



Electrical Energy Storage

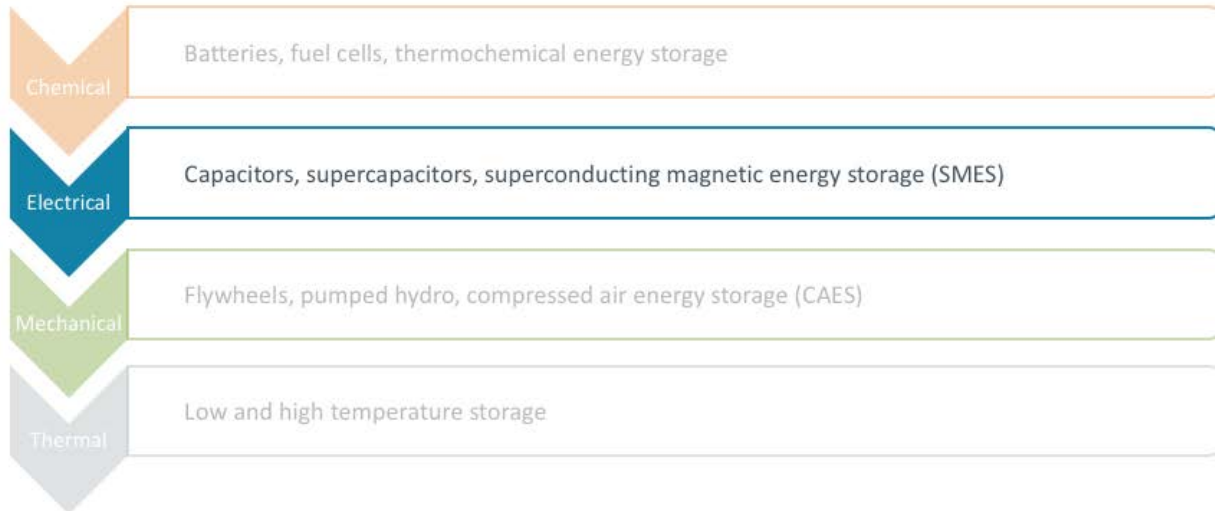
2020

Capacitors, Supercapacitors, SMES

Recommended for grades 7-12

This lesson is aligned with the Alberta curriculum. See the lesson plan for more details.

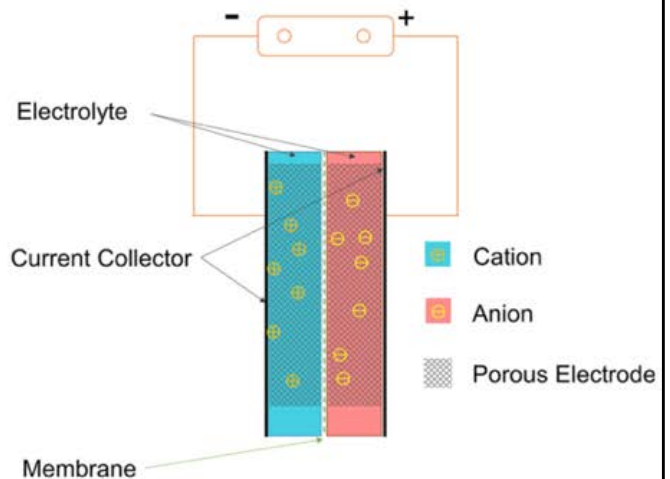
Electrical Energy Storage



In this lesson we are learning about electrical energy storage. This includes capacitors/supercapacitors and superconducting magnetic energy storage (SMES) technology.

Supercapacitors

- European Association for Storage of Energy definition:
 - “An energy storage system based on electrostatic effects that occur between **two carbon electrodes** with high specific surface areas per volume”
- Supercapacitors are also called Electrochemical Double Layer Capacitor (EDLC)
- EDLC’s store more energy than conventional capacitors
- Operating temperature: **-40°C to 70 °C**



Supercapacitor Components:
 2 Carbon electrodes
 1 Electrolyte
 1 Dielectric Membrane

Dielectric: A non-conducting substance. One that transmits an electric charge without conducting it. An insulator.

