Contents

[Models 4](#_Toc194496616)

[Electrochemical cell 4](#_Toc194496617)

[Lithium-ion battery 4](#_Toc194496618)

[Battery electrolytes 6](#_Toc194496619)

[Different parts of batteries 7](#_Toc194496620)

[Different types of batteries 9](#_Toc194496621)

[Lead-Acid Batteries 10](#_Toc194496622)

[Nickel-Cadmium (Ni-Cd) Batteries 11](#_Toc194496623)

[Nickel-Metal Hydride (NiMH) Batteries 12](#_Toc194496624)

[Lithium-Ion (Li-Ion) Batteries 13](#_Toc194496625)

[Alkaline Batteries 14](#_Toc194496626)

[Zinc-Carbon Batteries 15](#_Toc194496627)

[Zinc-Air Batteries 15](#_Toc194496628)

[Solid State battery 16](#_Toc194496629)

[Cells vs batteries 18](#_Toc194496630)

[Cells 18](#_Toc194496631)

[Primary cells vs secondary cells 18](#_Toc194496632)

[1. Daniel Cell 19](#_Toc194496633)

[Photovoltaic Cell: 19](#_Toc194496634)

[2. Voltaic (Galvanic) Cell 21](#_Toc194496635)

[**3. Electrolytic Cell** 21](#_Toc194496636)

[Grove cells 22](#_Toc194496637)

[Solar cells 23](#_Toc194496638)

[Hydrogen Fuel Cells 26](#_Toc194496639)

[Dry cells 27](#_Toc194496640)

[Primary vs Secondary batteries 29](#_Toc194496641)

[How batteries work? 30](#_Toc194496642)

[Energy storage systems 31](#_Toc194496643)

[1. Pumped Hydroelectric Storage 31](#_Toc194496644)

[2. Compressed Air Energy Storage (CAES) 31](#_Toc194496645)

[3. Lithium-Ion Battery Systems 32](#_Toc194496646)

[4. Flow Batteries 32](#_Toc194496647)

[5. Flywheel Energy Storage 32](#_Toc194496648)

[6. Hydrogen Energy Storage 32](#_Toc194496649)

[7. Thermal Energy Storage 33](#_Toc194496650)

[8. Gravity-Based Energy Storage 33](#_Toc194496651)

[Battery density 33](#_Toc194496652)

[Environmental impact of batteries 34](#_Toc194496653)

[Important people in sustainable energy 35](#_Toc194496654)

[Important people in wind power 38](#_Toc194496655)

[Lithium production 39](#_Toc194496656)

[Timeline 39](#_Toc194496657)

[Battery management system 40](#_Toc194496658)

[Safety considerations 41](#_Toc194496659)

[Lithium-ion production 42](#_Toc194496660)

[Energy density 43](#_Toc194496661)

[Photovoltaic effect 43](#_Toc194496662)

[Statistics 44](#_Toc194496663)

[Battery density 44](#_Toc194496664)

[Formula’s 45](#_Toc194496665)

[Ohms law 45](#_Toc194496666)

[Voltage 45](#_Toc194496667)

[Current 45](#_Toc194496668)

[Resistance 45](#_Toc194496669)

[Energy (Wh) 46](#_Toc194496670)

[Battery life 46](#_Toc194496671)

[Power output of a solar panel 46](#_Toc194496672)

[Capacitance 47](#_Toc194496673)

[Parallel plate capacitor 47](#_Toc194496674)

[Discharge current 47](#_Toc194496675)

[Series circuit 47](#_Toc194496676)

[Parallel circuit 47](#_Toc194496677)

[Charging time 47](#_Toc194496678)

[Power 48](#_Toc194496679)

[Resistors in parallel 48](#_Toc194496680)

[Resistor in series 48](#_Toc194496681)

[Power loss 48](#_Toc194496682)

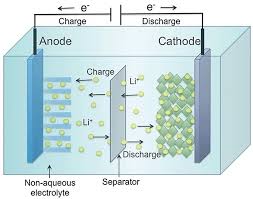
[Energy loss 49](#_Toc194496683)

[Charge 49](#_Toc194496684)

Sustainable energy

# Diagram of an anode and cation flow Description automatically generatedModels

Electrochemical cell - This image represents a simple electrochemical cell. The setup includes two electrodes, an anode (on the left) and a cathode (on the right), submerged in an electrolyte solution. The anode is connected to the negative terminal of the external circuit, while the cathode is connected to the positive terminal. The flow of electrical current is facilitated by the movement of ions in the electrolyte. Anions (negatively charged ions) flow towards the anode, and cations (positively charged ions) flow towards the cathode. This ion movement completes the internal circuit, while electrons flow externally from the anode to the cathode, lighting up the bulb in the circuit. This process illustrates the principles of electrolysis and the fundamental workings of an electrochemical cell.

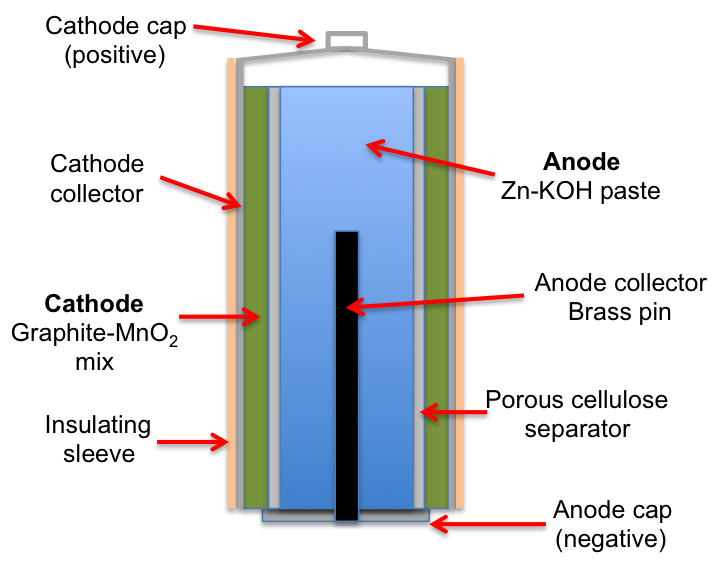


Lithium-ion battery - This image illustrates the working principle of a lithium-ion battery during charge and discharge cycles. The battery consists of two electrodes: an anode on the left and a cathode on the right, separated by a non-aqueous electrolyte and a separator. During charging, lithium ions (Li⁺) move from the cathode to the anode through the electrolyte, while electrons (e⁻) flow externally through the circuit to the anode. The anode stores the lithium ions, and this process is referred to as intercalation. During discharge, the process is reversed: lithium ions move back from the anode to the cathode through the electrolyte, and electrons flow from the anode to the cathode through the external circuit, providing electric power. The separator prevents direct contact between the electrodes while allowing ion flow. This model highlights the reversible movement of lithium ions and electrons, which is the key mechanism behind the rechargeable nature of lithium-ion batteries.

A graph showing the number of years

Description automatically generated with medium confidenceA graph showing the cost of a product

Description automatically generated with medium confidence



Alkaline battery

# Average voltage of batteries, and cells

|  |  |
| --- | --- |
| **Battery / Cell Type** | **Average Voltage (V)** |
| **Lead-Acid Battery** | 2.0 V per cell |
| **Nickel-Cadmium (Ni-Cd)** | 1.2 V |
| **Nickel-Metal Hydride (NiMH)** | 1.2 V |
| **Lithium-Ion (Li-Ion)** | 3.6 – 3.7 V |
| **Alkaline Battery** | 1.5 V |
| **Zinc-Carbon Battery** | 1.5 V |
| **Zinc-Air Battery** | 1.4 V |
| **Daniel Cell** | 1.1 V |
| **Photovoltaic Cell (Solar Cell)** | 0.5 – 0.6 V per cell |
| **Voltaic (Galvanic) Cell** | 1.0 – 2.0 V (depends on metals used) |
| **Electrolytic Cell** | Varies (Requires external voltage; no fixed value) |
| **Grove Cell** | 1.9 V |
| **Solar Cell** | 0.5 – 0.6 V per cell (same as photovoltaic) |
| **Hydrogen Fuel Cell** | 0.7 – 1.0 V per cell |

