CONSORTIUM FOR
BATTERY
INNOVATION

An innovation roadmap for advanced lead batteries

Technical specifications and performance improvements

The Consortium for Battery Innovation

The Consortium for Battery Innovation is the only global pre-competitive research organization funding innovation in lead batteries for energy storage and automotive applications.

Our work

Research

Improving lead battery performance through pre-competitive research

Testing/Standards

Ensuring lead battery merits are recognised in key global tests and standards

Marketing

Improving recognition of lead battery benefits in utility and renewable energy storage applications

Communication

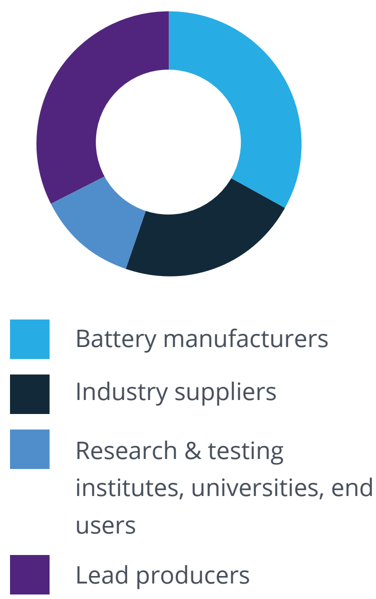
Positioning lead batteries as a future, innovative technology

Membership

Our membership comprises the whole value chain associated with lead batteries, with over 90 members globally.

Map of members

CBI member representation



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Contents

1.1 Executive summary – fueling the advanced battery revolution

The vast growth in demand for battery energy storage is fueling the race to design and deliver ever more impressive and innovative batteries.

As countries rush to reduce their carbon dependency, battery energy storage is set to be one of the defining technologies of the century.

Conducting cutting-edge, market-driven research and innovation has never been a higher priority for governments and companies alike. And that is why the Consortium for Battery Innovation is focusing on research projects which will make a tangible difference to lead battery performance, and which meet the ever-increasing demands of end-users.

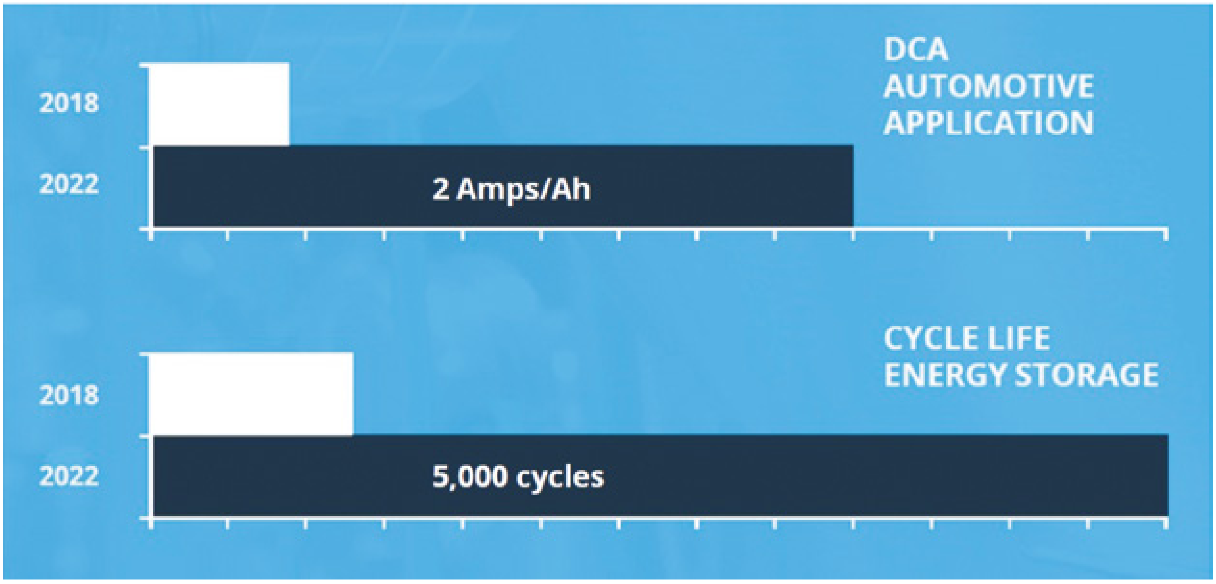
Working with members of the Consortium, we have developed this technical roadmap for advanced battery research and innovation. It is based on extensive market research, and discussions with end-users -from car companies to the renewable energy industry, and from data centers to utilities- in a bid to better understand customers' technical requirements for the future.

The result is a set of research objectives designed to deliver short term goals and targets for significant improvements in performance and lifetime for batteries in the automotive and energy storage sectors.

In the automotive sector the highest priority target research goal is to **increase dynamic charge acceptance by 5 times by the year 2022 to 2 Amps/Ah.** Dynamic charge acceptance is a key future technical parameter for micro and mild-hybrids, vehicles which deliver significant CO2 and fuel savings. This work is essential for maximizing the performance of advanced lead batteries in the ever-increasing number of micro and mild-hybrid vehicles on the road.

For energy storage batteries which support utility and renewable energy projects, demand is growing substantially driven by governments around the world setting ambitious goals and targets for decarbonization and electrification. This growth is so significant, the demand cannot be met by one technology alone. Lead batteries are one of the technologies with the scale and the performance capability able to meet these requirements and ensure these ambitious goals and targets can be met.

Continuing to improve cycle life is therefore a core technical research priority for these applications. The Consortium is looking to **increase battery cycle life by 5 times by 2022 to 5,000 cycles,** which would contribute to lower operating costs, a key parameter for utility and renewable energy applications.



Highest priority research objectives

Achieving these research objectives will demonstrate the vital role lead batteries play in meeting future electrification and decarbonization targets across the globe.

However, this roadmap is just a stepping-stone to the future. Working with universities and advanced laboratories worldwide, the Consortium aims to unlock the full potential of lead battery technology–a potential that is nowhere near fully exploited. Our work will continue to open up opportunities for this critical technology.

We are entering a golden era for battery technologies and the Consortium is pioneering research into the next generation of advanced lead batteries.

