European Association for Storage of Energy

Overview of the current state of art in energy storage technologies

Strategic contribution of Energy Storage
to Energy Security and Internal Energy Market

High Level Roundtable

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Outline

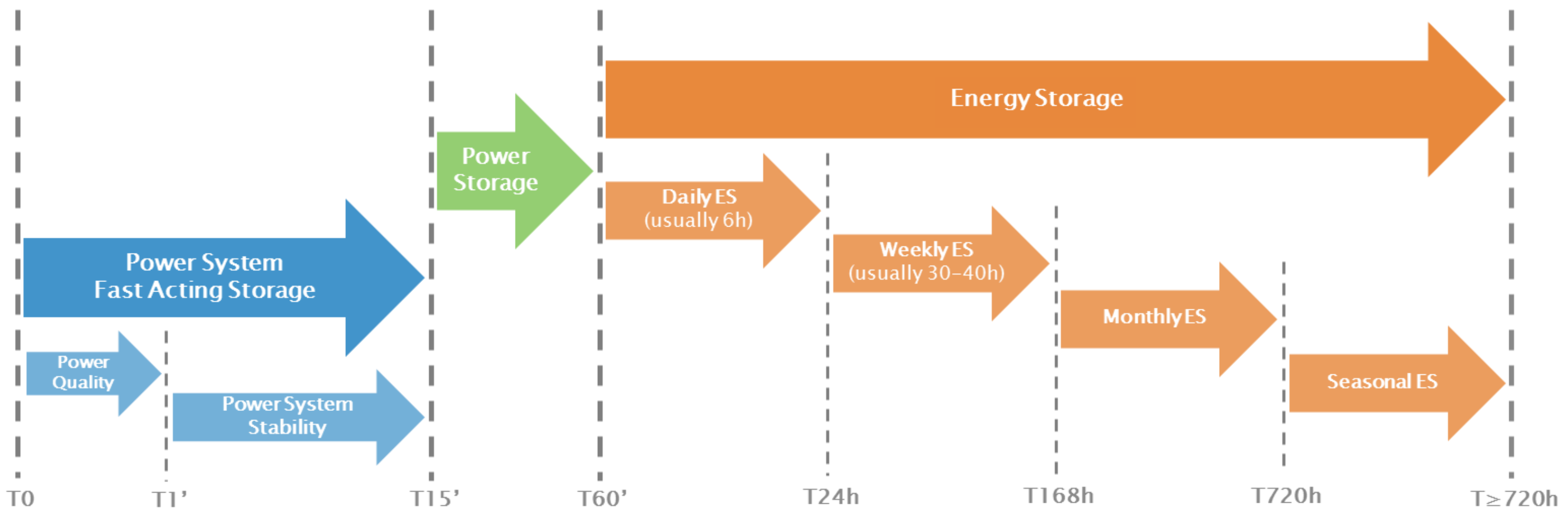
I. What is Energy Storage?
II. Energy Storage Technologies
III. Energy Storage in the new Energy System
IV. Energy Storage: what for?
V. Energy Storage – a reality
VI. Conclusions

I. What is Energy Storage?

"**Energy Storage Facility**" for the electricity vector:

is a facility used for the intake and stocking of electricity in different suitable energy forms. The release of this energy, at a controlled time, can be in forms that include electricity, gas, thermal energy and other energy carriers.

Segmentation of Energy Storage in time



II. Energy Storage Technologies

Five technology families

Chemical
- Hydrogen
- Synthetic Natural Gas

Electrical
- Capacitors
- SMES

Electrochemical
- Classic Batteries
  - Lead Acid
  - Li-Ion
  - Li-Polymer
  - Li-S
  - Metal Air
  - Na-Ion
  - $Na-NiCl_2$
  - Na-S
  - Ni-Cd
  - Ni-MH
- Flow Batteries
  - Vanadium Red-Ox
  - Zn-Br

Mechanical
- Flywheels
- Adiabatic Compressed Air
- Pumped Hydro
- Diabatic Compressed Air
- Pumped Heat Electrical Storage
- Cryogenic Energy Storage

Thermal
- Heat (Hot Water/PCM)
- Molten salt (Heat/CSP thermal)
- Packed-bed Heat Storage
- Smart Electric Thermal Storage

