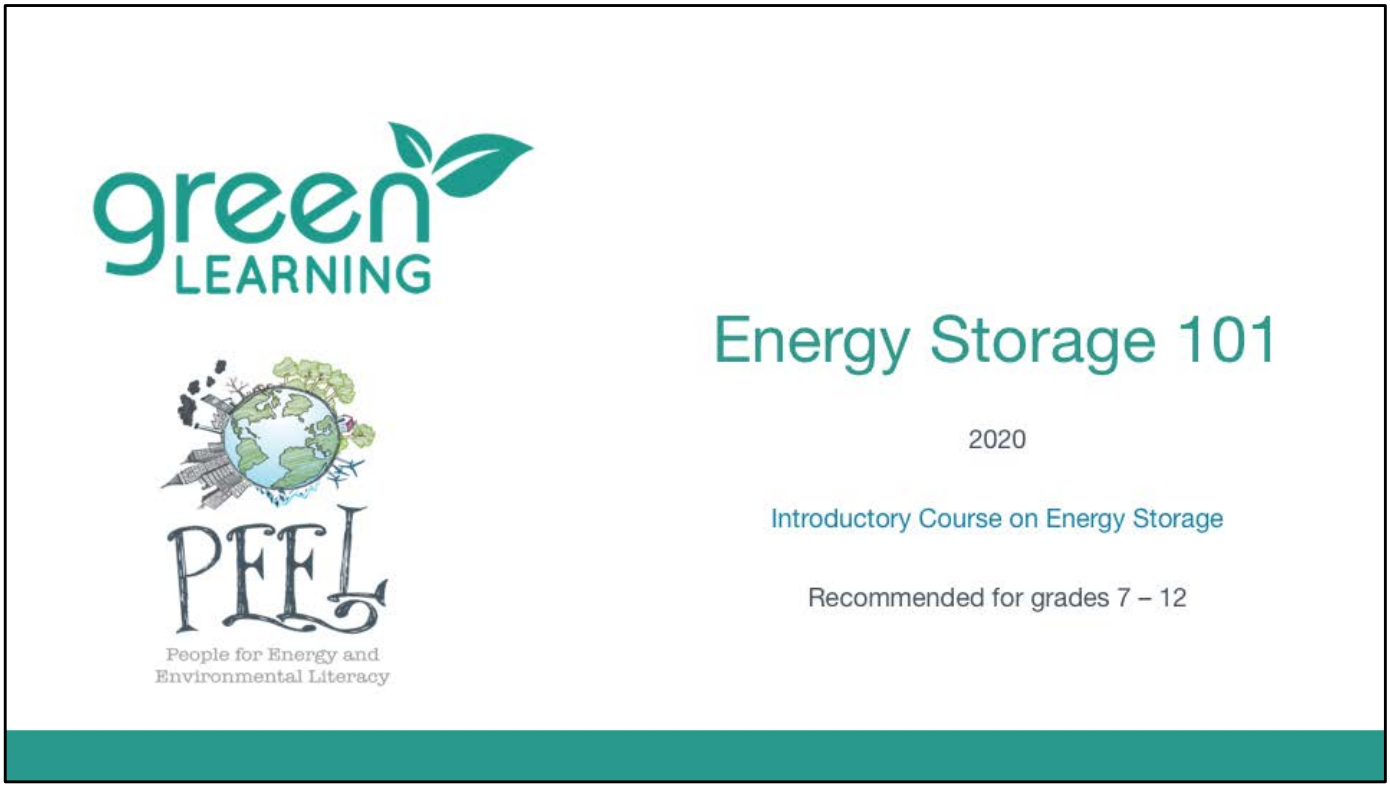
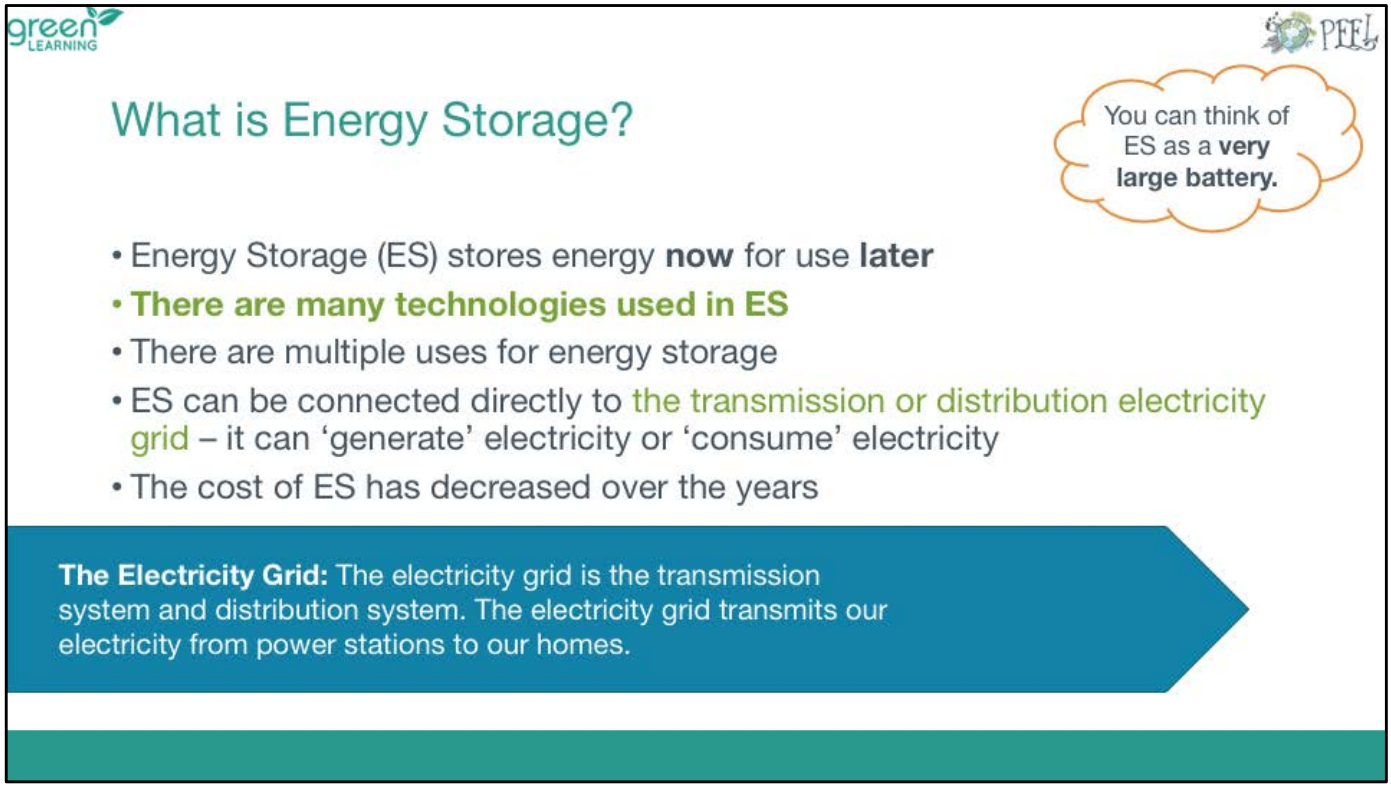


Energy Storage 101 is aligned with the following subjects in the Alberta Curriculum:

- Grade 7 Science:
  - Interactions and Ecosystems
- Grade 8 Science:
  - Mix and Flow of Matter
- Grade 9 Science:
  - Matter and Chemical Change
  - Electrical Principles and Technologies
- Science 10:
  - Energy and Matter in Chemical Change
  - Energy Flow in Technological Systems
  - Energy Flow in Global Systems
  - Stewardship
- Science 20
  - Science Technology and Society
- Science 30
  - Chemistry and the Environment
  - Energy and the Environment
- Social Studies 10
  - To what extent should we embrace globalization? (10-1)
  - Living in a Globalizing World (10-2)



This video gives a quick explanation of what the grid is.
https://www.youtube.com/watch?v=nbPmsBmo03Y

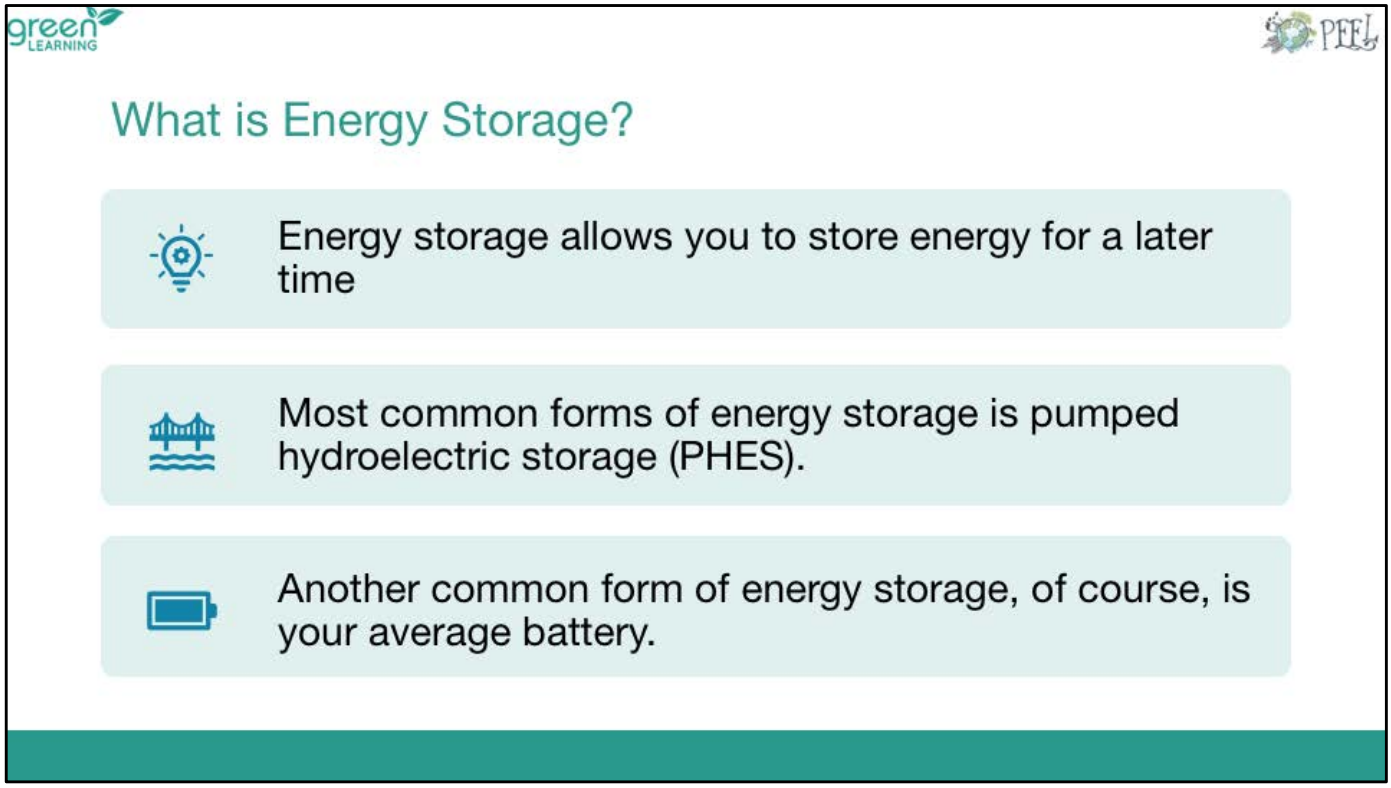
Some forms of Energy Storage is a newer technology such as lithium ion batteries, however pumped hydro has been around for many years.