The first electrical energy storage technology is called a capacitor/supercapacitor. We are going to look at supercapacitors as they have a higher energy capacity than capacitors. Supercapacitors are also known as electrochemical double layer capacitor.

Here are two descriptions of supercapacitors from Battery University:

- “Supercapacitors are ideal when a quick charge is needed to fill a short-term power need (batteries are chosen to provide long-term energy).” – BU
- “Supercapacitors are most effective to bridge power gaps lasting from a few seconds to a few minutes and can be recharged quickly.” – BU

As mentioned, supercapacitors are ideal for providing short, quick bursts of energy to help level the energy demand on the grid.

The device is composed of two carbon electrodes, an electrolyte, and a dielectric membrane. A dielectric membrane is a **non-conducting** substance. This means the substance transmits an electric charge without conducting it. The substance acts as an insulator.

This picture in the top right is a schematic of what a supercapacitor looks like. You can see the charge separation on the electrodes (positive on the left and negative on the right).

Supercapacitors operate at a wide temperature range - from -40°C to 70 °C!

<https://www.sciencedirect.com/topics/engineering/electrochemical-double-layer-capacitor>

Supercapacitors Basics



- Capacitors are like batteries – they both store **electrical energy**
 - Batteries use chemical reactions to produce electrons at one terminal and absorb the electrons at the other terminal
- Capacitors do not have two terminals. Instead they have **two plates**
- Capacitors do not produce electrons like batteries, rather, they **store already existing electrons**
- The two plates are separated by a dielectric material (electrical insulator):
 - Dielectric materials are **mica, ceramic, cellulose, porcelain, Mylar, Teflon, and air**
- Capacitance is the storage potential of a capacitor, and is measured in Farads

The pictures on this slide show the difference between a supercapacitor, and a regular battery. There is a lot of similarities between the two, but one is capable of discharging for extended periods, and the other for short burst only.

Both batteries and supercapacitors store electrical energy; however, supercapacitors do not produce electrons like in batteries. Instead, they transfer the existing electrons between the electrodes.

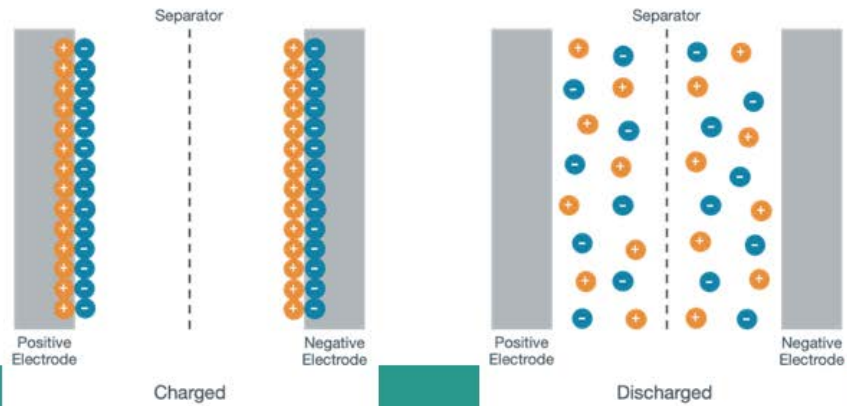
The dielectric material (insulating material) that separates the electrodes is typically one of the following: mica, ceramic, cellulose, porcelain, Mylar, Teflon and air. Depending on energy requirements, certain materials will be better suited.

The total storage capacity of a supercapacitor is measured in **capacitance**. The units are Farads.

<https://electronics.howstuffworks.com/capacitor.htm>

How do Supercapacitors Work?

- Capacitors store energy based on the **electrostatic effects** between the two carbon electrodes
- When charged, cations (+) accumulate at the negative electrode, and anions (-) accumulate at the positive electrode
 - This forms the **Helmholtz-Layer**



Electrostatic Effect

- Electrostatic effect is the force electric charges exert on one another.
 - Coulomb's Law
- It is the buildup of an electrical charge on a surface
- When two objects are rubbed together, the electrons are transferred between each other
- Examples:





ACTIVITY: Electrostatic Effect

- **Materials:**

- Balloon
- Water faucet

- **Instructions:**

- Blow up the balloon
- Turn tap on so there is a light stream
- Rub the balloon against something (try different surfaces and materials)
- Hold the balloon near the water stream. What happens?

