A COMPARATIVE STUDY AND RECENT RESEARCH OF BATTERY TECHNOLOGIES

By

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ABSTRACT

India's electric car market is growing at a slower pace than other countries. The main issues confronting the EV market are a lack of charging stations, majority of components and batteries being imported from other countries, raising the cost of EVs, concerns about vehicle fuel and whether they can reach their destination, and inconsistent policies. However, much research is being done to build batteries with the highest power and energy densities feasible, but these batteries are expensive. However, as battery technology progresses to the point that it can be used in all applications where lead-acid batteries are currently the most common, their prices will naturally fall. This paper compares and contrasts several battery technologies, as well as current advancements. This study gives knowledge over the factors to consider before using an EV or Hybrid Electric Vehicle (HEV).

Keywords: Electric Vehicle (EV), Battery, Energy Density, Coulombic Efficiency, Voltage Efficiency.

INTRODUCTION

The term "battery" was originally used to indicate a "grouping of similar objects organised together to accomplish a purpose," such as a battery of guns. Benjamin Franklin coined the word to describe a series of capacitors he had connected for his electricity experiments shown in Figure 1. Later, the word was applied to any electrochemical cells that were joined together to generate electricity (Hymel, n.d.).

Batteries are made up of one or more cells, each of which produces an electron flow in a circuit through chemical reactions. An anode (the '-' side), a cathode (the '+' side), and some forms of electrolyte are the three basic components of all batteries (a substance that chemically reacts with the anode and cathode).

A chemical reaction occurs between the anode and the electrolyte when the anode and cathode of a battery are linked to a circuit. This reaction sends electrons across the circuit and back to the cathode, where they undergo another chemical reaction. The battery is unable to produce power when the material in the cathode or anode is consumed or is no longer usable in the reaction. The battery is "dead" at that point. Figure 2 shows batteries in a variety of shapes, sizes, and chemistries.

Components

An anode, a cathode, and an electrolyte are the three essential components of a battery as shown in Figure 3. If the electrolyte is insufficient, a separator is frequently employed to keep the anode and cathode from contact. Batteries normally have some form of casing to store these components. Electrodes come in two varieties: anode and cathode. Electrodes are conductors that allow electricity to enter or exit a circuit component.

Electric Vehicle

An electric vehicle, abbreviated as an EV, is a vehicle that runs on electricity. EVs are vehicles that are powered entirely or partially by electricity.

Electric vehicles have low operating expenses since they have fewer moving parts to maintain, and they are also very eco-friendly because they consume little or no fossil fuels (petrol or diesel). While some EVs employed lead-acid or nickel-metal hydride batteries, lithium-ion batteries are currently the standard for modern battery electric vehicles since they have a longer lifespan and are better at retaining energy, with a self-discharge rate of only 5% per month. Despite this increased efficiency, there are still issues with these batteries, since they are susceptible to thermal runaway, which has resulted in fires or explosions in the Tesla Model S, despite efforts to improve battery safety.

The global automobile industry is exhibiting a strong interest in using electricity to power automobiles. They also seek to delight customers by producing an automobile that is both high-performing and easy to maintain. The goal is to reduce pollution and the usage of petroleum products in the environment. The battery is the primary source of electrical energy in most HEVs and PHEVs (Husain & Hardy, 2003; Babu & Ashok, 2012). However, it is clear that, in the current market situation, no battery technology can deliver a range greater than that of a modern IC engine, assuming equivalent battery weights and a fuel tank full of gasoline or diesel. This is the fundamental reason why IC engines are still more popular in the market than EV or HEV drives. A lot of work is being done to tap into the untapped potential of current and advanced battery technologies like Lithium-ion batteries and their derivatives.

Figure 1. Battery of Leyden Jar "capacitors" linked together

Figure 2. Batteries come in a Variety of Shapes, Sizes, and Chemistries

Types of Electric Vehicles

There are three types of EVs on the road today as shown in Figure 4 ("Types of Electric Vehicles", n.d.).

