



Mechanical energy storage

Hydropower, pumped hydro, flywheels, compressed air



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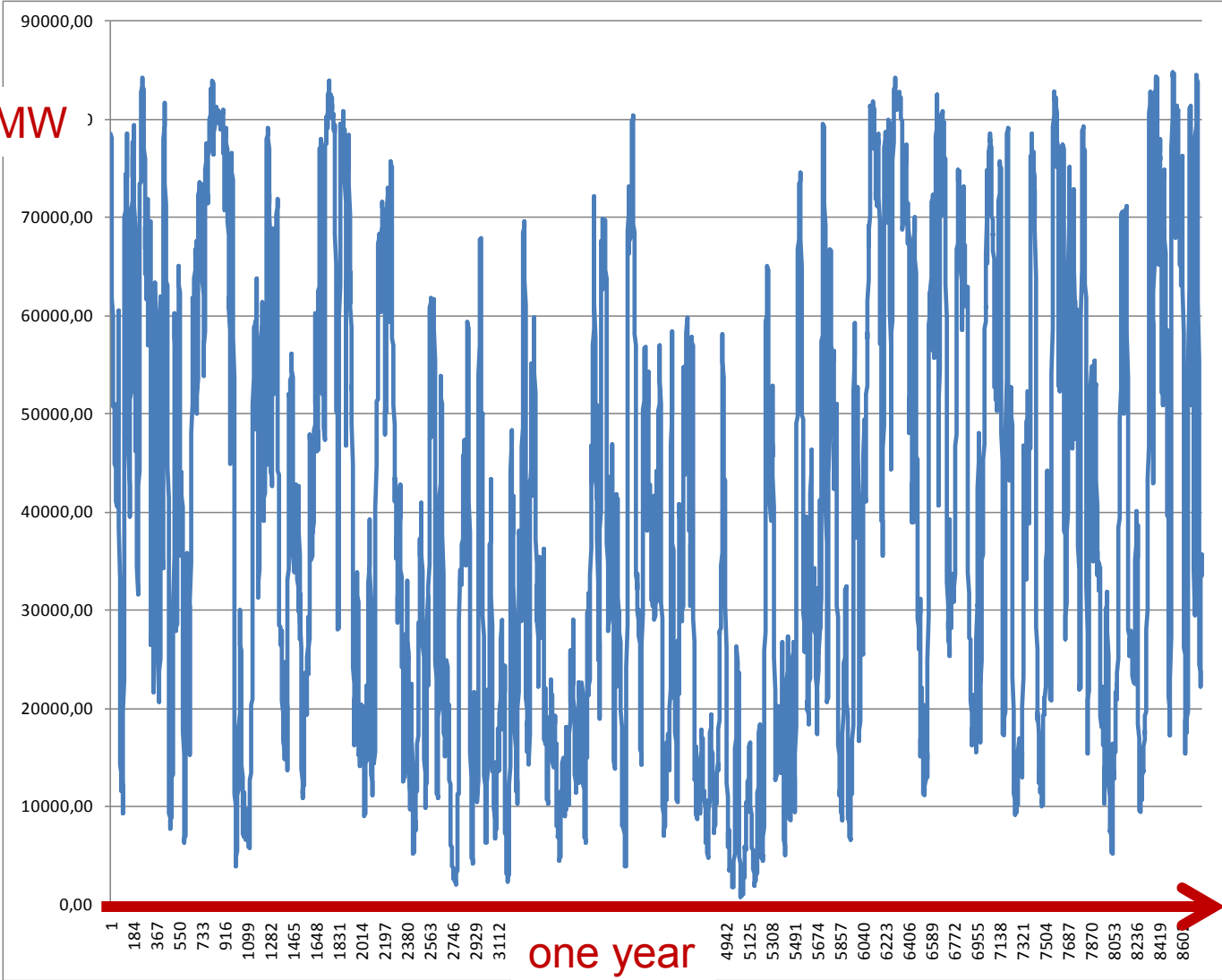


***Atle Harby, SINTEF Energy Research,
Centre for environmental design of renewable energy - CEDREN***



Simulated wind production in the North Sea area in 2030 – 95 000 MW installed capacity

80 000 MW



Mechanical storage

Hydro



- Operates typically on weeks to hours
- Many applications for both energy and storage
- World-wide potential

Compressed air



- Operates typically on hours
- Two commercial energy storage plants
- Need for more research

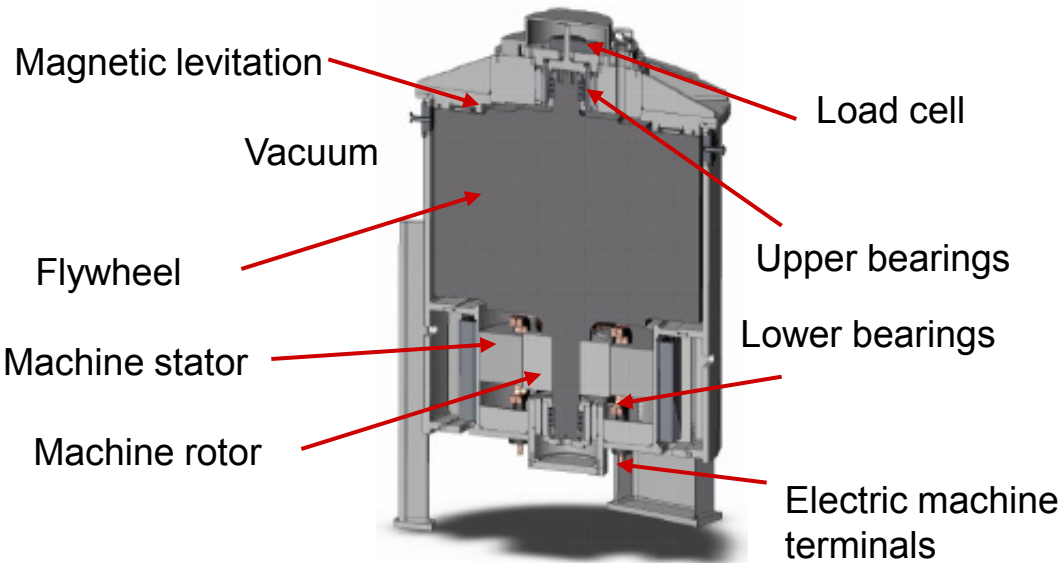
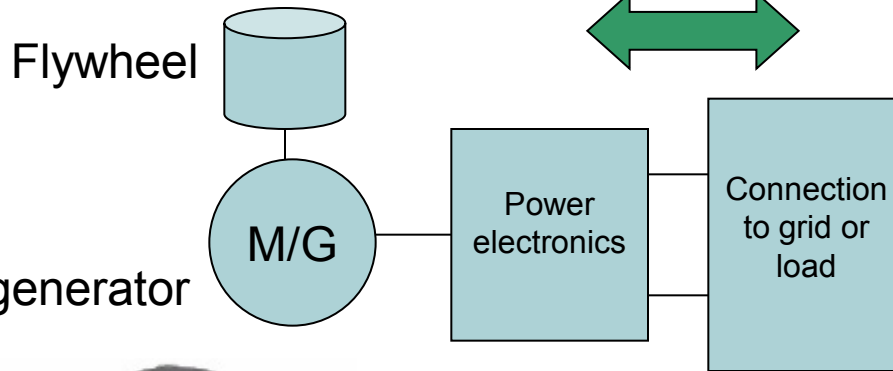
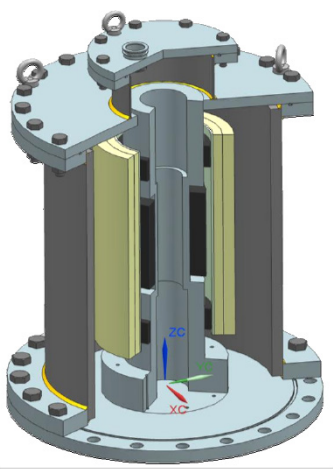
Flywheels



- Operates typically on seconds to minutes
- Used a lot in many other sectors
- Few large-scale energy storage applications

What is a flywheel?

