Battery Council International (BCI)

Comments on DE-FOA-0002360: Request for Information on the Department of Energy (DOE) Energy Storage Grand Challenge

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Battery Council International (BCI) appreciates the opportunity to offer comments on DE-FOA-0002360: Request for Information on the Department of Energy's Energy Storage Grand Challenge. BCI is a not-for-profit trade association formed in 1924 to advance the interests of the lead battery industry. BCI has member companies worldwide engaged in every facet of the industry: lead battery manufacturers and recyclers, marketers and retailers, suppliers of raw materials and equipment, and expert consultants.

The comments from BCI also reflect comments from the Consortium for Battery Innovation (CBI), a pre-competitive research organization in Durham, NC, funding innovation in lead batteries, and the Lead Battery Science Research Program (LBSRP), a consortium based in Phoenix, AZ, of North American lead battery manufacturers and suppliers engaged in a Cooperative Research and Development Agreement (CRADA) with Argonne National Laboratory and the U.S. Department of Energy.

I. Introduction

The U.S. lead battery industry strongly supports the three objectives of the Energy Storage Grand Challenge: Innovate Here, Make Here and Deploy Everywhere.

Innovate Here:

Innovation is the lifeblood of the lead battery industry. The batteries of today look and perform nothing like the battery invented by Gaston Planté in 1859, and the lead batteries of tomorrow similarly will outstrip the lead batteries of today. The North American lead battery industry's longevity is the result of constant innovation, supported by more than a century's worth of scientific knowledge and research. But the incredible electrochemical opportunities presented by the basic lead battery chemistry have yet to be fully tapped. BCI's U.S. members spent $100.4 million on research and development in 2018 to prepare the industry for the next generation of lead batteries.

The lead battery industry is on the threshold of another generation of discovery with the potential to achieve far greater performance from the materials inside the battery and the performance enhancements offered by new architectures. Recent discoveries and inventions show that the lead battery basic chemistry and construction technologies are poised to make dramatic advances in the coming years, moving this domestic industry to the forefront of energy storage technologies. Unique among the major battery chemistries under development, future generations of lead batteries are designed to be compatible with and fully recycled by a recycling infrastructure that already recycles 99% of end-of-life batteries.

The current draft of the DOE Energy Storage Grand Challenge Roadmap characterizes lead batteries as a “mature” technology, and properly recognizes the significant capital cost advantages presented by lead battery systems. Because the lead battery industry operates in a “mature” and stable manufacturing and recycling environment in the U.S., there is a unique opportunity to focus public and private research and investment on the substantial potential for growth in performance of the chemistry. The mature domestic manufacturing and recycling foundation allows the lead battery industry rapid path to market for new discoveries because the chemistry-specific infrastructure and know-how is already here.

The draft roadmap, however, incorrectly suggests that lead battery designs have hit a ceiling in energy density and state of charge. (ESGC Draft Roadmap, page 64). The data presented in the draft roadmap only describe lead battery systems and architectures designed to the specific requirements of existing applications and do not accurately reflect new design technologies already being deployed and the significant advances that are currently under research and development through private industry efforts as well as public-private research programs. The theoretical energy density for lead batteries is approximately 170 Wh/kg, but conventional lead batteries have historically only realized a gravimetric energy density of 30-40 Wh/kg. Newer battery designs entering the market today have already doubled the energy density to 60-70 Wh/kg. But significant potentially capacity remains, and the research efforts described below are poised to unlock that potential.

There have been many innovations over the past few years that have provided strong pathways for lead battery performance improvement. The improved architecture of bi-polar batteries increases energy density, and new types of grid alloys, silicon wafer grids, and ceramics as key structural components serve as a key target area for inclusion into more advanced lead battery designs. To complement these new electrode materials and lead battery designs are a host of additives for the active material and electrolyte, from carbon nanotubes and graphene to ionic salts and liquids, that have shown demonstrable impacts on recharge capability and lifetime of lead batteries. They have yet to be fully evaluated for energy storage systems and as a result serve as significant jumping off point for study and performance enhancement.

U.S.-driven research into new battery architectures such as bi-polar batteries and new technologies such as carbon additives promise to provide lead-based batteries with performance comparable to lithium technologies, while preserving the abundant domestic supply chain and closed-loop recycling framework. These advances are described in Section 1 - Technology Development – D.3 Technology Pathways. With appropriate support and engagement from federal resources, this critical American industry can maintain its competitive performance against foreign-made batteries with its unparalleled sustainable industry footprint.

Make Here:

The U.S. lead battery industry directly employs approximately 24,700 U.S. workers and spends $1.7 billion annually on payroll. In addition to the workers directly employed, the lead battery industry supports 30,900 supplier jobs and another 36,600 jobs from spending in different industries. Together, these impacts total 92,200 jobs, providing more than $6 billion in labor income and more than $26.3 billion in economic output in 2018. In addition, BCI member companies spent $100.4 million on research and development to prepare the industry for the next generation of lead batteries.

The vast majority of lead batteries sold in North America are manufactured in the U.S. The U.S. lead battery industry operates within the world's most stringent regulatory environment, which helps ensure that manufacturing and recycling plants are clean, safe and efficient. No other battery chemistry comes close to the sustainability profile of lead batteries.

Further, 99 percent of used lead batteries in the U.S. are recycled. [1] This means that the raw materials used to manufacture lead batteries in the U.S. and North America are recycled and produced domestically, including the lead, plastic, and electrolyte. According to the U.S. Geological Survey, domestic U.S. recycling of used lead batteries and other lead-bearing scrap provided approximately 72% of the domestic demand for lead in 2019, of which battery production accounted for 93% of demand.[2] In addition, more than half of the imported lead came from Canada and Mexico, where the largest facilities are owned by or have long-term relationships with U.S. companies.[3] That unparalleled domestic supply chain ensures that the primary input material for lead batteries is readily available and insulated against major international supply chain interruptions.

Building upon the existing domestic manufacturing and recycling capacity of the lead battery industry will allow Energy Storage Grand Challenge goals for "make here" to be met in a more timely and certain manner and will ensure that this critical U.S. battery industry remains vibrant and insulated from international supply chain disruptions. Taking advantage of the innovations possible with lead batteries optimized for grid energy storage assures there will be a secure domestic manufacturing supply chain that is independent of foreign sources of critical materials by 2030. The security of the materials used in the manufacturing of lead batteries combined with end-of-life stewardship provides a safe, reliable, and sustainable energy storage solution for the US. There is strong potential to implement lead batteries into ESS applications on a large scale today.

Deploy Everywhere:

Lead batteries are an important asset in responding to America's need for a new generation of storage technologies. In the case of vehicle technologies, for example, lead batteries are vital for use not only in conventional vehicles with drive trains powered by internal combustion engines, but also a new generation of hybrid electric vehicles. Even with the advent of vehicles powered exclusively by electrified drive trains with lithium-ion batteries, lead batteries remain essential for powering vehicle starting, lighting and ignition systems and also safety, connectivity and infotainment functions. With vehicle-to-grid technologies on the horizon, charging stations are essential. Lead batteries can be deployed in numerous ways, including vehicle charging units equipped with solar panels. Moreover, lead batteries can help make the planning and operation of the nation's electric power industry more efficient by minimizing the need for new power plants or transmission lines, thereby helping reduce emissions from fossil fuels used for power generation.

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[1] https://batterycouncil.org/page/Battery_Recycling

[2] U.S. Geological Survey, 2020, Mineral commodity summaries 2020: U.S. Geological Survey, 200 p., https://doi.org/10.3133/mcs2020

[3] Approximately 55% of the imported lead supply was produced in Canada and Mexico in 2019.

Lead batteries are well-positioned and ready to help the U.S. economy embrace the transition to a more secure, efficient, environmentally beneficial and sustainable future.

II. Discussion of Storage Need

To enable the widespread adoption of battery energy storage by the electric power industry, the cost of battery systems must be reduced from the costs presented by lithium systems today. The lead battery industry has already demonstrated the lead battery chemistry's ability to drive cost-savings. For example, innovative lead batteries have proven particularly effective at providing immediate carbon emission savings for internal combustion vehicles through the deployment of micro-hybrid and stop-start applications. On a cost-per-carbon-savings basis, these vehicles can provide more cost-efficient reductions in emissions than pure electric vehicles. These applications have demonstrated the adaptability of lead battery technologies, and the rapid advancements that can be achieved by leveraging this robust domestic research and development and manufacturing capacity.

Among the many challenges facing the electric power industry in maintaining a reliable and resilient grid is integrating power from variable energy resources such as wind and solar. Because battery performance requirements for grid storage applications require longer discharge than those for electric vehicles, the cost targets are more stringent for stationary – rather than vehicle – functions.[4] As a result, the DOE Energy Storage Grand Challenge Draft Roadmap issued July 14, 2020, correctly recognizes that different storage technologies may be required for different applications:

> "The present-day commonality between mobile and stationary storage technologies may diverge. With much greater duration requirements and much less stringent density or weight constraints, non-lithium storage technologies may emerge as the most cost-effective solutions for these new use cases."

As a result, lower-cost energy storage, particularly batteries, will be increasingly relied upon for ensuring efficient integration of renewables to the grid. BCI offers for DOE's consideration a road map consisting of fundamental, applied, and demonstration research components.

BCI's remaining comments respond to specific sections of the ESGC RFI:

[4] "Energy Storage System Requirements for Grid-Scale Solar Generation," Argonne National Laboratory, 2012

III. Responses to Specific RFI Sections

Section 1 Technology Development – D.1 Use Cases

The ESGC Draft Roadmap contains a Use Case Overview chart listing several major drivers that define the scope for various use cases:

Table 1. Use Case Overview

Use Case	Scope		Major Drivers
1. Facilitating an Evolving Grid	The U.S. electric power system	√	• Increasing adoption of variable renewable energy • Dynamic changes in customer demand • Weather, physical, and cyber threats
2. Serving Remote Communities	Island, coastal, and remote communities	√	• Electricity premium due to fuel logistics and maintenance • Fuel supply disruptions
3. Electrified Mobility	• Charging infrastructure, including the distribution grid • Energy storage systems for electric vehicles	√	• Fast charging can stress distribution grids • Leveraging lower costs and improved performance of electric vehicle batteries
4. Interdependent Network Infrastructure	Infrastructure sectors critical to electric grid operations, including: • Natural gas, water • Communications • Information technology • Financial services	√	• Interdependencies mean loss of function, and service within these infrastructures can have far-reaching costs and impacts
5. Critical Services	Critical sectors, including: • Defense, government facilities • Emergency services, healthcare • Companies with stringent operational requirements	√	• Disaster-related and other power outages
6. Facility Flexibility, Efficiency, and Value Enhancement	6a. Commercial and Residential Buildings	√	• Enhance the overall facility value to the owner, operator, and the end consumer
	6b. Energy-Intensive or Generation Facilities, including: • Electric Power Generation • Industrial Process Applications	√	• Opportunities to improve economics, flexibility, and market diversity

√ Functions served by lead batteries

Lead batteries already serve all of the use cases described. Lead batteries contain up to 60% or more lead metal and lead compounds by weight, and are unique among battery chemistries in that the batteries have a positive net value at the end of life. When a lead battery or cell is replaced in a BESS, or at the time of system decommissioning, the system owner is often compensated by the original battery installer or a third-party collector who then recycles the valuable metal and other materials. By stark contrast, at this time the decommissioning of a lithium-based BESS will require the system owner to pay for the disposal of the batteries in the system – likely in a hazardous waste landfill. Furthermore, the intrinsic value of used lead batteries enables lead battery system developers to offer customers options unavailable from other chemistries, such as significantly discounted replacement cells, and some integrators are offering customers system leasing options which require little to no up-front capital expenditures, reduced total-cost-of-deployment, and guaranteed disposal at end-of-life.