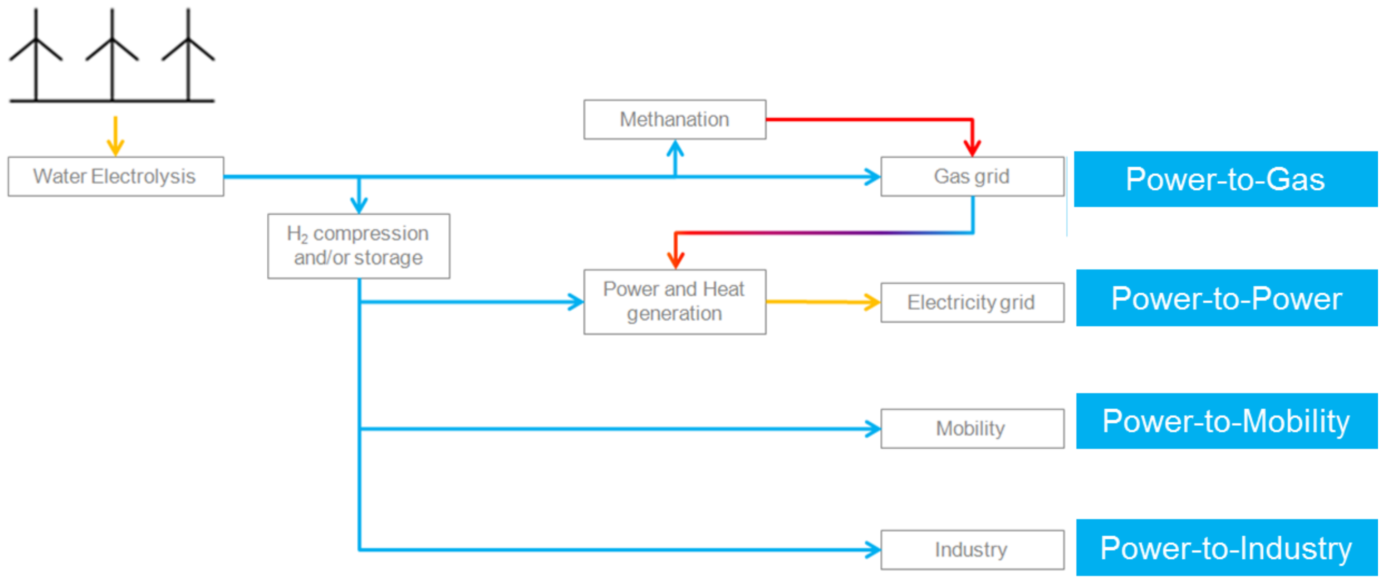
II. Energy Storage Technologies

Chemical Energy Storage: Hydrogen Storage Systems

Physical Principles

1. Electrical energy is stored by electrolysing water to produce hydrogen and oxygen.
2. The oxygen is released and the hydrogen is then stored.
3. For grid electrical energy storage applications the hydrogen is then re-electrified (e.g. via fuel cells) recombining hydrogen with oxygen to produce electricity.
4. Heat and water are released as a by-product. Alternatively gas turbines or engines can reconvert hydrogen to electricity.

Design variants are defined according to the application:



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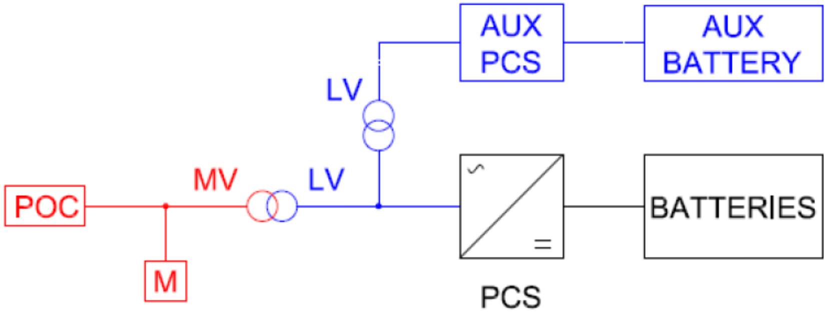
II. Energy Storage Technologies

Electrochemical Energy Storage: Battery System

Physical Principles

1. Based on a variety of different specific chemical systems.
2. Consists 2 or more electrochemical cells using chemical reaction(s) to create a flow of electrons – electric current.
3. Primary elements of a cell include the container, 2 electrodes (anode and cathode), and electrolyte material.

Today the most commonly used technologies on the market available are lead-based, lithium-based, nickel-based and sodium-based batteries.
Other technologies are slowly appearing and their TRL are increasing.



Block schematic of the grid connection of an electrochemical energy storage system
POC point of connection | M meter | MV medium voltage (in red) | LV low voltage (in blue) | PCS power conversion system

II. Energy Storage Technologies

Electrical Energy Storage: Electric Double Layer Capacitors

Physical Principles

1. Set up is similar to batteries.
2. Highly responsive storage medium.
3. Electrical charge is stored in an electric double layer at the interface between a high-surface-area carbon electrode and a liquid electrolyte.
4. Mechanism is highly reversible. EDLC can be charged and discharged thousands of times.
5. Electrode surface area in capacitors determines the capacitance and thus, the energy storage capability of the device.
6. The amount of energy stored by these devices is very large compared to a standard capacitors because of the enormous surface area created by the porous carbon electrodes and the very small charge separation created in the double layer.

II. Energy Storage Technologies

Battery Systems & Supercapacitors

Status of development of major electrochemical & electrical storage systems for grid applications

Status	
Mature	Lead-acid
Commercial	Lead-acid, NaS (sodium-sulphur)
Demonstration	ZnBr (zinc bromine), advanced lead-acid, VR (vanadium redox), NiMH (nickel-metal hydride), Li-ion (Lithium-ion)
Prototype	Li-ion, FeCr (Iron Chromium), ZEBRA (sodium nickel chloride = Na-NiCl2)
Laboratory	Zinc-air, advanced Li-ion, new electrochemical couples (other Lithium-based)
Idea -concept	Nano Supercapacitors, new electrochemical couples (metal-air, Na-ion, Mg-based and so on)

Source: *Joint EASE/EERA recommendations for a European Energy Storage Technology Development Roadmap towards 2030*, 2013