- Battery Electric Vehicles
- Plug-in Hybrid Electric Vehicles
- Hybrid Electric Vehicles

Battery Electric Vehicles

BEVs (Battery Electric Vehicles) and EVs (Electric Vehicles) are entirely electric vehicles with rechargeable batteries that do not have a gasoline engine. The battery pack, which is recharged from the grid, provides all of the

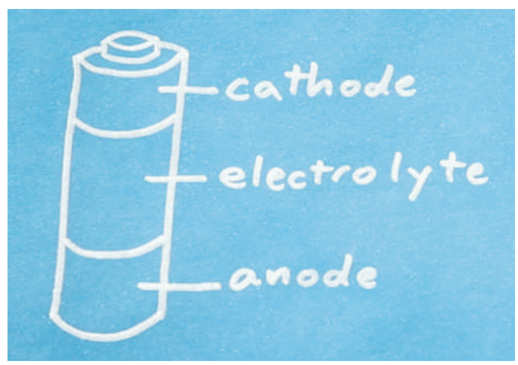

Figure 3. Components of Batteries

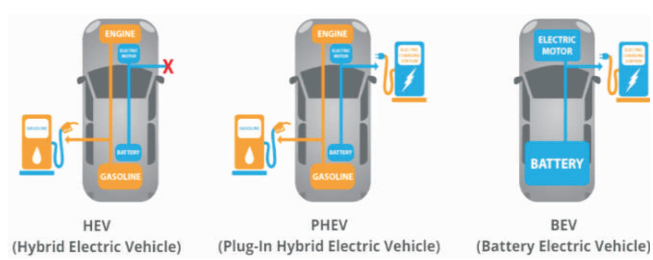

Figure 4. Different Types of Vehicles

vehicle's energy. BEVs are zero-emission vehicles, as they emit no hazardous exhaust emissions or pollute the air in the same way that typical gasoline-powered vehicles do.

Plug-in Hybrid Electric Vehicles

PHEVs, or Plug-in Hybrid Electric Vehicles, have both an engine and an electric motor to power the vehicle. They can recharge their battery through regenerative braking, just like traditional hybrids. They vary from normal hybrids in that they have a considerably larger battery and can recharge by plugging into the grid. While normal hybrids can travel 1-2 miles before the gasoline engine kicks in (at moderate speeds), PHEVs may travel anywhere from 10 to 40 miles before the gas engine kicks in. When the all-electric range is depleted, PHEVs switch to a standard hybrid mode and can travel hundreds of miles on a single tank of gas. An EV go L2 charger can charge any PHEV, but most PHEVs are not capable of fast charging.

Hybrid Electric Vehicles

Hybrid Electric Vehicles, or HEVs, are vehicles that are powered by both a gas engine and an electric motor. Regenerative braking, which recoups otherwise wasted energy in braking to help the gasoline engine during acceleration, provides all of the energy for the battery. This braking energy is generally wasted as heat in the brake pads and rotors of a traditional internal combustion engine car. Regular hybrids can't charge with EVgo or plug into the grid to recharge.

1. Literature Survey

According to (Zhang, 2006), three charging profiles were used to investigate the impact of charging profiles on the ageing mechanism of commercial 18650 Lithium-ion battery cells: constant current (CC) charging, constant power (CP) charging, and multistage constant current (MCC) charging. The findings demonstrate that fast charging promotes capacity fading and shortens the battery's cycle life. They recommend a charging plan that employs a low current to charge the battery's initial 10% capacity and near the conclusion of the charge.

To minimise the charging time and extend the cycle life of high voltage LFP batteries, Anseán et al. (2013) used a multistage rapid charging approach. The influence of charging and discharging pulses on the cycling behaviour of commercial lithium-ion batteries is presented in (Li et al., 2001), where the authors offer another charging profile. The findings show that the charging profile, which consists of pulse charging with brief rest periods and short discharge, is effective in lowering charging time, enhancing cycle life, and removing concentration polarisation. However, further research is needed to determine the best charging procedure for lithium-ion batteries.

Human beings have been alerted by global warming. According to reports, the temperature in the Arctic Circle reached 32 degrees Celsius in the summer of 2018, and deaths as a result of excessive heat occurred throughout the world, including in Europe, Japan, and Canada. Some researchers may argue that the production of electricity for charging battery electric vehicles (BEVs) or the production of hydrogen for fuel cell electric vehicles (FCEVs) can produce a significant amount of GHG emissions that are not even less than those from ICEVs based on an equivalent assessment, but this is based on the hypothesis that electricity is generated using fossil fuels such as coal and oil. In reality, according to a Well-to-Wheel (WTW) analysis, GHG emissions from the production of electricity or hydrogen are highly dependent on basic energy sources (Yazdanie et al., 2016).

