



## Lithium-ion Battery Market Analysis for Hybrid, Plug-in and Solar-Powered Electric Vehicles

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### ABSTRACT

Currently, the world is combating with diverse types of challenges related to climate change and fuel costs. However, the research field of the electrical vehicles has given a considerable substitute for conventional vehicles. Moreover, the global involvement in the advancement of Hybrid Electric Vehicles (HEVs) and Plug-in Hybrid Vehicles (PHEVs) is getting higher. The mountaineering prices and reducing oil under the earth is distressing the world's economy adversely. In 1991, the battery market in the world was estimated to be at \$21 Billion Dollars yearly by S.L. Deshpande estimated. As of this present day, electric and hybrid electric vehicles have become more protuberant and widely accepted by the public, this indicates the battery market will be more than double the 1991 value by now. Because of the increase in the number of vehicle users, the rate of CO<sub>2</sub> emissions has risen, drastically. These discharges, combined with the challenge of coming up with other energy sources for crude oil and natural gas have led to the success of the battery market, most particularly in the EV and HEV business. The demand for ecologically friendly vehicles has risen so that different research works have gone into battery cells technology to produce electric vehicles and to support internal combustion vehicles to form hybrid electric vehicles. The Lithium-ion, Lead-acid, Nickel Metal Hydride, Lithium battery are a few types of batteries used as energy storage systems to drive EV and HEV vehicles. Selection of a battery is based on efficiency, cost, durability, performance, power, energy, etc. This paper seeks to examine and discuss the utilization of different secondary batteries and their use as energy storage systems as well as in EVs and HEVs. The Lithium-ion battery will particularly be the center of discussion in this paper, its role in battery market and economics.

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### 1. Introduction

Till now, the progress achieved in the field of combustion motor is the height of technology. In today's world, the advancement in the motor vehicle has fulfilled the primary need of emerging, a better societal and ethnic era, and it provides a facility for the transportation of the goods and people. There exist many causes and factors which ignite people to think about energy resources. In a meantime, the sensational topic of discussions in

the universities and research organizations is turned towards renewable resources and processes for efficient recycling [1-2]. The running down of resources is up-surfing rapidly which becomes a powerful cause to discover new resources, still, the usage of these resources is inadequate. Energy consumption is going in a one-way irreversible path in which consumed energy cannot be replenished as fast enough as the rate of consumption. These, being a real problem has been the basis for a lot of research on alternative energy sources that can be used together with already

developed energy sources like gas, crude oil and coal (fossil fuels) [3-4]. The long-term goal is to have alternative energy sources that will eventually be able to sustain the world's energy demands long after conventional sources have been exhausted. A good number of alternative energy sources that are renewable are already being harnessed and utilized to meet the energy demands in the world. Developed countries like the U.S.A, Canada, Germany, Netherlands, etc. already used solar, tidal, wind, biomass, and geothermal energy sources to meet their various energy demands. These energy sources also contribute to each of the country's power grid as conventional energy sources do. The solution to depleting energy sources includes practices such as conservation of energy and energy consciousness attitude, improved efficiency, and energy storage systems. It is believed that adopting these solutions will outperform renewable energy sources in the short term. Energy economics is the field that studies the human utilization of energy resources and energy commodities and the consequences of their utilization [5-7].

This paper analyzes the market and economics of the Lithium-ion batteries in which the factors that determine the construction, designing, distribution, consumption and performance level of the batteries have been considered. Also, the future market analysis of the Lithium-ion batteries compared to the other types of batteries for electric vehicles has been performed.

This paper is organized as follows. Section 2 provides a short description of energy storage systems. The electric vehicles electrification and the architectures of the electric vehicles are discussed in Section 3 and 4, respectively. Section 5 focuses on battery economics. Also, the descriptions of the Lithium-ion batteries are provided in Section 6. Section 7 and 8 investigate the industry trend and the Lithium-ion battery market analysis, respectively. Lastly, Section 9 indicates the conclusions.

