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The international quarterly for the battery technology industry

Advanced Automotive Battery Conference

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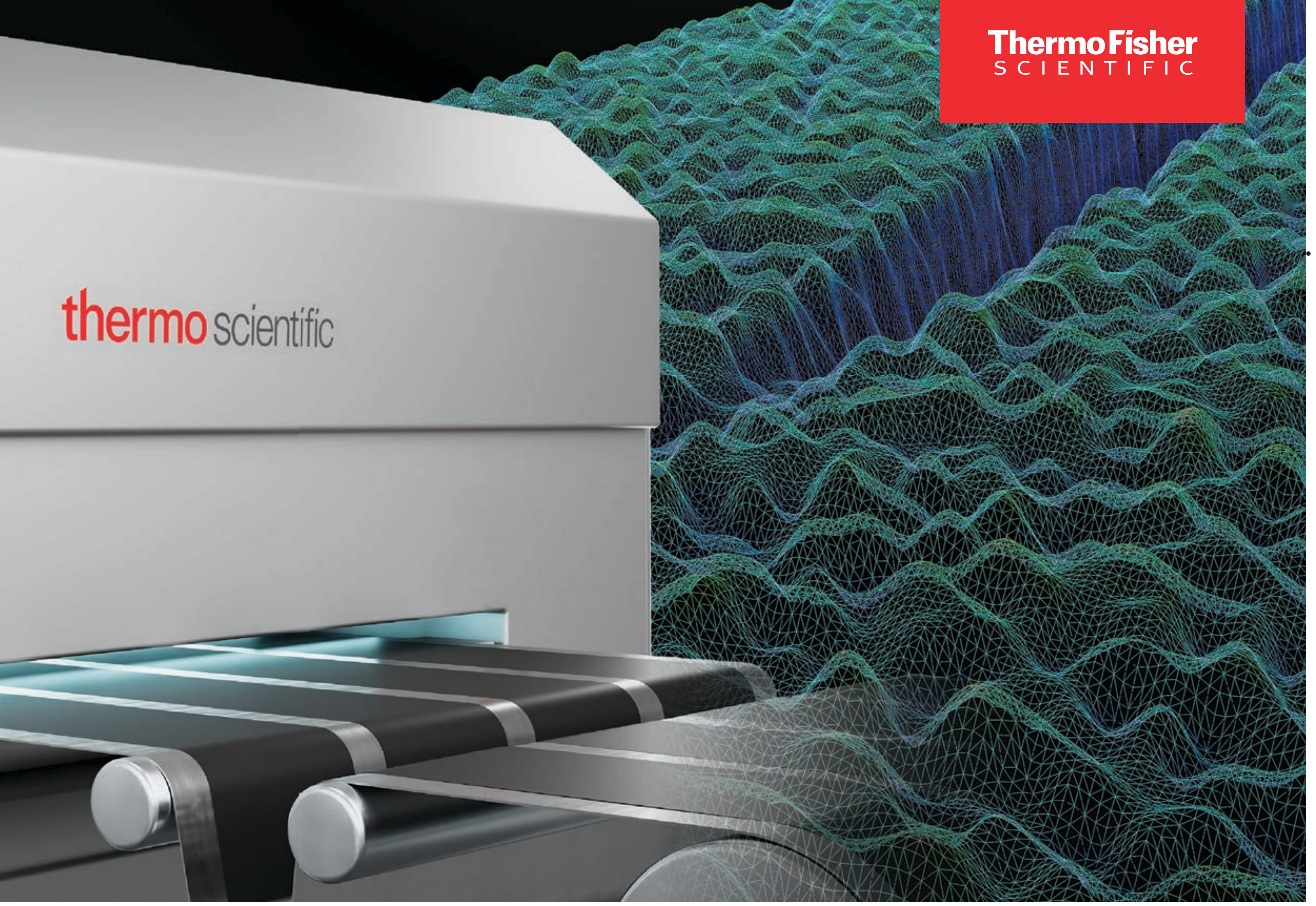

Welcome to the 14th International Advanced Automotive Battery Conference!

