Innovation Pathways for Lead–Acid Batteries: The CBI 2019–2022 Technical Program

CBI Perspectives and Research

Presented by:

Matthew Raiford, Ph. D.

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- Swinburne
- 天能集团 Tianneng Group
- UCLA
- Warwick – The University of Warwick
- Wroclaw University of Science and Technology

CBI membership

Map of members

CBI areas of work

RESEARCH

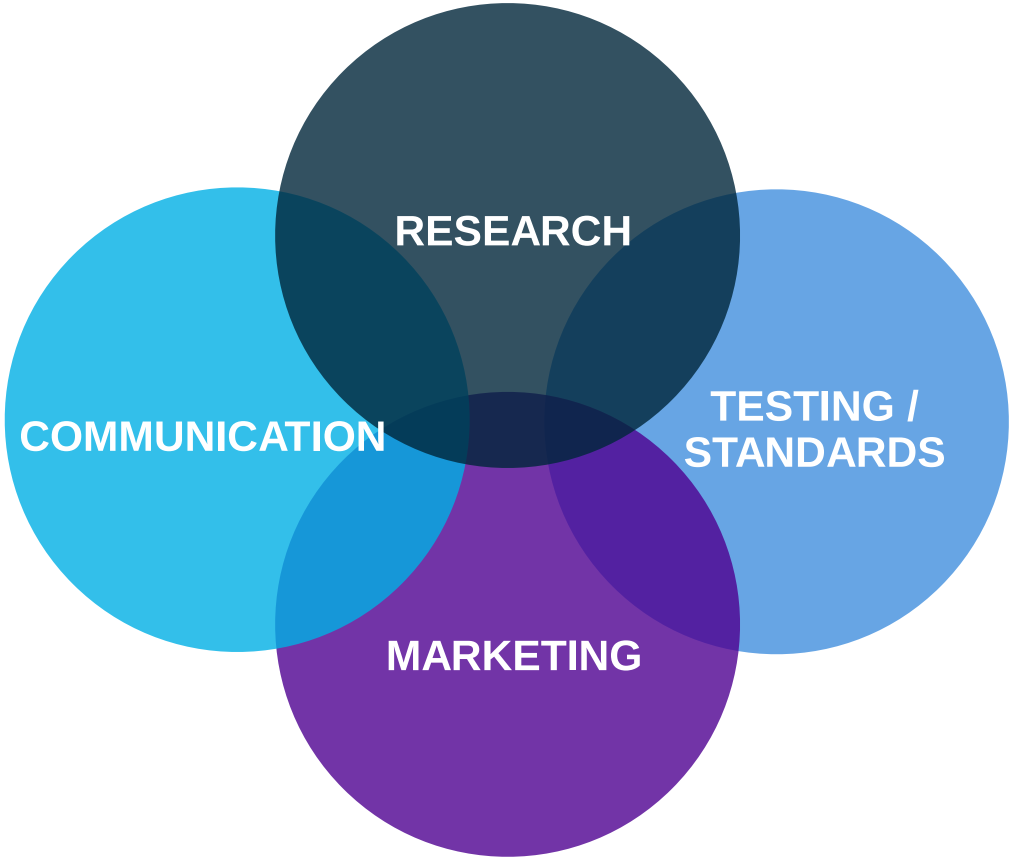
Better batteries

Improve battery and systems performance

TESTING / STANDARDS

Better framework

Tests and standards that recognize lead battery materials



COMMUNICATION

Better recognition

Communicating innovation in lead battery performance and applications.

MARKETING

Better recognition

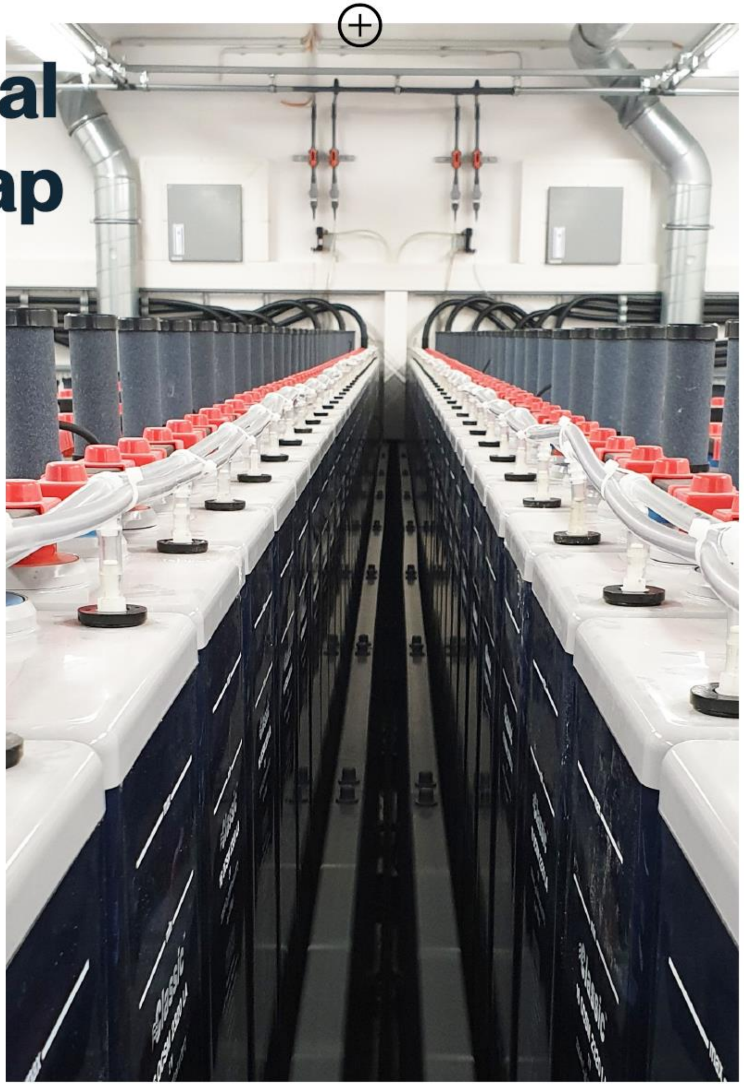
Improve end user recognition of lead battery benefits

CONSORTIUM FOR BATTERY INNOVATION

Technical Roadmap

Research and innovation pathways for next-generation advanced lead batteries

September 2021



Automotive
(start-stop/micro-hybrid)

Ensure that recent improvements in Dynamic Charge Acceptance (DCA) are maintained, whilst improving high-temperature performance and ensuring no trade-offs in key parameters such as Cold Crank Amps (CCA) and water loss.

Automotive
(low-voltage EV)

Improve DCA and charge acceptance, whilst increasing charging efficiency and lifetime.

Energy Storage Systems

Improving cycle life, calendar life and round-trip efficiency whilst reducing acquisition and operating costs.

Industrial applications

Improving cycle and calendar life, whilst reducing battery costs.

