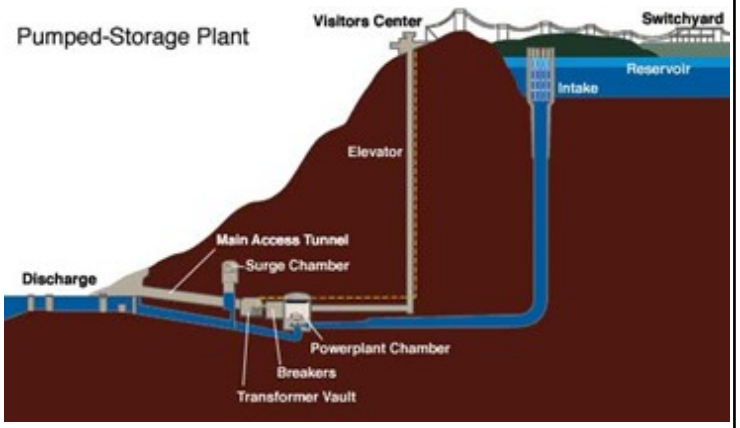
Pumped hydroelectric storage

- Uses electricity to pump water from low lying areas to a reservoir at a higher altitude (e.g. up a hill or mountain).
- Pumping takes place at night when demand for electricity is low.
- When energy is needed, this water is released downhill, passing through a hydroelectric turbine which generates electricity.
- Currently used in the UK to help stabilise the national grid when electricity demand rises suddenly, or other power plants go off-line without warning.



Cutaway Diagram of a Typical Pumped Hydro Plant. (Sandia National Labs, 2015)

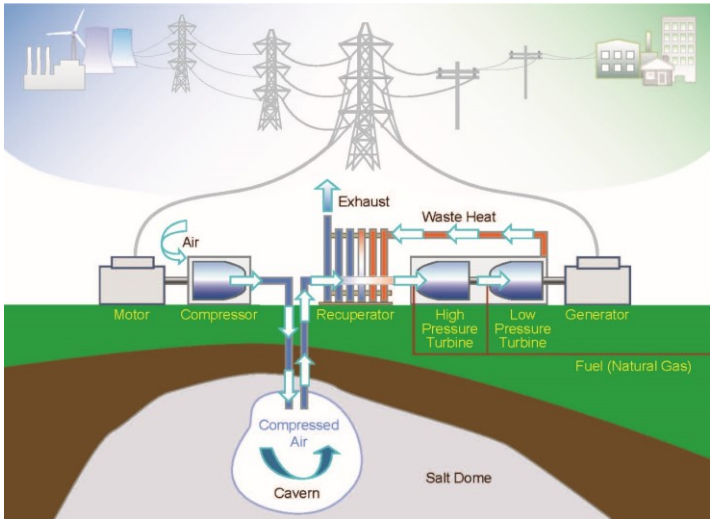
Key facts	
Technologies:	Pumped hydro-electric
Location:	National electricity grid
Readiness:	Currently used
Environmental impacts, safety and resource use:	• Requires large reservoirs and excavations which can be disruptive to local environments and ecosystems. • Limited to hilly or mountainous areas

Applications

- Enables more renewables
- Storage across hours & days
- Less network upgrades
- Back-up power

Compressed air energy storage

- Uses electricity to pump air into confined spaces at high pressure. When electricity is needed, the air is released through a turbine to produce electricity.
- Suitable for storage over long periods such as across days and seasons.
- Underground spaces (salt caverns; aquifers etc) can be used to store large amounts of energy for when demand is high.
- Smaller containers like tanks and underwater balloons store less energy, but can be used in more places.