On behalf of myself and my colleagues, it is my great pleasure to welcome you to Strasbourg and the 14th International Advanced Automotive Battery Conference Europe! As the Executive Director of Conferences, it is my privilege to extend this heartfelt greeting to each and every one of you.

This year's conference promises to be an exceptional gathering of industry leaders, innovators, researchers, and enthusiasts in the field of advanced battery technologies for automotive applications. With the EV landscape evolving at an unprecedented pace, our event serves as a pivotal platform for the exchange of knowledge, ideas, and insights that will shape the future of electric vehicles.

Throughout the duration of the conference, you will have the opportunity to engage in thought-provoking discussions, attend informative sessions, and network with fellow professionals who share your passion for advancing battery science and technology. From cutting-edge research presentations to practical applications and market trends, the program is designed to inspire, educate, and empower all participants.

The AABC Conference series was founded more than 20 years ago to review the status of automotive battery technology and provide informed glimpses into the future. The program will uncover the underlying technical and business issues that will impact the pace and path of vehicle electrification worldwide.

As we embark on this journey together, I encourage you to make the most of your time at the conference. Whether you are a seasoned industry veteran or a newcomer to the field, your contributions and perspectives are invaluable to our shared mission of driving progress and innovation in automotive electrification.

On behalf of the organising committee, I extend my sincere gratitude to our sponsors, exhibitors, speakers, and attendees for their support and dedication. Together, we will make the 14th International Advanced Automotive Battery Conference Europe a resounding success and a catalyst for positive change in the global battery ecosystem.

Thank you for your participation, and I look forward to meeting you all in person at the conference!

Warm regards,

Craig Wohlers
Executive Director of Conferences
Cambridge EnerTech

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For inclusion in the preview guide, please contact Les Hawkins. Email: les@bestmag.co.uk, Phone: +44 7745 665 513

For more details on the conference, please contact:
Craig Wohlers
Executive Director, Conferences
Cambridge EnerTech
Phone: (+1) 781-247-6260
Email: cwohlers@cambridgeenertech.com

For event sponsorship information, please contact:

Companies A-Q
Sherry Johnson
Senior Business Development Manager
Cambridge EnerTech
Phone: (+1) 781-972-1359
Email: sjohnson@cambridgeenertech.com

Companies R-Z
Rod Eymael
Senior Business Development Manager
Cambridge EnerTech
Phone: (+1) 781-247-6286
Email: reymael@cambridgeenertech.com

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The silicon advantage: powering the future of high-energy density, cost-effective batteries

Manuel Wieser, CTO, AnteoTech Ltd.

