The Current State and Future Prospects of Battery Thermal Management Systems in The Green Automobile Industry

A Review of Varied Battery Types and Cooling Systems Employed in Electric Vehicles

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Abstract

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Abstract

The introduction of electric vehicles (EVs) to the world automobile industry has made a significant impact in every kind of ways due to its great contribution to the environment. As human is in the race of protecting and rehabilitating the plant, the invention of this new green vehicles is receiving lots of attention and positive feedback from consumers. Despite its remarkable advantages, the EVs possesses a potential threat to consumer’s life in some ways and the hazards which came across along the way. Thus, this paper is going to discuss about the EVs in general, then going into details about the causes and why as well as how to fix the problems. In specific, there will be analysis about different types of batteries used and many options of cooling system available as well as the battery thermal management system. Afterwards, the future of lithium battery and battery thermal management system (BTMS) will be reviewed with many trends are predicted to lead the industry in the long run.

Keywords

Cooling system, Cooling techniques, Battery Electric Vehicle, Battery Thermal Management System, BTMS, EV, BEV.

Contents

Key terms and abbreviations

AC	Alternating Current
AI	Artificial Intelligence
ALD	Atomic Layer Deposition
BEV	Battery Electric Vehicle
BTMS	Battery thermal management system
CO_2	Carbon dioxide
DC	Direct Current
EG	Ethylene Glycol
EV	Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
IEA	International Energy Agency
LCO	Lithium Cobalt Oxide batteries
LFP	Lithium Ferrum Phosphate batteries
LIBs	Lithium-ion batteries
Li-ion	Lithium ion
LMO	Lithium Manganese Oxide batteries
LTO	Lithium Titanium Oxide batteries
NCA	Lithium Nickel Cobalt Aluminium Oxide batteries
NiMH	Nickel-Metal Hydride batteries
NMC	Lithium Nickel Manganese Cobalt batteries
PCM	Phase change material
PG	Propylene Glycol
PHEV	Plug-in Hybrid Electric Vehicle
UPS	Uninterruptible Power Supply
WHO	World Health Organization

WMO	World Meteorological Organization

1 Introduction

In recent years, the world has witnessed an incredible growth in the electric vehicles (EVs) market. It has risen by leaps and bounds in providing their supremacy in the auto industry. The EVs trend is getting even more promising due to the fact that it might not only make a difference along the way but also contribute to protecting the planet. There are many elements affecting the expansion of the EVs trend, namely pricing, and operating expenses, environmental regulations and government assistance, operability, safety, battery replacement, and manufacturer strategy.

The age of EVs is on the rise due to many concerns. First of all, the use of EVs will contribute to protect the environment by reducing carbon dioxide (CO2) emissions. According to World Health Organization (WHO), several nations that are densely populated believe that almost every household possesses an internal combustion engine vehicle (ICEV). This could result in a noise population, which will negatively impact customers' psyche and health. (Faulkner & Murphy 2018.) Moreover, due to over-exploitation and fossil fuels are increasingly depleted, human is concerning about the alternative fuel when gasoline runs out. In the meantime, Tesla was the first electric car company to develop a vehicle powered entirely by electricity rather than an internal combustion engine. (Gregersen & Schreiber 2021.) In ten years' time, the natural environment will be seriously threatened, according to World Meteorological Organization (WMO) (2021), climate changes will result in melting ice and increasing sea level. Furthermore, carbon dioxide, methane, and nitrous oxide are rapidly increasing, which leads to global warming effects and harmful to human health. In addition, the Finnish Ministry of Transport and Communications (2021) is encouraging households and businesses to switch to EV or PHEV in order to contribute to the reduction of greenhouse gas emissions. Thus, due to all of the above, the future for EVs is obviously outlined. In 2021, sales of EVs and PHEVs were dramatically increased, accounting for a third of first-registered vehicles. Besides, the government has approved a new subsidy decision under which an individual can apply for a grant of 2000 euros with a total cost not exceeding 50,000 euros.

Both EVs and ICEVs have advantages and limitations. It is believed that EVs can completely replace the ICEVs due to the fact that they can eliminate noise, do not rely on fossil fuels, and could save energy. EVs accelerates faster, without delay compared to ICEVs because EVs transmit 100% of the torque generated to drive the wheels and take less time to generate power. (Poornesh et al. 2020, 1179–1183.) However, EVs have to face many limited ranges of movement due to insufficient battery capacity (approximately 480 km when fully charged), lack of battery charging stations, poor cooling system, and the high cost of replacing batteries in EVs. (Deng et al. 2018, 511–515). Since batteries electric vehicle (BEV) includes chemicals such as lead, mercury, and other compounds, it is critical to come up with the most effective cooling system and maintain the battery at a low level when it releases a considerable amount of heat. If the BEV explodes, it will threaten the life of the driver and the surrounding, not only causing property damage but also seriously affecting the ecosystem because the compounds in the battery are difficult to handle the waste. If the battery temperature rises by more than 50˚C while driving an EV, the electrolyte surface expands and the internal resistance increases, contributing to a significant reduction in power supply due to the gradual reduction of the internal cells over time if the temperature is not closely maintained at the ideal level when using or charging the battery. (Sourav & Eswaramoorthy 2020, 1–2.)

Currently, there are various types of cooling systems used in the market, such as fan cooling, air cooling, phase change cooling, thermoelectric and liquid cooling. However, due to unequal temperature distribution for all cells in a package, current leading heat dissipation techniques do not provide adequate efficiency. For the reasons stated above, the battery's heat dissipation is critical and required to balance the cells and deliver charging and discharging power. This thesis is going to analyse, compare the popular cooling systems of BEVs and discuss about the future of BTMS. The goal is to come up with the most effective cooling technology for the entire battery system, avoid overheating when operating or charging as well as extend the battery lifespan, increase safety first, and enhance the machine's performance to make it move faster and more smoothly. The current trend of BTMS will be demonstrated as to predict the propensity which the industry moving towards, or in another word, the future of BTMS.

2 Batteries Electric Vehicles (BEVs)

Due to the threat of oil depletion and environmental contamination, the auto industry has developed a variety of alternative fuel-powered automobiles. Battery electric vehicles (BEVs) are among the most popular non-petroleum solutions. One of the primary advantages of BEVs is that they emit no emissions (do not produce greenhouse gases or pollutants). Furthermore, these cars operate on fully-electricity, which can be generated through more sustainable and ecologically responsible manner. EVs uses are powered by a power source built inside the battery. Once EVs achieve the requirements, it is almost guaranteed that they will dominate the market and make ICEVs obsolete in the near future, probably until 2030, when they will be totally supplanted.

Figure 1 illustrates the diagram of BEV operated. The power supply for an electric car is transformed from a DC battery to AC for the electric motor, which is the working principle. The accelerator pedal transmits a signal to the controller, which changes the frequency of the AC current from the inverter to the motor, allowing the vehicle's speed to be adjusted. A gear links the motor and rotates the wheels. When the brake is applied or the electric vehicle slows down, the engine transforms into a generator, producing energy that is returned to the battery. Because the battery pack provides DC power, it must be converted to AC power before it can be supplied to the induction motor. Hence, the inverter is connected to the battery pack. This power electronic device not only converts DC to AC, but it also assists in the regulation of AC power frequency. This is a simple method of controlling the speed of an induction motor. (Arivazhagan & Atiso 2020, 4294.)

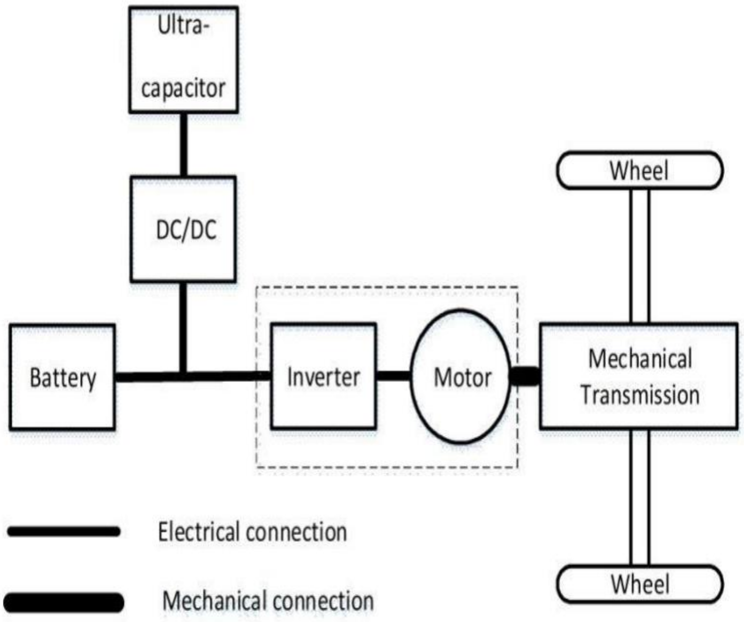


Figure 1. Battery-powered EVs Block Diagram (Arivazhagan & Atiso 2020, 4294).

The standard components of BEV include an electric motor and a substantial battery system. The operation of the vehicle solely relies on the electric motor, obviating the necessity for a combustion engine or exhaust system. The vehicle is powered either through recuperation or by connecting to the power grid. Currently, compact EVs typically possess a battery capacity ranging from 16 to 24 kWh, whereas luxury EVs may feature a battery system with a capacity exceeding 50 kWh. (Santolaya et al. 2023).

2.1 Battery Types

BEVs are known as secondary batteries or accumulators. This is a rechargeable battery that allows the battery and charger to be connected to a power source and the charging cycle to be repeated several times. BEVs are made up of series-connected battery cells that have a cathode (positive electrode), anode (negative electrode), and an electrolyte.

