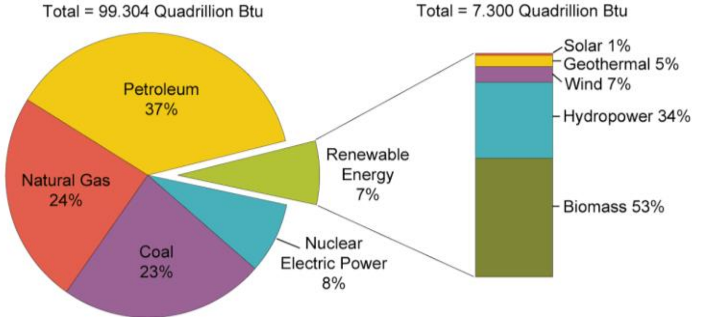
Unit 4

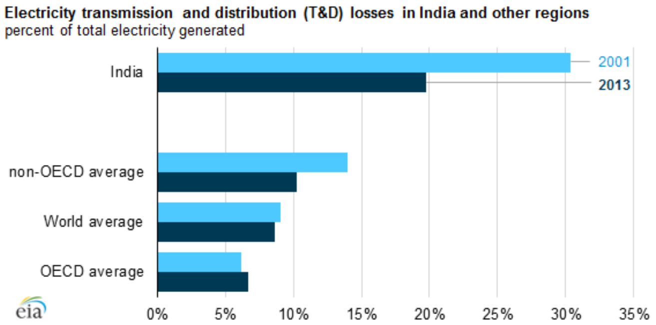
Energy Storage Systems

Smart Grid

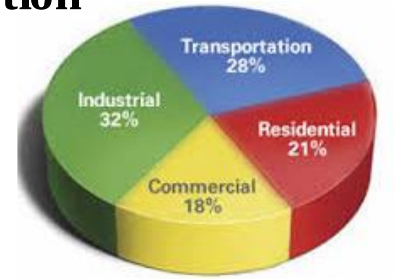
Generation

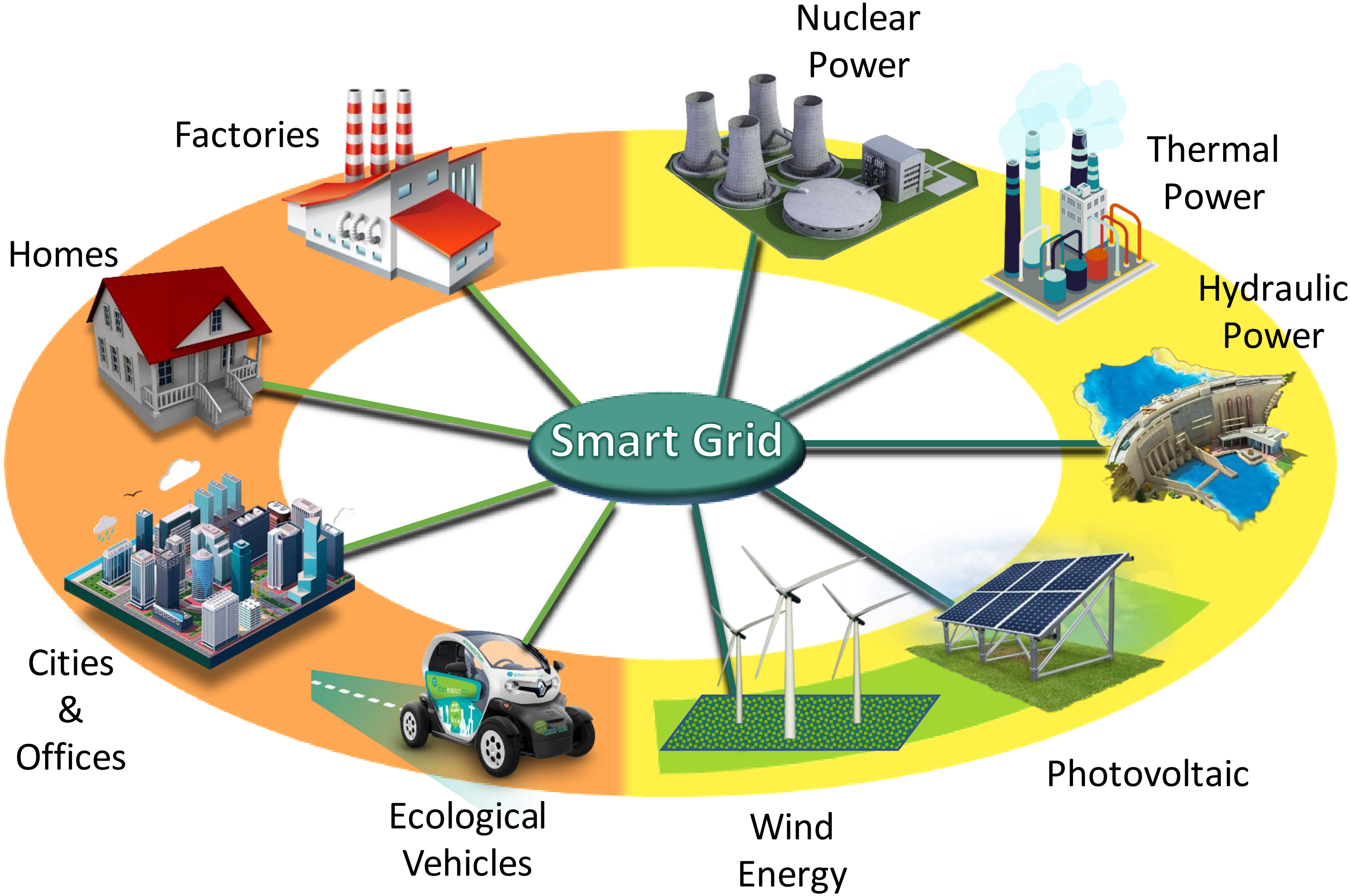


Transmission



Distribution





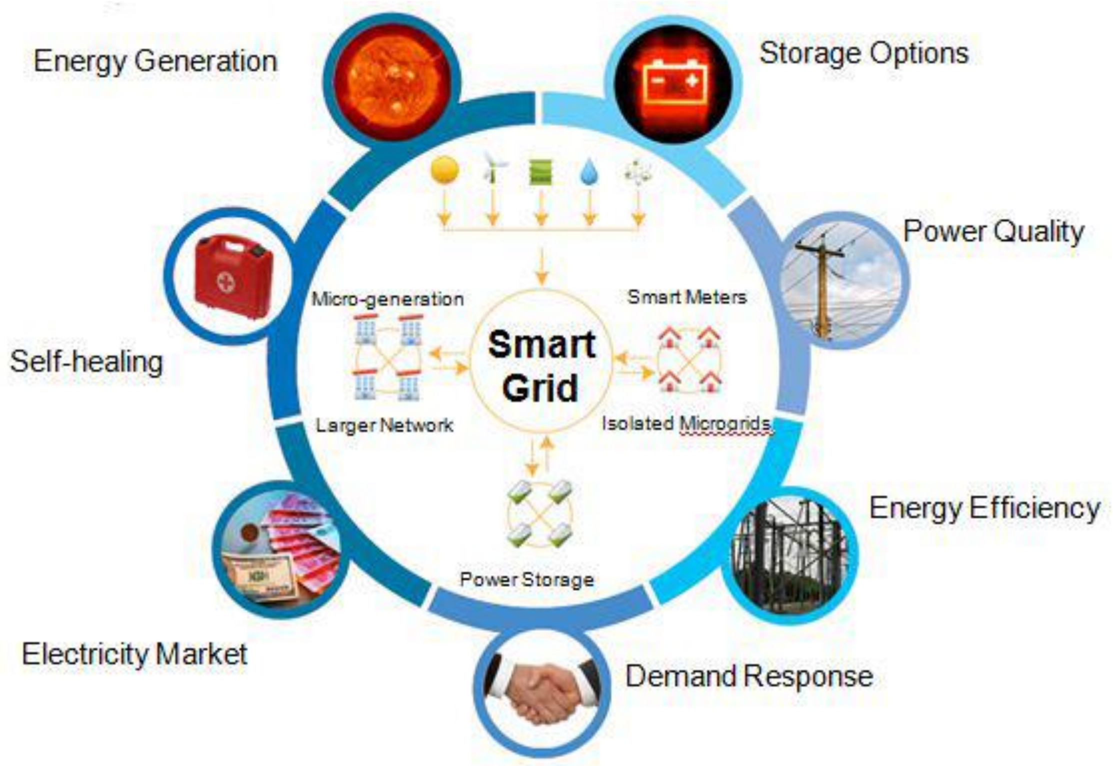
Smart Grid

Advantages of Smart Grid

A) Reliable source of power
B) Flexibility in network topology
C) Sustainable infrastructure
D) Market-demand

- GRIDs are the heart of the total system
- Grids should be stable and reliable to continuously balance the supply and demand of energy.

- Energy Storage Systems (ESS) are needed to
  - Supply a smooth output power to the power grid
  - It can also serve as back-up power sources



Energy Storage System

Energy storage

It is the capture of energy produced at one time and storing it for use at a later time or when need arises

Energy storage system (ESS)

It is the set of methods or technologies involved in energy/electricity storage

Benefits of Energy storage system

1) ESSs enhances the reliability and flexibility of grid power.
   - stores energy when there is more supply
   - discharges the stored energy during peak demand periods.
   - serve as back-up power sources in an emergency.
2) Efficient use of energy by electrical load equalization.
3) support the use renewable energy. contribute to the decarbonization
4) reduced toxic emission/pollution from conventional (non-renewable sources) methods distributed and centralized renewable electricity generation is expected to increase
5) clean and localized power supply can be achieved

India gets first grid-scale battery energy storage system

The 10 MW system at Tata Power Delhi Distribution's Rohini substation is said to be South Asia's largest.

FEBRUARY 13, 2019 UMA GUPTA

NEWS

India likely to require energy storage capacity of 2,400 Gigawatt Hour by 2032

Share Like Comment Mar 18, 2020 10:31 am GMT 149 views

Source: Energy Monitor Worldwide

Energy Storage System

Energy Storage Systems

Electrical
- Super-capacitor
- Superconductive Magnetic coil

Mechanical
- Pumped hydro power
- Compressed air energy storage system
- Flywheels

Thermal
- Thermoelectric storage

Chemical
- Lithium-ion battery
- Lead-acid battery
- High temperature batteries
- Flow Batteries
- Hydrogen storage
- Natural gas storage system

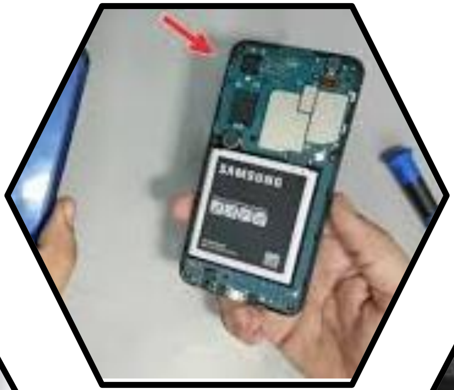
Short *Medium* *Long*

Energy Storage Systems:

1)Battery

2) Fuel Cell

3) Hydrogen generation and storage


SAMSUNG


ALKALINE BATTERY
Energizer

Battery


Panasonic
CR 2025
3V


EXIDE
Excell
EXIDE
Excell
12v. 72Ah 640A (EN)

A battery is an electrochemical cell that converts chemical energy into electrical energy.

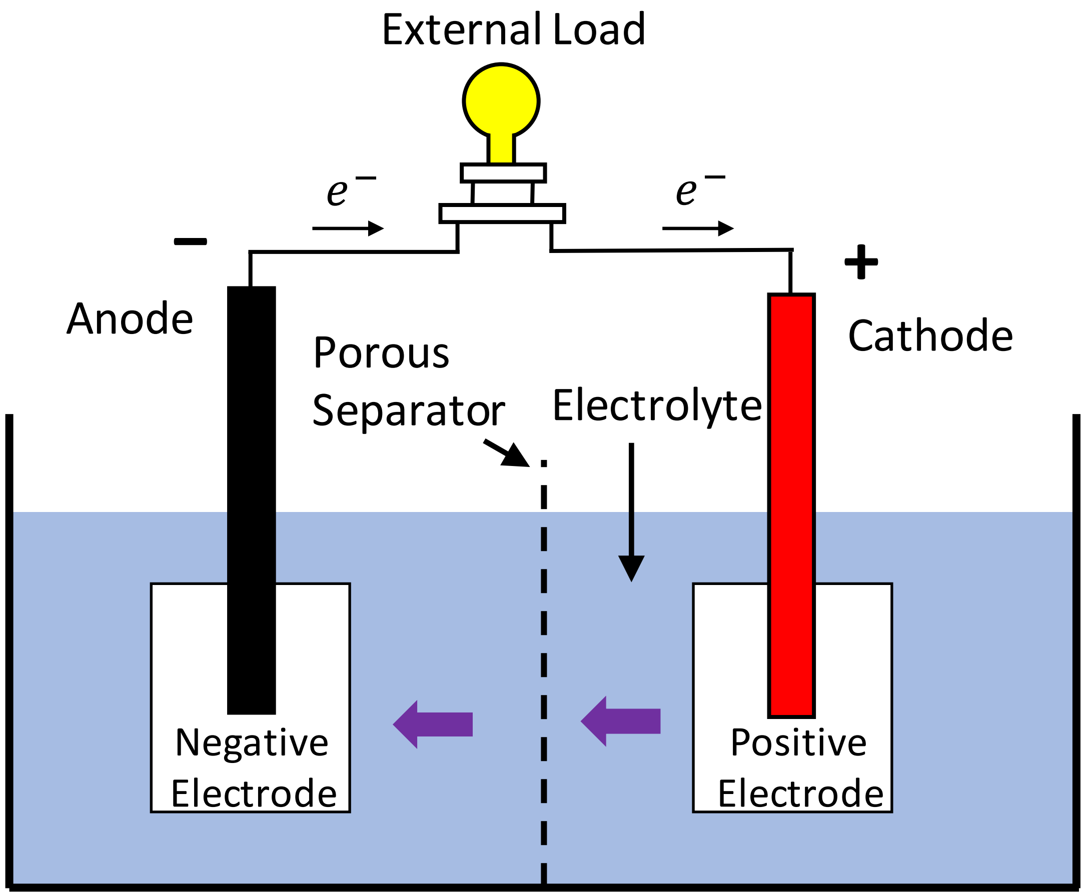
Different components of a battery

1) **Anode :-** Negative electrode …. Oxidation

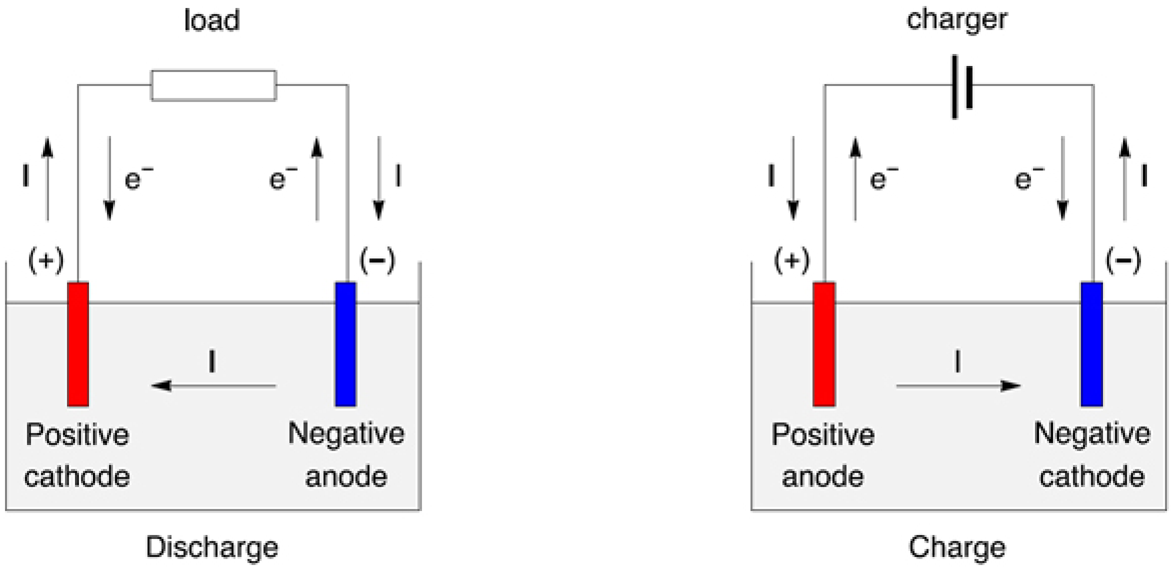
2) **Cathode :-** Positive electrode……Reduction

3) **Electrolyte :-** Ionic conductivity

4) **Separator :-** Physical barrier to prevent shortening <u>& permeable to ions only not for electrons</u>



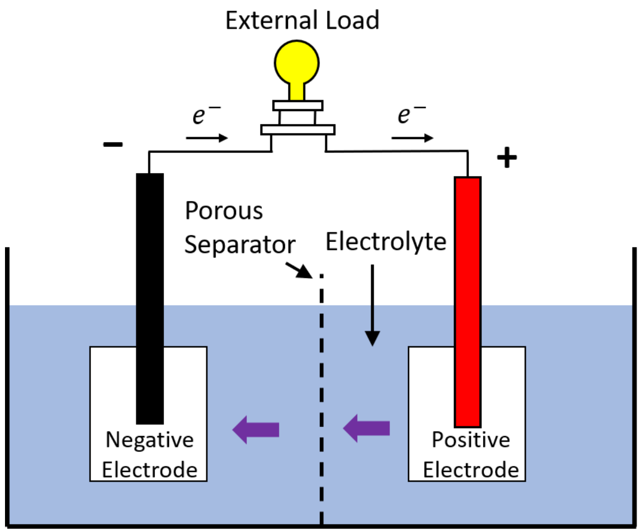
- The electrode with the higher potential is referred to as positive
- The electrode with the lower potential is referred to as negative.

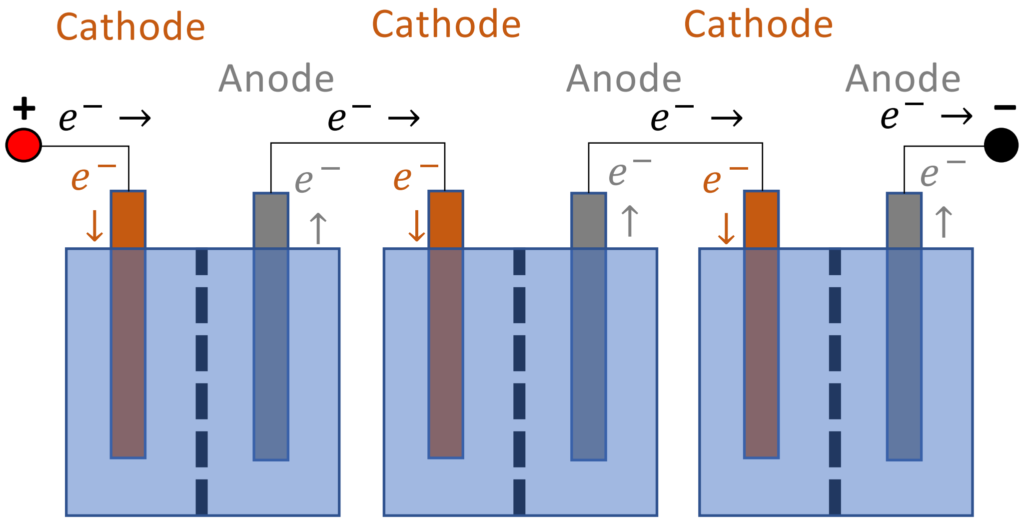


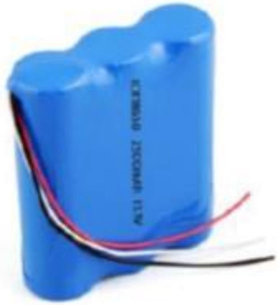
- The electrical potential difference between the cathode and the anode, which can drive the electrons in the external circuit, is called electromotive force (emf).

$$Cu^{2+} + 2e^- \rightarrow Cu \qquad E^o = 0.337$$
$$Zn \rightarrow Zn^{2+} + 2e^- \qquad E^* = 0.763$$

Cell or Battery ?







