

A Study of Electricity Storage Systems and Scope

Suresh Bhati ¹, Dr. Vinayak N Shet ²

P.G. Student, Department of Electrical and Electronics Engineering, Goa College of Engineering, Goa, India¹

Professor, Department of Electrical and Electronics Engineering, Goa College of Engineering, Goa, India²

ABSTRACT: Electrical Energy Storage(EES) technologies for key applications are reviewed. Particular attention is paid to *batteries, fuel cells and supercapacitors*. Technical characteristics applications are compared. Energy storage can mitigate the intermittency of solar and wind power, it can also respond rapidly to large fluctuations in demand, making grid more responsive and eliminating need for backup power plant. The effectiveness of energy storage facility is determined by how quickly it can react to changes in demand, the rate of energy lost in storage process, its overall storage capacity and its recharge time. Demand for more dynamic and cleaner grid has led to significant increase in the construction and development of new energy storage projects. Advanced Energy Storage has been key enabling technology for the portable electronics and Electric Vehicles(transportation industry), it's on the same track for utility grid. If a *renewable energy* is to become prevalent during demand due to electrification, energy storage is critical component

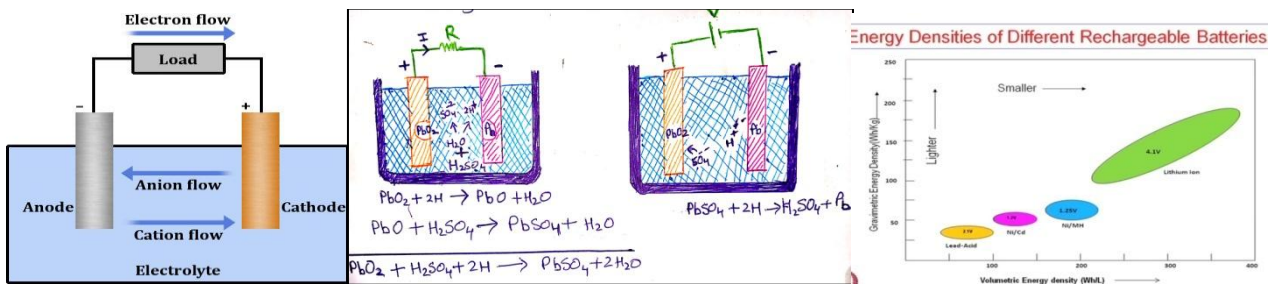
KEYWORDS: Lithium Ion(Li⁺), Electron(e⁻), Oxidation Reduction, Anode-Cathode, Voltage-Current, energy density, power density.

I. INTRODUCTION

Electrical Energy Storage(EES) refers to a process of converting electrical energy from a power network or source into a form that can be stored and converted back as and when needed. EES's can be categorised based on function and form. Function is based on power delivering capabilities at a given time and the capacity of the EES. EES with high capacity and tolerable power deliverability are of energy management category and with high power deliverability at a time are of power quality and reliability category. EES's on the basis of form of storage are of 3 kind: (i) electrical energy storage: electrostatic- *supercapacitors* (ii) mechanical energy storage- *Dams, pumped hydroelectric, flywheel* etc (iii) chemical energy storage-*Batteries, fuel cells*.

II. BATTERY

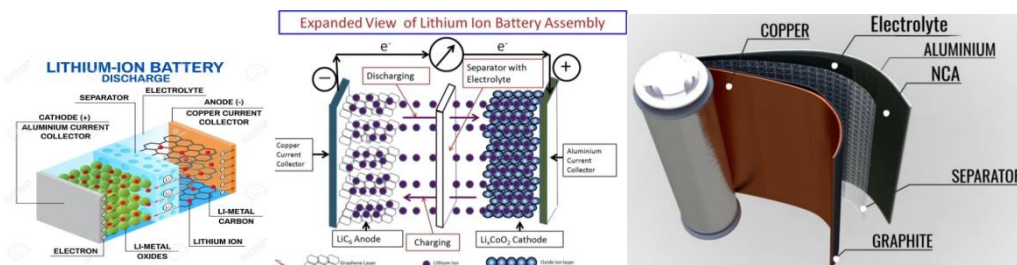
Rechargeable/Secondary batteries stores electricity in form of chemical energy. A battery is comprised of one or more electrochemical cells and each cell consists of liquid, paste or solid electrolyte with positive electrode(anode) and negative electrode(cathode). During discharge electrochemical reaction occurs at the two electrode generating a flow of electrons through an external circuit. The reactions at the electrodes are reversible allowing recharging by applying external voltage. *Li* ion batteries have high energy density compared to other batteries.