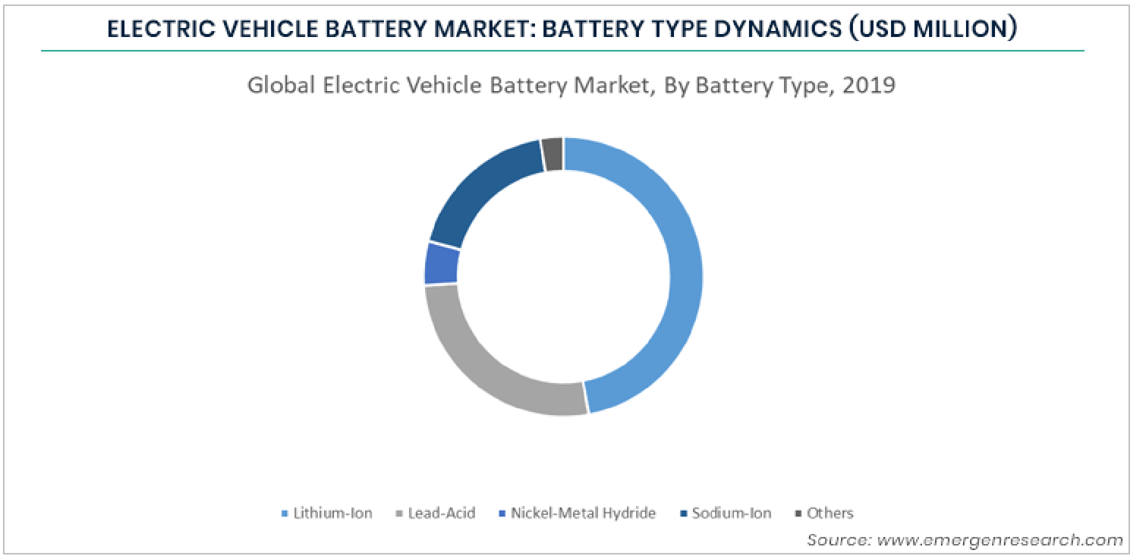


Figure 2. Global Electric Vehicle Battery Market (Emergen Research 2020).

Electric vehicles (EVs) have gained significant popularity due to their low environmental impact and lower fuel costs. However, the success of EVs depends on the battery technology used. According to Figure 2, the four most common types of batteries for EVs are Lithium-ion, Lead-Acid, Nickel-Metal Hydride, and Sodium-ion. To be specific, the above battery lines will be listed more clearly and understand each battery has its own characteristics.

2.1.1 Lithium-ion Batteries

In recent years, there has been a growing prevalence of Lithium batteries, particularly in the automotive industry where they are widely used in electric vehicles. The popularity of these batteries can be attributed to their light weight and high energy density, which allows a great amount of energy to be stored in a small space. Additionally, lithium-ion batteries are known for their high efficiency, meaning that they can convert a large percentage of the stored energy into electrical power. This is particularly important for electric vehicles, as it allows them to travel further on a single charge. (Arivazhagan & Atiso 2020, 4294.)

Furthermore, the lifespan of lithium-ion batteries is relatively long compared to other types of batteries, which is another reason why Li-ion are popular in the automotive industry. This means that Li-ion do not need to be replaced as frequently, reducing maintenance costs, and increasing the overall efficiency of the vehicle. Nevertheless, it is important to note that the manufacturing expenses associated with Li-ion batteries are relatively high when combined with alternative battery technologies. Despite this, their numerous benefits make them a popular choice for electric vehicle manufacturers, and it is likely that their popularity will continue to grow in the future.

It is worth noting that despite the many benefits of lithium-ion batteries, there are still some drawbacks to their use. One of the main concerns is the safety of these batteries, particularly in the event of a thermal runaway. This occurs when the battery becomes overheated, leading to a chain reaction that can cause the battery to explode or catch fire. Although such incidents are rare, they can still cause significant damage and are a cause for concern among some electric vehicle users.

Additionally, specific minerals such as lithium and cobalt will take part in the production of lithium-ion batteries, through mining and other processing. This can have a negative impact on the environment, and there are concerns about the sustainability of this practice. However, there are ongoing efforts to develop more sustainable and environmentally friendly ways of producing these batteries, such as recycling and using alternative materials.

Despite these concerns, lithium-ion batteries are still the most popular type of battery used in electric vehicles. They offer numerous benefits, including high energy density, efficiency, and a long lifespan, making them an excellent choice for electric vehicle manufacturers. Due to the development of technology, it is likely that further improvements will be made, and may see the emergence of new battery types that are even more efficient and environmentally friendly. (Fayaz et al. 2021, 130.)

2.1.2 Lead-Acid Batteries

Lead-Acid batteries, which have been around for several years, are the oldest type of rechargeable battery. They continue to be a popular choice due to their affordability and accessibility. However, as technology advances, it is becoming increasingly clear that their energy density is low when compared to other battery types. This results in heavy and bulky batteries which are a disadvantage, as they limit the range of electric vehicles and make them less efficient overall.

Moreover, Lead-Acid batteries have a shorter lifespan than other types of batteries, which means they require replacement more frequently. This can be a hassle for electric vehicle owners, who may need to spend more time and money on maintenance. However, it is important to note that there are other types of batteries available with a longer lifespan and higher energy density, which can ultimately result in cost savings over time.

Despite these drawbacks, Lead-Acid batteries remain a viable option for many applications. They are still widely used in various fields, such as backup power supplies, telecommunications, and uninterruptible power supplies. Additionally, they are often preferred in certain industries, such as the marine industry, due to their robustness and ability to withstand harsh conditions. Overall, while Lead-Acid batteries may not be the most advanced or efficient option, they continue to have a place in the battery market and will likely remain a popular choice for years to come. (Dinçer et al. 2017, 51–52.)

2.1.3 Nickel-Metal Hydride Batteries

Nickel-Metal Hydride (NiMH) batteries represent a rechargeable battery variant that presents a viable substitute for Li-ion batteries, demonstrating numerous advantages in comparison to other battery categories. Notably, NiMH have a higher energy density than Lead-Acid batteries, which makes them more compact and lighter in weight. Additionally, they are more environmentally friendly than Lithium-ion batteries because they contain metals that are friendly to the environment. Furthermore, Nickel-Metal Hydride batteries can withstand high temperatures and are less prone to explosion and fire than Lithium-ion batteries. However, they are more expensive to produce due to their complex manufacturing process, and they have a shorter lifespan than Lithium-ion batteries, which can be a disadvantage for some applications. Despite these limitations, Nickel-Metal Hydride batteries are still a great alternative for many applications such as hybrid and electric vehicles, portable electronic devices, and renewable energy systems. (Dinçer et al. 2017, 52–54.)

Moreover, NiMH batteries exhibit a diminished self-discharge rate in comparison to alternative battery types, affording them the capability to maintain their charge over extended durations. This makes them an ideal choice for applications that require long-term storage, such as emergency backup systems. NiMH batteries are more tolerant of overcharging than Lithium-ion batteries, which can extend their lifespan and reduce the risk of damage.

In recent years, there have been several advancements in NiMH batteries technology that have improved their performance and efficiency. Manufacturers have developed Nickel-Metal Hydride batteries with a higher energy density, which can provide more power in a smaller package. Additionally, some NiMH batteries are not only with a longer lifespan, which can reduce the cost of ownership over time, but also can be charged quickly.

In conclusion, NiMH batteries are a promising alternative to Lithium-ion batteries that offer several advantages in terms of energy density, environmental impact, and safety. Despite their elevated production costs and comparatively shorter lifespan in contrast to Li-ion batteries, they remain a commendable selection for diverse applications, including hybrid and electric vehicles, portable electronic devices, and renewable energy systems. As technology continues to advance, we can expect to see further improvements in NiMH batteries technology that will make them an even more attractive option for consumers and businesses alike.

2.1.4 Sodium-ion Batteries

Sodium-ion batteries are a new type of battery that is currently being developed and tested, but they hold great promise for the future of energy storage. These batteries boast a high energy density, making them more flexible in a wide range of applications. Additionally, they are less expensive to produce than Lithium-ion batteries, making them an attractive alternative for businesses and consumers alike. Not only are they cost-effective, but they are also more environmentally friendly than Lithium-ion batteries. This is because they use sodium, which is a more abundant element than lithium, and therefore easier to obtain. However, there are still some challenges that need to be addressed before Sodium-ion batteries can become the preferred option for energy storage. One of the main issues is that they are not as efficient as Lithium-ion batteries. Furthermore, the lifespan of Sodium-ion batteries is still being tested, and it remains to be seen how long they will last in real-world applications. Nonetheless, the potential benefits of Sodium-ion batteries are significant, and researchers are working hard to overcome the hurdles that currently exist.

Recent studies have shown that Sodium-ion batteries have a higher theoretical energy density than Lithium-ion batteries, which implies that they have the power to reserve more energy per unit of mass or volume. This is a significant advantage as it allows for the development of smaller and lighter batteries with higher energy storage capacity. This makes Sodium-ion batteries ideal for use in portable electronic devices, electric vehicles, and renewable energy systems. (Zhao et al. 2023, 175–176.)

Another advantage of Sodium-ion batteries is their lower cost. Sodium is a more abundant element than lithium, and it is easier to extract and process. This makes Sodium-ion batteries less expensive to produce, which can result in cost savings for manufacturers and consumers. Additionally, the utilisation of Sodium-ion batteries has the potential to mitigate the environment footprint associated with energy storage, given that their production process requires fewer resources and generates less waste.

Despite these advantages, Sodium-ion batteries still face some challenges that need to be addressed before they can become the preferred option for energy storage. One of the main drawbacks is their lower efficiency compared to Lithium-ion batteries. Sodium-ion batteries are not able to store and release energy as efficiently as Lithium-ion batteries, meaning that they may not be suitable for applications that require high power output. (Zhao et al. 2023, 176–177.)

