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# Energy Storage Systems in Electric Vehicles

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**Abstract**— Electric Vehicle (EV) technology can solve number of global issues of the 21st century such as carbon dioxide (CO2) and greenhouse gas emissions. However, there is nothing perfect within the world. The main issue of the EV technology is the energy storage systems (ESS) according to their safety, cost, size and management systems. This article reviews types and main characteristics of ESSs of EVs. Moreover, lithium ion battery, its constituent electrode and electrolyte materials and their technological specifications are widely described in this paper. In expansion to this, viewpoints of battery innovation by implies of Na-ion batteries are center of this article.

**Keywords**—ESSs, EVs, Lithium ion battery, electrodes, electrolytes, Sodium ion battery, graphene-based ESS.

## I Introduction

In Power market, ESSs are demonstrating essential role in terms of expanding the use of renewable energy, reducing CO2 emission and introducing the smart grid technology. ESSs have vital impact on various electric systems. For example, ESSs are considered as a reliable type of service for customers during power crisis because of natural disasters and reducing the electricity price by storing energy during off-peak hours at lower cost and supports the peak demand. Looking at the past decades, one can see that renewable energy has been distributing the off-grid power consumers with the help of ESSs. In that sense, EVs are alternative technology to conventional vehicles with ESSs as replacement for fossil fuels if and only if energy resources used in EVs come from renewable energy technologies. Hence, in order to power EVs, high-performance ESSs are very important. EVs consumes electricity stored in batteries, fuel cells (FCs), and ultracapacitors (UCs). Based on the type of power storage, EVs are divided into battery-powered electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles, photovoltaic electric vehicles and fuel cell electric vehicles. EVs use considerably efficient source of power and electric motor rather than conventional vehicles do. The rate of energy waste is also low because of regenerative breaking and thermoelectric generators. The braking process of the vehicle assimilates its energy, changes over it back to electrical energy, and returns the energy to the batteries, whereas the thermoelectric generator changes over heat from the engine and machine frameworks to power automatically. EVs do not require a gearbox as utilized by electric motors and have high torque at a wide extend of speed. Besides, the EV does not use any power when it is not running and expends more than 75% of energy during run time. There are many requirements for electric energy storage in EVs such as management system, power conversion, power electronics interface, cost, protection ad safety are important requirements for ESS application in EVs. It is well known fact that today, the most used energy storage systems are electrochemical batteries. As declared above, ESSs have their own general requirements. Moreover, being a type of the ESSs, Electrochemical Energy Storage have also its own requirements for EV application in the industry. For example, large energy storage capacity in order to cover desired driving range; high enough input power to achieve good acceleration, good regenerative breaking and to accept fast charging time; long enough life-time battery comparing to the automotive component life; durability against harsh environment such as climatic and mechanical stresses; safety of the battery under extreme conditions (e.g. overcharge, internal short-circuits). In electrochemical storage systems , energy can be transformed from chemical to electrical and vice versa with the help of reversible process where energy efficiency and low physical changes are required.[1]

## II Types of ESSs

There are number of classifications of ESSs according to their energy formations and such as mechanical, electrochemical, chemical, electrical, thermal and hybrid energy storage systems. Each system is divided into different types