III. LITHIUM ION BATTERIES

The Cathode(+) in this kind of battery is lithiated metal oxide($LiCoO_2, LiMnO_2, LiNiO_2, LiFePO_4$) and Anode(-) is graphitic carbon(LiC_6) with layering structure. Both anode and cathode are Li intercalated materials with sufficient electronic conductivity. *Electrolyte*(liquid or paste):- Alkyl Carbonate + $LiPF_6$ [Solution of $LiPF_6$ in a mixture of Ethylene Carbonate and D-Methylene Carbonate(EC- DMC)], it is semi permeable liquid or paste which allows only Li^+ ions to pass and blocks passage of e^- . Anode(Graphite) doesn't have role in the chemical reaction of the lithium cells it is only a storage medium for Li^+ ions. *Electrochemical potential* is the tendency of a metal to lose electrons Li has the highest tendency to lose electrons and hence have highest electrochemical potential. Li has one electron in its outer shell. Li in its pure form is highly reactive and unstable but when a part of suitable metal oxide it's stable.

Charging: The positive side of power source attracts all the e^- from cathode which flows through the external circuit and reach the anode, in the meantime the Li^+ ions get attracted towards anode and flow through the electrolyte and reach the graphite layered space and gets trapped, this process continues till fully charged. Charged state is an unstable state for Li . **Discharge cycle:** Li^+ ion wants to go back to its stable state that is at cathode and hence Li^+ ion moves through electrolyte and e^- through external load leading to discharge.



If the internal temperature of the cell rises due to abnormal conditions, the liquid electrolyte will dry up and there will be a short circuit between the electrodes and this can lead to fire or explosion. To avoid such situation an insulating layer called the separator is placed between the electrodes (onto the electrolyte), the separator is permeable for Li^+ ions but blocks e^- passage because of its microporosity.

The graphite and Li metal oxide are coated onto copper and Aluminium foil/plate respectively which acts as current collector foils. These 3 layers are sandwiched and placed in various ways to form prismatic or cylindrical cells.

The pattern is simply throwing off Li^+ ions and e^- from ground to hill (cathode to anode) and stored on the hill until pushed back (connecting load) to the ground.

Formation of *SEI* (Solid Electrolyte Interface) layer during the initial charging process prevents electrons to come in contact with the electrolyte (prevents degradation). Improved material development, improvement in terms of *energy density* (increase from 75 to 200 Wh/kg) *life cycle* (as high as 10,000), efficiency of the battery is 95 to 99%. Although 5% Li is used during *SEI* formation leaving 95% Li .

Charge Rate: denoted as C or C -Rate and signifies charge or discharge rate equal to capacity of a battery in 1 hour. For a 1.6 Ah battery $C=1.6$ Ah, charge rate of $C/2$ equal $=0.8$ A would need 2 hours and the charge rate of $2C = 3.2$ A will need 30 minutes to fully charge the battery from its empty state.

