Czech-Austrian Winter and Summer School: The relevance and costs of short vs. long term storage with comparison of Austrian and the Czech Republic possibilities

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Content

1. ABSTRACT

Energy storage is a key component in providing flexibility and supporting renewable energy integration in the energy system. It can balance centralized and distributed electricity generation, while also contributing to energy security. Energy storage will supplement demand response, flexible generation and provide a complement to grid development. Energy storage can also contribute to the decarbonisation of other economic sectors, and support the integration of higher shares of variable renewable energy (variable RES) in transport, buildings or industry. Therefore, energy storage can make an overarching contribution to the implementation of the Energy Union, in particular through its contribution to the internal market and decarbonisation dimensions.

This study aims to compare energy storage technologies in Austria and Czech Republic, which technologies already exists and in which areas can the both countries deploy their capacity.

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2. Introduction

Energy storage as term is nowadays often mentioned in media, university lectures, and also in our lives when we think and talk about energy.

The main reason is that the demand and supply (generation) of energy needed to meet just at every moment in the past, but the problem was the demand that fluctuates during days and months as it is shown in chapter 2.3. The solution was to control the production.

However, in 21st century we know that we need to change our path to economically, environmentally and socially sustainable way and thus to introduce low carbon technologies and carbon capture technologies also with energy efficiency improvements. So now not only the demand, but since renewable energy sources were introduced into the energy markets, also the production can differ a lot based on time, weather and other conditions.

So either we need perfect control of energy consumption and abate a lot of luxury we are used to in our lives and industry to be able to use the energy only when we have it based on available energy sources, or we need a perfect storage so that we don't need to change anything in the usage, or we need both as it will be mentioned in the following chapters: storage and also consumption control so that we can rise the efficiency of energy usage and continue on the way to low carbon economics that is sustainable in environmental, economic and social way to the future.

2.1. Source of information

As the main source of our information about energy storage and its usage we used "**Technology roadmap: Energy storage**" publication written by **International Energy Agency** in 2014 since we found it as relevant and reliable (scientifical) source of information, and otherwise also our knowledge from lectures and online sources.

The Technology Roadmap: Energy Storage, developed in 2014 by the International Energy Agency (IEA), is a response to demands for a deeper analysis of energy storage, specifically on the role of accumulating energy in the ongoing transformation of energy systems. In a study focusing on the accumulation of electrical and thermal energy, current technologies are summarized and plans for the development and implementation of R & D technologies are presented. [1]

2.2. Goal of the paper

The goal of this paper is to make an overview about energy storage reasons, options, technologies and their comparison (technical, economical), and comparison of actual states of energy storage and its usage in the Czech Republic and Austria, also with a view into the future, and how is it going with legislation and European plans.

2.3. Energy (electricity) demand varies during days and months

As it was already mentioned before, supply and demand of energy varies during days of the week, during weeks and months in years. If we do have a look at energy diagrams in our states (Austria and the Czech Republic), we will see how much they differ during days and during months, as the figures follow (source of the data used to create diagrams: Transparency ENTSO-E), firstly for last week and both countries, secondly for last 365 days for both countries:

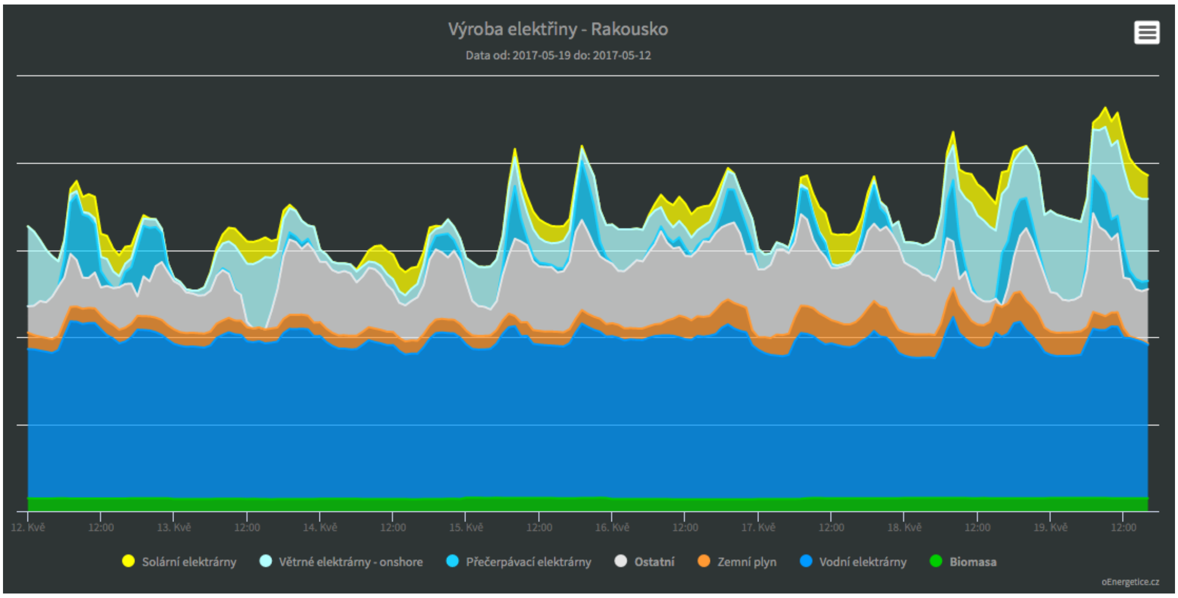


Figure 1 - Energy production in Austria from 12. 5. 2017 till 19. 5. 2017, source: oEnergetice.cz/energostat [2]

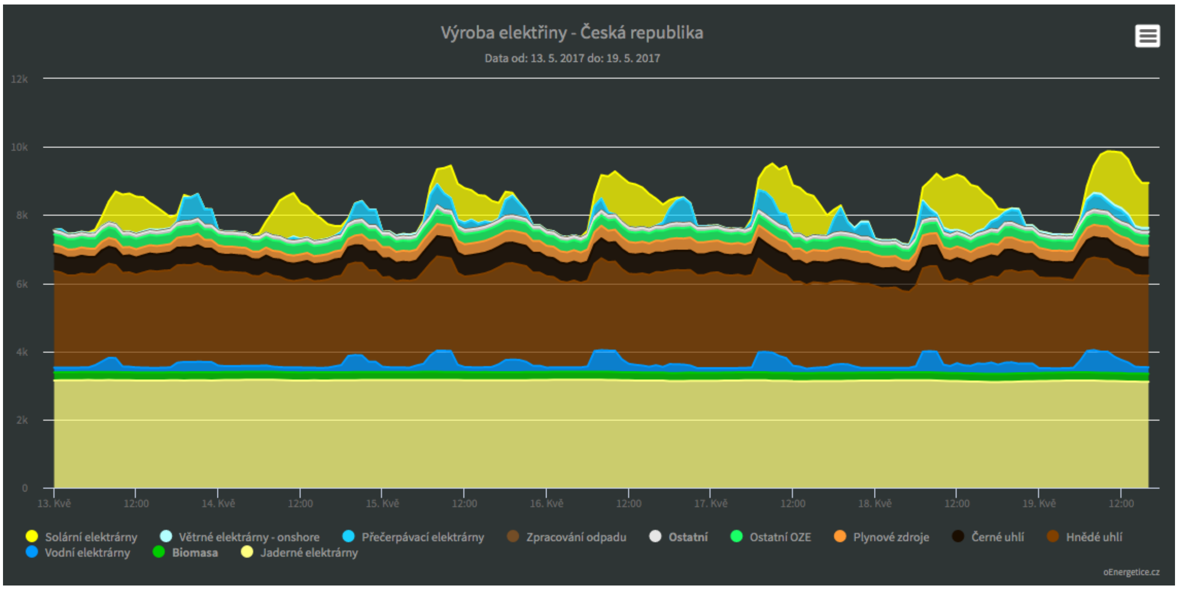


Figure 2 - Energy production in the Czech Republic from 13. 5. 2017 till 19. 5. 2017, source: oEnergetice.cz/energostat [2]

What can we see on those daily diagrams? We can see the difference of energy needs during days (when most of the people are active) and during nights, with morning and evening peaks (when they are at their homes using electrically powered tools) and also during week, when the needs are lower during weekends => short term storage.

