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DG ENER Working Paper

The future role and challenges of Energy Storage

Energy storage will play a key role in enabling the EU to develop a low-carbon electricity system. Energy storage can supply more flexibility and balancing to the grid, providing a back-up to intermittent renewable energy. Locally, it can improve the management of distribution networks, reducing costs and improving efficiency. In this way, it can ease the market introduction of renewables, accelerate the decarbonisation of the electricity grid, improve the security and efficiency of electricity transmission and distribution (reduce unplanned loop flows, grid congestion, voltage and frequency variations), stabilise market prices for electricity, while also ensuring a higher security of energy supply.

Currently, there is limited storage in the EU energy system (around 5% of total installed capacity) almost exclusively from pumped hydro-storage, mainly in mountainous areas (Alps, Pyrenees, Scottish Highlands, Ardennes, Carpathians). Other forms of storage – batteries, electric cars, flywheels, hydrogen, chemical storage - are either minimal, or at a very early stage of development.

The Commission would like to give more attention to the issues around energy storage with a view to addressing them more effectively in EU energy policy. This paper considers the key questions which need to be considered in promoting energy storage development and deployment:

1. What is the role of energy storage in today's and tomorrow's energy system?
2. Why is storage becoming more important for energy policy?
3. At which level of electricity networks should storage be integrated?
4. What is the state of play for main storage technologies?
5. What are the barriers to further development and deployment?
6. Why is this an important issue for the EU?
7. How could the regulatory framework be adjusted to integrate storage better in the supply chain?
8. What can the EU do to enable the short and medium term development and deployment of storage at all levels?

1. What is the role of energy storage in today's and tomorrow's energy system?

Energy storage is essential to balance supply and demand. Peaks and troughs in demand can often be anticipated and satisfied by increasing, or decreasing generation at fairly short notice. In a low-carbon system, intermittent renewable energy (RES) makes it more difficult to vary output, and rises in demand do not necessarily correspond to rises in RES generation. Higher levels of energy storage are required for grid flexibility and grid stability and to cope with the increasing use of intermittent wind and solar electricity. Smart cities, a key energy policy goal, require smart grids and smart storage.

Energy storage is an established technology. Pumped Hydro Storage Systems (PHS) for large scale electricity storage represents almost 99 % of current worldwide storage capacity. **Pumped Hydro was attractive, and essential, when Europe's networks were mainly composed of a large number of regional grids with very weak interconnections.**

A German study showed that today a one hour error on the forecast of upcoming wind creates a need of 5 GW to 7 GW of electricity. This needs to be covered by electricity storage: gas fired power plants will be able to deliver the electricity within an hour or two; electricity storage has to deliver during this gap of time

Today, modern fossil fuel based power plants (and especially natural gas combined cycles) are becoming more and more flexible. Their ramping up speed in response to rapid changes in demand is increasing. They can provide reliable and flexible back-up power. **In the short term, therefore, electricity storage needs to fill the gap between the ramping down time of wind and solar and the ramping up time of these back-up plants.** The challenge is to increase existing storage capacities and increase efficiencies.

Gas storage is therefore closely linked to electricity storage. Some demand for storage, or seasonal variations in demand, can be covered by natural gas storage. Europe has an average gas storage capacity of some 51 days (see table below). Gas is an important fuel for electricity production and natural gas power plants have a very high efficiency (above 60% for the best available technology), a very high flexibility and low CO2 emissions (replacing an old coal fired power plant by a natural gas fired power plant reduces the CO2 emissions per kWh up to 80%. In the future, injection of biogas and hydrogen into the natural gas grid, and the longer term commercialisation of Carbon Capture and Storage will further decarbonise gas-powered generation).

Indeed, the expansion of natural gas fired power plants, the increased efficiency and the reduced costs of flexible combined-cycle and simple-cycle natural gas turbines combined with the strong and fast growing interconnection of the grid on an EU-level and falls in gas prices, have reduced the economic competiveness of pumped hydro storage. So, utilities are tending to rely on combined-cycle gas turbine systems.

Storage serves several purposes in today's power system

Application in power system / Functionalities of storage	Transmission grid-central storage (national and European level)	Distribution grid storage (city level)	End-user Storage (household level)
Balancing demand and supply	Seasonal / weekly fluctuations Large geographical unbalances Strong variability of wind and solar (electricity and gas storage need to be integrated)	Daily / hourly variations Peak shaving (electricity and heat/cold storage need to be integrated)	Daily variations (electricity and heat/cold storage need to be integrated)
Grid management	Voltage and frequency regulation Complement to classic power plants for peak generation Participate in balancing markets Cross-border trading	Voltage and frequency regulation Substitute existing ancillary services (at lower CO_2) Participate in balancing markets	Aggregation of small storage systems providing grid services
Energy Efficiency	Better efficiency of the global mix, with time-shift of off-peak into peak energy	Demand side management Interactions grid-end user	Local production and consumption Behaviour change Increase value of PV and local wind Efficient buildings Integration with district heating /cooling and CHP

European and global energy policies based simultaneously on a reduction of CO_2 emissions, a shift towards intermittent renewable power while maintaining secure energy supplies changes the ground rules for storage and calls **for a new approach to storage as a key component of the future low-carbon electricity system.**

Decisions to invest into the development of storage and deployment of adequate storage capacity will depend on the evolution of the whole energy system. They are closely linked to developments such as (a) electricity super-highways with large-scale RES in North Sea and North Africa combined with distributed/regional RES solutions; (b) penetration of electric vehicles; (c) improvements in demand response/demand side management/smart grids.

	Maximum working volume (million m³)	Maximum withdrawal capacity per day (million m³)	Average days of storage (volume/capacity)
Austria	4744	58	82
Belgium	600	12	50
Bulgaria	600	4	150
Cyprus	0	0	0
Czech Republic	3127	52	60
Denmark	1020	18	57
Estonia	0	0	0
Finland	0	0	0
France	11900	200	60
Germany	21297	515	41
Greece	0	0	0
Hungary	6330	72	88
Ireland	230	3	77
Italy	14747	153	96
Latvia	2325	24	97
Lithuania	0	0	0
Luxembourg	0	0	0
Malta	0	0	0
Netherlands	5000	145	34
Norway			
Poland	1640	32	51
Portugal	159	2	80
Romania	2760	28	99
Slovakia	2785	39	71
Slovenia	0	0	0
Spain	2367	13	182
Sweden	9	1	9
Switzerland	0	0	0
Turkey	2661	18	148
UK	4350	86	
Total EU-27 plus Switzerland, Turkey	**88651**	**1475**	**51**

Courtesy: Eurogas, statistical report 2011

In addition, the main energy storage functionalities such as Energy time-shift, Quick energy injection and Quick energy extraction are expected to make a large contribution to security of power supplies, power quality and minimisation of direct costs and environmental costs.

The greatest need for electricity is for a few hours only, providing gas generation or turbines are available quickly and in adequate volumes, for example at times of zero wind or PV (e.g. the cold period in Europe in January 2012). Of vital importance is the ramping up/ramping down of wind-based electricity and the ramping up of storage systems and (usually natural gas based) back-up power. Back-up power is usually to slow to compensate for rapid ramping up/down of wind. In the future, as wind and PV increase their share of supplies, electricity system, storage systems will have to be very fast and cover the intermediate period between the falling off the wind and the coming on-line of any back-up capacity.

Therefore, the dynamic behaviour of storage is even more important than its long term capacity. This is indicated in Table 1 (source: JRC) in the power rating, the energy rating and the response time, whereas the capacity (in kWh) is considered of lesser importance.

2. *Why is storage becoming more important for energy policy?*

The need to promote more energy storage is related to the increase in intermittent wind and solar and to the demand peak increase.

When the intermittent renewable share is lower than 15% to 20 % of the overall electricity consumption, the grid operators are able to compensate the intermittency. This is not the case when the share exceeds 20-25%, as is reached at times in Denmark, Spain and Germany. When these levels of 25% and above are reached, intermittent RES need to be curtailed during the low consumption periods in order to avoid grid perturbation (frequency, voltage, reactive power) and grid congestion, unless the RES excess can be stored. Alternative resources – back-up and/or storage are needed when demand does not fall at the same time as the fall in RES generation.

