Energy Storage

Unit 4

Unit 4

Energy Storage

Batteries: Types, Parameters and Technical characteristics, Selection of Battery pack, Properties of Batteries. Ultracapacitor, Fuel Cells, Flywheel

ENERGY STORAGE

“In simple terms, energy storage provides a way to save **previously generated energy** and use it at a **later time**”.

ESS **- Energy storage system**

- ➔ Energy Storage Systems refer to equipment that can store various types of energy safely, efficiently and conveniently.
- ➔ ESS refers to the device of converting electrical energy from power systems into a form that can be stored for converting back to electrical energy when needed.

Long-term energy storage system:

1) Compressed air energy storage, 2) Battery, 3) Hydrogen storage.

Short-term energy storage system:

1) Supercapacitor, 2) Flywheel,

BATTERY

- ***BATTERY - cell - power packs - power sources***
- Is a source of energy, obtained by the conversion of chemical energy from chemical reaction into electrical energy
- Thus BATTERIES represent a silent form of energy producing chemical devices, which generate electricity on demand

COMPONENTS IN BATTERY

1. CATHODE
2. ANODE
3. ELECTROLYTE
4. SEPARATOR

CELL REACTIONS IN A BATTERY SYSTEM

1. **ANODE REACTION**: is an oxidation reaction which releases electrons (Anode is the –ve electrode in EC cell) CELL REACTIONS IN A BATTERY SYSTEM
2. **CATHODE REACTION**: is a reduction reaction which consumes electrons (Cathode is the +ve electrode in EC cell) .
3. **ELECTROLYTE** is an ion-conducting medium which conducts ions between the electrodes so that the above reactions can take place

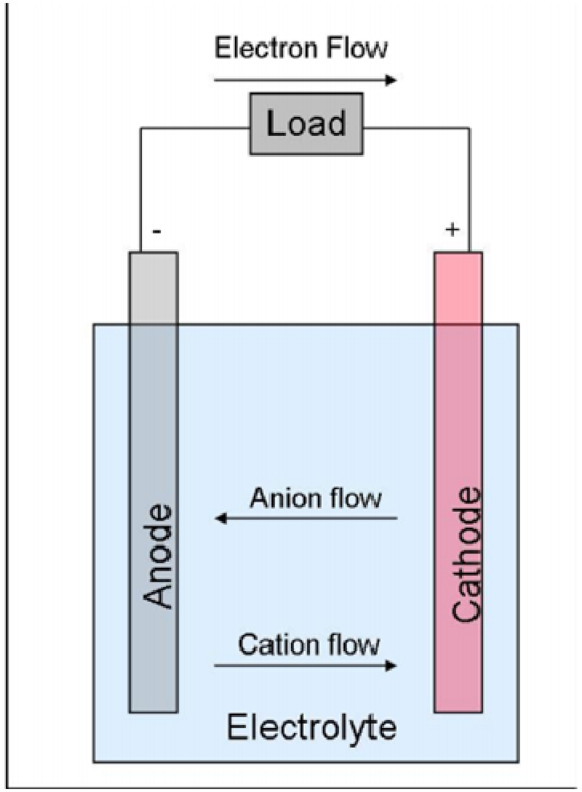
CLASSIFICATION OF BATTERIES

1. **PRIMARY BATTERY** - for single use only
2. **SECONDARY BATTERY** - for repeated us

- Cathode
    - Positive terminal
    - Chemical reduction occurs (gain electrons)
- Anode
    - Negative terminal
    - Chemical oxidation occurs (lose electrons)
- Electrolytes allow:
    - Separation of ionic transport and electrical transport
    - Ions to move between electrodes and terminals
    - Current to flow out of the battery to perform work

Battery Basics

- ➔ Batteries store energy chemically and through electrochemical reactions produce electricity.
- ➔ The presence of an anode, cathode, and electrolyte provides the basis for storing energy and satisfying energy loads.
- ➔ There are a wide range of battery types, sizes, designs, operating temperatures, control mechanisms, and chemistries.
- ➔ Beyond storing energy, all batteries are not created equal.



Terminology

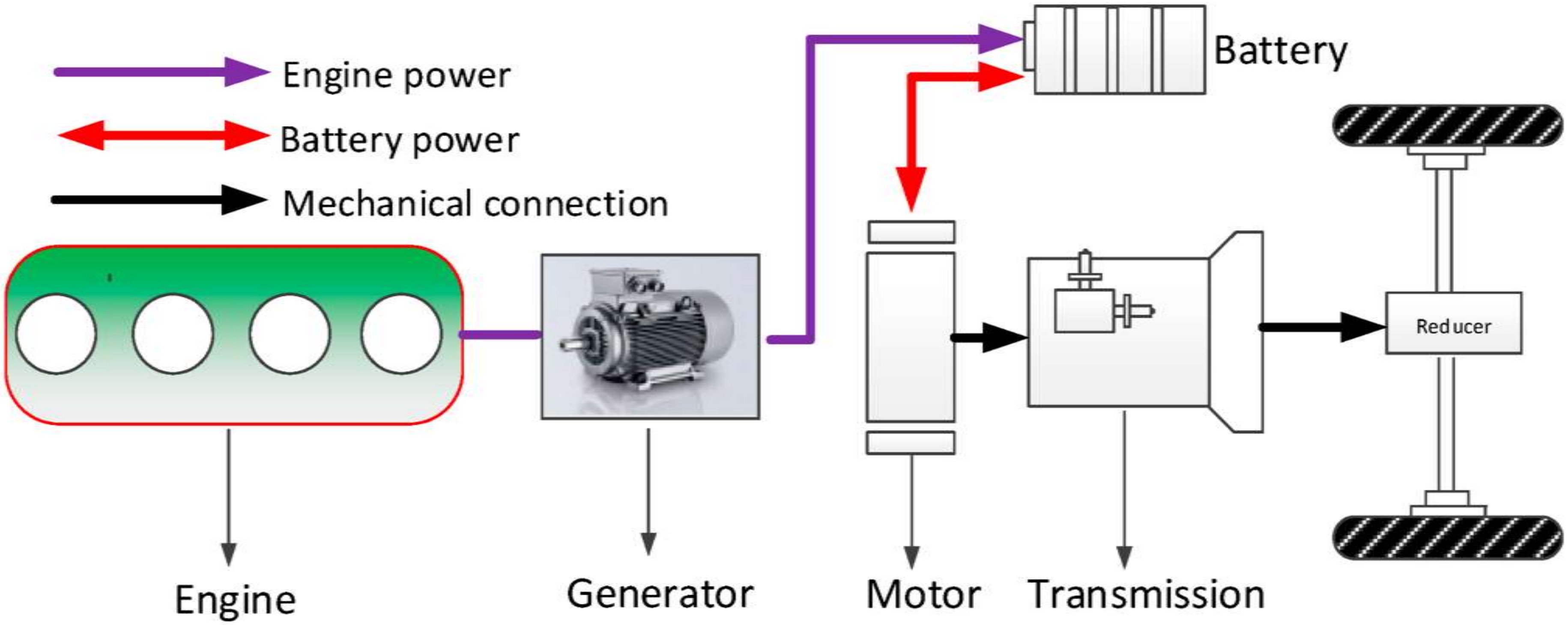
- ***Anode:*** The definition for the anode is the electrode at which an oxidation reaction occurs. This means that the anode electrode is a supplier of electrons. However the electron flow reverses between charge and discharge activities. As a result, the positive electrode is the anode during charging and the negative electrode is the anode during discharging.
- ***Cathode:*** The definition of a cathode is the electrode in a battery or other system at which a reduction reaction occurs. The electrode takes up electrons from an external circuit. Accordingly, the, the negative electrode of the battery or cell is the cathode during charging and the positive electrode is the cathode during discharging.
- ***Capacity:*** The capacity of a battery or cell is defined as the amount of energy that it can deliver in a single discharge. Battery capacity is normally specified in amp-hours (or milli-amp-hours) or as watt-hours.

- ***Cell:*** The definition of the cell is the basic electrochemical unit that is used to create electrical energy from stored chemical energy or to store electrical energy in the form of chemical energy. A basic cell consists of two electrodes with an electrolyte between them.
- ***Charge rate or C-rate :*** The definition of the charge rate or C-rate of a battery or cell is the charge or discharge current in Amperes as a proportion of the rated capacity in Ah. For example, in the case of a 500 mAh battery, a C/2 rate is 250 mA and a 2C rate would be1 A.
- ***Constant-Current Charge:*** This refers to a charging process where the level of current is maintained at a constant level regardless of the voltage of the battery or cell.
- ***Constant-Voltage Charge:*** This definition refers to a charging process in which the voltage applied to a battery is held at a constant value over the charge cycle regardless of the current drawn.
- ***Cycle Life:*** The capacity of a rechargeable cell or battery changes over its life. The definition of the battery life or cycle life of a battery is number of cycles that a cell or battery can be charged and discharged under specific conditions, before the available capacity falls to a specific performance criteria - normally 80% of the rated capacity.

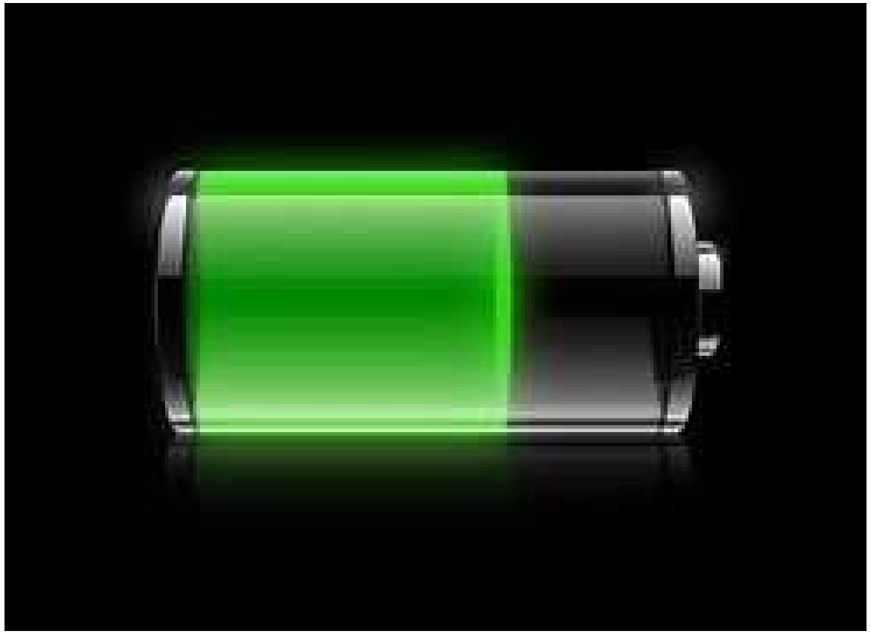
- ***Cut-off voltage:*** As a battery or cell is discharged it has a voltage curve that it follows - the voltage generally falling over the discharge cycle. The definition for a cell or battery of the cut-off voltage cell or battery is the voltage at which the discharge is terminated by any battery management system. This point may also be referred to as the End-of-Discharge voltage.
- ***Deep Cycle:*** A charge discharge cycle in which the discharge is continued until the battery is fully discharged. This is normally take to be the point at which it reaches its cut-off voltage, typically 80% of discharge.
- ***Electrode:*** The electrodes are the basic elements within an electrochemical cell. There are two in each cell: one positive and one negative electrode. The cell voltage is determined by the voltage difference between the positive and the negative electrode.
- ***Electrolyte:*** The definition of the electrolyte within a battery is that it is the medium that provides the conduction of ions between the positive and negative electrodes of a cell.
- ***Energy Density:*** The volumetric energy storage density of a battery, expressed in Watt-hours per litre (Wh/l).
- ***Power Density:*** The volumetric power density of a battery, expressed in Watts per litre (W/l).
- ***Rated Capacity:*** The capacity of a battery is expressed in Ampere-hours, Ah and it is the total charge that can be obtained from a fully charged battery under specified discharge conditions

- ***Self-Discharge:*** It is found that batteries and cells will lose their charge over a period of time, and need re-charging. This self-discharge is normal, but various according to a number of variables including the technology used and the conditions. Self-discharge is defined as the recoverable loss of capacity of a cell or battery. The figure is normally expressed in a percentage of the rated capacity lost per month and at a given temperature. The self-discharge rate of a battery or cell is very dependent upon the temperature.
- ***Separator:*** This battery terminology is used to define the membrane that is required within a cell to prevent the anode and cathode shorting together. With cells being made more compact, the space between the anode and cathode becomes much smaller and as a result the two electrodes could short together causing a catastrophic and possibly explosive reaction. The separator is an ion-permeable, electronically non-conductive material or spacer that is placed between the anode and cathode.
- ***Specific Energy:*** The gravimetric energy storage density of a battery, expressed in Watt-hours per kilogram (Wh/kg).
- ***Specific Power:*** The specific power for a battery is the gravimetric power density expressed in Watts per kilogram (W/kg).
- ***Trickle charge:*** This terms refers to a form of low level charging where a cell is either continuously or intermittently connected to a constant-current supply that maintains the cell in fully charged condition. Current levels may be around 0.1C or less dependent upon the cell technology.

Energy Management System in EV

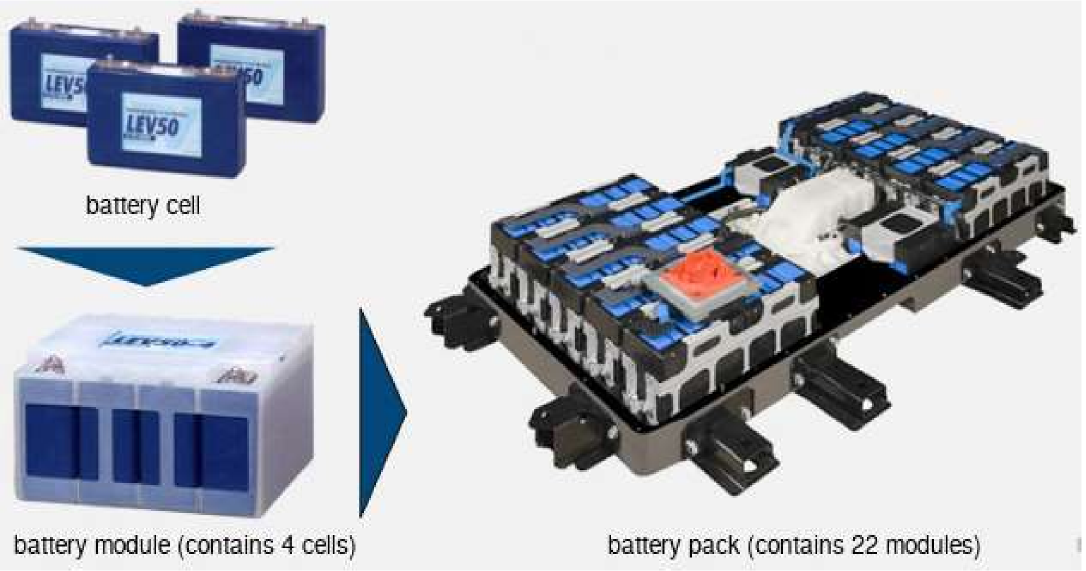


Battery Considerations



Basic Considerations

- ➢ Life Span
- ➢ Safety
- ➢ Cost



Basic Considerations

1. **Life Span**

Various factors influence the life cycle of a battery. You could give EV batteries a life cycle of 8 years or 160,000 km. Some factors before picking your pick would be:

The purpose of the battery

Operating conditions

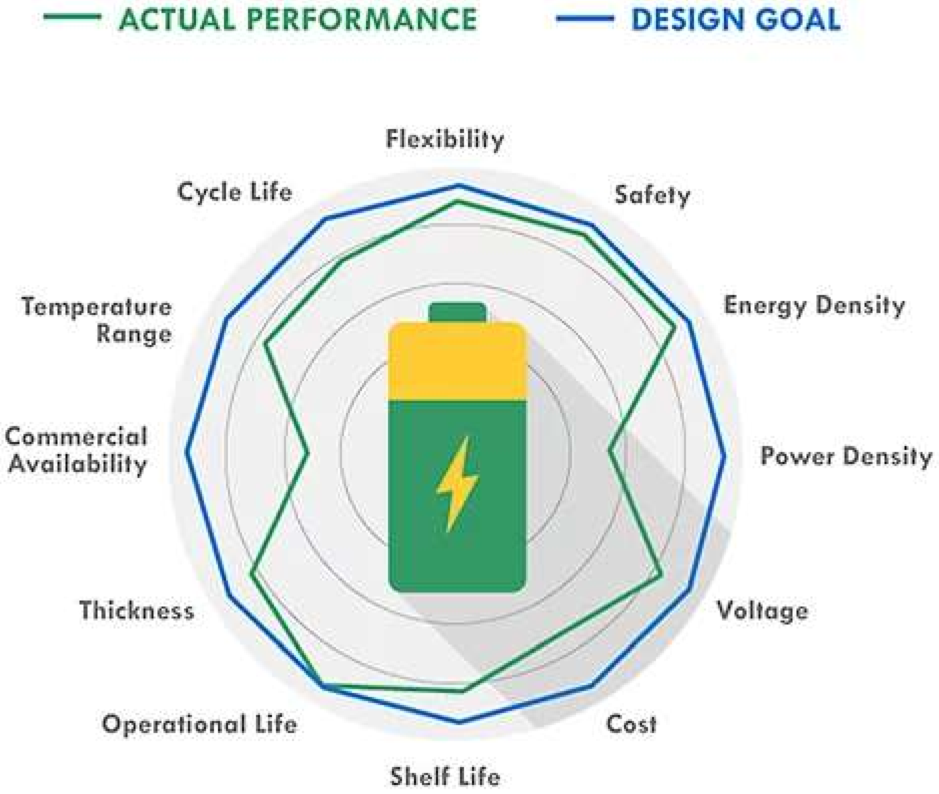
The depth of battery discharge, but you can generally estimate EV battery life as 8 years or 160,000 km (100,000 miles).

1. **Safety**

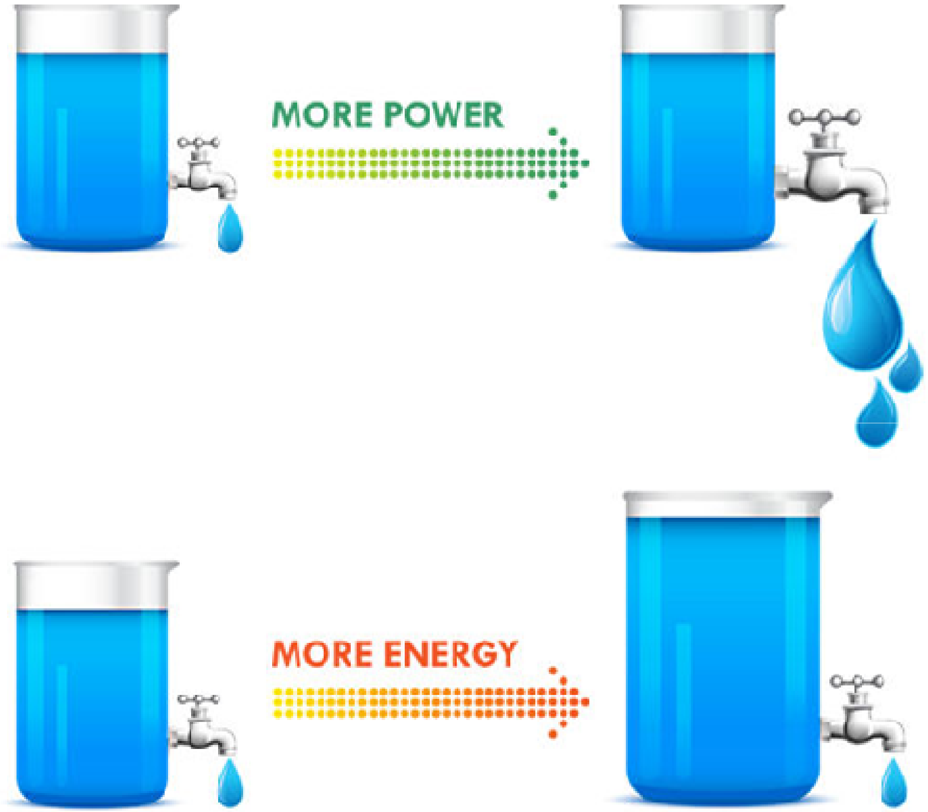
Driving an EV takes a lot of power, which is why it must be managed properly. A carefully designed battery management system (BMS) assures safe operation.

1. **Cost**

Compared to ICE vehicles this is a disadvantage for EV's. The cost of a small ICE vehicle and an EV battery system is pretty much the same.



Battery Selection



ENERGY VS POWER

1. The higher the power, the higher the drain rate.
2. To increase energy, you would typically increase the battery size, but to increase power you decrease internal resistance.
3. Cell construction plays a huge part in obtaining batteries with high power density.

Technical requirements for battery selection

Battery Selection

1. Electrical requirement
2. Temperature and humidity
3. Charging condition
4. Life
5. Dimensions, mass and shape
6. Other

Technical requirements for battery selection :

1. **Electrical requirement**
- Voltage: Vmax,Vmin
- Continuous load : mA(max,avg,min)
- Intermittent load (pulse load): mA(max,avg,min)
- ON/OFF condition : On time / OFF time

1. **Temperature and humidity**
- Ambient temperature and humidity Min & max degree celsius . [min and max%]
- Storage temperature and humidity Min & max degree celsius . [min and max%]

Technical requirements for battery selection :

3. **Charging Condition**
   - Cycle charge
   - Trickle/Float Charge
   - Charging time
   - Charging temperature atmosphere

4. **Life**
   - Cycle life [Cycles]
   - Trickle life [years]
   - Storage period

1. Battery Chemistry

- **Lithium-Ion (Li-ion)**: Most common; high energy density and efficiency.
- **Lithium Iron Phosphate (LiFePO4)**: Stable and safe, but lower energy density.
- **Nickel Manganese Cobalt (NMC)**: Balances energy density and thermal stability.
- **Solid-State Batteries**: Emerging technology with higher energy density and safety.

2. Energy Density

- **Specific Energy**: Measured in Wh/kg, indicating how much energy the battery can store relative to its weight. Typical values rang from 150 to 250 Wh/kg for Li-ion.
- **Volumetric Energy Density**: Measured in Wh/L, representing how much energy is stored per unit volume.

3. Capacity

- **Ampere-Hours (Ah)**: Indicates the total charge capacity of the battery. Common capacities range from 20 Ah to over 100 Ah for EVs.
- **Total Energy Capacity**: Typically measured in kilowatt-hours (kWh), affecting range (e.g., 60 kWh, 100 kWh).

4. Cycle Life

- Number of charge-discharge cycles before significant capacity degradation occurs. Commonly ranges from 500 to over 2,000 cycl depending
- on chemistry and usage.

5. Charging Characteristics

- **Charge Rate**: Measured in C-rate (e.g., 1C means charging in one hour). Fast charging capabilities may allow rates of 0.5C to 3C.
- **Charging Time**: Varies based on charger type (Level 1, Level 2, DC fast charging).

6. Temperature Range

- Operating temperature range typically between -20°C and 60°C. Performance can degrade outside this range.

7. Power Density

- Measured in kW/kg, indicating how quickly a battery can deliver power. Higher power density is crucial for performance.

8. Safety Features

- Built-in thermal management systems, battery management systems (BMS), and features to prevent overcharging, short-circuiting, and thermal runaway.

9. Weight and Size

- Critical for vehicle design; battery packs are designed to be as lightweight and compact as possible while maximizing capacity.

10. Environmental Considerations

- Recycling capabilities, sustainability of materials, and overall lifecycle impact.

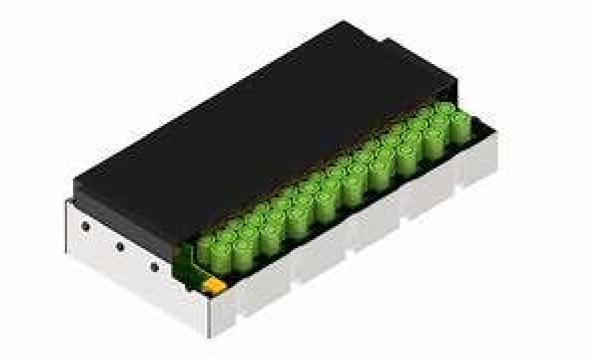
Technical requirements for battery selection :

5. Dimensions,mass and shape

- Height
- Length
- Width
- Mass
- Terminal Shape

6. Other

- Atmosphere pressure
- Mechanical condition
- Safety
- Interchangeability
- Marketability
- Price



Batteries

1. **Lithium-Ion (Li-ion) Batteries**
2. **Solid-State Batteries**
3. **Nickel-Cadmium (NiCd) Batteries**
4. **Nickel-Metal Hydride (NiMH) Batteries**

Key Parameters Used in EV Batteries

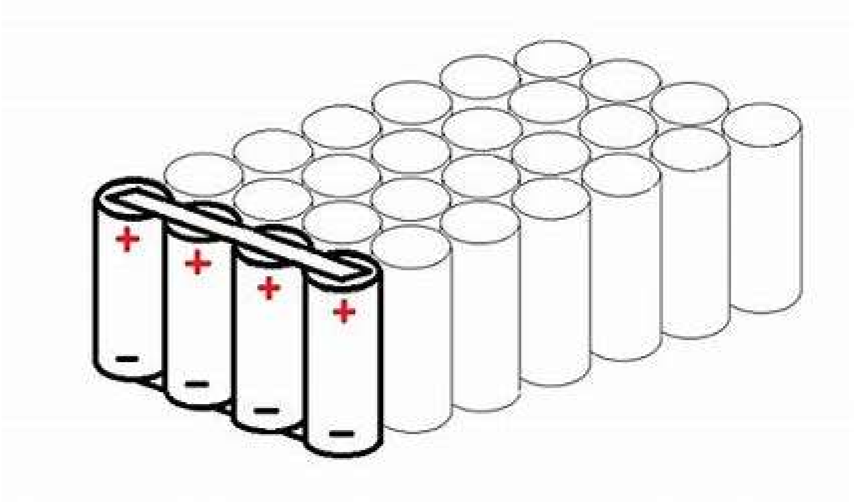
1. **Energy Density**
    - **Specific Energy (Wh/kg)**: Energy stored per kilogram of battery mass.
    - **Volumetric Energy Density (Wh/L)**: Energy stored per liter of battery volume.
2. **Capacity**
    - **Ampere-Hours (Ah)**: Total charge capacity; higher values indicate more energy storage.
    - **Total Energy Capacity (kWh)**: Total energy available from the battery, impacting range.
3. **Cycle Life**
    - Number of complete charge-discharge cycles a battery can undergo before its capacity falls below a certain percentage (usually 80%).
4. **Charging Characteristics**
    - **Charge Rate (C-rate)**: Rate at which the battery can be charged. Higher rates can lead to faster charging.
    - **Charging Time**: Duration required to fully charge the battery, dependent on charger type.

5. **Power Density**
    - **Power (kW/kg)**: Measure of how quickly energy can be delivered, impacting acceleration and performance.
6. **Temperature Range**
    - Operating temperature range for optimal performance; extreme temperatures can affect efficiency and lifespan.
7. **Self-Discharge Rate**
    - The rate at which a battery loses charge when not in use; lower rates are preferable for EV applications.
8. **Internal Resistance**
    - Resistance within the battery that affects efficiency and heat generation during charge/discharge cycles.
9. **State of Charge (SOC)**
    - Percentage that indicates how much energy is currently stored in the battery relative to its total capacity.
10. **Battery Management System (BMS)**
    - Monitors and manages battery performance, ensuring safety, optimizing charging/discharging, and extending lifespan.

Electric vehicles (EVs) mainly use:

1. Lithium-Ion: Most common, high energy density, lightweight.
2. Nickel-Metal Hydride (NiMH): Used in some hybrids, stable but less efficient.
3. Solid-State: Emerging tech, potentially higher energy density and safety.
4. Lead-Acid: Older tech, heavier, mainly in low-speed EVs.
5. Lithium Iron Phosphate (LiFePO4): Safe, long-lasting, but lower energy density.
6. Zinc-Air: Experimental, high energy density potential.