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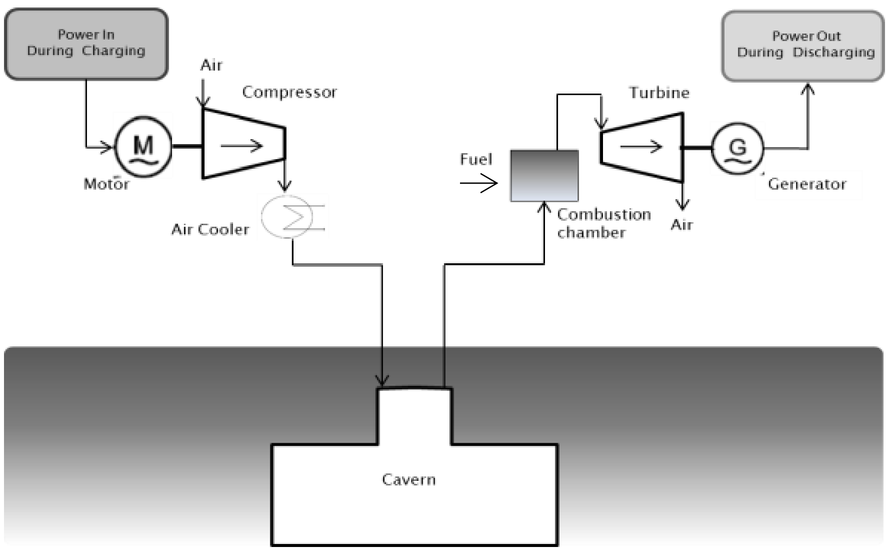
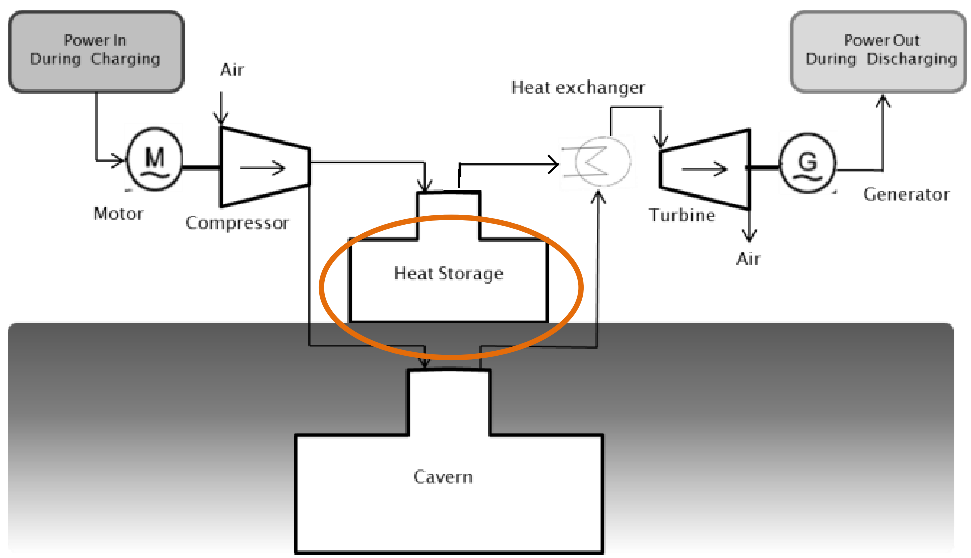
II. Energy Storage Technologies

Mechanical Energy Storage: Compressed Air

Physical Principles

1. During charging the electrical energy is converted into potential energy of the pressurised air and stored in this form.
2. Ambient air is compressed and stored under pressure in underground caverns.
3. Heat generated during compression can be stored (adiabatic) in order to increase the round-trip efficiency.
4. When electricity is required, the pressurised air is heated and expanded in an expansion turbine driving a generator for power production.



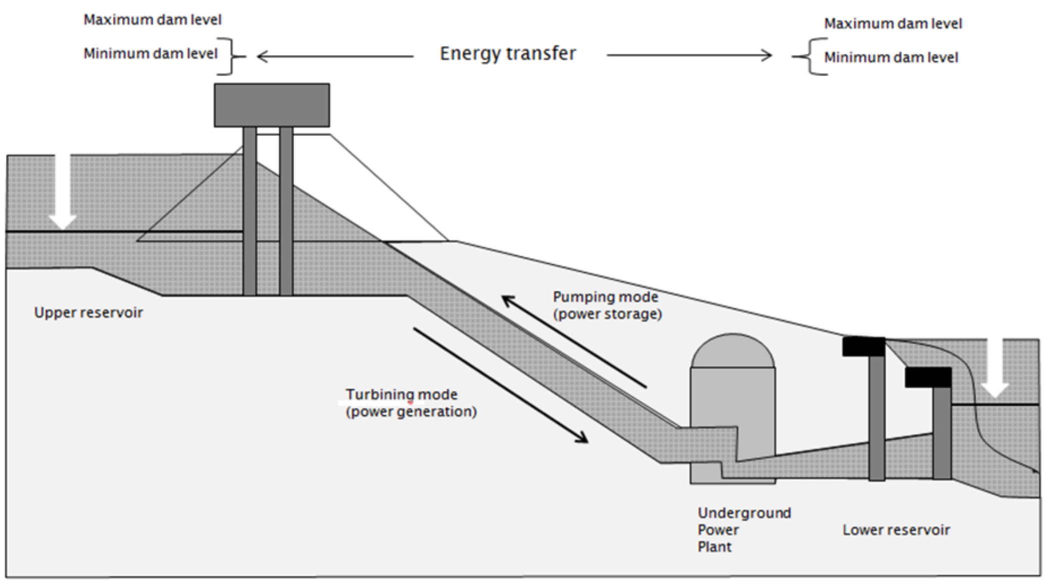


II. Energy Storage Technologies

Mechanical Energy Storage: Pumped Hydro Storage

Physical Principles

1. Store electrical energy by utilising the potential energy of water.
2. When excess energy is available, water will be pumped and stored in an upper reservoir/pond.
3. On demand, the potential energy of the stored water can be released and transformed into electrical power within a short reaction time.



II. Energy Storage Technologies

Thermal Energy Storage Systems

Physical Principles

1. Key element for effective and efficient generation and utilisation of heat where heat supply and heat demand do not match spatially and in time.

