Handouts

Challenges for renewable energies: energy storage

In this document you will find the slides and notes of the webinar **"Challenges for renewable energies: energy storage"**.

Webinar:
Renewable energy on islands

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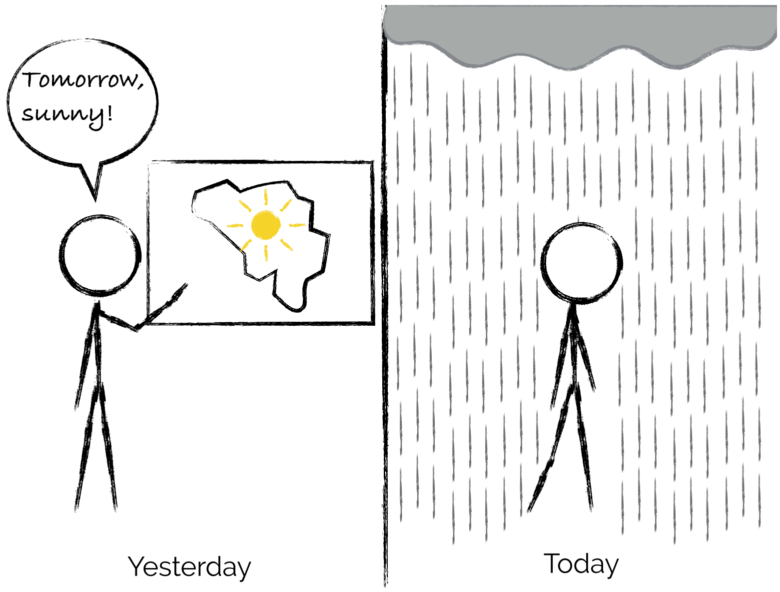
Energy storage

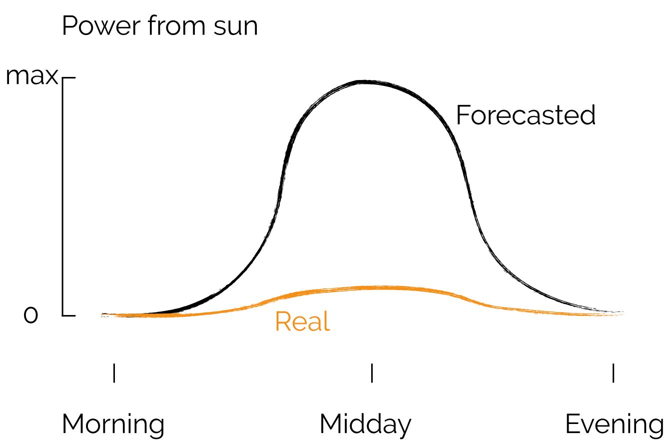
UCLouvain iMMC

How does a 100%-renewable world look like?

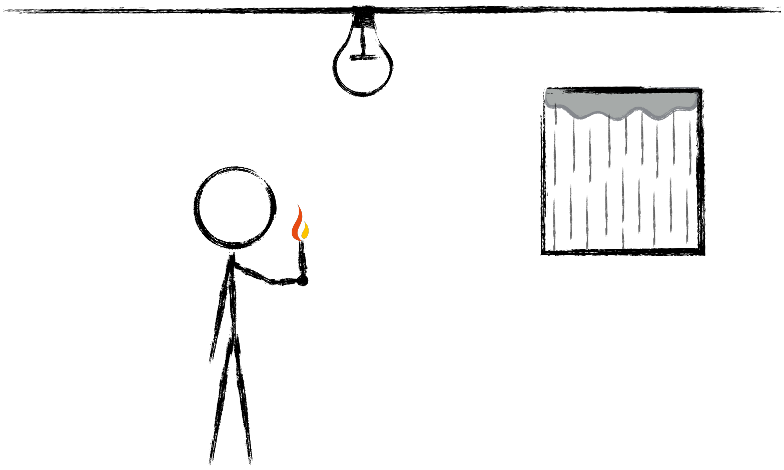
What will be the major challenges?