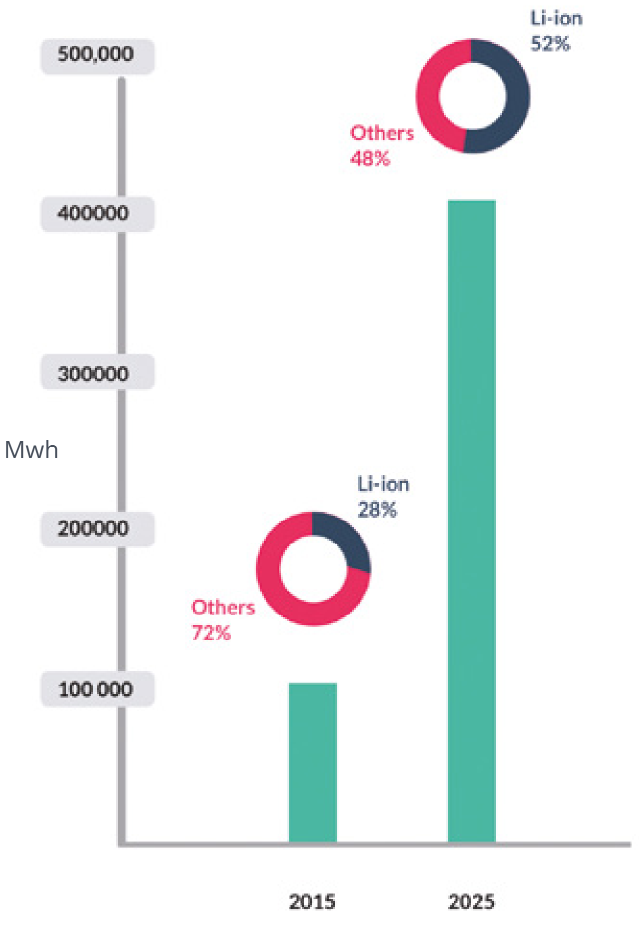
Dr Alistair Davidson
Director, Consortium for Battery Innovation

1.2 Background

The Consortium for Battery Innovation (formerly the Advanced Lead-Acid Battery Consortium) is a pre-competitive research consortium funded by the lead and the lead battery industries to support innovation in advanced lead batteries.

The Consortium identifies and funds research to improve the performance of lead batteries for a range of applications from automotive to industrial and, increasingly, new forms of requirements such as renewables energy storage.

In the 25 years since it was formed, the Consortium has been highly successful in improving the cyclic characteristics of valve-regulated lead-acid (VRLA) batteries, the performance of automotive batteries in micro-hybrid applications and for many other duty cycles. The introduction of start-stop technology in cars worldwide is just one example of innovation by the industry to achieve reduced emissions in vehicles and contribute to climate change objectives.



This innovation roadmap will help determine priorities for 2019 and beyond. It has been developed to ensure lead batteries continue to meet current and future technical requirements, to both retain existing market and support customers' requirements and opportunities in new markets. The latest data from analysts globally suggests that demand for rechargeable energy storage is set to increase significantly in the next 10-15 years as governments transform their economies and energy companies invest in technologies to support climate change objectives, which provides significant future opportunities for lead batteries.

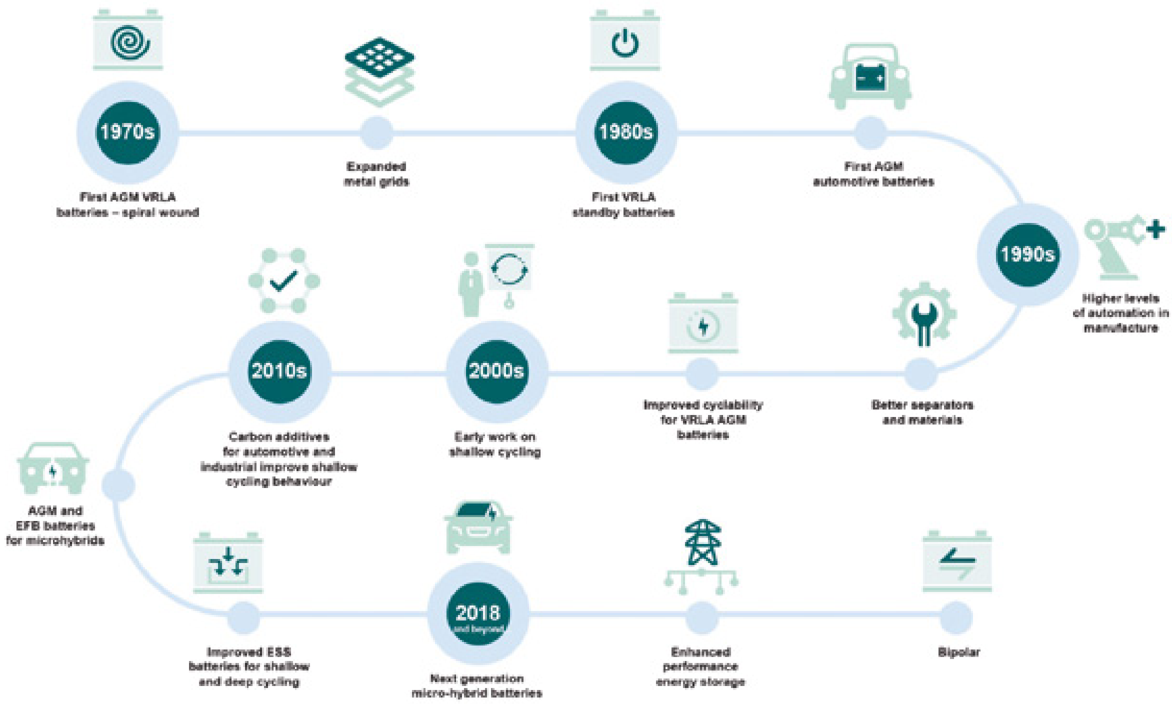
Figure 1 - Growth of battery for energy storage applications (Avicenne – ALABC report, 2018).

This roadmap has defined clear research objectives and Key Performance Indicators (KPIs) and identifies the principal research areas which members of the Consortium believe should be studied in order to meet the KPIs.

1.3 Marking more than 25 years of successful innovation

The Consortium was originally formed in 1992 with the aim of improving performance of VRLA batteries especially where better cycle life was required. This was achieved and the success of VRLA batteries in automotive and industrial service is, in no small measure, the result of much of this work.

More recently, research has been directed towards the development of batteries with enhanced shallow cycle life in high-rate partial state-of-charge (HRPSoC) service with carbon-enhanced designs for automotive start-stop or micro-hybrid duty cycles and for energy storage. Recently this has focused on improving the understanding of the function and behavior of different forms of carbon in the negative plate, and whilst battery performance is meeting current technical requirements, increasing demands for energy recovery in automotive service and for partial state-of-charge in energy storage are providing a strong impetus for further work.



Evolution of lead battery technologies since the 1970s.

1.4 The battery industry in 2019

The battery industry has seen unprecedented growth over the last 25 years. Lead batteries have continued to be more widely used in automotive and industrial applications and still provide 75 per cent of global rechargeable energy storage. New technologies have entered the market and lithium-ion (Li-ion) batteries in particular are set to grow substantially in electric vehicles of all types and in energy storage.

However, significant growth in demand for energy storage is predicted over the next 5-10 years and this will require battery technologies that can demonstrate continuous improvement and scale-up quickly to meet new requirements.

- In 1990 the rechargeable battery market was ~$15BN worldwide for lead batteries and ~$3BN for nickel-cadmium batteries.
- By 2017, the lead battery market had grown to $37BN and Li-ion battery sales were $36BN with ~$3BN for other rechargeable batteries including nickel-metal hydride which has overtaken nickel-cadmium.
- Lead batteries, however, represent 75% of the market in MWh because of the large price difference in $/MWh.
- For the future, Li-ion battery sales will continue to grow, and the total battery market is expected to double in value to ~$150BN by 2025.

