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Battery Technology – A Comprehensive Review

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Abstract

Depletion of fossil fuels, stringent pollution norms have made a way for research on the systems that can store energy from renewable sources like solar and wind. Electrical vehicles (EVs) and hybrid vehicles (HEVs) density worldwide are increasing at faster rate and have projection estimate of more than 140 million (HEVs) and EVs on the road by 2030. Design of these advanced engines are based on the availability power source namely lithium-ion (Li-ion) battery. This paper focuses on available battery technologies, components of Li-ion batteries, key features of the battery such as energy density, power density and so on and opportunities of recycling, extraction of valuable metals from the waste batteries are also included.

Keywords: *Electrical vehicles, Hybrid vehicle, lithium-ion, recycling.*

1.0 Introduction

Battery is a system comprising of single or multiple cells configured in series or parallel where chemical energy is converted into electricity and used as a source of power.

A typical battery cell comprises of an outer container, two electrodes cathode and anode, barrier, an electrolyte and conductive current collectors.

Types of Batteries

The two major battery types are:

1. Primary Batteries
2. Secondary Batteries

1. Primary Batteries

In primary batteries electrochemical reactions cannot be reversed, hence these are not rechargeable in nature. These batteries are environmentally friendly, have higher energy density, low cost, leak free and found practical applications in wrist watches, toys, remotes, emergency lights and many more. These are again classified into:

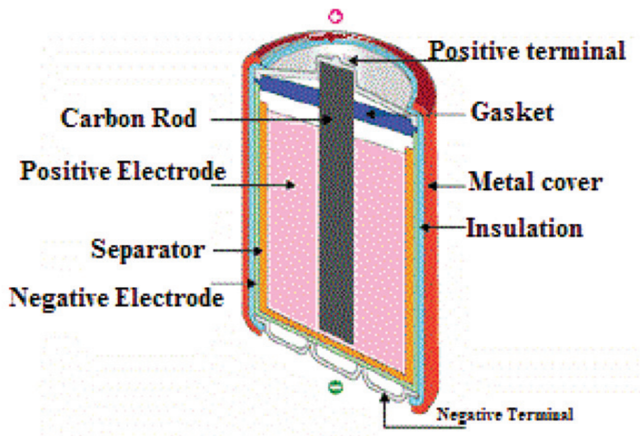

Figure 1: Primary Battery

I. Solid state batteries – Here ‘solid state’ of the battery refers to the usage of solid electrolyte and the ion transmission between the electrodes takes place in a solid, non-electrically conductive material, usually a polymer.

II. Batteries with a solid cathode – These are small cylindrical batteries.
III. Batteries with soluble cathodes – Structural change of cathode is observed during operation [15], [13].

2. Secondary Batteries

An electrical battery which can rechargeable in nature and the chemical reaction of electro-chemical cells are reversible by applying certain voltage are referred to as secondary batteries. These are generally used alongside inverters to supply electricity, electrical vehicles and small capacity batteries are used in cell phones, emergency lights, toys and many more.