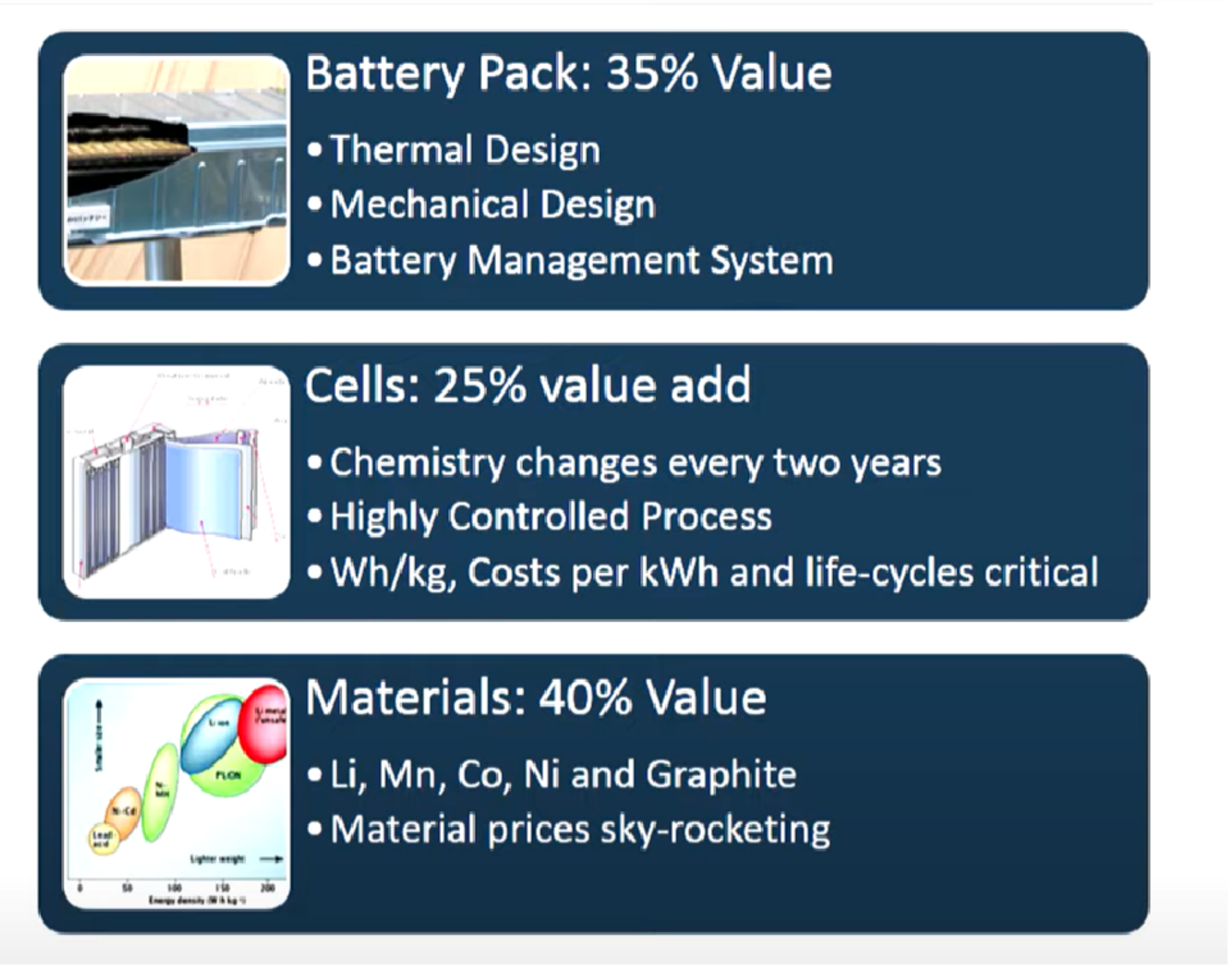
Battery pack design



Battery Pack

The 4 Main Types of Battery Pack Designs

1. 12V Battery Packs for Accessories
2. Hybrid Battery Packs
3. EV Battery Packs
4. High Performance Battery Packs



Battery Pack: 35% Value

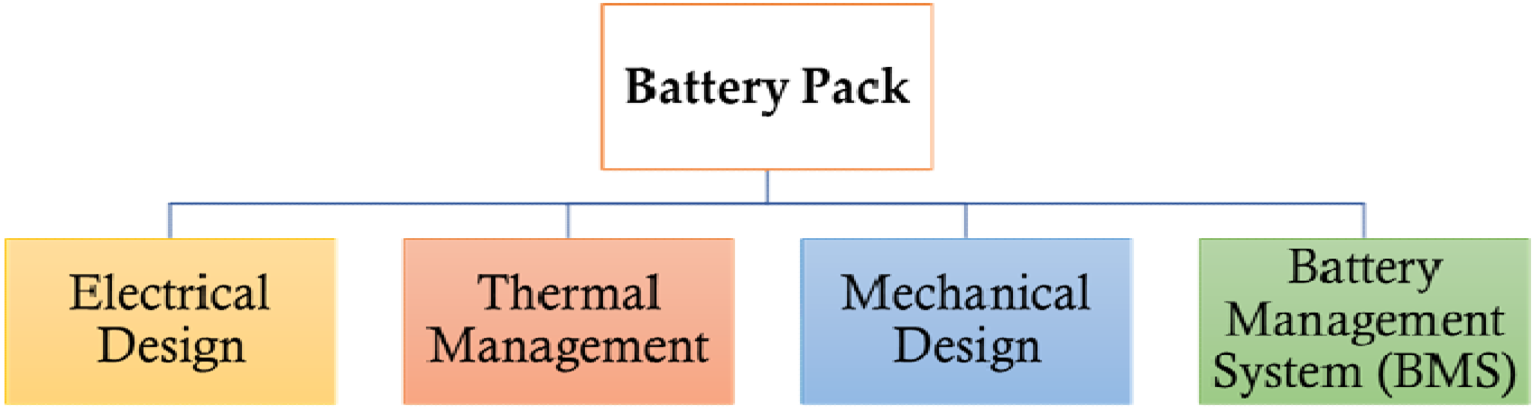
- Thermal Design
- Mechanical Design
- Battery Management System

Cells: 25% value add

- Chemistry changes every two years
- Highly Controlled Process
- Wh/kg, Costs per kWh and life-cycles critical

Materials: 40% Value

- Li, Mn, Co, Ni and Graphite
- Material prices sky-rocketing


Battery Pack
Electrical Design
Thermal Management
Mechanical Design
Battery Management System (BMS)

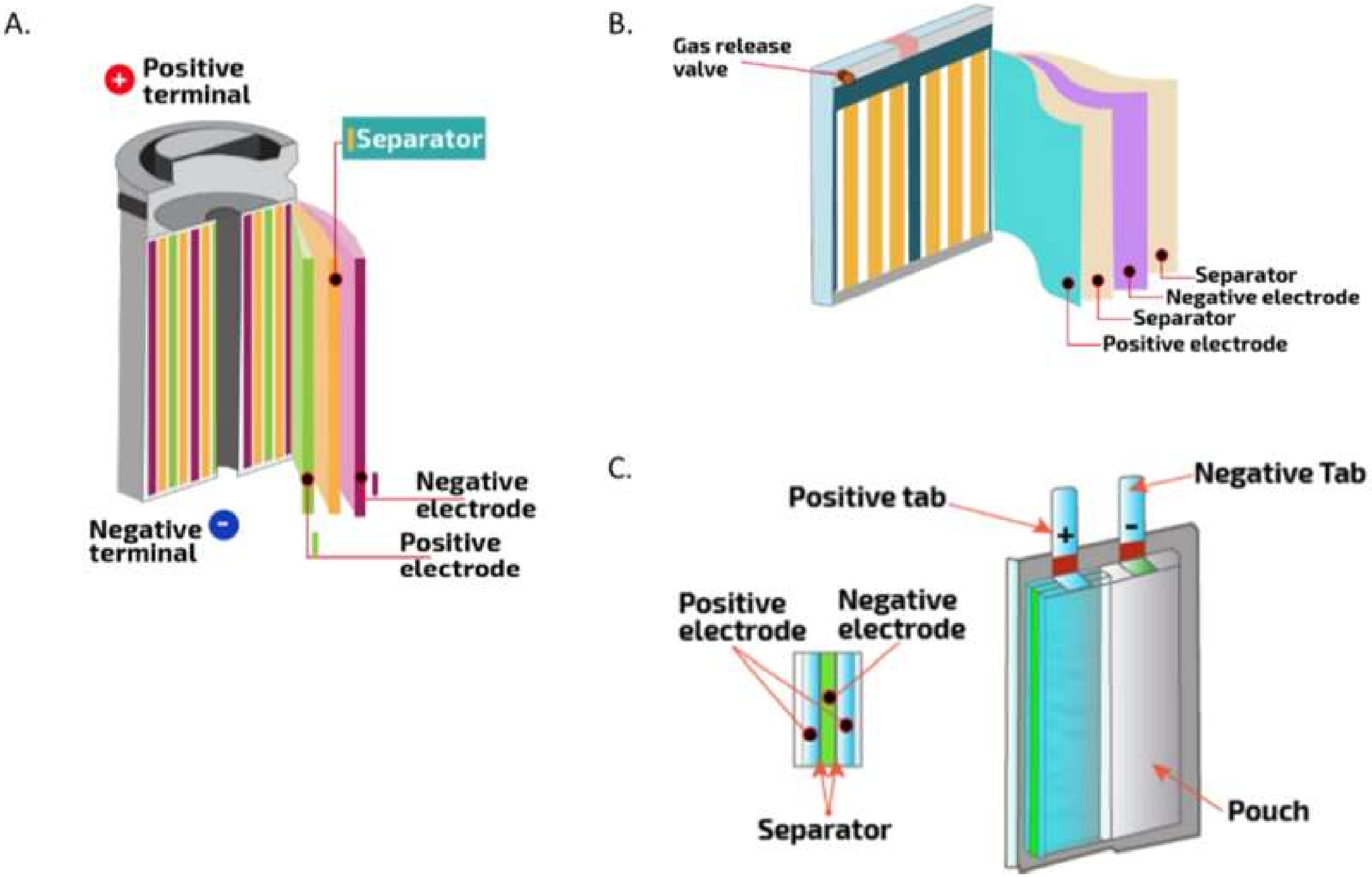

Cell Configuration
Battery pack structure
Safety test
Applications

Models

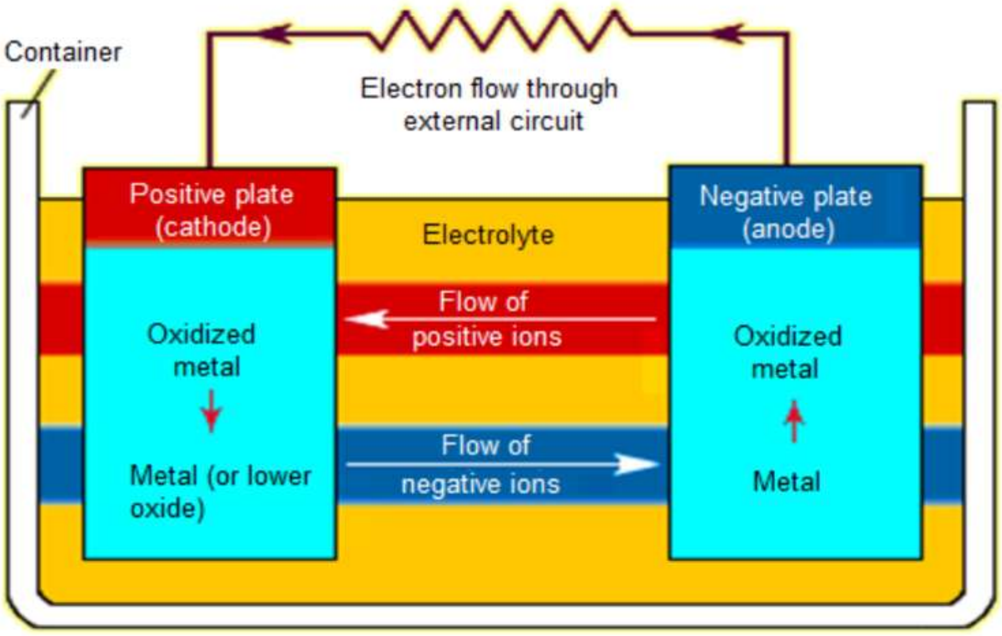
Common battery capacity ranges, on the other hand, are as follows:

1. Hybrid vehicles: 0.5 to 2 kWh
2. Plug-in hybrid vehicles: 4 to 20 kWh
3. Electric vehicles: 30 to 100 kWh or more.

Lithium Batteries

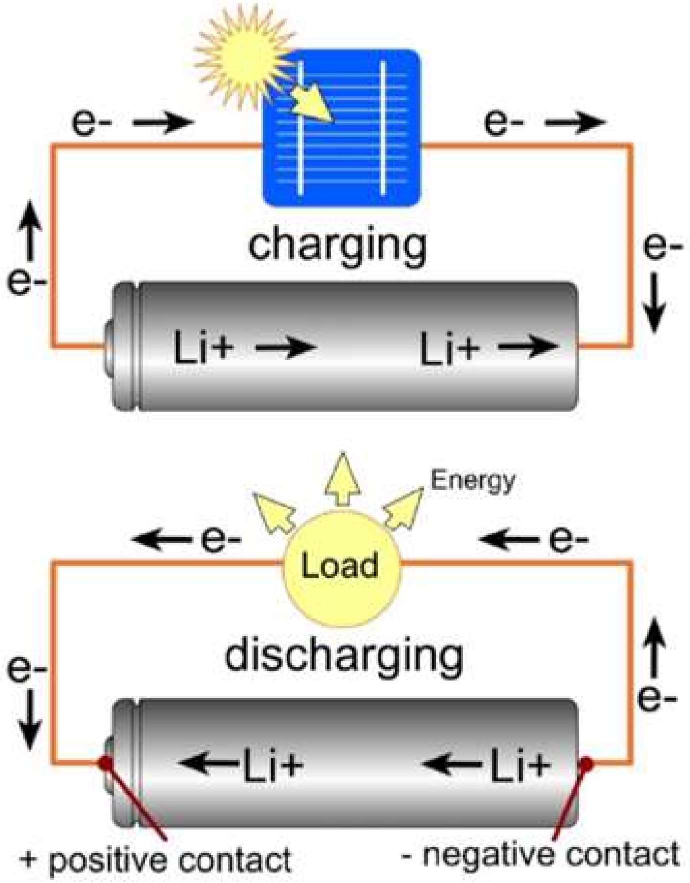


Schematics of various form factors for Li-ion cells, including: A) cylindrical, B) prismatic, and C) pouch



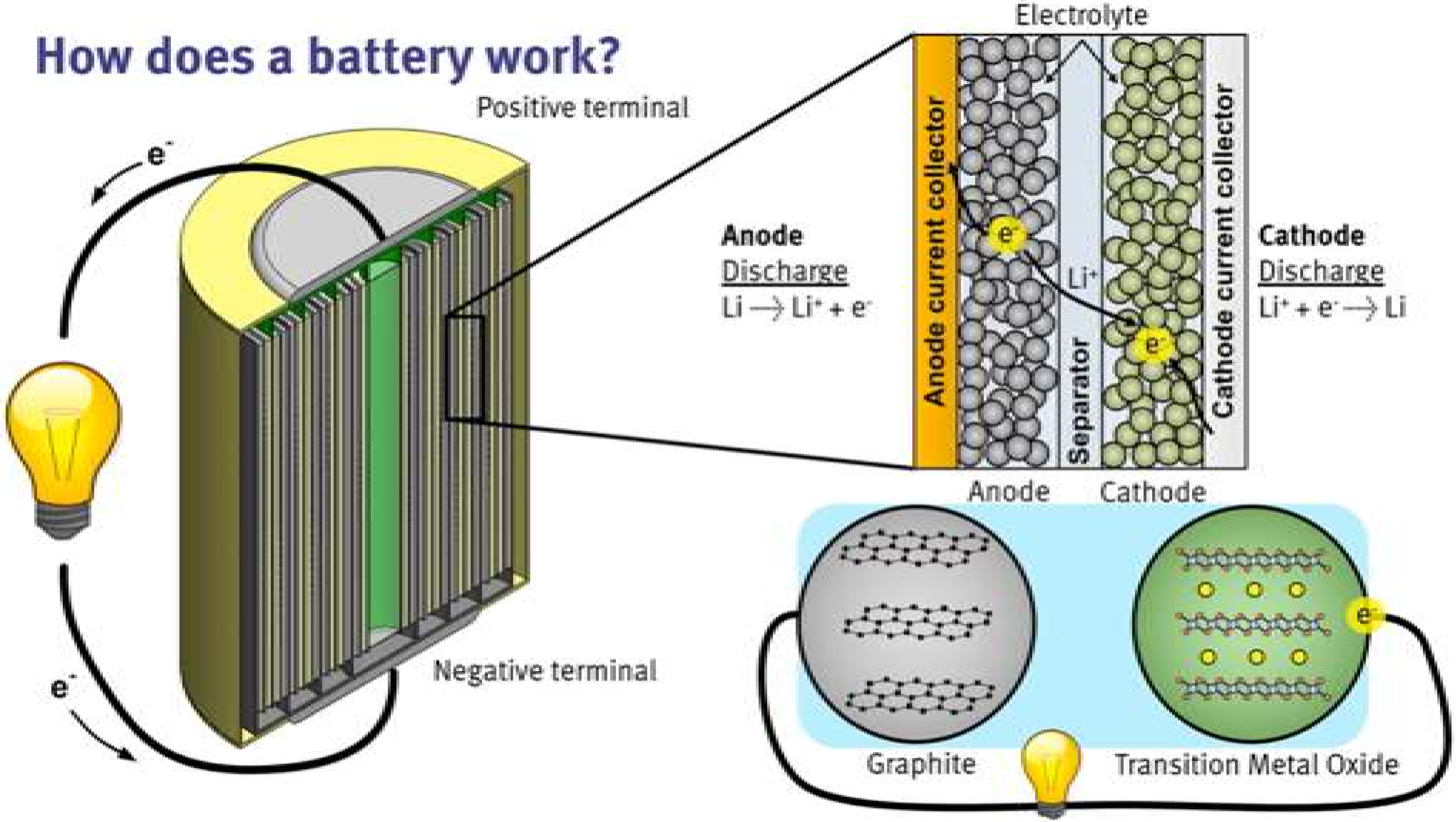
Electrochemical Cell

Anode →Oxidation→ Loss of electrons
Cathode →Reduction→ Gain of electrons



LITHIUM ION AND ELECTRON FLOW IN A LI-ION CYLINDRICAL CELL WITH EXTERNAL CIRCUIT

How does a battery work?



Discharge Reactions

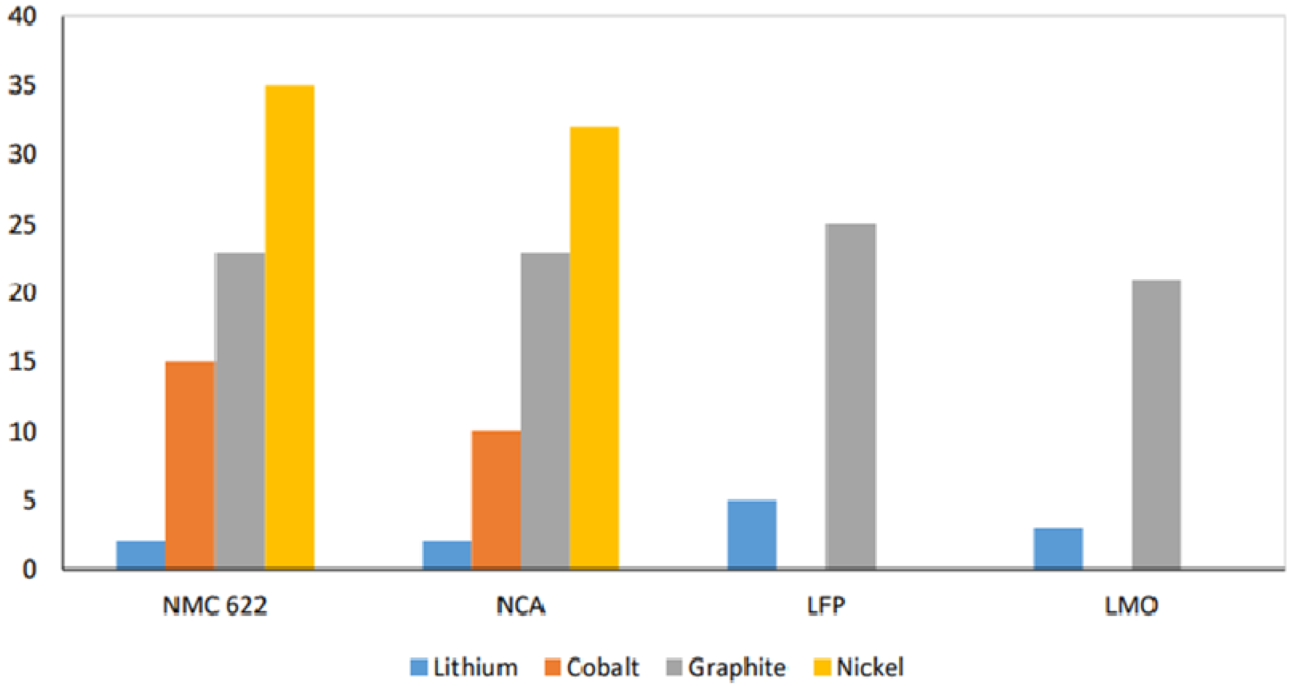
(1) electrochemical: $4Li^{+} + 4O_2 + 4e^{-} \longrightarrow 4LiO_2$

(2) chemical: $4LiO_2 + 2H_2O \xrightarrow{\text{via the action of LiI}} 4LiOH + 3O_2$

Charge Reactions

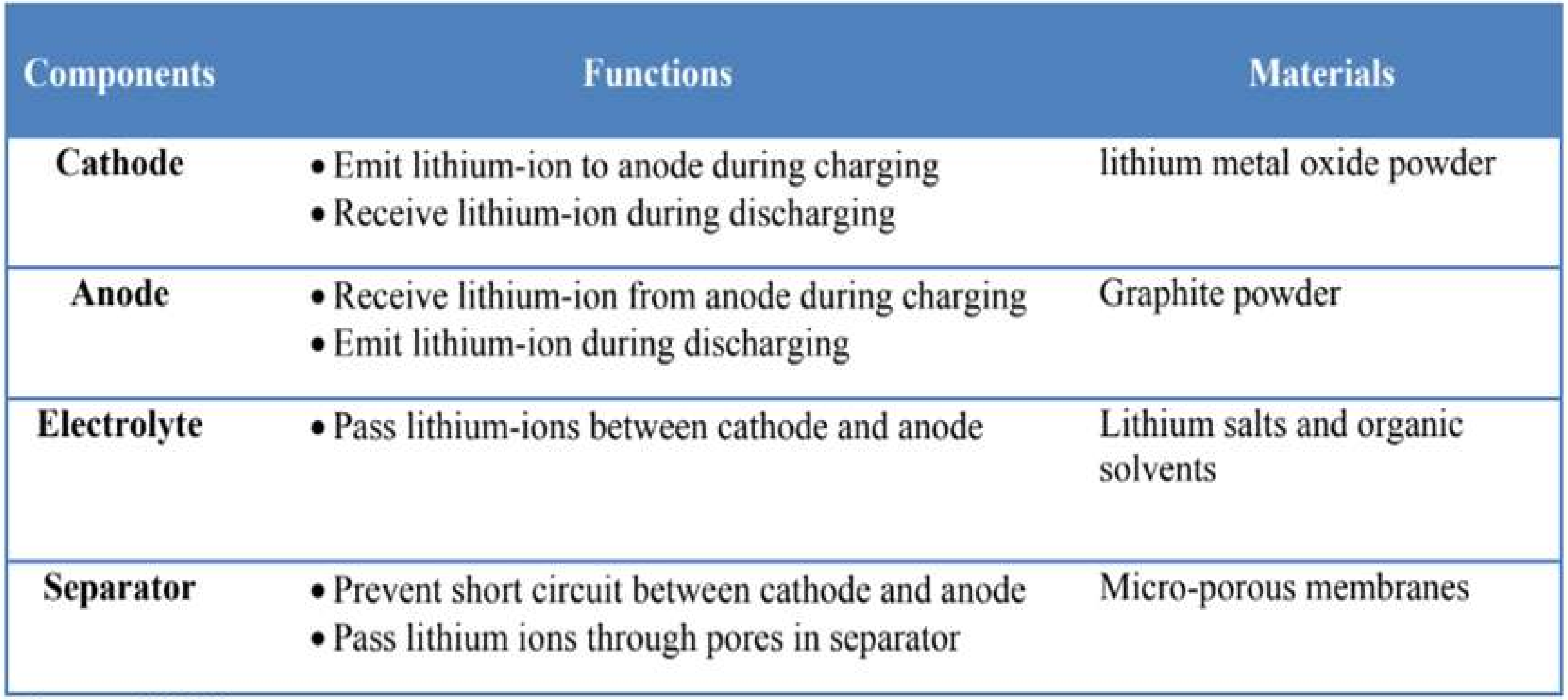
(1) electrochemical: $6I^{-} \longrightarrow 2I_3^{-} + 4e^{-}$

(2) chemical: $4LiOH + 2I_3^{-} \longrightarrow 4Li^{+} + 6I^{-} + 2H_2O + O_2\uparrow$

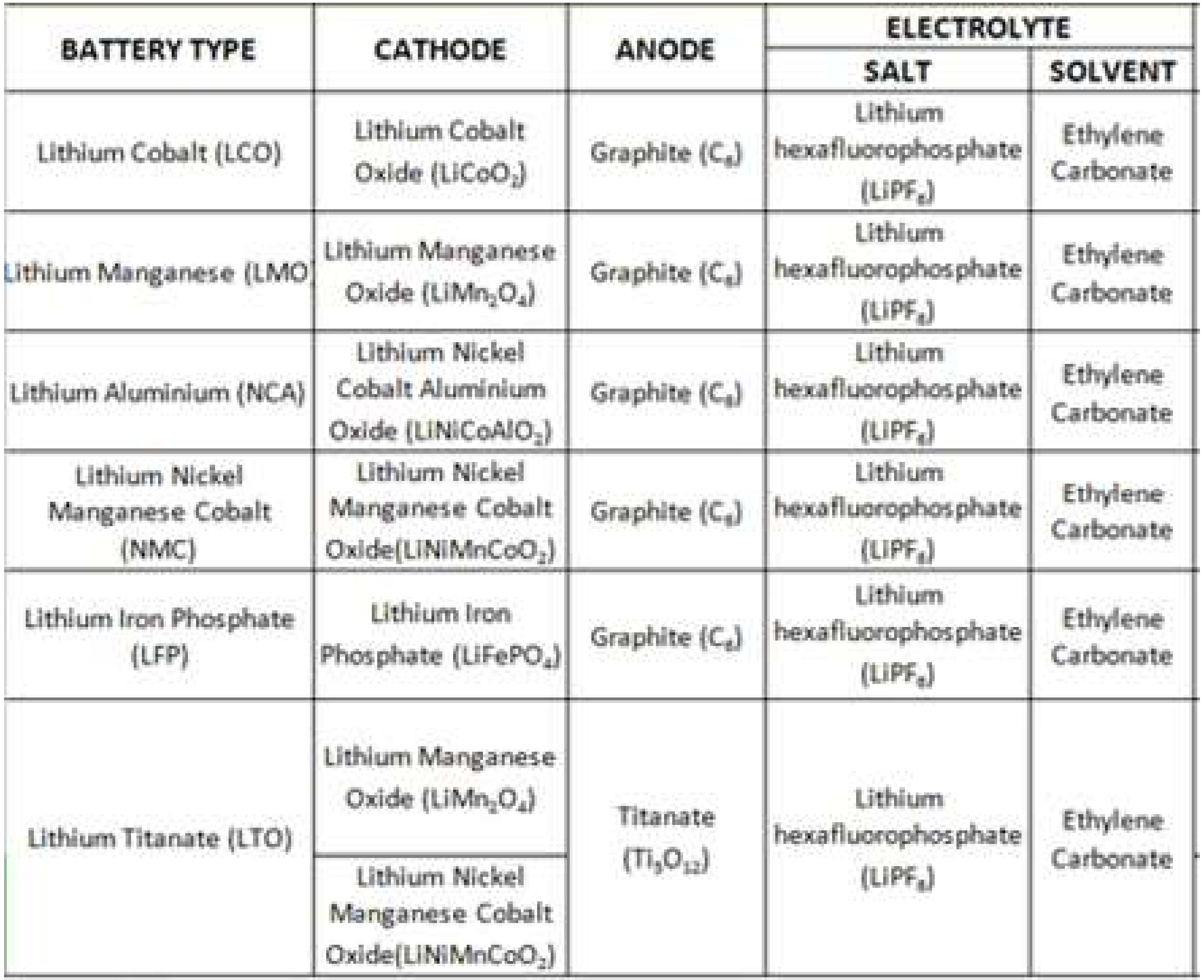


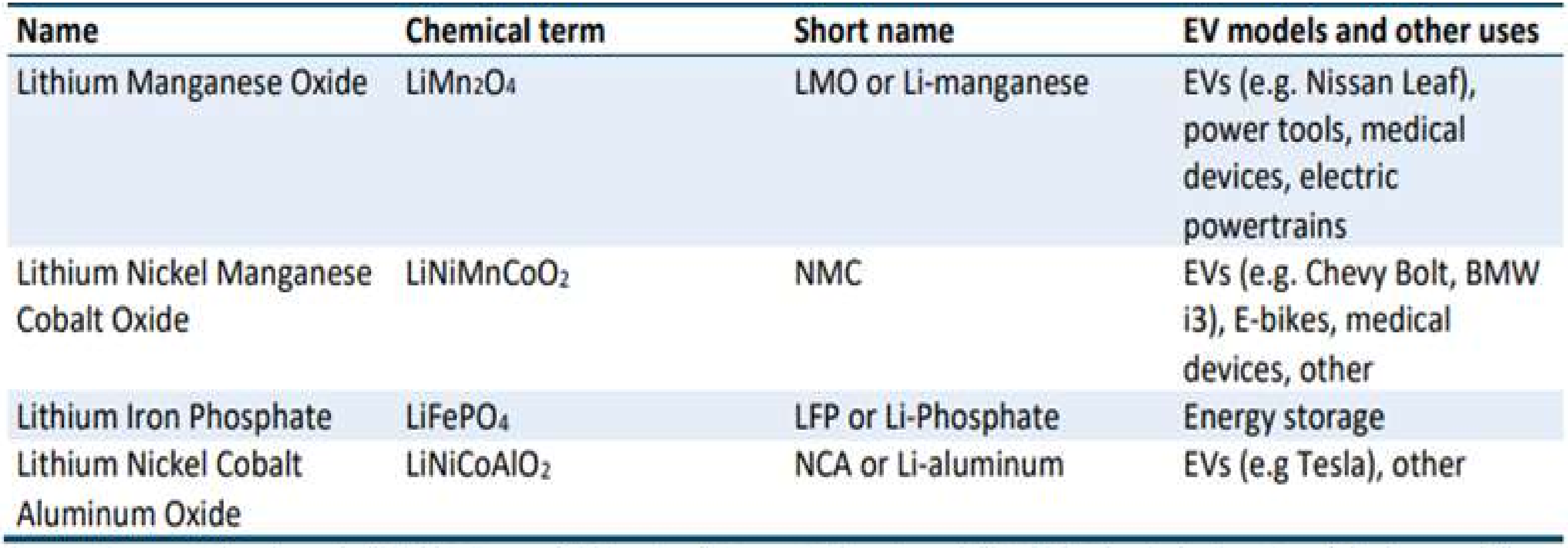
4 Key material share of common LIB compositions, by weight

Source: Argonne National Laboratory, 2018 and staff calculations.