Additionally, the lifespan of Sodium-ion batteries is still being tested, and it is unclear how long they will last in real-world conditions. Lithium-ion batteries have a proven track record of longevity and durability, and it will take time for Sodium-ion batteries to match this standard.

Despite these challenges, researchers and manufacturers are working hard to overcome the limitations of Sodium-ion batteries. New materials and designs are being tested to improve the efficiency and lifespan of these batteries. Researchers are exploring the use of solid electrolytes, which can improve the stability and safety of Sodium-ion batteries. Furthermore, new manufacturing techniques are being developed to reduce production costs and increase the scalability of Sodium-ion batteries.

In conclusion, Sodium-ion batteries are promising alternative to Lithium-ion batteries that hold great potential for the future of energy storage. They offer a higher theoretical energy density, lower cost, and reduced environmental impact compared to Lithium-ion batteries. However, there are still some challenges that need to be addressed before they can become the preferred option for energy storage. Nonetheless, with ongoing research and development, it is likely that Sodium-ion batteries will play a significant role in the future of energy storage.

2.1.5 Conclusion

In summary, Lithium-ion batteries are currently the most popular batteries used in electric vehicles due to their high energy density, efficiency, and long lifespan. Other promising alternatives include Nickel-Metal Hydride and Sodium-ion batteries, which have their own unique advantages. Despite their popularity, Lithium-ion batteries still have position for improvement in terms of cost and safety. Several BEV manufacturers and researchers are exploring new battery technologies, such as solid-state batteries, which offer improved performance and safety. The choice of battery depends on various criteria, including cost, energy density, and environmental impact. Efforts are being made to develop more sustainable and environmentally friendly ways of producing and disposing of batteries. Furthermore, expanding the charging infrastructure is crucial to addressing potential EV owners about range and accessibility. Overall, battery technology will continue to play a vital role in the future of transportation, and advancements are being made to ensure its sustainability and environmental friendliness.

2.2 Why do the EVs industry still rely on 12V Lead-Acid batteries?

The Electric Vehicle (EV) industry is rapidly growing and paving the way for a more sustainable future. However, despite advancements in battery technology, many EVs still rely on 12V lead-acid batteries.

Figure 2 indicates that the Lead-Acid battery is ranked second, demonstrating that its significant contribution to the auto industry cannot be replaced or abolished. An electric automobile with a big lithium battery pack may provide power ranging from 400 to 800V, but a standard 12V lead-acid battery, like in an internal combustion engine vehicle, is still required.

Because to Tesla's foresight, most electric vehicles currently use a 12V battery (typically lead-acid batteries). The Roadster, a convertible electric sports automobile introduced in 2008, was entirely powered by the car's primary battery pack. In 2012, an original Tesla Roadster was stored for two months without a charger plugged in. When it was used again, the owner of the automobile was unable to unlock or even start the vehicle and was unable to do anything else other than phone for assistance. This Tesla Roadster was eventually confirmed to have entirely failed the Lithium-Ion battery due to it being unable to be recharged; the replacement cost was up to 40,000 dollars, nearly half the value of the car. (Gregersen & Schreiber 2021.) All of these extra expenses may be avoided if this Tesla is outfitted with a 12V battery, which typically costs a few hundred dollars. A 12V battery pack will aid in the maintenance of typical electrical equipment in a vehicle, particularly when powering laptops and other vital electronic devices. Following the above incident, Tesla altered the design and used more 12V batteries in subsequent models. Many automakers have learned from Tesla's experience and added a 12V battery location to their electric vehicles (Bradley Berman, 2012).

Furthermore, in the case of an accident or damage, a 12V battery will assist in the maintenance of electrical equipment such as emergency lights, illumination, communication systems, and so on. To avoid a fire, the computer has automatically cut off the primary battery power. When the prices are compared, it is obvious that a 12V lead acid battery will be less expensive than a lithium battery of the same voltage. Meanwhile, lead-acid batteries have the benefit of being more durable in difficult conditions, especially in cold regions (Garche et al. 2015).

According to the experts, lithium batteries can be discharged from -20 to 60°C but can only be charged if the temperature is from 0 up to 45°C. Furthermore, lithium-ion batteries function best when the operating temperature is between 25 and 40°C. (Souvar & Eswaramoorthy 2020, 1–2). As a result, if using a 12V Lithium-ion battery, it will be easily destroyed when the temperature dips below freezing. Lead acid batteries, on the other hand, do not freeze until -40°C and are able to charge from -20 to 50°C without failure. Furthermore, due to its popularity and low cost, lead acid batteries can be easily installed in any vehicle while lithium-ion batteries are both costly and scarce.

Many automobile manufacturers are considering updating the electrical system in cars to 24V or 48V instead of the present 12V system as they develop electric vehicles. However, the car industry is increasingly standardizing third-party components such as airbags, lights, wiper motors, power windows, power liftgates, mirrors, fans, power steering, and so on. Because power brakes, A/C, and other components run on 12V battery, changing other voltages is both costly and unneeded.

In conclusion, the EV industry still relies on 12V Lead-Acid batteries due to their affordability, reliability, and ability to handle auxiliary power demands. However, as battery technology continues to advance and the demand for sustainable transportation options grows, it is likely that we will see a shift towards the use of more efficient and environmentally friendly propulsion batteries in EVs.

2.3 Lithium batteries for Electric Vehicles

2.3.1 Lithium Cell components

An electrochemical system's essential building unit is the cell, which are created in a variety of forms, including cylindrical, pouch, prismatic, and large format design. Figure 3 depicts that cell are assembled into battery modules, and modules are assembled into battery packs and battery systems. For automobile battery packs, there are two design options such as parallel and series. These designs are created at the request of automobile owners, based on the required capacity, capacity, and durability. These battery packs are now built-in parallel design to ensure maximum capacity and amperage needs, although series design is frequently used to improve the energy stored provided.

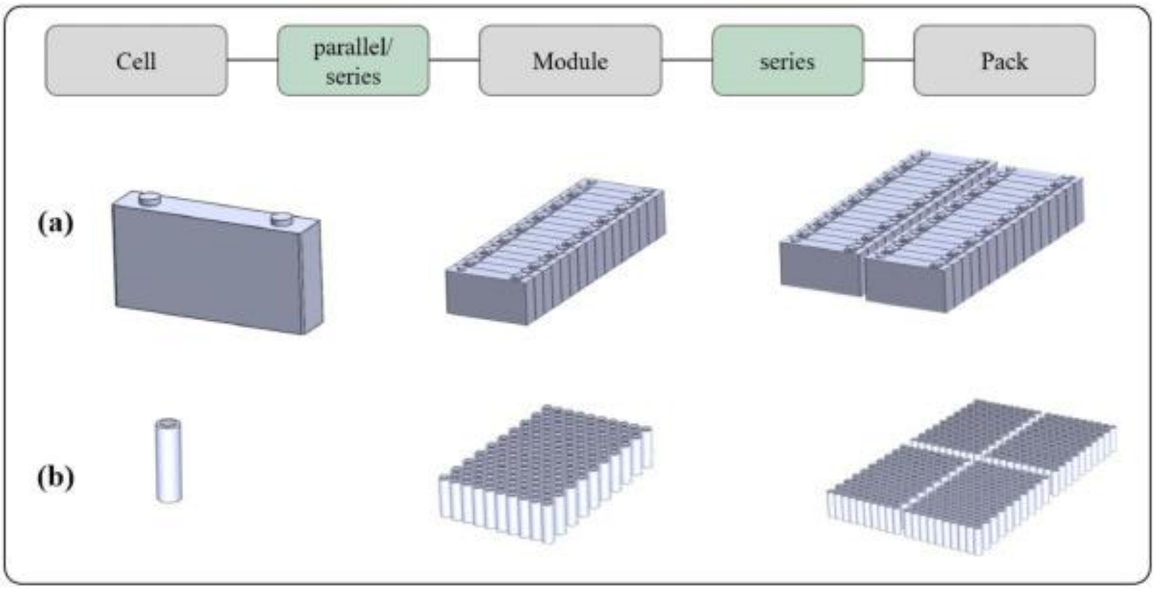


Figure 3. The conversion of an electric car battery from a single cell to a package by parallel and series design (Zwicker et al. 2020).

The construction of the battery involves the distinct chemical components within each cell. These components surround the cathode, serving as the positive electrode responsible for electron uptake subsequent to battery discharge. Conversely, the anode functions as the negative electrode, releasing electrons during battery discharge. The electrolyte, a substance integral to the battery cell, facilitates the transportation of ions between the anode and cathode. Additionally, the separator, a solid material situated between the anode and cathode, serves a dual role. Firstly, it impedes direct electron transfer from the anode to the cathode, thereby preventing internal short circuits. Secondly, the separator establishes a conduit for ionic conduction within its interconnected porous structure in the liquid electrolyte, facilitating the smooth flow of ions between the anode and cathode. (Stephens et al. 2017, 2-2.)