Drawbacks- High cost ($> \$170$ /KWh) due to special packaging, use of Cobalt and Nickel and internal overcharge protection circuits, *memory effect*, growth of *Li dendrites*

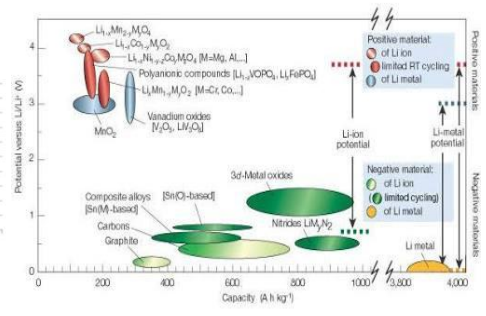
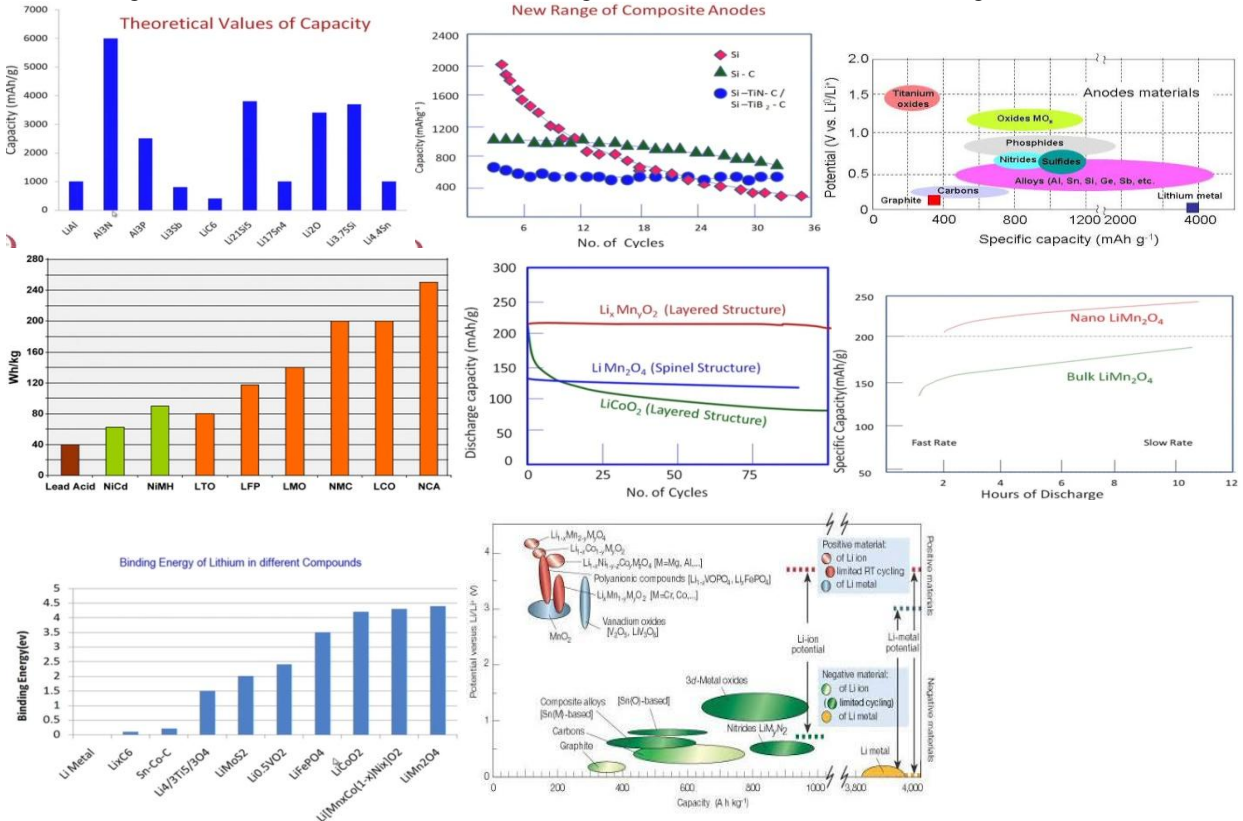
Several companies are working to reduce manufacturing cost to capture high energy markets [Lithium Battery Energy Storage Technology Association (LIBES)]. The cost is assumed to fall $< \$100$ /KWh by 2025 and recently used for large-scale energy storage and EV's. Companies like Tesla, Panasonic and many more have already developed *Powerwalls* (13 KWh) for home. There is continuous experiments with different materials and composition for anode, cathode and electrolyte to increase capacity, discharge rate, charging rate and mainly safety.