Pause the lesson and try this activity. – See student worksheet

In groups, have the students blow up one balloon. Students should brainstorm different surfaces to rub the balloon against (i.e., their hair, a piece of cotton or wool, a table, etc.). Have them identify what works and what does not. Students should then bring the balloon near the stream, without touching the water. They should see the water move. If the water does not move, the balloon is not charged, and students should find something else to rub the balloon against.

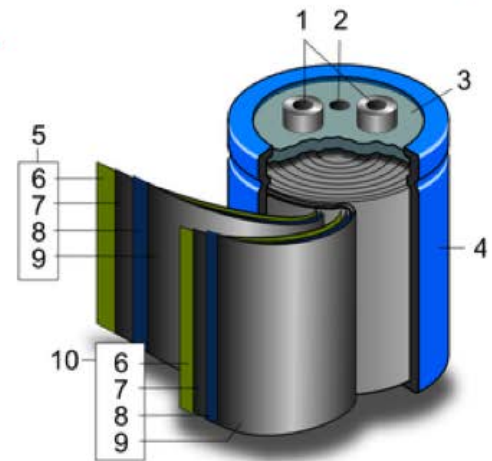
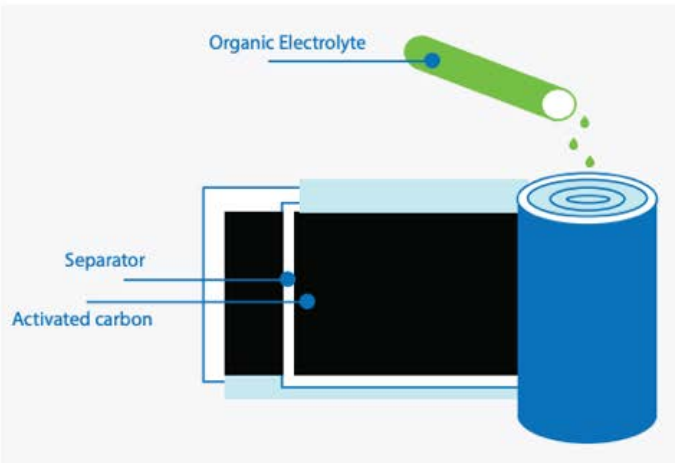
Rubbing the balloon will charge it (charges move from one object to another), shifting the balloon from neutral to negatively charged. The negative charge will accumulate on the surface of the balloon. When brought near a neutral object, the negative charge of the balloon will cause the charges to separate in the other object and attract the objects to one another.

If students try to rub the balloon on metal, they will not charge it. This is because metal acts as a ground and brings the balloon back to neutral.

What are some other examples of electrostatic effect? (socks after being in the dryer, shuffling your feet on the carpet – creates a shock, which is another form of electrostatic charge).

Now that students understand how the electrostatic effect works, they have a stronger understanding of how a supercapacitor works.

Components of a Supercapacitor



- | | |
|------------------|---------------------|
| 1. Terminals | 6. Separator |
| 2. Safety vent | 7. Carbon electrode |
| 3. Sealing disc | 8. Collector |
| 4. Aluminum can | 9. Carbon electrode |
| 5. Positive pole | 10. Negative pole |

EASE – Electrochemical Double Layer Capacitor

This is what the inside of a supercapacitor looks like. There are 10 components to note.