And based on the geographical conditions (and climate), we can also see the difference between energy sources used to produce the energy: mostly hydro powered plants in Austria used also as baseload as well as biomass (perfect with storage when the energy is stored /firstly in the snow and glaciers, secondly in the dams/ when the turbines and generators are perfectly controllable with fast response and long lifetime of the machinery), and in Czech nuclear and coal powered plants with a small contribution of RES and hydro powered plants.

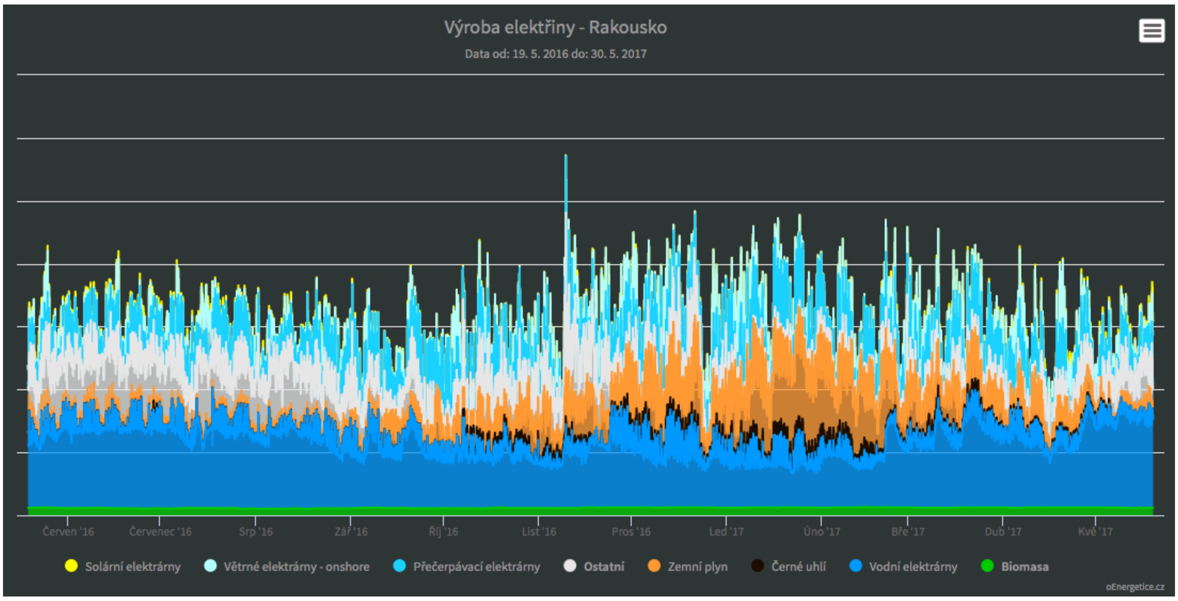


Figure 3 - Energy production in Austria from 19. 5. 2016 till 19. 5. 2017, source: oEnergetice.cz/energostat [2]

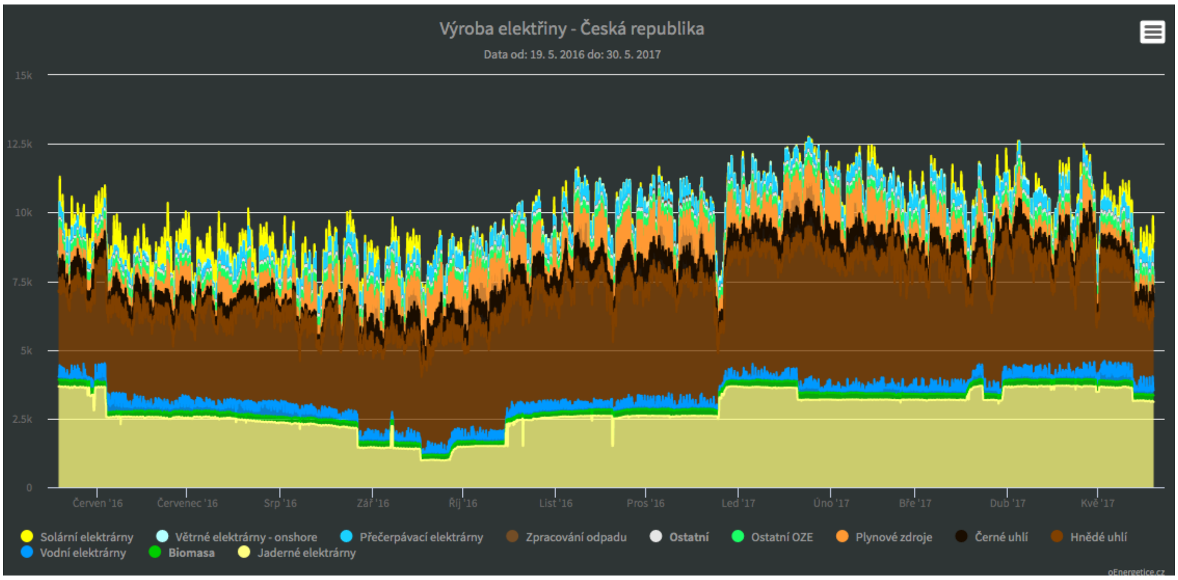


Figure 4 - Energy production in the Czech Republic from 19. 5. 2016 till 19. 5. 2017, source: oEnergetice.cz/energostat [2]

As well as the daily basis diagrams were used to illustrate the differences between days, the yearly diagrams are used to illustrate the differences between months, mostly based on the time of sunlight and average temperature and thus heating power needed.

The peaks are made of daily peaks and power generated by intermittent sources of energy.

All those are the main reasons for us to use storage, **short term storage** for daily basis fluctuation (see Figure 1 and 2) and weather conditions, and **long term storage** for weekly or monthly basis, depending on the available capacity of storage systems.

2.4. Future vision of electricity consumption and production

As it was mentioned before, there are two options for the future that are becoming real:

- **Demand control** when smart grids can control the energy consumption of energy highly consumptive activities, as well as washing, heating, water heating => activities not based on actual moment need, but based on long lasting states, and especially heating/cooling consumes a lot of energy that we can use for demand shifting (see chapter 3.1.)
- **Supply uncotrol** when renewable energy sources are a good way to decarbonisation, but not a good energy source in the meaning of accurate production when their production is intermittent (solar, wind).

So when the production varies a lot more than today, we need storage, and consumption control can help us a lot to be energy efficient and thus having not only carbon clean energy, but also save a lot of energy at all, and meet our environmental goals.

2.5. Hypothesis of CR and Austrian comparison

As well as we also compare two countries in this project: Austria and the Czech Republic, the hypothesis based on the geographical data we know is, that there are a lot of possibilities in Austria to store energy in snow and glaciers (natural storage in the Norwegian way – see chapter 4.4) as long term storage and hydro powered plants with dams as shorter term storage because of its large capacity, long lasting and safe technology that is friendly to the environment. It is necessary also to mention that those dams can be connected with tunnels and rebuilt to pumped hydro powered plants (as in Norway).