2.3.2 Lithium battery operation

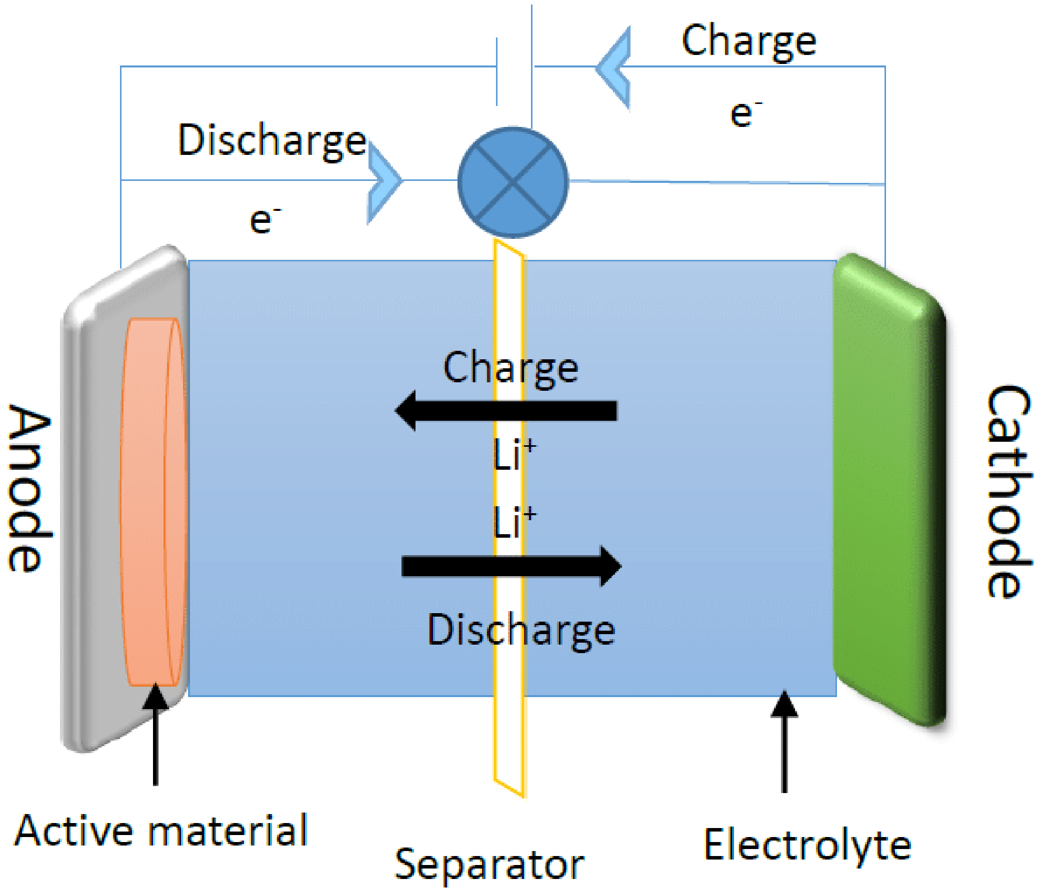


Figure 4. Charging and discharging processes of Li-ion batteries. (Gao et al. 2017, 8).

The positive and negative poles act as raw materials for electrochemical reactions of the electrolyte solution, resulting in a Li+ transmission medium that moves between the two poles. Figure 4 depicts the current going outside the circuit during the charging and discharging operation.

The discharge process involves the movement of Li+ ions from the cathode to the anode via the electrolyte, where a reaction takes place. The external circuit contains an electron that goes from the cathode to the positive pole for each Li-ion displacement and stimulates current to flow from the anode to the negative pole. This contributes to establishing a charge balance between the two terminals.

In contrast to the discharge process, electrons are pushed to travel from the positive terminal of the battery under the charging current, while Li+ ions separate from the anode and return to the negative electrode.

The Li+ atom in the bond ionizes and separates from the electron during each discharge cycle. It will then pass from the anode's electrode to the cathode via the electrolyte. They merge with other electrons and become electrically neutral at this point.

The charger supplies a constant current to the battery via a stable voltage that steadily increases until the battery's critical potential is achieved in constant current mode. In balance mode, the charger progressively decreases the charging current to the battery or controls the charging current on and off, until the charging condition of each battery cell reaches equilibrium in the whole circuit, and all cells in the circuit are balanced. Some chargers maintain the balance by charging each battery cell in turn, but this increase charging time. Developing an algorithm that optimizes this balancing can improve performance and reduce battery charging time. In balanced voltage mode, the charger provides a voltage equal to the critical potential of each cell multiplied by the number of cells put in series across the whole battery; this is called the discharge process, so the current will drop. If the charge or discharge rate exceeds the maximum voltage and current, the battery may explode.

2.3.3 Lithium Battery Operating Temperature

The charging limit temperature of the battery is more essential than the discharge temperature (the temperature at use). The scientists discovered that it was operating at an excessively high temperature (although not for an inordinately long period of time), which affected battery life. When charged at 5 - 45˚C, the battery performs optimally, and high-speed charging is feasible. Temperatures below 0 - 5˚C can be charged, although the current will be reduced; nonetheless, the temperature of the battery will rise somewhat throughout the charging process owing to the internal resistance of the battery. The phenomenon of increased temperature when charging is the reason for poor battery performance; if the temperature increases beyond 45˚C, the battery will degrade fast. However, while charging at low temperatures, the internal resistance of the battery increases, reducing charging speed and lengthening charging time.

LIB batteries should avoid charging in temperatures that fall below 0˚C. Although the battery system appears to be charging normally at this temperature, at low temperatures, the poor conductivity of the electrode material reduces the reactivity of Li+ ions with the electrode material, causing Li+ to be plated on the electrode surface rather than diffusing deep into the material and participating in the reaction under cold charging conditions; this coating adheres to the electrode even if it continues to charge or discharge. As a result, most batteries cannot run above from 0 to 45 ˚C for safety concerns. (Sourav & Eswaramoorthy 2020, 1–2.)

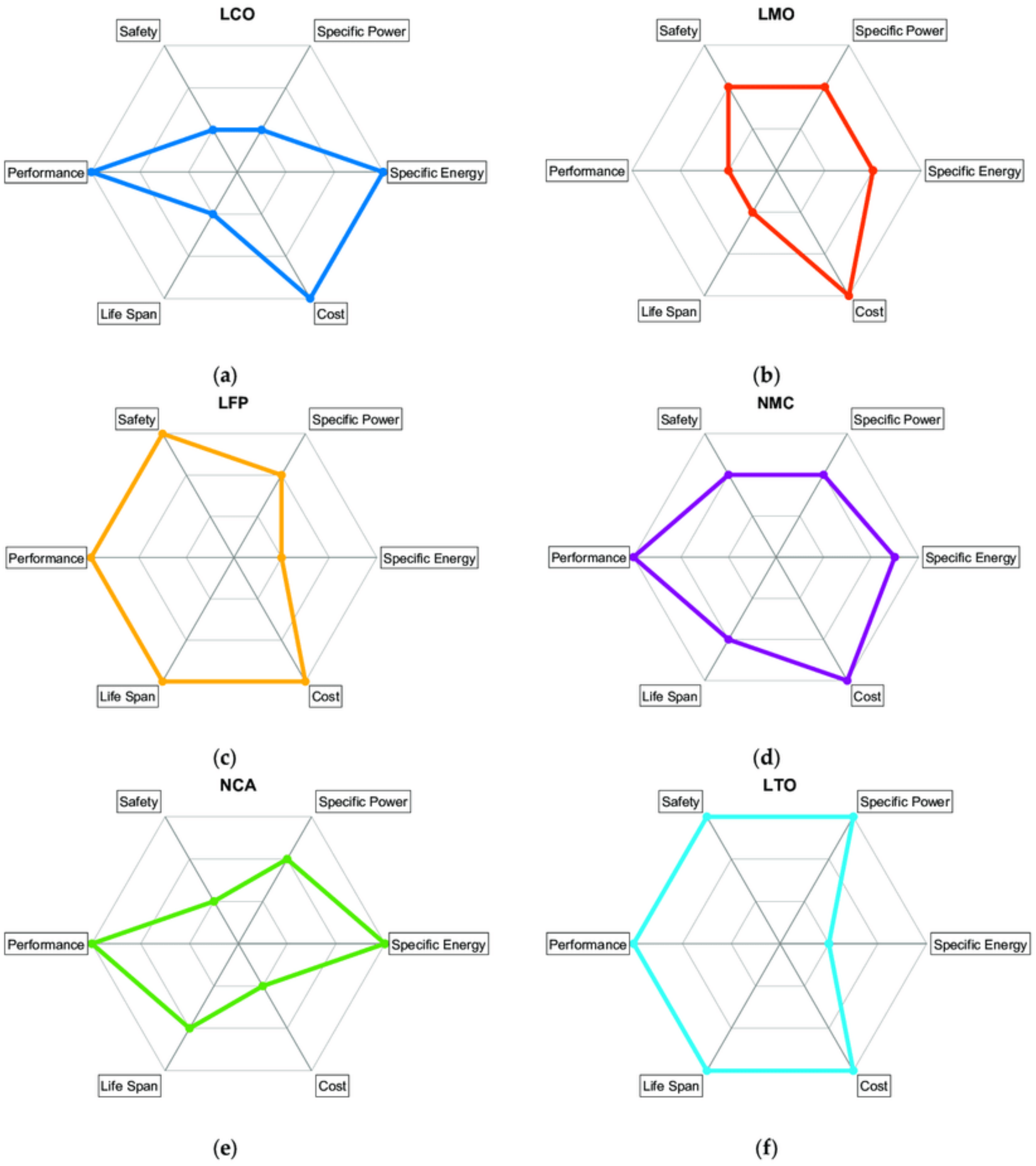
2.3.4 Compare advantages and disadvantages of Lithium battery

Table 1. Brief description of the benefits and disadvantages of Lithium-ion batteries. (Stephens et al. 2017, 2–2).

Advantages	Disadvantages
• Extensive shelf life and life cycle. • High energy density and specific energy • No memory impacts. • Closed cell – no need for electrolyte replacement. • A wide range of cathode, anode, and electrolyte modifications serve as the foundation for flexibility in design. • Capability to fast charge and discharge with an extremely capacity in a short period of time.	• High-temperature deterioration. • When charged too rapidly at a low temperature (0°C) or overcharged, there is instability and possibility of thermal runaway or capacity loss. • Expensive than more typical batteries. • In multi-cell modules, complex management circuitry is required. • Limited supply of the raw materials to make Lithium batteries. • Can be dangerous if they are damaged or overcharged due to Lithium batteries can overheat and catch fire.