Cell

Battery

Multiple Cell Batteries

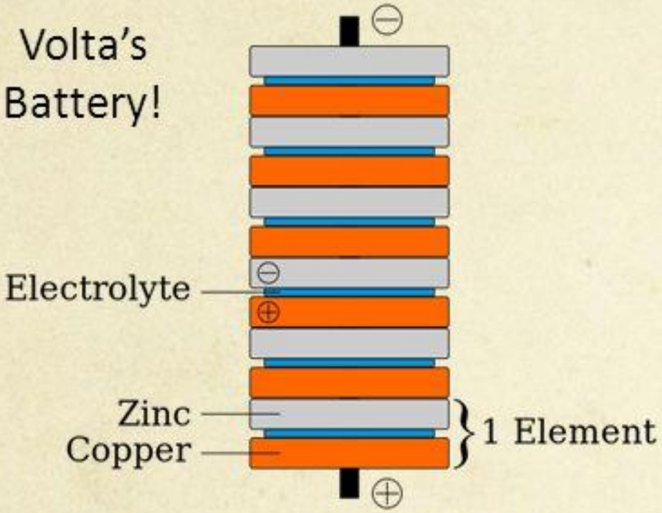
12-Volt Car Batteries-are made of six 2.0 volt cells

9-Volt Batteries – are made of six 1.5 volt cells

Battery History

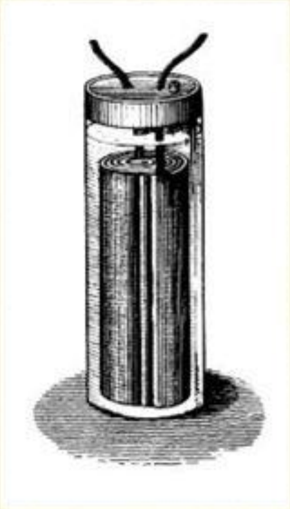
The word circuit comes from the Latin *circuitus*, which means "to go around"

Volta's Battery!



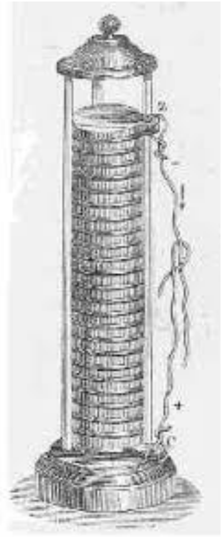
The first battery was created by Alessandro Volta in 1798. Volta was an Italian professor in physics and chemistry

We honor him today by calling our standard measure of electricity the "volt"



Planté's Lead-acid Battery!

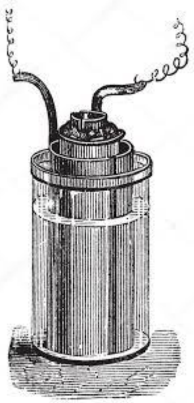
In 1859, Gaston Planté invented the lead-acid battery, the first-every battery that could be recharged by passing a reverse current through it.



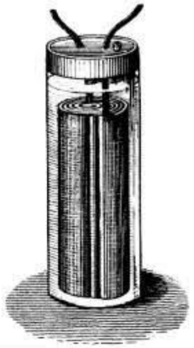
1.

Volta cell

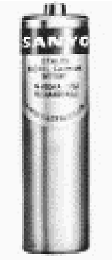
History of battery development		
1600	Gilbert (Britain)	Establishment of electrochemistry study
1791	Luigi Galvani (Italy)	Discovery of “animal electricity”
1800	Alessandro Volta (Italy)	Invention of voltaic cell (Zinc and Copper disks)
1802	Cruikshank (Britain)	First electric battery capable of mass production
1820	Ampere (France)	Electricity through magnetism
1833	Faraday (Britain)	Announcement of Faraday’s Laws
1836	John F. Daniell (Britain)	Invention of the Daniell Cell
1839	William Robert Grove (Britain)	Invention of the fuel cell (H_2/O_2)
1859	Geston Plante (France)	Invention of the lead scid battery
1868	Geroge Leclanche (France)	Invention of the Lechlanche cell
1899	Waldemar Jungner (Sweden)	Invention of the nickel-cadmium battery
1901	Thomas A. Edison (US)	Invention of nickel-iron battery
1932	Schlecht and Ackermann (Germany)	Invention of sintered pole plate
1947	Neumann (France)	Successfully sealing the nickel-cadmium battery
1949	Lew Urry, Eveready Battery	Invention of the alkaline-manganese battery
1970s	Group Effort	Development of the valve regulated lead acid battery
1990	Group Effort	Commercialisation of the nickel-metal hydride battery
1991	Sony (Japan)	Commercialisation of the lithium-ion battery
1996	Moli Energy (Canada)	Introduction of the Li-ion with manganese cathode
2006	Valence, A123 System (US)	Introduction of Li-ion with phosphate cathode



2. Daniel cell



3. Lead acid battery

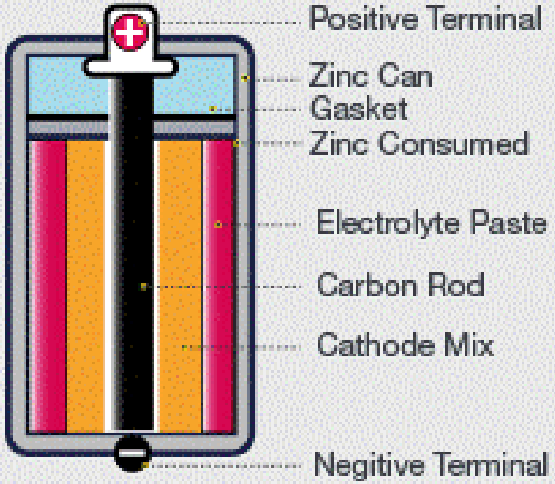


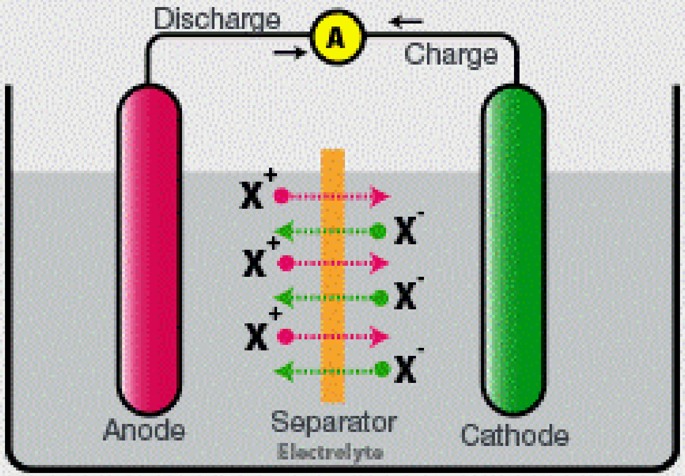
An early nickel-cadmium battery
Sanyo's Cadnica N-450AA

4. Ni-Cd battery

5.

DIFFERENCE BETWEEN PRIMARY CELL AND SECONDARY CELL





PRIMARY CELL

A PRIMARY CELL IS A BATTERY THAT IS DESIGNED TO BE USED ONCE AND DISCARDED, AND NOT RECHARGED WITH ELECTRICITY AND REUSED LIKE A SECONDARY CELL IN GENERAL, THE ELECTROCHEMICAL REACTION OCCURRING IN THE CELL IS NOT REVERSIBLE, RENDERING THE CELL UNRECHARGEABLE.

SECONDARY CELL

A SECONDARY CELL IS A TYPE OF ELECTRICAL BATTERY WHICH CAN BE CHARGED, DISCHARGED INTO A LOAD, AND RECHARGED MANY TIMES, AS OPPOSED TO A DISPOSABLE OR PRIMARY BATTERY, WHICH IS SUPPLIED FULLY CHARGED AND DISCARDED AFTER USE.

DIFFERENCES

Primary Batteries	Secondary Batteries
Cell reaction is irreversible	Cell reaction is reversible.
Must be discarded after use.	May be recharged
Have relatively short shelf life	Have long shelf life.
Function only as galvanic cells .	Functions both galvanic Cell & as electrolytic cell.
They cannot be used as storage devices	They can be used as energy storage devices (e.g. solar/ thermal energy converted to electrical energy)
They cannot be recharged e.g. Dry cell.	They can be recharged. $Li\text{-}MnO_2$ battery. Lead acid, Ni-Cd battery.

2. SECONDARY BATTERY

- Rechargeable (cell reactions are reversible)

Lead-Acid Battery (Pb/H+)

Nickel-Cadmium Battery (Ni-Cd)

Nickel-Iron Battery (Ni-Fe)

Nickel-Metal hydride Battery (Ni-MH)

Lithium battery (Li-LiM_xO_y)

Lithium-Ion battery (C-LiM_xO_y)

Lithium-Ion Polymer Battery (C-LiM_xO_y)

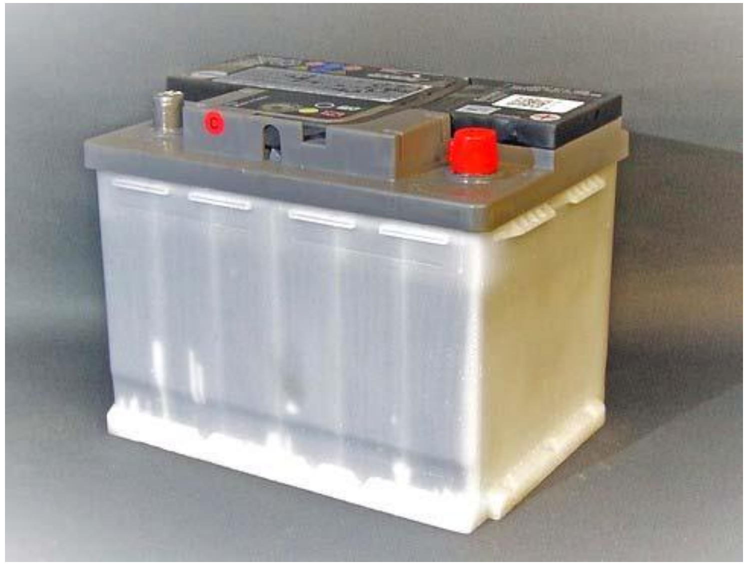
Ni-Cd Battery

Aircraft
Photography
Memory devices
Toys

Ni-metal hydride(MH) Battery

Portable electronic devices

Lead Acid Battery



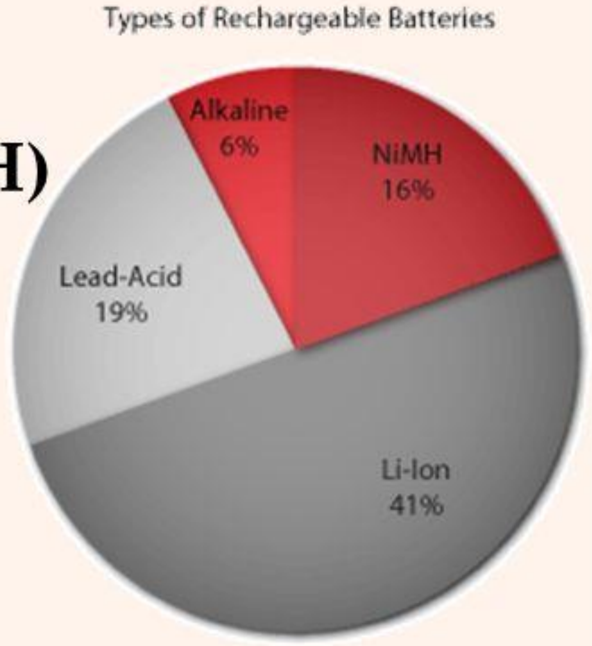
Automobiles
Emergency utility

Li ion Battery

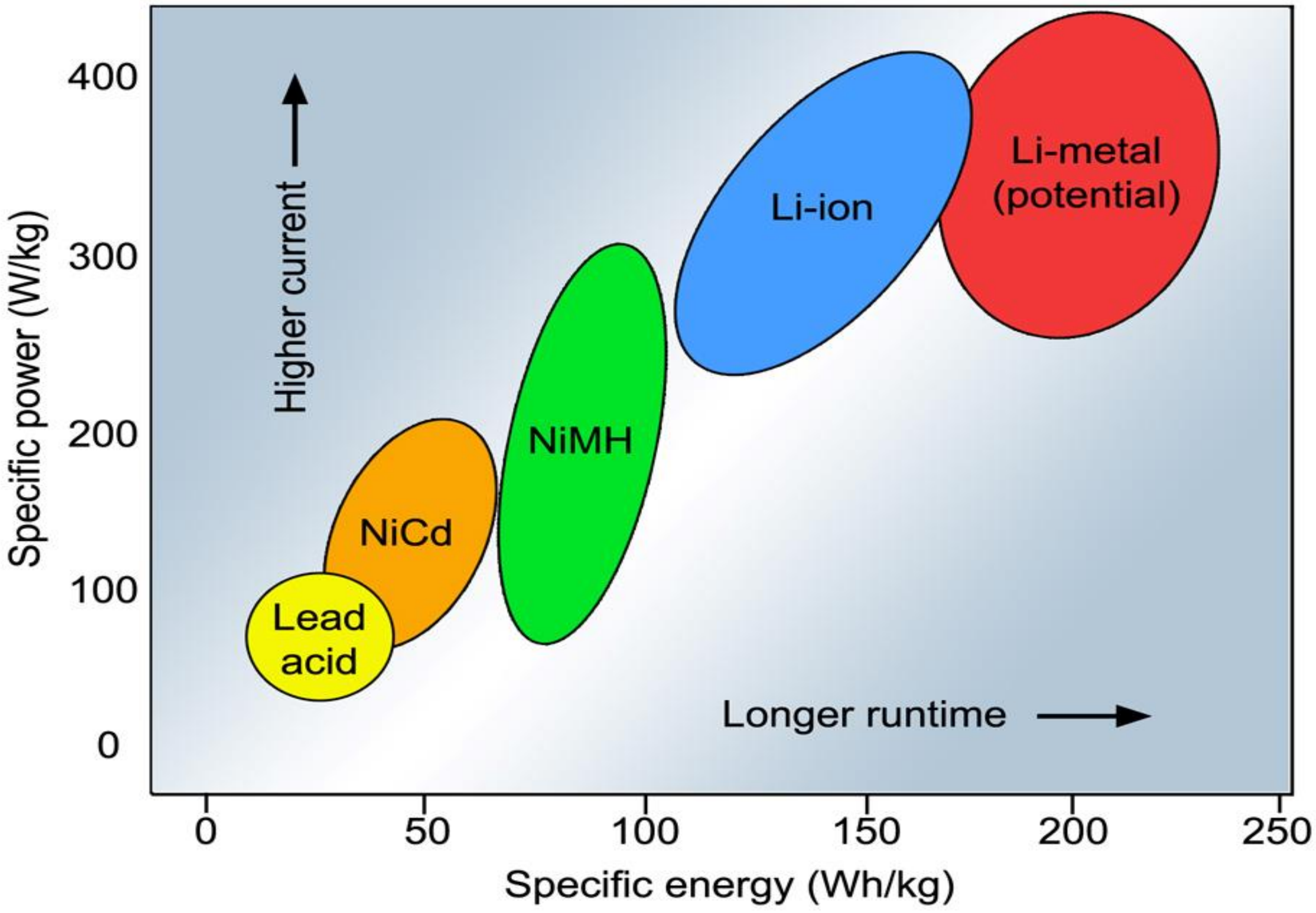
Portable devices
Laptop
Smart mobiles
Aerospace
Military

The Different Types of Rechargeable Battery:

-Nickel Cadmium **(NiCd)**
-Nickel Metal Hydride **(NiMH)**
-Lithium-ion **(Li-ion)**
- Sealed Lead Acid **(SLA)**



- Better option than disposable batteries
- Reduce the amount of waste generated



Specific energy: Capacity a battery can hold (Wh/kg)

Specific power: Ability to deliver power (W/kg)

There are two types of Lithium Batteries

Primary Battery

Lithium metal
(metallic)

Non-rechargeable
- Heart pace makers
- Defense
- Instrumentation
- Oil drilling

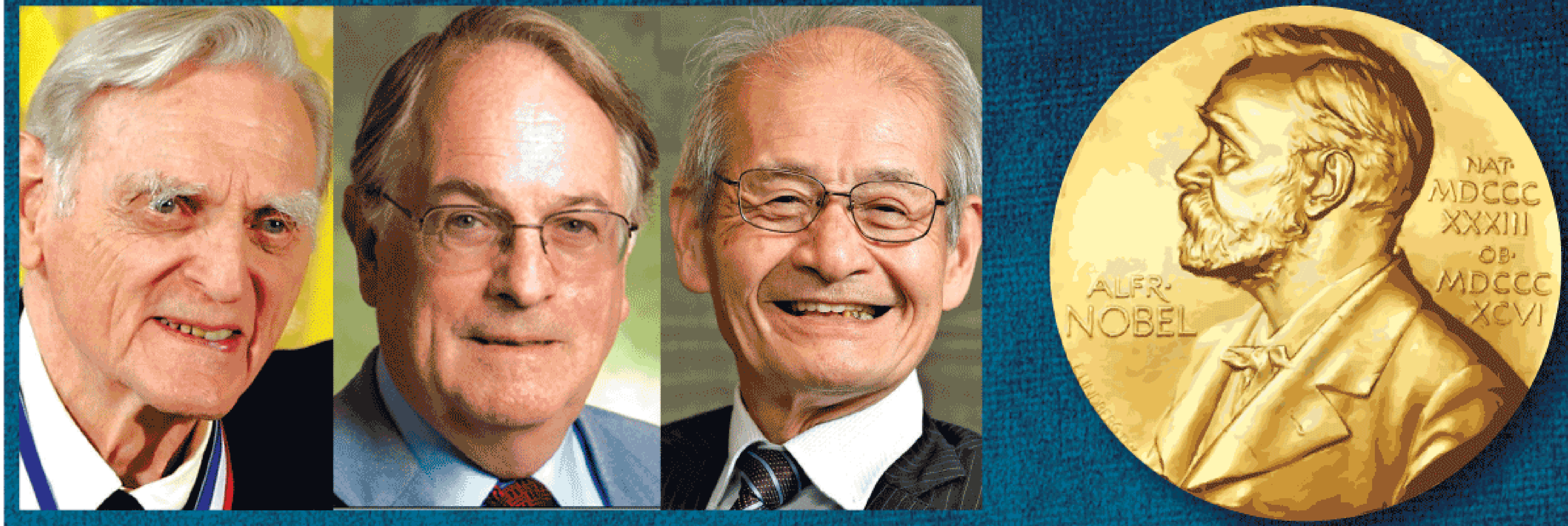
Lithium ion
(intercalated lithium compound)