# Battery reactions

|  |  |  |  |
| --- | --- | --- | --- |
| **Battery/Cell** | **Full Reaction** | **Oxidation Half-Reaction** | **Reduction Half-Reaction** |
| **Daniell Cell** | Zn(s) + Cu²⁺(aq) → Zn²⁺(aq) + Cu(s) | Zn(s) → Zn²⁺(aq) + 2e⁻ | Cu²⁺(aq) + 2e⁻ → Cu(s) |
| **Photovoltaic Cell** | Converts sunlight into electricity (no chemical reaction) | N/A | N/A |
| **Voltaic (Galvanic) Cell** | General term for a spontaneous electrochemical cell (e.g., Daniell cell) | Depends on the specific reaction | Depends on the specific reaction |
| **Electrolytic Cell** | Uses electrical energy to drive a non-spontaneous reaction (e.g., electrolysis of water) | 2H₂O(l) → O₂(g) + 4H⁺(aq) + 4e⁻ | 4H⁺(aq) + 4e⁻ → 2H₂(g) |
| **Grove Cell** | Zn(s) + 2HNO₃(aq) + PtO₂(s) → Zn(NO₃)₂(aq) + H₂O(l) | Zn(s) → Zn²⁺(aq) + 2e⁻ | PtO₂(s) + 4H⁺(aq) + 2e⁻ → Pt(s) + 2H₂O(l) |
| **Solar Cell** | Converts sunlight into electricity (no chemical reaction) | N/A | N/A |
| **Hydrogen Fuel Cell** | 2H₂(g) + O₂(g) → 2H₂O(l) | 2H₂(g) → 4H⁺(aq) + 4e⁻ | O₂(g) + 4H⁺(aq) + 4e⁻ → 2H₂O(l) |
| **Dry Cell (Zinc-Carbon)** | Zn(s) + 2MnO₂(s) + 2NH₄⁺(aq) → Zn²⁺(aq) + Mn₂O₃(s) + 2NH₃(aq) | Zn(s) → Zn²⁺(aq) + 2e⁻ | 2MnO₂(s) + 2NH₄⁺(aq) + 2e⁻ → Mn₂O₃(s) + 2NH₃(aq) + H₂O(l) |
| **Alkaline Battery (Zn-MnO₂)** | Zn(s) + 2MnO₂(s) + H₂O(l) → Zn(OH)₂(s) + 2MnO(OH)(s) | Zn(s) + 2OH⁻(aq) → Zn(OH)₂(s) + 2e⁻ | 2MnO₂(s) + 2H₂O(l) + 2e⁻ → 2MnO(OH)(s) + 2OH⁻(aq) |
| **Lead-Acid Battery** | Pb(s) + PbO₂(s) + 2H₂SO₄(aq) → 2PbSO₄(s) + 2H₂O(l) | Pb(s) + SO₄²⁻(aq) → PbSO₄(s) + 2e⁻ | PbO₂(s) + 4H⁺(aq) + SO₄²⁻(aq) + 2e⁻ → PbSO₄(s) + 2H₂O(l) |
| **Nickel-Cadmium (NiCd) Battery** | Cd(s) + 2NiO(OH)(s) + 2H₂O(l) → Cd(OH)₂(s) + 2Ni(OH)₂(s) | Cd(s) + 2OH⁻(aq) → Cd(OH)₂(s) + 2e⁻ | 2NiO(OH)(s) + 2H₂O(l) + 2e⁻ → 2Ni(OH)₂(s) + 2OH⁻(aq) |
| **Nickel-Metal Hydride (NiMH) Battery** | MH(s) + NiO(OH)(s) → M(s) + Ni(OH)₂(s) | MH(s) + OH⁻(aq) → M(s) + H₂O(l) + e⁻ | NiO(OH)(s) + H₂O(l) + e⁻ → Ni(OH)₂(s) + OH⁻(aq) |
| **Lithium-Ion Battery** | LiC₆(s) + CoO₂(s) → C₆(s) + LiCoO₂(s) | LiC₆(s) → C₆(s) + Li⁺(aq) + e⁻ | CoO₂(s) + Li⁺(aq) + e⁻ → LiCoO₂(s) |

# Battery electrolytes

* **Lead-Acid Battery** – Sulfuric acid (H₂SO₄) in water
* **Nickel-Cadmium (Ni-Cd) Battery** – Potassium hydroxide (KOH)
* **Nickel-Metal Hydride (NiMH) Battery** – Potassium hydroxide (KOH)
* **Lithium-Ion (Li-Ion) Battery** – Lithium salt (e.g., LiPF₆) in an organic solvent
* **Alkaline Battery** – Potassium hydroxide (KOH)
* **Zinc-Carbon Battery** – Ammonium chloride (NH₄Cl) or zinc chloride (ZnCl₂)
* **Zinc-Air Battery** – Potassium hydroxide (KOH)

# Different parts of batteries

**Common Battery Components (All Types)**

1. **Anode (- terminal)** – Releases electrons during discharge.
2. **Cathode (+ terminal)** – Accepts electrons during discharge.
3. **Electrolyte** – Conducts ions between the anode and cathode.
4. **Separator** – Prevents direct contact between the anode and cathode to avoid short circuits.
5. **Current Collectors** – Conducts electricity from electrodes to external circuits.

**Alkaline Battery**

1. **Zinc Powder (Anode)** – Provides electrons in chemical reactions.
2. **Manganese Dioxide (Cathode)** – Accepts electrons to complete the circuit.
3. **Potassium Hydroxide (Electrolyte)** – Allows ion flow between electrodes.
4. **Steel Can** – Provides structural support and acts as the cathode collector.
5. **Plastic Gasket** – Seals the battery to prevent leakage.

**Lithium-Ion Battery**

1. **Graphite (Anode)** – Stores and releases lithium ions.
2. **Lithium Metal Oxide (Cathode)** – Accepts lithium ions and releases electrons.
3. **Lithium Salt Solution (Electrolyte)** – Facilitates ion movement.
4. **Porous Polymer (Separator)** – Blocks direct electron flow while allowing ion movement.
5. **Aluminum Foil (Cathode Collector)** – Conducts electrons from the cathode to the external circuit.
6. **Copper Foil (Anode Collector)** – Conducts electrons from the anode to the external circuit.
7. **Battery Management System (BMS)** – Regulates voltage, temperature, and charge levels.

**Lead-Acid Battery**

1. **Lead (Pb) (Anode)** – Reacts with sulfuric acid to release electrons.
2. **Lead Dioxide (PbO₂) (Cathode)** – Accepts electrons and reacts with acid.
3. **Sulfuric Acid (Electrolyte)** – Facilitates ion exchange.
4. **Fiberglass Mat (Separator)** – Prevents short circuits.
5. **Lead Grid** – Supports active materials and enhances conductivity.
6. **Plastic Casing** – Protects internal components.
7. **Vent Caps** – Releases excess gas buildup.

**Nickel-Cadmium (NiCd) Battery**

1. **Cadmium (Anode)** – Releases electrons during discharge.
2. **Nickel Hydroxide (Cathode)** – Accepts electrons during discharge.
3. **Potassium Hydroxide (Electrolyte)** – Conducts ions between electrodes.
4. **Porous Separator** – Prevents short circuits.
5. **Steel or Plastic Case** – Provides structural integrity.

**Nickel-Metal Hydride (NiMH) Battery**

1. **Metal Hydride Alloy (Anode)** – Stores hydrogen ions.
2. **Nickel Oxyhydroxide (Cathode)** – Accepts hydrogen ions.
3. **Potassium Hydroxide (Electrolyte)** – Facilitates ion movement.
4. **Separator** – Prevents short circuits.
5. **Steel Casing** – Protects internal components.

# Different types of batteries

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Battery Type | Nominal Voltage (V) | Typical Efficiency (%) | Pros | Cons | Uses |
| **Primary batteries** |  |  |  |  |  |
| Lead-Acid | 2.1 | 75-85 | Inexpensive, Reliable, High Surge Current | Heavy, Low Energy Density, Limited Cycle Life | Automotive (Starter Batteries), UPS Systems |
| Nickel-Cadmium (Ni-Cd) | 1.2 | 70-80 | Durable, High Discharge Rates, Long Life | Memory Effect, Contains Toxic Cadmium | Power Toolls, Aviation, Medical Devices |
| Nickel-Metal Hydride (Ni-MH) | 1.2 | 66-75 | Higher Capacity than Ni-Cd, Environmentally Friendly | Shorter Lifespan, Higher Self-Discharge | Consumer Electronics (Toys, Cameras) |
| Lithium-Ion (Li-ion) | 3.6 | 85-95 | High Energy Density, Lightweight, Low Self-Discharge | Expensive, Sensitive to Overcharging, Aging | Smartphones, Laptops, Electric Vehicles |
| **Secondary Batteries** |  |  |  |  |  |
| Alkaline | 1.5 | 60-80 | Long Shelf Life, Widely Available, Inexpensive | Non-Rechargeable, Reduced Performance in High-Drain Devices | Remote Controls, Flashlights, Toys |
| Zinc-Carbon | 1.5 | 50-60 | Low Cost, Readily Available | Short Lifespan, Low Energy Density | Low-Drain Devices (Clocks, Radios) |
| Zinc-Air | 1.4 | 60-70 | High Energy Density, Lightweight | Sensitive to Humidity, Limited Lifespan Once Activated | Hearing Aids, Medical Equipment |

## Lead-Acid Batteries

Lead-acid batteries are one of the oldest and most commonly used rechargeable batteries, widely found in automobiles, backup power supplies, and industrial applications. They operate through a chemical reaction that converts chemical energy into electrical energy and vice versa during charging and discharging.

**Energy Conversion**

Lead-acid batteries store and release energy through electrochemical reactions. When the battery discharges, chemical energy is converted into electrical energy, supplying power to a connected device. Conversely, during charging, electrical energy is converted back into chemical energy, restoring the battery’s capacity.

**Cathode and Anode**

A lead-acid battery consists of two electrodes submerged in an electrolyte solution of sulfuric acid (H₂SO₄):

* **Cathode (Positive Electrode):** Lead dioxide (PbO₂)
* **Anode (Negative Electrode):** Sponge lead (Pb)

**Electron Transfer During Discharge**

During discharge, the battery undergoes a redox reaction:

* The **anode (Pb)** loses electrons (oxidation), forming lead sulfate (PbSO₄).
* The **cathode (PbO₂)** gains electrons (reduction) and reacts with sulfuric acid to also form lead sulfate (PbSO₄) and water (H₂O).

During charging, this process is reversed:

* The **lead sulfate (PbSO₄)** on both electrodes converts back into **lead dioxide (PbO₂)** at the cathode and **sponge lead (Pb)** at the anode.
* The sulfuric acid concentration increases again as sulfate ions return to the solution.

The lead-acid battery remains popular due to its reliability, cost-effectiveness, and ability to deliver high surge currents, making it ideal for engine starters and backup power systems.

## Nickel-Cadmium (Ni-Cd) Batteries

Nickel-Cadmium (Ni-Cd) batteries are a type of rechargeable battery commonly used in portable electronics, power tools, and emergency lighting. They function by converting chemical energy into electrical energy during discharge and reversing the process during charging.

**Energy Conversion**

Ni-Cd batteries store and release energy through electrochemical reactions. When the battery discharges, chemical energy is converted into electrical energy, powering the device. During charging, electrical energy is converted back into chemical energy, restoring the battery’s charge.

