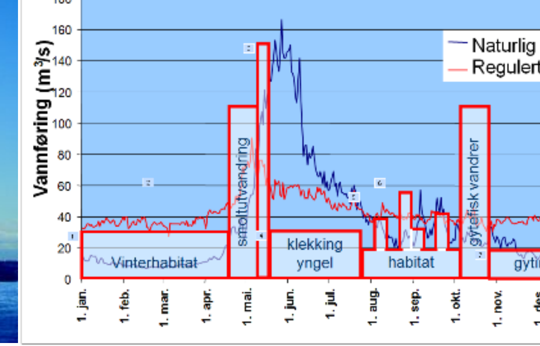






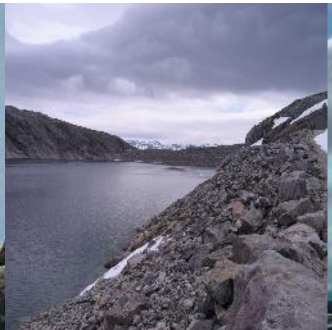
Mechanical energy storage

Hydropower, pumped hydro, flywheels, compressed air

Julie Charmasson, SINTEF Energy Research

Centre for environmental design of renewable energy - CEDREN





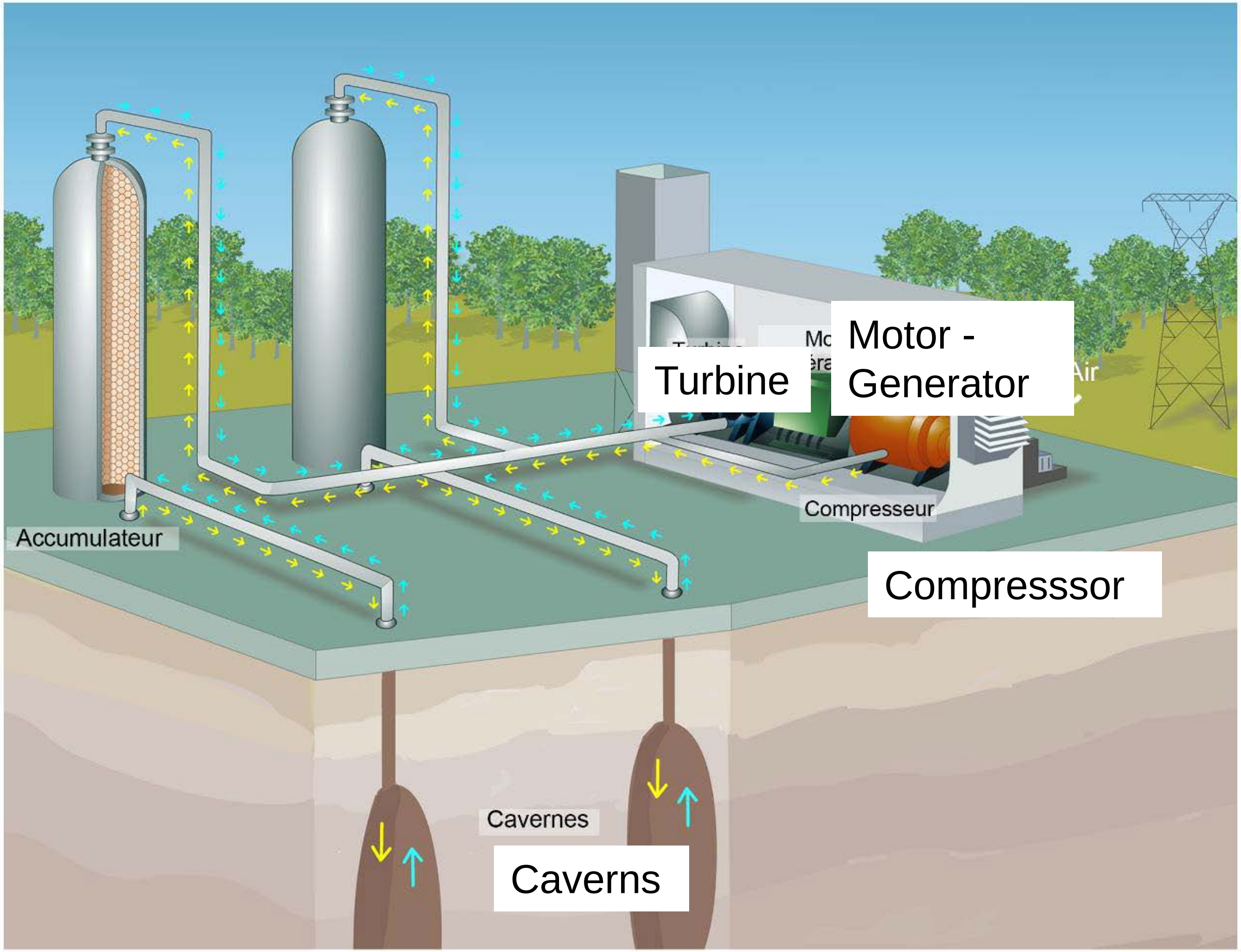
Mechanical storage

Flywheels

Hydro

Compressed air

Compressed Air Energy Storage (CAES)