$LiCoO_2$
$LiMn_2O_4$
$LiNiO_2$

Secondary Battery

Rechargeable
- Mobile phones
- Laptops
- Power tools
- Electric powertrains

Nobel Prize in Chemistry

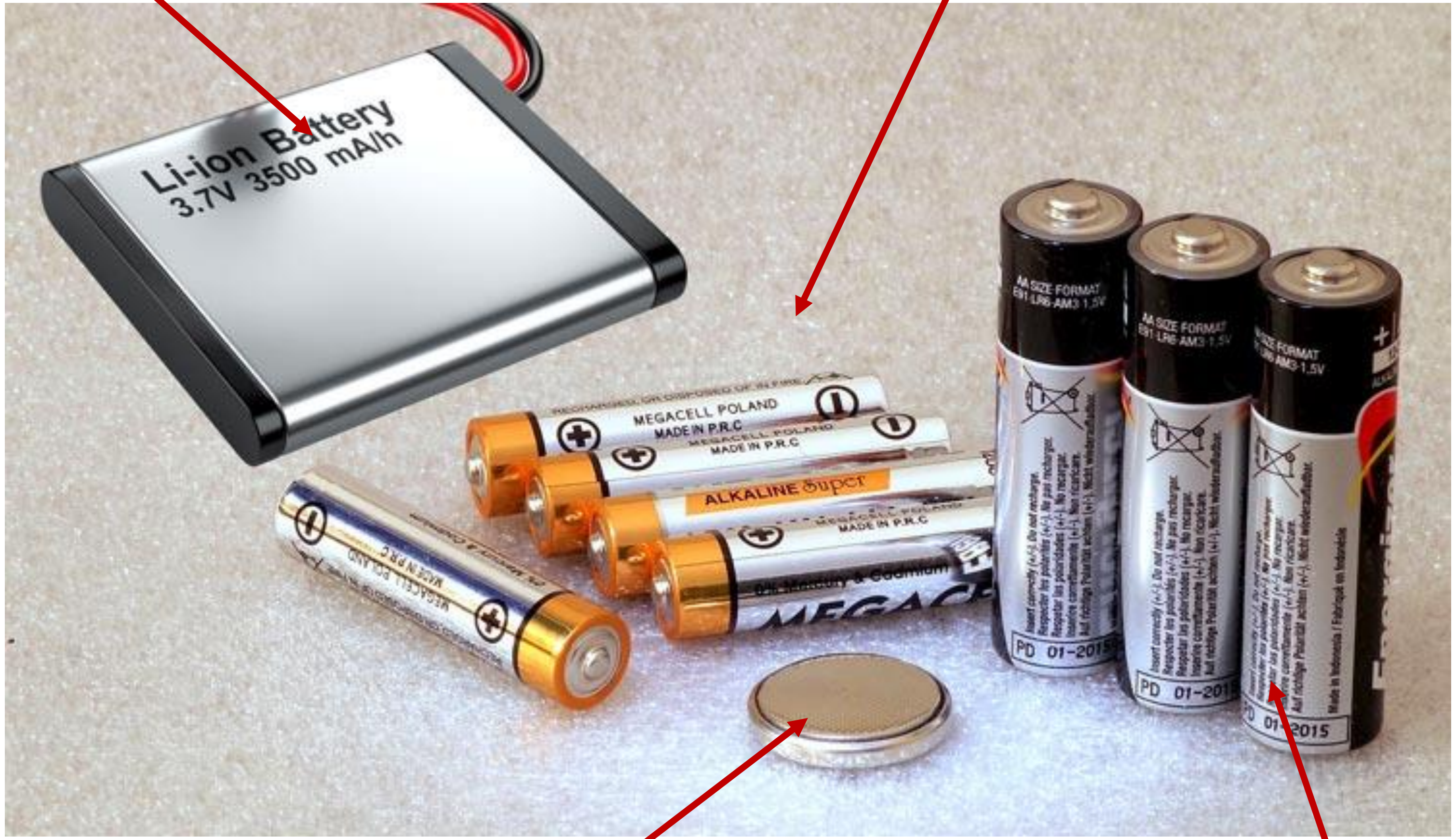


John B. Goodenough ***(USA, left)*****, M. Stanley Whittingham** ***(UK, centre)*****, and Akira Yoshino** ***(JPN, right)*** **share the Nobel Prize for the development of lithium-ion batteries**

Different Li ion battery

Prismatic Cell

Pencil Cell



Pouch Cell

Coin or button Cell

Cylindrical Cell

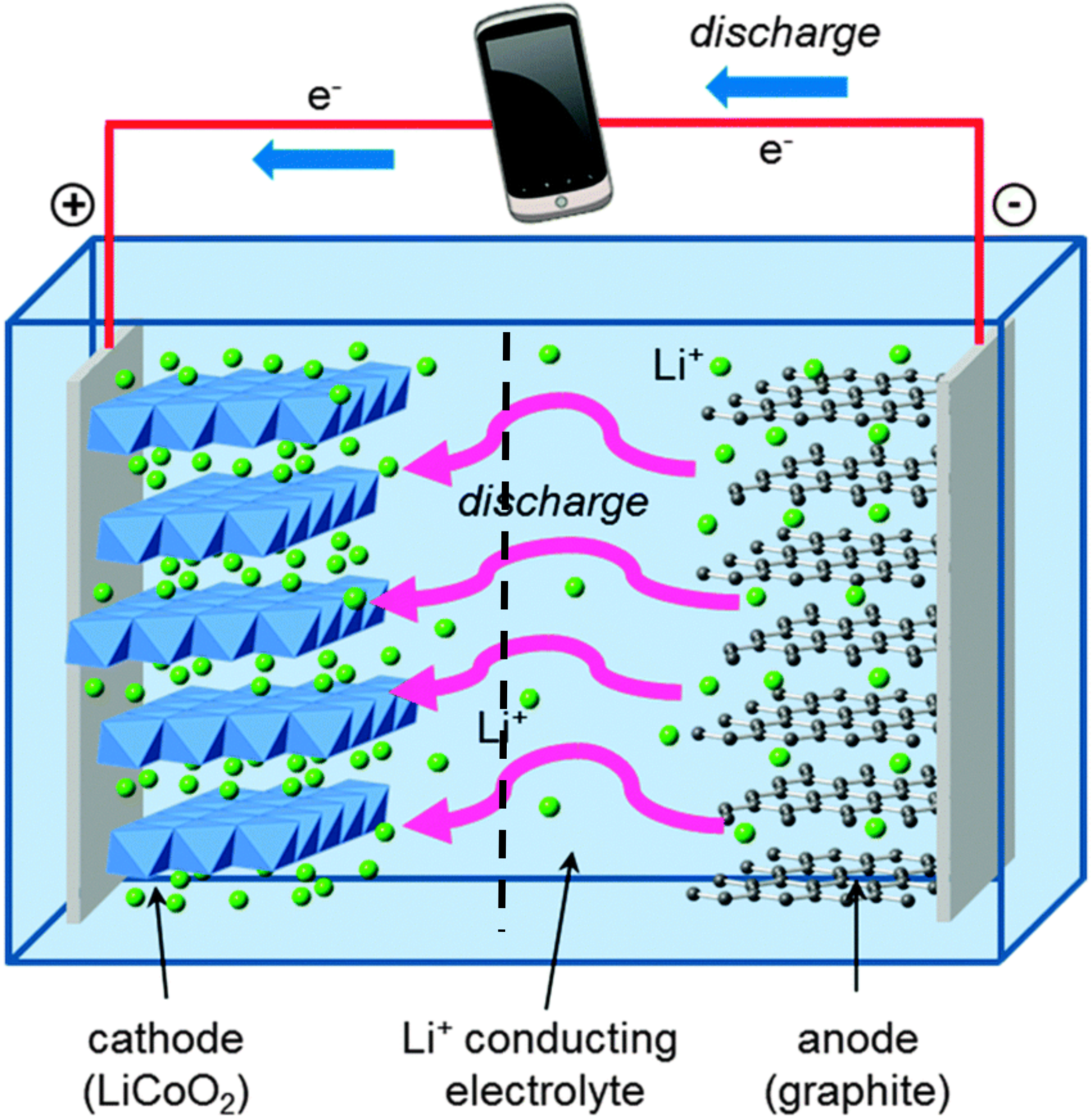
Construction of Li ion battery – 4 layered structure

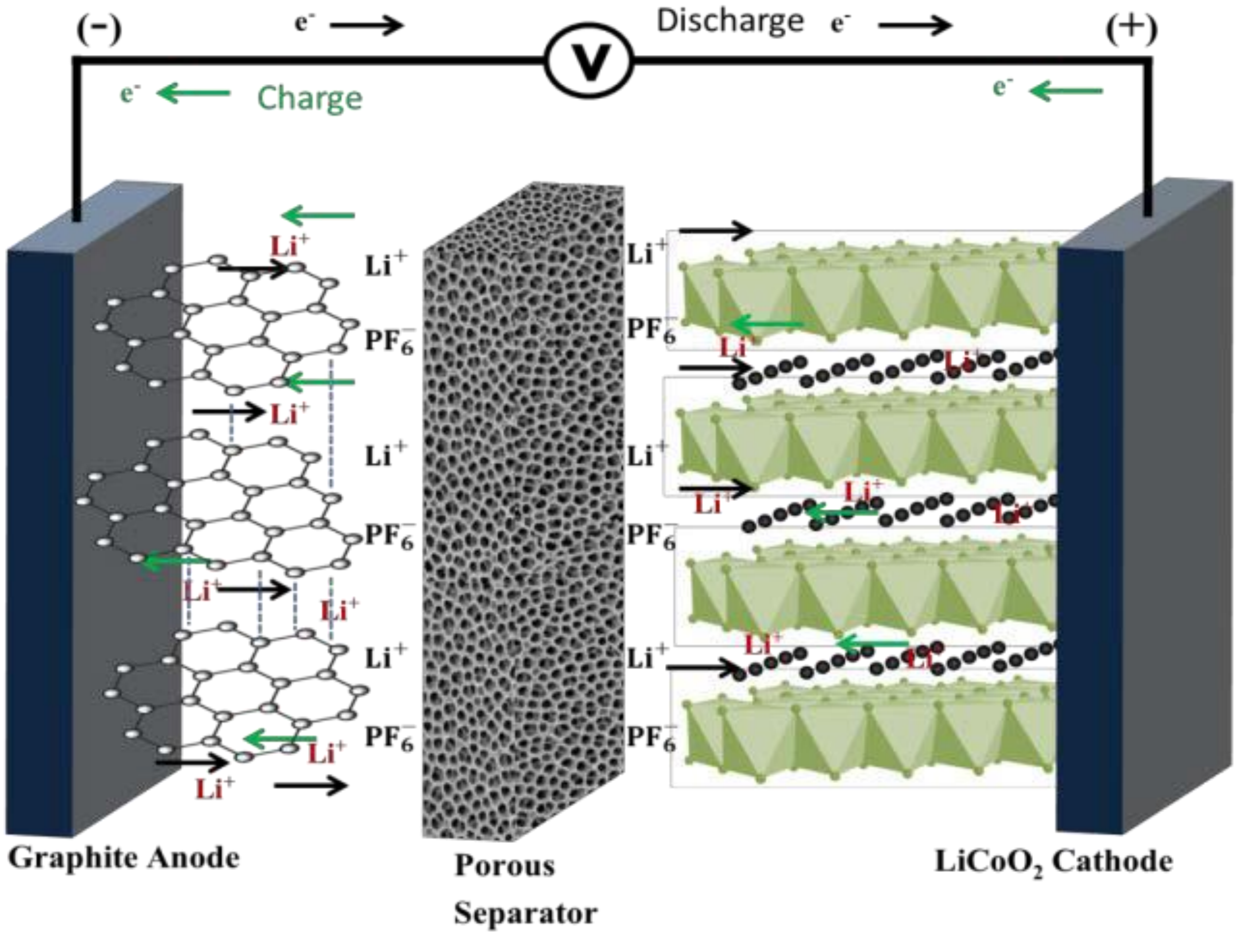
1) **Anode :-** Negative electrode …. Speciality carbon coated on Cu foil

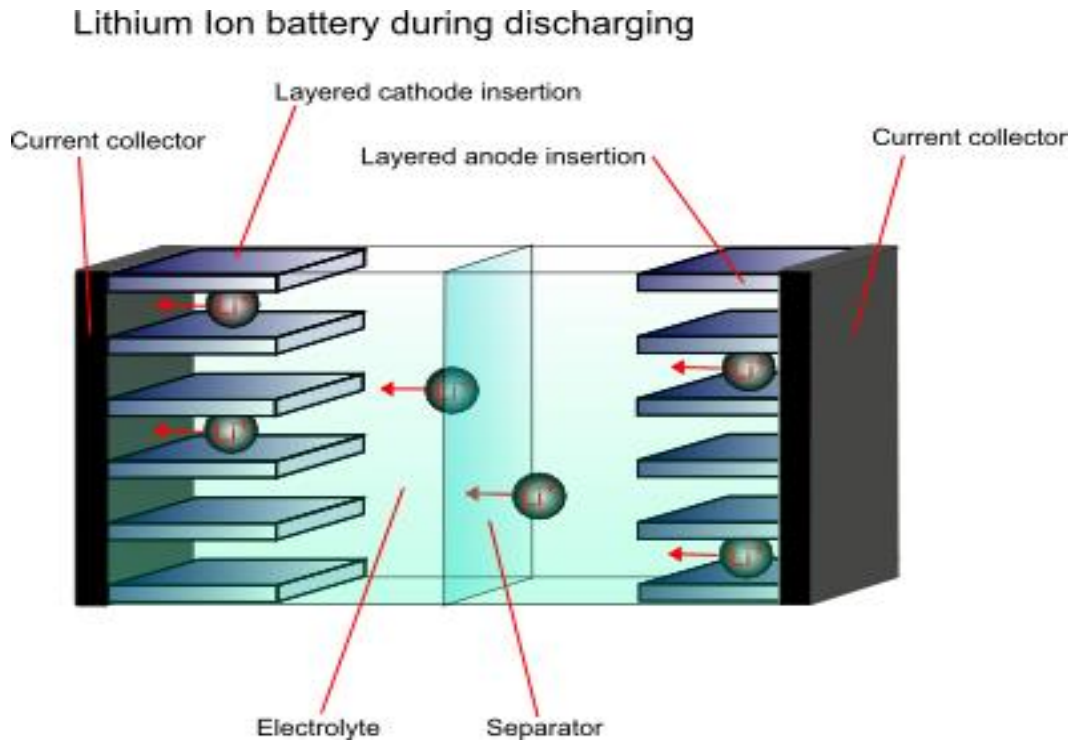
2) **Cathode :-** Positive electrode…… $LiCoO_2$ coated on Al foil

3) **Electrolyte :-** Li salt dissolved in organic solvent (ethylene carbonate, dimethyl carbonate and diethyl carbonate…..$LiPF_6$)

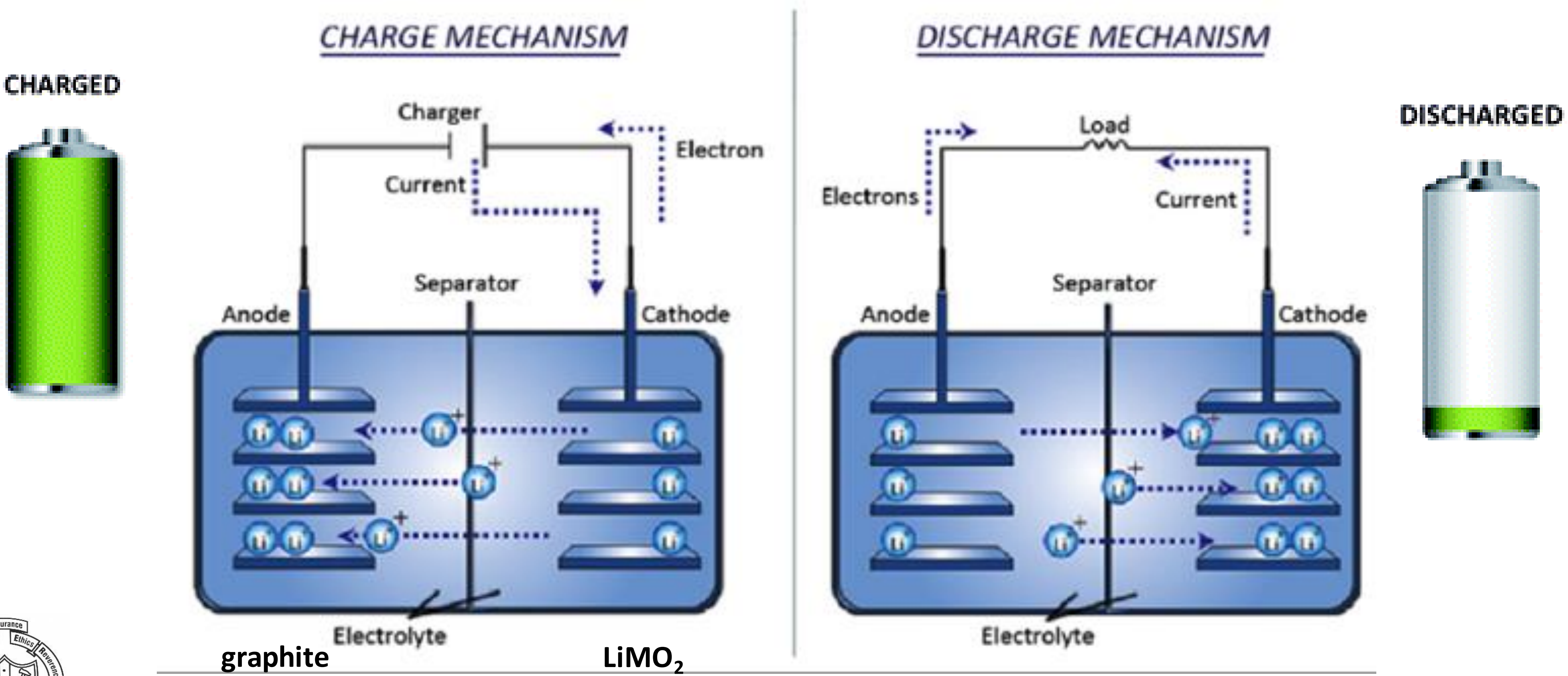
4) **Separator :-** porous polymer (PE,PP)




(-)
e-
Discharge
e-
(+)
V
e-
Charge
e-
Li+
PF6-
Graphite Anode
Porous
Separator
LiCoO2 Cathode


Lithium Ion battery during discharging
Layered cathode insertion
Current collector
Layered anode insertion
Current collector
Electrolyte
Separator

How Lithium-Ion Batteries Work



https://www.youtube.com/watch?v=VxMM4g2Sk8U
https://www.youtube.com/watch?v=azACL3lLMo8

Why Li?

