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NEXT-generation physics and data-based Battery Management Systems for optimised battery utilisation

NEXTBMS - Deliverable report

D1.1 - Report on stationary and mobile use cases

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Project summary

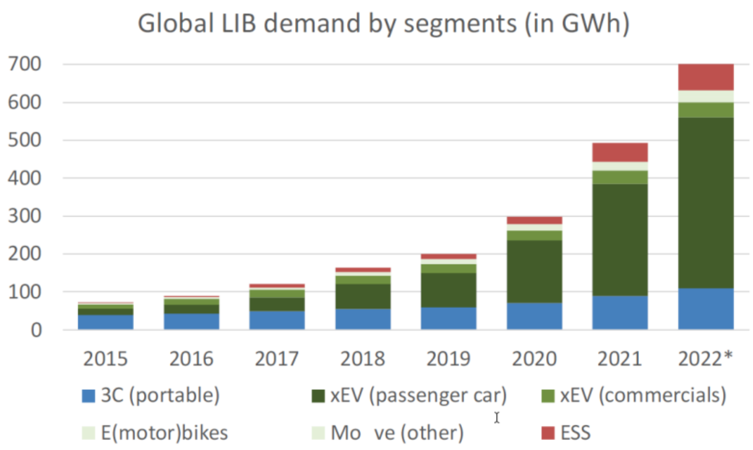
NEXTBMS will develop an advanced battery management systems (BMS) built on fundamental knowledge and experience with the physicochemical processes of lithium-ion batteries, which will enable the significant enhance of current modelling approaches, including the readiness for upcoming lithium (Li) battery material developments. These modelling approaches will be further improved by optimising sensors and measurement techniques to meet modelling needs (and optimising models based on physical sensor data) and the physical cell configurations to form a framework that supports improving the battery state prediction and -control. By solving these challenges, NEXTBMS will ensure that the next generation of BMSs will enable higher performance, safety, and longer lifetime of the battery cells for an overall optimal utilisation of the battery system.

Publishable summary

The globally and fast increasing demand for battery electric energy storage systems in all areas, from consumer goods over electric mobility to stationary energy storage systems, requires customised concepts, both in terms of the battery system and its control. To this end, the NEXTBMS project is developing new solutions that facilitate the efficient and durable use of batteries with the view to improve their performance both

- in the mobile sector, i.e. by phasing out the use of fossil fuels for vehicles and moving towards electrification, and
- in stationary applications such as grid balancing and storage of energy from variable renewable sources (e.g. wind or solar energy)

as an enabling European activity.



VDMA Roadmap: Lithium Ion Battery (LIB) production equipment 2030, update 2023

The aspect of an entire sustainable lifecycle for batteries is supported by NEXTBMS. One example for it is the combination of different use case within begin of life until end of life. So mobile use in 1st life can be combined with a less challenging stationary use case in 2nd life. Finally, also recycling indications can be given for an efficient re-use of battery material in the end.

The focus is on current and future battery-electric mobile and stationary applications, on the basis of which requirements regarding

- Lifetime (cyclic and calendar)
- Battery chemistry - materials and composition
- Challenging use case related electric loads
- Hardware – to bring up improved sensor concepts with the aim of achieving higher accuracy of measured variables
- Software – generation of improved battery models with the aim of achieving a higher accuracy of calculated variables and states for the battery management system (BMS)

to achieve higher vehicle range or operating hours and a longer, reliable battery service life.

Thus, the NEXTBMS project will also contribute to minimize climate change, e.g. by reducing CO_2 emissions by extending battery life and efficient operation through more advanced BMS functions. Which also means a better utilisation of energy and raw materials, needed for battery production.

The first NEXTBMS work package addresses the derivation of most relevant mobile and stationary use cases. The use cases are linked and translated to technical KPIs. These KPIs are the basis for the following HW and SW related requirements engineering steps within the NEXTBMS project. The following table summarizes the most important and challenging KPIs concerning BMS targets. In addition, related drivers and the supporting NEXTBMS approach is mentioned.

Use case related KPI	Dominating drivers	NEXTBMS solution
High calendar life (up to 25y) and related predictions	Stationary and 2nd life applications; need for sustainability; profitability	Improved state control & predictions (via improved model, sensor basis & cloud)
High cycle life (up to > 5000 EFC)	Stationary and CV use, sustainability, profitability, safety predictions	Improved state control & predictions (via improved model, sensor basis & cloud)
High dynamic load control	Sub-second loads of up to > 5C, EV/CV drive cycles, fast charge	Improved short-term state control & predictions (via improved models)
Battery technology readiness (for secondary Lithium)	Trend towards higher energy densities and lower prices	Adjustable model parameters and appropriate sensor topology
Cloud connectivity	Entire energy management, fleet learning, calculation efficiencies, AI	NEXTBMS cloud interfaces for technical and cost efficient HW/SW topologies
2nd life and 2x operations	Battery directive, sustainability, inter-operability	NEXTBMS improved state estimations, predictions and (communication) interfaces

Not all the challenging KPIs might have to be followed for the one and the other use case, but the final NEXTBMS solution will be able to be applied in most relevant applications in the mobile and stationary field, both first and 2nd life related.

