Lithium Batteries for Commercial Vehicles
The Workhorses among Energy Storage Units

Lithium-ion batteries for commercial vehicles have to differ from accumulators for passenger cars. This is due to higher power, longer service life and a multitude of smaller charge increases. Akasol demonstrates further differences and explains advantages of a liquid cooling system in comparison to purely passive concept and active air cooling system at different current rates.

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COMMERCIAL VEHICLES – THE OPTIMUM APPLICATION

The storage of electrical energy will be a key element in the energy supply of the future. The forms that this storage can take, and the applications that make use of it, are as diverse as you can imagine. The lithium-ion battery is an essential tool of choice for electricity storage, and its application in commercial vehicles is particularly exciting. Its scope ranges from trucks (especially for short-range distribution) to buses, specialist vehicles, and off-road applications such as agricultural and construction machinery.

Although these vehicles are rarely the focus of public attention, they are generally predestined for either electrification or hybridisation. On the one hand, this is because they are used in locations – often urban areas – that are sensitive in terms of exhaust and noise emissions. On the other hand, the usage profiles are for the most part clearly defined. It is therefore possible to determine a definite figure for the energy and power requirements, which can in turn be used to determine the optimum dimensions for the energy storage units. On this basis, it

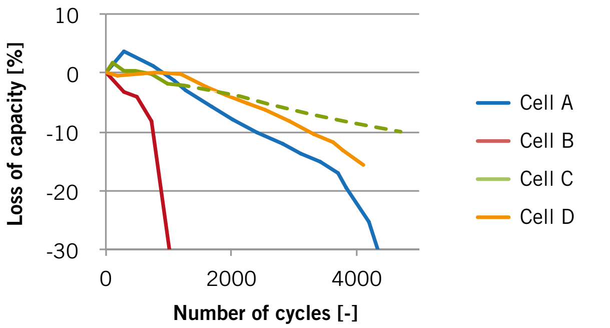

FIGURE 1 Capacity of various lithium-ion cells in the course of a cyclical aging test (© Akasol)

is possible to calculate the costs over the entire service life (Total Costs of Ownership, TCO), which are typically a key factor in the decision to buy commercial vehicles. In many cases, therefore, the electrification of commercial vehicles is already economically viable today and is set to become more so in the future.

"THE" LITHIUM-ION BATTERY – ONE FOR ALL?

Firstly, it is important to know that even in terms of the materials used, there is no such thing as "the" lithium-ion battery. Battery chemistry features a wide variety of technologies, which have a key influence on the cell's characteristics. The first thing to consider are the active materials. They are consisting on the one hand of the electrodes, which are responsible for storing the lithium ions – in other words, for the actual energy storage. On the other hand, the other part is the electrolyte, which allows ionic conductivity and thereby enables the current to flow. In addition, you need a separator, which prevents a short-circuit from taking place between the electrodes. All of this must be placed in mechanical packaging, equipped with current collectors, and supplemented with safety components if necessary. It is the combination of all of these elements that determines the key characteristics of energy density, performance, service life, and safety.

In addition to these chemical influences, which are exerted by the active materials, the characteristics are also shaped by the structural design of cell, module, and system, as well as by their production processes. Akasol has been investigating a variety of lithium-ion cells and modules for over ten years. For example, **FIGURE 1** shows the large disparities in aging between different large-format cells in a comparable test cycle even though the cells appear, at first glance, to contain the same chemistry (anode: graphite; cathode: nickel manganese cobalt).

CAR ACCUMULATORS DIFFER FROM TRUCK BATTERIES

Ultimately, this begs the question: Which properties are actually important for the specific application? In this context, the strategy of many commercial vehicle manufacturers is to use batteries from the private car sector. They do so because very large accumulator quantities are manufactured in this sector, and this scaling paves the way for extremely low manufacturing costs. In terms of demands, private consumers use their cars in an individual way under variable and demanding environmental conditions.