Overcoming problems: Degradation of electrolyte due to *SEI* can be mitigated by using different electrolyte additives, recent breakthrough has increased safety and life by using *Aqueous Halogen intercalation* or some have also used *Solid State Electrolyte*. Use of different composite of *Anode* - recent works on replacing graphite (~ 370 Wh/kg) with Silicon (Si) which increase its capacity by 12 times but there is considerable expansion and contraction of silicon crystal (4x) dimensions on charge and discharge therefore combination of graphite with Si crystals is under experiment, Si fibres are tricky to make. ***Li Anode*** :- Carbon based anode (~ 370 Ah/kg), low average voltage (150 mV vs Li/Li^+), ***Lithium titanate*** ($Li_4Ti_5O_{12}$) - regarded as highly useful electrode material because of its zero volume change during lithiation, leading to an extremely long operational lifetime for the electrode coupled with improved safety owing to an extremely flat discharge and charge plateau at about 1.55 V vs Li/Li^+ . ***Lithium***



metal Anode -very large capacity(3860Ah/kg),lowest negative electrochemical potential-->prove challenging due to growth of metallic dendrites during lithium plating/stripping which short circuits the battery.

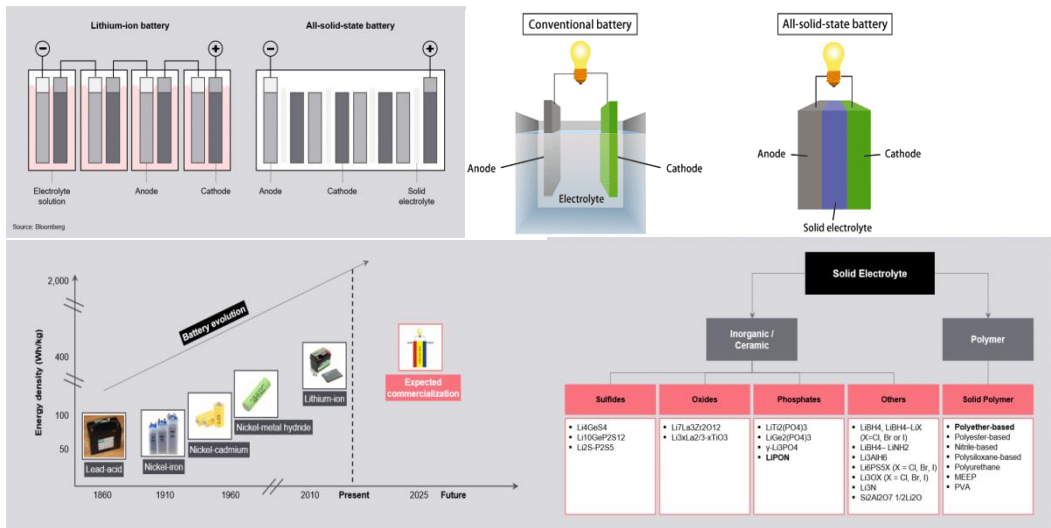
Various combination for Cathode have been also tested- $LiCoO_2$ (~140Wh/kg~3.6V vs Li/Li^{++}), $LiMn_2O_4$ (~110Wh/kg~3.8V vs Li/Li^{++}), $LiFePO_4$ (~140Wh/kg~3.2V vs Li/Li^{++}), $Li(Ni_{1-x-y}Mn_xCo_y)O_2$ (~200Wh/kg~3.8V vs Li/Li^{++}), $LiNiCoAlO_2$ (~250Wh/kg~3.6V vs Li/Li^{++}), Li_2TiO_3 (~70Wh/kg~2.8V vs Li/Li^{++})



