Energy Storage

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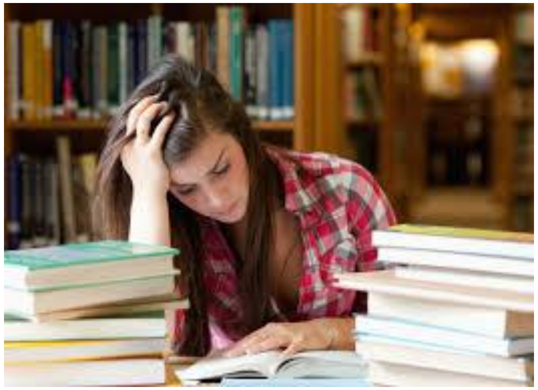
- What?
- Why?
- How?
- Which?
- … in the future?
- and eni?

Energy is the capacity of a physical system to perform work

Energy Storage definition

Methods and techniques for storing energy derived from some primary source in a form convenient for use at a later time when a specific energy demand is to be met, often in a different location.

Store energy and use it when and where it is useful



Energy storage examples

Some other definitions …

- **Power** is the rate of doing work

  power = energy / time

- **Energy Efficiency**: useful energy / used energy

- **Energy density**: the amount of energy stored in a given system per unit volume [Wh/L]

- joule [J] is the SI unit for energy
- watt [W] is the SI unit for power

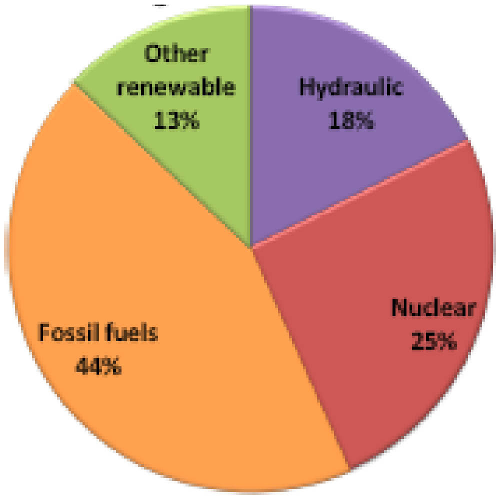
  energy 3600 J = 1 Wh

Electric energy

- Electricity is the most common and diffuse form of energy

- Total energy demand in europe (2013) is 3082 TWh !!!

280,000 billions of smartphone



Electric energy storage

- Electronics

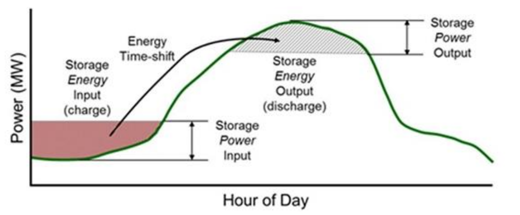
- Transportation

- Stationary

Why electric energy storage? Some benefits …

Electric supply

- Electric energy time shift
- Electric supply capacity

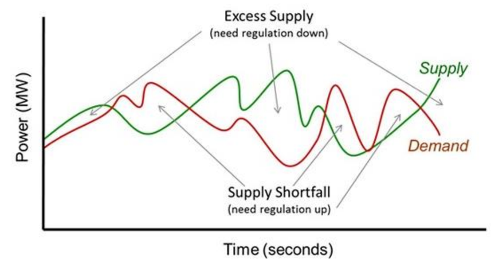


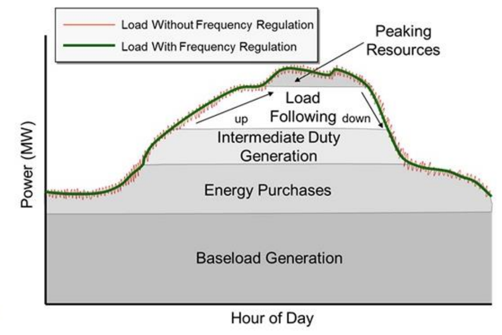
End user

- Cost/charge management
- Electric service Reliability (UPS)

Grid operation

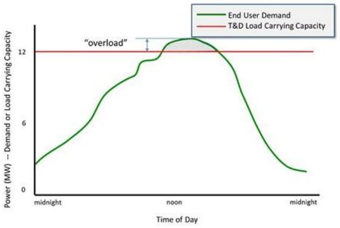
- Load Following (h)
- Ramping (min)
- Frequency Regulation (s)
- Frequency Response (ms)





