EVs: A Review on Past, Present, Future

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***Abstract*—Electric vehicles offer a significant alternative to traditional automobiles that use petrol and diesel as fuel. Instead of burning fossil fuel, electric energy from a battery is used to power the vehicle's motor. In India, a country that is the fourth largest greenhouse emitter in the world, with 7.08% of all the emissions, and has some of the most populated cities, there is a growing concern about the population of the environment. As a result, people and governments are increasingly turning to cleaner sources of energy, with electric vehicles being a major focus. In India's transportation sector, road transport is a primary contributor to carbon dioxide emission, accounting for 94.5% of the estimated 258.10 Tg of CO2 emitted from the sector between 2000 and 2004. This has led to increased research into electric vehicles and their components, with batteries being their critical components. This review paper aims to determine which of the presently available battery technologies is more efficient and advanced.**

I. Introduction

A. Why Do We Need To Switch To EVs?

Greenhouse gas emissions are increasing day by day and this is the primary cause of the depletion of our precious bodyguard of UV rays. Major contributors to GreenHouse gas emissions are the fossil fuels that we burn for our daily usage such as in thermal power plants, automobiles, industrial applications, and many more. But among this hefty amount of contribution is of automobiles we use daily. That's why there is a need to shift to EVs. EVs will help in countering the growth of greenhouse and will in return help in protecting the environment. EVs are vehicles that run on electricity. As there is no use of fossil fuels, they are sustainable for our environment. Electric Vehicles can be used in various sectors such as public transport, goods vehicles, and also the private sector. In India, the number of electric vehicles is increasing but at a slower pace. As per the Ministry of Heavy Industries, there are only 13,34,385 Electric Vehicles and 27,81,69,631 non-electric vehicles in India posted on 19 July 2022 by PIB Delhi. This is a very low number and there is an extreme need to switch to EVs.[1]

B. 1.2 Battery - Primary Component of EV:

Electric vehicles work on electricity and that needs to be stored somewhere which is called a battery. But currently, there are many problems associated with batteries, making EVs non-reliable for human beings. Different types of batteries are present in the market but each battery has a different drawback of its own making it difficult for a consumer to choose which to leave and which to buy. Moreover, the charging time and capacity of a battery also play a vital role in choosing a more reliable battery. So we analyzed different types of batteries measuring various parameters for each battery. We observed that some of the major batteries that come in the market are Lead acid, Nickel Cadmium batteries, Nickel-metal Hydride batteries, Li-ion(cobalt) batteries, Li-ion(manganese) batteries, etc. There are many problems existing in batteries and we analyzed different batteries with different parameters to conclude which one is best for a consumer. Under Phase-1 of the FAME-India Scheme, the Ministry of Heavy Industries has sanctioned 520 EV Charging stations, of which 479 charging stations have been installed until 1st July 2022. (For Eg 48 charging stations have been installed in Chandigarh,94 in Delhi,49 in Rajasthan, etc.) But we observe that the number of charging stations is very low in a vastly populated country like India.[2]

C. Types of cells

EV batteries are the most important component of EVs. Batteries comprise small cells that make up the whole battery. These cells are 4 types of cells:-

1) Cylindrical cells: They are the most common type of cell. They are generally made of metal (such as aluminum or steel), and have a cathode made up of lithium cobalt oxide and an anode made up of graphite. They have high energy density and high temperature tolerance. Example Tesla car batteries.

2) Pouch cells: They are the least popular among all cells. They are generally made up of flexible pouches with a cathode made up of lithium cobalt oxide and an anode made up of graphite. They are low-weight and can be shaped to fit in different spaces of different dimensions. Examples that are used in consumer electronics such as smartphones.

3) Prismatic cells: They are also commonly used in EV batteries. They are shaped like rectangular metal boxes with a cathode of lithium cobalt oxide and anode of graphite. They have high energy density. Example an energy-intensive application due to the large size of the cell.

4) Coin cells: They are used for research and development, but never in actual EVs.