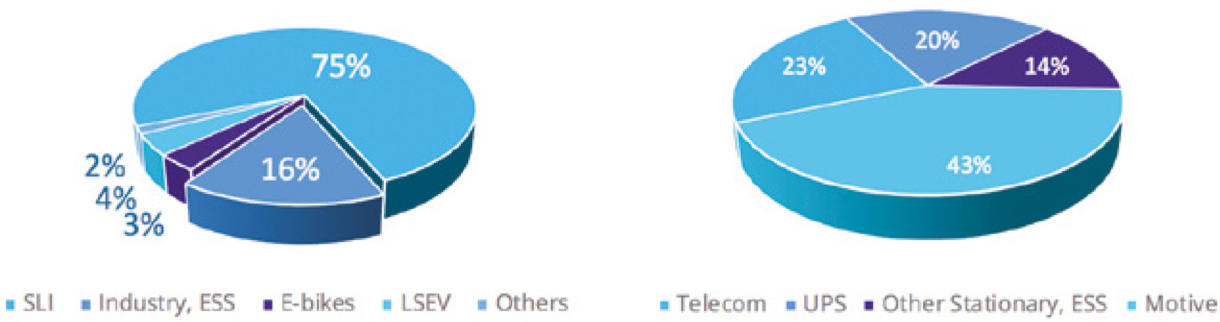


Figure 2 - Growth of battery for energy storage applications (Avicenne – ALABC report, 2018).

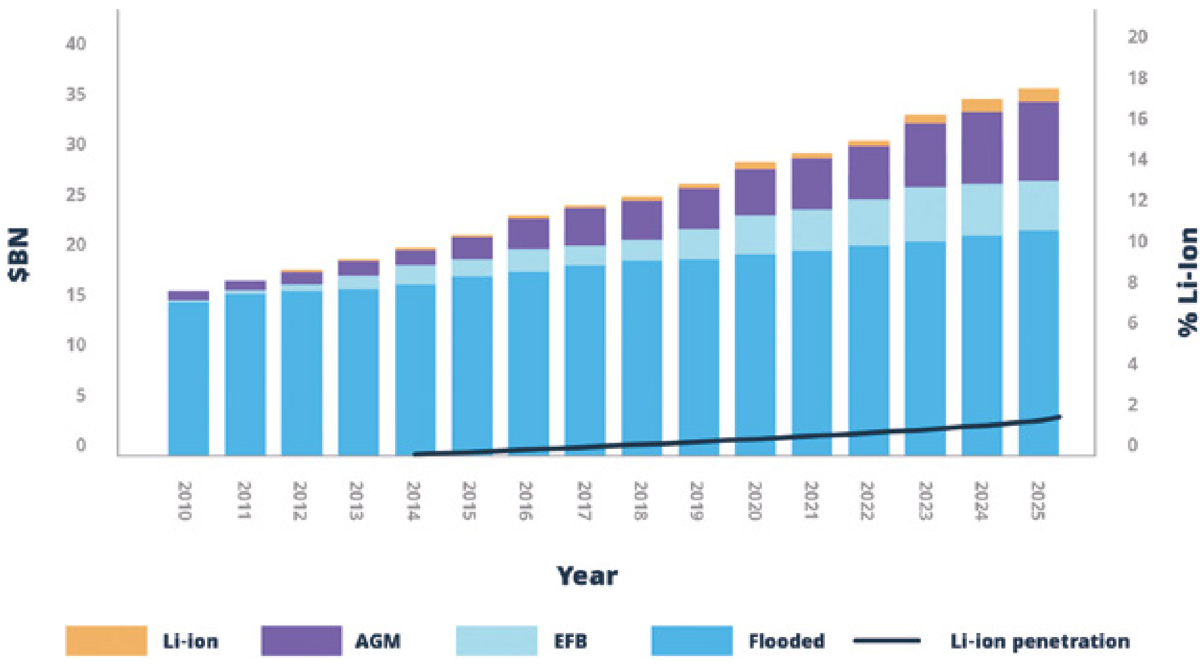


Figure 3 - Actual and projected sales of automotive batteries by type from 2010 to 2025 in $BN and percentage of Li-ion batteries.

The projections by market analyst firm Avicenne[1] indicate there will be growth for lead batteries particularly for automotive applications. Figure 2 shows the forecast sales for lead batteries in automotive service by type:

- A penetration of 5% for new cars by Li-ion 12 V batteries is forecast by 2025 but since 70-80% of the automotive market is for replacement, less than 2% of the market will move to Li-ion batteries.
- The original equipment market (OEM) will continue to use enhanced flooded batteries (EFB) and absorptive glass mat (AGM) batteries in increasing numbers and there will be a growing market for these types in the replacement market.
- However, a substantial part of the market will continue to use conventional flooded SLI batteries.
- In Europe, 80% of OEM sales will be micro-hybrid by 2025 with the United States and other regions following more slowly.

The overall market shows:

- Growth by ~5% annually in MWh and ~6% annually in $BN driven by continued growth in vehicle production and the car parc.
- Electric vehicles of all types will also use lead 12 V auxiliary (AUX) batteries, and as more functions are electrified on internal combustion engine vehicles, AUX batteries will also be used as secondary batteries for safety and security.

[1]Avicenne Worldwide Rechargeable Battery Market Report, 2018, 27th edition.

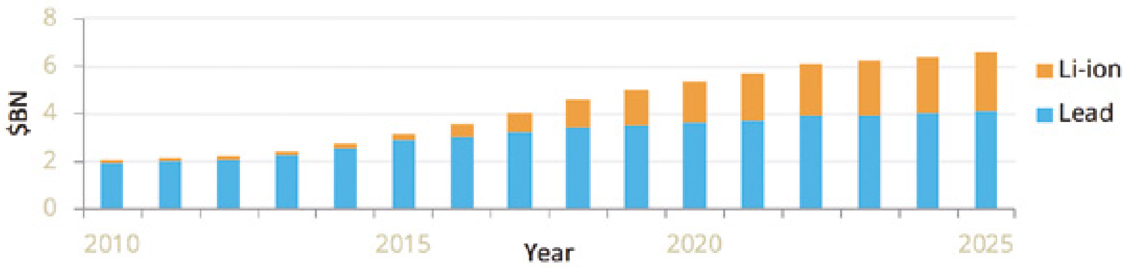
- This provides a significant future opportunity for lead batteries if they are able to adapt, improve and meet current and future OEM technical requirements.

For industrial batteries, the competitive position of Li-ion is different:

- Overall sales of batteries for telecommunications are forecast to grow by 2% annually from $3.2 to $3.8BN with Li-ion batteries potentially taking around15% market share which would mean a small contraction of the market of 1% for lead batteries. Li-ion batteries can offer a lower lifetime cost for certain applications.

