PÖYRY

PUMPED HYDRO TECHNOLOGIES OVERVIEW

Vantaa, April 2018

Ernst Zeller

PUMPED STORAGE TECHNOLOGIES – AN OVERVIEW

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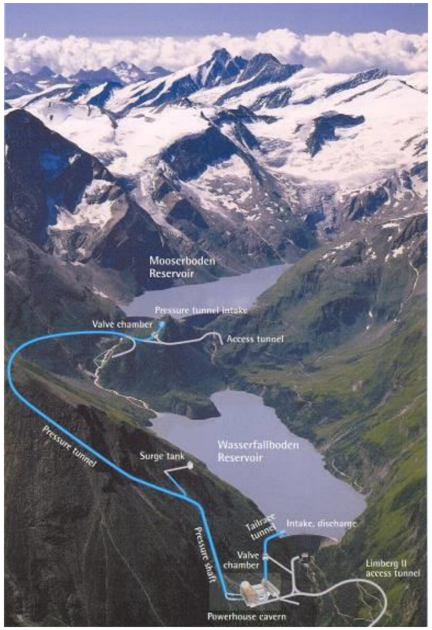
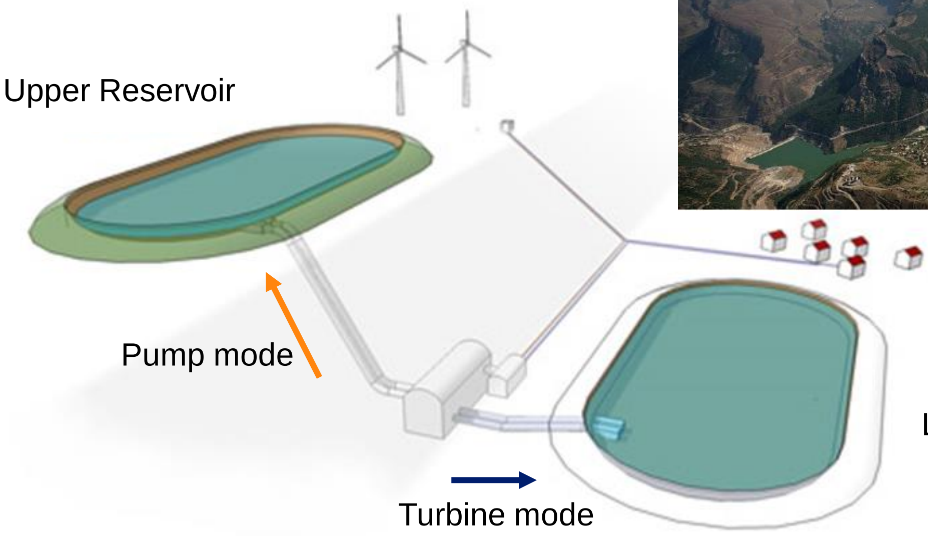
PUMP STORAGE TECHNOLOGY

Pumped storage facility is made by two water basins, connected by a pressure pipe, with the water running through a pump-turbine rotating motor-generator

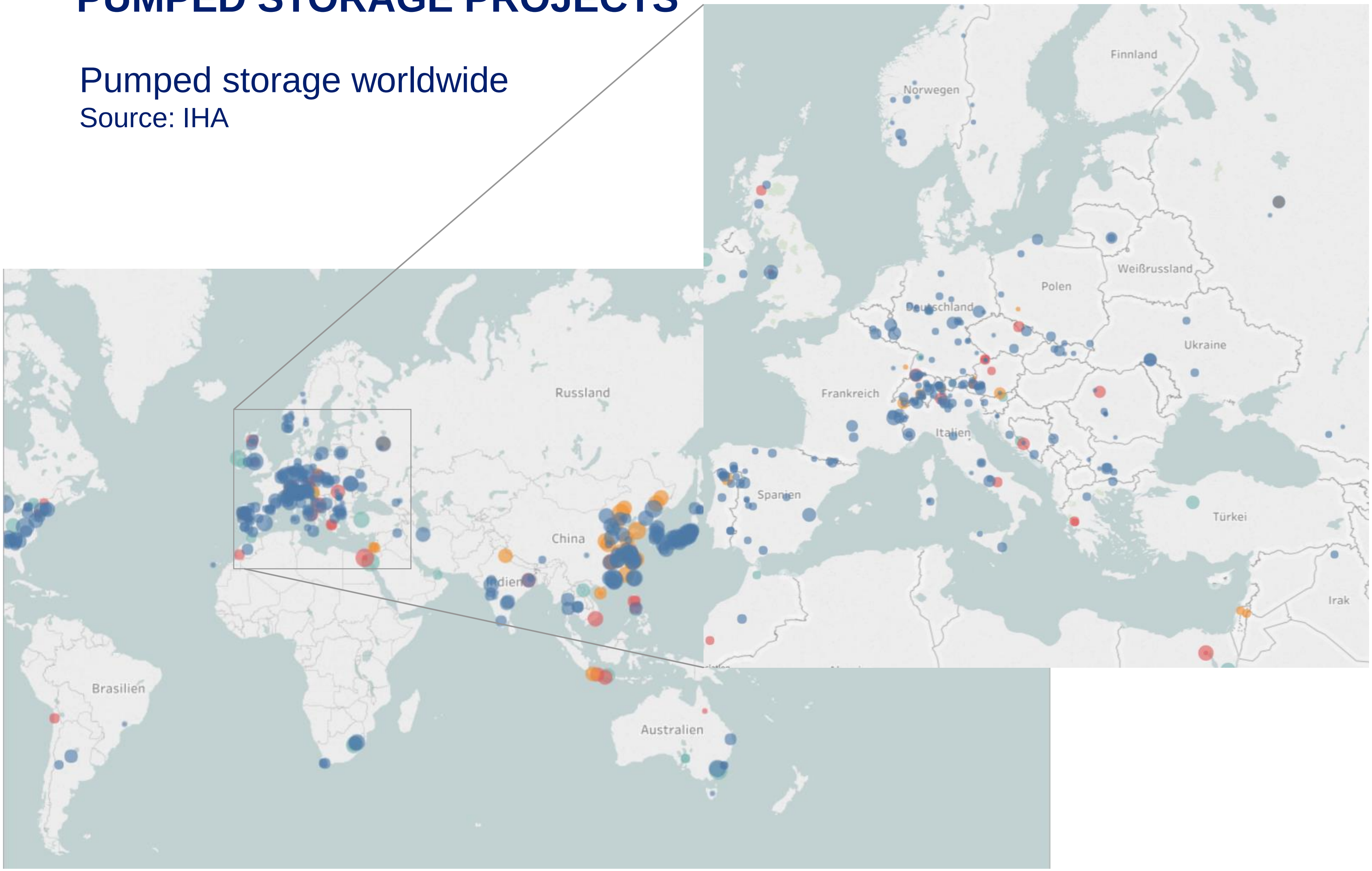




Storing potential energy by pumping the water from the lower basin to an upper one and using that energy by releasing the water back when required

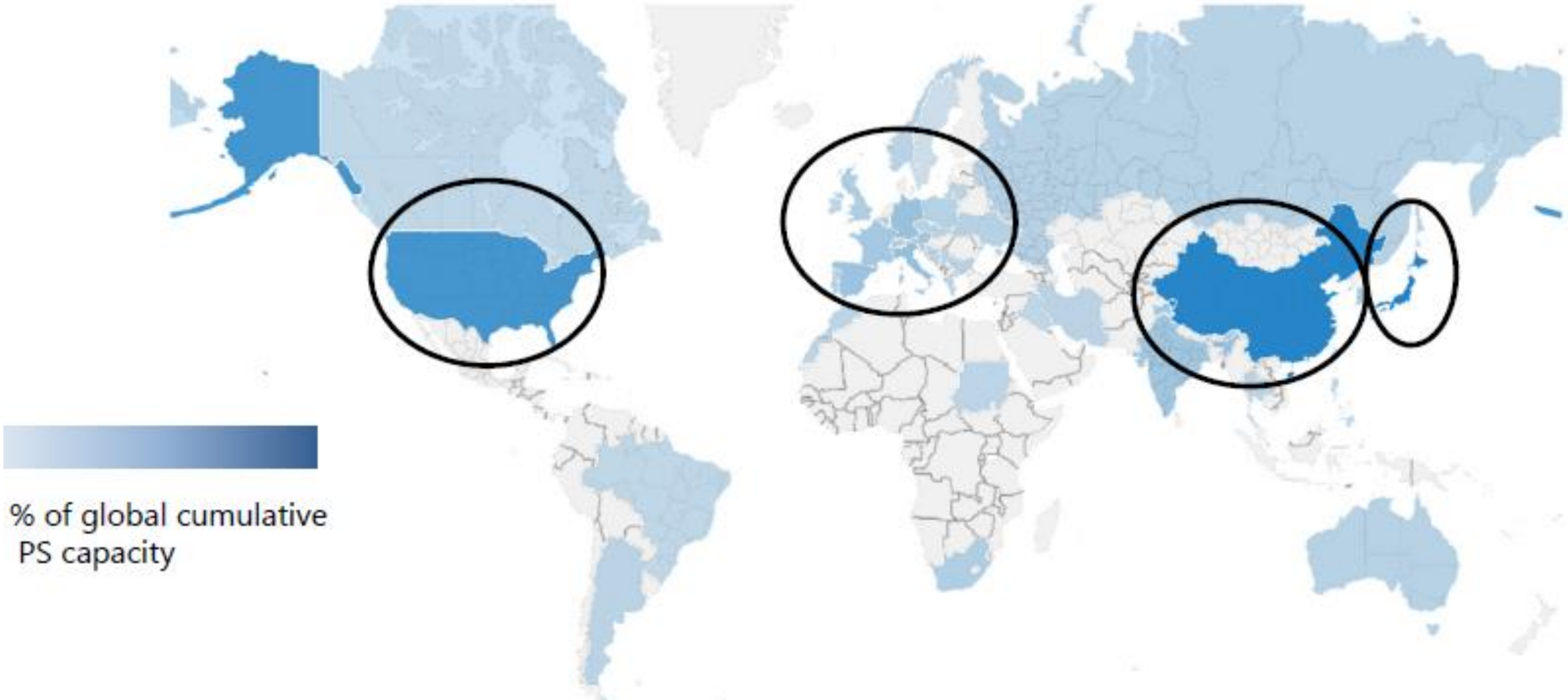
PUMPED STORAGE PROJECTS

Pumped storage worldwide
Source: IHA



PUMPED STORAGE PROJECTS

Pumped storage worldwide: 149 GW by 2016

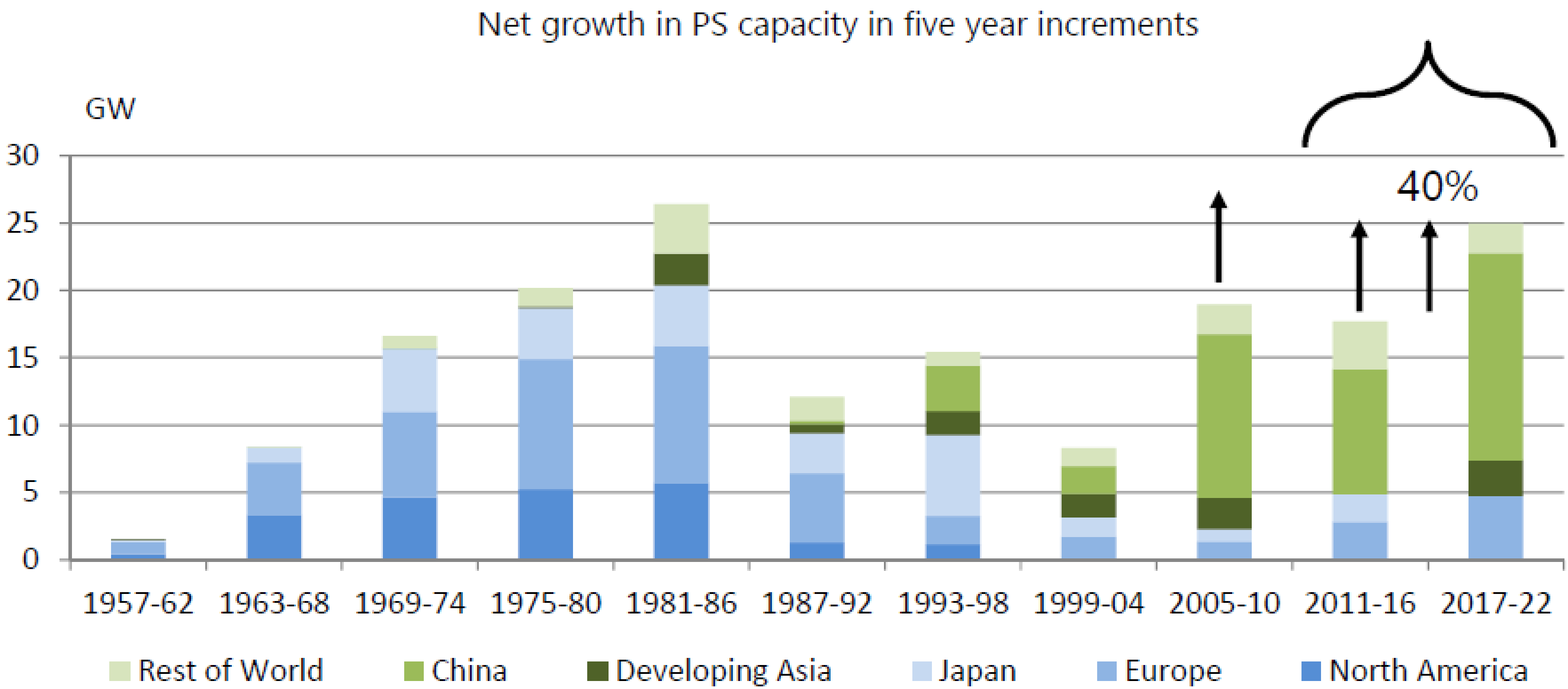


Over 80% of the world's PS capacity is concentrated in four markets: Europe, Japan, China, and the United States.