Unfortunately, this is a scenario we have all faced.



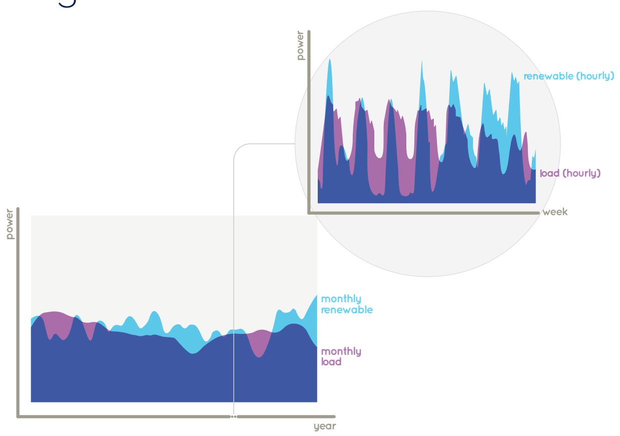
When a forecasted sunny day becomes a typical rainy day, the difference between the expected power production coming from the sun and the real production is significant.
In the current context, this leads to no real issues except some headaches for the transmission system operators, and the distribution system operators.



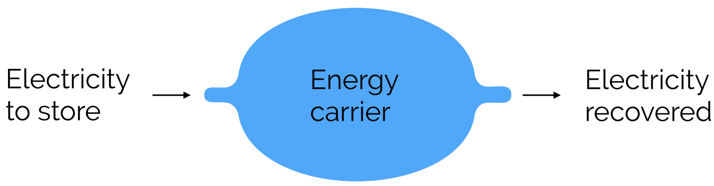
Tomorrow?

In a future where we hope to have much more renewables. Is this going to be a problem?

World with 100% renewable energy, storage at different timescales



Within 2050, we expect to have a significant portion (if not all) of the electricity produced from renewable sources. Some of these sources are hardly predictable and anyway in mismatch with our consumption. This mismatch is not only at the scale of a year but also at the scale of minutes.
Therefore storage is needed in a large span of timescales.



The main objective of electricity storage is to accumulate energy under a storable carrier—electricity cannot be directly stored as such—and recover this energy in the form of electricity. Converting the electricity into the carrier and back to electricity will involve processes. Of course, these intermediate processes will include losses, as the storage itself will include a certain amount of self-discharge.

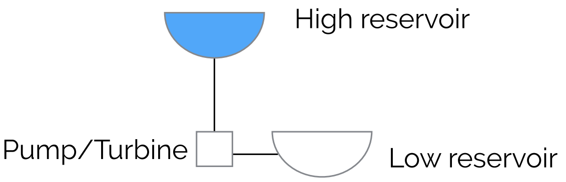
What forms of energy storage do you know?

- Mechanical effect
- Batteries
- Fuel production
- Capacitor and magnetic
- Thermal effect

- Mechanical effect
- Batteries
- Fuel production
- Capacitor and magnetic
- Thermal effect

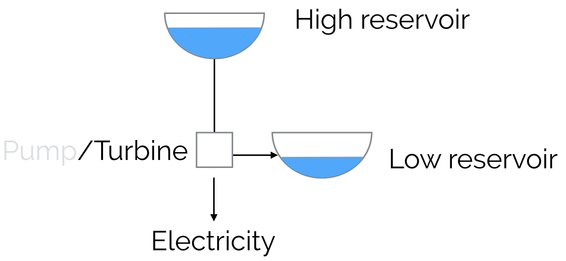
Pumped Hydroelectric Storage

95% of the energy storage worldwide



Pumped Hydroelectric Storage

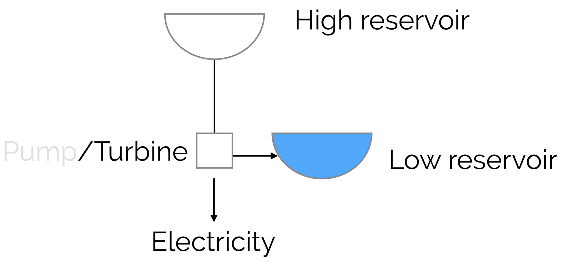
95% of the energy storage worldwide



When generating electricity, the water from the high reservoir drives the turbine.

