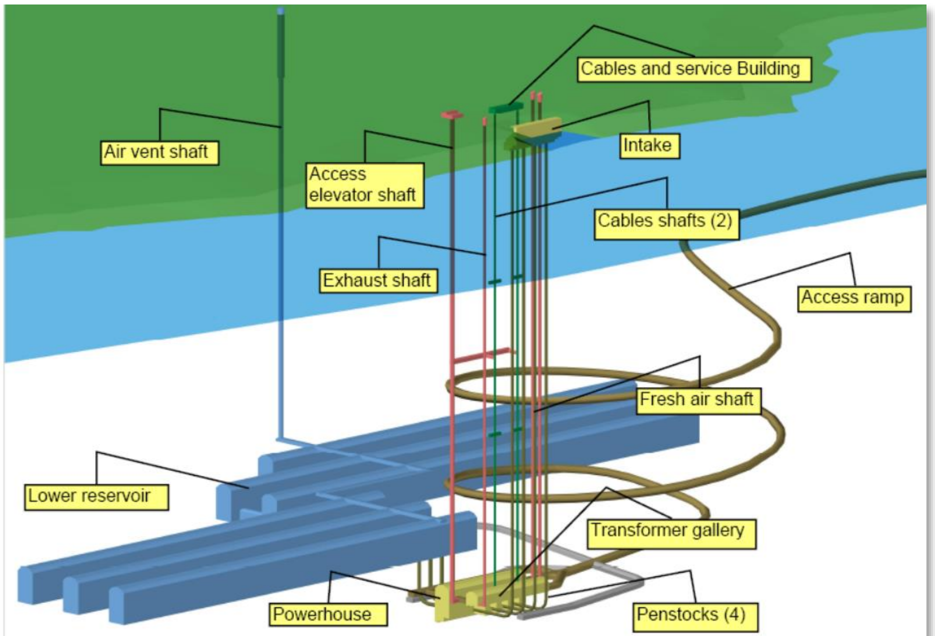




Source: European Energy Research Alliance, Fact Sheet 2018

Possible layout of underground pumped hydro storage in newly excavated rock formation.

UPHS In Virgin Rock Mass

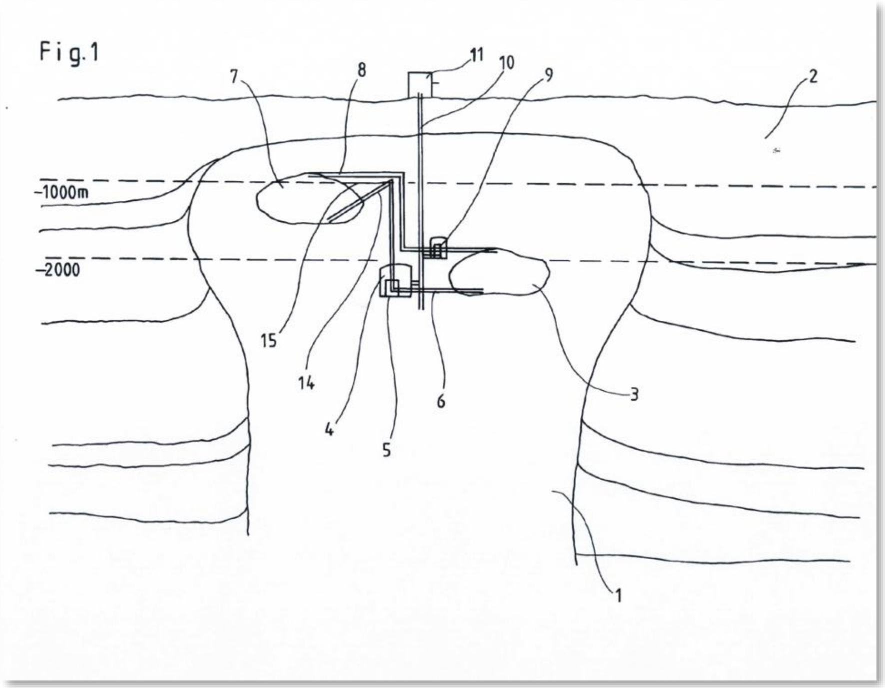


Total installed power	1 000 MW
Number of units	4
Max. generation time (at full power)	6 hours
Max. pumping time	8 hours
Maximum static head	573 m
Minimum static head	533 m
Plant rated discharge (turbine mode)	215 m^3/s
Lower reservoir useful volume	4.6 million m^3
UNDERGROUND RESERVOIR	
Height	48 m
Width	27 m
Total Length	4 300 m
Total volume of blasted rock	5.6 million m^3
UNDERGROUND POWERHOUSE	
Height (generator floor to machine hall crown)	21 m
Width	26 m
Length	126 m
PENSTOCK	
Number	4
Type	Concrete and steel lined
Diameter	4 m
Length	670 m
PERMANENT ACCESS RAMP	
Height	8 m
Width	12 m
Slope	10%
Underground length	5 900 m