## 2. Energy Storage Systems

The principle of energy storage systems is a general system that most, if not all branches of engineering can relate to in one way or another. The energy storage is the capture of energy produced at a time stored, to be used later. Energy storage systems involve converting energy from forms that are hard to store into more convenient and economically storage systems. Electrical energy storage system, which is the most efficient energy storage systems is made of batteries and supercapacitors. Compressed air, flywheels, and

compressed elastic are all examples of the mechanical energy storage system. Batteries were once thought to be energy storage systems used to power only portable electronics and medium-sized devices. However, due to the advancements in technology and necessity, the batteries have now become a major option for powering vehicles right now and in the future. Batteries can be categorized into two classes, non-rechargeable and chargeable batteries [5-8].

### A. Non-Rechargeable Battery

Non-rechargeable batteries do not have recharge capability when they have been fully/partially discharged. They are designed to be used one time and discarded. The electrochemical reactions occurring in the cell is not reversible. Most non-rechargeable batteries are used for power portable electronic devices. A good example is the Alkaline Zinc battery (Duracell).

### B. Rechargeable Battery

Rechargeable batteries have recharge capability when they have been fully/partially discharged. Rechargeable batteries are composed of one or more electrochemical cells. They can store energy through a reversible electrochemical reaction. These types of batteries are majorly used in hybrid solar-powered and plug-in electric vehicles. They typically cost more than non-rechargeable batteries. Some good examples are the Lead-acid, Nickel-metal-hydride, Nickel-cadmium, Lithium-polymer, and the Lithium-ion batteries. The Lithium-ion batteries have risen to prominence, since their inception into the battery market in 1991. These types of batteries are considered the most promising batteries for electric vehicles due to its high energy density and long cycle life.

To solve the challenge of finding sustainable urban freight transportation solution, different measures have been investigated. In the transportation research field, electric vehicles are considered as a solution for sustainable transport. The high cost of electric vehicles as compared to the conventional counterpart is seen as a barrier to large-scale adoption by consumers. Capacitors generally store charges; Supercapacitors are the energy storage devices also used in start-stop technology in EVs and PHEVs. They occupy the lower part of the electrification ladder and are of importance because they help meet emissions standard. Over the past decade, the reception received by EVs and PHEVs has been impressive as this was not the case in the distant past. Now, better designed, high-performance electric vehicles are available in the market and are attracting a lot of attention from the public.

## 3. Electric Vehicles Electrification

The electric vehicle concept has been known right from the 1900's, but due to the massive success of the Internal Combustion (IC) engines and its dominance, electrified vehicles were displaced and considered ineffective. Now, as a result of improvements in the energy storage systems, the electric vehicles have become relevant in a world still dominated by IC engine vehicles. Electric vehicles include road and rail vehicles, surface and underwater vessels, electric aircraft and electric spacecraft. The two main reasons for electric vehicle relevance now are [7-8]:

- To ease the demand for fossil fuels like crude oil, natural gas, and coal which are the major source of energy in the world. With the high demand of fossil fuel every day and a consumption rate of 22 billion barrels per year, it is predicted that the oil reserves will only last just 45–100 years.
- To reduce the rate of greenhouse gas emission to the atmosphere. The amount of CO<sub>2</sub> gas released to the atmosphere by IC engine vehicles has risen over the years due to a large number of vehicles. The CO<sub>2</sub> emitted can be reduced considerably, if electric or hybrid vehicles were adopted by a large number of the population. Hybrid vehicles emit less amount of CO<sub>2</sub> when compared to conventional internal combustion engines.

#### 4. Architectures of the Electric Vehicles

The architecture of the electric vehicles depends upon their specific purposes that are being designed for. Different EVs serve different purposes. Some EVs may be used for regular operations, while they can be used for the commercial, as well. That is the reason that EVs' architectures may vary from one to another. However, there are basically two pure architectures that can be used to design and operate an electric vehicle, the combination of these two is also used in some cases.

##### A. Series Hybrid Electric Architecture

As a definition, a specific architecture is defined as a series architecture when solely one mechanical source of power driving the propeller can be identified [9]. In the series hybrid architecture, both the fuel and electric modules are connected in series with the electric motor. Figure 1 shows the series hybrid electric architecture.

