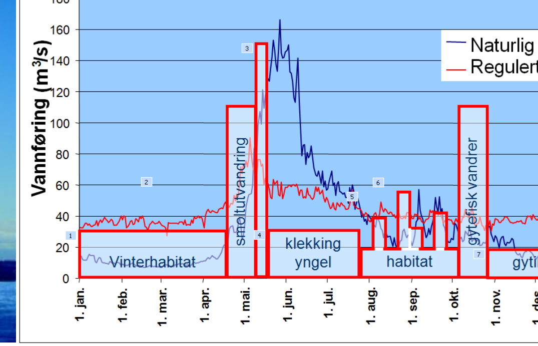
    

Energy storage technologies

HydroBalance User Meeting 18 Nov 2014

SINTEF
NTNU
100 skapende år
NINA
NATURHISTORISK MUSEUM
UNIVERSITETET I OSLO
NIVA
uni Research

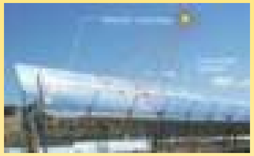
Atle Harby, SINTEF Energy Research,
Centre for environmental design of renewable energy - CEDREN

The benefit of storage

Generation

Fluctuating
e.g. Wind, Solar

Heat
Process Heat


Non-fluctuating

Energy Conversion

Storage / Transmission / Transport

Electrochemical, Chemical, Thermal, Mechanical, Superconducting Magnetic



- Time-Shift
- Grid, Pipe, Wheels (TES)

Energy Conversion

Demand


Industry Energy Suppliers


Electro & Hybrid & Hydrogen

Energy Balancing –
Smoothing / Ramping

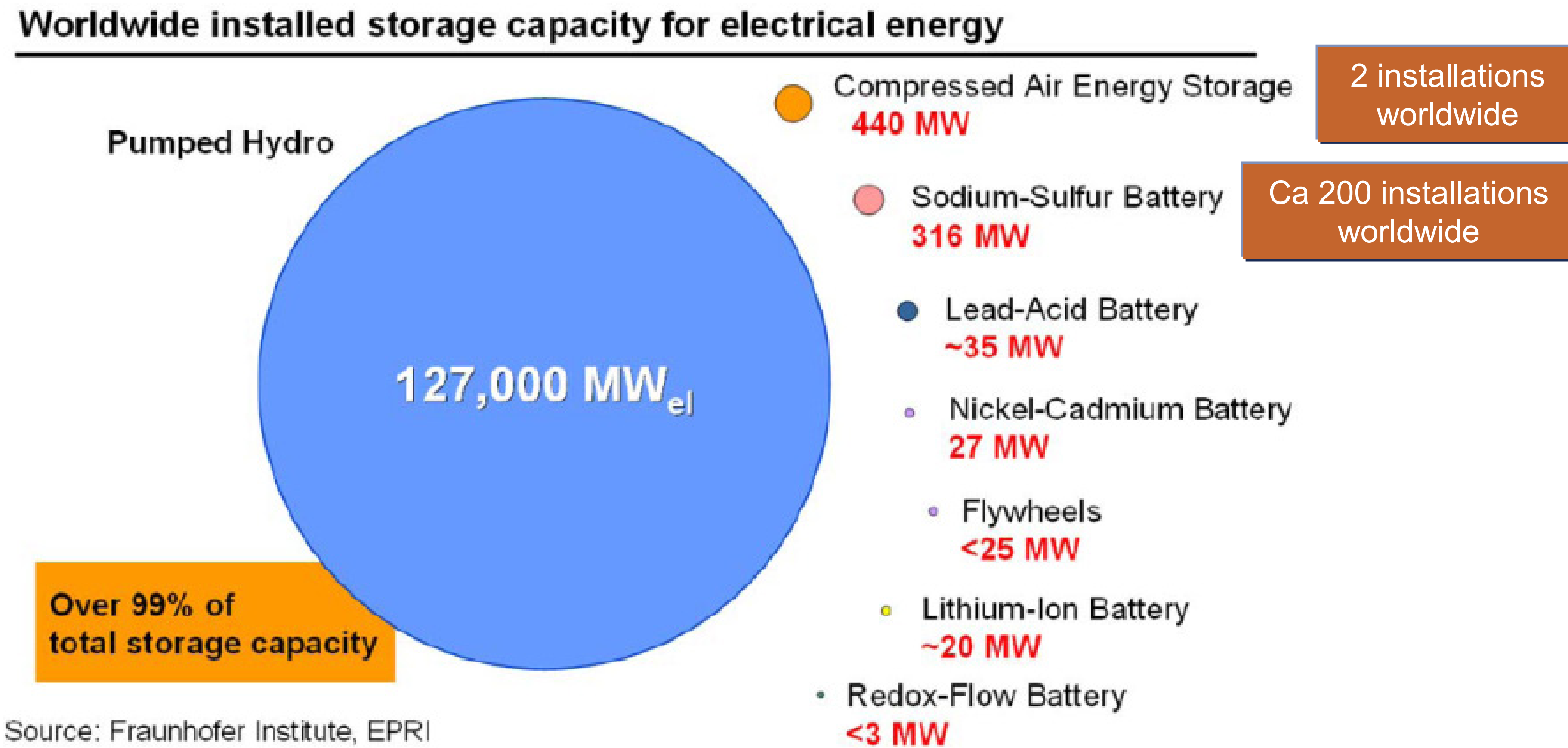
System stability
Voltage Regulation
Energy Service - Peak shaving,
Power Reliability -

Energy scenarios

- ❑ Transmission and distribution <u>infrastructure</u>
- ❑ Energy <u>storage</u> technologies
- ❑ Demand side <u>management</u>
- ❑ Improved <u>forecasting</u> of resource availability

Maybe as much as 340 TWh of storage volume and 150 GW of balancing capacity needed in Europe by 2050

Electrical Energy Storage capacity



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

Energy storage technologies

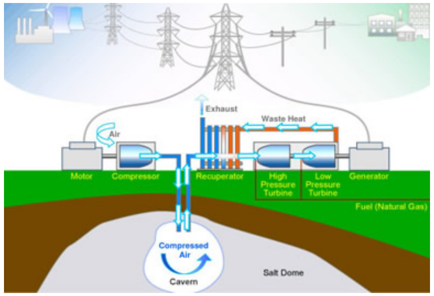
1) **Electrochemical Storage**
   Batteries, Super Capacitors