Motive Power

Lowering TCO by increasing cycle life, recharge time, and producing maintenance-free batteries.

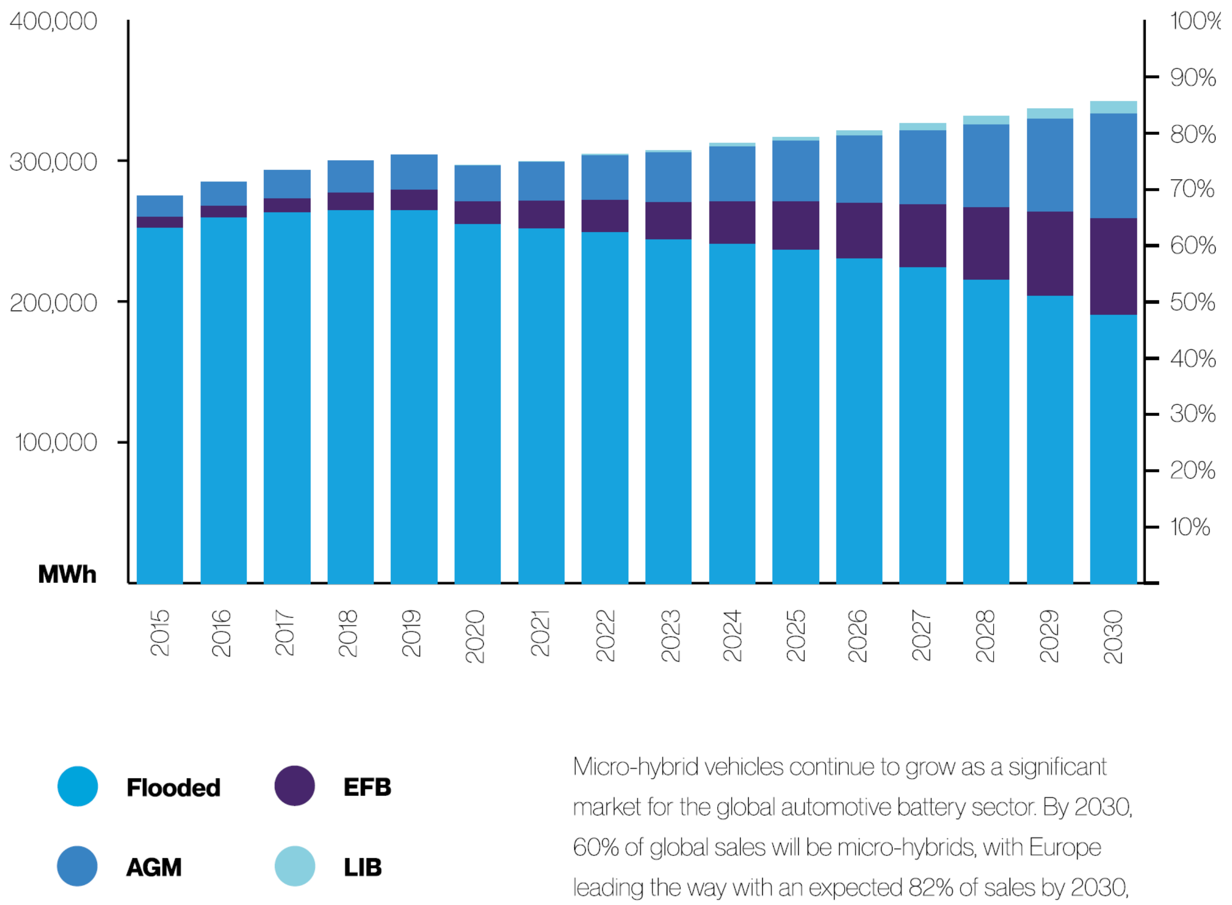
Other applications
(including e-bikes)

Improving gravimetric energy density, recharge capability and service life.

12 V Automotive Battery and Market

CBI market report 2021, Avicenne

Battery Market for SLI



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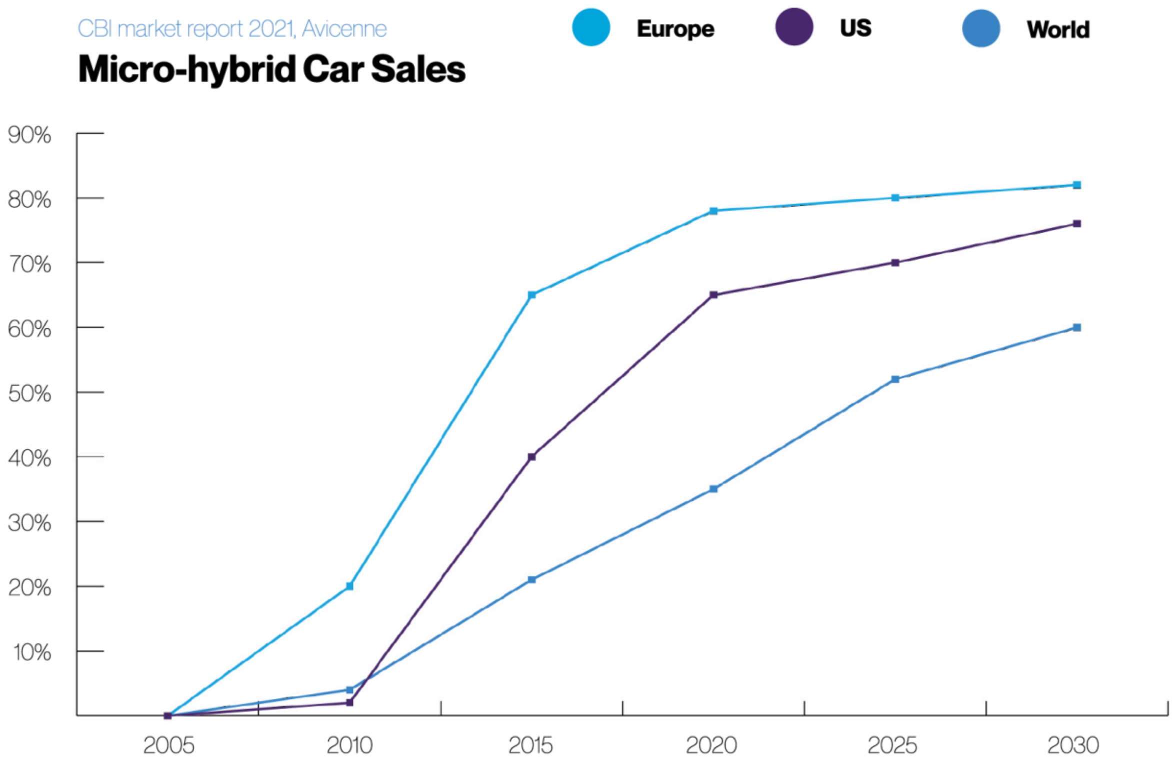
Micro-hybrid Car Sales



Micro-hybrid vehicles continue to grow as a significant market for the global automotive battery sector. By 2030, 60% of global sales will be micro-hybrids, with Europe leading the way with an expected 82% of sales by 2030, and the US close behind with 75%.