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Abbreviations & Definitions

Abbreviation	Explanation
AC	Alternating Current
BCU	Battery Control Unit
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
BMS	Battery Management System
BOL	Begin of Life
C	Charging rate
CH	Charge (direction)
CV	Commercial Vehicle
DC	Direct Current
DCH	Discharge (direction)
DOD	Depth of Discharge
EFC	Equivalent Full Cycles
EOL	End of Life
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
HC	Hard Carbon
HPC	High-Power Charging
HW	Hardware
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LIB	Lithium Ion Battery
LFP	Lithium Iron Phosphate
LFMP	Lithium Iron Manganese Phosphate
MCS	Megawatt Charging Systems
NCM	Nickel Cobalt Manganese
PC	Passenger Car
PHEV	Plug In Hybrid Electric Vehicle
SDR	Self-Discharge Rate
SIB	Sodium Ion Battery
SOC	State of Charge
SOH	State of Health
SOHC	State of Health Capacity related
SOHP	State of Health Power related
SOHR	State of Health electric Resistance related
SW	Software
T&D	Transmission and Distribution
UC	Use Case
V2B	Vehicle to Building
V2G	Vehicle to Grid
V2H	Vehicle to Home

1 Introduction

Lithium secondary batteries are dominating the global battery market today. Among those, Lithium-Ion Batteries are most prominent. That is the reason why the NEXTBMS project focusses on the related BMS research, supported by the fact, that foreseeable cognate technologies (like Sodium Ion or non-liquid electrolyte batteries) can be managed on comparable BMS HW, SW and modelling approaches. Besides mobile applications, also the stationary market is dominated today by Lithium-Ion Batteries, see Figure 1 for an example of industrial stationary batteries in Germany.

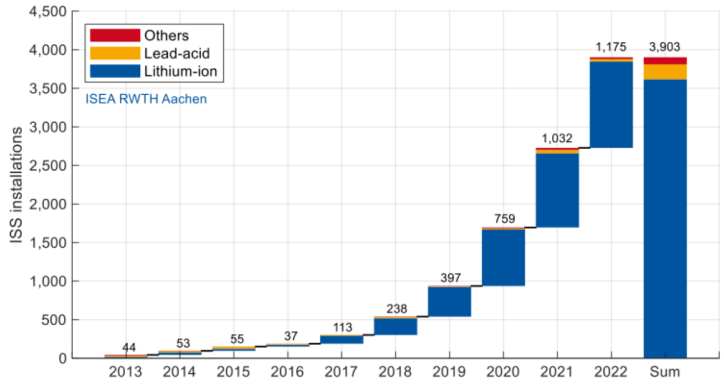


Figure 1: Estimated number of industrial BESS installations in Germany [1]

Looking at the global battery market (Figure 2), the demand for bigger mobile and stationary applications is growing fast. Besides EVs, the stationary market is most relevant when looking at shares and market volume, supporting the integration of renewable energy sources. The 3C segment is related to small-format cells, that are typically managed by less complex BMS set-ups for less challenging lifetime requirements, not targeted primarily in NEXTBMS. The coefficient 3C means that the battery is fully charged or discharged within 20 minutes.

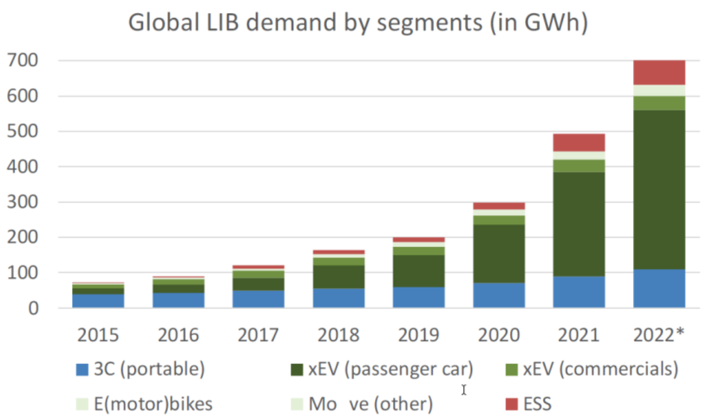


Figure 2: Trend for the global Lithium-Ion Battery demand by segment in GWh [2]

In the following sections, the most prominent mobile and stationary use cases of the related applications will be identified. This is the basis for the following development steps in the project that need to define all relevant technical requirements. Having most relevant use cases detected, synergies and differences in between stationary and mobile application can be used to design efficient BMS solutions.

Battery stationary and mobile use cases are in focus of the NEXTBMS technical advances. In the following these two application fields are specified in more detail to define the basis of the related BMS requirements and functionalities. Finally, not all stationary and mobile battery applications can be part of the NEXTBMS solution. Batteries with minor market relevance and less challenging BMS functions will have to be kept out here, to focus on most relevant EU industry and environmental impact.

1.1 Definition of the term “use case”

NEXTBMS is a technical development project. That is why we focus here on using the term “use case” as a technical (battery) system function in an application. Users can be a persons or organisations. From another perspective, business use cases can be defined and linked to technical use cases. Those “business cases” are part of our use case descriptions but are not use as classification criteria here.

1.2 Use case derivation process

The derivation of relevant mobile and stationary use cases is set-up as in a process (Figure 3) that incorporates input from all NEXTBMS partners, active in WP1. It started with a questionnaire to pick up the project team knowledge and was followed by also other external, actual literature studies, dealing with battery storage use cases. The derived use cases are then classified with regards to technical categories. These categories are finally linked to dominating KPIs, as a basis for the requirements engineering processes, needed for WP2 ff.