Through continued innovation, the lead battery remains the technology of choice, providing a strong foundation of validation for lead technology through financing, customer collaborations, assurance of performance and warranty claims. For example, utilities for many years have used flooded lead batteries to provide standby backup power in substation and power generation plants. A study by the U.S. Bureau of Reclamation confirms that lead batteries are generally preferred at federal power dams because of their low acquisition costs and safer operational characteristics.[5]

Valve-regulated lead (VRLA) batteries were developed so that the battery would no longer require the continuous monitoring of electrolyte level. VRLA batteries are designed in two ways: gel electrolyte and absorbed glass mat (AGM). Gel batteries, introduced in the 1960s, use electrolyte in gel form for greater stability. They are outstanding in deep cycling and long-term energy storage systems. The AGM battery, which came to market in the 1980s, uses porous glass mats to absorb and hold the electrolyte and uses mechanical compression of the plates to facilitate internal recombination conditions for oxygen released at the end of charge. The AGM batteries are particularly popular in stop-start, micro-hybrid and high-performance vehicles and they also are used in industrial applications.

In recent years, the lead battery industry has come through with other innovations, including:

> The advanced "lead-carbon" battery that greatly expands the cycle life of the traditional VRLA battery by sharply reducing the sulfation of the negative plate at partial state of charge. This dramatically increases battery life to the point where an advanced lead-carbon battery can now equal—and in some cases even exceed—the performance of nickel-metal hydride (NiMH) and lithium-ion (Li-Ion) batteries, but at far lower cost.
>
> Thin Plate Pure Lead (TPPL) battery takes lead carbon a step further with plates measuring 1mm compared to conventional 2-4mm plates. Combined with stronger electrolyte, batteries have a higher energy density and faster charging capabilities.

As the nation's electric power system began increasing the integration of power from variable renewable energy (VRE) resources such as wind and solar facilities, the utility industry began evaluating the feasibility of large-scale battery storage to "bank" power for discharge during periods of reduced wind or sunshine.

One of the first such large storage facilities was installed by Southern California Edison in 1988 with lead batteries in a 10MW, 40MWh unit at a sub-station in Chino. It consisted of eight parallel strings of 1,032 cells with a capacity of 2,600Ah. The system was designed for 2,000 cycles over an eight-year period and in fact operated for nine years. Connected to a 12.5kV line that in turn fed into a 69kV line from the sub-

[5] "The flooded lead acid batteries are currently the best options due to their lifespan, cost, and dependability. Our research shows that 150 years later, there is still no cost-effective alternative battery technology that is better than lead acids for DC station service power." Department of the Interior, Bureau of Reclamation, "Study the use of alternate battery chemistry solutions," Research and Development Office, Science and Technology Program (Final Report) ST-2017 (ID)-1727.

station, it was used to demonstrate a variety of function including peak shaving, load levelling, spinning reserve, and black start. The lead battery system succeeded in all respects.

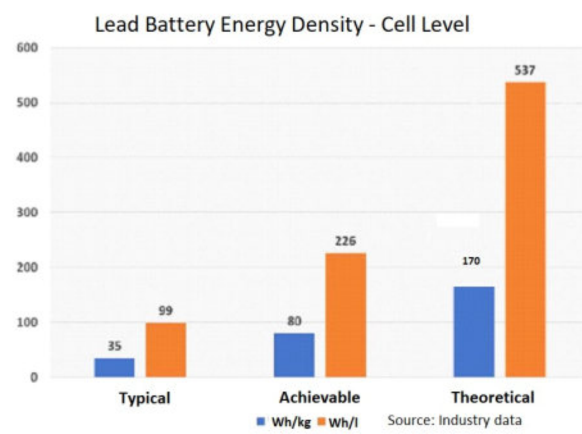
The lead battery industry has continued its work with electric utilities. In 2018, City Utilities of Springfield, MO installed a 1.1-MW, /2.5MWh system with 1,140 12-volt lead batteries to help the utility manage load requirements particularly under the stress of hot summer days. The utility selected lead batteries for use at the $1 million station not only because of battery cost, but because of concern that a comparable lithium-ion system could lack the battery end-of-life recycling feature of lead batteries.[6] Attached as Appendix A are case profiles from around the world of energy storage systems using lead batteries, which demonstrate that the technology is deployable in the U.S. Further case profiles can found on the CBI website.[7]

Most recently, lead battery industry innovation has been accelerated through the teaming of the North American lead industry with Argonne National Laboratory researchers to study the fundamental precipitation and dissolution reactions within lead batteries. This work is organized as the Lead Battery Science Research Program and is focused on innovations to support a variety of applications, including grid storage.

Section 1 - Technology Development – D.2 Technology Portfolios Metrics

The price point for batteries to be economically viable for grid storage applications has been estimated by industry observers to be approximately $55-85/kWh.[8] The DOE Office of Electricity (OE) has postulated several prospective, indicative cost goals for various battery chemistries and technologies:

Cost Goals for Focus Technologies Manufactured at scale	
Li-ion Batteries (cells)	$100/kWh
V/V Flow Batteries (stack+PE)	$300/kWh
Zinc Manganese Oxide (Zn-MnO_2 2 Electron System	$50/kWh
Low Temperature Na-NaI Based Batteries	$60/kWh
Aqueous Soluble Organic (ASO) Redox Flow Batteries (stack+PE)	$125/kWh
Advanced Lead Acid	$35/kWh
Source: DOE OE – Energy Storage Digital Series, May 11, 2020	



It should be emphasized that these are not predictions of battery costs. Rather, they reflect the theoretical potential of various battery technologies to achieve certain cost goals. OE is conducting intense research into a variety of battery technologies. It is research that requires significant commitment from both government and industry. BCI is pleased to note that OE includes advanced lead

[6] Energy News Network, April 27, 2018 https://energynews.us/2018/04/27/midwest/missouri-utility-looks-to-energy-storage-to-extend-life-of-substation/

[7] https://batteryinnovation.org/interactive-map/

[8] Argonne, op.cit.

batteries in its research of cost-competitive technologies and is working closely with OE on a variety of programs.

CBI and BCI are working as an industrial liaison sharing battery ESS data with key research institutions as they conduct economic assessments of energy storage technologies. For example, as PNNL conducts detailed analysis of technoeconomic models utilized to gain key insights into the total cost of ownership (TCO) and levelized cost of storage (LCOS) of ESS systems, CBI is currently providing the most current ESS data for the next iteration of the PNNL Energy Storage Technology and Cost Characterization Report.

To assess the economic value and impact of these research initiatives, it is necessary to undertake a TCO analysis that takes into account the unique qualities of lead batteries:

- Total utilization of domestically available materials
- Void of critical materials
- Well established American manufacturing capabilities
- Well-developed market supply logistics
- Inherent operational safety reducing siting and insurance costs
- Fully developed recycle chain providing a true circular lead economy

Unknown issues remain, however, relative to the capability of lead batteries to compete in the grid energy storage market on a TCO basis with lithium technology. To investigate the drivers of lead battery grid energy storage TCO, the analytic resources of the Argonne National Laboratory (ANL) and the National Renewable Energy Laboratory (NREL) have been organized to propose a technoeconomic analysis of lead battery grid energy storage and a comparison with equivalent capabilities using lithium battery technology. The Grid Storage Program at ANL and the Behind the Meter Storage Program at NREL have coordinated with the lead battery industry, to propose six tasks:

1. <u>Prepare initial battery-based solar + storage system analysis</u>:
   An inclusive 1st pass cradle-to-grave Technoeconomic Analysis (TEA) for both a lithium and a lead battery-based grid energy storage system of 2 – 5 MWh.

2. <u>Update initial battery analysis:</u>
   This task solicits and incorporates comments on the analyses prepared in Task 1.

3. <u>Adapt initial analysis for ***alternative*** lead battery design technologies:</u>
   Include novel types of lead battery technology options.

4. <u>Investigate additional application scenarios which are potentially economically attractive, using learnings from Tasks 1-3:</u>
   Determine opportunities for costs reduction and review cost and performance impacts of lead battery use in additional applications (e.g. EV fast charging, commercial building demand reduction, utility construction deferral, etc.).

5. <u>Prepare detailed analyses for different lead battery applications:</u>
   Conduct cost analyses for three application/size scenarios showing cost minimization of:

   a. Battery cells/modules

b. Battery management and system control systems
c. System support infrastructure (balance of plant)
d. Safety systems
e. Operating & maintenance costs
f. Decommissioning costs

6. Final reporting:

   This task includes a written MSWord document report and MS PowerPoint presentation providing details of the work conducted in Tasks 1-5.

Section 1 - Technology Development – D.3 Technology Pathways

The lead battery industry has, through the Consortium for Battery Innovation (CBI), developed a technical roadmap outlining research projects which will make a tangible difference to lead battery performance and meet the ever-increasing demands of end-users. This technical roadmap is based on extensive market research and discussions with end-users from car companies to the renewable energy industry, and also from data centers to utilities in an effort 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. This technical roadmap is attached as Appendix B, and is available on the CBI website.[9]

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 projected to be so significant that the demand cannot be met by one technology alone. Lead batteries are one of the technologies with the scale and the performance capability to help the power industry meet these changing requirements. Continuing to improve cycle life is therefore a core technical research priority for these applications. CBI 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.

Below, we summarize several promising projects with particular applicability to the areas addressed by the Energy Storage Grand challenge. Many others are being carried out through individual company efforts, which will be discussed by other commenters.

Ongoing Public-Private Research Programs

In collaboration with BCI and CBI, the Lead Battery Science Research Program (LBSRP)[10] is entering the third year of its Cooperative Research and Development Agreement (CRADA) with Argonne National Laboratory to undertake a fundamental research program into the behavior of materials within the lead

[9] https://batteryinnovation.org/wp-content/uploads/2019/09/CBIRoadmap_FINAL.pdf

[10] LBSRP members include Clarios, Crown Battery, Doe Run Co., Exide Batteries, East Penn Manufacturing, EnerSys, RSR Technologies, Trojan Battery Co. Associate LBSRP members: Advanced Battery Concepts, Borregaard, Cabot, Gridtential, Microporous, Superior Graphite and Teck. The LBSRP is administered by Electric Applications Inc.