Recently, the world of technology is experiencing a trend towards renewable energy with the demand for bigger battery capacity. Along with this, there is rising concern regarding safety issues because the operating temperatures of the battery system are unstable. Also, because there is an electrolyte element in LIBs, it makes the battery flammable and easily gets exploded. However, of all the batteries available on the market, the Lithium battery line remains the most stable because it can endure high temperatures and has a longer average life than other batteries. In the future, there may be new energy batteries that can replace Lithium batteries, but the current outstanding advantages they bring are undeniable.

2.3.5 Most Lithium Battery types for Electric Vehicles using



(a) (b) (c) (d) (e) (f)

Figure 5. Characteristics of Lithium-ion batteries in EVs. (a) LCO; (b) LMO; (c) LFP; (d) NMC; (e) NCA; (f) LTO. (Saldaña et al. 2019).

Lithium battery technology now dominates the global energy market, with the majority of automobile manufacturers using this battery technology into their electric vehicles. According to the study of Saldaña and et al, Figure 6 describes a comparison of the most well-known Lithium-ion batteries, mainly including Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO), Lithium Ferrum Phosphate (LFP), Lithium Nickel Manganese Cobalt (NMC), Lithium Nickel Cobalt Aluminium Oxide (NCA), and Lithium Titanium Oxide (LTO). Because the various batteries contain different chemical ingredients, their performance characteristics will change. The LFP battery was chosen due to it fits the following critical criteria: high safety and performance, long life cycle, low toxicity, and suitable price. The above characteristics is going to impact their capability in terms of range and power, as well as their cost to the auto manufacturer; because the price of batteries accounts for over half of the cost of electric vehicles, this may affect the price of electric vehicles for customers. Fortunately, this LFP battery does not include cobalt and nickel, and the cathode is made of phosphate material. Therefore, the product pricing will be ideal for popular and low-cost EVs, and it can also minimize the risk of fire, explosion, and short circuit since this is the battery with the highest temperature stability in the lithium series. Although the energy density of LFP battery is not equal to the others Lithium series, but in terms of safety is paramount.

Table 2. Characteristics of different LIB chemistries. (Hentunen et al. 2017, 18).

Characteristics	**Li-ion battery chemistries**					
	LCO	**LMO**	**LFP**	**NMC**	**NCA**	**LTO**
Safety	1*	2	3	2	1	2
Power	1	2	2	2	3	2
Energy	3	2	1	3	3	1
Cost *(The cheapest)*	1	3	3	2	2	2
Life span	3	1	3	2	2	3
Performance	3	1	2	2	2	3
Total	***12***	***11***	***14***	***13***	***13***	***13***
*. "3": The best; "2": Good; "1": Average						

Table 2 shows that LFP battery has the highest score of 14, when compared to the rest of the Lithium-ion battery series. LFP batteries were chosen because there are three properties that make it the logical option for demanding work. It is thermally stable up to extremely high temperatures, implying that there is no thermal runaway, and it is also safety to use in temperature as high as 60˚C. Competing chemistries are either too expensive (LTO) or too unstable (NCA). Overall, not all lithium batteries are made equally. Several criteria contribute to the development of a high-performance, long-lasting, and the most essential of which is safety battery.

Table 3 provides a concise overview of the fundamental performance attributes associated with prevalent Li-ion chemistries currently employed. (Warner 2015, 77).

Table 3. Comparative synthesis of the properties of different LIB chemistries (Warner 2015, 77).

Lithium-ion Battery	LCO	LMO	LFP	NMC	NCA	LTO
Nominal voltage (V)	3.6 – 3.8	3.8	3.2 – 3.3	3.6 – 3.7	3.6	2.2 – 2.3
Operating range (V/cell)	3.0 – 4.2	3.0 – 4.2	2.5 – 3.65	3.0 – 4.2	3.0 – 4.2	1.8 – 2.85
Energy density (Wh/L)	600	250 – 265	220 – 250	325	210 – 600	130
Power density (W/L)	1200 – 3000	2000	4500	6500	4000 – 5000	1400
Specific energy (Wh/kg)	120 - 150	105 – 120	80 – 130	150 – 220	80 – 220	70
Specific power (W/kg)	600	1000	1400 – 2400	500 – 3000	1500 – 1900	750
Charge	0.7 – 1C	0.7 – 1C	1C	0.7 – 1C	0.7C	1C
Discharge	1C	1C; 10C	1C; 25C	1C; 2C	1C	10C
Self-discharge (% per month)	1 – 5%	5%	< 1%	1%	2 – 10%	5%
Thermal runaway (˚C)	150	250	270 (Safest)	210	150	200
Life span	< 1000	< 700	< 12000	< 2000	< 20000	< 7000

Operating temperature range (˚C)	-20 – 60	-20 – 60	-20 – 60	-20 – 55	-20 – 60	-40 – 55
Cost ($ per kWh)	250 – 450	400 – 900	400 – 1200	500 – 900	600 – 1000	600 – 2000
Applications	Smartphone Smartwatch Tablet Laptop Camera	Electric powertrain Industrial equipment Power tool	EVs E-bike Portable & Stationary	EVs E-bike Industrial equipment	EVs Electric powertrain Industrial equipment	EVs UPS

3 Battery Thermal Management System (BTMS)

The advancement of new and modern technologies has assisted EV manufacturers in gradually overcoming battery restrictions such as the number of charging cycles and the ability to store energy. In addition, the electric car cooling system is continually being developed, not only to increase the battery's life and operational range, but also to provide optimal cooling efficiency for the battery. The energy of EVs is stored in the battery and transmitted directly to the engine when operating. Therefore, the battery is regarded as the spirit, and the technology that carries the core value of this electric vehicle.

When the BEV overheats, it needs be cooled quickly to ensure that the appropriate temperature is maintained to allow the battery and automobile motor to perform efficiently. The battery thermal management system (BTMS) controls the electric car battery cooling system. This system is responsible for ensuring that the BEV do not become too hot or too cold. When the BTMS detects overheating, it activates the cooling system to remove heat or cool the car's electrical system. That's why electric vehicle battery packs integrate sensors and software into a complex management system that continually monitors temperature and other critical operating parameters.

During the research process, the battery is improved by maintaining the optimal operating temperature in the range of 20˚C to 40˚C, which is always the top goal and priority of the manufacturers. If the EV is operated at temperatures below 0˚C, the chemical reactions of the battery will occur slowly, causing the capacity to decline dramatically, the car will be unable to accelerate rapidly, and the risk of the battery being damaged during charging is higher than usual. Nevertheless, the battery also degrades rapidly when exposed to temperature exceeding 45˚C. In order to react quickly to rapidly occurring chemical processes, the battery will emit a considerable quantity of heat. The higher the temperature, the more electrical energy the battery consumes, and probably the engine would overheat, causing the automobile to catch fire and explode. Therefore, this is extremely dangerous for the safety of human life and the surrounding. At this moment, the cooling system on EVs must fulfil requirements such as high capacity, fast charging and improve driving performance to play the role of supporting the battery to operate in the most ideal temperature range. These rapid changes in batteries must be carefully monitored and managed to avoid safety and temperature-related problems. According to the current research, BTMS is classified into two types, which are active and passive cooling.

3.1 Classification of BTMS in EVs

Figure 6 shows two main categories of BTMS which is active and passive method. Active cooling system is based on the principle of operation of air, thermoelectric or specialized liquid coolant. With these methods, the cooling efficiency is greatly improved but is susceptible to the influence of the external ambient temperature under certain circumstances. Passive cooling systems employ PCM or combine more than two passive methods. Passive cooling on EVs consumes no electrical energy, however it is challenging to maintain the cooling effectiveness. This stage will concentrate on four primary cooling systems for EVs including air cooling, thermoelectric cooling, liquid cooling, and phase change material cooling. Each system has unique advantages and drawbacks, making it critical to choose the ideal thermal management system for electric vehicle batteries.

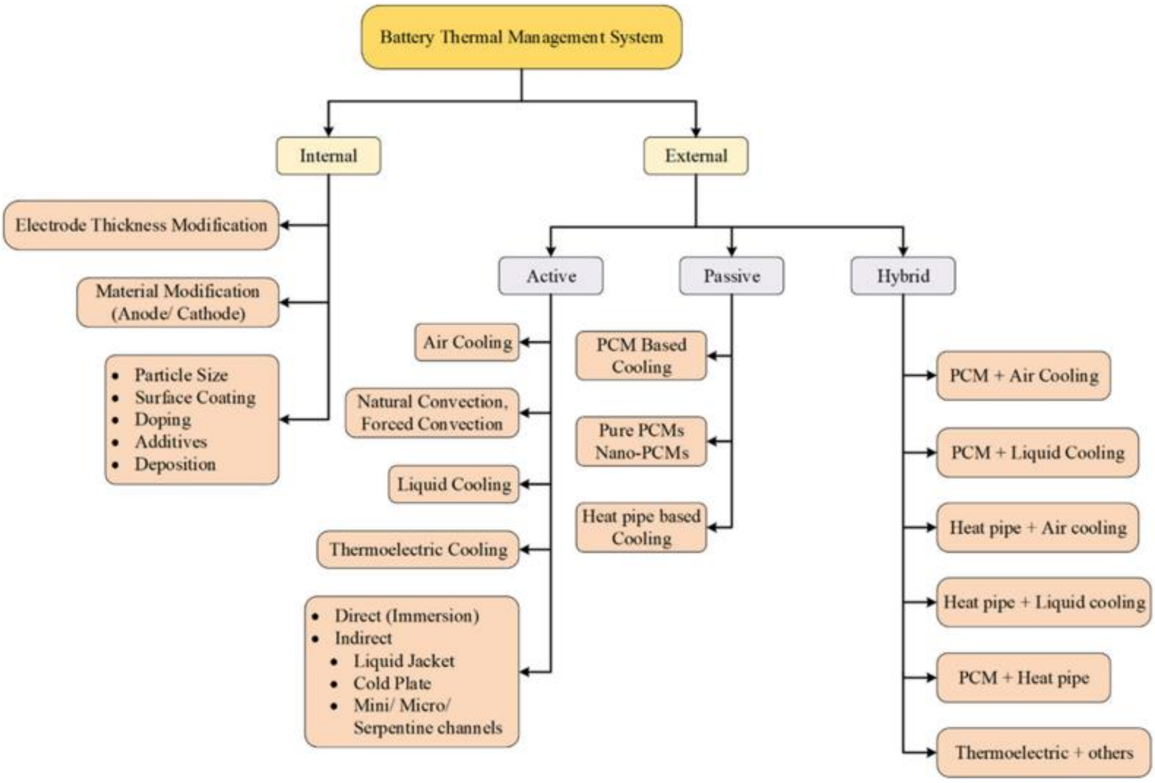


Figure 6. Types of BTMS. (Kumar et al. 2023, 105797).