In comparison to ICEVs and typical HEVs with a small battery, PEVs have another potential benefit: they can be used as distributed energy storage systems to link to a smart grid. This connection's power flow can be bidirectional. Excess energy in PEV energy storage devices could be supplied back into the grid during periods of high peak demand or to compensate for renewable power output variability. The grid's excess energy can be stored by charging batteries or electrolyzing water to make hydrogen. This vehicle-to-grid (V2G) option can provide ancillary services, load leveling, and assist in improving the grid's power quality and stability while reducing the consequences of renewable production intermittency (Nian et al., 2019; Shaukat et al., 2018; Richardson, 2013; Zakariazadeh, 2015; Tan et al., 2014).

PEV charging consumes a lot of electricity from the grid, putting a strain on the grid's capacity. Charging during peak hours, in particular, necessitates consumers paying a higher tariff rate. Furthermore, as the number of PEVs grows and energy demand rises, charging stations are being created at an increasing rate. Renewable energy sources such as solar and wind energy can be used to charge PEVs to relieve the pressure (Bhatti et al., 2016). Solar PV systems are becoming increasingly popular in charging stations. PV charging can be divided into two types: PV-grid and PV-standalone. When PV-generated power is insufficient, PEVs can be continually charged through the grid supply, and surplus PV electricity can be pumped into the grid. PV-standalone charging, on the other hand, is more practical and useful in remote places where utility supply is unavailable or prohibitively expensive (Bhatti et al., 2016a,b).

2. Factors to be Considered to Choose a Battery

A battery is an electrical energy storage device that produces DC output (Ehsani et al., 2018; EVgo, 2021; Zhang, 2006; Anseán et al., 2013; Li et al., 2001). Because there is a lot of research going on in battery technologies, there are a few things to think about when choosing the correct battery for a PHEV:

2.1 Load Requirement of the Vehicle

The amount of battery capacity required for a PHEV is determined by the vehicle's gross load demand. The battery chosen must be able to meet the vehicle's peak load for an extended period. The model that can give the most power for the same weight is usually the best pick. The smaller the battery is, the better. However, there are a few more aspects to consider.

2.2 Power or Energy Density

The energy density (Specific Energy) in Wh/kg and the power density (Watts/kg) are other good criteria for choosing a battery type. Any of the aforementioned factors with a maximum value suggests that the battery can support a given load for longer than other battery types with a lower specific energy or power density.

2.3 Effectiveness

Another indicator of a battery's ability to meet a particular load is its efficiency. A battery's net efficiency can be measured in two ways: a) Coulombic Efficiency and b) Voltage Efficiency.

Coulombic efficiency (CE), also known as current efficiency or faradaic efficiency, is a measurement of charge efficiency in batteries based on the rate at which electrons transmit. Throughout a full cycle, it is defined as the ratio of the total charge extracted from the battery to the total charge placed in the battery. Li-ion is one of the most efficient rechargeable batteries, with over 99 percent efficiency and the highest CE ratings. This is only achievable when the battery is charged at low current and cool temperatures. Because of losses due to charge acceptance and heat, ultra-fast charging lowers the CE.

Another technique to assess battery efficiency is voltage efficiency, which is the ratio of the average discharge voltage to the average charge voltage. As a result, the battery voltage's reliance on BSOC will have an impact on voltage efficiency. If all other parameters are equal, a battery whose voltage varies linearly with BSOC would have poorer efficiency than one whose voltage is constant with BSOC.

For the same ampere-hour rating, the higher the efficiency better is the battery.

2.4 Vehicle Range

Another obvious strategy to choose the best battery is to choose the one that has the longest drive range between two full charges (Yazdanie et al., 2016).

2.5 Battery Cost

In addition to the previous performance indications, battery cost is another essential factor that influences the final battery decision. In most circumstances, the best compromise between the above parameters and the battery cost is used to make the ultimate decision.