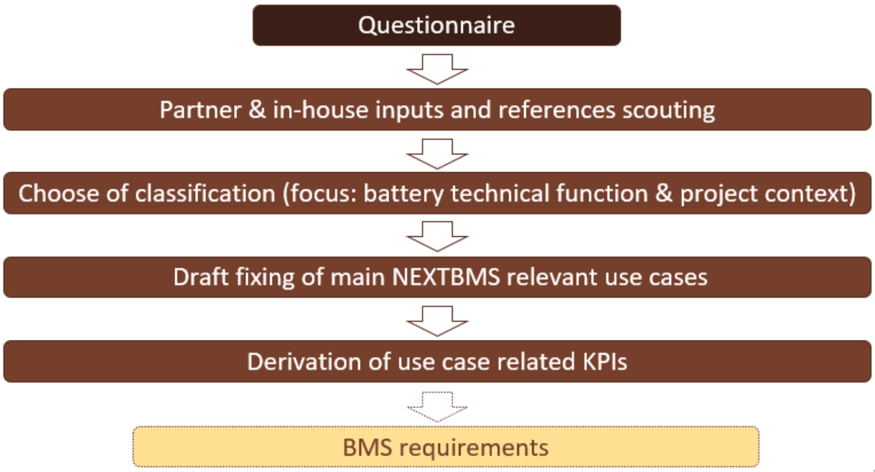
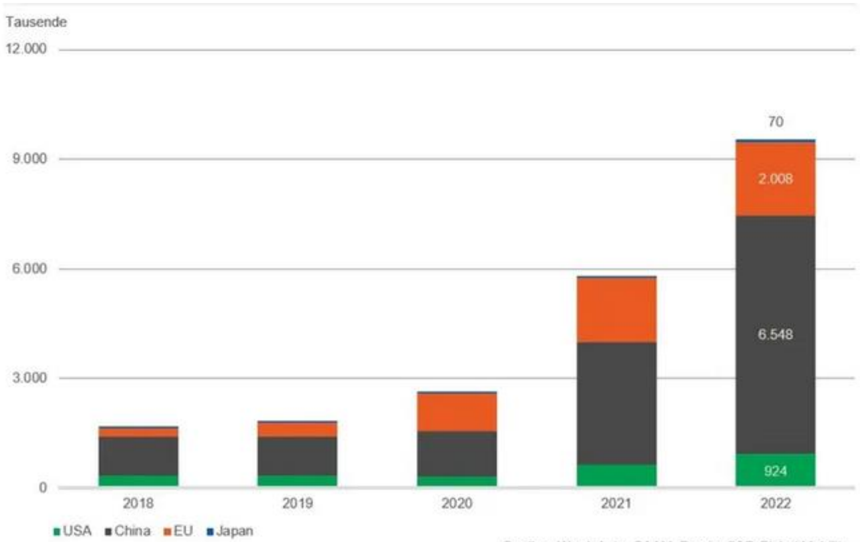


Figure 3: The NEXTBMS use case derivation process roadmap

2 Mobile battery use cases

In recent years, the global advance of electromobility has continued steadily in terms of new car registrations.

With around 12 million new passenger cars with an electric drive (BEV, PHEV or FCEV) registered globally, 2022 was another record year (Figure 4). In 2023, up to 14 million new electric vehicles will hit the roads around the world. At least that is what the IEA (International Energy Agency) predicts in its 'Global EV Outlook 2023'. One in six cars sold worldwide is now electric; 73 % of these are BEVs [5]. The largest electric car market in 2022 was once again China by a wide margin, where more than every second electric car was sold worldwide. The USA was in second place worldwide in 2022, with Europe in third place.



Quellen: WardsAuto, CAAM, Fourin, S&P Global Mobility

Figure 4: International electromobility - Sales of electric cars (BEV, PHEV, FC) in the most important markets [6]

The size of the batteries varies a lot from region to region. According to the IEA, an average of 25 kWh batteries are installed in small electric cars in China, 35 kWh batteries in Europe and 60 kWh batteries in BEVs in the USA (source: IEA).

Even though the boom in e-vehicles is usually attributed to passenger cars, it makes sense to also consider other types of vehicles that are gradually becoming more environmentally friendly. From e-scooters and two- and three-wheeled e-vehicles to heavy-duty e-trucks and buses for public transport. China dominates the market for electric two-wheelers. India is in the lead when it comes to electric three-wheelers. Together with China, these two countries accounted for almost 99 % of global three-wheeler sales.

In the countries of the European Union, new directives on clean vehicles set targets for the public procurement of electric buses. France, Germany, Spain and Finland are just some of the EU countries where sales of electric buses are on the rise.

The electrification of the heavy goods vehicle sector is a crucial step on the road to a zero-emission future, because although they only account for 10 % of all internal combustion vehicles, they are responsible for 70 % of their CO_2 emissions.

Many countries have committed to sell 100 % zero-emission trucks by 2040. The USA and the EU have already proposed higher emission standards for heavy commercial vehicles for 2022.

The rise in new registrations of electric cars is leading to an increase in the production of lithium-ion batteries worldwide. Overall, global demand for vehicle batteries will increase by 65 % in 2022 compared to the previous year. China remains the main supplier for the global battery industry.

In 2022, the production of vehicle batteries accounted for around 60 % of lithium demand, 30 % of cobalt demand and 10 % of nickel demand. Just five years earlier, this figure was only 15 % for lithium, 10 % for cobalt and 2 % for nickel [7].