But the Czech Republic has no glaciers nor high mountains, so for now we have two big PHS plants, but otherwise a lot needs to be done for safe future in the energy sector, however, we are still waiting for the technologies to become cheaper before installing them, so I believe in a few more PHS plants and batteries, as well as usage of old mines (gravity modules or PHS maybe) for coal and metals.

3. STORAGE OPTIONS AND COMPARISON

3.1. Storage categories/applications

Energy storage technology absorbs energy, stores it and then, after a certain period of time, secures its return to the system or directly to the final consumer. This process makes it possible to overcome the time or geographical differences between production and consumption, both on a large scale and on a small scale. Usage covers a wide range of energy systems from centralized systems to autonomous areas and objects.

In the past, energy storage sources have been installed primarily to exploit volatile energy demand. The current increased emphasis on decarbonisation of the energy sector points to the use of these resources to increase the efficiency of energy processes (for example, the use of waste heat through heat accumulation) and to support the development of renewable energy plants with fluctuating production - photovoltaic and wind power plants.

Energy storage is used across the energy sector - in the power grid, district heating and cooling systems, scattered and off-grid applications. However, not only supply and demand fluctuation satisfaction is the reason for energy storage usage, but the categories/possibilities of usage of energy storage are also different possible: [1 – p10]

- **Seasonal storage (long term energy storage):** use of energy storage capacities for days, weeks or months to compensate interrupted energy supplies or for changes in supply and consumption of a given type of energy in the long term (eg heat storage in the summer of its subsequent use in winter for underground storage of heat energy or snow storage in Norway used in summer to produce energy from hydro powered plants).
- **Stored energy trading:** storage of cheap energy in a low demand period and its subsequent sale at a higher price in times of increased demand, usually on a daily basis, when good example from the past would be pumped hydro power plants combined with nuclear power plants.
- **Frequency control:** automatic balancing of electricity generation and consumption to maintain frequency in the specified band.
- **Voltage regulation:** absorption or injection of reactive power from / into the transmission and distribution system to maintain the required voltage.
- **Black start availability:** when all the support mechanisms fail, followed by so-called blackout, the ability to get out of the dark is the ability to move, reach a given voltage and connect to a network without supporting from an external source.
- **Transmission and distribution system relief / deferring infrastructure investment:** using time and / or geographical shift of production or consumption to relieve the transmission and distribution system or to defer the need for large investments in infrastructure.
- **Demand shifting and reducing peak load (short term storage):** changing the time of certain activities with high energy needs (eg heating or water heating).

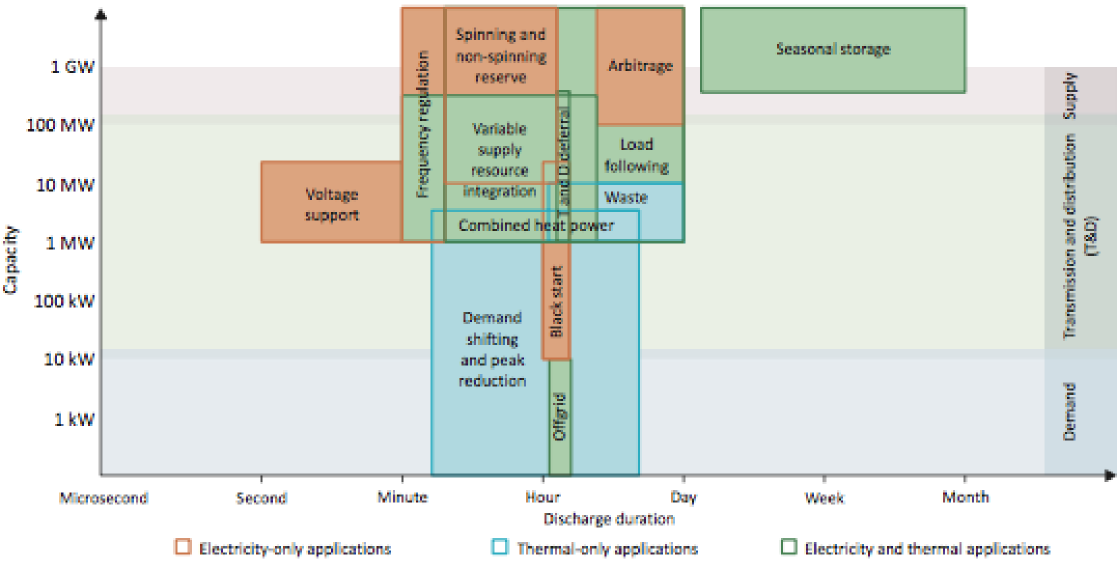
- **Off-grid consumption:** consumers not connected to the system often use fossil and intermittent renewable sources to acquire heat and power. Accumulation of energy ensures the possibility of economic and continuous energy supply.
- **Integration of intermittent energy sources:** use of energy accumulation to change and optimize the performance of intermittent sources (eg sun, wind), suppression of sudden and seasonal power changes, management of production balance and energy consumption.
- **Waste heat utilization:** use of energy storage technologies to temporarily and geographically separate heat production (eg cogeneration power plants, condensing power plants) and consumption (for example, central heat supply systems).
- **Combined generation of electricity and heat:** storage of electrical and thermal energy in order to bypass the gap between the production time and the time of electricity and heat consumption.

Application	Output (electricity, thermal)	Size (MW)	Discharge duration	Cycles (typical)	Response time
Seasonal storage	e,t	500 to 2 000	Days to months	1 to 5 per year	day
Arbitrage	e	100 to 2 000	8 hours to 24 hours	0.25 to 1 per day	>1 hour
Frequency regulation	e	1 to 2 000	1 minute to 15 minutes	20 to 40 per day	1min
Load following	e,t	1 to 2 000	15 minutes to 1 day	1 to 29 per day	<15min
Voltage support	e	1 to 40	1 second to 1 minute	10 to 100 per day	millisecond to second
Black start	e	0.1 to 400	1 hour to 4 hours	< 1 per year	<1 hour
Transmission and Distribution (T&D) congestion relief	e,t	10 to 500	2 hours to 4 hours	0.14 to 1.25 per day	>1hour
T&D infrastructure investment deferral	e,t	1 to 500	2 hours to 5 hours	0.75 to 1.25 per day	>1hour
Demand shifting and peak reduction	e,t	0.001 to 1	Minutes to hours	1 to 29 per day	<15 min
Off-grid	e,t	0.001 to 0.01	3 hours to 5 hours	0.75 to 1.5 per day	<1hour
Variable supply resource integration	e,t	1 to 400	1 minute to hours	0.5 to 2 per day	<15 min
Waste heat utilisation	t	1 to 10	1 hour to 1 day	1 to 20 per day	< 10 min
Combined heat and power	t	1 to 5	Minutes to hours	1 to 10 per day	< 15 min
Spinning reserve	e	10 to 2 000	15 minutes to 2 hours	0.5 to 2 per day	<15 min
Non-spinning reserve	e	10 to 2 000	15 minutes to 2 hours	0.5 to 2 per day	<15 min

Sources: IEA (2014a), *Energy Technology Perspectives*, forthcoming, OECD/IEA, Paris, France. EPRI (Electric Power Research Institute) (2010), "Electrical Energy Storage Technology Options", Report, EPRI, Palo Alto, California. Black & Veatch (2012), "Cost and performance data for power generation technologies", *Cost Report*, Black & Veatch, February.