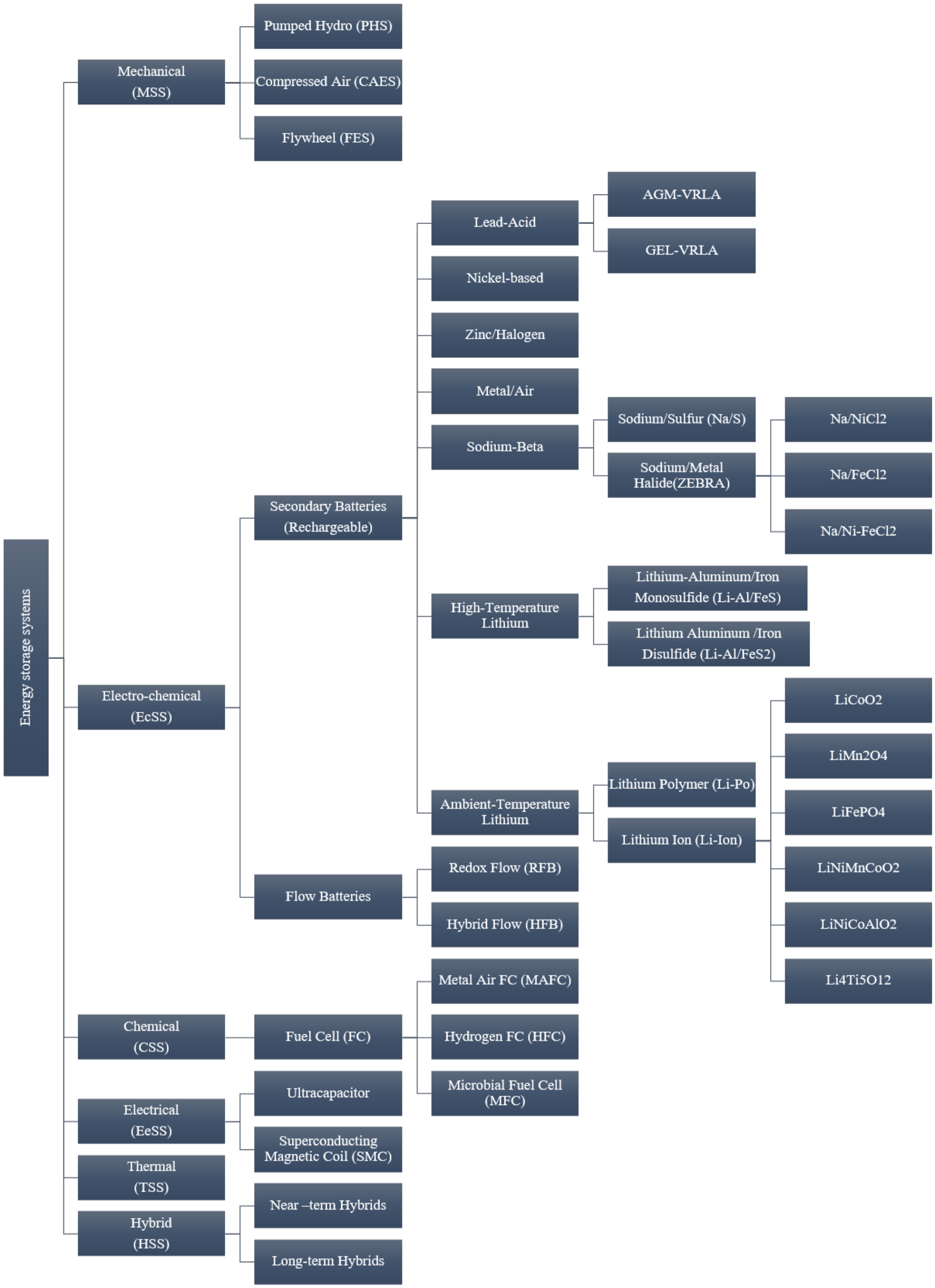


**Fig. 1:** Classification of energy storage systems (ESS)

of subsystems according to the formations and composition of materials [2]. All the sub-categories of ESSs are under research in the world. In Figure 1, you can get detailed information about all the types of ESSs where grey colored boxes show commonly applicable ESSs for EVs. For instance, Secondary electrochemical batteries, Fuel cells, Ultracapacitors, Flywheel, Superconducting magnetic coils and Hybrid ESSs are widely used in EVs as power source. Analysis and complexity of chemically constituent of materials have been clear due to the broad explanations in the number of academic research papers and our previous publications opened us a clear way for the prospective of electric vehicles and their conceptual problems [3,4].

## III Lithium ion Batteries

On average, most of the available energy storage technology incorporated in EVs is based on electrochemical battery. It is believed that with short-term use of an energy storage device and secondary energy sources with a fast response to charging/discharging are analyzed to improve EV performance [5].