2) **Chemical Storage**
   Hydrogen, Methanol, Ammonia

3) **Thermal and Geothermal Storage**
   Heat, Advanced Fluids, PCM, Cold

4) **Mechanical Storage**
   Hydro, Flywheels, Compressed Air

5) **Superconducting Magnetic Energy Storage**



Electrochemical storage – grid scale

Deployed

- Pumped hydro & CAES
- NaS batteries
- Li-ion Batteries
- Pb-Acid batteries
- Flywheels

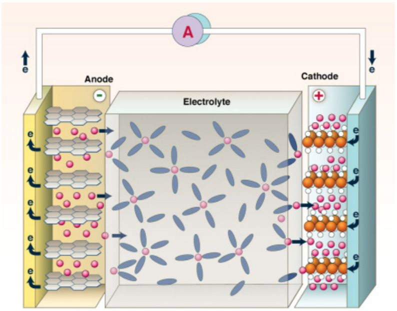
Demonstration

- Flow Batteries
- Electrochemical Capacitors
- Superconducting Magnetic energy storage

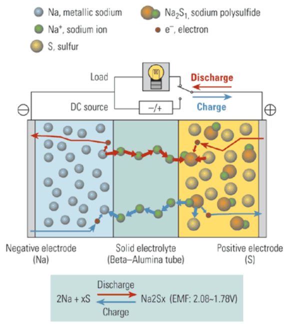
Early stage technologies

- Hydrogen
- Synthetic NG
- Liquid metal batteries
- Metal – Air batteries

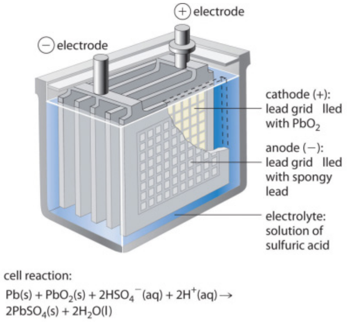
- Lithium-ion batteries
  - High cost, high density



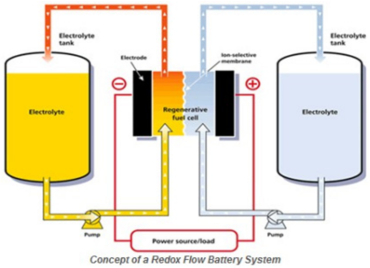
- NaS batteries
  - High density, tolerates high T

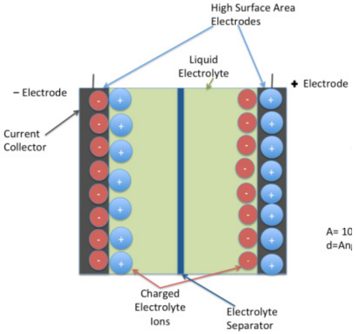


- Lead-acid batteries
  - Low density, low costs

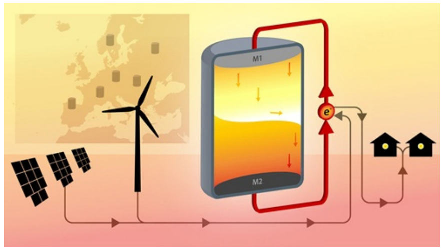


- Flow batteries
  - Many cycles, low density





- Super-capacitors



- Liquid metal batteries

Duke Energy Notrees Wind Storage Demo Project, USA: 36 MW, 20 MWh

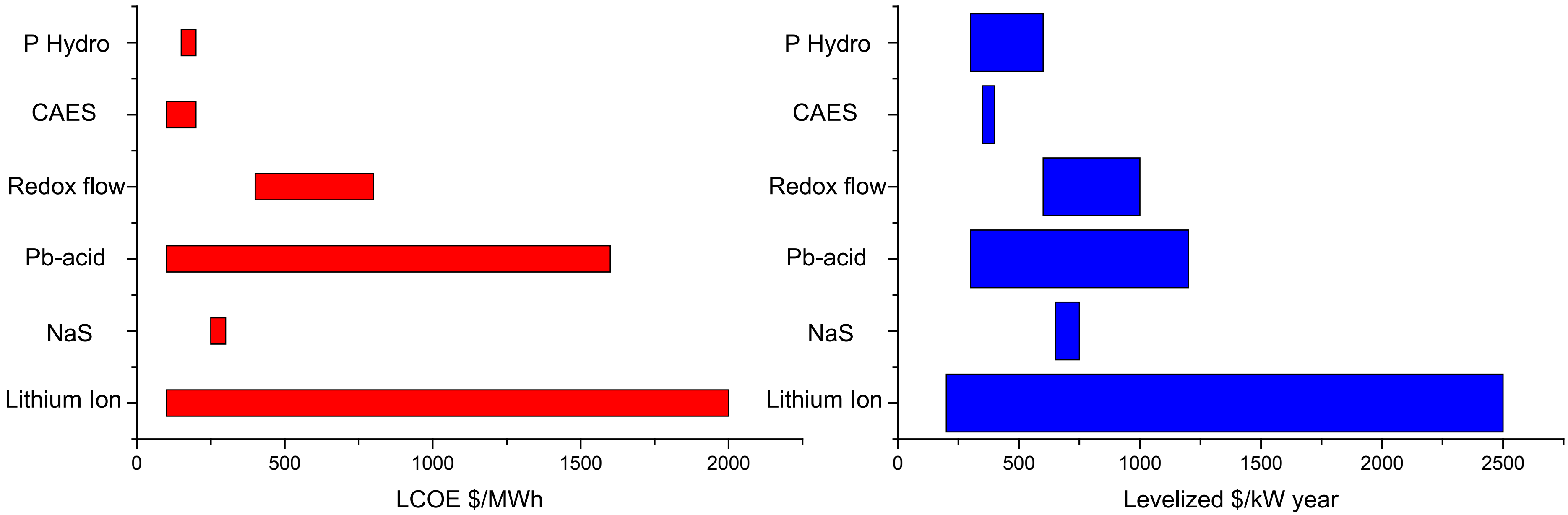
Flow batteries:
Gills Onions, California: 600kW, 3.6 MWh