- For UPS the overall market will grow at 3% annually from $2.8 to $3.5BN and although lead batteries retain the cost advantage, Li-ion batteries will take an overall share of 14%, with a small growth (1%) for lead batteries.

a)



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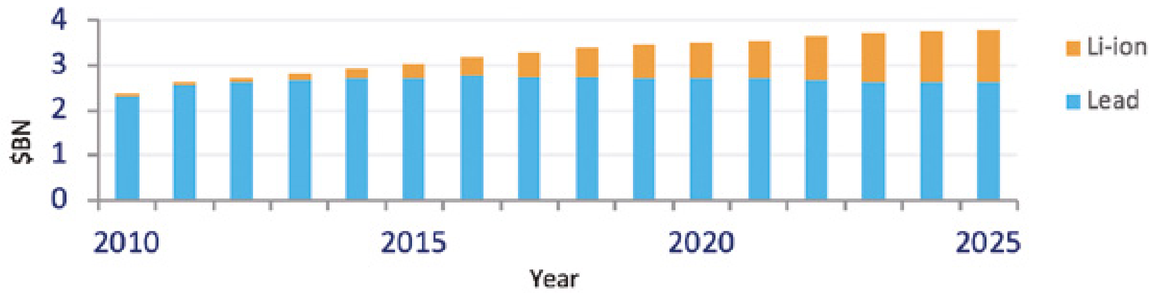


c)

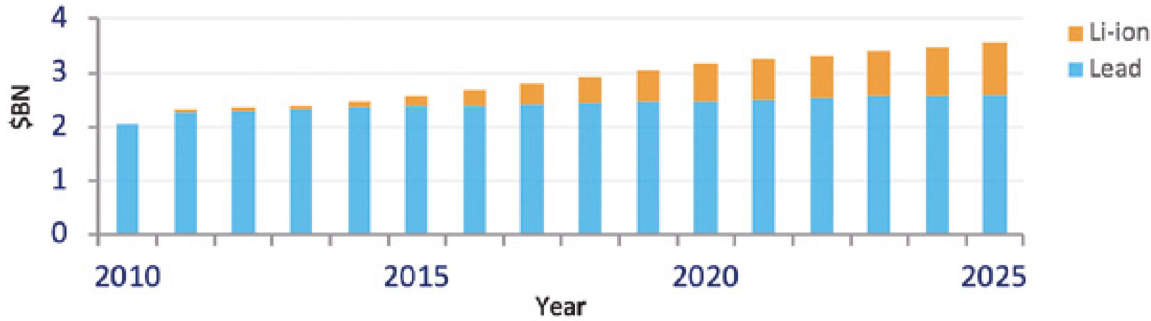


Figure 4 - Forecast sales for lead and Li-ion batteries for (a) telecommunications, (b) UPS and (c) traction applications in $M from 2010 to 2025.

For traction batteries, lighter and more compact Li-ion batteries are not an advantage for counterbalance trucks, but fast charge and more intensive use will allow Li-ion batteries to take a 15% market share. The market for lead batteries is forecast to grow from $3.2 to $4.1BN (3% annually). Overall the industrial battery market for lead batteries will grow in the forecast period but Li-ion batteries will take a significant share.

East Penn battery bank, PNM energy storage installation, New Mexico, United States.

Future growth and opportunity

Significant opportunities exist for growth for advanced lead batteries in energy storage systems (ESS), particularly in four key sectors:

1. **Renewable energy integration:** A wide range of systems will be needed to support smart grids and remote area power supplies for which lead batteries are ideally suited. The Consortium has identified case studies across the world where lead battery installations are demonstrating their value and effectiveness.
2. **Transmission and distribution reserves and investment deferral:** There are potential options in this sector with smaller systems (<5 MW, <10 MWh).
3. **ESS for residential applications:** This market is shared with Li-ion and lead batteries can expect to develop a significant share of the market going forward based on cost and performance. Lead batteries are currently used more widely in these applications in India, China and Africa.
4. **ESS for commercial and industrial applications:** There are excellent opportunities for lead batteries to expand in this sector, especially for residential applications in India, China and Africa.

As a conservative estimate, analysts suggest ESS has the potential for new business with a value in the range from $600M to $1.2BN for lead batteries in the forecast period. However, this could be significantly higher with greater levels of uptake of renewable generation, which governments and administrations are supporting through new climate change targets and policies.

1.5 The 2016-18 research program

The previous Consortium program concentrated on fundamental pre-competitive research to improve the dynamic charge acceptance (DCA) of lead batteries under partial state-of-charge conditions (PSoC) and increased shallow cycle lifetime for automotive batteries.

For ESS, research priorities were identified to improve lifetime under PSoC cycling and to improve cycle life. The following projects were funded under the 2016-2018 program. All reports and data generated from these projects is available for members on the Consortium website www.batteryinnovation.org.

Brno Technical University: Carbon and other additives for better negative active material performance in partial state-of-charge operation.

Bulgarian Academy of Sciences: Carbon additives for the negative active mass and hydrogen evolution at elevated temperatures.

Electric Applications Incorporated, CSIRO, NorthStar Battery, Swinburne University: Influence of electrolyte concentration local to the negative active mass on dynamic charge acceptance.

ISEA (RWTH), Battery Engineers, Karlsruhe Institute of Technology: Evaluation of dynamic charge acceptance and water loss in partial state-of-charge conditions.

Tianneng Power: Stability of the negative active mass in automotive batteries.

Technical University of Berlin, ISC Fraunhofer, Ford Research: Effect of additives and negative active mass microstructure on dynamic charge acceptance in micro-hybrids.

Jinkeli Battery: Improving the cycle life of energy storage batteries by the use of nano-silica sol technology.

Shuangdeng Group (ChinaShoto): Alloys for low carbon energy storage batteries operating at elevated temperatures.

Exide Technologies: Carbon nano materials in the positive active mass of energy storage batteries.

Narada Power: Life and cost optimization of absorptive glass matt valve-regulated lead-acid batteries for frequency regulation and load following to IEC 61427-2 for on-grid energy storage systems.

MeasX: Development of a portable, compact and inexpensive in-situ measurement of water loss and evolved gas composition.

Moving research to the next level

These programs form a balanced portfolio of work and have delivered important results which supported improvements in lead battery technology.

However, some projects are taking our research program to a completely new level.

The Consortium has initiated a major new project with US members, Electric Applications Incorporated (EAI) and Argonne National Laboratory (ANL) through the Argonne Collaborative Centre for Energy Storage Science (ACCESS) – the U.S. Government funded laboratory[2]. The collaborative research project will use the ANL facility's ultra-bright, high-energy X-ray beams to investigate the complex interactions taking place inside lead batteries *in-situ* and in real time.

The Consortium is exploring new partnerships with governments and universities worldwide to develop batteries which continue to push the boundaries and can support global drives to reduce carbon emissions and provide reliable and cost-effective energy storage.

Advanced Photon Source, Argonne National Laboratory, Chicago, United States.