Automotive KPIs – SS/Micro-hybrid

- **Key Driver is DCA**
  - Reported values of 1.25 A/Ah in current products.
  - Preliminary cases of DCA above 2.0 A/Ah.
- **High Temperature Durability is an important OE metric.**
  - Lead batteries currently meet OE needs.
  - HTE test development in line with SAE J2801 performance.
- **Performance of other metrics must be sustained.**

Indicator (start-stop, micro/hybrid)	**2021/2022**	**2025**	**2030**
DCA (EN 50342-6, A/Ah)[a]	1.25	2.0	2.0
Ford Run-In Test B (A/Ah)	1.0	1.5	2.0
Durability: HTE (IEC/CENELEC draft)	16	20	20
Water Loss – EN/HTE (g/Ah)	<3	<3	<3
CCA, RC (comment)	Must not be compromised	Must not be compromised	Must not be compromised

EN 50342-6:2015 (M1, M2, M3 classification) should be used for cycle life requirements
Maintain 15 weeks of SAE J2801

2019 RFP – Focus Areas and KPIs

Application specific fundamental research

EastPenn – East Penn Manufacturing Co. · Borregaard LignoTech · Fraunhofer ISC · CABOT · HAMMOND – The Change Catalyst · Wrocław University of Science and Technology

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EN 50342-6:2015 (M1, M2, I… …uld be use…
Maintain 15 weeks of SAE J…

The University of California – UCLA · Ford · Fraunhofer ISC · Technische Universität Berlin · MOLL Batterien

Lignotech, East Penn, Cabot, Hammond

Investigation into the Combined Influence of Carbon Black and Organic Expander to Improve Micro-Hybrid Service of Enhanced Flooded Batteries

CABOT

HAMMOND THE CHANGE CATALYST®

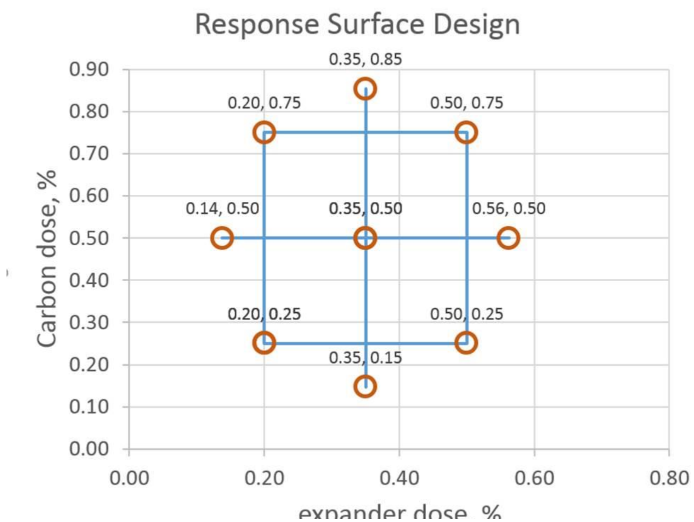
EASTPENN East Penn Manufacturing Co.

Borregaard LignoTech

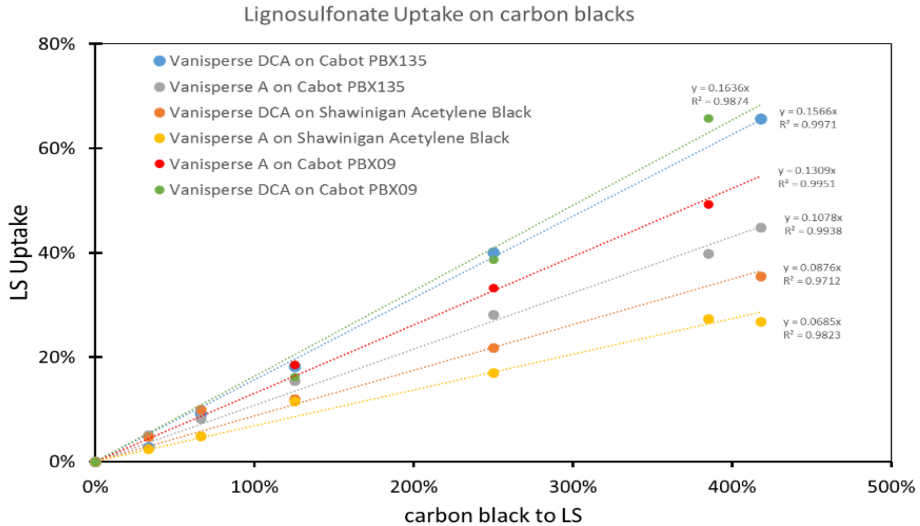
The objective of this investigation is to systematically vary the content and ratios of both additives in accordance with DOE principles and measure the resulting performance change in the above KPIs.

- Carbon and organic expander additives present in the negative electrode influence the four KPIs:
  - **DCA**
  - **PSoC endurance**
  - **Water loss**
  - **Corrosion** (SAE J2801)

- Prescribing the dosage and ratio of both additives is a daunting task facing battery engineers given the absence of relevant scientific publications.



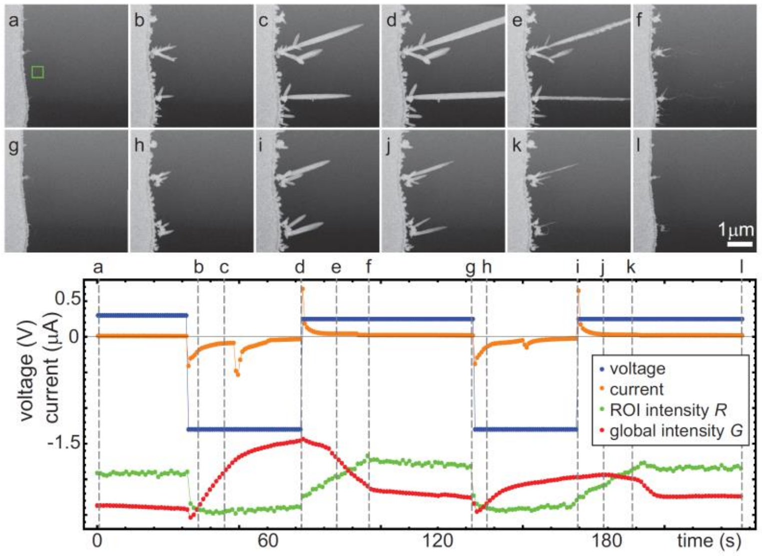
Schematic of additive dosage combinations.

