Li-ion Batteries: Fundamentals and Recent Developments

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Abstract - *Batteries are essentially a form of storage that consists of two electrodes submerged in an electrolyte. This electrolyte acts as a conduit for the ion exchange that generates electricity. There has been extensive research done on various battery technologies and applications, and batteries of all shapes and sizes are thought to be one of the best ways to store energy. However, the environmental effects of widespread battery use remain a significant issue that needs further investigation. Li-ion batteries are the preferred technology for hybrid and fully electric vehicles, power tools, and portable gadgets due to their unmatched combination of high energy and power density. Li-ion batteries will dramatically reduce greenhouse gas emissions if electric vehicles (EVs) replace the majority of gasoline-powered transportation. The main Li-ion battery components are presented and contrasted in this study, along with the accompanying battery management systems and methods for enhancing battery efficiency, capacity, and lifespan. Battery performance is shown to be critically dependent on material and thermal properties. The physical implementation of Li-ion batteries, the positive and negative electrode materials, and the electrolytes are discussed.*

Key Words: **Li-ion batteries, different types of batteries, greenhouse gases, battery management systems, battery efficiency, electrode materials.**

1.Introduction:

Anode and cathode electrodes in an electrolyte act as the basic building blocks of batteries. The ion exchange that produces electricity uses this electrolyte as a channel. Each battery has unique advantages and disadvantages, but because to recent advancements in Li-ion technology, these batteries are now the market leader for usage in the majority of handheld and portable electronics as well as electric vehicles [1]. The key reasons for this are their high efficiency, lengthy cycle life, and specific energy (Wh/kg). They do have disadvantages, such costing a lot of money and requiring complex safety and monitoring systems.

Because of its unmatched mix of high energy and power density, lithium-ion batteries are the preferred technology for portable gadgets, power equipment, and hybrid and completely electric cars. If most gasoline-powered vehicles are replaced by electric vehicles (EVs), Li-ion batteries will significantly reduce greenhouse gas emissions. The high energy efficiency of lithium-ion batteries may also allow for their use in a range of electric grid applications, such as improving the quality of energy obtained from renewable sources like wind, solar, geo-thermal, and other energy sources, thereby encouraging their wider adoption and the growth of an energy-sustainable economy. There has recently been a lot of research in this field as a result of the increased interest in Li-ion batteries from both commercial and government funding organizations [2].

Lithium-ion batteries (LIBs) have drawn the most attention and importance among the created batteries in recent years. LIBs have a long service life, high coulombic efficiency, high discharge power, and high energy density when compared to other batteries [3,4]. Due to these qualities, LIBs have made great strides in a variety of fields, including stationary applications, portable and flexible electronics, and electric vehicles. The need to often update the community is vital because the subject of LIBs is developing quickly and drawing more researchers [5].

In Li-ion batteries, which may be thought of as energy storage devices that depend on insertion processes from both electrodes, lithium ions act as the charge carrier. Given this broad definition, there are different cell chemistries that make up the Li-ion battery family [6]. Most Li-ion batteries include negative electrodes made of carbon or lithium titanate ($Li4Ti5O12$), while research is also being done on novel materials such lithium metal and lithium (Si) alloys. To promote ion transport, different lithium salts, such as $LiPF6$, are typically coupled with an organic solvent, such as diethyl carbonate, depending on the electrode material chosen. A dividing membrane allows lithium ions to pass between the electrodes, preventing an internal reaction [7,8].

Lithium-ion Using Li-ion batteries in high-performance electric vehicles is a desirable option. Li-ion offers a very high specific energy and a lot of charge-discharge cycles as compared to other rechargeable batteries. Additionally, the price is fair [9]. Li-ion batteries are therefore favored over alternative options like nickel-metal-hydride and silver-zinc batteries. However, Li-ion batteries are now only offered in tiny sizes on the market. In order to attain the appropriate battery sizes, several cells must be joined in series and parallel topologies. Making highly efficient, very reliable battery packs for use in electric cars is a challenge because of these and safety concerns [10,11].