Energy storage needs to be integrated in network-based energy systems, in the electrical grid system, heat and cooling network and gas networks. It can also provide an important contribution to the development and emergence of the Smart Grid concept at all voltage levels.

Energy storage can become an integrated part of Combined Heat and Power (CHP), solar thermal and wind energy systems to facilitate their integration in the grid.

The peak increase issue can also be solved where energy storage is available at different levels of the Electrical System: centralised energy storage as a reserve; decentralised storage in the form of demand management and demand response systems. In CHP district networks, the storage of heat (or cold) can be much more cost effective than the storage of electricity, if the CHP system is operated according to the electricity demand.

3. At which level of electricity networks should storage be integrated?

Energy storage can be integrated at different levels of the electricity system:

- Generation level: Arbitrage, balancing and reserve power , etc.
- Transmission level: frequency control, investment deferral
- Distribution level: voltage control, capacity support, etc.
- Customer level: peak shaving, time of use cost management, etc.

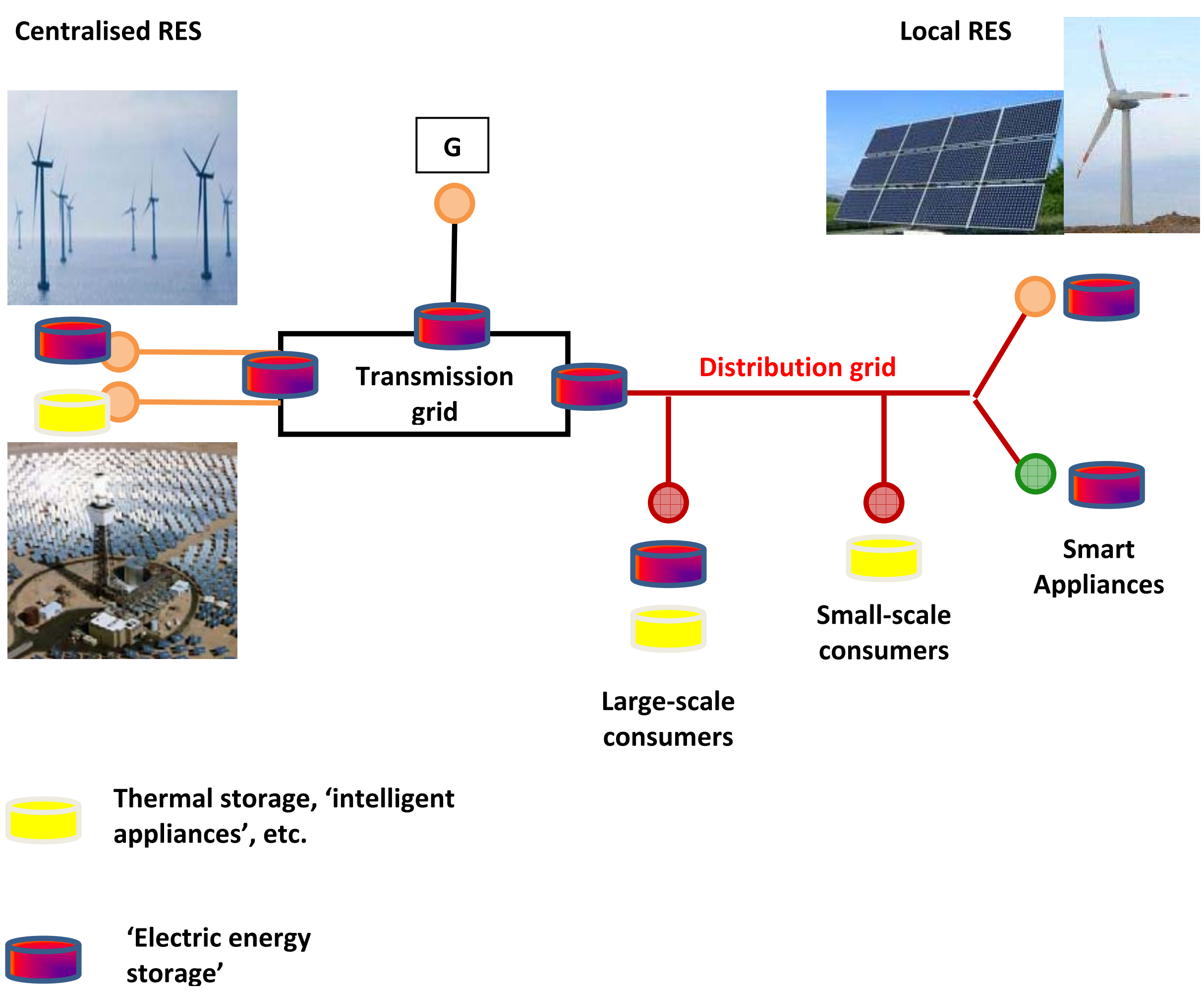
These different locations in the power system will involve different stakeholders and will have an impact on the type of services to be provided. Each location will provide a specific share of deregulated and regulated income streams.

Different energy storage systems will have to be considered (centralised and decentralised) and specific business models will have to be identified.

A localisation map will help to define the possible needs for regulatory change and incentives.

It is important to ensure that electricity from RES keeps its RES label, even if it has been stored before the final consumption. Possible feed in tariffs should not be affected by intermediate storage. Only the share of renewables at the point of pumping should qualify as renewable electricity.

In a future low-carbon energy system, storage will be needed at all points of the electricity system



4. What is the state of play for the main storage technologies?

Energy storage technology can serve at various locations at which electricity is produced, transported, consumed and held in reserve (back-up). Depending on the location storage can be large-scale (GW), medium-sized (MW) or micro, local systems (kW). **Research and technological development is needed to enable the wider application of many known technologies, and to develop new ones.** Some of the key technologies, not all of which are at the stage of commercial application are:

- **Large bulk energy (GW):**
  - Thermal storage, pumped hydro;
  - Compressed Air Energy Storage (CAES);
  - Chemical storage (e.g. hydrogen - large scale >100MW, up to weeks and months)

- **Grid storage systems (MW)** able to provide:
  - Power: super-capacitors, Superconducting Magnetic Energy Storage (SMES), flywheels,
  - Energy : batteries such as Lead Acid , Li-ion, NaS & Flow batteries
  - Energy & Power: LA & Li-ion batteries
  - Hydrogen Energy Storage / CAES / Pumped Hydro Energy Storage (PHES) (small scale, 10MW< P > 100MW, hours to days)

- **End-user storage systems (kW)**:
  - Power: super-capacitors, flywheels
  - Energy: batteries such as Lead acid and Li-ion
  - Energy & Power: Li-ion batteries

Table 2 and Annex 1 summarise the technical and economical features of power storage technologies.

Energy storage needs, and patterns of access are changing (e.g. not only driven by demand side variations). Technologies will need to respond accordingly. Storage capacity also depends on the size of the reservoir. This determines the time where this power is available. In the past, with one cycle per day, energy storage was rated mainly in GWh (energy capacity); today the same systems are used up to 10 and 20 times per day; the installed power in GW (given by the number and the size of the installed turbines) becomes more important, as the service requested has changed over the years. This dynamic behaviour of existing storage will increasingly move in the direction of quick and powerful response to the needs of the grid.