Source: IEA

PUMPED STORAGE PROJECTS

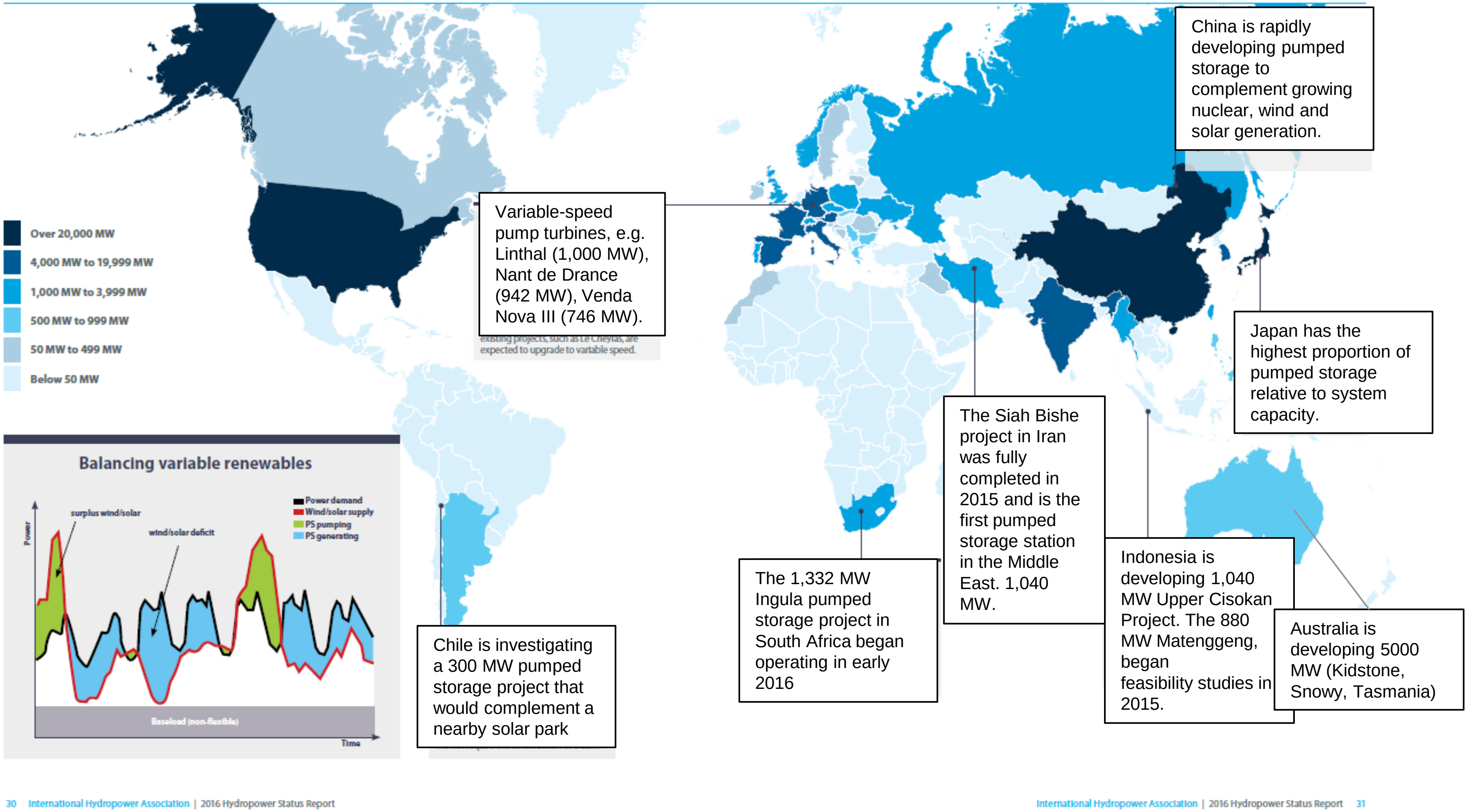
Rebound in PS - Development



Over 2017 – 2022, PS is expected to grow by 25 GW, second highest period of growth in its history, led by China followed by Europe and developing Asia

Source: IEA

PUMPED STORAGE: WORLDWIDE DEVELOPMENT, SERVICES AND HIGHLIGHTS



China is rapidly developing pumped storage to complement growing nuclear, wind and solar generation.

Variable-speed pump turbines, e.g. Linthal (1,000 MW), Nant de Drance (942 MW), Venda Nova III (746 MW).

Japan has the highest proportion of pumped storage relative to system capacity.

The Siah Bishe project in Iran was fully completed in 2015 and is the first pumped storage station in the Middle East. 1,040 MW.

The 1,332 MW Ingula pumped storage project in South Africa began operating in early 2016

Indonesia is developing 1,040 MW Upper Cisokan Project. The 880 MW Matenggeng, began feasibility studies in 2015.

Australia is developing 5000 MW (Kidstone, Snowy, Tasmania)

Chile is investigating a 300 MW pumped storage project that would complement a nearby solar park

PUMPED STORAGE TECHNOLOGIES – AN OVERVIEW

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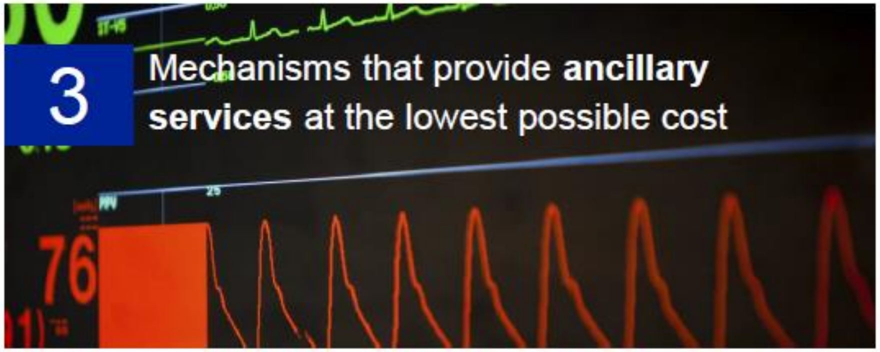
REQUIREMENTS OF STORAGE PLANTS

Key elements of energy systems of the future

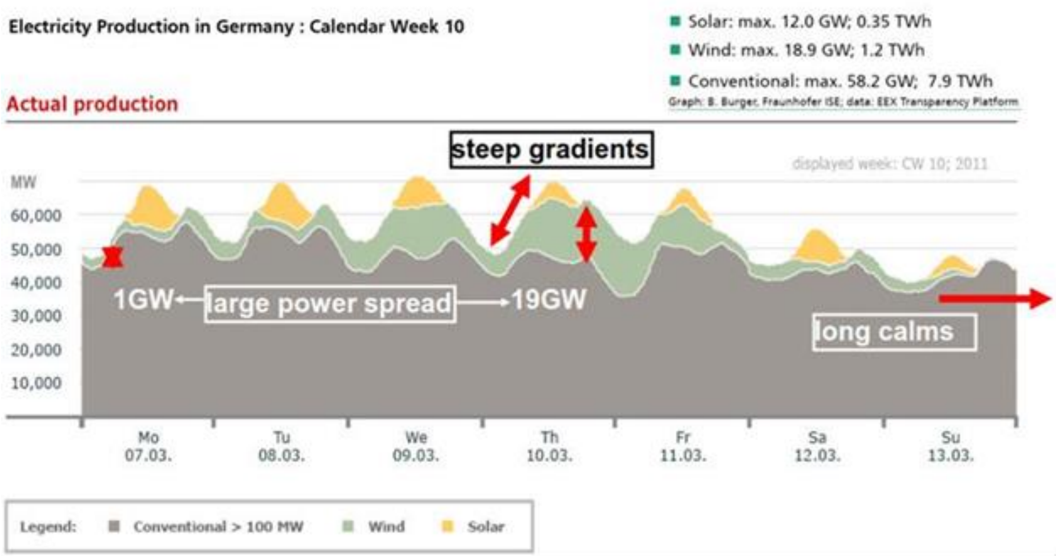


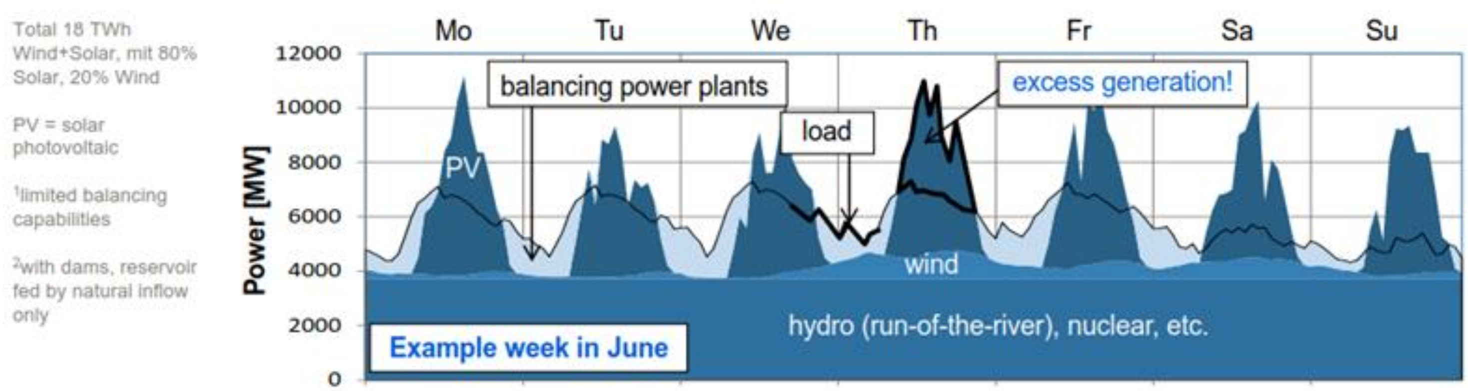
REQUIREMENTS OF STORAGE PLANTS

- **Storing Energy**
  - Provide a substantial contribution towards a balance between electricity generation and consumption
  - Absorb excess power in the grid particularly when balancing energy produced by wind and solar plants
    - wind and solar erratic through 24 hour period
    - Increase of Wind capacity in many emerging countries
    - Solar power starts
- **Balancing Services**
  - Provide required regulatory functions contributing to grid stabilization and frequency regulation at primary and secondary levels in generating mode
  - Black Start services
- **Increasing Effectiveness of Renewables**
  - Diversify the energy mix
  - Absorb base load production particularly from nuclear and coal plants at night and release during peak hours in morning and evening
- **Lower the dependency on non-renewable fuels**
  - Combining the generation of Wind- Solar- and Hydro Energy with Pumped Storage Power plants
- **Reducing Transmission costs**
  - Installing Storing systems close to Demand and Generation of Wind Power