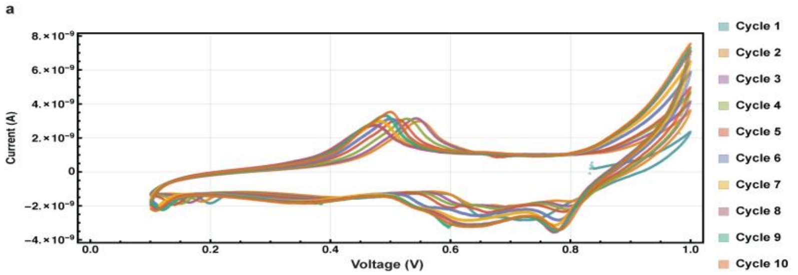


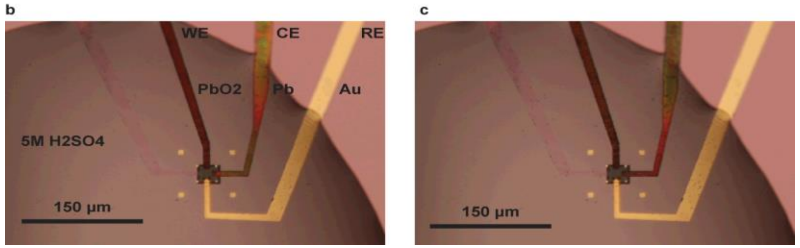
Innovative approach of using in-situ liquid TEM, looking at crystallization and dissolution.

- Current work has focused on experiments of both Pb (negative) and PbO_2 (positive) electrodes.

- Several experiments are lined up for study.
  - PbO_2 neck and contact loss experiments.
  - Formation type sequences. These will be done in the final chemical transformation of the evaporated lead.
  - The growth related to $Pb/PbSO_4$ in the NAM with an without carbon (graphite for starters).





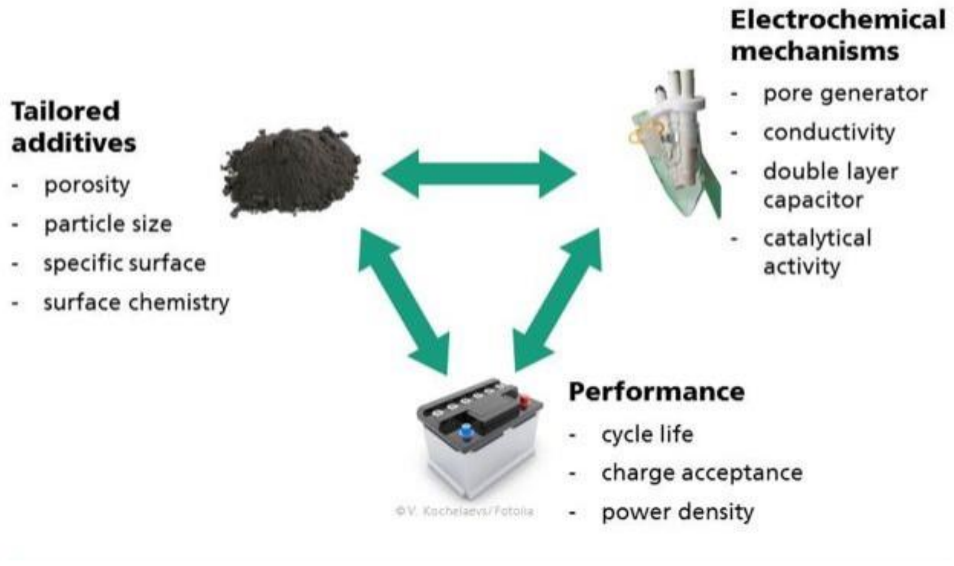


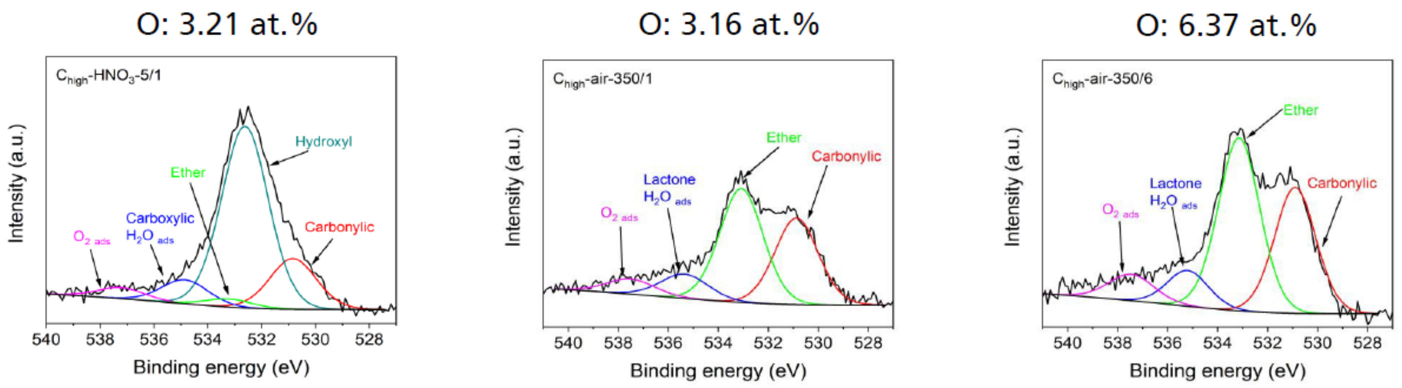
Fraunhofer ISC/WUST

Investigations on the effect of carbon surface functional groups on electrochemical behavior of lead-carbon electrodes

The main focus of this research project is the investigation of various surface functional groups of carbon additives and their impact on the electrochemical behavior of lead-carbon electrodes.

- Two different amorphous carbons with a tailored specific surface area will be modified in order to introduce acidic (oxygen, sulfonic) and basic (nitrogen) groups on the carbon surface.
- A comprehensive characterization of the synthesized carbons will allow understanding the influence of carbon's surface chemistry on dynamic charge acceptance DCA, cold cranking ability CCA and hydrogen evolution activity of negative lead-carbon electrodes.
  - pH
  - TGA
  - Nitrogen and water absorption
  - SEM
  - Rotating disk electrode
  - XPS
  - Elemental Analysis
  - XRD



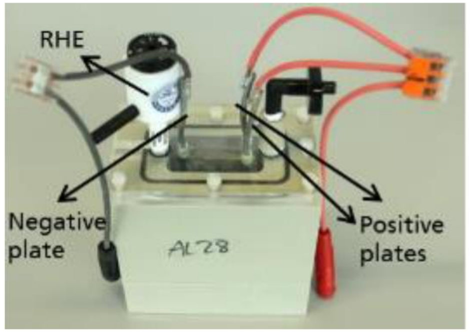


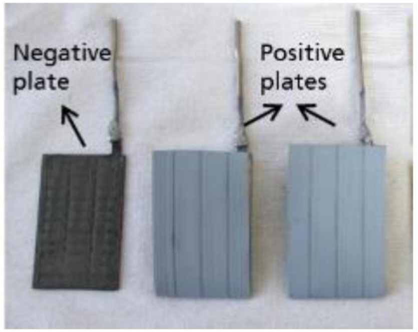
Fraunhofer ISC, Technical University of Berlin, Ford Motor Company, Moll Batterien

Best practices of cell testing for EFB regarding DCA and high-temperature durability

The main objective of this research proposal is to improve laboratory, cell-level test methods for:

- water loss
- high temperature durability
- dynamic charge acceptance (DCA).