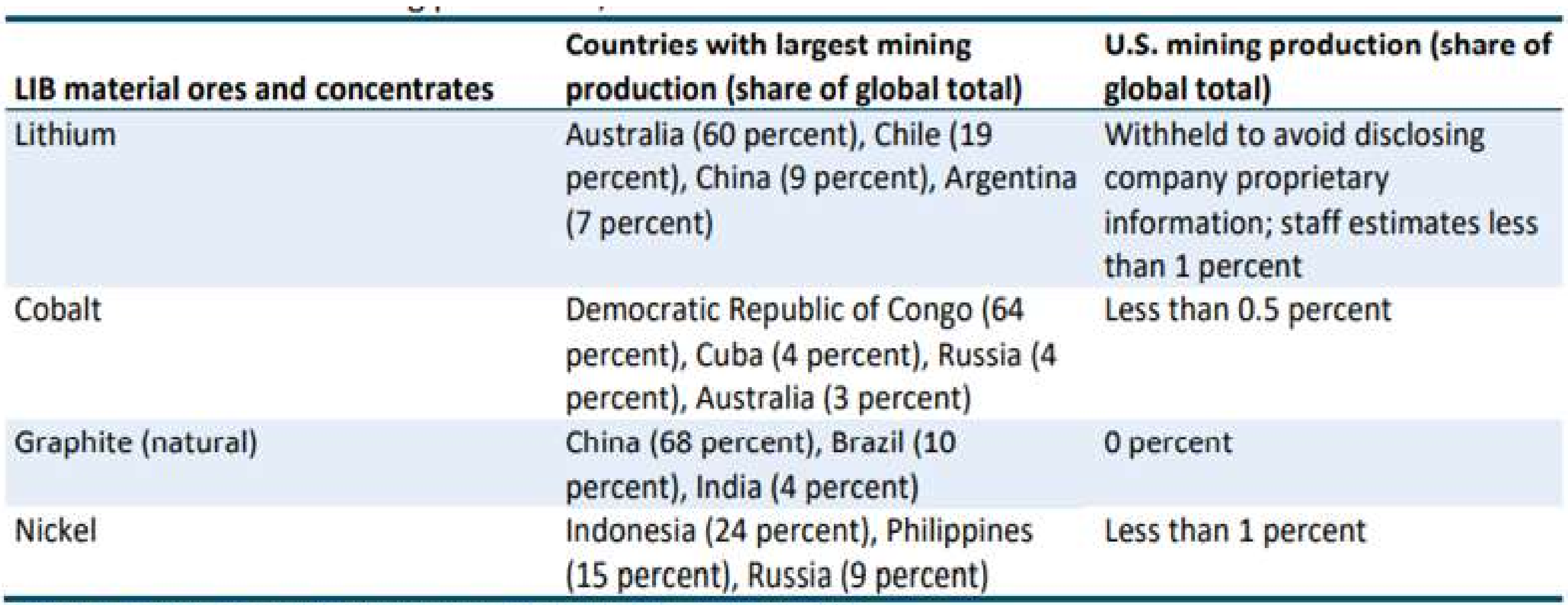


Components	Functions	Materials
Cathode	• Emit lithium-ion to anode during charging • Receive lithium-ion during discharging	lithium metal oxide powder
Anode	• Receive lithium-ion from anode during charging • Emit lithium-ion during discharging	Graphite powder
Electrolyte	• Pass lithium-ions between cathode and anode	Lithium salts and organic solvents
Separator	• Prevent short circuit between cathode and anode • Pass lithium ions through pores in separator	Micro-porous membranes





Name	Chemical term	Short name	EV models and other uses
Lithium Manganese Oxide	$LiMn_2O_4$	LMO or Li-manganese	EVs (e.g. Nissan Leaf), power tools, medical devices, electric powertrains
Lithium Nickel Manganese Cobalt Oxide	$LiNiMnCoO_2$	NMC	EVs (e.g. Chevy Bolt, BMW i3), E-bikes, medical devices, other
Lithium Iron Phosphate	$LiFePO_4$	LFP or Li-Phosphate	Energy storage
Lithium Nickel Cobalt Aluminum Oxide	$LiNiCoAlO_2$	NCA or Li-aluminum	EVs (e.g Tesla), other



LIB material ores and concentrates	Countries with largest mining production (share of global total)	U.S. mining production (share of global total)
Lithium	Australia (60 percent), Chile (19 percent), China (9 percent), Argentina (7 percent)	Withheld to avoid disclosing company proprietary information; staff estimates less than 1 percent
Cobalt	Democratic Republic of Congo (64 percent), Cuba (4 percent), Russia (4 percent), Australia (3 percent)	Less than 0.5 percent
Graphite (natural)	China (68 percent), Brazil (10 percent), India (4 percent)	0 percent
Nickel	Indonesia (24 percent), Philippines (15 percent), Russia (9 percent)	Less than 1 percent

Source: U.S. Geological Survey, Mineral Commodity Summaries, February 2019.

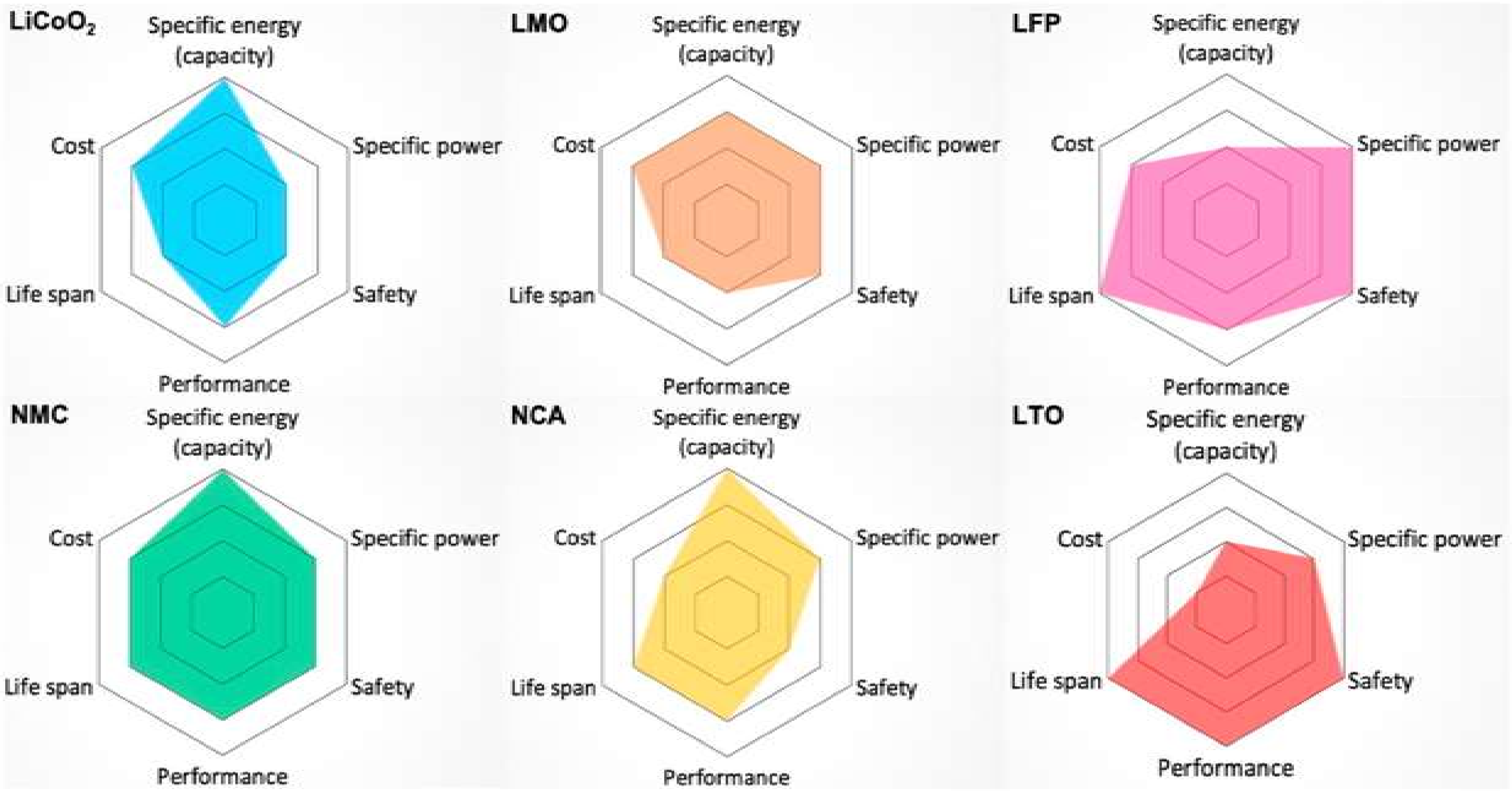
Advantages

- Li has greatest electrochemical potential
- Lighter than others
- Shape and size variation
- High open circuit voltage
- No memory effect
- Low discharge rate 5-10%.

Disadvantages

- Internal resistance of lithium ion battery is high as compared to other batteries.
- Due to overcharging and high temperature capacity will diminish.

Characteristics	Value
Cell voltage	1.2 – 1.35 V
Specific energy	40 – 110 Wh/kg
Specific power	200 – 300 W/kg
Energy density	40 – 300 kWh/m^3
Power density	10 – 600 kW/m^3
Efficiency	50 – 80 %
Working temperature	– 30 – 70 °C
Lifetime cycles	300 – 1800
Lifetime	2 - 15 years
Max. depth of discharge	100 %
Self-discharge rate	5 – 20 % per day
Power rating	0.01 – 3 MW
Energy cost	170 – 640 €/kWh
Power cost	200 – 470 €/kW


LiCoO$_2$
Specific energy (capacity)
Specific power
Safety
Performance
Life span
Cost
LMO
Specific energy (capacity)
Specific power
Safety
Performance
Life span
Cost
LFP
Specific energy (capacity)
Specific power
Safety
Performance
Life span
Cost
NMC
Specific energy (capacity)
Specific power
Safety
Performance
Life span
Cost
NCA
Specific energy (capacity)
Specific power
Safety
Performance
Life span
Cost
LTO
Specific energy (capacity)
Specific power
Safety
Performance
Life span
Cost

Prismatic cell

- High mechanical stability
- High packing density
- Lower energy density than pouch
- Used in phones

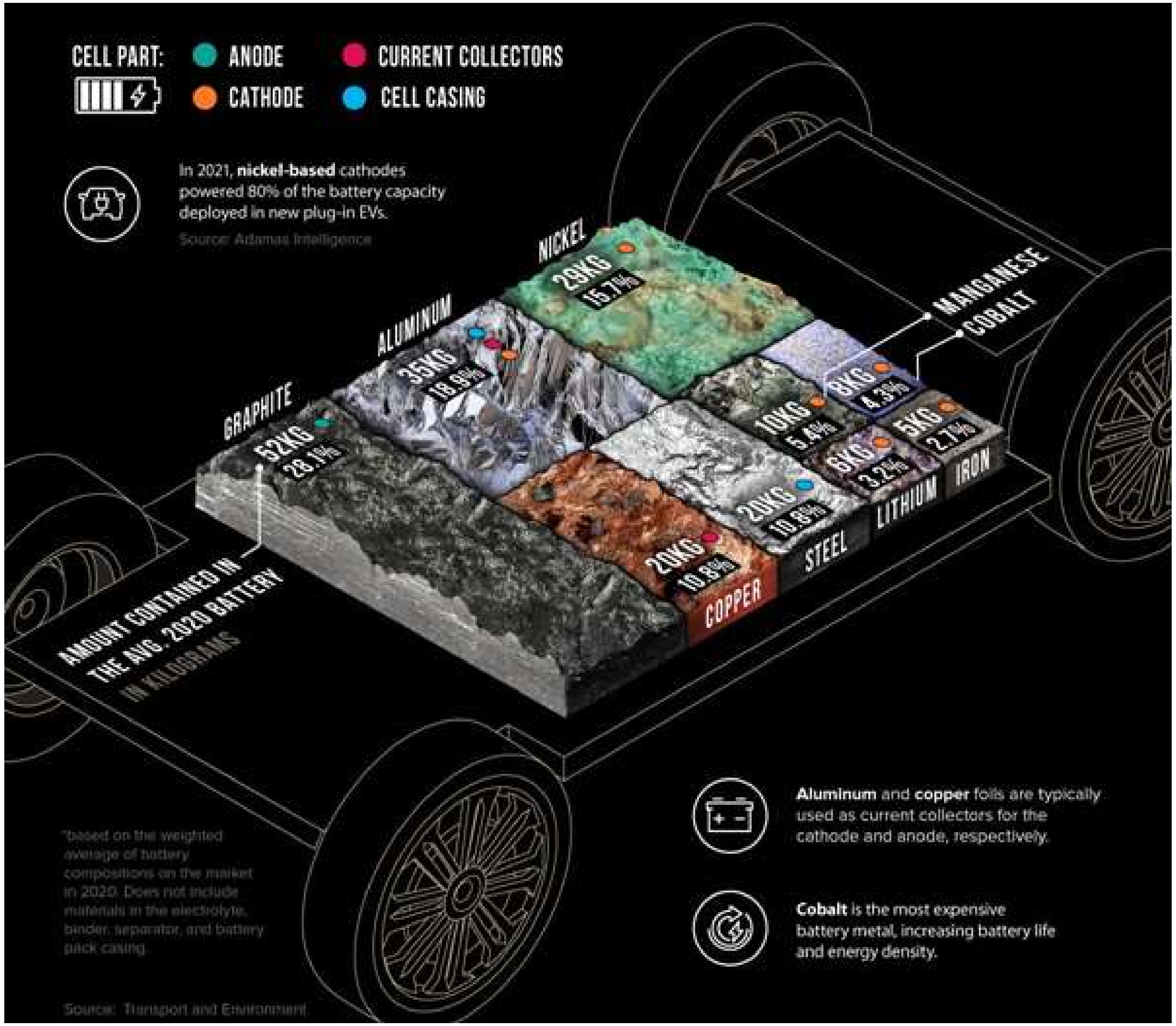
Cylindrical cell

- High mechanical stability
- Generally lower cost
- Most commonly available
- Used in power tools/EVs

18650 - 18 mm diameter,
65 mm long

Pouch cell

- Low mechanical stability
- High packing density
- High packing density
- Used in drones



In 2021, **nickel-based** cathodes powered 80% of the battery capacity deployed in new plug-in EVs.

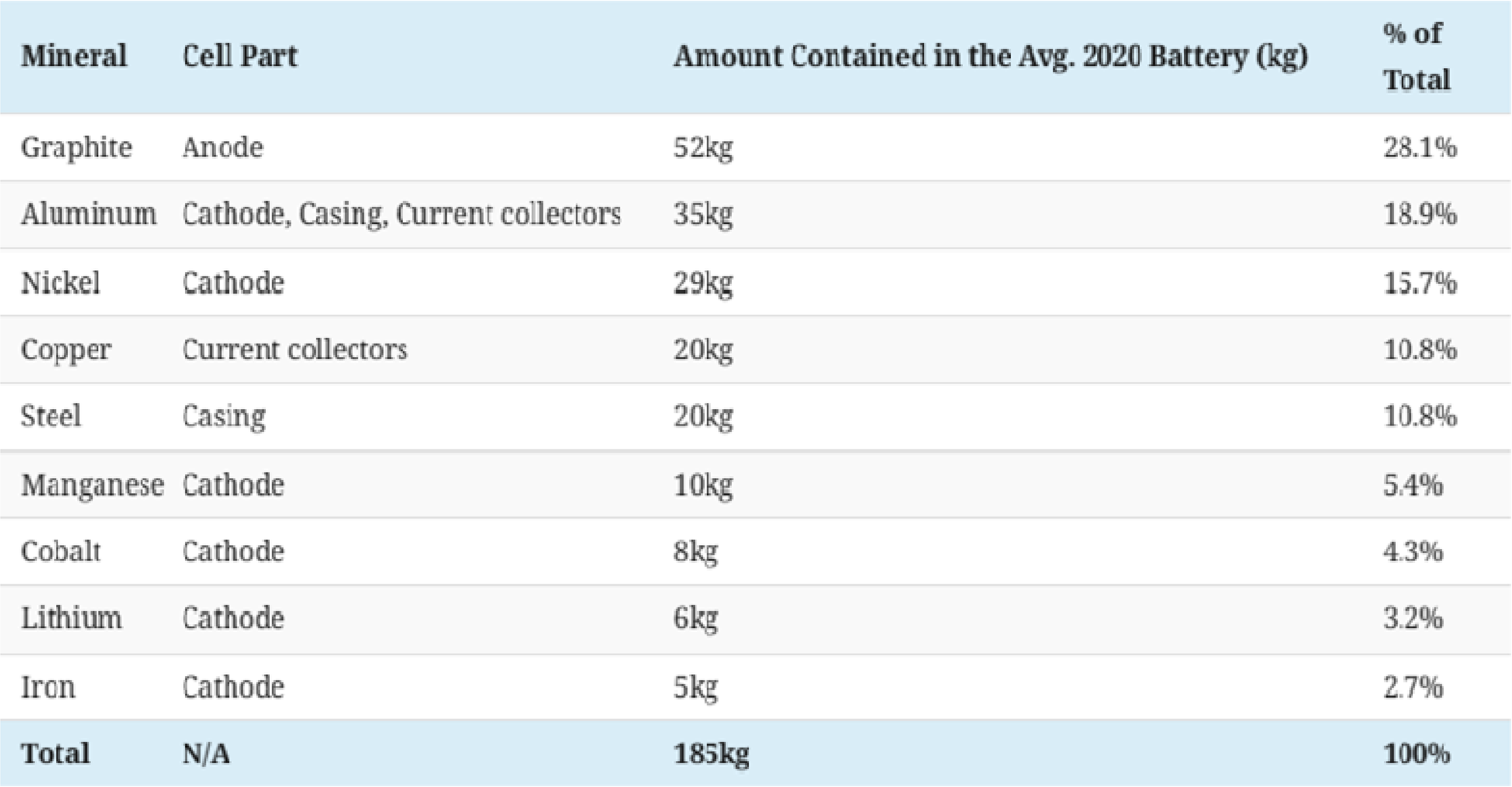
Source: Adamas Intelligence

Aluminum and **copper** foils are typically used as current collectors for the cathode and anode, respectively.

Cobalt is the most expensive battery metal, increasing battery life and energy density.

*based on the weighted average of battery compositions on the market in 2020. Does not include materials in the electrolyte, binder, separator, and battery pack casing.

Source: Transport and Environment



Mineral	Cell Part	Amount Contained in the Avg. 2020 Battery (kg)	% of Total
Graphite	Anode	52kg	28.1%
Aluminum	Cathode, Casing, Current collectors	35kg	18.9%
Nickel	Cathode	29kg	15.7%
Copper	Current collectors	20kg	10.8%
Steel	Casing	20kg	10.8%
Manganese	Cathode	10kg	5.4%
Cobalt	Cathode	8kg	4.3%
Lithium	Cathode	6kg	3.2%
Iron	Cathode	5kg	2.7%
Total	**N/A**	**185kg**	**100%**

Battery Minerals Mix

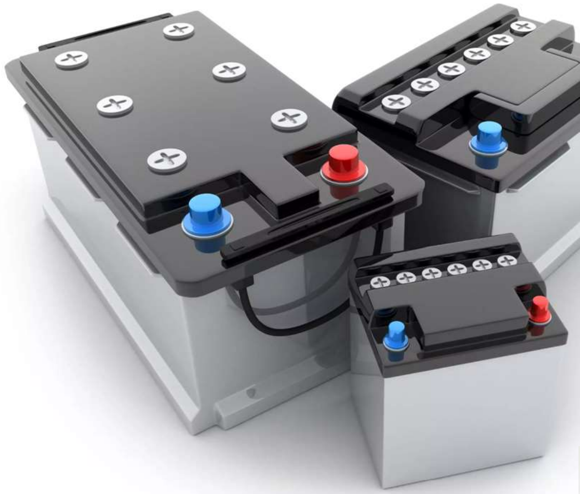
HOW BATTERY CHEMISTRIES DIFFER, BY MINERAL CONTENT

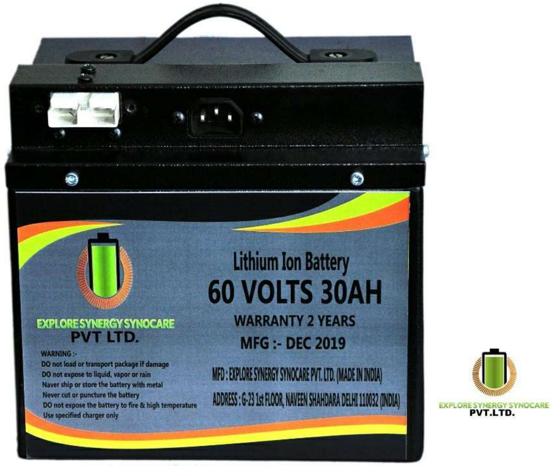
FOR A 60KWH LITHIUM-ION BATTERY

The name of the battery chemistry typically indicates the composition of the cathode.

	NMC811 Nickel (80%) Manganese (10%) Cobalt (10%)	**NMC523** Nickel (50%) Manganese (20%) Cobalt (30%)	**NMC622** Nickel (60%) Manganese (20%) Cobalt (20%)	**NCA+** Nickel Cobalt Aluminum Oxide	**LFP** Lithium iron phosphate
LITHIUM	5KG	7KG	6KG	6KG	6KG
COBALT	5KG	11KG	11KG	2KG	0KG
NICKEL	39KG	28KG	32KG	43KG	0KG
MANGANESE	5KG	16KG	10KG	0KG	0KG
GRAPHITE	45KG	53KG	50KG	44KG	66KG
ALUMINUM	30KG	35KG	33KG	30KG	44KG
COPPER	20KG	20KG	19KG	17KG	26KG
STEEL	20KG	20KG	19KG	17KG	26KG
IRON	0KG	0KG	0KG	0KG	41KG

ELEMENTS



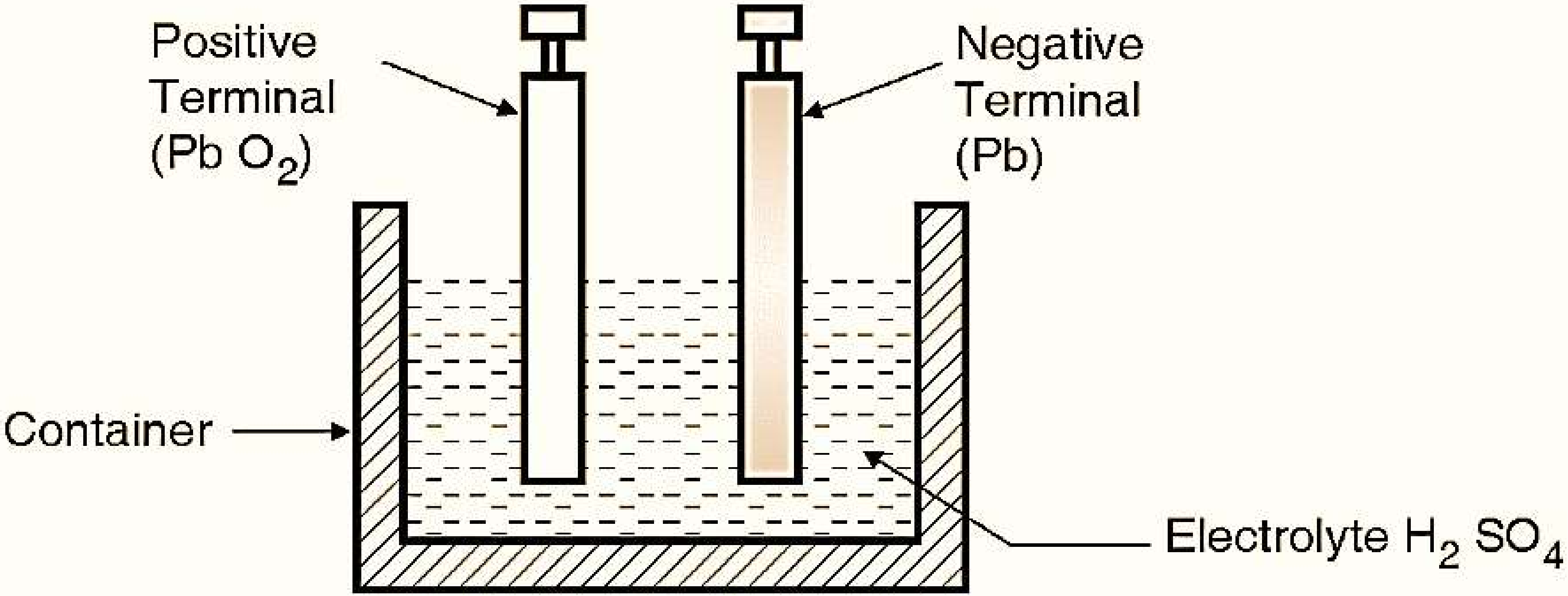

EXPLORE SYNERGY SYNOCARE
PVT LTD.
Lithium Ion Battery
60 VOLTS 30AH
WARRANTY 2 YEARS
MFG :- DEC 2019
WARNING :-
DO not load or transport package if damage
DO not expose to liquid, vapor or rain
Naver ship or store the battery with metal
Never cut or puncture the battery
DO not expose the battery to fire & high temperature
Use specified charger only
MFD : EXPLORE SYNERGY SYNOCARE PVT. LTD. (MADE IN INDIA)
ADDRESS : G-23 1st FLOOR, NAVEEN SHAHDARA DELHI 110032 (INDIA)
EXPLORE SYNERGY SYNOCARE
PVT.LTD.