In most cases, however, the passenger car is actually used only over relatively short times and distances. Indeed, the average distance travelled per journey is just 14.7 km in a journey time of 21 min [1]. On average, therefore, the car is required to complete significantly less than one cycle per day. For example, for a car with a range of 400 km per charge, which is the aim of many current development projects, 500 full cycle equivalents are perfectly sufficient in order to cover a distance of over 200,000 km. At the same time, partial cycles have a positive effect on service life.

Unlike cars, commercial vehicles are typically operated to a highly-planned schedule for many hours a day. This involves a large number of braking and acceleration processes. The vehicles are also heavy and require powerful drives, which place a corresponding demand on the energy storage units in this profile. As a result, the typical storage unit in commercial vehicles is effectively operated continuously at high power during both charging and discharging, as well as experiencing a multitude of smaller charge increases, possibly combined with larger increases over the course of the day. Faced with these tough requirements, a design service life of eight years is often sufficient to remain economically competitive over the life cycle. Over this period, up to 20,000 full cycle equivalents are delivered – 40 times as many as a car battery.

Analogous observations can be made in relation to stationary storage systems,

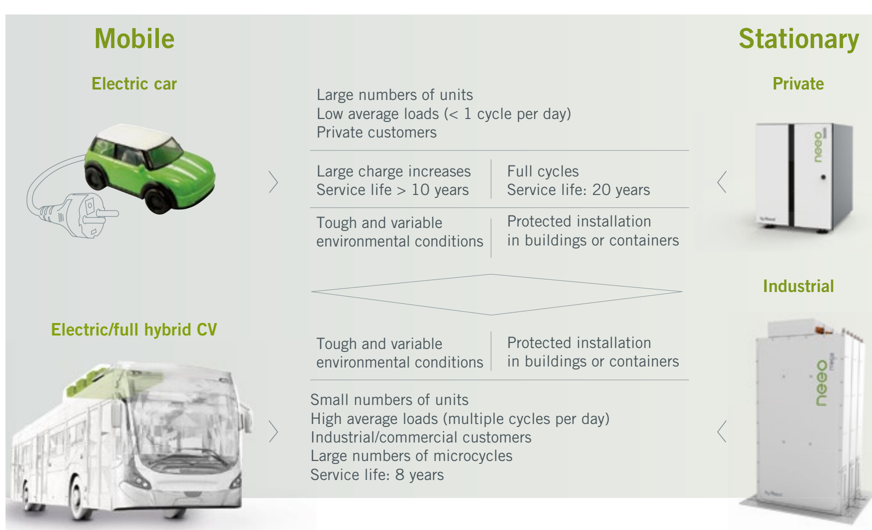

FIGURE 2 Applications of lithium-ion battery systems with their typical constraints according to the sectors of Mobile for Car/CV (Commercial Vehicle) as well as Stationary for Private/Industrial (© Akasol)

which are either currently in discussion or already on the market. These include, on the one hand, the primarily smaller storage units for private households and, on the other, the storage units used for commercial and grid stabilisation purposes. This is described in greater detail in [2].

FIGURE 2 further illustrates the different constraints present in the various sectors of Mobile for Car/CV as well as Stationary for Private/Industrial schematically in order to highlight common features and differences. Comparing the characteristics required for the respective applications on this basis results in **FIGURE 3**. Here, we see a spider diagram, in which the most important requirements for the battery system are plotted for the four different sectors. The classification ranges from 0 (completely unimportant) to 100 (very important).

For the classification of cost relevance, a situation is assumed, in which the "Mobile Car" and "Stationary private" sectors are already fully established and large-volume production is set up. In this case, the manufacturing costs are a key factor in the price of the product. The situation is different for systems used in smaller numbers, which is true of commercial vehicles and large-scale stationary storage units. Here, the development costs have to be shared over a smaller number of units, so they are clearly reflected in the product price and must accordingly be kept at a low level.

It is clear that there are a relatively large number of commonalities between the car sector and the private photovoltaics battery market. The same applies to commercial applications in the mobile and stationary sector. Essentially, it is the demanding environmental conditions that separate the mobile market from the stationary one. The key differences between batteries for cars and commercial vehicles lie in their output and cyclical service life. However, as described before, these are precisely the characteristics that are shaped by the cell chemistry and by the structural design of the cell and system.