- It has become obvious on battery level that single-pulse tests for DCA and continuous overcharging for water consumption bear only weak correlation with results obtained under simulated field conditions, particularly when most advanced (high DCA) battery technologies are addressed.

- Consequently, material screening and mass recipe optimization should employ other, more complex methods on cell level, too.

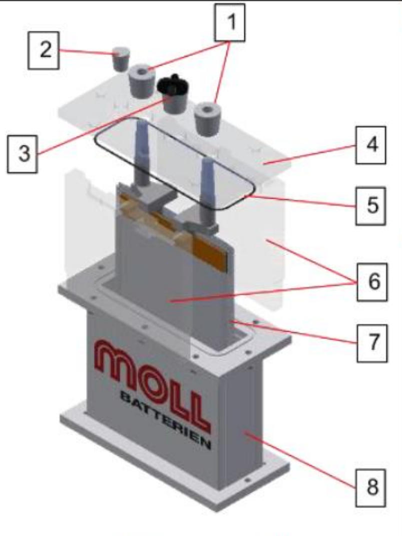


Figure 3: MOLL universal test cell design.

MOLL universal test cell description

1) Plugs for terminals
2) Plug for acid density measurement opening
3) Flame arrestor
4) Lid
5) Sealing ring
6) Inserts (thickness adjustable)
7) Plate group including straps
8) Test cell

Highlights:

a) The most standard test specifications [e.g. EN, SAE, JIS, VDA, OE-standard,...] can be tested.
b) Variable plate set from 1P/1N to 9P/9N (10Ah-75Ah) with variable inserts for each variation (to control the ratio between mass and acid)
c) Max. test current: 760 A
d) Direct gas measurement (eGas) is possible.
e) hermetic sealing at different temperatures (-28 °C to 75 °C)

ESS Growth

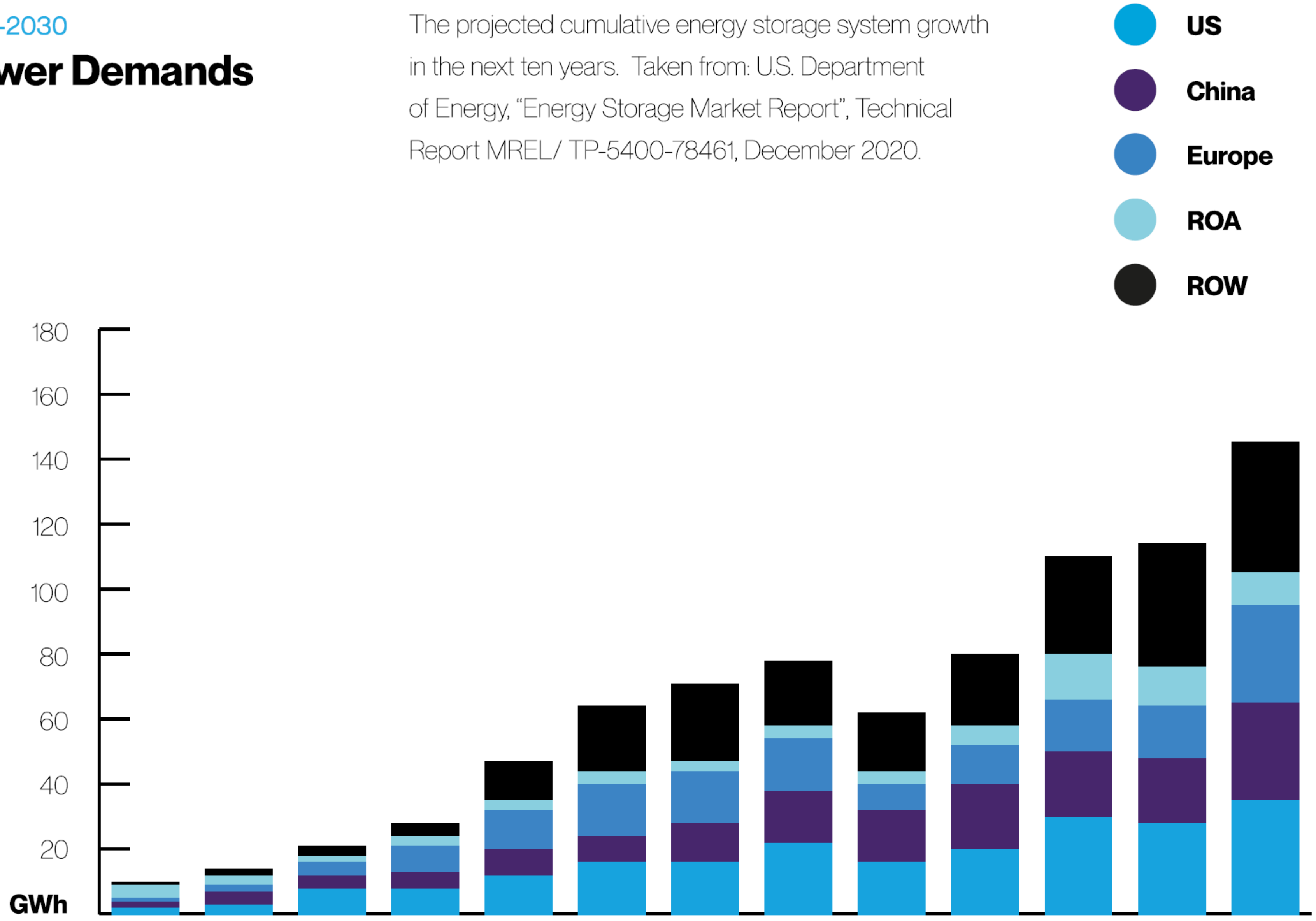
2018-2030

Power Demands

The projected cumulative energy storage system growth in the next ten years. Taken from: U.S. Department of Energy, “Energy Storage Market Report”, Technical Report MREL/ TP-5400-78461, December 2020.

- **Conservative reporting predicts massive growth.**
  - Strong growth in all areas.
  - 100’s of billions of dollars of government moneys directed toward this sector.

- **Key growth area for lead battery industry.**
  - Productization is vital.
  - Residential (Safe, advanced batteries)
  - 1-10 MW industrial (Multiple technology approach
  - Long duration, shallow cycling (Lead battery chemisty excels in this duty cycle).