Today, application of Li-ion batteries are largely expanded in EV manufacturing industry. Lithium has interesting electrochemical characteristics being the lightest of all metals. Comparing the Li-ion battery with other battery types, Li-ion batteries are more compatible with today's requirements, such as capacity, discharge time, total output power, self-discharge, depth of discharge, life cycle, efficiency, size, weight and cost of electric vehicles batteries [6]. Indeed, lightweight of Lithium allows a very high thermodynamic voltage, which leads to a high specific energy and specific power. However, modern energy storage devices are limited by the characteristics of their constituent materials. Overcoming these limitations requires an understanding of many interactions that carry ions or electrons in these devices, physical and chemical processes that decompose them [7]. Existing Li-ion batteries' main components are positive electrode - cathode and a negative electrode - anode and membrane soaked with a Li-ion conducting electrolyte. To achieve the development of high performance batteries advanced electrodes – cathode, anode and electrolyte materials and innovative technologies are very important, where the batteries must have high gravimetric (Wh/kg) and volumetric (Wh/L) energy density [8,9]. Obviously, there are two ways to increase the energy capacity of rechargeable batteries: 1st - applying new battery chemistry, 2nd - engineering improvements which reducing the weight and volume of inactive parts of the battery.

Li-ion secondary battery is composed of an anode, cathode current collectors for both electrodes and a separator filled with electrolyte. The electrodes of Li-ion batteries are considered as composite and active materials. Typically, metal oxides are used for cathodes and graphite for anodes. Their main function is to store Li ions. There are some other components called inactive materials such that carbon additive, separator, electrolyte, binder and current collector which do not stand for storing Li ions.

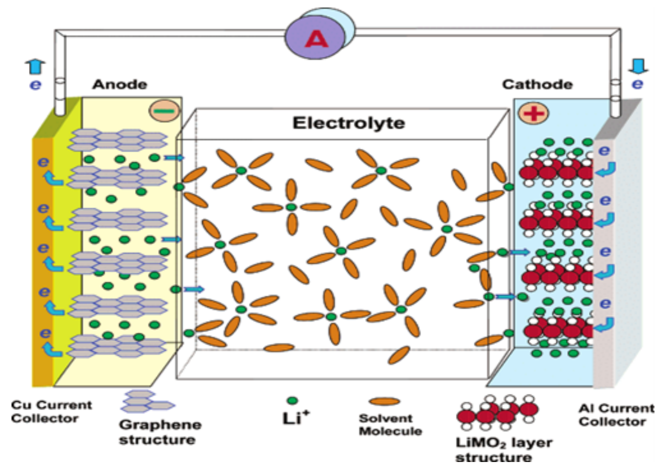


**Fig. 2:** Schematic description of Lithium ion battery

Nevertheless, they help to improve electronic conductivity between two electrodes, keep electrodes together and attach them to the current collector [10]. Most of Li-ion batteries use carbon (graphite), Lithium Titanate ($Li_4Ti_5O_{12}$) or novel materials under development – Li metal and Li(Si) alloys to make a negative electrode. $LiCoO_2$, $LiMn_2O_4$, $LiFePO_4$ and $Li(Ni_xMn_yCo_zAl_{1-x-y-z})O_2$ are considered as commonly used positive electrode materials. Being cost-effective high capacity battery is directly related to properly combination of anode and cathode materials. For example, let us choose $Li_4Ti_5O_{12}$ and $LiFePO_4$ as negative and positive half-cells respectively. Then, the nominal open circuit voltage: $V_{oc} = V_+ - V_-$ (1) would be equal to 1.95V. Here V+ ( 3.45 V vs. $Li/Li^+$) is positive half-cell potential and V- ( 1.5 V vs. $Li/Li^+$) is negative half-cell potential [11,12].