2.6 Maturity of Technology

Although there are numerous battery technologies available today, not all of them are ready for commercial deployment in automobiles (Linden, 1995; Cole, 1988). More study is needed before it can be properly cost-effectively implemented into automobiles.

2.7 Other Limitations

Aside from the aforementioned performance indicators, each battery technology will have its own set of disadvantages, such as concerns with operation over a large temperature range, the risk of fire, and so on. This should also be considered before making a final battery selection.

3. Comparison Between Various Battery Technologies

Tables 1 and 2 compare several battery technologies in terms of the performance indices mentioned earlier (Hornstra & Yao, 1982; Tomazic, 1992). Other important characteristics such as advantages, disadvantages and, battery kinds are also covered.

The oldest and most extensively used battery type in most cars is the Sealed Lead Acid Battery, which is explained. Other sophisticated battery technologies, however, have distinct advantages over the Sealed Lead Acid Battery. The extent to which certain battery types can be used in HEVs or PHEVs is covered in the next section.

4. Recent Research in Battery Technology

4.1 The Next Generation Lithium-Ion

The flow of lithium ions from the positive to the negative electrode back and forth via the electrolyte provides energy storage and release in lithium-ion (Li-ion) batteries. The positive electrode serves as the initial lithium source, whereas the negative electrode serves as the lithium host in this technique. Li-ion batteries are a collection of chemistries that are the result of decades of careful selection and optimization of positive and negative active materials. The most typical materials utilised as present positive materials are lithiated metal oxides or phosphates. Negative materials include graphite, graphite/silicon, and lithiated titanium oxides (Saft, 2021).

Li-ion technology is predicted to hit its energy limit in the next years, based on current materials and cell designs. Nonetheless, recent discoveries of new families of disruptive active materials may be able to break through current barriers. These novel compounds can store more lithium in both positive and negative electrodes, allowing for the first-time energy and power to be combined. Figure 5 shows the charge and discharge process of lithium-ion. Furthermore, the scarcity and criticality of raw materials are taken into account with these novel molecules.

Li-ion battery technology currently has the highest energy density of all the state-of-the-art storage technologies. The wide range of cell designs and chemistries allows for fine-tuning of features such as quick charging and temperature operating window (-50°C to 125°C). Furthermore, Li-ion batteries have a low self-discharge rate and a long lifetime and cycling performance, with thousands of charging and discharging cycles on average.

Before the first generation of solid-state batteries, a new generation of enhanced Li-ion batteries is scheduled to be deployed. They'll be perfect for applications like renewable energy storage and transportation (marine, trains, aviation, and off-road mobility) where high energy, high power, and safety are required.

4.2 Lithium-Sulfur

Lithium ions are inactive materials in Li-ion batteries, which act as stable host structures during charge and discharge. There are no host structures in lithium-sulfur (Li-S) batteries. Figure 6 shows the lithium-sulfur battery. The lithium anode is consumed during discharging, and sulphur is converted into a variety of chemical compounds; when charging, the process is reversed.

The active components in a Li-S battery are extremely light: sulphur in the positive electrode and metallic lithium in the negative electrode. This is why its theoretical energy density is four times higher than that of Li-ion batteries. As a result, it's a suitable fit for the aerospace and aviation sectors.

The most promising Li-S technology based on solid state electrolyte has been chosen and favoured by Saft. This technical path provides a very high energy density, a long life, and eliminates the main shortcomings of liquid-based Li-S (limited life, rapid self-discharge, and so on).

Furthermore, because of its better gravimetric energy density (+30% in Wh/kg), this technology is a complement to solid state Li-ion.

Major technological obstacles have already been overcome, and the maturity level is rapidly approaching full-scale prototypes. This technology is likely to hit the market shortly after solid-state Li-ion for applications demanding lengthy battery life.