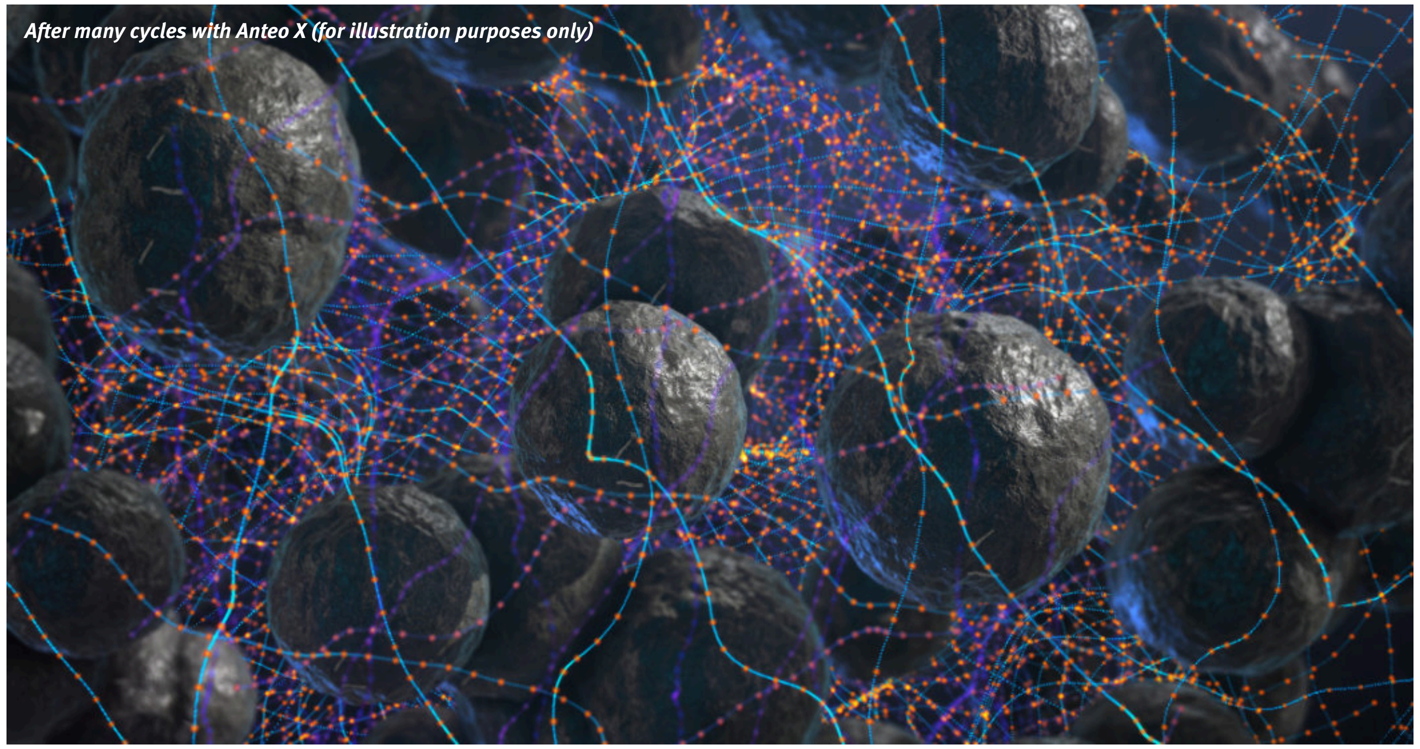
As Head of the Energy Division at AnteoTech his work is focused on enabling high silicon content anodes leading the development of the AnteoTech's silicon anode program.

With the ongoing growth of the electric vehicle (EV) market, there is an increasing demand for high-performance, cost-effective battery solutions. Enhancements in battery chemistry are pivotal for driving the evolution towards next-generation electric vehicle batteries capable of meeting the performance requirements presented by the transition to EV.