1. Terminals
 - This conducts the electricity
2. Safety vent
3. Sealing disc
4. Aluminum can
5. Positive plate
6. Separator
7. Carbon electrode
8. Collector
9. Carbon electrode
10. Negative pole

<https://www.sciencedirect.com/topics/materials-science/supercapacitors>

Supercapacitors

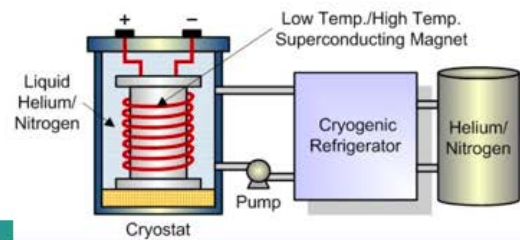
Key Performance Data – European Association for Storage of Energy

| | |
|----------------|---|
| Power Range | MW's |
| Energy Range | kWh's |
| Discharge Time | Seconds to minutes |
| Cycle Life | 1 million cycles |
| Life Duration | 10 years at room temperature |
| Reaction Time | 5 milliseconds |
| Efficiency | 90% |
| Applications | Backup power, load balancing, engine start/acceleration for hybrid vehicles, energy storage for intermittent renewable energy |

Here is the key performance data of a supercapacitor, as provided by the European Association for Storage of Energy (EASE)

Superconducting Magnetic Energy Storage (SMES)

- SMES uses **superconducting coils** to store energy in the magnetic field
- What are superconductors?
 - A material that will create electricity with little to no resistance below the critical temperature.
- No resistance is important because it means no energy losses
- When a superconductor is charged, the electrical current stored will flow through the closed superconducting coils indefinitely, until acted upon by another force.
- Unlike other storage technologies, SMES stores the energy in its electrical form and does not require further conversion
- The superconducting coil prevents the energy from dissipating within milliseconds



Superconducting Magnetic Energy Storage (SMES) uses a superconducting coil to store energy in the magnetic field. Superconductors are a special type of conductor. A conductor is an object (typically metal) that allows the flow of electrons. A superconductor does the same thing, but without resistance. No resistance is an important characteristic of SMES because it allows the technology to store electricity without any loss due to heat. Another important feature of SMES is the cryogenic refrigerator. The coil must be cooled to its critical temperature in order to achieve zero resistance.

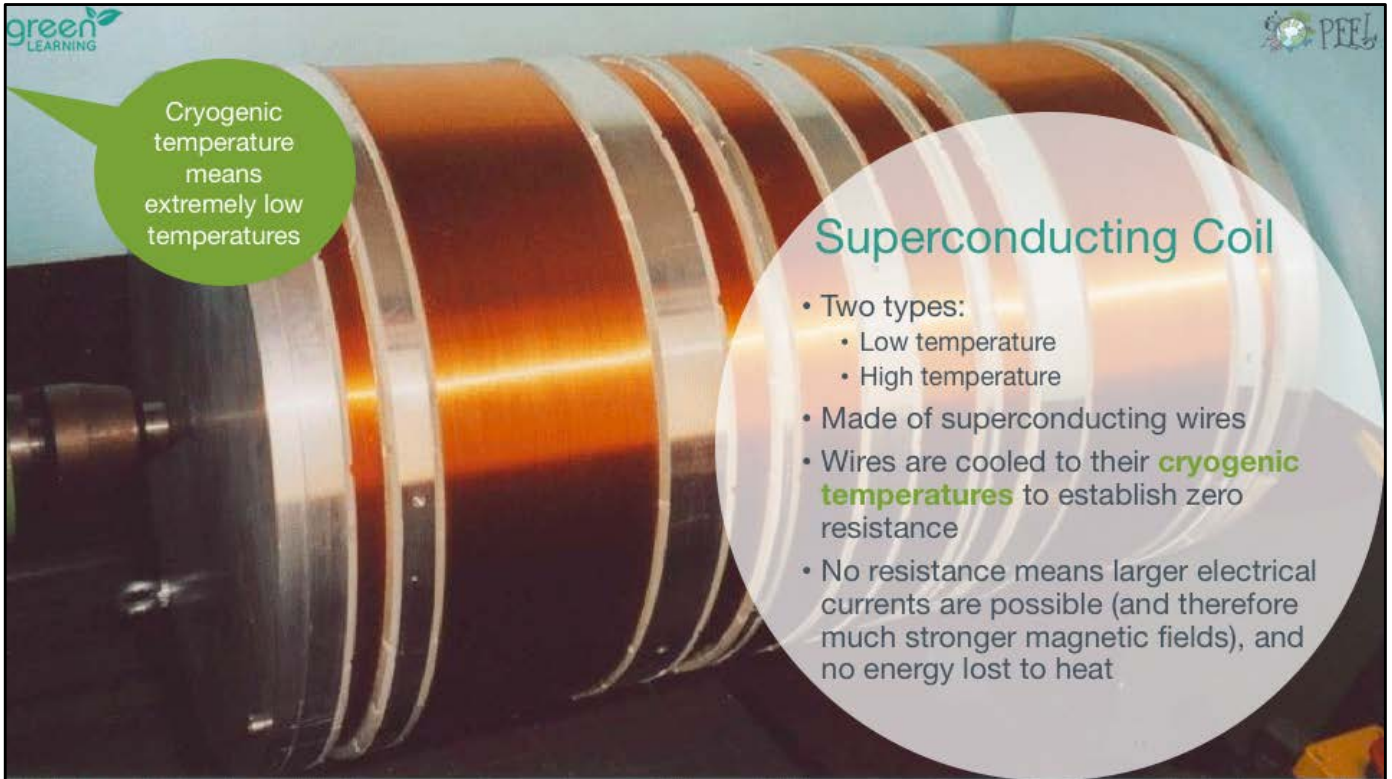
Energy is placed in the SMES to charge it up. The energy is stored in the coil, which is wrapped around a magnetic, and travels at high speeds. The energy can be stored indefinitely because there is no loss due to resistance.