CAES system. Copyright Ridge Energy Storage and Grid Services LP

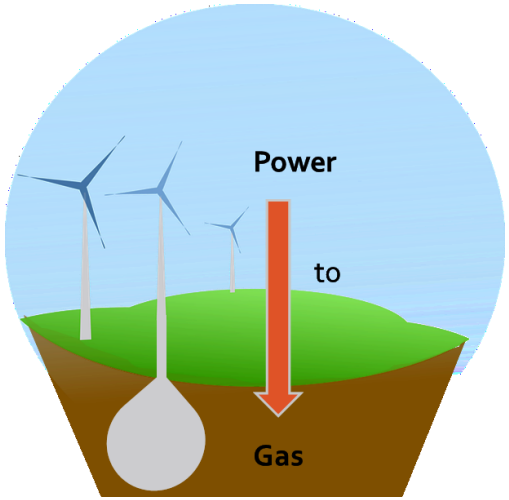
Key facts	
Technologies:	Compressed Air, underground caverns, pressurised containers
Location:	National grid. Communities.
Readiness:	Demonstration stage.
Environmental impacts, safety and resource use:	• Pressurised containers can explode if damaged. • Mining is often required to create underground cavities and reservoirs. This is less harmful than some forms of mining but can be disruptive to local ecosystems.

Applications

- Enables more renewables
- Storage across seasons
- Storage across hours & days
- Less network upgrades
- Power quality
- Back-up power

Power-to-gas

- Uses electricity to produce hydrogen- a flammable fuel that can be used to generate electricity or as a transport fuel.
- Producing hydrogen using electricity is not very energy efficient but, once it is made, hydrogen can be stored for long periods without losing energy.
- Hydrogen can also be used as a heating fuel. This would require expensive modifications of household appliances and the natural gas grid.
- Hydrogen can be combined with CO_2 to create synthetic natural gas which could be used without making changes to the gas network.



Power to gas from wind energy. Image adapted from Open Clipaart Vectors (2013), Creative Commons CCO

Key facts	
Technologies:	Hydrogen, synthetic natural gas (SNG)
Location:	National electricity & gas networks
Readiness:	Demonstration stage
Environmental impacts, safety and resource use:	• Hydrogen and SNG are highly flammable and pose a fire risk if not handled carefully. • Burning SNG releases CO_2 which contributes to climate change.

Applications

- Enables more renewables
- Storage across seasons
- Storage across hours & days
- Less network upgrades
- Use in remote areas
- Back-up power
- Transport fuel (hydrogen only)

Batteries on the grid

- Store and release energy using reversible chemical reactions that are activated by an electrical current.
- Efficient over short periods but lose charge over hours and days.
- Because the chemicals inside batteries are often corrosive, they break down over time and may not last as long as some other storage technologies.
- Individual battery cells do not store very much energy but can be stacked inside shipping containers and warehouses to store energy at larger scales.

Shipping container containing stacked batteries in Somerset. Copyright Western Power Distribution & British Solar Renewables

Key facts	
Technologies:	Lead acid, lithium ion, nickel cadmium, sodium sulphur
Location:	National grid. Communities.
Readiness:	Demonstration stage
Environmental impacts, safety and resource use:	• Batteries contain a range of toxic materials which need to be mined and disposed of after use. These activities can be highly polluting to local environments. • Most batteries contain corrosive chemicals or operate at high temperatures posing fire risks. They need to be produced to high quality standards to ensure safety.

Applications

- Enables more renewables
- Storage across hours & days
- Less network upgrades
- Use in remote areas
- Back-up power
- Power quality

Batteries in homes

- Store and release energy using reversible chemical reactions that are activated by an electrical current.
- Efficient over short periods but lose charge over hours and days.
- Because the chemicals inside batteries are often corrosive, they break down over time and may not last as long as some other storage technologies.
- Batteries in homes could be charged using rooftop solar panels, or from the grid when plenty of electricity is available. This could be used in evenings when demand for electricity is higher.

Powervault battery installed in household kitchen/utility room. Copyright Powervault.

Key facts	
Technologies:	Lithium ion batteries.
Location:	Homes.
Readiness:	Demonstration stage
Environmental impacts, safety and resource use:	• Made using lithium a toxic element. Lithium mining it can be highly polluting to local environments. Lithium can be recycled. • Due to the risk of fires, lithium ion batteries need to be produced to high quality standards to ensure safety.