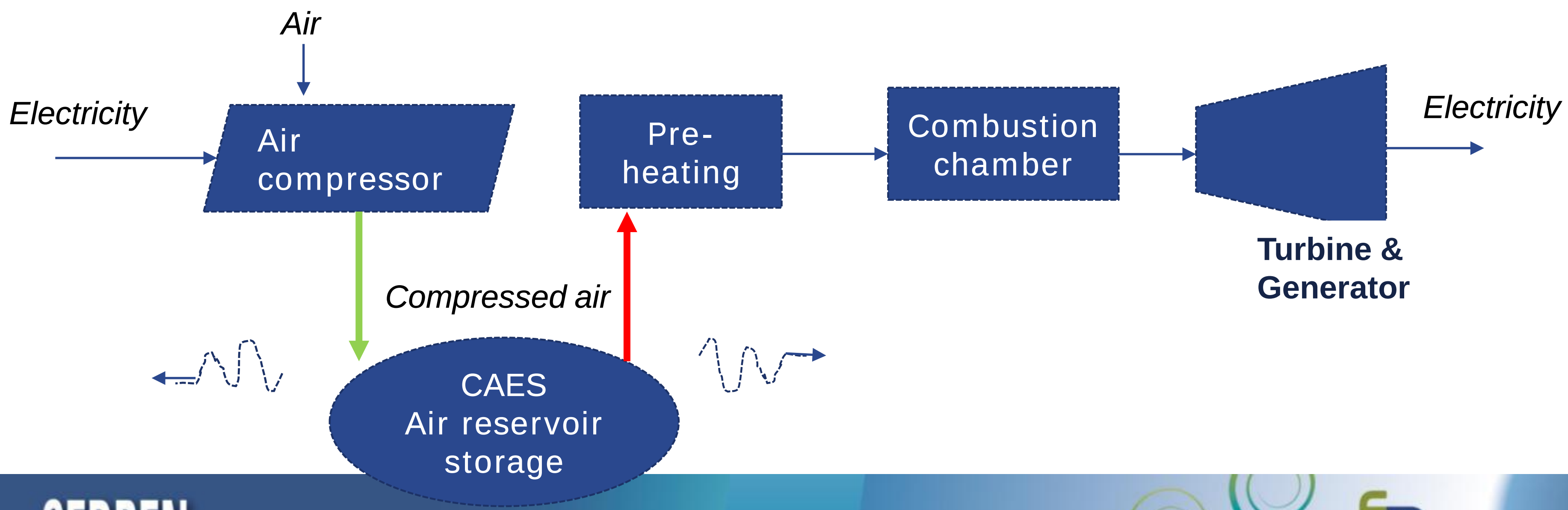


Modified from C.Beurtey

CAES: Principle

- Air is **compressed** (compressor) and **store** in **undergrounds caverns** or storage tanks during off-peaks hours.
- Air is then used for running a **gas-fired turbine** at time of peak demand.

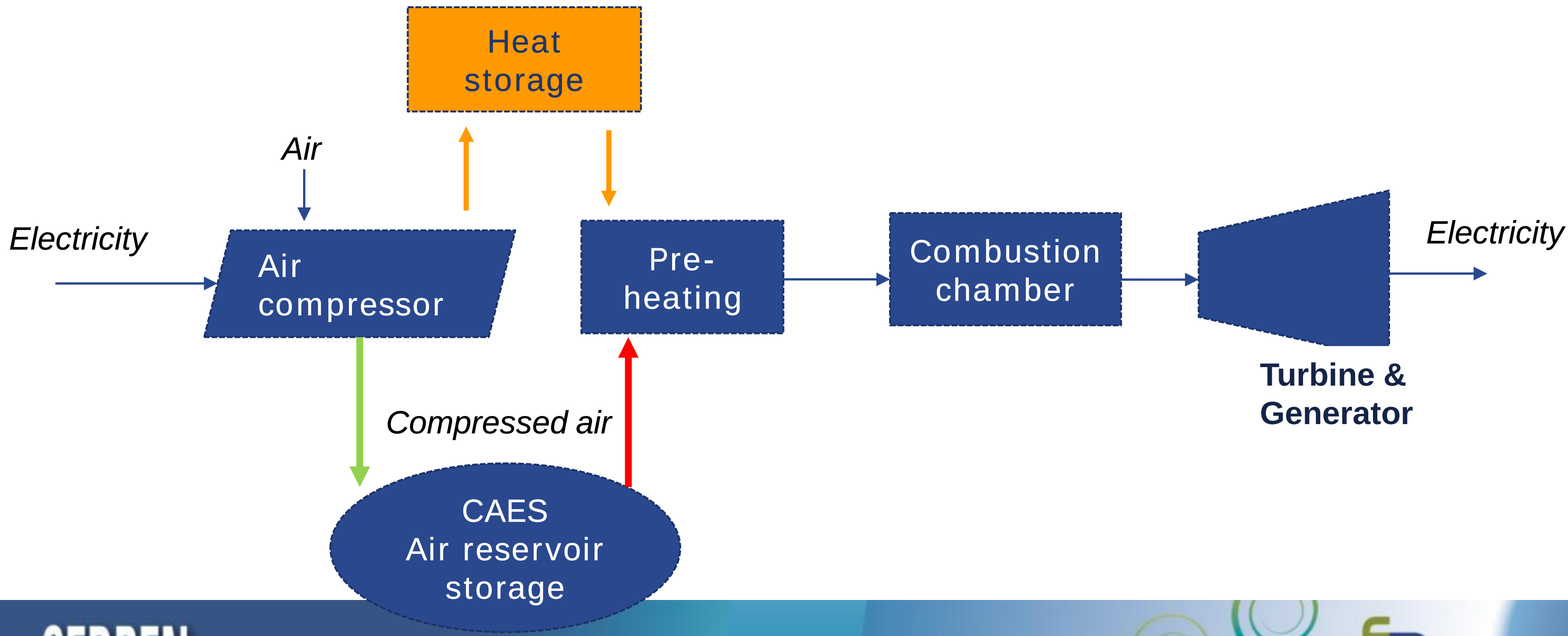
- 3 types:
  Conventional / Adiabatic / Isothermal