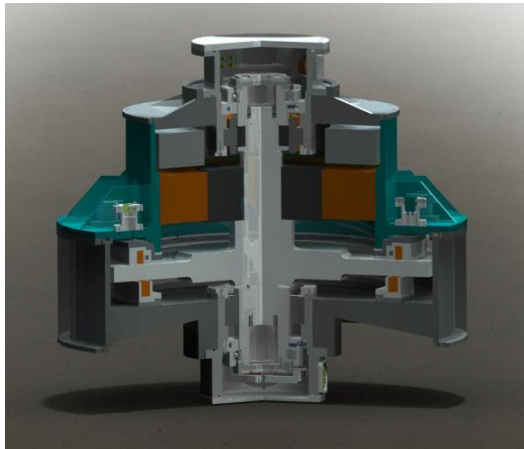
$$E = \frac{1}{2} \cdot J \cdot \Omega^2$$



From Lafoz

Flywheels – kinetic energy storage

- Rotating mass
 - High power and energy density
 - Very fast regulation
 - A large number of life cycles
- Transportation
 - Electric and hybrid cars, buses
 - Light trains, trams, underground
 - Ferries
 - Power system services
 - Grid stability
 - Frequency regulation
 - Voltage support
 - Industry
 - Uninterrupted power supply
 - Cranes and elevators



Beacon Power

Hazle Township, Pennsylvania, USA

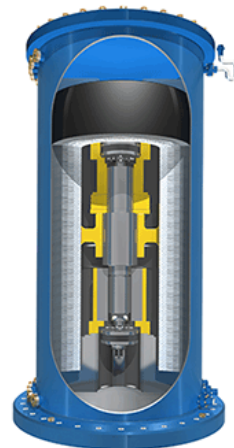
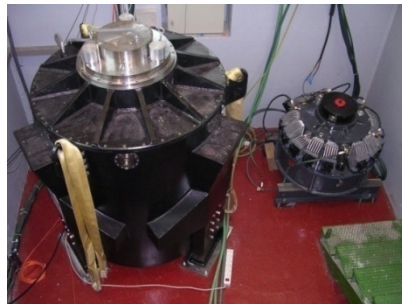
20 MW in total, 200 flywheels, ~1 300 kg each



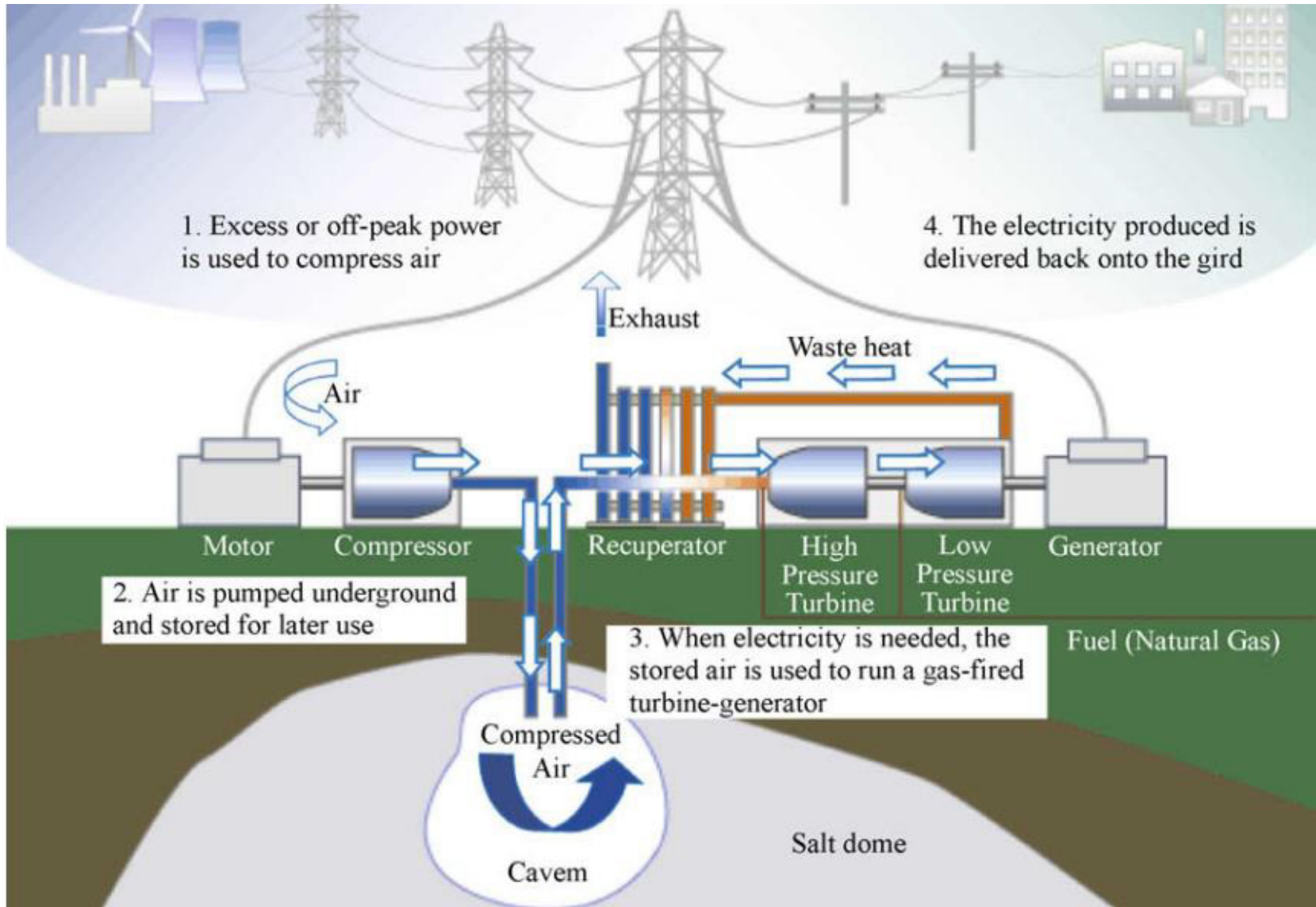
- Frequency regulations for the power grid
- Three plants in USA connected to the grid