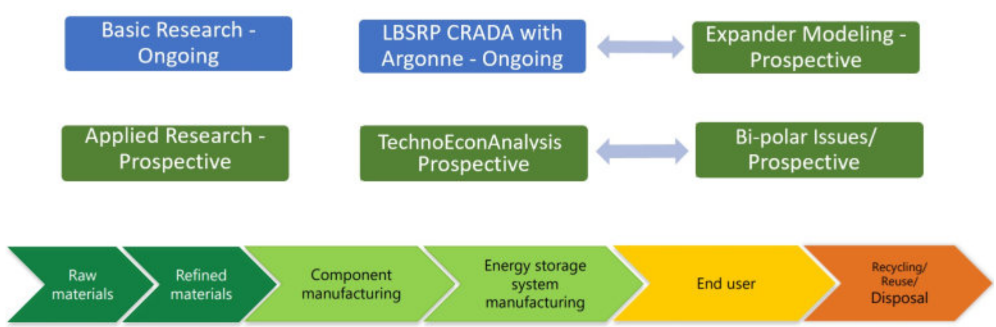
battery. This CRADA is unique because while most research on other battery chemistries focuses on primary-sourced raw materials, this lead battery research is focused on the performance of materials that are almost exclusively recycled. The CRADA already has revealed important information about material performance. For example, the lead battery industry has long known that the rate at which a battery discharges its power is faster than its ability to recharge for the next cycle. One of the CRADA's objectives is to better understand the relationship between electrolyte and electrode longevity. New data from the industry's work with Argonne is bringing greater clarity to it. The specific gravity of the electrolyte directly affects the uniform distribution of lead oxide and the lead sulfate crystals that form as the battery discharges at the start of a cycle. The lower the specific gravity, the more uniform the distribution. But, since a higher specific gravity increases the power output, it is necessary to examine how chemical reactions can be better formed to enable higher output. Further study into the electrolyte is required. Access to Argonne's Advanced Photon Source (APS) is enabling scientists to plan a new series of tests on battery cells in real time, something the lead battery industry so far has been unable to undertake.

Additional work with DOE has been initiated to fund the testing of discoveries from the work at Argonne and to focus government and industry attention on the potential of lead batteries in grid energy storage applications. This work through DOE's Behind the Meter Storage (BTMS) at the National Renewable Energy Laboratory (NREL) is to include fabrication of test cells incorporating LBSRP discoveries and testing of these cells under various test cycles to benchmark the resulting performance improvements.

In a separate development, RSR Technologies, a member of BCI, CBI and the LBSRP, has used the Argonne facilities to test and verify the performance of a new lead alloy, SUPERSOFT-HYCYCLE®, that dramatically increases the cycling of lead batteries. This alloy is being tested at Pacific Northwest National Laboratory under a program within the DOE Office of Electricity.

New opportunities for DOE and the lead battery industry

The LBSRP, BCI and CBI offer for DOE's consideration a comprehensive basic to applied to demonstration program consistent with the Grand Challenge's Innovate Here, Make Here and Deploy Everywhere objectives.



In addition to the work being conducted on carbon, barium sulfate and electrolyte within the LBSRP's CRADA with Argonne, another area of inquiry in the category of basic science centers on the relationships among materials that form "expanders" to separate the plates inside a battery so that current can flow without the plates coming into direct contact. Of particular interest is an investigation into synthetic elements that could be an alternative to traditional expanders. This program is designed to investigate lignosulfonate, a naturally occurring organic expander material used to maintain the optimum operation of the negative active material. For many years, the lead battery industry has known that while lignosulfonate facilitates the flow (or discharge) of power from the battery, it can have the opposite effect when the battery recharges. Simply put, the battery discharges more efficiently than it can recharge. This charge efficiency disparity limits both fast recharging and overall cycling capability, which in turn limits battery life.

The purpose of this proposed project is to understand why this occurs and what are the critical molecular components of the lignosulphonate materials that can be identified and evaluated. It is being proposed as part of a larger, more comprehensive program for a public-private-academic partnership to carry out basic and applied scientific research into lead battery performance.

Lead Bi-Polar batteries

While the basic science initiative the LBSRP has with Argonne and other national laboratories is crucial in the development of improved materials, an applied research program would be particularly beneficial to assist industry in addressing manufacturing scale up issues with novel “bi-polar” lead battery designs. Several LBSRP member companies are in the early stages of bringing to the commercial market a bi-polar lead battery, a dramatic and innovative battery architecture. The need to scale up manufacturing capabilities can provide an opportunity for DOE’s advanced manufacturing program.

The traditional monopolar lead battery has been the rechargeable battery of choice for more than 150 years, but the evolving market is demanding higher voltage products. The bi-polar battery is different from a monopolar battery because it uses a single, horizontal plate with active materials on both sides (hence the name bi-polar) rather than two (positive and negative) plates. This results in current flowing more evenly and efficiently and significantly reduces the amount of lead in the battery without compromising the electrochemical process, thereby reducing production costs and extending the life of a higher voltage battery.

The fundamental advantage of bi-polar lead batteries for high power applications is due to low cell-to-cell resistance and efficient discharge. It achieves these advantages with lightweight construction, a thermodynamically stable conductor in the bi-polar plate, and the absence of auxiliary equipment such as cooling loops and heavy storage containers required by conventional monopolar battery systems. Bi-polar batteries are capable of achieving large high-power formats. Engineering samples of 60v, 3kWh, with 40cm x 40cm cells have been constructed. Single pi-polar batteries of 1m x 1m cell size with 200 volts and more than 30 kWh are possible for grid storage applications.

In a typical bi-polar design, the cells are stacked to produce higher voltage without the requirement for a bigger battery. The straps, posts, and metallic grids that carry the current in a conventional monopolar battery design are no longer needed in bi-polar batteries, reducing both weight and ohmic resistance. These designs also significantly reduce the volume of lead required to manufacture a battery, potentially by more than 45%. Critically, bi-polar lead batteries maintain the same recycling, safety, domestic resource and cost base as conventional lead batteries.

Since the poles are at each end of the battery stack, the electron flow is perpendicular to the plate, ensuring a uniform current and potential distribution. The resistive losses which occur across the plate in the monopolar design are virtually eliminated. The bi-polar design can therefore have a significantly higher peak power compared to a traditional monopolar design. Bi-polar lead batteries can provide improved power densities in a variety of applications, including very high pulse power discharges, capacitor charging, and aircraft and automotive starting.

High voltage bipolar batteries also have advantages in stationary applications. They can reduce the weight and cost of small uninterruptible power supplies (UPS) by eliminating the power transformer. The estimated total costs of bi-polar and monopolar batteries are similar, but bi-polar batteries can have approximately one-third the weight and one-fourth the volume of conventional designs.

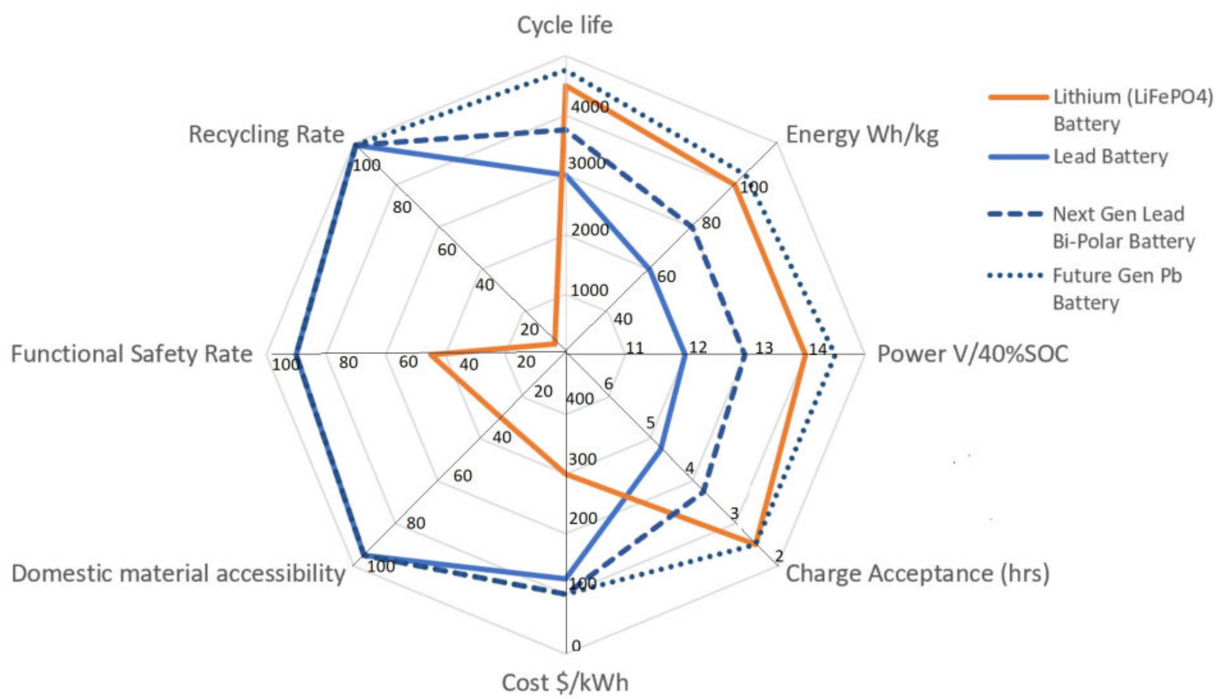
Among the U.S. companies with compelling bi-polar lead battery designs are Advanced Battery Concepts in Michigan, East Penn Manufacturing in Pennsylvania, and Gridtential in California. While each company has a unique approach in the design of a bi-polar battery, their technologies represent fundamentally novel ways of constructing batteries and face steep scale-up curves to bring these innovations to mass production. The nation's national laboratory system, which has helped many industries deal with scale up challenges, can work with leading universities and industry companies to help the lead battery industry address its own scale up challenges with bi-polar batteries.

DOE should convene a public-private workshop to design and construct prototype bi-polar cells for grid demonstration.

Lead Battery Cycle Life Research

The Consortium for Battery Innovation (CBI) has an active research program looking at research in how to improve lead battery cycle life in all application aimed at reaching key performance goals outlined its lead battery innovation roadmap.[11] The main performance goals for lead batteries in ESS applications is improving deep discharge and partial-state-of-charge cycle life. Below is a comparison of where lead battery performance is and where the technology needs to improve to stay competitive and meet both the acquisition cost ($/kWh) and operational cost ($/cycle/kWh) metrics put out by DOE.

[11] CBI Roadmap, op. cit.



The above chart compares the state of performance for conventional lead batteries (blue line), advanced lead bi-polar batteries (dashed blue line), and lithium iron phosphate batteries (orange line). The involvement of the national lab system, aiding in both the scale-up of advanced lead batteries (i.e. bi-polar) and implementation of crystal growth additives could push the future generation of lead batteries (blue dotted line) into new performance plateaus.

Section 2 - Domestic Manufacturing – M.3 Supply Chain Resilience

In the U.S., 99% of used lead batteries are recycled. No other battery chemistry can claim such complete recycling success.

The lead battery industry has built a robust and reliable domestic supply chain for raw materials, and has achieved an essentially complete circular economy, with 99% of used lead batteries recycled to generate the raw materials to manufacture new batteries. By volume, lead and lead compounds are the majority component materials in lead batteries. The other raw materials for a typical lead battery include electrolyte, separator materials, and the plastics used to create the battery container. All of these materials have robust domestic supply and recycling networks. [12]

According to the U.S. Geological Survey, domestic U.S. recycling of used lead batteries and other lead-bearing scrap provided approximately 72% of the domestic demand for lead in 2019, of which battery production accounted for 93% of demand. More than half of the imported lead came from Canada and Mexico, where the largest facilities are owned by or have long-term relationships with U.S. companies. All of the lead produced in the U.S., and most of the lead produced abroad, comes from used lead

[12] BCI incorporates by reference the comments filed by BCI in response to DE-FOA-0002358, Request for Information on the Office of Energy Efficiency and Renewable Energy's in support of Battery Critical Materials Supply Chain R&D.

batteries. The industry's unparalleled majority-domestic, closed-loop supply chain ensures that the primary raw input material for lead batteries is readily available, sustainability produced, and insulated against major international supply chain disruptions.

