Electric Vehicle Battery Cells

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Nowadays, batteries for electric vehicles are expected to have a high energy density, allow fast charging and maintain long cycle life, while providing affordable traction, and complying with stringent safety and environmental standards. Extensive research on novel materials at cell level is hence needed for the continuous improvement of the batteries coupled towards achieving these requirements.

Keywords: electric vehicle ; battery material ; anode ; cathode ; electrolyte ; battery safety ; end-user demands

1. Introduction

Nowadays, batteries have become an essential part of everyday life. With products and devices becoming increasingly electrified, battery usage has grown heavily over the past decade. Currently, they are mainly used in portable electronics, mobility applications and stationary storage. Mobility applications, comprising different categories of electric vehicles (EVs), represent the biggest share of the global battery market and are expected to continue growing, following the expected increase in electromobility [1]. EVs are projected to demand 90–95% of the total production of Li-ion batteries (LIBs) by 2030 with most predictions indicating around 150 million EVs on the roads by that time. Because of the dominating share on the battery market, the demands of the electrification of vehicles and their end-user expectations have been the primary drivers for the development of advanced battery technologies over the past decade. In the automotive industry, the end-user is demanding batteries that should be safe, sustainable and have affordable traction combined with high volumetric and gravimetric energy density and power, excellent electric performance and durability in a wide ambient temperature range, low self-discharge and long shelf-life. In addition, the ability to sustain fast charging with a minimal impact on cell ageing is becoming increasingly important as electromobility is rolling out in increasing numbers to a wider circle of users and locations [2][3].

A variety of different materials have been thoroughly analysed and tested on battery components, aiming to meet and balance all these requirements while ensuring complementarity and stability when combined in a battery cell. Up until now, LIBs have proven to be the most robust technology enabler for the development of EVs. Different chemistries have been demonstrated to be more suitable for different applications, as shown in **Figure 1**. Incremental improvements over time and the Ni-rich cell chemistries currently available on the market have made LIBs even more suitable by improving aspects such as their specific energy and power among others. However, the quest for even higher energy density and specific energy as well as fast-charging capabilities remains a priority for the industry. At the same time, the demands from the end-users change with time as the mobility applications evolve and new usage patterns and behaviours are established. This accentuates the need for further improvements and has accelerated the need for development of novel battery materials that can meet the needs of future generations of EVs. Several articles have reviewed different novel battery materials and their influence on the different parameters of the battery in terms of performance, safety, cost etc. However, most articles make this review from a technology push perspective and do not take into account the future end-user demands.

		Performance						Main Applications						
Type	Chemistry	Energy	Power	Calendar Life	Cycle Life	Safety/Stability	Cost	Consumer Electronics	Power Tools	Light Duty Vehicles	Cars	Trucks/ Commercial Vehicles	Buses	Grid
LFP (Lithium Iron Phosphate)	$LiFePO_4$	++	++	++	++	+++	+	•	•	•	•	•	•	•
NCA (Lithium Nickel Cobalt Aluminium Oxide)	$LiNiCoAlO_2$	+++	+++	++	++	+	+	•		•	•			•
LMO (Lithium Manganese Oxide)	$LiMn_2O_4$	+	+++	-	++	++	++	•	•	•	•			•
LCO (Lithium Cobalt Oxide)	$LiCoO_2$	++	++	+	+	+	+	•						
LTO (Lithium Titanate Oxide)	$Li_4Ti_5O_{12}$	-	+++	+	+++	+++	-				•		•	•
NMC (Lithium Nickel Manganese Cobalt Oxide)	$LiNi_xCo_yMn_zO_2$	+++	++	++	++	++	++	•	•	•	•	•	•	•
HE-NMC (High Energy Lithium Nickel Manganese Cobalt Oxide)	$LiNi_xCo_yMn_zO_2$	++++	++	+	+	-	++	•	•	•	•	•	•	•
HVS (High Voltage Spinel)*	$LiMn_{1.5}Ni_{0.5}O_4$	++++	++	+	+	-	+	•	•	•	•	•	•	•
Solid State**		++++	++	++	-	+++	++	•	•	•	•	•	•	•

* currently at TRL6-7
** currently at TRL4-5

Figure 1. Li-ion battery overview (TRL = technology readiness level).

2. Projected Demand from End-User Side

Looking from the side of the end-users, in addition to the need for affordable and safe EVs, one of the main drivers is "range anxiety", caused by a combination of limited EV driving range and relatively long charging times plus an underdeveloped charging infrastructure [2][3].

All things remaining the same, increasing the battery energy density will translate into longer driving ranges in vehicles, as there will be more energy available for propulsion per battery unit. If the added energy comes with improved fast charging capability, this would be even better, as it would reduce the refuelling time, and further enhance freedom to move with minimum inconvenience [4]. In the interest of sustainability, the combination of high energy density with fast charging capability opens another possibility, namely, to reduce the battery size and to rely on frequent, fast charging events to accumulate mileage. The latter option has the potential to significantly reduce the cost of the traction battery as well as decrease the material resources and energy consumption needed to produce the battery. However, it would also require batteries with improved cycle life to ensure that the total lifetime of the battery is not shortened. The traction battery currently represents up to 30–50% of the total cost to produce a battery-powered vehicle, depending on the level of electrification [5]. By reducing the battery size, the current cost gap between conventional internal combustion engine vehicles and EVs can potentially be closed and make them more affordable and achievable to a wider customer base [6][7].