CAES: Principle

- Air is **compressed** (compressor) and **store** in **undergrounds caverns** or storage tanks during off-peaks hours.
- Air is then used for running a **gas-fired turbine** at time of peak demand.

- 3 types:
  Conventional / Adiabatic / Isothermal



CAES: Characteristics

Target power	Efficiency	Response time	Discharge time	Lifetime	Investments costs
100-500 MW	40-55 % Up to 70%	min.	h	30 y	400-1200 € /kWh

McIntosh CAES plant (USA)
https://www.wired.com/2010/03/compressed-air-plants/

CAES: Characteristics

Target power	Efficiency	Response time	Discharge time	Lifetime	Investments costs
1	40-55 % Up to 70%		h		400-1200 € /kWh

High power

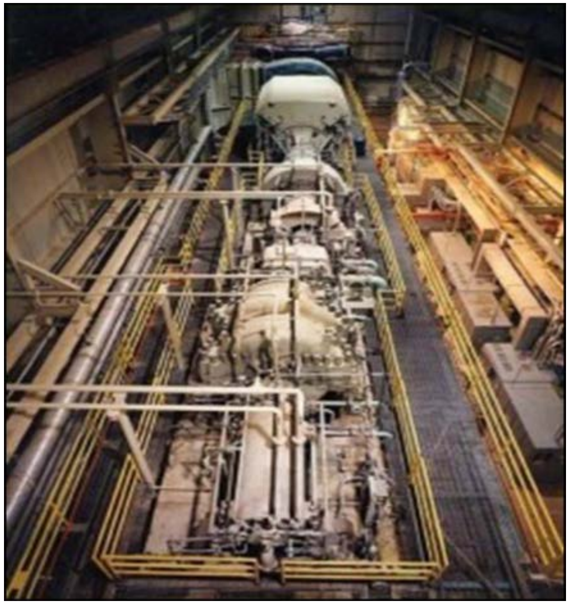
Fast regulation

Large number of cycle lifes

McIntosh CAES plant (USA)
https://www.wired.com/2010/03/compressed-air-plants/

CAES: Maturity

Power plant	year	Power	Storage
Huntorf (GE)	1979	290 MW	3h
McIntosh (USA)	1991	110 MW	26h
ADELE (GE)	2018	90 MW	4h
PG&E (USA)	2021	300 MW	10h
Norton (USA)		Up to2700 MW	16h



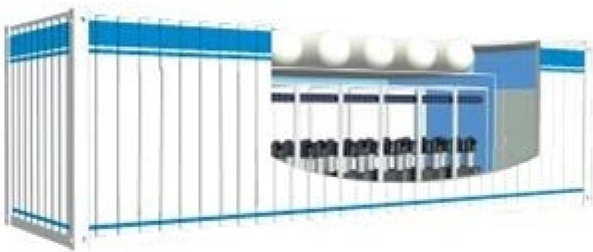
McIntosh CAES plant (USA)
http://www.apexcaes.com/caes