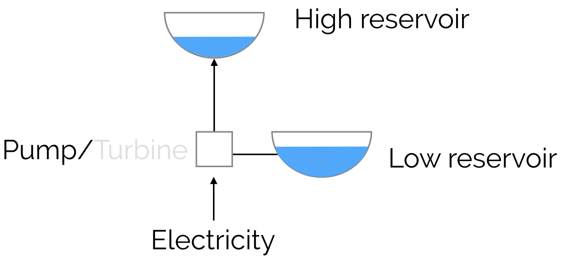
Pumped Hydroelectric Storage

95% of the energy storage worldwide



Pumped Hydroelectric Storage

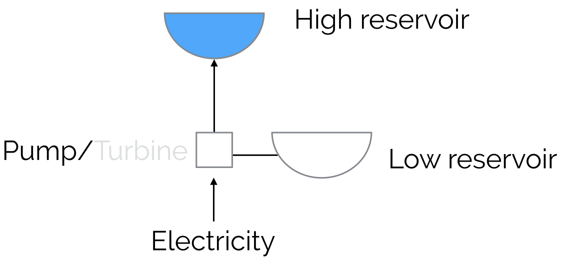
95% of the energy storage worldwide



When electricity needs to be stored, it is used to pump the water from the low reservoir back to the high reservoir.

Pumped Hydroelectric Storage

95% of the energy storage worldwide



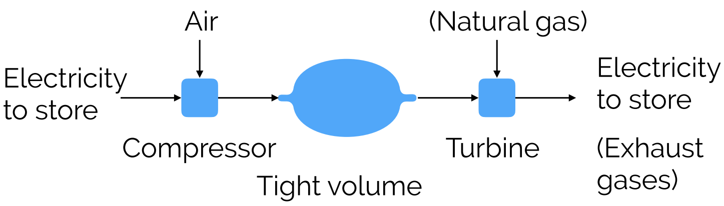
Pumped Hydroelectric Storage

Advantages	Drawbacks
High efficiency (70-85%)	Poor energy density (0.5-1.5 Wh/kg)
High power (100-5000 MW)	Scarcity of available sites
Fast response time (less 60 s)	High cost for construction 500-1500 €/kW 70-150 €/kWh
Long storage period (up to year)	
Long life time (40-60 years)	

This is a picture of the pumped hydro-electric storage of Coo-Trois-Ponts.

Compressed Air Energy Storage

Second largest storage system



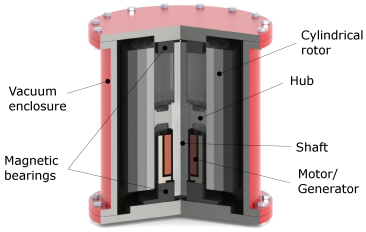
Two large plants:
Huntorf (Germany): 290 MW
Macintosh (Alabama): 110 MW

Compressed air energy storage stores electricity by compressing a gas (generally air) and storing it at high pressure (40 to 80 bar) into a tight volume (e.g. an underground cavern). When electricity is needed, the compressed air drives a gas turbine. In diabatic versions, natural gas is used to heat up the stored air before going into the turbine. More advanced versions (adiabatic) retrieve the compression energy and avoid natural gas.