Storage technology	PHS	CAES	Hydrogen	Flywheel	SMES	Supercap	Conventional Batteries		Advanced Batteries			Flow batteries	
							Pb-acid	NiCd	Li-ion	NaS	NaNiCl ZEBRA	VRB	ZnBr
Power rating, MW	100-5000	100-300	0.001-50	0.002-20	0.01-10	0.01-1	0.001-50	0.001-40	0.001-0.1	0.5-50	0.001-1	0.03-7	0.05-2
Energy rating	1-24h+	1-24h+	s-24h+	15s-15min	ms-5min	ms-1h	s-3h	s-h	min-h	s-hours	Min-h	s-10h	s-10h
Response time	s-min	5-15 min	min	s	Ms	ms						ms	ms
Energy density, Wh/kg	0.5-1.5	30-60	800-104	5-130	0.5-5	0.1-15	30-50	40-60	75-250	150-240	125	75	60-80
Power density, W/kg			500+	400-1600	500-2000	0.1-10	75-300	150-300	150-315	90-230	130-160		50-150
Operating temp (°C)				-20 - +40		-40- +85				300-350	300	0-40	
Self-discharge (%/day)	~0	~0	0.5-2	20-100	10-15	2-40	0.1-0.3	0.2-0.6	0.1-0.3	20	15	0-10	1
Round-trip efficiency	75-85	42-54	20-50	85-95	95	85-98	60-95	60-91	85-100	85-90	90	85	70-75
Lifetime (years)	50-100	25-40	5-15	20+	20	20+	3-15	15-20	5-15	10-15	10-14	5-20	5-10
Cycles	$2x10^4$-$5x10^4$	$5x10^3$-$2x10^4$	10^3 +	10^5-10^7	10^4	10^4-10^8	100-1000	1000-3000	10^3-10^4+	2000-4500	2500+	10^4+	2000+
Power cost €/kW	500-3600	400-1150	550-1600	100-300	100-400	100-400	200-650	350-1000	700-3000	700-2000	100-200	2500	500-1800
Energy cost €/ kWh	60-150	10-120	1-15	1000-3500	700-7000	300-4000	50-300	200-1000	200-1800	200-900	70-150	100-1000	100-700

Note. The power price reported for hydrogen relates to gas turbine based generator. The power price for fuel cells is in range of 2 000-6 600 €/kW.
Sources: Schoenung and Hassenzahl, 2003; Chen et al., 2009; Beaudin et al., 2010; EERA, 2011; BNEF, 2011b; Nakhamkin, 2008.

Technical and economical features of power storage technologies [1] (see also Annex 1 for more details)

[1] JRC (2012) – 2011 Technology Map of SET Plan

5. *What are the barriers to further development and deployment?*

The main challenges for storage are

i) **technological**

- increasing capacities and efficiencies of existing technologies,

- developing new technologies for local (domestic), decentralised or large centralised application,

- and market deployment;

ii) **market and regulatory issues**

- creating appropriate market signals to incentivise the building of storage capacity and provision of storage services,

- building up a European-level market and common balancing markets, as exist in Nordic countries and between Germany and Austria,

iii) **strategic**

- developing a systemic or holistic approach to storage, bridging technical, regulatory, market and political aspects.

Above all, the main challenge for energy storage development is economic.

The economic and business case varies from case to case, depending, among other things, on where the storage is needed: generation, transmission, distribution or customer level. The benefits for users/operators is also closely linked to the question of storage location.

A number of uncertainties strongly affect the value assessment of energy storage:

- The existence of compensation schemes for storage: this is a key issue when some stakeholders are part of the regulated market (TSO's/DSO's) and the other are part of the deregulated market (e.g. producers and end customers)
- The potential to develop new and innovative business models: energy storage studies in both Europe and US demonstrate that the provision of a single service (e.g. kWh) was not sufficient to make the storage scheme cost effective; services such as frequency stabilisation and voltage stabilisation have a much higher commercial value.
- Ownership of the future energy storage systems whatever the location and the grid connection (Transmission or Distribution): should storage be owned by utilities or TSOs?

Another challenge is grid integration. Energy Storage should not be seen as a stand-alone technology. It will certainly compete and /or complement other ways to improve the grid flexibility. A whole package of integrated measures is needed:

- Large centralised and small decentralised storage
- Flexible generation systems (centralised and decentralised)
- Back-up capacity

- More cables: Transmission and Distribution grid upgrades are a vehicle for flexible sources and allows to share flexibility over a larger geographic area, including interconnections and interoperability of different smart energy networks (heat and electricity, demand side management and demand response

A further issue is overall system cost. One single solution will probably not be the most cost-optimal solution. A mix of all solutions is needed, tailored for each region and system architecture.

Another issue which present challenges to storage development are the future of the CO2 emissions framework, public acceptance of cables, grid access and investment priorities. If they are adequately addressed, the situation for energy storage could be considerably improved.

6. *Why is this an important issue for the EU?*

The development of a low-carbon electricity system, set out in the EU 2050 Energy Roadmap, requires Member States work together to optimise the different technologies, drive the necessary investments and to harmonise the different rules within the European energy market.

European energy storage development requires new, European rules to enable its speedy development while avoiding distortion in competition and allowing cross-border trading.

Installed Pumped Hydro Storage power capacity in Europe

	Pumped Hydro (MW installed end 2010)	Pumped Hydro (MW to be installed 2011-2015)
Italy	8,895	
Germany	7,326	74
Spain	5,657	1,270
France	5,229	
Austria	3,774	1,027
UK	3,251	
Switzerland	2,729	1,628
Poland	1,948	
Norway	1,690	
Bulgaria	1,330	
Czech Republic	1,239	
Belgium	1,186	
Luxembourg	1,146	200
Portugal	968	1,660
Slovakia	968	
Lithuania	820	
Greece	729	

Ireland	594	
Turkey	500	
Sweden	466	
Romania	378	
Slovenia	185	
Finland	0	
Latvia	0	
Hungary	0	
Netherlands	0	
Denmark	0	
Cyprus	0	
Estonia	0	
Malta	0	
Total EU-27 plus Norway, Switzerland, Turkey	**51,008 MW**	**5,859 MW**

Data updated by the Hydro Equipment Association (HEA) in March 2012 for this strategy paper; small and large pumped hydro is included. (Source: MacKay, David J.C. 2007. Enhancing Electrical Supply by Pumped Storage in Tidal Lagoons. University of Cambridge. March 2007).

Energy storage is closely related to policy on renewable electricity. Here, Member States have differing interests and possibilities and are at different stages of development (from near zero to over 50% of electricity generation). The EU is able to provide greater coherency of actions, as well as technological cooperation and a wider market.

Improved market conditions and regulations agreed at EU level could spur an massive effort in technology development. Today, development is very slow due to the poor economic/business case and related uncertainties (see above). However, by investing heavily in RTD, European industry could bring to the market a large number of innovative storage technologies within a few years. Once these technologies have successfully passed the R&D phase, some large scale, European demonstration projects on commercial scale could be launched. The EU has suitable instruments: e.g. the RTD Framework Programme and Horizon 2020, the Strategic Energy Technology plan (SET-Plan).

Annex 2 illustrates some of the weaknesses in the regulatory framework in EU (Survey on National Regulation related to Energy Storage - source: European Association for Storage of Energy - February 2012).

7. How could the regulatory framework be adjusted to integrate storage better in the supply chain?

The regulatory framework should aim to create **an equal level playing field for cross-border trading of electricity storage.**

- The regulatory framework needs to provide clear rules and responsibilities concerning the technical modalities and the financial conditions of energy storage.
- It must address barriers preventing the integration of storage into markets. It should guarantee a level playing field vis-à-vis other sources of generation, exploit its flexibility in supplying the grid, stabilise the quality and supplies for RES

generation. This will require new services and business opportunities linked to the deployment of electricity storage solutions.

- The framework should be technology neutral, ensuring fair competition between different technological solutions (not picking a winner).
- It should ensure fair and equal access to electricity storage independent of the size and location of the storage in the supply chain.
- It should ensure medium-term predictability in the investment and financial conditions (taxes, fees etc), enabling favourable conditions for all kinds of storage, particularly micro-storage (home and district level).
- It could help improve the business/economic model for energy storage. The principal domains where intervention are needed relate to ancillary services and the grid tariff. For example, the grid tariff should be based on the principle of cost causality: if an energy storage system is systematically using the grid during off-peak periods and not during peak periods, it should not generate grid investment. Thus, the introduction of a time component in grid tariffs could take account of the part of grid investment due to energy storage[2].

Electricity storage will make business sense only if it addresses this multitude of problems and is integrated in a holistic way with the whole energy system across national borders

Today, energy markets are mainly connected to the day-ahead horizon. As a result, the balancing products (tertiary frequency reserve) are only to a limited extent exchangeable cross-border among Member States. Connecting and harmonization on EU-level of the actual very heterogeneous intra-day and balancing markets is a precondition for energy storage development and needs to be addressed urgently.