D. Benefits of EV

The success of electric vehicles is heavily reliant on advancements in battery technology, as EVs rely on batteries as their primary power source. Battery research is essential for improving EVs' performance, range, and affordability by developing more,longer-lasting, and faster-charging batteries that can make EVs more appealing to consumers. Environmental benefits: One of the main advantages of EVs is their reduced environmental impacts compared to gasoline-powered vehicles. However, the manufacturing and disposal of EV batteries can still have negative environmental effects. Battery research aims to develop batteries that are more environmentally sustainable, with a reduction of carbon footprints and improved recycling methods. Energy storage: Advances in battery technology can help make energy storage more efficient and cost-effective, which can help to promote the use of renewable energy sources. High energy density batteries must be used which can store energy in lesser volume and less weight. Economic benefits: The market of EV batteries is expected to grow significantly in the coming years, which could have significant economic benefits for countries that are leaders in battery technology. Research on EV batteries can be commercialized and exported, creating jobs and economic growth.

II. LITERATURE REVIEW

A. Review of the literature:

EV batteries have a long history. The batteries we use today and advancements in the batteries have been a collaborative effort of various scientists for many years. Following are the findings of scientists during their respective periods

TABLE I
DISCOVERY OF DIFFERENT RESEARCHER[3]

S.No.	Scientist(s)	Discoveries
1	Gaston Plante	In 1859 Gaston Plante discovered rechargeable lead-acid batteries.
2	Camille Faure	In 1881 Camille Faure discovered how to manufacture lead-acid batteries.
3	Neill Weber and JT Kumme	In 1967 they developed a sodium-sulfur battery while working at Ford.:
4	Exxon	In 1976 Exxon introduced lithium-titanium batteries but they were unable to stop them from exploding.
5	John Goodenough	In 1980 John Goodenough invented a lithium-cobalt-oxygen battery which is one of the basis of today's lithium-ion technology.
6	Dr. Yoshino	Invented and patented the world's first lithium-ion battery. He had about 60 patents on lithium ion during his career.

B. Period Of Evolution

With the exponential increase in demand for EVs, technology is also remodeling day by day. There are now many technologies available that are increasing the efficiency of EVs, including regenerative braking systems, smart power management through AI, and more. Batteries, which are a crucial component of EVs, have also undergone significant developments since the discovery of electric charge in the late 600 BC. These advances have led to smaller, lighter, and more efficient batteries that are helping to extend the range and reduce the charging times of EVs. In 1800 when Alessandro Volta invented the 'Voltaic pile, which consists of alternating disks of copper and zinc separated by brine-soaked cloth no one ever thought that one day we could store electrical energy in small boxes. In 1982 when Nokia introduced the 10 kg smartphone no one had ever thought that one day (in 2022) a sports car (Tesla Model Y) could fully run on batteries and compete with cars with turbochargers. In 1991 Sony introduced Li-Ion batteries for the handheld camera but today in 2023 every electrical device that runs on battery uses a Li-ion battery as its primary power source. The prediction table shows that by 2025 electric vehicles will account for 25% of the total car market. By itself, by 2030 Li-ion batteries will have a $100bn market. From Voltaic plate(1800) to rechargeable lead-acid battery(1859)to iron-nickel battery(1902) to sodium-sulfur battery(1967) to lithium-cobalt-oxygen battery(1980) to sony Li-ion(1982) we have done a lot of effort to store electrical energy but in last Li-ion has proven its might in storing electrical energy. With high charge density and low maintenance, Li-ion has proved competent in many ways.

C. Batteries Existing in the Market

In EVs the major focus is on green energy, there are numerous types of batteries in the EV sector such as Lead Acid, NiCd, NiMh, Li-ion(Cobalt), and Li-ion(Manganese). The major parameters that we took into account while figuring out which battery to use are to have a maximum specific energy density, good cycle life, least charging time, low charging temperatures, and less maintenance requirement. Following is the comparison between different types of batteries existing in the market

TABLE II
COMPARISON OF DIFFERENT BATTERIES [4]

Specification	Lead Acid	NiCd	NiMh	Li-ion (Cobalt)	Li-ion (Manganese)
Specific Energy Density(Wh/kg)	30-40	45-80	0-120	150-190	100-135
Cycle Life	200-300	1000	300-500	500-1000	500-1000
Charging Time[hr][5]	8-16	1	2-4	2-4	1 or less
Charging Temperature(°C)	-20 to 50	0 to 45	0 to 45	0 to 45	0 to 45
Maintenance Requirement(months)	3-6	1-2	2-3	Not required	Not required
In use since	the Late 1800s	1950	1990	1991	1996

As we can see in Table II specific charge density is good in Li-Ion(Cobalt) batteries, the cycle life of NiCd batteries is maximum and Li-Ion(Manganese) has the least charging time among all the batteries. Lead Acid has low charging temperatures. A very crucial feature is that Li-Ion batteries don't require regular maintenance or changing of chemical components to keep them working.