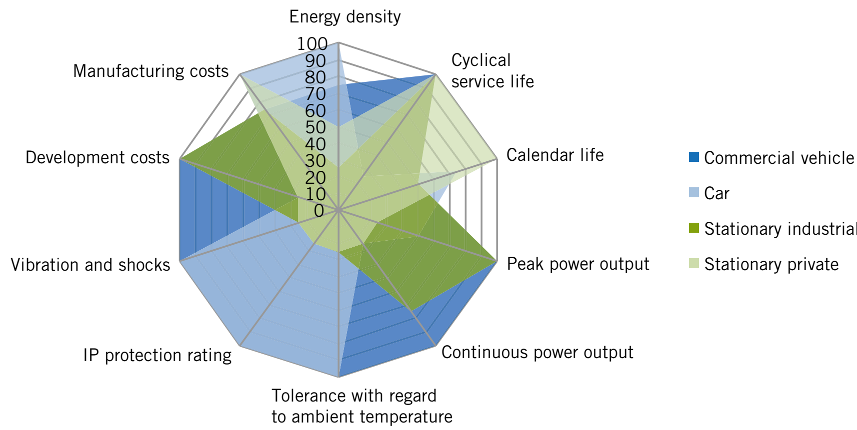

FIGURE 3 Weighting of requirements in different applications (© Akasol)