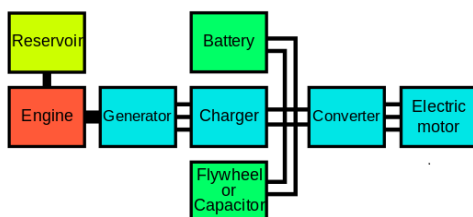


Fig. 1: The series hybrid electric architecture

##### B. Parallel Hybrid Electric Architecture

Based on the definition, an architecture is specified as a parallel when multiple sources of mechanical power are present in the system [9]. In the parallel hybrid architecture, the battery and reservoir are connected in parallel which facilitates the operation of the vehicle with the need of both energy sources to act individually or in combination to power the motors. Figure 2 illustrates the parallel hybrid electric architecture.

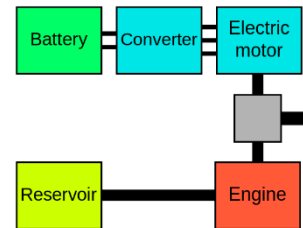


Fig. 2: The parallel hybrid electric architecture

##### C. Series-Parallel Hybrid Electric Architecture

An architecture is defined to be a series-parallel hybrid electric architecture if the system can switch between the operations in series or parallel modes with the requirement of the situation [9]. In this architecture, the design is made to optimize both sources, as they can be utilized in different combinations as required by the operational needs of the hybrid electric vehicle. Figure 3 demonstrates the series-parallel hybrid electric architecture.

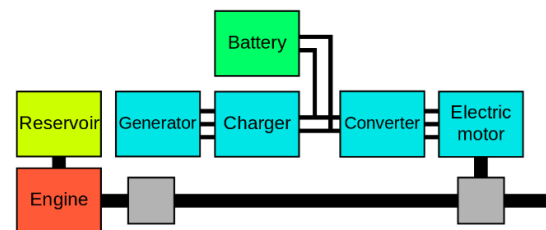


Fig. 3: The series-parallel hybrid electric architecture

#### 5. Battery Economics

Resulting from the high demand of environmentally friendly vehicles, that is hybrid and solar-powered electric vehicles do not give off CO<sub>2</sub> emissions, many research works have gone into the field battery cells to either support IC engines for power propulsion or full support of propulsion via electric motors. In the recent present, the research works have not only been carried out in the areas of battery efficacy but also in the areas of battery durability, cost of batteries, which is also influenced by the durability of the battery, and lastly the stability and performance of the battery cell. Some examples of the batteries used for hybrid and solar-powered electric vehicles that provide good battery

economy, which are high-performance characteristics, durability, and battery efficiency, are the Lead-acid, Nickel Metal Hydride, and the Lithium-ion batteries [10-11]. The Lithium-ion batteries have been the most widely used in recent times due to their high power density and high energy density. The Lithium-ion batteries have had some challenges in the past, as they could not be operated under certain temperatures as it affected the performance of the battery. Previously, the lead-acid batteries were widely used in hybrid and solar-powered electric vehicles, but with recent advancements in the area of the Lithium-ion batteries, the market has seen a surge in the Lithium-ion batteries.

The fuel economy of a hybrid electric vehicle is considered by the liters of gas consumed for every 100 km that the vehicle is driven. To improve the fuel economy of automobiles, automakers have combined traditional combustion engines with high voltage batteries and motors to create hybrid electric vehicles. In general, the hybrid and solar-powered electric vehicles provide better fuel economy and the vehicle performance is not provided by the IC engine alone, but by high voltage and economical batteries, as well. Some of the ways in which battery economy has helped to improve the fuel economy in hybrid and solar-powered electric vehicles are through regenerative braking, engine down-sizing, shutting the engine off instead of idling, and improvement of the engine operating point. A hybrid electric vehicle can utilize high operating point due to its continuous variable transmission-like (CVT) characteristics. This means, the hybrid electric vehicle can operate at lower speed and higher torque compared to conventional IC engines. This also increases the overall efficiency of the vehicle and its operations. Another feature that is exploited is that the vehicle can shut off completely during slow speed and run or operate completely on electric mode. This feature improves the efficiency of the vehicle even further and especially over one drive cycle because the engine is usually inefficient under low power conditions. However, the battery power used during the electric mode must be replenished while the vehicle is running. Improving battery efficiency and economy invariably improve vehicle efficiency. However, improving vehicle efficiency is very challenging and has cause for concern. This involves producing a battery to give high power and high energy density ratios, and durability. Energy storages are defined as devices that store charges electrochemically or electrostatically and deliver these charges to the load when needed. Most of the proposed batteries for hybrid and solar-powered electric vehicles are chemical batteries (Lead-acid, Nickel Metal Hydride, and Lithium-ion), ultracapacitors/supercapacitors and flywheels.