Li-Ion
ELECTRIC
VEHICLE
BATTERY

LITHIUM ION MANUFACTURING

- The Indian Space Research Organisation has selected 10 companies for transfer of its Lithium-ion cell technology.
- Amara Raja Batteries Limited, Chittoor
- Bharat Electronics Limited, Pune
- Carborundum Universal Limited, Kochi
- Exicom Tele-Systems Limited, Gurgaon,
- GOCL Corporation Limited, Hyderabad
- National Aluminium Co Limited, Bhubaneswar
- Sukhbir Agro Energy Limited, New Delhi
- Tata Chemicals Limited, Mumbai
- Thermax Limited, Pune
- Jyoti CNC Automation Limited, Rajkot

LEAD ACID BATTERIES

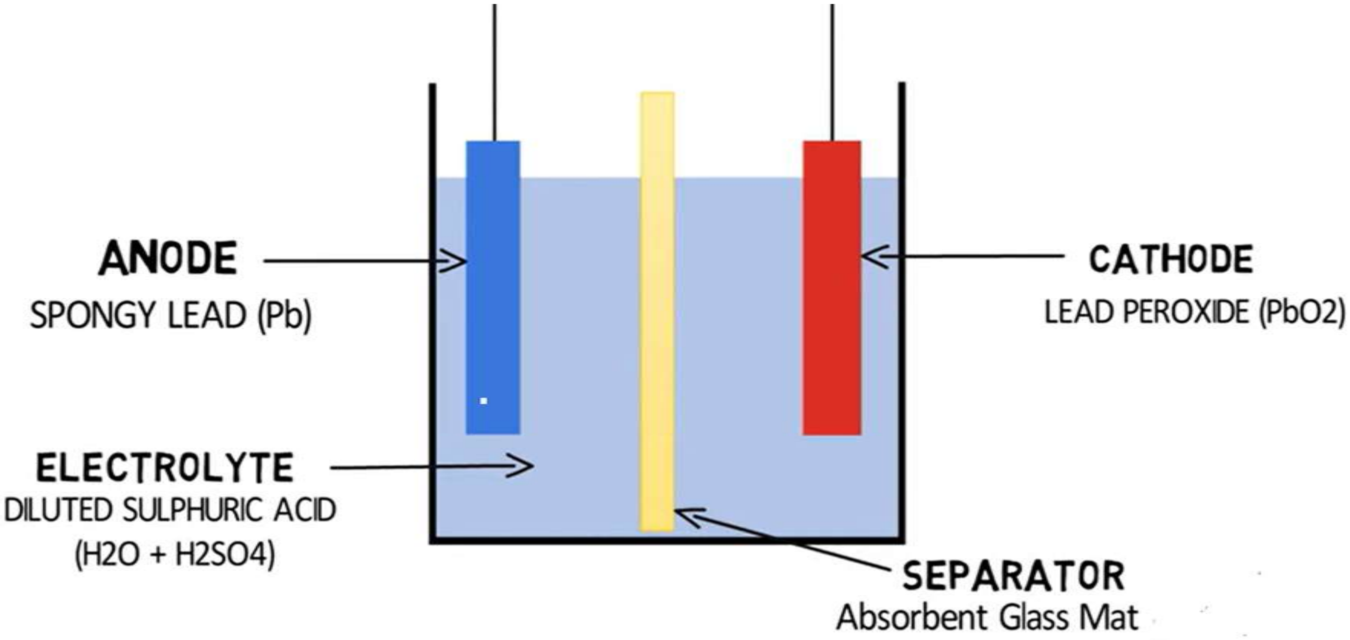

Positive
Terminal
(Pb O$_2$)
Negative
Terminal
(Pb)
Container
Electrolyte H$_2$ SO$_4$

Construction

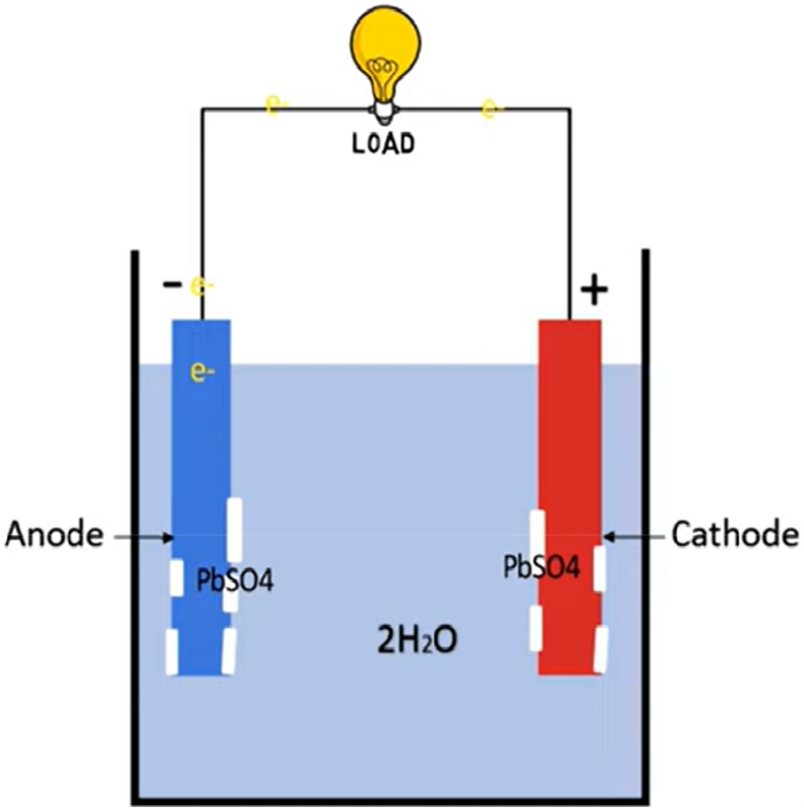
- Anode or positive terminal (or plate).
- Cathode or negative terminal (or plate).
- Electrolyte.
- Separators.

Construction

1. **Anode or positive terminal (or plate):** Lead peroxide (PbO2) [dark brown colour].
2. **Cathode or negative terminal (or plate)**: Lead (Pb) [gray].
3. **Electrolyte** : Dilute sulphuric acid (H2SO4) [3-parts of distilled water mixed with one part of H2SO4]
4. **Separators** : Thin plates - rubber.
5. **Container** : Plastic/ ceramic or rubber. All plates and electrolyte is placed in it.



Material of Lead acid battery



ELECTOLYTE:

$$2H_2SO_4 \rightarrow 4H^+ + 2SO_4^{2-}$$

AT ANODE:

$$Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$$

AT CATHODE:

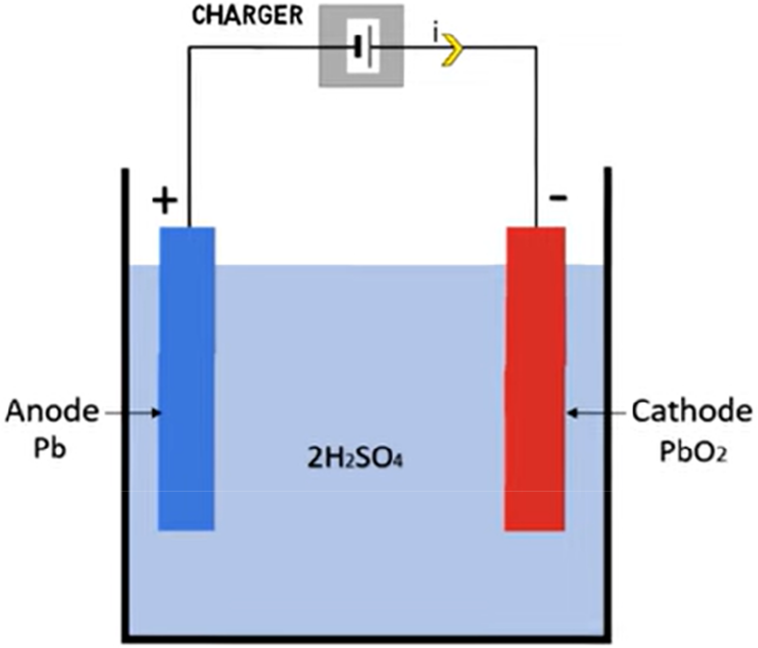
$$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$$

CELL REACTION:

$$PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$$

Discharging action of the cell

Electrolyte losses sulphuric acid and gains water



ELECTOLYTE:

$$2H_2O \rightarrow 4H^+ + 2O^{2-}$$

$$4H^+ + 2SO_4^{2-} \rightarrow 2H_2SO_4$$

AT ANODE:

$$PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$$

AT CATHODE:

$$PbSO_4 + 2O^{2-} \rightarrow PbO_2 + SO_4^{2-} + 2e^-$$

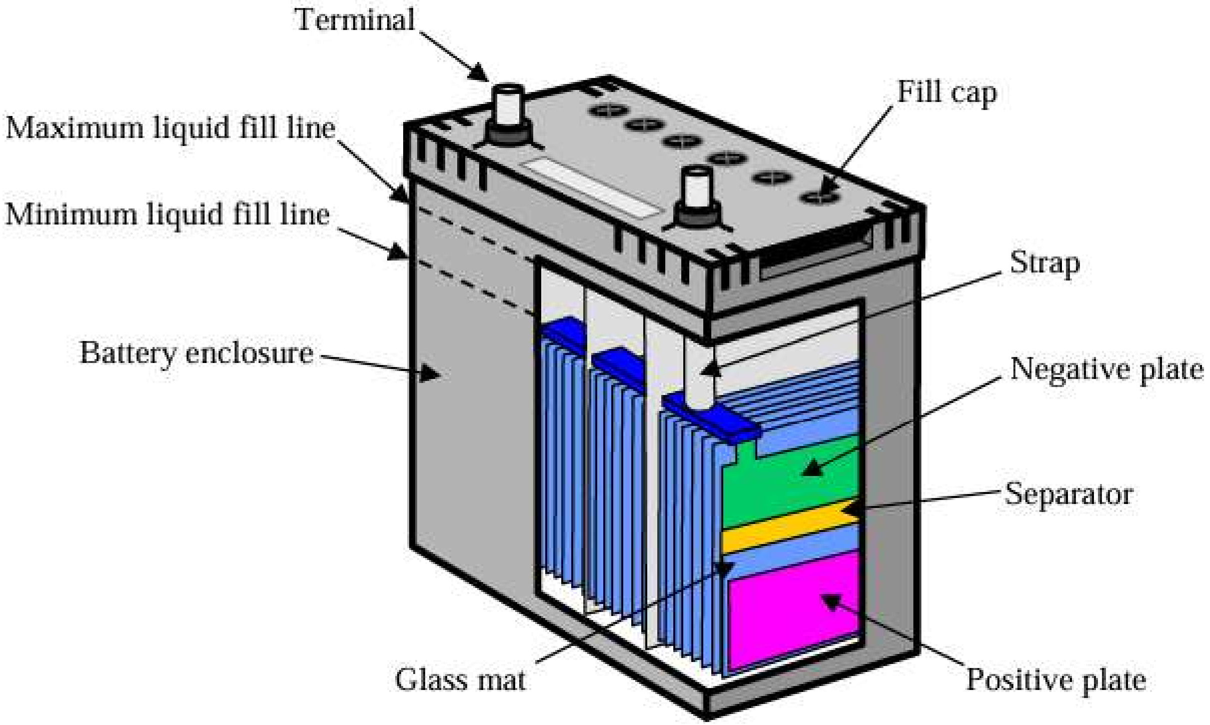
CELL REACTION:

$$2PbSO_4 + 2H_2O \rightarrow PbO_2 + Pb + 2H_2SO_4$$

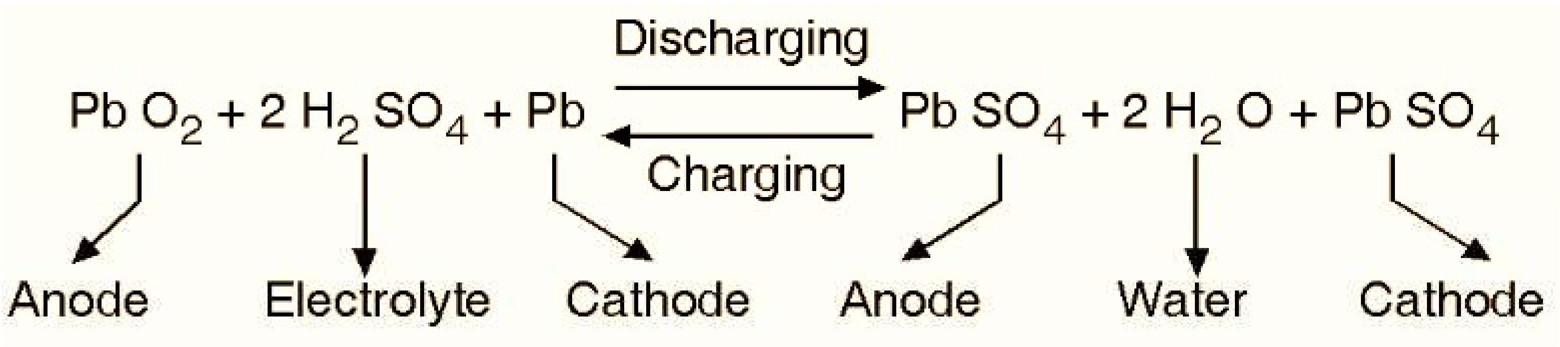
Charging action of the cell

Electrolyte sulphuric acid concentration increases

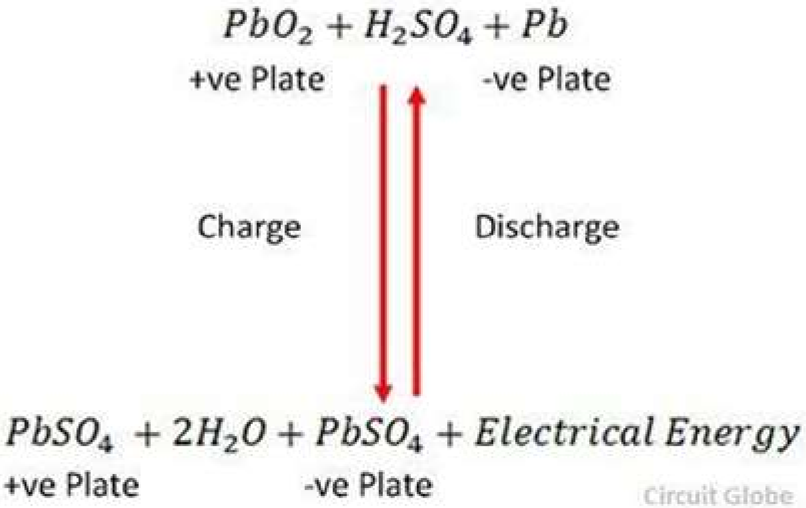
Parameter	Value
Nominal voltage	2 V
End-of-charge voltage	2.4 V
End-of-discharge voltage	1.75 V
Minimum SoC	20%
Maximum SoC	90%
Charging efficiency	89.5%
Discharging efficiency	89.5%



Structure of a vented lead-acid battery



$$PbO_2 + 2H_2SO_4 + Pb \underset{\text{Charging}}{\overset{\text{Discharging}}{\rightleftarrows}} PbSO_4 + 2H_2O + PbSO_4$$

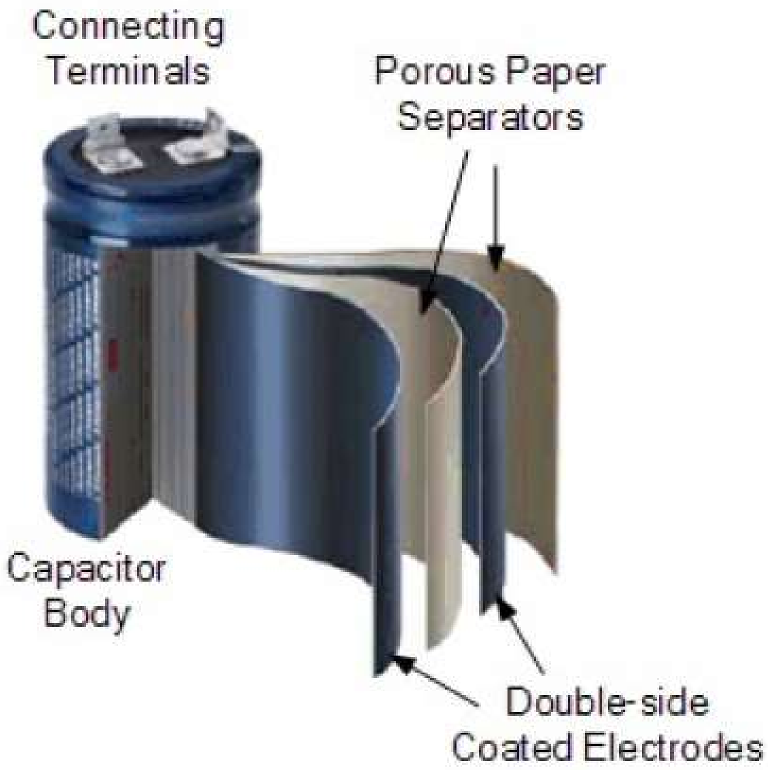

$PbO_2 + H_2SO_4 + Pb$
+ve Plate
-ve Plate
Charge
Discharge
$PbSO_4 + 2H_2O + PbSO_4 + Electrical\ Energy$
+ve Plate
-ve Plate

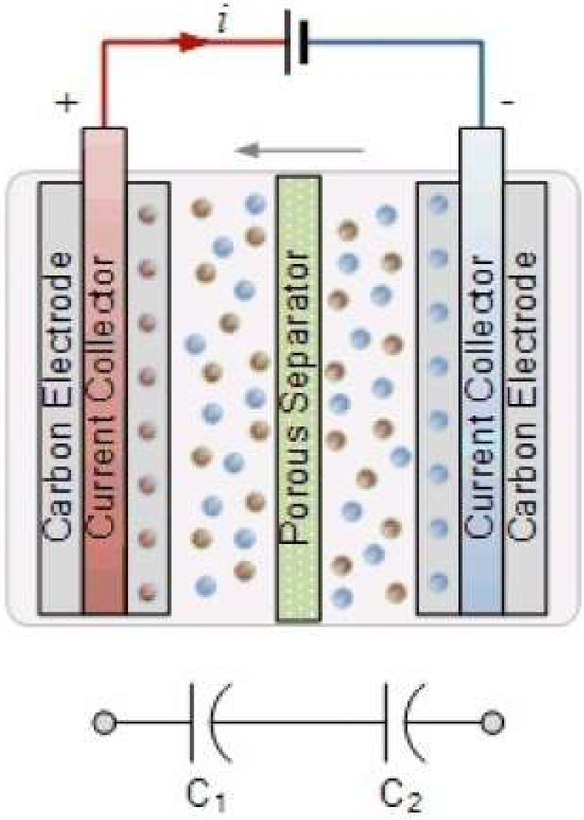

Maintenance-Free Battery
HI-POWER
75Ah - 12V
Maintenance-Fre
HI-POW
75Ah - 12V
5 year Guarantee


XUPAI®
Model No. 6-EVF-200
Constant Voltage Charge
Voltage Regulation
XUPAI POWER CO.,LTD
Made in China
WEB:http://www.xupai.com
CE


UPPER LEVEL
LOWER LEVEL
tp
TRUEPOWER
INVON BATTERY
ULTRA LOW MAINTENANCE HEAT SEALED BATTERY
EXTRA HEAVY DUTY, EXTRA POWER
JAPANESE TECHNOLOGY

Supercapacitor


Connecting Terminals
Porous Paper Separators
Capacitor Body
Double-side Coated Electrodes


i
+
-
Carbon Electrode
Current Collector
Porous Separator
Current Collector
Carbon Electrode
C_1
C_2

❖ Energy Storage: Ultracapacitors

1. Store energy as an **electric charge** in a polarized liquid layer between an ionically electrolyte and conducting electrode
2. Primarily used for acceleration, climbing hills and regenerative braking
3. A capacitor (originally known as condenser) is a passive two-terminal electrical component used to store energy in its electric field.
4. When a capacitor is attached across a battery, an electric field develops across the dielectric, causing positive charge +Q to collect on one plate and negative charge −Q to collect on the other plate.

Using HESS system in place of conventional Energy systems

- Ultracapacitors are introduced in to the system, which act as a buffer that gives to Energy systems
- Battery will only provide power directly whenever the Ultracapacitor voltage drops below battery voltage. Therefore, a relatively constant load profile is created for the battery also satisfying the real-time peak power demands
- Battery is not used to directly harvest energy from the regenerative braking; thus, the battery is isolated from frequent charges, which will increase battery life.

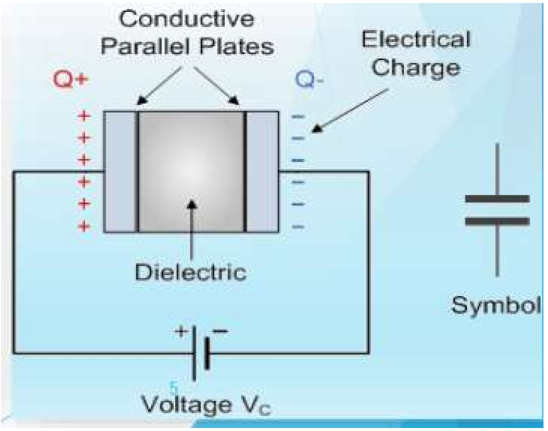
- A capacitor is made up of two conductors separated by an insulator called dielectric

$C = \frac{\varepsilon_0 A}{D}$ ε_0 = Dielectric constant or Permittivity of the medium

A = Area of the plates

D = Distance between the plates

- The dielectric can be made of paper, plastic, mica, ceramic, glass, a vacuum or nearly any other nonconductive material
- When a potential difference applied across the capacitor, electric field develops across the dielectric causing positive charge +Q to collect on one plate and negative charge −Q to collect on the other plate

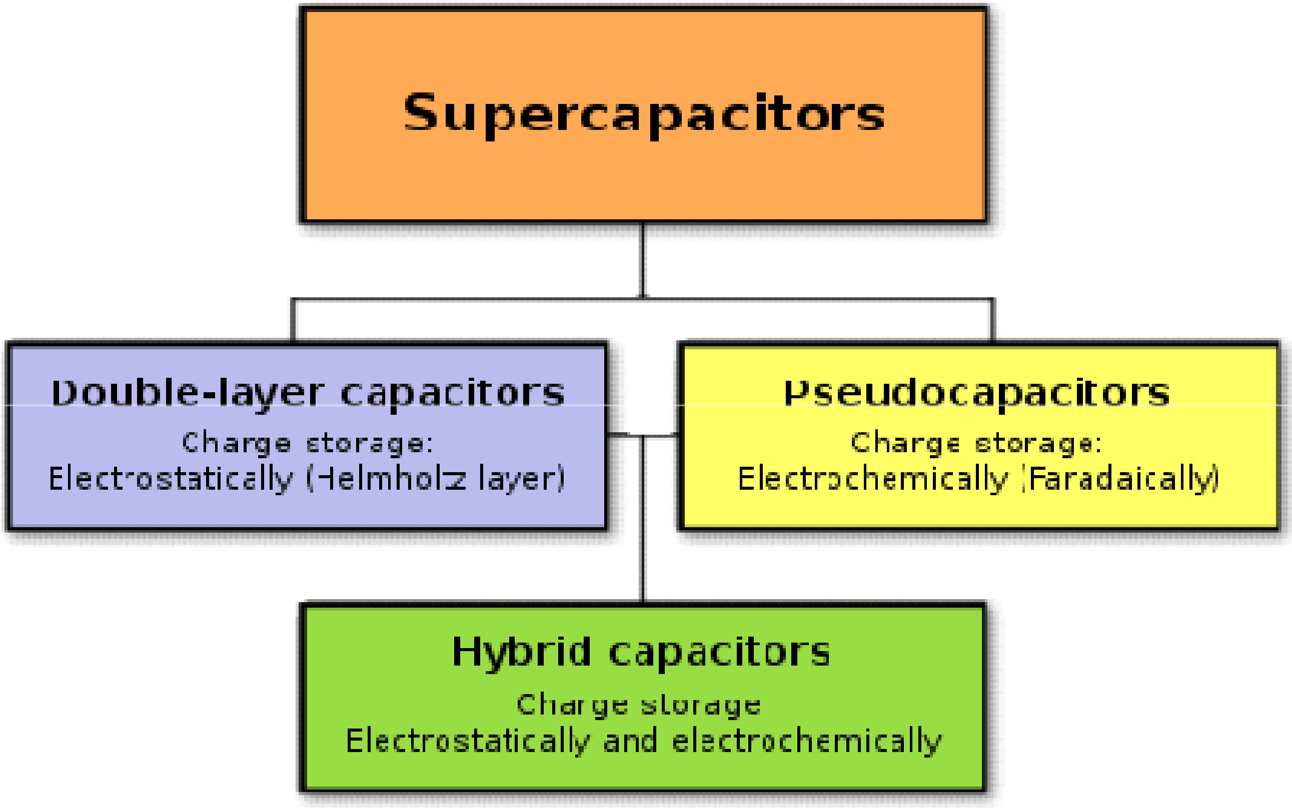


Ultracapacitors

- Also called Supercapacitors or Double layer capacitors , Invented by engineers at Standard Oil of Ohio(SOHIO) in 1966
- High-capacity electrochemical capacitor with capacitance value much higher than other capacitors that bridge the gap between electrolytic capacitors and rechargeable batteries
- 10 to 100 times more energy per unit volume than electrolytic capacitors
- Capacitance ranges up to **5000f**
- **Principle**:- Energy is stored in ultracapacitor by polarizing the electrolytic solution.
- The charges are separated via electrode–electrolyte interface
- Types

a. EDLC(Electrochemical Double Layer),

b. Pseudocapacitors and Hybrid capacitors


Supercapacitors
Double-layer capacitors
Charge storage:
Electrostatically (Helmholz layer)
Pseudocapacitors
Charge storage:
Electrochemically (Faradaically)
Hybrid capacitors
Charge storage
Electrostatically and electrochemically

An ultracapacitor cell basically consists of two electrodes, a separator, and an electrolyte

- As ,

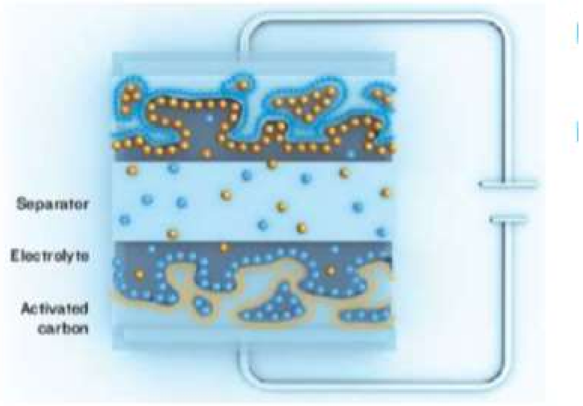
$C = \varepsilon 0 A / D$,in order to increase the capacitance, need to change A, Materials with highest specific surface area used for electrodes

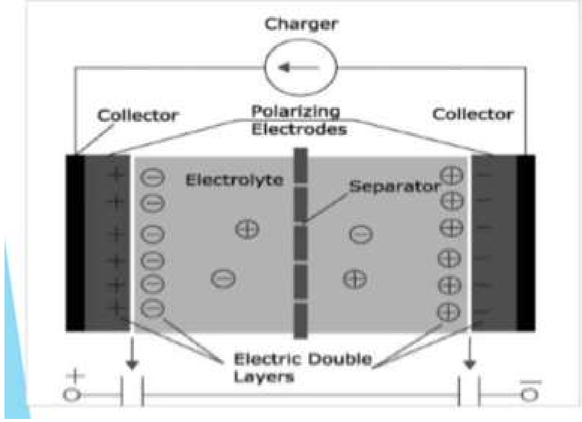
eg: Highly porous carbon , Activated carbon, Carbon nanotubes , graphite etc.