[2] "Battery Mainstay headed for a high tech makeover", Steve Koppes, October 16th 2018 https://www.anl.gov/article/battery-mainstay-headed-for-hightech-makeover

1.6 Drivers for the Consortium's technical roadmap

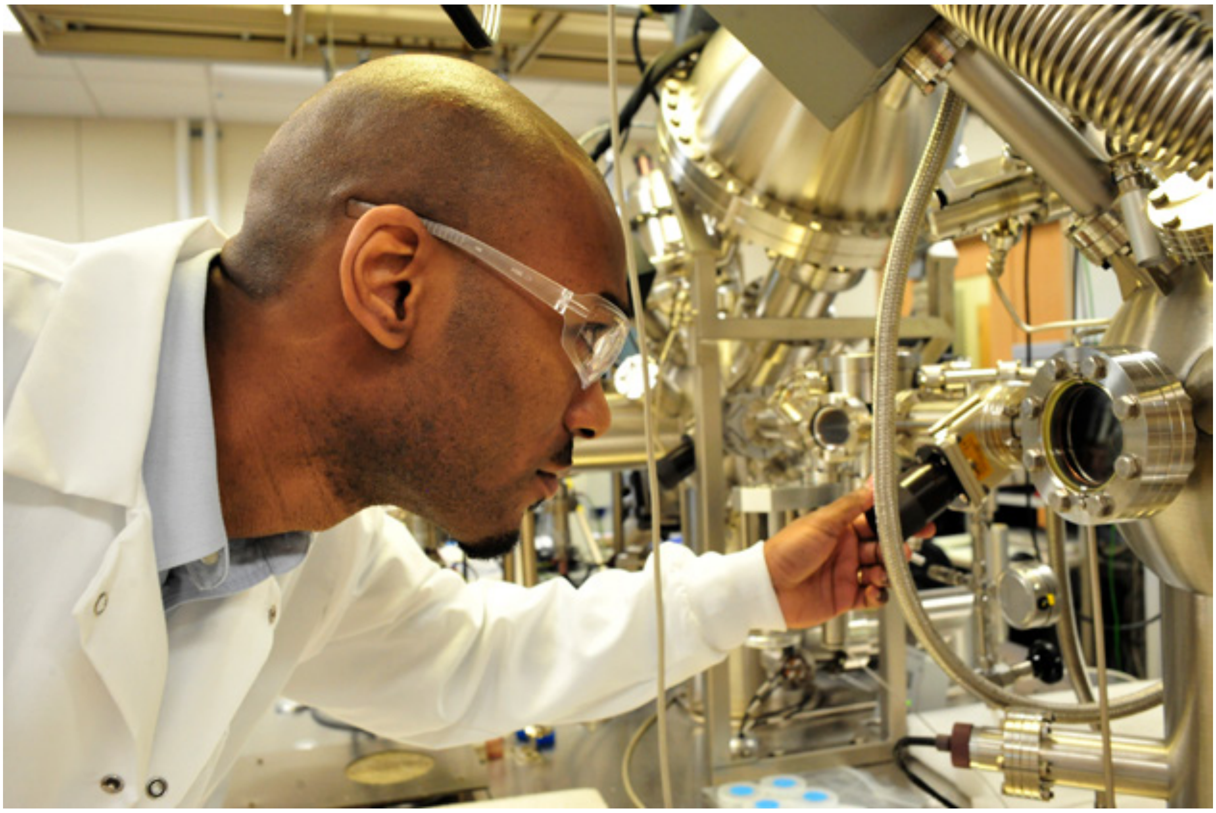
The roadmap has been developed in to order ensure future research projects are market-driven and deliver results that will make a tangible difference to lead battery performance. The roadmap will be used to prioritize research projects for 2019 onwards.

The roadmap is based on a detailed analysis of:

- Market trends
- Future technical requirements of end-users

The process has involved defining Key Performance Indicators (KPIs) and research objectives for future lead battery research. Specific research areas have been agreed, which the membership believe will deliver on the research objectives and KPIs.

The roadmap will be regularly reviewed both in the light of research results and the evolution of market needs. It is intended to be continually updated.



Argonne National Laboratory, Chicago, United States.

1.7 Current technical requirements for lead batteries

SLI	ISS / Micro - hybrid	Auxiliary batteries
CCA 20 h capacity 5 – 7 year life Low cost Recyclable	+ DCA + HRPSoC	20 h capacity High rate performance 5+ year life Low cost Recyclable

SLI	ISS / Micro - hybrid	Auxiliary batteries	Auxiliary batteries
Calendar life 8 – 9 h capacity Low cost Recyclable	Calendar life 15 m performance Low cost Recyclable	Cycle life 5 h capacity Low cost Recyclable	Calendar life Cycle life + PSoC operation Low cost Recyclable

Table 1 - High level requirements for lead batteries.

Table 1 encapsulates the requirements for lead batteries of all types and highlights the main areas where improvements have been made in recent years and remain as priorities. For automotive batteries, standard SLI batteries are specified for cold cranking performance (CCA), low rate capacity at the 20 h rate and for durability to provide the expected service life. For use in start-stop (SS) or micro-hybrid service, either with an AGM or EFB construction, DCA and high-rate partial state-of-charge operation (HRPSoC) become essential and must improve[3]. Auxiliary batteries are in use today both for electric vehicles of various types and for internal combustion engine vehicles. Most are AGM at present as they have been developed from standby batteries but could be flooded. The key requirements are low rate capacity, sufficient high rate performance to perform prescribed emergency duty cycles over a range of SoC and good calendar life. For all types low cost and good recycling characteristics are a given.

For industrial standby batteries, calendar life in floating service depends on the application requirements and operating conditions and can be up to 20 years. The technical performance differs by application; for telecommunications 8-10 hour discharges are required and for UPS, a discharge rate of 15 m is a good benchmark. Cycle life is generally not important unless the local power quality is poor. For traction batteries, cycle life is the main requirement and discharge is at the 5 h rate. For ESS batteries, both calendar life and cycle life are important, and the duty cycle may involve PSoC operation, for example in solar PV service, and, therefore, cycle life and PSoC operation are highlighted as areas for improvement. As for automotive batteries low cost and high sustainability are essential.

[3][1] EN 50342-1: 2015 Lead-acid starter batteries – Pt 1: General requirements and methods of test, [2] EN 50342-6: 2015 Lead-acid starter batteries – Pt 6: Batteries for micro-cycle applications

E-bikes are an important application for VRLA batteries and are under competitive pressure from Li-ion batteries. The discharge rate is faster than for traction batteries at 2-3 h and the main technical feature required is good cycle life.

The Consortium has identified start-stop or micro-hybrid automotive and ESS industrial batteries as the priority areas for the 2019 onwards. However, it is assumed that the results of the research projects will be beneficial for developing lead batteries for all applications.

Lead battery in use in an e-bike in Chengdu, China

1.8 Automotive batteries

Function	Current Status	Research Priorities
DCA for energy recuperation	Poor performance, decreases in use	Top priority. Additive screening may be flawed as high water loss options rejected. New durability tests needed
PSoC durability, fast SoC recovery, robust ISS capability over life	Reasonable PSoC durability	Lower priority
Lower warranty rates in hot climates	Unsatisfactory but needs to be achieved without using thicker plates	Design, materials and charging procedures need to be considered
Safety and vehicle electrification (driving assistance, functional safety)	No major technical performance issues. Better SoH and SoC detection and failure prediction	Understanding of BMS parameters and diagnostics

Table 2 - Technical status for start-stop/micro-hybrid batteries.

Table 2 summarizes the technical status for start-stop (SS)/micro-hybrid batteries with an assessment of the research priorities. The first requirement is improved DCA. For new research work, this is the top priority and the note regarding additive screening reflects the difference between water loss in field trials and bench testing to established procedures which have resulted in work to devise new durability standards.