After comparing the batteries, now we compared the existing EV models which use different types of batteries and technologies. Following is the table showing the comparison:

As we can see in Table III, most of the car companies are using Lithium-Ion and according to the technology of the type of charger they use and the current/voltage specifications, the charging times of the above-mentioned EVs are different. Due to this, the range of EVs and the life cycle of batteries also varies. In the further part, we will do a complete analysis of EVs and their parameters.

Many types of Li-ion batteries are available in the commercial market with each having its own specification. Some of the existing li-ion batteries are lithium manganese oxide(LMO), lithium nickel cobalt aluminum oxide(NCA), lithium-iron phosphate(LFP), lithium titanium oxide(LTO), and lithium manganese cobalt oxide(NMC). Table IV gives a description of the characteristics of these Lithium-ion batteries.

TABLE III
COMPARISON OF DIFFERENT EVS[6]

S.No	Model Name	Type of battery	Charging Time(in hrs)	Life Cycle(in Kms)	Technology Used	Range (KMs)
1	Tesla Model S [7]	Lithium-ion	0.25	3,00,000	444 Panasonic NCR18650B cells in 6s74p config.	647
2	Nissan Leaf [8]	Lithium-ion	0.66(80% charge)	1,60,000	1670Wh module with 8 metal cells of 3.65V each 1670Wh module with 8 metal cells of 3.65V each	417
3	Ford Mustang Mach-E [9]	NCM batteries/LFP batteries	0.75	2,40,000	Standard range 70.0kWh battery	475
4	Hyundai Kona [10]	Lithium -ion polymer	1.25	2,00,000	Standard/Long range battery pack with 64kWh/77.4 kWh with regenerative braking	484
5	Audi etron [11]	Lithium -ion	0.5	2,40,000	83.7kWh energy with 33 cell modules each comprising of 12 pouch cells.	329
6	Tata Nexon [12]	Lithium -ion	1	6,50,000	Ziptreon battery module.	465
7	Citroen E-C3 [13]	lithium ferrous phosphate battery	1	321868.8	battery pack of Chinese firm Svolt.	320

D. Forthcoming li-ion Systems

As the demand is rising and the global population is moving toward clean energy li-ion batteries are a great source to store these energies for future use to cope with the growing demand advanced and extensive research is being carried out to give better, faster, and more efficient outcomes from the limited resources.

Table V gives us insight information regarding the upcoming battery technology mainly focused on li-ion.

TABLE IV
COMPARISON BETWEEN DIFFERENT LI-ION TECHNOLOGIES[14,15]

Li-ion battery technology	Cell voltage(v)	Specific Energy (Wh/kg)	Cycle Life (cycles)	Applications
LMO	3.7	100-150	300-700	EV
LFP	3.2	90-120	2000	EV
NCA	3.6	200-250	1000-1500	EV
NMC	3.7	140-200	1000-2000	EV
LMO/LTO	2.5	50-80	6000	EV, UPS
LMC/LTO	2.3	50-80	27000	Hybrid EV
LFP/LTO	1.8	50-80	20000	Hybrid Ev

TABLE V
UPCOMING LI-ION TECHNOLOGIES[15]

Technology	Characteristics	Cell Voltage(V)	Specific Energy (Wh/kg)	Cycle Life
Lithium Sulphur	Anode of Li metal with a protective layer of lithium nitrate (LiNO3). The cathode is made of sulfur-graphene with an ionic liquid-based electrolyte.	4	500	1500
Solid-state Li-Ion Battery	The anode is made from lithium metal and the cathode from NMC with solid polymer as an electrolyte.	3-4.3	500	23,000
Li-Metal	Anode is made from Li with Li coated with asphalt-graphene substrate with sulfurized carbon cathode and Concentrated electrolyte	1.7-1.8	900	30-40
Li-Air	The Anode Is made from lithium metal and the cathode from pure oxygen infuse into carbon with Organic electrolyte	2.4	150-6000	700
Flexible thin-film Lithium	The anode is made from Silicon and the cathode is made from Lithium oxide with polymer as electrolyte	4.8-5	300	40,000