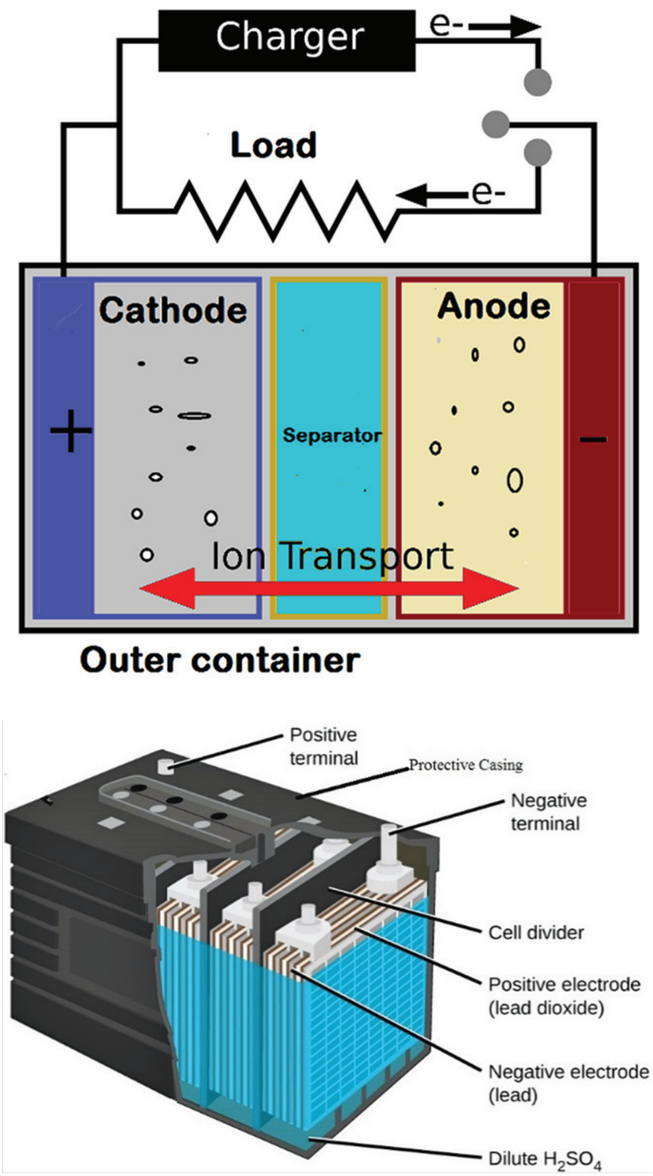

Figure 2: Secondary Battery

Secondary batteries are again classified into following types,

1. Lithium-ion (Li-ion)
2. Nickel Cadmium (Ni-Cd)
3. Nickel-Metal Hydride(Ni-MH)
4. Lead-Acid

Types of Lithium Ion Batteries

In the current generation lithium ion batteries can be seen in almost all household applications, each and every individual carries a lithium ion batteries with them in a mobile. Lithium ion batteries are getting greater interest by the virtue of its higher energy density, faster rechargeability and these are long lasting.

The general lithium ion batteries are

Table 1: Types and Properties of batteries

Type	Properties
Lithium-Cobalt Oxide Battery	Used mostly in handheld electronics (Cell phones, Laptops and Cameras) Risky especially when damaged Cobalt is scarce and expensive Low discharge rates Highest energy density (110-190) Watt-hour
Lithium-Titanate Battery	Can operate at very low temp (–40°C) Rapid charge and discharge used in Mitsubishi i-MiEV lower inherent voltage 2.4 V (compared to 3.7 V) lower energy density (30-110) watt-hour
Lithium-Iron phosphate battery	Dramatically reduces the risks of overheating and fire. Offers much less volumetric capacity used in power tools and medical equipment longer-life and inherently safe lower energy density (95-140) Watt-hour
Lithium-nickel manganese cobalt oxide battery	Longer life and inherent safety cobalt is scarce and expensiveLess prone to heating used in power tools, e-bikes and electric power trains lower energy density (95-130) Watt-hour
Lithium-manganese oxide battery	Lower cost longer life and inherently safe used in hybrid vehicles, Cell phones, Laptops high discharge rates lower energy density (110-120) watt-hour

Current generation need uninterrupted power supply 24 hours a day as all the devices which we use run on electricity. With the depletion of fossil fuels reserves, stringent pollution norms and higher support for renewable energy sources, the need for power storage devices are increasing as the power availability from renewable energy sources such as wind and solar are not continuous.

Energy Storage for the Electricity Grid

The unevenness of solar and wind power energy availability, it is hard to supply electricity and to integrate them into the electricity grid. Grids need to be reliable and stable, and continuously balance the supply and demand of electricity. This can be achieved by having a storage batteries which in turn connected to grid and it will also help during peak demand hence has a less chance of grid overloading.[11]

Energy Storage Systems for Rooftop Solar Panels and off the Grid

Many parts in the world are not accessible with electricity grid. In such places rooftop solar panels are used to generate electricity, this can be stored by using batteries and even these can be used along with diesel generators [11].

Energy Storage for Electric Vehicles and Hybrid Electric Vehicles (HEVs)

As the interest towards electrical vehicles is increasing, the need for storage devices has got great potential. High energy density batteries can be used to supply for both electrical and hybrid vehicles.

Selecting of Battery

Present technology is focused on artificial intelligence (AI) and internet of things (IOT) but thing that is pulling back the progress rate is power supply for a long time from the batteries. The parameters to be considered for the selection of battery are as follows:

1. Energy Density: It is the total amount of energy that can be stored per unit mass or volume. Energy density specifies how long the device stays on before it needs a recharge [9].
2. Power Density: This can be expressed in mass basis or volume basis. It is the maximum rate of energy that can be discharged from the battery per unit mass or volume.
3. Safety: The main parameter to be considered in the selection battery is working condition such as ambient temperature, operating temperature. Generally, at high operating temperatures performance of most batteries diminutions [14].
4. Life cycle durability: Energy density and power density of a battery must remain constant over the life span.
5. Cost: In any project economy also plays a major role, hence based on the application the batteries need to be selected to suit the chosen application.