Lead battery manufacturing and recycling sites exist throughout 38 states. Lead batteries are distributed and collected for recycling in all 50 states. More than 40 states have adopted lead-battery specific legislation, supported by industry, to ensure that lead batteries are not disposed of in landfills and are instead collected at retail sites for recycling. A well-established, vibrant transportation network throughout North America enables the lead battery industry to function at all levels in a circular, closed-loop manner, with recycling a key component in the supply of materials for the manufacturing process.

BCI nevertheless is concerned about the export of spent lead batteries to illegal or underperforming reclamation facilities outside North America that lack comparable environmental and safety standards. Such practice undercuts the economic viability of state-of-the-art lead battery recyclers in North America. BCI strongly endorses the safe and environmentally sound reclamation of lead and other components from used lead batteries. By contrast, the unsafe, informal, or illegal recycling of lead batteries can create serious threats to employee or public health. They also may competitively disadvantage companies that endeavor to meet more rigorous standards. These practices should be eliminated.

BCI therefore supports national efforts to bring all regulatory schemes throughout the world to levels existing in the United States, Western Europe and many other areas. BCI also supports international efforts to identify and discourage the unsafe and unsound activities of facilities whose operations are carried out in flagrant disregard of basic health, safety and environmental protection practices.

BCI supports adoption of consistent recordkeeping and documentation obligations on shippers and transporters of used batteries. These obligations should include the use of standard and accurate descriptions of materials transported, and should rely for recordkeeping principally on the typical documentation historically associated with shipments and transactions, rather than requiring independent, additional manifests or other documentation.

<u>Section 3 - Technology Transitions – T.1.21 In light of recent lithium-ion battery incidents, how significant are concerns regarding safety of any storage technology?</u>

BCI strongly asserts that the safe operation of any battery system must not be compromised for any reason. Further, the safe operation comes at a cost that must be factored into any life cycle or levelized cost that is calculated in the initial stage of any product design, deployment and end-of-life management. The techno economic analysis program outlined in Section 1 Technology Development – D.2 Technology Portfolios Metrics section of these comments should be carried out.

When a new battery system is designed, for example, care should be taken to ensure that recycling is incorporated at the initial design stage. BCI commends DOE for undertaking initiatives such as the ReCell program at Argonne, NREL and Oak Ridge national laboratories. Further, BCI encourages DOE to monitor ongoing activities at the National Fire Protection Association (NFPA), which presently is revising its 855 Standard for the Installation of Stationary Energy Storage Systems.

<u>Section 4 – Policy and Valuation – P.6 Policy, Regulatory, and Market Considerations</u>

Sustainable, scalable, safe and durable energy storage is needed to meet America's increasing demand for electricity. Energy storage technologies must be able to meet those standards. Moreover, the success of any storage technology will depend on how it will measure up to the competitive pressures of the modern-day utility electricity markets. Composed, primarily, of large-scale grid facilities with renewable energy entrants that serve industry and residential customers, the markets are fiercely competitive, measuring cost against return on equity regulatory allocations. Consequently, energy storage technologies will be assessed by clients who will demand that the technology performs safely, efficiently, and durably, while being environmentally benign.

In order to economically and reliably integrate more clean energy sources, all viable energy storage technologies must be recognized and encouraged for integration. Stakeholders should avoid pre-determining a technical solution to the ESS challenges of the future. BCI believes that legislators, regulators, utilities, and others considering the merits of Energy Storage Systems (ESS), including Battery Energy Storage Systems (BESS), must use technology agnostic assessment criteria when selecting ESS. The criteria must ensure a level playing field for all technologies. Tax incentives, legislative mandates, and other market-distorting policies aimed at choosing certain energy storage technologies over others are unnecessary and will result in picking winners and losers through political processes rather than through free markets.

Battery Council International (BCI) submits the following minimum criteria for ESS technologies to be used as technical solutions are considered for various applications:

- Performance and Design Criteria:
  1. Must reliably meet system performance requirements and ensure adequate energy supply
  2. Should provide system adaptability (e.g., ESS system should use an adaptable architecture to satisfy future performance or demand growth)
  3. Prefer "shovel-ready" technologies that are mature, proven, and ready for deployment

- Prefer North American manufacturing and recycling of cells and batteries

- Safety Considerations:
  1. Prefer inherently fire-resistant chemistries
  2. Prefer technologies that resist thermal runaway conditions
  3. Prefer technologies that do not suffer from self-propagating fire hazards during failures

- Cost Considerations:
  1. ESS systems should have a reasonable cost per MWh capacity capital investment cost
  2. ESS systems should minimize operation and maintenance costs
  3. ESS systems should minimize the cost to the user of end-of-life management (e.g., decommissioning and disposal/recycling costs)

- Environmental Sustainability Considerations:

1. Require existing infrastructure for recovery and recycling at end of life (BESS owners should not be expected to manage end-of-life on their own)
2. Require a demonstrated industry capacity to recycle ESS at end-of-life that achieves minimum recycling rates equivalent to best industry practice (speculative or theoretical capacity for recycling or reuse should be discounted)
3. Minimize the disposal of end-of-life wastes in landfills, and include an evaluation of potential impacts on solid waste landfills and related environmental endpoints
4. Prefer cells and batteries manufactured with recycled content

Conclusion

BCI strongly supports the goals of the Energy Storage Grand Challenge to Innovate Here, Make Here and Deploy Everywhere. The North American lead battery industry is proud of its accomplishments for more than 100 years and looks forward working with the Department of Energy to serve our growing and changing economy with new state-of-the-art storage products. We are focused on a comprehensive program of basic to applied research to bring about active material improvement combined with innovative product architecture. The national lab system, together with institutions of higher learning, provide the vital means necessary to meet not only issues related to innovating and scaling-up the next generation of lead batteries.

Appendix A

CONSORTIUM FOR BATTERY INNOVATION

NorthStar BATTERY

LEAD BATTERIES: ENERGY STORAGE CASE STUDY

NorthStar Battery

Community Now Has Power When They Need It

City Utilities, Missouri, USA

A community-owned electricity supplier in Missouri, serving more than 100,000 people, is being supported by an energy storage solution powered by lead batteries.

The facility (pictured) in Springfield is managed in a partnership between City Utilities and NorthStar Battery, where the company has installed a 1 MWh lead battery energy storage facility at a sub-station in a residential area of the town.

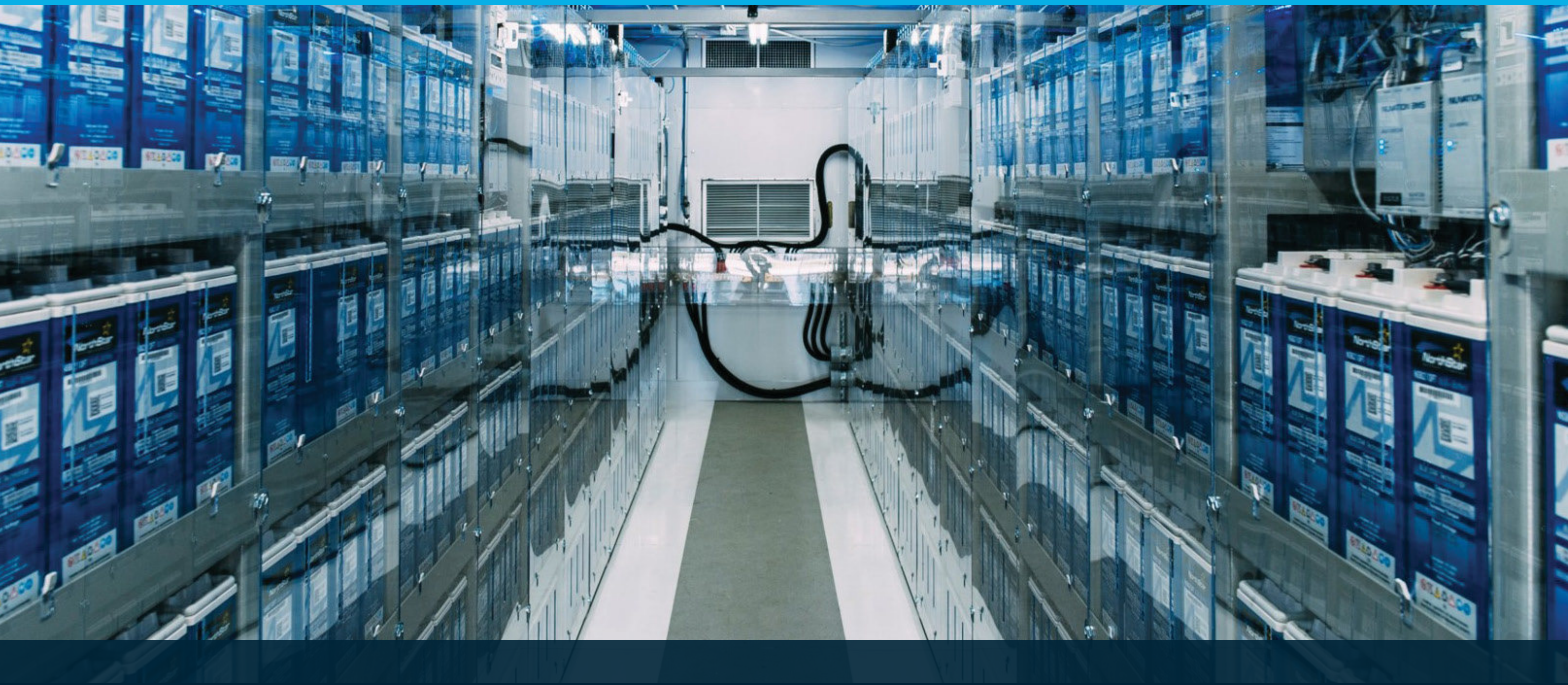
> “ We can draw power when we need to, we can deploy power when we need to, and in the event of an ice storm, we have two-and-a-half-megawatt hours of energy available for the local community.”
>
> Dr. Frank Fleming, co-founder NorthStar Battery

Technical Specification

The battery energy storage system (BESS) contains 15-parallel strings, each containing 76 x 12V-monoblocs of the NorthStar Battery BLUE+ absorbed glass mat (AGM) lead battery technology, giving a total of 1,140 x monoblocs, housed in two 40-foot pre-fabricated modular buildings.

The BESS has a total storage energy of 2.5MWh, but in daily operation is limited to a 40 percent depth of discharge to maximize discharge energy throughput for its operational life. Full battery energy is available for emergency situations such as severe weather events.

NorthStar lead batteries are intrinsically safe in normal operation, present no inherent fire risk and are virtually 100 percent recyclable at the end-of-life, presenting no environmental concerns.



About the Company

NorthStar Battery is a global leader in designing, manufacturing and deploying an innovative range of batteries and power solutions using thin-plate pure lead technology.

The company was established in 2000 by a group of experts in the lead battery industry, who together hold more than 100 years of experience. NorthStar products are so reliable and cost-effective they are used in more than 150 countries.

NorthStar employs over 500 people worldwide, with headquarters in Sweden and major operations in the USA and China. NorthStar also has global distribution and service centres, which include Indonesia, Dubai and Singapore.

> " NorthStar Battery is "world class when it comes to battery technology and battery storage systems."