Research and development are constantly working on improving batteries to promote the future of electromobility, with technological advances being made in the following areas in particular:

- Battery chemistry
- Energy density → Energy consumption
- Battery size

These changes will ultimately lead to massive cost reductions and increased production efficiency. Thanks to new technologies and developments, the range of electric cars can be significantly increased, and the batteries can also be manufactured and recycled much more sustainable.

Another aspect is the precise determination and prediction of battery sizes, which are decisive for the battery lifetime. For battery electric vehicles, the battery is the most expensive component of the drivetrain and therefore a major cost driver. It is therefore important to always know the exact state of health of the battery (SOH) and to assess it correctly to maximise the operational availability of the vehicles. Customised predictive maintenance strategies with the aim of reducing vehicle failures will also be increasingly used in EVs in the future.

Such procedures can no longer be carried out on a single battery control unit (BCU) due to the large amount of data required and the complex algorithms. These processes are realised on an external storage medium, e.g. a cloud. This means that device-cloud connectivity (connected cars) is emerging for battery applications, which can also be recognised in the consumer sector, e.g. for power tools, household appliances, etc. The challenge is to precisely determine the relevant operating variables, carry out efficient data-cleaning (detect anomalies, fill data gaps, etc.) and use suitable models - from equivalent circuit models of the battery over complex physical models to AI methods - to determine or predict the meaningful battery variables with a high degree of accuracy.

Worldwide, e-vehicles consumed around 110 TWh of electricity in 2022, twice as much as a year earlier. By 2030, e-vehicles will be responsible for around 4 % of global electricity consumption [7].

As energy demand increases, the power supply and electrical infrastructure must also be guaranteed in the future. Careful planning, the widespread use of smart charging and the use of intelligent energy management solutions for load management will be crucial to ensuring balanced power grids in the future.

In 2022, the use of electric vehicles around the world saved more than 80 million tonnes of CO_2 equivalents. Forecasts in the IEA's Stated Policies Scenario predict that electric vehicles will help to save around 700 million tonnes of CO_2-equivalent greenhouse gas emissions in 2030.

Although the total number of e-vehicles will significantly increase the electricity consumption, the total installed battery storage capacity of the e-vehicles will also increase. For energy suppliers, this means that e-vehicles can offer cost-effective energy storage. Without high investment and operating costs. This will be particularly interesting with a growing share of renewable energies, as these are subject to major fluctuations during production. Here, batteries can have a balancing effect at peak times, as they can take surplus electricity from the grid at short notice and store it (V2G). The utilisation of energy from the vehicle battery to supply energy to various consumers in a house (V2H, V2B) is also in preparation.

2.1 Classification of vehicles

The regulations for motor vehicles of all kinds are described in various European Union (EU) regulations.

Two- or three-wheeler vehicles (vehicle category L) in EU Regulation 2013/168, vehicles for the carriage of passengers (vehicle category M) and for the carriage of goods (vehicle category N) in EU Regulation 2018/858.

In addition, there are also off-road vehicles such as agricultural and forestry vehicles (tractors), mobile machinery (excavators), aircraft and ships, which are becoming increasingly electrified.

In this project, the focus of mobile applications in electromobility is on the passenger car and commercial vehicle sector. These are analysed in more detail in the following chapters and their battery technology features are compared. A forecast of how these characteristics will change in the future is also provided to derive future requirements for the battery.

The following overview shows the classification and, where applicable, sub-classification (segmentation) of the vehicles under consideration.

EU-Classification:

- L: Light motor vehicles with 2, 3 wheels
- M: Motor vehicles for the purpose of passenger transport, e.g. passenger cars (PC)
  Segments: - small- & lower-class (A, B)
  - compact- & middle-class (C, D)
  - upper middle- & upper-class (E, F)
  - Sport Utility Vehicles (G)
- N: Commercial vehicles (CV) for the carriage of goods, e.g. trucks, but also buses
  - light duty CV up to 3,5t (N1)
  - medium duty CV 3,5t – 12t (N2)
  - Duty up to heavy duty CV > 12t – 40t (N3)

and additional:

- Off-road vehicles, e.g. working machines (excavator)
- Air- / water-mobility, e.g. Airplanes / ships

2.2 Passenger cars

Table 1 shows an overview of the technical KPIs of batteries in different EV-passenger cars as they are installed in vehicles today.

Table 2 gives an outlook of the same KPIs for the year 2030.

Table 1: Technical KPIs of batteries in passenger cars – State of the art

	small- & lower-class	compact- & middle-class	upper middle- & upper-class	Sport Utility Vehicles
cell chemistry	NCM/LFP	NCM/LFP	NCM/LFP	NCM/LFP
battery size	30 – 60 kWh	40 – 80 kWh	80 – 100 kWh	80 – 120 kWh
	300 kg	500 kg	650 – 700 kg	700 kg
	350 l	400 l	450 l	450 l
battery voltage	400 V	400 V	400 – 800 V	400 – 800 V
Installed energy	200 – 250 Wh/kg	200 – 250 Wh/kg	200 – 250 Wh/kg	200 – 250 Wh/kg
	150 – 300 Wh/l	150 – 300 Wh/l	150 – 300 Wh/l	150 – 300 Wh/l
energy consumption	16 – 20 kWh/ 100 km	18 – 22 kWh/ 100 km	20 – 23 kWh/ 100 km	20 – 25 kWh/ 100 km
required range	250 km	350 km	450 km	480 km
cycle-life	> 1.500 EFC	> 1.500 EFC	> 2.000 EFC	> 2.000 EFC
milage / calendar-life	> 200.000 km / 8 years	> 200.000 km / 8 years	> 200.000 km / 8 years	> 200.000 km / 8 years
charging strategy	AC/DC	AC/DC	AC/DC	AC/DC
charging rate	1 – 2C	1 – 3C	1 – 3C	1 – 3C
charging power	Normal charging, up to 43 kW	Fast charging, up to 160 kW	HPC, up to 250 kW	HPC, up to 250 kW
cloud connected	no – few	no – few	no – few	no – few
V2X	no	no	no	no