Research needs - Flywheels

- Evaluate the potential in stabilization of frequency from renewables
- Design a test machine connected to a wind turbine
- Large scale applications for energy storage
- New materials
- Experimental set-up
- Tests



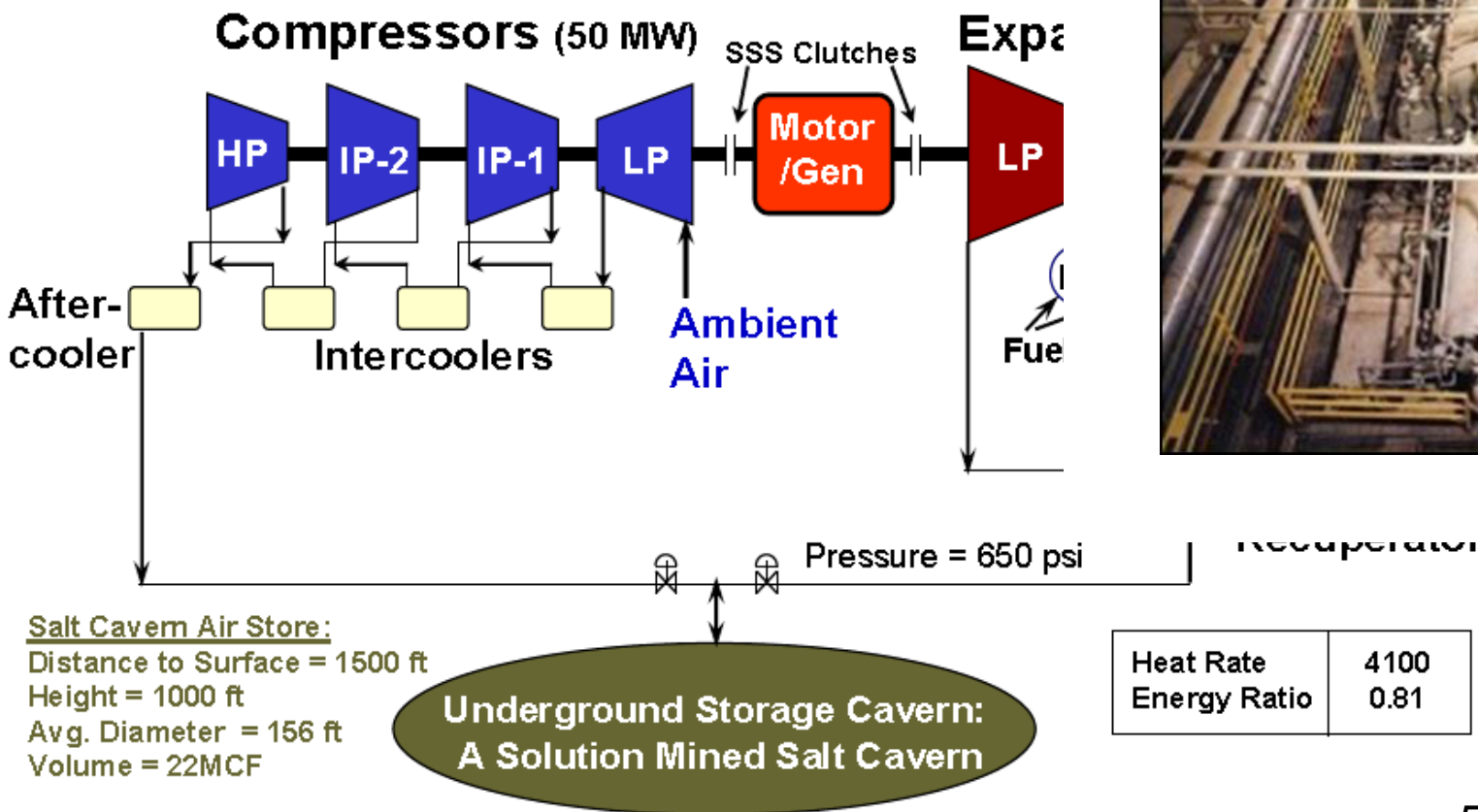
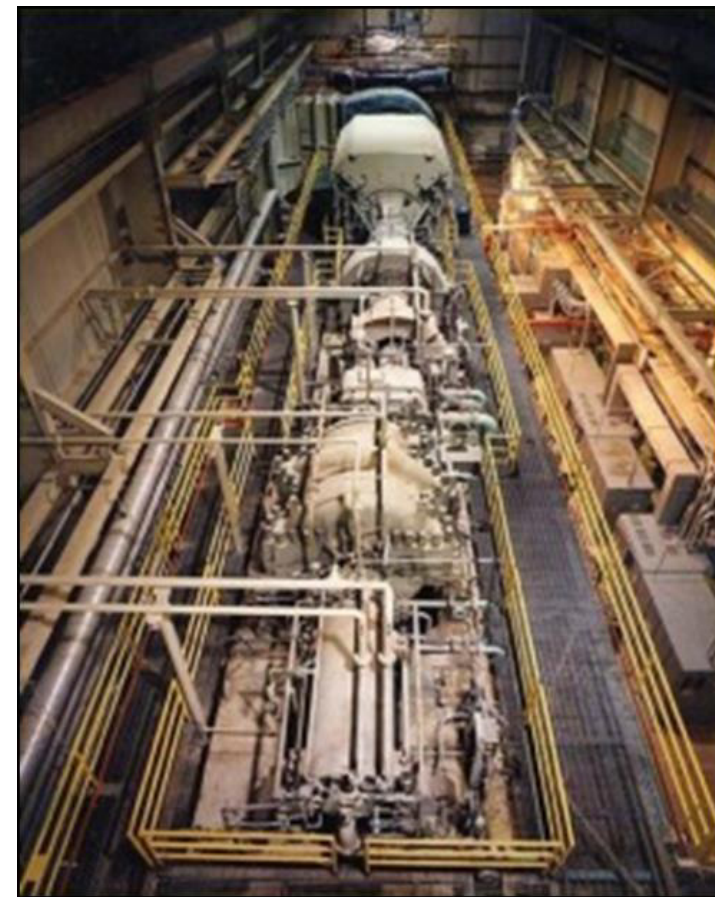
Compressed Air Energy Storage (CAES)



From Luo and Wang

McIntosh CAES plant

(one of two commercial plants - first generation CAES)