NEED OF GRID REGULATION

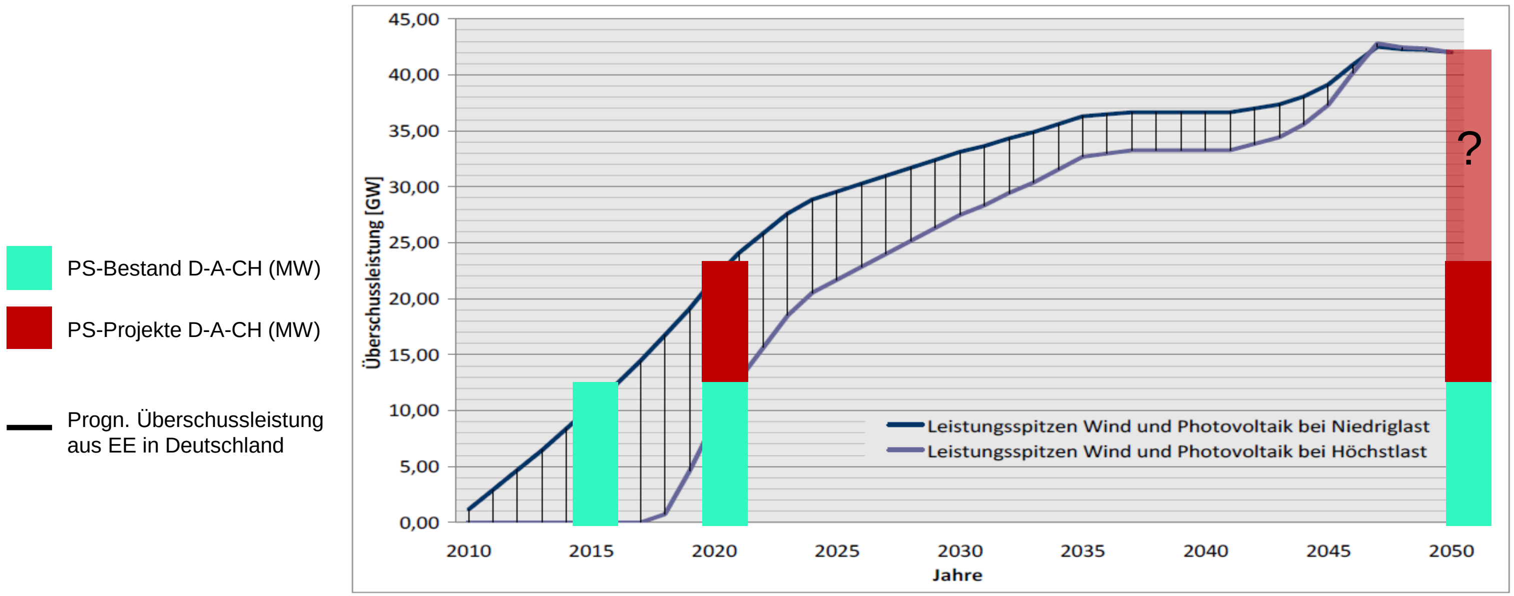
Situation in the connected European market – Different and more critical situation expected in island grids





PUMP STORAGE AND EXPECTED SURPLUS IN CENTRAL EUROPE

- Currently installed pump storage capacity > surplus power from renewables
- Pump storage plants are currently used mostly in the balancing of the energy market
- With rapid implementation of all new planed pump storage projects, the max. surplus power expected in 2020 could be cached by pumped storage power
- By 2050 further need for storing (pump storage or other) will be needed



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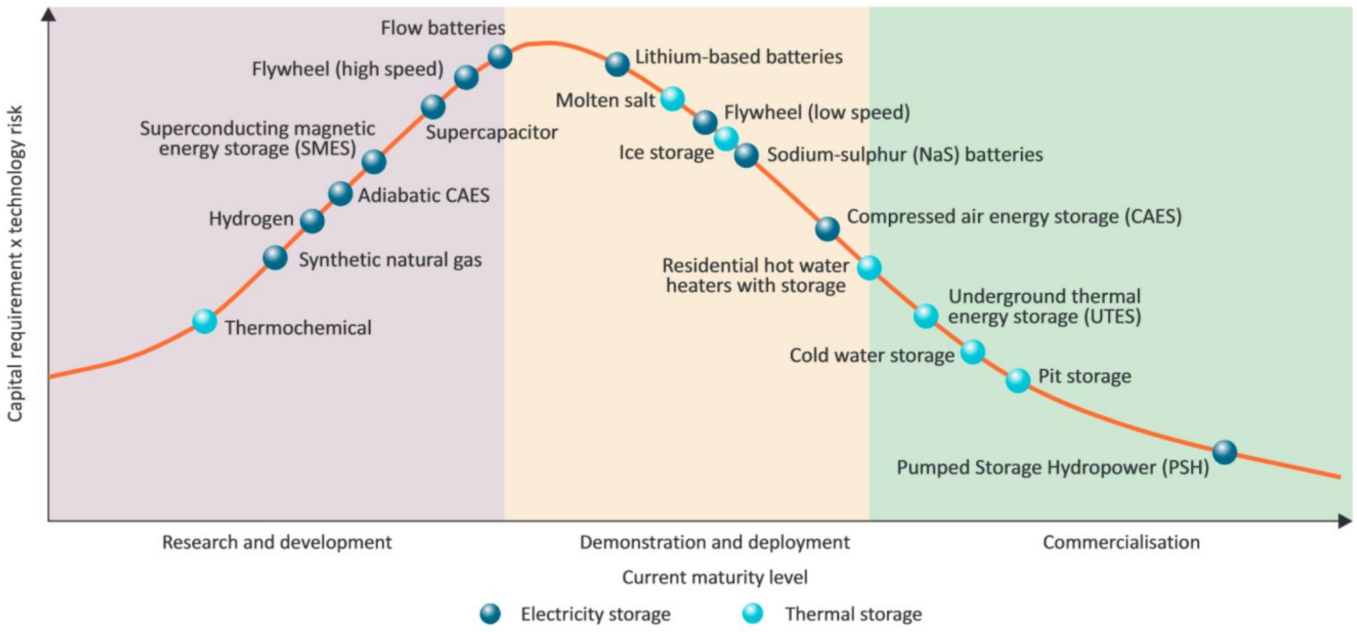
PROVEN MATURE TECHNOLOGY



Source: Decourt, B. and R. Debarre (2013), "Electricity storage", *Factbook*, Schlumberger Business Consulting Energy Institute, Paris, France and Paksoy, H. (2013), "Thermal Energy Storage Today" presented at the IEA Energy Storage Technology Roadmap Stakeholder Engagement Workshop, Paris, France, 14 February.

World Energy Council 2015:

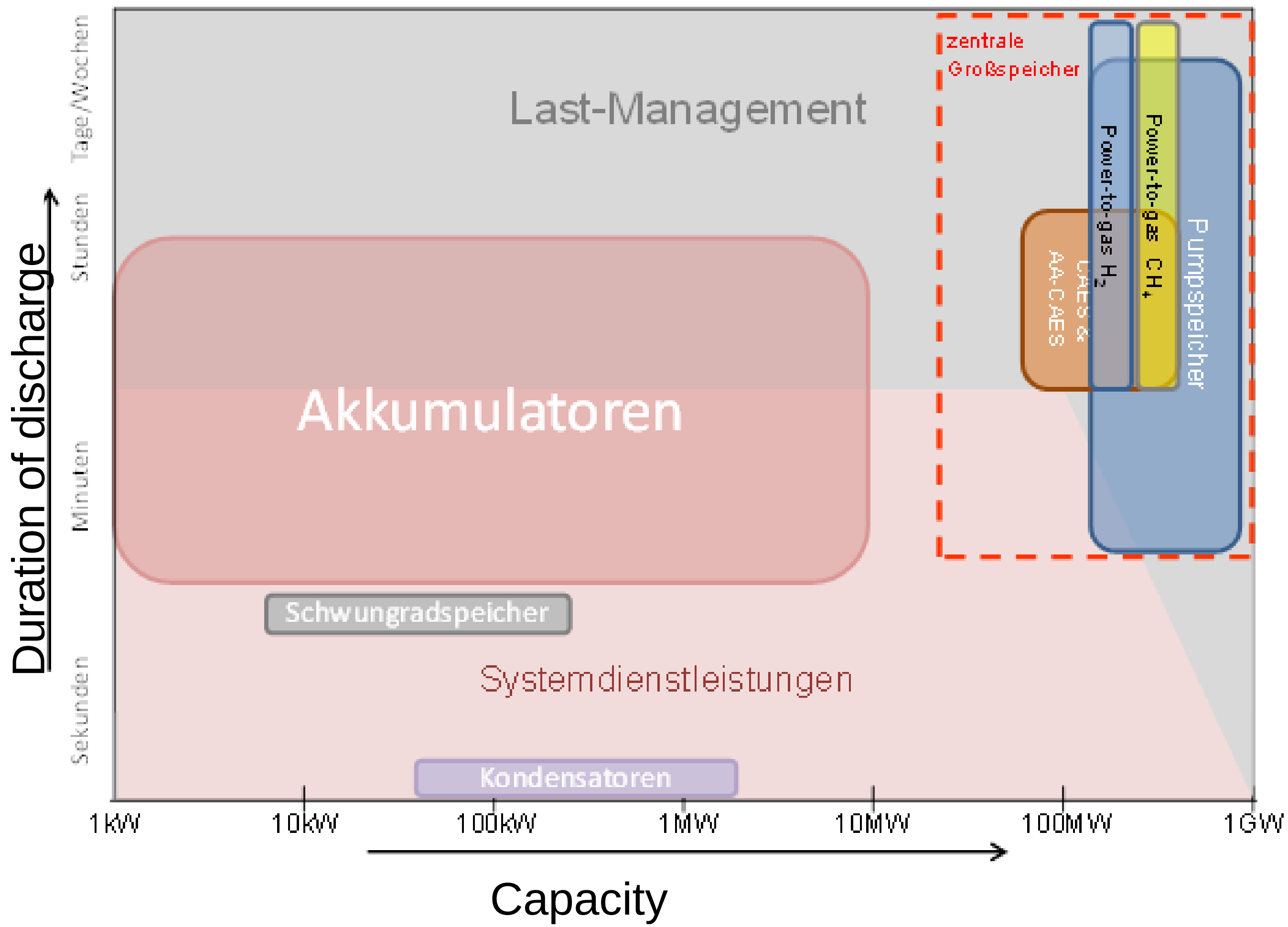
" 99% of world's operational electricity storage is in hydropower (pump storage)"

IEC 2016:

"PSP is a significantly cheaper energy storage alternative compares to batteries, answering all national grid dynamic benefits needs "

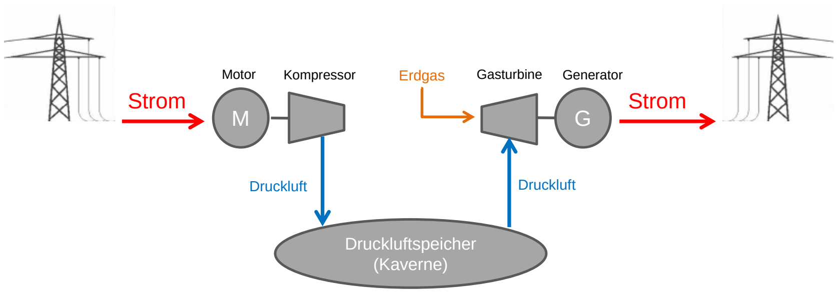
PROVEN MATURE TECHNOLOGY

Focus on large Storage Capacities and discharge duration

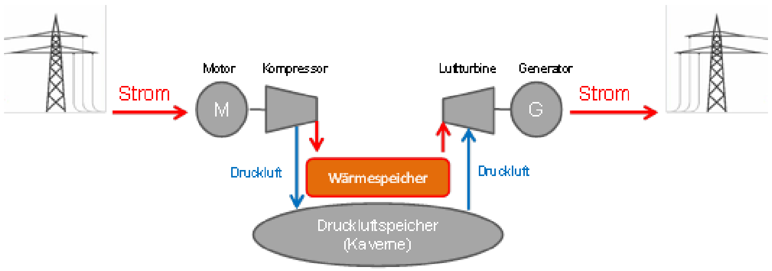


LARGE SCALE STORAGE TECHNOLOGIES

Compressed Air Storage

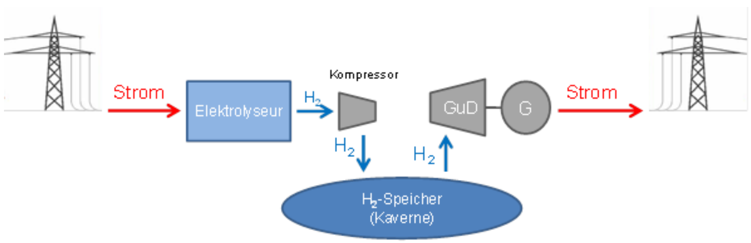


Compressed Air Energy Storage – CAES

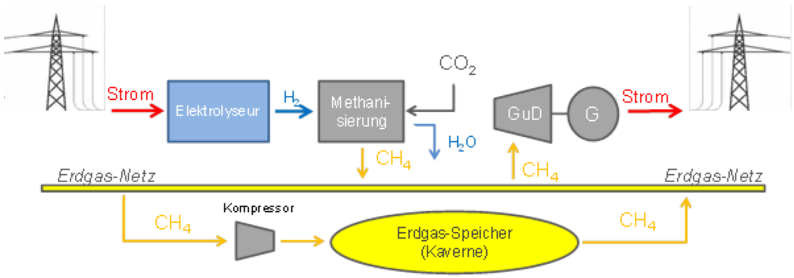


Advanced Adiabatic-Compressed Air Energy Storage – AA-CAES

Power to Gas Storage



Power to Gas Storage - H2



Power to Gas Storage – CH4

PUMPED STORAGE VS BATTERIES (PSP VS BAT)