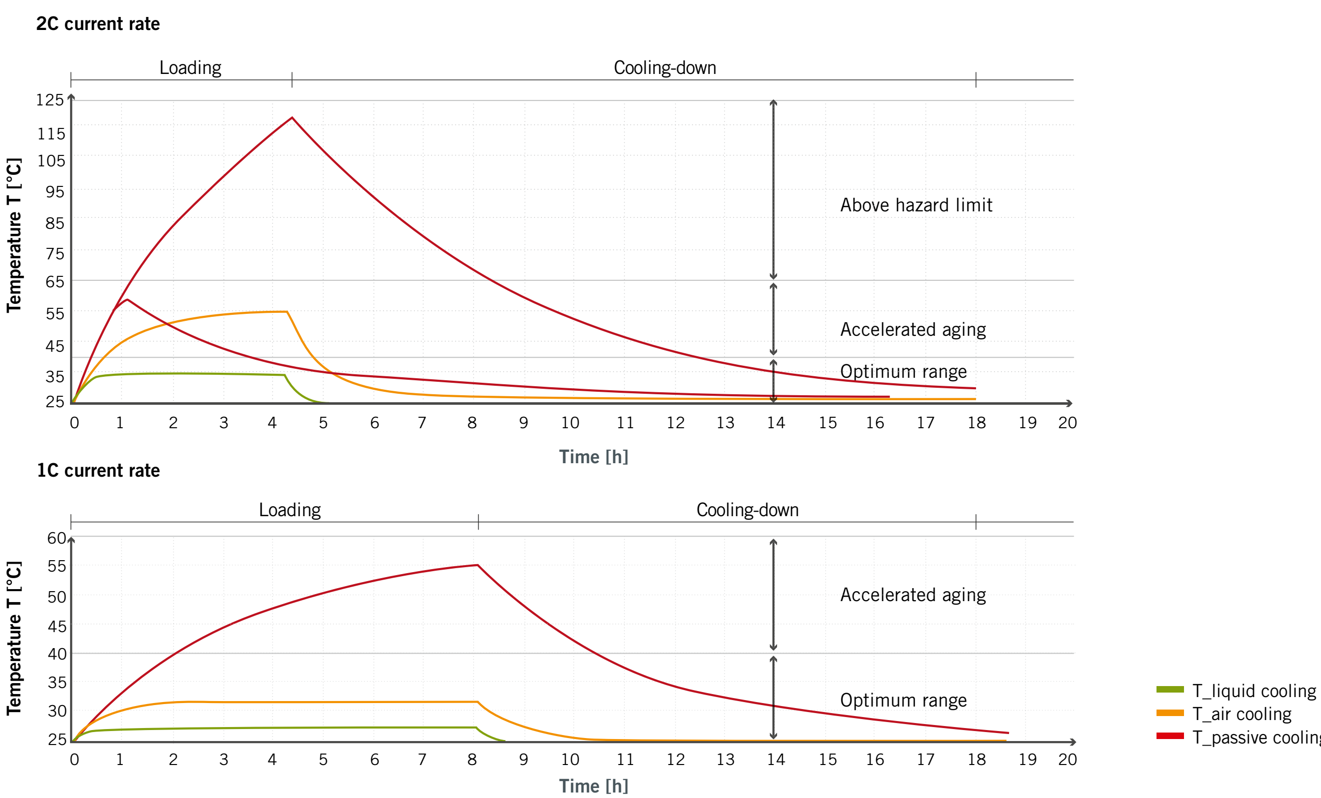

FIGURE 4 Typical temperature variations for lithium-ion battery systems with different loads (1C and 2C current rates) and three kinds of cooling designs (© Akasol)

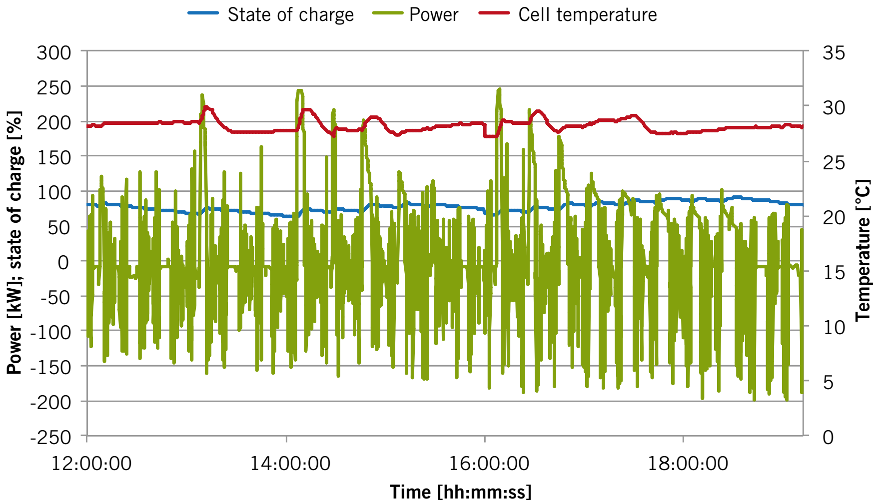

FIGURE 5 Graphs of state of charge, power, and cell temperature over a loading profile derived from an application in a city bus (© Akasol)

THE ROUTE FROM CELL TO APPLICATION

The previous section discussed the highly disparate behaviour that can, in principle, arise simply based on cell design. Is that enough to allow us to choose the right cell? If we recall that temperature has a massive influence on reaction dynamics in chemical processes, it quickly becomes clear that this is not the case. As a rule of thumb, a battery ages twice as quickly for each 10-K increase in temperature. In principle, this behaviour has been replicated in measurements by Akasol on various cells in the relevant region between 35 and 65 °C. Conversely, excessively low temperatures also lead to problems as they generally cause a sharp drop in output and especially as they often necessitate significant restrictions on charging current. Keeping the cells at the right temperature is therefore a key requirement for reliable operation over a period of many years.

As the losses that contribute to warming within the battery rise in proportion to the square of the current, efficient cooling is a more than worthwhile investment for batteries subject to heavy use. **FIGURE 4** presents the warming effect within a battery system for three cooling concepts at two different current rates (ratio C between current in ampere and nominal capacity in ampere hours). The assumed cooling systems were a purely passive concept, an active air cooling system, and a liquid cooling system. We can see that the temperature increase is still relatively manageable at a current rate of 1C – this corresponds, for example, to a current of 100 A for a battery with a nominal capacity of 100 Ah. However, efficient cooling becomes indispensable if the current rate is doubled to 2C – in this example, to 200 A.

These requirements are found in commercial vehicles as these typically use either fast-charging or hybrid concepts for reasons of availability. **FIGURE 5** shows an example graph of state of charge, power and cell temperature for a city bus in the second half of the day: The cooling system keeps the cell temperature within an optimum region between 25 and 30 °C despite its continuous operation.