Electrochemical energy storage in the world

-some numbers from DOE energy storage database

Σ = 1 GW

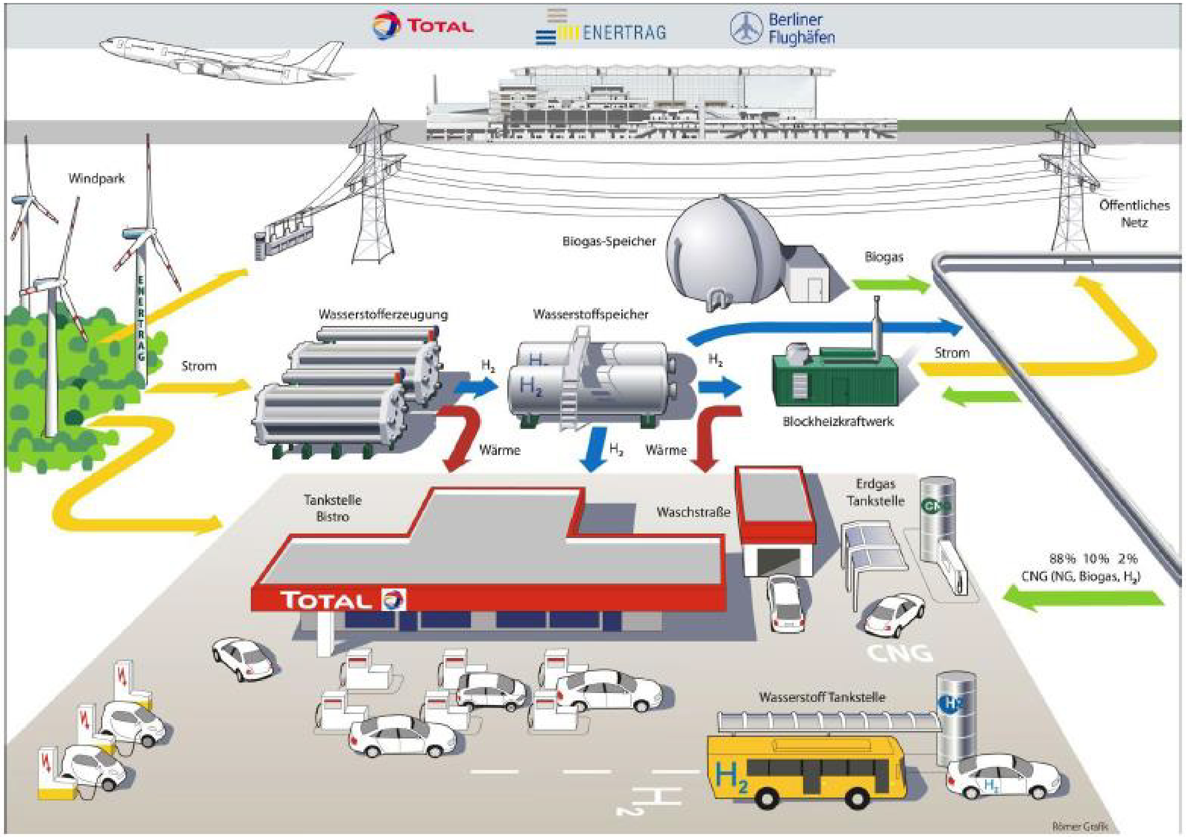
Typical life cycle costs



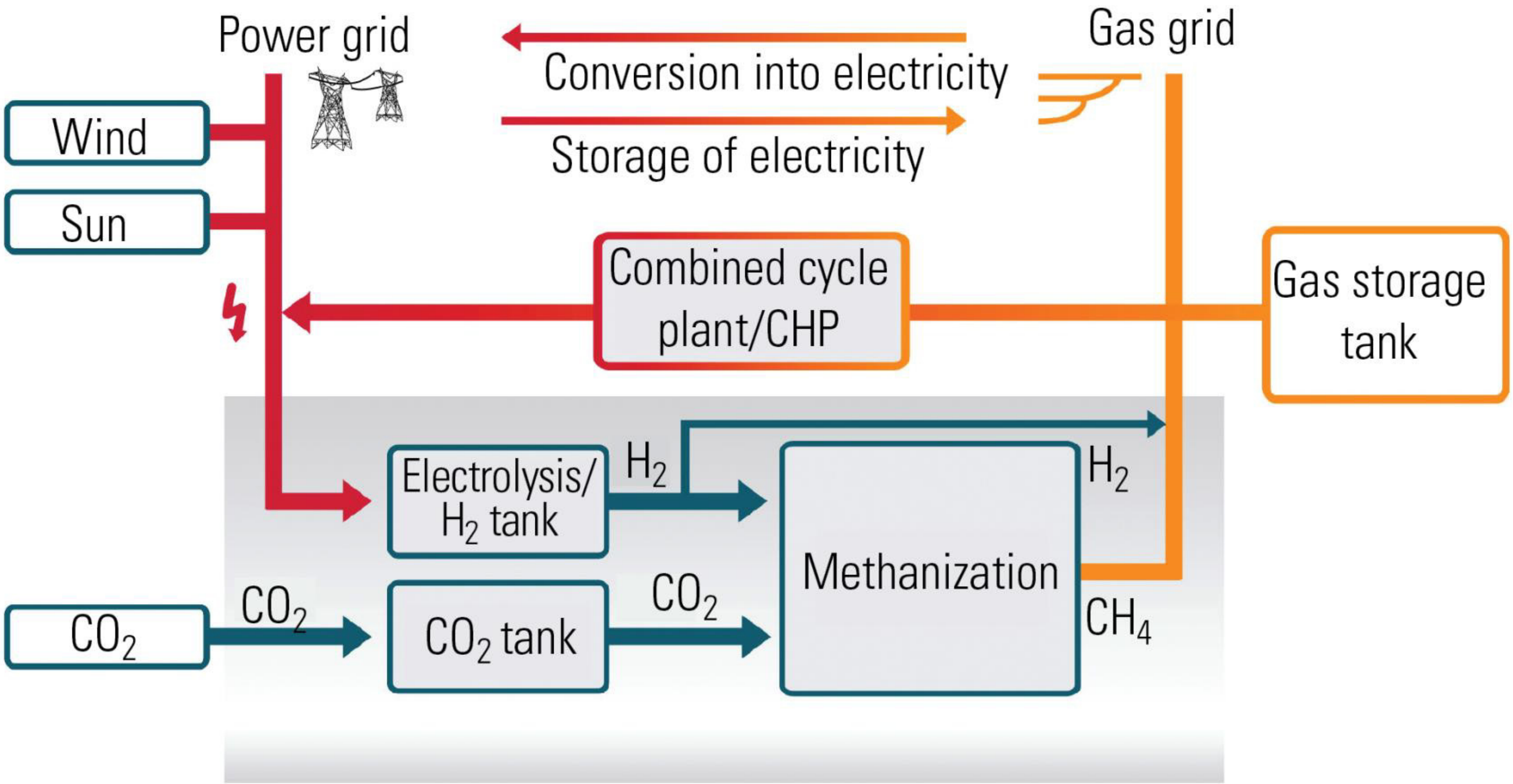
DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA Sandia National labs July 2013