In terms of durability under PSoC cycling, rapid recovery of SoC and stable SS/micro-hybrid capability over life, current batteries are satisfactory but as DCA improves, longer PSoC life becomes more important. OEMs are looking for lower warranty rates in hot climates without using thicker plates.

Battery design, materials and charging procedures need to be considered but this is not a priority research area for the Consortium. The use of 12 V SLI or SS/micro-hybrid batteries for safety and support functions on vehicles with higher levels of electrification is becoming more widespread. There are no major technical issues for batteries as such but better SoH and SoC estimation are becoming more important so that battery reliability can be assured when functional safety is essential.

<table>
<tr><th>Function</th><th>Current Status</th><th>Research Priorities</th></tr>
<tr><td>AUX (E) battery in xEV (BEV, PHEV, HEV, 48 V) with no engine start function</td><td>Reasonably satisfactory, good cycle life needed and performance over a wide SoC window</td><td rowspan="2">Lower priority.
Requirements for higher performance at low SoC, better diagnostics for safe and secure operation and standardization as a route to lower costs</td></tr>
<tr><td>AUX (P) battery for transient load response</td><td>As AUX (E) but with high performance at low SoC and fast charge capacity</td></tr>
</table>

Table 3 - Technical status for auxiliary batteries.

Table 3 summarizes the status for auxiliary (AUX) batteries. AUX (E) refers to a 12 V lead battery in an electric vehicle which has no engine start function. This can be on a pure battery electric vehicle (BEV), a plug-in hybrid electric vehicle (PHEV), a hybrid electric vehicle (HEV) or a vehicle with a 48 V battery which starts the vehicle so that the AUX (E) battery only supports other 12 V functions. AUX (P) refers to a battery on a vehicle with a 12 V lead SLI, EFB or AGM battery for engine start, SS/micro-hybrid capability and other functions which provides power for transient loads for safety and security functions in order to ensure a redundant power supply. Both types have reasonable performance at present. AUX (E) batteries need to have a good cycle life and performance over a range of states-of-charge (SoC). AUX (P) batteries operate more in standby mode and so cycle life is less important but good recovery after discharge is needed and the duty cycle will usually require a moderately high discharge rate even at a SoC. There are no special research requirements but as for SLI, EFB or AGM batteries providing safety and support systems, better SoC and state-of-function (SoF) detection and failure prediction is needed for the highest levels of functional safety.

Overall, OEM battery requirements are moving rapidly, especially in Europe, to meet ever increasing emission standards. Lead batteries still retain most of the market both now and in the medium-term, but Li-ion are getting better and cheaper. Improving DCA and resolving the associated water loss issues needs to be addressed urgently. The requirements are high and stable DCA, PSoC durability with fast SoC recovery to provide stable SS/micro-hybrid capability over life and lower failure rates in hot climates. More realistic high temperature tests are a key to improved DCA. More precise SoC and SoH measurements are needed for batteries supporting safety and vehicle functions whether they are SLI, EFB, AGM or AUX batteries. Li-ion batteries are always fitted with a BMS and lead batteries need to have a similar capability if they are safety critical.

1.9 Key Performance Indicators for automotive batteries

Indicator	2019	2022	2025
DCA. A/Ah	0.4	2.0	2.0
PSoC, 17.5% DoD	1500 EFB	2000 EFB	3000 EFB
Water loss, g/Ah	< 3	< 3	< 3
Corrosion, J2801, Units	12	18	22

Table 4 - DCA does not need to exceed 2.0-2.5 A/Ah for small cars (L3 battery) as this matches the alternator output; PSoC continuous test; water loss and corrosion targets are not important if new life tests are specified. Priority areas in red.

The analysis of battery performance requirements has resulted in the definition of a small number of KPIs, shown above as the main objectives defined by the technical roadmap. The DCA and PSoC targets are the first priority and are highlighted in red. The DCA level is set at 2.0 A/Ah as the priority KPI. The alternator output of a 70Ah battery is typically 2.0-2.5 kW. The key system requirements for micro hybrid applications will be met if the battery can accept charge at this rate (2.0 A/Ah). An intermediate DCA level of 1 A/Ah would be a useful improvement, especially if this was stable over the lifetime of the battery. The current relevant standards for demonstrating these improvements in DCA are:

- EN 50342-6: 2015 Lead-acid starter batteries – Pt 6: Batteries for micro-cycle applications.
- SAE J2801_200704 Comprehensive life test for 12 V automotive storage batteries.

In the case of the KPI for PSoC, it should be measured in a continuous test as defined in IEC 50342-6.

1.10 Automotive battery research objectives

The principal research objectives for automotive batteries identified in section 1.8 required to meet the KPIs are summarized below (the activities in bold are the highest priorities):

- **Improve DCA and extend capability to lower temperatures**
- **Improve HRPSoC life**
- Understand water loss under cyclic/overcharge conditions to re-specify tests for durability
- Increase corrosion resistance of positive grids
- Increase intrinsic high temperature durability
- SoC/state-of-health (SoH) measurement techniques
- Development of AUX batteries.

Lead batteries continue to be widely used in automotive applications.

1.11 Priority research areas for automotive batteries

In-depth discussions have identified a number of promising areas where research efforts should be directed for the current program. It is felt that work in these research areas is most likely to help meet the research objectives and KPIs for automotive batteries.

These are summarized as:

- Optimization of the beneficial effect of carbon in the positive and negative plates. In particular further study of function of carbon in following areas:
    - carbons coated with other materials by chemical or physical methods
    - carbons with different functional groups bonded to the surface
    - carbons in concert with selected trace elements
- Studies of water loss and gassing behavior in HRPSoC operation at high temperature
- Studies of alternative additive materials and their interactions
- Understanding the effect of rest periods on DCA by examination of the active mass and electrical performance
- Further work on how to optimize behavior for different duty cycles
- Studies of how BMS/SoC/SoH measurement techniques improve charging and battery life.