E. Parameters of Different Batteries

After studying multiple research papers, a critical analysis must be carried out to get to a conclusion about what type of battery is best in every aspect. Necessary features that an EV must hold are a better life cycle of different batteries, market share of batteries, demand per year, charging time of batteries, and range of batteries. As we can see in Table III, all the car companies are using Li-Ion batteries with different configurations. So, this shows that among all the batteries available in the market Li-Ion is the best, and the following is the data to justify the statement.

1) The high energy density of Li-Ion Batteries[16]: Batteries are mainly compared based on two densities. First gravimetric and second volumetric density. Specific energy density or gravimetric energy density is the measure of the energy of a battery concerning the weight of the battery whereas the volumetric energy density of the battery is defined as the energy stored concerning volume. High energy density means storing high energy in a lesser volume and having a lighter weight. After studying various batteries and their energy densities, the graph has been plotted below.

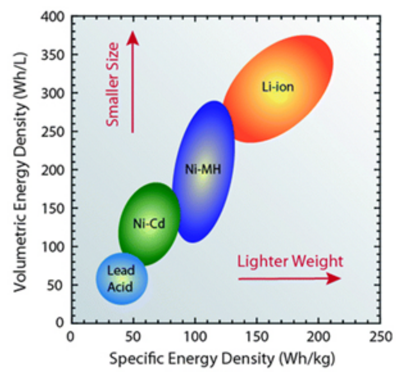


Fig. 1. Specific Energy Density Vs Volumetric Energy Density[16]

As we can see in Fig 1, a graph has been plotted between specific energy density(Wh/Kg) along the x-axis and volumetric energy density(Wh/L) along the y-axis. Li-Ion batteries have a higher energy density which means they can store a higher amount of energy in smaller sizes and will attain lighter weight which is a vital attribute to be considered while manufacturing an EV.

2) The good life cycle of Li-Ion[17]: Another factor that comes into a customer's mind is the life cycle of batteries, these must be future-safe and there must be no need to replace them in a shorter span of life. Various parameter comparisons have been plotted below comparing different batteries.

According to the histogram in Fig 2, Li-Ion has the second highest life cycle after vanadium redox flow battery but in the overall comparison of various aspects such as energy density, power density, nominal voltage, depth of discharge, round trip efficiency and estimated cost, Li-Ion is the best. Li-Ion has a good life cycle of 2000-2500 life cycles which ensures future safety and there is no need to replace the batteries for 10-15 years. This reduces the fear of customers.

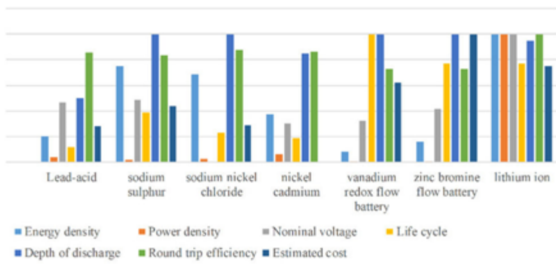


Fig. 2. Various parameters comparison between different batteries[18] Growth of the lithium-ion battery market

3) High Demand for Li-Ion: Another question that comes into the mind of the consumer is that the EV he might purchase today must hold a good price value in the future also if he wants to replace the car. The following graph shows the market capture of Li-Ion in the upcoming years.