Specifications	Li-cobalt	Li-manganese	Li-phosphate	NMC ¹
Voltage	3.60V	3.70V	3.30V	3.60/3.70V
Charge limit	4.20V	4.20V	3.60V	4.20V
Cycle life ²	500	500-1,000	1,000-2,000	1,000-2,000
Operating temperature	Average	Average	Good	Good
Specific energy	150-190Wh/kg	100-135Wh/kg	90-120Wh/kg	140Wh/kg
Specific power	1C	10C, 40C pulse	35C continuous	10C
Safety	Average. Requires protection circuit and cell balancing of multi cell pack. Requirements for small formats with 1 or 2 cells can be relaxed		Very good, needs cell balancing and V protection	Good, needs cell balancing and voltage protection
Thermal runaway ³	150°C (302°F)	250°C (482°F)	270°C (518°F)	210°C (410°F)
Cost	Raw material high	Material 30% less than cobalt	High	High
In use since	1994	2002	1999	2003
Researchers, manufacturers	Sony, Sanyo, FDK, Saft	NEC, Samsung, Hitachi	UT, QH, MIT, A123, Valence	Sony, Sanyo, Nissan Motor

IV. SOLID STATE BATTERY

Similar to Lithium ion conventional battery, only difference is that this battery uses solid state electrodes and solid state electrolyte. Serves as to be a potential alternative to conventional lithium-ion batteries which use liquid or polymer electrolytes. Experiments on this battery show results of high performance(coloumbic efficiency),high safety at low cost in addition they have low flammability, higher electrochemical stability and higher energy density as compared to liquid electrolyte batteries. NASICON type phosphate glass ceramic.

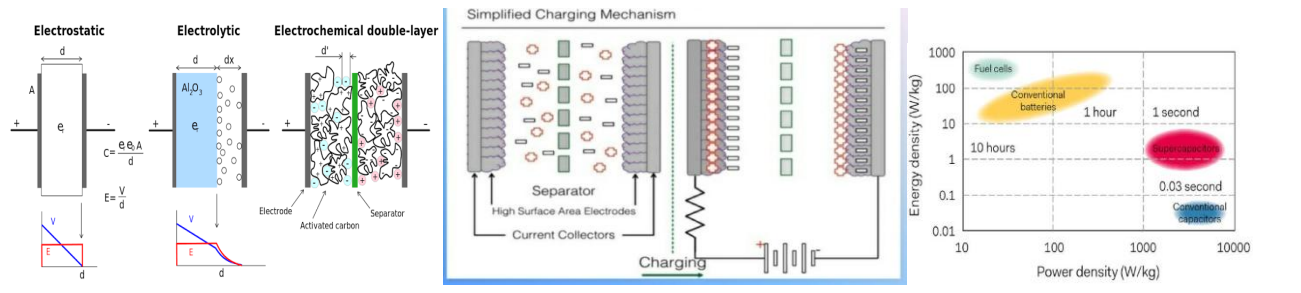


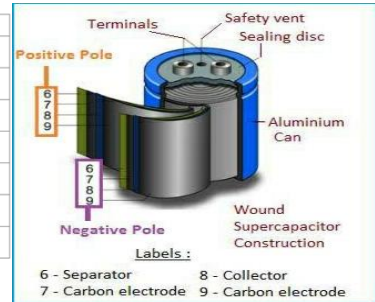
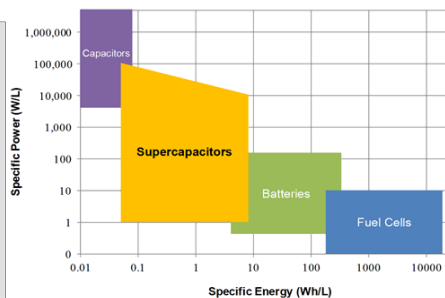
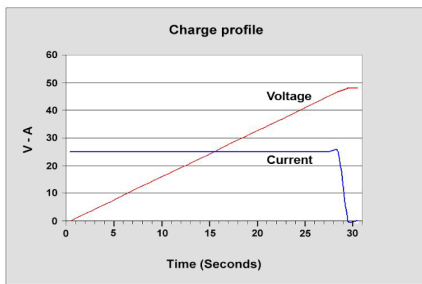
In September 2014, Dyson Lmt. introduced solid state lithium ion battery with higher energy density at lower cost. In 2017 a new solid state battery was introduced with glass electrolyte and metal anode manufactured from Lithium sodium and potassium. Recently Samsung has built a major solid state battery which solve problem of lithiation at the anode(Lithium metal) by using silver-carbon coating on anode.

