Electricity Storage

INSIGHTS FOR POLICYMAKERS

Electricity storage is a key technology for electricity systems with a high share of renewables as it allows electricity to be generated when renewable sources (i.e. wind, sunlight) are available and to be consumed on demand. It is expected that the increasing price of fossil fuels and peak-load electricity and the growing share of renewables will result in electricity storage to grow rapidly and become more cost effective.

However, electricity storage is technically challenging because electricity can only be stored after conversion into other forms of energy, and this involves expensive equipment and energy losses.

At present, the only commercial storage option is **pumped hydro** power where surplus electricity (e.g. electricity produced overnight by base-load coal or nuclear power) is used to pump water from a lower to an upper reservoir. The stored energy is then used to produce hydropower during daily high-demand periods. Pumped hydro plants are large-scale storage systems with a typical efficiency between 70% and 80%, which means that a quarter of the energy is lost in the process.

Other storage technologies with different characteristics (i.e. storage process and capacity, conversion back to electricity and response to power demand, energy losses and costs) are currently in demonstration or pre-commercial stages:

- **Compressed air energy storage (CAES)** systems store energy by compressing air. They require large, low-cost natural buffers (e.g. caverns) to store compressed air, which is then used in gas-fired turbines to generate electricity on demand.
- **Flywheels** store electricity as mechanical energy, which is then converted back to electricity.
- **Electrical batteries and vanadium redox flow cells** store electricity as chemical energy. In particular, traditional lead-acid batteries offer low costs but short-lifetimes; Li-ion batteries offer higher efficiency and lifetime and are widely used for portable devices, but they require further R&D and cost reduction for application to solar and wind plants; novel battery concepts (e.g. NaS batteries) and vanadium redox flow cells have already been used in small- to mid-size renewable power systems.
- **Supercapacitors** store electricity as electrostatic energy and are often combined with batteries.
- **Superconducting magnetic storage** use superconducting technology to store electricity efficiently but need more research to be developed.
- **Thermal energy storage** is under demonstration in concentrating solar power (CSP) plants where excess daily solar heat is stored and used to generate electricity at sunset (see ETSAP E10 and E17).

No single electricity storage technology scores high in all dimensions. The technology of choice often depends on the size of the system, the specific service, the electricity sources and the marginal cost of peak electricity. Pumped hydro currently accounts for 95% of the global storage capacity and still offers a considerable expansion potential but does not suit residential or small-size applications. CAES expansion is limited due to the lack of suitable natural storage sites. Electrical batteries have a large potential with a number of new materials and technologies under development to improve performance and reduce costs. Heat storage is practical in CSP plants. The choice between large-scale storage facilities and small-scale distributed storage depends on the geography and demography of the country, the existing grid and the type and scale of renewable technologies entering the market.

While the energy storage market is quickly evolving and expected to increase 20-fold between 2010 and 2020, many electricity storage technologies are under development and need policy support for further commercial deployment. Electricity storage considerations should be an integral part of any plans for electric grid expansion or transformation of the electricity system. Storage also offers key synergies with grid interconnection and methods to smooth the variability of electricity demand (demand side management).

Please send comments to Giorgio.Simbolotti@enea.it and Ruud Kempener (RKempener@irena.org), Authors, and to Giorgio.Simbolotti@enea.it, Giancarlo Tosato (gct@etsap.org) and Dolf Gielen (dgielen@irena.org), Project Co-ordinators

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HIGHLIGHTS

■ **PROCESS AND TECHNOLOGY STATUS –** Electricity storage is a challenging and costly process as electricity can only be stored by conversion into other forms of energy (e.g. potential, thermal, chemical or magnetic energy). In today's grids, electricity storage capacity is modest (about 110 GW power capacity on a global basis), and power generation varies continuously to meet demand fluctuations and ensure grid voltage and frequency stability. More electricity storage could help ensure grid balance and reduce the need for costly peak-load capacity. Electricity storage can also support the grid integration of variable renewables (i.e. wind and solar power), the production of which depends on meteorological conditions and varies daily and seasonally. There is a variety of storage technologies based on various processes and suited to different services (e.g. bulk storage and load-levelling, voltage and frequency regulation, renewable integration, back-up power). Major storage technologies include pumped hydro, compressed air energy storage (CAES), flywheels, supercapacitors, flow cells and rechargeable batteries (e.g. Li-ion batteries) and super-conducting magnet energy storage (SMES). Among these, pumped hydro is the only widely used technology (i.e. 100 GW worldwide) for large-scale electricity storage. Li-ion batteries dominate the market of energy storage for portable devices and are also the primary candidate for energy storage in electric vehicles and distributed renewable power. All other technologies are under demonstration or in a pre-commercial phase. Storage technologies also include electricity conversion into hydrogen via electrolysis (see ETSAP P11) and thermal energy storage in concentrating solar power (CSP) plants (see ETSAP E10 and E17). Electric utilities are also considering the storage potential of electric vehicles: overnight charging of batteries could offer a unique opportunity for distributed electricity storage at virtually no cost. The US Department of Energy estimates that two million vehicles could help accommodate up to 10 GW of wind power.