1.1 Li-ion Batteries:

In recent years, Li-ion batteries, one of the most technologically advanced rechargeable batteries, have received a lot of attention. They are only found in cell phones and laptop computers, although they now hold a monopoly on mobile power sources for portable electronics [12]. Around 20 years ago, roughly around the same time when Li-ion batteries were first made available for purchase, the personal digital electronic revolution began, and Li-ion batteries are now regarded as its driving force. As one may have already observed from his or her daily life, better Li-ion batteries are constantly needed to support the growing functionality of mobile electronics. For instance, charging a cell phone with more features less frequently than one's present phone will enhance one's quality of life.

Electric and hybrid vehicles, which demand next-generation Li-ion batteries with not only high power, high capacity, high charging rate, and long life, but also significantly enhanced safety performance and low cost, are another significant expanding market for Li-ion batteries. Obama's administration in the United States has an extremely ambitious target of one million plug-in hybrid automobiles on the road by 2015. Similar strategies are being used globally to promote hybrid and electric cars. To underscore the widespread interest in Li-ion batteries, the Foreign Policy magazine even wrote an article headlined "The great battery race" [14].

Particularly as demand from electric vehicles rises, Li-ion battery demand is rising quickly. To meet the demands from consumer use and electric vehicles, it is anticipated that roughly 100 GW hours of Li-ion batteries will be needed [15]. By 2018, the latter will account for around 50% of Li-ion battery sales. Additionally, Li-ion batteries will be used to smooth the gap between energy supply and demand in order to buffer the intermittent and erratic green energy supply from renewable resources like solar and wind. For instance, additional solar power produced during the day can be stored in Li-ion batteries to provide power at night when there is no sun light. Large-scale Li-ion battery production for grid applications will necessitate low-cost next-generation battery production [16].

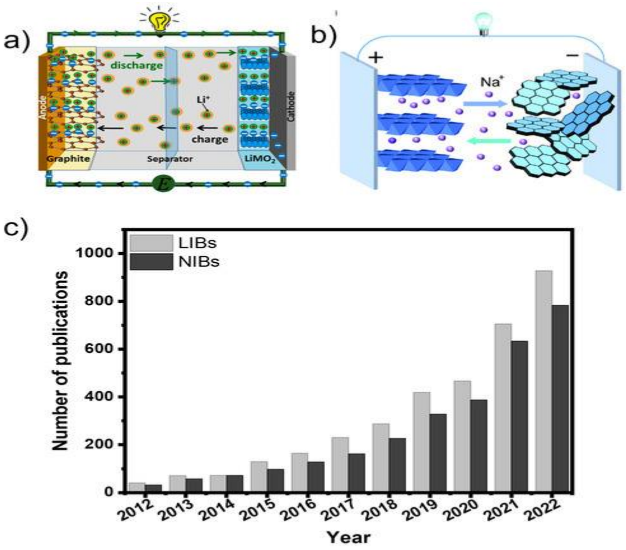

Fig. 1. In two decades, Li-ion battery demand will increase. With permission [17], reproduction.

Over the past 10 years, the number of scientific papers has increased tenfold as a result of the call for sustainable bio-based electricity storage systems [17–18]. Numerous studies have addressed the use of carbon anodes made from biomass in batteries to date. The primary properties of bio-based carbon anodes for batteries can be distilled down to a few key benefits, such as:

Excellent physical-mechanical stability is provided by the wide interlayer gaps during the ion intercalation/de-intercalation process [19].

- Many, varied surface functions that enhance charge transfer.
- High specific surface area (SSA), well-developed pore architectures with various nanoscale sizes, superior thermal stability, and quick mass transfers [20] are all positive characteristics.
- To improve the electrochemical performance (such as lifetime, capacity, and safety), the surface and structure of bio-based carbons can be easily adjusted or altered in terms of their chemical structure and surface functions, such as via heteroatom doping (nitrogen, oxygen, sulphur, etc.).
- The development of multiple carbon anodes employing various biomass carbons and composites is made easier by the vast availability and accessibility of these materials [21].