Table 2: Technical KPIs of batteries in passenger cars – forecast for 2030

	small- & lower-class	compact- & middle-class	upper middle- & upper-class	Sport Utility Vehicles
cell chemistry	NCM/LFP/LMFP/SiB	NCM/LFP/LMFP/SiB	NCM/LFP/LMFP/SiB	NCM/LFP/LMFP/SiB
battery size	30 – 60 kWh	40 – 80 kWh	80 – 120 kWh	80 – 150 kWh
	250 – 300 kg	450 – 500 kg	550 – 600 kg	650 kg
	350 l	400 l	450 l	450 l
battery voltage	400 V	400 V	800 V	800 V
Installed energy	300 Wh/kg	300 Wh/kg	300 Wh/kg	300 Wh/kg
	up to 300 Wh/l	up to 300 Wh/l	up to 300 Wh/l	up to 300 Wh/l
energy consumption	up to 12 kWh/ 100 km	up to 14 kWh/ 100 km	16 – 18 kWh/ 100 km	up to 20 kWh/ 100 km
required range	300 km	450 km	550 km	600 km
cycle-life	> 2.500 EFC	> 2.500 EFC	> 2.500 EFC	> 2.500 EFC
milage / calendar-life	> 300.000 km / 8 years	> 300.000 km / 8 years	> 300.000 km / 8 years	> 300.000 km / 8 years
charging strategy	AC/DC	AC/DC	AC/DC	AC/DC
charging rate	1 – 2C	2 – 5C	3 – 6C	3 – 6C
charging power	Normal charging, 43 kW Fast charging, 50 kW	Fast charging, up to 350 kW	HPC, up to 500 kW	HPC, up to 500 kW
Cloud connected	yes	yes	yes	yes
V2X	yes	yes	yes	yes

The pack design will be decisive for the battery size, volume and weight. There is an emerging trend away from battery modules towards a battery pack consisting solely of individual battery cells. This will entail changes in the connection as well as changes in the cooling system.

2.3 Commercial vehicles

In the CV market, other technical features are relevant for the battery than it is the case in the passenger car market. The range and charging strategy are particularly important here (Table 3). Due to legally regulated driving times, which must not be exceeded, driving time breaks (45 minutes) must be used to recharge the battery as much as possible. The aspect of battery ageing (SOH) is also at the forefront, as a battery replacement, which is due in the duration of a CV's life, represents an enormous cost factor for the transport company.

Table 3: Technical KPIs of batteries in commercial vehicles – State of the art and forecast for 2030

	Light-CV State of the art	Heavy duty CV State of the art	Light-CV forecast 2030	Heavy duty CV forecast 2030
battery size	35 – 50 kWh	up to 480 kWh	60 – 120 kWh	up to 600 kWh
battery voltage	400 V	400 V	800 V	800 V and more
energy consumption	up to 60 kWh/100 km*	up to 140 kWh/100 km*	up to 50 kWh/100 km*	up to 110 kWh/100 km*
daily range	up to 150 km	600 – 800 km	up to 150 km	> 1.000 km
milage/year	20.000 km	135.000 km	20.000 km	150.000 – 200.000 km
cycle-life	> 2.500 EFC	> 2.500 EFC	> 2.500 EFC	> 2.500 EFC
milage / calendar-life	up to 300.000 km / 8 years	> 300.000 km / 8 years	up to 300.000 km / 8 years	> 1.000.000 km / 15 years
charging strategy	AC/DC	DC	AC/DC	DC
charging rate	1 – 2C	2 – 5C	2 – 3C	3 – 6C
charging power	Normal charging, 43 kW Fast charging, 50 kW	HPC, up to 250 kW	Normal charging, 43 kW Fast charging, 50 kW	HPC and MCS

*: depending on the tonnage

2.4 Load variants and trends of charging

Another trend in the field of electromobility is smart charging, i.e. with charging points that are connected to a cloud. They enable greater convenience and control over electricity consumption for logistic companies and private individuals.

Finally, vehicle-to-grid (V2G) technology makes it possible to feed the electricity stored in the batteries of electric vehicles back into the grid - in the same way that stationary electricity storage systems are connected to the grid.

The trend in charging technology is continuing towards fast charging. For many, fast charging is a 'game changer' for the success of electromobility. Here, too, the technology is constantly being developed to provide a cost-effective and efficient service. HPC, i.e. charging with an output of 150 kW or more, is also becoming more important. Fast charging stations in this HPC power range can be produced ever more cost-effectively and the power range itself is also becoming ever higher.

Megawatt Charging Systems (MCS) require a special charging infrastructure. Such systems, in the form of charging parks, must be designed from the grid connection to the charging station to meet the space requirements and energy supply, and the grid must also be expanded accordingly. Work is currently underway on this type of charging station. The first product that meets the requirements of the logistics (CV market) should be available by 2025. MCS will also be used in the future in the travel sector, for example in buses.