Research needs - CAES

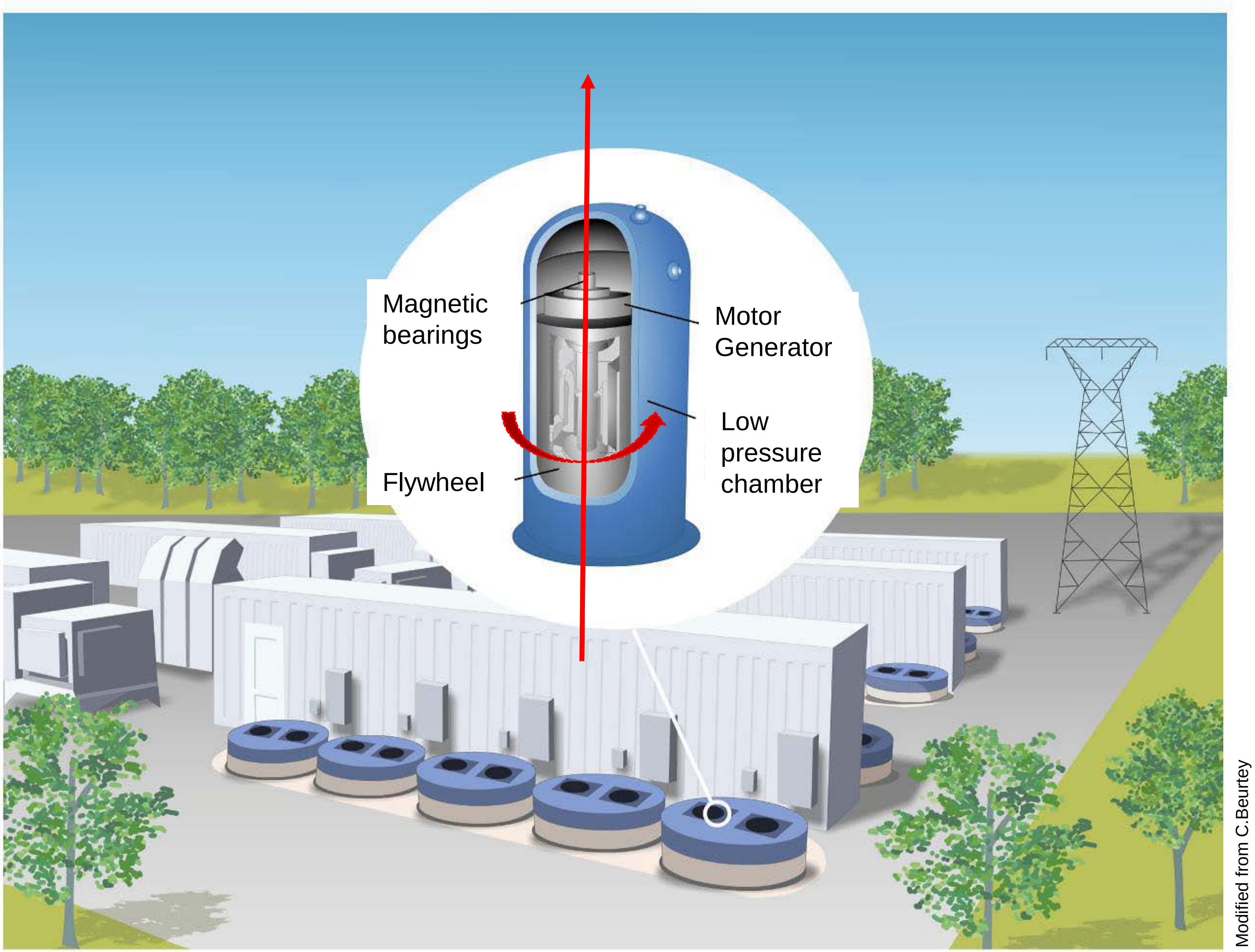
$$[\dot{X}_{air}] = \frac{d}{dt}\left(\frac{n}{V}\right) = \frac{\dot{n}}{V} - \frac{\dot{V}n}{V^2} = (\frac{\dot{m}}{M})/V - \frac{\dot{V}}{V^2} \times \frac{m}{M}$$

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

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



Flywheels


Magnetic bearings
Motor Generator
Low pressure chamber
Flywheel
Modified from C.Beurtey

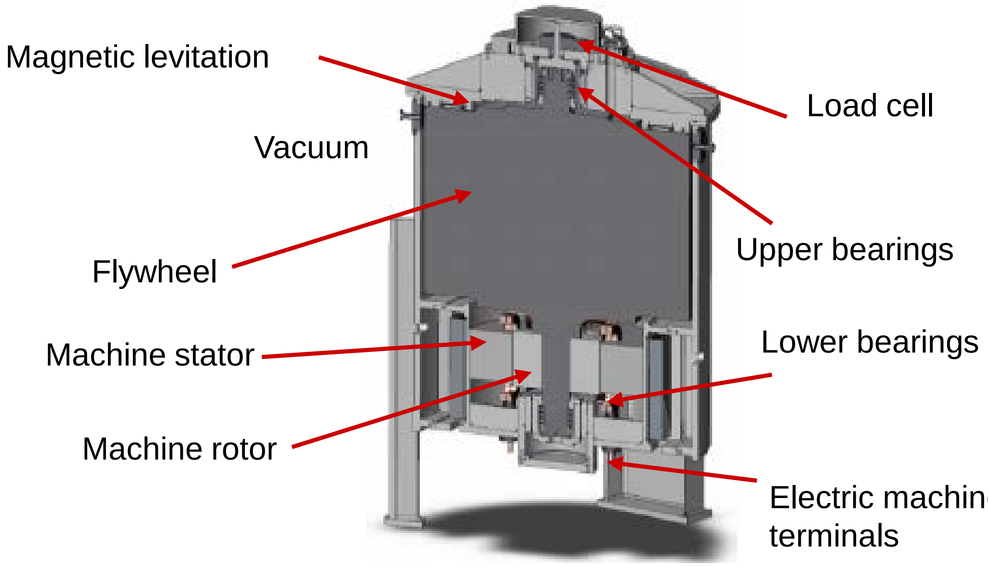
Flywheels: Principle

- Mass (Flywheel) is **rotating** around an **axis** (fixed) in a vacuum **chamber** and connected to an **electrical machine**.