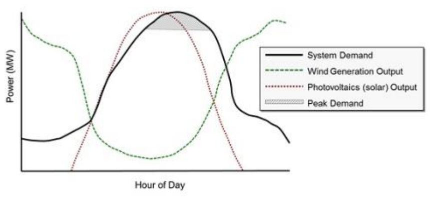
Grid infrastructure

- Increase load carrying capacity
- Manage T&D congestion



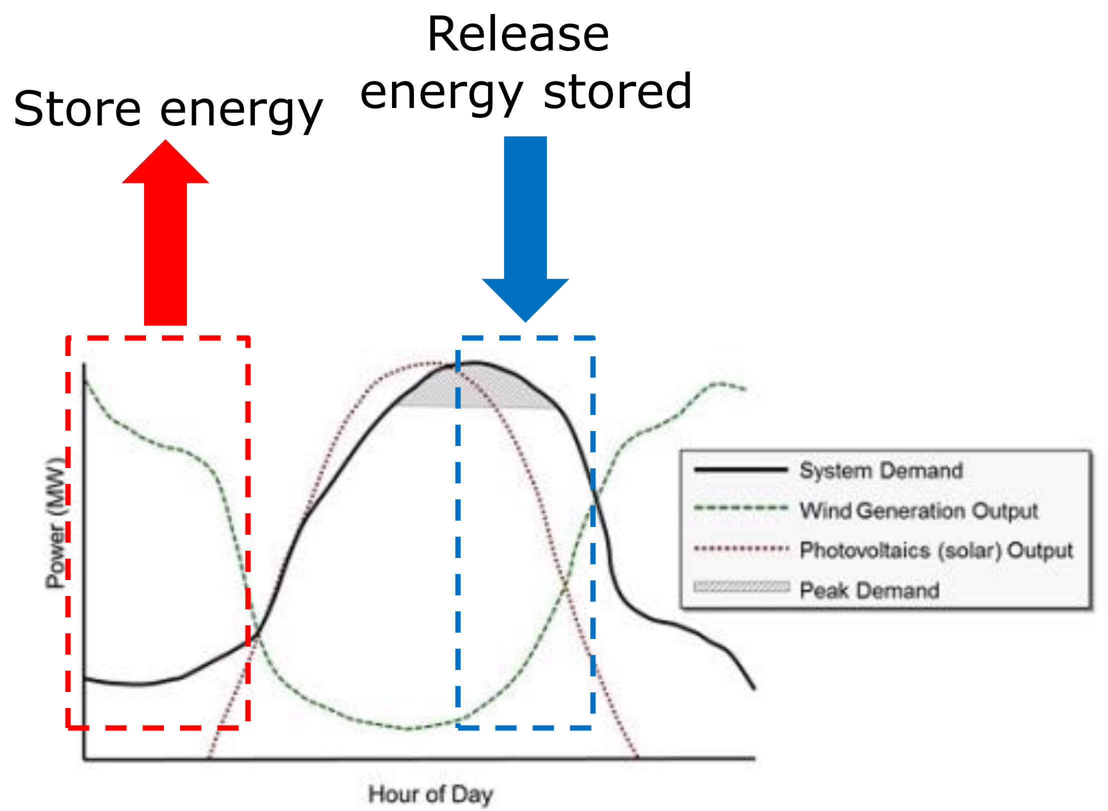
Renewable integration

- Short-long duration variability
- Management forecasting uncertainament
- Power quality