1) It is lightest metal. Therefore, can be used in light weight devices

2) It is highly reactive, because it readily loses its outermost electron,

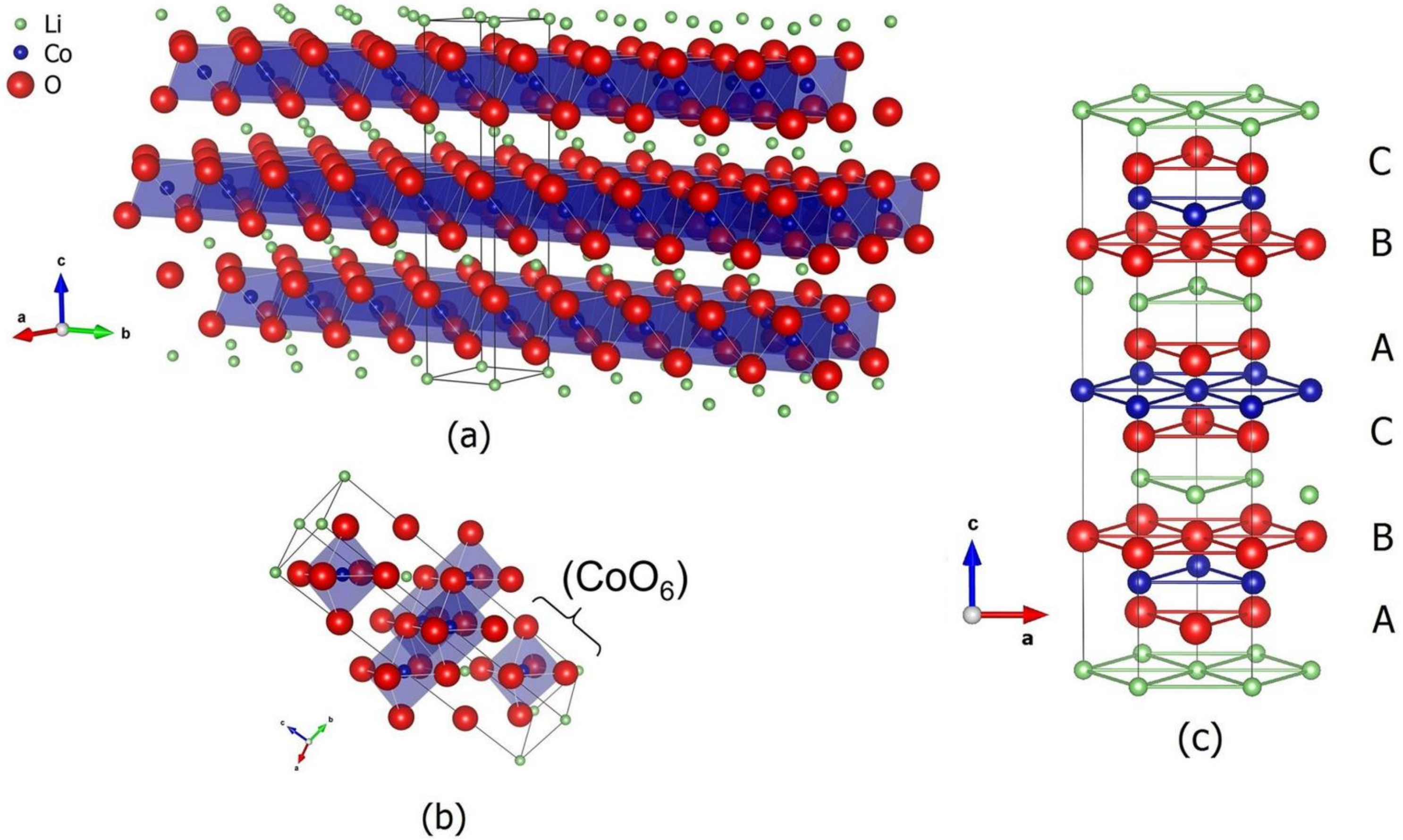
3) making it easy to get current flowing through a battery.

4) Electrochemical properties are excellent

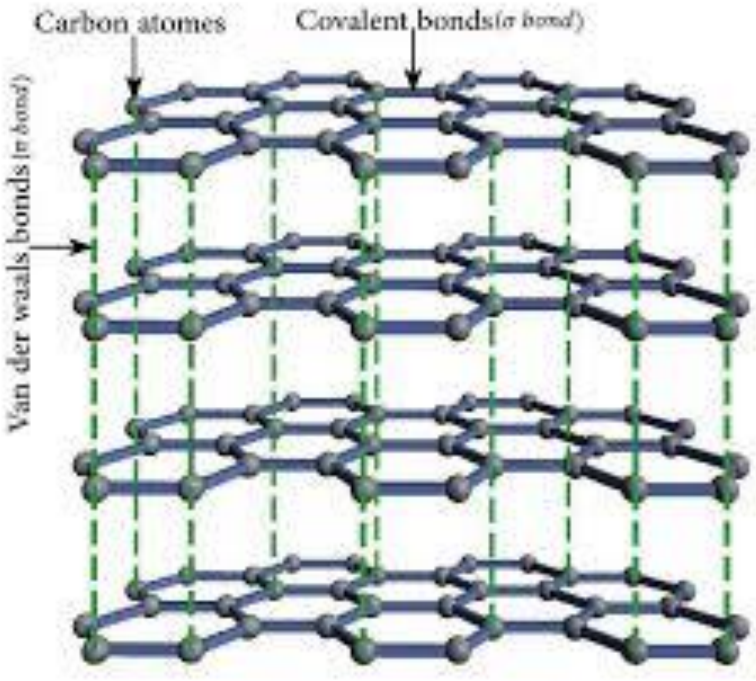
5) It can achieve high energy and power density

6) It made the battery sec or rechargeable battery as lithium ions and electrons move easily back into negative electrodes

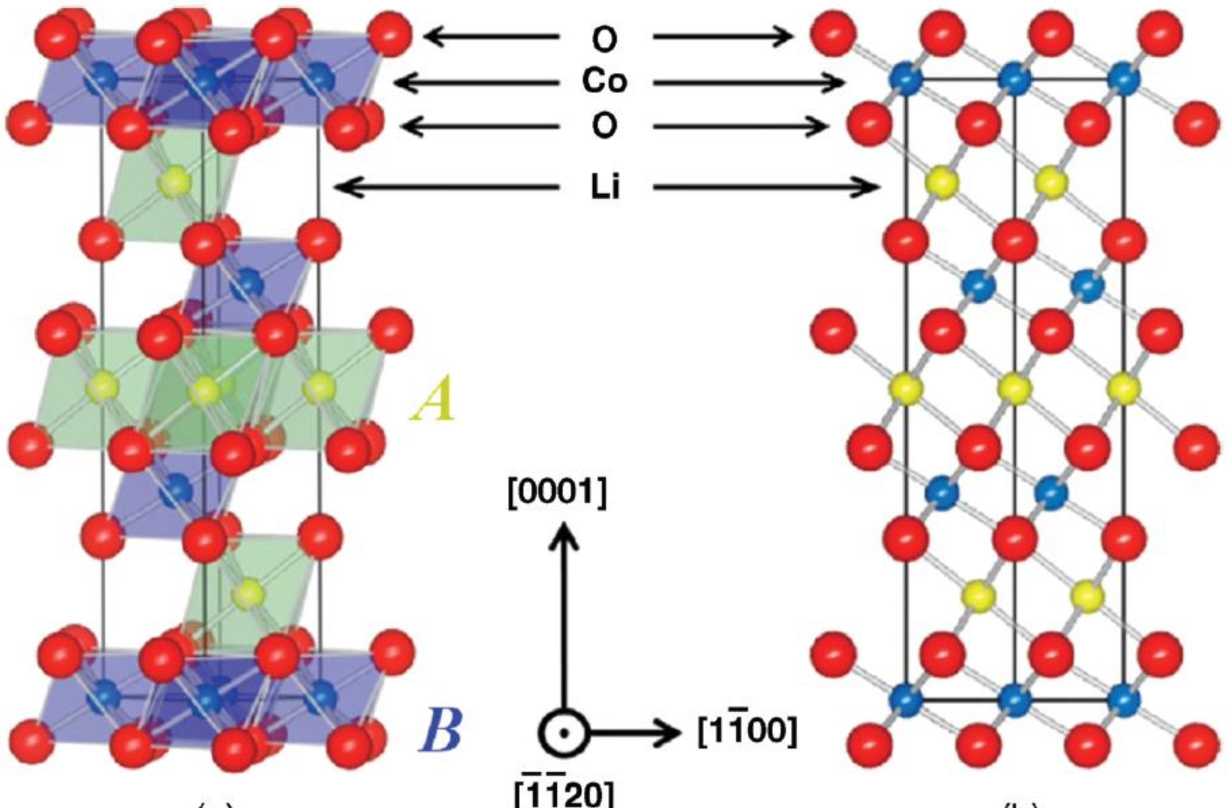
Structural Advantage of cathode and anode materials



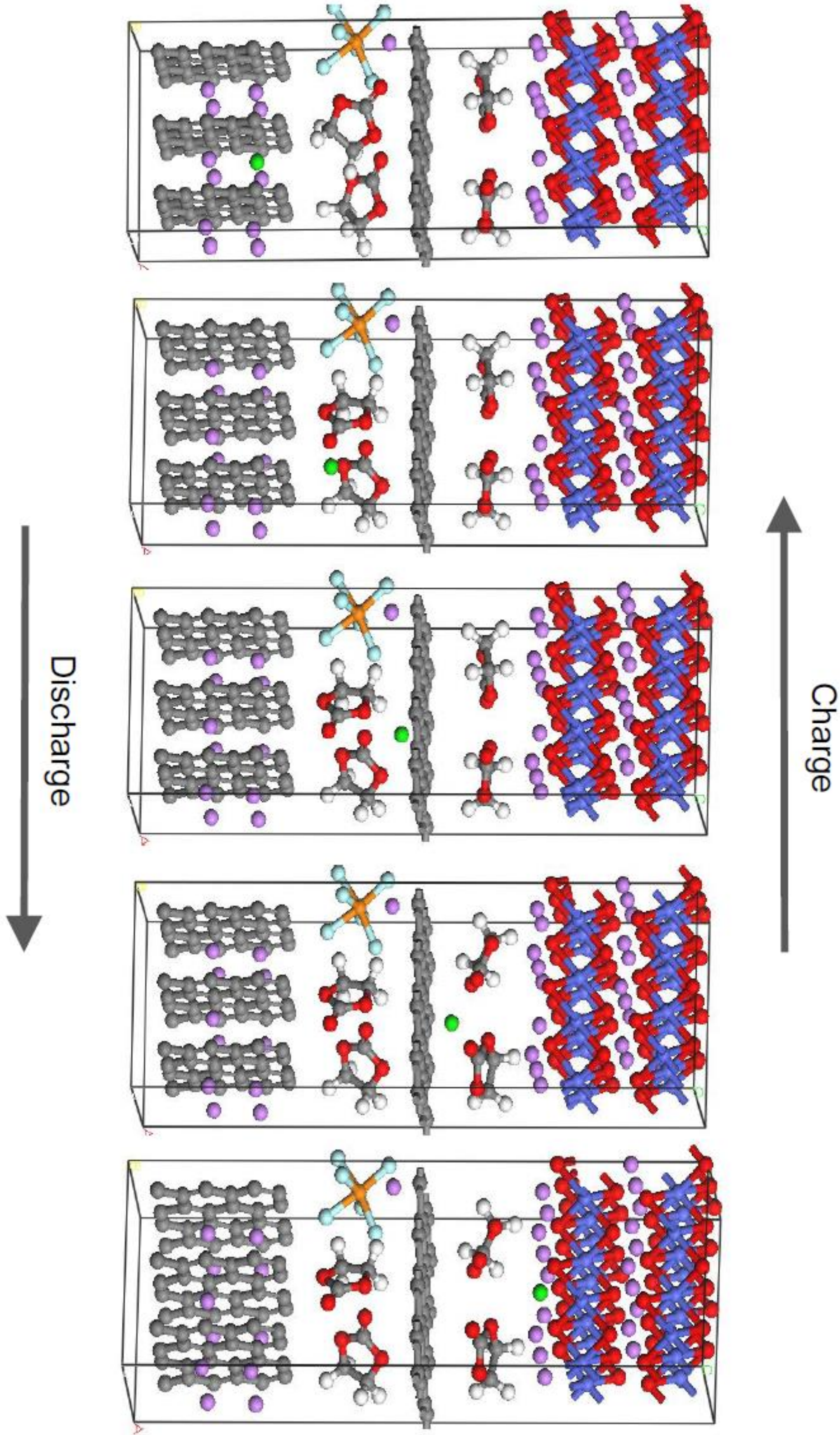
Positive electrode



Negative electrode



(a) (b)



Advantages of $LiCoO_2$

1) The cobalt and oxygen bond together to form layers of octahedral cobalt oxide open structures, where in between the layers Li ions can be inserted or intercalated.
2) It's important that this structure allows the cobalt ions to change their valence states between Co^{+3} and Co^{+4} (lose and gain a negatively-charged electron) when charging and discharging.

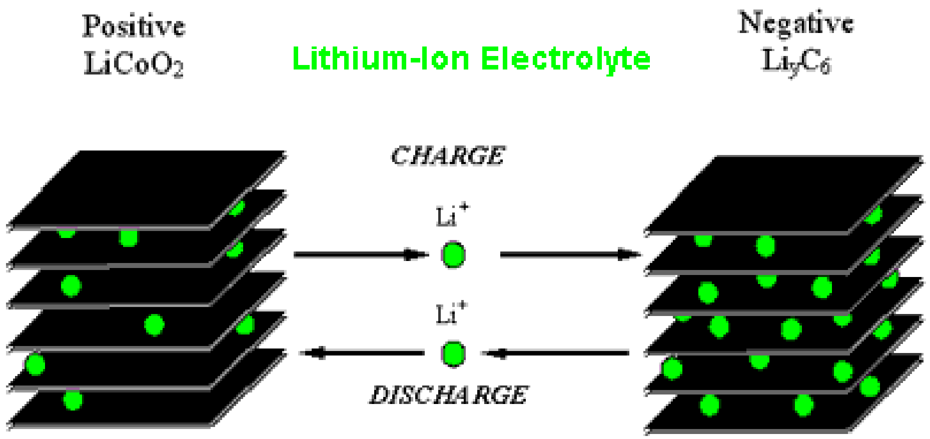
Advantages of speciality carbon or graphite

1) It is layered structured bonded by weak Van der Waal's forces where Li can be inserted or extracted
2) It doesn't participate in reaction and its role is to just trap the Li ions.

Advantages of separator

If battery is stored at high temperature or it gets overheated during charging then electrolyte can get evaporated and cell can become dry. In such condition cathode and anode are shorten and leads to huge explosion as Li ion and electron both combine. To avoid such situation separator is used which is permeable only to ions and not for electrons.

Effect of battery without Separator



Principle of Li Ion battery

Li-ion batteries

- Chemical reaction (discharge)
  - Positive electrode $\quad LiCoO_2 \longrightarrow Li_{1-x}CoO_2 + xLi^+ + xe^-$

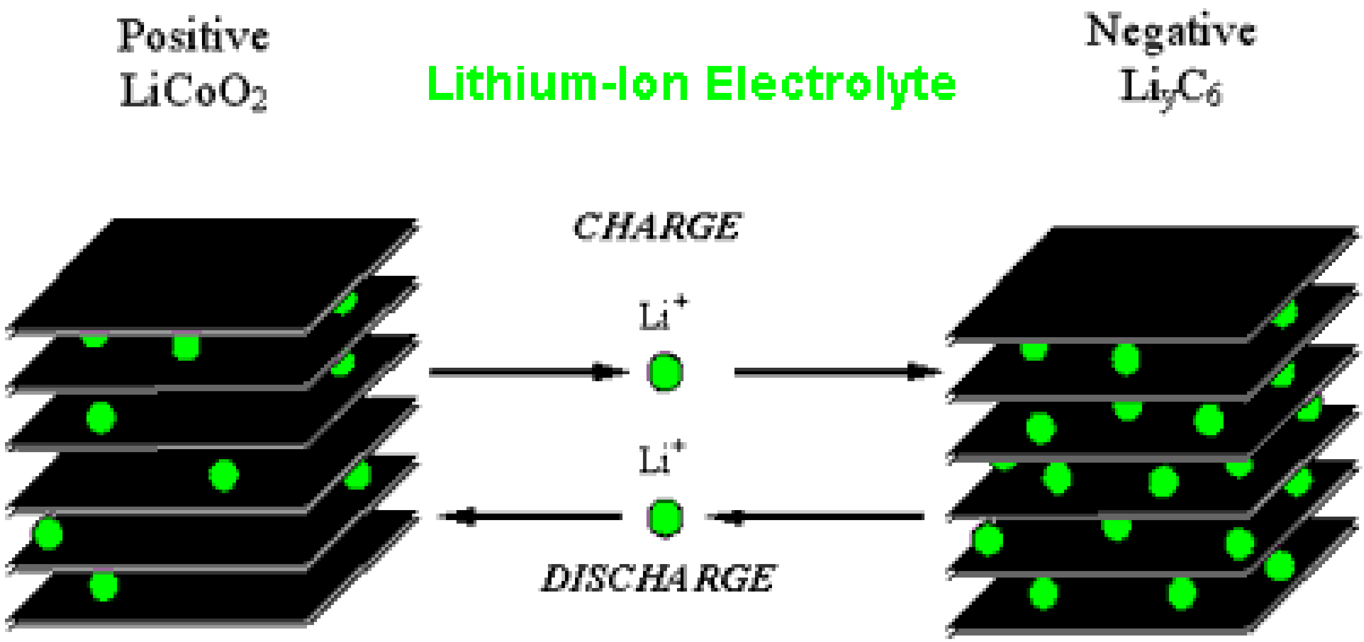
    Through electrolyte

  - Negative electrode $\quad xLi^+ + xe^- + 6C \longrightarrow Li_xC_6$

    Through load

  - Overall $\quad LiCoO_2 + C_6 \longrightarrow Li_{1-x}CoO_2 + C_6L_x$

- In the above reaction *x* can be 1 or 0
- With ~~discharge~~ charging the Co is oxidized from Co^{3+} to Co^{4+}. The reverse process (reduction) occurs when the battery is being charged.



Electrochemical Reactions

- Cathode

$$LiCoO_2 \underset{d}{\overset{c}{\rightleftharpoons}} Li_{1-x}CoO_2 + xLi^+ + x\,e^-$$

- Anode

$$C_n + xLi^+ + x\,e^- \underset{d}{\overset{c}{\rightleftharpoons}} C_nLi_x$$

- Overall

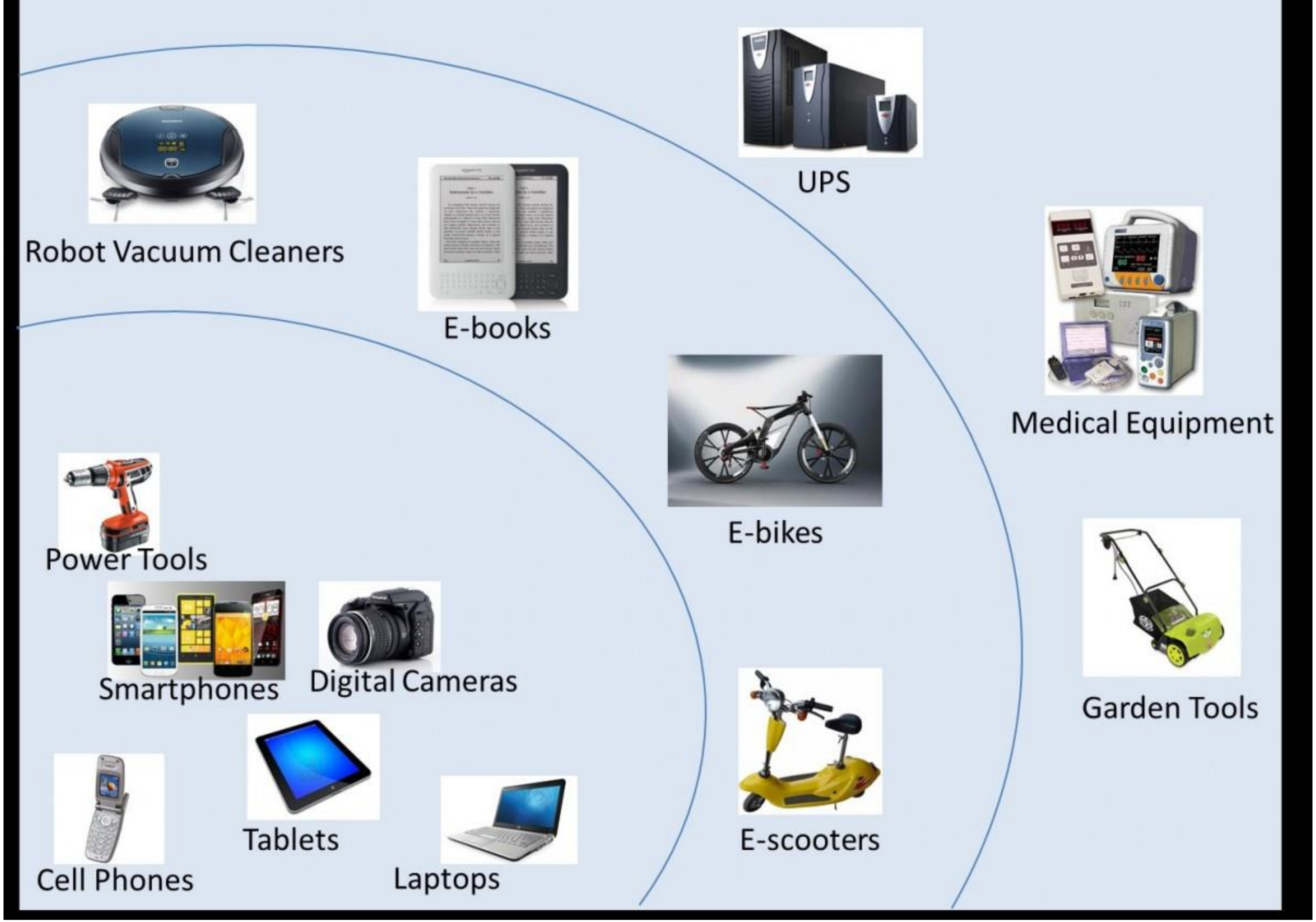
$$LiCoO_2 + C_n \underset{d}{\overset{c}{\rightleftharpoons}} Li_{1-x}CoO_2 + C_nLi_x$$