Applications

- Enables more renewables
- Storage across hours & days
- Less network upgrades
- Use in remote areas
- Back-up power

Heat storage in homes

- Uses electricity to heat up materials stored inside insulated containers such as water tanks and storage heaters. This might be done using rooftop solar panels or from the grid when plenty of electricity is available.
- When central heating or hot water are needed, air or water is passed through the insulated container to warm-up.
- Hot water tanks take up space in homes and many have been removed since the 1980's.
- Some companies are developing 'heat batteries', insulated boxes containing molten salt. These operate at higher temperatures and take up less space than water tanks.

Hot water storage tank in a UK property. Workman (2010)

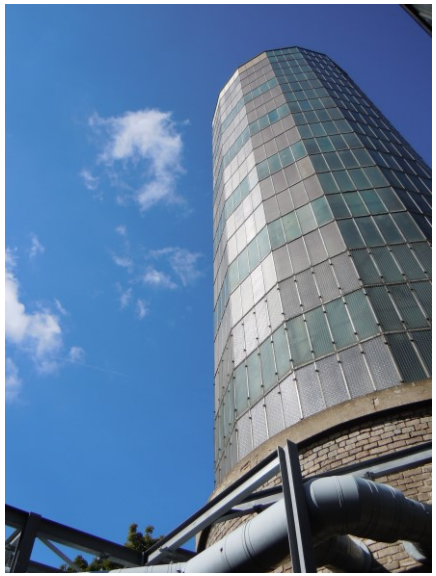
Key facts	
Technologies:	Water tanks, storage heaters, heat batteries.
Location:	Homes
Readiness:	Currently used (water tanks and storage heaters). Under development (heat batteries)
Environmental impacts, safety and resource use:	• Can cause damage to homes in the event of a leak. • Molten salts in heat batteries are non-toxic but operate at high temperatures. As with water tanks can cause scalding if the container is damaged.

Applications

- Enables more renewables
- Storage across hours
- Less network upgrades
- Use in remote areas

Heat storage in communities

- In some places it may become more efficient to generate heat for entire communities in district heating schemes- networks of pipes that carry heat to nearby houses and blocks of flats.
- If powered using solar or wind energy, this would require large heat stores that can be charged when demand for heat is low and discharged when it is needed.
- Large hot water tanks can be used to store heat for use during the evening when it is colder.
- It is also possible to store large amounts of water in deep pits or boreholes, where the warmth from the ground provides additional insulation. This allows heat to be stored for longer periods across days and seasons.



Hot water storage tower at Pimlico District Heating Undertaking, London. Kevan (2012)

Key facts	
Technologies:	Water tanks, gravel pits, boreholes
Location:	Communities
Readiness:	Currently used
Environmental impacts, safety and resource use:	• Communal energy stores require a lot of space either above or below ground.

Applications

- Enables more renewables
- Storage across seasons (underground stores only)
- Storage across hours & days
- Less network upgrades

Peak electricity generation

- At the moment we use highly efficient gas turbines to generate electricity. These can adjust their output to match demand most of the time.
- When demand is at its highest, we use a smaller number of less efficient gas power plants that can be switched on and off very quickly.
- At the moment this is the cheapest way of matching energy supply with demand.
- Natural gas could be used as a back up for intermittent renewable supplies or on its own if the UK were to weaken its commitment to reducing CO_2 emissions.

Natural Gas Power Station in North Killingholme , Lincolnshire. Copyright David Hebb

Key facts

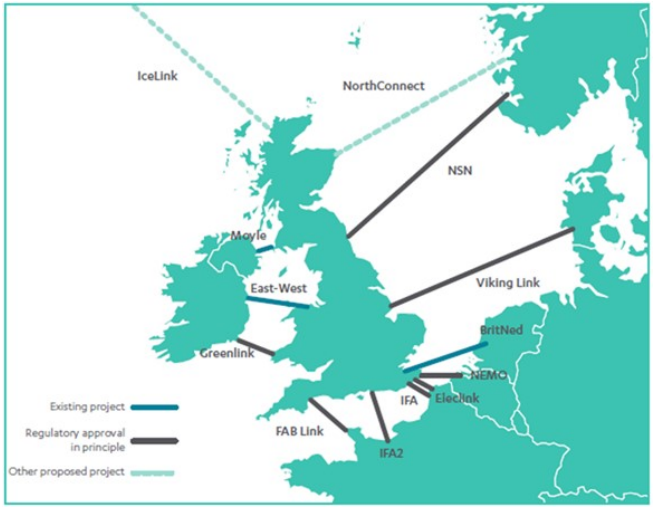
Technologies:	Natural gas power plants
Location:	National Grid
Readiness:	Currently used
Environmental impacts, safety and resource use:	• Natural gas is a non-renewable resource. • Burning natural gas generates CO_2 which contributes to climate change.