LIFE TIME

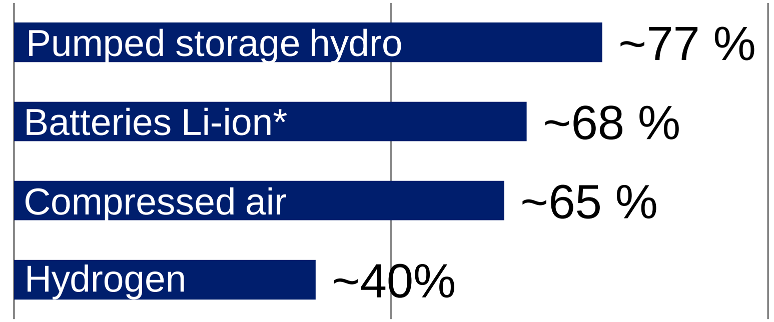
PSP BAT

> 50 years vs. ~15 years

*Batteries Lifetime is 11-15 years**
Batteries storage capacity decreases substantially after 3 years

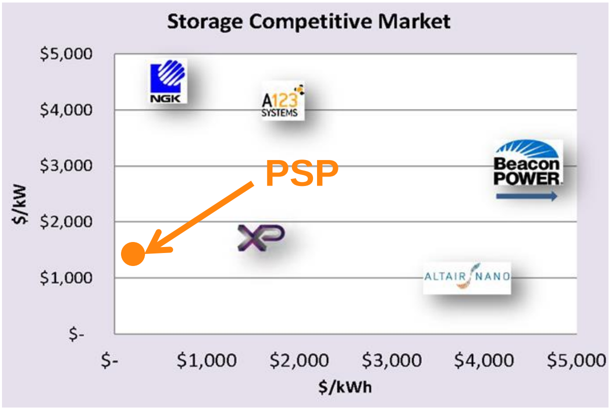
* According to NREL Predictive Models of Li-ion Battery Lifetime

TECHNOLOGY



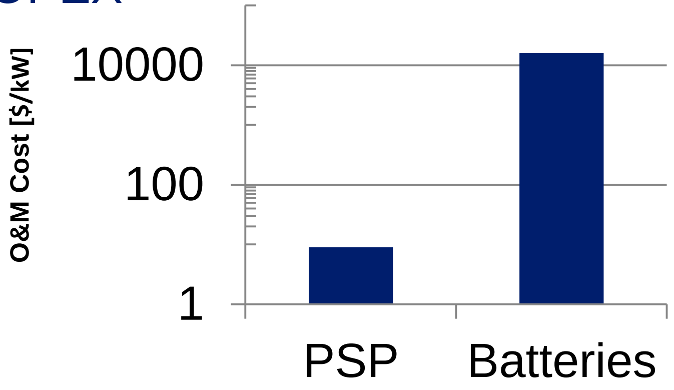
* Average Efficiency, which declines over the years for Batteries

CAPEX



According to EPRI Energy Storage Project A

OPEX



According to Energy Storage Screening Study For Integrating Variable Energy Resources within the PacifiCorp System July 9, 2014

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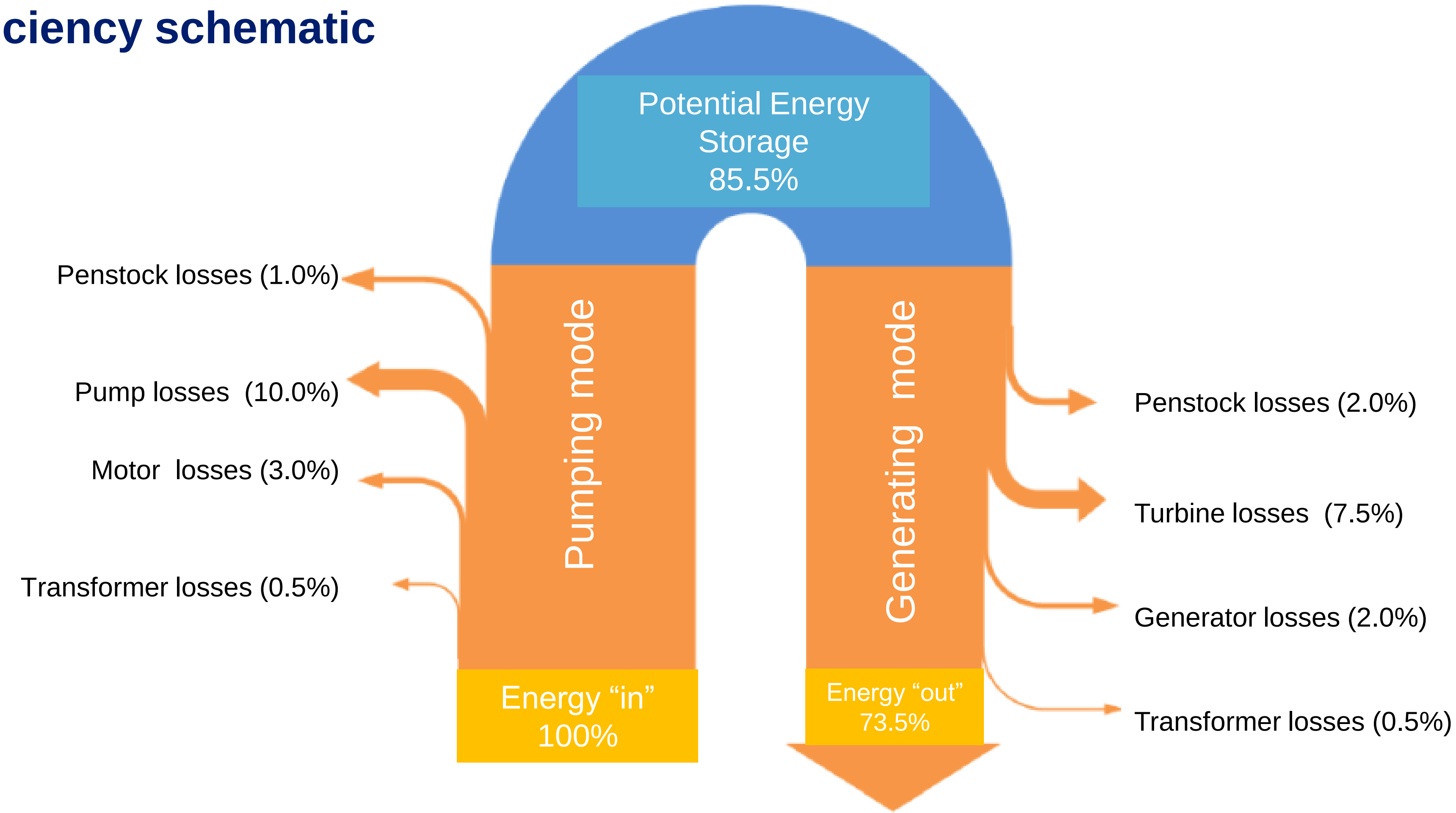
PUMPED TURBINE TECHNOLOGY

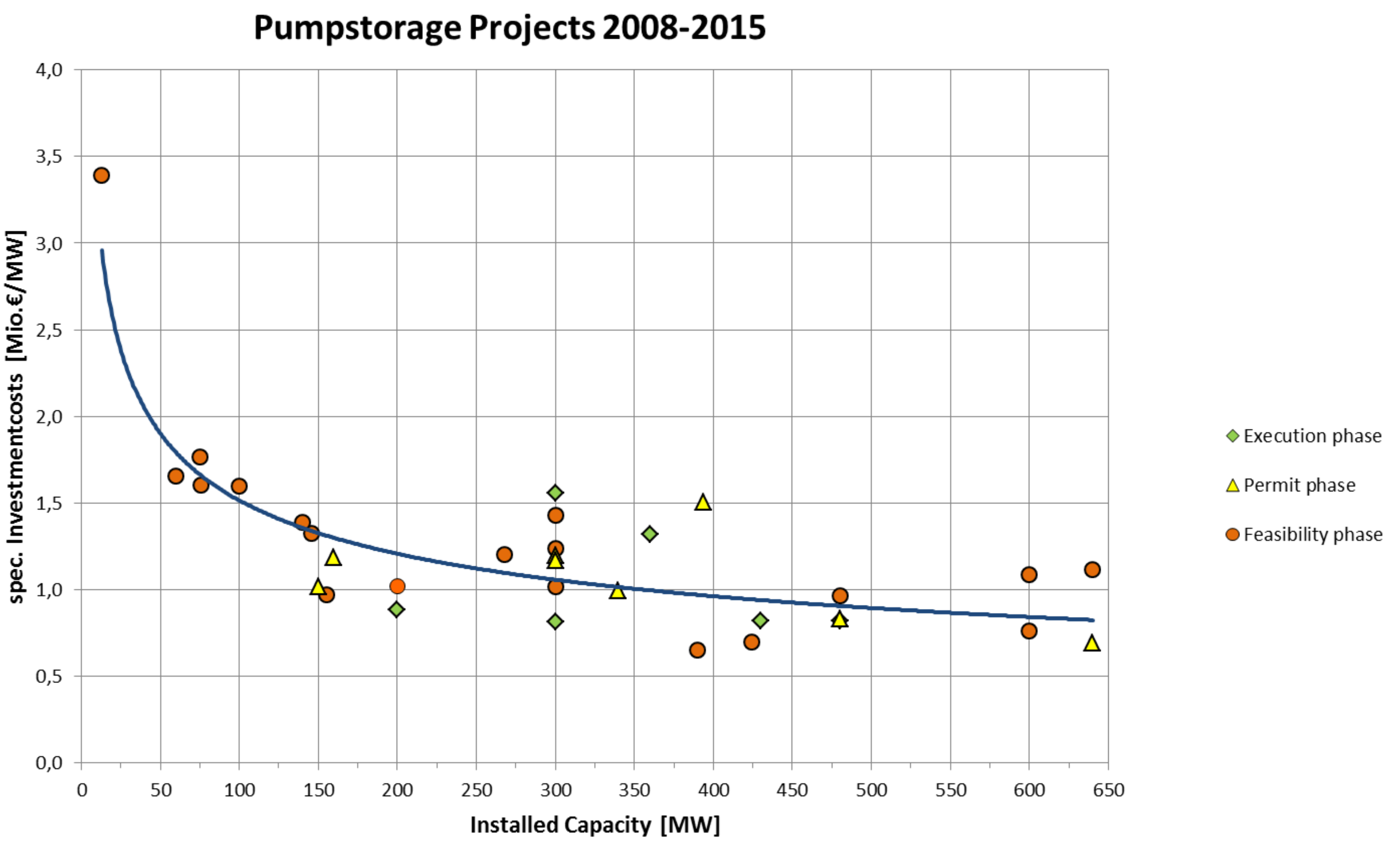
Efficiency schematic



- Pumped storage operations have efficiencies typically in the range of 70-80%
  - Layout and configuration of the scheme has major effect on efficiencies

SPECIFIC COSTS OF PUMPSTORAGE POWER PLANTS

Specific Investmentcosts



MARKET CHALLENGES AND EM SOLUTIONS - PSPP:

Technological complex solutions

Reversible pump turbine fix speed → horizontal / vertical

Concepts with pump turbine

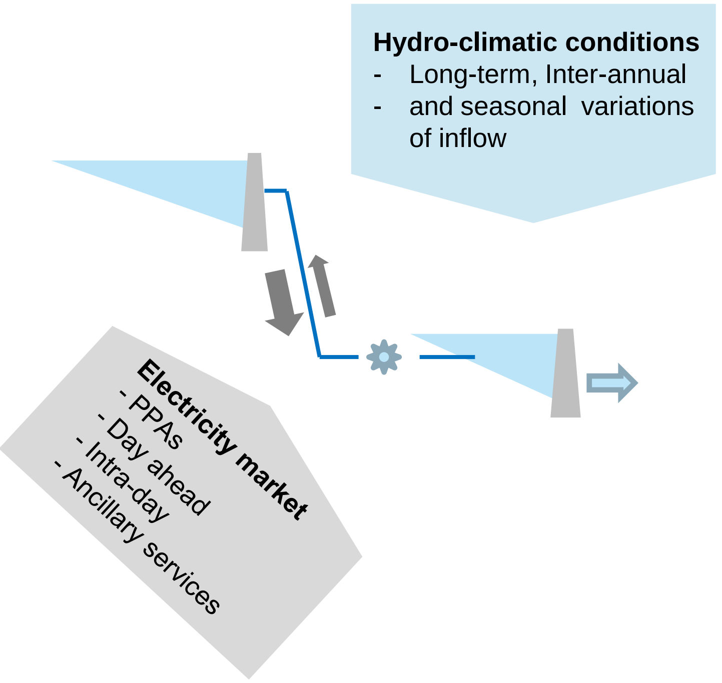
Reversible pump Turbine variable speed → asynchronous / full size converter

Split unit set (separate pump & turbine) → horizontal / vertical

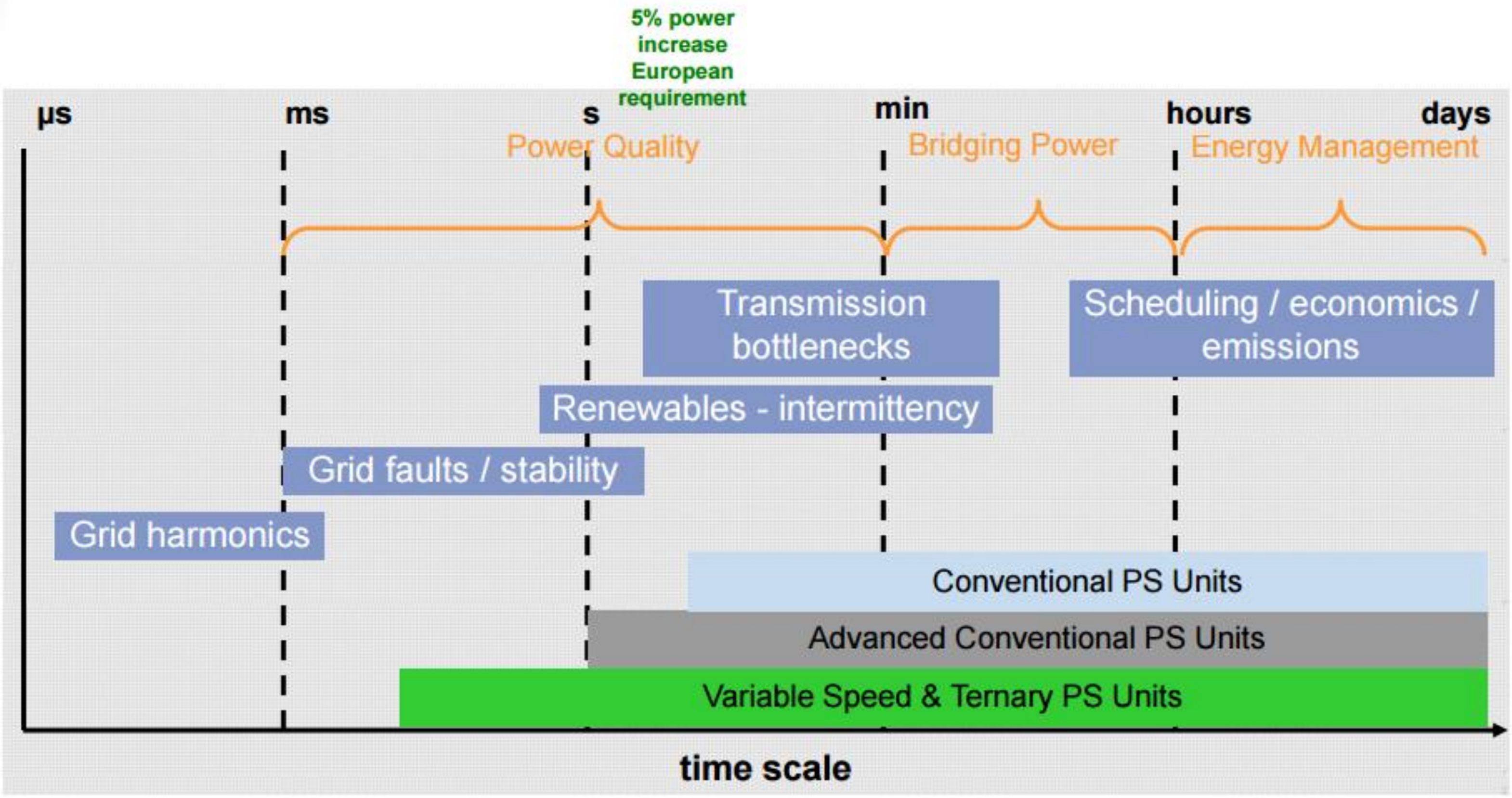
Concepts with split pump and turbine

Combined operation mode

- Combined pump storage plant (open system)
- Conventional hydro scheme with ability to pump
- Optimized Powerhouse solutions



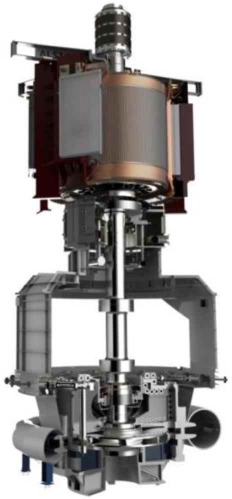
GRID POWER CONTROL NEEDS AND PUMPED STORAGE SOLUTION



ELECTRIC POWER RESEARCH INSTITUTE

POSSIBLE PUMP STORAGE CONCEPTS – PUMP TURBINE

1. Reversible pump turbine – fix speed



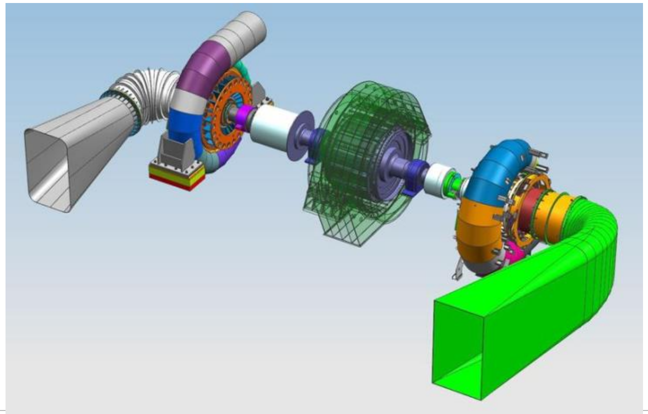
- \+ Investment costs
- \+ Minimum space requirements
- \+ References
- \+ High efficiencies at full load
- \- Flexibility & part load efficiencies
- \- Lowest input for grid stabilization
- \- Slow switch over times
- \- Blow down system required

2. Reversible pump turbine – variable speed

- \+ Flexibility in Pump/Turbine mode
- \+ High input for grid stabilization
- \+ Fast switch over times
- \+ High efficiencies at partial load
- \- Investment costs
- \- Additional space requirements
- \- References
- \- Additional Converter losses

3. Ternary Unit (horizontal or vertical)

- \+ High flexibility in P/T operation
- \+ Optimal design for P/T
- \+ Fast switch over times
- \+ High efficiencies at full load
- \- High investment costs
- \- High space requirements
- \- Additional hydr. Mech. Equipment
- \- Complex bifurcation design



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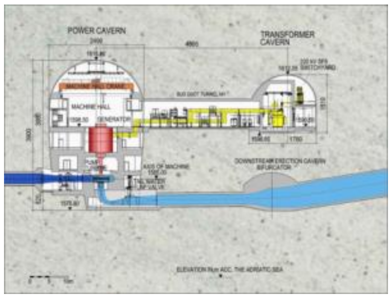
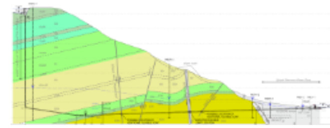
PÖYRY – LEADING ENGINEERING COMPANY FOR PSPP DESIGN

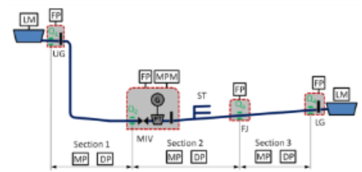
PSPP Reisseck II



- Location: Austria
- Capacity: 430 MW
- Head: 495 m
- Storage: 11.6 GWh
- Operation since: 2016
- CAPEX: 450 Mio. USD

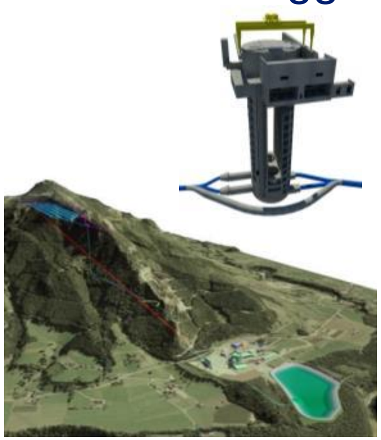
PSPP Manara





- Location: Israel
- Capacity: 340 MW
- Head: 700 m
- Storage: 2.9 GWh
- EPC model
- CAPEX: 380 Mio. USD

PSPP Bernegger



- Location: Austria
- Capacity: 300 MW
- Head: 650 m
- Storage: 1.8 GWh
- Underground reservoir
- CAPEX: 380 Mio. USD

PSPP Limberg II

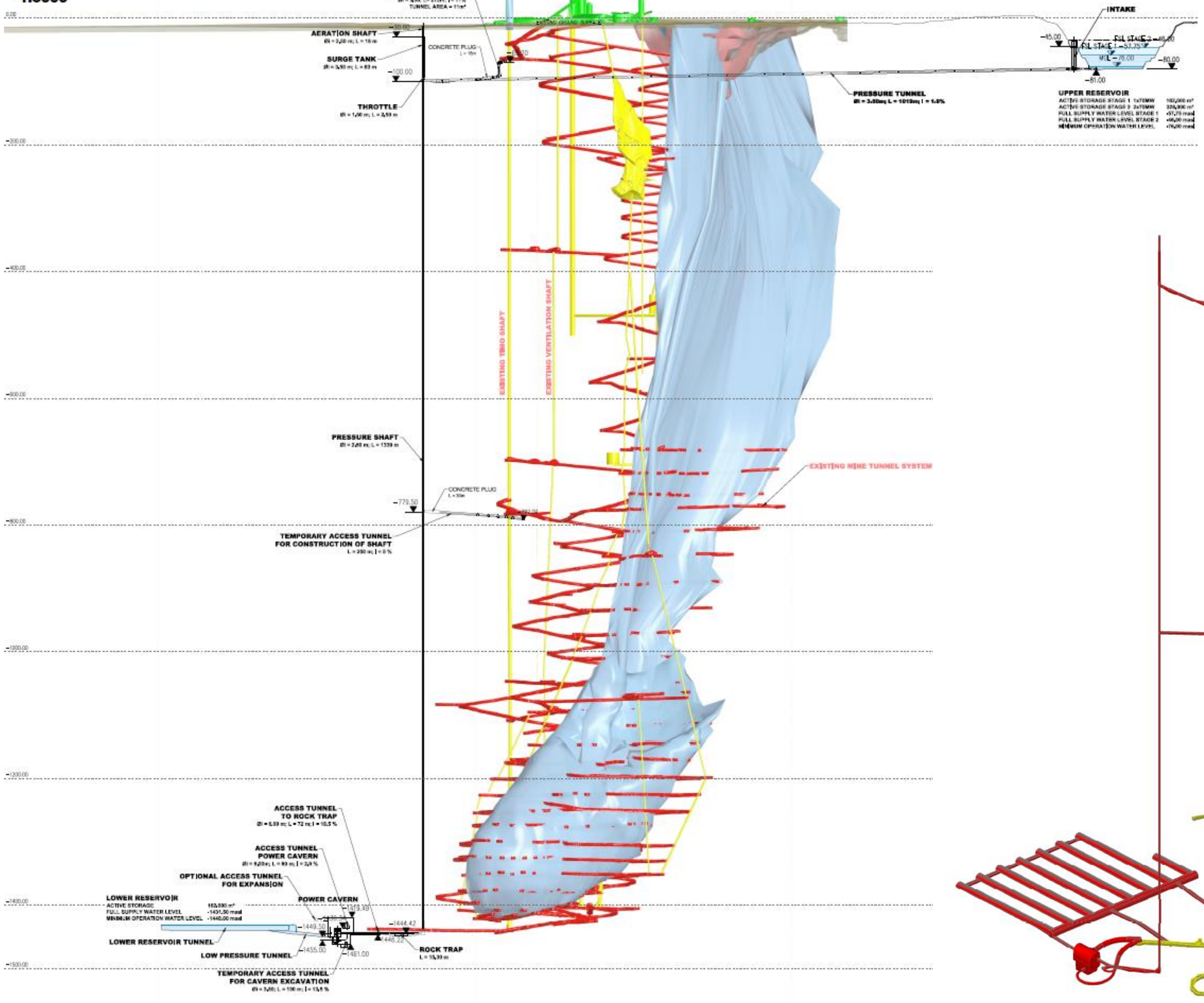
- Location: Austria
- Capacity: 480 MW
- Head: 365 m
- Storage: 75 GWh
- Operation since:2011
- CAPEX: 480 Mio. USD