Power to gas: Hydrogen

- Hydrogen as energy storage medium links stationary sector to transportation



Power to gas: Synthetic natural gas



Thermal Energy Storage

High temperature storage

District heating,
Theiß, Austria

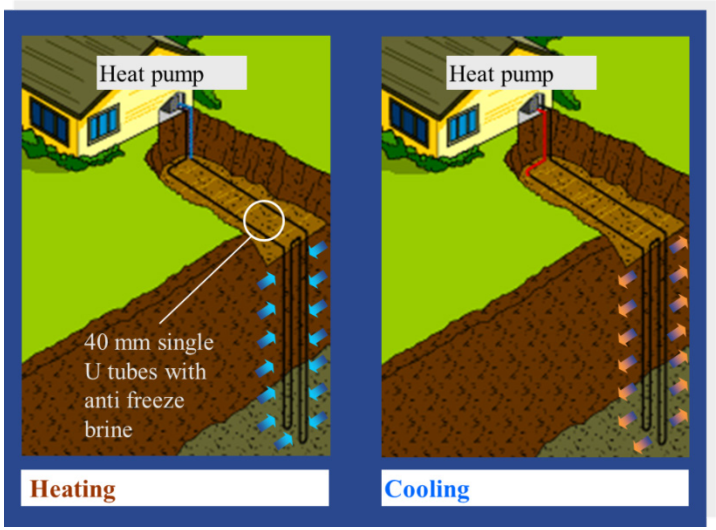
Steam accumulator,
Aerated concrete
manufacturing

Cowper storage,
blast furnace
industry >500 ºC

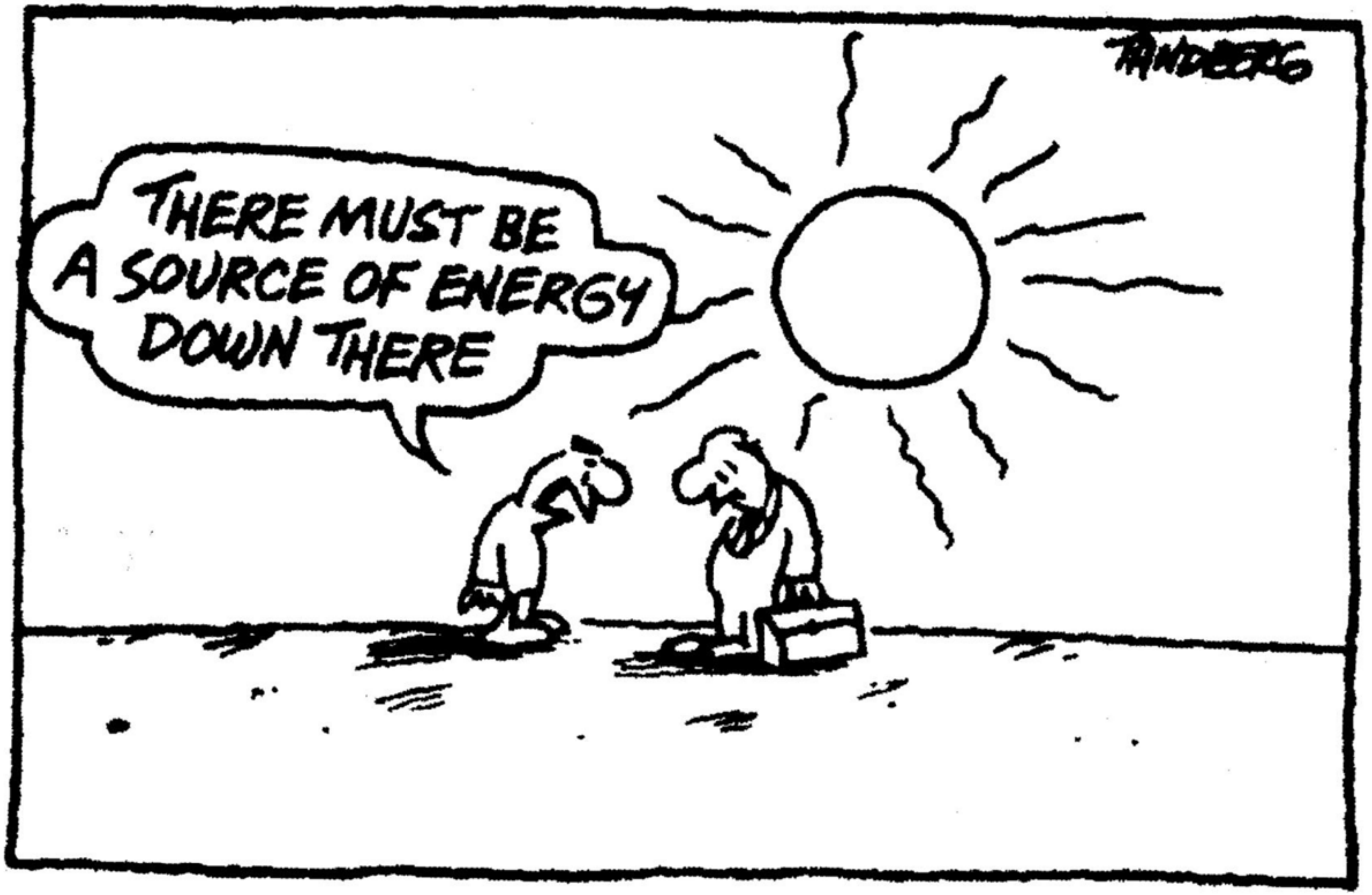
Molten salt storage,
Andasol power plant,
Spain: up to 400/565 ºC

Cold storage (ice)