The third internal market package can help. The regulators are currently drafting a framework guideline for a European balancing and reserve power market. This will be followed by a legally binding network code drafted by the European Network of Transmission System Operators (ENTSO-E).

As mentioned above, ownership of storage energy systems has a significant impact on the viability of the business model and on competition. The question is: which ownership model is likely to make the business case more attractive – one driven by regulation, or deregulation? More reflection is urgently needed regarding the issue of competition: regulated vs. deregulated; deregulated actors within one MS, or deregulated actors in different MS. This issue should be addressed as high priority.

[2] In United Stated the favourable environment for energy storage can be explained at least partly by the well-developed ancillary services market: energy storage is allowed to participate and provide services that account for both its qualities (e.g. fast response) and shortcomings (e.g. energy-limited supply).

8. What can the EU do to enable the short and medium term development and deployment of storage at all levels?

The issue of energy storage should be clearly positioned within EU energy and climate policy: the internal market, 2020 and 2050 targets and infrastructure priorities. EU policy needs to give clear and consistent signals to technology developers, the industry and consumers. The optimisation of the power system and the synergies between the existing system and storage technologies must be explored and promoted.

To enable the short term and large scale deployment of storage on an EU-wide level a number of urgent actions could be undertaken:

- *Strategic:* Developing and assessing visions for the role of storage in integrating variable renewable electricity generation, optimising the use of generation and energy network capacities, providing services to the electricity system and promoting distributed generation to improve energy efficiency and reduce CO_2 emissions, as envisaged by the EU's 2020 binding targets and the indicative targets for 2050 (RES Directive, Roadmap 2050). Synergies could be made by a common approach to storage for electricity systems and storage for transport (upcoming Electric vehicles, Plug-in hybrid vehicles);
- *Consumer level:* Supporting the development of consumer-based energy storage services linked with local RES production, smart meters and smart local grids that ensure financial benefits for the consumers; distinctions have to be made between short-term needs (up to 2020) and long-term visions (2020 to 2030) storage used in Smart Cities and in RES integration) ('roadmaps');
- *Market issues:* Developing a level playing field – removing barriers related to accessing neighbouring markets and cross border trading;
- *Regulatory:* Support for storage within the EU internal electricity market and regulatory adjustments to enable storage to facilitate the progress towards a single internal electricity market in Europe;
- *Technological development:* Mapping storage potential, storage technology development and demonstration including the interoperability of different smart energy networks and deployment through Horizon 2020 (RTD, Demonstration) – especially regarding how to integrate storage into the SET plan activities (European Industrial Initiative);
- *Investment support:* All different forms of energy storage could be supported providing they contribute towards the European climate and energy targets (technology neutral; target oriented).

Conclusion

Therefore, there should be a **stronger focus on storage in EU energy and climate policies,** and **improved coordination** between the issue of storage and other key policy issues. **Energy storage should be integrated into, and supported by, all relevant existing and future EU energy and climate measures and legislation**, including strategies on energy infrastructure, including the Connecting Europe Facility; RES promotion; Smart Cities and Communities; completion of the Internal Market; Energy Efficiency Directive; Horizon 2020; 2050 Roadmap; as well as the forthcoming discussion on a 2030 Strategy.

This note sets out the case for a stronger focus on storage in our policies, and improved coordination between the issue of storage and other key policy issues, such as completing the single market, smart cities, RTD etc.

Annex 1. Technology overview

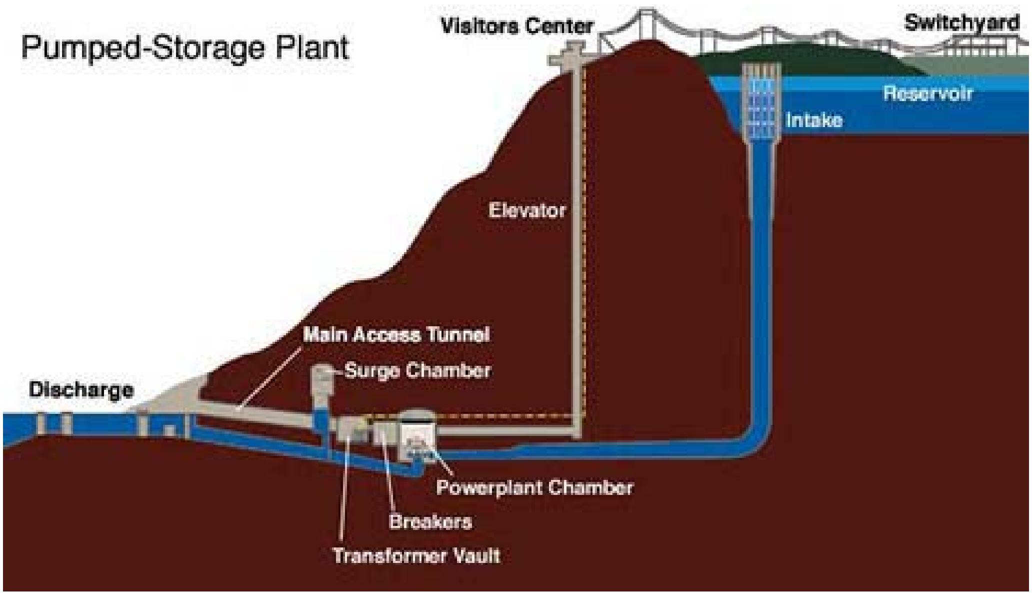
Main developments in the field of storage (technology priorities) – horizon of time

Past and present	Short term	Medium/ long term
Pumped hydro	Innovative pumped hydro	Advanced pumped hydro
Batteries	Batteries	Hydrogen
		Advanced Batteries
		Thermal storage (local level and for CSP technology)

Today, and for the next decade, excess electricity is stored in pumped hydro systems (over 99%). In the medium term, excess renewable electricity may also be converted to hydrogen. Hydrogen storage technology exists on all scales. This will open a multitude of new routes, such as feeding hydrogen directly into the natural gas grid up to 50 to 10% (these are gigantic quantities, and the natural gas storage and distribution may be used for free). Hydrogen may also be used to power fuel cell cars. Hydrogen may also be converted to natural gas (power to gas concept), or to methanol (for cars), or to be converted back to electricity (through stationary fuel cells or gas engines). The hydrogen/storage route opens a very large multitude of new paths that may contribute substantially to the Energy Roadmap 2050.

Past and present developments

The vast majority of existing large scale energy storage is based on **pumped hydro storage**. Pumped hydro storage systems were built purely for electricity management. They were initially built for pumping at night (supply of electricity higher than demand) and producing electricity during day time (supply of electricity lower than demand). Then the application of storage was demand levelling.



These pumped hydro plants made business sense in times where Europe's grid was much less interconnected as today and all pumped hydro storage aimed to stabilise a small regional areas majorly serving to level the energy demand as described earlier. Today, Europe's grid is much better integrated. This is why the market faces a problem for building new large capacity even under the old generation scheme: the business case for pumped hydro performed not as well as other options.

Large scale hydro dams were built mainly in the middle of the 20th century, mainly as a combined measure of water management and electricity production. Some of these hydro dams have been extended with a smaller pumped storage system. They are hybrid systems of renewable energy production and energy storage.

Pumped hydro storage in Limberg, AT: two dams are visible
(courtesy: *Hydro Equipment Association)*

Pumped hydro storage systems follow more and more cycles per day. This tendency is driven by the needs of the existing grid. The demand varies more stochastically: the increased electricity production from renewables brings additional variability to the supply; the predictability of renewables is still insufficient; the equilibrium between demand and supply is more difficult to obtain through grid balancing and switching on/off reserve capacity.

Many existing pumped hydro systems are foreseen to be upgraded by adding more turbines. The overpowered storage systems will become more flexible and produce higher power outputs over a shorter time. They produce more GW, but the GWh stay constant. The overall storage capacity will not increase (the size of the reservoir stays the same). This proves the higher degree of volatility in the system which is a result of both, intermittent RES and schedule changes in conventional generation. However the grid of today and especially the grid of tomorrow needs more storage capacity as well as more flexibility and more dynamic reaction time, since volatile generation will constitute the major part of our consumed energy, while the controllable conventional one will be less and less in operation.