The solid state batteries gains more importance because of commercialization of solid state batteries as lithium metal [LIM] as the anode. Solid state batteries have a freedom to enhance the gravimetric and volumetric energy density of

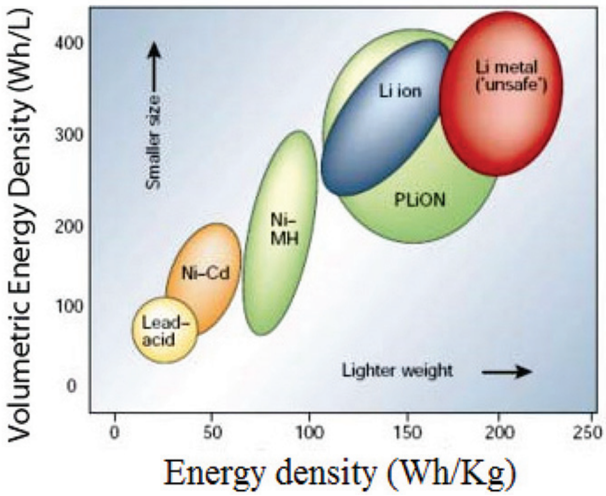

Figure 3: Energy density of various batteries [11], [12]

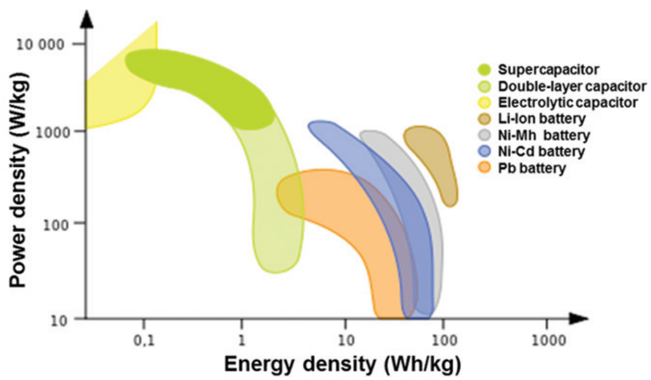

Figure 4: Power density v/s Energy density

Table 2: Comparison of different battery technologies [6], [7], [9]

Battery type Parameter	Lead acid	NiMh	LiNMC/Graphite	$LiFePO_4$/graphite	Vanadium redox-flow
Energy density (Wh/Kg)	40	75	160	110	45
Power density (W/Kg)	350	600	1300	4000	120
Cycle Lifetime	600	900	2500	5000	12000
Efficiency %	85	75	93	94	80

LIBs by enabling the use of LIM. The investigator should address the active material weights, in specific the amount of LIM used, and inactive material weights, in specific the density and thickness of the solid state batteries, for the correct comparison to current Li-ion batteries. The most hopeful solid state battery is a low density sulfide, being low density polymer should be begian with the adequate room temperature conductivity. There are utilization in which the solid state electrolyte have benefits which include very quick charge and dis-charge and it has an improved freedom. The drawback of the solid state electrolyte is speedy reducing of cost of liquid electrolyte [1].

Detracting to battery accomplishment the material and thermal characteristics. The opportunities to recycle the batteries are given more importance in the present scenario. The performance of existing lithium batteries is heavily dependent on material and thermal characteristics.

As discussed, most of the heat from the battery is produced at the electrodes and further investigation in several cooling approaches and electrode design measures is needed to decrease or compensate for the heat, therefore, enhancing the battery life and capacity.

Li-ion batteries as a method for energy storage for EVs. Diverse materials for positive and negative electrodes, various kinds of electrolytes and the physical execution of Li-ion batteries are presented and equated, and parts of battery management systems are described. As EV batteries reach the end of their useful life, investigation is showing the different methods to repurpose them as an addition to the existing power grid or reprocess the battery materials when they are no longer feasible [2].

For an average person, lithium-ion technology, at least until the last year or so, was denoted by the black-box-like batteries in high-end consumer campaigns such as laptop computers. Mobile phone batteries use similar chemistry, although in that case the batteries are often lithium-polymer types that are often defined as if they constitute a completely different technology [3].

The recent story about safety issues and consumer battery memories we are seeing lithium-ion batteries being endorsed for power tools, electric vehicles and also standby-power applications. New terms is appearing, such as iron phosphate and lithium titanium, and nanotechnology is being combined into some designs. Mix-up controls, since all of these products fall into the same broad ‘lithium-ion’ group.

Li-ion batteries are the heart for the digital electronic revolution, exclusively used in mobile phones and laptop computers. The achievement of commercial Li-ion batteries in the 1990s was not an instant success, but an outcome of intensive investigation and involvement by several great scientists and engineers. Then much efforts have been put to further improve the performance of Li-ion batteries, reached certain significant development.