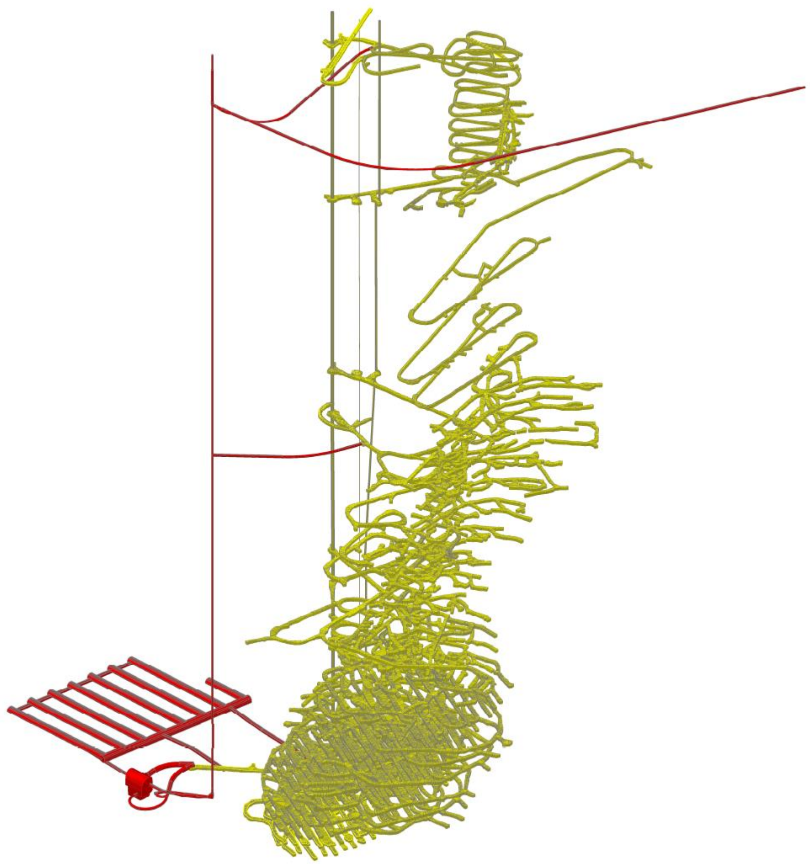
PYHÄSALMI MINE

- **Provides 1400 m of head!**
- **Perfectly investigated geology with best rock conditions**
- **Infrastructure on ground and in 1400 m depth including access tunnel**
- **Excavated open pit for a upper reservoir, 110 kV connection and substation**
- **Good location in balancing the Finnish power grid**
- **Mine operation will run until 2019**