Compressed Air Energy Storage

Advantages	Drawbacks
Good (45%) to high efficiency (85%)	Emission from combustion when using natural gas
High power (50-300 MW)	Losses during compression
Long storage period (up to year)	Scarcity of available sites
Long life time (20-40 years)	Low energy density 30-60 Wh/kg
	High cost for construction 500-1500 €/kW 50-250 €/kWh

Flywheel



Electricity is stored by increasing rotation speed with motor

Electricity is retrieved by decreasing rotation speed with generator

Flywheel

Advantages

High efficiency (90-95%)

Long life time (20-40 years)

Small response time (ms)

Drawbacks

Only short-term storage

High self-discharge (up to 20%/hour)

Small power (up to 250 kW)

High cost
500-2000 €/kW
2000-8000 €/kWh

Medium energy density
100 Wh/kg

Mechanical effect

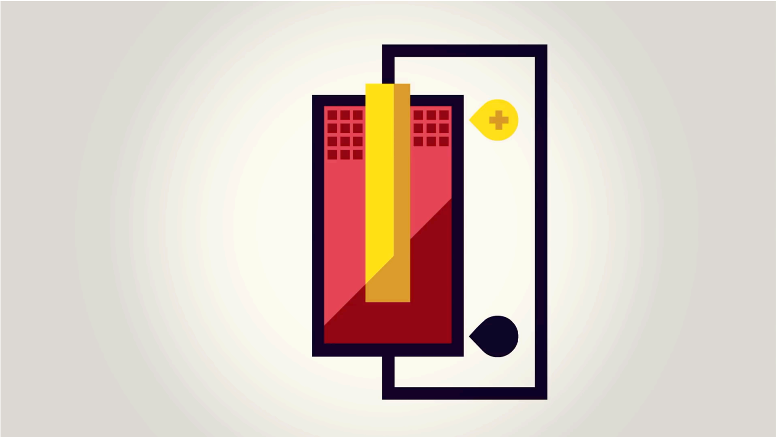
Batteries

Fuel production

Capacitor and magnetic

Thermal effect

Batteries



Learn more about batteries: https://www.youtube.com/watch?v=9OVtk6G2TnQ

Batteries

Advantages

Good (60%) to
high efficiency (95%)

Small response time

Drawbacks

Short life-time
(5-15 years, 1000 cycles)

Medium energy density
50-200 Wh/kg

High cost
500-2000 €/kW
200-800 €/kWh

Mechanical effect

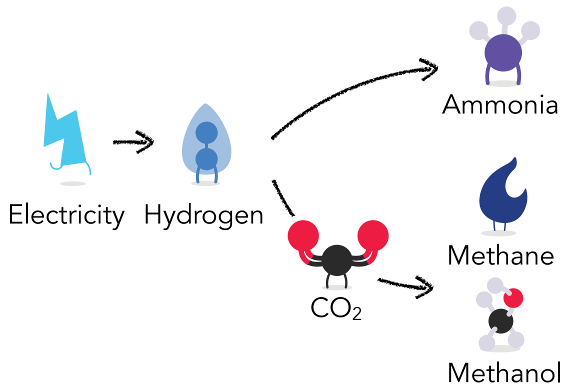
Batteries

Fuel production

Capacitor and magnetic

Thermal effect

With or without CO_2, fuels can be produced



When storing electricity into fuels. Several options are available. The first step is generally water splitting and the production of hydrogen in an electrolyser.
When no CO_2 is available, we can use the nitrogen from air and produce ammonia (NH_3).
When CO_2 is available, we can further convert hydrogen into methane or methanol.

With or without CO_2, fuels can be produced

Hydrogen

120 MJ/kg but 4.5MJ/l @700 bar
Very difficult to store
Carbon free, only produces H_2O

Methane

50 MJ/kg - 16MJ/l @700 bar
Difficult to store
Requires CO_2

Ammonia

Liquid at 9 bar and 20°C
18.7 MJ/kg, 13 MJ/l
Does not require CO_2

Methanol

Liquid at atm. conditions
20 MJ/kg, 16 MJ/l
Requires CO_2

Hydrogen has a very small density and therefore is very difficult to store. Converting hydrogen to ammonia helps solving the density problem since ammonia is easily liquified. Converting hydrogen to methane or methanol has the advantage to reusing CO_2 as a building block and building a circular carbon economy. Going to methanol provides an additional benefit since it is liquid at atmospheric conditions and then with higher energy density. Carbon capture will be an intrinsic part of the power-to-fuel solution. During the transition towards sustainable energy, it will limit the emissions of CO_2. After that, it will continue to collect the building block necessary to the fuels.