Pumped hydro storage systems should not be mixed with hydro power. Hydropower is renewables electricity generation with excellent generation management. Experts don't call it energy storage but fuel piling (like a coal pile in front of a coal fired power plant).

Pumped Hydro Storage in Vianden, Luxembourg
This is the largest electricity storage system in Europe with 11 turbines and 1.3 GW:
the upper reservoir is an artificial construction;
the river (with dam) is the lower reservoir

(courtesy: *Hydro Equipment Association)*

Hydropower accounts for 16% of the European electricity generation portfolio. Hydropower's competitive advantage is related to its capability to stabilise fluctuations between demand and supply. In addition, it provides the necessary flexibility capacity to ensure the stability of the network. The key features of hydropower are stability and flexibility.

Hydropower produces electricity. Pumped hydro storage systems (PHS) don't produce any energy; PHS stores electricity (like a battery) and PHS loses about 15% to 25% of electricity (round trip efficiency about 75% to 85%).

Current investment and market regulatory framework - There is no particular investment framework for pumped hydro storage. It is worth mentioning that from the investment decision to starting operation of a pump storage investment requires a period almost ten year long. Time and efforts are consumed in permits' granting.

Pumped hydro storage is seen as an electricity consumer and electricity generator. Therefore, pumped hydro storage pays in most EU countries double fees (tariffs) for access to the network; some TSOs charge nothing for the pumped hydro storage's role as electricity consumer; other TSOs charge nothing for the little net consumption of PHS (withdrawal-injection) or recognize it as a renewable based generator

There is no EU legislation to regulate this issue and TSOs treat pumped hydro storage as they see it fit to their local market circumstances. The different approaches across national markets create distortions which have an impact on access and related costs for pump storage energy in neighbouring markets. A first overview of national regulation in the EU on Energy Storage (in force early 2012) is included in annex.

Batteries

Batteries history

The first operational battery was invented by Alessandro Volta (University of Pavia, Italy), around 1800. It consisted of coins of copper and zinc, separated by a cardboard soaked in salt water. It was not rechargeable.

Lead–acid batteries, invented in 1859 by French physicist Gaston Planté, are the oldest type of rechargeable battery.

Batteries and cars: The first electric vehicles used non rechargeable batteries since 1830; the rechargeable lead acid batteries dominated the world car market from 1860 to 1920. Electric engines were the preferred methods for motor vehicle propulsion, providing a level of comfort and ease of operation that could not be achieved by the gasoline cars of the time. The gasoline engine won the technology race when Henry Ford pushed exclusively for gasoline engines. Only in 1920 the world car fleet of gasoline engines surpassed the electric car fleet. One hundred years later, we seem to see history reverting to electric vehicles.

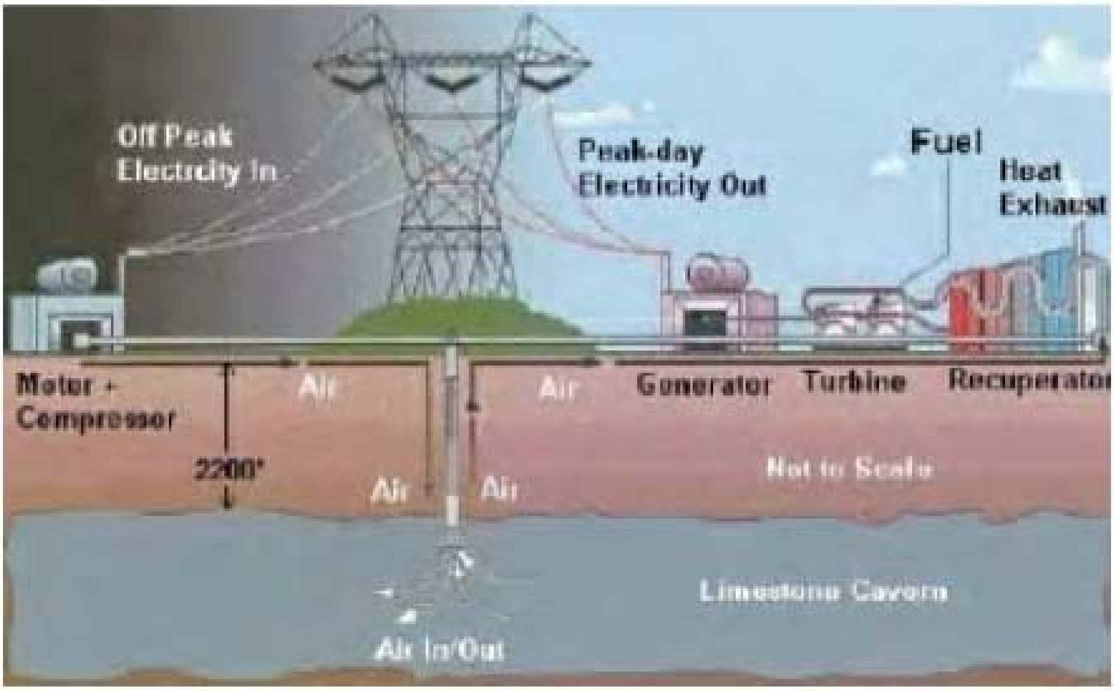
Today batteries are mainly used in consumer electronics and cars.

Batteries and the grid: Today, there is simply no battery technology capable of meeting the demanding performance requirements of the grid: uncommonly high power; long service life time, very low cost. Less than 1% of the grid storage is done by batteries, mainly for excessive cost reasons.

Today, lead acid batteries dominate in the car market. Despite having a low energy-to-weight ratio and a low energy-to-volume ratio, their ability to supply high surge currents means that the cells maintain a relatively large power-to-weight ratio. These features, along with their low cost, make them attractive for use in motor vehicles to provide the high current required by automobile starter motors, but not for propulsion.

Compressed air energy storage

CAES Plant with underground storage



(Source: California Energy Commission, November 2011).

When electricity supply is higher than demand, air is compressed and stored underground. When demand exceeds supply a gas turbine is fired up. All gas turbines need compressed air. In this case the compressed air is available and the turbine starts up rapidly. In the "normal" case, the gas turbine has to drive an air compressor that eats up a large part of the energy generated by the gas turbine (above 20%). Also the start-up of the turbine is slower as the combustion air needs to be compressed first. In summary, CAES increases the efficiency and the start-up time. It is a realistic alternative to pumped hydro storage in regions that lack the mountains. However, without heat recovery, the efficiency is very low (42% to 54%).

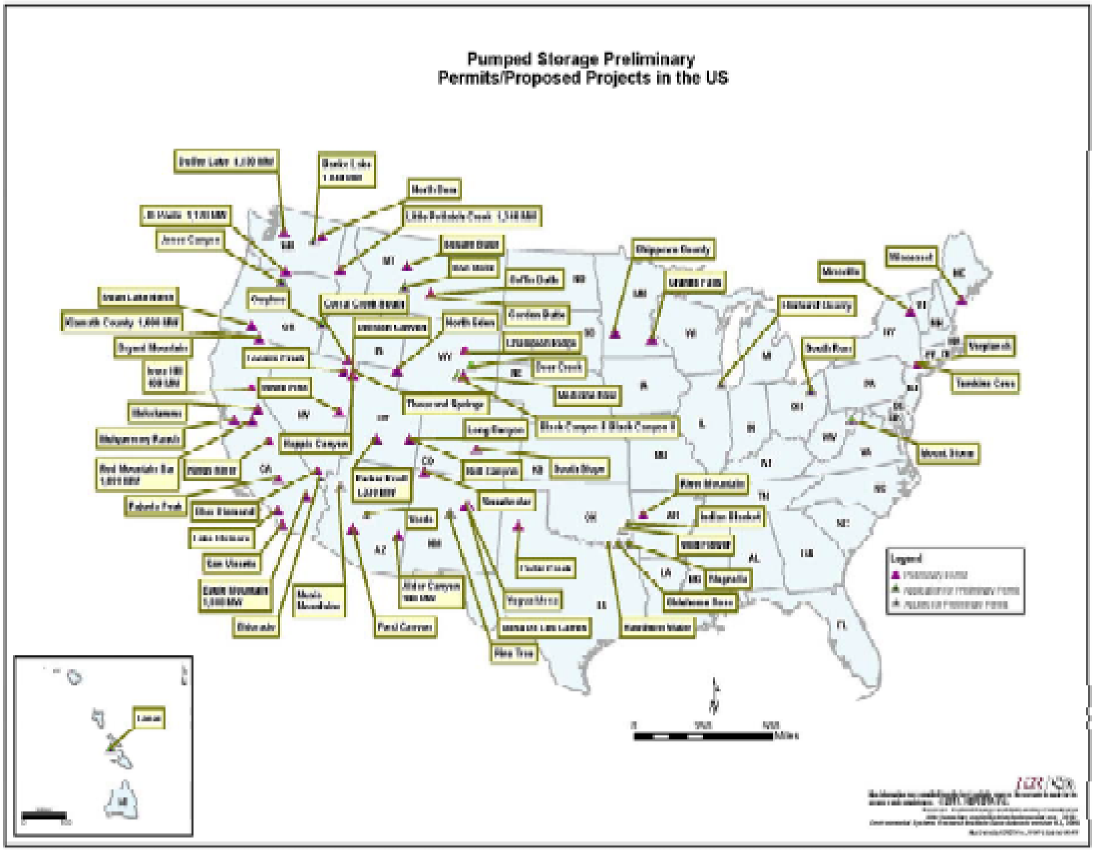
Compressed air storage with heat recovery will address the efficiency; however it exists on pilot scale only.