Scott Miller, General Manager of City Utilities

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CONSORTIUM FOR BATTERY INNOVATION

MISSOURI S&T

LEAD BATTERIES: SOLAR MICROGRID CASE STUDY


Photo Credit: Terry Barner/Missouri

Missouri University of Science and Technology (Missouri S&T)

Consortium Launches Study of Lead Battery Solar Microgrids in Homes

Missouri S&T EcoVillage Project

The Consortium for Battery Innovation (CBI) has joined other members of the Missouri S&T Microgrid Industrial Consortium to provide resources for the construction of advanced lead battery microgrids at the Missouri S&T EcoVillage. Two on-campus high-tech homes will act as ”living laboratories” for studying renewable energy sources – and storage – for communities of the future. The project’s duration is 2018 – 2021.

Goal

The demonstration microgrids will allow research on the performance of advanced lead batteries in a small solar-based microgrid and in the economic aspects of sharing energy at the local/neighborhood level.

Background

The Missouri S&T EcoVillage is a small neighborhood comprised of solar homes designed by S&T students for competition at the U.S. Department of Energy’s Solar Decathlon. The microgrids will initially power the 2013 and 2015 solar homes. The university plans to expand EcoVillage into a “community of tomorrow,” with a total of six solar houses that will help advance renewable energy microgrid research, sustainable infrastructure, and human technology interaction. The site will provide the capability for hands-on training in renewable energy and microgrid technologies.

“This project will enrich the learning experiences of S&T students, while also deepening the knowledge of many stakeholders with the real-world application of a grid-tied residential system with solar power generation and energy storage.”

Grant Grunewald, Engineering Support Manager, EnerSys

Participant Contributions

*Based in Missouri:

- **Missouri S&T* –** Provided two solar homes used as living laboratories and a microgrid management system that allows power sharing between homes.
- **CBI and The Doe Run Company* –** Provided support for design and installation of batteries and development of the microgrid system.
- **NorthStar* and EnerSys* –** Provided each home with its own AC-coupled advanced lead battery back-up system.
- **McClure Engineering* –** Microgrid design
- **Meyer Electric* –** Project construction

Technical Specifications

Each house has an AC combiner and critical load distribution load center panel board. AC-coupled advanced lead battery back-up system consists of:

- 7 strings in parallel = 48V, 28 Cells, 67.5 kWh
- Battery racks and cabling from batteries to inverter
- Unique charge algorithms on how to control the batteries

Installations local to each house installed on existing 240/120V 2-pole single-phase utility feed include:

- Shed with poured-concrete pad
- Each shed has a glass front for public viewing of interactive screens that provide live power plant data
- 2 Sunny Island 6kW inverters per house at 12kW
- Sunny Island inverters were installed downstream of the main panel via 2 single-pole 50A CBs (one for each single 6kW Sunny Island)
- 2-pole sub panel 100A based on 12kW max load from Sunny Island inverters and PV arrays
- Rewiring of critical loads to be fed from the new sub-panel

Photo Credit: Terry Barner/Missouri S&T

"This project provides the opportunity to demonstrate the performance capability and long-term durability of advanced lead batteries as a critical component in the adaptation of renewable energy sources, such as wind and solar."

Dr. Frank Fleming, Co-Founder, NorthStar

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CONSORTIUM FOR BATTERY INNOVATION

CONVERGENT

C&D TECHNOLOGIES

LEAD BATTERIES: ENERGY STORAGE CASE STUDY

Convergent / C&D Technologies

Trailblazing Energy Storage Facility in North America

Boothbay, Maine, US

Located in a small coastal town with a population of 2,000 people is the first non-wires alternative (NWA) application of battery-based storage for utility infrastructure in the US, using advanced lead batteries.

Since 2015, Boothbay's electricity grid, which experiences increased peak load during the summer's major tourism surge, has been reliably supplied by a 0.5 MW energy storage NWA solution.

"By utilizing advanced lead batteries and a versatile design, Convergent Energy and C&D Technologies were able to provide the people of Boothbay Harbor with a more cost-effective, reliable and safer energy storage solution than alternative technologies. The modular solution allows for scalability in the future without costly infrastructure conversions."

Ken Sigman, Chief Commercial Officer, C&D Technologies

Technical Specification

Working with GridSolar, Convergent designed and engineered a 0.5 MW / 3 MWh energy storage facility, located adjacent to the radial 34.5 KW sub-transmission line that feeds the Boothbay peninsula.

The facility is connected to a local substation that serves the peninsula's load pocket, allowing Convergent to alleviate 500 kW of strain on the upstream feeder during summer peak loads.

With a project specification of 0.5 MW for 6 hours, C&D Technologies' advanced lead batteries were used for the project, a cost-effective, reliable and robust technology.

The NWA system is on-call to provide voltage support to the region from 9am-9pm during peak summer months, with a guaranteed response time of under five minutes.

System:

- **C&D Technologies**: 1,800 VRLA batteries
- **Lockheed Martin**: Modular system consisting of three 40’ energy storage modules:
  - Each contains 600 batteries
  - Capable of providing 1 MWh of energy at 600V DC
- One 20’ power control system module
- Each module is equipped with robust heating and cooling, fire suppression, isolation breakers and remote monitoring and responding systems.
- **Princeton Power**:
  - Bi-directional power inverters
  - Five grid-tied inverters
  - Capable of inverting/rectifying 100 kW
  - Fully synchronized with the grid power supply, allowing the system to rapidly charge or discharge power onto the grid

The system maintains 100% uptime during peak summer months, demonstrating the reliability and responsiveness of energy storage as a utility resource.

About Convergent

Convergent Energy + Power is the leading independent developer of energy storage solutions in North America. Convergent deploys state-of-the-art technology to significantly lower commercial and industrial customers’ electricity bills and provide utilities with cost-effective grid solutions.

About C&D Technologies

C&D Technologies, Inc. is a technology company that produces and markets systems for the power conversion and storage of electrical power, including industrial batteries and electronics. This specialized focus has established the company as a leading and valued supplier of products in reserve power systems and electronic power supplies.

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CONSORTIUM FOR BATTERY INNOVATION

Rolls BATTERY ENGINEERING

LEAD BATTERIES: ENERGY STORAGE CASE STUDY

Rolls Battery Engineering / Surrette Battery Company

Remote Community Now Has 24-Hour Power

Fair Isle, Scotland, UK

Fair Isle is an isolated Scottish Island half way between the Orkney and Shetland Isles and is one of the UK's most isolated communities. Until recently, electricity was provided by a diesel generator with some wind power. Night-time blackout was from 11.30pm until 7.30am.

Now, with a solar photovoltaic (PV) system, new wind turbines and a battery installation, the community has been provided with continuous power.

"We are very pleased to have been part of this unique and monumental microgrid installation, and we work closely with global partners to offer a full range of high-quality products for small to large-scale renewable energy applications. The lead batteries chosen for this system will provide years of uninterrupted power and dependable energy storage for the residents of Fair Isle."

Jeff Myles, Marketing Manager, Rolls Battery Engineering

Technical Specification

The batteries were provided by Rolls Battery Engineering and the entire installation comprises seven strings of 48 Rolls 2YS 27 P batteries.

These are flooded deep cycle batteries in single 2 V cells with a capacity of 2,970 Ah at the 100 h rate and offer extended lives in renewable energy systems.

The whole system has 52 kW of PV panels connected to three SMA Sunny 15 kW inverters, three 60 kW Harbon wind turbines and there are two 80 kW diesel generators now used only for backup.

These batteries each feed into an inverter cluster comprising three Sunny Island inverters and a total of 21 inverters provide a power output of 126 kW with 588 kWh of stored energy available.

The whole system is monitored and controlled by an SMA Data Manager which can be remotely viewed as required.

Installation

The solar PV system was installed by Wind and Sun along with the battery, inverters and the control system to integrate the network. Harbon installed the wind turbines and GMI energy installed the back-up generators which replaced older equipment.

Scottish and South Electricity oversaw and carried out electrical works across the island with a new 3.3. kV distribution networks, transformers and controls.

The system also has intelligent controls so that excess energy can be used for water heating and electric storage heaters.

About the Company

Rolls Battery Engineering is a long-established Canadian manufacturer of industrial lead batteries and is the brand name of Surrette Battery Company. They supply flooded and valve-regulated lead batteries for many applications and specialize in renewable energy storage.

Technical Summary

Battery specification	7 strings – 48 Rolls 2YS 27 P Flooded deep cycle in single 2 V cells
Capacity	2,970 Ah 100 h rate
System	52 kW PV Panels
Inverters	3-15 kW SMA Sunny
Wind Turbines	260 kW Harbon
Diesel Generators	2x80 kW
Overall Power Output	126 kW
Available Stored Energy	588 kWh

"We're pleased and proud to have built on our previous experience and completed our most challenging project yet, both technically and in terms of logistics, helping this island community with one of the most sustainable electricity systems in the country."

Steve Wade, Manging Director, Wind & Sun

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LEAD BATTERIES: ENERGY STORAGE CASE STUDY

Narada

Large-scale Grid Frequency Regulation System

Bennewitz, Germany

Located in Bennewitz, Saxony, is a large-scale, 25 MWh lead-carbon battery energy storage system.

Narada, one of China's leading battery energy storage system suppliers partnered with energy storage operator, Upside Group, in a 16 MW frequency regulation project for the German power grid.

The 25 MWh installation has been connected to the local utility grid since May 2019.

""As Narada deploys more and more projects in Germany and worldwide, this is an exciting step forward for our company and our innovative technology, bringing us further into the energy storage market."

Zhu Baoyi, CEO, Narada

Technical Specification

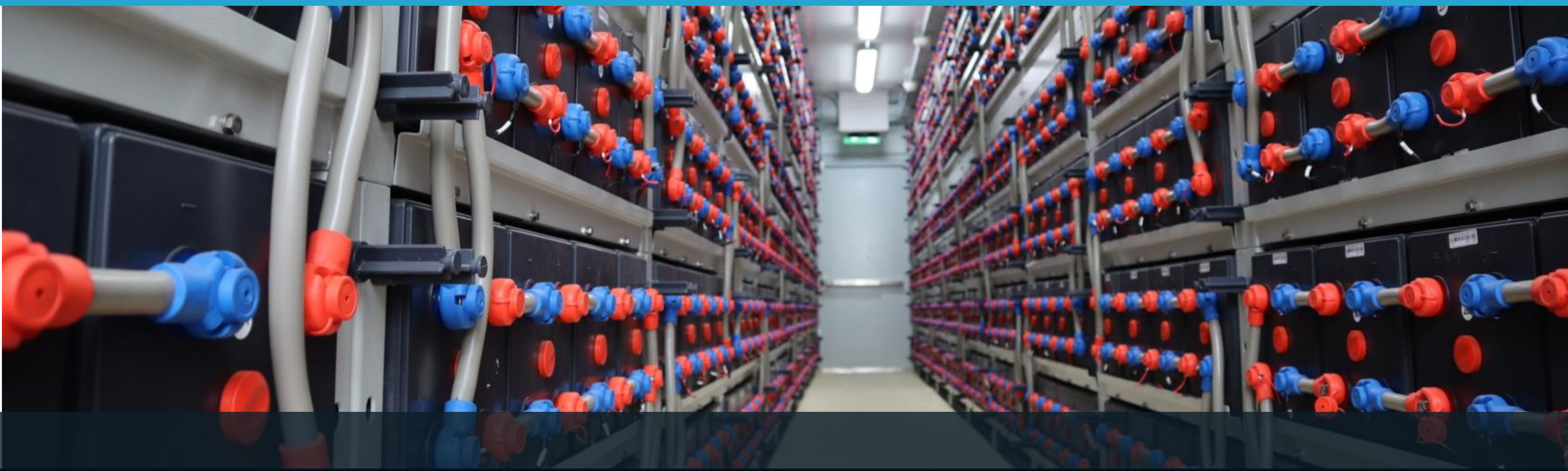
The battery system houses more than 10,500 individual battery cells with nine battery inverters, in 18 containers.