Li-ion batteries have affected nearly everybody in the world. The achievement of commercial Li-ion batteries was a result of intensive investigation and influence by many great scientists over few decades. Newly, much effort was put into further improvement on the performances of Li-ion batteries, achieving certain level of success. [4]

Alternate Technology for Lithium-ion Batteries

Even though lithium-ion batteries are widely used because of high energy density but needs shield from overcharging and prevention from short-circuiting. The recent innovation has made a way to overcome those drawbacks by using iron as the multivalent charge carrier. Iron is cheaper and has got great potential in the field of rechargeable batteries. [Research by Dr. S. Ramaprabhu sundra, IIT Madras]*

Methods of Recycling Lithium-ion Batteries [19], [16]

Lithium-ion batteries can be recycled to extract the valuable metals by the following methods:

Hydrometallurgy-Dominant Methods (HDM)

The separation of valuable metals are aided by leaching, precipitation and solvent extraction in the solution system, which is mainly composed of acid/alkali/organics.

Pyrometallurgy-Dominant Methods (PDM)

Physico-chemical transformation rate is accelerated by applying high temperature (>1400°C) to extract valuable metals.

Mild Recycling Methods (MRM)

It’s a combined method that utilizes the advantages of hydrometallurgy-dominant and pyrometallurgy-dominant method that reduces the acid usage and requirement of high temperature.

Direct Recycling (DR)

Direct recycling, an emerging recycling method, is a solvent extraction process where supercritical carbon dioxide (CO_2) is used to extract cathode and anode materials.

*https://www.thehindu.com/sci-tech/science/iit-madras-registers-initial-success-with-iron-ion-battery/article28976853.ece

Steel research towards decreasing energy requirement and efficient lithium recovery has got great potential. Pyrolysis method can be employed to recover the Zn content by carbothermal reduction. By this method Zn recovery has reached 99%. [10].

Recycling cathode materials from spent batteries make a way for sustainable source of materials, which offers an economic alternative for some of the high value elements such as cobalt and nickel. By using direct recovery method the cost of cathode can be recovered by 43% which made from virgin metals [16].

Among the available methods PDM is less time consuming and can be scaled up, hence it is generally used in the industries even though it has a disadvantage of high energy consumption and loss of lithium with slag [19]. The energy consumption and application of acids in the processed is somehow decreased in MRM technique. Research towards decreasing energy requirement and efficient lithium recovery has got great potential.

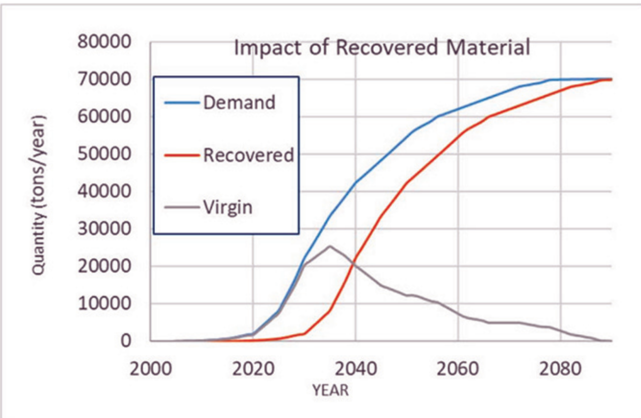

Figure 5: Material vs Cathode cost [JEFF Spangenberger, Argonne national laboratory March 22nd, 2018,]

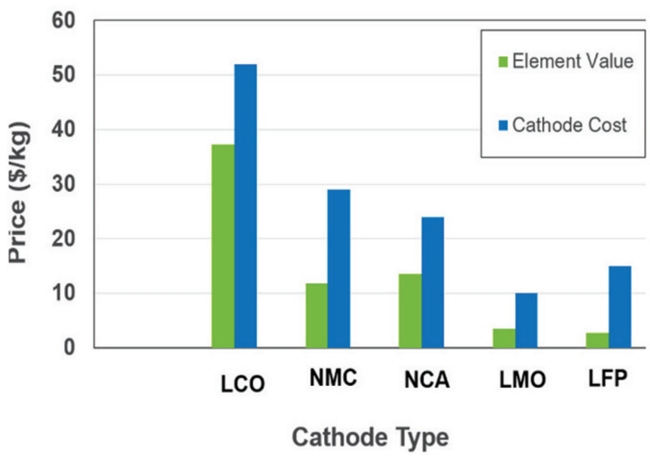

Figure 6: Estimated Cathode cost v/s Constituent cost

2.0 Conclusion

This paper provides the information on primary and secondary batteries and different types of Lithium ion batteries. A brief discussion is including on iron-ion batteries. Current generation has got great potential for battery technology research and methods to recover valuable metals from spent batteries and the same is highlighted in this paper.

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