Alliance Nationale de Coordination de la Recherche pour l'Énergie

Decarbonization Wedges Exercise

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ELECTRICITY STORAGE

In most countries, decarbonizing the electricity system will imply deploying variable renewable energies which may need to develop large energy storage capacities in order to insure the safety of the electricity grid. Developing electricity storage devices addresses the issue of variable renewable energy and it may also provide new services for the electricity system.

1. State of the art and current development in different world regions

Technology 1: PHES
PHES is a mechanical, gravity technology in which turbines pump water into an upper reservoir and store it when demand is low; when demand peaks, the water is released through turbines to a lower reservoir. PHES can ramp up to full production capacity within minutes, thus providing a quick response for peak-load energy supply and displays several assets to balance the grid during unplanned outages.

Currently PHES technology is by far the most used storage technology in the world —98% of storage technologies. Underground Pumped Hydro (UPH) is a new generation of PHES technology under research in which the low reservoir is located underground.

Technology 2: CAES
CAES is an electric storage technology based on air elasticity: air is first compressed by compressors; it is stored in underground salt caverns. When needed, air is released, which drives the expander during the expansion phase following the reheating phase. This technology requires external heat input —i.e. by natural gas— before the expansion phase. The adiabatic method is a new generation of CAES[1] technology currently under research, in which the heat from compressed air is recovered to preheat the gas in the expansion phase —hence the need for thermal energy storage— as a substitution to natural gas.

Technology 3: Batteries
Batteries are electrochemical energy storage devices based on a variety of different specific chemical systems: currently the most commonly used technologies on the market are lead-based, lithium-based, nickel-based and sodium-based batteries. Because they can deliver high power almost instantaneously, batteries are used in numerous applications

Technology 4: Flywheels
Flywheels are a mechanical kinetic technology for electricity storage. Electricity is converted into kinetic energy through discs or cylinders rotated at high speed —with magnetic bearings to limit friction— and contained in a robust housing —usually vacuum. Given their limitations in terms of capacity, flywheels are mainly used for their fast discharge time.

Thermal storage has not be assessed in this template. Nevertheless, it could be a real opportunity for energy storage and corresponding technologies could be explored in a next future. Supercapacitors will not be taken into consideration either, insofar as they are an electrochemical technology, which is currently mostly used for transportation applications: indeed, thanks to their very short charge and discharge time, they can help to recover braking energy.

2. Maturity level and technological perspectives

Large scale PHES is a mature technology but the efficiency of small scale PHES is not sufficient if the technology is to be developed on a large scale. Similarly CAES technology needs a significant increase of its round trip efficiency. Generally the number of cycles, the lifetime and the energy density of batteries need to be increased. Flywheel performances are already good in terms of cycles but energy density still needs to be improved.

[1] CAES is sometimes called AACAES when it is advanced (AACAES: Advanced Adiabatic CAES)

Maturity of electricity storage

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
PHES	4	5	5	5	5
CAES	2	3	3	4	5
AACAES	2	2	2	3	4
Batteries	3	3	4	4	4-5
Flywheels	3-4	4	4	4	4

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Potential development of electricity storage

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

	2020	2030	2040	2050
All technologies	2	3	4	4

Most of electricity storage methods will probably involve PHES and batteries —about 30% of all storage technologies for both technologies whereas CAES will probably account for 20% of all storage methods. The remaining 20% will involve flywheels, H_2 storage, thermal storage, etc.

3. Technological, economic and social bottlenecks[2]

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

[2] Source: EASE (European Association for Storage of Energy), EERA (European Energy Research Alliance), *Joint EASE/EERA recommendations for a European Energy Storage Technology Development Roamap towards 2030* (2013).