Mario Turgeon, Michel Claisse, and Geneviève Landry
Groupe RSW inc.
1010 De La Gauchetière Street West
Suite 500
Montreal, Quebec H3B 0A1
Canada

- Wiscasset PSP, Maine, USA
- Upper reservoir in the Montsweag Bay (Atlantic Ocean)

UPHS in Excavated Salt Caverns



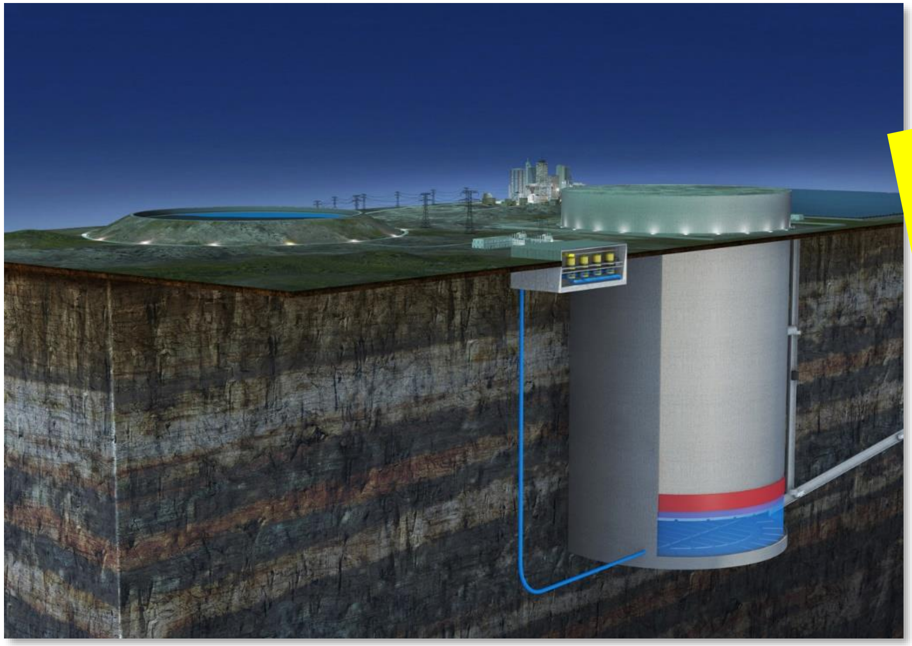
- Both caverns for upper and lower reservoir are located sub surface (Oest, 2007).
- A concept hardly to be realized.

UPHS in Virgin Rock

The construction of a new mine involves major risks and costs, because of

- need for comprehensive geological exploration
- construction of at least two access shafts,
  one of which is suitable for extremely large machines

Pumped Gravity Storage



Is this posible?

The “Heindl” gravity storage – a huge rock cylinder is pumped upwards.