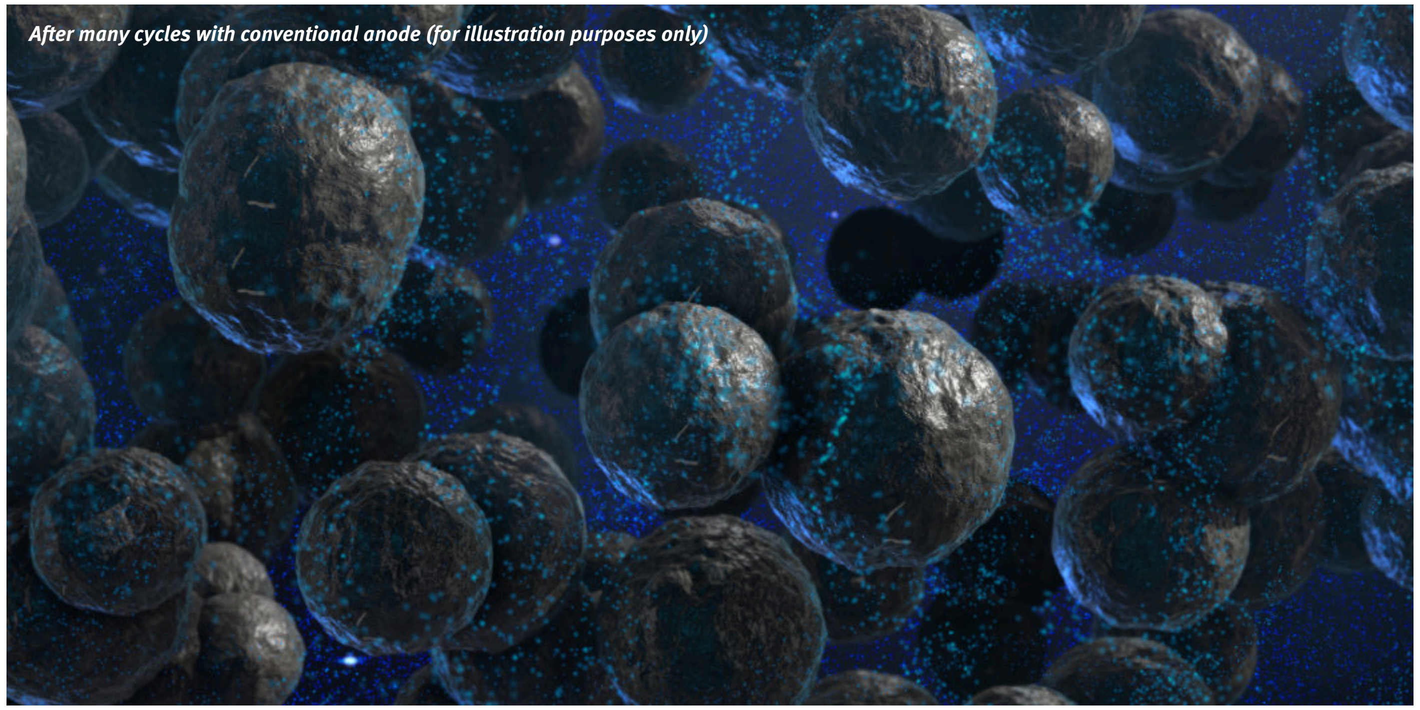
While lithium-ion battery anodes have conventionally relied on graphite as the active material, silicon-based alternatives are emerging as game changers, with the promise of faster charging and cheaper, performance-enhancing batteries.

The shift to higher silicon content anodes has been a key focus for EV and battery manufacturers since early 2021. However, maintaining anode stability and overcoming performance degradation when silicon is incorporated into anodes in concentrations greater than 10% has been a challenge. Conventional binder technologies struggle to manage structural expansion and retain electrode integrity.

Managing this expansion requires suitable enabling technologies capable of improving the long-term performance of silicon-containing lithium-ion batteries.



After many cycles with Anteo X (for illustration purposes only)



After many cycles with conventional anode (for illustration purposes only)

Introducing Anteo X™: A High-Performance Additive to Overcome the Silicon Challenge

AnteoTech, a clean energy technology company based in Australia, is leading the charge with its groundbreaking high-performance anode additive, Anteo X.

Anteo X is a powerful cross-linker additive that reinforces battery binders in high-silicon lithium-ion batteries, enhancing the structural integrity of the anode during long-term cycling, thereby helping to manage the degradation and expansion behaviour of the anode.

By cross-linking the battery binder, Anteo X creates a uniform 3D network structure within the electrode, facilitating enhanced capacity for extended range, an extended lifecycle and superior mechanical properties. The result? Cost-effective, high-energy density lithium-ion batteries capable of powering electric vehicles more efficiently.

With its drop-in nature, this proprietary battery additive offers a simple way to enhance the performance of binder chemistries without the need for extensive chemical synthesis or changes to established manufacturing processes as it can be easily incorporated into the anode during production.

Key Benefits of Anteo X

- Improved Performance

Proven to extend the cycle life of high-silicon content anodes across various silicon active materials including SiOx, Si/C composites and Si.

- Cost Optimisation

Offers a low-cost alternative to complex binder synthesis, with an ability to minimise inactive materials while maintaining optimal performance levels.

- Ease of Use

Compatible with a wide range of binder materials, Anteo X is water-soluble, non-hazardous, easy to transport and store, and effortlessly integrates into existing manufacturing processes.