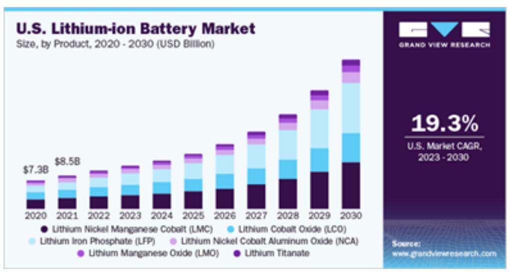


Fig. 3. Growth of the lithium-ion battery market[19]

At present, the global lithium-ion battery market is valued at US$ 59.8 Billion and is projected to grow to US$ 307.8 Billion by 2032 which shows that the demand for Li-Ion is increasing significantly [19] and it is reliable in future use also. The growth prediction of lithium-ion batteries is about 19.3% from 2023 to 2030 as shown in Fig 3. subsectionAs we talked about the key features that Li-Ion holds but it also has some drawbacks such as high initial life cycle costing and high replacement costs of batteries. Let's discuss these drawbacks with factual data.

4) High Initial Life-Cycle Costing: Nowadays, automobiles running on various fuels are available in the market and each fuel has its own key features and drawbacks. Initial life cycle costing is another factor that should be kept in mind while purchasing an EV which is how much each life cycle of battery costs with respect to operating time(KM).

As seen in Fig 4, after plotting the graph between LCC and operating time(in KMS), we can see that the life cycle cost of an electric motor with replacement batteries used in electric vehicles is slightly on the higher side than other fuel engines. This is one of the major reasons why people resist switching to EVs.

5) High Replacement Cost of Batteries [21]: In non-electric vehicles, there are fewer chances of engine failure and replacing the engines. But in EVs after years of discharging and charging, there is a need to replace the batteries and this is another issue with electric vehicles.

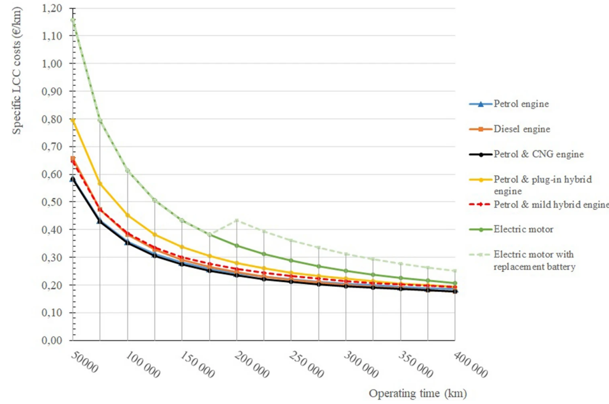
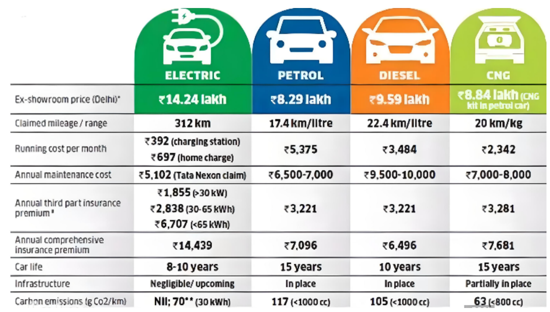


Fig. 4. LCC vs operating cost[20]



	ELECTRIC	PETROL	DIESEL	CNG
Ex-showroom price (Delhi)*	₹14.24 lakh	₹8.29 lakh	₹9.59 lakh	₹8.84 lakh (CNG kit in petrol car)
Claimed mileage / range	312 km	17.4 km/litre	22.4 km/litre	20 km/kg
Running cost per month	₹392 (charging station) ₹697 (home charge)	₹5,375	₹3,484	₹2,342
Annual maintenance cost	₹5,102 (Tata Nexon claim)	₹6,500-7,000	₹9,500-10,000	₹7,000-8,000
Annual third part insurance premium*	₹1,855 (>30 kW) ₹2,838 (30-65 kWh) ₹6,707 (<65 kWh)	₹3,221	₹3,221	₹3,281
Annual comprehensive insurance premium	₹14,439	₹7,096	₹6,496	₹7,681
Car life	8-10 years	15 years	10 years	15 years
Infrastructure	Negligible/ upcoming	In place	In place	Partially in place
Carbon emissions (g Co2/km)	Nil; 70** (30 kWh)	117 (<1000 cc)	105 (<1000 cc)	63 (<800 cc)

Fig. 5. Comparison between cars with different power sources [21]

In Fig 5, we can see that electric vehicles are better in running cost per month, and annual maintenance cost but the issue arises in the case of high initial cost and short life span of batteries. Due to the fear of replacing batteries and the cost of replacing batteries is high, people do not switch to EVs due to the short life span of about 10-15 years.