Advantages of Li-ion Batteries

- They have high energy density than other rechargeable batteries
- They are less weight
- They produce high voltage out about 4 V as compared with other batteries.
- They have improved safety, i.e. more resistance to overcharge
- No liquid electrolyte means they are immune from leaking.
- Fast charge and discharge rate

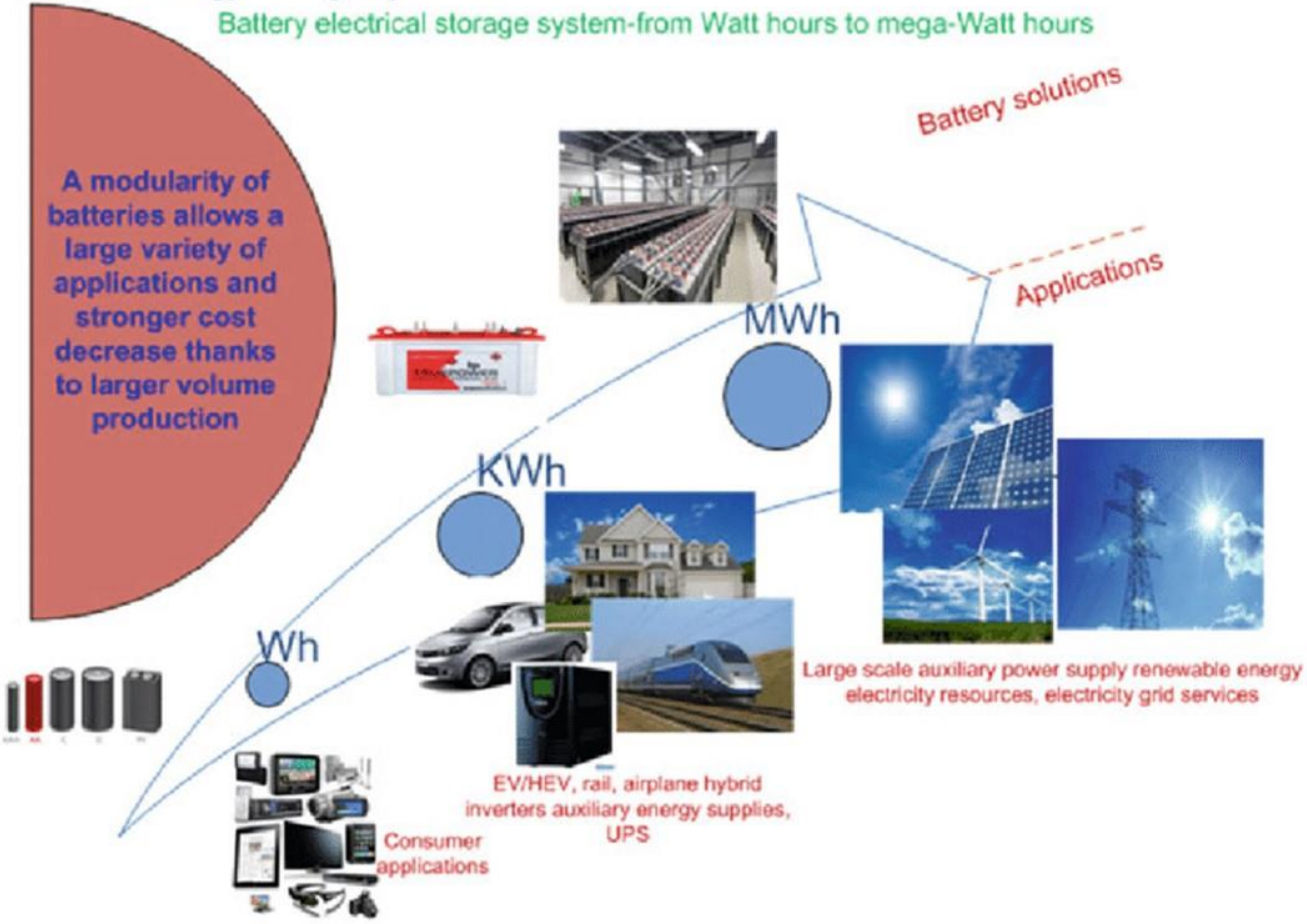
Disadvantages

- They are expensive
- They are not available in standard cell types.


UPS
Robot Vacuum Cleaners
E-books
Medical Equipment
E-bikes
Power Tools
Smartphones
Digital Cameras
Garden Tools
Tablets
Cell Phones
Laptops
E-scooters

Energy storage systems

Battery electrical storage system-from Watt hours to mega-Watt hours



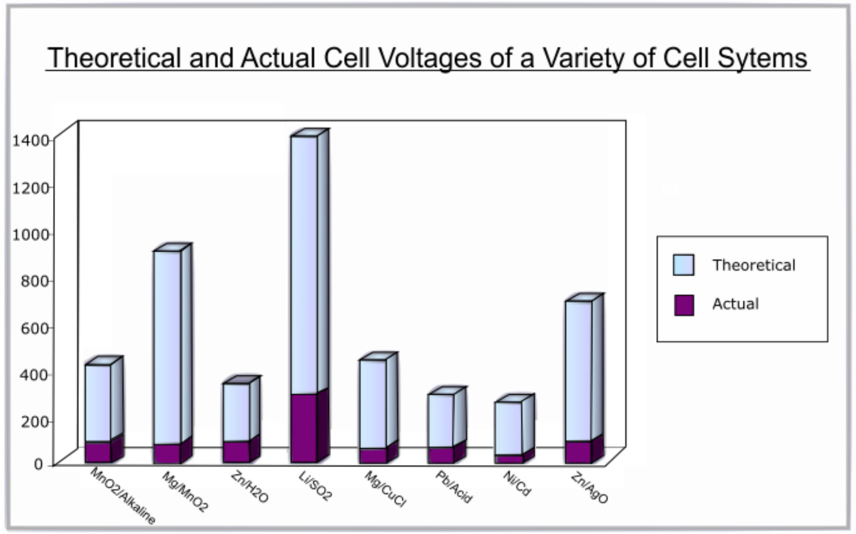
Battery Characteristics – 15 points

1) **Type – Primary/ non-rechargeable and Secondary /rechargeable**

2) **Physical requirement – Size, shape, geometry and position of terminals**

3) **Voltage (V) – electromotive force**

$$E^{o}_{(cathodic)} - E^{o}_{(anodic)} = E^{o}_{(cell)}$$



- This is the standard theoretical voltage
- Actual voltage is lower than this value due to polarization and IR drop
  - Temperature
  - State of charge
  - Age of cell
- Actual voltage at terminals should be sufficient application
- Ni/Cd ~ 1.2V Li-ion ~3.7V

Battery Characteristics – 15 points

4) Capacity (Ah/g) Quantity of electricity involved in the Electrochemical reaction

$$Q_{charge} = x\,n\,F$$

$$M = x\,M_r$$

$$Q_{specific} = \frac{nF}{M_r}$$

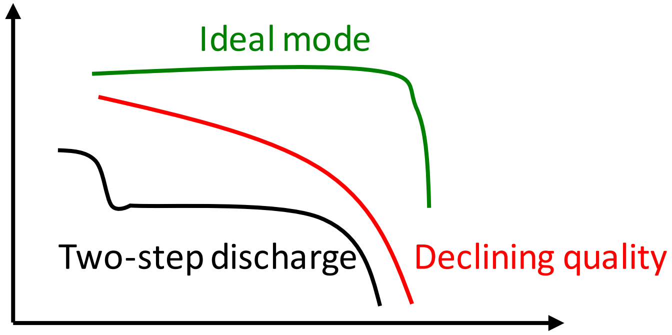
Q_{charge} = theoretical molar capacity of a battery
x = no. of moles of chosen electroactive component that take place in the reaction
n = no. of electrons transferred per mole of reaction
F = Faradays constant = 96485.332 C·mol^{-1}
M = mass of the electroactive component
M_r = molecular mass of the electroactive component
$Q_{specific}$ = specific capacity given in terms of mass A·h·g^{-1}

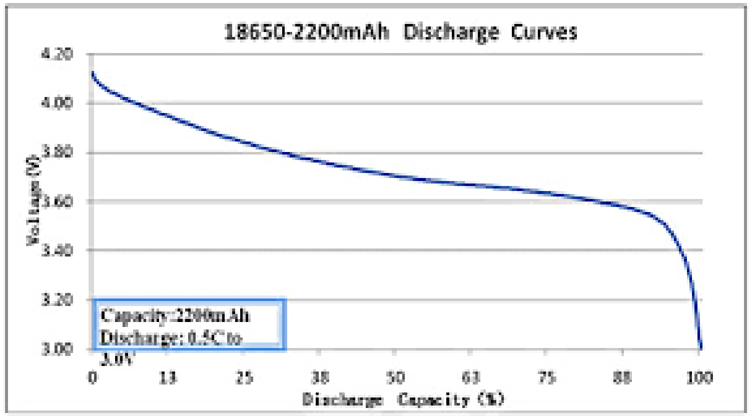
rated capacity of a given cell = specific capacity x mass of the electroactive component in the cell OR total mass

- full battery capacity is never realized
- higher discharge rate leads to faster discharge

5) Discharge Curve

- Plot of voltage against percentage of capacity discharged
- Flat discharge curve is desirable



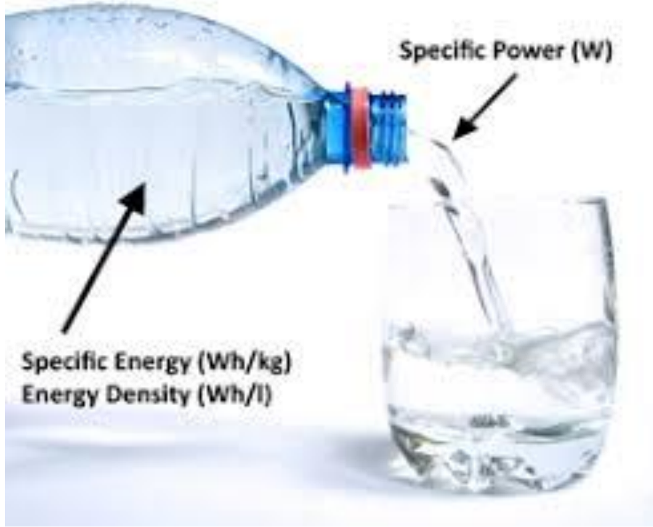


6) High energy density (Wh/L) **250-340**

The energy density is the energy that can be derived per unit volume of the weight of the cell

7) High specific energy density (Wh/kg) **100-265**

- Energy that can be derived per unit weight of the cell (sometimes per unit weight of the active electrode material)
- Product of the specific capacity and the operating voltage in one full discharge cycle



8) High power density (W/kg) **250-340**

Power that can be derived per unit weight of the cell

9) Charge and discharge cycle

a. Voltage necessary to charge

b. Time necessary to charge

c. Availability of charging source

d. Safety hazards

10) Longer Cycle life/ Shelf Life/Service life

Number of discharge/charge cycles it can undergo before its capacity falls to 80%

a. Overcharging

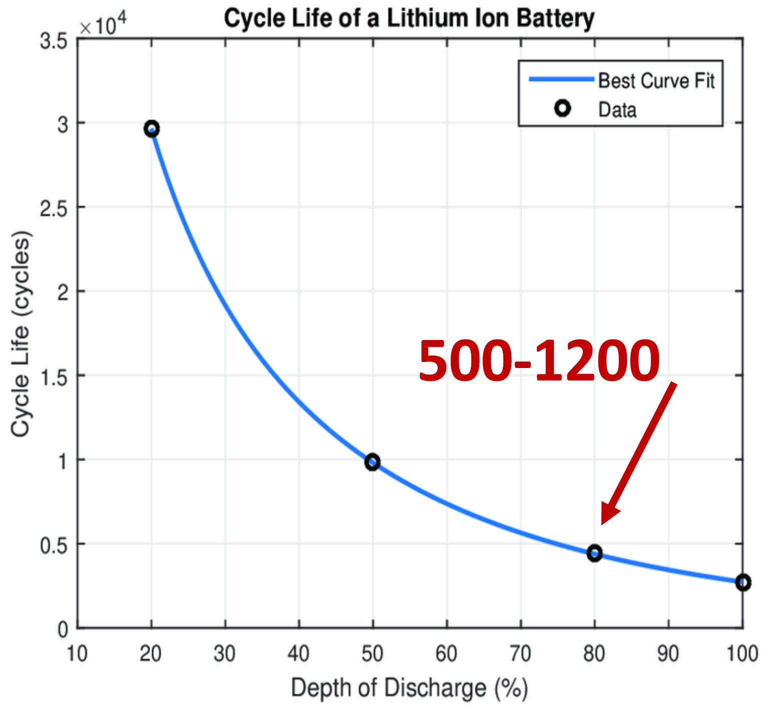
b. Over discharging

c. Short-circuiting

d. Subjected to high temperature

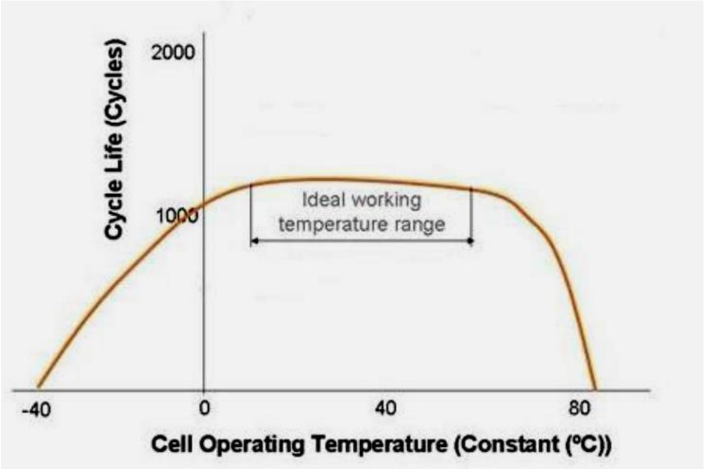
e. Voltage delay

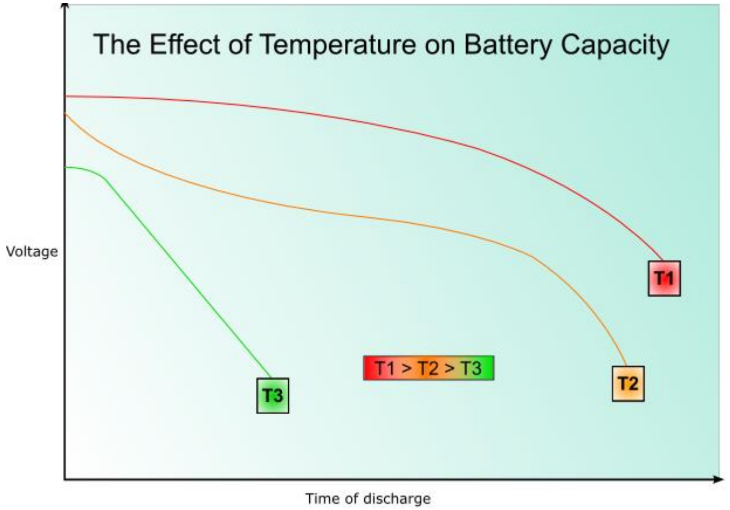
f. death due to aging



11) Temperature dependence

- The rate of the cell reaction varies with temperature dependent according to theories of kinetics.
- Internal resistance varies with temperature





12) Ability to deep discharge

- logarithmic relationship between "depth of discharge" and "battery life"
- life of a battery can be significantly increased if it is not fully discharged

13) Low self discharge ability

14) Cost initial cost + charging cost + maintenance cost

15) Application requirement

Characteristics of Li-ion Batteries

For full lithium utilization,

$$\text{Cell Capacity} = \frac{\mathrm{nF}}{\mathrm{M_r}} = \frac{1 \times 96485.33}{6.941}\ \mathrm{Asgm^{-1}}$$

$$= \frac{1 \times 96485.33}{3600 \times 6.941}\ \mathrm{Ahgm^{-1}}$$

$$\cong 3860\ \mathrm{mAhgm^{-1}}$$ of Lithium

Specific capacity of cell,

$$\frac{3860 \times \mathrm{w_{Li}}}{1.2 \times \mathrm{w_{Li}}(\mathrm{f_A} + \mathrm{f_C})} = \frac{3860}{1.2(\mathrm{f_A} + \mathrm{f_C})}\ \mathrm{mAhgm^{-1}}$$ of Cell weight

$$W_{cell} = w_{Li} f_A + w_{Li} f_C + w_{aux}$$

Usually, w_{aux} is 20% of the weight of active part of cell

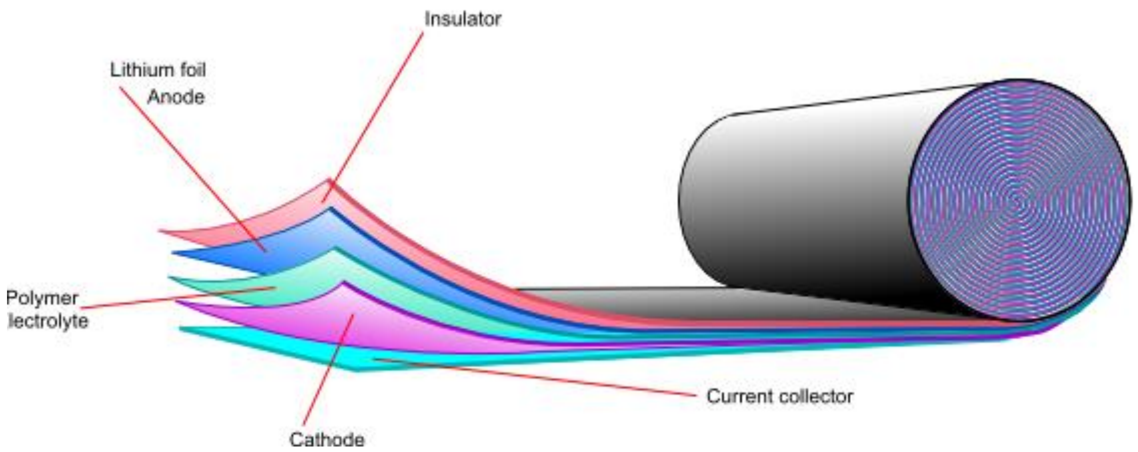
$$W_{cell} = 1.2\, w_{Li}(f_A + f_C)$$

- Theoretically, f_A = 10.3 and f_C = 25
- In practice, only 50% of Li is available f_A > 21 and f_C > 50
- Voltage also ranges from 4.2 V to 2.8 V with $V_{avg} \approx 3.35V$
- Practical specific energy density 160 Wh/Kg of Li-ion cell
- Typical cycles: 500-1000