Underground storage



Energy Storage



Mechanical storage

Hydro

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

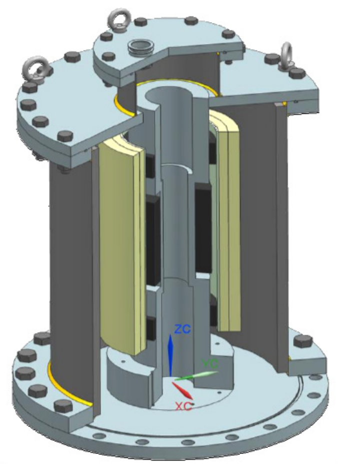
Compressed air

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

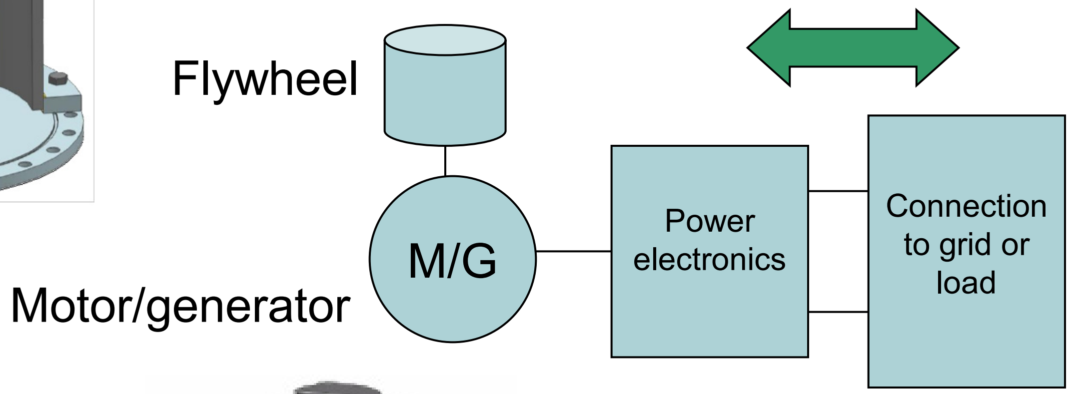
Flywheels

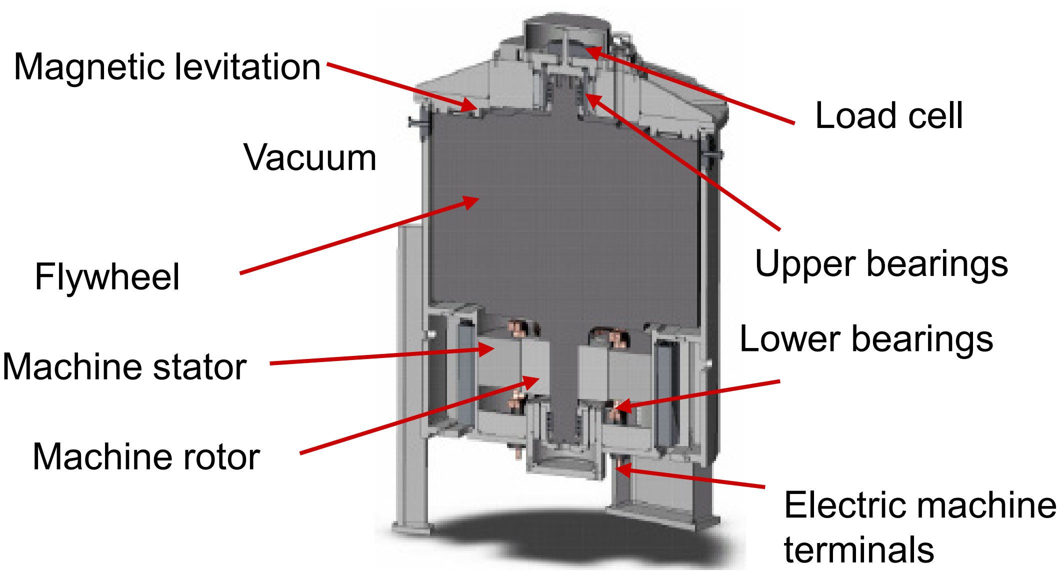
- Operates typically on seconds to minutes
- Used a lot in many other sectors
- Few large-scale energy storage applications

What is a flywheel?



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



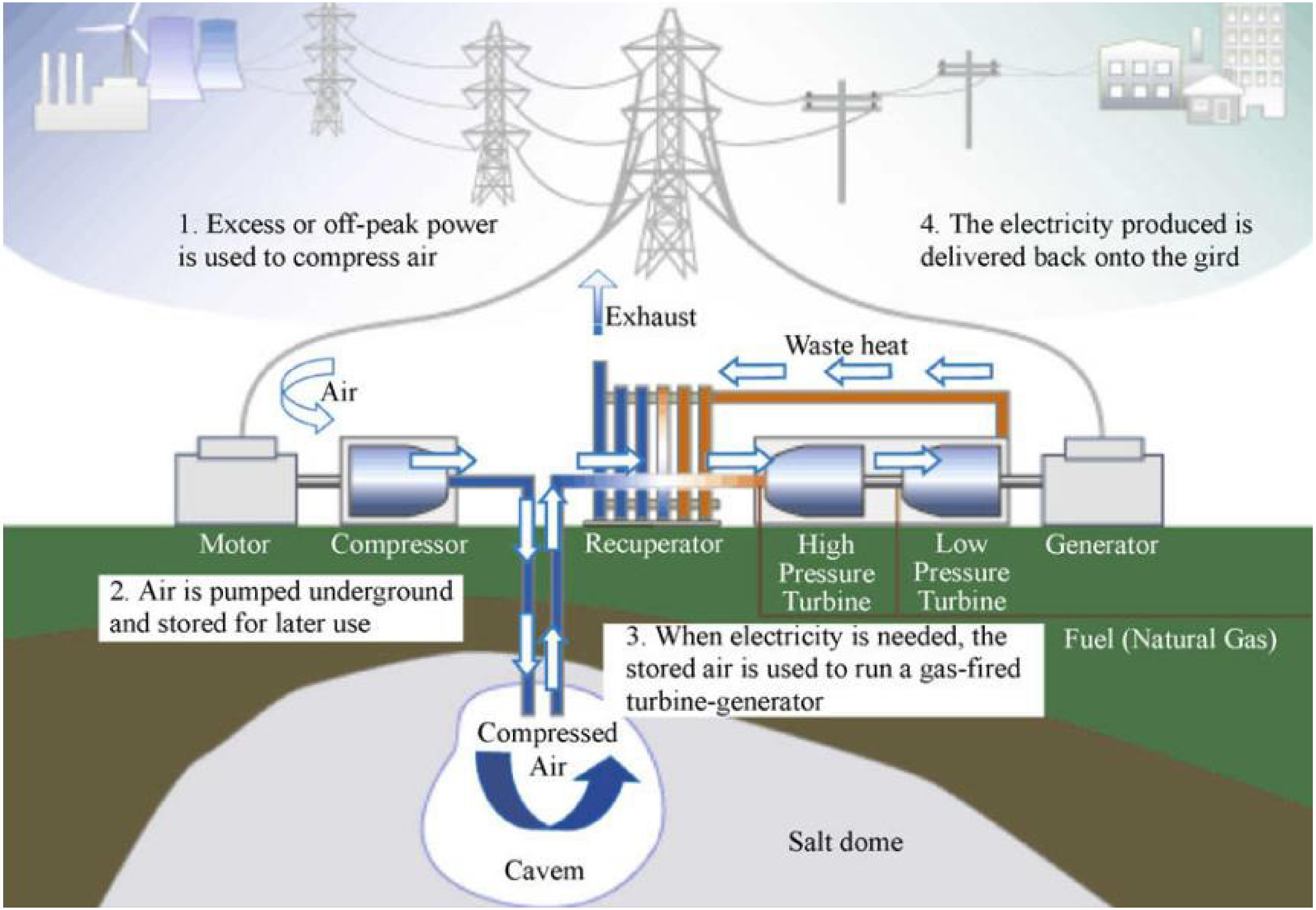


From Lafoz

Beacon Power
Hazle Township, Pennsylvania, USA
20 MW in total, 200 flywheels, ~1 300 kg each