Battery Technologies	Advantages	Disadvantages
Sealed Lead Acid Battery	Life Free maintenance Good low and high-temperature performance Availability is more Per watt-hour cost is less 500–800 cycles durability. Well established battery technology and widely used in all types of automobiles	Their construction, use, disposal, or recycling shows the impact on the environment. It occupies (25–50%) portion of the final mass of the vehicle. The energy density is lower than petroleum fuels-in this case, 30-40 Wh/kg Efficiency (70–75%) and storage capacity of the current generation of common deep cycle lead-acid batteries decrease with lower temperatures. Diverting power to run a heating coil reduces efficiency and range by up to 40%. 3–20% self-discharge rate/month.
Nickel Metal Hydride Battery	The energy density of 30–80 Wh/kg (far higher than lead-acid). Exceptionally long lives (above 160,000 km). Has been chosen by leading car manufacturers, such as Toyota and Nissan, for their line of HEV's Has evolved to an extent that it is now in production and is being used in HEVs (made by Toyota and Nissan).	Do not have sufficient cycle stability. Less efficient (60-70%) in charging and discharging than even lead-acid. Its added weight would negatively impact the efficiency of the HEV. High self-discharge Poor performance in cold weather. High cost. Patent encumbrance has limited the use of these batteries in recent years.
Zinc Air Cells	Significantly high energy density A prototype of such a battery has been made.	A multiple increases in the approx. 100 charging cycles are required before wide-scale future applications. This storage technology has not evolved to an extent that it can be widely used in HEVs or PHEVs.
Sodium Sulphur Battery	Low cost. Easily available raw materials	Safety concerns High operating temperatures of 300 °C, resulting in thermal self-discharge in vehicles that are not in operation for longer periods. Low power electrolyte.
Sodium Nickel Chloride Battery (Zebra Battery)	Relatively mature technology. An energy density of 120Wh/kg. Reasonable series resistance. Cold weather doesn't strongly affect its operation. Can last for a few thousand charge cycles. Are nontoxic. Prototypes of Mercedes A-Class were built. Zebra batteries have been used in the Modec vehicle commercial vehicle since it entered production in 2006. Only FZ Sonick SA, part of Italian automotive supplier FIAMM Group, still supplies a niche market with small electric vehicles fitted with sodium nickel chloride batteries.	Increasing heating costs especially in cold weather. Poor power density (<300 W/kg). Requirement of having to heat the electrolyte to about 270 °C (520 °F), which wastes some energy and presents difficulties in long-term storage of charge. Not widely used. The Renaissance of this battery is not in sight at the moment.
Lithium-Ion Battery	Lithium has the most negative redox potential of all elements, thus allowing high voltages to the cathode. Low weight. High energy densities. Impressive 200+ Wh/kg energy density and good power density. 80 to 90% charge/discharge efficiency. Potential for about 30% improvements in Energy Density of batteries. The maturity of this technology is moderate. Lithium-ion (and similar lithium polymer) batteries, widely known through their use in laptops and consumer electronics, dominate the most recent group of EVs in development. Most other EVs are utilizing new variations (phosphates, titanates, spinels, etc.) on lithium-ion chemistry that sacrifice energy and power density to provide fire resistance, environmental friendliness, very rapid charges (as low as a few minutes), and very long life spans.	High cost-Nearly 400 Euro/kWh. Short cycle lives (hundreds to a few thousand charge cycles). Significant degradation with age. The cathode is also somewhat toxic. Can pose a fire safety risk if punctured or charged improperly. Cannot accept or supply charge in cold conditions. Expensive and energy-efficient systems are necessary to warm them up.
Lithium-Air Battery	The theoretical achievable range is 11,000 Wh/kg. (without considering mass of oxygen).	Research is ongoing. At present they are present only in Labs, and not widely used in HEVs or PHEVs.
Lithium Sulphur Battery	The theoretical achievable range is 3350 Wh/kg. (so far only 350Wh/kg achieved). Prototype made.	Security issues due to dendritic lithium deposits

Table 1. Advantages and Disadvantages of Various Battery Technologies

Sl.No	Type of Battery	Coulombic Efficiency	Range obtainable in the vehicle for a battery weight of 350kg	Wh/kg	W/kg	Cost in $ (current cost + future cost + environmental cost)
1	Sealed Lead Acid Battery	78% - Chloride (Flooded Lead Acid) 97% - Delco (Sealed Lead Acid)	<100 km	30–40 (60–75 Wh/ltrs)	180 (412 for advanced lead acid batteries)	100+100+low with recycling
2	Nickel Metal Hydride Battery	88% - Ovonice 80% - Panasonic	Between 100 and 150 km.	60–120	220	1000+200+low
3	Zinc Air Cells	Is said to have high efficiency but is not widely used	60000 km (tested for a 20 kW battery system by General Motors)	More than 300 (non-rechargeable)	100	300+100+low
4	Sodium based energy storage solutions	Not widely used	Approx. 150 km for both Sodium Sulphur Battery and Sodium Nickel Chloride Battery (Zebra Battery)	Theoretically 792 for Sodium Sulphur Battery Theoretically 787 for Sodium Nickel Chloride Battery (Zebra Battery)	100 for Sodium Nickel Chloride Battery (Zebra Battery)	X+300+X for Sodium Nickel Chloride Battery (Zebra Battery)
5	Lithium-Ion Battery	80–90%	>200km (approx. 250 km)	120–130.(Up to 250)	315 or more	X+X+low