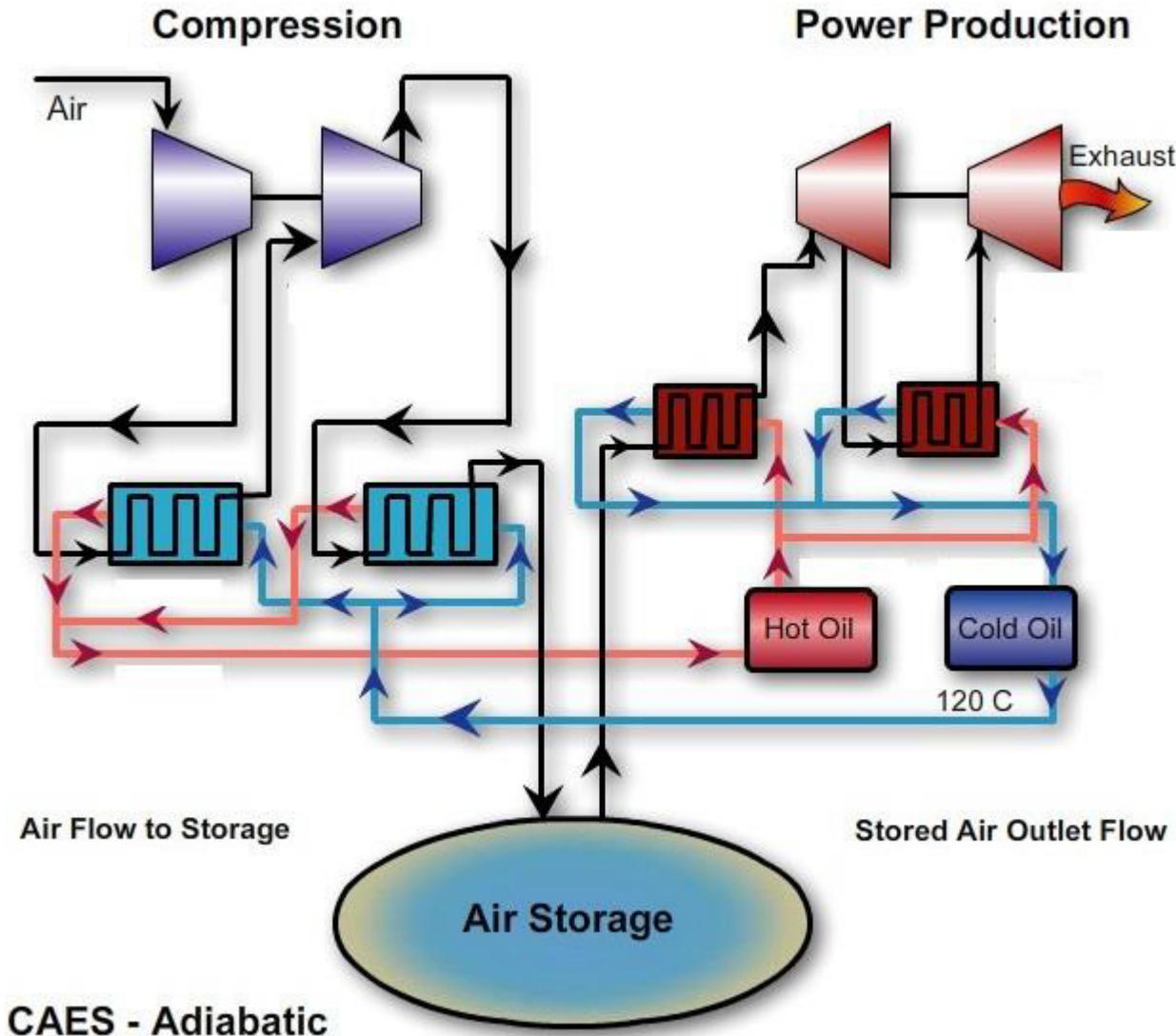
Heat Rate	4100
Energy Ratio	0.81

From Luo and Wang

Adiabatic CAES

"Managing the heat"

Small scale CAES:
Competing with batteries

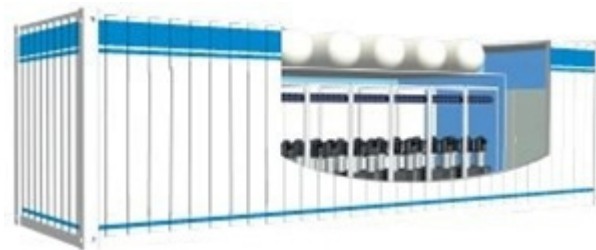


From Luo and Wang

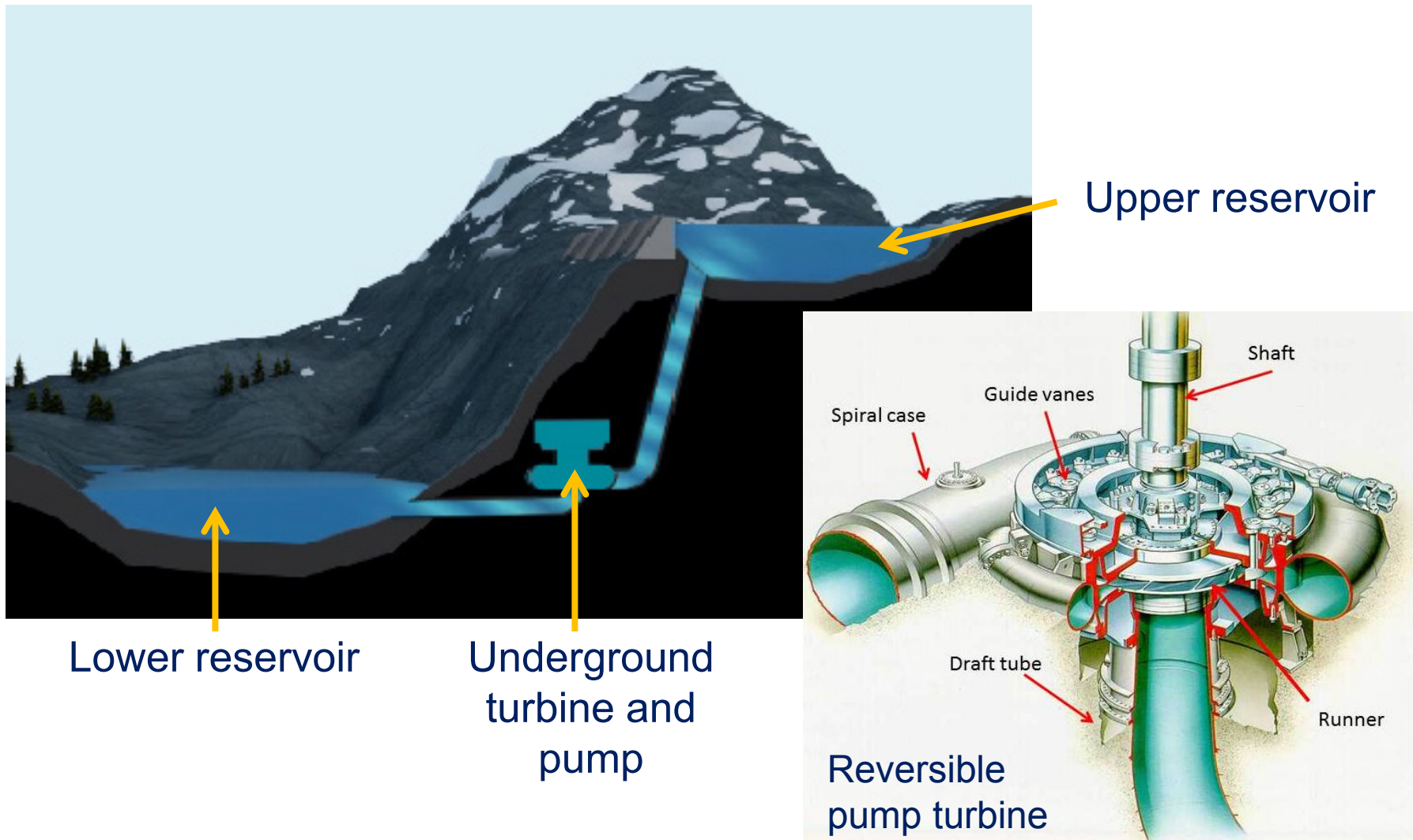
- System design
- Technical solutions for underground compressed air storage
- Under water or tank storage systems
- Environmental impacts and safety
- Development of turbines only running on compressed air using scroll expanders
- Adiabatic storage

$$[\dot{X}_{ar}] = \frac{d}{dt} \left(\frac{n}{V} \right) = \frac{\dot{n}}{V} - \frac{\dot{V}n}{V^2} = \left(\frac{\dot{m}}{M} \right) / V - \frac{\dot{V}}{V^2} \times \frac{m}{M}$$