Energy storage has been studied by the Alberta Electric System Operator and additional information is found here:

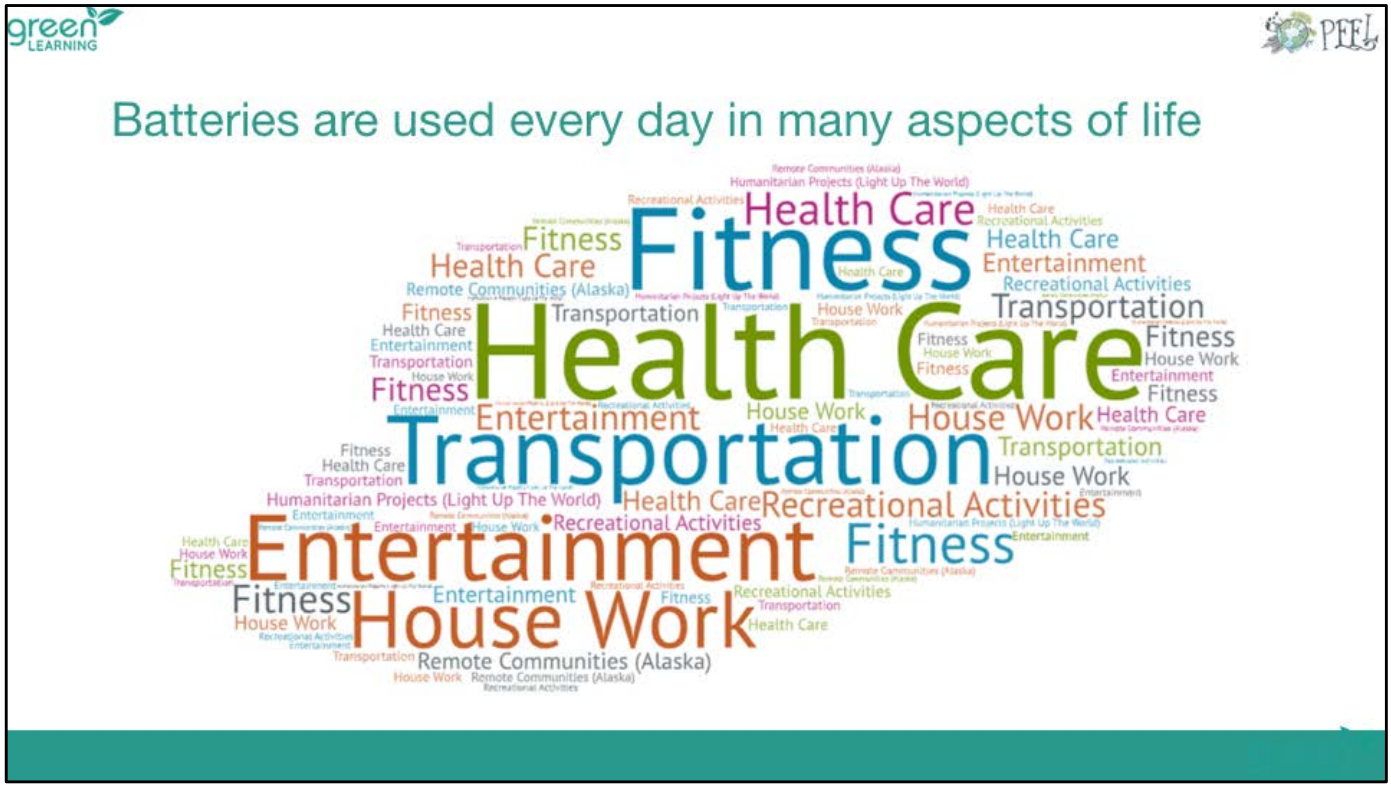
https://www.aeso.ca/assets/Uploads/Energy-Storage-Roadmap-Report.pdf

For more background information on energy storage:

https://www.pembina.org/reports/rmp-storage-fact-sheet-v10.pdf



PHES - Hydro companies use electricity to pump the water uphill when the cost of electricity is low and generate more power from the water when rates are high.



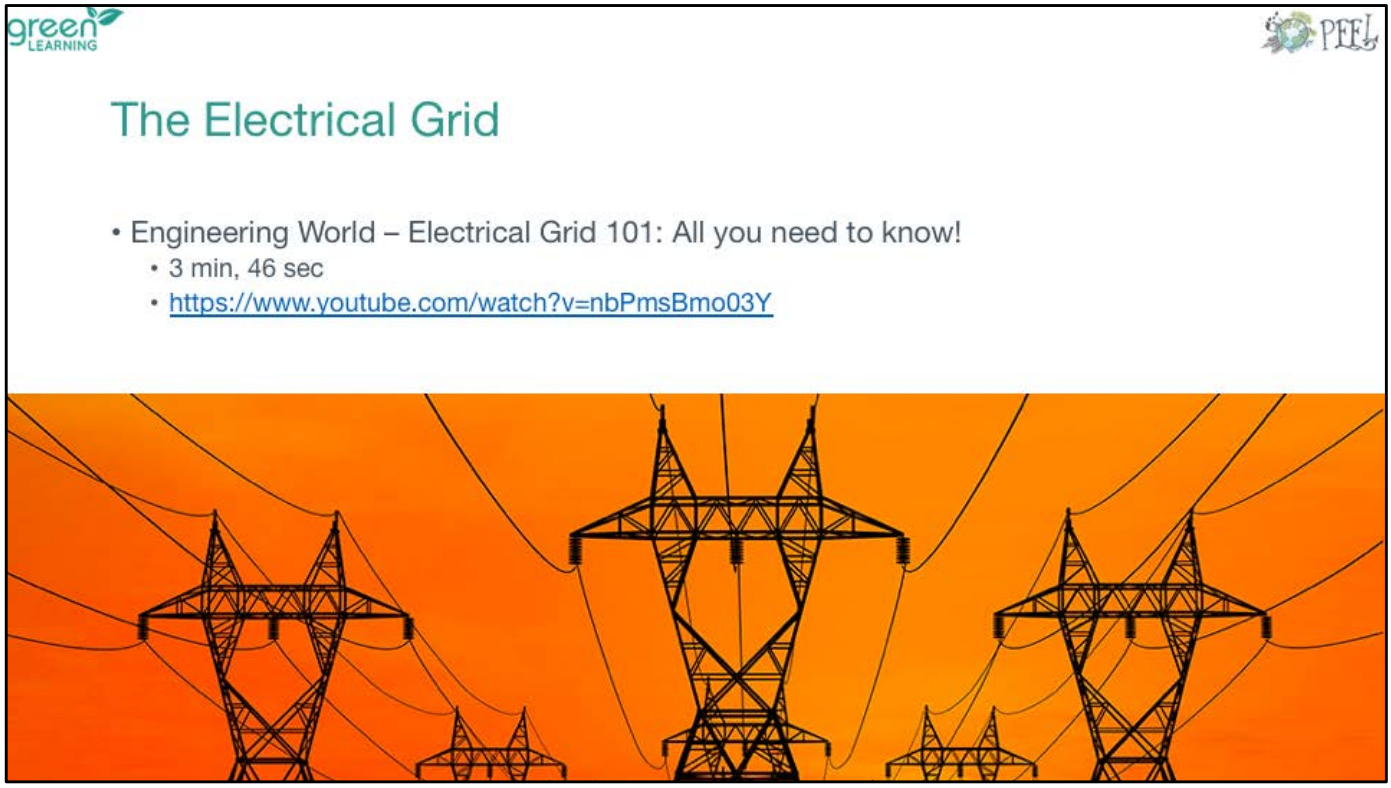
Batteries have endless applications in our every day lives. There are few things we used that don't require a battery. Can you name a few? Some key areas that use batteries include transportation, health care, fitness, humanitarian projects (I.e., light up the world*), entertainment, recreational activities, housework, remote communities (i.e., Alaska**).

*Light up the world is a humanitarian not-for-profit organization that works in third-world countries to provide individuals with light. The organization is based on the principle that access to energy changes lives. LUTW works in communities that do not have access to electricity and provide individuals with solar PV systems to transition away from fossil fuel lighting, and to help save money. They also provide batteries that can be charged for use in lights. (see lutw.org for more details).

**Alaska is home to a number of remote communities. This means there is limited access to resources, including electricity because of the limited transmission line access. Batteries allow community members to store electricity and use for periods of time.

Our lives are centered around energy storage

Look at the devices you currently have on you. Which of these use batteries? Batteries are everywhere! Our lives revolve around the storage of energy.