Amongst all the requirements for battery economy in the automobile applications, which are specific energy, specific power, efficiency, maintenance, cost, safety, etc., specific energy is the most important and critical as this determines the range that the vehicle can operate under the full electric mode. Looking particularly at battery economy, the Lithium-ion batteries provide the most battery economy in recent years due to its high power and high energy density ratios.

## 6. Lithium-ion Battery

Lithium is the lightest of all metals and has very intriguing characteristic features. It provides high voltage capacity which invariably leads to high specific energy and specific power. Lithium Polymer and Lithium-ion are the most common technologies used for Lithium-based batteries.

### A. Lithium Polymer Batteries

The Lithium polymer batteries utilize lithium metal and an oxide for negative and positive electrodes. They are structured in a way that the lithium ions can be removed during discharge and charge cycles. A thin solid polymer electrolyte is used, which provides the advantage of improved safety and flexibility during design. During discharge cycles, the Lithium ions are formed at the negative electrode and are moved to the positive electrode. During the charge cycle, the process is reversed, and ions are moved to the cathode and are moved from the anode.

### B. Lithium-ion Batteries

The Lithium-ion battery is a type of rechargeable batteries in which lithium ions move from the negative anode to the positive cathode amid release and back while charging. Lithium-ion batteries use carbon material for the negative electrode instead of metallic lithium, and a metal oxide for the positive electrode. During discharge and charge cycles, lithium ions migrate between the positive electrode and the negative electrodes. The cobalt-based Lithium-ion batteries have higher power specific energy and higher energy density, but their costs and discharge rate are high, as well. The manganese-based Lithium-ion batteries are significantly the lowest in terms of cost and the specific energy. Lithium-ion batteries are essentially battery economy and environmentally friendly. Typically, Lithium-ion batteries come in 3 to 4.5 V per cell. Due to the facts that Lithium-ion batteries have higher voltage per cell, better life-cycle, and higher energy density, Lithium-ion batteries have become increasingly important in industrial applications. It also should be noted that the excellent low-temperature performance, low self-discharge capability, and simple charging methods are the other highlighted features of Lithium-ion

batteries among the other types of batteries. These features place the Lithium-ion batteries as the most preferred batteries for commercial use.

## 7. Industry Trend

Lithium-ion battery was estimated over USD 24 Billion and is predicted to witness gain over 12% from 2017 to 2024. Stringent government standards toward the transfer of lead combined with the developing interest for electronic gadgets will enlarge the lithium particle battery advertise. Rising interest in cell phones, movement trackers, PCs, and brilliant watches shape creating nations will decidedly invigorate the item entrance over the gauge course of events. Longer release cycles alongside enhanced the timeframe of realistic usability are a portion of the key fundamental parameters which will additionally give force to business development. Figure 4 shows the trend of using Lithium-ion batteries in different applications in 2016 and 2024 [7-8, 10-11].

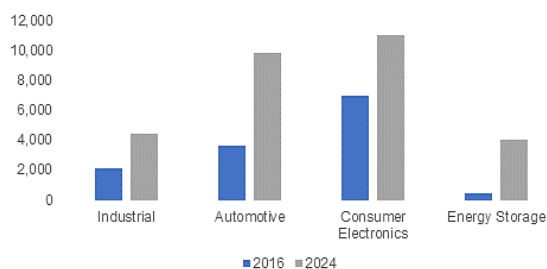


Fig. 4: Trend of using Lithium-ion batteries in different applications in 2016 and 2024

Developing reception of half breed and electric vehicles alongside promising government approaches toward practical advancements will drive the market development. In recent years, China, the U.S., UK, and Germany have witnessed a huge upsurge in electric vehicles request by the virtue of emanations standard and cost intensity. In 2016, more than 250,000 electric vehicles were sold in China speaking to 75% expansion from 2015 [7-8].