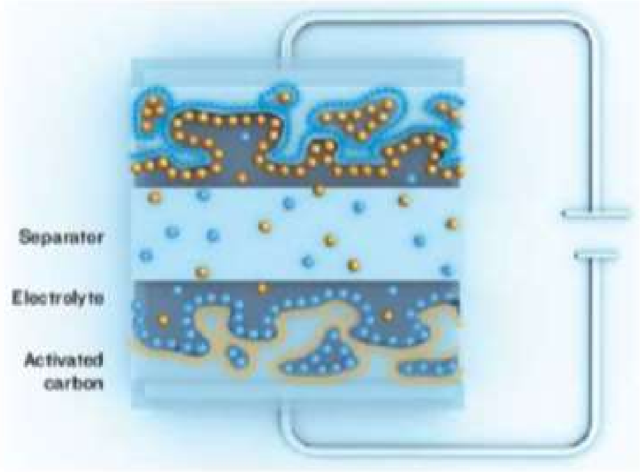
D - The distance between the plates is in the order of angstroms(10-10 meters)

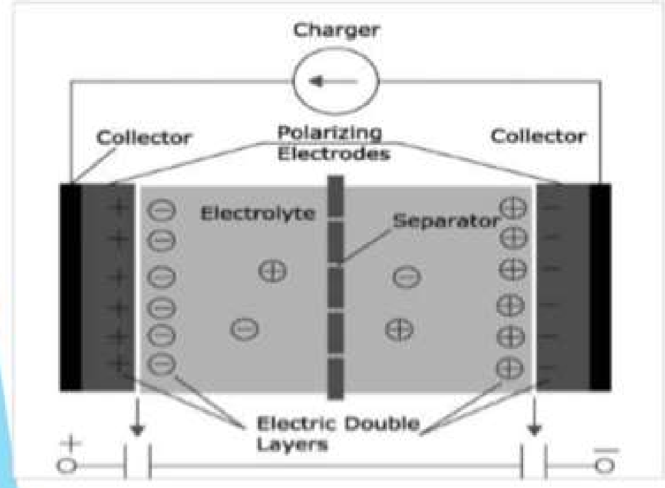
$\varepsilon 0$ - Electrolytic solution with high conductivity and adequate electrochemical stability

- Separator is to prevent the charges moving across the electrodes
- The amount of energy stored is very large as compared to standard capacitor, the small charge separation created by the dielectric separator.

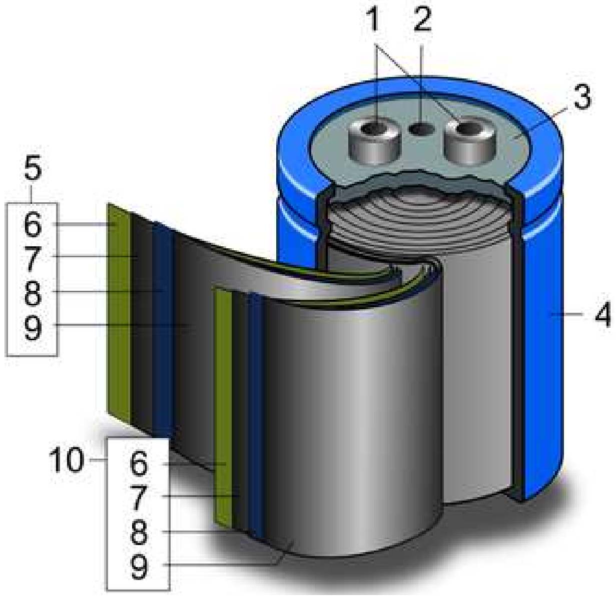





Separator
Electrolyte
Activated carbon

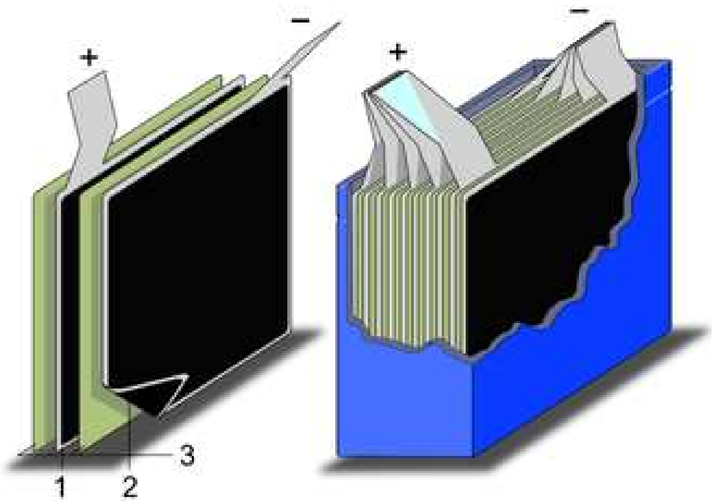

Charger
Collector
Polarizing Electrodes
Collector
Electrolyte
Separator
Electric Double Layers
+
−

- Supercapacitors are constructed with two metal foils, each coated with an electrode material such as activated carbon.
- The electrodes are kept apart by an ion permeable membrane (separator) used as an insulator to protect the electrodes against short circuits.
- The construction is subsequently rolled or folded into a cylindrical or rectangular shape and is packed in an aluminum can



Schematic construction of a wound supercapacitor

1. terminals, 2. safety vent, 3. sealing disc, 4. aluminum can, 5. positive pole, 6. separator, 7. carbon electrode, 8. collector, 9. carbon electrode, 10. negative pole



Schematic construction of a supercapacitor with stacked electrodes

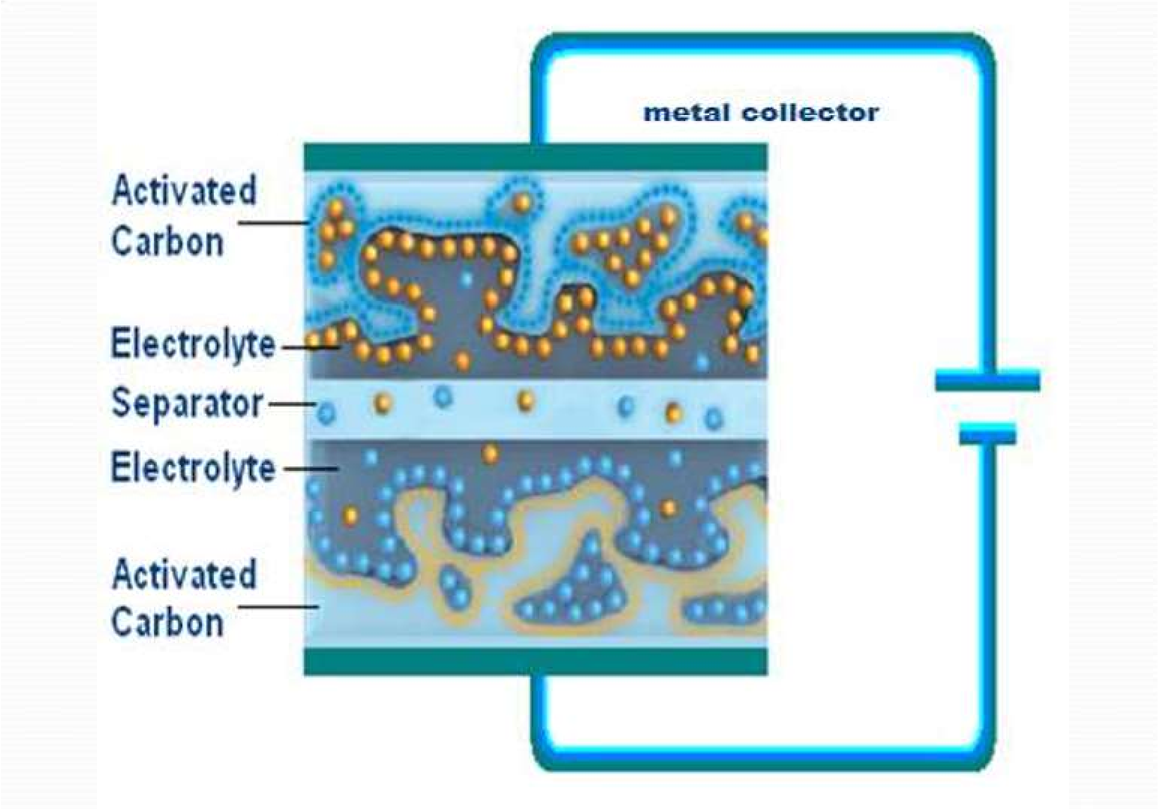
1. positive electrode, 2. negative electrode, 3. separator

WORKING OF SUPERCAPACITOR

I. In a supercapacitor, there is no conventional dielectric. Both plates are soaked in an electrolyte and separated by a very thin insulator.

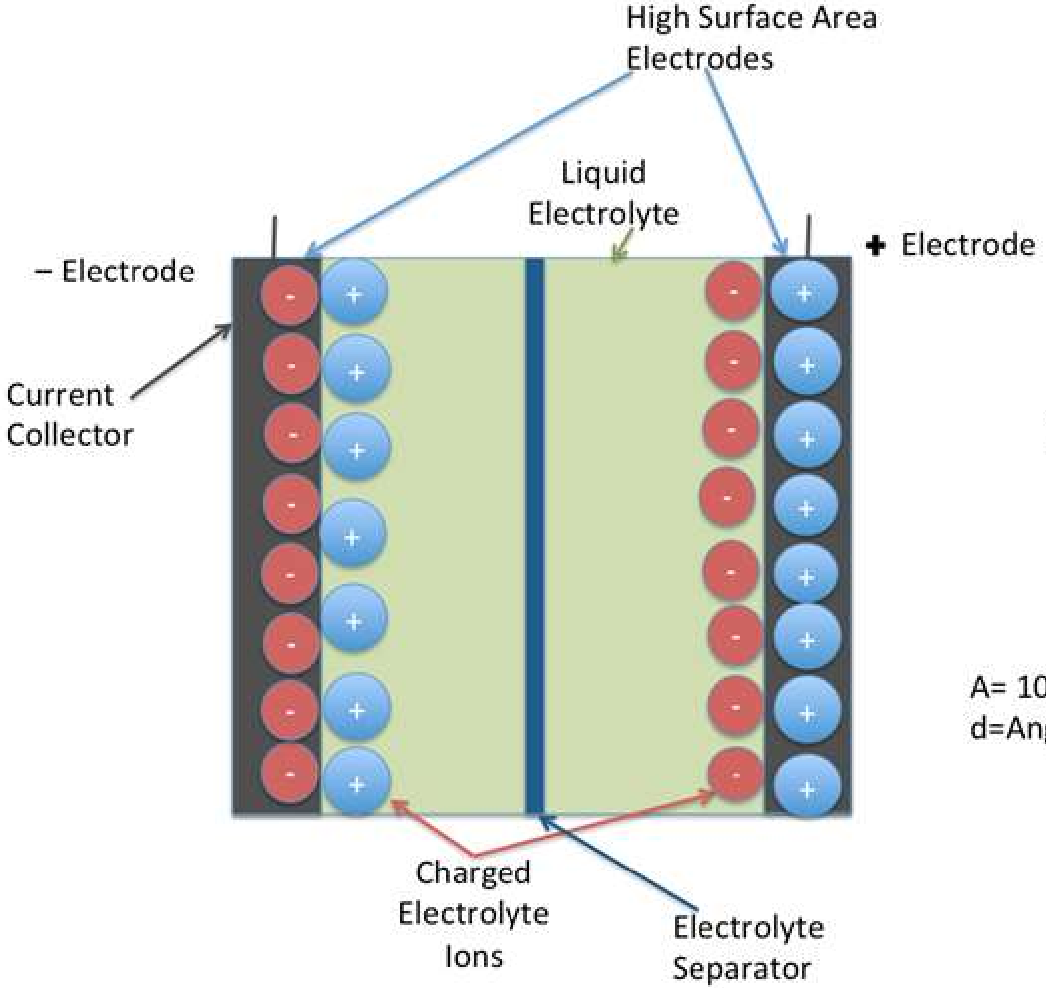
II. When the plates are charged, an opposite charge forms on either side of the separator, creating what's called an electric doublelayer.

III. This is why supercapacitors are often referred to as double-layer capacitors


metal collector
Activated Carbon
Electrolyte
Separator
Electrolyte
Activated Carbon

❖ TECHNOLOGY USED

1. Carbon nano tubes, carbon aerogels are used for supercapacitors plates or electrodes.
2. Sodium perchlorate (NaClO4) or lithium perchlorate (LiClO4) are used as electrolytes.
3. Polyacrylonitrile(C3H3N)n is used as a separator(thickness 0.3-0.8 nm).
4. Aluminium as a packing component.



High Surface Area Electrodes

Liquid Electrolyte

− Electrode

+ Electrode

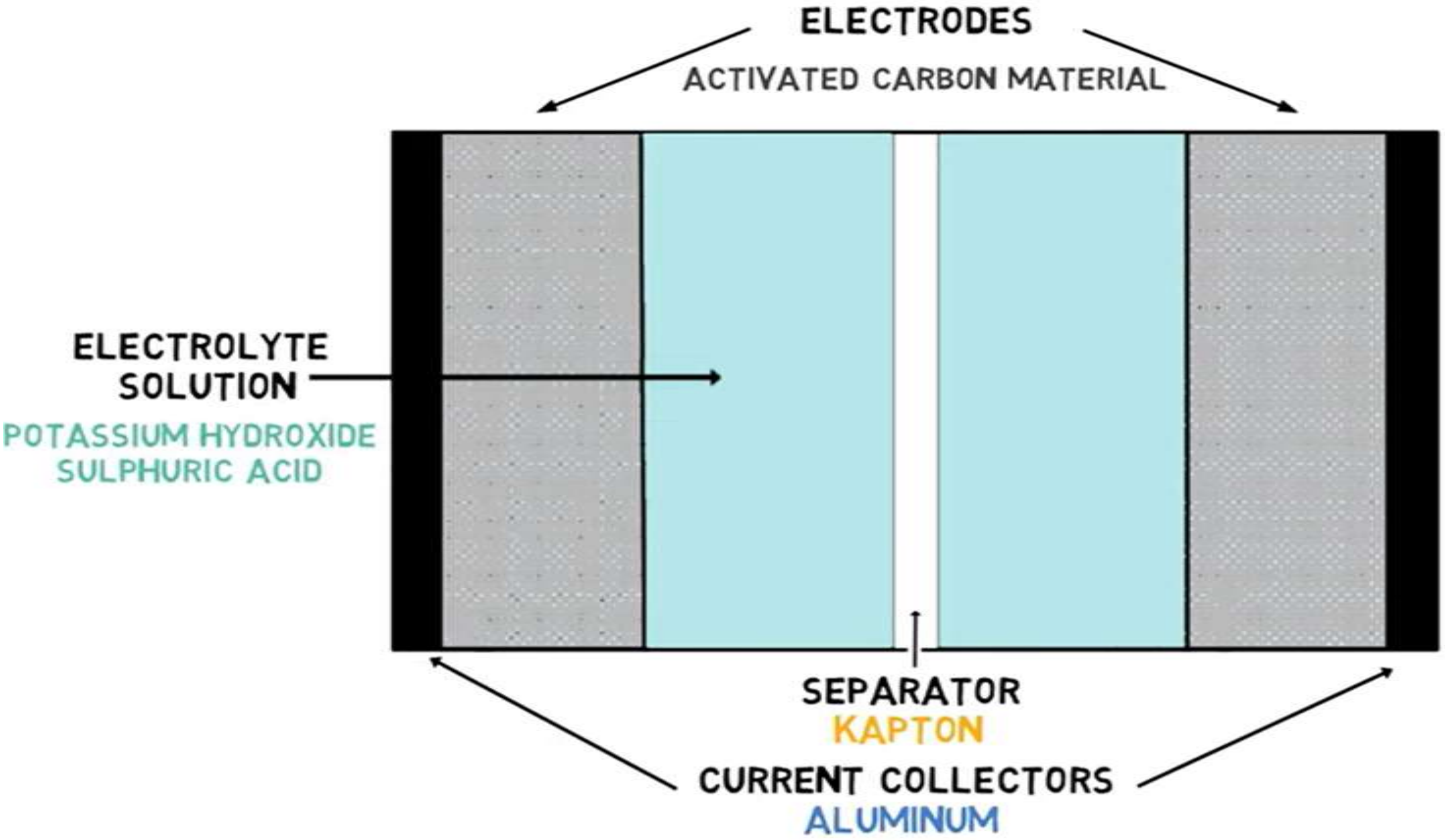
Current Collector

Charged Electrolyte Ions

Electrolyte Separator

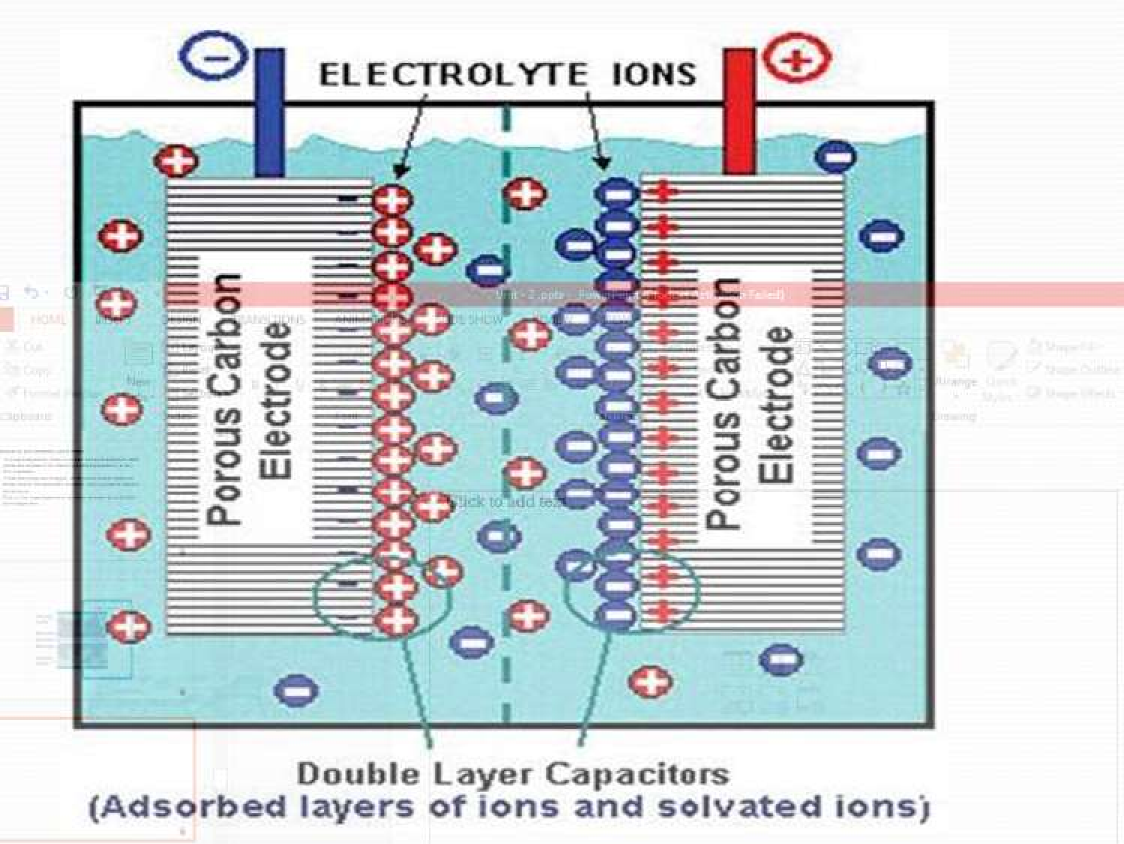
$$C \propto \frac{A \uparrow\uparrow}{d \downarrow\downarrow}$$

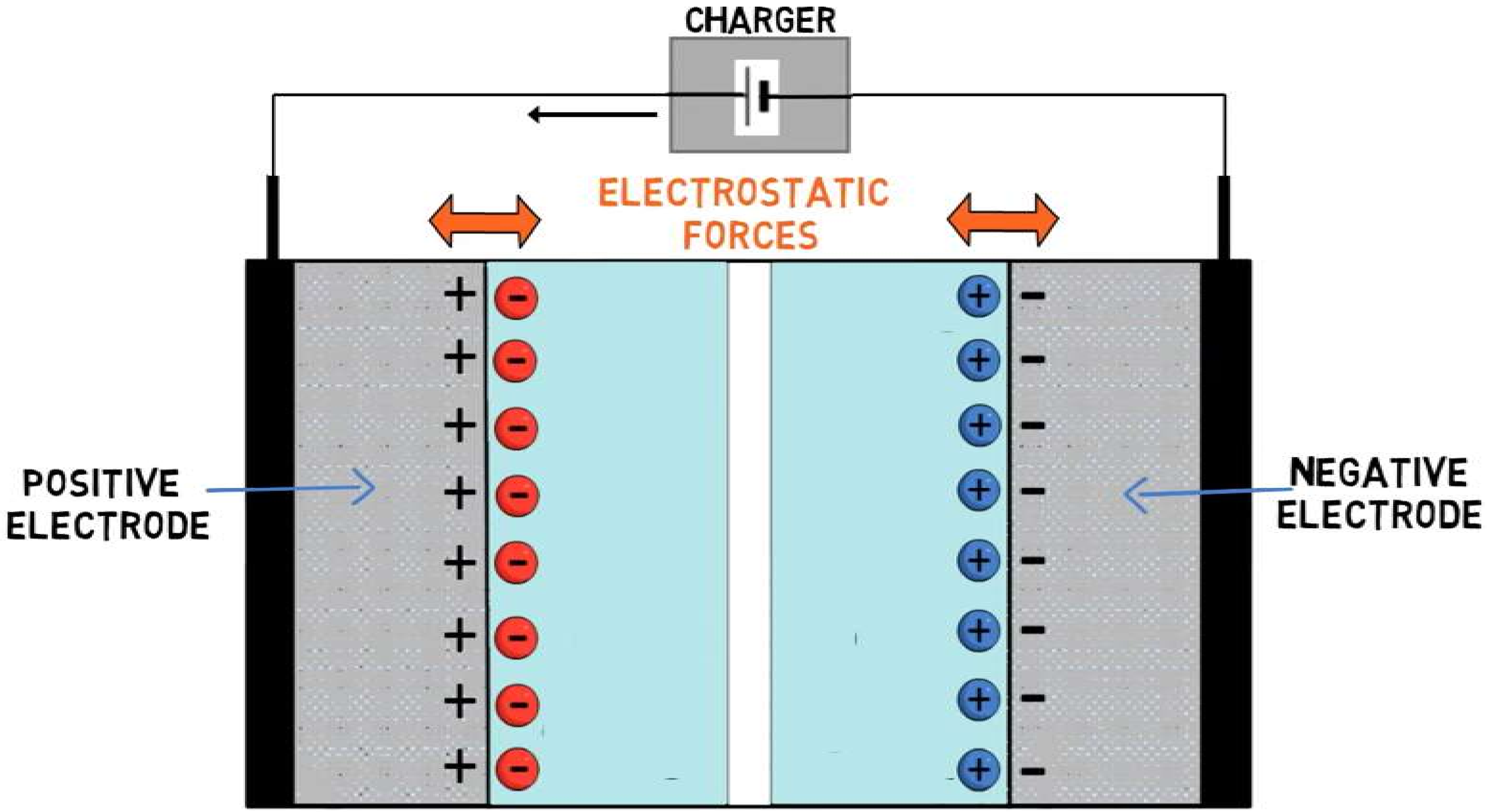
A= 1000 or more m^2/g
d=Angstroms


ELECTRODES
ACTIVATED CARBON MATERIAL
ELECTROLYTE SOLUTION
POTASSIUM HYDROXIDE
SULPHURIC ACID
SEPARATOR
KAPTON
CURRENT COLLECTORS
ALUMINUM