- **Cinetic** (rotational) energy is stored

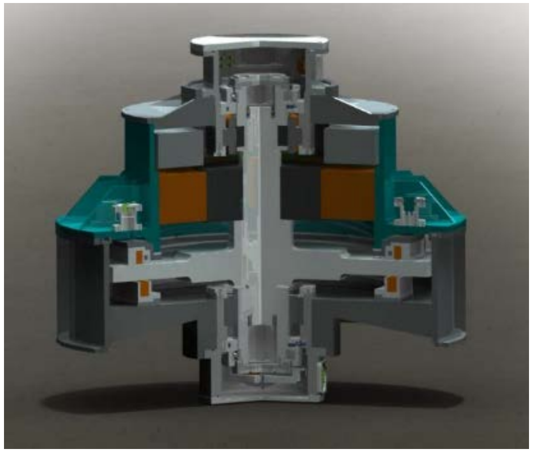
$$E = \frac{1}{2} \cdot J \cdot \Omega^2$$

- **Storage phase**:
  - Motor
  - Eel used → speed ↗
- **Discharging phase**:
  - Generator
  - Eel released → speed ↘



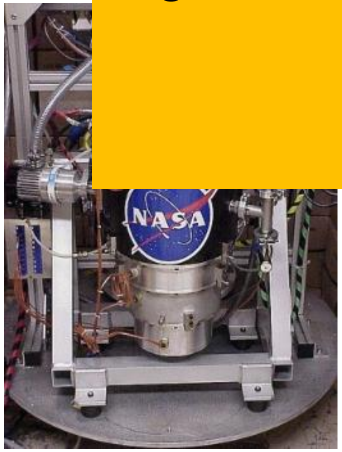
Flywheels: Characteristics

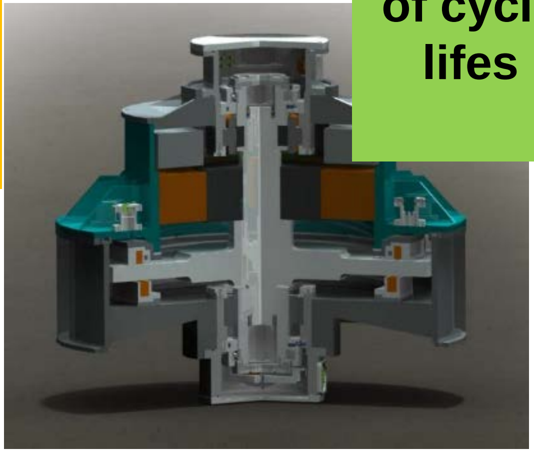
Target power	Efficiency	Response time	Discharge time	Lifetime	Investments costs
100-1500 kW	80 %	ms	s to min	20 y	200-3000 € /kWh



Flywheels: Characteristics

Target power	Efficiency	Response time	Discharge time	Lifetime	Investments costs
High power	80 %	**Very fast regulation**	s to min	**Large number of cycle lifes**	200-3000 € /kWh





Flywheels: Applications

- **High** power during **short** time

- 2 types

Low speed	Steel	v > 10 000 tr/min
High speed	Carbon fiber	v → 50 000 tr/min

- Applications:

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

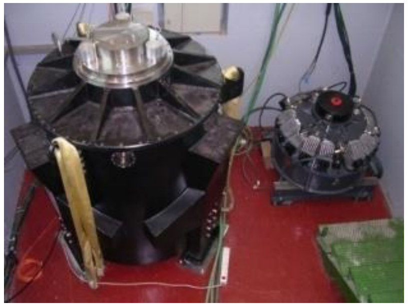
20 MW in total, 200 flywheels, ~1 300 kg each

http://beaconpower.com/hazle-township-pennsylvania/

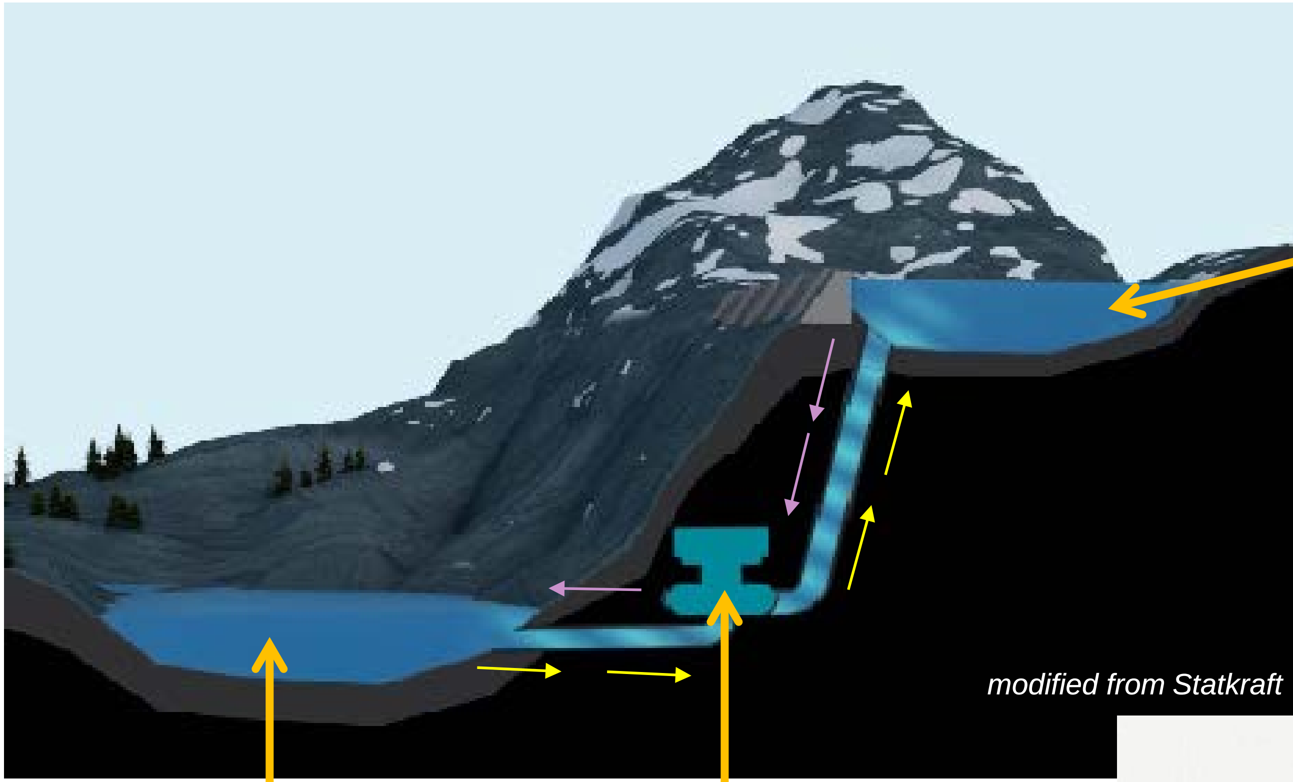
- Frequency regulations for the power grid
- Three plants in USA connected to the grid