Revolutionising Lithium-Ion Battery Technology

AnteoTech's Clean Energy Technology division is committed to solving the challenges associated with high silicon content in lithium-ion batteries, developing proprietary solutions capable of harnessing the full potential of silicon: Anteo X and UltrAnode — an ultra high-silicon content anode.

By maximising the benefits of silicon, AnteoTech addresses the growing demand across the entire battery ecosystem for advanced, high-energy density battery technology that is proven to increase charge duration and capacity while reducing costs.

In the quest for solutions that enhance the performance of lithium-ion batteries, AnteoTech is emerging as a global leader addressing the challenges to technology uptake that enables the widespread adoption of high-energy lithium-ion batteries, paving the way for a sustainable future.

Silicon isn't just silicon: A navigation through the world of silicon anode materials with technological and commercial insights

Ines Miller, Team Lead Battery Cells, E Mobility, P3 Automotive GmbH

A comprehensive overview of how silicon materials are evolving as the most promising anode technology for next-gen battery cell designs, offering improved performance parameters such as enhanced energy densities and fast charging.

The global battery market is experiencing a substantial growth, with demand projected to grow by a factor of five to 5TWh by 2030, predominantly driven by the automotive sector (>70%) and with increasing focus on segmentation that places an emphasis on delivering tailored products for entry, volume and premium / performance segments.

Especially for the latter, performance improvements are continuously being achieved by increasing Nickel shares in the cathode along with using graphite-based anodes. As the increase in Ni-shares approaches its threshold, a stronger focus is put on the integration of Silicon engineered materials (up to six times higher specific capacity) in the anode.

Silicon, though still in its early development stage, offers compelling advantages, including enhanced energy densities and fast charging capabilities, positioning them as key contenders in advancing battery performance and meeting the growing demands of modern energy storage applications. It presents itself in various forms & modifications mostly developed by start-ups trying to enter this competitive environment.

Therefore, this presentation will navigate through the evolving landscape of Silicon anode materials, emerging as the most promising technology for next-generation battery cell designs as they are furthest developed and commercialised yet. The presentation will entail a comprehensive overview of the diverse range of Silicon-based anode materials, examining their technological maturity, current industrialisation status, and competitive positioning in the battery anode materials market.

Silicon's characterisation extends beyond its generic classification, encompassing various material classes and morphologies that influence battery development with distinct levels of technological maturity. Nowadays, the Silicon anode material landscape is dominated by SiOx (<10% share in anode) and only a few materials, such as Silicon composites (Si/C), can reach cycle life requirements without significant capacity fade. Therefore, those materials are anticipated to gain prominence, especially when Si/C materials are fully engineered & mass market-ready, they are expected to surpass existing technology performance by enabling high Silicon shares in the anode. SiOx compounds hereby show limited performance improvements at ratios >20% and pure Silicon has not reached technology maturity yet.

Therefore, the presentation will dive into the different types of Silicon anode materials, such as nanostructured silicon, silicon-carbon composites, and silicon-based alloys, comparing their unique properties, electrochemical performance, production processes and cost potentials by integrating the materials batteries for next-gen designs.

Each Silicon variant presents its own set of challenges and opportunities, requiring innovative approaches in raw material supply, material synthesis, electrode design, and battery architecture to unlock their full potential. Furthermore, the current status of industrialisation of silicon-based anode materials will be discussed, addressing the scalability, manufacturability, and commercialisation challenges associated with integrating these innovative materials into mass-produced batteries.

Don't miss this opportunity and join us to learn more about the exciting advancements of Silicon-based anode materials, contribute to the ongoing dialogue on technological innovation, and explore the potentials of these promising materials in improving the performance for next generation battery designs with the increase of energy densities and the enhancement of fast charging capabilities.

Making Cobalt-Free Lithium/Manganese-Rich Cathodes Work: Stable, Safe, High-Capacity CAM Made by Stratus Materials

Ian Matts, PhD, Director, Product Develpoment, Stratus Materials

This data-intensive talk will cover the development of LXMO, a new class of Lithium/Manganese (LMR) cathode material by Stratus Materials and show how this material succeeds in common full cell testing configurations.