■ **PERFORMANCE AND COSTS –** Performance and costs of storage systems are to be assessed with respect to the service. For example, back-up power for uninterruptable power systems (UPS) requires immediate (i.e. within seconds) response and moderate power output and can usually bear high costs in return for high reliability. Grid voltage and frequency regulation require a response time from seconds to minutes and higher power output. Daily load-levelling requires extensive power to be available for hours, and the cost it can bear depends on the marginal price of peak-load electricity. Investment costs for storage equipment are highly variable as technologies are mostly in pre-commercial phases with little operating experience except for pumped hydro. Cost projections are also scarce or unavailable. Pumped hydro and CAES provide utility-size storage (i.e. up to GW-size power output for several hours) for both load-levelling and voltage/frequency regulation but are not suited to small-size distributed storage or back-up power for UPS. They are the cheapest storage options per unit of energy, with investment costs largely dependent on plant site and size, i.e. US $2000-4000/kW for pumped hydro and $800-1000/kW for large CAES (assuming cheap, natural underground storage). Flywheels can make available kW- to MW-size power output for a limited time (seconds to minutes) with very short response time. They can be used for UPS, frequency regulation and wind power support in small grids. Their cost is also sensitive to the size, ranging from $1000/kW for small, simple flywheels to $4000/kW for MW-size multi-wheel systems. Supercapacitors also offer very short response time and high power density. They could be used as instantaneous voltage compensators or in combination with battery storage. Vanadium redox flow cells offer power capacity from kW-size to MW-size. They can be used to support wind power generation at a cost of $3000-5000/kW with prospects for a rapid reduction to $2000/kW. Rechargeable batteries (e.g. traditional lead-acid batteries, NaS batteries and large Li-ion batteries) are the technology of choice for distributed storage (e.g. residential/commercial PV systems up to MW-size). They can also be used for frequency regulation and UPS. Among batteries, Li-ion cells offer the best energy density (up to 630 Wh/l), cycle efficiency (90%) and durability, along with the lowest self-discharge (5-8% per month at 21°C). Small Li-ion batteries for portable devices are commercially available at relatively low prices, but batteries for power applications are still expensive. They cannot simply be scaled-up and need enhanced safety and reliability. However, high learning rates (30%) in portable applications and large research efforts on batteries for electric vehicles and wind energy storage promise a rapid cost reduction to less than $1000/kW. SMES systems offer high efficiency (>90%) and immediate response but are currently used in pilot projects or devices for other applications.

■ **POTENTIAL AND BARRIERS –** Energy storage technologies are quickly evolving since the share of renewable electricity is growing fast and there is an increasing need for storage capacity. Storing low-cost electricity (e.g. overnight) and selling it during peak-demand periods could soon become cost effective due to the increasing cost of peak electricity. Estimates suggest a global grid-tied storage market rising from $1.5 billion in 2010 to about $35 billion in 2020. Explorative simulations assuming high renewable energy share (IEA ETP 2008 Blue Scenario) suggest that in Western Europe a storage capacity of about 90 GW would be needed by 2050 to cope with net variations of 30% of then-current wind power capacity. On a global scale, the storage capacity needed to accommodate wind power variations by 2050 is estimated to be between 190 GW and 300 GW. Among storage technologies, pumped hydro and CAES have a moderate expansion potential, a major barrier being the need for suitable installation sites. A strong market growth is anticipated for grid-tied Li-ion batteries ($6 billion by 2020, IHS estimates) in relation to the deployment of smart grids. Other storage technologies need more demonstration to enter the market. Policy measures are needed to support market uptake of electricity storage.

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