Electrolyte- presently there are more than 25 types of solid state electrolyte such as oxides,sulfides phosphates,polyethers, polyesters, nitrite based,poly siloxanes,polyurethane etc.mechanical property is the major difference between inorganic/ceramic or polymer solid electrolytes. High elastic moduli of ceramics make them suitable for rigid battery systems while low elastic moduli of polymer makes them more suitable for flexible devices,polymer are easier to process than ceramics. LIPON & Polyether based electrolytes are commonly used in solid state batteries.

V. SUPERCAPACITORS/ULTRACAPACITORS.

These are made from special carbon structure called Graphene. Supercapacitors also known as Electric double layer capacitors or *Electrochemical double layer capacitors(ELDC)* or *Ultracapacitors* are electrochemical capacitors that have an unusually high energy density when compared to common capacitors, 100 to 1000 times greater than typical electrolytic and Electrostatic capacitor but lower working voltage. It consists of two electrodes separated by an ion permeable membrane(separator) and electrolyte electrically connecting both electrodes, when the voltage is applied ions in the electrolyte form double layers of opposite polarity to the electrodes polarity I.e. positive electrode will have layers of negative ions and negative electrodes will have layer of positive ions.





Function	Supercapacitor	Lithium-ion (general)
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	500 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)	\$0.50-\$1.00 (large system)
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)

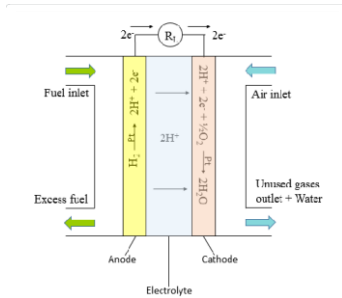
Carbon nanotubes, carbon aerogels are used for supercapacitor plates or electrodes. Sodium Perchlorate ($NaClO_4$) or Lithium Perchlorate ($LiClO_4$) are used as electrolytes. Polyacrylonitrile (C_3H_3) and is used as a separator. Aluminium as a packing component. The super capacitor has amazing features- high capacitance, high specific power density, high rates of charge and discharge, little degradation over thousands of cycles, low toxicity, high cycle efficiency (95%), rapid charging within seconds, it although has high self discharge higher than electrochemical battery, low operating voltage of each cell. The amount of energy stored per unit weight is considerably lower than that of an electrochemical battery (3 to 7Wh/kg compared to 180 to 290Wh/kg). Recent companies like *Skeleton* have developed supercapacitor with an energy density of 20Wh/kg.

These supercapacitors because of its high specific power density finds application in many ways- It can be coupled with a Lithium ion battery to make a hybrid battery pack in which the long-run power can be supplied by *Li* ion and the sudden power requirement or instantaneous power requirement which requires high current at time of quick throttle can be easily delivered by supercapacitor by eliminating stress on *Li* ion battery and increasing the battery life. Regenerative braking energy can be quickly stored by this capacitors and again this capacitors can deliver the instantaneous power on the sudden throttle hence increasing range. Super capacitors can be used in the multiple ways for power quality assessment.