**Cathode and Anode**

A Ni-Cd battery consists of two electrodes submerged in an alkaline electrolyte (typically potassium hydroxide, KOH):

* **Cathode (Positive Electrode):** Nickel oxyhydroxide (NiO(OH))
* **Anode (Negative Electrode):** Cadmium (Cd)

**Electron Transfer During Discharge**

During discharge, the battery undergoes a redox reaction:

* The **anode (Cd)** loses electrons (oxidation) and forms cadmium hydroxide (Cd(OH)₂).
* The **cathode (NiO(OH))** gains electrons (reduction) and converts to nickel hydroxide (Ni(OH)₂).

During charging, this process is reversed:

* The **cadmium hydroxide (Cd(OH)₂)** at the anode converts back into metallic **cadmium (Cd)**.
* The **nickel hydroxide (Ni(OH)₂)** at the cathode reverts to **nickel oxyhydroxide (NiO(OH))**.

Ni-Cd batteries are valued for their durability, ability to handle high discharge rates, and long cycle life. However, they suffer from the memory effect, requiring proper charging cycles to maintain optimal performance.

## Nickel-Metal Hydride (NiMH) Batteries

Nickel-Metal Hydride (NiMH) batteries are a type of rechargeable battery commonly used in consumer electronics, hybrid vehicles, and power tools. They function by converting chemical energy into electrical energy during discharge and reversing the process during charging.

**Energy Conversion**

NiMH batteries store and release energy through electrochemical reactions. When the battery discharges, chemical energy is converted into electrical energy, powering the device. During charging, electrical energy is converted back into chemical energy, restoring the battery’s charge.

**Cathode and Anode**

A NiMH battery consists of two electrodes submerged in an alkaline electrolyte (typically potassium hydroxide, KOH):

* **Cathode (Positive Electrode):** Nickel oxyhydroxide (NiO(OH))
* **Anode (Negative Electrode):** A hydrogen-absorbing metal alloy (MH)

**Electron Transfer During Discharge**

During discharge, the battery undergoes a redox reaction:

* The **anode (MH)** loses electrons (oxidation) and forms a metal hydride.
* The **cathode (NiO(OH))** gains electrons (reduction) and converts to nickel hydroxide (Ni(OH)₂).

During charging, this process is reversed:

* The **metal hydride (M)** at the anode absorbs hydrogen and converts back into **MH**.
* The **nickel hydroxide (Ni(OH)₂)** at the cathode reverts to **nickel oxyhydroxide (NiO(OH))**.

NiMH batteries offer higher energy density than Ni-Cd batteries and do not suffer from the memory effect, making them a preferred choice for many modern applications.

## Lithium-Ion (Li-Ion) Batteries

Lithium-Ion (Li-Ion) batteries are a type of rechargeable battery commonly used in smartphones, laptops, electric vehicles, and other portable electronics. They function by converting chemical energy into electrical energy during discharge and reversing the process during charging.

**Energy Conversion**

Li-Ion batteries store and release energy through electrochemical reactions. When the battery discharges, chemical energy is converted into electrical energy, powering the device. During charging, electrical energy is converted back into chemical energy, restoring the battery’s charge.

**Cathode and Anode**

A Li-Ion battery consists of two electrodes submerged in a lithium salt electrolyte:

* **Cathode (Positive Electrode):** Lithium metal oxide (e.g., LiCoO₂, LiFePO₄, or LiMn₂O₄)
* **Anode (Negative Electrode):** Graphite (carbon-based material)

**Electron Transfer During Discharge**

During discharge, the battery undergoes a redox reaction:

* The **anode (Graphite)** loses electrons (oxidation) as lithium ions move to the cathode.
* The **cathode (Lithium metal oxide)** gains electrons (reduction) as lithium ions intercalate into its structure.



During charging, this process is reversed:

* **Lithium ions** move back to the anode and are stored in the graphite layers.
* The cathode releases lithium ions, returning to its charged state.

Li-Ion batteries offer high energy density, low self-discharge rates, and no memory effect, making them one of the most widely used rechargeable battery technologies today.

## Alkaline Batteries

Alkaline batteries are a type of primary (non-rechargeable) battery commonly used in household electronics, such as remote controls, flashlights, and toys. They function by converting chemical energy into electrical energy through an electrochemical reaction.

**Energy Conversion**

Alkaline batteries store and release energy through electrochemical reactions. When the battery discharges, chemical energy is converted into electrical energy to power a device. Since they are non-rechargeable, the reaction is not reversible.

**Cathode and Anode**

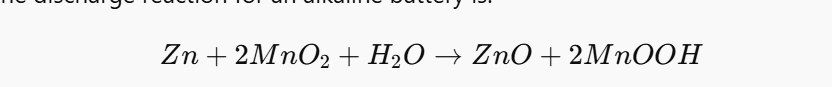
An alkaline battery consists of two electrodes submerged in an alkaline electrolyte (typically potassium hydroxide, KOH):

* **Cathode (Positive Electrode):** Manganese dioxide (MnO₂)
* **Anode (Negative Electrode):** Zinc (Zn)

**Electron Transfer During Discharge**

During discharge, the battery undergoes a redox reaction:

* The **anode (Zinc)** loses electrons (oxidation) and forms zinc oxide (ZnO).
* The **cathode (Manganese dioxide)** gains electrons (reduction) and forms manganese oxide (Mn₂O₃).

Since alkaline batteries are not rechargeable, once the reactants are consumed, the battery is depleted and must be replaced. They are widely used due to their long shelf life, stable voltage output, and affordability.

## Zinc-Carbon Batteries

Zinc-carbon batteries are a type of primary (non-rechargeable) battery commonly used in low-drain devices such as remote controls, clocks, and flashlights. They function by converting chemical energy into electrical energy through an electrochemical reaction.

**Energy Conversion**

Zinc-carbon batteries store and release energy through electrochemical reactions. When the battery discharges, chemical energy is converted into electrical energy to power a device. Since they are non-rechargeable, the reaction is not reversible.

**Cathode and Anode**

A zinc-carbon battery consists of two electrodes submerged in an acidic or mildly alkaline electrolyte (typically ammonium chloride, NH₄Cl, or zinc chloride, ZnCl₂):

* **Cathode (Positive Electrode):** Manganese dioxide (MnO₂)
* **Anode (Negative Electrode):** Zinc (Zn)

**Electron Transfer During Discharge**

During discharge, the battery undergoes a redox reaction:

* The **anode (Zinc)** loses electrons (oxidation) and forms zinc ions (Zn²⁺).
* The **cathode (Manganese dioxide)** gains electrons (reduction) and forms manganese oxide (Mn₂O₃).

Since zinc-carbon batteries are not rechargeable, once the reactants are consumed, the battery is depleted and must be replaced. They are widely used due to their low cost and widespread availability but have a lower capacity and shorter lifespan compared to alkaline batteries.

## Zinc-Air Batteries

Zinc-air batteries are a type of primary (non-rechargeable) and secondary (rechargeable) battery commonly used in hearing aids, medical devices, and some industrial applications. They function by converting chemical energy into electrical energy through an electrochemical reaction involving oxygen from the air.

**Energy Conversion**

Zinc-air batteries store and release energy through electrochemical reactions. When the battery discharges, chemical energy is converted into electrical energy to power a device. Oxygen from the air acts as a reactant, eliminating the need for a separate cathode material, which increases energy density.

**Cathode and Anode**

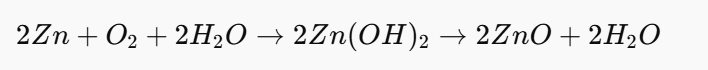
A zinc-air battery consists of:

* **Cathode (Positive Electrode):** Oxygen (O₂) from the air
* **Anode (Negative Electrode):** Zinc (Zn)

**Electron Transfer During Discharge**

During discharge, the battery undergoes a redox reaction:

* The **anode (Zinc)** loses electrons (oxidation) and forms zinc hydroxide (Zn(OH)₂), which further converts into zinc oxide (ZnO).
* The **cathode (Oxygen from air)** gains electrons (reduction) and reacts with water and electrons to form hydroxide ions (OH⁻).

Since zinc-air batteries rely on oxygen from the air, they require small openings to allow air access. This design provides high energy density, making them lightweight and efficient. However, once activated by exposure to air, they have a limited lifespan before drying out or depleting their reactants. Rechargeable variants are being developed for broader applications, including electric vehicles.

# Solid State battery

**Solid-State Batteries: The Future of Energy Storage**

**Introduction** Solid-state batteries (SSBs) are an advanced energy storage technology that replaces the liquid or gel electrolyte found in conventional lithium-ion batteries with a solid electrolyte. This innovation enhances safety, energy density, and lifespan, making them a promising solution for various applications, including electric vehicles (EVs) and consumer electronics.

**Key Components**

* **Electrolyte**: Solid ceramic, sulfide, or polymer-based electrolytes replace traditional liquid electrolytes.
* **Anode**: Typically lithium metal, silicon, or graphite.
* **Cathode**: Common materials include lithium cobalt oxide (LiCoO₂), lithium iron phosphate (LiFePO₄), or lithium nickel manganese cobalt oxide (NMC).

**Chemical Reaction** During discharge: Li → Li⁺ + e⁻ (Anode reaction) Li⁺ + e⁻ + CoO₂ → LiCoO₂ (Cathode reaction) Overall reaction: Li + CoO₂ → LiCoO₂

**Key Advantages**

* **Higher Energy Density**: SSBs can store more energy in a smaller, lighter package, increasing battery life and efficiency.
* **Improved Safety**: Solid electrolytes reduce the risk of thermal runaway, fires, and leaks compared to liquid electrolytes.
* **Longer Lifespan**: Reduced degradation leads to more charge cycles, extending the overall battery life.
* **Faster Charging**: Some SSB designs enable rapid ion movement, significantly reducing charging times.