Lithium-ion batteries (LIBs) are the battery technology that has been around the longest and is currently the most used in our society. It has helped make portable electronics devices possible and is revolutionizing the auto sector. Intense research is being done on high energy density batteries all around the world, and LIBs, which have emerged as one of the most promising energy storages despite rising costs and uncertainty surrounding the source of component materials, are growing in popularity.

Li and Gr are becoming increasingly important strategic resources, nonetheless, as a result of the increasing demand and uneven geographic distribution [22–24]. Lithium-ion batteries (LIB) use Li4Ti5O12 (LTO) or Gr as the anode and lithium-ion cathode materials such as lithium cobalt oxide (LCO), lithium iron phosphate (LFP), lithium manganese oxide (LMO), lithium nickel-manganese-cobalt (NMC), and lithium nickel-cobalt-aluminum oxide (NCA). The majority of LIBs in the world—nearly 95%—are made in Asian nations including China, Taiwan, South Korea, Japan, and South Korea. However, due to its limited energy capacity and unreliable operation, Gr has been widely employed as an anode material for LIBs and was unable to meet the requirements.

In contrast, a number of anode materials have been extensively researched and attempted to replace Gr. These materials include silicon, tin, simple binary transition metal oxides, even Li metal for solid-state batteries, and particularly biomass-derived carbon materials with special morphologies and structures because they typically exhibit high specific capacity [25,26].

1.2 Batteries of Various type:

There are two basic types of batteries:

1. Primary batteries
2. Secondary batteries

1. **Primary batteries:** Primary batteries are “single-use” and cannot be recharged [27].
   Example:
   - Alkaline Batteries.
   - Lead-acid Batteries.
   - Ni-MH Battery.
   - Ni-Cd Battery.
   - Li-Po battery.

- **Alkaline battery:**

  Example: D cells, C cells, AA Cells, AAA Cells, AAAA cells, N Cells, 9Volt cells, Button Cells.
  Lead-acid Batteries:

Example: Flooded Acid, Gelled Acid, Advanced AGM (Absorbed Glass Mat).

- **Ni-MH Battery:** NiMH hydride batteries are used in.

Example Batteries for hybrid cars, electric razors and toothbrushes, cameras, camcorders, phones, pagers, and a wide range of other devices are just a few examples.

- **Ni-Cd Battery:**

Example: Specialty Emergency lighting, cordless and wireless phones, and other devices all employ Ni-Cd batteries. There are two different types of NiCd batteries: sealed and vented. Both have relatively low internal resistance and may deliver significant surge currents [28].

- **Li-Po battery:**

Example: LiPo cells provide manufacturers with compelling advantages. They can easily produce batteries of almost any desired shape. For example, the space and weight requirements of mobile devices and notebook computers can be met. They also have a low self-discharge rate, which is about 5% per month.

2. **Secondary batteries:** A secondary battery is a portable voltaic cell that is rechargeable [29].

Examples:
- Nickel-cadmium (NiCd)
- Lead acid, and lithium-ion batteries.

- **Nickel-cadmium (NiCd):** The nickel-cadmium battery (commonly abbreviated NiCd or NiCad) is a type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes. The abbreviation NiCad is a registered trademark of SAFT Corporation, although this brand name is commonly used to describe all nickel-cadmium batteries.
- **Lead acid, and lithium-ion batteries:** Lead acid batteries are currently produced in three different forms, and each type can be designed and constructed for either starting or deep cycle uses. These varieties include Advanced AGM (Absorbed Glass Mat), Flooded Acid, and Gelled Acid.

Battery Management System:

In order to prevent any detrimental effects on the power-intake profile, a battery-management system (BMS) recognizes unexpected circumstances and confirms the appropriate strategy for controlling the battery's temperature behavior. BMS is essential to the reliable and effective operation of batteries. It makes use of state estimation, a vast area of study.

The consequences of operations at various states, power requirements, temperatures, and health states should be minimized via BMS design. It often uses model base estimation, which, in order to function effectively, needs a precise battery model and a strong estimating approach. A well-designed BMS is necessary to support the safety, dependability, and overall performance of lithium-ion battery systems since LIBs charge faster than conventional battery technologies [30].