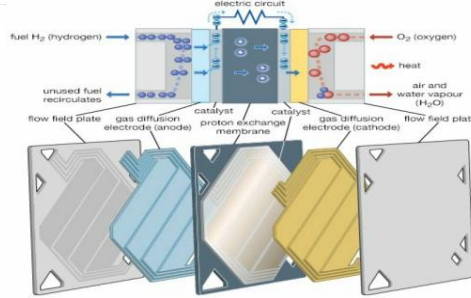
VI. FUEL CELL

Device that convert the chemical energy of a fuel directly into electricity by electrochemical reaction. Fuel cell resembles a battery in many respects but it can supply electrical energy over a much longer period of time. Fuel cell essentially has the same kinds of components as a battery, each cell of fuel cell system has a matching pair of electrodes (anode(-) and cathode(+)) which mostly be immersed in and separated by an electrolyte (solid or liquid). Fuel such as hydrogen is supplied to the anode where it is oxidised producing H^+ ions and e^- and oxidizer such as oxygen is supplied to cathode where the H^+ ions from anode through external circuit absorb electrons from the latter and react with oxygen to produce water and heat as byproduct, catalyst is usually used to speed up the reaction at the electrodes. The difference between energy levels of electrodes (EMF) is the voltage per unit cell. The amount of current available to external circuit depends on chemical activity and amount of substance is supplied as fuels. The current producing process continues for as long as there is supply of reactants unlike battery where in once the stored energy is utilised we must recharge the battery to its potential energy storage. Fuel cells can vary from tiny devices producing few watts of electricity right up to large power plants producing megawatts. Fuel cells are classified according to the nature of the electrolyte they use, each type requires particular materials, fuels, operational temperature and is suitable for different application. *Benefits*- low to zero-emission, high efficiency (60%), reliability, fuel flexibility, high energy density, energy security, durability, scalability, quiet operation.

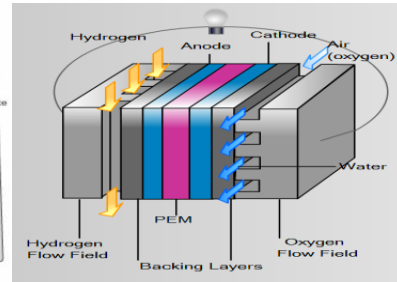
(a)



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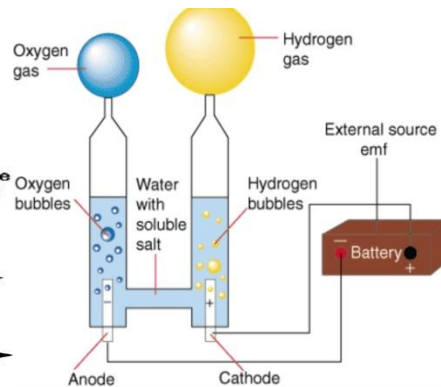
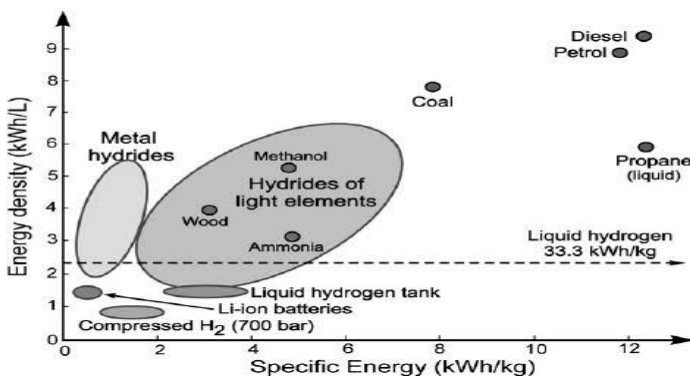
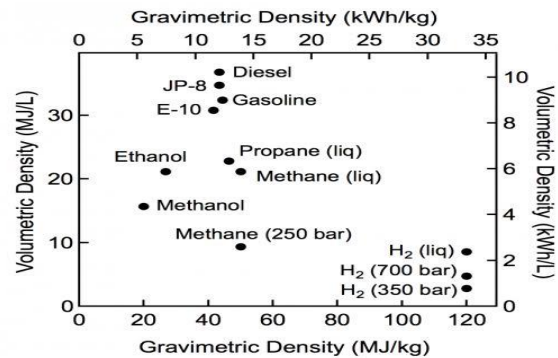


(c)