3.1.1 Air cooling and heating system

Air cooling/ heating system was one of the first cooling systems used by EV manufacturers. Air cooling /heating system is comparable to the fin cooling approach, which uses air convection to transfer heat away from the battery pack. When EVs move, air flows through the heated battery surface, allowing heat to escape to the outside. However, this cooling method is simple but not suited for high-performance engines. Because high-efficiency motors require a large amount of power, which means the battery pack will also create high temperatures, the cooling impact from the air is insufficient to fulfil the cooling demands of the battery configuration. Furthermore, this EV cooling system is not ideal for using in hot climates. The cooling efficiency will be diminished because the air supply from the environment is already high.

Convection is the mechanism by which molecules in a gas move according to mass. Heat transfer between the object and the gas occurs by conduction, then a large heat transfer occurs due to gas motion. Thermal expansion happens when the battery is heated. This action is repeated, resulting in convection and heat transfer. Figure 7 shows two methods of convection, which are passive and active of air cooling/ heating system. The main difference between the two is the mechanism that drives the air flow. (Pandya & Timbadia 2021, 381.)

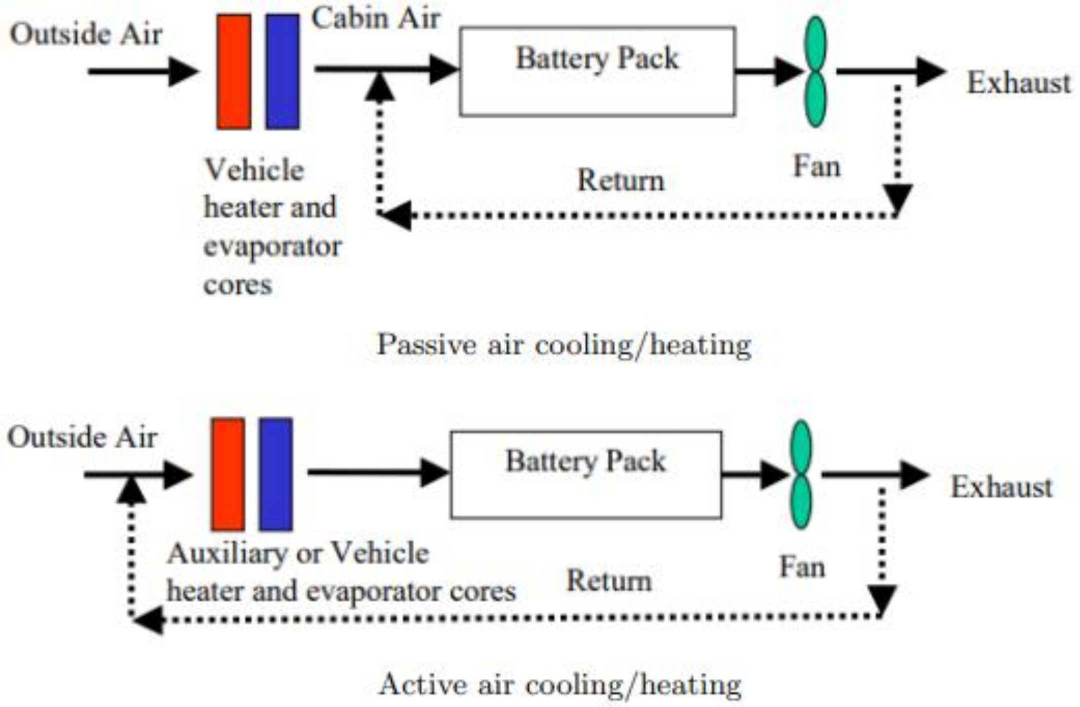


Figure 7. Active and Passive of Air-cooling/ heating system. (Durgam et al. 2021, 4).

The passive and active air-cooling/heating system plays a crucial role in managing the temperature of electric vehicles, ensuring the efficient and safe operation of the battery and other electronic components. The active air-cooling/heating system typically employs a fan to directly intake ambient air into the components requiring temperature control, facilitating rapid and effective temperature regulation. Conversely, the passive system utilizes a coolant, to transfer heat from the components requiring temperature regulation out of the vehicle through thermal conduits. While the passive system is generally more versatile in maintaining a stable temperature across diverse conditions, it also demands a more complex infrastructure. (Durgam et al. 2021, 4.)

3.1.2 Thermoelectric cooling system (TECs)

The TECs is a relatively new technology in the world of EVs, but it is now trusted and valued by many manufacturers due to its modern design and capacity to efficiently reduce battery heat. Figure 8 shows TECs uses a whole operational module comprised of two positive and negative terminals directly connected to the battery. A thermoelectric module is a solid-state energy converter made up of a series and parallel connection of thermocouples. During operation, the temperature of the battery rises, resulting in a substantial temperature differential. At this point, the module will transform the heat energy into electricity.

It operates on the Peltier effect, which causes a temperature difference by transporting heat between two electrical connections. To generate an electric current, a voltage is delivered across the connected conductor. When current flows across the two conductors, heat is eliminated, cool happens at one of the junctions and heat is deposited at the opposite junction. The most important purpose of the Peltier effect is not only to cool the battery pack, but also can be utilized to heat or control the operating temperature between 25 and 40˚C. The most potential use of TEC is in BTMS, where it is combined with phase change material to transform a passive system into a semi-passive system, boosting BTMS efficiency. (Pandya & Timbadia 2021, 381.)

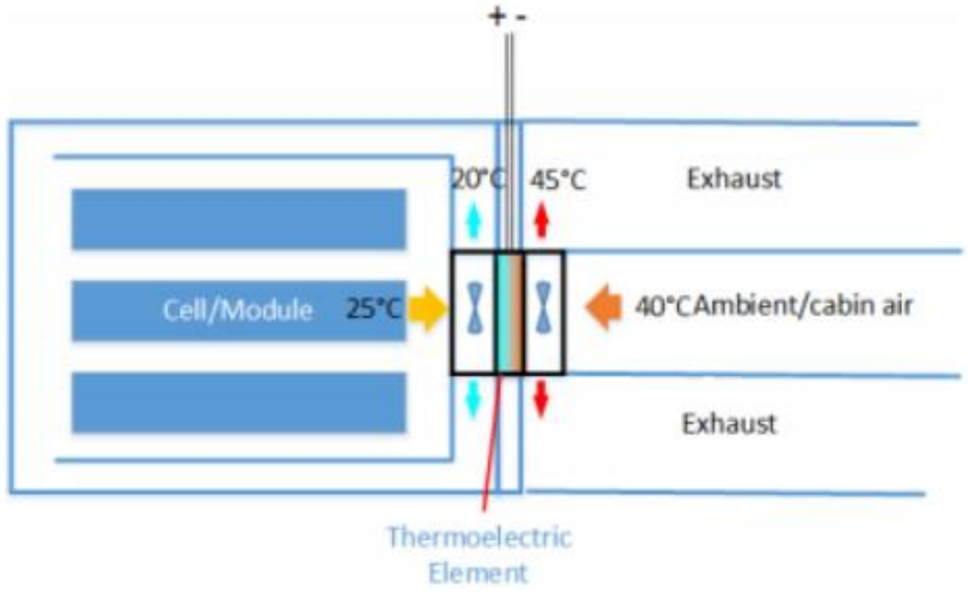


Figure 8. Diagram of Thermoelectric cooling system for BEV. (Li & Zhu 2014, 17).

3.1.3 Liquid cooling and heating system

Cooling BEVs with a specialized coolant including Ethylene Glycol (EG) and Propylene Glycol (PG) maintains optimal temperatures for battery cells, preventing corrosion, and minimizing evaporative losses. Notably, both cooling agents receive acclaim not only for their heat dissipation capabilities from BEVs but also for their effectiveness in heat transfer and cooling various vehicle components. According to research, liquid cooling stands out as one of the most promising cooling methods compared to other alternatives, optimizing performance, enhancing vehicle durability, and ensuring consistent operation at ideal temperatures.

The cooling system utilizing liquid comprises two primary types of fluids, which are dielectric and conductive. Each fluid type necessitates distinct designs. Direct-contact systems employ dielectric coolant, often immersing modules in mineral oil. In contrast, indirect-contact systems use conductive coolant, featuring diverse arrangements such as protective layers surrounding battery modules, component tubes around each module, placing battery modules on cooling/heating plates, or integrating with cooling/heating fins. The operational principles of both liquid direct-contact and indirect cooling systems will be detailed below.