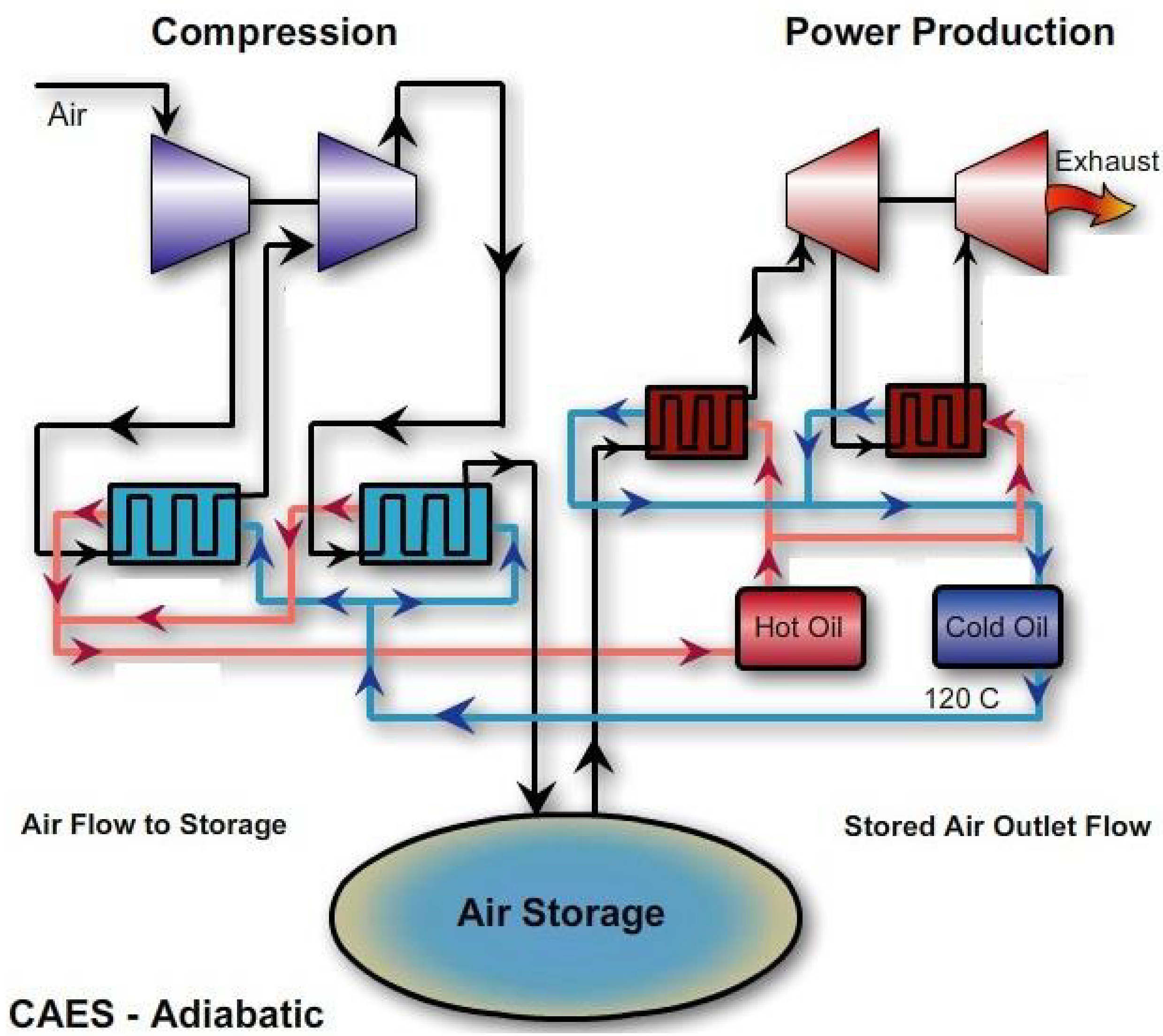
- Frequency regulations for the power grid
- Three plants in USA connected to the grid

Compressed Air Energy Storage (CAES)



From Luo and Wang

Adiabatic CAES



"Managing the heat"