AI strategies in battery management systems:

A well-designed BMS is crucial to support the safety, dependability, and overall performance of lithium-ion battery systems since LIBs charge faster than conventional battery technologies. Due to the fact that a Li-ion battery is a highly time-variant, non-linear, and complex electrochemical system, it is difficult to estimate the SOC of a Li-ion battery accurately. The direct measurement approach, bookkeeping estimation method, model-based method, and computer intelligence method are the four major categories into which the SOC estimating methods have been divided. Their benefits, shortcomings, and estimation mistakes from previous studies are discussed critically. To enhance online estimation, certain suggestions are made depending on the advancement of technology [31].

The BMS is in charge of cell balance, thermal management, safety, and the SOC, SOH, SOP, and remaining usable life (RUL) of the battery pack.

A battery is controlled by a software and hardware system known as a battery management system (BMS) in order to work properly [32]. A BMS is composed of numerous functional components, including a state machine, temperature monitors, a real-time clock, a cut-off field effect transistor, a cell voltage monitor, and a cell voltage balance [33]. The market is flooded with many types of BMS-integrated chips. For various systems, the functional components are arranged differently; they could be anything from a straightforward analogue front end with a microcontroller capable of balancing and monitoring to a stand-alone fully automated.

There are many different actuators, controllers, and sensors that the BMS in EVs may use. Batteries must be protected, operated within reasonable limits of voltage, current, and temperature, and have their characteristics correctly monitored by BMSs [34]. Modular architectures, centralised systems, and distributed systems have all been employed in hardware architecture. For maintaining and monitoring a battery's status, Richter and Meissner presented a layer structure [35]. According to Gold, the various functionalities of BMSs can be used to categorise them. These ideas could be applied to develop a substantial framework with fundamental functionalit

Data is gathered at the monitoring layer by several sensors housed within the battery pack. The vehicle control processor and each component of the battery pack are connected to the BMS. BMSs have a long history of using safety [36].

Cell balancing is done to improve battery performance without overcharging and over-discharging; it aims to group cells with comparable SOC levels. Based on the amount of charge each cell can hold, the controller will use a sophisticated programme to govern the charging process. A precise SOC calculation of each cell is thus a crucial part of improving balance. Smart data evaluation is necessary to send battery fault warnings and detect out-of-tolerance conditions.

Historical data will be preserved and used to display the circumstances prior to an alarm going off [37]. Users must have access to the crucial BMS data through the interface. The remaining range ought to be shown on the dashboard based on the battery's SOC. Through alarms and replacement suggestions, the consumers must also be informed about the prediction and estimation of the aforementioned battery.

The functionality of the BMS can be divided into the following categories.

- **Defence:** against high or low temperatures, overcharging, over discharging, overcurrent, and short circuits.

- **High-voltage** Control and Sensing: monitor temperature, voltage, current, thermal control, contactor, pre-charge, and ground fault detection.

- **Diagnostics:** estimations of state-of-life (SOL), state-of-health (SOH), and abuse detection.

Performance management, including computation of the power limit, cell balancing/equalization, and SOC estimation.

- Interface: range estimation, reporting, data recording, and communications.

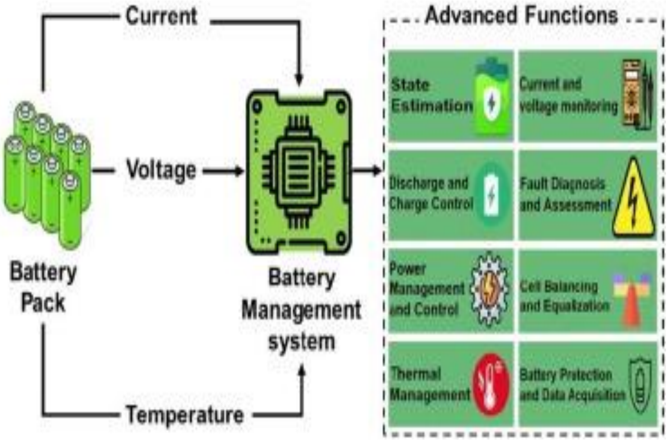

Fig. 3. Advanced Functioning Blocks of a BMS.