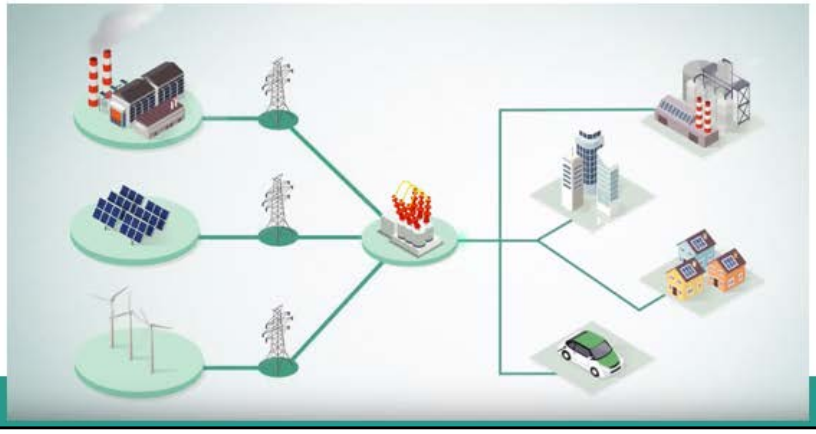


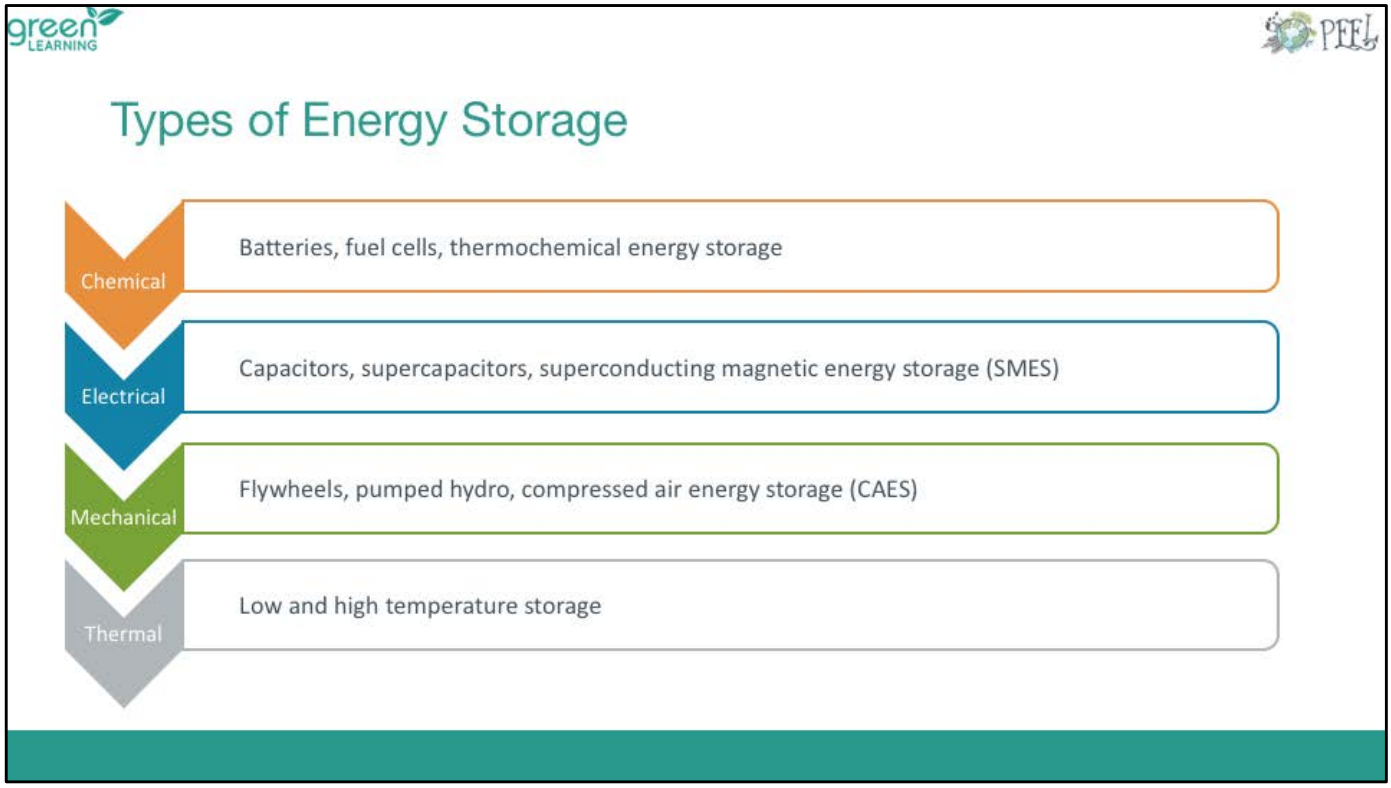
Watch this video with the students to give them an understanding of how the electrical grid works.


green LEARNING
Why Energy Storage?
• Energy storage helps to mitigate problems we face with energy in terms of cost and availability
• Energy Storage allows us to **store energy now** and **use later.**
  • For times of low generation capacity, and for times of high cost
• Energy generators can store excess energy for later use
• Customers can purchase energy during off peak hours and sell during on peak hours to save money

Energy Storage Video

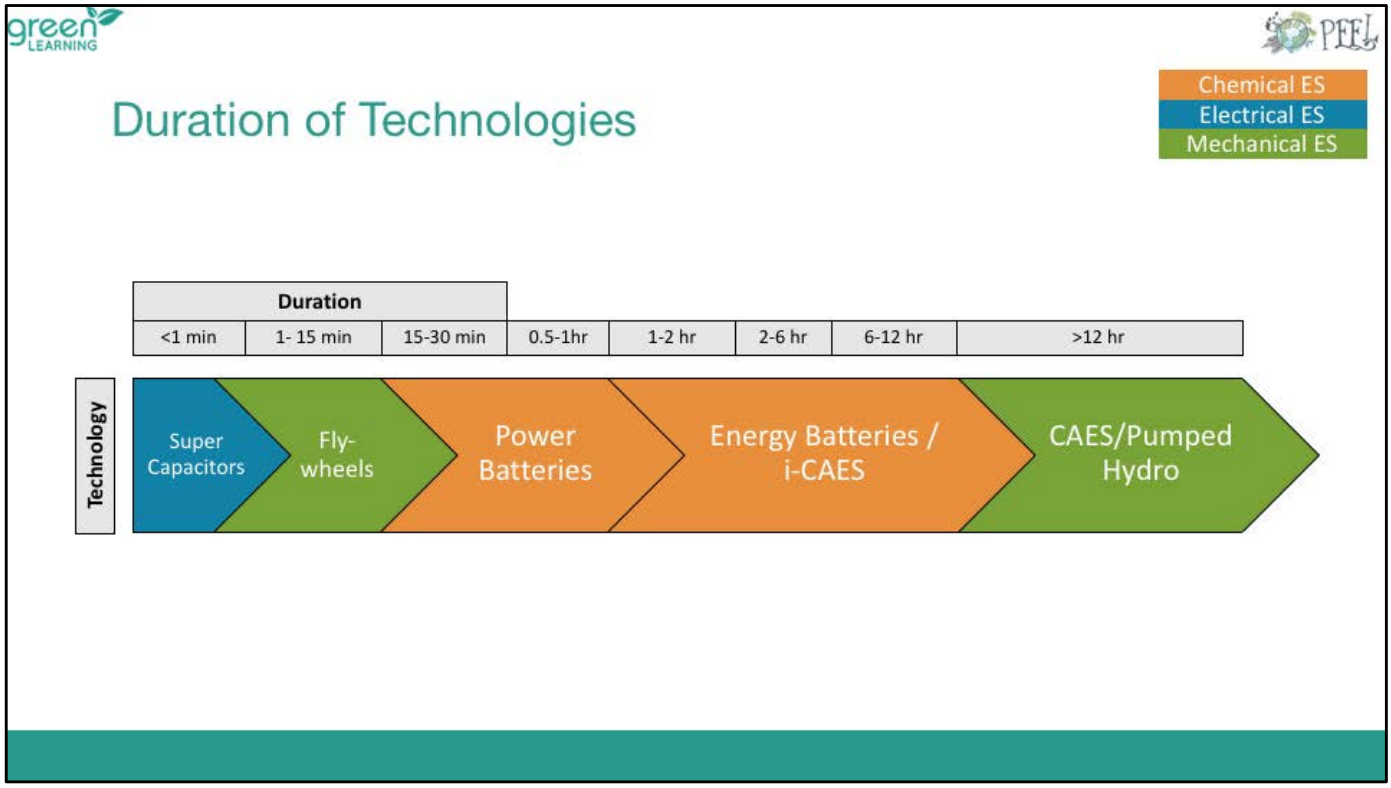
- Parker Products – Battery Energy Storage System | Electromechanical and Drives Technology
  - 2 minutes, 42 seconds
  - https://youtu.be/9SGlfM9XZig





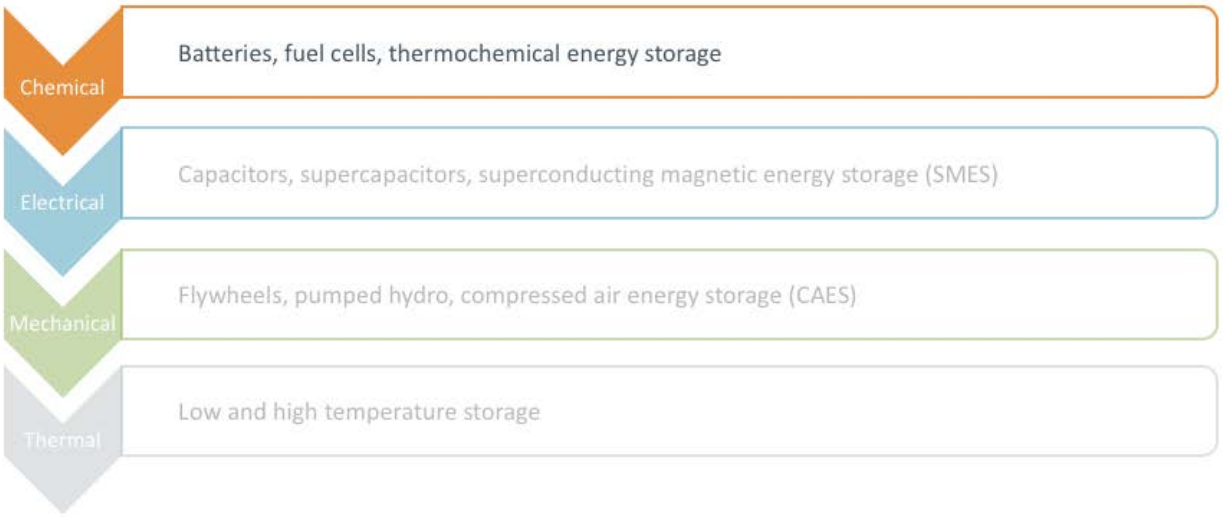
Note: Sometimes Chemical energy storage is split into chemical and electrochemical energy storage