The batteries used are 1200 Ah lead-carbon valve-regulated provided by Narada.

Power is delivered through nine SMA Sunny Central Storage Inverters, supplied by SMA Solar Technology, each capable of delivering 1.8 MVA.

SMA also installed a Hybrid Controller for optimized battery charging and discharging.

The coordinated system solution allows optimal control to provide grid relief for the entire region, and the stabilization of the Central European utility grid.



All the battery cells are individually monitored to ensure any deviation in performance is detected and corrected before there is a problem. The battery is operated at partial state-of-charge to that it can accept and deliver charge at all times.

Each container has 588 units 2 V cells which are installed on site.

The Narada lead-carbon technology used was developed in partnership with CBI, and the REX Carbon cells have a calendar life of 15 years and an extended cycle life in shallow cycle service.

They have been extensively deployed in China for peak shaving, off-grid wind power installations, and in telecommunications hybrid solutions and energy storage model datacenters.

Technical Summary

POI	20 kV
PCR Power	16 MW
Plant Power	16.4 MW
Storage Tech	Lead-carbon
Storage Cap.	25 MWh
Plant Design Life	20 years
Architecture	9 MVPS 18 Storage

About the Company

Narada was established in Hangzhou, China in 1994 and has evolved into one of the world's leading battery suppliers. The company majors in valve-regulated lead batteries and lithium batteries for various applications.

The renewable energy storage section is a major market for the company and Narada has an increasing presence in international markets.

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CONSORTIUM FOR BATTERY INNOVATION

Narada

LEAD BATTERIES: ENERGY STORAGE CASE STUDY

Narada

20 MW / 160 MWh Industrial Energy Storage Installation

Wuxi, Jiangsu, China

One of the largest customer-serving energy storage projects in world, located in Wuxi, China, has been powered by lead-carbon batteries since August 2017.

The 20 MW project provides time shift/storage services for a modern industrial zone serving more than 50,000 people working in industries including precision electronics, communications and manufacturing.

"This project demonstrates the diversity of advanced lead batteries for energy storage. Lead batteries are used across the global energy storage sector, and the Wuxi Industrial Zone project is an example of the fantastic option lead-carbon batteries offer for large-scale energy storage projects."

Dr Alistair Davidson, Director, Consortium for Battery Innovation

Technical Specification

Delivering 160 MWh, the battery system used for this project consists of 107,520 lead-carbon batteries provided by Narada Power Source.

Developed in partnership with CBI, the REXC-1000 batteries offer extended cycle life in shallow service, ideal for energy storage systems.

The energy storage system includes:

- Power Conditioning System (PCS)
- Transformer (16000 KVA/ 1200KVA)
- Battery management system (BMS)
- Monitoring and control system

Through providing time shift/storage service, the 20 MW project improves the utilization of energy in the power system by balancing peak load.

Narada's lead-carbon technology offers a reliable, cost-effective and sustainable energy storage solution for this large-scale project. This is combined with facilitating electricity bill savings for the industrial zone due to optimization of energy use in different time periods.

Technical Summary

POI	10 kV
Plant Power	20 MW
Storage Tech	Lead-carbon
Storage Cap.	160 MWh
Plant Design Life	10 years
Architecture	80 sets of 250 kW / 2 MWh battery banks

About the Company

Narada was established in Hangzhou, China in 1994 and has evolved into one of the world's leading battery suppliers. The company majors in valve-regulated lead batteries and lithium batteries for various applications.

The renewable energy storage section is a major market for the company and Narada has an increasing presence in international markets.

Narada's lead-carbon batteries have been extensively deployed in China and globally for peak shaving, off-grid wind power installations, and in telecommunications hybrid solutions and energy storage model datacenters.

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CONSORTIUM FOR BATTERY INNOVATION

shoto

双登集团 SHUANGDENG GROUP

LEAD BATTERIES: ENERGY STORAGE CASE STUDY

China Shoto

World’s Highest Solar Farm

Yangyi, Tibet, China

On a plain 4,700 metres above sea level in Tibet, a vast 20 MWh solar energy farm is soaking up the sun’s rays to help feed China’s ever-expanding demand for energy.

The technology behind this state-of-the-art renewable energy plant is a bank of lead-carbon batteries which store and supply electricity generated by the photovoltaic panels directly into the Chinese grid.

> “The plant in Tibet is providing quality electricity in a controlled and stabilised environment, acting as a trailblazer for renewable energy storage systems elsewhere. This is clean energy, with reliable and long-lasting storage operating at high altitude.”

Lucie Yi, Deputy Chief Engineer, China Shoto Energy Storage

Technical Specification

With up to 14 hours of sunlight a day in summer months, the plant produces 30 MW of solar power, supported by 20 MWh of energy storage.

The system uses lead-carbon battery technology because of its robustness in harsh conditions and reliable operation at temperatures down to freezing point.

The installation uses 9,600 of Shoto’s long life lead-carbon batteries, housed in 16 40 ft ESS containers. The LLC-1000 batteries can reach 4,000 cycles at 70% depth of discharge.

The batteries are capable of being fully recycled at end-of-life, making the process of generating, storing and distributing electricity at the plant completely sustainable.

About the Company

Shoto is a leading integration service provider of green energy storage in the era of big data, using cutting-edge energy technology with customers around the world.

Shoto provides a complete series of energy storage solutions and solid green energy security for the telecommunications industry.

For the power industry, Shoto is a core hub that creates future smart grid networks. Shoto also supplies new, clean and high-efficiency power energy for the transportation industry to facilitate green travel.

Shoto is active in the recycling industry for lead batteries, making energy recyclable and renewable whilst also reducing loss of resources.

"The use of carbon and other additives, new grid alloys and active materials have resulted in significant improved shallow cycling performance and energy density of advanced lead batteries. It has also demonstrated an increase in cycle life and calendar life, making it an excellent option in renewable and utility energy storage applications, including at high altitude."

Dr Alistair Davidson, Director,
Consortium for Battery Innovation

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Appendix B

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

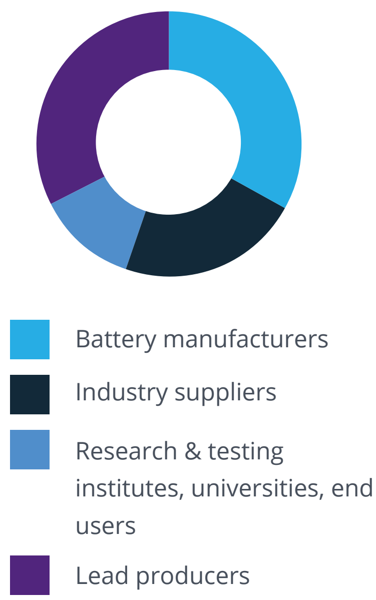
Positioning lead batteries as a future, innovative technology

Membership

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

Map of members

CBI member representation



CONSORTIUM FOR BATTERY INNOVATION

An innovation roadmap for advanced lead batteries

Technical specifications and performance improvements

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.

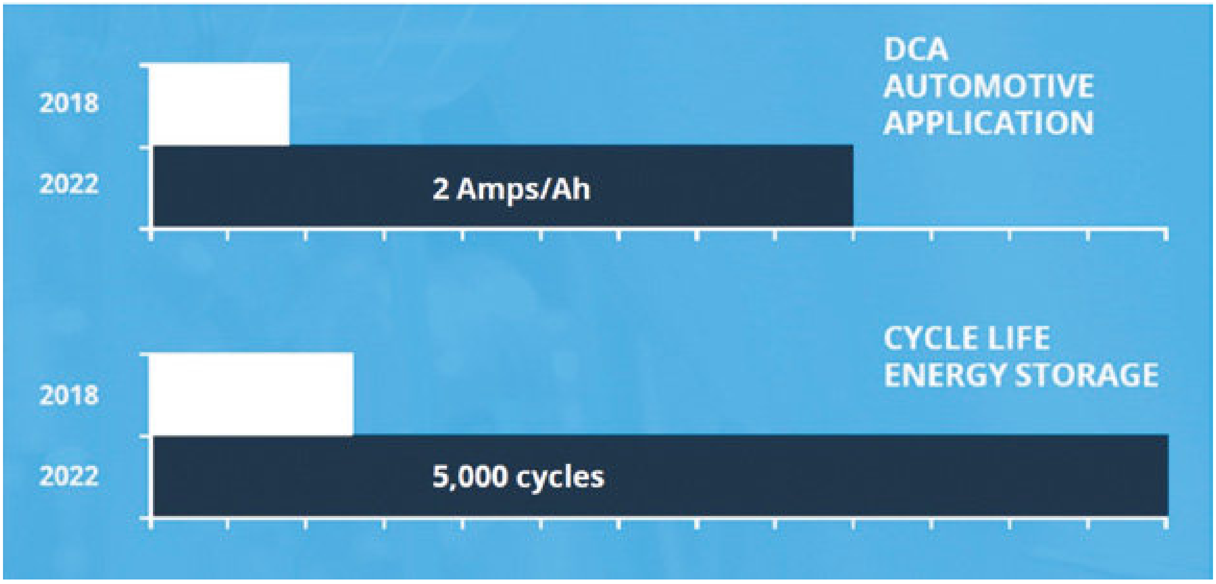
Working with members of the Consortium, we have developed this technical roadmap for advanced battery research and innovation. It is based on extensive market research, and discussions with end-users -from car companies to the renewable energy industry, and from data centers to utilities- in a bid to 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 CO_2 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.

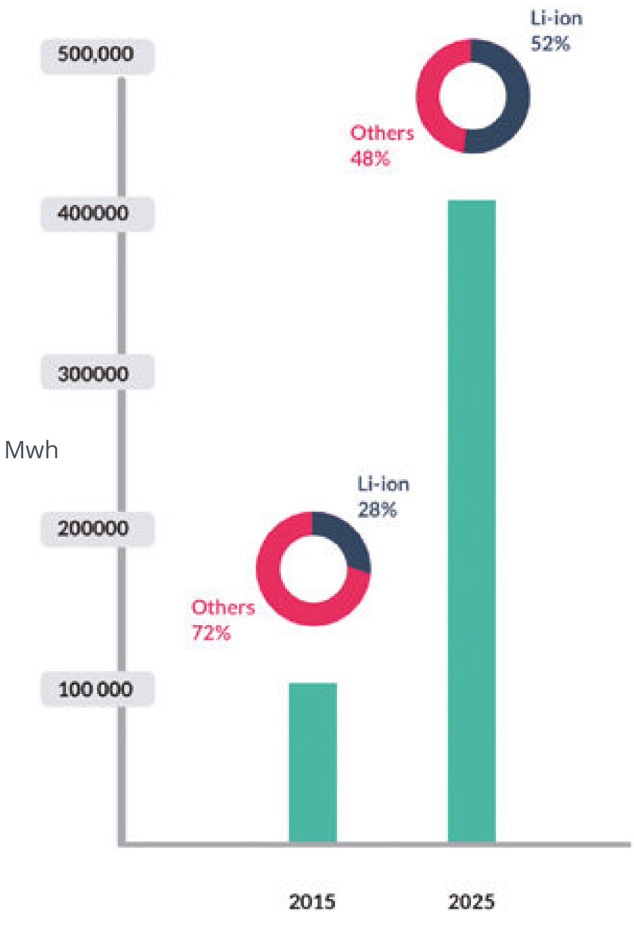
Dr Alistair Davidson
Director, Consortium for Battery Innovation

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.