Limitation of Li Ion battery

1) Degradation at high temperature
2) No rapid charge possible at freezing temperature (0°C)
3) Circuit protection at high temperature
4) Severe transport regulations required when shipping

Lithium Ion Polymer Batteries



Unit 4

Energy Storage System

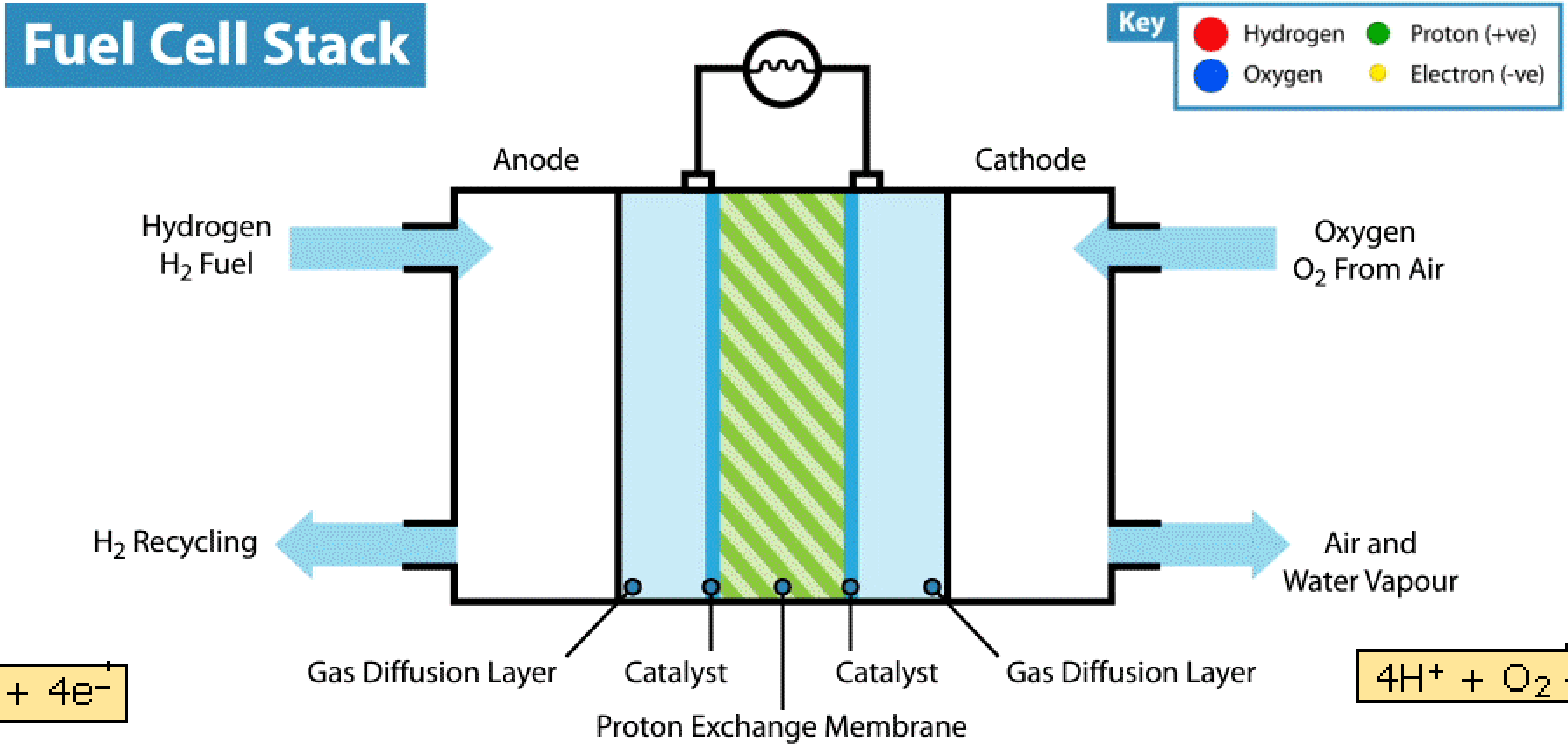
Fuel Cell

Why we need fuel cell?

- Due to energy crisis all over the world.
- Due to the issue of global warming.
- Due to the unavailability of different renewable sources at each and every place due to geographic condition.
- Fuel cell provides an alternate efficient non polluting power source that produces no noise and has no moving parts.
- It is expected that by 2050 the global energy demand is going to rise by 2 to 3 times.
- This calls for optimization of generation of energy through well-known sources, preferably renewable energy for commercial exploitation.

What is a Fuel cell?

A fuel cell is an electrochemical cell which converts the chemical energy contained in a readily available fuel-oxidant system into electrical energy by electrochemical process



$2\,H_2 \longrightarrow 4H^+ + 4e^-$

$4H^+ + O_2 + 4e^- \longrightarrow 2\,H_2O$

$$2H_2 + O_2 \longrightarrow 2H_2O + energy$$

https://www.youtube.com/watch?v=-oGF7kIbtqI

❖ Ordinary Combustion process of fuel is

❖ The process of fuel cell is

- Conventional Process to produce electricity

- Fuel cell Process to produce electricity

Principle of Fuel Cell:

- Fuel cell consists of electrodes, electrolyte & catalyst to facilitate the electrochemical redox reaction.
- The basic arrangement in a fuel cell can be represented as follows:

Fuel | Electrode | Electrolyte | Electrode | Oxidant

- The Fuel cell can be represented as:

At anode	• $2H_2 \rightarrow 4H^+ + 4e^-$
At Cathode	• $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Overall Reaction	• $2H_2 + O_2 \rightarrow 2H_2O$

- Large number of these cells are stacked together in series to make a battery called as fuel cell battery or fuel battery.

Advantages of Fuel cell

1. High efficiency of energy conversion about 70-80%

2. Constant efficiency at low load.

3.Clean energy system and doesn’t produce polluting exhaust.

4.Excellant substitute for the use of fossil fuels hence saves fossil fuel.

5.Mostly by product is water and waste heat which is environmental friendly.

6. Low noise and less thermal pollution.

7. Low maintenance cost

8. Fuel cell performance s independent of the power plant size, its MW or KW or W size.

9. Fast start up time for low temperature systems.

10. The demand for variations in power and energy densities is easiy met as required .e.g. laptop, computers requires low power density and high energy density where as automobile requires high power density , high energy density. Both can be powered by fuel cells

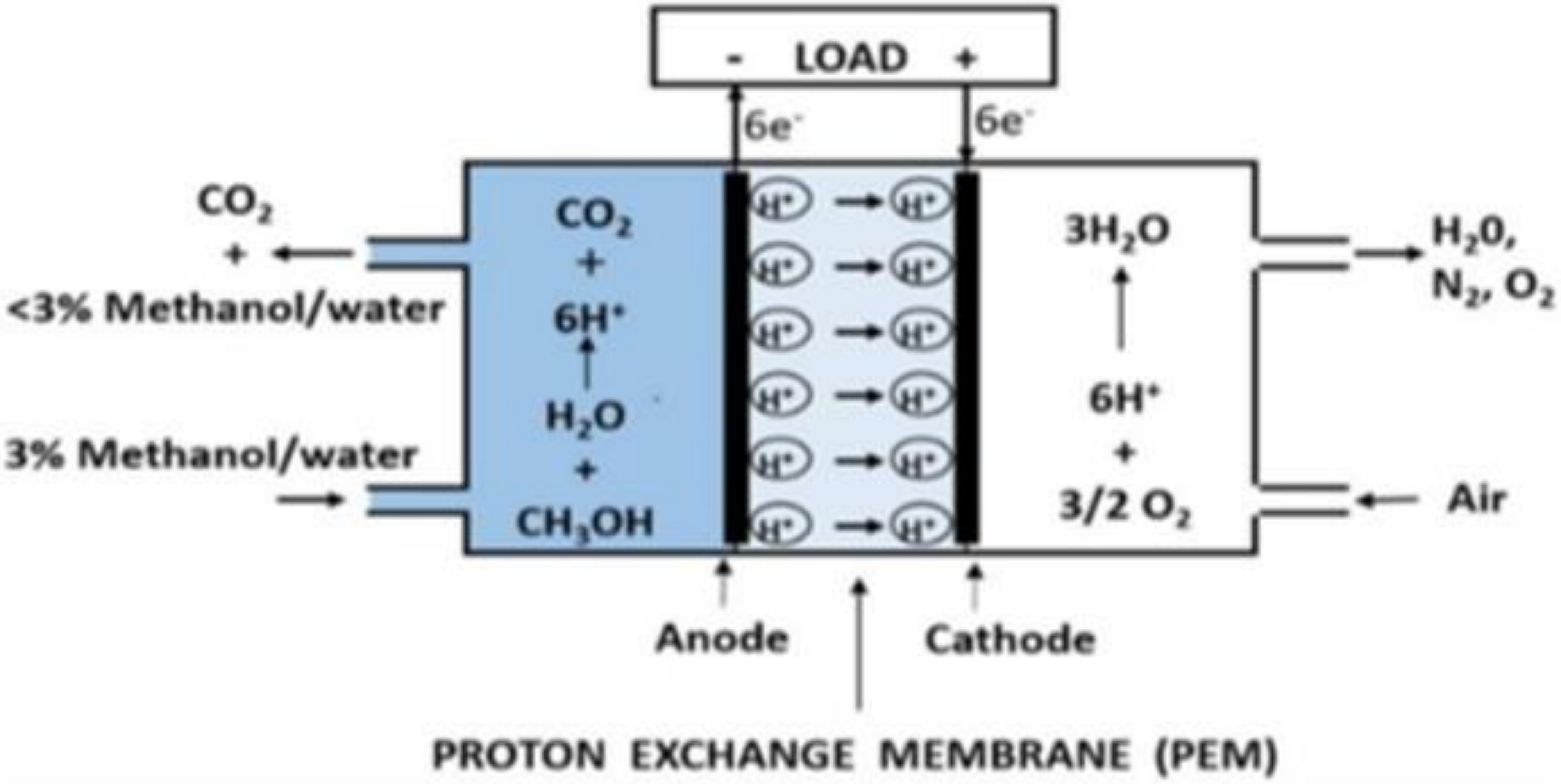
Disadvantages of Fuel Cells

- High initial cost.
- Life times of the cells are not accurately known.
- Large weight and volume of gas fuel storage system.
- High cost of pure hydrogen.
- Hydrogen can be stored in lesser volume by liquefaction but liquefaction itself require 30% of the stored energy.
- Lack of infrastructure for distributing hydrogen.

Types of Fuel cell

Fuel Cell	Electrolyte	Operating Temperature	Electrical Efficiency	Fuel 'Mixture'
Alkaline Fuel Cell (AFC)	Potassium hydroxide (KOH) solution	Room temperature to 90°C	60-70%	H_2 - O_2
Proton Exchange Membrane Fuel Cell (PEMFC)	Proton exchange membrane	Room temperature to 80°C	40-60%	H_2 - O_2 or Air
Direct Methanol Fuel Cell (DMFC)	Proton exchange membrane	Room temperature to 130°C	20-30%	CH_3OH - O_2 or Air
Phosphoric Acid Fuel Cell (PAFC)	Phosphoric acid	160-220°C	55%	Natural Gas, Biogas, H_2 - O_2 or Air
Molten Carbonate Fuel Cell (MCFC)	Molten mixture of alkali metal carbonates	620-660°C	65%	Natural Gas, Biogas, Coalgas, H_2 - O_2 or Air
Solid Oxide Fuel Cell (SOFC)	Oxide ion conducting ceramic	800-1000°C	60-65%	Natural Gas, Biogas, Coalgas, H_2 - O_2 or Air

Direct Methanol Fuel Cell



https://www.youtube.com/watch?v=qng8NZ7iwN8

Electrochemical reactions involved in DMFC

Anodic reaction(Oxidation): 0.046 V

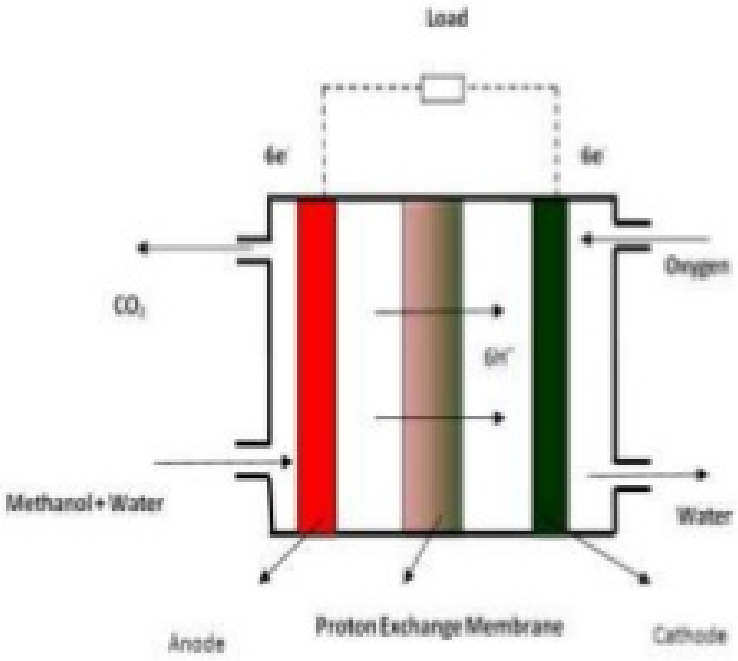
$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathodic reaction (Reduction): 1.23V

$3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

Overall reaction: 1.18 V

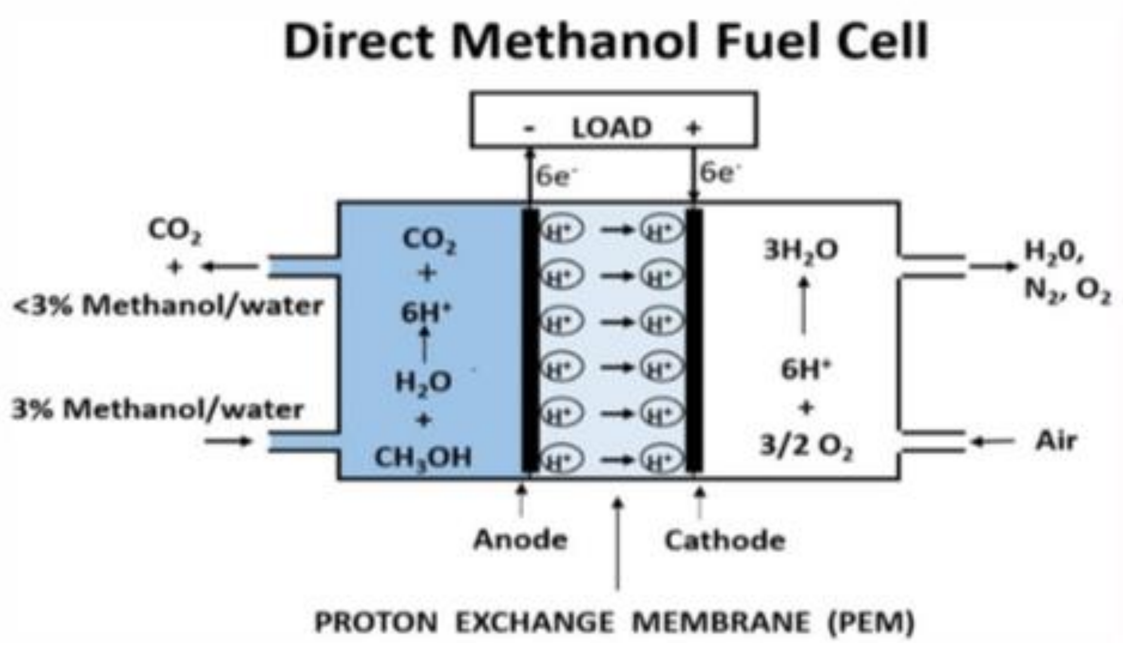
$CH_3OH + 3/2\ O_2 \rightarrow CO_2 + 2H_2O$



Principle of DMFC

1.Methanol should oxidised spontaneously above anode potential (0.046 V vs RHE)

2.Oxygen should reduced spontaneously below cathode potential (1.23 V)



Anodic reaction(Oxidatior 0.046 V

$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathodic reaction (Reduction): 1.23V

$3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

Overall reaction: 1.18 V

$CH_3OH + 3/2\ O_2 \rightarrow CO_2 + 2H_2O$

In practical the output of DMFC fuel cell is lower than the ideal cell due to

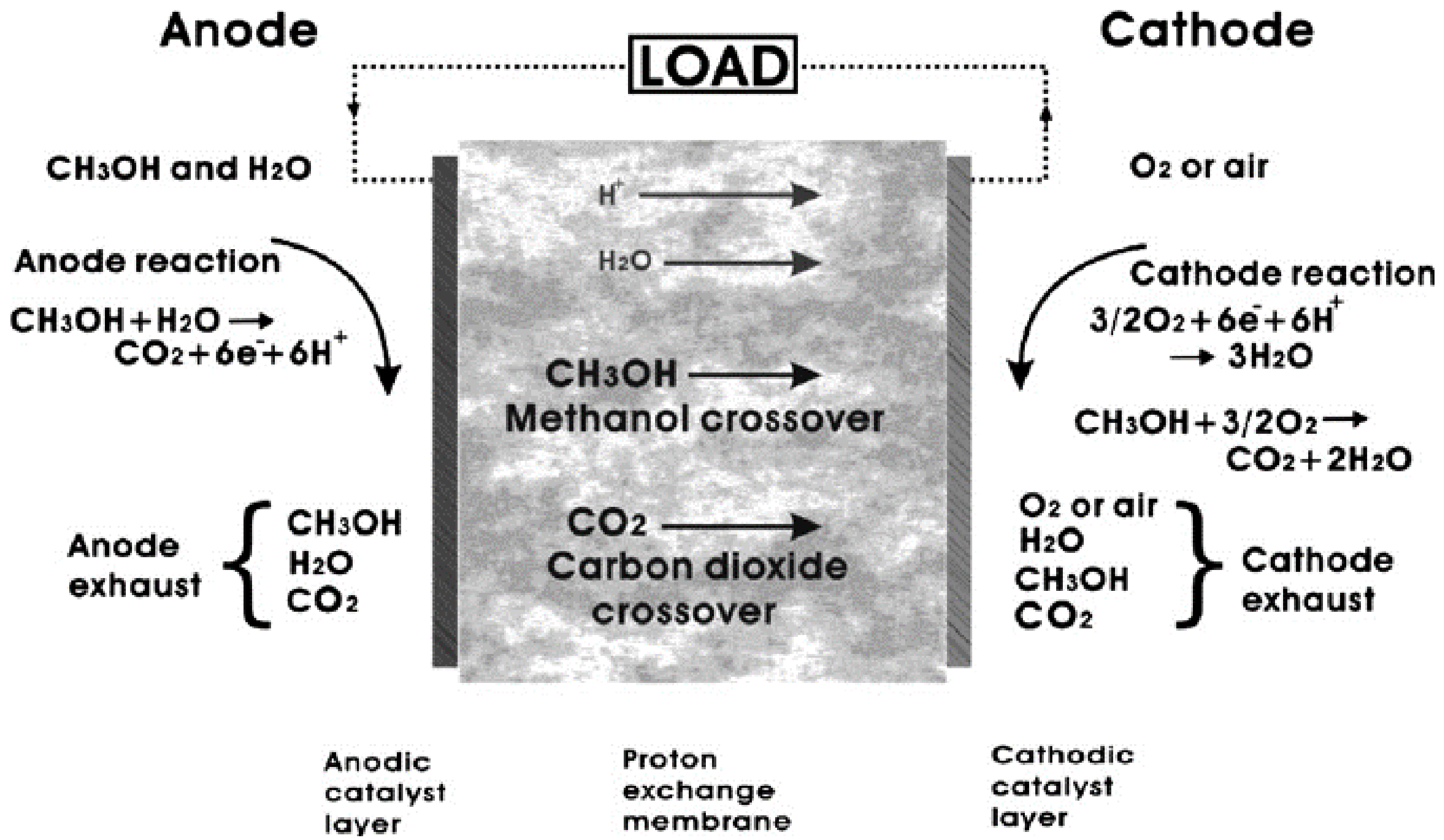
1. Kinetic losses : Any kind of reaction/electrochemical reaction rate when slows down due to some issues is called Kinetic losses. Such losses lowers the efficiency of fuel cell.