2. Systems are diversified with respect to temperature, power level and use of heat transfer fluid; each application is characterised by its specific operation parameters.

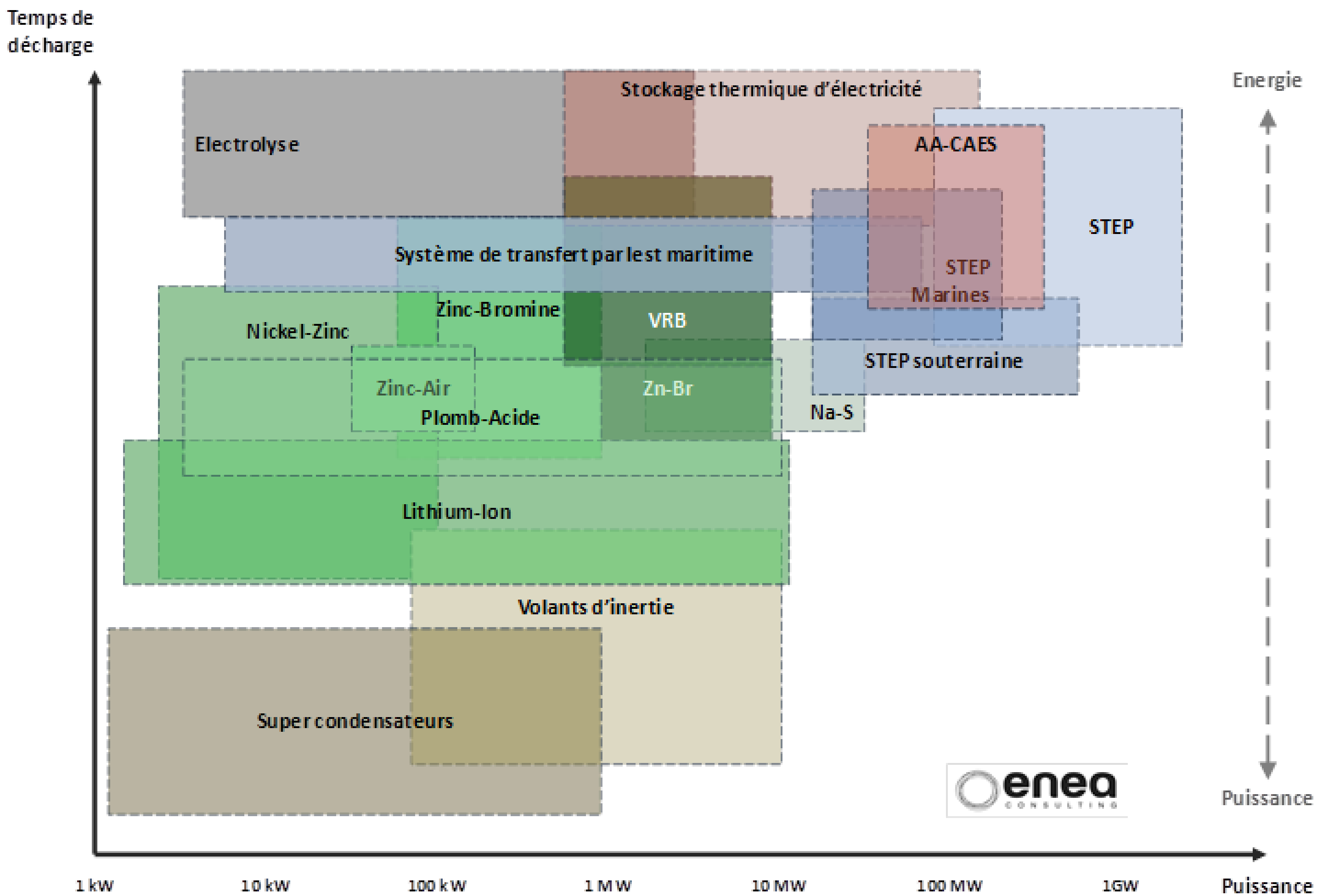
3. Heat can be stored in a number of ways:
   - Sensible Heat Storage results in an increase or decrease of the storage material temperature

   - Latent Heat Storage is connected with a phase transformation of the storage materials (phase change materials – PCM), typically changing their physical phase from solid to liquid and vice versa.

   - Thermochemical Heat Storage is based on reversible thermochemical reactions. The heat stored and released is equivalent to the heat (enthalpy) of reaction.