Fuel cell is a high efficiency device it make convert fuels to useful energy at an efficiency has has 60% where as internal combustion engine is limited to 40% or less. A fuel cell can be designed to work reversibly i.e hydrogen oxygen cell that produces H₂O can be used to produce H₂ and O₂ gases this type of fuel cell need special arrangements and assembly for separating and storing H₂ and in some cases O₂ gas. *Types of fuel cells-* Alkaline fuel cell, Phosphoric acid fuel cell, Molten carbonate fuel cell, Solid Oxide fuel cell, Proton exchange membrane fuel cell (PEMFC), Direct Methanol fuel cells. PEMFC is one of the most advanced fuel cell designs, hydrogen gas under pressure is forced through a catalyst typically platinum on the anode(-) of fuel cell, at this catalyst e⁻ are stripped from the hydrogen atoms and carried by an external circuit to cathode, H⁺ ions pass through PEM to catalyst on cathode(+) side where it react with O₂ and e⁻ to form H₂O and heat. PEMFC is mostly used to power EVs.

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 ₃ OH - 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

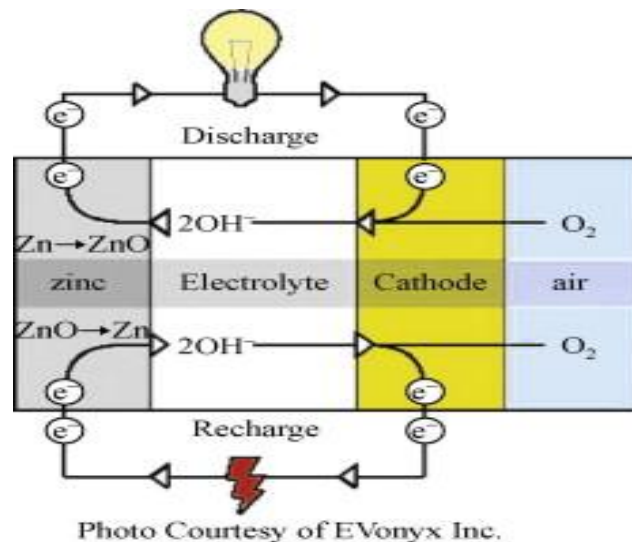


Hydrogen based energy storage systems are receiving increasing attention at present time particularly in relation to their integration with renewable power sources. There are a range of approaches to producing hydrogen directly from

thermochemical or photochemical process using concentrated solar energy or even using PV array for electrolysis. High energy density- 1.2 to 30 KW /kg.

EVs like Toyota Mirai(Hydrogen run) have already been launched(range of 500km) , largest industrial hydrogen fuel cell power plant in world to use only hydrogen recycled from petrochemical manufacturing has been installed by Hanwa energy in South Korea with the capacity of 50MW. Hydrogen fuel cell have opened of numerous opportunities to tap renewable energies.

Metal Air Battery- can be regarded as a special type of fuel cell using metal(aluminium or zinc) as a fuel and air has oxidant. the most compact and potentially the least expensive battery/ Fuel cell. Main Disadvantage however is that electrical recharging of this battery is very difficult and inefficient,although many manufacturers offer refuel units where the consumed metal is mechanical replaced and processed separately. While the high energy density(1.35 KWh/kg to 2KWh/kg) and low cost of metal Air batteries may make them ideal for many primary battery application ,the electrical rechargeability of these batteries needs to be developed. many companies are already working on developing metal layer Technology for commercial purpose.



VI. CONCLUSION

There has been a drastic advancement in Electrical Storage Technology in past 10years and its advancing at a very good pace presently. Electric revolution in transportation has led to research in developing the next generation battery which will have high specific energy density,high specific power, high efficiency,high stability and reliability. It is evident now that the future economy will be driven by electrical energy and storage systems plays key role especially for Integrating Renewable power source.We prioritize environment and Energy business as key business areas and promote our Electrical Energy Storage business.Every Country must focus on developing Electrical systems in which storage systems need key focus to secure high Energy Security.

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