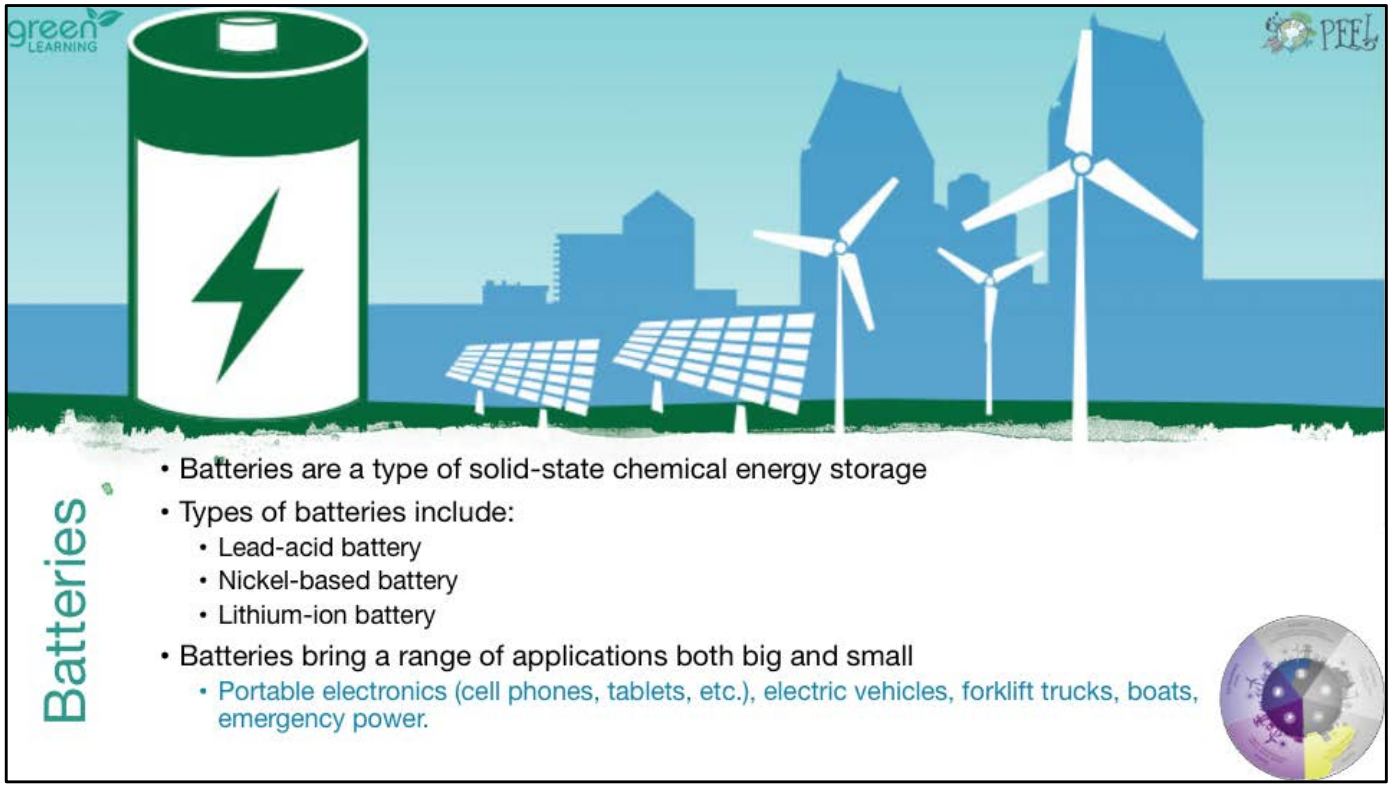
Here, we are going to take a look at the different energy storage technologies.



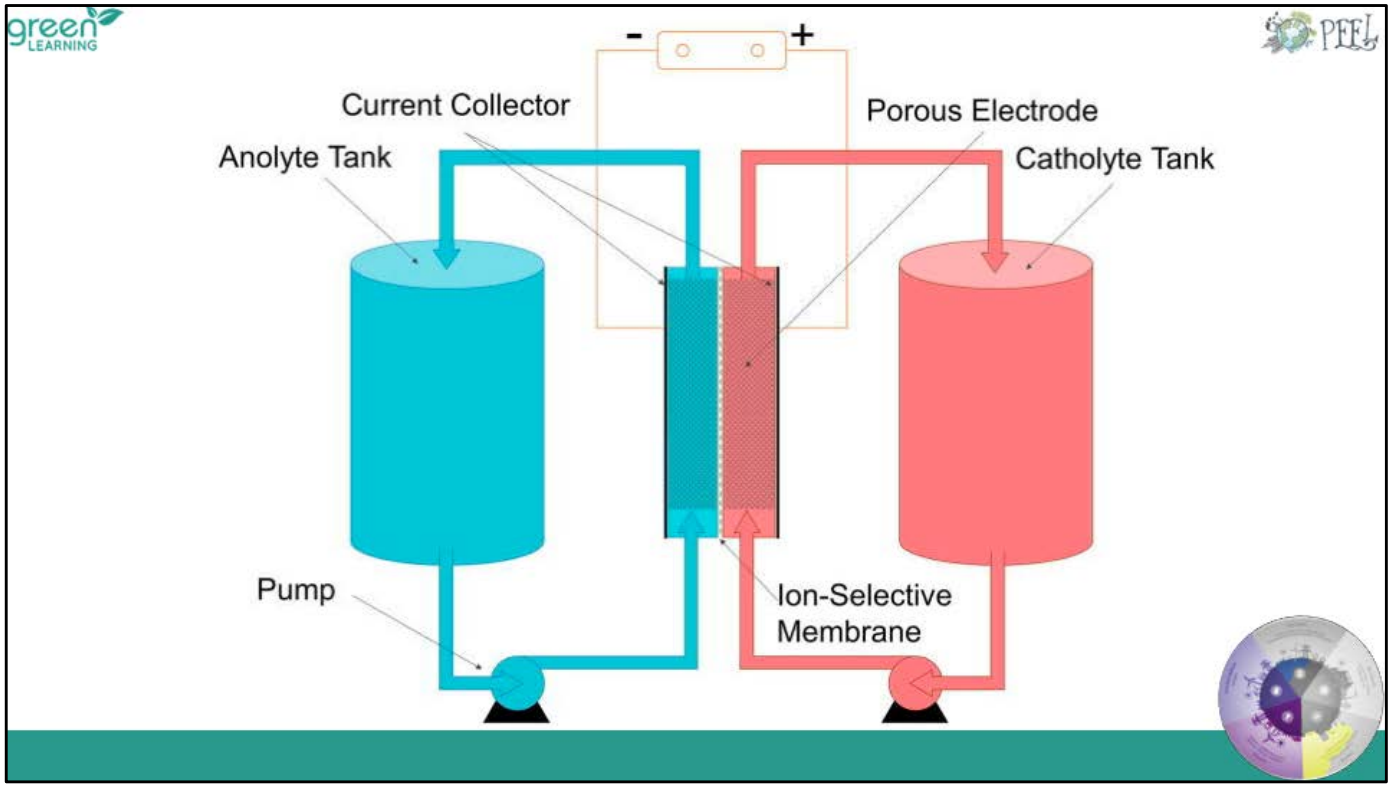
Duration is how long the technology holds on to the stored energy before it begins to self-discharge. The duration is dependent on the specific need.

Chemical Energy Storage





https://www.sciencedirect.com/topics/engineering/chemical-energy-storage



In flow batteries, chemical energy is converted to electricity via the flow of dissolved electroactive elements in the electrolyte.

A flow battery is a mix between a conventional rechargeable battery and a fuel cell battery.
The tanks contain metallic salt electrolyte. The electrolyte is pumped through a positive and negative electrode. Electrons are exchanged at the electrodes, and a current is generated.

The electrolyte is typically sulphuric acid and vanadium salt. The electrodes are made of graphite bipolar plates.

Flow batteries can undergo over 10,000 cycles and have a lifetime of 20 years. If you require a larger capacity battery, you can replace the electrolyte tanks with larger ones (capacity is proportional to the volume of electrolyte). This is significantly cheaper than purchasing a new battery.

Currently, flow batteries cost ~$350/kWh.

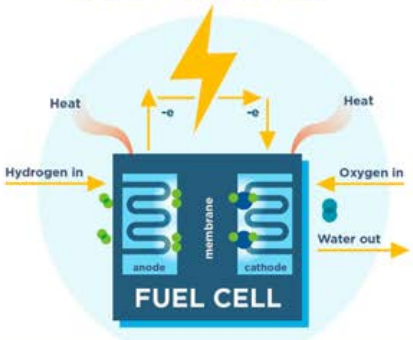
There are different types of flow batteries, such as: redox, hybrid and membraneless flow batteries

Picture source: Wikipedia/flow battery

https://batteryuniversity.com/learn/article/bu_210b_flow_battery

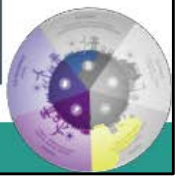
Fuel Cells

- Fuel cells can be used in replace of traditional combustion engines
- Fuel cells typically convert hydrogen-based fuel into electricity
- Components:
  - Anode
  - Cathode
  - Electrolyte Membrane