3. Efficiency, Capacity, And Lifespan Material and Thermal Characteristics:

Efficiency: Compared to the average lead acid battery's 85% efficiency, lithium batteries charge with a nearly 100% efficiency. This is particularly crucial when using solar power to charge because you want to get the most out of each amp before the sun sets or is obscured by clouds [39]. They also have an excellent high-temperature performance, a high power-to-weight ratio, great energy efficiency, and minimal self-discharge. The majority of lithium-ion battery parts can be recycled; however, this is still a costly process for the industry [40,41].

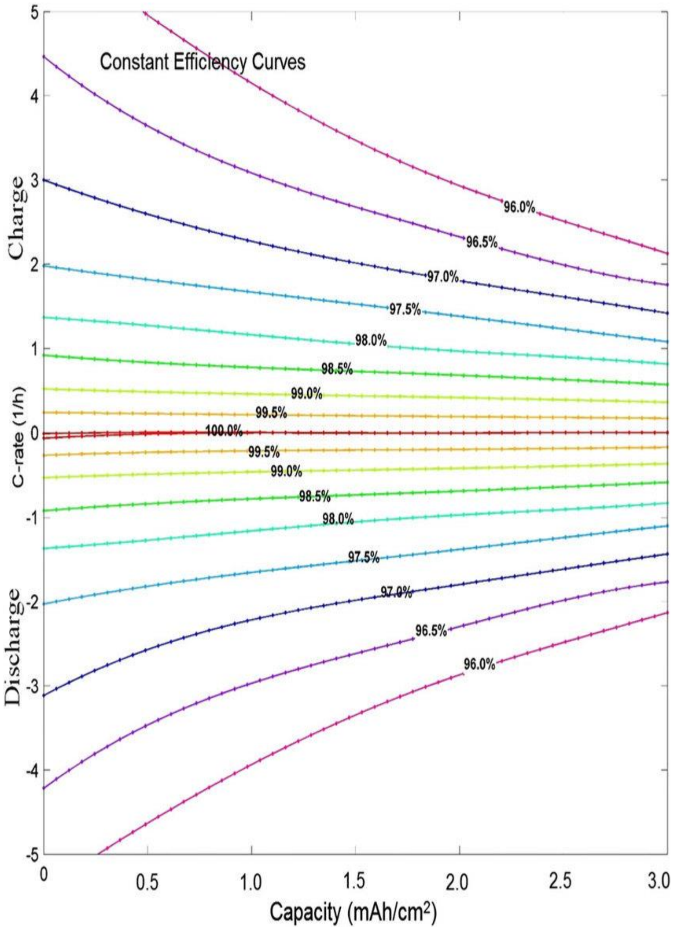

Fig. 4. Energy efficiency map of a typical lithium-ion battery family with a graphite anode and lithium iron phosphate (LFP) cathode that operates at a temperature of 25 °C and is charged and discharged within a state-of-charge interval of unity (SOC = 1). The color curves are constant energy efficiency curves.

Capacity: The specific capacities of positive electrodes in the range of 150-200 mAh g-1, which are constrained by the degree of lithium intercalation into transition metal oxides, account for the majority of the lithium-ion system's battery capacity.

Thermal Characteristics: The most significant factor affecting UPS battery ageing and the potential cause of early battery failure is high ambient temperature [43].
Higher temperatures result in a quicker chemical reaction within the battery, which accelerates corrosion and increases water loss [44].
According to calculations, a typical lithium-ion battery has a positive electrode thermal conductivity of 5 W/(m/K), a separator thermal conductivity of 0.334 W/(m/K), and a negative electrode thermal conductivity of 1.04 W/(m/K) on average [45].

4. Material Characterization:

XRD (R-Hitachi, Tokyo, Japan) was used to perform X-ray diffraction. Transmission electron microscopy (TEM; J-200C, Tokyo, Japan) and scanning electron microscopy (SEM; J-6700, Tokyo, Japan) were used to analyse the materials' shape, size, and texture. The element distribution in the nanocomposites was investigated using Oxford-X energy dispersive X-ray spectroscopy (EDX) [46]. The thermogravimetric analysis (TGA; STA 409 P-NETZSCH) was carried out in an air environment with an ideal heating rate (10 °C/min), while Raman spectroscopy was done using a Renishaw-X Plus source. Utilizing [47], the chemical composition and bonding of the synthesized materials were verified.