- Short term technology development

An ambitious call for proposals was launched in 2011 (FP7-Energy-call 2011). It called for large scale storage systems to demonstrate innovative technology on ideally one GWh scale in the real commercial world.

One large project on **innovative pumped hydro** (total cost >80 million euros) proved that there is still a potential to innovate: the project will demonstrate a full size new generation of a variable turbine, that will allow a very precise load following and will react in seconds instead of minutes. If successful (final results are expected by the end of 2013), this technology would allow a major retrofit programme of hundreds of turbines within a few years.

Proposed pumped storage projects in USA (2012)



(Source: California Energy Commission, November 2011).

- Medium/long term technology development

Many storage technologies are competing for the future market: Advanced pumped hydro (variable, ultra-fast reacting generation), fly wheels, compressed air, batteries (of different types), super-capacitors, etc. aim to store and to produce electricity. These storage technologies all have different properties, aim to deliver different services, have different capacities, dynamics, ramp rates, reaction times and costs. Progress is slow today, mainly as industry does not invest too much money into their development; today in Europe there is practically no business case foreseeable in the near future. Europe does have a chance to stay/become a world leader if the right market conditions are created and the right long term stable signals are given to our industry to massively invest into these technologies.

Advanced pumped hydro still has potential for improvement: combining variable turbines with variable pumps and new generators reacting in seconds will open new business for holistic integration into smart grid management. It urgently deserve a high attention for close to market or first of its kind demonstration. The market time line is estimated at 3 to 10 years by different experts.

Hydrogen storage aims for long term storage and for more flexible systems and allow for integrating energy storage with chemicals production. Hydrogen is discussed within the HFC Joint Undertaking. It has promising properties, but it is still early to predict when hydrogen storage would become commercially available in very large volumes. Expert's opinions vary from 10 to 40 years. Also round trip efficiency is low: 20% (wind to electrolysis to hydrogen to fuel cells to electricity) to 50% (chemical production of hydrogen from natural gas). However, despite low efficiency, hydrogen could achieve low and attractive costs.

The strongest argument for hydrogen is its extremely large versatility: it can be stored (the technology is mature); be used directly in cars; be used to produce electricity (through engines or fuel cells); be used as a primary chemical for many products; be used for hydro cracking in refineries; be injected into the gas grid (up to 5 to 10%, which is a major volume); etc.

The weakest link in the chain is the electrolyser: electrolysers have a one-way efficiency of some 60%. Research is going on for higher efficiency (up to 80%) at high temperatures. However electrolysers are not suited for variable operation for technical reasons. Also for economic reasons electrolysers should be operated in full load, as they have a very high CAPEX and a low OPEX. This problem of costs and variability should be solved urgently; however it is only one of 30+ priorities of the HFC JU instead of being the priority number one, where 80% plus of the funds should be concentrated. The market time line is estimated at 10 to 40 years by different experts.

Battery technologies are by far the most discussed technologies; however expert opinions and believes of the future reduction of the costs of batteries diverge enormously. Batteries can provide energy storage (the time and power is proportional to the number of modules) and other important ancillary services (e.g. voltage and frequency stabilisation). Batteries can be close to wind farms or PV systems coupled with the transmission grid, the distribution grid, be stationary (district storage) or mobile (electric vehicles). Their technology, optimum size and location have to be determined case by case.

The relative weakness of the Japanese grid strongly encouraged the Japanese Industry to develop new battery technologies (such as Sodium-Sulphur) to support the grid. Furthermore, the leading position of the Japanese consumer electronic industry contributed a lot to the development of strong battery leaders in Ni-MH/Li-Ion technologies that are expected to be involved in the Intermittent Renewable Integration.

The emergence of new actors in the field of consumer electronics impacts a lot the advanced battery industry with the introduction of Li-ion/Ni-MH batteries coming from Korea and China. In 2011 about 95% of all Lithium batteries were produced in Japan, Korea and China. China has by far the highest number of well educated, young electrochemists (about 100 times more than the EU).

In a second step, the emergence of the electric vehicles (including plug-in hybrid vehicles) is expected to contribute to the creation of a new battery market segment related to large battery systems and composed of Asian, European & US actors. The Intermittent Renewable Integration sector will benefit from these developments especially in the materials part but will also contribute to a creation of new battery segments that will be composed of the existing battery manufacturers and will incorporate new entrants.

This domain is expected to represent a good opportunity for the development of the Battery Network (battery industry, battery suppliers, battery service and battery research) and to encourage the emergence of new technologies such as Advanced Lead-Acid, Advanced Li-Ion, Flow batteries, etc. This research should also take into account the resource scarcity in Europe of rare earth elements (95% of the resources of actually used rare earth elements in Li-Ion batteries sold today are located in China; this issue needs to be addressed by EU research programmes).

The recent example of the development of the US battery activity induced by the Mobility and Grid applications make understand that the Europe industry could do the same if the same markets are growing locally.

The market time line is estimated at 5 to 15 years by different experts.

Thermal Storage - In cities, a large amount of electricity is used for driving individual electric air-conditioning systems. These units are typically switched on-off over the same period; thus causing major stress to the electric grid. Many of these units are mounted on south-facing room; the external heat exchanger is exposed to the sun on the south facing facades; this further ruins the already weak efficiency. Every year, several millions of units are mounted in the EU.

Centralised air-conditioning systems have a much higher efficiency; some demonstration projects successfully demonstrated the added value, if these air-conditioning systems are operated overnight, with ice-storage: cheap electricity is used overnight; the peak demand is shifted from noon to night. This has a major positive impact on the grid; it is one of the most efficient forms of indirect electricity storage. It is also one of the most efficient examples of the added value of systems integration: Cooling can be provided at about one tenth of the costs.

CHP power plants are usually integrated into district heating (cooling) systems and operated according to the heat demand, while the electricity produced is fed into the grid, independent of the electricity needs. Some demonstration projects of the CONCERTO initiative proved that the reverse operation, i.e. according to the demand of the electric grid while storing the heat has high benefits: heat storage is much cheaper than electricity storage. This indirect form of storage needs a smart energy management system over the whole district. The technology exists; further deployment should be achieved in the Smart

Cities initiative in the coming years; the ultimate aim is to achieve rapid and large scale replication before 2020.

The next generation of Compressed Air Storage with heat recovery (called adiabatic CAES) intends to store also the heat produced during compression. This heat can exceed 650°C; the heat exchanger will be very large (larger than the Berlaymont building). An on-going pilot project in Germany intends to solve the materials problems of such extreme temperature variations (ambient temperature to 650°c and back to ambient temperature in minutes, twenty times per day is not easy, nor cheap). A demonstration project might be ready to start in 2015. If successful, commercialisation might start in 2020.