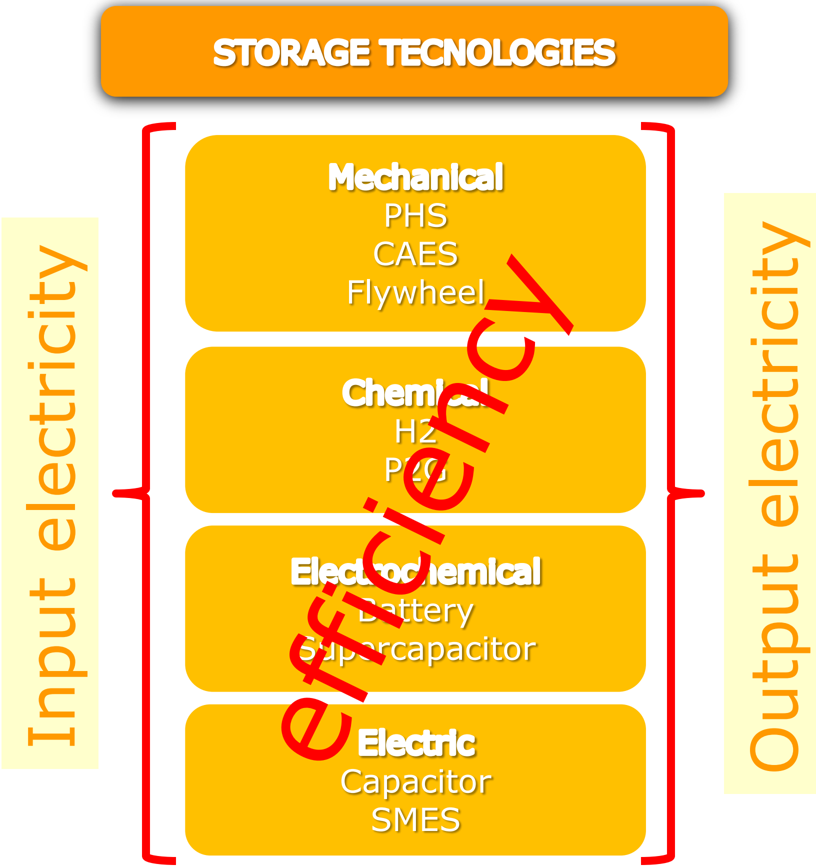


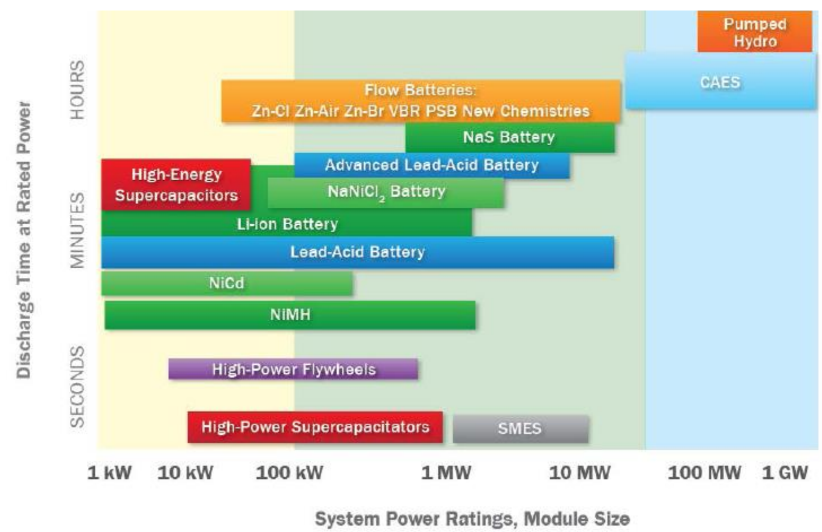
Renewable integration

Renewable integration



Electric energy storage





Electric energy storage

STORAGE TECNOLOGIES

Mechanical
PHS
CAES
Flywheel

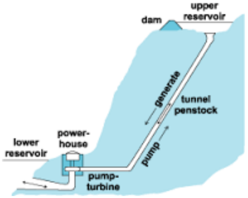
Chemical
H2
P2G

Electrochemical
Battery
Supercapacitor

Electric
Capacitor
SMES

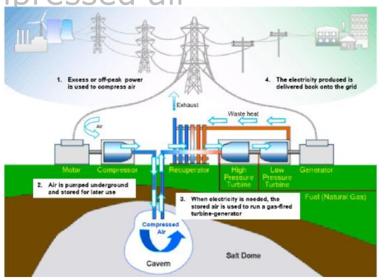
PHS - Pumped-storage hydroelectricity

- Worldwide 98% of total power storage installed (150 GW) is PHS
- long term storage
- efficiency 50-85%
- very long life



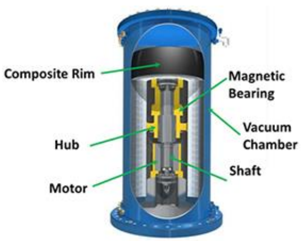
CAES – Compressed Air Energy System

- use cavern or tank to store compressed air
- need of thermal storage of fuel utility
- long term storage
- efficiency 27-70%
- very long life



Flywheel

- use rotors suspended by magnetic bearings
- 20,000 - 50,000 rpm in a vacuum enclosure
- short term storage
- efficiency 90-95%
- low energy stored