II. Energy Storage Technologies

Various storage possibilities: Energy & Power



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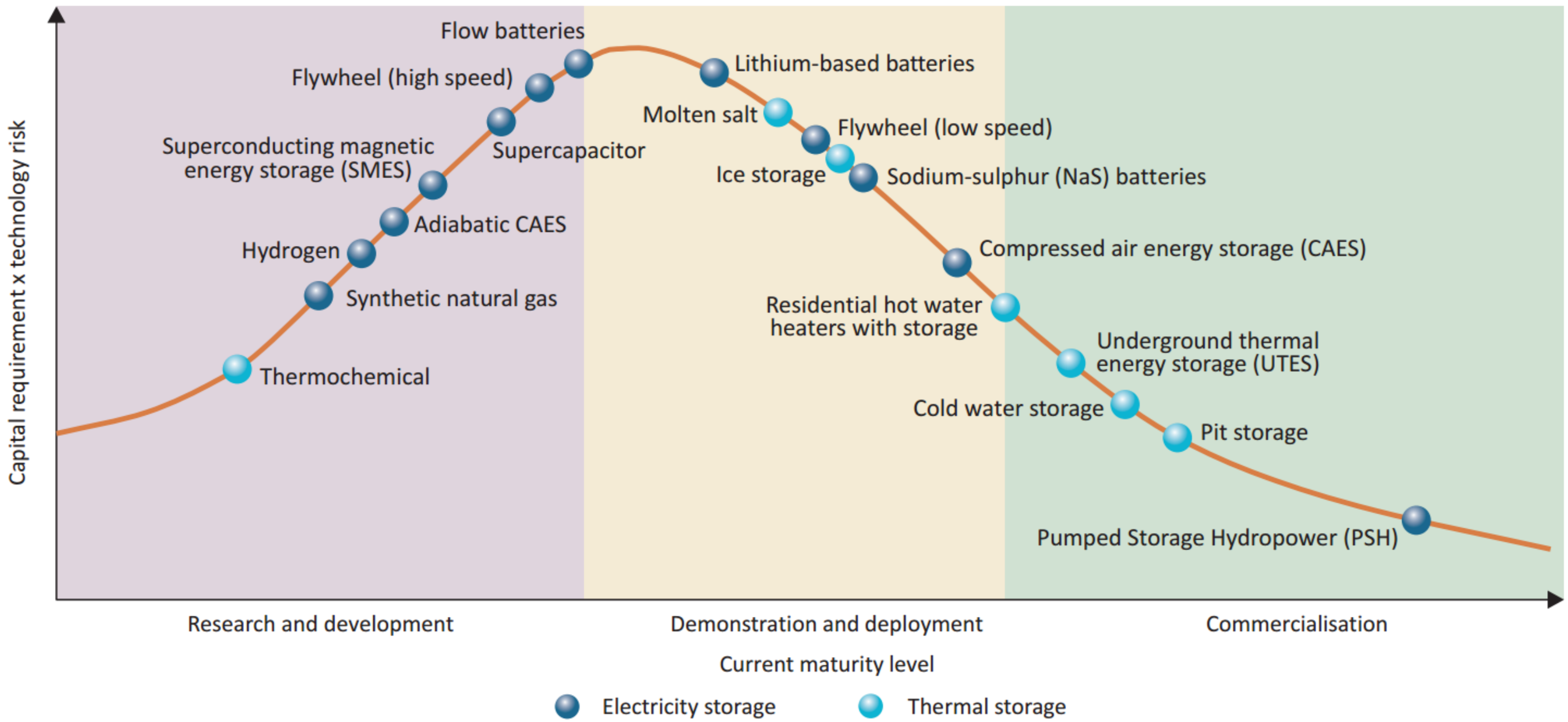
II. Energy Storage Technologies

Various storage possibilities: different maturities



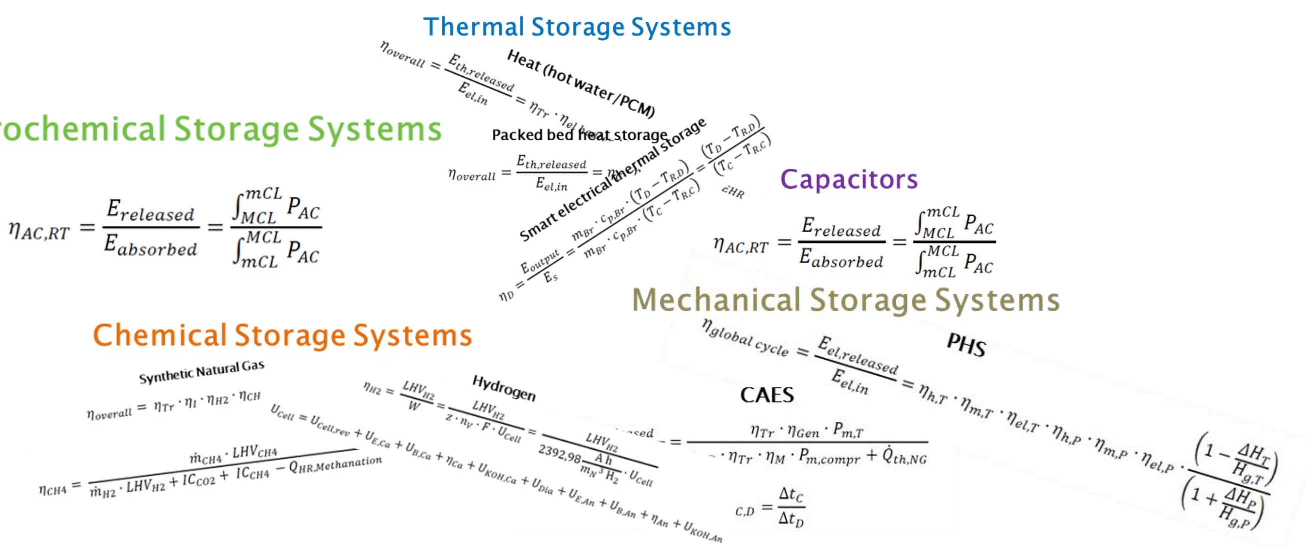
Sources: *Technology Roadmap Energy Storage*, IEA, 2014