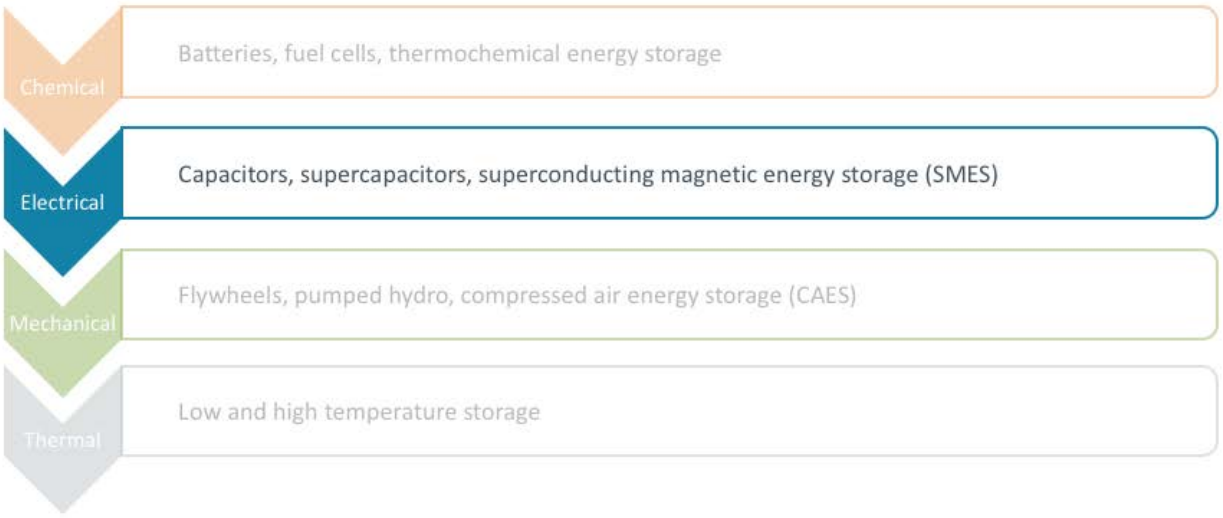
- **At the anode:**
  - Hydrogen flows in
  - Hydrogen molecules split into electrons and protons
  - Electrons flow through a circuit and protons through the membrane

- **At the cathode:**
  - Oxygen flows in
  - Electrons, protons, and oxygen combine to form water
  - Water flows out



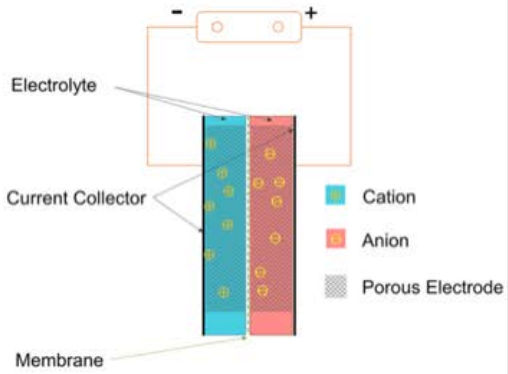
Picture Source:
http://www.fchea.org/fuelcells

Electrical Energy Storage



Capacitor and Supercapacitor

- What is a capacitor?
  - "An electronic component that stores electrical charge"[1]
  - "A passive electrical element, which accumulates energy in the electric field between the two conducting electrodes"[2]
- A capacitor is made up of two conducting plates separated by insulating material
- When supplied with a charge, one plate becomes positively charged and the other becomes negatively charged
- **Capacitance** (the amount of electric charge stored in that capacitor at 1 volt) is measured in Farad (F)
- A supercapacitor has a higher capacity and energy density than a conventional capacitor



https://batteryuniversity.com/learn/article/whats_the_role_of_the_supercapacitor

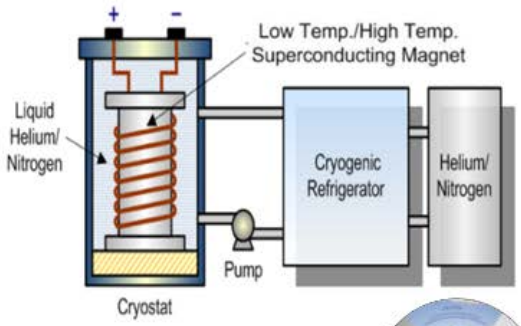
[1] https://www.rapidtables.com/electric/capacitor.html#what

[2] https://www.spscap.com/difference-capacitor-supercapacitor.html

*Supercapacitors accept and deliver charge faster than rechargeable batteries. They also tolerate many more charge cycles than batteries.

Superconducting Magnetic Energy Storage (SMES)

- SMES' store energy in the magnetic field induced by **superconducting** coils.
- The superconducting coils are cooled below the superconducting critical temperature
- There is no resistance at this temperature
- Energy is stored in the coil when temperature is extremely low
- The energy current cycles through the coil



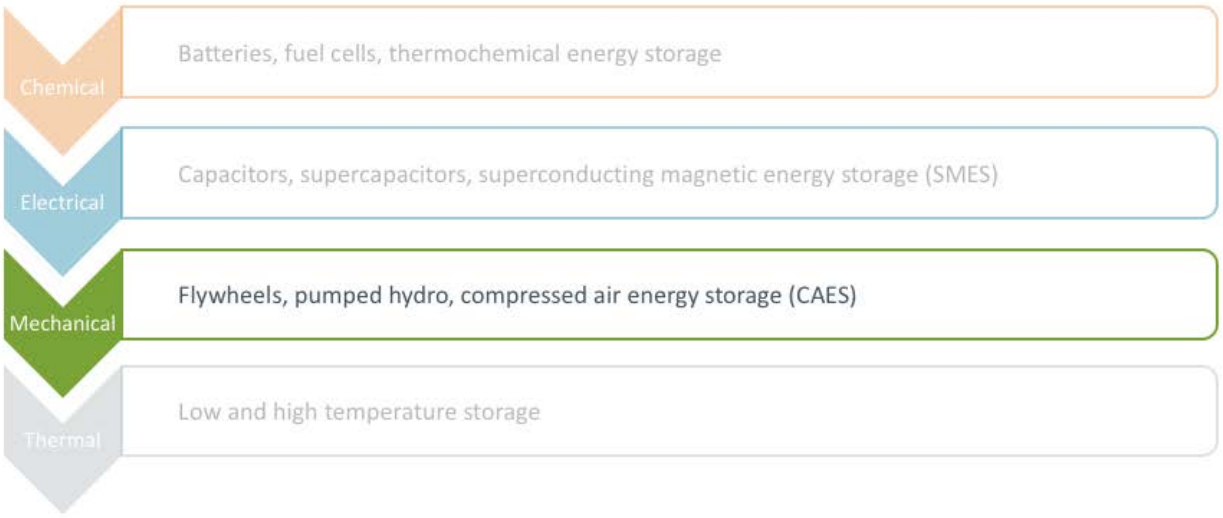
SMES is electrical energy storage. Energy is stored in the magnetic field induced by the flow of current through a superconducting coil. This technology has a near-zero energy loss, meaning almost all the energy is preserved and not lost to heat. SMES is capable of discharging energy instantaneously. The technology is advantageous as it can provided stability to the grid when there is intermittency. SMES can discharge and store energy as needed. Additionally, SMES can undergo nearly infinite cycles.

For an SMES to work, the coil muse be cooled to below the critical temperature of the superconducting material (temperature dependent on material used). This is accomplished through the **cryogenic refrigerator.** The SMES is charged by applying a DC current to the system. This causes the current to cycle through the coil. The current is then isolated and is left to run continuously. Since there is no resistance, the current can flow for a long time, and without any losses due to heat. The switch is flipped to release the stored energy. The electricity is in the form of alternating current (AC).

Another benefit of SMES' is that the coils do not experience degradation due to repetitive charge/discharge cycles.
Image Source: https://www.rednewswire.com/superconducting-magnetic-energy-storage-systems-market-2018-hyper-tech-research-southwire-company-nexans-sa-luvata-u-k/
http://www.superpower-inc.com/content/superconducting-magnetic-energy-storage-

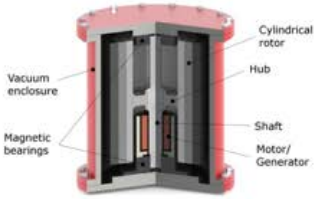
smes

Mechanical Energy Storage



Flywheels

- Flywheels store rotational energy
- The energy is contained in the device when rotated at high speeds
- When energy is discharged, the rotational speed decreases
  - Principle of conservation of energy
- Alternatively, when energy is added, the speed increases
- Flywheels have a lifetime of decades with little maintenance



NASA G2 Flywheel!

Canadian Flywheel Example:
Ontario Minto Flywheel
2 MW located in Wellington, Ontario
Constructed in 2014.

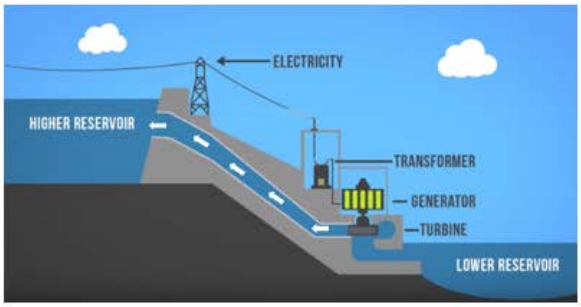
Flywheels are a mechanical energy storage technology. The amount of energy a flywheel can store is proportional to the square of its rotational speed and mass – the larger a flywheel is and the faster it can spin, the more energy it can store. You can easily change the amount of energy stored by changing the rotational speed. This can be accomplished without changing the mass of the device.

NASA G2 Flywheel

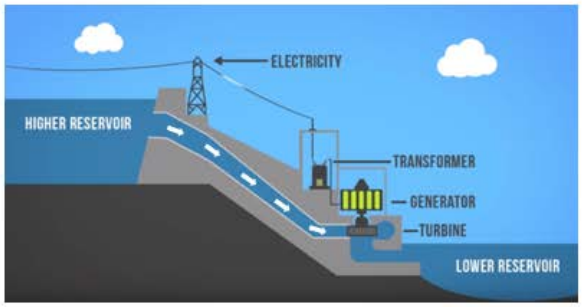
https://www.planete-energies.com/en/medias/close/flywheel-energy-storage
http://www.ieso.ca/en/Powering-Tomorrow/Technology/High-Performance-Flywheel-Energy-Storage-Systems-Temporal-Power)

Pumped Hydro

- 99% of storage technology is pumped hydro
- This technology is mainly used to fill the gaps in the supply and demand requirements, or for arbitrage (buy low, sell high)
- It can store large quantities of energy for days.