Source: Beacon Power, LLC

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H2- Hydrogen

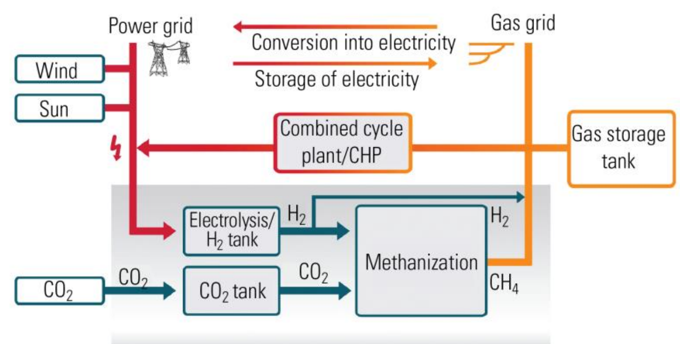
- 3 main phase:
  - **production (electrolysis)**
  - **storage**
  - **electricity generation (Fuel cell)**

$$H_2O \rightleftarrows H_2 + O_2$$

- low energy density storage
- long term storage
- efficiency 20-50%

P2G – Power to Gas

- fuel production starting from hydrogen and carbon dioxide
- use existing storage infrastructures to stare methane



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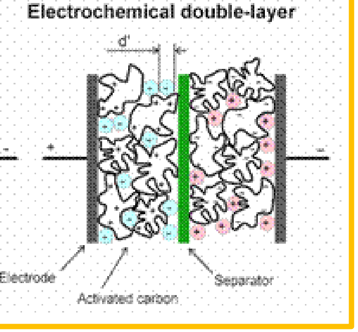
Battery

- use redox reaction to produce electricity
- secondary battery
- flexible device
- several types of chemistries
- relative short life
- efficiency > 70 %

Supercapacitor

- use electrostatic capacitance and/or electrochemical pseudocapacitance to store energy
- low energy density
- very long life
- efficiency > 90%



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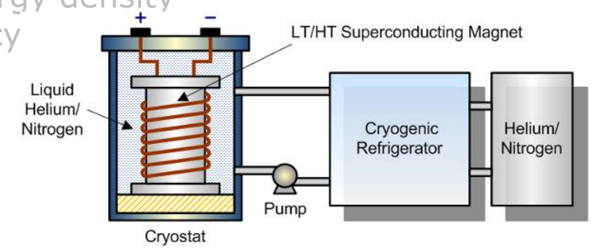
Capacitor

- store electrostatics energy
- energy stored in dielectric material
- very low energy density

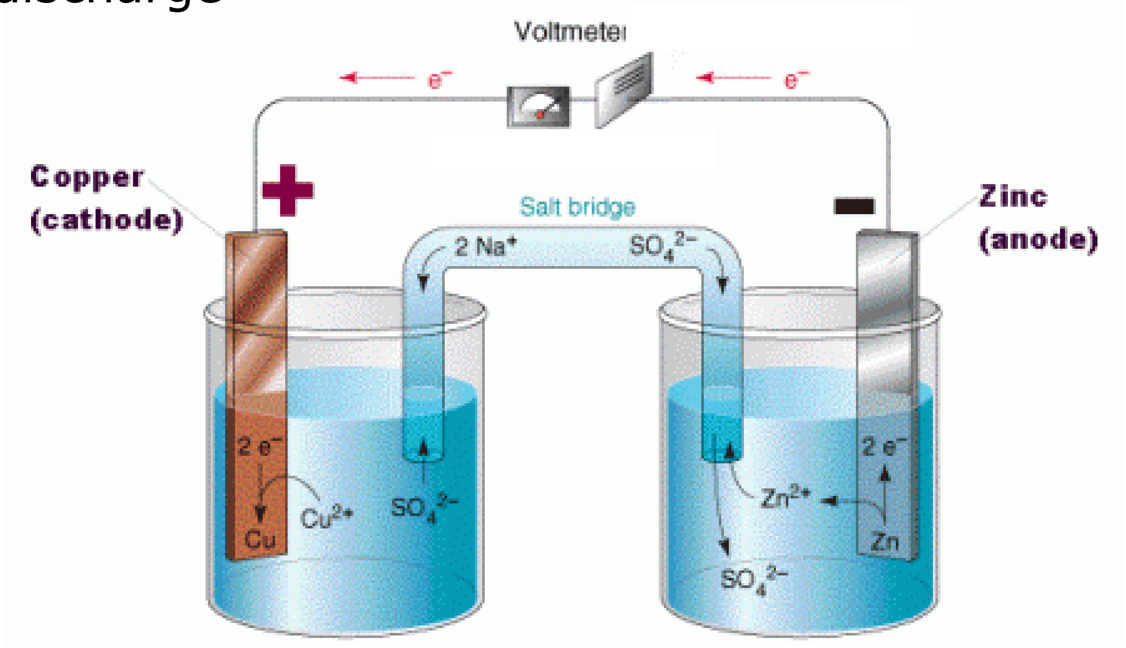
SMES - Superconducting Magnetic Energy Storage