The battery electric vehicle supply chain has identified Lithium-rich Manganese-rich (LMR) cathode active materials as a promising next-generation cathode active material (CAM) solution due to its combination of high energy density, high safety, and low cost. Despite widespread interest and substantial development efforts, LMR materials have yet to be widely commercialised because persistent voltage and capacity stability issues have thus far led to unacceptably rapid cell energy fade. To overcome this challenge, Stratus Materials is introducing LXMO™, a highly stable form of LMR, to finally bring this class of CAM into the battery electric vehicle (BEV) market.

Stratus Materials, a Breakthrough Energy Ventures-backed startup, was founded in Pittsburgh PA in 2022 by Dr. Jay Whitacre, Trustee Professor of Energy at Carnegie Mellon and former founder and CTO of Aquion Energy. Stratus's core technology, which comprises both formulation and process IP, has been shown to practically eliminate voltage fade in LXMO. Stratus is producing its CAM at the pre-pilot scale in its Pittsburgh facility using a scalable and economically viable process, with plans to expand to the pilot scale by early 2025.

LXMO is actively being sampled to electric vehicle manufacturers and battery cell-makers for validation testing at the multi-kilogram scale. Testing to date includes materials assessments in various Li-ion battery cell formats, including pouch cells up to 6Ah and cylindrical cells. Current LXMO pouch cell testing extends beyond 800 cycles with >85% capacity retention and >97% voltage retention.

However, in the CAM world, material energy density isn't everything; Stratus is working to make a product that is highly compelling to BEV OEMs, which means also focusing on safety and cost. Across different safety tests in multi-Ah pouch cells, LXMO-based cells show significant improvements over other high energy density materials, in particular high-nickel NMC, with significant increases in thermal runaway onset temperatures and reductions in overall energy released. In terms of cost, LMR materials such as LXMO are viewed as a low-cost alternative to NMC materials given their reduction in nickel and cobalt content. This change in metal content results in up to a 40% cost reduction per kWh at current lithium prices.

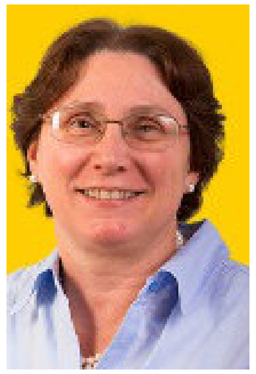
Further, less safe nickel-rich materials require more costly mitigation measures at the battery pack level to make BEVs safe to drive. This means that more space inside of the pack must be dedicated to thermal management, thereby reducing overall pack level energy densities. This fact is one driver of recent shifts from NMC materials to LFP materials in the BEV industry. LFP CAM is inherently safer, so cells can be packed densely using the highly efficient "cell-to-pack" design paradigm, thus lessening the volumetric energy penalty incurred by additional safety features. LXMO enables production of battery cells with high energy density while also maintaining a degree of safety approaching LFP, allowing for similar "cell-to-pack" designs. The result would be LXMO-based BEV packs with almost twice the pack energy density of current NMC811 packs at significantly lower cost.

"If we can show that LXMO provides energy density at or above NMC811 with costs and safety similar to LFP, we think choosing LXMO is a no-brainer," says co-founder Scott Pearson, President and Chief Commercial Officer at Stratus.

With a focus on manufacturing flexibility, Wildcat leaps into high-capacity CAM production

Dee Strand, PhD, CSO, R&D, Wildcat Discovery Technologies, Inc.

The intersection of Wildcat Discovery Technologies' materials experience with the U.S. goal of a domestic supply chain provides a unique opportunity. We will describe Wildcat's plan and progress to manufacture advanced cathode materials. Our product pipeline consists of materials that 1) provide a range of energy densities; 2) are free of cobalt and nickel; 3) show promising material safety performance; and 4) have synergies in manufacturing unit operations.



Among the bustling labs and engineering spaces at Wildcat Discovery Technologies headquarters is the John B. Goodenough Conference Room. Named for the esteemed Nobel lauereate and inventor of lithium iron phosphate (LFP), the room is an inspiration for the company's bold, new strategy to manufacture high-performance cathode materials in the United States.