2. Ohmic losses : Losses due to internal resistance or barriers with in the cell

1:Kinetic losses :

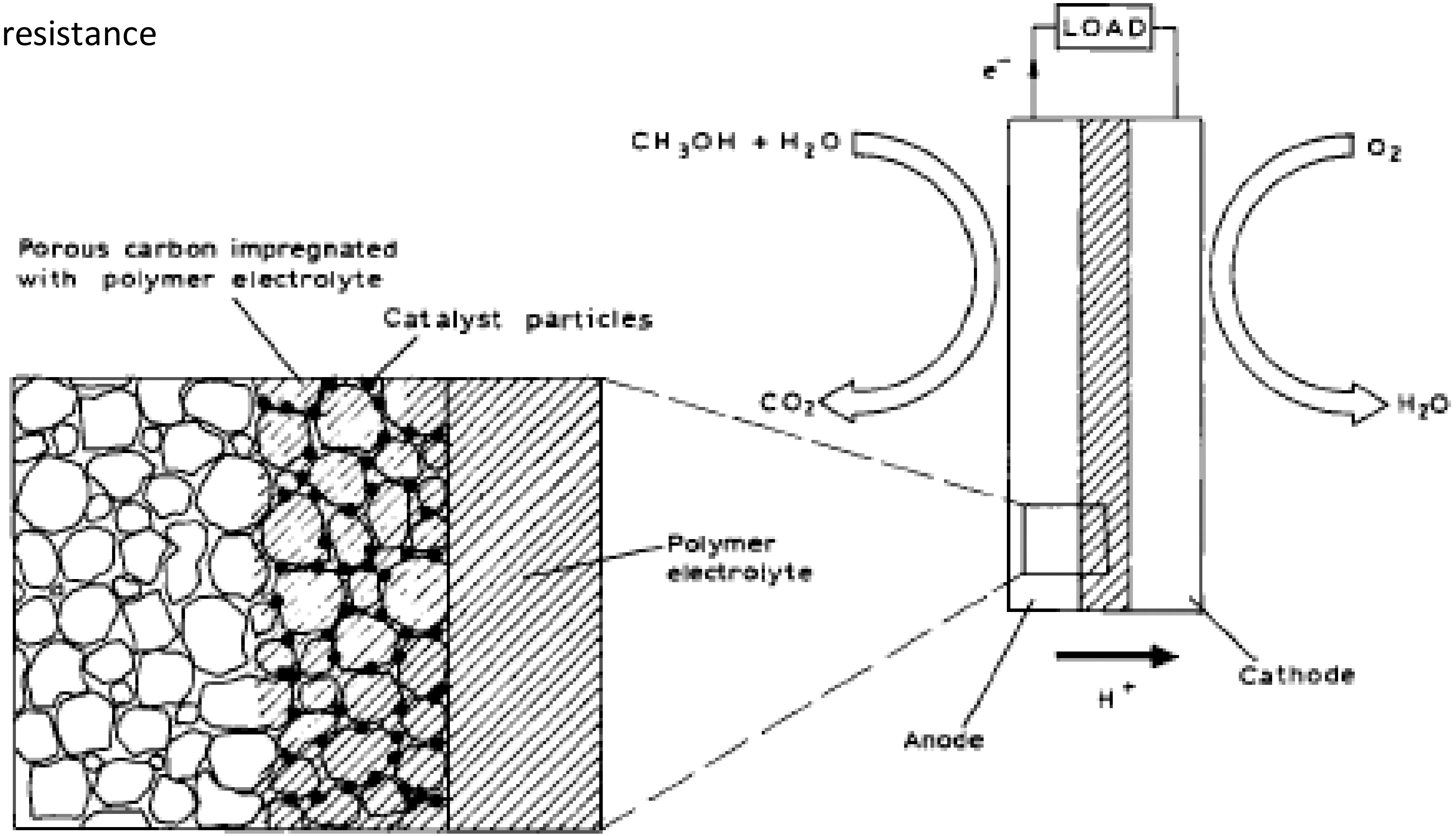
a) Methanol crossover

b) CO_2 crossover



2. Ohmic losses :

Internal resistance



Limitations of DMFC

1.Capital cost

2.Excessive methanol cross over

3.CO_2 poisoning

4.Slow dynamic response

5.Membrane used is Nafion (sulfonated tetrafluroethylene co-polymer)

Battery vs Fuel Cell

Similarity

1.Both are energy storage devices

2.Both are electrochemical cell where stored chemical energy is converted into electricity.

3.Component of both have anode, cathode and electrolyte.

Dissimilarity

1.Like fuel cell battery doesn’t have fuel-oxidant system.

2.In fuel cell along with electricity heat energy is also liberated during electrochemical reaction whereas in battery only electricity is generated

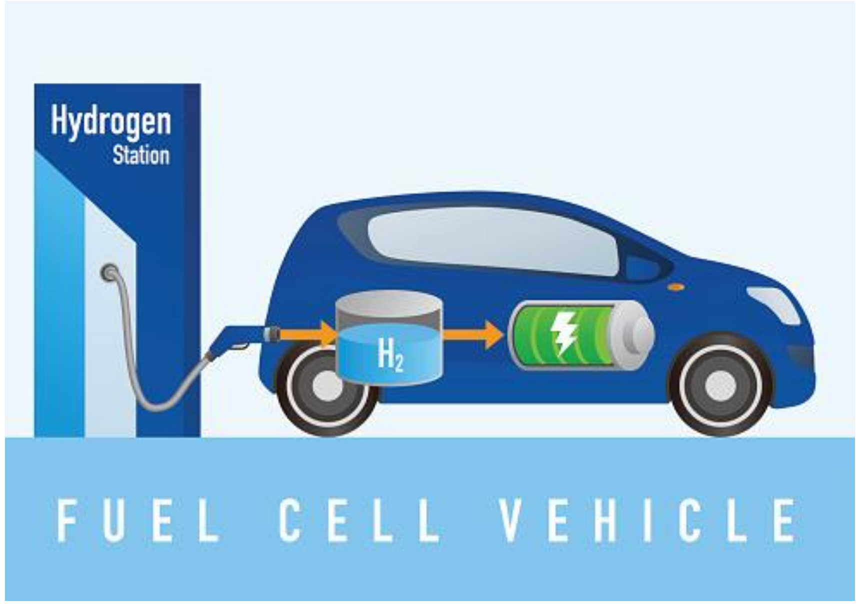
3.In battery cathode and anode electrodes are made up of $LiMO_2$ and graphite respectively, whereas in fuel cell electrodes are carbon coated catalyst on which gases are passed.

4.Like battery ,Fuel cell doesn't undergo charging and discharging. It can work continuously till the fuel-oxidant supply is available.

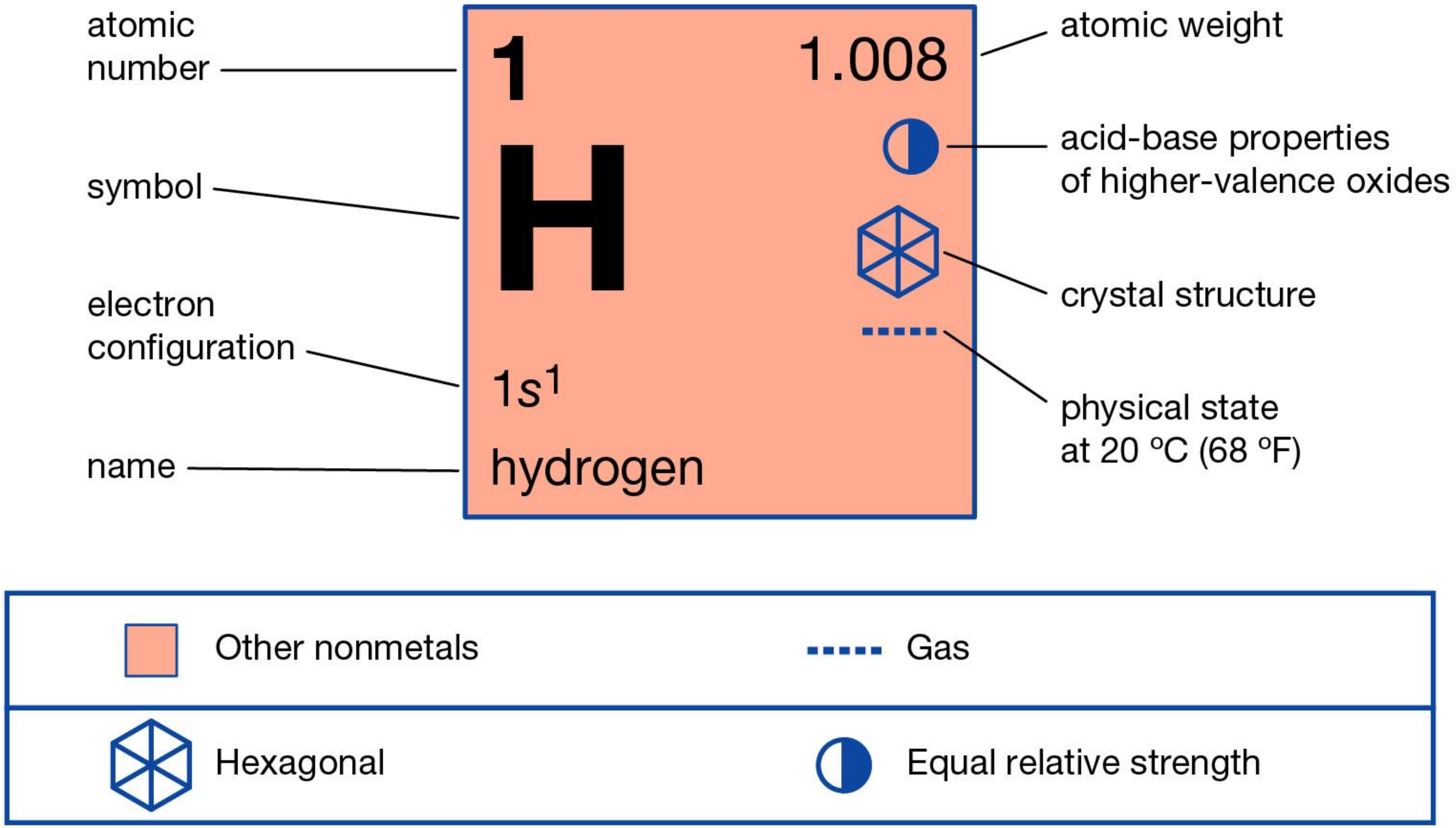
Unit 4

Energy Storage System

Hydrogen Production



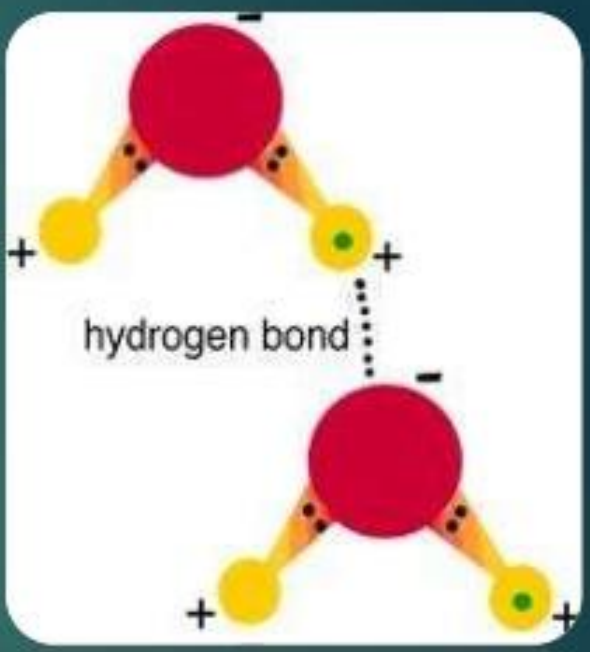
Hydrogen



atomic number
1
1.008
atomic weight
H
symbol
acid-base properties of higher-valence oxides
crystal structure
electron configuration
$1s^1$
physical state at 20 ºC (68 ºF)
name
hydrogen
Other nonmetals
Gas
Hexagonal
Equal relative strength

PHYSICAL PROPERTIES OF H_2

- ➢Dihydrogen is a :
- ➢Colourless ,
- ➢Odourless
- ➢Tasteless
- ➢Combustible gas
- ➢Lighter than air
- ➢Insoluble in water
- ➢It's melting point – 18.73 K
  & boiling point – 23.67 K



It is a better conductor of heat than other gases, its conductivity is about five times that of air

CHEMICAL PROPERTIES OF H_2

- Hydrogen gas does not usually react with other chemicals at room temperature, because the bond between the hydrogen atoms is very strong and can only be broken with a large amount of energy.
- Since its orbital is incomplete with $1s^1$ electronic configuration, it does combine with almost all the elements .

  It accomplishes reactions by:

  1.loss of one e- to give H^+

  2.gain of an e- to form H-

  3.sharing electrons to form a single covalent bond.

Chemical properties of Hydrogen

- Hydrogen reacts with most elements

- Hydrogen burns in oxygen or air to form water
- $2H_2 + O_2 \longrightarrow 2H_2O$

- A mixture of hydrogen with O_2 or air explodes violently when kindled, provided either gas is not present in excess.

Reaction with Non-metals

- $H_2 + F_2$ ------→ $2HF$
- $H_2 + Cl_2$----→ $2HCl$
- $N_2 + 3H_2$ -----→ $2NH_3$

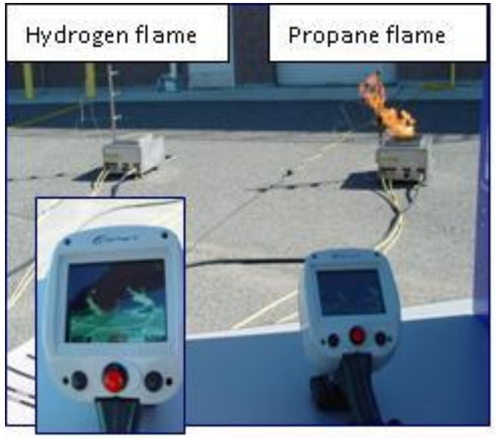
Reducing properties:

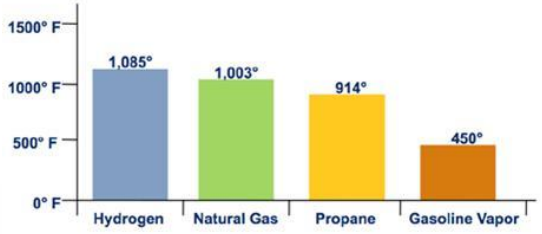
- When passed over heated metallic oxides(copper oxide, iron oxide, lead oxide) they are reduced to metals
- $CuO + H_2 \longrightarrow Cu + H_2O$

HYDROGEN H_2

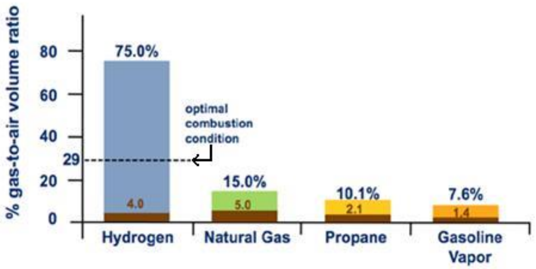
HAZARDOUS PROPERTIES OF GASEOUS HYDROGEN

- **UNDETECTABILITY:** HYDROGEN GAS IS COLOURLESS, ODOURLESS AND NOT DETECTABLE BY HUMAN SENSES. HYDROGEN LEAKS ARE MORE FREQUENTLY HEARD THAN SEEN.
- **FLAMMABILITY :** MIXTURES OF HYDROGEN WITH AIR, OXYGEN OR OTHER OXIDIZERS ARE HIGHLY FLAMMABLE OVER A WIDE RANGE OF COMPOSITIONS.
- **AUTOIGNITION :** TEMPERATURES OF ABOUT 1050^{O}F (565^{O}C) ARE USUALLY REQUIRED FOR MIXTURES OF HYDROGEN WITH AIR OR OXYGEN TO AUTO IGNITE AT 14.7 PSIA. HOWEVER, AT PRESSURES FROM 3-8 PSIA, AUTOIGNITIONS HAVE OCCURRED NEAR 650^{O}F(343^{O}C).