- store energy in the magnetic field created by the flow of direct current
- superconduction needs cryogenics temperature
- low energy density
- efficiency

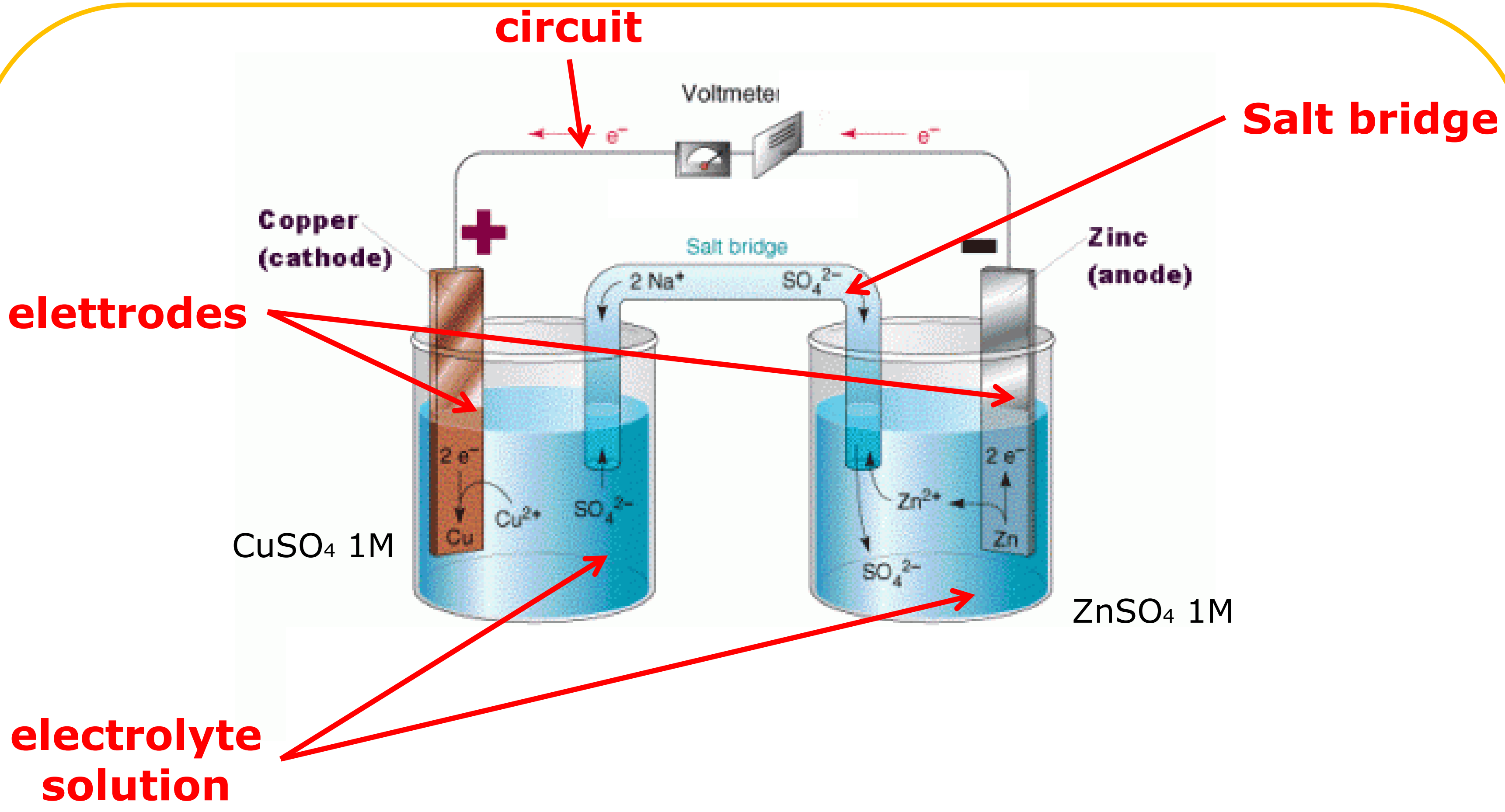


Example of primary battery

Only discharge



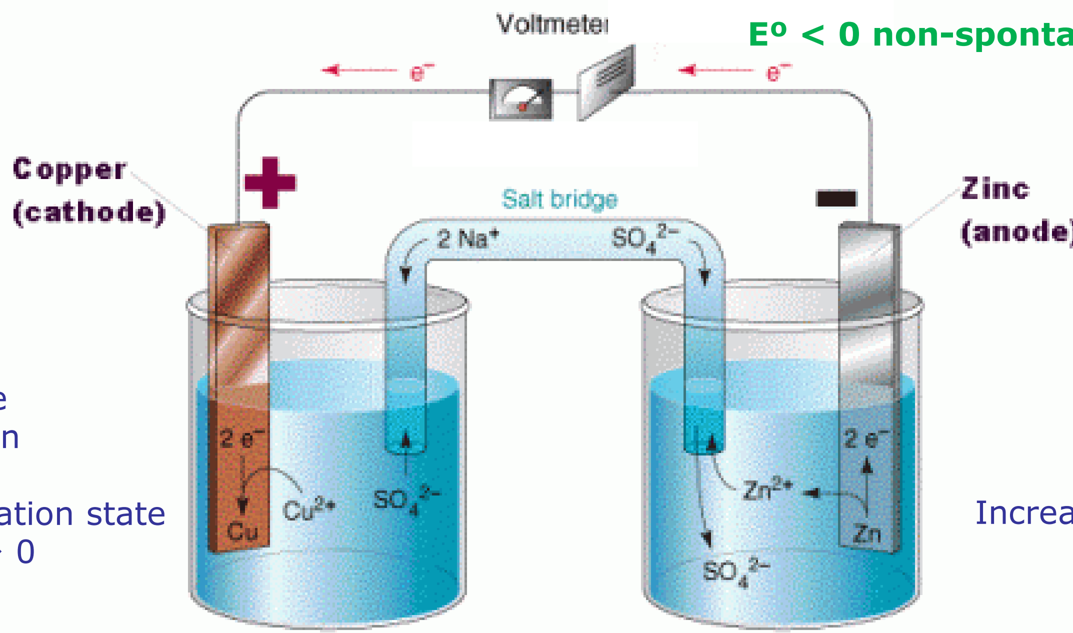
Example of primary battery



Example of primary battery

$E^o > 0$ spontaneous → discharge

$E^o < 0$ non-spontaneous → charge



Cathode
Reduction

Reduction of oxidation state
Cu: 2+ → 0

Anode
Oxidation

Increasing of oxidation state
Zn: 0 → 2+