The simplicity of accessibility, high vitality thickness, and long cycle life are some the fundamental variables which will encourage worldwide piece of the overall industry. These items can convey higher current when contrasted with accessible partners which makes the best to control serious applications. The worldwide Lithium-particle battery showcase is relied upon to achieve USD 93.1 Billion by 2025, developing at a Compound Annual Growth Rate (CAGR) of 17.0%, as per another report by Grand View Research Inc. Expanded utilization of the Lithium-particle batteries in electric vehicles, convenient buyer hardware, and matrix stockpiling

frameworks inferable from its high vitality thickness and high well-being level are relied upon to drive advertising request. Innovative progressions to lessen the heaviness of batteries, costs, and increment their capacity yield, are required to increase industry development. Furthermore, skilled appropriation channels are probably going to be a vital method to pick up an upper hand. Vitality stockpiling framework is relied upon to witness the speediest development over the conjecture time frame at a CAGR of 21% from 2017 to 2025 attributable to the advancements in the wind and photovoltaic in nations including the U.S., Germany, and China. The Asia Pacific was the predominant market and represented 48.3% of the worldwide offer in 2016 [7-8, 10-12].

## 8. Lithium-ion Battery Market Analysis

Worldwide revenue of 47.5 Billion USD reached by battery market in 2009. The proportion of rechargeable batteries was 76.4% and primary batteries proportion was 23.6% of total revenue. It was forecasted to rise to 82.6% by 2015. As a result of research and development, great progress has been made in rechargeable batteries to increase specific energy and specific power to increase the runtime and provide extraordinary power delivery [8, 10-11].

To manufacture vehicles with electric drivetrains, great attempts have been pursued by automotive manufacturers worldwide. Also, the great efforts have been made to increase vehicle range and energy density while reducing costs. Lithium-ion batteries have replaced NiMH batteries in the hybrid electric vehicle and now Lithium-ion batteries are also introduced in stop-start vehicles. Figure 5 shows the comparison on demand for the rechargeable batteries from 1995 to 2015 [10-11].

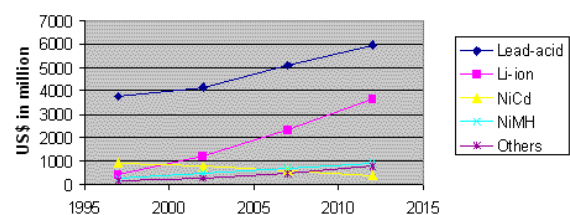


Fig. 5: Demand for the rechargeable batteries from 1995 to 2015

Figure 6 shows the global Lithium-ion battery market size and forecast in Billion U.S. Dollars from 2015 to 2024. Also, figure 7 illustrates the total vehicle Lithium-ion battery revenue by region from 2015 to 2024 [10-11].

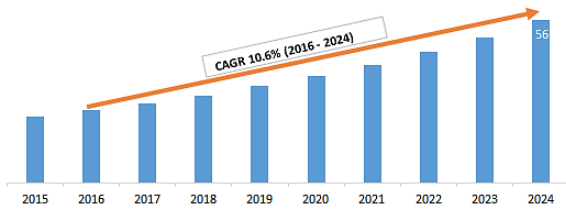


Fig. 6: Growth in Lithium-ion battery market size in the world

Worldwide market of the Lithium-ion batteries expected to reach the level of USD 30.6 Billion in 2024 from USD 7.6 Billion in 2015 specifically in light-duty and medium/heavy-duty vehicles. North America will maintain its position to be the largest market of PHEVs while the increment in the sales of BEVs in Europe will be noted. By the end of the predicted period, it will become more crucial for the global automotive Lithium-ion battery manufacturer to fulfil the demand of the Lithium-ion battery which is expected to see the noteworthy rise. If rising the micro-hybrid technology administer on its assurance of fuel efficiency on less cost increment and the important number of the OEMs select to implement it with the Lithium-ion battery packs, then this USD 30.6 Billion value can be more. The capacity of the Lithium-ion battery in 2024 is expected to reach 93.1 GWh from 15.9 GWh in 2015. It represents a CAGR of 21.7% [7, 10-12].