Table 2. Battery Options

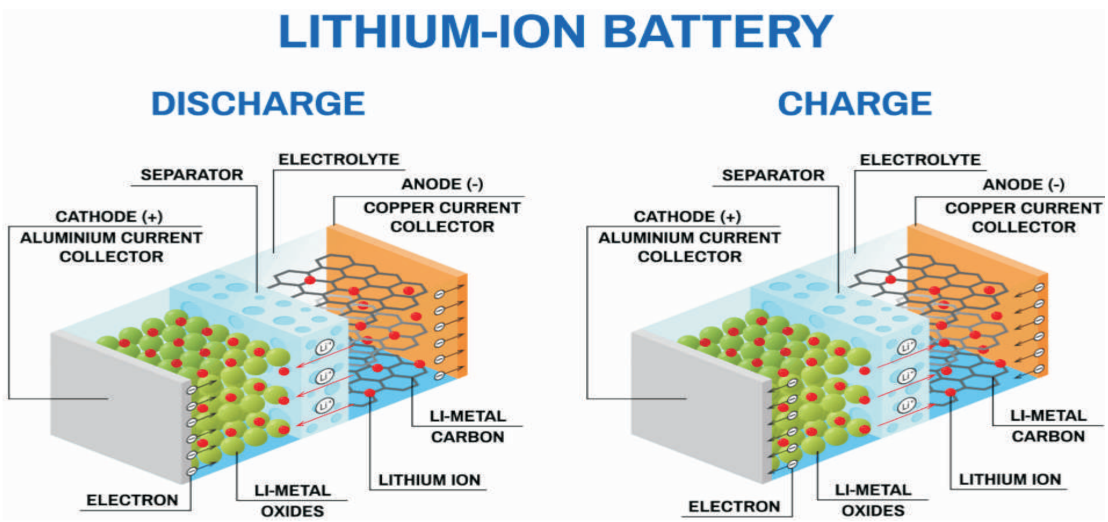

Figure 5. Charge & Discharge of Lithium-Ion Battery

4.3 Solid-State

Solid-state batteries constitute a technological paradigm leap. Ions migrate from one electrode to another across the liquid electrolyte in modern Li-ion batteries (also called ionic conductivity). The liquid electrolyte is replaced by a solid component in all-solid-state batteries, but lithium ions can still travel through it. During the last ten years, new families of solid electrolytes with extremely high ionic conductivity, akin to liquid electrolytes, have been developed, allowing this particular technological barrier to be surmounted. Figure 7 shows the solid-state battery.

Today, Saft's research and development efforts are focused on two categories of materials: polymers and inorganic compounds, to achieve a synergy of physico-chemical properties such as processability, stability, conductivity, and so on.

The first major benefit is a significant increase in cell and battery safety: solid electrolytes, unlike liquid electrolytes, are non-flammable when heated. Second, it allows for the use of cutting-edge, high-voltage, high-capacity materials, resulting in denser, lighter batteries with longer shelf lives due to reduced self-discharge. Furthermore, it will