Liquid air storage is a new concept that deserves attention: it is based on a new combination of modules that have been proven on industrial scale. The market time line is estimated at 10 to 20 years by different experts.

Fly wheels - Recent failures (2011) in an US installation of fly wheels for frequency regulation raised some doubts about this technology[3]. Another failure in a German lab (an engineer was killed in August 2011) added further safety issues. Their technical maturity is well advanced. Fly wheels will always stay in niche applications, as they suffer from high self-discharge (20% to 100% per day); from extremely high costs for high capacity storage (€/kWh). The market for flywheels will be focussed more on selling ancillary services to distribution grids (voltage stabilisation, frequency stabilisation, etc). Their main market competitor is Li-ion batteries, which are capable of providing further services apart from pure power services. Their timeline for market penetration seem to be in about 10 years.

Super capacitors - Their technological development, their timeline for market penetration and their potential market segment are very similar to fly wheels.

Storage to chemicals and materials- This route has an enormous potential, but it is underestimated and insufficiently researched. Excess electricity can easily be transformed into bulk chemicals that can easily be transported by ships or pipelines over long distances; at arrival, these chemicals can be used directly or be transformed into electricity, heat or other useful products. Scientists and researchers from all over Europe have presented to the Commission more than 20 ideas; all make scientifically, technically and economically sense, but no pilot plant has been built up to date. These routes include power to hydrogen, Power to gas, Power to chemicals, Power to materials, etc.

The hydrogen to chemicals route: The gasification of biomass and other low rank feedstock or low rank coal can provide the necessary gaseous fuels (syngas – IGCC process) to produce electricity and heat to back up the intermittent Renewable generation. The use of carbonic gaseous fuels also paves the way for the chemical storage of renewable energy sources. There is the option for a syngas based production of storage fuels, which are usable to equalize fluctuating power demand by incorporating renewable hydrogen. At the same time it could supply the chemical industry by new raw materials in a syngas based chemistry process (replacement of petroleum by biomass, coal, low rank feedstocks without CO2 emissions). This is a promising way to decarbonise power production and to store electricity indirectly. The market time line is estimated at 15 to 40 years by different experts.

[3] Beacon Power's Stephentown, NY, frequency regulation plant (20 MW), which was only commissioned in July 2011 lost one of its 100-kW-Flywheels on 27th of July and another one on 13th of October.

Power to gas: Today the cheapest way to produce hydrogen is the chemical reaction of natural gas. The gas industry plans to use the reverse reaction to produce natural gas from hydrogen. This well-known reaction is mature and used in oil and gas industries since decades. The adaptation from CO as carbon carrier towards CO2 and the dynamic use in a RES power system still is rather at pilot and demonstration scales.

The weakest link in the chain is the production of hydrogen from variable wind electricity (see above). Thus power to gas and hydrogen will penetrate the market, once cheap and electrolysers allowing variable operation have been developed. The market time line is estimated at 10 to 40 years by different experts.

Aluminium production needs huge quantities of electricity for its production. Producing aluminium in Southern countries from solar power plants is feasible and transporting aluminium by ships is very easy (it is lightweight, solid, may have different shapes, etc). Some experts call aluminium "solid electricity" because of the high amounts of embedded electricity. This could be a good intermediate solution for project such as Desertec or Helios in the intermediate phase when the transmission cables are not ready yet. One major constraint would be that plants have to be installed close to the coast. However, this should not be a problem, as the majority of the population lives close to the coast; they would benefit directly from large sources of cheap and green electricity; this will lead towards economic development for the regions and reduce the main reasons for excessive immigration to the EU. These regions would be developed, and new manufacturing industry would install close to the solar plants.

Water desalination (and purification of dirty water to drinking water) are well suited for variable supply of energy (pumps and membranes can stand large variations); during periods where supply exceeds demand for electricity the water can easily be stored in plastic bags in the sea. These installations will not be obsolete when large transmission cables to the EU are ready. It is estimated that the MENA countries will need some 200 GW locally before any electricity is transmitted to Northern Europe (internal study of P. Menna and J.M. Bemtgen, 2011). Such huge quantities of electricity need local storage and local demand side management for the short and also the very long term.

These routes need careful follow up. They deserve a high attention for research in Horizon 2020.

Annex 2. Survey on National Regulation related to Energy Storage **(source: European Association for Storage of Energy - status Feb. 2012)**

EU Country	**Regulation**	**Regulation & Standards**			**Segmentation**		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Austria	**Yes** (for natural gas storage)	**Regulated** in market rules, every contract to be agreed by regulator (www.e-control.at)	**Market rules by regulator** - Gaswirtschaftsgesetz (GWG) 2011	n.a.	n.a.	bundled and unbundled products	decentralised
Belgium	**No,** there is no specific regulation for electrical or gas storage	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Czech Republic	**Yes -** access to underground gas storage as well as storage capacity allocation are subject to regulation but prices are market-based (set in auctions). No specific regulation for gas exists	There are two basic pieces of legislation covering **Storage System Operators (SSO):** • The **Energy Act (458/2000)** Setting out the commercial conditions and public administration rights in the energy sector • **Market Model Decree (365/2009)** Laying down the rules for the organisation of the gas market There are additional pieces of legislation relevant for the **underground gas storage business**, including: • **Decree on Network Codes (401/2010)** Setting out the scope and contents of transmission and distribution network codes, storage codes and Gas and Electricity Market Operator's Terms and Conditions • **Decree on Gas Grid Connections (62/2011)** Setting out the conditions under which users and infrastructure can be connected to the gas grid • **States of Emergency Decree (334/2009)** Setting out groups of protected customers, supply standards and actions to be taken in emergency situations • **Decree on Licensing in the Energy Sector (426/2005)** Setting out details for licensing of entities in the energy sector		No incentive schemes for gas storage apart from TPA exemptions as provided for by the Energy Act	**No segmentation by technology/ application / location.** Czech mining regulation (The Mining Act, No. 61/1988) covers the gas storage business under the category of "interventions in the earth's crust" with no specific segmentation regarding the type of storage (e.g. depleted field vs. cavern) or technology/ application.		

Commission européenne/Europese Commissie, 1049 Bruxelles/Brussel, BELGIQUE/BELGIË - Tel. +32 22991111
Office: DM24 06/145 - Tel. direct line +32 229-68475 - Fax +32 229-65801

Jean-Arnold.Vinois@ec.europa.eu

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Denmark	Power storage is not mentioned in the Danish regulations and standards, but on the other hand the regulations are in-directly discriminating storage. One example is that power storage will be considered as consumption, which mean that you have to pay tax, and transport of the stored power. Therefore we (DONG Energy and DTU) will contact the authorities to discuss this subject. Storage of Natural gas is mentioned in the Danish law for supply of Natural Gas.Natural - Act on Natural Gas (Naturgasforsynings loven).	The Danish Act on Natural-gas - chapter 3	The Danish Act on Natural-gas - chapter 3	Free – non discriminating - competition	Storage of Natural gas alone	n.a.	n.a.