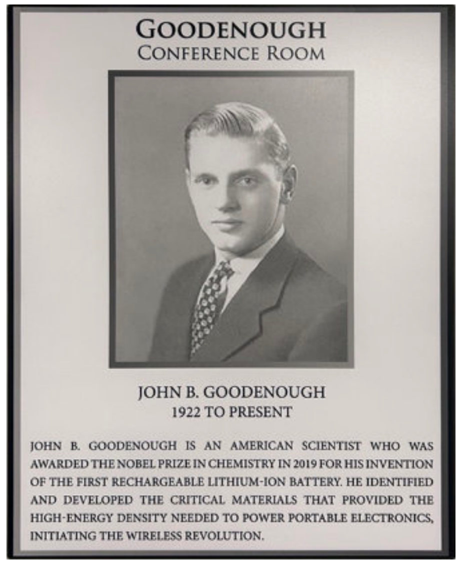
Dr. Goodenough discovered LFP at the University of Texas in the 1990s, and Chinese companies soon were mass producing the technology. Today, China produces more than 95% of LFP, leading to supply chain risk as cell producers face the related costs and geopolitical uncertainties.

For Wildcat, the lopsided global CAM supply is a ripe opportunity to serve customers in a new way. The company has been a leading battery materials developer since 2006, and it is leveraging its broad expertise, unique technology, and worldwide partnership network to bring LFP production back to the U.S.

"Customers worldwide seek dependable nearshore alternatives to China-based cathode materials, and Wildcat's strategy is to manufacture and supply the high-performance products they need," said Wildcat President and CEO Mark Gresser.

Building a plant and providing samples

Wildcat is a battery materials pioneer known for its unique high throughput platform (HTP) that performs comprehensive materials testing 10 times faster than conventional methods. In collaboration with 85 companies, Wildcat has optimized solutions for battery components in 225 projects and more than 500,000 unique experiments spanning multiple industries.