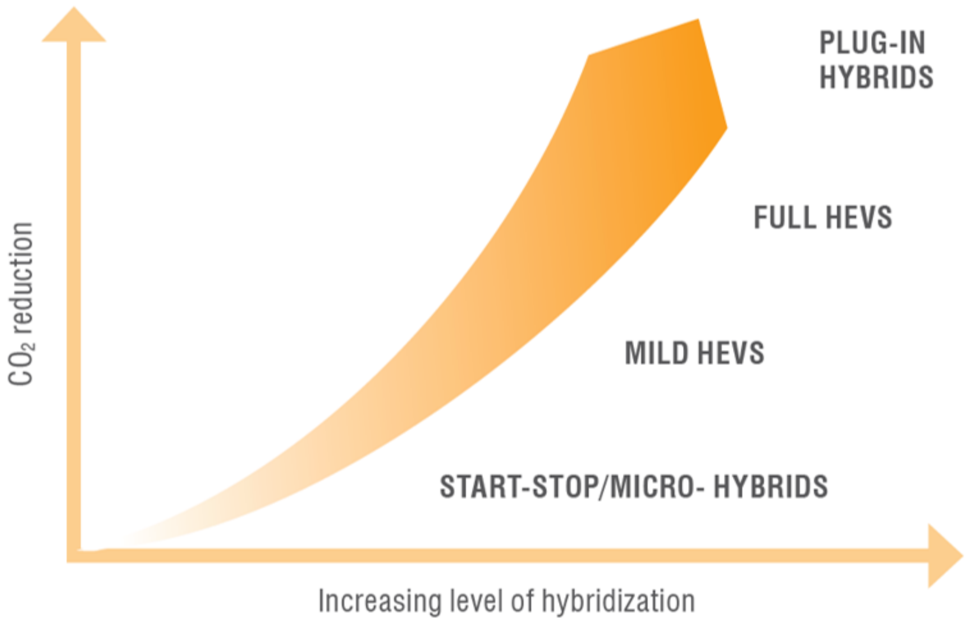
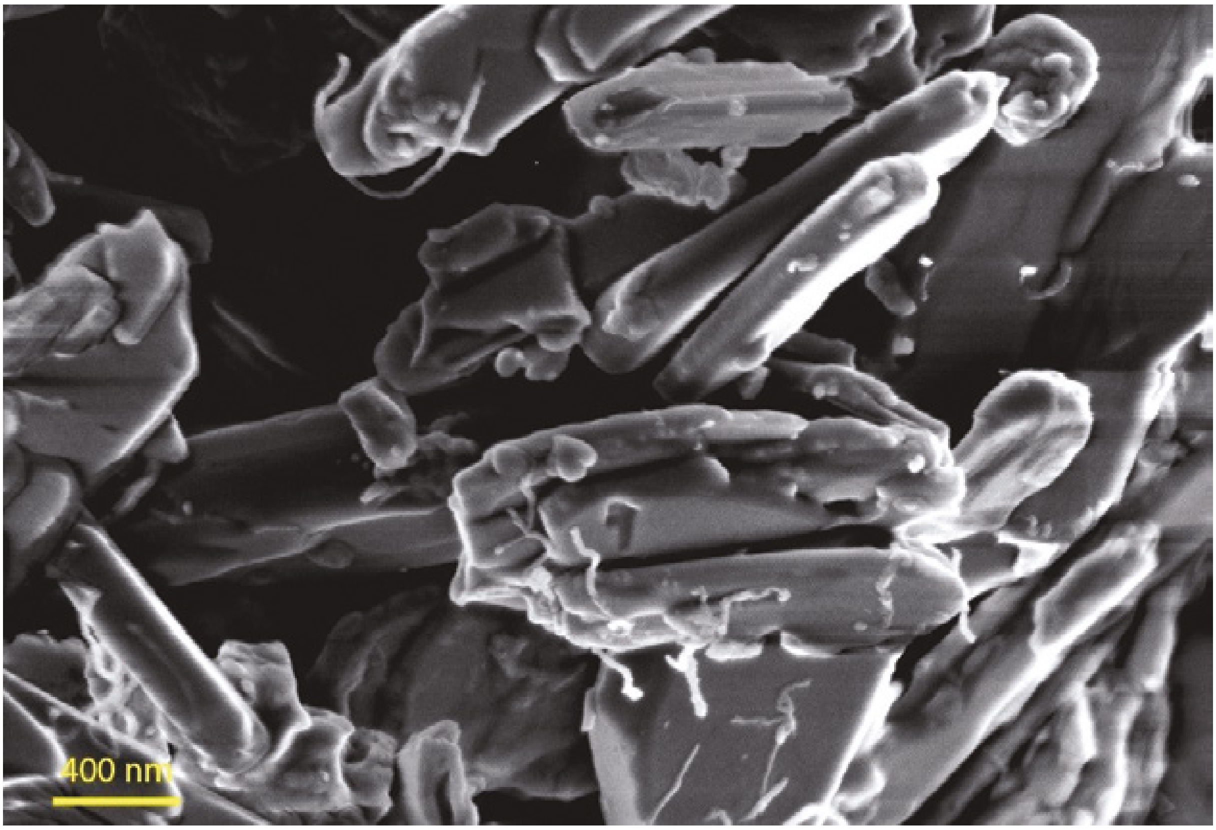


Figure 5 - The levels of automotive electrification readily available in the current market. Lead batteries provide a vital role in all of these platforms.

It is clear that the function of carbon in the negative active material is complex and that there are a number of useful directions for research work. There are three mechanisms for the improvements in negative plate performance: physical effects, extending the conducting surface for electrochemical and chemical processes and capacitance effects. The physical effects can be to obstruct the growth of lead sulphate crystals, to improve the electrolyte flow within the electrode and to reduce stratification. Carbon may extend the conducting surface for reactions that take place on the surface of the carbon. Capacitance effects may be purely electrostatic with charge absorbed into the double layer or pseudo-capacitance where there is electrochemical storage involving electron transfer with, for example, surface functional groups that allow intercalation of ions. Studies of carbons treated as indicated will help to elucidate mechanisms and increase their effectiveness as well as controlling water loss.



One of the research areas for the Consortium is the use of new carbon materials in lead batteries. Carbon additives, such as Exide Technologies' carbon nanotubes (CNT)s pictured above in the active mass of a positive electrode in a lead battery, open new avenues for improvements in cycle life and DCA.

1.12 Industrial and ESS batteries

For ESS batteries the first requirement is longer cycle life. The best in class VRLA batteries can achieve 5000 cycles to 70% DoD[4]. There is also a need for improved PSoC performance as the use of batteries with renewables is often in conditions where a full charge may not be routinely achieved. Many of the innovations for SS/micro-hybrid batteries have been adapted for ESS applications and further work is needed. Lead batteries compare unfavorably with Li-ion batteries both on gravimetric and volumetric energy density and whilst it is impossible to significantly reduce the difference, innovations to improve the volumetric energy density will be useful. High temperature durability is another area for improvement.

At system level, ESS with lead batteries must be fully packaged with enclosures, air conditioning if required, fire detection and suppression, BMS and, if specified, inverters and rectifiers. Suppliers need to offer a full solution with support and service over life. These are not Consortium research activities but they are part of the product offer that needs to be available.

NorthStar Battery bank, Springfield energy storage project, Missouri, United States.

The Consortium will, however, support work to generate tools that will allow the total cost of ownership (TCO), levelized cost of electricity (LCOE) or levelized cost of storage (LCOS) for lead batteries to be calculated and compared objectively with Li-ion batteries and other systems.

[4] [1] GS Yuasa 2 V, 1000 Ah VRLA batteries Type SLR-1000 provide 5000 cycles at 70% DoD at 25oC; Hitachi Chemical 2 V, 1500 Ah VRLA batteries Type LL 1500-WS provide 4500 cycles at 70% DoD at 25oC and a 17-year calendar life.

1.13 Key Performance Indicators for ESS batteries

Indicator	2019	2022	2025
Service life, Y	12+	12-15	15-20
PSoC, PV	1500	2000	2500
Cycle life	1000 - 3000	5000	6000
Charge efficiency	85 – 90%	90 – 95%	> 95%

Table 5 - Key Performance Indicators for ESS batteries.