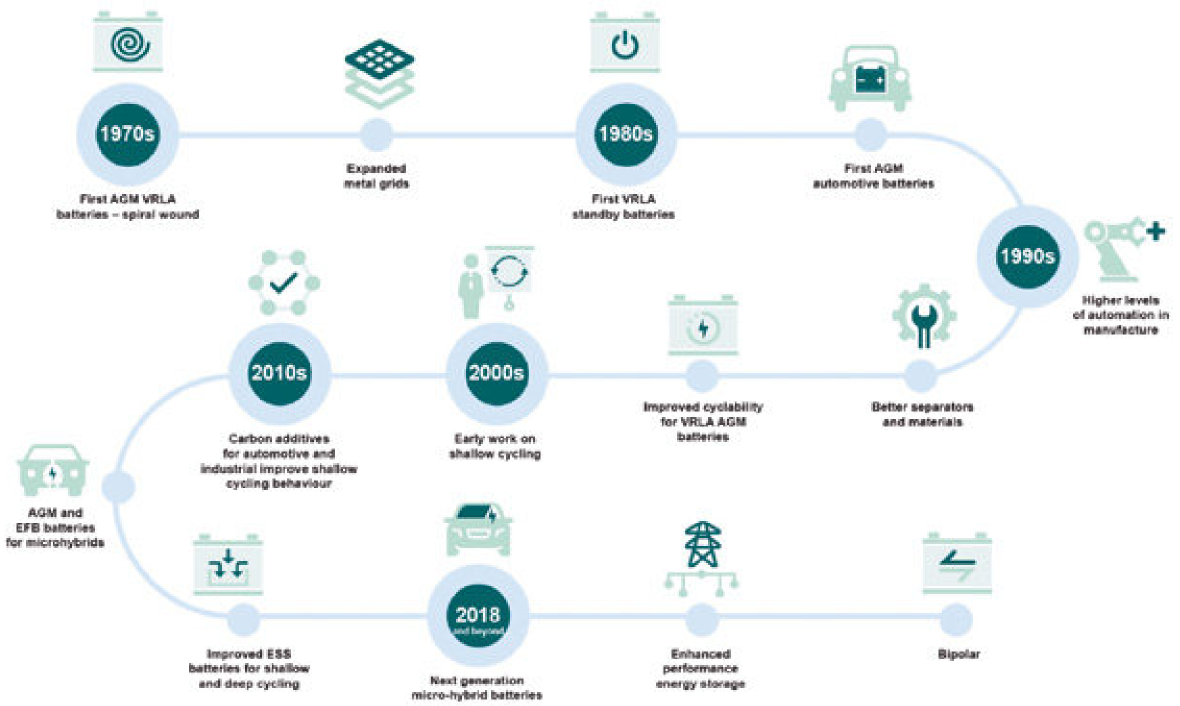
Figure 1 - Growth of battery for energy storage applications (Avicenne – ALABC report, 2018).

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.

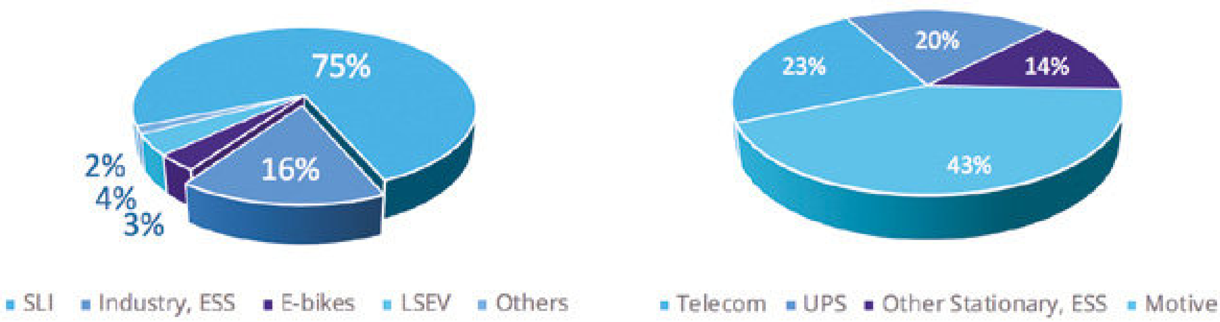


Figure 2 - Growth of battery for energy storage applications (Avicenne – ALABC report, 2018).

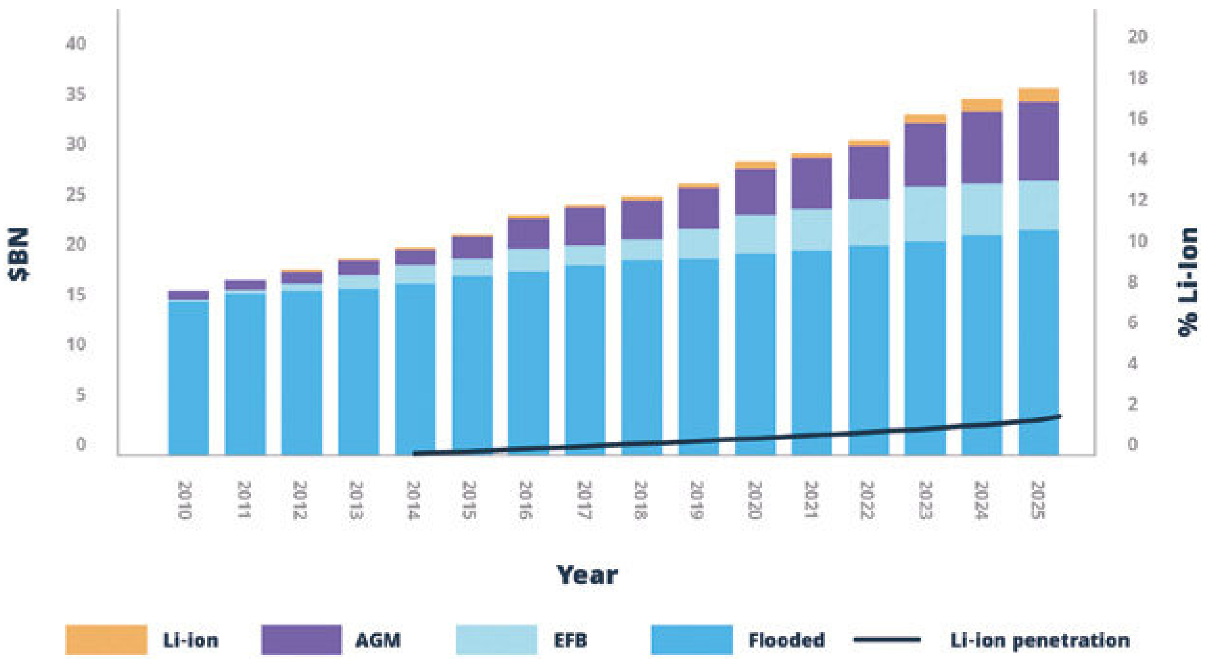


Figure 3 - Actual and projected sales of automotive batteries by type from 2010 to 2025 in $BN and percentage of Li-ion batteries.

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.

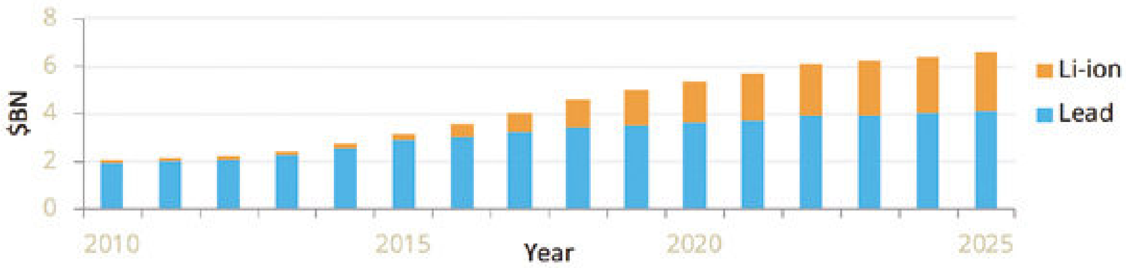
[1] Avicenne Worldwide Rechargeable Battery Market Report, 2018, 27th edition.

- 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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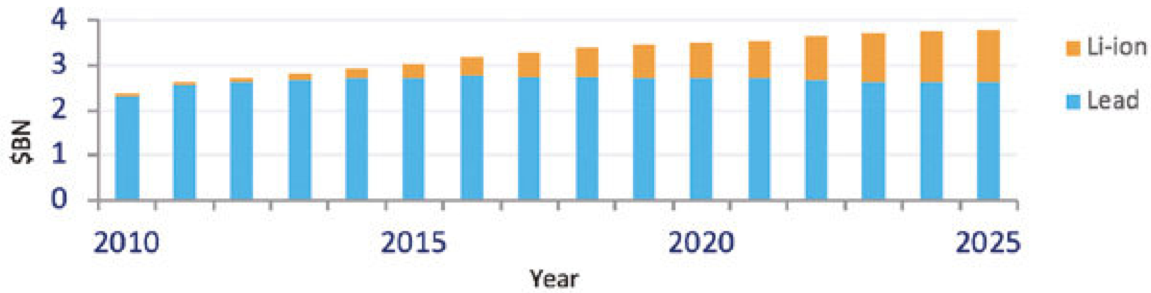

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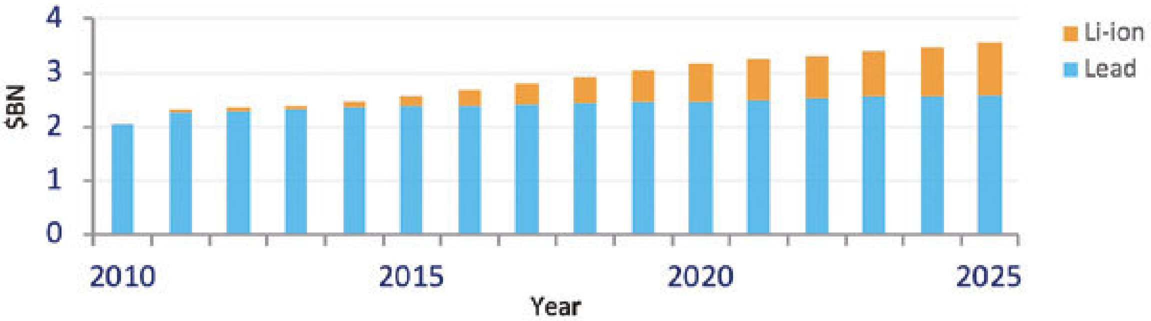


Figure 4 - Forecast sales for lead and Li-ion batteries for (a) telecommunications, (b) UPS and (c) traction applications in $M from 2010 to 2025.