6) Life Cycle Global Warming Emissions [22]: In Fig 6, a brief comparison is given between the EVs, and Gasoline cars and trucks. As we can see there is a 52% reduction in global warming emissions if we switch from a gasoline car to an electric car. Also, there is a 57% reduction if we switch from a gasoline truck to an electric truck. **MPG** - Miles Per Gallon

F. Heating and Cooling of EV

1) Impact of High Temperatures: Electric cars can get overheated faster and their efficiency decreases in turn their range becomes shorter. The following are the two main reasons:

1) In hot weather, due to high temperatures electrons in the battery undergo rapid collisions which in turn reduces the speed of electrons, which reduces power efficiency.
2) In conventional cars, combustion takes place, due to which heat gets dispersed. As there is no combustion happening inside an EV, the heats get trapped which causes overheating which in turn reduces its range.

2) Impact of cold Temperatures: Cold weather also impacts battery efficiency as does hot temperatures:

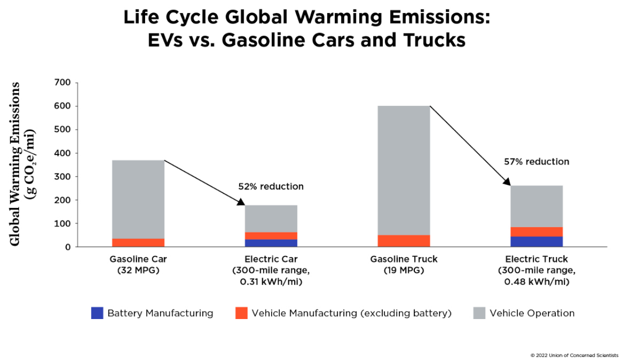


Fig. 6. EVs vs Gasoline Cars and Trucks [22]

According to studies, the battery efficiency in cold temperatures is 15-20% lower than in summer.

1) Batteries take longer charging time in cold temperatures.
2) Battery capacity to store energy also decreases in winter which in turn decreases the range of EVs.

As we can see both the high and low temperatures impact the battery efficiency which decreases the range of an EV, a driver has to keep in mind the temperature conditions around him before deciding to go out.

Fig. 7 shows the Real-World Range vs the Rated Range concerning temperature(°C). [23]The above graph is based on the average efficiency of 5.2 million trips taken by 4200 EVs of 102 different make/model/year combinations. Also, according to this figure which is being made after deep analysis of various conditions, it is found that 21.5°C (70°F) is the temperature at which EV has best efficiency.

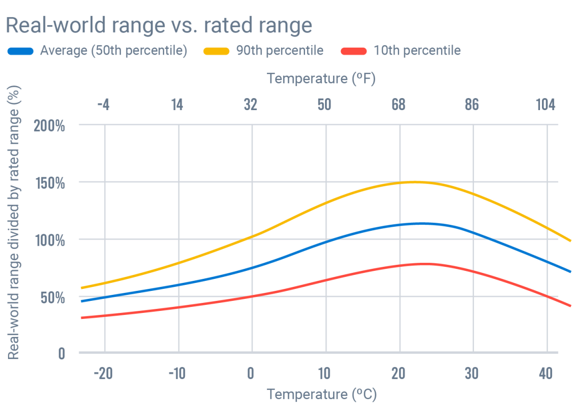


Fig. 7. Real-World Range vs Rated Range w.r.t. Temperature[23]

G. *Disposal of Li-Ion*

Lithium-ion batteries are currently dominating the electric vehicle field. Due to their large usage, it becomes important to dispose of them suitably so that it does not cause any harm to nature, humans, or any other factor. They contain hazardous metals such as lithium, cobalt, and nickel whose improper disposal can lead to contamination of water bodies, and soil and a threat to human and animal life. Here are some problems related to current methods of disposing of Li-ion batteries:-

1) Many countries lack proper infrastructure for better recycling of lithium batteries. These recycling processes are expensive due to the separation of metals like cobalt and lithium.
2) My areas lack proper guidelines for the disposal of Li-ion batteries because too many useable resources are getting wasted.
3) There is no proper transportation and handling facility for Li-ion batteries due to which they cause fires or accidents.
4) Growing the number of lithium batteries increases more electronic waste that is contaminating the environment.