2.5 Sustainability

Many batteries are still functional when they are removed from an EV (SOH < 80 %) and can be used for further applications (2nd life), e.g. for intermediate storage of the energy generated by photovoltaic systems. This extends the overall life cycle of the battery (LCA, Life Cycle Assessment), which is an advantage from an economic and ecological point of view, especially for expensive components. In addition, there are more and more requirements regarding a "circular economy", which demands an increasing maximisation of the use of a battery over its entire service life.

In addition to 2nd life applications, many batteries are now also recycled to recover the raw materials contained in the battery. The most valuable part of the battery is the cathode material, which often contains the elements nickel, manganese, cobalt and lithium. The European Union is aiming for a binding recycling value of at least 20 % cobalt, 12 % nickel and 10 % lithium by 2035.

Both methods therefore make a significant contribution to the sustainability of electrical energy storage systems.

3 Stationary battery use cases

Stationary use cases (Figure 5) comprise industrial and private owned battery applications. Bigger private owned battery systems of > 1 kWh are typically linked to PV energy storage tasks and the related, local self- consumption of electric energy. On the other hand, industrial stationary batteries have more diverse tasks in local or distributed electric networks. The details are described in the following chapters.

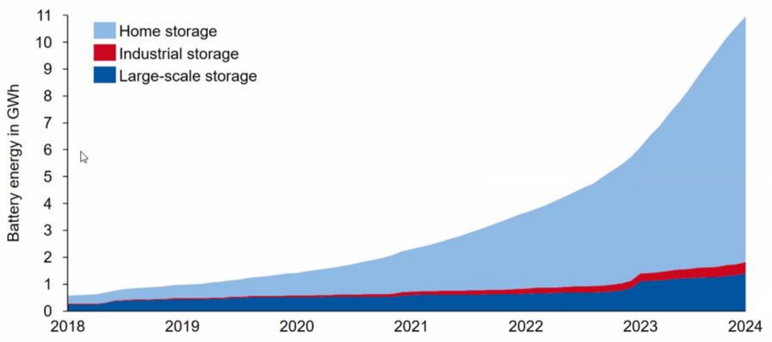


Figure 5: Installed stationary battery capacity, example: Germany [3]

The classification of stationary battery system use cases can be done by different criteria (Table 4). In the following, we mainly differentiate in between the main applications "home storage", "grid services" and "off grid". Today, in the EU, home storage and grid storage are the most important market segments concerning energy volume [8], followed by other industrial and commercial application fields. Home storage is representing a "behind the meter" application that can be also found for similar tasks in the industrial environment. The share in between home storage and grid storage is strongly depending on country specific situations. In Germany, for example, home storage is dominating the scene (Figure 5).

Besides one-family houses, the dimensioning and design of stationary batteries can be very diverse (Figure 6). This situation is reflecting the specific local applications for electric energy storage and supply, mainly differentiated by voltage level, as well as power and energy demand. In this report, it is avoided to be too granular to finally get more general messages related to the derived KPIs. References dealing with the overall diversity of application fields can be found e.g. in [4].

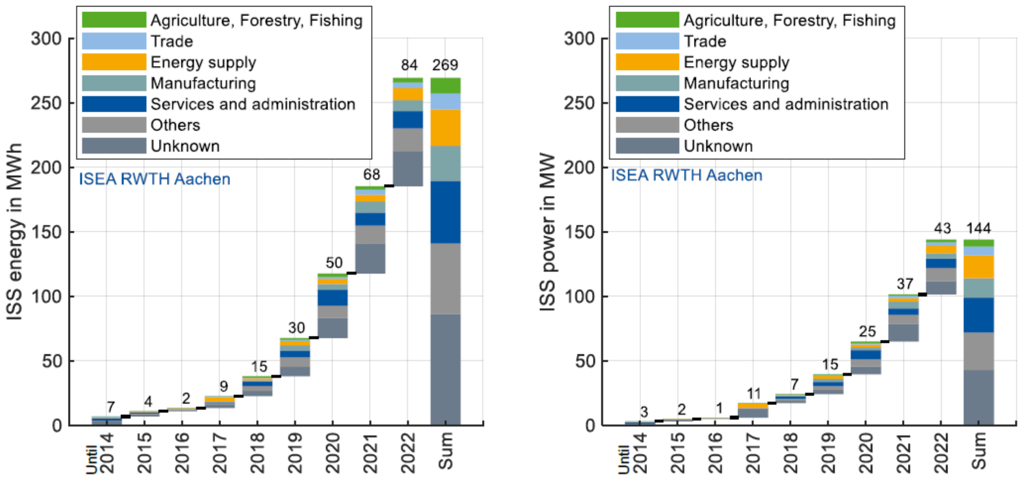


Figure 6: Picture, showing exemplary the diversity (independent from size) with respect to different final usage - only for the segment of industrial BESS, example of the German market [1]

Apart from singular use cases, stationary BESS can be also designed to support multi-use applications like peak shaving together with UPS and energy feeding management. In this case integral KPIs will have to be derived and design optima might have different targets.

3.1 Grid services

Grid services are the main application for big stationary battery storage systems > 100 kWh. As one example, short to mid-term fluctuations in the power net can be balanced by electric storage systems. They are able to react within seconds or minutes from zero to 100 % of their power in charge or discharge direction. Besides these high dynamic load cases also energy shifting with less power dynamic are part of grid services, by supporting cost efficient widespread networks.