SMES is different than other storage technologies we have explored because the energy is stored as electrical energy. Other technologies store electricity as chemical energy, potential energy, kinetic energy or thermal energy.

A superconducting coil is used because a regular coil would not hold the energy, and would dissipate within milliseconds.

<http://www.supraconductivite.fr/en/index.php?p=applications-electricite-smes>

<https://www.youtube.com/watch?v=QU05d43dw6g>



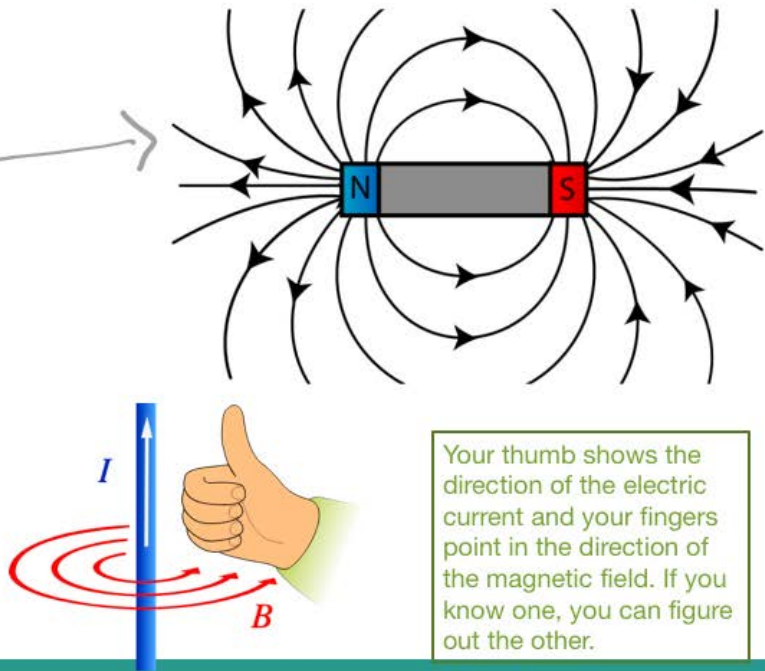
Here is an example of a superconducting coil. The coil can be low temperature or high temperature. The wire is cooled to the cryogenic temperature, which reaches zero resistance. Cryogenic is a physics phenomena where the production and behavior of materials occurs at very low temperatures. These temperatures alter physical properties of materials such as the strength, thermal conductivity, ductility and electrical resistance. In the case of SMES, the electrical resistance of the coil is altered. This is called superconductivity. Superconductivity was discovered in 1911 following the discovery of cryogenics and the liquefying of elements such as air and helium.