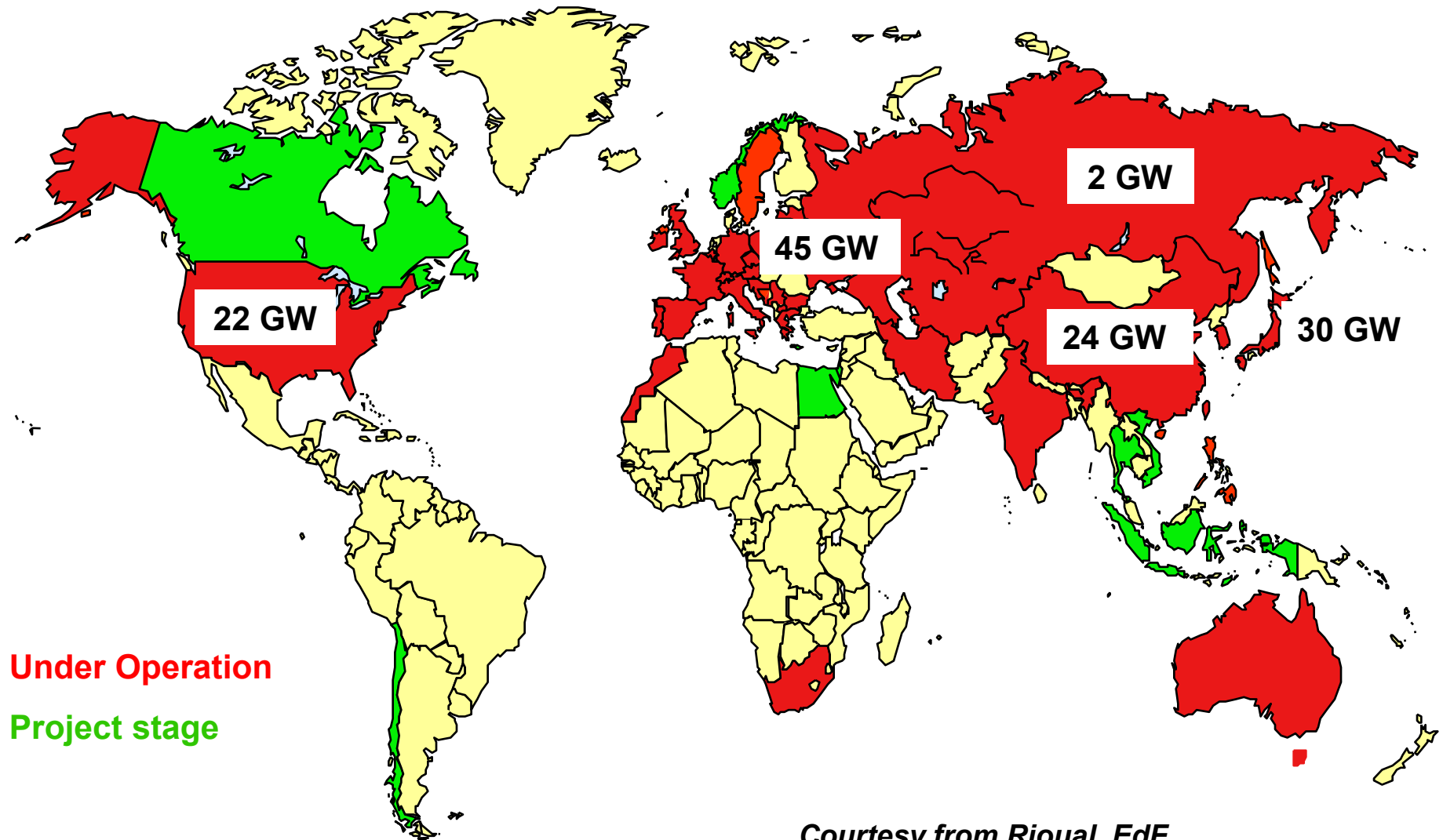
$$\dot{T}_c = \frac{(\dot{m}_m h_m / V_c) - (\dot{V}_c / V_c) ([X_{ar}] \hat{h}_c) - [\dot{X}_{ar}] \hat{h}_c + P_c [\dot{X}_{ar}] / [X_{ar}]}{[X_{ar}] C_{p,ar}(T_c) - P_c / T_c}$$