**Challenges**

* **Manufacturing Complexity**: High production costs and material challenges hinder large-scale adoption.
* **Limited Commercial Availability**: Research is ongoing to overcome performance and scalability issues.
* **Interface Stability**: Maintaining stable contact between the electrodes and solid electrolyte remains a key obstacle.

**Applications**

* **Electric Vehicles (EVs)**: Increased range and safety make SSBs a prime candidate for future EVs.
* **Consumer Electronics**: Lighter, longer-lasting batteries for smartphones, laptops, and wearables.
* **Aerospace & Defense**: High reliability and energy efficiency for demanding applications.

**Conclusion** Solid-state batteries represent a transformative step in battery technology. While challenges remain, ongoing research and development efforts are expected to make them a commercially viable alternative to traditional lithium-ion batteries in the near future.

# Cells vs batteries

A screenshot of a cell phone

AI-generated content may be incorrect.

# Cells

## Primary cells vs secondary cells

**Primary Cells (Non-rechargeable):**

Single-use: Cannot be recharged once depleted.

Chemical Reaction: Irreversible.

Lifespan: Longer shelf life when not in use.

Common Examples: Alkaline batteries, zinc-carbon batteries, lithium primary batteries.

Applications: Remote controls, flashlights, watches, and medical devices.

**Secondary Cells (Rechargeable)**

Reusable: Can be recharged multiple times.

Chemical Reaction: Reversible through electrical charging.

Lifespan: Shorter shelf life but longer operational use.

Common Examples: Lithium-ion (Li-ion), Nickel-Metal Hydride (NiMH), Lead-acid batteries.

Applications: Mobile phones, laptops, electric vehicles, UPS systems.

## 1. Daniel Cell

The Daniel cell, a classic example of a galvanic cell, is composed of two half-cells: one containing a zinc electrode in a zinc sulfate solution and the other containing a copper electrode in a copper sulfate solution. The two half-cells are connected by a salt bridge, which allows ions to flow and maintain electrical neutrality. In this setup, zinc acts as the anode, where it undergoes oxidation (Zn → Zn²⁺ + 2e⁻), releasing electrons. These electrons travel through an external circuit to the copper cathode, where they participate in the reduction of Cu²⁺ ions to copper metal (Cu²⁺ + 2e⁻ → Cu). This flow of electrons generates an electric current that can be harnessed to do work. The Daniel cell is noteworthy for its simplicity and historical significance, as it was one of the earliest practical sources of electrical energy. It laid the groundwork for the development of more advanced batteries and electrochemical cells.

**Pros:**

* Historical significance as one of the earliest practical sources of electrical energy.
* Simple design, easy to construct and understand.
* Provides a stable voltage and current output.
* Useful for educational purposes and demonstrations of basic electrochemical principles.

**Cons:**

* Limited power output, not suitable for high-demand applications.
* Requires maintenance of the electrolyte solutions and salt bridge.
* Can suffer from polarization and degradation over time.

## Photovoltaic Cell:

1. **Semiconductor Material**:
   * The core of a photovoltaic cell is typically made from semiconductor materials like **silicon**, which is highly efficient at converting sunlight into electricity. These materials are specially treated to create a **p-n junction**.
2. **P-N Junction**:
   * The **p-type** (positive) side is made by adding impurities to the silicon to create an abundance of **holes** (lack of electrons), while the **n-type** (negative) side has extra electrons. When these two materials are joined, an electric field is created at the junction between them.
3. **Electrical Contacts**:
   * Metal contacts are placed on the top and bottom of the cell to allow the electrical current generated by the PV cell to flow out and be used.

**Working Principle:**

1. **Light Absorption**:
   * When sunlight (composed of photons) hits the semiconductor material in the PV cell, it **excites electrons** in the material, knocking them loose from their atoms.
2. **Generation of Electron-Hole Pairs**:
   * This energy from the sunlight creates **electron-hole pairs**. The excited electrons are freed from their atoms, and the holes represent the absence of electrons.
3. **Electric Field and Current Flow**:
   * The electric field at the p-n junction pushes the freed electrons towards the n-type side and the holes towards the p-type side. This movement of electrons creates an **electric current**.
4. **Electricity Generation**:
   * The electrons flow through the external circuit (e.g., to a battery, inverter, or power grid) to return to the p-type side, creating an electrical current that can be used to power electrical devices or stored for later use.

**Efficiency Factors:**

* The efficiency of a PV cell depends on various factors, including the quality of the semiconductor material, the angle at which sunlight strikes the cell, and the temperature of the cell. Newer technologies, like **perovskite solar cells** or **thin-film photovoltaics**, are continually being researched to improve the efficiency and cost of solar energy.

## 2. Voltaic (Galvanic) Cell

A voltaic cell, also known as a galvanic cell, is an electrochemical cell that generates electrical energy from spontaneous redox reactions. It consists of two half-cells, each containing an electrode immersed in an electrolyte solution. The anode is the site of oxidation, where electrons are released, while the cathode is the site of reduction, where electrons are gained. These two electrodes are connected by an external circuit through which electrons flow, creating an electric current. Additionally, a salt bridge or porous membrane maintains ion flow between the two half-cells, ensuring electrical neutrality. The overall cell potential, or electromotive force (EMF), is determined by the difference in electrode potentials between the anode and the cathode. Voltaic cells are the basis for many common batteries, such as alkaline and lithium-ion batteries, and are widely used in portable electronic devices, power tools, and electric vehicles. The principles of voltaic cells are fundamental to the understanding of electrochemistry and energy conversion.

**Pros:**

* Generates electrical energy from spontaneous redox reactions.
* Widely used in many types of batteries, including alkaline and lithium-ion batteries.
* Provides a stable and reliable source of power for various applications.
* Relatively simple design and easy to scale for different power needs.

**Cons:**

* Limited lifespan compared to some other battery types.
* Can suffer from internal resistance and self-discharge over time.
* Performance can be affected by temperature and environmental conditions.

## **3. Electrolytic Cell**

An electrolytic cell is an electrochemical cell that uses external electrical energy to drive non-spontaneous chemical reactions. Unlike voltaic cells, electrolytic cells require an external power source, such as a battery or power supply, to provide the energy needed for the reactions. The cell consists of two electrodes: the anode, connected to the positive terminal of the power source, and the cathode, connected to the negative terminal. In this setup, oxidation occurs at the anode, and reduction occurs at the cathode, but the direction of electron flow is opposite to that in a galvanic cell. Electrolytic cells are widely used in various industrial processes, including electroplating, electrorefining, and the production of chemicals such as chlorine and hydrogen gas. For example, in the electroplating process, a metal object (the cathode) is coated with a thin layer of another metal, such as gold or silver, by reducing metal ions from a solution onto the object's surface. The versatility and applications of electrolytic cells make them essential tools in manufacturing, metallurgy, and chemical industries.

**Pros:**

* Can drive non-spontaneous chemical reactions, making it useful for industrial processes.
* Widely used in electroplating, electrorefining, and chemical production.
* Versatile applications in manufacturing, metallurgy, and other industries.
* Provides a controlled environment for specific chemical reactions.

**Cons:**

* Requires an external power source to operate.
* Can be expensive to maintain and operate due to energy consumption.
* May produce unwanted by-products or waste materials.
* Safety concerns with handling high voltages and reactive chemicals.

## Grove cells

The Grove cell is a type of electrochemical cell, invented by the British chemist William Robert Grove in 1839. It consists of a zinc anode and a platinum cathode, both immersed in their respective electrolyte solutions. The zinc anode is placed in diluted sulfuric acid, while the platinum cathode is submerged in concentrated nitric acid. A porous ceramic cup, or diaphragm, is used to separate the two electrolyte solutions, allowing ions to pass through while preventing the direct mixing of the acids. The chemical reactions at the electrodes produce an electromotive force, generating a voltage typically around 1.9 volts. The Grove cell was a significant improvement over earlier designs due to its higher voltage and efficiency, and it played an important role in early telegraph systems and other electrical applications before being eventually replaced by more advanced and safer battery technologies.

**Pros:**

* Higher voltage output (around 1.9 volts) compared to earlier cell designs.
* Significant historical importance in early telegraph systems and electrical applications.
* Efficient and reliable for its time.
* Demonstrates the use of different electrolyte solutions and separation techniques.

**Cons:**

* Involves the use of concentrated nitric acid, which is highly corrosive and dangerous.
* Can produce toxic fumes and requires careful handling.
* Limited to historical and educational contexts, as modern battery technologies are safer and more efficient.
* Not suitable for modern high-demand applications due to safety and efficiency concerns.

## Solar cells

**Solar Cells: A Two-Pager Overview**

**1. What are Solar Cells?**

Solar cells, also known as photovoltaic (PV) cells, are devices that convert light energy directly into electrical energy through the photovoltaic effect. They are fundamental components in solar panels, which harness sunlight for renewable energy generation.

**2. How Solar Cells Work**

Solar cells are made of semiconductor materials, typically silicon. When sunlight hits the solar cell, photons (light particles) transfer their energy to electrons in the semiconductor material. This energy knocks the electrons loose, creating electron-hole pairs. The electric field inside the solar cell forces these free electrons to flow in a specific direction, generating an electric current.

* **Key Process:**
  1. **Absorption**: Sunlight is absorbed by the solar cell.
  2. **Excitation**: Photons excite electrons, causing them to move.
  3. **Current Generation**: The movement of electrons generates an electric current, which can be used to power electrical devices.