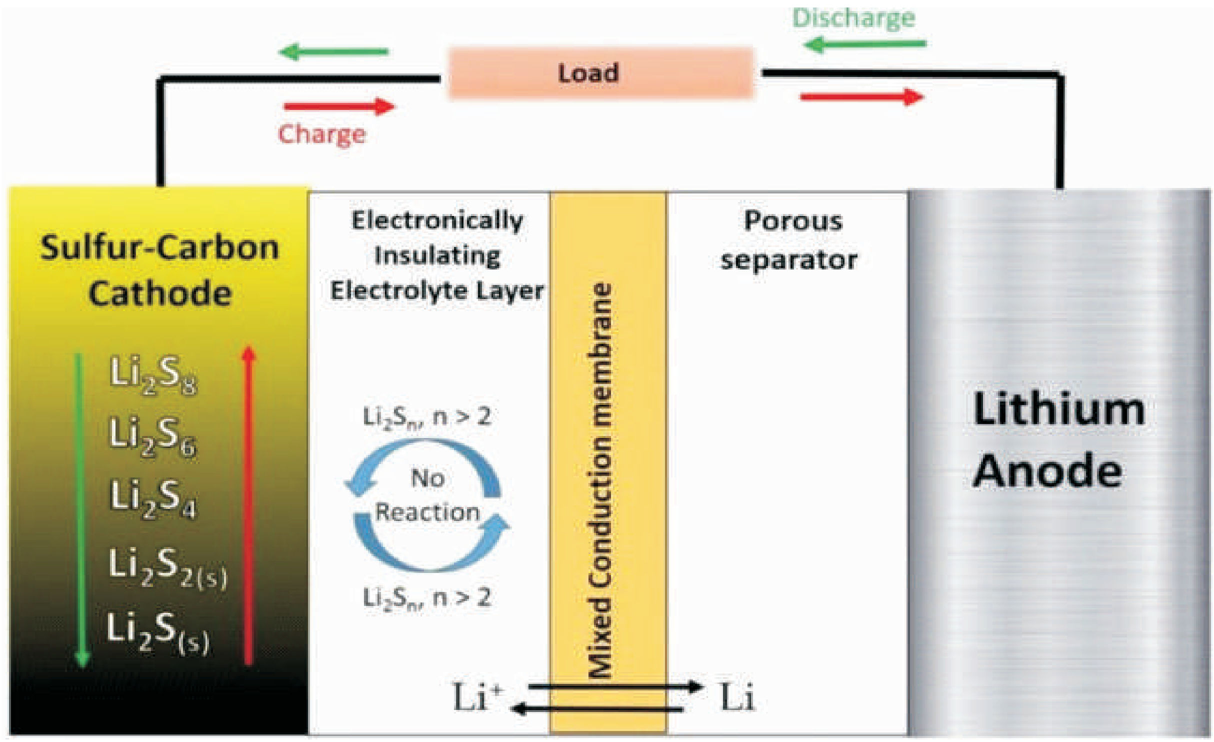

Figure 6. Lithium-Sulfur Battery

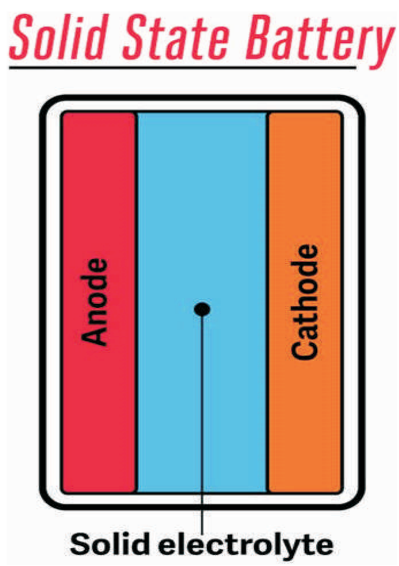

Figure 7. Solid State Battery

provide additional benefits at the system level, such as simplified mechanics, as well as thermal and safety control. The batteries may be excellent for use in electric cars due to their high power-to-weight ratio.

As technology advances, a variety of all-solid-state batteries are likely to hit the market. Solid-state batteries with graphite-based anodes will be the first, delivering increased energy performance and safety. Lighter solid-state battery solutions based on a metallic lithium anode should be commercially available shortly.

Conclusion

As a result, it can be inferred that because NiMH and

Lithium-Ion Batteries have high energy densities, they can be employed in situations where efficiency is critical. However, in applications where cost is more important than efficiency, a Lead Acid Battery may be the best option. However, there are a few applications where both efficiency and overall system costs are equally important restrictions. In such instances, a hybrid battery pack containing both lead-acid and lithium-ion (or NiMH) cells in ideal quantities can be used to meet the load with the maximum possible efficiency at the lowest possible cost.

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