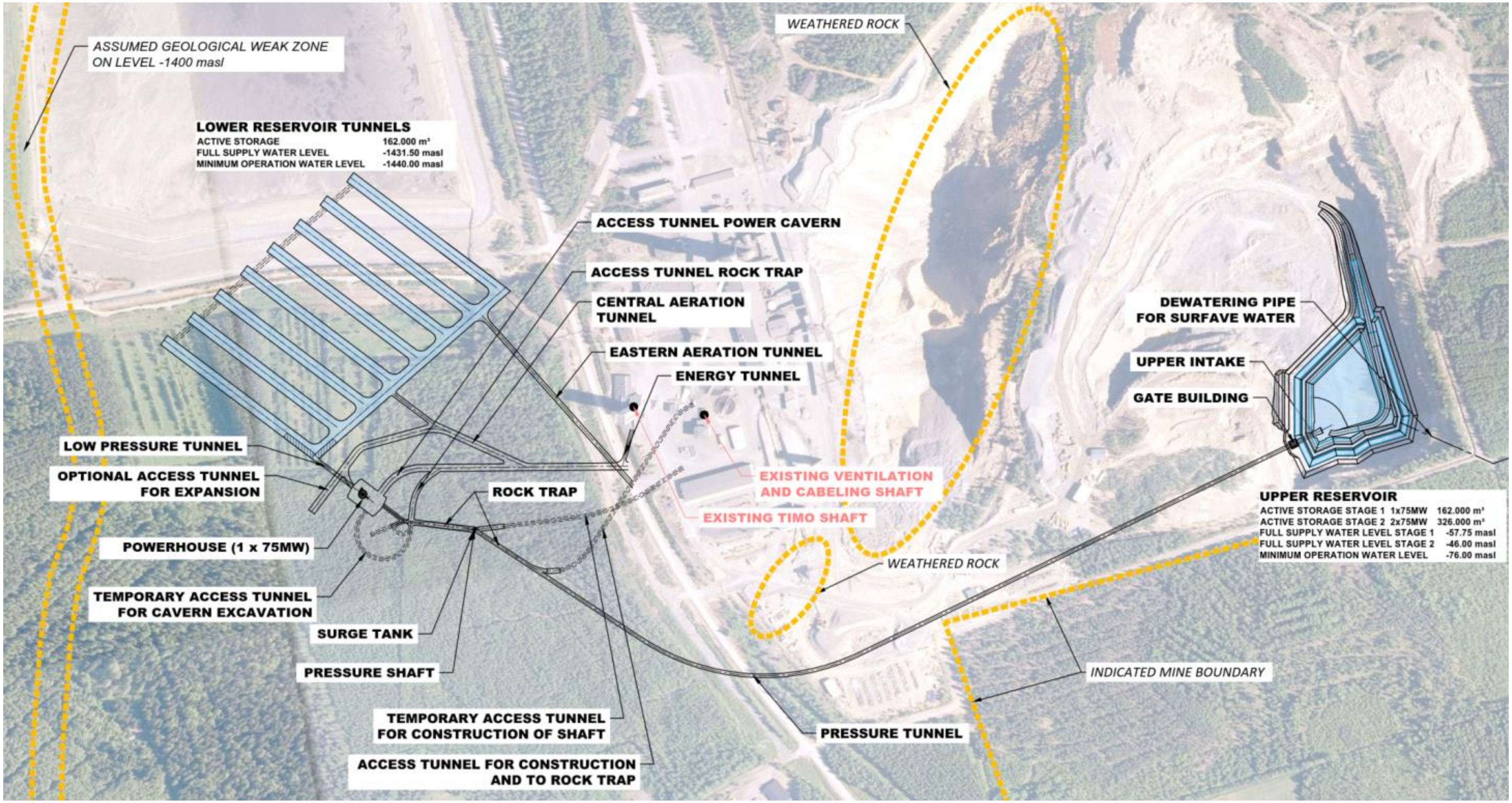
MAIN PLANT SECTION – 75MW

LONGITUDINAL SECTION IN POWERWATER WAY AXIS
1:3000

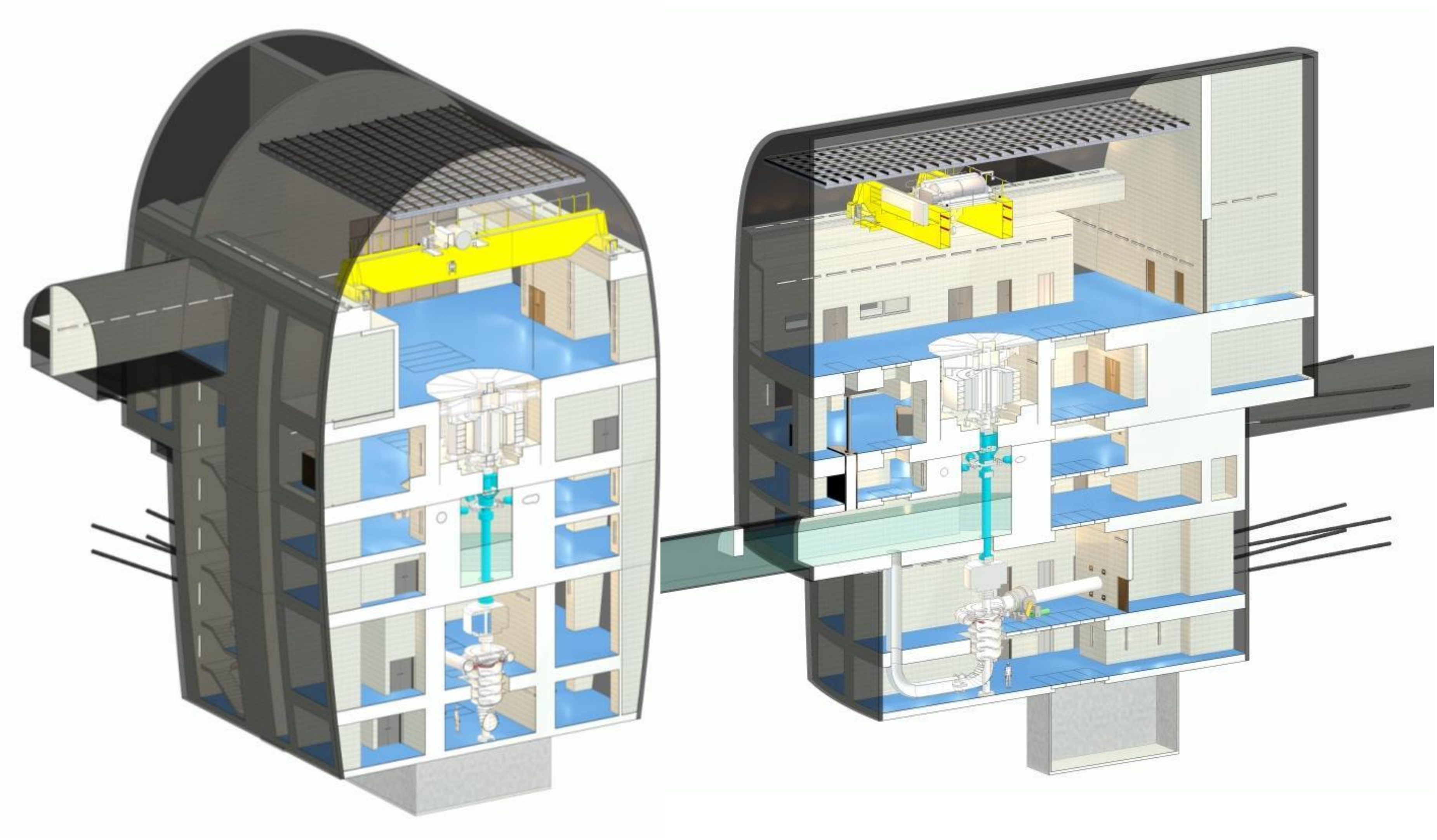




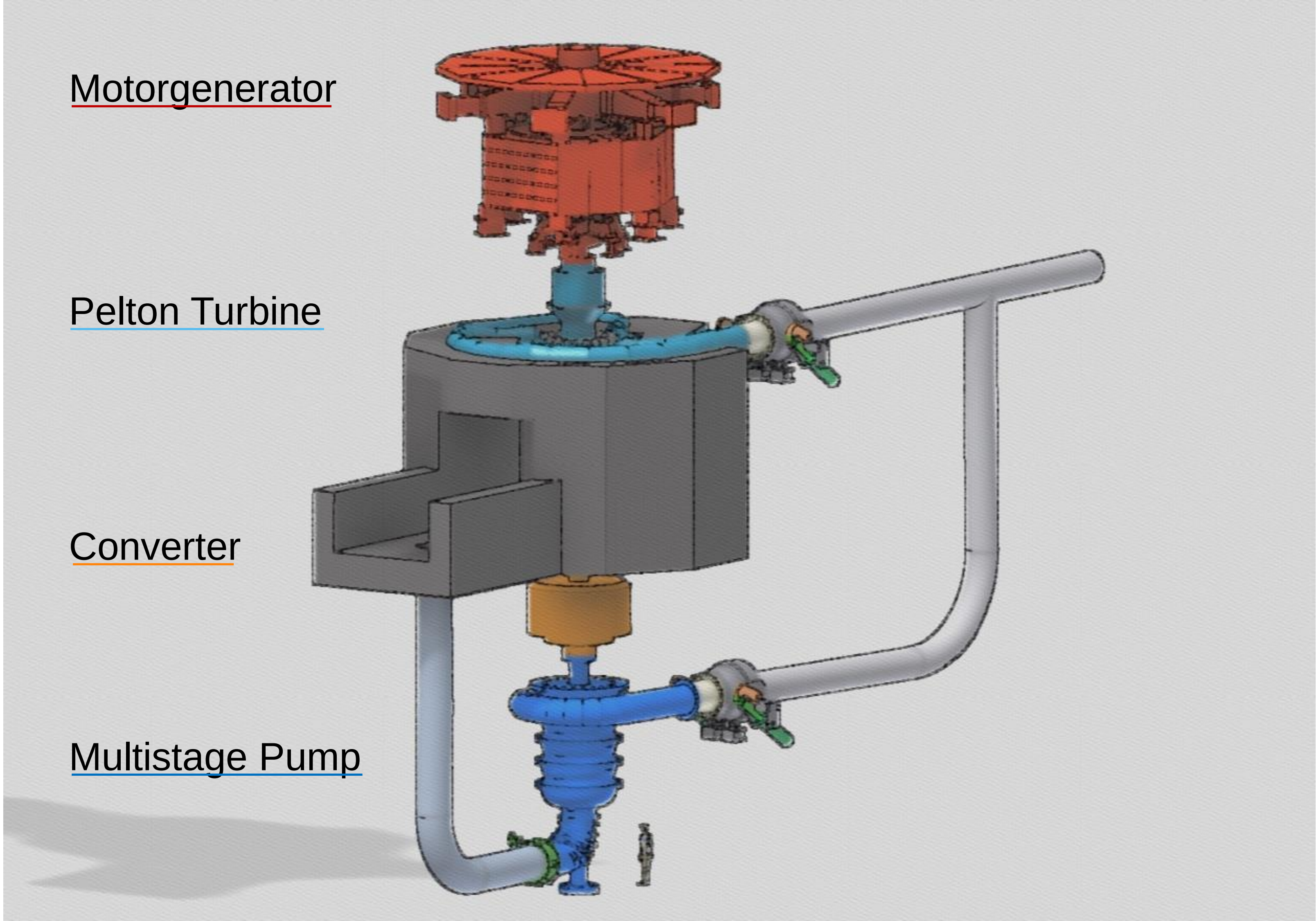
MAIN PLANT LAYOUT – 75MW



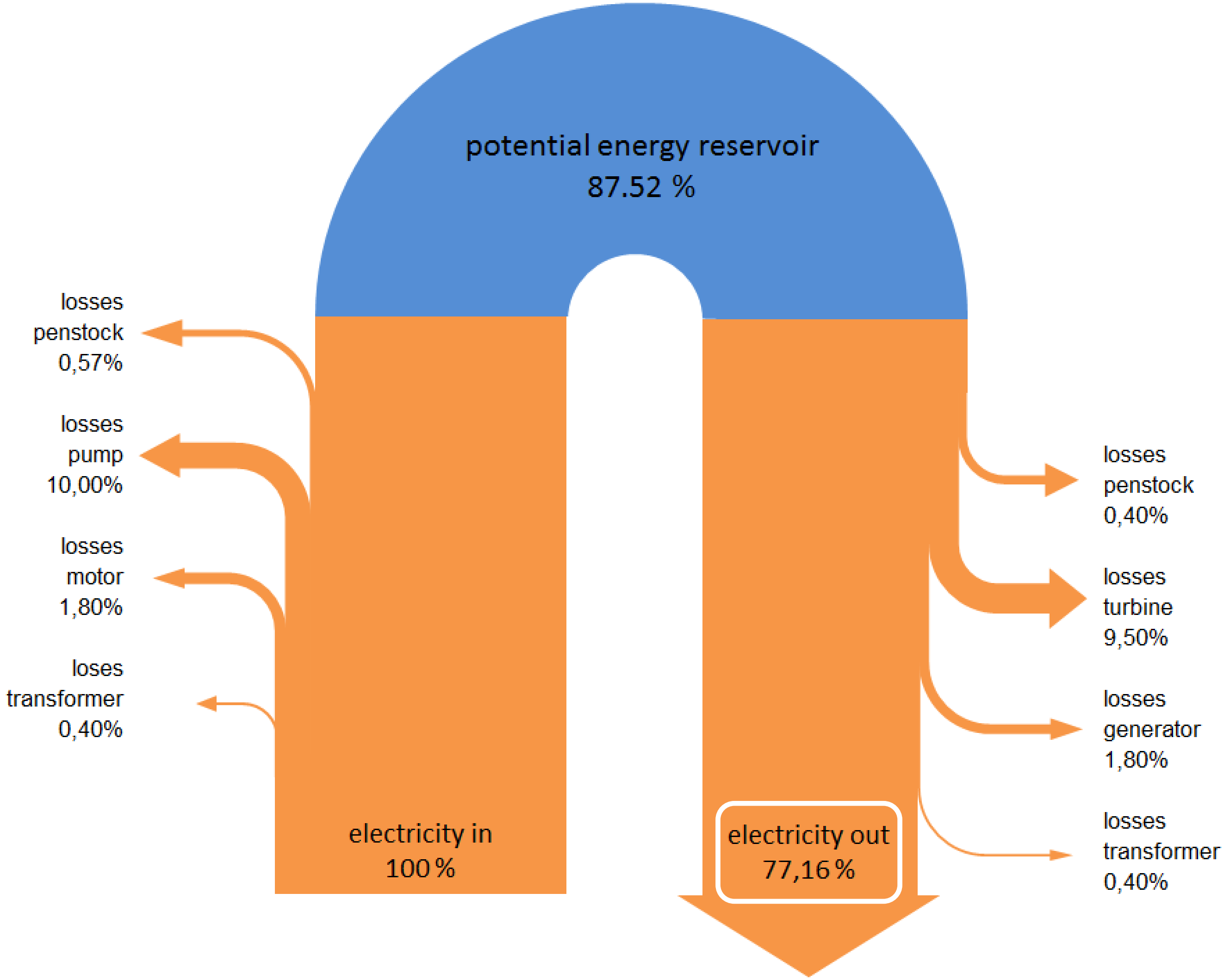
ES PYHÄSALMI - CAVERN DESIGN – 75MW



TERNARY UNIT SET - 75 MW UNIT SET



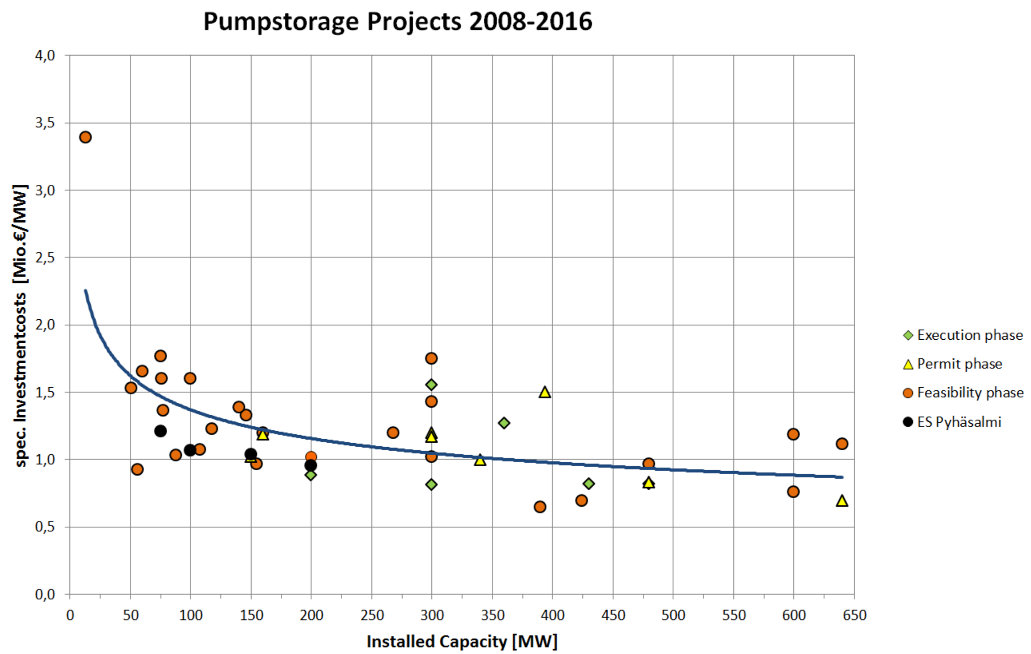
CYCLE EFFICIENCIES AT RATED OPERATION POINT



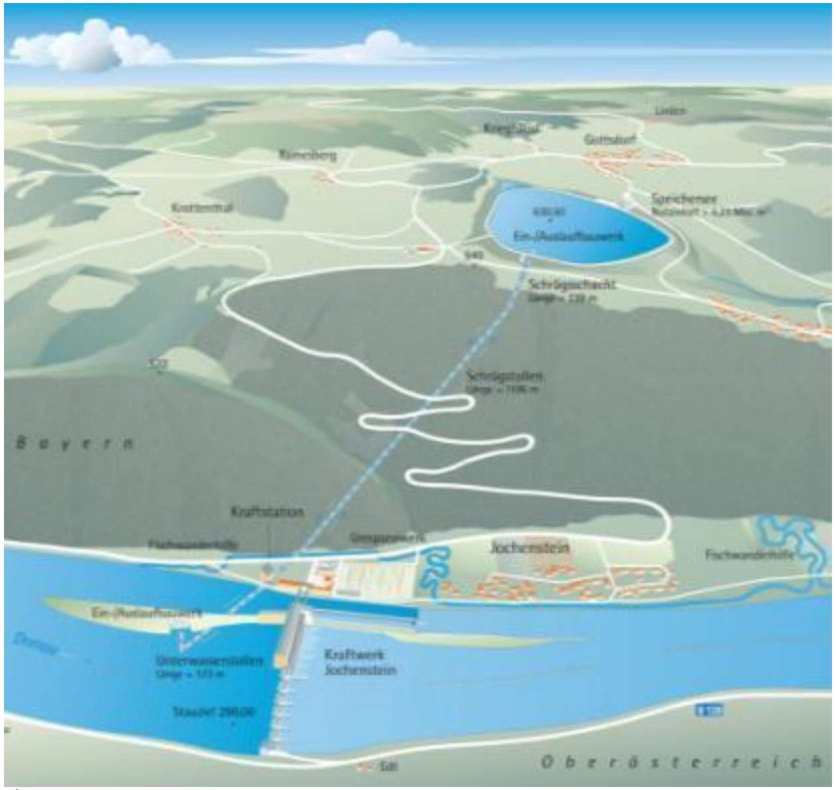
CONCLUSION

- Preferred location at -1400 m depth in order to utilise the full head and to minimise related storage volume.
- No technical “show stoppers” have been identified.
- Technical and construction advantages due to excellent geological conditions.
- Ternary unit set with pressured turbine-tailwater chamber is the preferred arrangement.
- Specific costs are in the lower range compared to other PS projects.
- Economic evaluation (Pöyry’s BID3 market model) showed challenging conditions for PS in Finland.

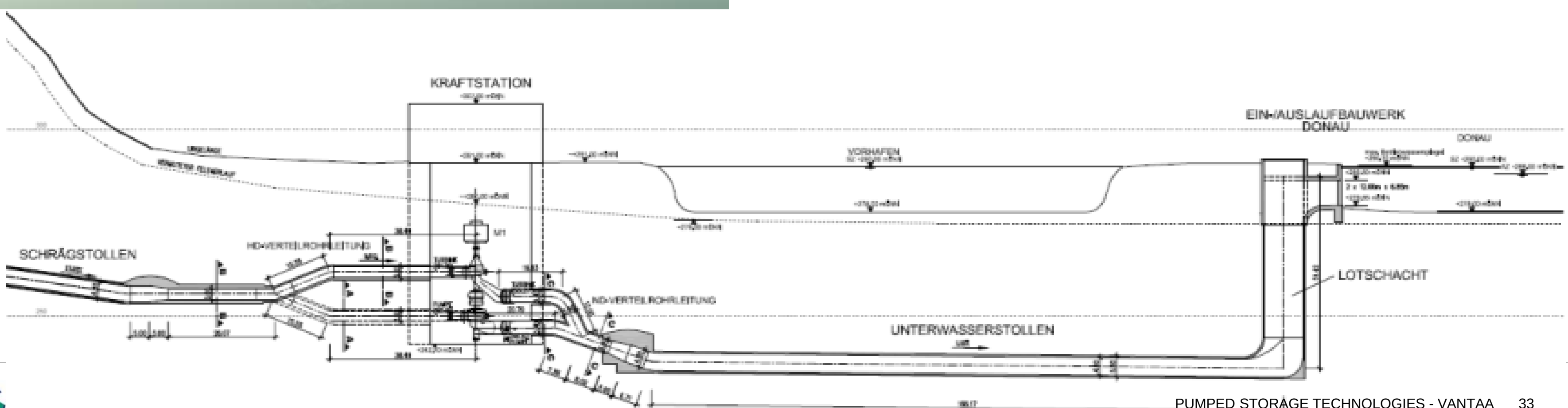
If realised it will likely be the pumped -storage plant with the highest head worldwide.