There is also a structural hurdle that obstructs the route from a cell to a complete system: The mechanical coupling between the cell and its surroundings can also lead to changes in aging and safety behaviour. Correct mechanical connection of the cells is therefore another important element if surprises are to be avoided during subsequent use. For example, in the event of unsuitable structural design, deviations by a factor of 2 have been observed in service life at the cell and system level. Statistical scattering of cell aging is also significant at the system level, as the cell, that ages most quickly, determines the behaviour of the overall battery. In principle, this phenomenon can be tackled by connecting the cells in parallel, as shown in [3], for example. However, studies into how widely the individual aging is scattered in large-format cells are very time-consuming and cost-intensive. The key is to ensure high-quality, consistent cell production and seamless monitoring of process quality, including the preceding material processing.

In order to satisfy the described applications as well as possible, Akasol has continually optimised its battery systems for these uses over the last few years. Two product series have now emerged for commercial vehicles in order to serve the mentioned variable requirements in the best way possible and according to the specific focus, **FIGURE 6**. However,

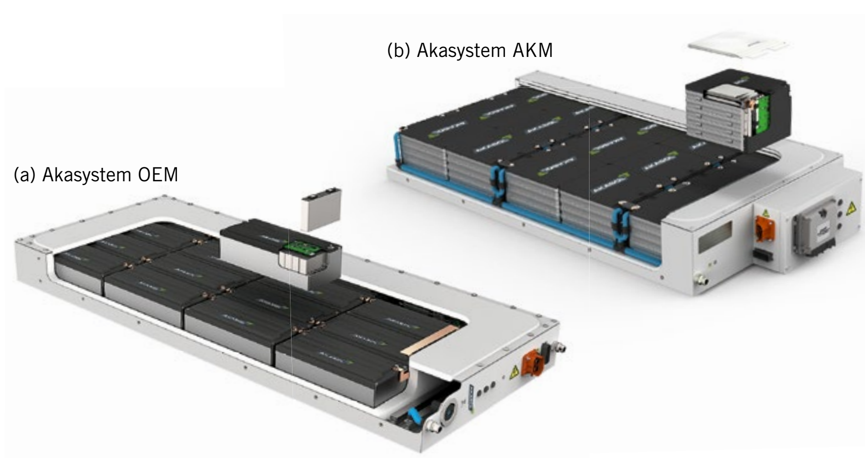

FIGURE 6 Mobile battery systems for commercial vehicles: (a) OEM system with tested safety according to EUCAR, GB/T, UN 38.3 and ECE R100; (b) AKM system with tested safety according to USABC, IEC, SAE and UN 38.3 (© Akasol)

a common feature of both OEM and AKM series is a compact design with liquid cooling in order to generate optimum cost-benefit ratios in the commercial vehicle sector. The system architecture generally consists of solid base modules, typically with 12 cells, a stainless steel housing with defined fire-protection properties, and the battery management system along with sensors and actuators.

SUMMARY AND OUTLOOK

The demands on commercial vehicle batteries in certain areas are significantly greater than those in other sectors, and especially those in cars. On the basis of various cells and system architectures, it is possible to develop lithium-ion batteries with very different characteristics that can therefore be optimised for specific purposes. Consequently, taking systems that were developed for cars and using them in commercial vehicles can only lead to unsatisfactory results. Special developments or at least adaptations are necessary and justified, as the higher up-front costs are clearly offset by the longer service life.

Lithium-ion batteries have experienced rapid development in recent years and stand on the threshold of a decisive breakthrough into all relevant applications. Following a final phase of technical refinement thanks to large-scale field experience, as well as economies of scale, this threshold will be crossed in the next few years and by 2020 at the latest. But there is still a huge potential for development in terms of improving the characteristics of lithium-ion batteries step by step. At present, it remains impossible to predict with any certainty whether and when revolutionary new battery technologies – so-called post lithium-ion batteries – will genuinely be ready for use. However, this is no obstacle to the widespread introduction of electromobility, as the existing technology continues to evolve and possesses all of the necessary characteristics.

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