Power-to-fuel

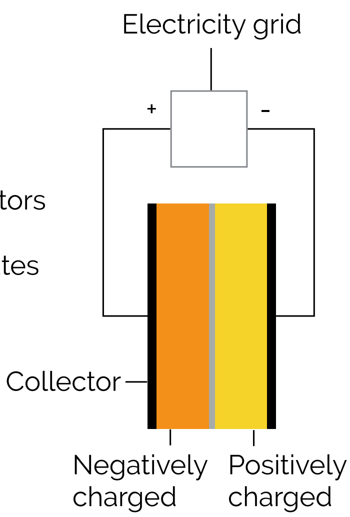
Advantages	Drawbacks
High energy density 5-10 kWh/kg	Medium power-to-power efficiency 35%
Methanol and ammonia easily storable	Hydrogen and methane not easy to store
Hydrogen and methane can be injected in natural gas	High construction costs
Low storage costs (except hydrogen)	

- Mechanical effect
- Batteries
- Fuel production (+ carbon capture)
- Capacitor and magnetic
- Thermal effect

Supercapacitor

Direct current charges the collectors

Charges accumulates in the material



Supercapacitor

Advantages	Drawbacks
High efficiency (95%)	High self-discharge: 20-40%/day
Small response time (ms)	Short-term storage
Long life time (20 years)	Low energy density 5-15 Wh/kg
	High cost 200-500 €/kW 5000-20000 €/kWh

Superconducting Magnetic Energy Storage

Superconducting coil
no resistance but needs cooling

Electricity is transformed
into direct current by inverter/rectifier

Energy is stored in the magnetic field
created when the current flows

Superconducting Magnetic Energy Storage

Advantages	Drawbacks
No self-discharge (superconducting)	Short period of time (cooling)
High efficiency (95%)	High cost 200-500 €/kW 5000-10000 €/kWh
Small response time (ms)	
Long life time (20 years)	

Mechanical effect

Batteries

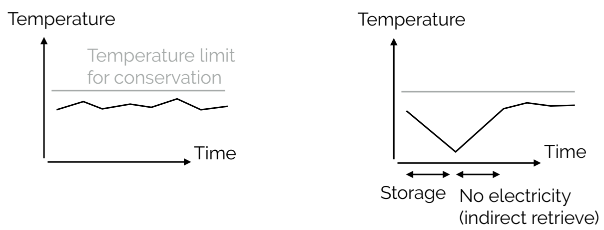
Fuel production (+ carbon capture)

Capacitor and magnetic

Thermal effect

Thermal processes can buffer energy as an indirect way to store energy

An indirect form of storage can be achieved by using thermal inertia. For example, in the food industry, the operator could decrease the temperature below the usual one in order to absorb extra electricity available on the grid. When electricity is needed, the operator stops using electricity, which enables others to use what they need with the available electricity.



Mechanical effect

Batteries

Fuel production (+ carbon capture)

Capacitor and magnetic

Thermal effect

Key messages of the lesson

No "free lunch",
storing involves losses

Each storage has its specificity
no "winner takes all" but combination

Even if storage will be necessary in a fully renewable world, it implies losses—either during storage, retrieve, or as self-discharge.
Every storage systems have specific advantages and drawbacks. Only a combination will make sense to address all challenges.
By obtaining intermediate products that can be used in other sectors—fuels produced with excess electricity could be used in transport—we couple sectors through the storage.