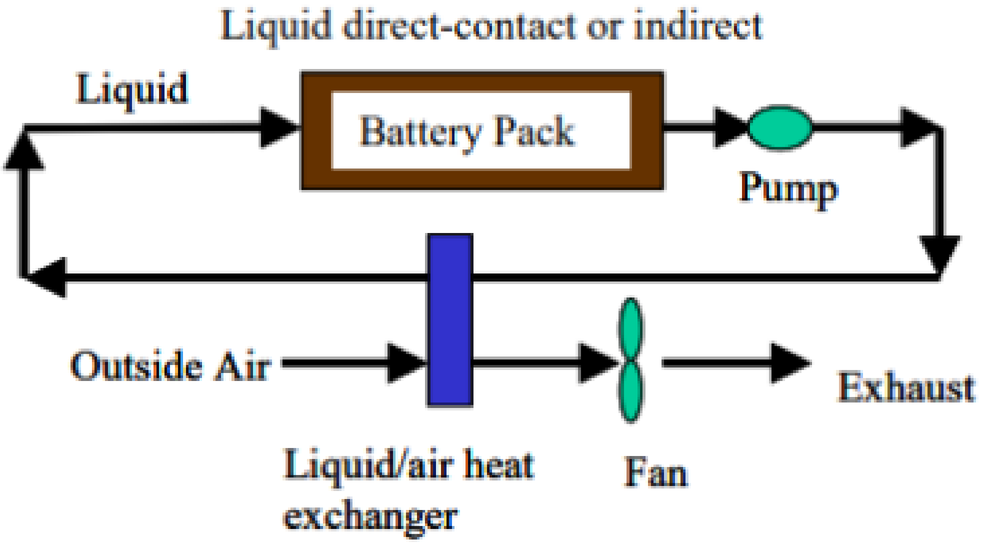


Figure 9. Schematic diagram of Liquid indirect-contact system. (Durgam, et al. 2023, 5).

Figure 9 illustrates the schematic diagram of liquid indirect-contact system, also known as passive cooling system. This system exclusively dissipates heat through a heat exchanger without heating capabilities. The cooling fluid circulates within a closed system, passing through specific machine components, directly contacting hot parts like the battery module surfaces. This circulating fluid absorbs heat and releases it through a heat exchanger. Behind the heat exchanger is a fan that aids in effective cooling. However, this system operates less efficiently when the external air temperature exceeds the battery temperature. (Durgam, et al. 2023, 5.)

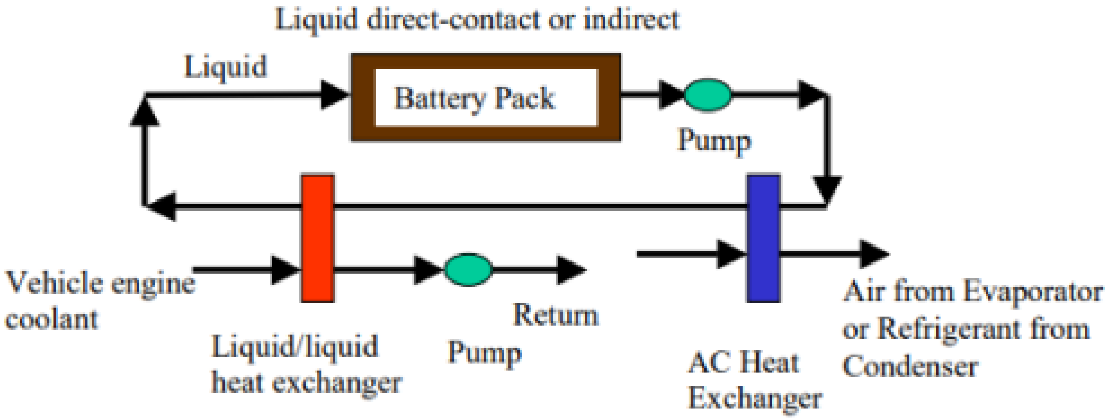


Figure 10. Schematic diagram of Liquid direct-contact system. (Durgam, et al. 2023, 5).

Figure 10 depicts the schematic diagram of liquid direct-contact system, comprising both primary and secondary loops, also known as active cooling system. The primary loop operates similarly to the indirect-contact system. An additional strength of this system lies in the inclusion of a secondary loop, capable of efficient heating if the external air is cold, maintaining operations at the ideal temperatures. The secondary loop functions as a heat exchange loop of the air conditioner. In cooling mode, the upper heat exchanger operates as an evaporator to cool and connects both loops. In heating mode, the 4-way valve switches, and the upper heat exchanger functions as a condenser, while the lower heat exchanger acts as an evaporator. (Durgam, et al. 2023, 5.)

3.1.4 Phase change material cooling system (PCM)

PCM is an appropriate method for balancing the surface temperature of the battery module by assisting the material in absorbing or releasing a sufficient amount of heat at a fixed point during the phase transition process, including melting, solidification, and evaporation, which can provide cooling or heating effects at external and internal ambient temperatures. The PCM melting temperature can be changed flexibly in various temperature conditions to guarantee the battery does not overheat or cool down and is always kept at a stable level so the battery can perform optimally.

During the melting process, energy will be stored. When the battery module releases the heat, PCM will absorbs that heat by transitioning from solid to liquid. By doing this, it will decrease the chance of a sudden rise in the temperature of the battery module. The advantages of PCM are the high number of charge-discharge cycles, high storage density, and isothermal properties of the phase change temperature. Additionally, PCM can store dissolute heat over a narrow temperature range. There will be two cases. First of all, if the temperature is below the melting point, the PCM is in solid form and the heat is absorbed as sensible heat as the temperature increases. Or when the temperature reaches the melting point, then the heat is absorbed and stored as latent heat until the latent heat reaches its maximum without increasing the temperature. The structure of the PCM is simple, compact, and space-saving, and can be combined with an air or liquid cooling system to manage battery core temperature more effectively. The operating temperature of PCM ranges from -40 to 150˚C. PCMs can be classified into different types based on their chemical composition and activity. Figure 11 shows three main cooling systems of phase change materials, classified as organic, inorganic, and eutectic. (Pandya & Timbadia 2021, 380.)

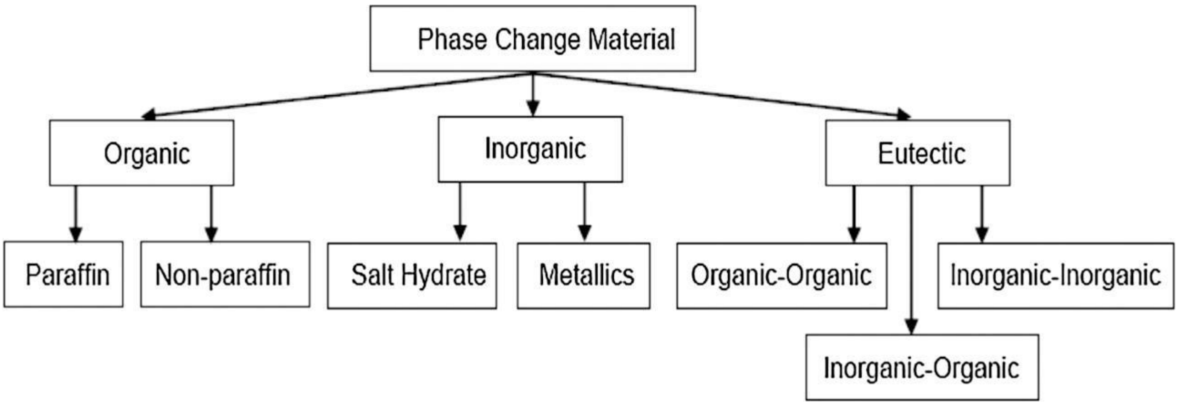


Figure 11. Diagram of PCM cooling system for BEV ((Kuta et al 2016, 2).

Organic PCM is classified into two types, including paraffin and non-paraffin. Because of its inexpensive cost, paraffin is chosen over non-paraffin. However, paraffin has a poor heat conductivity, ranging from 0.15 to 0.12W/mk, which affects cooling efficiency when compared to non-paraffin, and vice versa. When the performance of both materials is compared, non-paraffin handles better. Non-paraffin has a high heat density and latent energy due to its low volume expansion, stable non-toxic chemical composition, and compatibility with heat storage materials.

Inorganic PCM is divided into two main types, which are Salt hydrate and Metallics. Salt hydrate is an alloy combination of inorganic salt (AB) and water (nH2O), resulting in the compound AB. (NH2O). The dehydration and hydration of the salt in this PCM state is known as melting and freezing. Due to heterogeneous processes or deposition during smelting, this results in the production of salt hydrates. Dry salt settles to the bottom of the jar because it is heavier than water. When hydration is required, the system is distinguished by zones of different salt concentrations, rendering total hydration unattainable. Metal is a material that melts at low temperatures and has high thermal conductivity, hence increasing thermal conductivity is unnecessary. The advantages of salt hydrate over metallics are that they have high latent heat and thermal conductivity and can have low volume expansion when melted.

Eutectic PCM is a mixture of two or more PCMs that melts at a specific temperature. This kind functions by altering the phase of the materials to enable the absorption or release of thermal energy during the melting and solidification processes. On the other hand, when PCM solidifies, it releases energy as latent heat at a steady temperature. As PCM melts, it absorbs a significant quantity of heat from the surroundings. (Pandya & Timbadia 2021, 380.)

3.2 Compare advantages and disadvantages of BTMS

One of the significant advantages of BTMS is its capability to control the temperature of the battery, aiding in maintaining its performance and longevity. This system also helps prevent issues associated with overheating, particularly crucial when the battery undergoes rapid charging or operates at high power. Another advantage is its ability to cool the battery when necessary, ensuring that the battery operates within the ideal temperature range. However, there are drawbacks, including the production costs and the additional weight contributed by the system, which contribute to an increase in the overall cost and weight of the vehicle. The complexity in maintenance is also a challenge, especially when periodic repairs or upkeep are required. Nevertheless, ongoing technological advancements and continuous research may mitigate these disadvantages and enhance the efficiency of battery cooling systems in the future.