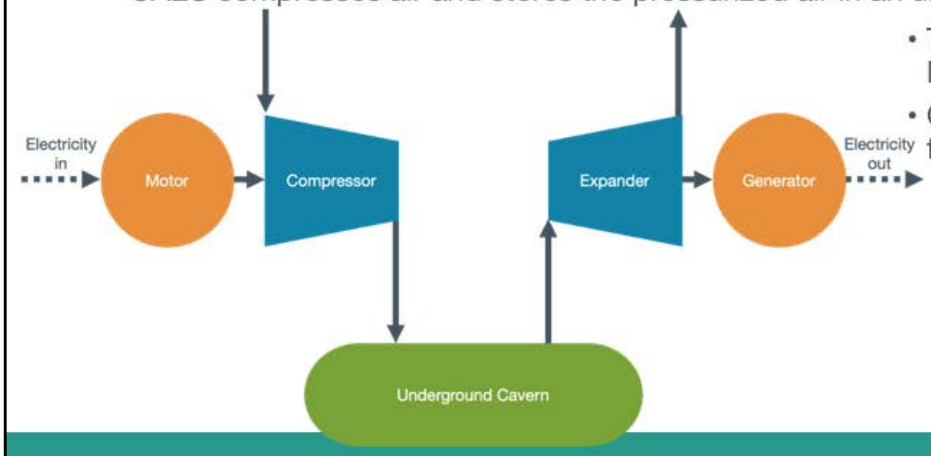
Charge

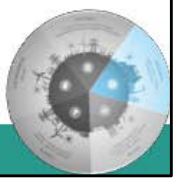


Discharge

Compressed Air Energy Storage (CAES)

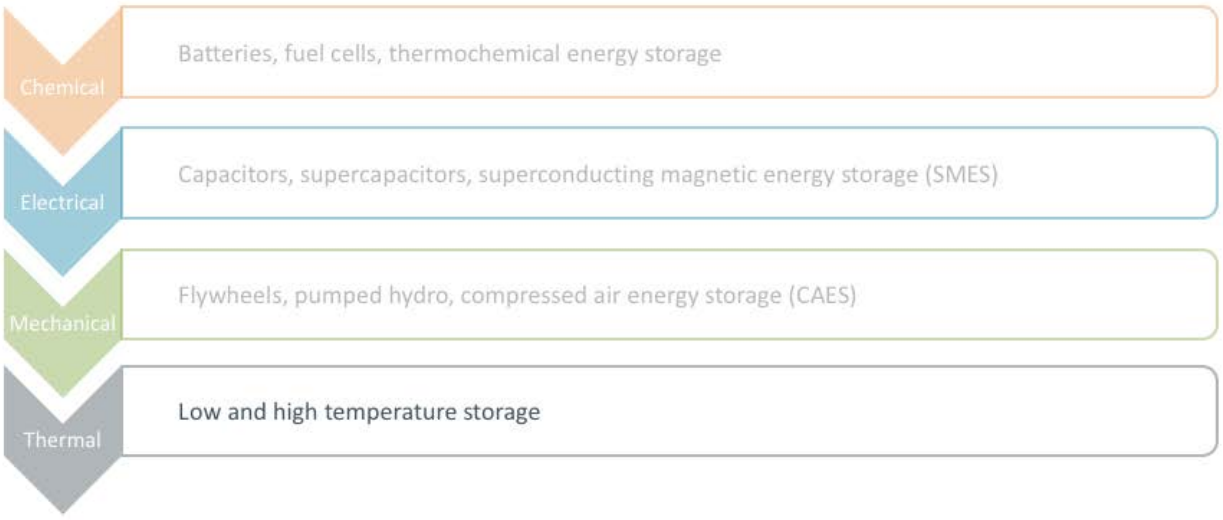
- CAES converts electrical energy into high pressured air. When the air is released, the air drives a turbine generator, and electricity is produced
- CAES compresses air and stores the pressurized air in an underground cavern
- Two types: Adiabatic CAES and Diabatic CAES
- Ontario has a 1.75 MW CAES facility in Goderich Ontario.





http://energystorage.org/compressed-air-energy-storage-caes

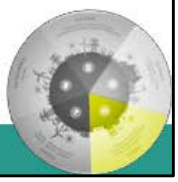
Thermal Energy Storage



Thermal Energy Storage

- Thermal Energy Storage uses extremely high or low temperature to store energy
- Types:
  - Sensible Heat Storage
    - "Shifting the temperature of a storage medium without phase change"[1]
  - Phase Change Storage
    - "Heat storage where a large part of the accumulated heat is released or taken up during the phase change of the heat storage material"[2]
  - Chemical Reaction Storage
    - Dependent on the heat released or absorbed through chemical reactions.

Molten salt storage tanks at the Solana Generating Station in Arizona, USA



[1] https://www.sciencedirect.com/topics/engineering/sensible-heat-storage

[2] DTU International Energy Report, 2013

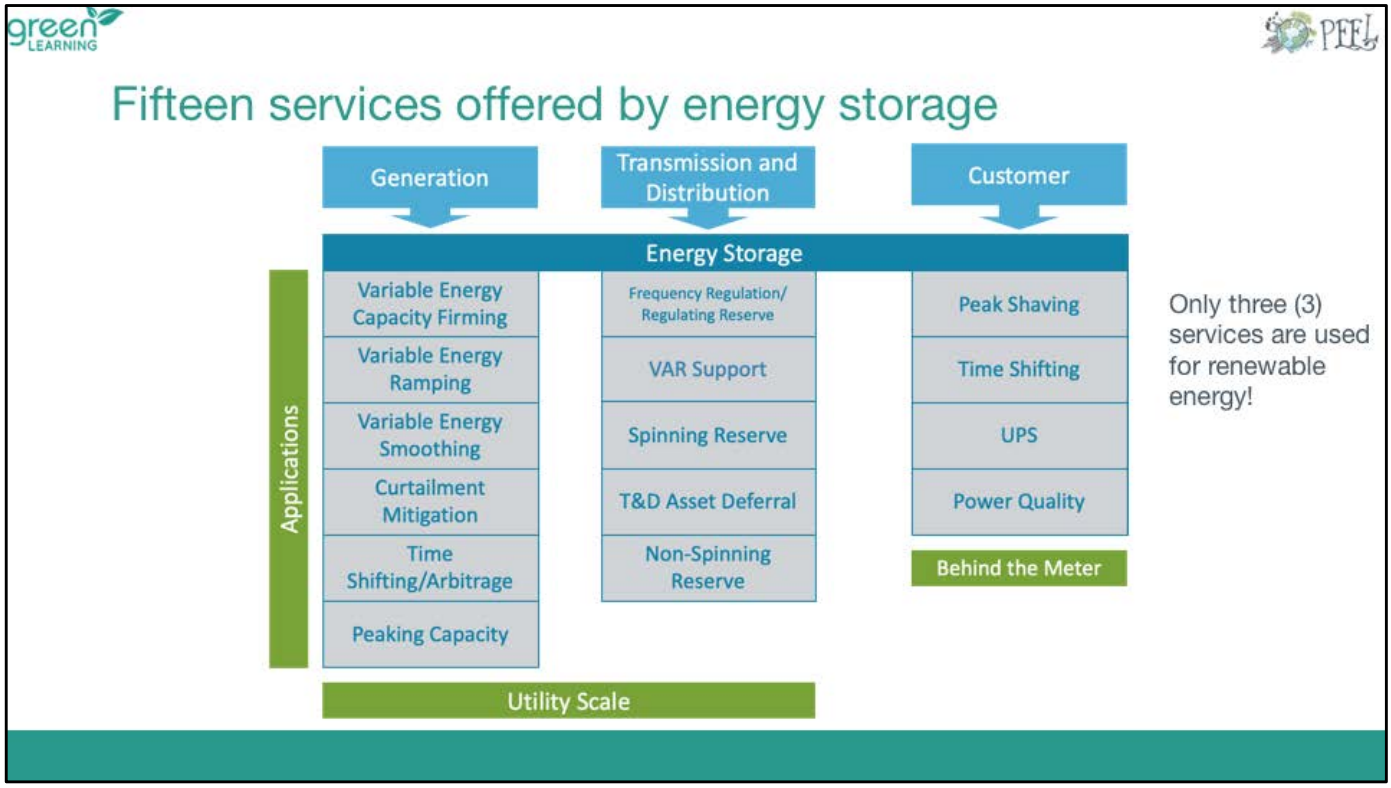
Picture: https://www.renewableenergyworld.com/articles/print/volume-18/issue-110/features/thermal-renewable-energy/commercializing-standalone-thermal-energy-storage.html#gref

Benefit of Energy Storage

Energy storage moves energy

from a time when:
- you don't need the energy,
- you don't want the energy, or
- you cannot take the energy

to a time when:
- you need the energy, or
- you want energy, or
- can take the energy.



When batteries are mentioned, people often think of price arbitrage (buy low, sell high), but in fact there are 15 applications for energy storage, and they can be supplied just about on the interconnected electric system.

Generator:

Variable Energy Capacity Firming – facilitate variable renewable generation to offer into the energy merit order
Variable Energy Ramping – limit up and down ramps of variable renewable generation
Variable Energy Smoothing – similar to ramping, but on shorter timescale
Curtailment Mitigation – store renewable energy that would otherwise be lost to curtailment and deliver to the grid at a later time
Time Shifting/Arbitrage – buy energy during low prices hours, sell during high priced hours
Peaking Capacity – supply electricity to the grid during periods of peak demand.

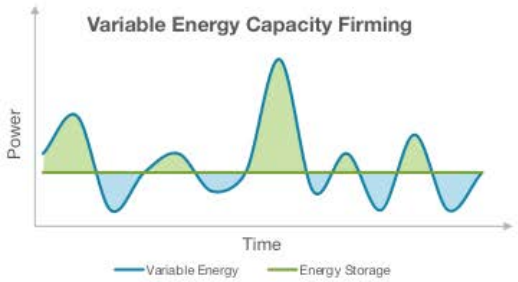
Grid Connected:

Frequency Regulation, VAR Support, Frequency Response – In Alberta, AESO controls dispatch of an asset via Regulating Reserve to maintain these electric system operating parameters.
Spinning Reserve – contingency generation capacity that is synched to the grid.

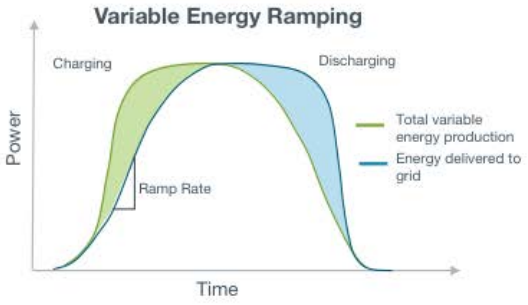
Non-Spinning Reserve – contingency generation that is not synched to the grid but can provide power within ½ hour.
T&D Asset Deferral – support weak transmission or distribution infrastructure in place of wire construction.