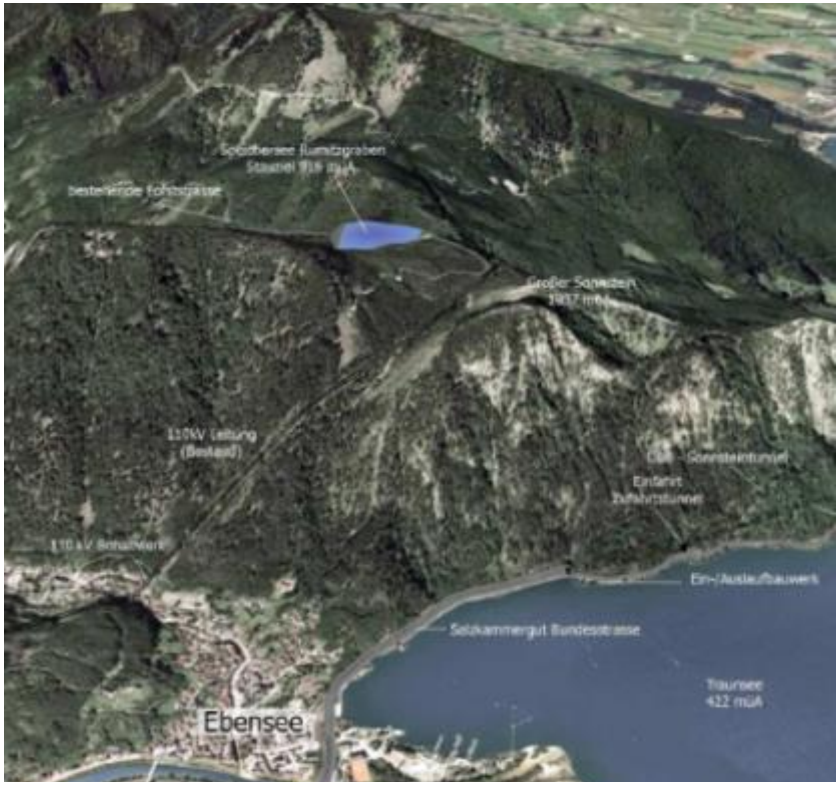
PSPP RIEDL, AUSTRIA



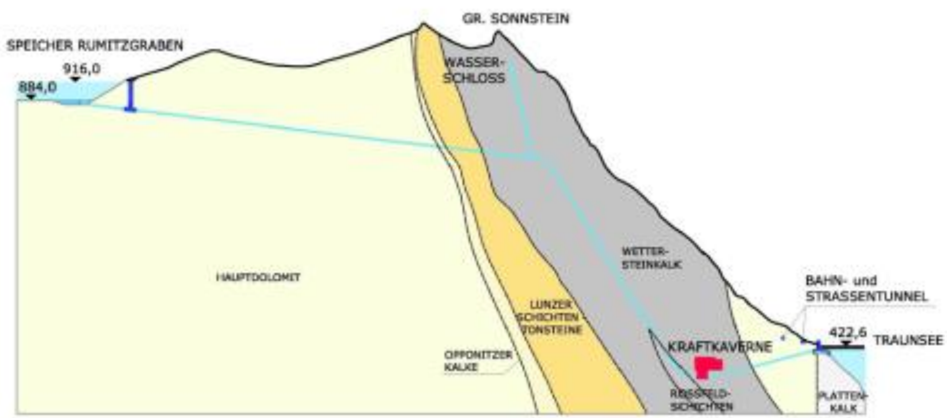
Client	**Donaukraftwerk Jochenstein AG**
Investment	**rd. 350 Mio. Euro**
Francisturbines	**2 x 160 = 320 MW**
Pumps	**2 x 150 = 300 MW**
Height	**330 m**
Services:	**Feasibility Alternatives** **- 2- Caverns** **- 1- Cavern** **- Shaft Powerhouse** **Approval Design**
Schedule	**2009 – 2012**

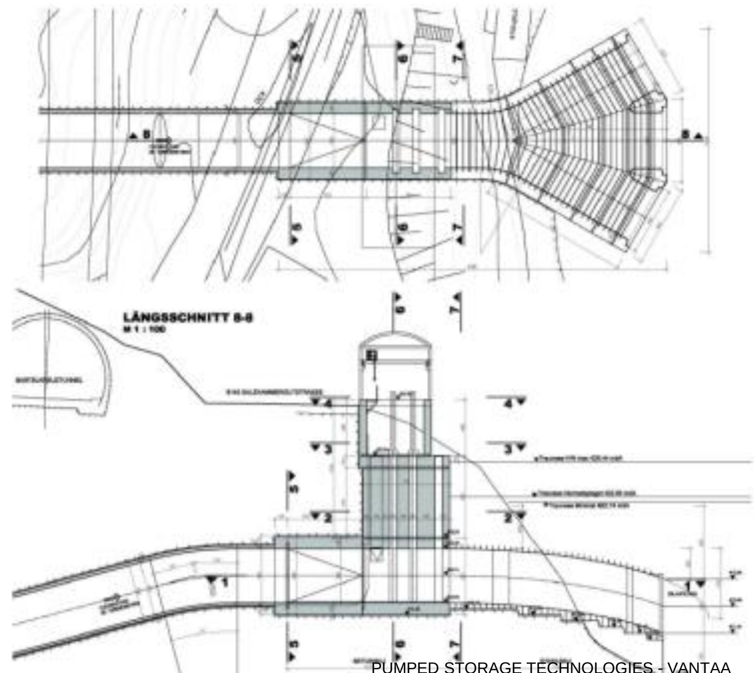


PSPP EBENSEE, AUSTRIA



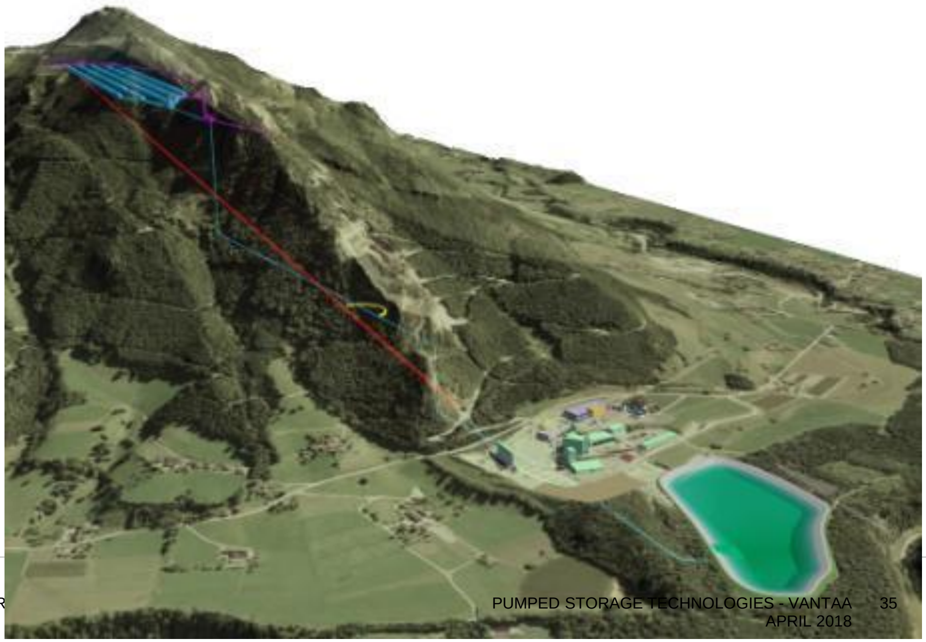
Client	**Energie AG**
Investment:	**rd. 150 Mio. Euro**
Pumpturbine	**1 x 150 MW**
Height	**490 m**
Services Design	**Feasibility, Approval**
Schedule	**2010 – 2011**
Forecast	**Tender Design – 2013**



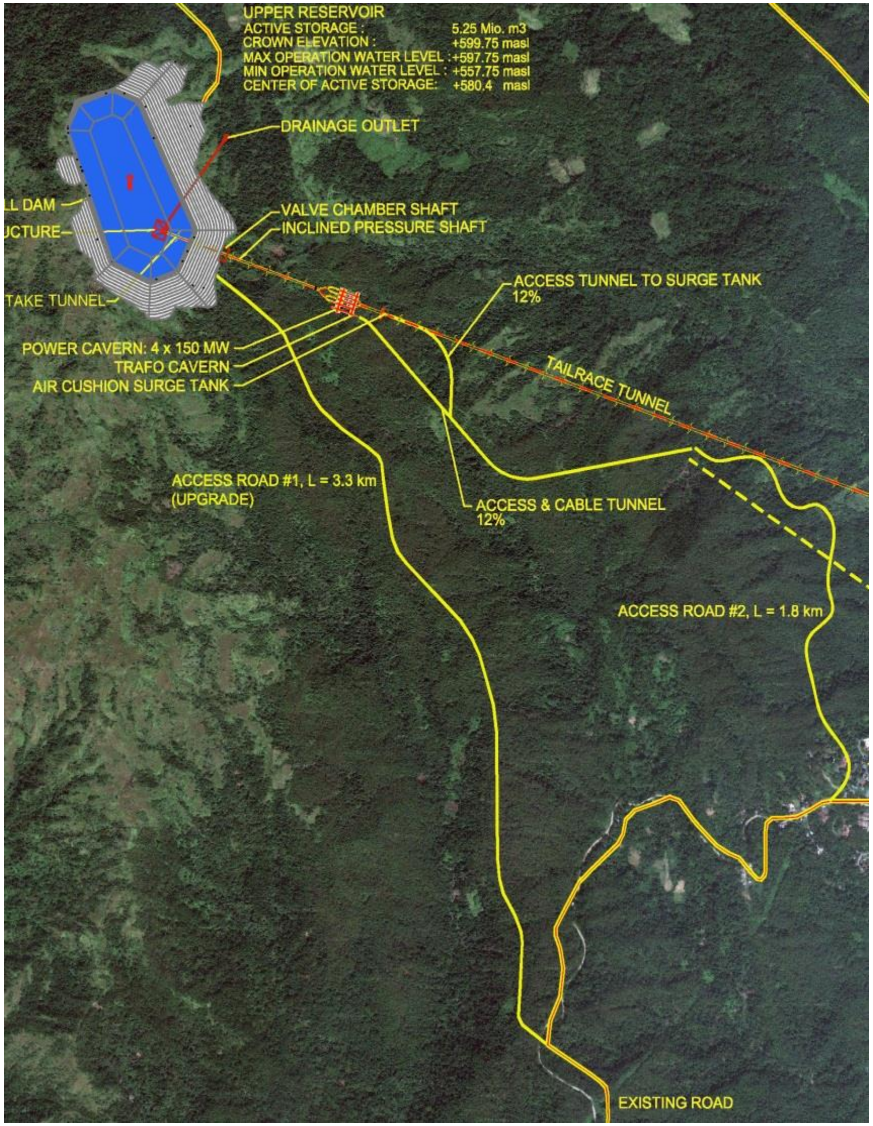


PSPP BERNEGGER, AUSTRIA

Client:	Bernegger GmbH / Wien Energie
Investment:	rd. 350 Mio. Euro
Pumpturbine	2 x 155 = 310 MW
Height	630 m
Services	Feasibility Approval Design Consulting Services



PSP PANTABANGAN, PHILIPPINES



Client	First Gen Premier Energy Corporation
Pump turbines	3 x 200 = 600 MW
Head	380 m
Height	40 m
Penstock	600 m
Shaft	320 m deep
Pressure tunnel	80 m high
Tailrace tunnel	3.35 km long
Active storage	5.25 million m3

PSP SIAH BISHE, IRAN

Client:	Kayson Construction Company
Pump turbines	4 x 260 = 1,040 MW
Head	520 m
Height	105, 85 m
Headrace Tunnels (2)	5.0 m dia, 2.2 km long each
Pressure shafts (2)	680 m long each
Powerhouse	Underground
Active storage	4.34 million m3

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