Figure 5 - Characteristics of storage systems in the energy system, source: [1 – p9]

As also the previous table shows, those means of energy storage can be divided based mainly on the power they provide and the discharge duration, which could be also represented by diagram for better understanding of what we are searching for based on the needs in the grid:



Sources: modified from IEA (2014), Energy Technology Perspectives, OECD/IEA, Paris, France. Battke, B., T.S. Schmidt, D. Grosspietsch and V.H. Hoffmann (2013), "A review and probabilistic model of lifecycle costs of stationary batteries in multiple applications", *Renewable and Sustainable Energy Reviews* Vol. 25, pp. 240-250. EPRI (Electric Power Research Institute) (2010), "Electrical Energy Storage Technology Options", Report, EPRI, Palo Alto, CA, United States. Sandia National Laboratories (2010), *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide, A Study for the DOE Energy Storage Systems*, Albuquerque, NM and Livermore, CA, United States. IEA-ETSAP (Energy Technology Systems Analysis Programme) and IRENA (2013), "Thermal Energy Storage", Technology Brief E17, Bonn, Germany.

Figure 6 - Power requirement versus discharge duration for some applications in today's energy system, source: [1 - p14]

3.2. Energy storage technologies

Energy storage technologies can be mainly divided into potential energy based and heat based technologies, but we also have kinetic and chemical based technologies to store energy. However, not all of them are commonly used, as the following figure shows their state on the way from laboratories to real usage:

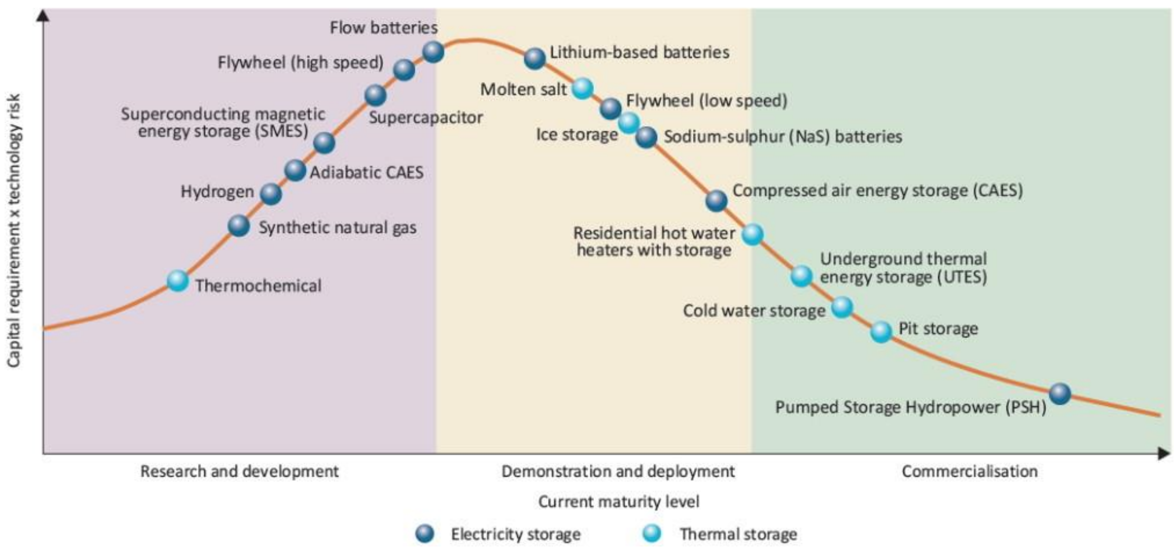


Figure 7 - Development of energy storage technologies, source: IEA 2014 [1]

As there is a lot of technologies available, a list and their technical basis follows: [1]

- **Pumped storage hydropower (PSH) /potential energy based storage/:** use energy storage at a time of low consumption in the form of potential water power for use at peak times. The water is pumped from the bottom tank into the upper tank, with the consumption of electricity. Subsequently, at the time of the peak, water is let into the inlet pipes and power is generated by driving the turbine, which shaft is connected to the generator. Most of those are large scale projects.
- **Underground heat storage (UTES) /heat energy based storage/:** A pump-driven system for storing heated or chilled water in an underground storage for later use. Trays can be artificially created or natural.
- **Compressed Air Accumulation (CAES) /preassure based energy storage/:** use of electrical energy at a time of low power to compress air and then store it in underground caverns or reservoirs. Compressed air is used in the peak for combustion in a gas turbine for the production of electricity.
- **Pit Storage System:** use of a deep pit filled with a mixture of water and earth and covered with a layer of insulating material. Water is pumped /pumped to/ from the pit when providing heating or cooling.
- **Molten salt accumulation /heat based energy storage/:** the salts used are solid at normal temperatures and atmospheric pressure. After heating (for example, in a solar power plant with a central tower), the molten salt is used to produce water vapor that drives a turbine in the production of electricity or is stored in a liquid state for later use.
- **Battery /chemical based energy storage/:** charging causes the current to flow through reversible chemical changes, which are manifested by different potential on the electrodes. This potential difference (voltage) can be used in discharging mode to draw battery power (such as lithium-ion, lithium-polymer, sodium-sulfur, lead-acid) in the meaning of direct current.
- **Thermochemical Storage:** recurrent chemical reactions in which energy is absorbed and released by breaking or re-creating molecular bonds.
- **Hydrogen accumulation:** utilization of hydrogen, obtained for example by electrolysis, as energy carrier. Electricity is transformed, stored and then used in the required form - for example, electricity, heat, liquid fuel.
- **Flywheels**: high-speed mechanical devices in which energy is stored in the form of rotational (kinetic) energy. Saved energy is later reused when the flywheel decelerates. The process of generating electricity is characterized by high power and short duration.
- **Supercapacitors**: electricity is stored in an electrostatic field between two electrodes. This technology allows fast power storage and discharging.
- **Surveillance Coils (SMES):** storage of electrical energy in a magnetic field that is created by passing a direct current through a superconducting coil. Supervision is

achieved by strong chilling of the conductor to a temperature where the material exhibits near zero resistances, allowing long-term current flow at almost zero energy losses.

- **Accumulation into solid media**: saving energy for later use in the area of heat and cold supply. In many countries, electric heaters contain a solid medium (eg concrete or bricks) to control power consumption.
- **Ice Storage:** storage in the form of latent heat, in which the material changes its state and on the basis of these changes, stores or releases energy.
- **Tanks with hot or cold water:** are used to meet the need for heat and cold. Typical examples of use are isolated hot water tanks in domestic installations as part of the boiler.

3.3. Energy storage technology comparison

Technology	Location*	Output	Efficiency (%)	Initial Investment cost (USD/kW)	Primary application	Example projects
Thermochemical	Supply, demand	Thermal	80 - 99	1 000 - 3 000	Low, medium, and high-temperature applications	TCS for Concentrated Solar Power Plants (R&D)
Chemical-hydrogen storage	Supply, demand	Electrical	22 - 50	500 - 750	Long-term storage	Utsira Hydrogen Project (Norway), Energy Complementary Systems H2Herten (Germany)
Flywheels	T&D	Electricity	90 - 95	130 - 500	Short-term storage	PJM Project (United States)
Supercapacitors	T&D	Electricity	90 - 95	130 - 515	Short-term storage	Hybrid electric vehicles (R&D phase)
Superconducting magnetic energy storage (SMES)	T&D	Electricity	90 - 95	130 - 515	Short-term storage	D-SMES (United States)
Solid media storage	Demand	Thermal	50 - 90	500 - 3 000	Medium temperature applications	Residential electric thermal storage (USA)
Ice storage	Demand	Thermal	75 - 90	6 000 - 15 000	Low-temperature applications	Denki University (Tokyo, Japan) , China Pavilion project (China)
Hot water storage (residential)	Demand	Thermal	50 - 90	**	Medium temperature applications	Peak demand reduction (France), TCES (United States)
Cold-water storage	Demand	Thermal	50 - 90	300 - 600	Low-temperature applications	Shanghai Pudong International Airport (China)