Material

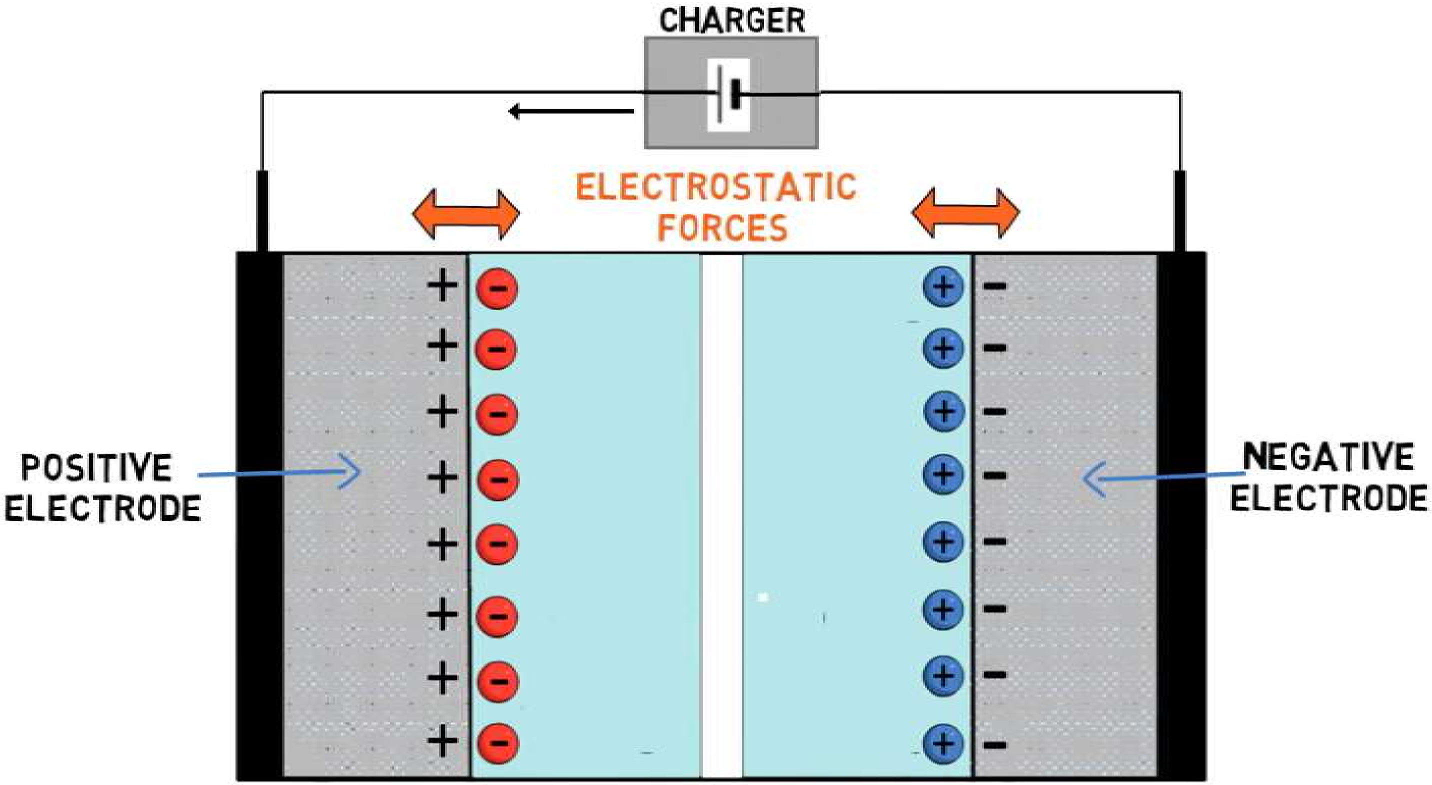
- **STRUCTURE OF EDLC**





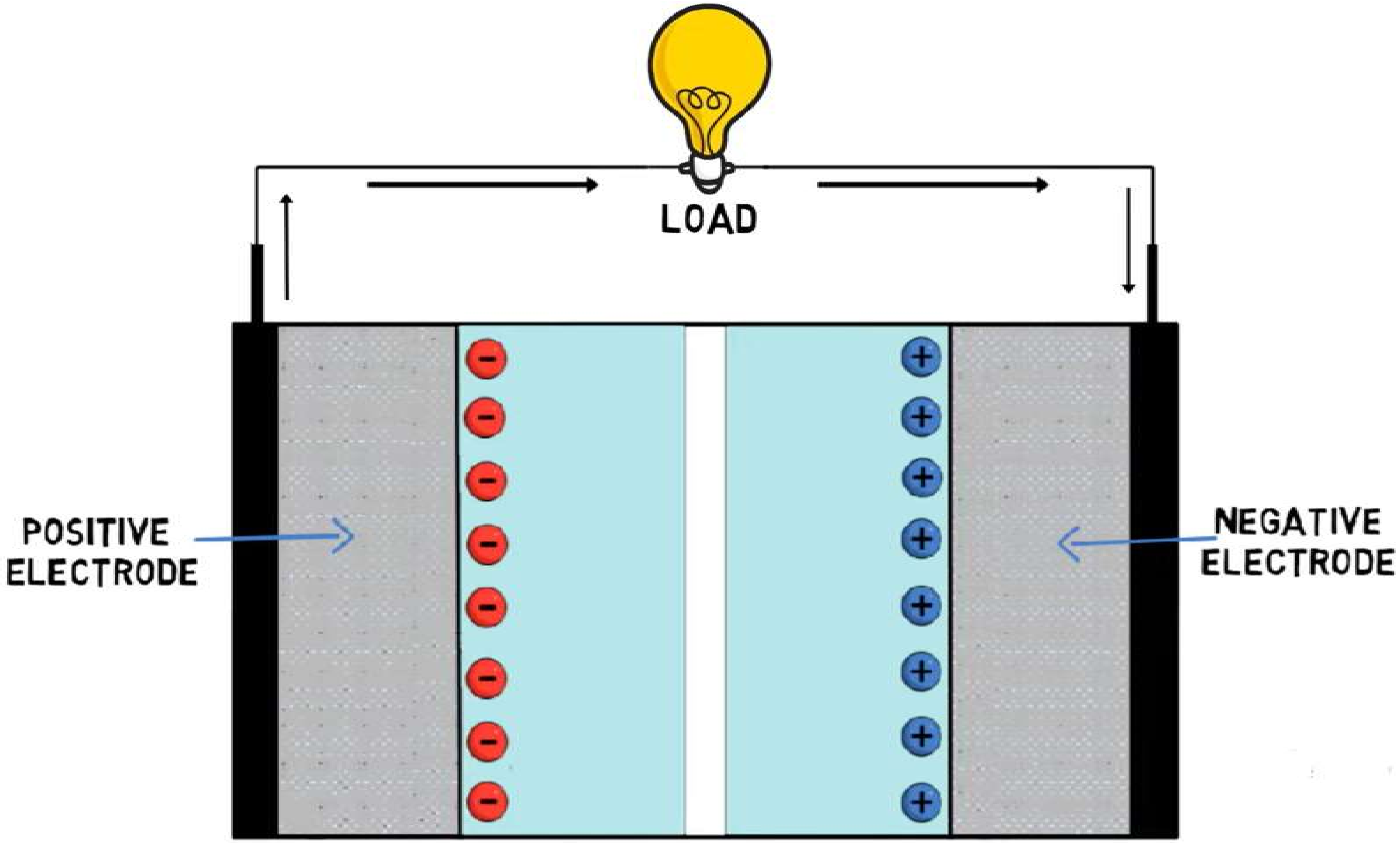
ALIGNMENT OF POSITIVE & NEGATIVE CHARGES

BOUNDARIES OF ELECTRODES & ELECTROLYTIC SOLUTION

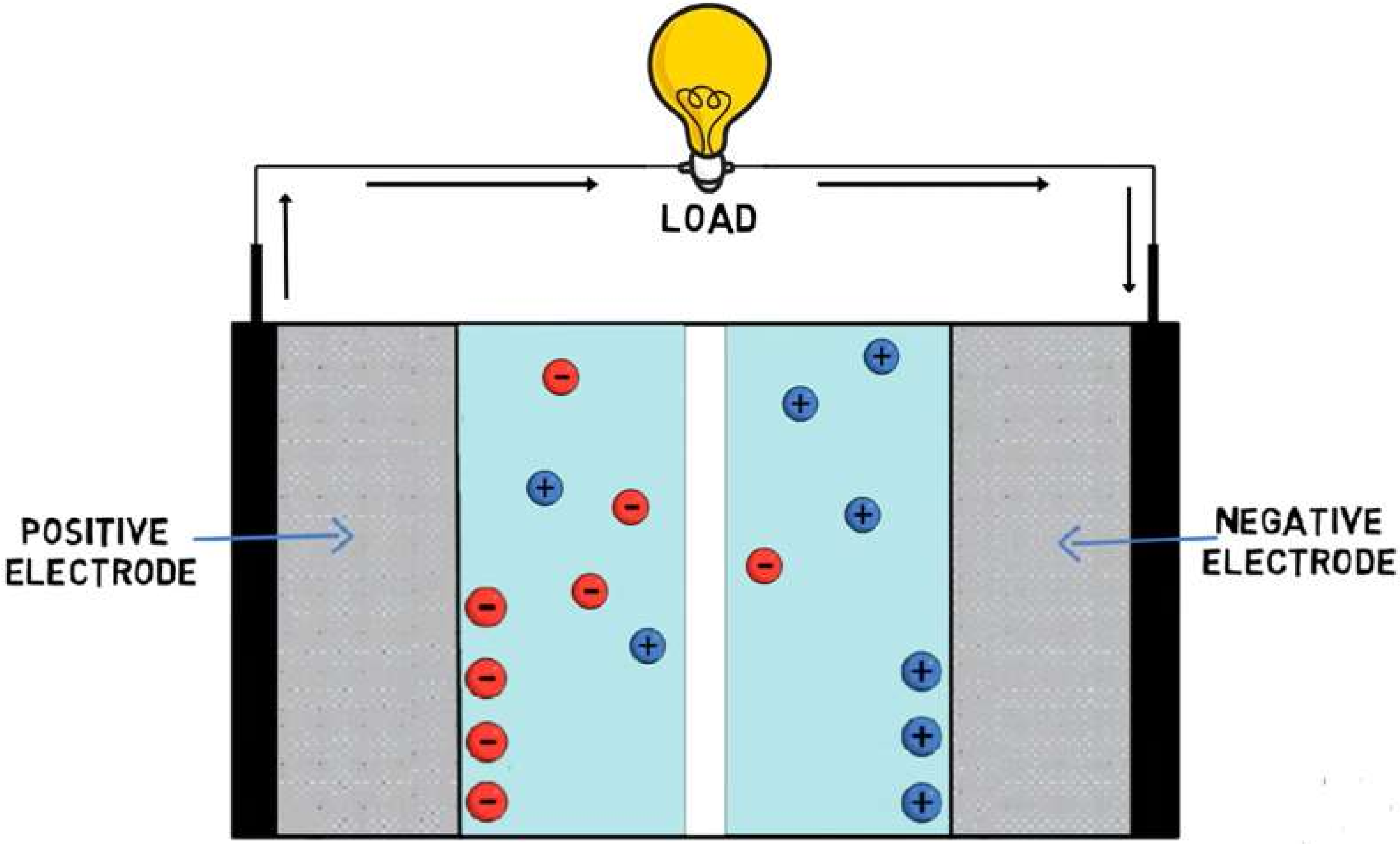


"ELECTRIC DOUBLE LAYER"

ELECTRICAL DOUBLE LAYER CAPACITOR (EDLC)



Discharging


LOAD
POSITIVE ELECTRODE
NEGATIVE ELECTRODE

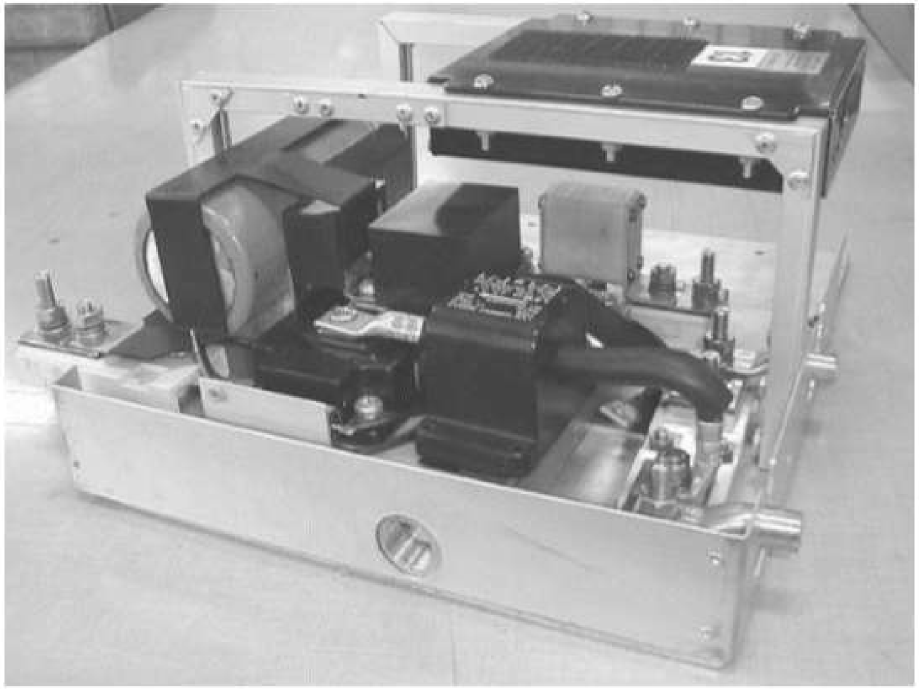
Advantages

- **Long life**: It works for large number of cycles without wear and aging
- **High power storage**: It stores huge amount of energy in a small volume
- **Very high rates of charge and discharge:** Ultracapacitor charges within seconds whereas batteries takes hours
- High cycle efficiency (95% or more)
- High specific power up to 17 kW/kg
- Wide working temperature(-400c to 600c).
- Eco-friendly
- Extremely low internal resistance.
- Quick charging time
- Safe

Drawbacks

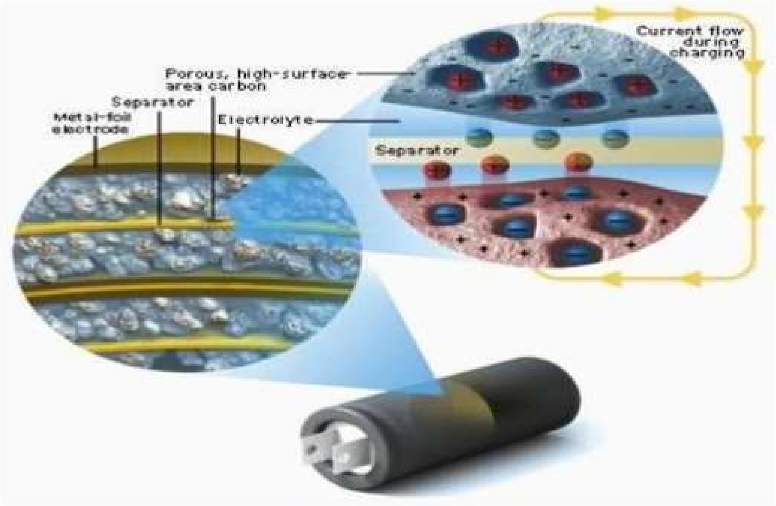
- Power density is low, incompatible to meet peak power demands ; usually holds 1/5 – 1/10 of a battery.
- Batteries with higher power densities are of higher cost and large size
- Needs intensive thermal management systems, to cool it and also to warm it up in cold temperatures
- Have high self-discharge rate.
- Individual cells have low voltages, and so serial connections are needed to obtain higher voltages.
- Requires expert electronic control.
- Cannot be used in AC and high frequency circuits.

- It cannot be used for high rate charge discharge operations, which causes unbalance of voltages between individual cells eventually the total capacity decreases [**Cannot use the full energy spectrum for some applications**.]
- Vehicles in most driving conditions requires instantaneous power input and output, a conventional battery(with cycle life up to 2000 times) is inappropriate for this application

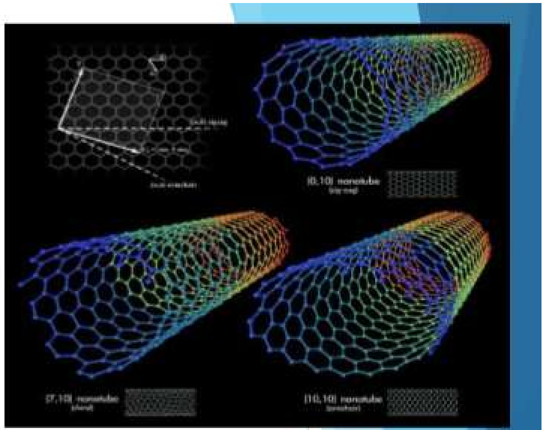



+
Maxwell
BOOSTCAP
Type: BCAP0013
C: 450 F
U: 2.5 V

Activated carbon



Inside-ultracapacitor



Carbon nanotubes


Maxwell
TECHNOLOGIES
Maxwell
Maxwell
Maxwell

Lamborghini Sian

TOYOTA FCHV

Capabus of CHINA

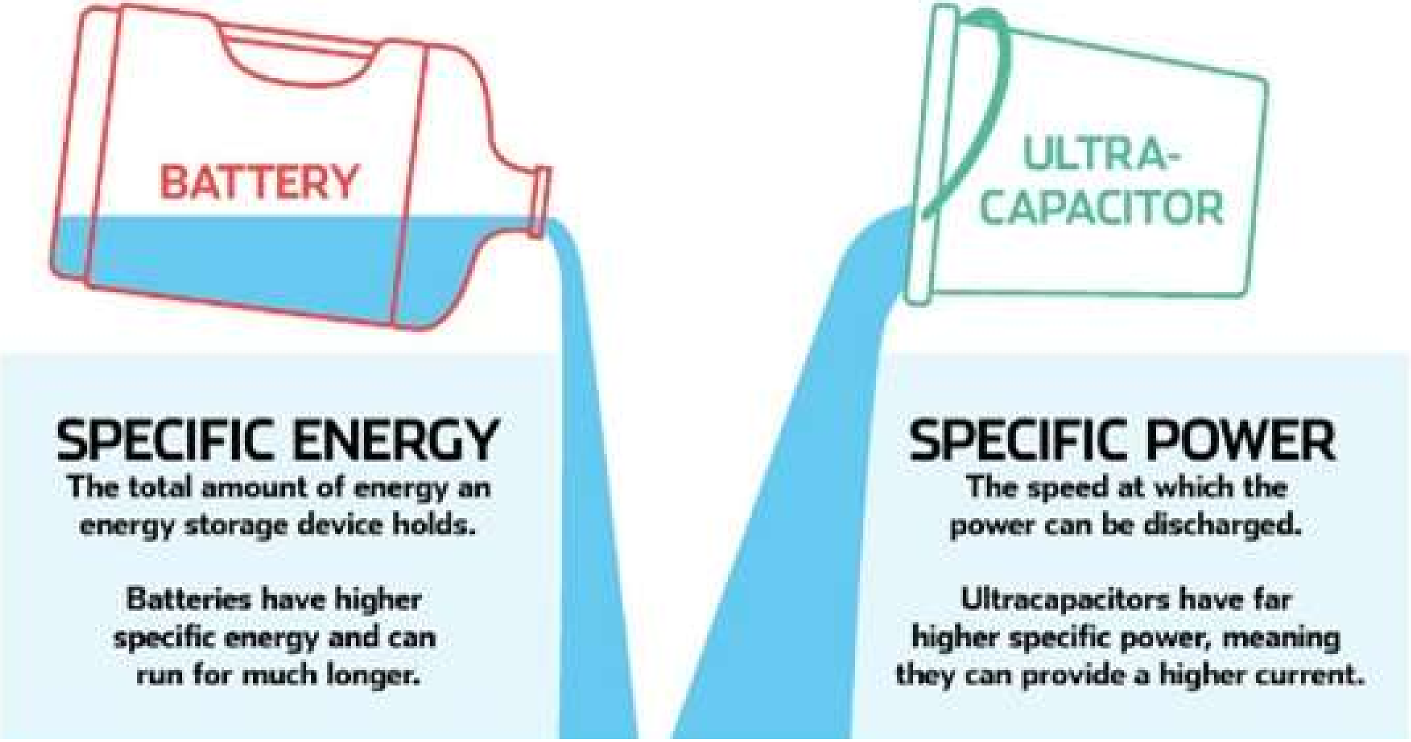
Hyderabad battery tech startup GODI makes India's first 3000F high power supercapacitors for EVs,

Supernova Sports Car

Gujarat-based **Golden Arrow Wireless Pvt Ltd.** has developed Supernova Electric Vehicle. This sports car has the capability to cover 1,000 kilometres at a top speed of 150 Km/hr in a single charge. However, experts doubt the company’s claim since Supernova’s range will be beating Tesla’s sports car range of 440 kms! Despite having a whopping price tag of **2.5 million rupees**, this Made-In-India concept has attracted many investors and it already has an order list of 250 units.

Gegadyne Energy

UpGone are the days when we had to import batteries and supercapacitors in India, but today with the vision of NITI Aayog, India has got companies who manufacture batteries for EVs. One such example is **Mumbai's start-up Gegadyne Energy** started by Jubin Varghese and Ameya Gadiwan. These two mechatronics engineering students went on to study Tesla's Model S and Model X cars and then went to a junkyard to create their new technology. Although they had to drop out of college to startup, their decision gave them ample time to research on rectifying mistakes in Supercapacitors.



SPECIFIC ENERGY

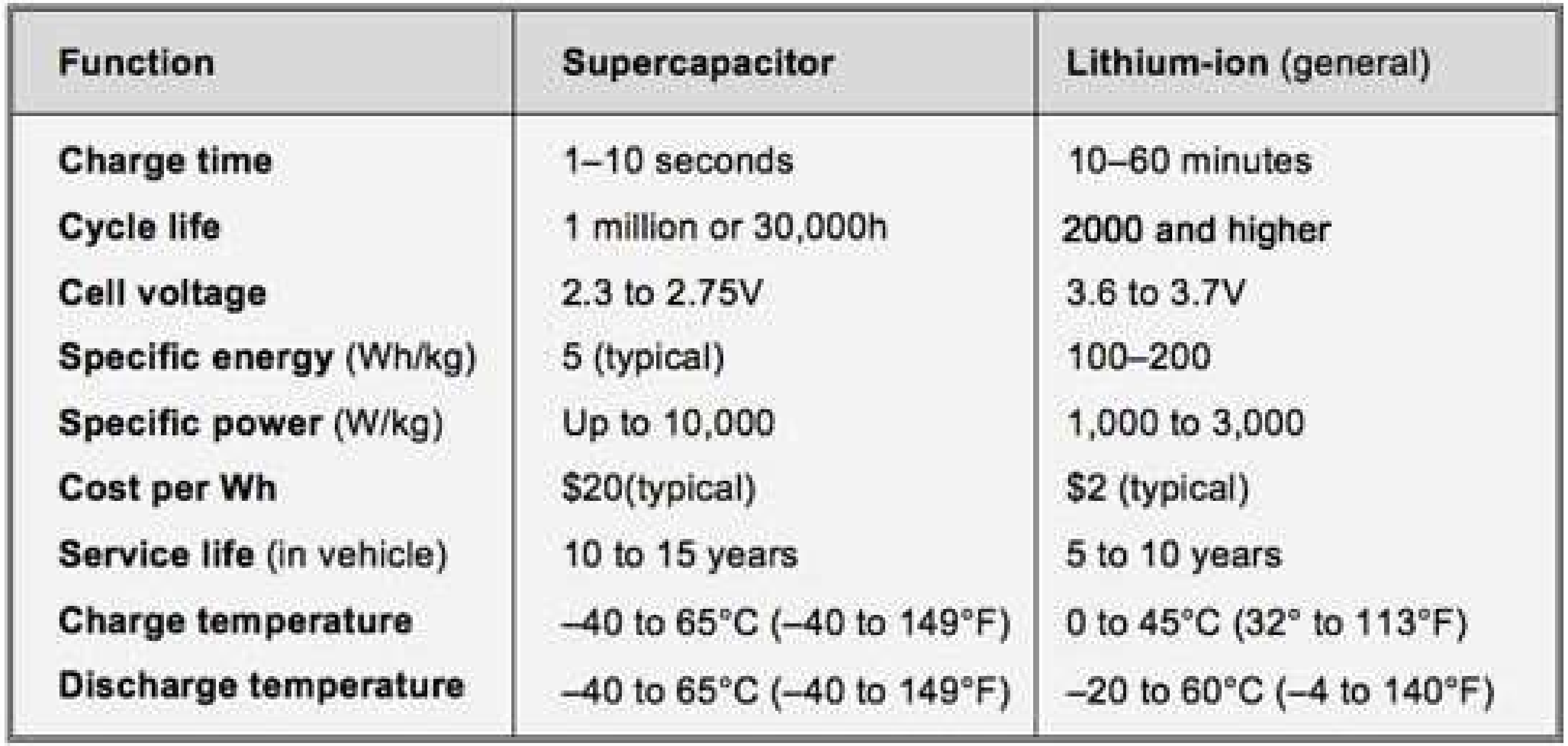
The total amount of energy an energy storage device holds.

Batteries have higher specific energy and can run for much longer.

SPECIFIC POWER

The speed at which the power can be discharged.

Ultracapacitors have far higher specific power, meaning they can provide a higher current.



Function	**Supercapacitor**	**Lithium-ion** (general)
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	2000 and higher
Cell voltage	2.3 to 2.75V	3.6 to 3.7V
Specific energy (Wh/kg)	5 (typical)	100–200
Specific power (W/kg)	Up to 10,000	1,000 to 3,000
Cost per Wh	$20(typical)	$2 (typical)
Service life (in vehicle)	10 to 15 years	5 to 10 years
Charge temperature	–40 to 65°C (–40 to 149°F)	0 to 45°C (32° to 113°F)
Discharge temperature	–40 to 65°C (–40 to 149°F)	–20 to 60°C (–4 to 140°F)

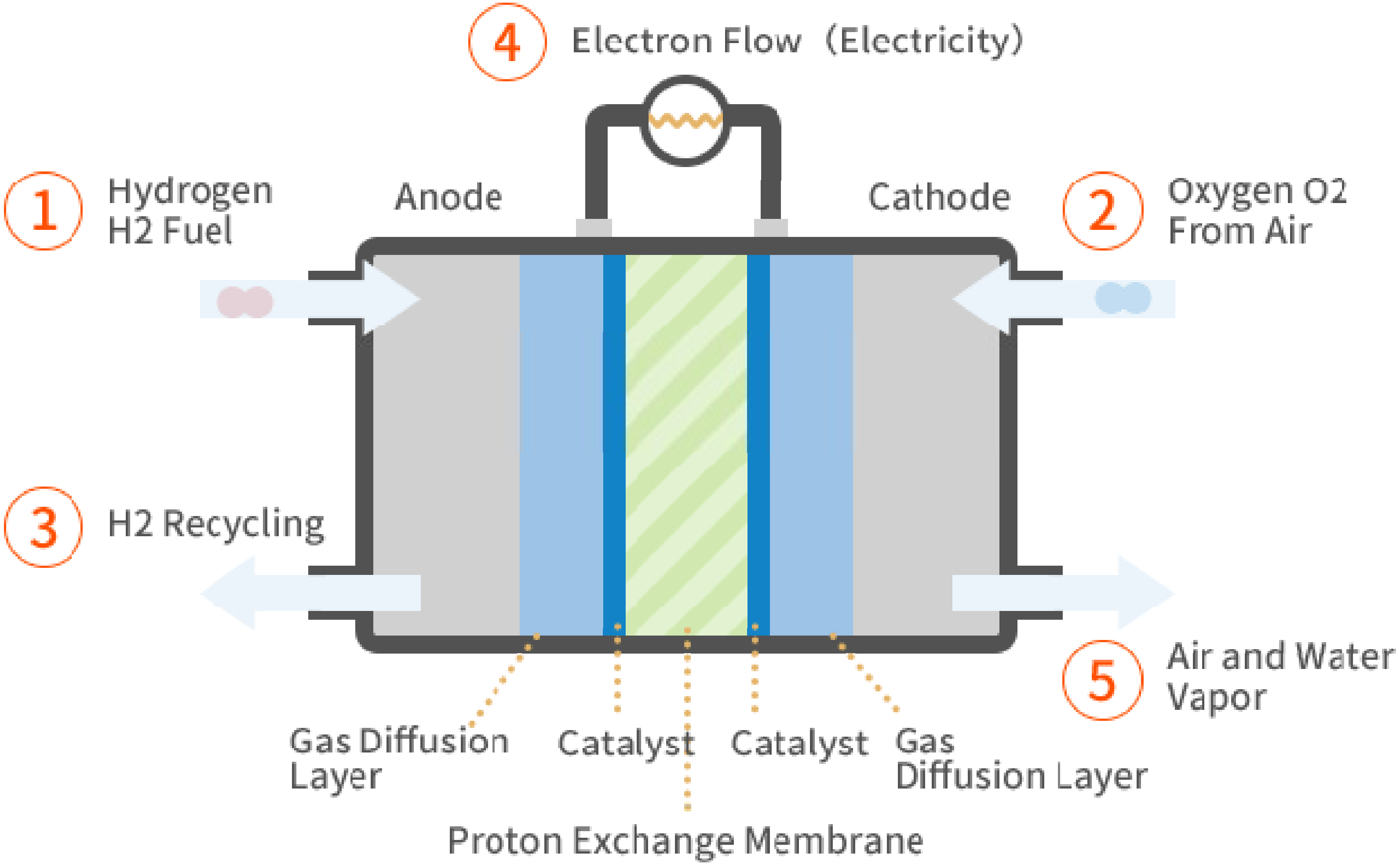
Table 1: Performance comparison between supercapacitor and Li-ion

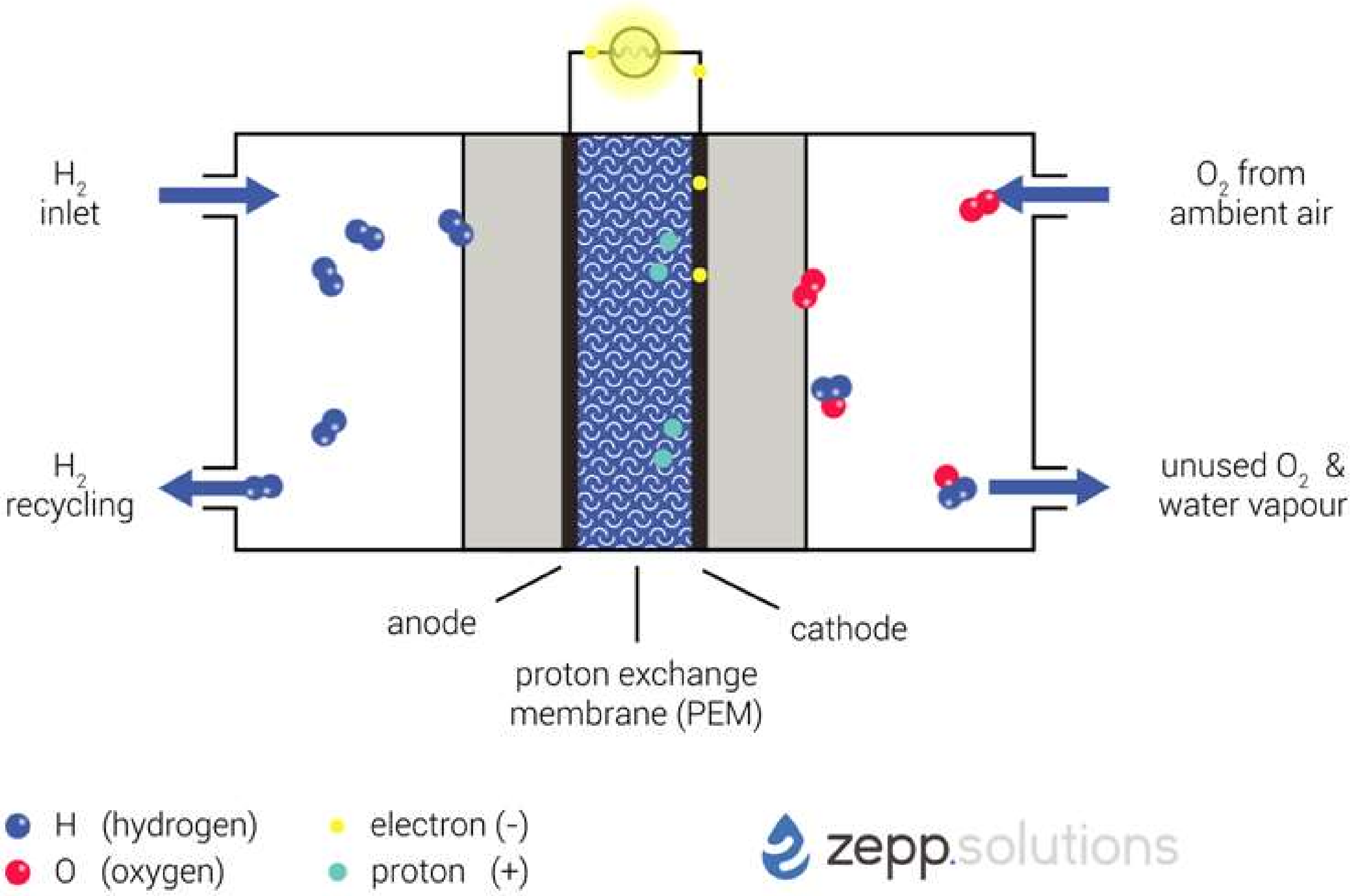
Courtesy of Maxwell Technologies, Inc. (updated)

FUEL CELL

Why Hydrogen Fuel Cell Electric Vehicles

- Hydrogen FCEVs are clean, efficient, refuel quickly, and provide long driving range
- Challenges include hydrogen infrastructure cost & reliability, fuel cell durability & reliability


④ Electron Flow（Electricity）
① Hydrogen H2 Fuel
Anode
Cathode
② Oxygen O2 From Air
③ H2 Recycling
⑤ Air and Water Vapor
Gas Diffusion Layer
Catalyst
Catalyst
Gas Diffusion Layer
Proton Exchange Membrane


H_2 inlet
H_2 recycling
O_2 from ambient air
unused O_2 & water vapour
anode
proton exchange membrane (PEM)
cathode
● H (hydrogen)
● O (oxygen)
● electron (-)
● proton (+)
zepp.solutions

How Does a Hydrogen Fuel Cell Work

1. **Hydrogen** is supplied to the negative or anode side of the fuel cell.
2. Anode catalyst activates hydrogen molecules, releasing **electrons**.
3. The electrons then travel from ***anode to cathode***, creating an electrical current.
4. The hydrogen molecules responsible for releasing electrons become **hydrogen ions**. These hydrogen ions also move to the cathode side of the fuel cells but they have to go through the polymer electrolyte membrane. During that process, they bond with electrons and ambient oxygen to form water.
5. Electricity produced by the fuel cell is directed to an ***electric motor*** that powers the vehicle.
6. Excess energy is stored in a secondary battery that provides auxiliary power to the electric motor.