### A *Main positive electrodes*

- $LiCoO_2$ ( 140 Ah/kg, 3.9 V vs. $Li/Li^+$)
- $LiMn_2O_4$ ( 110 Ah/kg, 4.1 V vs. $Li/Li^+$)
- $LiFePO_4$ ( 170 Ah/kg, 3.45 V vs. $Li/Li^+$)
- $Li(Ni_{1-x-y}Mn_xCo_y)O_2$ (e.g. NMC811 where 1-x-y = 0.8, x = 0.1 and y = 0.1
- $Li(Ni_{1-x-y}Co_xAl_y)O_2$ (NCA, 200 Ah/kg, 3.8 V vs. $Li/Li^+$) [13].

Below advantages and disadvantages of each positive electrode materials are briefly discussed.

Lithium Cobalt oxide ($LiCoO_2$)

Advantages: High energy density, easy to manufacture and long cycle life.

Disadvantages: Because of its reactivity Lithium Cobalt battery is suffer from poor thermal stability. Therefore, it must be monitored during during its operation. Less abundance of cobalt makes the cost higher [14].

Lithium manganese oxide ($LiMn_2O_4$)

Advantages: Three dimensional spinel structure can improve ion flow on electrodes that leads to improved current handling and lower internal resistance. At the same time, low internal cell resistance results to fast charging and high-current discharging.

Disadvantages: The chemistry of LiMn2O4 battery shows better thermal stability rather than lithium cobalt oxide battery but approximately 33% lower capacity and lower life span might be obtained [15].

Lithium Iron Phosphate ($LiFePO_4$)

Advantages: High current rating, long cycle life and low resistance is good electrochemical characteristics of Lithium iron phosphate. Besides, the phosphate prevents the electrode from overcharging and provides a higher tolerance to heat.

Disadvantages: Moisture can be a reason to limit the lifetime of the battery [16].

Lithium Nickel Manganese Cobalt Oxide ($Li(Ni_xMnyCo_{1-x-y})O_2$)

Advantages: High specific power and energy with high density. Combining nickel and manganese enhances each other's strengths such as high specific energy and remarkable thermal characteristics.

Disadvantages: Nickel has high specific energy but it has poor stability where manganese can form spinel structure to get low internal resistance but offers low specific energy.

Lithium Nickel Cobalt Aluminum Oxidec($Li(Ni_xCoyAl_{1-x-y})O_2$)

Advantages: It has similar characteristics with Li(NixMnyCo1-x-y)O2 such as high specific energy, specific power and long life cycle.

Disadvantages: It requires special safety monitoring to ensure safe use. Moreover, manufacturing also costs more expensive [17, 18].

### *B Main negative electrodes*

- Carbon-based electrodes
- Lithium Titanate ($Li_4Ti_5O_{12}$)

New types of negative electrodes under development:

- Lithium metal
- Alloy based electrodes
- Silicon based electrodes
- Conversion electrodes [19].

Advantages and disadvantages of each above-mentioned electrodes are discussed below.

Carbon-based electrodes

Advantages: High energy density, easy to manufacture and long cycle life.

Disadvantages: Because of its reactivity Lithium Cobalt battery is suffer from poor thermal stability. Therefore, it must be monitored during during its operation. Less abundance of cobalt makes the cost higher [14].

Lithium manganese oxide ($LiMn_2O_4$)

Synthetic graphite is commonly used as an active material for negative electrode. Advantages: Being relatively high specific capacity of 370 Ah/kg, low average voltage of 150 mV vs. $Li/Li^+$, low cost and non-toxic material.

Disadvantages: Under some specific conditions, such that thermal runaway or reacting carbon with some atmospheric oxygen the electrode might catch fire [20].

Due to its good electrical conductivity, high charge mobility and surface area, mechanical strength, graphene is a preferable anode material for lithium-ion battery. Normally, graphene sheets can deliver high gravimetric capacity in the range of 790 – 1050 Ah/kg. Specific capacity of graphene can be increased from 540 to over 700 Ah/kg by incorporating Carbon NanoTubes (CNT) and fullerence (C60) [21].

Lithium Titanate ($Li_4Ti_5O_{12}$)

Advantages: There are several advantages of titanium based anode materials such as low toxicity, low cost, low volume change during discharge/charge process, outstanding power and excellent life cycle.