Standard electrode reduction potential

Cathode	$Cu^{2+} + 2\,e^{-} \rightarrow Cu$	$E^o = +0.34$ V
Anode	$Zn \rightarrow Zn^{2+} + 2\,e^{-}$	$E^o = -0.76$ V

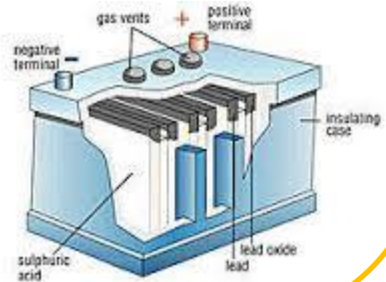
$$Cu^{2+} + Zn \rightarrow Cu + Zn^{2+} \quad E^o_{cell} = E^o_{cathode} - E^o_{anode} = +1.10\ V$$

Primary – non-rechargeable

- Daniell cell $Cu^{2+} + Zn \rightarrow Cu + Zn^{2+}$ $E^{o}_{cell} = +1.1\ V$
- Alkaline $Zn + 2MnO_2 \rightarrow ZnO + Mn_2O_3$ $E^{o}_{cell} = +1.4\ V$
- Mercury battery $Zn + HgO \rightarrow ZnO + Hg$ $E^{o}_{cell} = +1.4\ V$