Advantages

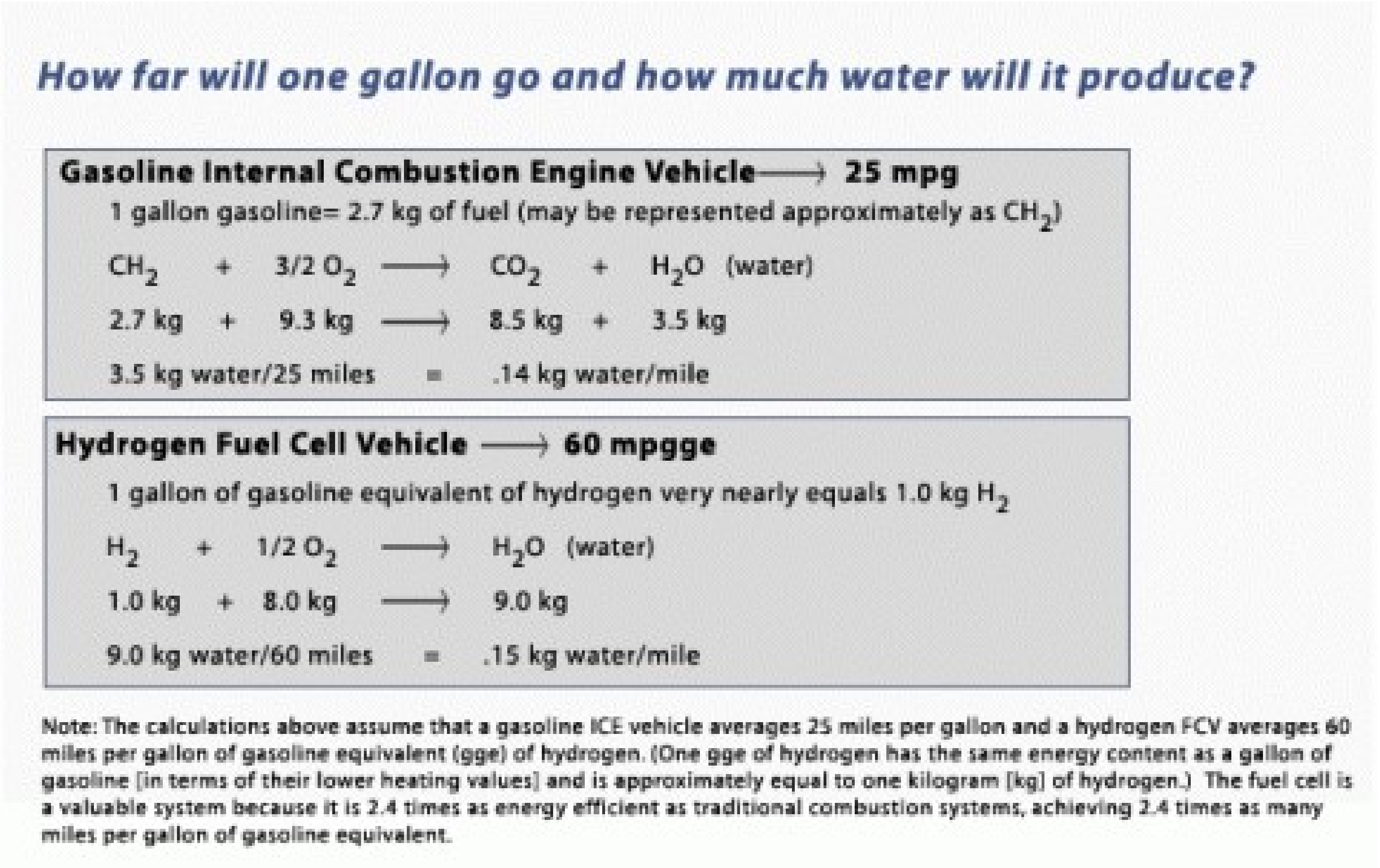
Fuel cells are a clean source of power as they produce electricity through an electrochemical reaction. Following are some key advantages

1. Fuel cells do not require a recharge like batteries. They can continue to produce electric current as long as the fuel source is available.
2. Since there are no moving parts, fuel cells are silent and very reliable.
3. Individual fuel cells can be "***stacked***" to generate more power.
4. A single fuel cell can generate enough voltage to power small applications.
5. On the other hand, stacked fuel cells can be combined to create multi-megawatt, large-scale installations.

Disadvantages

1. There are certain of hydrogen fuel cells.
2. First, hydrogen is very reactive so it can easily erode other material.
3. Not to mention it is also highly flammable.
4. These two factors make hydrogen fuel cells costly and difficult to transport.
5. The high cost and lack of building hydrogen infrastructure is another major problem.
6. Hydrogen fuel cells are costly to manufacture as their production involves manual processes and it is still small in scale.
7. Another key cost component is the hydrogen tank that takes up a lot of space because of its huge size.

Method of storage	**Type**	**Pros**	**Cons**
Gas	Compressed hydrogen	High efficient Lots of research Convenient	Expensive cylinder Fast filling is an issue.
Liquid	Liquid hydrogen	High density Storage efficiency	Consume large amount of time and energy Low temperature
Metal hydride	MgH_2 CaH_2 NaH	High safety High purity Large volume of hydrogen density	Absorbing impurities Reduce the lifetime of the tank and reduce the capacity
Carbon nanotubes	Gaseous hydrogen	Highly porous structure Interaction between carbon atom and gas molecules	Hydrogen capacity depends on many factors and immature technology
Metal-organic framework	Porous coordinated network	Highly porous High specific surface area	Storage at very low temperature far below operating temperature



How far will one gallon go and how much water will it produce?

Gasoline Internal Combustion Engine Vehicle ⟶ 25 mpg

1 gallon gasoline= 2.7 kg of fuel (may be represented approximately as CH_2)

$$CH_2 + 3/2\ O_2 \longrightarrow CO_2 + H_2O \text{ (water)}$$

$$2.7 \text{ kg} + 9.3 \text{ kg} \longrightarrow 8.5 \text{ kg} + 3.5 \text{ kg}$$

3.5 kg water/25 miles = .14 kg water/mile

Hydrogen Fuel Cell Vehicle ⟶ 60 mpgge

1 gallon of gasoline equivalent of hydrogen very nearly equals 1.0 kg H_2

$$H_2 + 1/2\ O_2 \longrightarrow H_2O \text{ (water)}$$

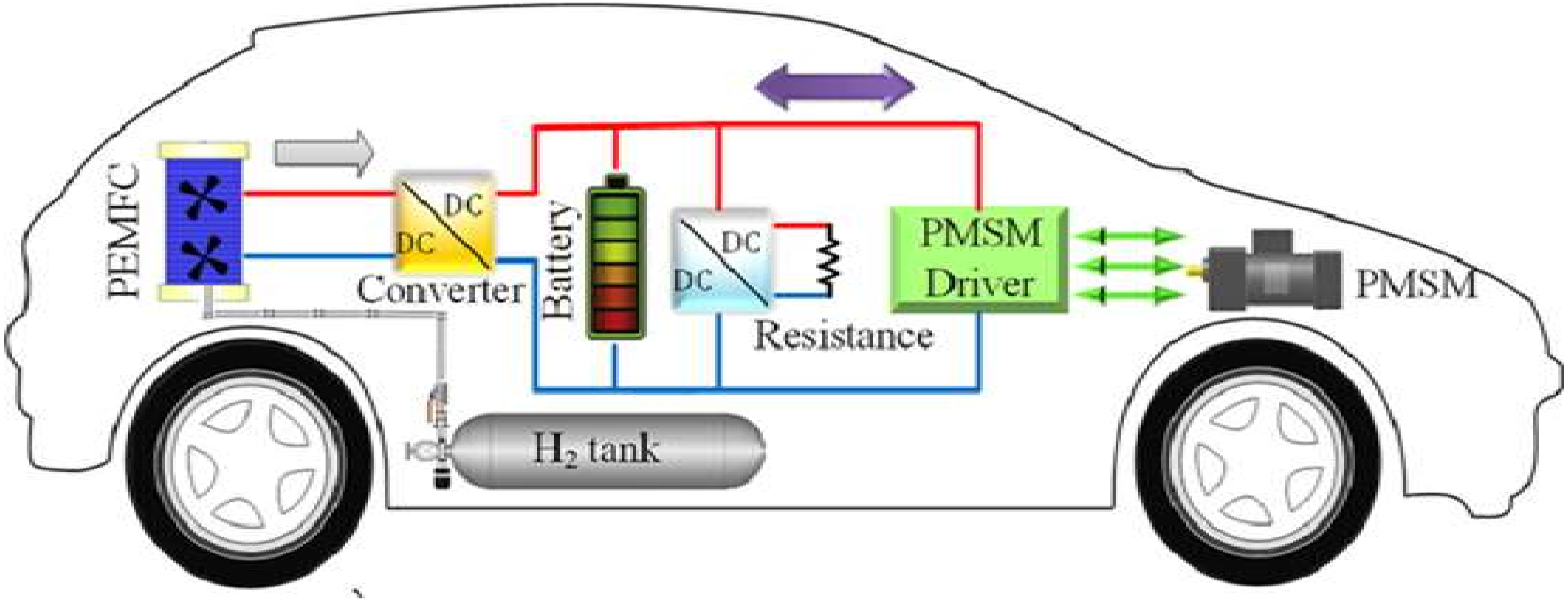
$$1.0 \text{ kg} + 8.0 \text{ kg} \longrightarrow 9.0 \text{ kg}$$

9.0 kg water/60 miles = .15 kg water/mile

Note: The calculations above assume that a gasoline ICE vehicle averages 25 miles per gallon and a hydrogen FCV averages 60 miles per gallon of gasoline equivalent (gge) of hydrogen. (One gge of hydrogen has the same energy content as a gallon of gasoline [in terms of their lower heating values] and is approximately equal to one kilogram [kg] of hydrogen.) The fuel cell is a valuable system because it is 2.4 times as energy efficient as traditional combustion systems, achieving 2.4 times as many miles per gallon of gasoline equivalent.

Applications

1. Cars, buses, trucks, and recreational vehicles.
2. Generating power on-site.
3. Material handling equipment.
4. Backup power source to critical communications and computer networks.
5. Act as a primary power source for residential, commercial, and industrial buildings or high-volume data centers.


PEMFC
DC
DC
Converter
Battery
DC
DC
Resistance
PMSM Driver
PMSM
H2 tank

FCEV

Toyota Mirai

Hyundai Nexo

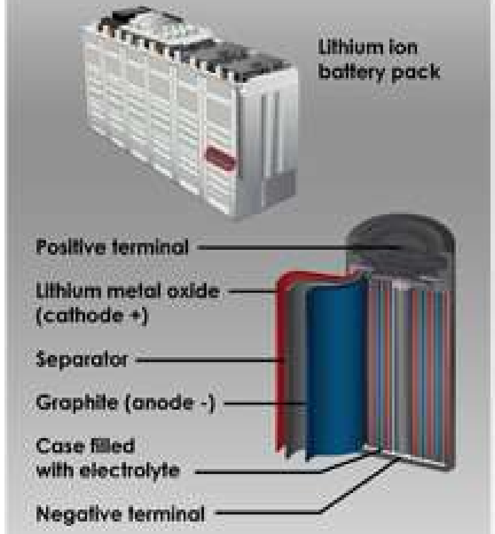
Toyota Kirloskar Motor claimed that Toyota Mirai is powered by a hydrogen fuel cell battery pack and capable of providing a range up to 650 km in a single charge, with a refuelling time of five minutes.March 22

Toyota Mirai FCEV pilot project begins in India - Autodevot

Consideration	Lead Acid Batteries	Lithium-Ion Batteries	Winner
Cost	$5K to $12K	$17.5K to $25K	**Lead-acid**
Hours of Operation	8 hrs in action; 8 hrs charging; 8 hrs cool down. Opportunity charging shortens life.	Capable of continuous operation with opportunity charging	**Lithium-ion**
Battery Life	1,500 charging cycles	2,500 to 3,000 charging cycles	**Lithium-ion**
Safety	Potential of acid spills. Toxic fumes generated during charging. Swapping out a 3,000 lb. battery can be dangerous.	Completely sealed. No toxic discharges during charging. No need to swap out battery	**Lithium-ion**
Maintenance	Battery must be topped up and equalized on a weekly or bi-weekly basis	Essentially maintenance-free	**Lithium-ion**
Power Level During Usage	Starts off strong but loses power during usage	Develivers close to rated power until 90% discharged	**Lithium-ion**
End of Life Disposal	Can be recycled. Extensive recycle industry developed	Recycling of Lithium-ion batteries still in its infancy	**Lead-acid**