ESS Battery KPIs

- **The following KPIs are aggressive:**
  - Must be competitive with Li-ion.
  - Federal stakeholders and utilities have set up truly severe technoeconomic drivers (US DOE and EU commission)
- **Operational cost and acquisition cost are vital.**
- Round Trip Efficiency primarily for renewable energy such as load following applications.
- **Productization is key** – configure and customize lead batteries to power conversion and control systems.
- **Opportunity, opportunity, opportunity!**

Indicator	2021/2022	2025	2028	Stretch Target 2030
Service life (years)	12-15	15-20	15-20	15-20
Cycle life (80% DOD) as an estimate for C10 or higher rates	4000	4500	5000	6000
Operational cost for low charge rate applications (above C10) – Grid scale, long duration	0.12 $/kWh/energy throughput	0.09 $/kWh/energy throughput	0.06 $/kWh/energy throughput	0.04 $/kWh/energy throughput
Operational cost for high charge rate applications (C10 or faster) - BTMS	0.25 $/kWh/energy throughput	0.20 $/kWh/energy throughput	0.15 $/kWh/energy throughput	0.10 $/kWh/energy throughput
Acquisition Cost (cell level) ($/kWh – 10 MW assumption)	175	140	100	75

CBI Technical Roadmap - ESS

Indicator	2021/2022	2025	2028	Stretch Target **2030**
Service life (years)	12-15	15-20	15-20	15-20
Cycle life (80% DOD) as an estimate for C10 or higher rates	4000	4500	5000	6000
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Energy Storage efficiency (Wh in vs Wh out)(%)	75-90	80-90	85-90	88-92
Round Trip Efficiency (%)	85	88	90	92
Acquisition Cost (cell level) ($/kWh – 10 MW assumption)	175	140	100	75
Energy Density (Wh/l)	80-100	110	120	140
Acquisition cost, ESS level ($/kWh)	350	325	300	275
Safety	Maintain safety – deploy charging algorithms to control gassing			

2019-2020

THE UNIVERSITY OF CALIFORNIA · UCLA · LET THERE BE LIGHT

Electric Applications Incorporated

2020-2021

EXIDE TECHNOLOGIES

HAMMOND — HAMMOND GROUP, INC.

icma — Instituto de Ciencia de Materiales de Aragón

EASTPENN

Gridtential

WARWICK — THE UNIVERSITY OF WARWICK

Electric Applications Incorporated

Loughborough University

EAI

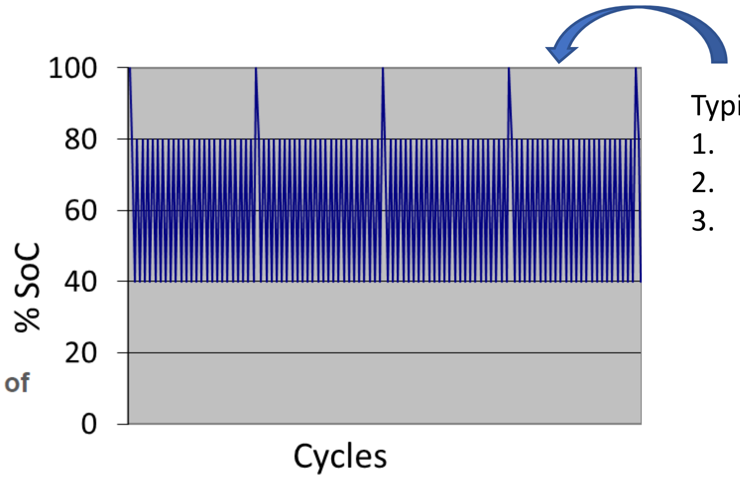
Improvement Using Controlled Overcharge

Electric Applications Incorporated

This project will focus on controlling the overcharge that lead battery strings during IEC 61427 testing.

- There is precedence that found using charge controllers to keep the overcharge level to 102.5% capacity resulted in a drastic increase in the total energy throughput and service life.
- This study will study several types of lead batteries in IEC testing and how controlling overcharge helps manage deterioration and failure, serving as "universal" management profile to increase lead battery performance in ESS applications.
- Each battery pack will be subjected to a charge-discharge cycle consisting of the following;
  - C/5 constant current discharge for 120 minutes to 40% DOD, and
  - C/5 constant current charge to a fixed overcharge percentage based on actual capacity discharged per string. The precise value of the overcharge return will be determined through initi characterization of the specific modules.

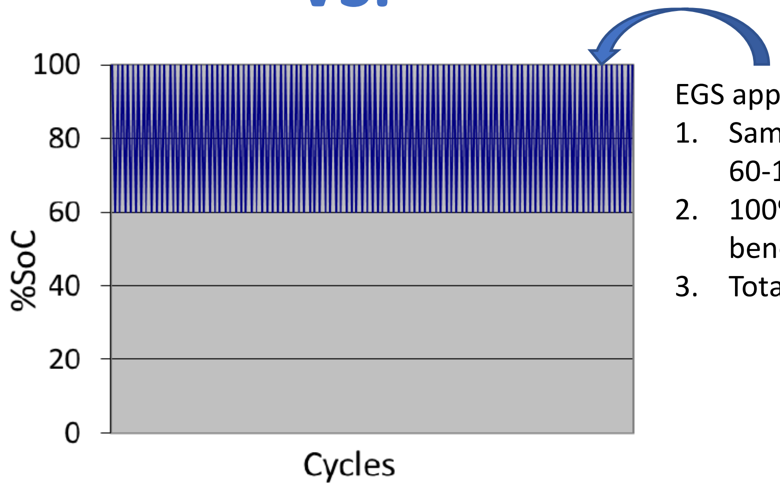
of



Typical approach for management:

1. Requires equalization
2. Operates in 40-80%
3. Reduced available battery capacity

VS.



EGS approach for management:

1. Same SOC window – but higher in SOC, 60-100%
2. 100% (101-103%) has enormous positive benefit on battery life.
3. Total capacity available.

University of Warwick, Loughborough University

HALO-SMART-ESS-LAB: Health And Lifespan Optimization with Smart Management Algorithms & Recuperative Testing of ESS of Lead Acid Batteries

The effort will be focused on application and system operation levels, rather than on internal battery chemistry or technology levels. Existing state-of-the-art battery types such as VRLA AGM batteries will be tested under different cycling profiles to explore in-depth:

- The optimal recuperative charging (frequency, duration, etc.) under partial state-of-charge operation
- The effects of ripple current on the battery health and performance
- The benefit of smart ESS control algorithms to optimize performance and health using the above and aided by on-line battery monitoring (voltage, temperature, etc.)
- The benefit of innovative monitoring-based balancing circuitry supported with deep learning and artificial neural networks to allow in-situ EIS characterization.

The aim is to provide practical design recommendations for ESS cycle life improvement.