**3. Types of Solar Cells**

* **Monocrystalline Silicon Solar Cells**:
  + Made from a single continuous crystal structure.
  + High efficiency and long lifespan.
  + Typically more expensive due to complex manufacturing.
* **Polycrystalline Silicon Solar Cells**:
  + Made from silicon crystals that are melted and poured into molds.
  + Slightly less efficient than monocrystalline but cheaper to produce.
* **Thin-Film Solar Cells**:
  + Made by depositing a thin layer of photovoltaic material onto a substrate (e.g., glass, plastic).
  + More flexible and lighter, but typically less efficient.
* **Perovskite Solar Cells**:
  + A newer, cheaper material with promising high efficiency.
  + Still undergoing development for long-term stability and commercial use.

**4. Efficiency of Solar Cells**

* **Conversion Efficiency** refers to how much sunlight a solar cell can convert into usable electricity.
* Typical commercial solar cells have an efficiency range of **15%-22%**. Research into new materials and technologies aims to push this efficiency further, possibly reaching over **30%** in the future.

Factors influencing efficiency:

* **Material quality**: Purity of silicon or the material used.
* **Manufacturing process**: How well the solar cell is fabricated.
* **Angle of installation**: Solar cells are most efficient when exposed directly to sunlight.

**5. Advantages of Solar Cells**

* **Renewable Energy Source**: Solar cells rely on sunlight, a limitless, renewable energy source.
* **Environmentally Friendly**: Solar energy produces no greenhouse gases or pollutants.
* **Low Operating Costs**: Once installed, solar cells require minimal maintenance and have low operational costs.
* **Energy Independence**: Solar cells provide a decentralized source of energy, reducing reliance on fossil fuels and national grids.

**6. Limitations of Solar Cells**

* **Intermittency**: Solar cells only produce electricity when there is sunlight, limiting their effectiveness at night or on cloudy days.
* **High Initial Costs**: While costs have decreased, the initial investment for solar panels and installation remains relatively high.
* **Land and Space Requirements**: Large solar farms require significant land area, which may not be suitable for densely populated areas.
* **Energy Storage**: Storing the energy generated during the day for use at night or in bad weather requires battery systems, which can be costly.

**7. Future of Solar Cells**

* **Improved Efficiency**: Ongoing research aims to develop more efficient solar cells, such as multi-junction cells and organic photovoltaics.
* **Lower Costs**: Technological advances and economies of scale are helping to reduce the cost of solar cells.
* **Integration with Buildings**: Solar cells are being integrated into windows, roofs, and walls, making them more versatile for urban environments.

**8. Conclusion**

Solar cells represent a critical technology in the transition to renewable energy. While challenges remain, advancements in material science and technology continue to improve their efficiency, affordability, and applicability, making solar energy an increasingly viable option for global energy needs.

## Hydrogen Fuel Cells

A hydrogen fuel cell is an electrochemical device that converts the chemical energy of hydrogen and oxygen into electricity, water, and heat through redox reactions. At its core, the fuel cell consists of an anode, a cathode, and an electrolyte, usually a proton exchange membrane (PEM). Hydrogen gas (H₂) is supplied to the anode, where it is split into protons (H⁺) and electrons (e⁻) through a catalyst. The protons pass through the PEM to the cathode, while the electrons travel through an external circuit, generating an electric current. At the cathode, the protons and electrons combine with oxygen (O₂) from the air to form water (H₂O) and release heat. Hydrogen fuel cells are highly efficient and environmentally friendly, as their only by-products are water and heat. They are used in various applications, including fuel cell vehicles, stationary power generation, and portable power systems.

A hydrogen fuel cell is an innovative electrochemical device that converts the chemical energy of hydrogen and oxygen into electricity, water, and heat through redox reactions. The concept of the hydrogen fuel cell dates back to 1839 when Sir William Grove, a British scientist, first demonstrated the "gas voltaic battery," the predecessor to modern fuel cells. The fuel cell consists of an anode, a cathode, and an electrolyte, typically a proton exchange membrane (PEM). Hydrogen gas (H₂) is supplied to the anode, where it is split into protons (H⁺) and electrons (e⁻) through a catalyst. The protons pass through the PEM to the cathode, while the electrons travel through an external circuit, generating an electric current. At the cathode, the protons and electrons combine with oxygen (O₂) from the air to form water (H₂O) and release heat. Hydrogen fuel cells are highly efficient and environmentally friendly, as their only by-products are water and heat. They are utilized in various applications, including fuel cell vehicles, stationary power generation, and portable power systems, offering a promising solution for clean and sustainable energy.

**Pros:**

1. **High Efficiency**: Converts chemical energy directly into electrical energy with high efficiency, often exceeding 60%.
2. **Environmentally Friendly**: Produces only water and heat as by-products, with no harmful emissions.
3. **Renewable Fuel**: Hydrogen can be produced from various renewable sources, including water electrolysis using solar or wind power.
4. **Quiet Operation**: Operates silently, making it ideal for residential and urban applications.
5. **Scalability**: Can be scaled for different applications, from small portable devices to large power plants.

**Cons:**

1. **Hydrogen Production**: Producing hydrogen in a sustainable and cost-effective manner remains a challenge.
2. **Infrastructure**: Requires a well-developed hydrogen infrastructure, including production, storage, and distribution facilities.
3. **Storage and Transport**: Hydrogen is difficult to store and transport due to its low energy density and high flammability.
4. **Cost**: High initial costs for fuel cell production and infrastructure development.
5. **Durability and Longevity**: Fuel cells can be sensitive to impurities in hydrogen and may have issues with durability and longevity over time.

## Dry cells

A dry cell is a type of electrochemical cell commonly used in portable electrical devices. Unlike wet cells, which contain liquid electrolytes, dry cells have a paste-like electrolyte that minimizes the risk of leakage and allows for more versatile and safer use. The typical structure of a dry cell includes a zinc anode, which also serves as the container for the cell, and a carbon rod cathode, embedded in a mixture of manganese dioxide and carbon powder. This mixture is surrounded by the electrolyte paste, often consisting of ammonium chloride and zinc chloride.

When the dry cell is in use, a chemical reaction occurs between the zinc and the electrolyte, producing electrons that travel through the external circuit and return to the cathode, where they facilitate the reduction of manganese dioxide. This flow of electrons generates an electric current, providing a steady voltage of around 1.5 volts. Dry cells are widely used in everyday applications, such as flashlights, remote controls, and various battery-operated devices, due to their convenience and reliability. Over time, dry cells have evolved to include more environmentally friendly materials and designs, making them a staple in modern battery technology.

**Pros:**

1. **Portability**: Compact and lightweight, making them ideal for portable devices.
2. **Convenience**: Ready-to-use and easily replaceable without the need for maintenance.
3. **Low Risk of Leakage**: The paste-like electrolyte reduces the risk of leakage compared to liquid electrolytes.
4. **Safety**: Reduced risk of spillage and corrosion, making them safer for consumer use.
5. **Availability**: Widely available and come in various sizes to fit different devices.
6. **Affordable**: Generally inexpensive, making them cost-effective for low-power applications.

**Cons:**

1. **Limited Capacity**: Lower energy density compared to some other types of batteries.
2. **Non-Rechargeable**: Most common dry cells are single-use and need to be replaced after discharge.
3. **Environmental Impact**: Disposal can contribute to environmental pollution due to heavy metals and chemicals.
4. **Voltage Drop**: Can experience a significant drop in voltage under heavy load or prolonged use.
5. **Temperature Sensitivity**: Performance can be affected by extreme temperatures, reducing their efficiency.
6. **Lower Power Output**: Not suitable for high-power applications or devices with high energy demands.

# Primary vs Secondary batteries

**Primary Batteries**

Primary batteries are designed for single-use and cannot be recharged. Once their internal chemical energy is depleted, they are discarded. Common examples include alkaline, zinc-carbon, and some types of lithium batteries. These batteries are typically more affordable upfront and readily available, making them suitable for devices with low power demands or infrequent use, such as remote controls, clocks, and smoke detectors. However, their limited lifespan and environmental impact due to disposal are significant \

**Secondary Batteries**

Secondary batteries, also known as rechargeable batteries, can be recharged multiple times by reversing the chemical reactions within them. This makes them a more environmentally friendly and cost-effective option in the long run, especially for devices that require frequent power cycles. Common examples include lead-acid, lithium-ion, nickel-metal hydride, and nickel-cadmium batteries. These batteries power a wide range of devices, from smartphones and laptops to electric vehicles and power tools. While they generally have a higher initial cost, their reusability significantly offsets this expense over time.

|  |  |  |
| --- | --- | --- |
| **Feature** | **Primary Batteries** | **Secondary Batteries** |
| **Rechargeability** | Not rechargeable | Rechargeable |
| **Lifespan** | Single use | Multiple charge-discharge cycles |
| **Energy Density** | Generally lower | Generally higher |
| **Cost** | Typically lower initial cost | Higher initial cost, but cost-effective over time with recharging |
| **Environmental Impact** | Higher environmental impact due to disposal | Lower environmental impact with proper recycling |
| **Common Uses** | Remote controls, clocks, toys, smoke detectors | Laptops, smartphones, electric vehicles, power tools |
| **Examples** | Alkaline, zinc-carbon, lithium (some types) | Lead-acid, lithium-ion, nickel-metal hydride, nickel-cadmium |

# How batteries work?

Batteries are devices that store chemical energy and convert it into electrical energy through electrochemical reactions. They consist of three main components: an anode, a cathode, and an electrolyte. The anode undergoes oxidation, losing electrons, while the cathode undergoes reduction, gaining electrons. The flow of electrons between these electrodes through an external circuit generates electricity, powering devices. Inside the battery, ions move through the electrolyte to balance the charge created by the flow of electrons, completing the circuit. This basic process underlies the functionality of all batteries, from simple alkaline cells to advanced lithium-ion systems.