Technology	Location*	Output	Efficiency (%)	Initial Investment cost (USD/kW)	Primary application	Example projects
PSH	Supply	Electricity	50 - 85	500 - 4 600	Long-term storage	Goldisthal Project (Germany), Okinawa Yanbaru Seawater PSH Facility (Japan), Pedreira PSH Station (Brazil)
UTES	Supply	Thermal	50 - 90	3 400 - 4 500	Long-term storage	Drake Landing Solar Community (Canada), Akershus University Hospital and Nydalen Industrial Park (Norway)
CAES	Supply	Electricity	27 - 70	500 - 1 500	Long-term storage, arbitrage	McIntosh (Alabama, United States), Huntorf (Germany)
Pit storage	Supply	Thermal	50 - 90	100 - 300	Medium temperature applications	Marstal district heating system (Denmark)
Molten salts	Supply	Thermal	40 - 93	400 - 700	High-temperature applications	Gemasolar CSP Plant (Spain)
Batteries	Supply, demand	Electricity	75 - 95	300 - 3 500	Distributed/ off-grid storage, short-term storage	NaS batteries (Presidio, Texas, United States and Rokkasho Futamata Project, Japan), Vanadium redox flow (Sumimtomo's Densetsu Office, Japan), Lead-acid (Notrees Wind Storage Demonstration Project, United States), Li-ion (AES Laurel Mountain, United States), Lithium Polymer (Autolib, France)

Note: see IEA Energy Storage Technology Annex for more information. www.iea.org/publications/freepublications/publication/name,36573,en.html.

* Typical locations in today's energy system. These locations may change as the energy system evolves.

** Energy storage capabilities present in hot water storage tanks can be utilised for negligible additional cost.

Sources: IEA (2014a), *Energy Technology Perspectives*, forthcoming, OECD/IEA, Paris, France. IEA (2011), *Technology Roadmap: Energy Efficient Buildings: Heating and Cooling Equipment*, OECD/IEA, Paris, France. Black & Veatch (2012), "Cost and performance data for power generation technologies", *Cost Report*, Black & Veatch, February. EPRI (Electric Power Research Institute) (2010), "Electrical Energy Storage Technology Options", Report, EPRI, Palo Alto, California. Eyer, J. and G. Corey, (2010), "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide", Sandia National Laboratory, Albuquerque, NM, United States. IEA-ETSAP and IRENA (2013), "Thermal Energy Storage" *Technology Brief E17*, Bonn, Germnay. IEA-ETSAP (Energy Technology Systems Analysis Programme) and IRENA (International Renewable Energy Agency) (2012), "Electricity Storage",*Technology Policy Brief E18*, Bonn, Germany. "Power Tower Technology Roadmap and Cost Reduction Plan", Sandia National Laboratories (2011), Albuquerque, NM and Livermore, CA, United States.

Figure 8 - Energy storage technologies: Current status and typical locations in today's energy system, source: [1 - p19]

3.4. Energy storage installed power statistics

Although there are data that quantifies global energy accumulation, attempts to detail the total installed power generation performance in the area of energy storage encounter problems such as the lack of available data, the conflict of energy-related definitions, and others.

Data that can be traced and can be used as a starting point is the world's total installed power in the storage of electricity. These show that at least 140 GW of installed power in energy storage systems is part of the power grid. The majority of used technology is PSH (99%). The remaining one percent holds batteries, CAES, flywheels and hydrogen accumulation. Graphically these data are processed in the following graph (values given in MW) showing also that there is a lot space for future development. [1]

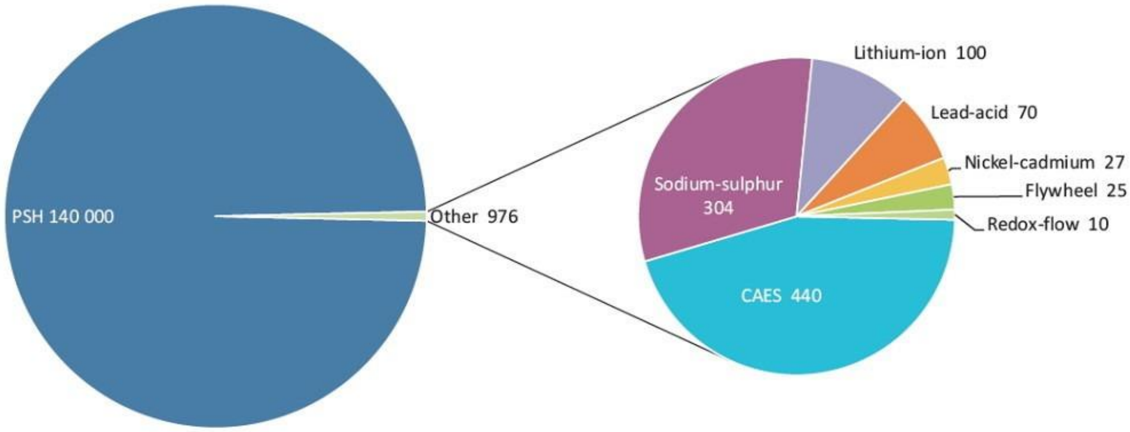


Figure 9 - Installed capacity of energy storage in 2014, source: IEA – Technology Roadmap: Energy Storage (2014) [1]

3.5. Future vision of energy storage technologies and installed capacity

Innovation and development of energy storage technologies have produced significant cost reductions and performance improvements, especially in batteries and power-to-gas technologies. This progress has increased the possible areas where energy storage can be applied at the same time as there is an increase in the needs for various services in the electricity system. Energy storage technologies could therefore provide alternatives to conventional solutions, and could help achieve the Energy Union's objectives.

The cost of the energy storage systems, their reliability and functionality can be tackled by research and innovation in terms of improved materials and technology demonstration with utility scale field tests. Further progress will require even greater research and innovation efforts and identification of new solutions.

However, the energy market is changing rapidly and it is difficult to distinguish next steps. If energy storage has to be economical, energy price difference is needed, the higher, the better for energy storage as technology in the meaning of stored energy usage, but as mentioned before, there are also some system services provided by storage that is benefitial for the grid system. (see chapter 3.1.)

Energy storage provides benefits through flexibility and through the possibility of better linking of various energy and economic sectors. It also provides benefits in terms of energy security.

The recognition of the benefits and complexity of energy storage solutions indicates a promising path towards an integrated low-carbon energy system, but the investments need to reach payback.

Based on the data we proposed, we think for the future:

- Storage will be needed more and more in the future as system service working together with renewable (intermittent) energy sources on the way to low carbon energy in a sustainable way to the future.
- Several technologies of storage are going out of the laboratories and their technical limitations and advanatges together with investment and running costs will make them real or not in the market with its needs of power and time of the discharge for system providing service.
- Storage technologies can vary a lot in the meaning of capacity, response and available power. According to this their usage as short term or long term storage can be established.
- The biggest stoarge yet used is pumped hydro storage, which has around 99 % of the capacity yet available. The reason is that chemical/thermochemical and other technologies are too new, and on the other water storage is weel known technology for a long time, also mainly built in large scale.

4. REGIONAL COMPARISON

4.1. Austria

Austria has significant hydro pumped storage capacity, which has been increasingly in use over the past decade. Total electricity in pumped storage was 5.6 TWh in 2012, more than twice the volume of 2.6 TWh stored in 2002.[6]. This increase coincides with higher imports, as water is often pumped back up to the storage by using cheap excess electricity from neighboring countries, particularly from Germany.