Applications

- Matching supply with demand
- Stabilising networks
- Back-up power
- Power quality

Interconnection and network upgrades

- New cables, transformers and substations could be built to help manage the strain of new power plants and higher electricity demand on the national grid.
- Interconnection with mainland Europe could allow us to export renewable electricity when we have too much or import it when we don't have enough.
- New cables can be disruptive to build and can be expensive.
- Interconnection should reduce the overall cost of energy across countries. However if European electricity prices became consistently higher, interconnection could push up bills in the UK.



Existing and proposed UK interconnectors. Source: NIC (2016)

Key facts	
Technologies:	Cables, transformers and substations. Undersea cables (Interconnectors)
Location:	National Grid. European electricity network
Readiness:	Currently used
Environmental impacts, safety and resource use:	• Laying cables and interconnectors may be disruptive to nearby landscapes and ecosystems. • Cables are made of copper. Copper mining and smelting can pollute local air and groundwater.

Applications

- Matching supply with demand
- Enables more renewables
- Power quality

Key

Applications:

Load levelling services (services associated with matching supply with demand)

- **Enables more renewables**= Allows intermittent renewables electricity to be used more flexibly, allowing network operators to match supply with demand over time. This enables more renewable resources to be integrated into the UK energy system without the overloading the grid or, risking times when not enough electricity is available to meet demand.
- **Storage across seasons**= allows energy to be stored across seasons, meaning fewer power plants would be needed to meet additional demands for energy during winter. Storing excess energy during the summer (rather than switching power plants off) allows energy companies to use power plants more efficiently and may be cheaper than building new power plants to meet peak winter demand. By making the system more efficient, this could reduce bills for consumers.
- **Storage across hours/days=** allows energy to be stored for hours/days, meaning fewer power plants would be needed to meet daily or weekly peaks in demand. By storing energy produced when demand is low, this also reduces the number of power plants running at less than full output, making it easier for generators to cover their costs. By making the system more efficient, this could reduce bills for consumers.
- **Matching supply with demand**= technology currently used to match supply of energy with demand. All technologies examined are capable of doing this.
- **Less network upgrades**= Helps to manage unstable energy supplies by absorbing excess generation or discharging when output is too low. This reduces the need for other grid reinforcement (new cables, substations etc) that may be needed to absorb unstable supplies from large-scale wind and rooftop solar energy.
- **Use in remote areas=** Operates at a small enough scale to allow users in remote locations to store locally produced energy without relying on the national grid.

Ancillary services (additional services provided to the energy system)

- **Power quality**= Replace devices that ensure reliable frequency and voltage on electricity transmission and distribution networks or ensure uninterrupted power supply without the need for back-up generators. These are necessary to ensure system stability and prevent blackouts.
- **Back up power**= Can activate quickly to replace a power plant that needs to shut down suddenly or to provide initial power supply to restart a power or gas grid after a full blackout- this task is usually performed by diesel generator

Images

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Kevan (2012), Pimlico District Heating Undertaking [image], https://www.flickr.com/photos/kevandotorg/8016073482 . Licensed for use under Creative Commons Attribution 2.0: https://creativecommons.org/licenses/by/2.0/

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Sandia National Labs (2015); Cutaway Diagram of a Typical Pumped Hydro Plant. (Sandia National Labs, 2015) p.34 in; DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA. Produced for US DOE- public domain document.

Western Power Distribution & British Solar Renewables (n.d). Battery strings in shipping container [image]. Image property of BSR & WPD, used with permission.

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