The core science behind batteries lies in redox (reduction-oxidation) reactions. During discharge, oxidation occurs at the anode, releasing electrons into the external circuit and ions into the electrolyte. At the same time, reduction occurs at the cathode, where ions from the electrolyte combine with incoming electrons. The energy released during these chemical reactions is determined by the electrode materials and the voltage difference between them, called the cell potential. Rechargeable batteries, such as lithium-ion and nickel-metal hydride, are designed so that these reactions can be reversed by applying an external current, restoring the battery's capacity for reuse.

The performance of a battery depends heavily on the materials used for its electrodes and electrolyte. For instance, lithium-ion batteries utilize lithium compounds for their high energy density and lightweight properties, making them suitable for portable electronics and electric vehicles. In contrast, lead-acid batteries rely on lead and sulfuric acid, which provide reliability and high surge currents for automotive applications. The electrolyte, whether a liquid, gel, or solid, facilitates ion movement and significantly influences the battery's efficiency, lifespan, and operating temperature range. Innovations in materials science aim to improve these properties, leading to safer, more efficient, and longer-lasting batteries.

While batteries are an essential energy storage solution, they face limitations in efficiency and capacity. A battery's efficiency is measured by how effectively it converts chemical energy into electrical energy, with some energy lost as heat due to internal resistance. Factors such as self-discharge, aging, and limited cycle life also impact performance. Moreover, environmental and safety concerns, such as the toxicity of materials (e.g., cadmium in Ni-Cd batteries) or the risk of thermal runaway in lithium-ion batteries, drive the need for more sustainable alternatives. Ongoing research focuses on improving battery technologies, including solid-state batteries and metal-air systems, to address these challenges and meet growing energy demands.

# Energy storage systems

### **1. Pumped Hydroelectric Storage**

* **Description**: Uses surplus energy to pump water to a higher elevation during low demand. When energy demand increases, the water is released to spin turbines and generate electricity.
* **Capacity**: Up to **1 GW or more** per plant.
* **Advantages**: High efficiency (70–85%) and long lifespan.
* **Disadvantages**: Requires specific geography (elevated reservoirs) and has high upfront costs.

### **2. Compressed Air Energy Storage (CAES)**

* **Description**: Excess energy compresses air and stores it in underground caverns or tanks. The air is released to drive turbines and generate electricity.
* **Capacity**: Hundreds of megawatts (MW).
* **Advantages**: Suitable for long-duration storage.
* **Disadvantages**: Moderate efficiency (40–70%) due to heat loss and limited by suitable storage sites.

### **3. Lithium-Ion Battery Systems**

* **Description**: Large-scale battery banks using lithium-ion technology to store renewable energy. Common in solar and wind farms.
* **Capacity**: Typically **100 MW–1 GW**.
* **Advantages**: High efficiency (85–95%), modular, and scalable.
* **Disadvantages**: High cost, thermal management issues, and material scarcity.

### **4. Flow Batteries**

* **Description**: Use liquid electrolytes stored in external tanks. Energy is stored/released by chemical reactions between the electrolytes during charge/discharge cycles.
* **Capacity**: Tens to hundreds of MW.
* **Advantages**: Long lifespan, easily scalable, and excellent for long-duration storage.
* **Disadvantages**: Lower energy density compared to lithium-ion batteries.

### **5. Flywheel Energy Storage**

* **Description**: Kinetic energy is stored in a spinning rotor. Electricity is converted to rotational energy and retrieved when needed.
* **Capacity**: Usually **10–20 MW** per unit.
* **Advantages**: High efficiency (85–95%), fast response times, and long cycle life.
* **Disadvantages**: Limited to short-duration storage and high initial costs.

### **6. Hydrogen Energy Storage**

* **Description**: Surplus energy is used to produce hydrogen through electrolysis. The hydrogen is stored and later converted back into electricity using fuel cells or turbines.
* **Capacity**: Large-scale systems can store **hundreds of MW or more**.
* **Advantages**: High energy density and potential for long-term storage.
* **Disadvantages**: Low efficiency (30–50%) and infrastructure challenges.

### **7. Thermal Energy Storage**

* **Description**: Excess energy is used to heat materials (e.g., molten salt, water, or rocks). The heat is stored and converted back into electricity via steam turbines.
* **Capacity**: Typically **50–300 MW**, with some systems scaling up further.
* **Advantages**: Cost-effective and compatible with solar thermal plants.
* **Disadvantages**: Energy loss during conversion and geographic limitations.

### **8. Gravity-Based Energy Storage**

* **Description**: Lifts heavy weights using surplus energy. The weights are lowered during high-demand periods, generating electricity via gravitational potential energy.
* **Capacity**: Typically **10–100 MW**, with scalability options.
* **Advantages**: Long lifespan and minimal degradation.
* **Disadvantages**: Requires large-scale infrastructure and suitable locations.

# Battery density

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Battery Type | Category | Energy Density (Wh/kg) | Typical Voltage (V) | Notes |
| Lead-Acid | Secondary | 30 - 50 | 2 | Common in vehicles; heavy, low energy-to-weight ratio. |
| Nickel-Cadmium (Ni-Cd) | Secondary | 40 - 60 | 1.2 | Toxic cadmium, used in power tools and older electronics. |
| Nickel-Metal Hydride (Ni-MH) | Secondary | 60 - 120 | 1.2 - 1.4 | Common in hybrid cars, camera batteries. |
| Lithium-Ion (Li-ion) | Secondary | 150 – 250 | 3.6 - 3.7 | Popular in smartphones, laptops, and electric vehicles. |
| Alkaline | Primary | 100 - 150 | 1.5 | Widely used in household devices. |
| Zinc-Carbon | Primary | 30 - 50 | 1.5 | Inexpensive, commonly used in low-drain devices. |
| Zinc-Air | Primary | 100 - 200 | 1.4 | Common in hearing aids and small electronics. |
| Photovoltaic Cell | Solar Energy | 150 - 250 | 0.5 - 0.7 (per cell) | Converts solar energy into electrical energy; used in solar panels. |
| Gasoline | Fuel | ~12,000 | N/A | High energy density, widely used in transportation. |
| Firewood | Fuel | ~4,000 | N/A | Traditional biomass fuel, variable energy output. |
| Hydrogen (Fuel Cell) | Fuel | ~33,000 | 0.6 - 1.2 | High energy density, used in hydrogen fuel cells. |
| Natural Gas | Fuel | ~13,000 | N/A | Used in power generation, heating, and vehicles. |

# Environmental impact of batteries

The production of batteries, especially those using materials like lithium, cobalt, and nickel, has significant environmental consequences. Mining these raw materials often leads to habitat destruction, water contamination, and soil degradation. For example, lithium extraction consumes large amounts of water, depleting local water resources and threatening ecosystems in arid regions such as South America’s Lithium Triangle. Cobalt mining, concentrated in the Democratic Republic of Congo, raises environmental and ethical concerns due to deforestation, toxic waste, and the exploitation of local communities. Additionally, the energy-intensive processes used in battery manufacturing contribute to greenhouse gas emissions, further exacerbating climate change.

While batteries help reduce greenhouse gas emissions by enabling renewable energy storage and powering electric vehicles, their use is not entirely without impact. Some battery technologies, like lead-acid and nickel-cadmium, contain hazardous materials that can leak into the environment if improperly handled. Additionally, the manufacturing and transportation of batteries can leave a carbon footprint, offsetting some of the environmental benefits of their deployment. As the demand for batteries increases, it is crucial to ensure the sustainability of the supply chain and improve the efficiency of battery recycling to reduce the need for raw materials and mitigate these impacts.

Battery disposal poses a significant environmental threat, especially when batteries end up in landfills. Toxic substances, such as lead, cadmium, and mercury, can leach into the soil and water, contaminating ecosystems and harming wildlife. Improper disposal of lithium-ion batteries can also result in fires or explosions, releasing harmful gases into the atmosphere. Although recycling can help recover valuable materials like lithium, cobalt, and nickel, current recycling rates remain low due to technical and economic challenges. Enhancing recycling technologies and establishing better collection systems are essential to minimize the environmental impact of battery waste and promote a circular economy.

# Important people in sustainable energy

**Alessandro Volta (1745-1827)**: Volta, an Italian from Pavia physicist, is credited with inventing the **first true battery,** known as the Voltaic Pile, in 1800. This invention marked a significant breakthrough in the field of electricity. The Voltaic Pile consisted **of alternating discs of zinc and copper/silver**, separated by pieces of cardboard soaked in saltwater. This arrangement created a steady flow of electric current, which was a revolutionary discovery at the time. Volta's invention laid the foundation for the development of modern batteries and earned him the title of the "**father of the electric battery**".

**John Frederic Daniell (1790-1845)**: Daniell, a British chemist, invented the Daniell Cell in 1836. This battery **used copper and zinc** in a solution of **copper sulfate and zinc sulfate**. The Daniell Cell provided a  more **stable and reliable source of electricity** compared to the Voltaic Pile. It was widely used in telegraphy and other early electrical applications. Daniell's work significantly improved the efficiency and practicality of batteries, making them more suitable for everyday use.

**Gaston Planté (1834-1889)**: Planté, a French physicist, invented the lead-acid battery in 1859. This was the **first rechargeable battery**, and it remains in use today, particularly in car batteries. The lead-acid battery consists **of lead dioxide and sponge lead plates immersed in sulfuric acid**. When the battery discharges, the lead dioxide and sponge lead react with the sulfuric acid to produce lead sulfate and water. When the battery is recharged, the lead sulfate is converted back into lead dioxide and sponge lead. Planté's invention was a major advancement in battery technology, as it allowed for the storage and reuse of electrical energy.