Pumped Storage Hydropower principle



Installed PSH world-wide: ~140GW



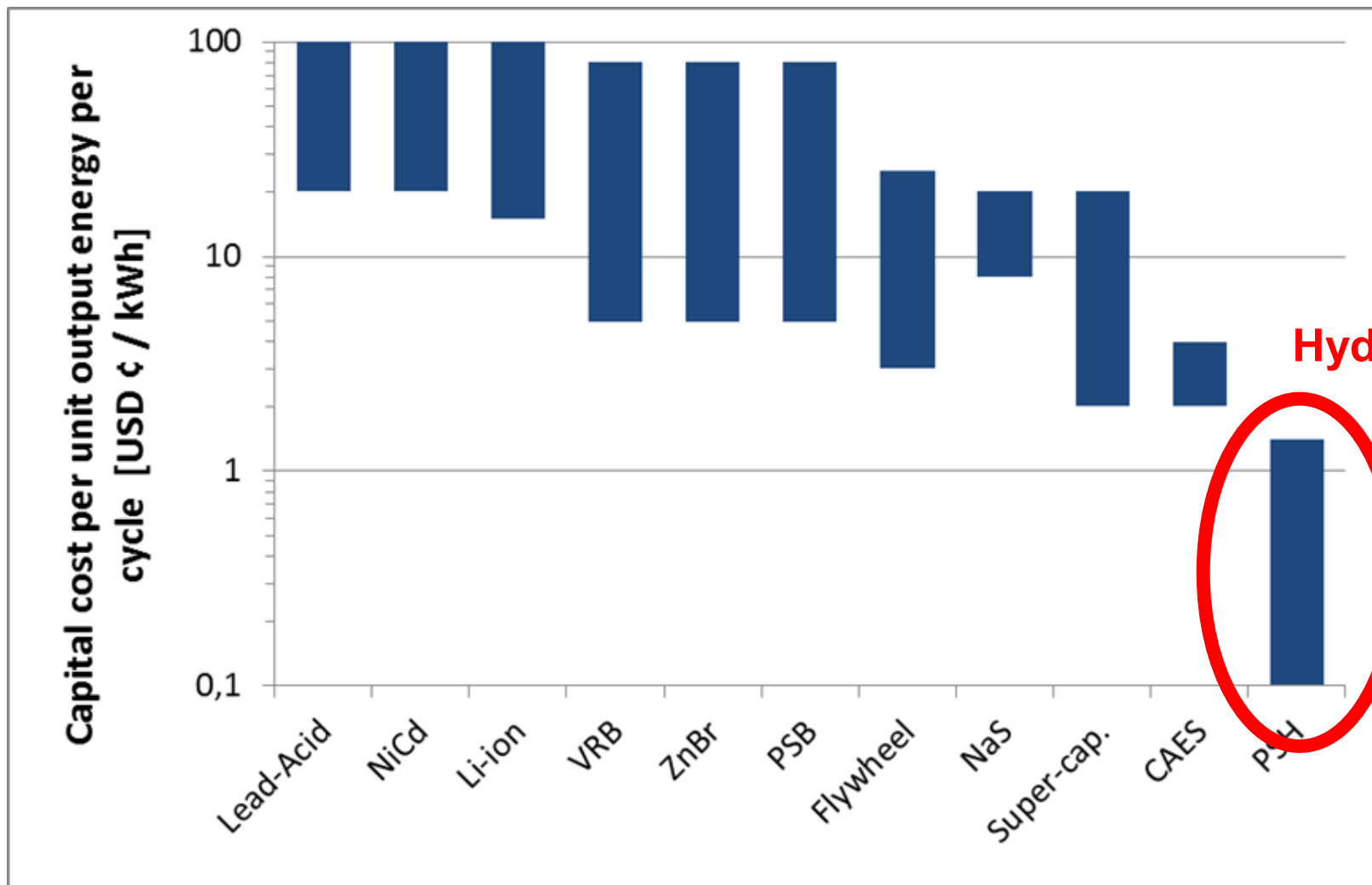
Under Operation

Project stage

Courtesy from Rioual, EdF

Capital costs per cycle:

Log scale



Hydro

Afourer, Marocco



Photo: Alstom

Nant de Drance, Switzerland

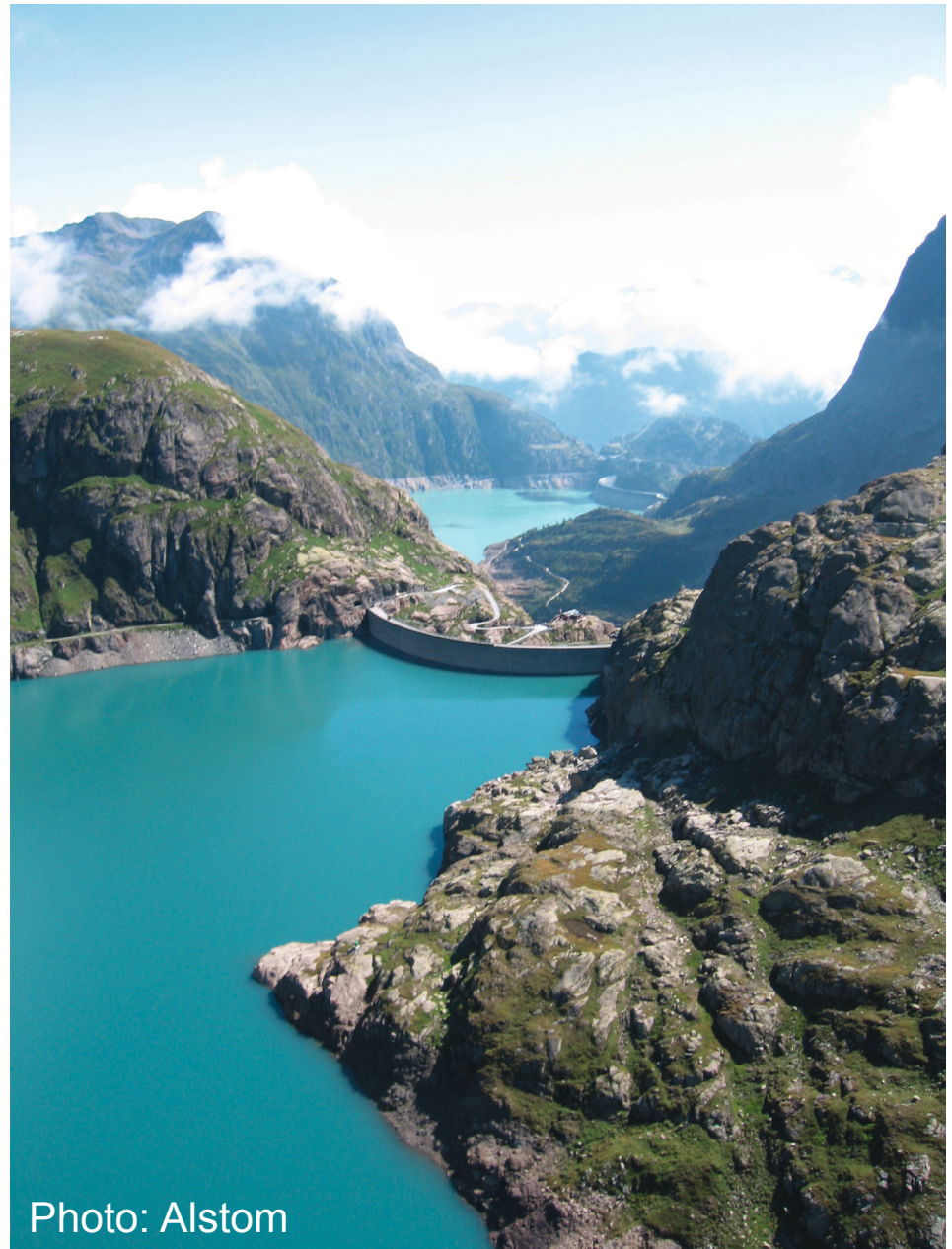


Photo: Alstom

Goldisthal, Germany



Limberg II, Austria



Grand Maison, France



1 800 MW turbine mode
1 275 MW in pump mode

Courtesy from Rioual, EdF

Vianden, Luxemburg

Upper reservoir

Lower reservoir:
The river

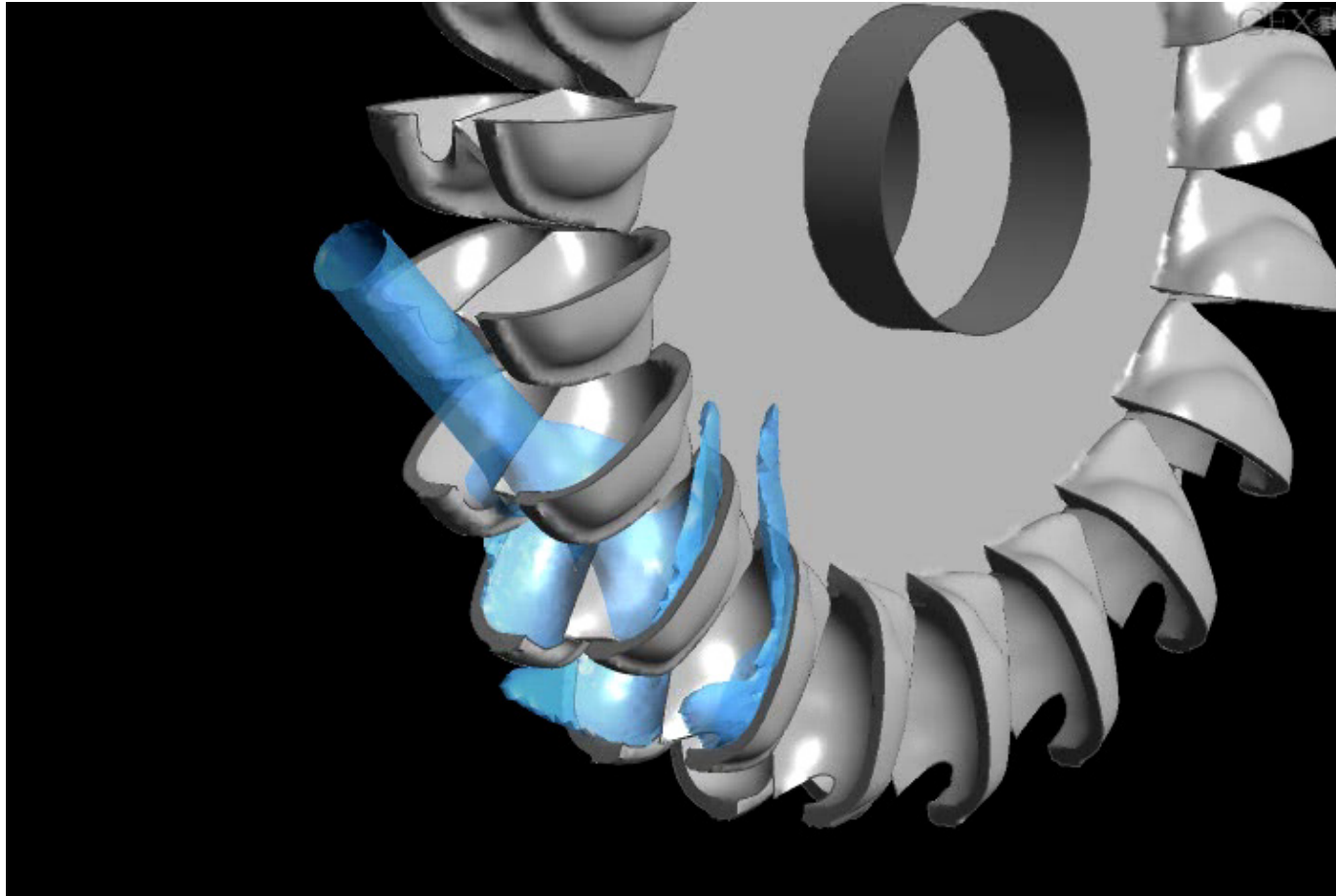
Photo: Alstom



EERA — Energy Storage - Mechanical Storage Sub-program meeting and workshop

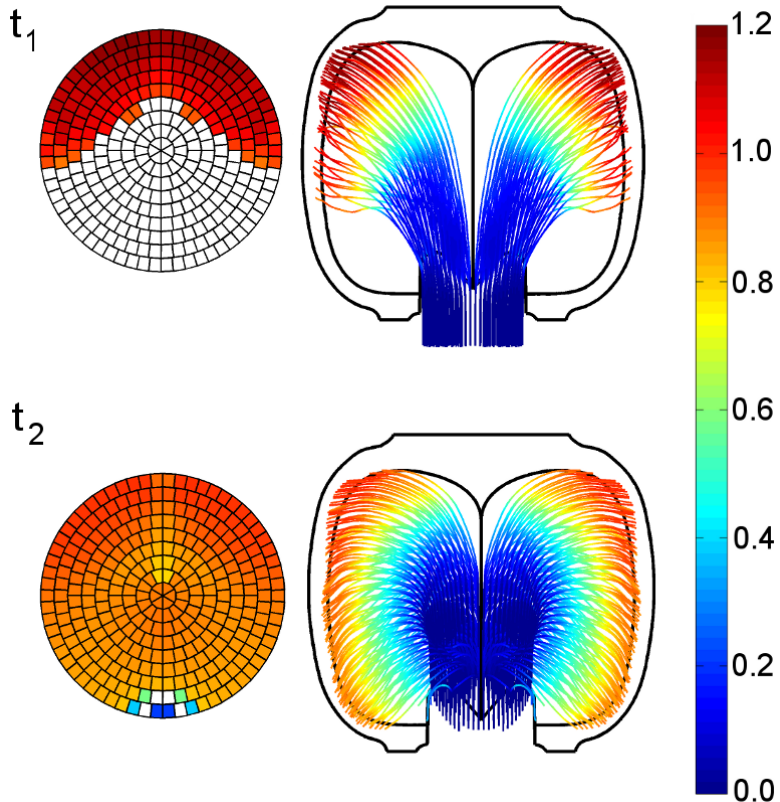


Research: Improvements of technology



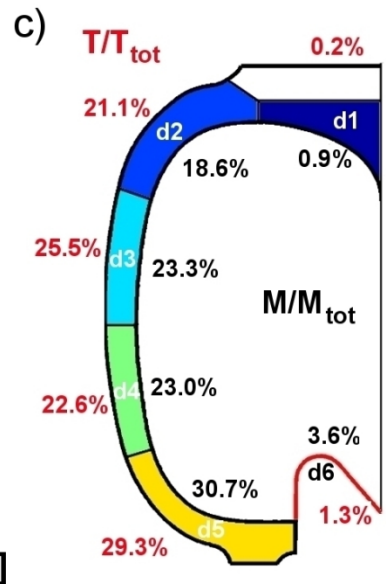
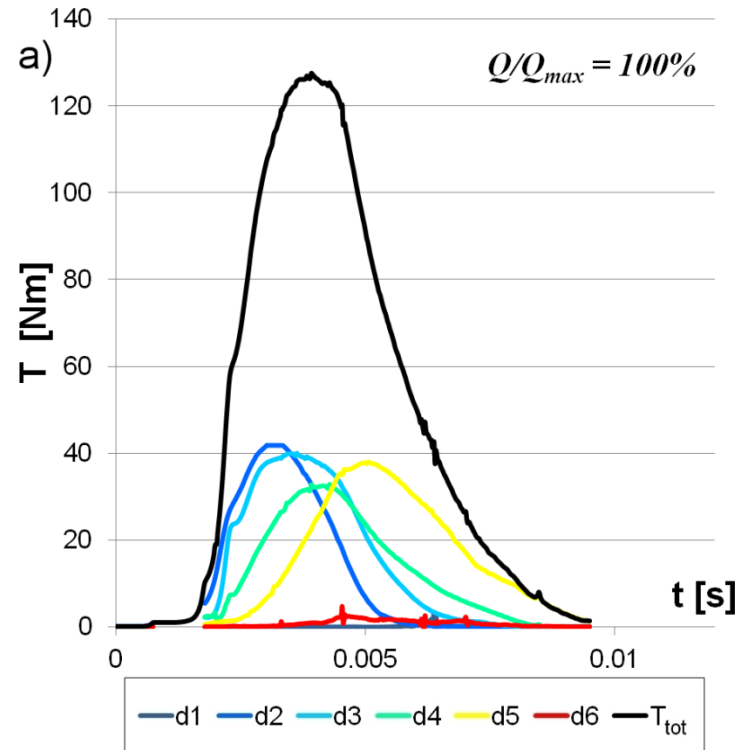
From Cavazzini