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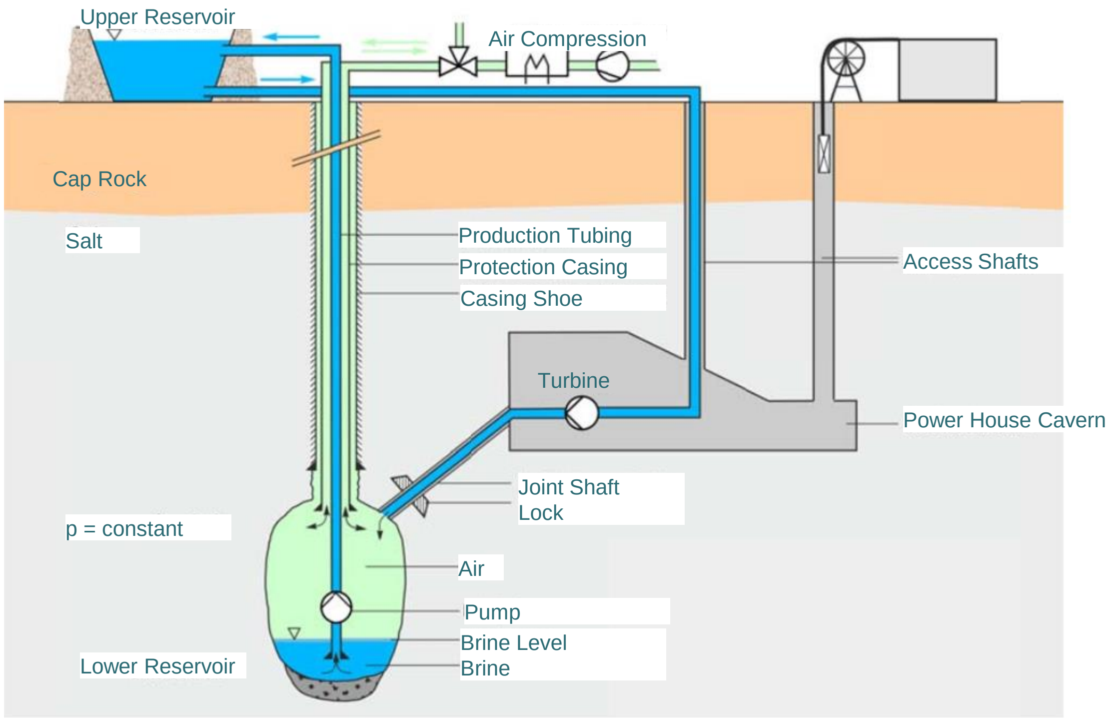
Leached Salt caverns For UPHS

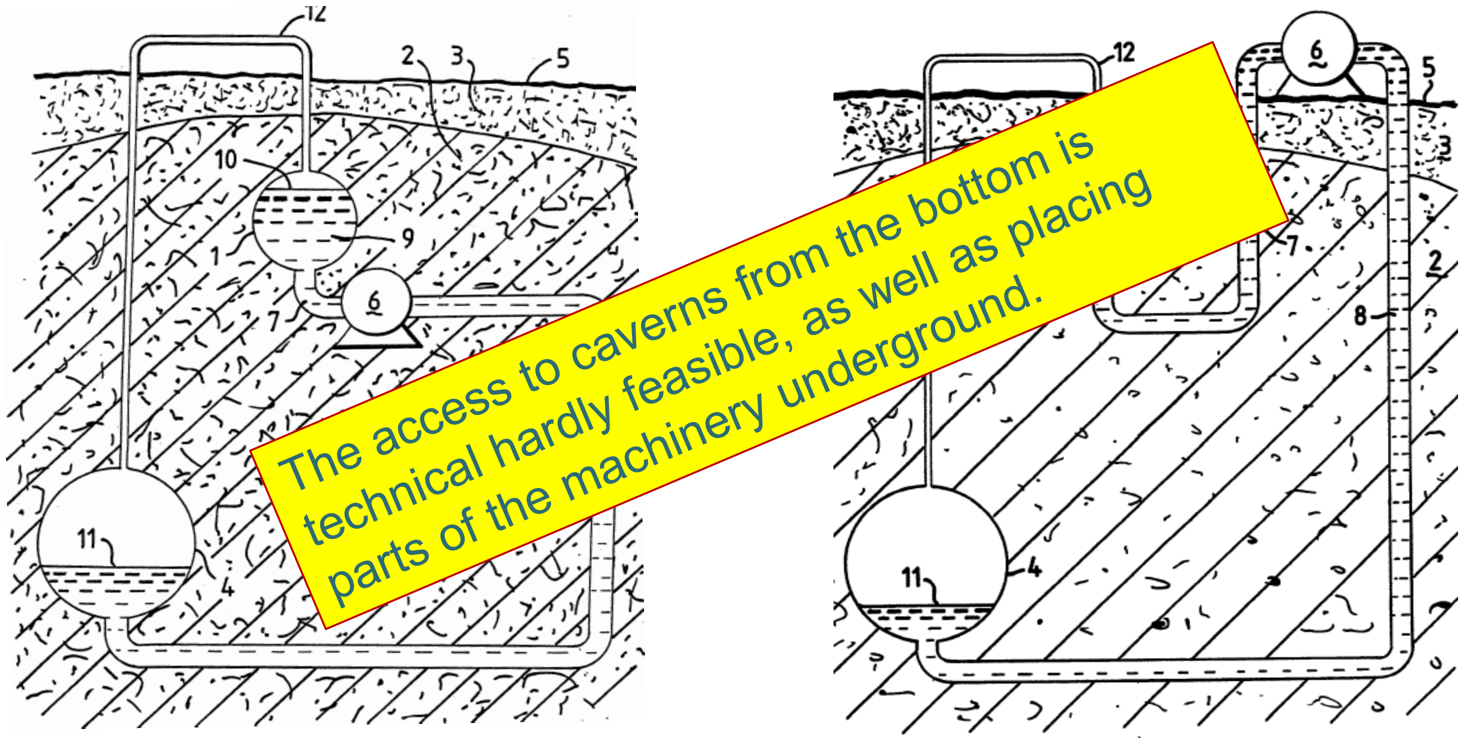
- Salt caverns can be built at much lower costs (€/m³) as mines because mined from surface.
- It is a proven technology being used for natural gas storage since more than 50 years.
- There is a big potential for leaching caverns in salt formations in Europe.