Disadvantages: Low theoretical capacity in the range of 175 – 330 Ah/kg and low electronic conductivity are main drawbacks of lithium titanate material [22].

Lithium Metal

Advantages: Lowest negative electrochemical potential and very high capacity of 3860 Ah/kg made the lithium metal to be considered as an anode material for lithium-ion battery. Remarkable capacity of the material decreases the mass of the electrode and the mass of the battery, too.

Disadvantages: Growth of metallic dendrites during stripping or plating of Li causes to the thermal runaway and explosion or fire [23].

Alloy based electrodes

All the attempts to construct the negative electrode from number of metals which electrochemical alloy with lithium are directed to achieve higher volumetric and gravimetric capacity of battery cell. Following metals and metalloids like C (LiC6), Si (Li3.75Si), Sn (Li4.4Sn), Al (LiAl), P (Li3P) and Sb (Li3Sb) electrochemically react with lithium to form the alloy. Among the alloy anodes listed above Si and Sn have shoved superior volumetric and gravimetric density. Their large volume change causes cracking of particle and pulverization by time, which results poor cycle life [24].

Silicon based electrode

Fully lithiated composition of lithium-silicon alloy Li15Si4 has 4200 Ah/kg theoretical capacity. Transition between Si and Li15Si4 generates high internal strain that leads to cracking and eventual Si material disintegration results to considerably reversible capacity fade. Moreover, high electrical resistivity and low $Li^+$ diffusion coefficient are other drawbacks of Si [25].

Conversion electrodes

General formula for conversion electrodes is

$$M_aX_b + (b*c)Li^+ + (b*c)e^- \Longleftrightarrow aM + bLi_cX \qquad (1)$$

Where M and X refer to a transitional metal and an anionic species correspondingly. Anions of conversion electrodes such as oxides and sulfides have high theoretical capacity in the range of 500 -1500 Ah/kg. Their stability provides additional safety to the battery system, decreases the risk of thermal runaway and also reduces the overall mass of the battery [26].

### C *Elecrolytes*

High transportation of lithium ion under general environmental use like from -30 oC to +60 oC (extreme conditions) is main requirement put on the electrolyte of the lithium ion battery. There are two main classes of electrolytes:

- Liquid (aqueous and organic) and
- Solid (polymer and ceramic)

Aqueous electrolyte can be a good choice for lithium ion battery because of restricted electrochemical voltage window of 1.23 V, lower potential environmental impacts and conceptually safer characteristics.

Organic Liquid electrolytes

The system of organic carbonates such as ethyl carbonate, propylene carbonate, dimethyl carbonate and dissolved lithium salts like LiPF6, LiBF4 or LiClO4 forms organic liquid electrolytes. In order to get high-performance battery with high lithium ion conductivity and good electrochemical stability suitable solvents and salts need to be used. The future development of organic liquid electrolytes is to adopt ionic liquids. As they are applicable for super capacitors, solar cells and batteries, they have low volatility, high electrochemical and thermal stabilities, and are non-flammable. However, all the conventional liquid electrolytes suffer from low boiling point, flammability and explosivity [27].

Polymer electrolytes

Development of solid electrolytes are promising alternative to the liquid electrolytes. They are composite materials based on poly(oxyethylene) POE and have low molecular weight or high polymer molecular weight which are essential for battery cell application.

Ceramic electrolytes

Developments showed that because of safety characteristics, ceramic materials can be used as electrolytes, specifically LiSICONs (Lithium Super Ion Conductors) and glassy materials with similar compositions. As a result, overall higher conductivities can be achieved. Moreover, at high temperature conditions ionic conductivity increases with increasing temperature [28]. Among the electrolytes declared above Solid Polymer Electrolytes (SPEs) are more preferable according to following characteristics : high durability, high energy density, long shelf life, light in weight, low reactivity towards the electrodes, great flexibility for cell design, eliminating solvent leakage problems, high ionic conductivities, excellent mechanical, electrochemical properties and reduced flammability. Moreover, SPEs represent wide range of thermal and chemical stability and low volatility, too [29].