II. Energy Storage Technologies

Efficiencies

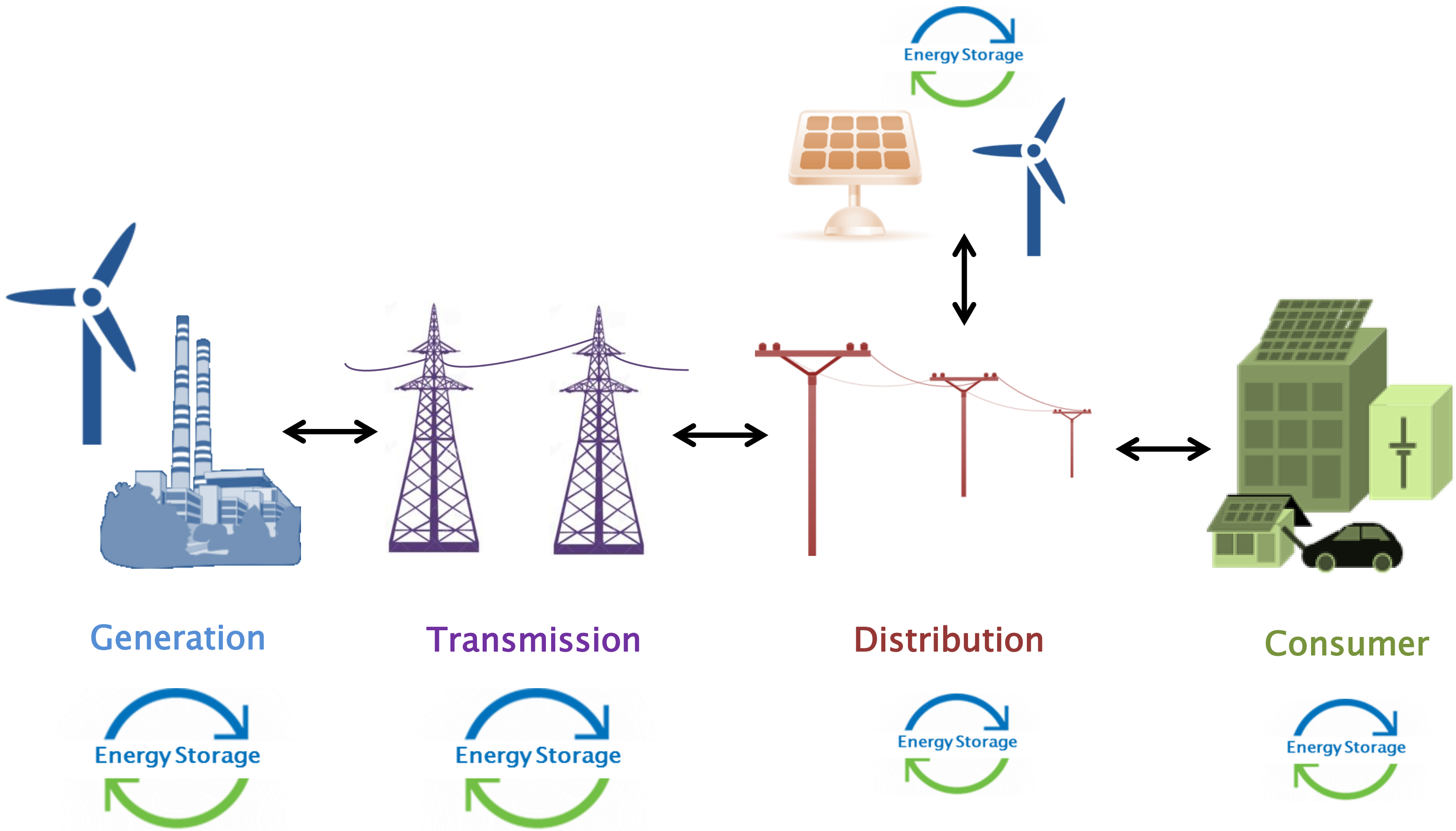
There is no single way of calculating efficiency for all Energy Storage technologies

- Energy Storage efficiency heavily depends on the type of storage, storage system components…



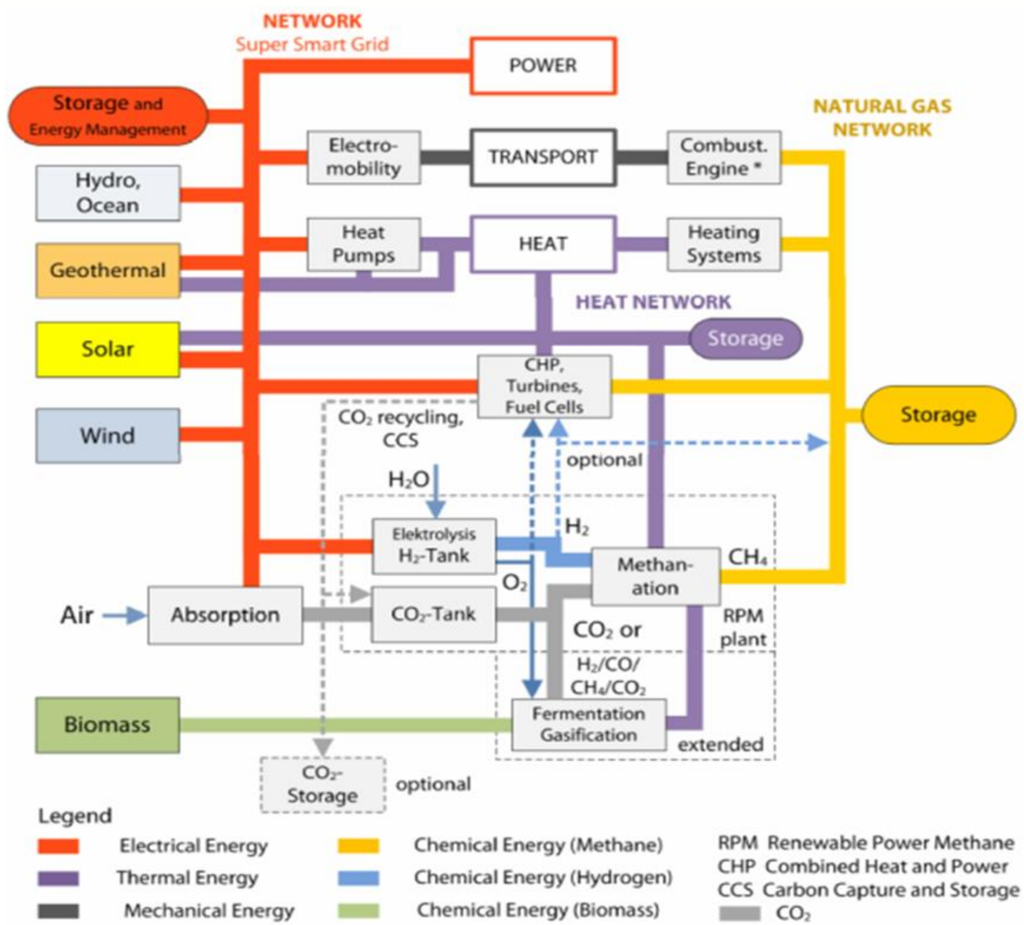
It is utmost important to define where the efficiency is measured and what is the energy considered as input and output