Technology		**Research & technological bottlenecks**	**Economy and Financial bottlenecks** (investment, risks)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
PHES	Rank	1	5	4	6	3	2
	Key-words	Efficiency	Cost reduction	New storage capacities; small size PHES	Water storage, high land footprint	Biodiversity	
AACAES	Rank	3	6	2	5	4	1
	Key-words	Advanced materials for high temperature, high pressures	Cost reduction	Appropriate when close to off-shore wind farm	Underground storage and surface containers.	High pressure container (200-300 bar) and high temperature gradients (600°C)	
Batteries	Rank	5	6	1	4	3	2
	Key-words	Intensive materials, increased applicability of batteries to grid applications	Cost reduction highly required, especially CAPEX	Quick load network; strong support from public policies	Materials beyond lithium, vanadium and sodium	Improving safety (temperature) technologies	
Flywheels	Rank	5	6	1	3	4	2
	Key-words	Reduced friction, higher rotation speed for strong materials like composites; power electronics	Cost reduction of rotor		Magnetic material	External case	Mature technology with several manufacturers

Technology 1: PHES

PHES technology can be considered today as mature but some researches are still necessary to allow and increase its use; recent technological advances focus on reversible dual regulator and variable speed to improve efficiency and to enable controlling the power exchanged with the network in real-time. The geographic preconditions are also a big restriction that might be solved thanks to the development of new PHES methods involving smaller systems using rivers —*en échelon* systems—, sea —on waterfront slopes and even on artificial islands— and underground reservoirs. However the possibility of small size PHES development will raise major issues of incentive public policies and public acceptance if the deployment of this new technology on rivers, seas borders or islands is massive.

Technology 2: CAES

The existing system needs to really improve its round trip efficiency —i.e. at least by reducing natural gas combustion for air preheating before expansion. That is why adiabatic technology has to be developed in order to capture, store and reuse the heat from compression. Technology innovations are also needed for turbine machineries, i.e. the compressor and the expander -to take into account high pressure for the former (over 300 bars) and high temperature for the later (up to 600°C) -. Geological research for other storage mediums than the ones currently used —i.e. salt caverns— could be conducted —ideas involve aquifers, limestone or basalt caverns, old mines, etc.— as well as research on small storage in subsurface reservoirs. The social point of view of high pressured reservoirs is clearly an issue.

Technology 3: Batteries

Significant scientific and technological progresses are still needed on various competing and emerging battery types to establish them on the market. The main issue with sodium- based battery —and, to a lesser extent, with lead-acid battery— is the high temperature required to operate them. For stationary use, cyclicity and life time are the main properties to improve. Charging time also needs to be reduced. As for CAES, large battery storage systems may raise issues of acceptability from the surrounding population.

Technology 4: Flywheels
Flywheels technology is mature and completely established on the industrial market. However, many technological aspects need to be improved —e.g. using stronger materials that can resist to centrifugal forces, reducing friction, increasing rotation speed, etc. Flywheels can complete batteries use by increasing their life-cycle.

On the long term it is very important to consider also the interest of distributed storage in the context of self-production and/or consumption —i.e. at low individual capacities of a few kW.

4. Potential radical and incremental innovations

Methodological information:

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		**Research & technological innovations**	**Economy and Financial innovations** (investment, risk)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
PHES	I or R	I	I	I	R	I	R
	Key-words				Land, water and lack of available resources		Public opinion, fish populations
CAES	I or R	I/R	I	I	I	I	R
	Key-words	Development of AACAES					
Batteries	I or R	R	I	I	R	R	R
	Key-words	Materials and lifetime extension			Life-cycle	Safe materials	
Flywheels	I or R	I	I	I	I	I	I
	Key-words	Composite materials					

Technology 1: PHES
As the technology can be considered mature and well-controlled, there are no radical innovations to be expected but rather incremental innovations.

Technology 2: CAES
No radical innovations are expected if the CAES system keeps the same technological trajectory, illustrated by the current two plants in operation. Conversely the development and deployment of small adiabatic CAES may need radical innovations research in the thermal energy storage part.

Technology 3: Batteries
Batteries are a mature technology but they still need important radical innovations to improve materials safety, life cycles, discharge times, etc. New applications with very innovative economic models will possibly stem from the development of the electricity market.

Technology 4: Flywheels
No radical innovations are expected for flywheels technology, except maybe for the use of new composite materials that would cut back weight —needed for transport applications— and accelerate operations. Innovations may occur with the use of flywheels combined with batteries in unexpected situations.