Small scale CAES: Competing with batteries

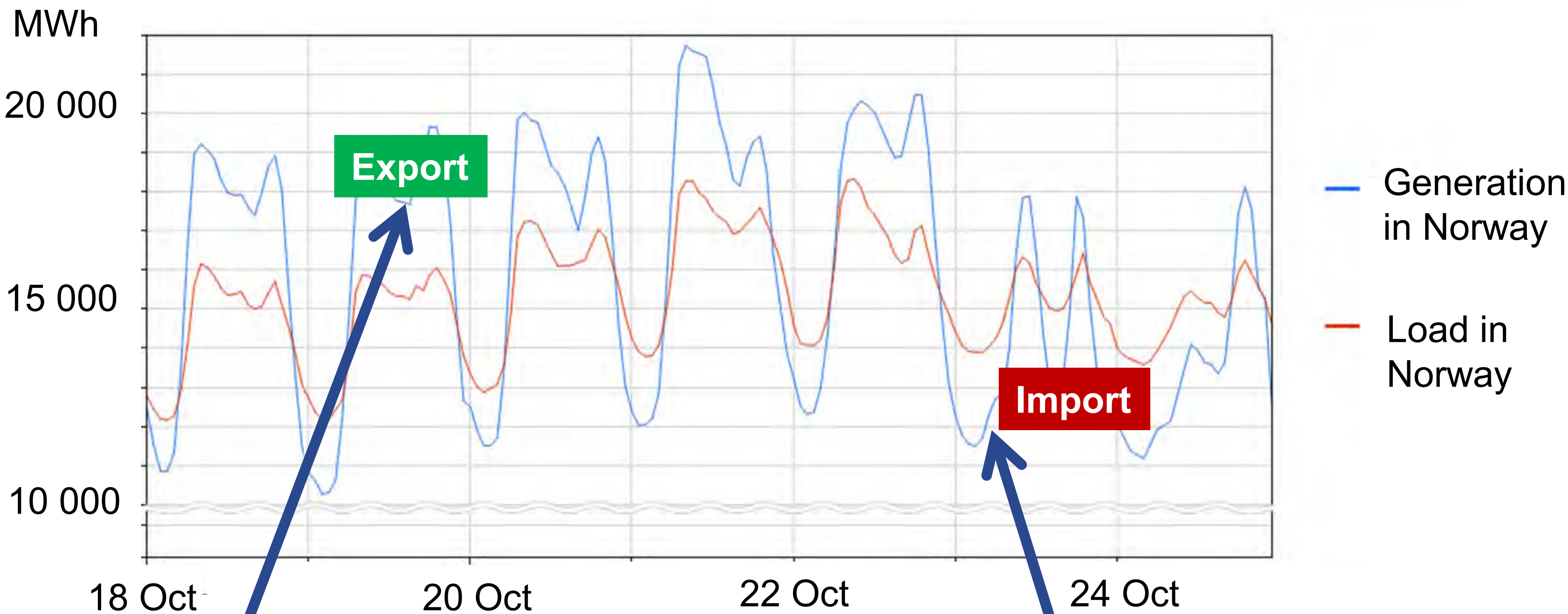
From Luo and Wang

Pumped storage hydro

Photo: Alstom

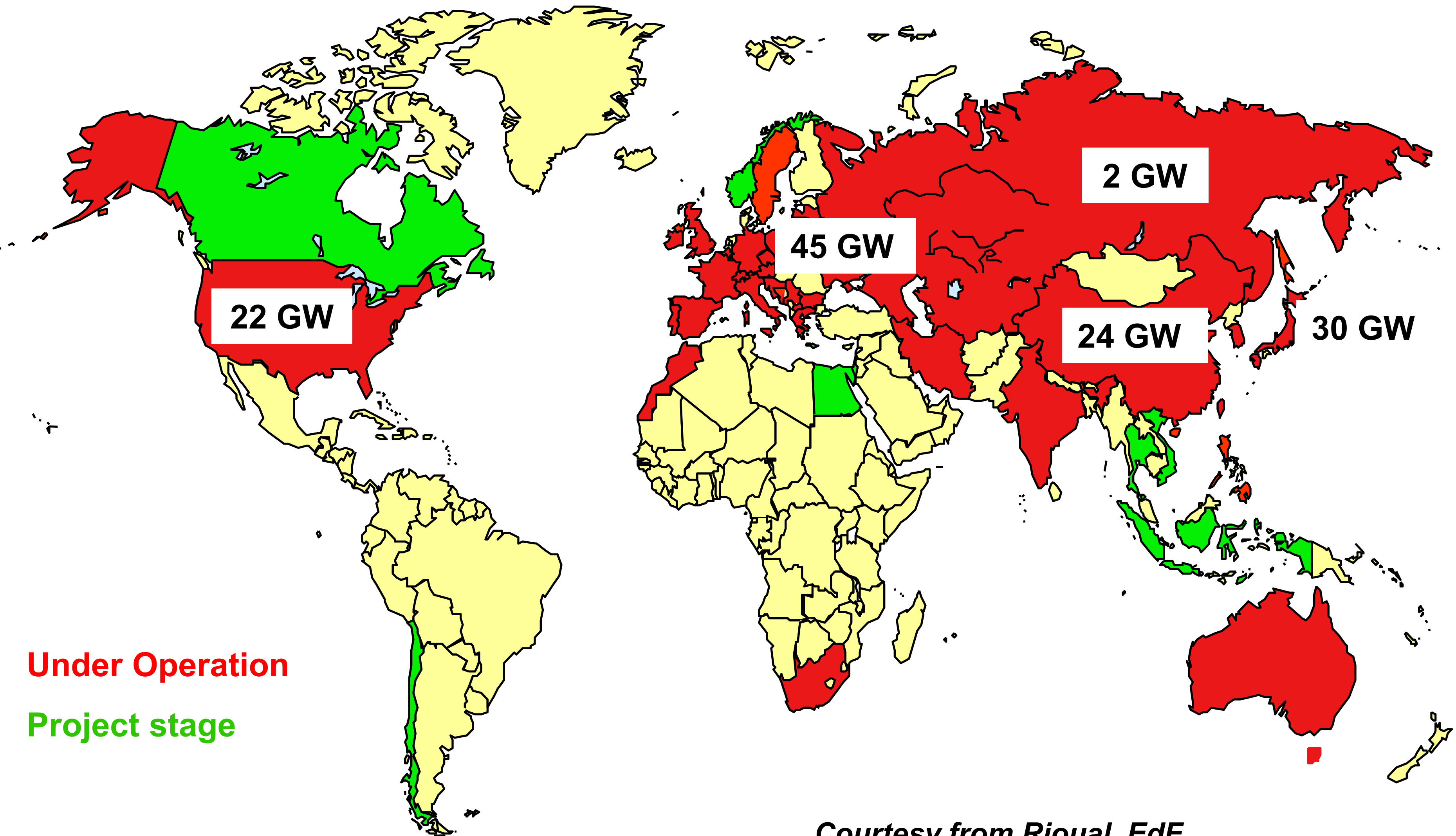
Afourer, Marocco

Norwegian hydro and Danish wind



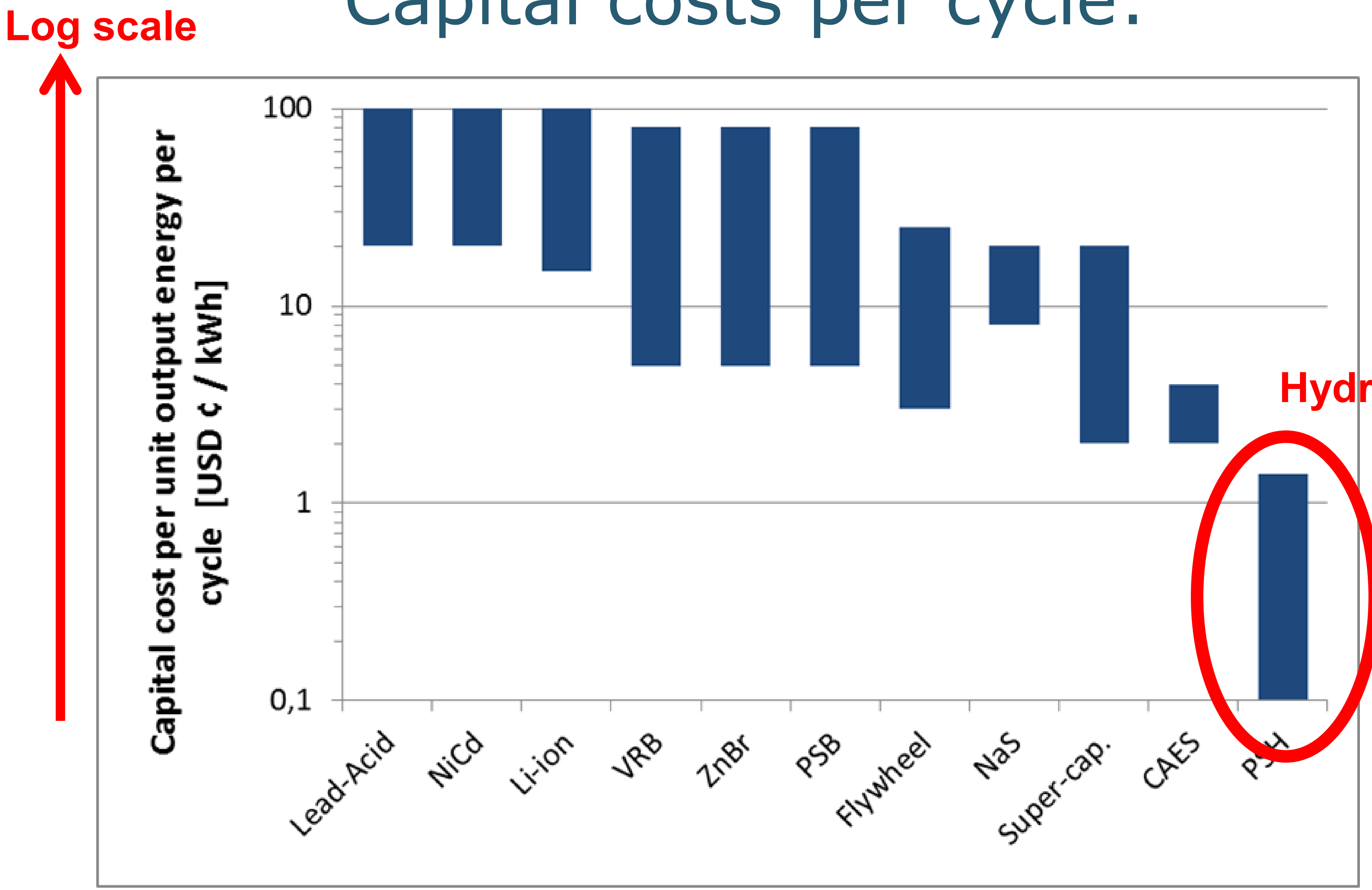
Danish wind cover underproduction

Installed PSH world-wide: ~140GW



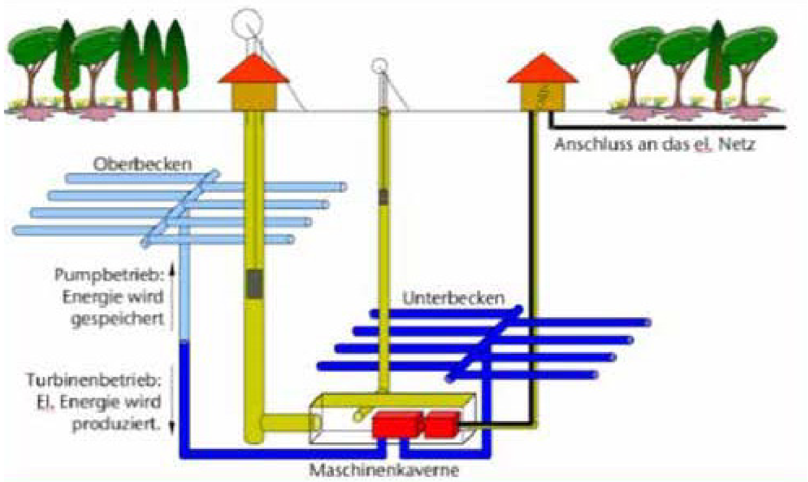
Courtesy from Rioual, EdF

Capital costs per cycle:



New technologies – pumped storage

- Underground PSP



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

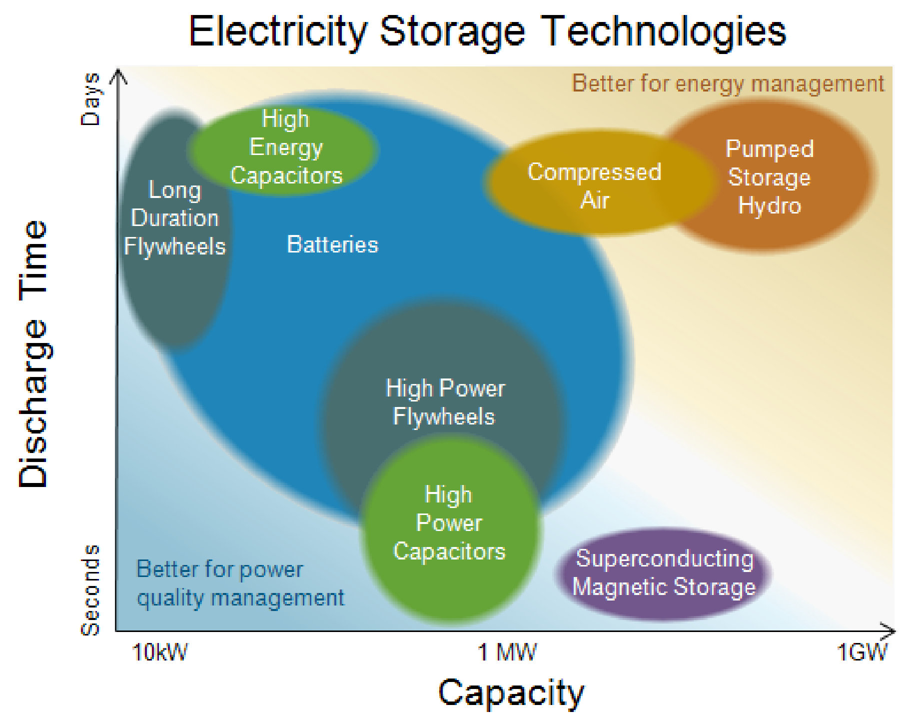
- Salt water PSP

Okinawa PSP - Japan

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

Blåsjø: 7.8TWh storage
- can this be used more frequent?

Conclusions



- We need more energy storage – better grid cannot solve all lack of storage
- We need all technologies for energy storage - plus some future ones
- Different technologies operate on different time scales with different volumes of storage
  → There is no "one size fits all"
- Use a combination of many storage options
- Reservoir and pumped storage hydro are the most efficient and cheapest large-scale storage option