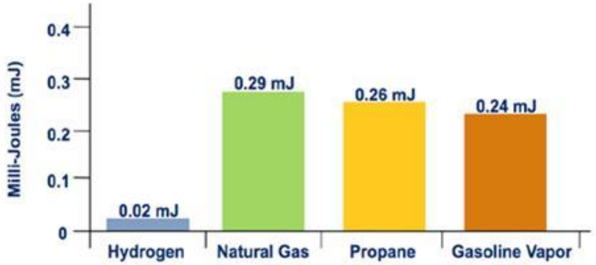




Auto-Ignition Temperature



Flammability Range



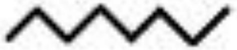
Minimum Ignition Energy

Combustive Properties of Hydrogen

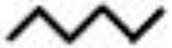
The properties that contribute to its use as a combustible fuel are its:

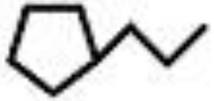
- wide range of flammability : 4% to 75% at 25°C
- low ignition energy : 0.02 mJ
- small quenching distance : 0.064 cm
- high auto ignition temperature : 585 °C
- High octane number: 130
- high flame speed
- high diffusivity
- very low density
- Hydrogen flames are very pale blue and are almost invisible in daylight due to the absence of soot

Octane Ratings of Hydrocarbons

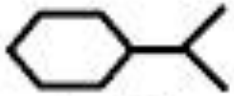
 n-octane -20

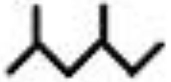
 n-heptane 0

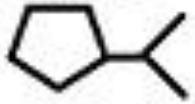
 n-hexane 25

 n-propylcyclopentane 32

 n-pentane 62

 isopropcyclohexane 63

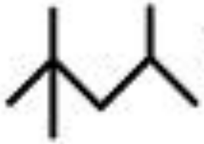
 2,4-dimethylhexane 65

 isopropylcyclopentane 81

 cyclohexane 83

 n-butane 94

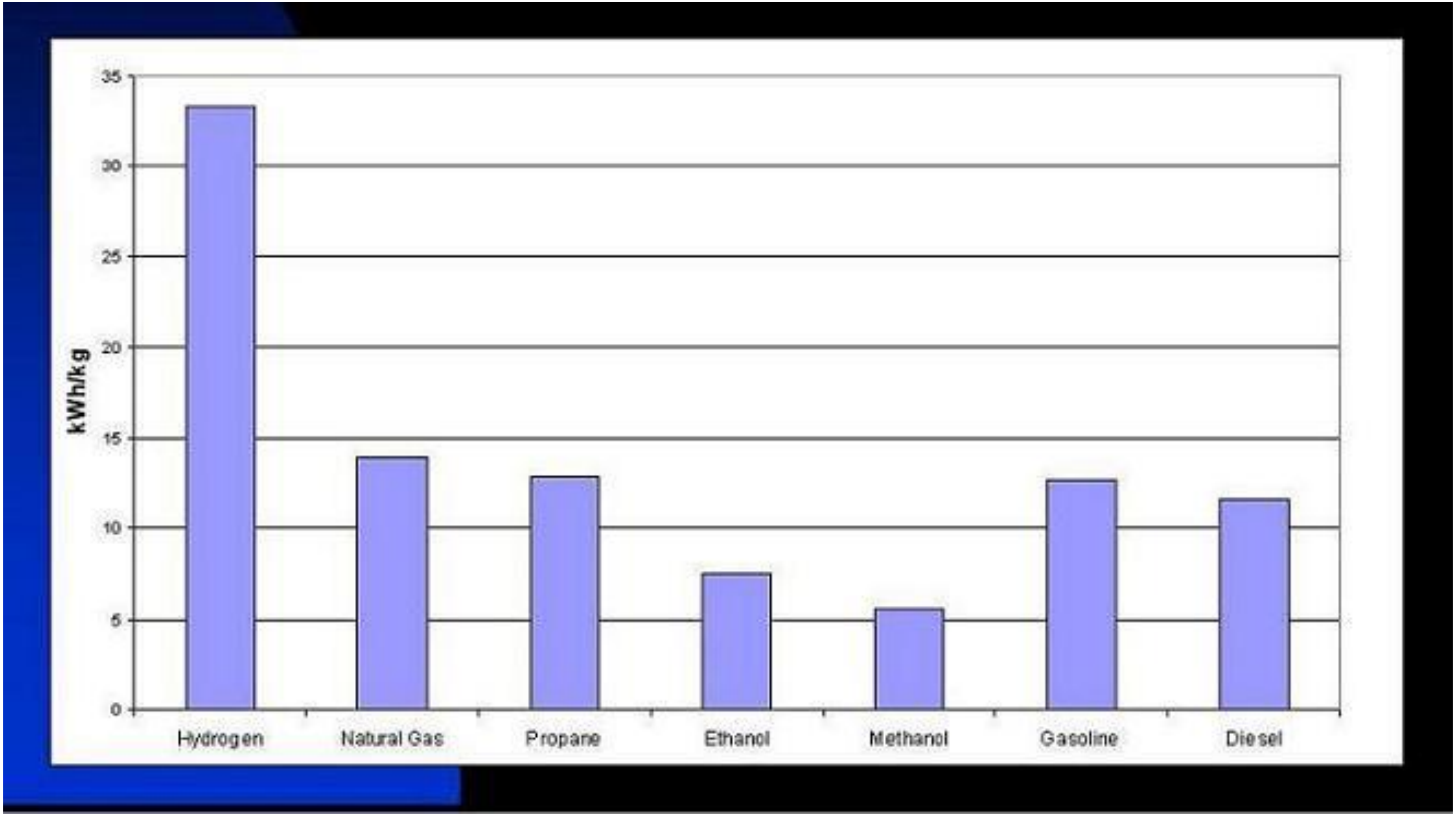
 propane 97

 2,2,4 trimethyl-pentane 100

 cyclopentane 101

 benzene 105.8

 CH_3 toluene 118

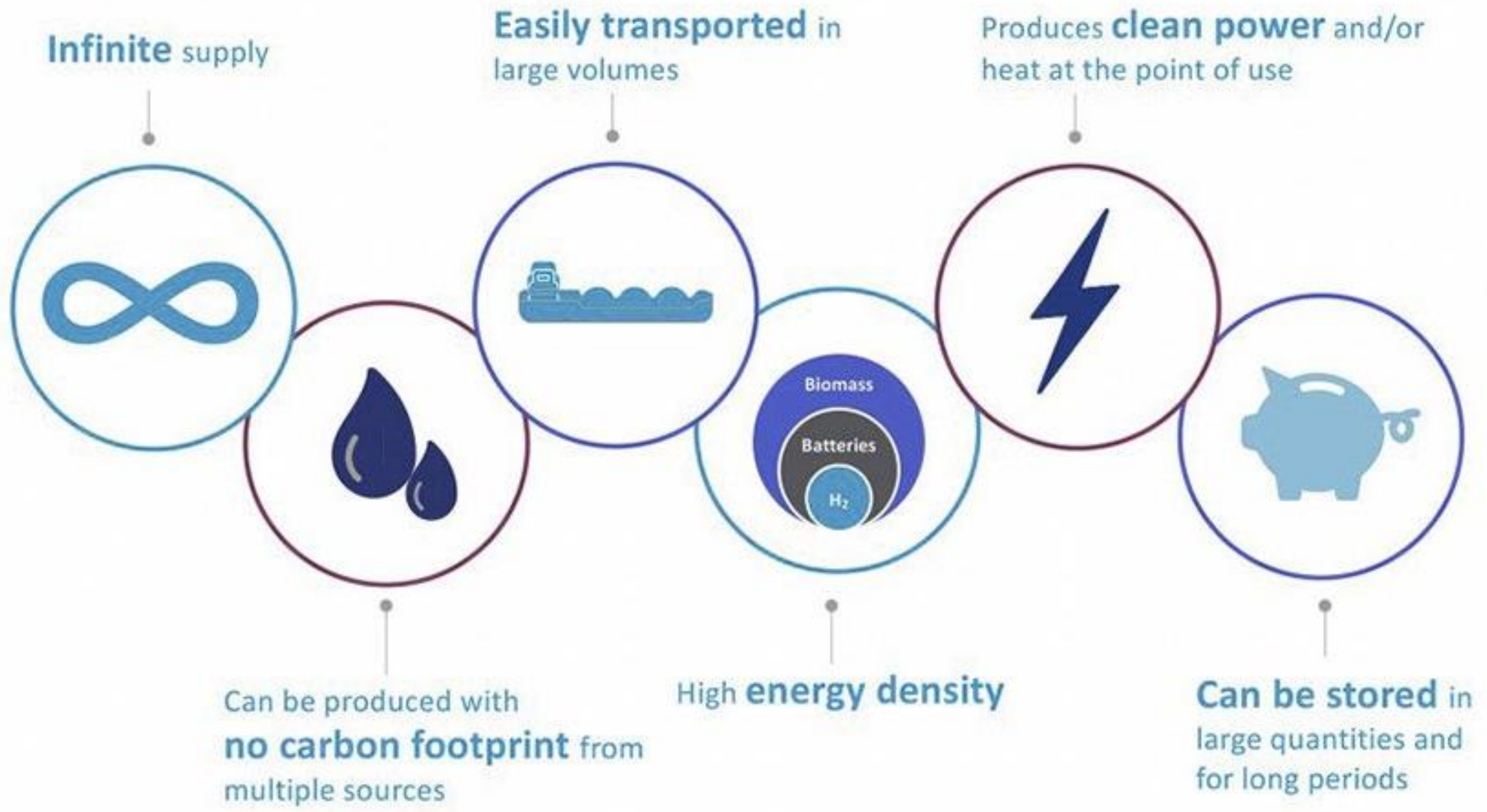

kWh/kg
35
30
25
20
15
10
5
0
Hydrogen
Natural Gas
Propane
Ethanol
Methanol
Gasoline
Diesel

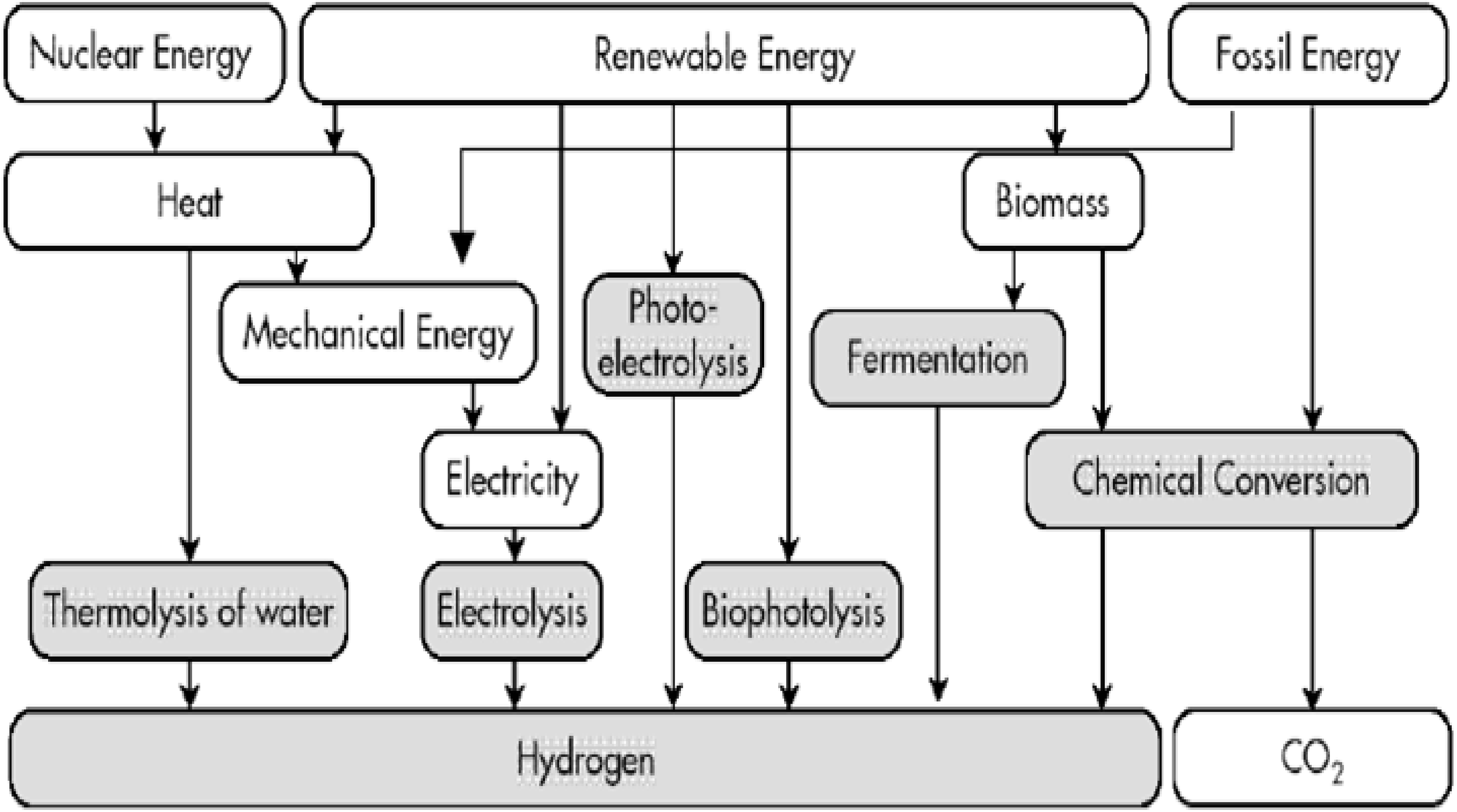
Uses of hydrogen

- commercial fixation of nitrogen from the air in the Haber ammonia process
- hydrogenation of fats and oils
- methanol production, in hydro-de--alkylation, hydro-cracking, and hydro-de-sulphurization
- rocket fuel
- welding
- production of hydrochloric acid
- reduction of metallic ores

Why hydrogen?

A versatile, zero-emission , efficient energy carrier




Nuclear Energy
Renewable Energy
Fossil Energy
Heat
Biomass
Mechanical Energy
Photo-
electrolysis
Fermentation
Electricity
Chemical Conversion
Thermolysis of water
Electrolysis
Biophotolysis
Hydrogen
CO_2

Hydrogen Production/Preparation Processes

Non-renewable

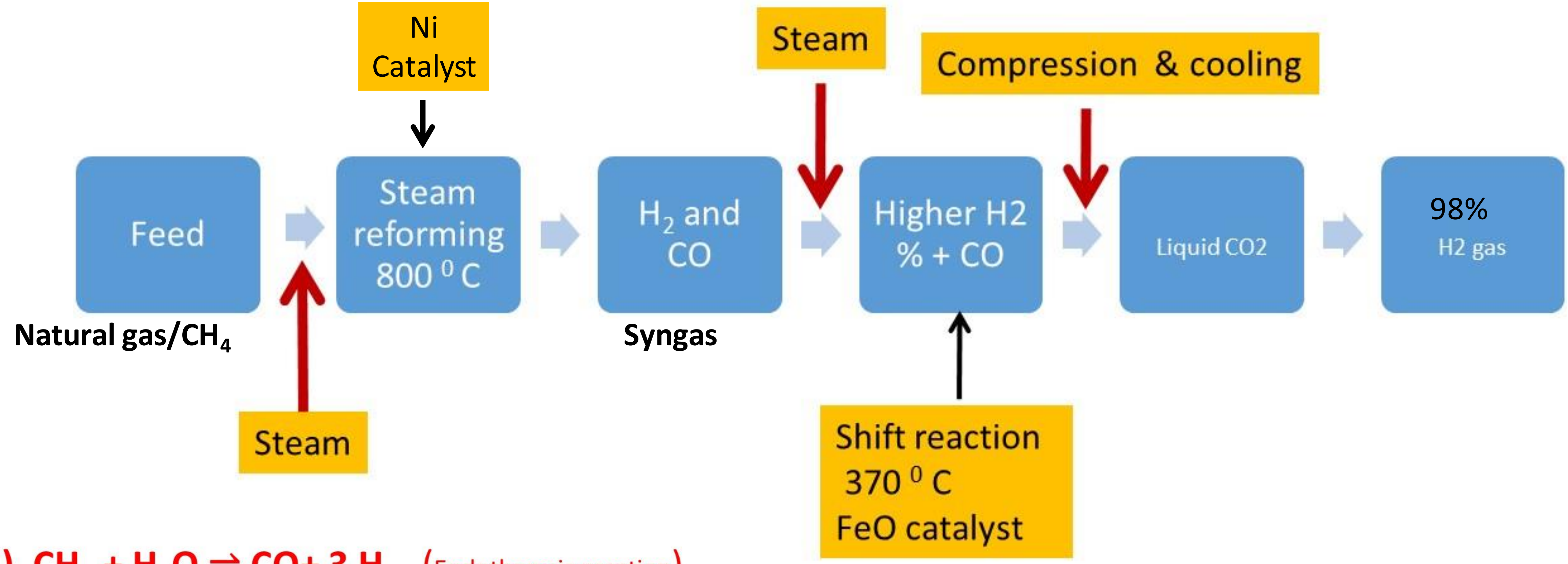
- **By Steam Methane Reforming**
- **By Coal and Steam Reaction**
- **By Action of Acids on Metals**

Renewable

- **Electrolysis**
- **Photocatalysis**
- **Biological methods**

Nuclear energy

Steam Reforming of Hydrocarbons



1) $CH_4 + H_2O \rightleftharpoons CO + 3\,H_2$ (Endothermic reaction)

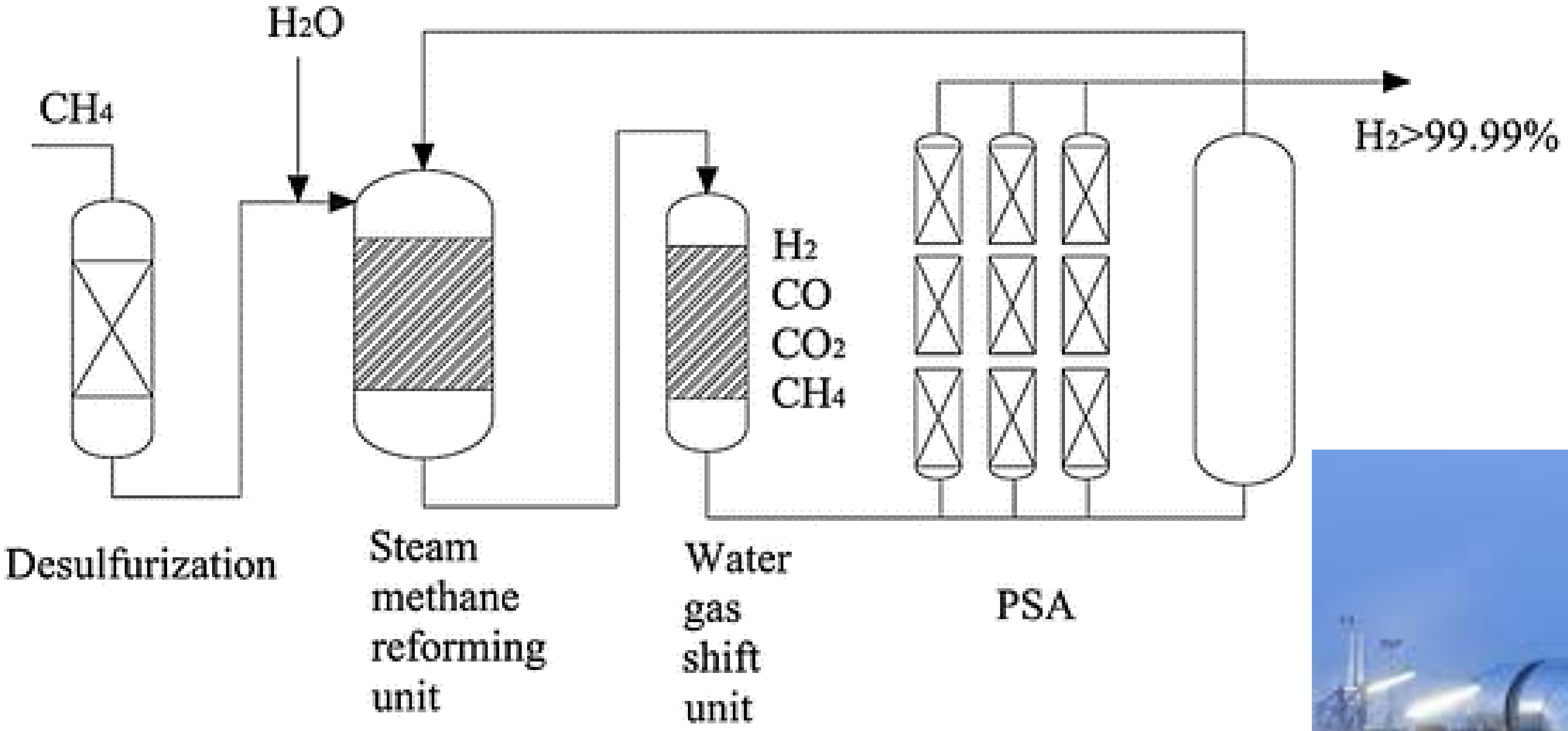
$\Delta H = 206.1$ KJ/mol

2) Shift reaction:

$CO + H_2O \rightleftharpoons CO_2 + H_2$ (Exothermic reaction)

$\Delta H = -41.2$ KJ/mol

- **Feed -----------> Sulphur free natural gas (CH_4), naphtha**
- **Catalyst------->Ni or FeO (reforming), FeO (For shift reaction)**
- **Temperature---> 800 ^{0}C (reforming), 370 ^{0} C (shift reaction)**
- **Pressure -------> Less than 1 atm**



H_2O
CH_4
$H_2>99.99\%$
H_2
CO
CO_2
CH_4
Desulfurization
Steam methane reforming unit
Water gas shift unit
PSA

https://www.youtube.com/watch?v=eoF2EoFhIJw

Advantages of SMR

1) Efficient net conversion efficiency of 65-70%.

2) SMR doesn't require external heat source as it is an exothermic reaction.

3) Stable during the transition of operation.

4) Natural gas is convenient and easy to handle.

5) It is a potential way to provide fuel to fuel cells.

Disadvantages of SMR

1) SMR is dependent on fossil fuels for the feedstock of methane

2) Depending on the scale of the production, SMR has high capital cost.

3) SMR requires high operating temperature which slows the start up.

4) Sulfur compounds produced during the reaction deactivates/poisons the catalyst which slows sown the reaction with period of time. Also, it provokes the need of sulphur tolerant catalyst for SMR

Why electric cars are less popular