Customer Services:

Peak Shaving – replace grid power at times of high customer and/or system demand, which results in savings in demand charges
Time Shifting – shift load from high priced hours to low priced hours
UPS – provide power to the customer in the event of a lack of supply from the grid
Power Quality – reduce voltage and frequency changes that can damage customer equipment.

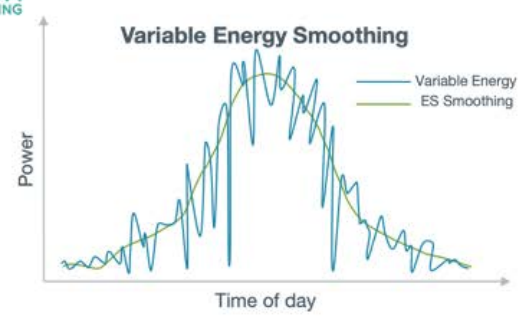


Capacity Firming allows variable energy generators to deliver consistent energy to the grid. When more energy is produced than needed, that energy is stored for when not enough energy is produced.
The green is excess energy stored (charged) and the blue is the energy released to the grid (discharged).

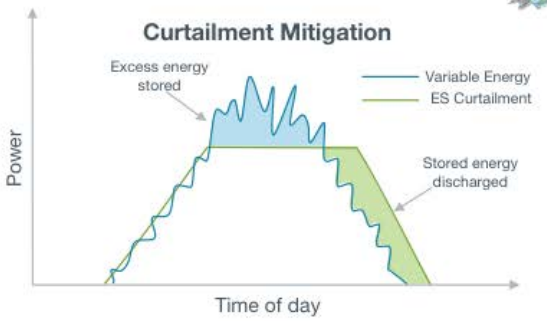


Energy storage changes the ramp rate (the slope of the graph) to allow variable energy to deliver energy to the grid at a faster rate – the steeper the slope, the faster the response time.

Generation Side ES Applications



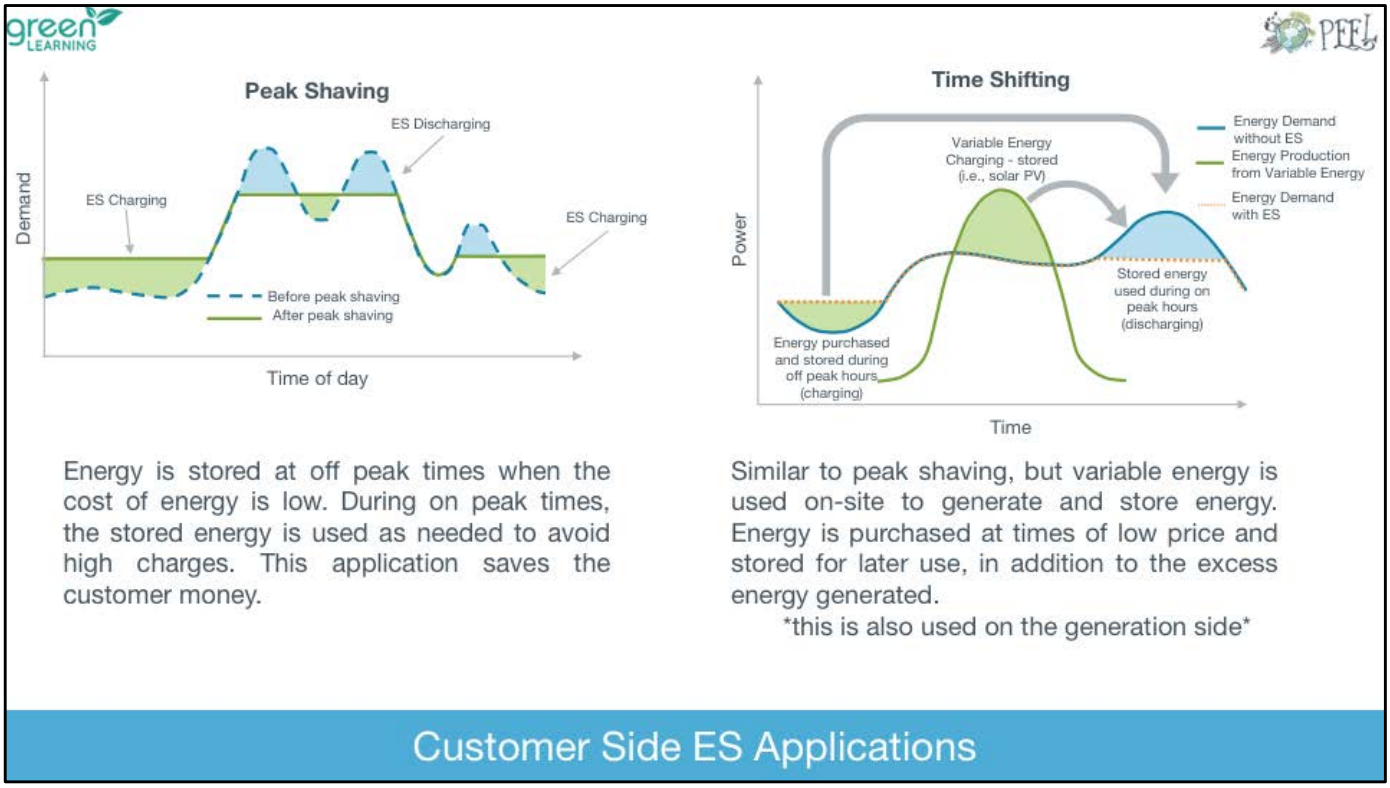
Variable energy's production fluctuates. For example, solar PV produces energy when the sun is shining, and wind energy produces energy when the wind is blowing. This results in variability in the total energy produced. Energy storage helps to smooth out the fluctuation by providing a constant supply. Energy produced from variable energy is stored into the energy storage system and is delivered to the grid from the energy storage.



Curtailment: the action or fact of reducing or restricting something

Sometimes, there is no need for all the energy produced by a generator. Energy storage allows a generator to continue producing energy during low times. This energy is stored until required later (see right side of the graph).

Generation Side ES Applications

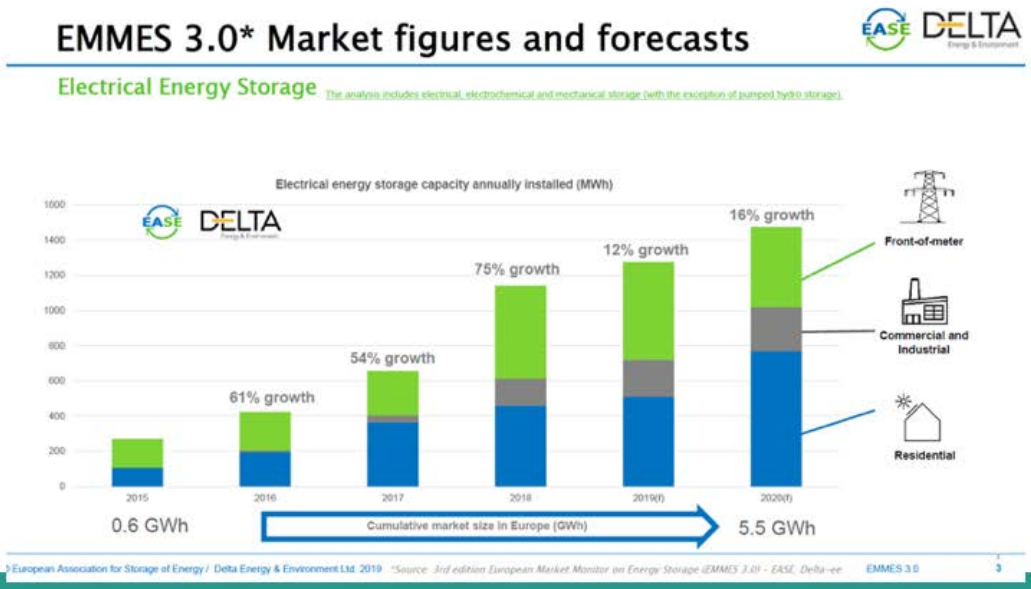


Peak shaving:
https://www.sciencedirect.com/science/article/abs/pii/S1364032117314272

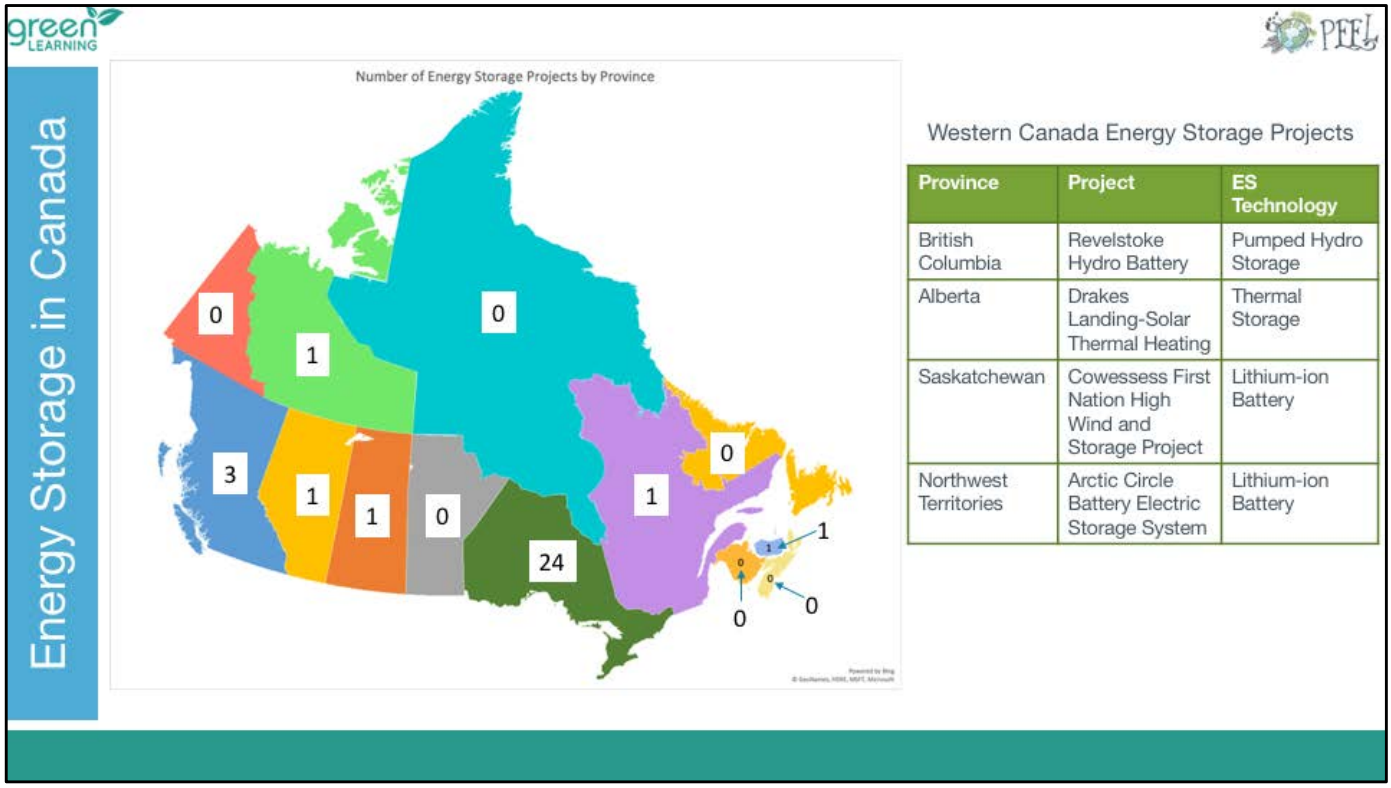
Time Shifting
https://saltxtechnology.com/media/Peak-Shifting_graph-2.png