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



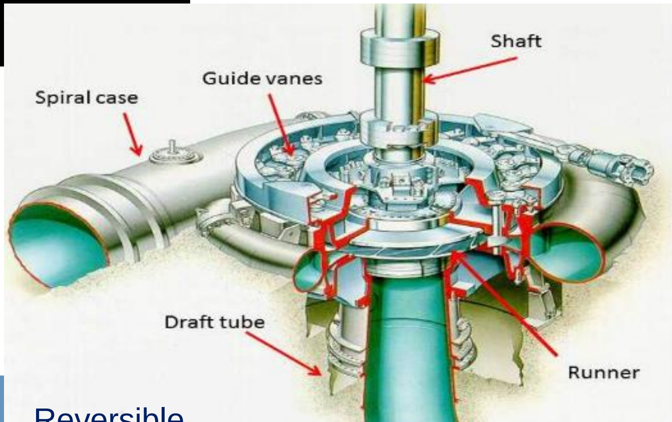
Pumped Storage Hydropower



Upper reservoir

Lower reservoir

Underground turbine and pump



Reversible pump turbine

Pumped Storage Hydropower: Principle

- **Storage phase :**
  - Water is pumped from a lower reservoir to a reservoir at higher elevation during off-peak period.
- **Discharging phase:**
  - Water flows back down to lower reservoir, generating electricity during peak periods

Head range:

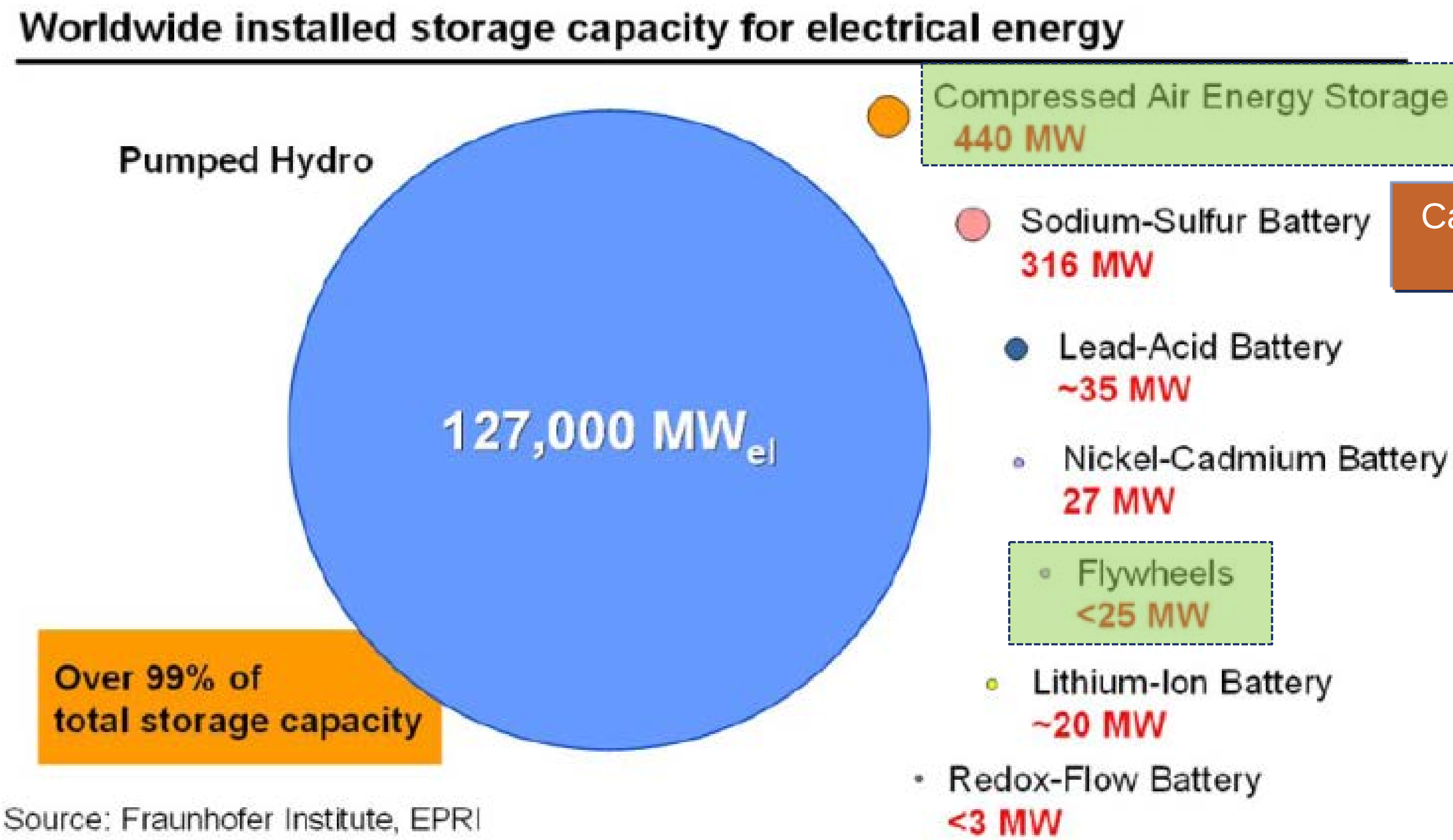
- 10 to 2000 m
- *100 m to 600 m reversible turbine*