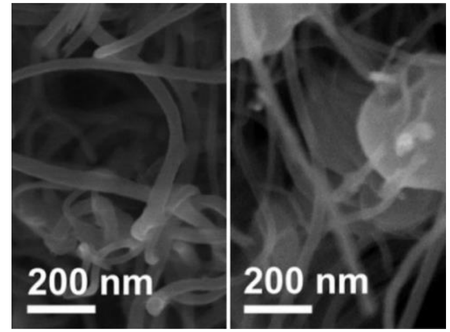
Secondary –rechargeable

- Lead-acid $Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$
- Li-ion $Li^{+} + e- + LiCoO_2 \rightarrow Li_2O + CoO$



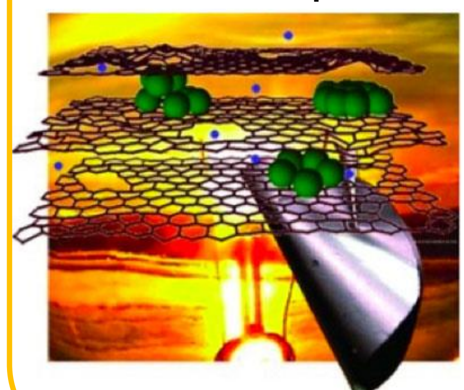
…In the future?

Carbon nanotube or
copper nanowire electrode lithium



Zn-Air &
Li-Air battery

Lithium silicon
Lithium sulphur

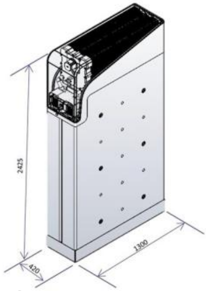


Storage in eni: R&D project

Technologies Scouting

Selection of breakthrough energy storage technologies and partners:

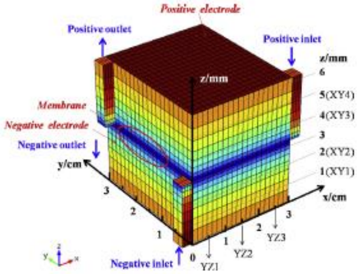
- Redox Flow Battery
- Metal – Air Battery
- Storage systems installer



Engineering Evaluation

Evaluation of potential attractive storage technologies selected by scouting:

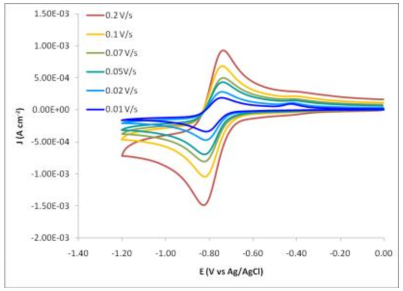
- Redox Flow Battery (Multhiphysic modelling COMSOL)
- Evaluation for energy storage termodynamic cicles (tecnology → process → economics)

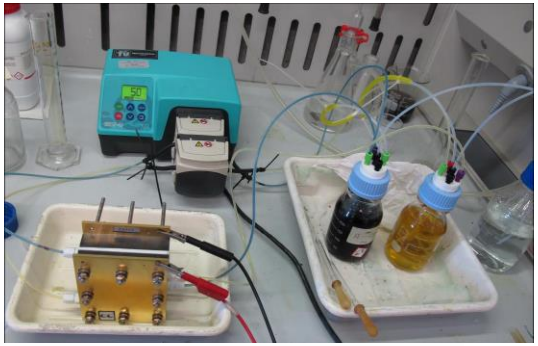


Lab Activity

Experimental study on redox flow battery:

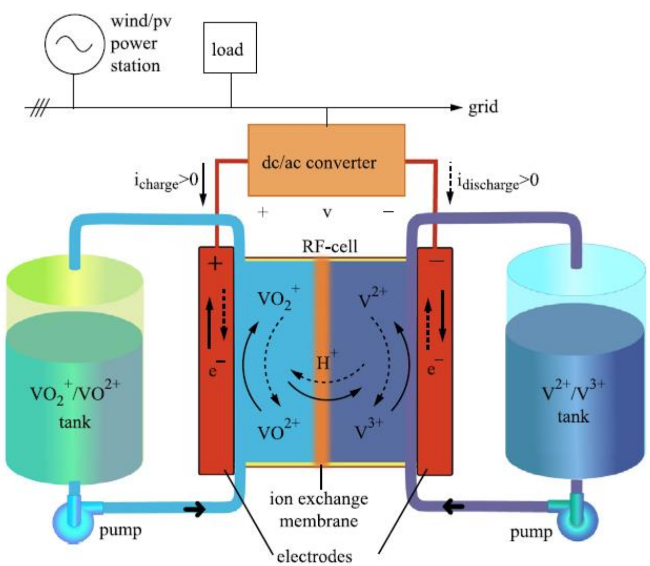
- Vanadium Redox Flow Battery benchmarking
- Innovative redox couple
- Electrodes configuration
- Ion exchange membrane
- Cell layout