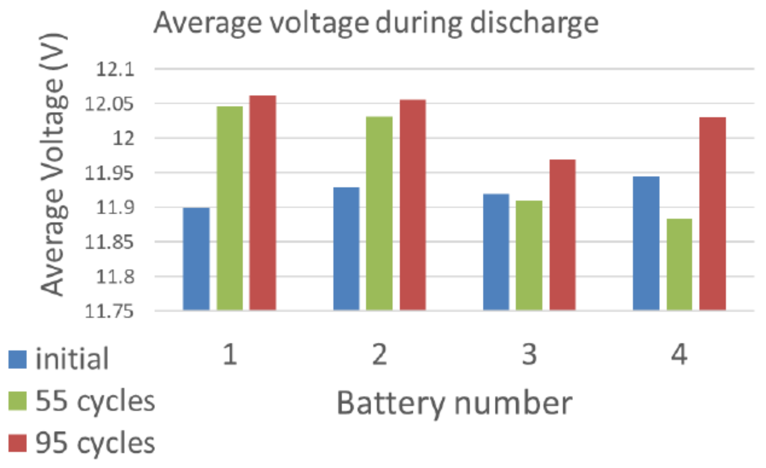


Figure 2. Effect of recuperative charging on the discharge voltage in partial state-of-charge operation. Battery number 1 has been subjected to highest number of overcharges (with the smallest interval between them) and battery number 4 has been subjected to the lowest number of overcharges (with the largest interval between them).

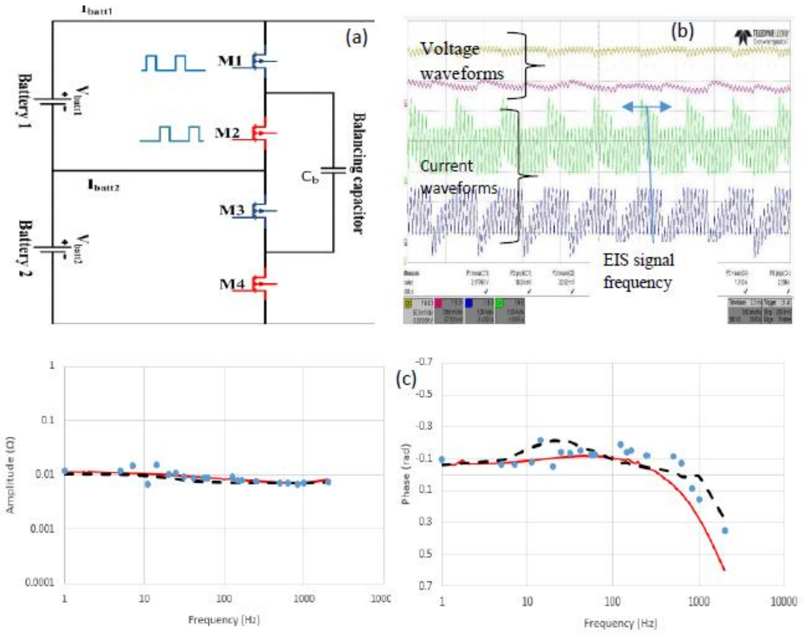


Figure 3. Fig 1. (a) A switched capacitor balancing circuit, (b) A switching waveform showing the current and voltage in two batteries with an excitation pulse of 125Hz (c) The measured impedance amplitude and phase (blue dots) compared to offline EIS (red) and simulation (black)

INMA, Exide Group

In-operando Neutron Scattering Analysis of the Charge/Discharge Processes inside the Battery Electrodes

Apply neutron scattering experiments to analyze the charge/discharge processes occurring in lead battery electrodes. Provide insight into the working processes of lead batteries in ESS.

- Design and fabricate cells with the appropriate materials and dimensions for the available neutron imaging instrumentation.
- Wave-selective neutron-imaging and Bragg-edge method will be applied for the main analysis.
- *Proof of Concept* (PoC) experiments were performed earlier at NIST.

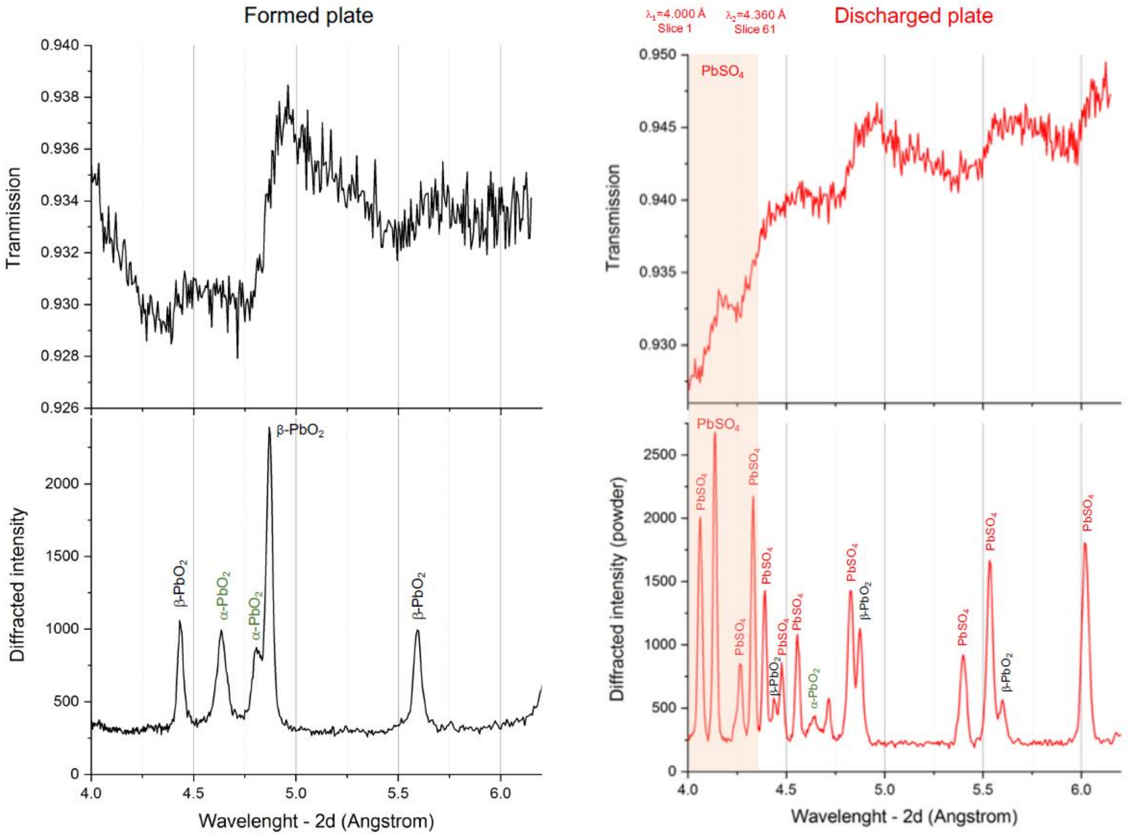


Fig. 5.- Left) Transmission profiles of a 3.4 mm thick positive formed plate (left) and of the 100 % discharged plate (right). Below each graph the neutron powder diffractogram is included for easy comparison and identification of the Bragg reflections. Wavelengths (λ_1=4.00 Å and λ_2=4.36) for Fig. 6 are already indicated.