Turbomachinery Design and Optimization



Hybrid Eulerian-Lagrangian numerical approach

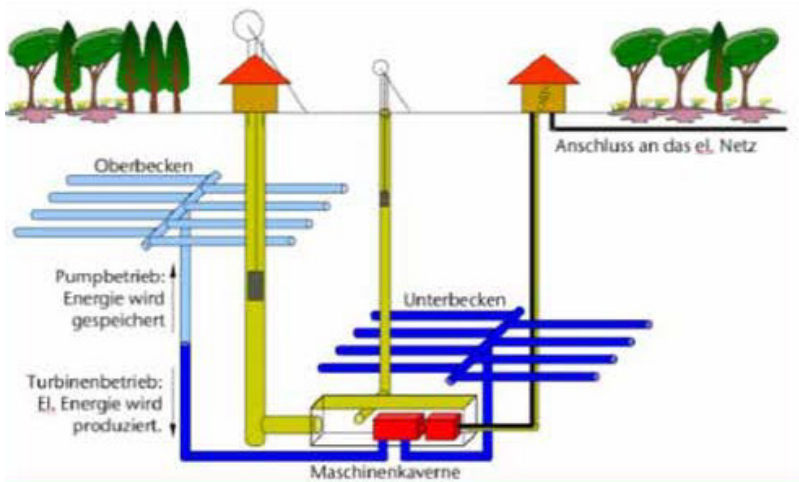
Optimization of the Pelton bucket geometry



From Cavazzini

New technologies – pumped storage

- Underground PSP



- Sub-sea PSP
- Artificial island PSP
- Retrofitting reservoir hydro
- Variable speed reversible pump turbines

- Salt water PSP



Okinawa PSP - Japan

- No access to lakes
- Scarce water resources
- Isolated grids (islands)
- Extra maintenance (salt)

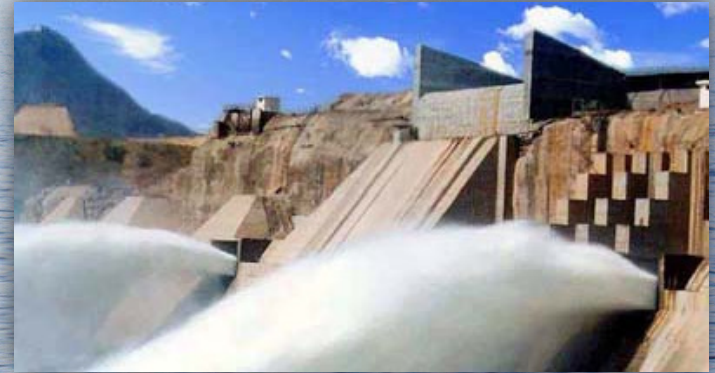


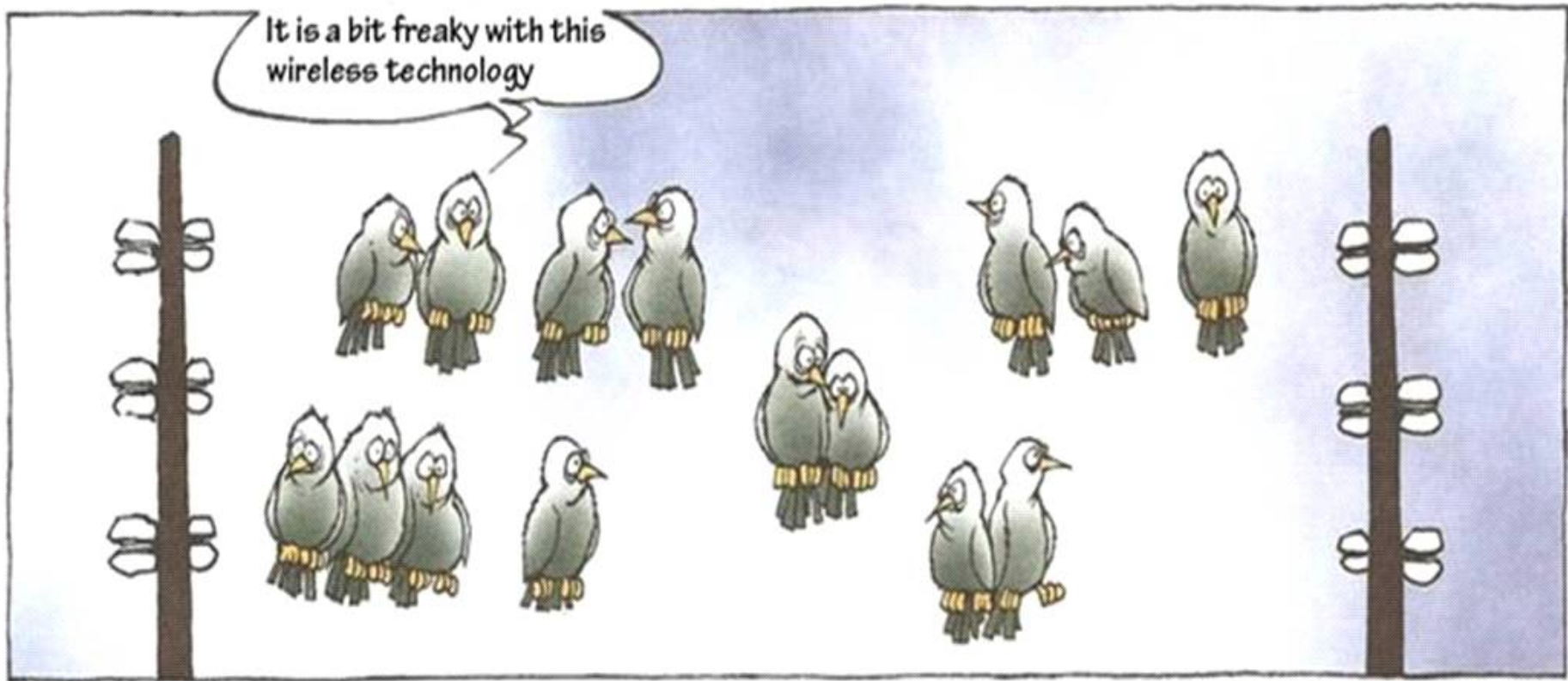
Blåsjø
7.8TWh RESERVOIR
(1000 times Goldistal)



Multiple roles for hydropower in water and energy

- **Electricity for heat, power and transport**
- **Energy storage for grid systems**
- **Water storage for**
 - **Flood/drought mitigation**
 - **Irrigation**
 - **Water supply**
 - **Navigation**
 - **Downstream flow regime**





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- Uncertain future – many scenarios, but all includes storage
- Rapid changes may come (...Fukoshima)
- Mechanical storage: Effective, necessary and in use at time intervals ranging from seconds to years
- Water in hydro reservoirs = always an excellent energy storage - also needed for other purpose and combined use possible