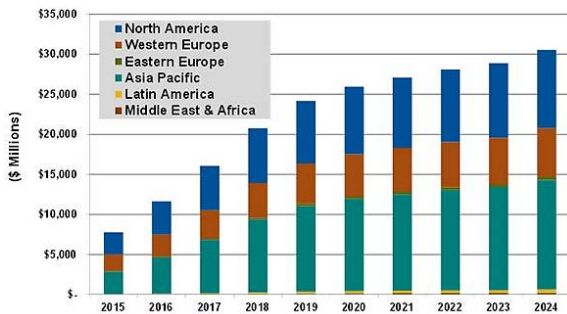


Fig. 7: Total vehicle Lithium-ion battery revenue by region, world market: 2015-2024

Developing appropriation of keen gadgets combined with the move toward digitization crosswise over modern and human services part will increase the U.S. showcase. Rising electric vehicles request because of the ideal government arrangements will additionally supplement business development. In 2015, the U.S. represented 11% expansion in offers of the electric vehicle from 2014 levels.

Expanding interest for customer hardware alongside uplifting viewpoint towards car part will drive the China Lithium-ion battery to advertise. Government activities to diminish contamination from battery waste will additionally invigorate business development. In 2016, the Government of

China acquainted controls with decrease harming from lead transfer industry. Germany, in 2016, represented more than 20% of Europe showcase. Rising interest in electric vehicles alongside rising customer attention to embrace eco-accommodating innovations will emphatically affect business development. Government activities including endowments for private lithium particle battery frameworks will additionally help the item request [8, 10-12].

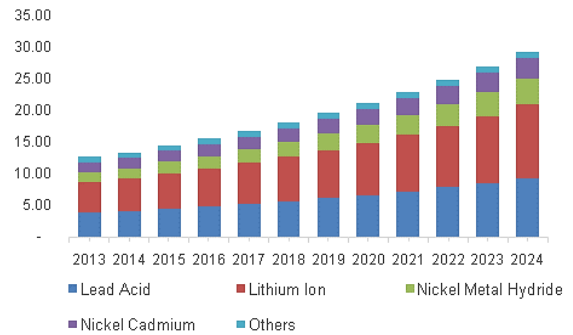


Fig. 8: Battery market analysis of different types of batteries up to 2024

## 9. Conclusions

Over the past decade, the rises to prominence of energy storage systems especially batteries have led to the improvement of human lives directly or indirectly. The importance of electric vehicles to humanity cannot be overstated as it helps reduce the emission of greenhouse gases to the environment which has the long-term harmful effects to human lives. The other major importance of battery in relation with electric vehicles is that it helps reduce the pressure of the demand for fossil fuels like petrol and diesel. By reducing the demand for these products, the products become available for other uses and reduces the rate depletion from its natural source.

Lithium-ion batteries dominate the electric vehicle industry because of its favourable battery economics, high energy density, and longer life cycle. Unprecedented growth is being observed in the battery market of rechargeable and non-rechargeable batteries in terms of both value and volume. As a result, many benefits can be generated, such as high reliability of rechargeable batteries, environmentally friendly, financial benefits, uninterrupted power supply when being used to power households and more advanced electric vehicles. In the years to come, it is proposed that more research and technological effort should be put into improving battery technology to make them highly reliable and charge faster with more energy density to last longer. More plug-in stations should be made available and widespread. Finally, efforts should be

made to make them cheaper for more people to afford battery-powered technologies, thereby reducing demand on fossil fuel and helping the environment. Considering the statistics of the Lithium-ion battery, it is clear that the world is moving towards the energy saving environment but a little costlier. There has been a tremendous growth in the automation area and it will keep advancing in the coming future. But, on the contrary with the research on the hand, the Lithium-ion battery product will be cost effective.

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