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

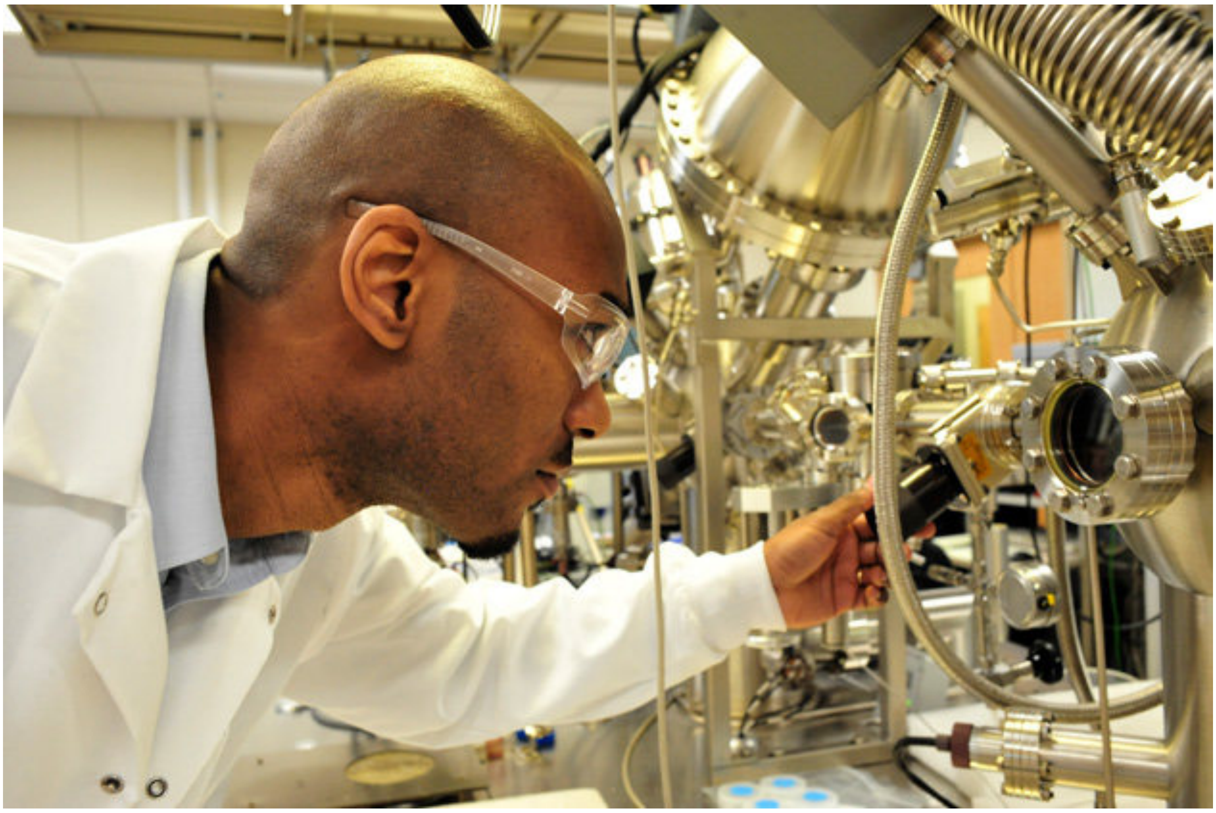
The roadmap has been developed in to order ensure future research projects are market-driven and deliver results that will make a tangible difference to lead battery performance. The roadmap will be used to prioritize research projects for 2019 onwards.

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.

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

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.

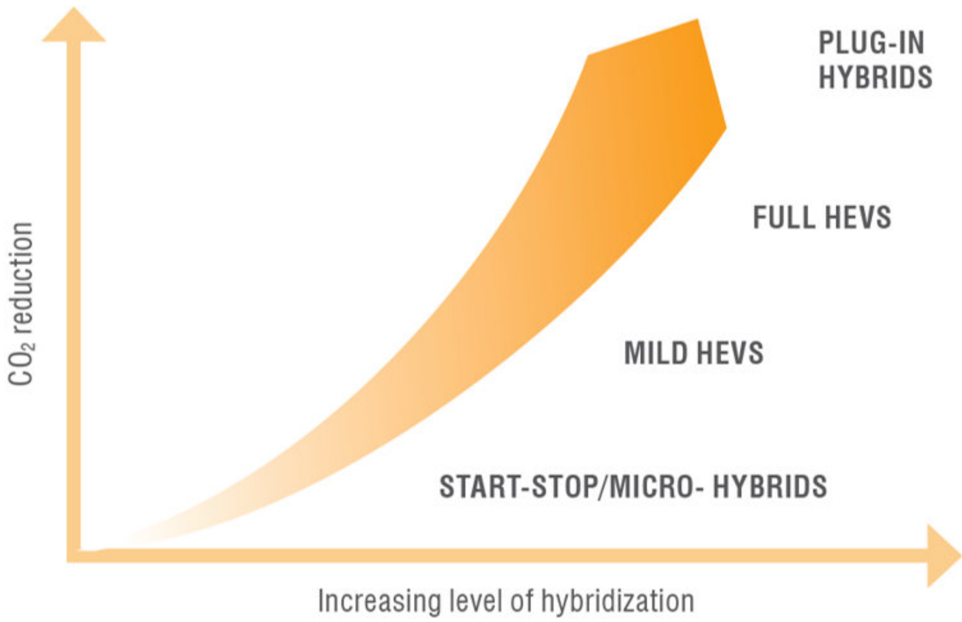
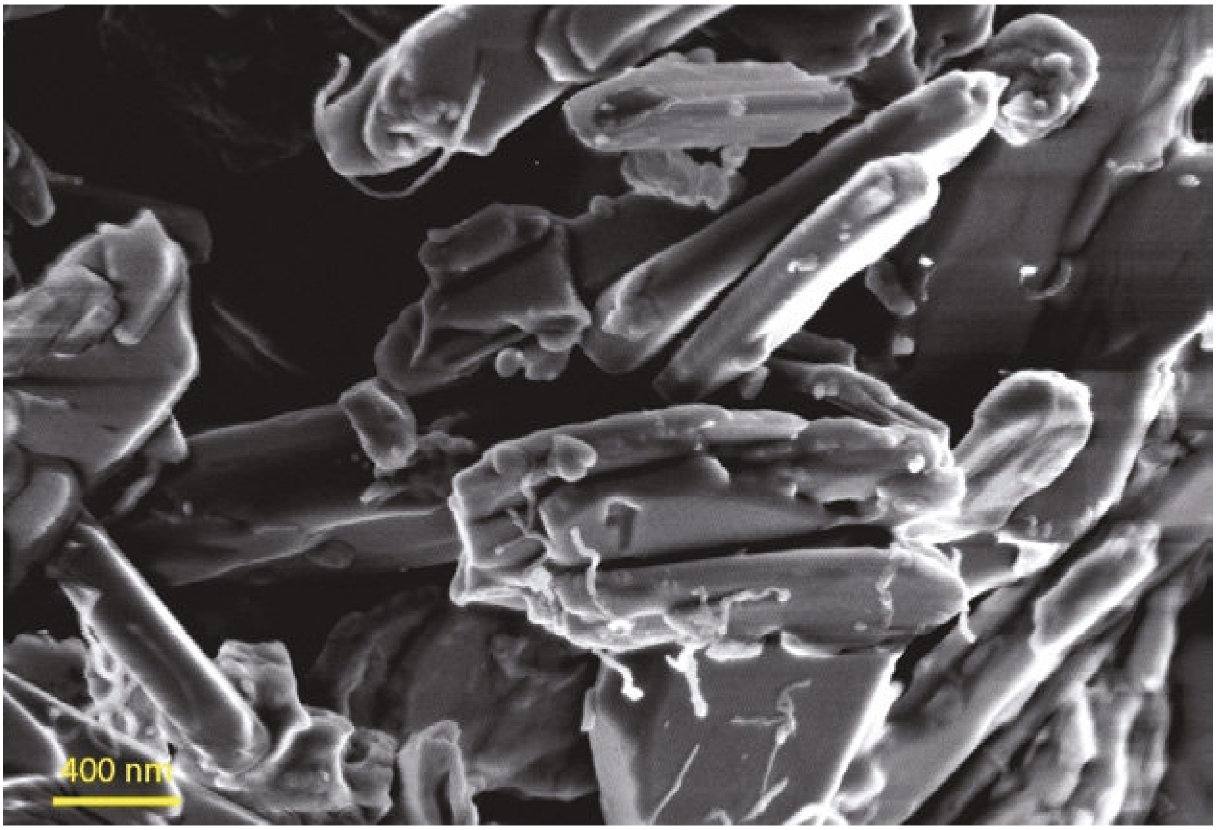


Figure 5 - The levels of automotive electrification readily available in the current market. Lead batteries provide a vital role in all of these platforms.

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.

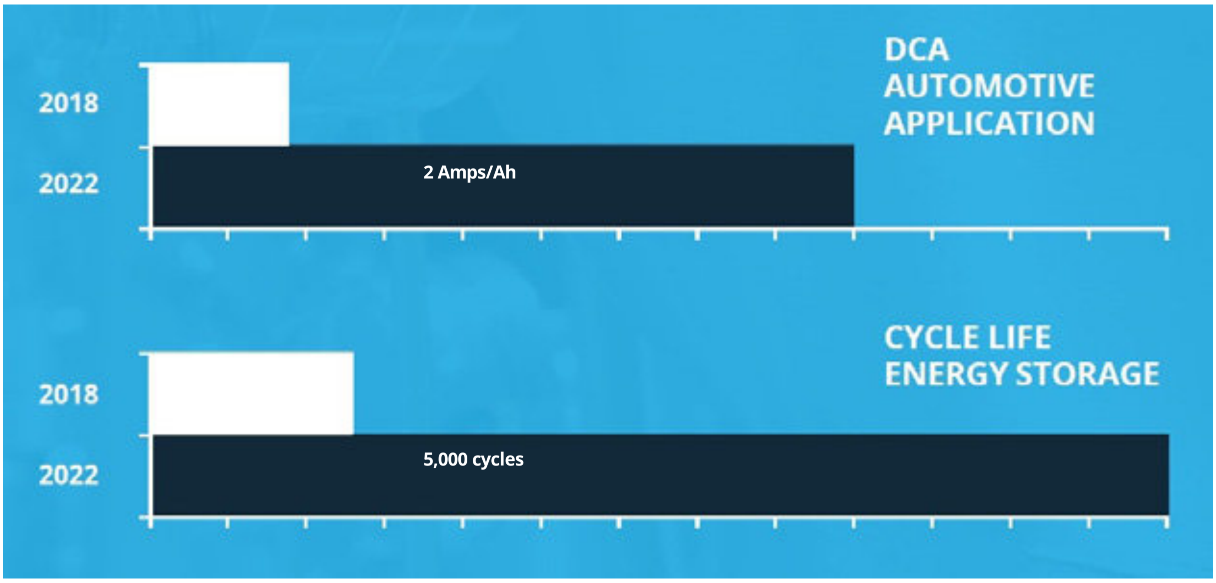
1.17 Conclusion

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

Acknowledgments

We would like to thank the Consortium's Technical Committee and the full CBI membership for their expert input into the technical roadmap which will shape the future of research into advanced lead batteries.

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