III. Energy Storage in the new Electricty System



III. Energy Storage in the new Energy System

Energy Storage can be everywhere: holistic approach



Source: EC presentation at Energy Storage Global Conference, Paris, 2014

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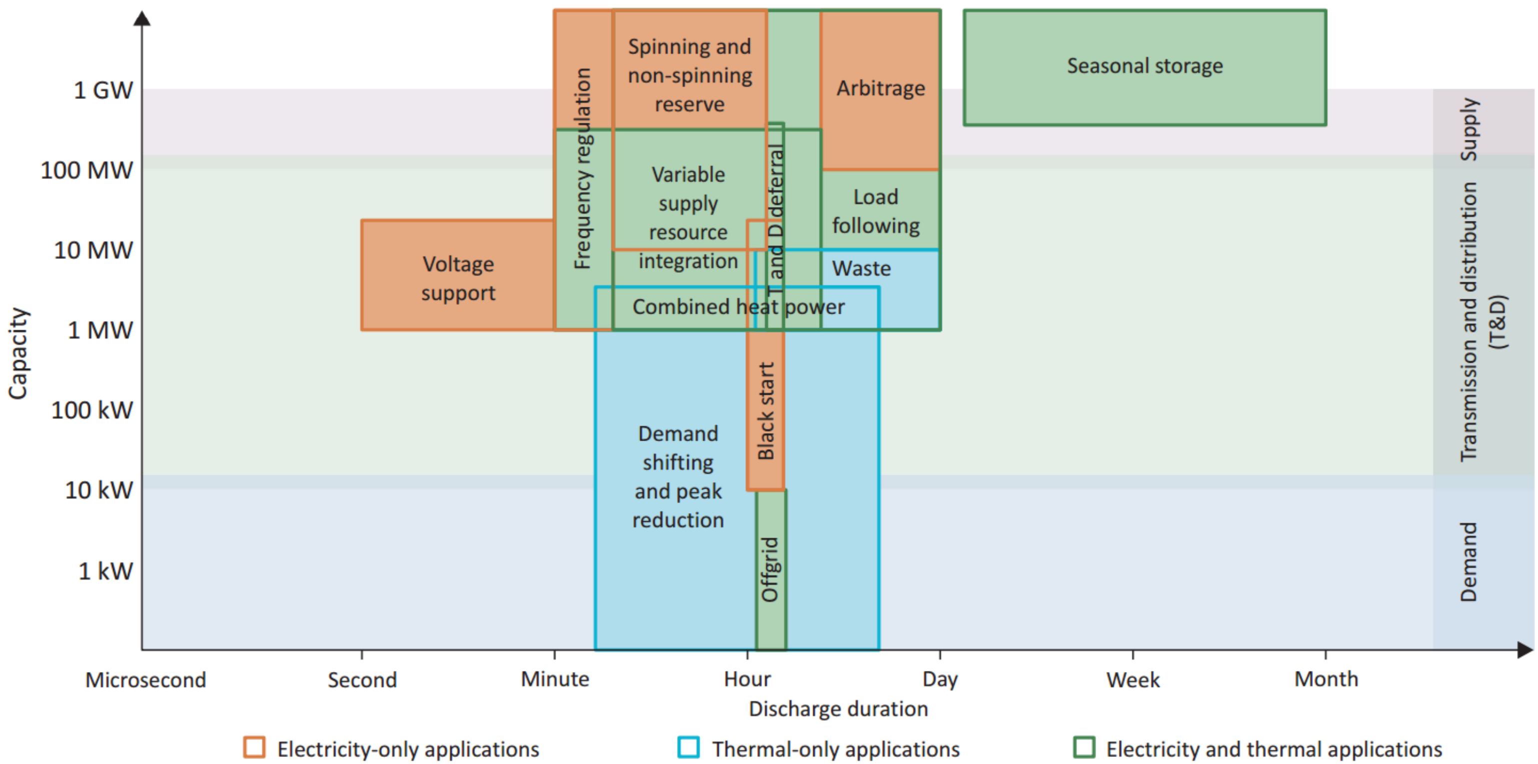
IV. Energy Storage: what for?