Europe's Energy Storage Forecast shows high growth rates

- High growth rate in residential, commercial/industrial and utility scale.
- The growth in 2018 was higher than expected and was the highest growth ever seen (75% increase)



http://ease-storage.eu/category/publications/emmes/



The table list the western Canada energy storage projects

Source: Sandia National Laboratories

Example Energy Storage Projects

Toronto Zoo Ice Bear Ice Thermal Energy – Toronto, Ontario

Goderich A-CAES Facility – Goderich, Ontario

Drakes Landing solar Thermal Heating (Thermal Storage) – Okotoks, Alberta

Cowessess First Nation Lithium-Ion Battery Storage

Here are pictures of some of the energy storage projects shown on the last slide. These projects range from announced to operational to decommissioned.

*Projects pulled from Sandia Laboratories Energy Storage Database

Video on Toronto Zoo: http://www.torontozoo.com/tz/icebear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People for Energy and Environmental Literacy
Thank you!
This is a project of GreenLearning offered in partnership with PEEL thanks to funding support from the Alberta Energy Efficiency Education Grant Program.
RBC Foundation
ALBERTA ecotrust
Energy Efficiency Alberta
Alberta

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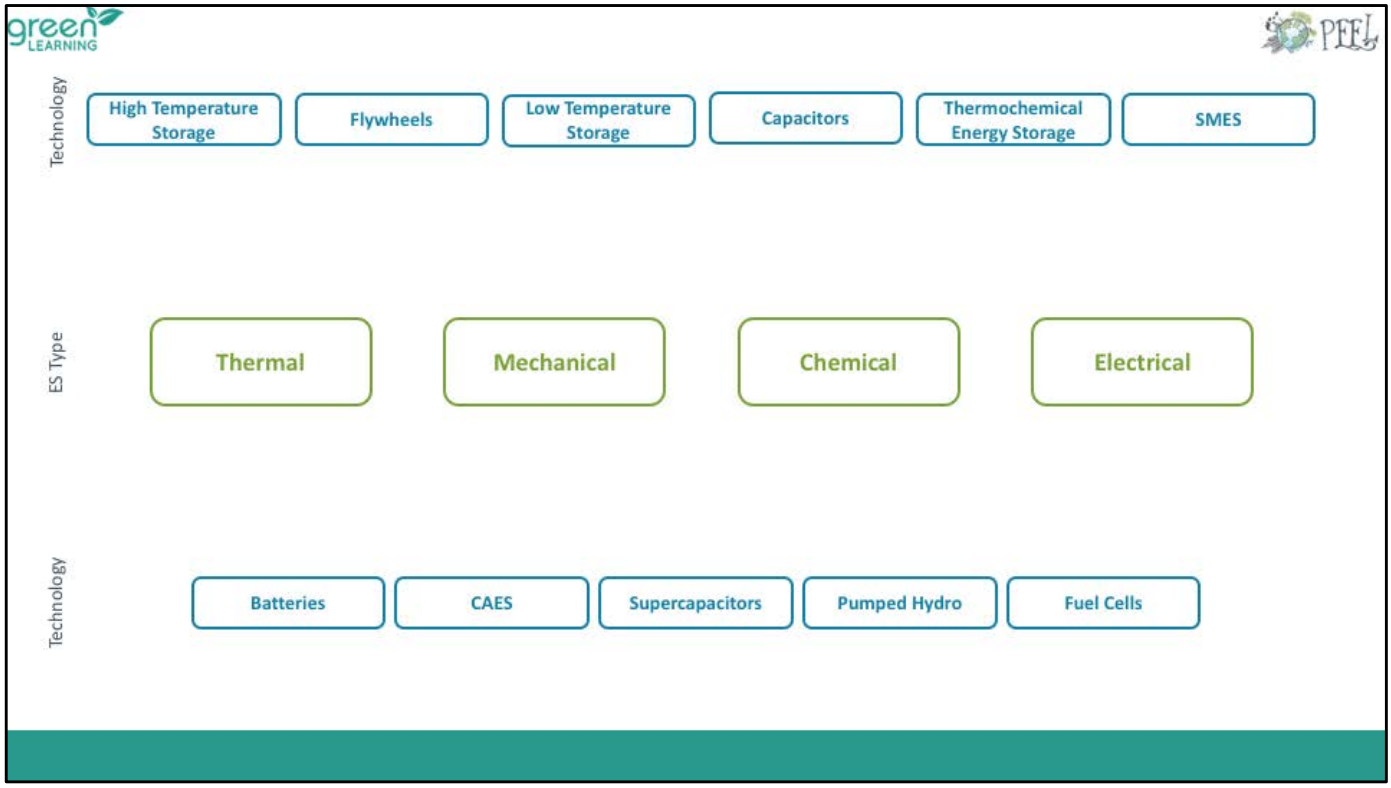
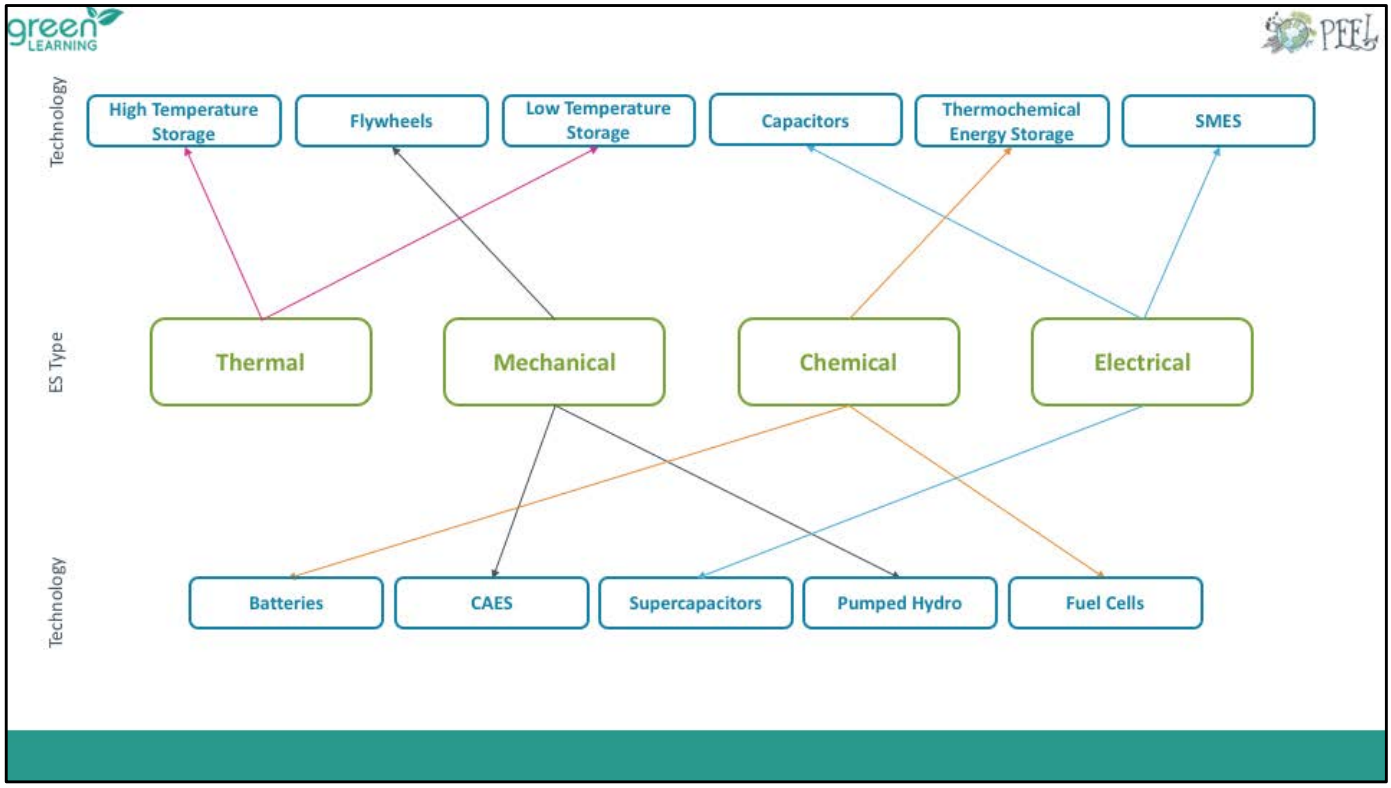
ACTIVITY



Match the technology to they type of energy storage


Technology
High Temperature Storage
Flywheels
Low Temperature Storage
Capacitors
Thermochemical Energy Storage
SMES
ES Type
Thermal
Mechanical
Chemical
Electrical
Technology
Batteries
CAES
Supercapacitors
Pumped Hydro
Fuel Cells

ANSWERS