**Thomas Edison (1847-1931)**: Edison, an American inventor, developed the nickel-iron battery in 1901. This battery was used in early electric vehicles and had a longer lifespan and greater durability compared to lead-acid batteries. The nickel-iron battery consists of **nickel oxide hydroxide and iron electrodes immersed in a potassium hydroxide solution**. Edison's work on batteries was part of his broader efforts to develop practical and reliable sources of electrical power for various applications.

**John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino**: These scientists were awarded the Nobel Prize in Chemistry in 2019 for their development of lithium-ion batteries**.** Lithium-ion batteries are widely used in portable electronics, electric vehicles, and renewable energy storage systems. They have a **high energy density, long cycle life, and low self-discharge rate**. The development of lithium-ion batteries has revolutionized the way we store and use electrical energy, making it possible to power a wide range of devices and applications.

**Benjamin Franklin (1706-1790):** Franklin was one of the first scientists to study electricity systematically. He coined the terms "positive" and "negative" charge and discovered the principle of electric charge conservation. His famous kite experiment demonstrated that lightning is electrical in nature, laying the groundwork for understanding charge flow in circuits.

**Georg Simon Ohm (1789-1854):** Ohm formulated Ohm’s Law, establishing the relationship between voltage, current, and resistance: *V = IR*. This equation is fundamental to understanding how batteries supply power to circuits, helping engineers design efficient electrical systems.

**James Clerk Maxwell (1831-1879):** Maxwell's equations describe how electric and magnetic fields interact, explaining how battery-generated electric currents produce electromagnetic effects. His work is foundational for battery applications in wireless communication and energy transmission.

**Michael Faraday (1791-1867):** Faraday discovered the principles of electromagnetism and electrochemistry. His laws of electrolysis explain how electric charge drives chemical reactions in batteries, essential for battery charging and energy storage.

**Stanford Ovshinsky:** Hewas an American inventor and scientist known for pioneering work in energy and information technologies, including the development of the nickel-metal hydride (NiMH) battery. His innovations in amorphous semiconductors and renewable energy had a lasting impact on battery storage, solar energy, and computing.

**Luigi Galvani (1737-1798):** Galvani's experiments with frog legs and electrical currents led to the discovery of "bioelectricity." His work inspired Volta to develop the Voltaic Pile, the first battery.

**Paul L. Richards (1919-1988):** Richards contributed to early lithium battery research, helping establish lithium as an efficient battery material due to its high energy density and lightweight properties.

**Samuel Ruben (1900-1988):** Ruben co-invented the mercury battery, a compact and stable power source used in military and medical applications. His work significantly improved battery reliability.

**Waldemar Jungner (1869-1924):** Jungner developed the nickel-cadmium (NiCd) battery in 1899, which had greater durability and rechargeability than earlier battery designs. His work paved the way for rechargeable battery technology.

**Kazuo Yoshino (b. 1948):** Yoshino built upon earlier lithium-ion battery research, creating the first commercial lithium-ion battery in 1985, making modern portable electronics possible.

**Robert G. G. Amstrong (20th century):** Amstrong's contributions to solid-state battery research have advanced energy storage technology, increasing efficiency and safety compared to liquid electrolyte batteries.

**Jean-Étienne Colladon (1802-1893):** Colladon helped refine early battery designs by studying the role of electrolyte conductivity in energy storage systems, leading to improvements in battery performance.

**Stanley Pons & Martin Fleischmann (20th century):** Though controversial, their work on cold fusion explored alternative battery chemistries and energy storage concepts beyond conventional electrochemical methods.

**Elon Musk (b. 1971):** While not a scientist, Musk has played a crucial role in advancing battery technology through Tesla’s development of high-capacity lithium-ion batteries for electric vehicles and renewable energy storage.

**Donald Sadoway (b. 1950):** Sadoway pioneered liquid metal battery technology, designed for large-scale energy storage with enhanced efficiency and longevity.

**Shuji Nakamura (b. 1954):** Nakamura contributed to battery efficiency improvements through LED technology, reducing power consumption and extending battery life in electronic devices.

**Robert Huggins (20th century):** Huggins researched sodium-ion battery chemistry, offering a cheaper and more sustainable alternative to lithium-based batteries.

**John Bannister Goodenough (1922-2023):** Goodenough co-developed lithium-ion battery cathode materials, significantly improving battery lifespan and performance.

**M. Stanley Whittingham (b. 1941):** Whittingham introduced intercalation chemistry, enabling lithium-ion battery charge and discharge cycles.

**Clare Grey (b. 1965):** Grey developed advanced imaging techniques to analyze battery materials at the atomic level, improving battery efficiency and longevity.

**Maria Helena Braga (21st century):** Braga's research into glass electrolytes has contributed to safer, more efficient solid-state batteries, potentially revolutionizing future energy storage.

## Important people in wind power

**Poul la Cour (1846-1908):** A Danish scientist and inventor, la Cour is often called the "father of modern wind power." He pioneered the use of wind energy for electricity generation and developed the first wind turbine with aerodynamic blades in the late 19th century. His research laid the foundation for modern wind turbine efficiency.

**Albert Betz (1885-1968):** A German physicist, Betz formulated Betz's Law, which states that no wind turbine can capture more than 59.3% of the wind’s kinetic energy. His work is crucial for optimizing wind turbine designs and improving energy efficiency.

**Ulrich Hütter (1910-1990):** A German engineer, Hütter developed lightweight, high-speed wind turbines using fiberglass-reinforced plastic blades. His work in the mid-20th century

influenced modern turbine designs by making them more aerodynamic and efficient.

**James Blyth (1839-1906):** A Scottish engineer, Blyth built the world’s first known wind turbine for electricity generation in 1887. His small wind turbine powered his home, demonstrating the potential of wind energy for personal and commercial use.

**Viggo V. Kristensen (20th century):** A key figure in Danish wind energy development, Kristensen played a crucial role in commercializing wind turbines and making Denmark a global leader in wind power. His contributions helped scale up wind energy production.

**Henrik Stiesdal (b. 1957):** A Danish engineer, Stiesdal helped commercialize modern wind turbines. He was instrumental in the development of the first grid-connected wind farm and advanced offshore wind turbine technology.

**Paul la Cour Jr. (20th century):** The grandson of Poul la Cour, he continued his grandfather’s work, refining wind turbine technology and improving efficiency, particularly in variable-speed turbines.

**William Heronemus (1920-2002):** An American engineer, Heronemus pioneered the concept of offshore wind farms in the 1970s. His vision led to the development of floating wind turbines, which are now key to expanding wind energy in deep waters.

**James G. McGowan (20th century):** An American researcher, McGowan played a major role in developing early wind turbine technology for large-scale power generation, particularly in the U.S. Department of Energy’s wind programs.

**Ditlev Engel (b. 1964):** Former CEO of Vestas, Engel helped turn the company into one of the world’s largest wind turbine manufacturers. Under his leadership, Vestas advanced turbine efficiency and expanded global wind energy markets.

# Lithium production

|  |  |
| --- | --- |
| Country | Estimated Lithium Production (Metric Tons) |
| Australia | 61,000 |
| Chile | 39,000 |
| China | 19,000 |
| Argentina | 6,200 |
| Brazil | 2,200 |
| United States | 5,000 |
| Russia | Minimal production |
| Mongolia | Minimal production |

# Timeline

* **1800 – Voltaic Pile**: Alessandro Volta invents the first true battery, the Voltaic Pile, using zinc and copper discs separated by saltwater-soaked cloth.
* **1836 – Daniell Cell**: John Frederic Daniell develops a more reliable and longer-lasting battery, used in telegraphy.
* **1859 – Lead-Acid Battery**: Gaston Planté invents the first rechargeable battery, which is still used in cars today.
* **1881 – Leclanché Cell (Zinc-Carbon Battery)**: Georges Leclanché introduces a practical dry-cell battery, making portable power more accessible.
* **1899 – Nickel-Cadmium (NiCd) Battery**: Waldemar Jungner invents the first rechargeable NiCd battery, offering improved energy density.
* **1901 – Nickel-Iron (NiFe) Battery**: Thomas Edison develops a rugged, rechargeable battery used in early electric vehicles and industrial applications.
* **1947 – Alkaline Battery**: The first modern alkaline battery is developed, offering longer life and better performance than zinc-carbon batteries.
* **1955 – Zinc-Manganese Dioxide (Modern Alkaline Battery)**: Lewis Urry improves alkaline battery chemistry, leading to today’s common household batteries.
* **1970s – Lithium Battery (Non-Rechargeable)**: The first commercial lithium primary batteries appear, offering high energy density.
* **1980 – Lithium-Ion Battery Concept**: John Goodenough and Koichi Mizushima develop a rechargeable lithium-ion battery using lithium cobalt oxide.
* **1985 – First Rechargeable Lithium-Ion Battery Prototype**: Akira Yoshino develops a safer lithium-ion battery by using a carbon-based anode instead of lithium metal.
* **1991 – Commercial Lithium-Ion Battery**: Sony releases the first commercial lithium-ion battery, revolutionizing portable electronics.
* **2004 – Lithium Iron Phosphate (LiFePO₄) Battery**: A new, safer lithium battery chemistry is introduced, offering longer life cycles and better thermal stability.
* **2011 – Solid-State Battery Research Gains Momentum**: Scientists explore solid-state batteries with the potential for higher energy density and safety improvements.
* **2020s – Next-Gen Battery Advances**: Developments in sodium-ion, lithium-sulfur, and solid-state batteries aim to increase efficiency, reduce costs, and improve sustainability.

# Battery management system

A **Battery Management System (BMS)** is an electronic system that oversees the operation of rechargeable batteries, such as lithium-ion or lead-acid types, to ensure they function efficiently and safely. The BMS performs essential tasks like monitoring voltage levels, state of charge (SOC), and state of health (SOH), as well as balancing the voltage of individual cells within a multi-cell battery pack. This system helps prevent conditions like overcharging, deep discharging, and thermal runaway, which can damage the battery or pose safety risks. By constantly tracking battery performance and making adjustments as necessary, the BMS optimizes energy use and enhances the overall efficiency of the battery.