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
France	**No,** there is no specific regulation for electrical storage	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Germany	**Yes**	ENWG (covers the eligibility of connection)(The grid codes make no special requirements on storage, however it must cope both on the requirements on load and generation depending on its operation mode)	ENWG (generally)EEG (covers storage of RES)Transmission Code, Annex D1-D3 (covers Primary, Secondary and Minute Reserve Markets, in a general manner but mentions storage)	ENWG (exempts new build storage and refurbished PHS from network usage fees)EEG (ensures that storage of RES will preserve the remuneration payable for RES directly fed into the grid)KWKG (support integration of heat storage into CHP sites)	ENWG (considers power and gas storage differently, provides special incentives for PHS)	Transmission Code (explicitly mentions storage only for Primary, Secondary and Minute Reserve, hence balancing Markets)EEG (focuses on storage for RES-System integration)	(ENWG – While actually neutral the tone of the regulation indicates a focus on large scale, centralised storage)

EU Country	**Regulation**	**Regulation & Standards**			**Segmentation**		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Hungary	**Yes** (natural gas storage)	**Basic regulations in force:** • Act XL of 2008 on natural gas supply • Government Decree 19/2009 (30 January) on the enforcement of certain provisions of Act XL of 2008 on the natural gas supply • Decree 81/2003 (10 December) of the Minister for Economy and Transport on the consumers with priority access to natural gas storages and transportation and distribution pipelines **Strategic natural gas stock:** • Act XXVI of 2006 on the strategic stockpiling of natural gas • Government Decree 265/2009 (1 December) on the limitation of natural gas off take, the use of the strategic natural gas stock and on necessary other measures in natural gas supply emergency situations • Decree 13/2011 (7 April) of the Minister for National Development on the amount, sale and re-supplement of the strategic natural gas stock **Natural gas storage tariffs:** • Decree 31/2009 (25 June) of the Minister for Transport, Telecommunications and Energy on setting the natural gas system usage tariffs • Decision 860/2011 of the Hungarian Energy Office on the natural gas storage tariffs applicable by MMBF Natural Gas Storage PLC as storage system operator from 1 January 2012 • Decision 861/2011 of the Hungarian Energy Office on the natural gas storage tariffs applicable by E.ON Natural Gas Storage PLC as storage system operator from 1 January 2012 **Codes and business rules:** • Decisions 799/2001 and 835/2011 of the Hungarian Energy Office on the approval and amendments of the Grid and Commercial Code of the Hungarian natural gas system • Decision 846/2008 of the Hungarian Energy Office on the approval of the business rules of MMBF Natural Gas Storage PLC as storage system operator • Decisions 320/2009, 817/2009, 628/2010, 732/2011 of the Hungarian Energy Office on the approval and amendments of the business rules of E.ON Natural Gas Storage PLC as storage system operator			No segmentation by technology in the regulation, in practice there are only UGS (underground gas storage) type of natural gas storages in Hungary, which are operated in depleted oil and gas production fields.	There is one special type of natural gas storage in Hungary which is called the strategic natural gas stock. This stock could be used only in specific cases, for limited time and for dedicated consumers, under specific rules and conditions. This stock is not to be used as normal commercial stock.	No segmentation by location in the regulation, in practice the strategic natural gas stock is operated in one specific location.

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Ireland	**No -** for electricity, **Yes-** for Gas, please refer to UK for gas	Grid Connections for Storage are dealt with the same as Thermal generation, in Republic of Ireland this is based on a gate process, in NI a generator may submit for a grid connection when it has planning.	Storage (specifically PHS) is dealt with as a Special Unit under the Trading & Settlement Code (T&SC). PHS is considered a Predictable Price Maker Unit therefore all Commercial Data are submitted as zero value.	n.a.	n.a.	The TSO in Ireland has indicated a desire to segment storage based on application and defining storage that does not participate in Unit Commitment as non generating assets but rather transmission assets.	n.a,

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Italy	**No -** There are no specific regulation regarding energy storage. At the moment the energy storage system connected to the grid have to respect the relative regulation for the connection of a generator to the distribution grid (CEI 0-21 for LV connection and CEI 0-16 for MV and HV connection).	**Art 36, paragraph 4, decree law 93/11** TSO (and DSOs) can build and operate batteries. However the TSO must justify, through a cost/benefit analysis, that the energy storage system is the most efficient way to solve the problem identified (E.g. compared to the build of new line…). In any case TSO should not receive a remuneration higher than the (measurable) cost of alternative solutions.		n.a.	n.a.	n.a.	n.a.
Netherlands	**No**	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Norway	no specific regulation on electricity storage exists, including for pumped hydro storage	in general, grid fees consist of a fixed contribution and a variable contribution depending on energy, which is different for production and consumption (pumping in the case of PHS) and which gives an additional "penalty" for consumption in periods with high load					

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Poland	**Yes-** Access, capacity allocation and price tariffs are subject to regulation. The basic legislation considering the energy market is the **Energy Act (of 10 April 1997, No 89/2006, pos 265,** with later changes). Specific issues concerning the underground gas storage are regulated through Minister of Economy's Decrees.	Minister of Economy's Decree (2 July 2010, No 133/2010, pos 891) regulating the conditions of gas systems operations. This Decree regulates the network access, balancing regime and fuel quality requirements for all the market participants, including underground storage facilities.	Minister of Economy's Decree (6 February 2008, No 28/2008, pos 165) regulating tariff structure, calculation and payments for the gas market sales. This Decree provides a detailed description of the requirements for the types of price structure allowed, tariff calculation based on the cost plus method and settlements between market participants.	There are no incentive schemes in place. All the underground storage facilities are regulated by the same rules, put forward by the aforementioned Decrees.	There is no segmentation based on technology. However, the only underground storage operator in Poland (PGNiG S.A.) provided separated tariffs (tariff groups) for salt cavern and depleted field storages. This segmentation was abandoned in the last tariff, differentiating the storages basing on their performance parameters only.	The requirement for strategic storage, put forward by the Strategic Storage Act (of 16 February 2007, No 52/2007, pos 52), is fulfilled by shippers by appropriate booking of storage capacities. There is no segmentations of the facilities based on the purpose they are used for.	Poland is a single balancing zone, therefore there is no segmentation based on location of the storage facilities.

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Slovakia	**Yes** (access to gas storage facilities and storage of gas regulation). Electricity Storage is only covered by tariffing.	**Act. No. 276/2001 Coll. On Regulation in the network industries** - this act besides others fields shall regulate the determination or approval of the manner, methods and terms and conditions of access to gas storage facilities and storage of gas regulation **Decree No. 409/2007 on rules of operation of the gas marke**t **–** this decree shall provide rules of operation of the gas market, namely for gas storage	**Decree No. 409/2007 on rules of operation of the gas market** – this decree shall provide rules of operation of the gas market, namely for gas storage	Reduced grid tariffs for pumping electricity of pumped hydro.	Through tariff exemptions above PHS get a special weight.	**Decree No. 409/2007 on rules of operation of the gas market** distinguishes following assignment of storage capacity: fixed storage capacity and interrupting storage capacity. In Slovakia, there are some operators of gas storage facilities and these operators have their own rules of operation of the gas storage facility approved by the Regulatory Office for Network Industries. Each of these operators is eligible to set its own conditions of operating the corresponding storage facility.	n.a.

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
Spain	**No**	n.a.	Pumped Hydro is considered as a power generation system and participates of the electric market.	In the **Royal Decree 661/2007** there was an article related to Fuel Cells which received a regulated tariff of 12.0400 c€/kWh but the Royal Decree 1/2012 January 27th abolished the bonus for renewable energies and cogeneration including Fuel Cells.	n.a.	n.a.	n.a.

EU Country	Regulation	Regulation & Standards			Segmentation		
		grid connection	market integration	incentive schemes	by technology	by application	by location
United Kingdom	**No** The special case of electricity storage is not recognised in the main legislation covering generation, transmission, distribution or supply of electricity. There are no specific licence conditions which apply to the ownership or operation of electricity storage. In effect electricity storage is currently not differentiated from the generation of electricity. There is considerable legislation covering the generation, supply, transmission and distribution of electricity, mainly derived from the Electricity Act 1989, and subsequently amended by other Acts and Statutory Instruments	Storage is considered in the same way as other technologies for grid connections. Connections to the transmission system must comply with the Connection and Use of System Code (CUSC), Balancing Settlement Code as well as the Grid Code. Connections to the distribution system must comply with the Distribution Code. Additional engineering requirements must be followed for connections to the distribution system as defined by the distribution network operator.	Storage is not considered separately and so is treated as any other market participant. The rules for market participation are based on the power rating of the storage, including compliance with the Grid Code and the Balancing and Settlement Code	There are no direct incentives for storage. However support schemes for Low Carbon Networks provide demonstration funds for innovative projects	n.a.	Segmentation in GB is directly related to size of the device (defined as medium / large) and connection point (transmission or distribution). In summary, within England and Wales devices greater than 50MWs are subject to different rules from those below. In Scotland the threshold is 30MW and 10MW depending on the location	At the distribution level some local schemes have been able to qualify as registered power zones with special incentives for innovation. This incentive is now closed.Market participation is also influenced by location as this affects the Transmission Network Use of System (TNUOS) Charges and the Distribution Use of System Charges. Storage may be required to pay TNUOS both as a generator and as a consumer.