UPHS in Salt Caverns with Surface Reservoir and Power House Cavern



The arrangement requires requires the sinking of a large diameter shaft for conventional excavating the cavern for the power house (DEEP 2013).

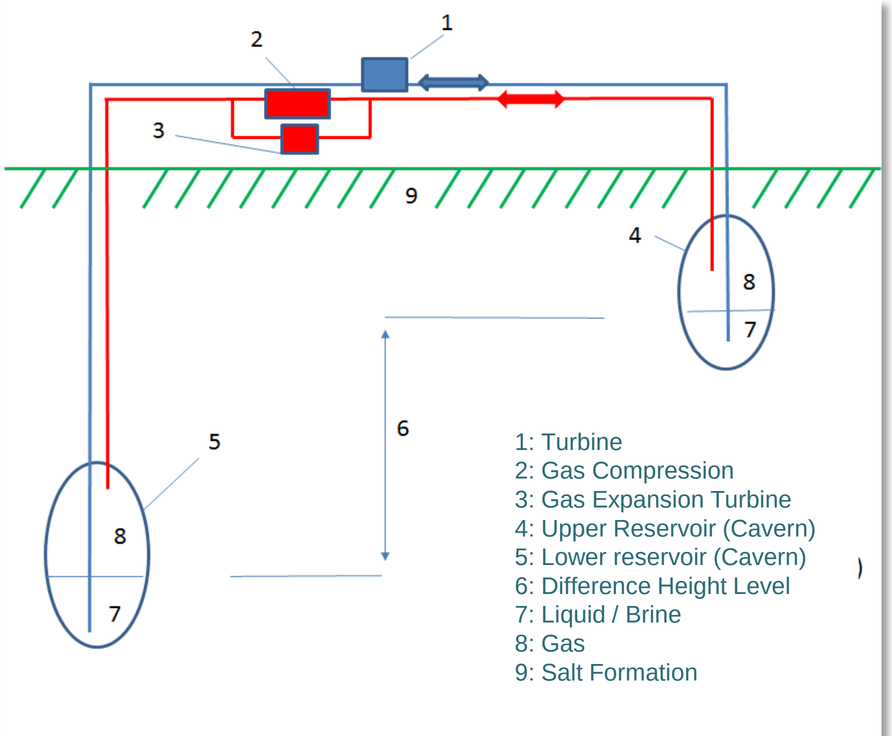
UPHS in Salt Caverns



EP 0 212 692 B1 Shell International Research 1986

- Access to Caverns from Top and Bottom and Use of 2 different Media

UPHS with Two Pressurized Caverns



- Two Caverns (Lower and Upper Reservoir) are connected with a Water Pipe and a Gas Pipe. The Elevated Gas Pressure allows the Installation of Turbines and Pumps on the Surface.
- Gas compression and expansion can be used instead of a pump-turbine setup. The assembly then works as an “adiabatic” Compressed Air Energy Storage.

Conclusions

- Pumped hydro storage below surface is an analogue to a well proven and established technology as a consequence of lack of suitable geodetic locations as well as the environmental impact of land consumption.

- Many concepts on Underground Pumped hydro storage have been proposed in:
  - Abandoned mines
  - Newly excavated water reservoirs in virgin hard rock
  - Man made salt caverns.

Conclusions

- In most of the proposed designs the power house (pumps and turbines) is located beneath the surface.
  - This requires extra cost for enlarging an existing or sinking a new access shaft
  - and may also be a safety risk
  - Pumped hydro means low volumetric energy density (MWh/m³); therefore in most known UPHS projects lower capacity and power output compared to conventional pumped storage power plants