### D Graphene-based nanocomposites for energy storage systems.

Graphene displays an exceptional chemical structure, and outstanding electronic, optical, thermal and mechanical properties. A large number of synthetic methods have been established to synthesize high quality graphene including chemical and physical strategies in order to meet the increasing demands for thin film processing, composite incorporation and device integration. Numerous materials have been composited with graphene, such as polymers, NPs of semiconductor, metals, metal oxides, sulphides, alloys, CNTs, organic materials etc. The enhancement in the properties of these composited materials not only depends on the individual components, but also on the interactions between them. Therefore, to improve the properties of graphene-based materials, it is necessary to control the distribution, density, kinds of chemical bonds, as well as three-dimensional arrangements of the composites. Thus, various assembly methodologies have been developed for the constant demand of property optimization; the particular efforts are directed towards the design and formation of specially constructed hybrid architectures rather than random mixtures. More effort should be directed to effectively enlarge the specific surface area, porosity, reduce the O/C ratio and increase the conductivity of the electrode. Although there is a lot of research regarding the manipulation of the properties of graphene-based materials, there are still some issues present like the low specific surface area and conductivity of the composites. During the composite formation, graphene layers restacked and the actual surface area of the graphene is not exposed. This problem can be solved by designing the unique morphology that can prevent the restacking of graphene and exposed its surface, also by incorporating the heteroatoms that can increase the conductivity andelectrochemical performance. Secondly, the stability of graphene-based composites in LIBs or supercapacitors decreases during lithium and/or electrolyte insertion and extraction. Thus, it is necessary to modify the chemical or physical interactions of the NPs with graphene to stabilize the structure in real applications.

Today, Lithium - ion batteries are considered dominant energy storage devises with their low reduction potentials

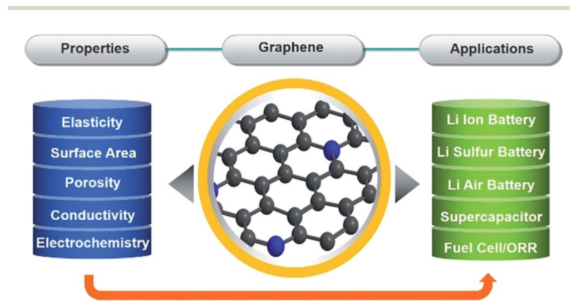


**Fig. 3:** Schematic illustration of applications of graphene based on its unique properties.

(-3.04 V vs. $Li/Li^+$), consistence gravimetric energy density up to 260 Wh/kg, volumetric energy density up to 700 Wh/L and smaller ionic size of Li (0.75Angstrom) which maintains fast electrochemical kinetics and smooth intercalation. Above-mentioned characteristics of the Li-ion batteries are directly related to the use of various electrode and electrolyte materials application in manufacturing [30]. In the early stages, $LiCoO_2$ was used as cathode material with a theoretical specific capacity of 274 Ah/kg while commercially it exhibited only about 165 Ah/kg capacity. In the next stage, it has replaced to LiFePO4 but its cell capacity is low. Lithium Nickel Manganese Oxide with its average discharge voltage of 4.7V and energy density up to 650 Wh/kg is cobalt free, novel and promising candidate for the future-commercialized lithium ion batteries. As anode material graphite is steel remaining almost unchanged with its maximum gravimetric capacity of 372 Ah/kg and volumetric capacity of 840 Ah/L. Si based alloying anode material with specific capacity of Si about 4200 Ah/kg is promising alternative material to the graphite. In addition, it is expected that composite materials based on graphene and CNTs will be commercialized in the future [31].