Hammond Group Inc., Eclipse Energy, East Penn

Examination of the Effects of Surfactant Coatings & Particle Size of Barium Sulfate on the Structure Changes and Overall Performance of NAM in Energy Storage Systems (ESS) Application

In this proposed work several types of barium sulfate consisting of a range of particle sizes and including different surface treatments or surfactants will be:

- Characterized using sedimentation particle size analysis, BET surface area, TGA/DSC, and SEM imaging. The differences and similarities of available types of barium sulfate to the battery industry will be noted.
- Once characterized, the various barium sulfates will be added to experimental laboratory scale paste mixes which will in turn be analyzed to determine the properties of the NAM.
- Comparative electrical testing will be performed on test cells containing these materials and evaluated under the IEC61427 cycle life procedure.
- The NAM from the different States of Health of the cell over the course of its cycle life will be examined to determine if any noticeable difference.
- The most promising materials will then be selected for final testing in full sized lead acid batteries following IEC61427 to evaluate the benefits to overall cycle life of barium sulfate of differing particle sizes and with different surface treatments.

Table 1. List of proposed Barium Sulfate Materials

Barium Sulfate Material List			
Model	Supplier	Median Particle Size	Surfactant / Surface Treatment
HD80	Solvay	1.0 +/- 0.2	None
EWO	Sachtleben	4.0 +/- 1.0	None
HU-N	Venator	0.04	None
HU-D	Venator	0.04	0.3% Triethanolamine
TBD	LongFu	0.3	None
TBD	LongFu	0.3	Steric Acid

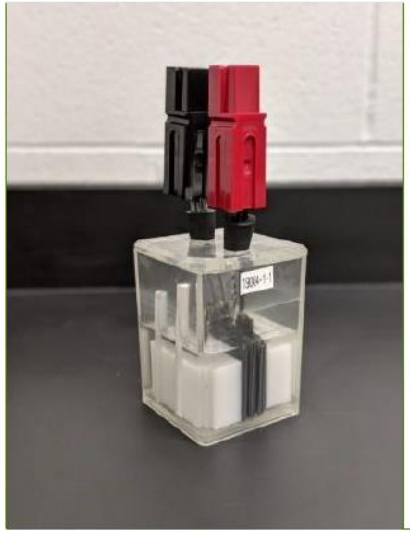


Figure 2. Hammond Research Electrochemical Cell Design

Gridtential, EAI

Bipolar Lead Batteries for Energy Storage Systems Applications

Develop high voltage bipolar lead batteries for grid energy storage applications.

- Conduct development testing to optimize the battery management system for renewable energy storage applications.

- Determine baseline performance of integrated bipolar battery system for PV time-shift service according to the IEC61427-2 standard.

- Provide input data from laboratory testing and / or residential field test site for further technoeconomic analysis.

- Preliminary post-cycle failure analysis of the test object batteries to identify failure modes unique to bipolar technology.

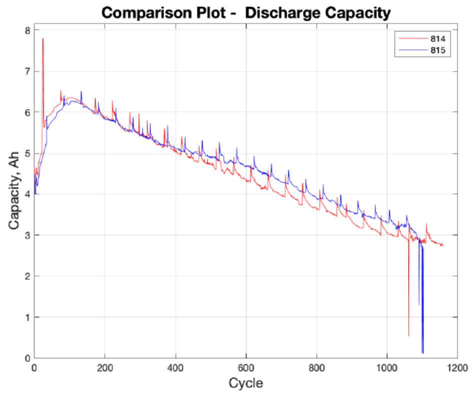


Figure 4: Cycling life of Gridtential 6V, 8Ah prototype battery under the BCIS-06 scheme at 100% depth of discharge.

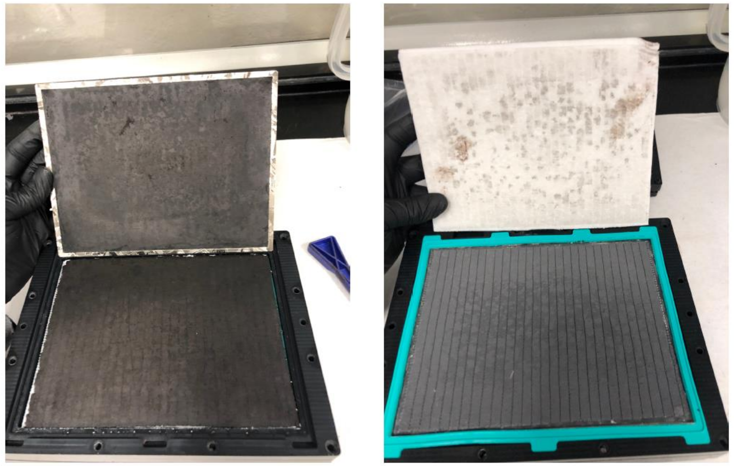


Figure 8: Example of tear down analysis of a Dev-Kit battery. (Left) Positive active material. (Right) Negative active material. The Dev-Kit platform enables disassemble of post-formation or post-cycle batteries conveniently.

Lead Battery KPIs for Micromobility (E-bikes, E-trikes, E-rikshaws)

Improve gravimetric energy density

The use of new battery designs and electrode materials to maximize performance and minimize weight. This is Important for e-bike batteries under current the regulatory climate.

Increased recharge capability

Lowering the internal resistance within the battery using new designs, pure lead materials, and other innovations will enable faster charge times, an important metric in this application.

Improving service life

Use stronger Pb alloys for better high temperature durability, study additives that improve active material cohesion, and focus on battery management techniques that maximize service life. This is an important metric to improve, aiming to have equitable performance when compared to other battery chemistries.

Other Applications…

- **2021 has turned out to be a great year for lead batteries, massive growth seen in Telecom and UPS, and positive growth observed for motive power.**
  - Much higher than predicted.
  - Data centers, 5 G deployment,
  - Amazon warehousing effect
- **CBI has produced market info and KPIs for these applications.**
- **RFP coming out soon!**

Research targets

KPIs for lead batteries in UPS applications

Indicator	2021/2022	2028
Calendar Life on float	10 y at 20°C	15 y at 20°C

Research targets

KPIs for lead batteries in motive power applications

Indicator	2021/2022	2025	2028
Service life	5	5-6	6-7
Energy throughput	1200 equivalent cycles	1400 equivalent cycles	1600 equivalent cycles

Research targets

KPIs for lead batteries in telecom applications

Indicator	2021/2022	2028
Calendar Life on float	15 y at 20°C	7-10 y at 40°C 20 y at 20°C
Cycle life (Testing should follow IEC 60896-21/22)	300 at 80% DoD	500 at 80% DoD
Cost	$175/kWh	$150/kWh

CONSORTIUM FOR BATTERY INNOVATION

Thank you!