The fabricated anode materials were characterized using electrochemical impedance studies (EIS; CHI660D, 0.01Hz-100 kHz, 5 mVs1) and Fourier-transform infrared spectroscopy (FTIR; IS50 FT-IR). The specific surface area was estimated using Brunauer Emmett Teller (BET; ASAP 2020M+CMICROMERITICS), and the pore size distribution was determined using the Barrett-Joyner-Halenda (BJH) method, which is based on N2 adsorption desorption isotherms [48].

Lithium-Ion Battery Features:

Size, fit, and performance of lithium-ion batteries can be tailored to the needs of the customer. The energy density of lithium-ion batteries is high (weight to volume ratio) [49].

Cellular voltage: The nominal voltage of lithium-ion batteries is 3.7 volts per cell. A battery pack can have any voltage in steps of 3.7 volts by using the cells in series. For instance, lithium-ion batteries can produce a battery of 11.1 volts using 3 cells, 14.8 volts using 4 cells, and 37 volts using 10 cells [50].

Lithium-Ion cells are connected in parallel to provide the necessary amp-hours (Ah). Depending on the needs of the application, the Ahs might be in the range of a few amps to hundreds of amps. For instance, lithium-ion batteries can create 7.8 Ah by connecting three 2.6Ah cells in parallel or 26 Ah by connecting ten 2.6Ah cells in parallel. Numerous cells with a high Ah rating are available that can be utilized to give you the CAPACITY needed for your application [51].

Lithium-Ion has a nominal maximum charge rate of 1C, while lithium-polymer has a nominal maximum charge rate of 2C. There are cells with up to 10C charge rates. You can create a Lithium-Ion battery pack that satisfies your needs by choosing the right cell.

Charge Technology: Only a charger made specifically for lithium-ion batteries with a normal Pack Protect circuit should be used because those batteries have a complex charging profile. However, if you use the SWE BMS (Battery Management System) with the built-in pulse charging, all you'll need to charge the battery pack is a straightforward DC power supply with continuous power or you may connect it directly to a solar panel using nothing but an isolation diode. In other words, the system is less expensive because a separate Li-Ion charger is not required.

Lithium-Ion batteries have a maximum discharge rate of 2C, whereas lithium-polymer batteries have a maximum discharge rate of 3C (but some lithium-polymer cells have discharge rates higher than a 30C rate) [53].

Discharge Temperature Range: The maximum discharge temperature for lithium-ion and lithium-polymer is between -20C and 60C. The enhanced limit for discharging down to -50°C has been chosen by SWE using empirical data and chemistry [54].

Storage: Recommended temperature range for storage: -20°C to 60°C (storage at temperatures below 20°C reduces permanent capacity loss). Recommended voltage range for short term storage is 3.0 to 4.2 V per cell in series. storage periods: Store Li-Ion batteries at about 75% capacity (3.85 V to 4.0 V) and at low temperature to reduce permanent capacity loss over long storage periods [55].

5. Conclusions:

This work aimed to review batteries are fundamentally a storage medium in the basic information the introduction and the working principal of the li-ion battery. In this study of the li-ion batteries and most advanced rechargeable batteries. They are currently the dominant mobile power sources for portable electronic devices, exclusively used in cell phones and laptop computers and sow fig sow in Demand for Li-ion batteries in two decades Reproduced with permission. There are various type batteries, example and Battery Management System, AI strategies in battery management systems. According to the BMS's functionality may be categorized as follows- Protection, High-voltage Control and Sensing, Diagnostics, Performance management, Interface, Capacity, Thermal Characteristics, Material Characterization. There are the Lithium-Ion Battery Features- Voltage Per Cell, Capacity, Max Charge Rate, Charge Technology, Max Discharge Rate, Discharge Temperature Range, Storage.

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