Cold temperatures make the molecules behave statically and ordered. This differs from heat, where the molecules move at random.

<https://www.britannica.com/science/cryogenics>

Magnetic Field (B)

- A **vector field** with **field line** notation
- A vector field is described by its magnitude (strength) and direction
- These lines never cross and point continuously from north to south (a closed loop)
- SI units: tesla (T)
 - The force applied to a moving charge due to the field
- The electric current (I) and magnetic field (B) are related by the *right-hand rule*



Your thumb shows the direction of the electric current and your fingers point in the direction of the magnetic field. If you know one, you can figure out the other.

OPTIONAL ACTIVITY: you can demonstrate a magnetic field to students with a magnet and iron filings on a surface. You will see the iron filings align along the field lines.

Vector is a quantity defined by magnitude and direction. The field lines used to show the magnetic field define the vector field. The top diagram shows that the field lines move from the north point to the south point.

When drawing a magnetic field, the lines never cross one another, and they flow continuously from north to south.

A magnetic field is measured by a unit called a tesla (T). A tesla is the force applied to a moving charge due to the field.

The electric current (I) – the flow of electrons – and the magnetic field (B) are related by the right-hand rule. You can determine the direction of one if you know the other. For example, if you know the direction of I , point your thumb in that direction and curl your fingers. The direction your fingers point is the direction of the magnetic field (B). If I is upwards, B will flow counterclockwise.

<https://www.khanacademy.org/science/physics/magnetic-forces-and-magnetic-fields/magnetic-field-current-carrying-wire/a/what-are-magnetic-fields>

SMES

Key Performance Data

| | |
|----------------|------------------------------|
| Power Range | 0.1 – 10 MW |
| Discharge Time | Milliseconds – 8 seconds |
| Cycle Life | Unlimited |
| Life Duration | 20 – 30 years |
| Efficiency | 95% |
| Applications | Uninterruptible Power Supply |


Here is some performance data on superconducting magnetic energy storage. SMES can store from 0.1 to 10 MW of energy and can discharge the energy anywhere from a few milliseconds to 8 seconds. The superconductive property means that the technology can undergo unlimited charge/discharge cycles, but has a life time of 20-30 years. The efficiency of the technology is 95%. This is high because of the zero resistance. SMES is best used for uninterruptible power supply – provides emergency power when required – because of its fast discharge time.


https://www.researchgate.net/figure/Technical-data-about-SMES_tbl1_261204920

https://energyeducation.ca/encyclopedia/Superconducting_magnetic_energy_storage

Advantages and Disadvantages of Electrical Energy Storage

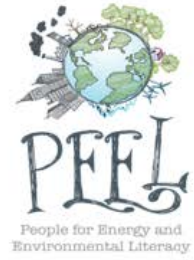
| ADVANTAGES | DISADVANTAGES |
|---|---|
| <ul style="list-style-type: none">• High energy efficiency:<ul style="list-style-type: none">• Capacitor and SMES – 90-95%• Fast responding – can respond instantaneously and provides energy for a brief period.• Provides power quality services for times of voltage sags and power outages• Environmentally friendly – does not require chemical reactions or produce toxins | <ul style="list-style-type: none">• SMES and supercapacitors are developed but not considered a mature technology• SMES requires large amounts of power to maintain the superconducting temperature• Suitable for short duration power supply only – limited hours in storage• High self-discharge for long periods (10-15%) |





SMES and capacitors are a highly efficient technology and can conserve nearly all of the energy stored. The energy can also be released immediately when required. Electrical energy storage is the flow of electrons in the technology and does not require harmful chemicals used in some other technologies.

Both SMES and supercapacitors are a relatively new technology and is therefore not as advanced or efficient as other energy storage technologies. Another disadvantage is the rate of self-discharge of the technology. Self-discharge is when the technology is not used for a period of time, and the stored energy dissipates. Some technologies hold onto charge longer than others.



Thank you!

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