3.1.1 Net stabilization

Balancing of production and consumption of electric energy in the range of seconds to approximately one hour. It is an established and well-known commercial business case for stationary batteries with a trend towards increasing compensations.

- Well known, established commercial business case
- Net frequency/voltage/load angle stabilization
- Supporting the trend towards increasing compensations
- Support of net reliability
- Electric energy transmission support

3.1.2 Shifting of energy

The management of peak and average power/energy demand within one or several days can be performed by BESS integration in power nets with the following positive effects:

- Hybridized power source management in industry
- Increase of the degree of autonomy in sub-networks
- Support of longer-range distribution and transmission of electric energy
- Arbitrage

3.1.3 Load shaving

Smoothing of power loads on electric network lead to a more efficient net usage.

- Cost reductions for electric power net installations; increase of net efficiencies
- Reduction of network charges
- Support of electric mobility related load scenarios

3.1.4 Black start and backup

Effects initiated by unstable net situations up to breakdowns can be avoided by installing emergency electric power supply systems. In addition, linked applications also support backup power, grid forming or black start tasks.

- Bridging of blackouts or maintenance times and phases of reduced net or generator power, including re-starts
- Support of optimal generator ramping, “hybridization” (conventional like CE or future like fuel cells)
- Safeguard for critical infrastructure and data processing centers (emergency power supply)
- Support of UPS tasks

3.2 Renewables self-consumption

Storing of excess mainly PV and wind electric energy in home storage and industrial sub-network systems leads to an increase of self-consumption for locally generated energy.

- Support of local green energy footprints
- Increased Independency from suppliers and markets
- Reduces loads on the external electric network.

3.3 Off-grid

Off-grid applications support island operations without any connection to a power net that is part of a national or international supply system. Exemplary applications are areas, too far away from any cable connection, like natural islands, spots in less developed regions or pure self-supplying houses, industry or public infrastructure. Off-grid battery storage services are typically a combination of before mentioned use cases and tasks, driven by the availability of classical sources and seasonal and/or daily, weather related cycles. For this kind of application, the power grid is often balanced using fossil-fired generation units. The aim of battery storage is to significantly reduce or even eliminate the need for this unsustainable electricity production. Because of their high regional relevance and importance in this project, this use case is mentioned separately.

- Capacity firming, “hybrid micro- or macro grids”
- Energy shifting
- Voltage and frequency stabilization
- Load following tasks
- UPS

3.4 Vehicle to grid or home

This use case is supposed to increase in relevance within the next decades. It combines mobile battery storage systems with stationary ones including the link to electric grids. The higher-level use cases behind are the same as mentioned before. Vehicle battery storage can support home and grid related tasks. The relevance of this use case for NEXTBMS is given by the need to care about potential, additive BMS requirements brought up here.

- Bi-directional storage at home (PV self-consumption, rate optimal energy supply)
- Load shaving
- UPS
- Frequency & load angle stabilization
- Arbitrage

Table 4: Overview of the derived main stationary use cases and their main characteristics

Use case	Main technical characteristic	Main application background
Net stabilization	high dynamic power, medium energy; seconds to hours; long lifetime	frequency/voltage/load angle stabilization; net reliability
Energy shifting	high power & energy; hour to week; high cycle numbers; deep cycles	multiple power source management; arbitrage; distribution & transmission grid support
Renewables self-consumption	day to month, small to medium energy and power; small to deep cycles; seasonal diversity	PV + Home storage; site autonomy increase
Load shaving	minute to hour; medium energy & power; high cycle numbers	net dimensioning, net fee reduction
Black start and backup	medium power & energy; short reaction time; small cycle numbers	net independent backup power and assist, critical infrastructure support
Off grid	day to seasonal; medium energy and power; high diversity	islands and missing infrastructure
V2H & V2G	diverse targets concerning multiple use cases; cloud management	PV integration, rate optimization, net support

3.5 Use case related KPIs

The evaluation of the above mentioned most important use cases leads to use case individual KPIs and requirement sets (Table 5). The comparison of the use cases is an enabler for the derivation of integral, synergetic requirements for the NEXTBMS technical solution. The NEXTBMS BMS solution will have to be able to serve all BESS use cases that are detected to be relevant for at least the EU market. Here we focus on the respective high level KPIs within mainstream applications, as the detailed NEXTBMS HW and SW requirements will be worked out separately in the work packages to come.