One of the primary functions of a BMS is to ensure safety. It continuously monitors factors like voltage, temperature, and current to detect any irregularities or potential faults such as overcurrent, short circuits, or overheating. If any of these issues arise, the BMS can disconnect the battery to protect it from damage. Additionally, it manages the charge and discharge process, ensuring that the battery is charged at the proper voltage and current levels, thus prolonging its lifespan. This protection and control extend the battery's operational life and maintain its performance.

The BMS is crucial in a variety of applications, including electric vehicles (EVs), renewable energy storage systems, consumer electronics, and large-scale grid storage. In EVs, for instance, the BMS ensures the battery operates at optimal levels, improving the vehicle’s range and performance. In renewable energy setups, it manages the storage of energy from sources like solar panels, balancing energy use and storage. As the use of rechargeable batteries continues to expand, BMS technology remains essential in maximizing battery life, efficiency, and safety across a wide range of industries.

# Safety considerations

When working with batteries, safety is paramount due to the potential hazards associated with improper use or malfunction. One of the primary safety considerations is the risk of **overcharging** or **overdischarging**. Overcharging a battery can lead to excessive heat generation, potentially causing the battery to swell, leak, or even catch fire. Similarly, discharging a battery beyond its recommended limits can cause chemical imbalances inside the cell, which can degrade its capacity, shorten its lifespan, or result in dangerous situations such as thermal runaway. Proper charging practices and the use of Battery Management Systems (BMS) are crucial in preventing these risks by ensuring that batteries operate within safe voltage and current ranges.

Another significant safety concern is **thermal management**. Batteries, especially lithium-ion types, are susceptible to overheating, which can lead to a range of problems including fires, explosions, or leakage of harmful chemicals. This is often referred to as **thermal runaway**, a chain reaction that occurs when a battery reaches an uncontrollable temperature. It’s essential to monitor the temperature of batteries and ensure that they are used in environments with proper ventilation or cooling systems. Effective thermal management systems are especially important in electric vehicles and large-scale energy storage, where batteries operate under high power loads and are at greater risk of overheating.

**Battery storage and disposal** also pose safety risks if not managed properly. When storing batteries, it is essential to keep them in cool, dry places away from direct sunlight, humidity, or sources of heat, as these conditions can degrade the battery or cause dangerous reactions. Additionally, improperly disposed of batteries can pose environmental hazards or lead to fires. For instance, punctured or damaged lithium-ion batteries can release hazardous chemicals or ignite. Recycling programs and safe disposal methods are essential to mitigate these risks and prevent toxic materials from entering the environment, ensuring that spent batteries are handled in a manner that minimizes harm to both people and the planet.

100,000 liters of water is consumed per metric ton of lithium-ion. This could pose significant changes to the region and could be taking your freshwater faster than we want it to. The problem is almost everything relies on lithium ion batteries, cars. As of 2024, approximately 50% to 90% of lithium-ion battery materials can be recovered through recycling processes, depending on the specific materials and methods used.

However, the actual global recycling rate for lithium-ion batteries is significantly lower, with estimates suggesting that only about 1% to 3% of lithium is recovered from recycled batteries. This disparity highlights the need for improved recycling technologies and infrastructure to enhance the recovery of valuable materials and reduce environmental impact. Approximately **99%** of lead-acid batteries are currently being recycled. This high recycling rate is due to the efficient closed-loop system in place, where the key materials—lead, plastic, and acid—are fully recyclable and reused in new batteries.

# Lithium-ion production

A screenshot of a graph

Description automatically generated

# Energy density

A table with numbers and symbols

Description automatically generated

# Photovoltaic effect

The photovoltaic effect is the process by which light is converted into electricity. Here’s how it works in simple terms:

1. **Light Hits the Solar Cell**: When sunlight hits a solar cell, the light is made up of tiny particles called photons.
2. **Photons Free Electrons**: The energy from the photons knocks electrons loose from the atoms inside the solar cell's material, usually silicon.
3. **Movement of Electrons**: Once the electrons are freed, an electric field inside the solar cell pushes them to move in a certain direction.
4. **Electric Current**: As the electrons flow through the material, they create an electric current, which can be used to power electrical devices.

In short, the photovoltaic effect is when light (photons) releases electrons in a material (like silicon) and causes them to move, creating electricity.

# Statistics

**Recycling Rates**:

* **5%** of batteries used in the U.S. are recycled properly.
* Over **95%** of lead-acid batteries are recycled globally, primarily used in vehicles.

**Battery Usage**:

* The average American uses around **20-25** batteries each year.
* Over **3 billion** batteries are sold in the U.S. each year.

**Environmental Impact**:

* About **40%** of the lead found in landfills comes from improperly discarded lead-acid batteries.
* **50,000 tons** of batteries are discarded in the U.S. every year, contributing to significant environmental harm if not properly recycled.

**Battery Composition**:

* **Nickel-Cadmium (Ni-Cd)** batteries contain toxic cadmium, which can cause severe environmental damage if not recycled.
* **Lithium-ion** batteries make up more than **90%** of the rechargeable battery market today, primarily used in phones, laptops, and electric vehicles.

**Recycling Benefits**:

* Recycling batteries saves **energy** (up to 95% for certain battery types) and reduces the need to mine new materials.
* Over **50%** of the materials in batteries, such as cobalt, lithium, and nickel, can be recovered and reused through recycling.

# Battery density

|  |  |  |
| --- | --- | --- |
| Battery/Fuel | Energy Density (Wh/kg) | Energy Density (MJ/kg) |
| Alkaline battery | ~110–150 Wh/kg | ~0.4–0.54 MJ/kg |
| Firewood | ~5 Wh/kg | ~0.018 MJ/kg |
| Gasoline | ~12,200 Wh/kg | ~44 MJ/kg |
| Hydrogen (fuel cell) | ~33,600 Wh/kg | ~121 MJ/kg |
| Lead-acid battery | ~30–40 Wh/kg | ~0.11–0.14 MJ/kg |
| Lithium-ion battery | ~150–250 Wh/kg | ~0.54–0.9 MJ/kg |
| Natural gas | ~13,900 Wh/kg | ~50 MJ/kg |
| Nickel-metal hydride (NiMH) battery | ~60–120 Wh/kg | ~0.22–0.43 MJ/kg |

# Formula’s

## Ohms law

### Voltage

V= I×R

V = Voltage (volts)

I = Current (amperes)

R = Resistance (ohms)

### Current

I = V/R

V = Voltage (volts)

I = Current (amperes)

R = Resistance (ohms)

### Resistance

R = V/I

V = Voltage (volts)

I = Current (amperes)

R = Resistance (ohms)

R = V^2/P

V = Voltage (volts)

R = Resistance (ohms)

P = Power

## Energy (Wh)

Wh = V \* C

Wh = Watt hours (Wh)

V = Voltage (volts)

C = Capacity (Ah)

Energy = Energy stored/efficiency

## Battery life

Battery life = Battery capacity/ Current \

Battery life (hours)

Battery capacity (mah)

Current (ma)

## Power output of a wind turbine

**P = ½ × ρ × A × v³**

Where:  
- **P** = Power (in watts)  
- **ρ** = Air density (kg/m³), typically around 1.225 kg/m³ at sea level  
- **A** = Swept area of the rotor (m²), A = π × r²  
- **v** = Wind speed (m/s)

## Power output of a solar panel

P=A×G×η

Where:

* P = Power output (in watts)
* A = Area of the solar panel (in square meters)
* G= Incident solar radiation (in W/m², typically ~1000 W/m² under full sun)
* η = Efficiency of the solar panel (as a decimal)

# Energy of a solar panel

**E = A × G × η × t**

Where:  
- **E** = Energy generated (in watt-hours or kilowatt-hours)  
- **A** = Area of the solar panel (in m²)  
- **G** = Solar irradiance (in W/m², typically ~1000 W/m² under full sun)  
- **η** = Efficiency of the solar panel (as a decimal, e.g., 0.18 for 18%)  
- **t** = Time the panel is exposed to sunlight (in hours)

# Energy of a wind turbine

**E = P × t**

Where:  
- **E** = Energy generated (in joules, or kilowatt-hours if P is in kW and t in hours)  
- **P** = Power output (in watts or kilowatts)  
- **t** = Time (in seconds or hours)

## Capacitance

C = Q/V

Q = Charge of a capacitor (farads)

V = Volts

C = Capacitance (coulombs)

### Parallel plate capacitor

C = (8.85 x 10^-12) x A / d

C = Capacitance

A = Area of one of the plates

D = separation between the plates

## Discharge current

I = C-rate \* capacity

I = discharge current

Capacity (Ah)

## Series circuit

Total V= V1 + V2 + V3

## Parallel circuit

V = V1

## Charging time

H = Capacity/ Charge current

H = Charging time

Capacity (mah)

Charge current (ma)

## Power Output

P = V × I

Where:  
- P is power (in watts, W)  
- V is voltage (in volts, V)  
- I is current (in amperes, A)

## Power

P = V^2/ R

P= Power

V = Voltage

R = Resistance

## Resistors in parallel

1/R1 + 1/ R2

R1 = Resistor 1

R2 = Resistor 2

## Resistor in series

R1 + R2

R1 = Resistor 1

R2 = Resistor 2

## Power loss

P = I^2R

P = Power loss (watt)

I = discharge rate

R = resistance

## Energy loss

E = P \* T

E = Energy loss (Watt-hour)

P = Power loss (watt)

T = time(hours)

## Charge

Q = C x V

Q = Charge

C = Capacitance

V = Voltage