Concerning to the electrolytes, most of the currently commercialized LIBs use liquid organic solvents in the electrolyte. However, their main issues are flammability and thermal run-away. Solid-state electrolytes are state-of-art materials, which can reduce flammability and thermal run-away [32]. There are some issues that we need to take into account, which are rarely abundance of Li resources in the earth's crust, and the usage of certain electrode and electrolyte materials are toxic and flammable. To overcome the challenges associated with LIBs, it is necessary to study alternative rechargeable battery systems. In this sense, Sodium Ion Batteries (SIBs) are considered promising alternative rechargeable battery to LIBs. Because, Na is the sixth most abundant element in the earth's crust, inexpensive procurement and processing, and possessing good performance in aqueous systems. However, relatively large ionic size of Na+ ion (1.02Angstrom) can cause to constraint smooth intercalation in the interstices of host electrode and to change of large volume. To commercialize SIBs electrode materials must be customized to maintain high energy and power density in the near future [33]. Anode materials suitable for Na-ion batteries are subdivided into carbon-based materials, alloy-based materials, metal oxides, and 2D materials, taking into account the density, rate capability, cycleability, and thermodynamic stability. Cathode materials are: layered transition metal oxides (TMOs), polyanionic compounds, phosphates, Sodium Super Ionic CONductor (NASICON) compounds and fluorophosphates, Prussian blue and organic materials. Reliability and longevity parameters of SIBs ensure its use in grid scale storage, while LIBs have some issues on grid storage application [34].

Moreover, Graphene is an atomically thin, planar membrane of carbon with exceptional properties, particularly electronic and electrochemical ones. graphene can be synthesized and modified by facile solution methods that enable its easy utilization for various fields. Interestingly, the replacement of various different types of atoms (N, B, S and P) with carbon in graphene further enhanced the conductivity and electrochemical properties of graphene. Note that the synergistic effects of graphene composited with other nanomaterials like metals, metal oxides, sulphides, alloys and polymeric40 materials make it promising for energy storage and conversion devices. Therefore, the use of graphene and graphene-based materials as low cost, environment friendly and high performance electrodes for ORR, supercapacitors and lithium-based batteries is highly favored.

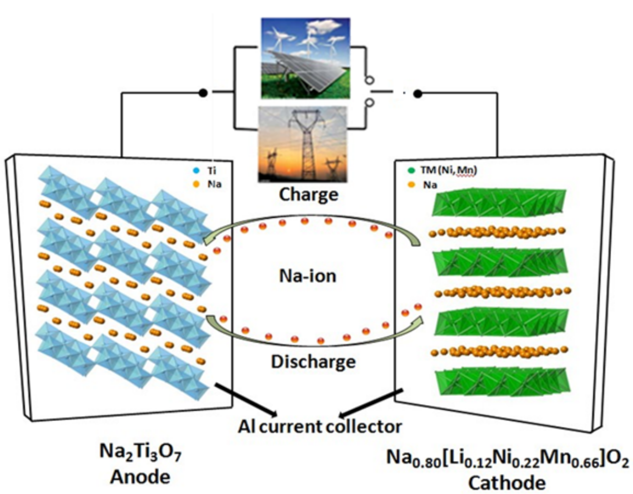


**Fig. 4:** Schematic Description of Sodium ion Batteries

## IV Conclusion

Today, Automobile industry of Uzbekistan is going to introduce EV manufacturing line in Uzbekistan. However, the most problematic field of manufacturing will remain the same that is the production of ESS of the vehicles. This challenge is becoming important point for all types EV, HEVs. For solving this problematic issue we can contribute to solve one of important problems of PEMFC, and all types of EVs in the industry[35,36] The challenges of ESS compartment in PEMFCs cause degradation process of the system and at result it effects the working principle and lifetime of the vehicle. Most probably, Lithium ion batteries will be used in production line as the point of interest of the current trend in EVs. This article will support the future engineers who will work in the EV manufacturing processes in Uzbekistan with the basics of battery chemistry and types of ESSs. Moreover, this review is recommend to use as a study guide for future generation who has interest for ESSs and Lithium ion batteries. The perspective of Automobile Industry is going to shift from ICE to EVs. In line with this, as an automobile manufacturing country, Uzbekistan will be needed highly specialized automotive engineers. In order to prepare such engineers, the material that we are offering can be introduced in the academic study programs of automotive engineering courses.

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