Limberg I, Austria, https://ec.europa.eu

Pumped Storage Hydropower: Characteristics

Typical power	Efficiency	Response time	Discharge time	Lifetime	Investments costs
200-350 MW	75-85 %	min	Several hours	40-80 y	200-3000 € /kWh

Installed Energy Storage capacity

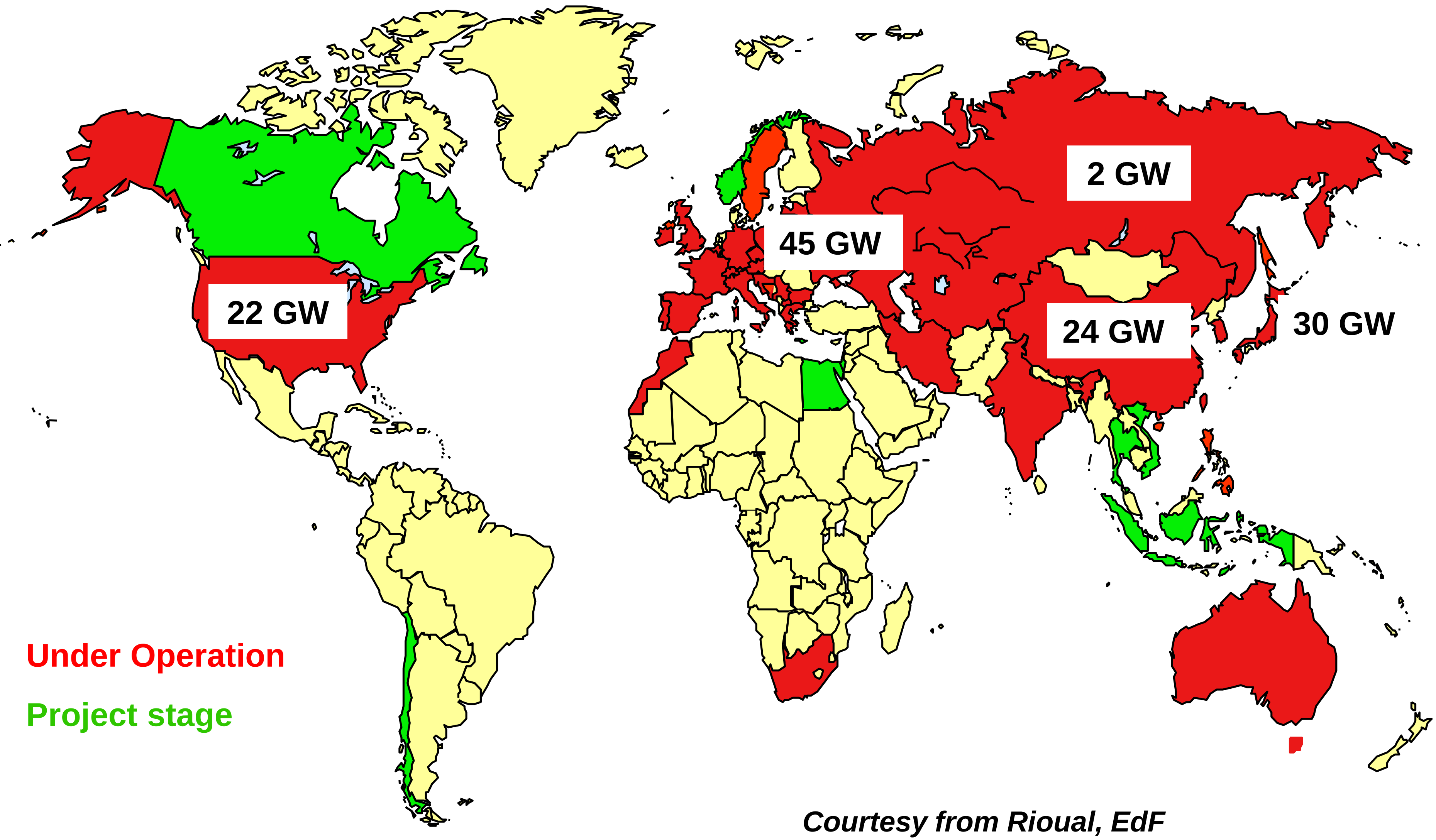


2 installations worldwide

Ca 200 installations worldwide

*Worldwide installed rated power of storage facilities for **electrical energy**. Such power level can be sustained for up to several hours or shorter*