Climatisation, of both the traction battery and the occupant compartment, is a notable load on the battery even today [8]. Owners of battery-powered vehicles who live in climate zones with seasonal variations will note a decline in the driving range per charge during sub-zero temperature periods, as the battery needs to be warmed for optimal electric performance. In warm climates, the battery needs cooling in order to prevent accelerated ageing at higher temperatures [9]. Hence, new battery systems with electrical and durability performances that are less affected by operating temperatures would have many advantages and free up battery energy for other uses on the vehicle, such as extending the driving range.

However, there are two parallel technology developments emerging alongside with electrification which are closely associated with the sustainability transition of the transport sector. These are autonomous (self-driving) cars and connected services. The gradual introduction of these technologies will likely have a major impact on the energy demand and usage of available energy in the battery in future EVs [10]. The energy demand from powering these applications is provided by the same battery that is also used for traction, which means that the total packed energy must be split between different loads. Autonomous driving requires 360° sensors, monitoring and online data processing to detect and manoeuvre obstacles, as well as to respond to the activities of all surrounding road users. The processors needed to manage these operations with sufficient speed and safety represent a significant energy load on the battery. In dense urban traffic, the energy consumption of these processors is typically of the same order of magnitude as the energy required to propel the vehicle. Under these conditions, future EV batteries would need to have double the energy density in order to retain the same driving range per charge cycle as they do today [11].

The energy consumption related to connected services depends on the nature of the over the air information exchange with the vehicle and how the systems are designed. For example, extensive use of the infotainment system and apps offering streaming services will have an impact on the amount of energy available for propulsion [12]. This technology is still very much in development, and it is not unlikely that the EVs will experience an evolution as the technology develops and matures, similar to the one we have witnessed in, e.g., mobile phones over the last two decades. The first mobile phones were very limited in what they could do and the smartphones currently on the market are a far cry from what we dreamed was even possible from the start. However, as with all other functions and features on the vehicle, the connected services will be powered by the traction battery and this will have an impact on the energy demand. The following section of this paper will show how the foreseen energy demand increase will be supplied by new battery technology with higher energy density as the research on novel components evolves and matures.

Ultimately, it is the driver and other vehicle occupants who will decide how the available energy in the EV battery is used, for example maximising driving range or accepting a shorter driving range to enjoy the freedom of a self-driving car and the on-board infotainment system. In addition to the on-board energy consuming functions discussed above, the future role of the EV batteries as energy storage support to the smart grids discussed in the context of the electrification transition should also be considered [13][14]. Making the traction battery available to vehicle-to-grid (V2G) applications will result in an increased total energy throughput over the battery lifetime [15]. This increase in battery usage yields a faster battery degradation. Preliminary studies show that over five years driving-related degradation accounts for 1–2.5% of capacity loss, V2G degradation is in the range of 1–2% and calendar ageing brings around 6% of the total capacity fade in a passenger car [16][17]. It is unlikely that vehicle owners will accept a trade-off that involves negative impacts on the durability performance of the battery in the vehicle [18][19]. Hence, improved cycle life and capability to retain long-term electric capacity with higher total energy throughput is also likely to emerge as increasingly important to meet the expectations and needs of the market and society. End-users' priorities regarding long-range or affordability are also going to be an important factor [3]. As the access to charging infrastructure improves, not only in city centres but also in more remote areas, the demand for affordable vehicles with smaller batteries is likely to increase, especially if the fast charging capability improves compared to now. Future batteries with higher energy densities would support these possible user trends, as well as other development directions that become possible as new technology advances in autonomous cars and connected services are made available and become mainstream. An overview of current demands and the corresponding battery requirements is provided in **Table 1** in light of the end-user needs.

Table 1. End-user needs overview.

Demand	Battery Requirements
Reducing range anxiety.	**Increasing energy density.**
Convenience of charging.	**Fast charging.**
Sustainable EV.	**Reduce size of battery by higher density + fast charging. Reduction of critical raw materials (Novel active materials that do not rely on critical elements and materials). Increase the recycling potential of the components.**
Climatisation.	**Wider operating temperature window.**
Autonomous driving.	**Increase energy density to maintain same range performance or higher energy throughput (cycle life).**
Connected vehicles.	
Comfort and infotainment.	
Temporary energy storage applications, e.g., vehicle-to-grid, vehicle-to-vehicle.	**Energy throughput not reflected by mileage and calendar life (cycle life).**
Reduced cost.	**Reduction of critical raw materials use, reduction of battery size.**
Increased safety.	**Non-flammable materials, high stability of components.**

Finally, it is also worth mentioning that there are ongoing regulatory developments that are likely to affect how batteries can be designed and used in electrified vehicles. Two examples are the Global Technical Regulation (GTR) on in-use battery durability within the UN ECE Vehicle Regulations framework [20] and the European Commission's proposal for a new Battery Regulation [21]. Both regulations are expected to be adopted during 2021 and they incorporate mandatory electrical performance and durability requirements on batteries. The proposed Battery Regulation also includes sustainability requirements for repair, remanufacturing, repurposing, recyclability and use of recovered substances in new cells and batteries, which may limit the cell chemistries, battery systems' design options and vehicle usage patterns that will be possible in the EU internal market. It is important to be watchful that these regulations and similar global initiatives do not introduce unintended technology restrictions, which create unsurmountable obstacles to developing batteries capable of meeting the demands and expectations of future applications.

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