Figure 4 will outline the strengths and weaknesses of each cooling system. No system is flawless, however, when evaluating a singular system, liquid-based cooling/heating proves to be the most efficient. Nevertheless, the optimal solution often involves the integration of diverse systems, encompassing Phase Change Material (PCM) and liquid-based cooling/heating. This combination system, or also known as hybrid system effectively solve thermal issues.

Table 4. Compare advantages and disadvantages of BTMS. (Amorim et al. 2022, 153).

BTMS	Advantage	Disadvantage
Air cooling	• Inexpensive and less complicated design. • Lightweight and easy control/ maintenance due to simple operation. • No risk of leakage or contamination.	• Limited heat dissipation capability. • Limited control over temperature distribution and inefficient utilization for high-performance EV.
Thermoelectric cooling (TEC)	• Compact, lightweight design and easy maintenance. • Noise-free and no internal chemical reaction. • Precise temperature control by reversing the current flow.	• More expensive than air cooling and unsuitable for EV model. • Inefficiency and high energy consumption. • Low thermal conductivity.
Liquid cooling	• Requires less energy consumption than air cooling. • Highly efficient in dissipating heat and in extreme temperature conditions. • High thermal conductivity. • Can be adjusted for specific temperature control needs. • Resist corrosion and perform for longer intervals.	• More expensive and more complicated with additional components. • Glycol degrades overtime. Any leakage during operation can be disastrous to the vehicle and battery. • Regular maintenance required to anti-freeze and boiling.
Phase change material (PCM)	• High thermal inertia and good heat storage capacity. • Reliable and long-lasting. • Passive system requires no additional energy input during operation.	• Complex design and require more space. • Slower response to temperature changes. • Limited heat dissipation because of ineffective heat control.

4 Integrated hybrid battery thermal management system (BTMS)

In a dynamic context where EV is operating remarkably, the search for an optimal BTMS has contributed to changes and innovation in cooling technology. The integration between liquid cooling and PCM might appear to be an attractive and efficient solution leading the way. The liquid cooling technique with its effective heat dissipation ability, as well as PCM exploiting the absorption features and releasing laten heat is extremely promising as a pioneered and modern cooling technology. It possesses the ability of ensuring precise temperature control of the battery, enhancing the efficiency, and increasing longevity and battery safety. While liquid cooling could easily and quickly handle the high heat flow, PCM cooling will act in temporary conditions or peak times to absorb excess heat and release it when the demand decreases. The symbiotic relationship between liquid cooling and PCM cooling reveals a promising step in improving the reliability and performance of EV, at the same time, reducing thermal challenges and contributing into EV sustainability.

However, the question is “Why not combining with other cooling techniques?”. Even though air cooling is simpler and less expensive, liquid cooling and PCM cooling is believed to far overcome air cooling in thermal management in the battery pack. Air cooling lacks the ability of adjusting heat in severe condition such as fast charging or high ambient temperature. On the other hand, liquid cooling brings about more effective heat dissipation methods as well as better control over thermal environment and guarantee stable operating temperature. Also, with the collaboration of PCM cooling, the performance of the system will be maximized. By providing passive heat absorption and dissipation, the integrated system will work as a protective measure against sudden increase in temperature while providing a more stable and safer thermal profile for the battery. Moreover, the combined technique secures better heat management which could contribute to better efficiency, longer life expectancy and the safety of battery system inside the car, which makes it the best and the most reliable choice among all other traditional techniques. (Yue et al. 2021.)

5 Future trends of Battery and BTMS for EVs

Over the past decade, the auto industry in general and the EVs market in specific, has achieved remarkable breakthroughs. International Energy Agency (IEA) (2023) stated that in the year of 2023, the number of consumers switching to own EV reached a peak at 13.9 million of EVs sold. To be specific, Europe’s market has witnessed 3.4 million in sales, which is 35 percent higher compared to that of the previous year. It is worth considering that, nowadays, the majority of car companies is investing a huge amount of money into research, manufacturing and upgrading new technology for EVs ranging from middle class to luxury. Along with the sustainability trend going on, it is undeniable that there is also an increasingly demand for EVs with zero emission. According to IEA (2021), by the end of 2050, the goal is to not only achieve zero carbon emission but also promote more sustainable technology.

Despite the fact that EVs are not producing any CO_2, however, the process of making the battery powering the vehicles, particularly Lithium-ion battery, will cause environmental pollution and other damage to the planet. The search for solution as to exploit, recycle batteries and improve the battery thermal management is a great challenge to not only the vehicle manufacturer but also the scientist. Thus, it goes without saying that the future of EVs or EVs trend will be all about environmental sustainability in the long run. In another word, EVs are a reform trend aims at sustainability and long-term development for the future.

Scientists are looking more into the battery manufacturing to come up with the most efficient option that help achieve the target. The most effective and used battery technology is believed to be the Lithium-ion battery, after going through many stages from researching, exploiting, and developing. (Crownhardt 2023.) However, since EVs have become more popular in recent years, research and development of the battery technology also become more necessary. According to Simon Erhard, a BMW engineer, it is relatively challenging to optimize Lithium battery since the battery density has already reached its peak and it is getting saturated with upgrading. (George 2022). Difficulties in improving the safety, storage capacity, enhancing performance and increasing energy density will open a revolution in battery technology for EVs. If these challenges could be tackled in the near future, the electric vehicle economy in general and the battery manufacturers in specific will bloom significantly and ensure the battery supply and consumption. Based on those ideas suggested by the scientists, battery-powered vehicles could possibly and totally replace vehicles powered by internal combustion engines once difficulties are resolved.

Below are examples of several battery technology trends that are believed to make a huge difference in the next few decades.

First to mention is the solid-state Lithium battery technology, which is being prioritized for research and development to replace traditional Lithium-ion batteries. This alternative is promised to bring about safer experience with better performance, higher energy density and faster charging and discharging time. In general, the solid-state battery's mechanism of action is verily similar to that of conventional batteries in obtaining, storing, and releasing energy. The difference lies in the electrolyte used, instead of liquid electrolyte, scientists are introducing solid electrolyte into use. The solid electrolyte demonstrates an obvious efficiency through its great lithium-ion conductivity, under temperature and pressure stability as well as the non-reaction with electrodes. Through many experiments ran by QuantumScape (2022), solid-state battery will reach 80% of capacity when being charged in 15 minutes and has the lifespan of charging loops is up to 800 times, which helps save a huge amount of time when traveling long distances. Moreover, since the current Lithium-ion battery is having problem with toxic substances leakage and chance of severe explosion, the solid-state version is believed to be the better and more sustainable solution in the future.

Secondly, the change in materials used for producing and developing the battery technology is also positive. New materials such as silicon, graphene, and atomic layer deposition (ALD) are believed to open up a new page for EVs battery industry, creating a future with better and more efficient energy storage devices and technologies.

Next future trend to be discussed includes fast charging technology, wireless charging and charging while using. Manufacturers are making an effort in developing the fastest charging technology that meets consumer demands. Super-fast charging technology is gaining attention and is receiving top priority from the industry due to the ability to supply power for the long haul in such a short amount of time required, minimize the waiting time, and improve the flexibility. Besides, since wireless charging is becoming more popular in other fields, going wireless for EVs battery charging is also promising. It will be considerably more convenient and efficient with the elimination of cable connection. There are two wireless charging roads developed by the start-up company called Electreon. The first one is the idea of installing magnetic coils underneath the asphalt to charge the battery wirelessly whereas the other one is running the charging line under the asphalt layer and setting up a charging outlet or socket on the ground. Through a wireless charging system under the road or on the road, scientists believe that will increase travel range and reduce congestion at traditional charging stations. These appealing theories and ideas are believed to lead the world into a different direction which will not only improve the consumer experience but also promote the human main goal of reaching zero emission and protecting the environment. (Manthey 2023.)

Last but not least, since Artificial Intelligence has become increasingly important in today's worlds withs its applications in many areas, it is unarguably believed to also contribute a massive role to the development of BTMS. With the help of AI, not only the battery temperature is maintained to an ideal level but also its performance and the durability is optimized. AI technology will be responsible to predict factors affecting battery temperature, from weather conditions to how to use the car. The system will automatically adjust the temperature from hot to cold as to prevent the chance of overheating or underheating, which is one of the main reasons affecting battery performance and battery life negatively. The flexibility of an AI-integrated temperature management system will benefit vehicle drivers remarkably. As far as concerned, AI will not only contribute to maintaining stable performance and lifespan of the battery, but it will also create smart driving experience which is promising sustainable in the long run. (Ghalkhani & Habibi 2023, 9–12.)

6 Summary

To summarize, designing or upgrading the electric vehicle batteries is essential for the future. Everything is changing quickly, and driving electric automobiles is critical to protect the environment and ecosystems, as well as ensuring our existence on this planet. It is undeniable that a good heat dissipation is remarkably vital as it will increase the life span of electric vehicles and consumers will no longer have to face the fear of explosion or electric shock occurs. As discussed above, the liquid cooling system upgrade will be the better solution which fosters the sales of electric vehicles for leading car business. With an efficient heat dissipation, maintenance and repair will also be much simpler and more cost-effective. The cooling of battery will boost the machine’s performance without consuming too much energy or overheating, which is even better. Because liquid cooling system is a relatively new technology, in the context of EV being a trend beginning in the 2020s, it most likely required a significant amount of time to study and research some articles online in attempt to develop this report. However, it can be seen that the future of this technology is promising.

Furthermore, as protecting the environment has always been the hottest topic over the past decades and it seems to keep leading the trend in the long run, technologies will also have to move toward the same direction. The world people living in is expecting everything with sustainable option and zero emission. Thus, the EVs industry will not be an exception. Current experiments and research are showing a better picture of a more sustainable world with better battery technology such as the solid-state Lithium battery, a change in battery materials, super-fast and wireless charging technology as well as AI integrated BTMS.

Figures

Table

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