Generation component/type			Allocated power plant and other power plants			
			Number	Capacity (MW)	Generation (GWh)	Number of hours used
Hydropower plants	Run-of-river	> 10 MW	90	4 433	21 024	4 743
		< 10 MW	601	782	4 252	5 440
	Reservoir hydro, including pumped storage	> 10 MW	67	7 615	11 996	1 575
		< 10 MW	44	150	429	2 857
	Other small hydro		1 869	220	0	N.A.
	Total hydro		**2 671**	**13 200**	**37 701**	**2 856**
Thermal pop-up plants	Hard coal		4	1 171	5 315	4 539
	Derivatives		7	444	1 931	4 349
	Petroleum derivatives		11	362	1 179	3 260
	Natural gas		64	5 102	11 556	2 265
	Biomass		103	401	2 345	5 841
	Other		394	769	3 506	6 635
	Total thermal		**583**	**8 249**	**25 832**	**3 132**
Renewables	Wind, PV, geothermal		198	1 107	1 985	1 793
	Other renewables		10 375	72	0	N.A.
	Total renewables		**10 573**	**1 179**	**1 985**	**1 683**
Total			**13 827**	**22 628**	**65 518**	**2 903**

Source: Energie-Control Austria.

Figure 10- Electricity generation capacity by energy source, 2011[6]

Austria's Alpine location allows for abundant hydroelectric resources, which account for around 64% of the country's power input. Additional electricity sources are well diversified, with natural gas, coal and biomass accounting for 14.1%, 9.1% and 7.6% of total electricity supply in 2011, respectively, with wind (3.6%) and oil (1.1%) also contributing marginal amounts to the energy mix. Austria's energy-intensive industrial sector accounts for more than 44% of the total electricity demand. Residential demand accounts for a further 27.9% of electricity demand, and the commercial and services sector for 22.5%.[6]

4.2. Czech Republic

As also anywhere else on the world, the main (99 % of capacity) storage providing technology is pumped hydro powered plants in the Czech Republic. And as mentioned in the introduction, their production is rising in last years: [3]

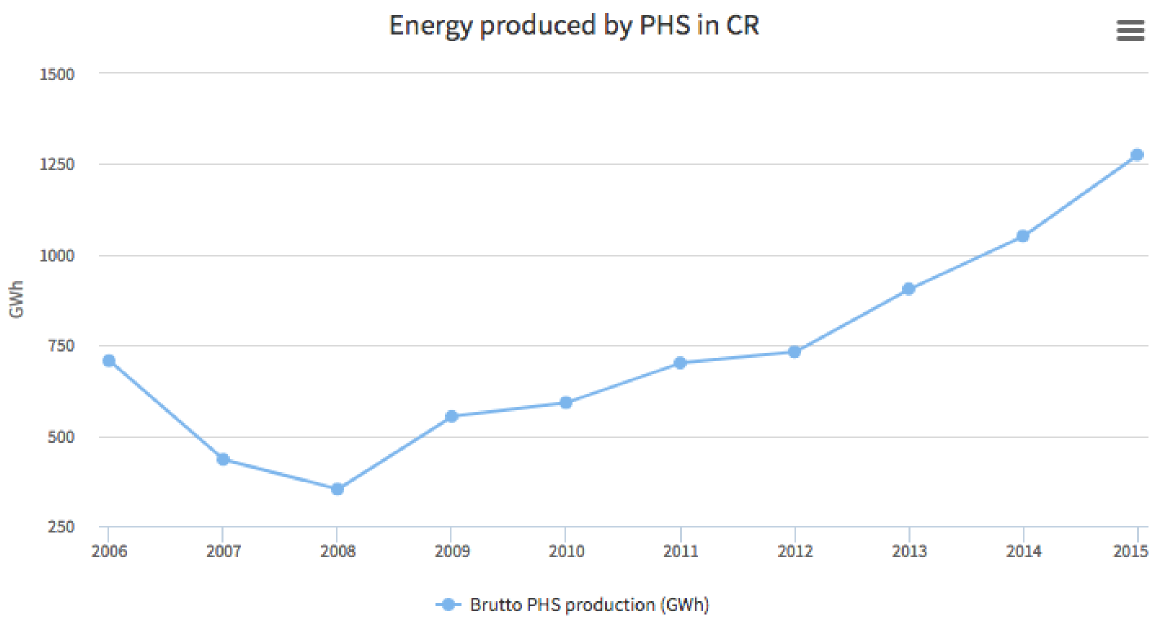


Figure 11 - Energy produced by PHS in CR

There was a PHS already in 1930 with available power of 1.5 MW with name "Cerne jezero" in the southern mountain range called Sumava / Bohmerwald. However its pumping regime is limited since 1960, but all the buildings still exist and maybe if it is profitable, a restoration and operation is possible still, even though it is a National Park.

Second PHS was built on the Polish border in 1938 with name Pastviny (Orlicke hory), but later was rebuilt into classic hydropower plant that works until now and I havent fund data if the pumping equipment was deconstructed or if it only needs profitable state to be restored and open again. [3]

From the ones still operating nowadays, all have reversible Francis turbine, Stechovice is the smallest one with power of 45 MW, situated around 30 km to the south from Prague. It was built in 1947 and reconstructed in 1996, and uses the height difference of 209.8 - 219.5 m. [3]

The main capacity is provided by two big PHS plants:

- Dalesice is a part of complex of nuclear power plant Dukovany, built in 1978 and reconstructed in 2007. It has 4 turbines of 120 MW, so overall power of 480 MW with height difference between dams 60 – 90 m. [3]

Figure 12 - plant Dukovany

- The biggest one is also the most famous one because of its design – Dlouhe Strane. This powerplant has two biggest reversible Francis turbines in Europe: 325 MW, and was built in 1996 (started in 1978, but stopped for some time in 1980s). According to its famous upper reservoir built on top of one of the mountains in Jeseniky, it has become a tourist attraction except of providing electricity services. It is able to reach maximal power in 100s and work for 6 hours. [3]

Figure 13 - Dlouhe Strane

Except of those mentioned power plants, there are also several project as plans or being tested for near future:

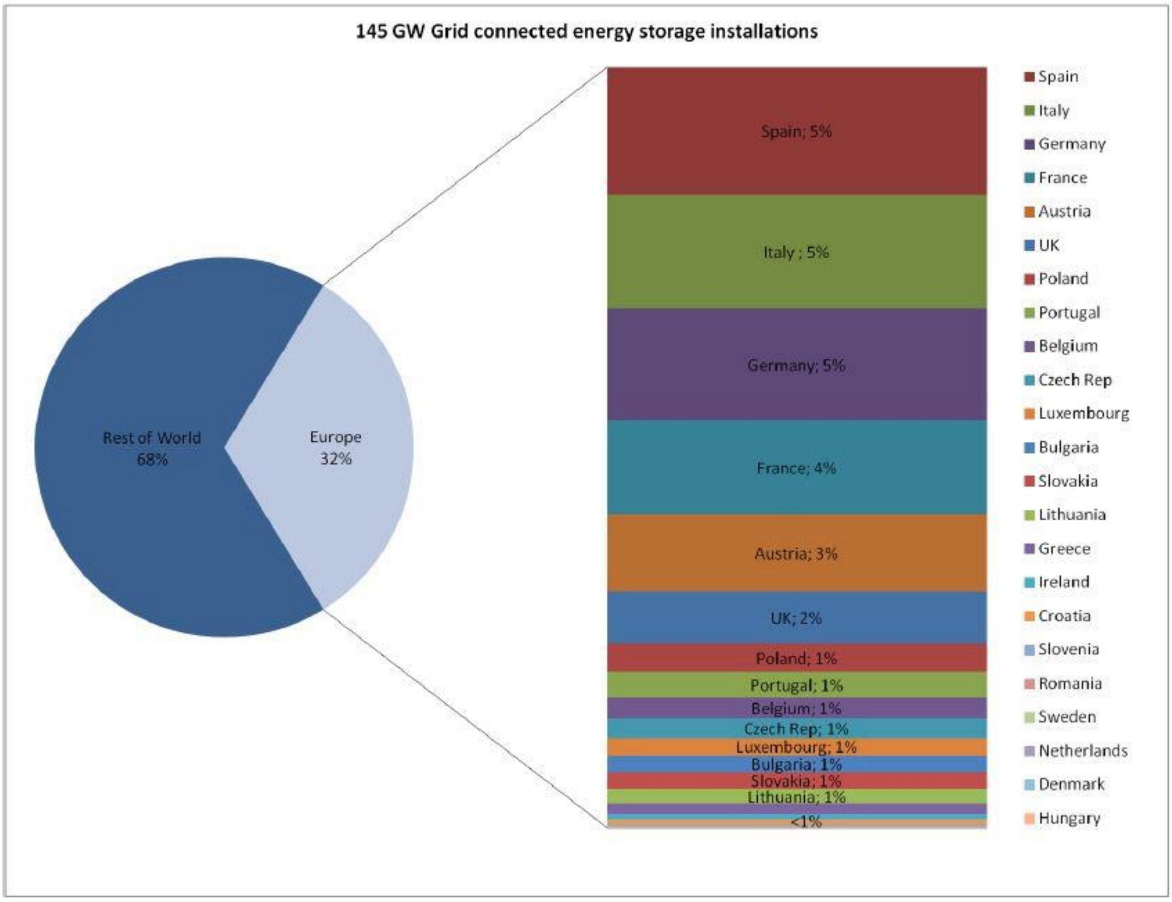
- The main energy company CEZ has done environmental impact assesment for building another PHS called Orlik (now classic hydropower plant) in 2013, but based on high investment costs and not sure fure, hasn't started of building it, as well as no reconstruction of above mentioned old PHS hasn't started.
- When parts of the state used to be rich in coal that was mined there, also some projects concerning this have started: there is a 650 kW PHS for scientific usage with a possibility to become commercial technology for mined areas, where usually upper reservoir is needed in the mountains to gain height difference, but here the lower reservoir can be underground. This technology is also concerned in Germany (Duisburg/Essen, mine Prosper- Haniel) as well as gravity modules technology also usable in old mines. [4]
- Battery storage is becoming famous but since the investment costs and operational limitations are making it not a best technology to be used, tehre is only 1 battery storage of 1 MW and capacity of 1 MWH built by EON in CR. [5]

Based on the mentioned data in the introduction and actual state and geographical conditions I believe that Orlik PHS will be built and also the old ones restored (the investment costs for restoration where the tunnels and buildings already exist are much lower than building new 2 reservoirs and all the infrastructure).

Since there already is a lot of old mines in the Czech Republic, I am glad that there is the experimental PHS in Ostrava, because this technology could be also used in a lot of other places and could be also exported to Germany and other places in the world as a recultivation possibility for old mines.

4.3. General comparison in the EU

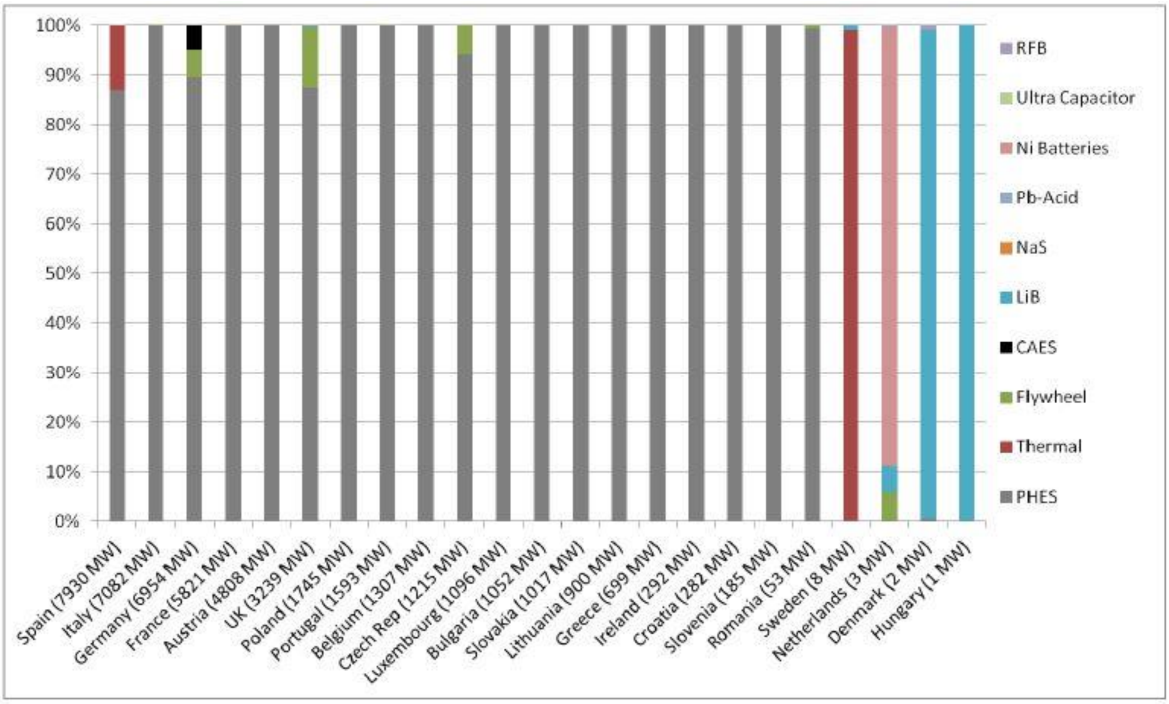
At present, the installed energy storage capacity connected to the grid in Europe is higher than 50 GW. Around 95% of this storage capacity is based on PHS installations. Worldwide, the situation is similar with around 98% of the capacity based on PHS. Globally, PHS capacity has grown at a pace of 2.7% in recent years to 145 GW today. The share of energy storage systems other than PHS has grown from below 1% in 2005 to more than 1.5% in 2010 and 2.5% in 2015 (a more than 10% growth rate) (IEA, 2015b), (DOE, 2015). Figure 7 shows the current share of installed storage capacity in the EU and in individual Member States.[16]



Source: (DOE, 2015).

Figure 14-*Share of EU and Member States grid connected storage installations*

Figure 14 shows the technology portfolio by size and share for different EU Member States. Figure 15 shows the European wide (grey) and worldwide (black) share of installed grid connected energy storage power by technology vs. the growth rate of new installations in the last 5 years. PHS is dominating but growth rates are higher for other technologies. In Europe, electrochemical and thermal storage technologies as grid-connected storage technologies are currently growing in importance compared to worldwide developments. The reason for the growth of thermal storage (e.g. molten salts) is the connection to Concentrated Solar Power (CSP) plants, especially in Spain. A reason for the particular growth of LIB and RFB compared to other battery technologies is the very high potential for technology improvement and cost reduction. Other batteries and capacitors show high growth rates, but the share of these technologies in the European energy storage portfolio is lower. Growth rates for CAES and Flywheel storage are low. Bulk storage like PHS and also natural gas storage can cover the demand for seasonal variations, but are not suitable solutions for the increasing role of fluctuating renewable energies (wind and solar). Certain battery systems could meet some of these needs as soon as technologies get mature and their costs decline sufficiently.