Main storage applications today…

Generation		Transmission	Distribution	Customer Services
Conventional	Renewable			
Black start	Distributed Generation flexibility	Participation to the primary frequency control	Capacity support	End-user peak shaving
Arbitrage	Capacity firming	Participation to the secondary frequency control	Dynamic, local voltage control	Time-of-use energy cost management
Support to conventional generation	Limitation of upstream perturbations	Participation to the tertiary frequency control	Contingency grid support	Particular requirements in power quality
	Curtailment minimisation	Improvement of the frequency stability of weak grids	Intentional islanding	Continuity of energy supply
		Investment deferral	Reactive power compensation	Limitation of upstream disturbances
		Participation to angular stability	Distribution power quality	Compensation of the reactive power
			Limitation of upstream perturbations	

IV. Energy Storage: what for?

Main storage applications today: Power versus Duration



Sources: modified from IEA (2014), Energy Technology Perspectives, OECD/IEA, Paris, France.

IV. Energy Storage: what for?

Future Application Mapping…

V. Energy Storage – a reality

Schwerin (DE)
Battery Energy Storage System
- Frequency Regulation
- Voltage Support
- Black Start

Bassin du Cheylas (FR)
Pumped Hydro Storage
- Electric Energy Time Shift
- Electric Supply Capacity
- Electric Supply Reserve Capacity – Spinning
- Frequency Regulation
- Voltage Support

Energy Storage

La Gomera, Canary Islands (ES)
Flywheels
- Frequency Regulation
- Electric Supply Reserve Capacity – Spinning

Falkenhagen (DE)
Power to Gas Technology
- Renewables Capacity Firming

VI. Conclusions

Some perspectives offered by Energy Storage

The added value of Energy Storage to the system can be very varied…

- **Responsiveness quality** (speed, accuracy) versus total balancing power/energy requirement
- **Modularity** allowing to **adapt to heterogeneous power system requirements** (congestions, harmonics, variable generation, variable load, up-/down-regulation needs… to name a few!)
- (numerous) reservoirs able to **supply synthetic inertia** through proper power electronics controls to **contribute to grid stability** and to compensate for progressive decoupling of mechanical frequency from electrical frequency due to massive inverter deployment
- **Available power/energy capacity at the point of use** (losses minimisation, congestion minimisation, investment deferral, stability margins improvement)
- **Increased observability of power system status** and **added power system controllability** (especially for distribution networks) due to measurement systems associated to storage enabling local state estimation techniques to be deployed and due to the fact that storage is in itself a network actuator.
- …

VI. Conclusions

How can we further stimulate the development of Energy Storage?

☺ The Technology Readiness Levels are quite high for many technologies and improving every day.

☺ The Costs of the Technology are decreasing due to technological developments and economies of scale.

☹ **Investment into this field remains at a standstill…**

Thank you for your attention!

Questions

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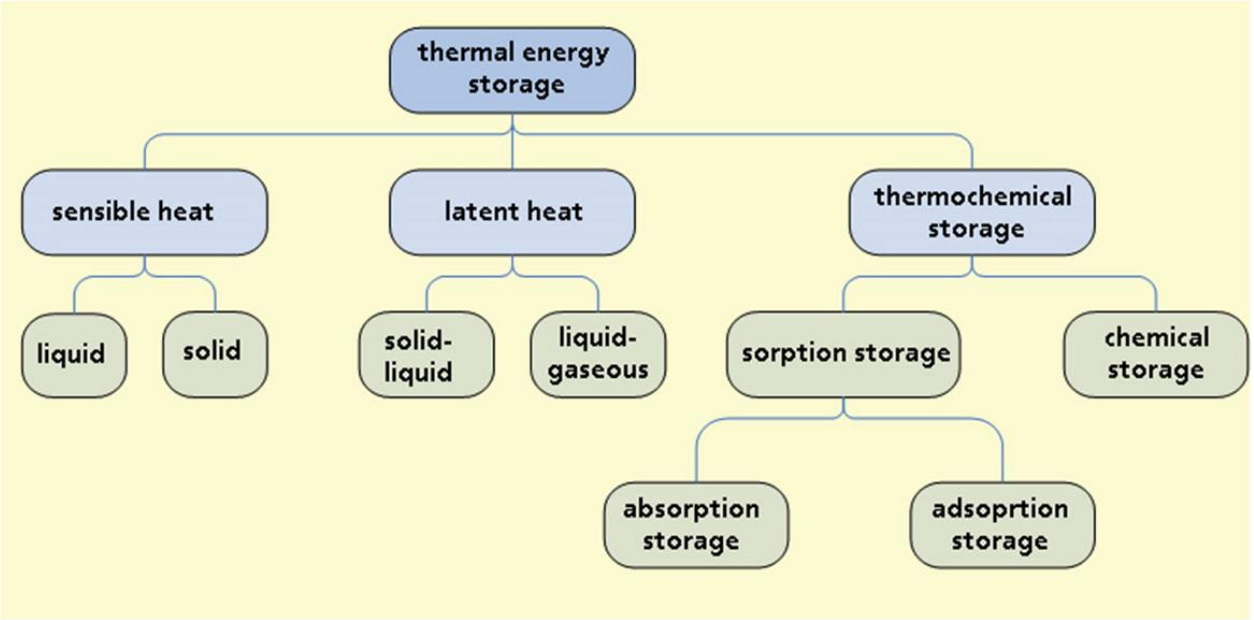
GL Garrad Hassan is now DNV GL Renewables Advisory

II. Energy Storage Technologies

Thermal Energy Storage Systems

Classification & Development Status of Thermal Energy Storage



- Sensible heat storage: mature
- Latent heat storage: maturing
- Thermochemical storage: least developed

Source: Birmingham Centre for Cryogenic Energy Storage, University of Birmingham