Table 5: Stationary battery related KPIs for the derived use cases

Indicator/use case	Renewable self-consumption	Net stabilization (f, U, ϕ)	Energy shifting	Load shaving	Ancillary & backup	Off-grid	V2 home & grid
Power /MW	0.003 - 0.03	0.1 - 100	10 - 1000	0.01 - 10	0.1 - 50	0.1 - 100	0.015 – 0.15
Energy / MWh	0.003 – 0.1	0.1 - 10	50 - 1000	0.2 - 20	0.1 - 5	0.1 - 50	0.03 – 0.1
Cycle life / EFC	> 3000	2000 - 7000	2000 - 7000	2000 - 7000	150 - 300	2000 - 7000	> 2000
Calendar life / y	> 12	> 15	> 15	> 15	> 15	15 - 25	> 8
Price level	medium	low	low	low	low	low	medium
T range / °C	-10 - 50	10 - 40	10 - 40	10 - 40	10 - 40	10 - 40	-30 - 50
Cloud obligatory	N	Y	Y	Y	Y	N	Y
2nd life option	N?	N?	N?	N?	N?	N?	Y
C rate max / mean CH/DCH	2 / 0.5	2 / 0.2 – 0.5	1 / 0.2 – 0.5	1 / 0.2 – 0.5	2 / 0.2 – 0.5	1 – 4 / 0.2 - 1	0.5 / 0.1 – 0.3
Specific and volumetric energy density	medium relevance	low relevance	low relevance	low relevance	low relevance	low relevance	high relevance
System reaction time	s - h	s - h	min - d	min - h	s - min	s - h	s - h
Typical DOD range / %	50 - 100	40 - 60	50 - 100	50 - 80	20 - 100	50 - 90	30 - 100
EFC per year	200 - 365	200 - 400	200 - 500	50 - 365	10 - 20	150 - 365	200 - 400
Cell chemistry	LFP, LMFP, NCM, NCA, metallized & alloy anodes, graphite, HC, SIB (future) // out of scope: VRLA, NaS, VRFB, …						

4 Results & Discussion

Having collected the dominating overall mobile and stationary use cases for the upcoming European market, it is possible to bring up entire KPIs that NEXTBMS results have to be able to address. This means to always reference to the most challenging BESS use case related KPI when BMS functionalities have to be developed. An exemplary selection of most challenging KPIs is described in the next section.

4.1 Results

Besides the use case specific KPIs, that can be found in the chapters 2 and 3, in the following a condensed overview of BESS KPIs and their link to the drivers behind is stated (Table 6).

1. Calendar and cycle lifetime requirements will increase. This is a result from foreseeable needs for improved sustainability, cost effectiveness and environmental footprints.
2. Precise load control and predictions are essential. They are the enabler for better energetic efficiencies and less overdesigned battery systems.
3. Modern BMS solutions will have to be able to follow chemical and physical battery design changes. Those have their root cause in cost and critical material optimal designs.
4. Cloud connectivity and its related functional basis are the enabler for efficient fleet control and improved aging and performance related state detections/predictions. Furthermore, it is the basis for lean 2nd life decision basis and V2x inter-operability.

Table 6: Main integral KPIs, derived from the overall set of use cases

Use case derived KPI	Dominating drivers	NEXTBMS solution
High calendar life (up to 25y) and related predictions	Stationary and 2nd life applications; need for sustainability; profitability	Improved state control & predictions (via improved model, sensor basis & cloud)
High cycle life (up to > 5000 EFC)	Stationary and CV, sustainability, profitability, safety predictions	Improved state control & predictions (via improved model, sensor basis & cloud)
High dynamic load control	Sub-second loads of up to > 5C, EV/CV drive cycles, fast charge	Improved short-term state control & predictions (via improved models)
Battery technology readiness (for secondary Lithium)	Trend towards higher energy densities and lower prices	Adjustable model parameters and appropriate sensor topology
Cloud connectivity	Entire energy management, fleet learning, calculation efficiencies, AI	NEXTBMS cloud interfaces for technical and cost efficient HW/SW topologies
2nd life and 2x operations	Battery directive, sustainability, inter-operability	NEXTBMS improved state estimations, predictions and (communication) interfaces

4.2 Contribution to project (linked) Objectives

This deliverable contributes to all of the NEXTBMS objectives as it sets up the initial input for all HW and SW requirement processes. The requirements then, will link the here derived use case related needs with all NEXTBMS HW and SW developments. This includes, for example, the physical sensor requirements, physical modelling targets & input parameters but also the algorithm functionalities.

4.3 Contribution to major project exploitable result

This deliverable is in-line with the required project targets by exploring the technical basis and respecting actual trends in the EU - as input for the following work packages and exploitations.

4.4 Contribution to NEXTBMS partners

This deliverable will contribute to each NEXTBMS partner for their future studies and road maps because the information in this document is compatible with actual and future trends.

5 Conclusion and Recommendation

The NEXTBMS project related KPI landscape for mobile and stationary has been derived from the respective use cases and has been established finally.
The specific and condensed KPI indications should be used as basis for the upcoming requirements related, development actions within WP1 and WP2 ff.

6 Risks and interconnections

6.1 Risks/problems encountered

Because the use cases outline the general boundary conditions for the following work packages no specific risks have been identified.

6.2 Interconnections with other deliverables

Based on the results of this WP, the requirements for

WP2: Physics and data-based models and BMS software,
WP3: Development and prototyping modular battery modules with BMS hardware, and
WP4: Use case realization on lab-scale and upscaling towards system-level validation

with which interactions exist are completed.

7 Deviations from Annex 1

No deviations.

8 References

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Project partners:

#	Partner short name	Partner Full Name
1	AIT	AIT Austrian Institute of Technology GmbH
2	TNO	Nederlandse organisatie foor toegepast natuurwetenschappelijk onderzoek TNO
3	UL	Univerza v Ljubljani
4	VUB	Vrije Universiteit Brussel
5	UNR	Uniresearch BV
6	AVL	AVL List GmbH
7	AVL-SFR	AVL Software and Functions GmbH
8	AVL-TR	AVL Arastirma ve Muhendislik Sanayi ve Ticaret Limited Sirketi
9	BOSCH	Robert Bosch GmbH
10	NXP	NXP Semiconductors Austria GmbH & Co KG
11	EDF	Electricite de France
12	TOFAS	TOFAS Turk Otomobil Fabrikasi Anonim Sirketi

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