The main areas for improvements to lead ESS batteries are in cycle life and PSoC cycling particularly when used with solar PV charging as highlighted in yellow. Service life can be achieved if the cyclic requirement is limited but to effectively use cycle lives of 5000 cycles or more the calendar life must be in the range of 15-20 years. Charge efficiency requires careful charge management as well as improvements in battery design.

1.14 Key Performance Indicators for traction, e-bike, telecoms/UPS

KPIs have been developed for traction, e-bike, telecommunications and UPS applications. These will not be specifically targeted by the Consortium research programs but will benefit from improvements in the main program and may merit some research effort. These are summarized as:

Traction

- Higher cycle life including AGM and gel types (2500 cycles for flooded at 80% DoD, 1500 cycles for VRLA at 80% DoD; BCI-06).
- Better charge efficiency (95%).
- Fast charge (40 A/100 Ah).

E-bike

- Higher cycle life for AGM (800 cycles at 100% DoD).
- High temperature durability.

Telecoms/UPS

- Longer float life at high temperatures (>10 years at 40oC).
- PSoc life for hybrid applications (>12000 cycles at 10% DoD).

Increases in warehousing result in an increase in fork lifts. Battery-powered fork lifts will become more popular in Europe and other areas in the next ten years.

1.15 ESS battery research areas

The principal research activities for ESS batteries required to meet the KPIs are summarized below (the activities in bold are the first priority and the others are secondary):

- **Improve deep cycle life (70-100% DOD)**
- **Improve PSoC life**
- Increase corrosion resistance of positive grids
- Increase high temperature durability
- Improve fast charge capability
- BMS functionality and TCO, LCOE and LCOS modelling.

1.16 Priority research objectives for ESS batteries

The same discussions that identified the most promising areas for the current program for automotive batteries suggested the following research areas for ESS batteries. Work in these research areas is most likely to help meet the research objectives and KPIs for ESS batteries. These are summarized as:

- Optimization of the beneficial effect of additives in positive and negative plates with reference to ESS duty cycles, especially shallow cycling
- Basic studies of active material degradation – examination of both active materials after different cycling regimes to recognized standards
- Understanding the beneficial effects of shallow cycling – reciprocity effects – morphology of active masses in state-of-the-art cells
- Studies of BMS requirements and how to use these to improve charging and battery life
- Modelling of TCO, LCOE, LCOS, and how this can be optimized for lead batteries.

As for automotive batteries, carbon additives to the negative active mass are important where PSoC operation is the usual regime but it was considered that for deeper cycling additives to the positive active mass capable of promoting enhanced cohesion over time should be investigated if they have sufficient promise. In cyclic applications further knowledge of changes in the morphology of both electrodes would be important. Also, the reasons for higher capacity turnover or cumulative Ah of throughput in shallow cycling should be studied in order to optimize calendar life of the battery.

The key standards are:

- IEC 61427-1: 2013: Secondary cells and batteries for renewable energy storage: General requirements and methods of test: Pt 1: Photovoltaic off-grid application
- IEC 61427-2: 2015: Secondary cells and batteries for renewable energy storage: General requirements and methods of test: Pt 2: On-grid applications.

For both automotive and industrial batteries, although the Consortium has defined KPIs for the technical roadmap, it is fully open to potential research contractors to propose work with different themes provided that they are clearly directed at the overall objectives of the program. The Consortium encourages new research and the areas identified may not be where new solutions will be discovered.

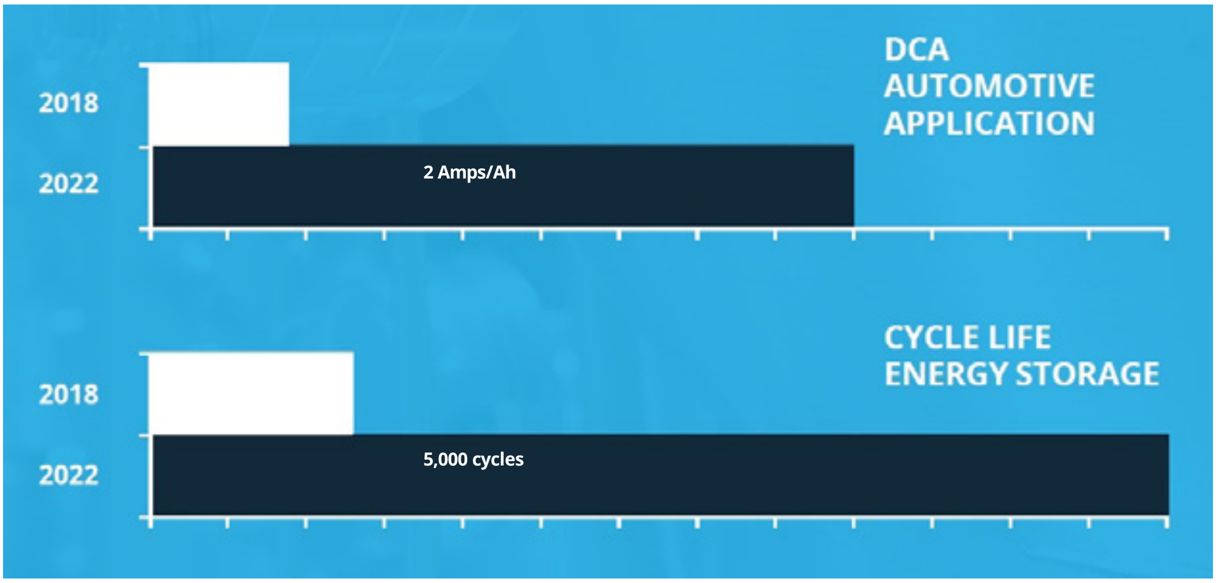
1.17 Conclusion

The energy storage market is poised to expand dramatically over the next ten years, with the lead battery acting as a primary contributor in this new societal impact of energy storage. Automotive application of 12 V lead batteries shows steady growth over the next ten years with insignificant Li-ion penetration into this market sector. Conversely, the industrial sector has seen an aggressive arrival of alternative technologies, threatening the position of lead batteries. Finally, lead batteries in ESS applications pose an opportunity for rapid market expansion but lead battery products must be poised to provide the proper performance. In each case, innovation is key to preserving or expanding the presence of lead batteries.

The Consortium has developed a technical roadmap for innovation to provide clear goals and metrics for lead battery product improvement. A preliminary set of metrics have been identified as the direction for the ESS, automotive, and industrial uses of lead batteries. Furthermore, research areas have been outlined as an example of study to directly benefit the KPIs listed in sections 1.9, 1.13, and 1.14.

Major common themes are present in the KPIs outlined for lead batteries in different applications. Cycle life and rechargeability (DCA or recharge time) need to be improved and are paramount to the improvement of lead battery in all applications.

The Consortium aims to use use this technical roadmap for innovation to increase product development and decrease adoption times for products in the lead battery industry. The Consortium will utilize the roadmap and KPIs to develop research programs focused on improving lead batteries in DCA/rechargeability and cycle life (or capacity turnovers). The technical roadmap document will be adapted and changed as the needs of the end-users and market change.



Highest priority research objectives

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