Source: (DOE, 2015).

Figure 15 - Grid connected storage installations and technology share in the EU

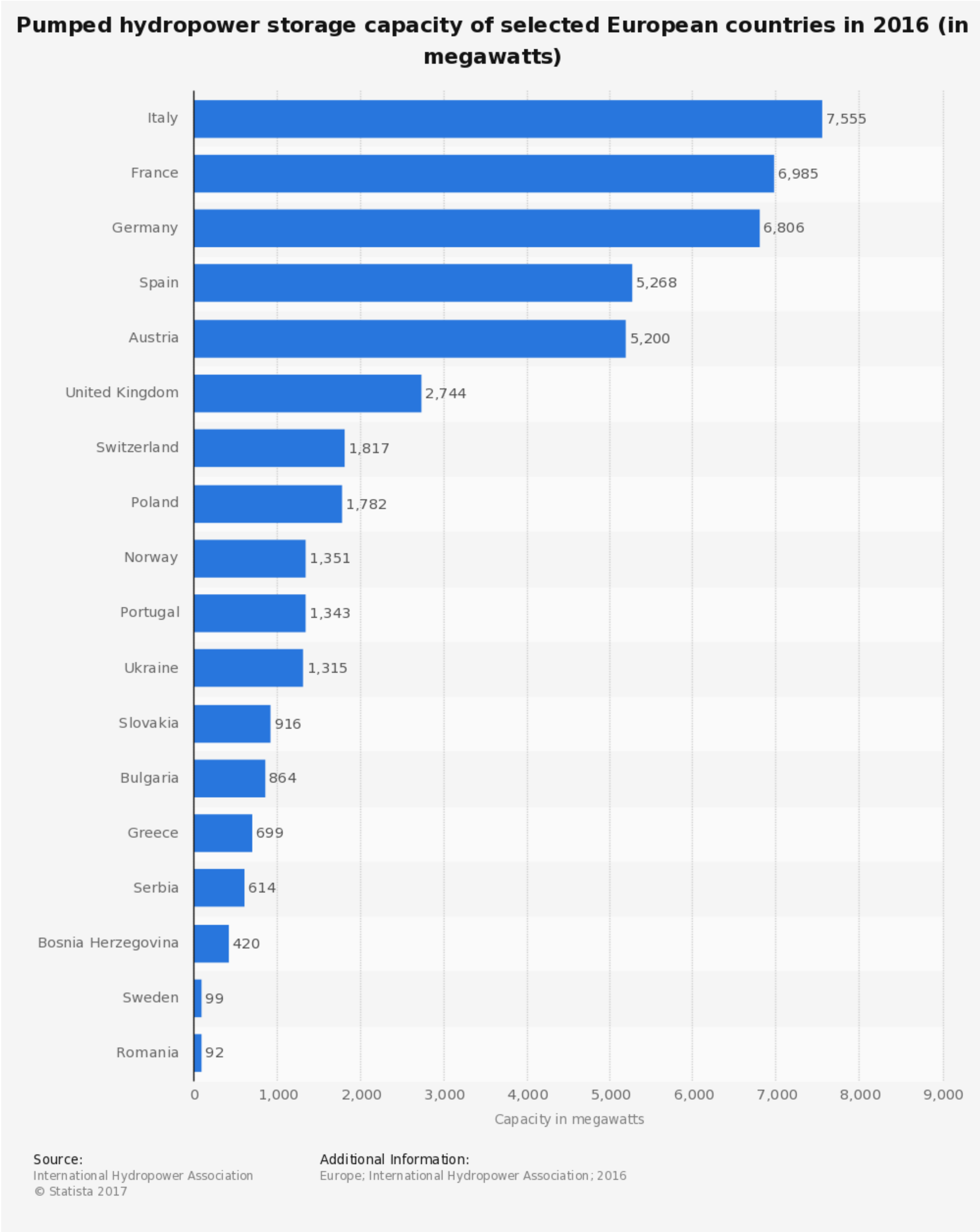


Figure 16 - **Share of installed grid connected energy storage by 2014 vs. annual growth rate of installations from 2010-2014.[statista.com]**

Investment needs for storage scenario to 2050

The level of investment required in electricity storage technologies varies the different scenarios, from an estimated USD 380 billion in the four regions modelled in the EV scenario to USD 590 billion in the 2DS and USD 750 billion in the breakthrough scenario. Capital costs for electricity storage technologies are assumed to be USD 1 500/ kW and USD 50/kWh in the 2DS and EV scenario, while in the breakthrough scenario they are assumed to be 1 200/KW and USD 30/kWh in 2050. These investment needs are just a fraction of the USD 18 trillion investments needed in power generation in the 2DS in these four regions[14].

5. LONG AND SHORT TERM STORAGE OPTIONS AND LIMITATIONS

Short-term (seconds-minutes) storage applications

Supercapacitors and SMES technologies use static electric or magnetic fields to directly store electricity. Flywheels store and then release electricity from the grid by spinning and then applying torque to its rotor to slow rotation. These technologies generally have high cycle lives and power densities, but much lower energy densities. This makes them best suited for supplying short bursts of electricity into the energy system. Modern technologies struggle in today's energy markets due to high costs relative to their market value.

Long-term (hours-seasons) storage applications

PSH are currently the most mature and widespread method for long-term electricity storage (IEA, 2012). In addition, two CAES facilities have been successfully used by utilities in the United States and Germany for several decades (Konidena, 2012). These technologies face high upfront investment costs due to typically large project sizes and low projected efficiencies for non-adiabatic CAES design proposals. In the case of pumped hydro and CAES, geographic requirements can lead to higher capital costs.

Today, there are two CAES systems in commercial operation, both of which use natural gas as their primary onsite fuel and are equipped with underground storage caverns. The larger of these two facilities is a 321 MW system in Huntorf, Germany. Commissioned in 1978, this system uses two caverns (300 000 m3) to provide up to 425 kilograms per second (kg/s) of compressed air (pressure up to 70 bars) produce efficiencies up to 55%. The other system, in McIntosh, Alabama, uses flue gas from its natural gas power plant for preheating to increase overall power plant efficiency (US DOE, 2013).

5. Conclusion

Besides the investment cost in terms of power (€/kW) and energy (€/kWh), the use over the lifetime (cycle and calendar lifetime) also has to be taken into account to determine which storage technologies are most suited for each application. The most suitable indicator to compare the different storage technologies is the levelized cost of energy storage (LCOE in €/kWh) which includes investment and use over full lifetime (e.g. costs for balance of plant, power conversion, operation and maintenance, replacement, recycling, discharge cycles and lifetime are typical factors to be included). Also, a number of factors considered in LCOE calculations depend on the application and the specific business case. LCOE assessments10 show that the most economic storage installations are PHS and large scale CAES. However, they have limited future cost reduction potential since they are mature technologies.

The Renewable Energy Directive (RED) stipulates priority access to the grid for electricity produced from renewable energy sources, but it does not give such operators any responsibility of contributing to system balancing.

Large-scale storage associated to centralized renewable energy production could effectively contribute to system adequacy. Large pumped hydro storage is cost competitive and already plays an important role in providing flexibility to the energy system. In the short term, there are no other storage technologies foreseen that can compete as well, but in the longer term, some other options could improve their business cases and become competitive. The profitability of large storage facilities has diminished in recent years due to the also decreasing spread of peak/base day-ahead prices.

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