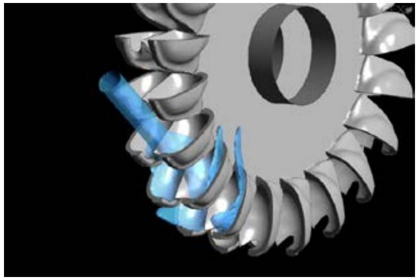
Installed PSH world-wide: ~140GW



Courtesy from Rioual, EdF

Research needs - Hydro

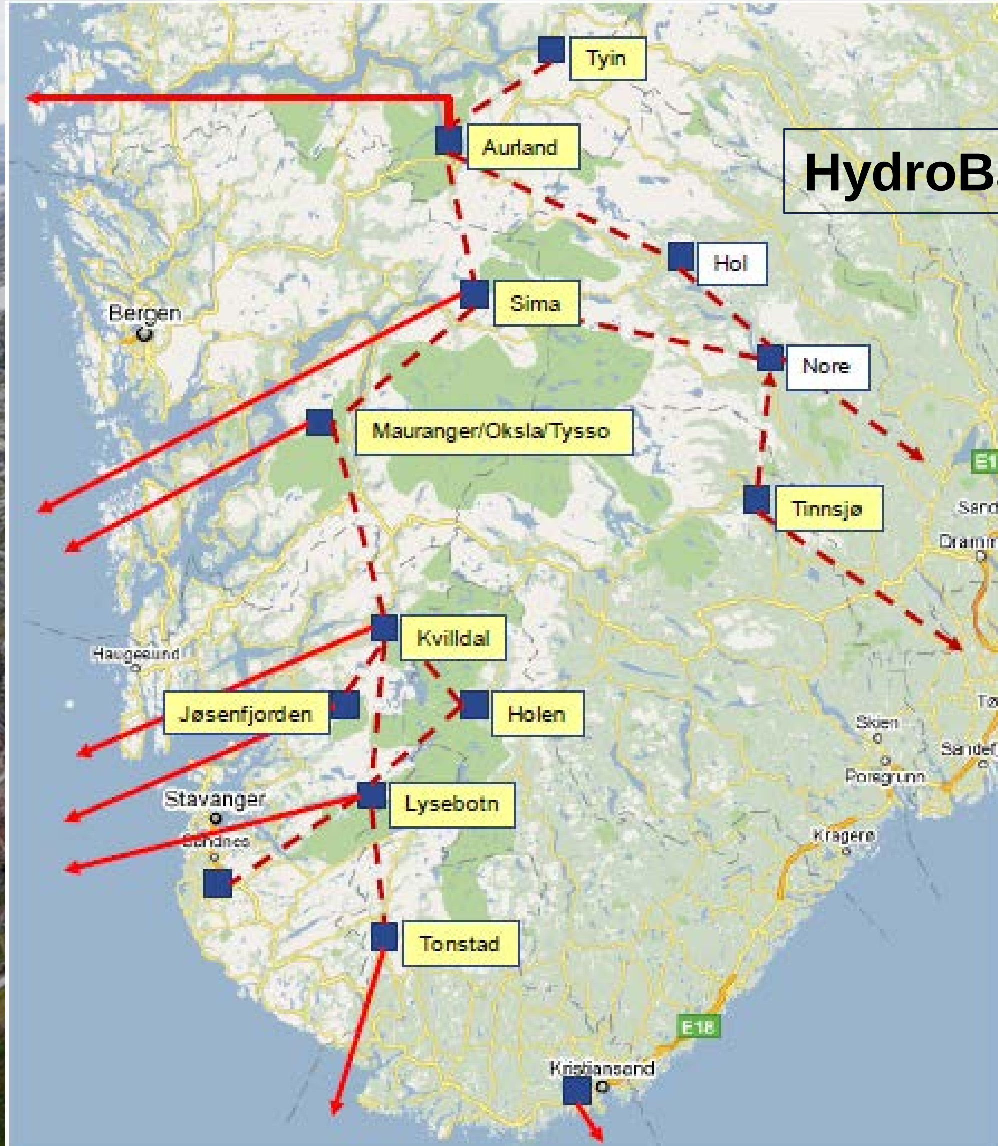
- **Market** models at multiple time scales
- **Environmental** impacts
- Social **acceptance**
- **Interconnections**, grids, HVDC technology
- Benefits of large-scale use of **storage hydro** combined with large scale offshore and onshore **wind and solar energy** production in Europe
- Design of **reversible pump turbine** plants
- System design to achieve **dynamic flexibility**
- Build a test facility
- Regulation



Norway can store 80 TWh of hydropower in existing reservoirs


Blåsjø
7.8TWh RESERVOIR
(1000 times Goldistal)

HydroBalance project- CEDREN



Blåsjø
7.8TWh RESERVOIR

Summary- 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