[24]So, seeing the effects of lithium-ion batteries due to improper disposal, here are the possible solutions that can be used for proper disposal of Li-ion batteries:-

1) There can be mainly possible possibilities i.e. remanufacture, repurpose, and recycle. The ideal for getting maximum output is remanufacturing and repurposing.
2) **Pyrometallurgical process**:- this is widely used for the recovery of cobalt. Batteries are decomposed by methods called preheating, pyrolysis, and smelting. In preheating the temperature is kept lower than 573K to avoid explosion. In pyrolysis, plastic is removed from the battery by maintaining it above 973K. In smelting, the battery is smelted into alloys to metals like copper, cobalt, nickel, and iron.
3) **Direct Physical Recycling**:- This method involves recovering components from a battery with the involvement of chemical methods. In this process, batteries are discharged in thousands of cells. Then these cells are treated with carbon dioxide, then by reducing the temperature and pressure this carbon dioxide can be separated from the electrolyte. Then finally cathode material is obtained.
4) **Hydrometallurgical Process**:- All the electrolytes and electrodes are treated separately to improve the output rate of the process. The process involves acid leaching and biological leaching. In acid leaching, inorganic acids such as hydrochloric acid, sulfuric acid, nitric acid, etc, and organic acids like citric acid, tartaric acid, etc are mostly used. The recovery rate is about 99% for cobalt and lithium and 98% for copper. In biological leaching, metals are extracted by metabolites exerted by microorganisms such as fungi and bacteria. These microorganisms release acids and enzymes that dissolve and extract metals such as lithium, nickel, etc.

III. Conclusion

Around[25] 1832 when Robert Anderson first built a crude electric vehicle in 2023 when the electric vehicle market had grown up toUSD 3.21 Billion (2022). EVs have grown exponentially but not up to their full potential. Despite facing many challenges and technological hurdles we have come a long way. With the changing world order and new technologies, we have made exponential progress in the field of batteries used in EVs. From nickel to lead acid and from nickel-cadmium to nickel hydride we have improved the efficiency in each step. Currently, the best solution according to our findings for EV battery manufacturing is the Li-ion. It has solved many problems like charge density, range anxiety, heating effect, and fast charging. Much more research is also going on to improve this existing technology like the removal of nickel and the introduction of liquid cooling charging cables. With the forthcoming technology, the efficiency and potential to deliver more power will increase exponentially.

IV. Future Scope

Batteries play a crucial role in reducing carbon emissions, mitigating the greenhouse effect, and decreasing our reliance on fossil fuels such as petrol and diesel. Currently, Lithium-ion batteries are the primary technology used in the world. However, many innovative EV charging methods are expected to emerge in the future EV market.

- Carbon Nanotube Electrodes:[26] Nawa Technologies has developed and obtained a patent for a Carbon Nanotube Electrode that can revolutionize the EV charging process. This innovative electrode is extremely fast, allowing for a charging time of just five minutes to achieve 80% battery capacity.
- Cobalt-free battery:[27] It is being developed by the University of Texas, which employs a cathode that does not contain cobalt. Instead, the cathode consists of 89% nickel, as well as aluminum and manganese, in a lithium-ion battery
- Silicon Anode Batteries: [28]To overcome the instability of silicon in lithium-ion batteries, a University of Finland researcher has discovered a technique for developing a hybrid anode. This anode incorporates mesoporous silicon microparticles and carbon nanotubes to enhance stability and performance.
- Power by Wi-Fi:[29] There is a groundbreaking concept being discussed regarding the possibility of recharging an EV wirelessly through Wi-Fi while it's in motion, thereby eliminating the need for plugging in a charger. This idea involves using a radio wave harvesting antenna developed by researchers, which can harness electromagnetic waves to recharge an EV.
- Zinc-Air Batteries:[30] The University of Sydney researchers have discovered a technique for producing cost-effective zinc-air batteries, which are more affordable than current zinc battery prices. These batteries are also safer, as they are not flammable, and offer faster charging times of up to 20 times, and longer-lasting performance than lithium-ion batteries.

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