Storage in eni: redox flow batteries

Operations



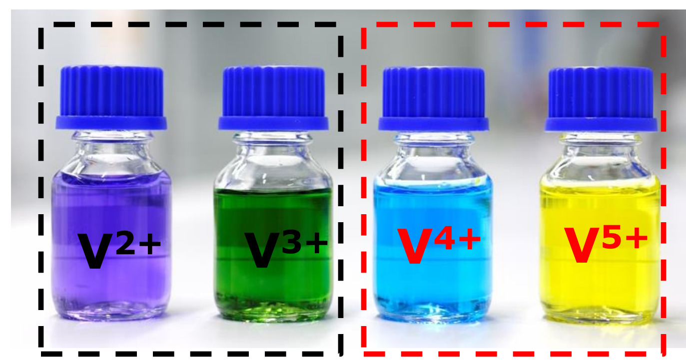
- Energy stored in in the electroactive species in the electrolyte not in the active electrode materials
- Full discharge without electrodes and electrolyte damage
- Power and energy are decoupled:
  - **Power**: number and size electrodes
  - **Energy**: concentration of electroactive species and volume of electrolyte

Efficiency ~ 80 %

$$V^{2+} \longleftrightarrow V^{3+} + e^-$$

$$VO_2^+ + 2H^+ + e^- \longleftrightarrow VO^{2+} + H_2O$$

$$E^0 = 1.26\ V$$



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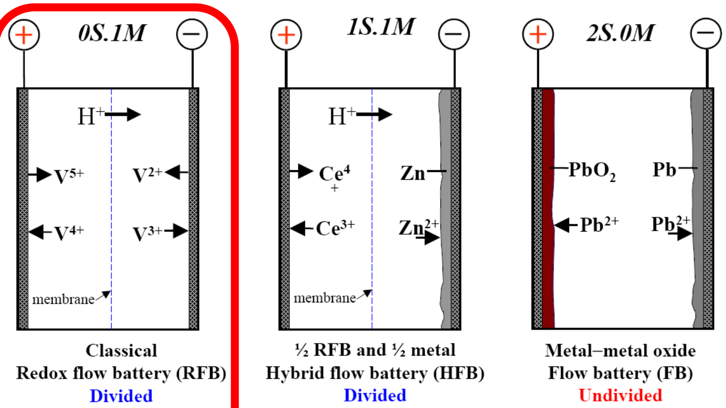
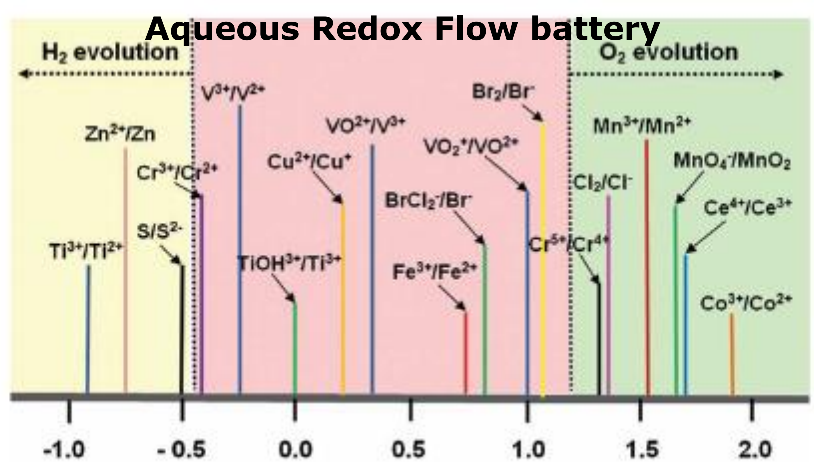
Storage in eni: redox flow batteries

Redox couple



Fe/Cr V/V V/Fe V/Ce …	Zn/Br2 Zn/Ce Li4Ti5O12/LiCoO2 …	Pb/PbO2 Cu/PbO2 Zn/Ni …

Pair of redox couples with high cell voltage
Both couple have to:
- be stable themselves and in combination
- kinetically reversible on electrode
- costly and HSE sustainable



Non-Aquouse redox flow battery may have higher cell potential (no limitation for water electrolysis) but lower solubility

Thank you for attention!!!