LITHIUM-ION

electrochemical



1x power density

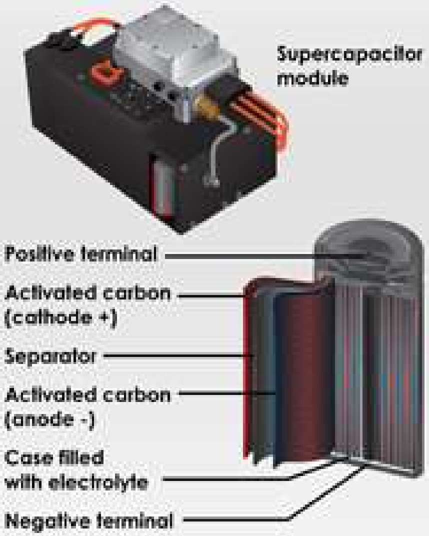
20x energy density

charges in minutes to hours

short life span

SUPERCAPACITOR

electrostatic



10x power density

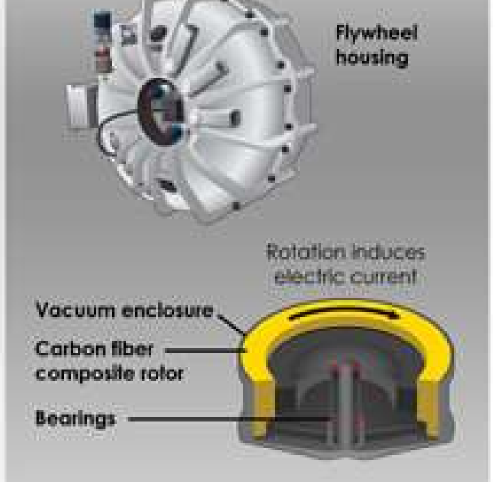
1x energy density

charges in seconds

long life span

FLYWHEEL

mechanical



10x power density

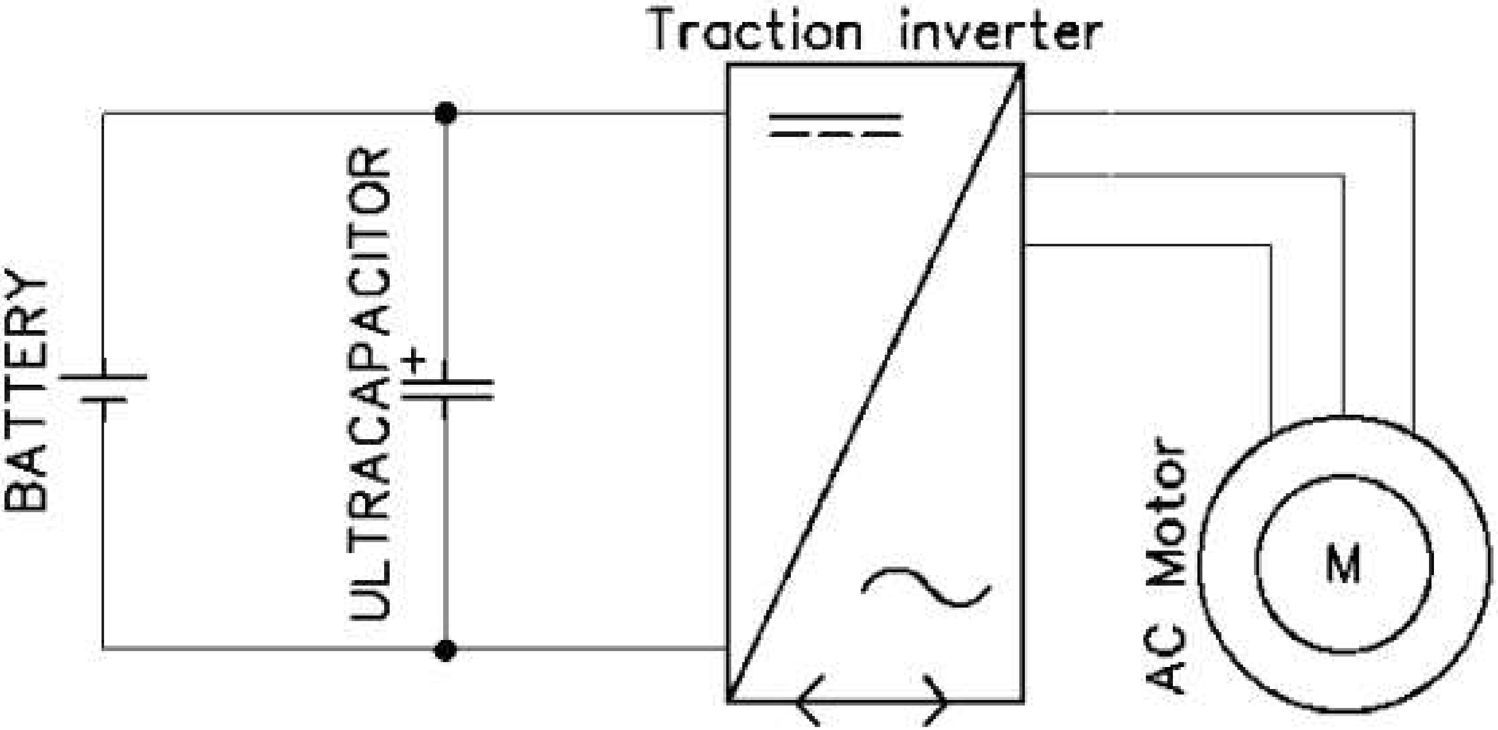
1x energy density

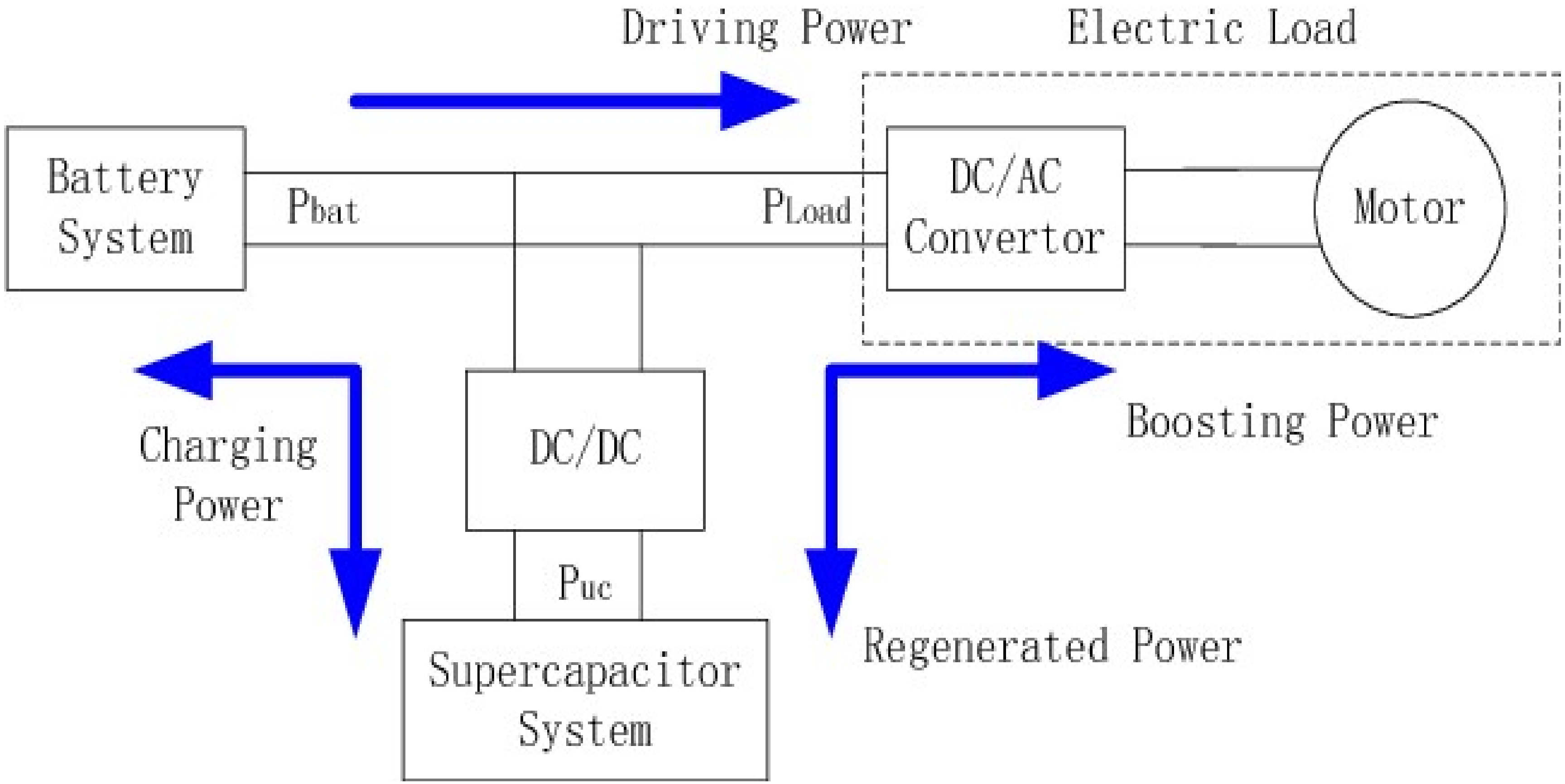
charges in seconds

long life span

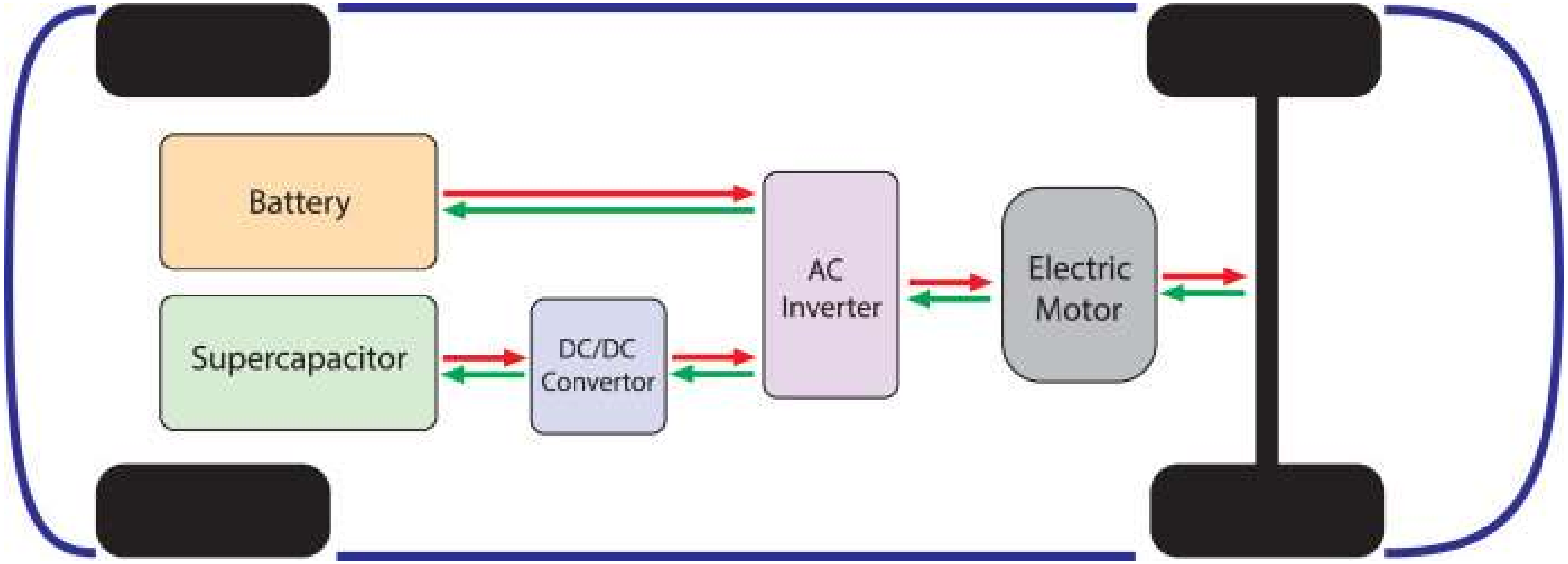
ENERGY STORAGE TECHNOLOGY

BASIC PARALLEL TOPOLOGY OF THE HESS

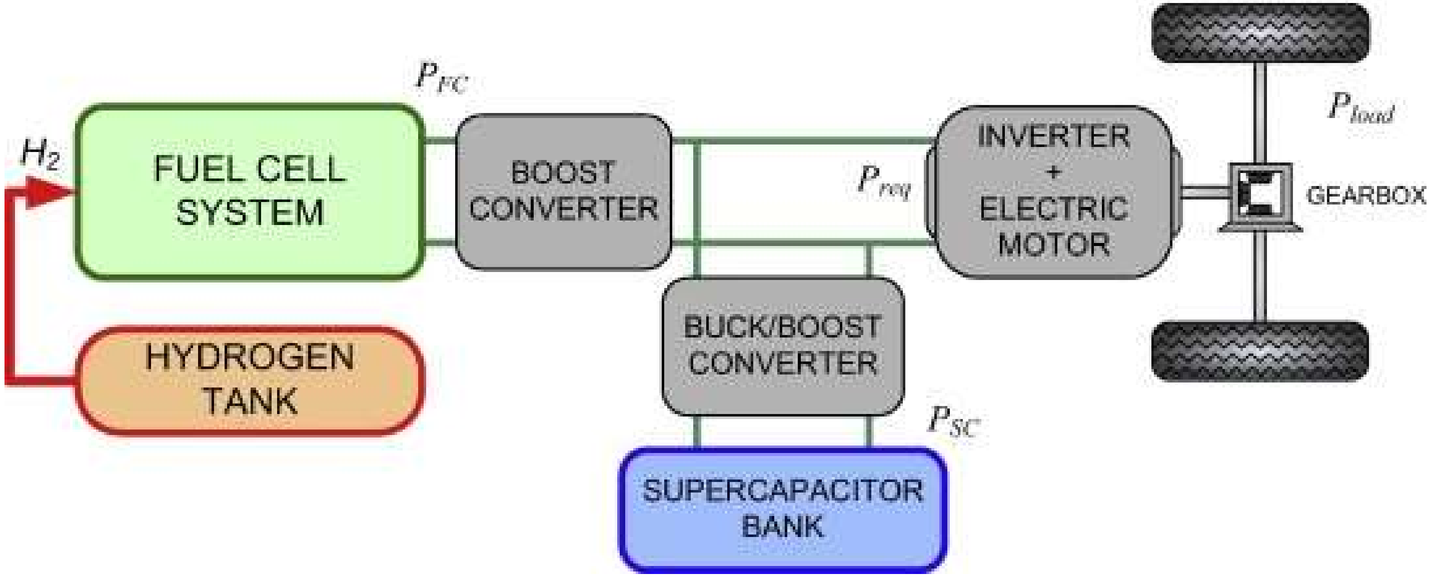


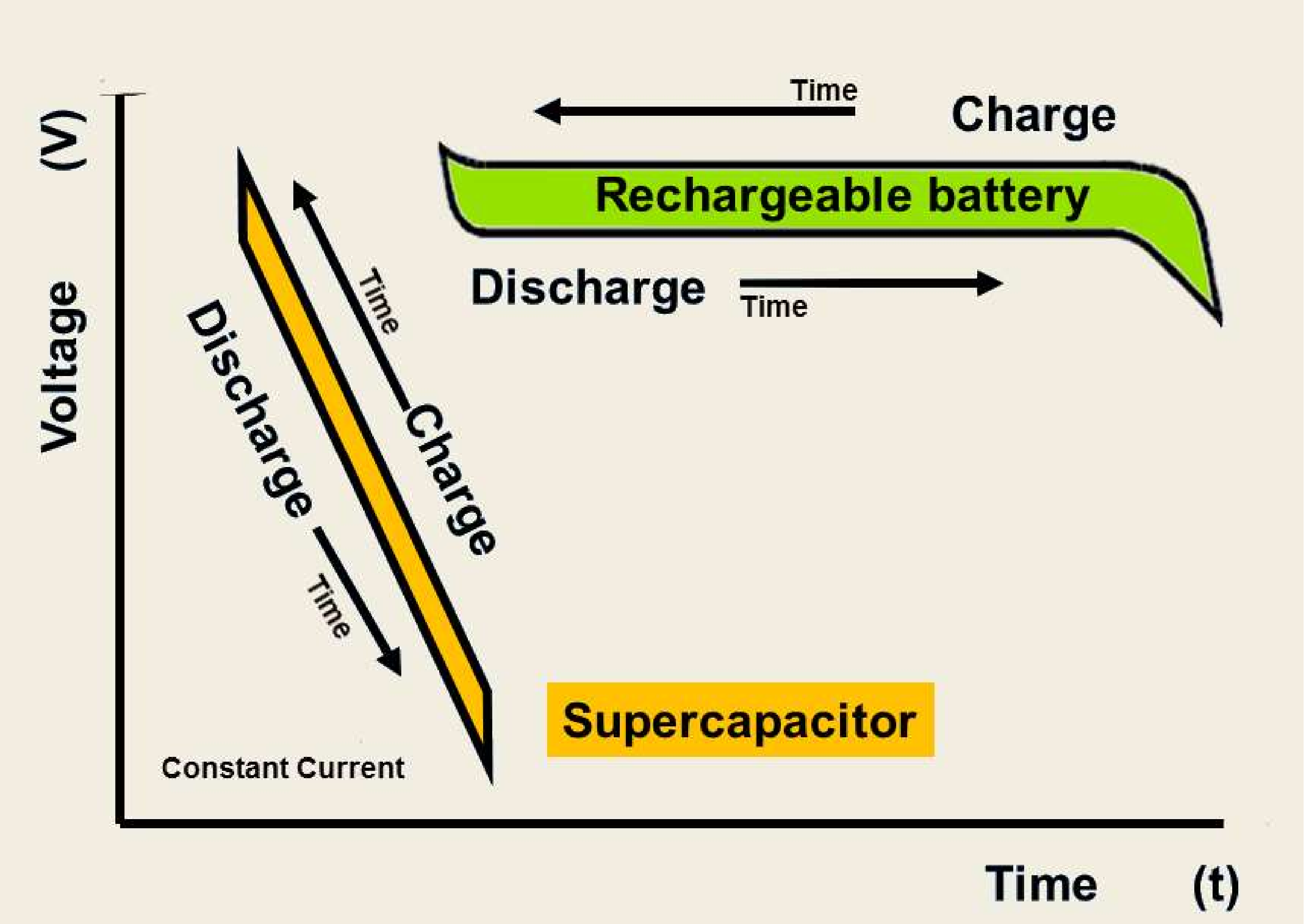

Driving Power
Electric Load
Battery System
P_{bat}
P_{Load}
DC/AC Convertor
Motor
Charging Power
DC/DC
Boosting Power
P_{uc}
Regenerated Power
Supercapacitor System

BATTERY + SUPERCAPACITOR ENERGY STORAGE



FUELCELL + SUPERCAPACITIOR ENERGY STORAGE




Voltage (V)
Time
Charge
Rechargeable battery
Discharge
Time
Time
Charge
Discharge
Time
Supercapacitor
Constant Current
Time (t)

Energy Storage: Flywheel

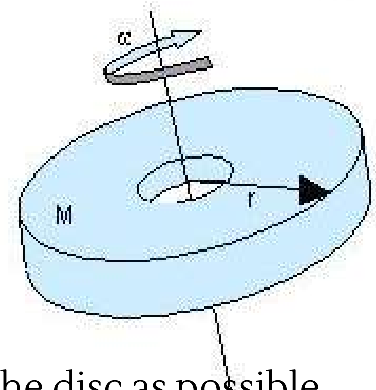
- A flywheel, in essence is a mechanical battery - simply a mass rotating about an axis.
- Flywheels store energy mechanically in the form of kinetic energy.
- They take an electrical input to accelerate the rotor up to speed by using the built-in motor, and return the electrical energy by using this same motor as a generator.
- Flywheels are one of the most promising technologies for replacing conventional lead acid batteries as energy storage systems.

Theory of Flywheels

- Kinetic energy: $E_k = \frac{1}{2} I \omega^2$

  where *I* is the moment of inertia and $\boldsymbol{\omega}$ is the angular velocity of a rotating disc.

$$I = \int r^2 dm$$



- For a cylinder the moment of inertia is

$$I = \frac{1}{2} r^4 \pi a \rho$$

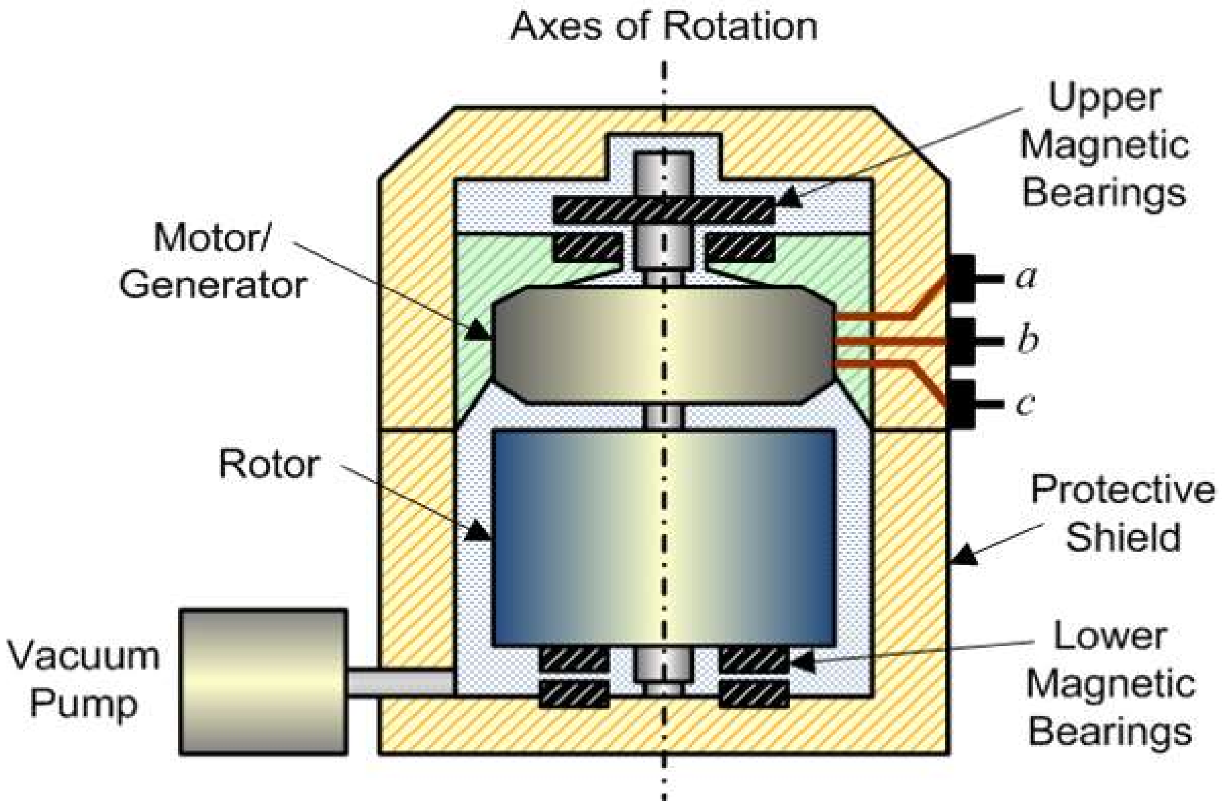
- So the energy is increased if $\boldsymbol{\omega}$ increases or if *I* increases.
- *I* can be increased by locating as much mass on the outside of the disc as possible.
- But as the speed increases and more mass is located outside of the disc, mechanical limitations are more important.

Design of flywheel energy storage system

- Flywheel systems are best suited for peak output powers of 100 kW to 2 MW and for durations of 12 seconds to 60 seconds .

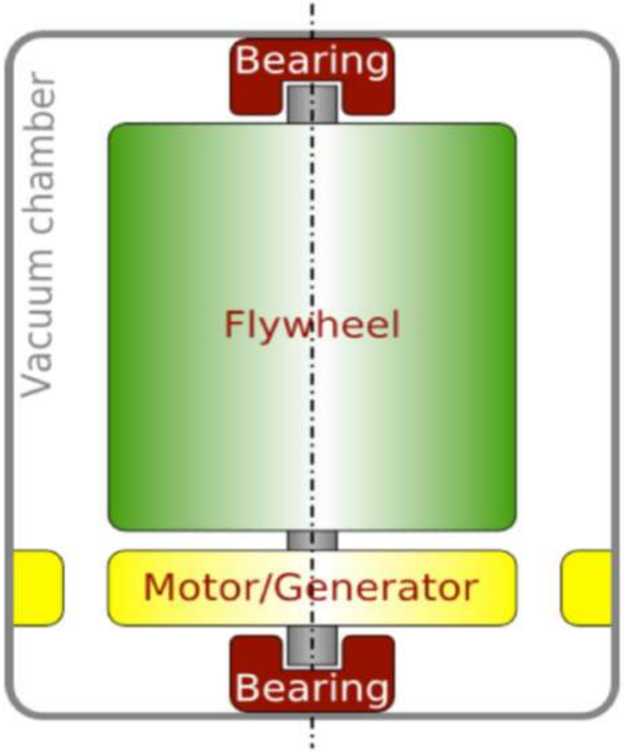
- The energy is present in the flywheel to provide higher power for a shorter duration, the peak output designed for 125 kw for 16 seconds stores enough energy to provide 2 MW for 1 second.

Flywheel Energy Storage System

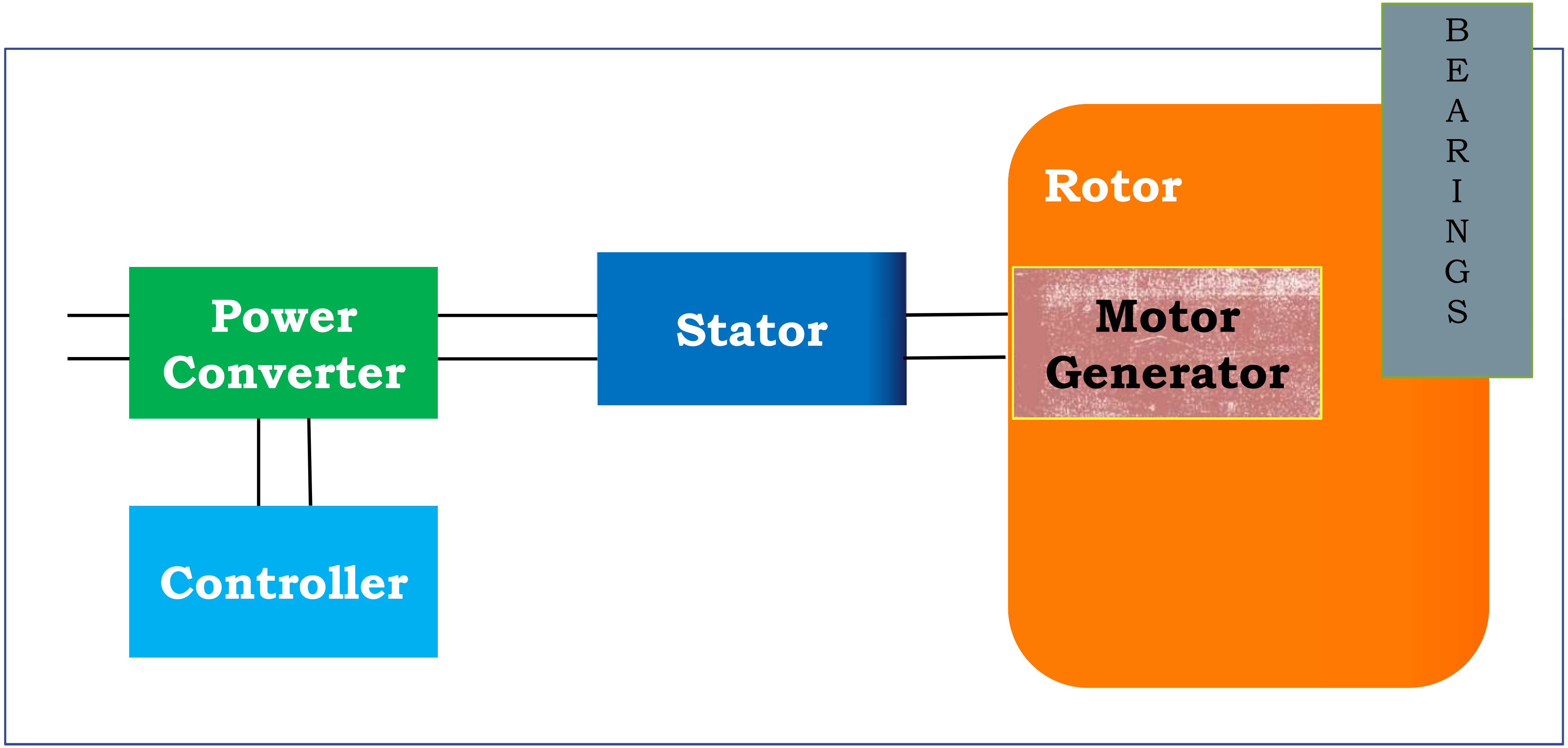


Component of FESS

- Flywheel
- Motor/Generator
- Power Electronics
- Magnetic bearings
- External Inductor



Block Diagram



Power Converter

Stator

Rotor

Motor Generator

BEARINGS

Controller

Motor/Generator

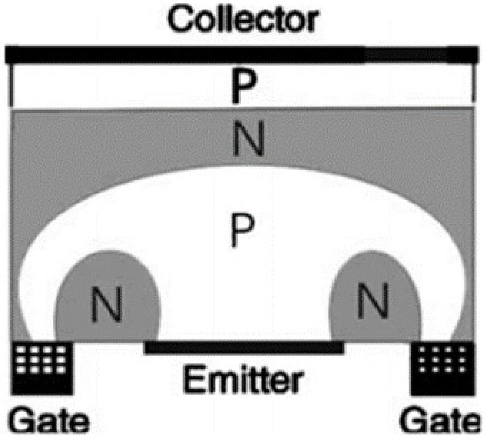
- Permanent Magnet (PM) machines have the most advantages, including higher efficiency and smaller size when compared with other types of motors/generators of the same power rating.

- PM also exhibit lower rotor losses and lower winding inductances, which make it more suitable for a vacuum operating environment and the rapid energy transfer of flywheel applications.

- The motor/generator is designed to be operated at high speed for minimize system size.

Power Electronics

- Flywheel energy storage system is the three-phase IGBT-based PWM inverter/rectifier.



- The IGBT is a solid-states device with ability to handle voltages up to 6.7 kV, currents up to 1.2 kA and most important high switching frequencies.

Magnetic Bearings

- Magnetic bearings consists of permanent magnets, which support the weight of the Flywheel by repelling forces, and electromagnets are used to stabilize the Flywheel.

- The best performing bearing is the high-temperature super-conducting (HTS) magnetic bearing, which can situate the Flywheel automatically without need of electricity or positioning control system.

- HTS magnets require cryogenic cooling by liquid nitrogen.

External Inductor

- The high-speed PM machines offer low inductances with low number of stator turns and large operating magnetic air gaps .

- The low inductances result in High Total Harmonic Distortion (THD) which increases the machine power losses and temperature.

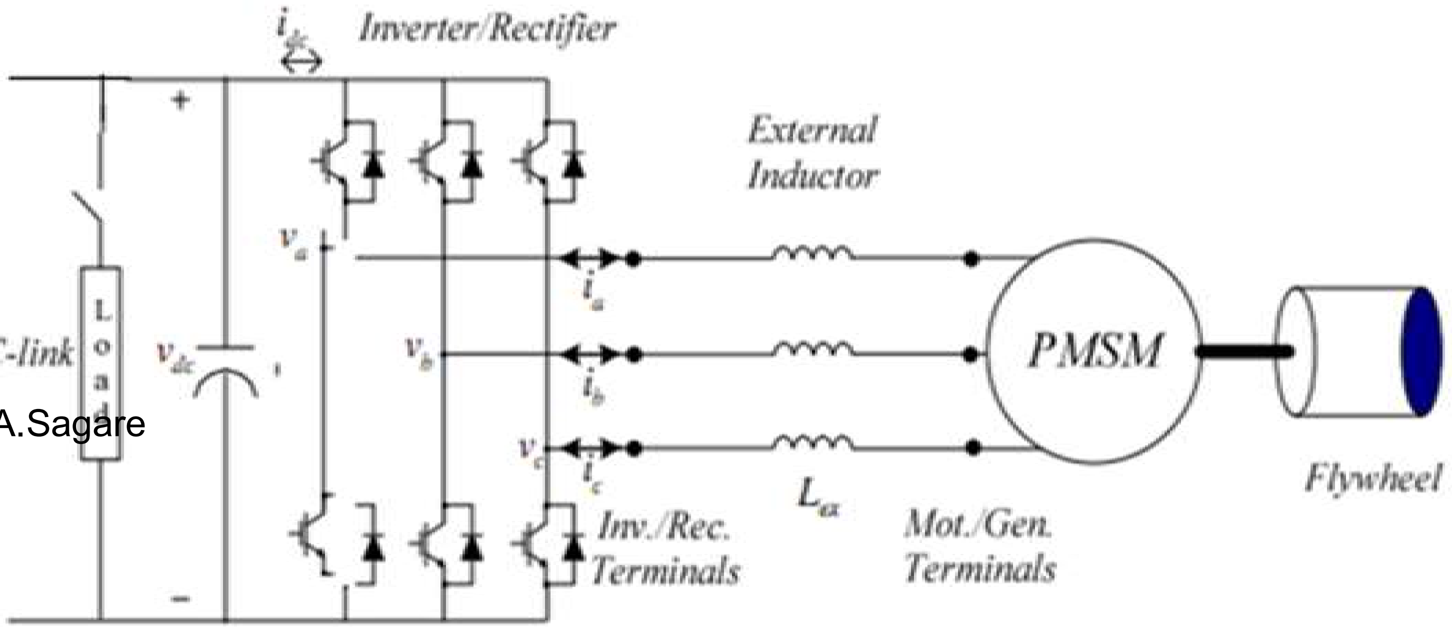
- Using an external inductor in series with the machine in charging mode is necessary to reduce the THD and bring it within an accepted range.

Working of a flywheel energy storage system

Its work in three mode:-

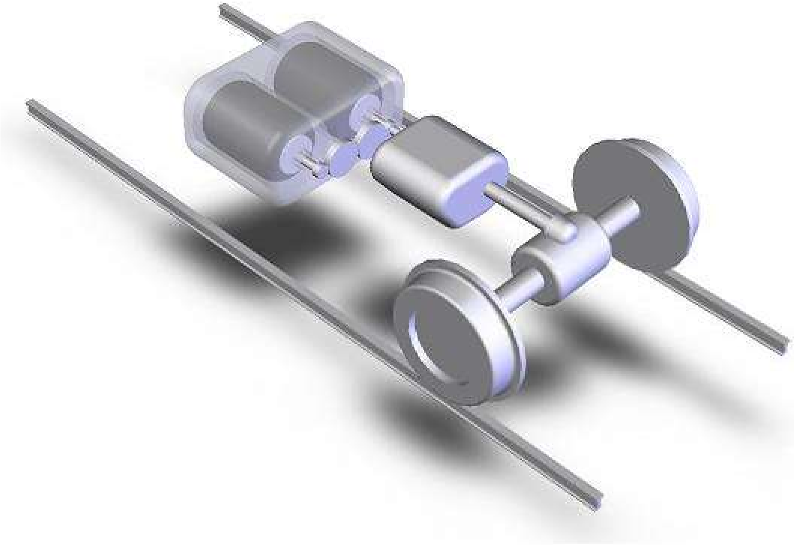
- Charging mode
- Stand by mode
- Discharging mode

Circuit diagram of FESS



Applications of FESS

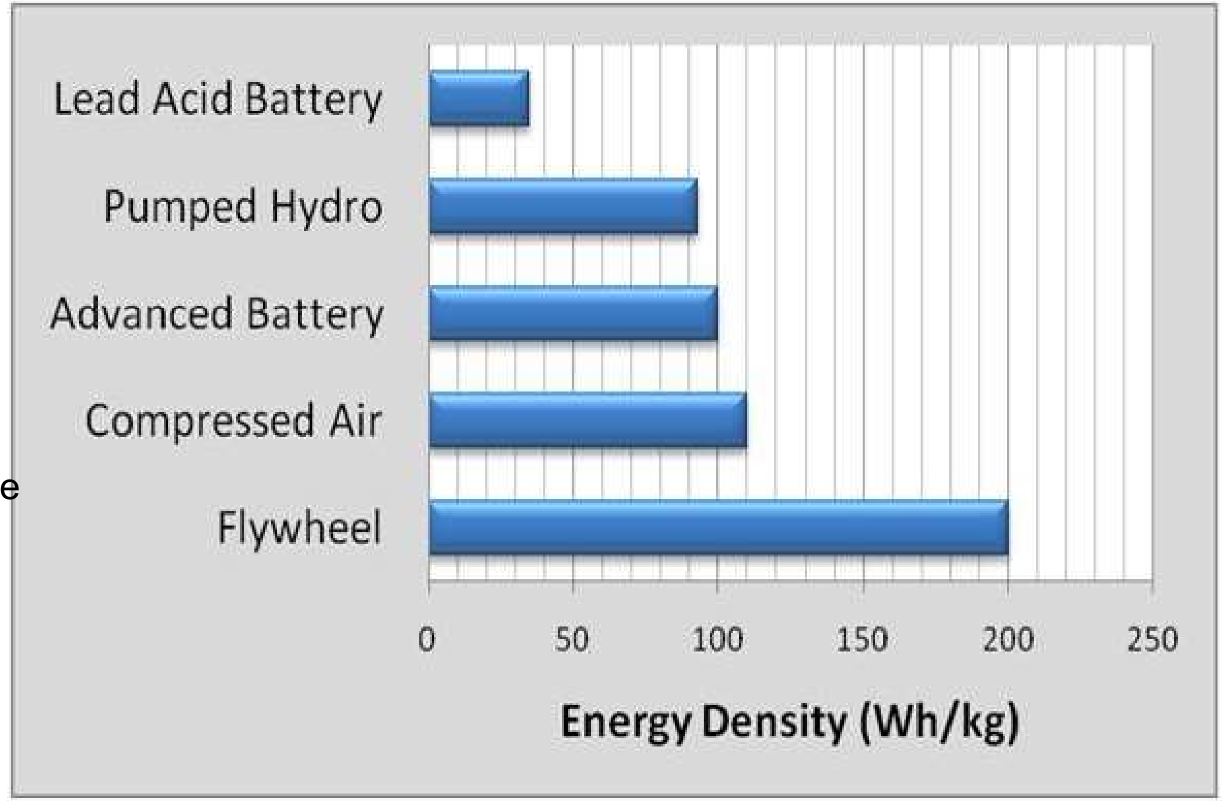
- Load Following for Distributed Generation
- Power Quality/UPS
- Industrial Pulsed Power
- Light rail power
- Flywheel in distribution network
- Hybrid and electric vehicles



Advantages of FESS

- High power density.
- High energy density.
- The lifetime of the flywheel is almost independent of the depth of the charge and discharge cycle.
- No periodic maintenance is required.
- Short recharge time.
- Flywheel systems are not sensitive to temperature since they are operating in a vacuum containment

Advantages of FESS



Prof.S.A.Sagare

Disadvantages of FESS

- Complexity of durable and low loss bearings
- Mechanical stress and fatigue limits
- Material limits at around 700M/sec tip speed
- Potentially hazardous failure modes
- Short discharge time