GOODENOUGH
CONFERENCE ROOM

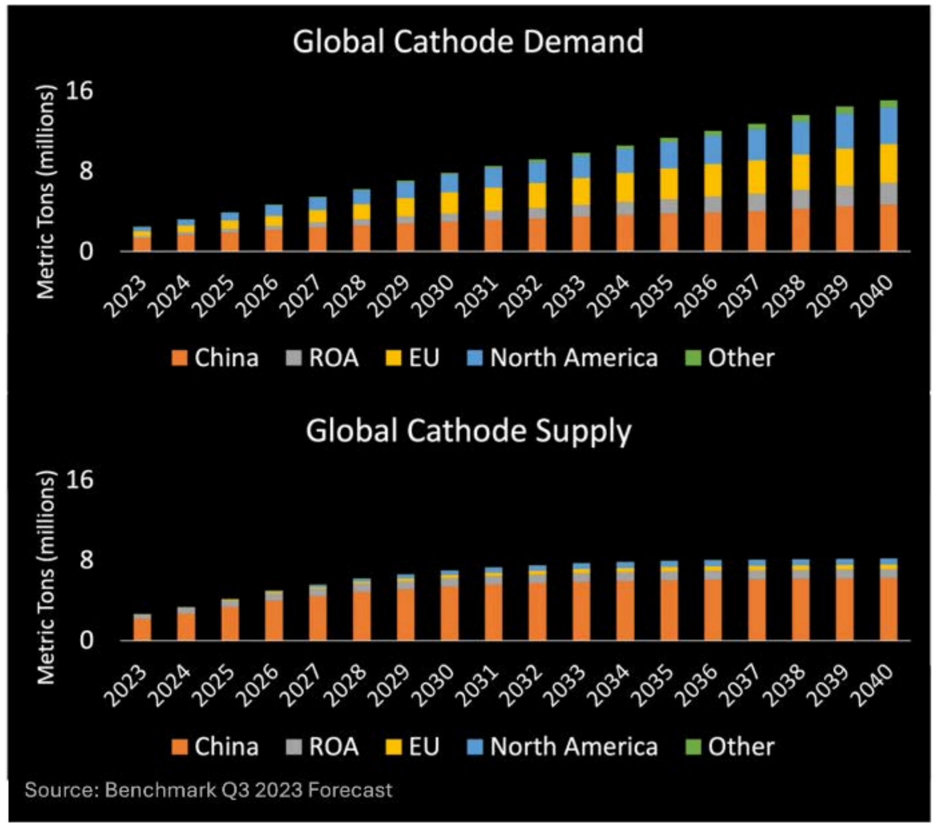
JOHN B. GOODENOUGH
1922 TO PRESENT

JOHN B. GOODENOUGH IS AN AMERICAN SCIENTIST WHO WAS AWARDED THE NOBEL PRIZE IN CHEMISTRY IN 2019 FOR HIS INVENTION OF THE FIRST RECHARGEABLE LITHIUM-ION BATTERY. HE IDENTIFIED AND DEVELOPED THE CRITICAL MATERIALS THAT PROVIDED THE HIGH-ENERGY DENSITY NEEDED TO POWER PORTABLE ELECTRONICS, INITIATING THE WIRELESS REVOLUTION.

Leveraging its experience and technology, Wildcat plans to build a U.S. plant to manufacture a portfolio of nickel-free and cobalt-free materials: LFP in late 2026, lithium manganese iron phosphate (LMFP) in 2027, and disordered rock salt (DRX) in 2028. The plant will open in 2026 with a 15,000-metric ton capacity, and it is set to double to 30,000 metric tons in 2028.

Wildcat already is providing pilot-scale LFP samples, enabling product testing with several battery cell makers and commercial truck and automotive manufacturers. The company is also advancing the design-build for its U.S. plant, adding top experts to its manufacturing team, and establishing a manufacturing advisory board.

"Customers' feedback on our LFP samples and overall strategy has been overwhelmingly positive, and their multiple offtake agreements represent enough volume to fill our 15,000-metric ton manufacturing capacity in the first year," said Dr. Dee Strand, Wildcat Chief Scientific Officer and a presenter at AABC Europe.



Global Cathode Demand

Global Cathode Supply

Source: Benchmark Q3 2023 Forecast

Flexibility to meet customer needs

Wildcat's unique product strategy involves using the same manufacturing process for all cathode materials, which enhances flexibility and reduces the risk of not meeting changing customer needs. With one common process, it will be easier and less costly for Wildcat to keep pace with industry changes and transition plant capacity from LFP to LMFP and DRX.

After proving its manufacturing capabilities with LFP, LMFP is the next logical step for production. LMFP will help bridge the gap between low-cost LFP and today's high-energy nickel manganese cobalt (NMC) batteries, relieving some of the supply chain pressure and sustainability concerns of NMC cells, while delivering superior cost and safety.

"We've garnered a lot of interest in our planned product offering of safe, low-cost, high-performance cathode materials, and customers seem pleased with our flexible manufacturing plan which enables us to shift product mix to suit customer demands," Gresser said.

Leading tomorrow with DRX and AI

Beyond the two phosphate-based products, Wildcat is poised to disrupt global CAM markets with DRX, which has gained significant attention in the field of energy storage due to its high energy density.

DRX cathodes can deliver high specific capacities due to redox on both the transition metals and the anion in the structure. Wildcat has harnessed its HTP methodology to advance the development of DRX cathodes, establishing strategic partnerships with BMW, McGill University, and other industry leaders to further drive innovation.

Wildcat's CAM development also benefits from the company's unique advantage in artificial intelligence. Since the most effective AI models require large amounts of data, Wildcat's 500TB of experimental data generated over 15 years of HTP testing ensures it has the foundation for accelerating materials development and predicting cell performance – which are critical to a customer-focused manufacturing strategy for the long term.

"Wildcat's vision is to be the first choice for battery materials development, integration, and supply, and our team continues to make great strides toward its execution," Gresser said.

Next-Generation Batteries (Silicon, Lithium-Metal, Sulphur): Status Update

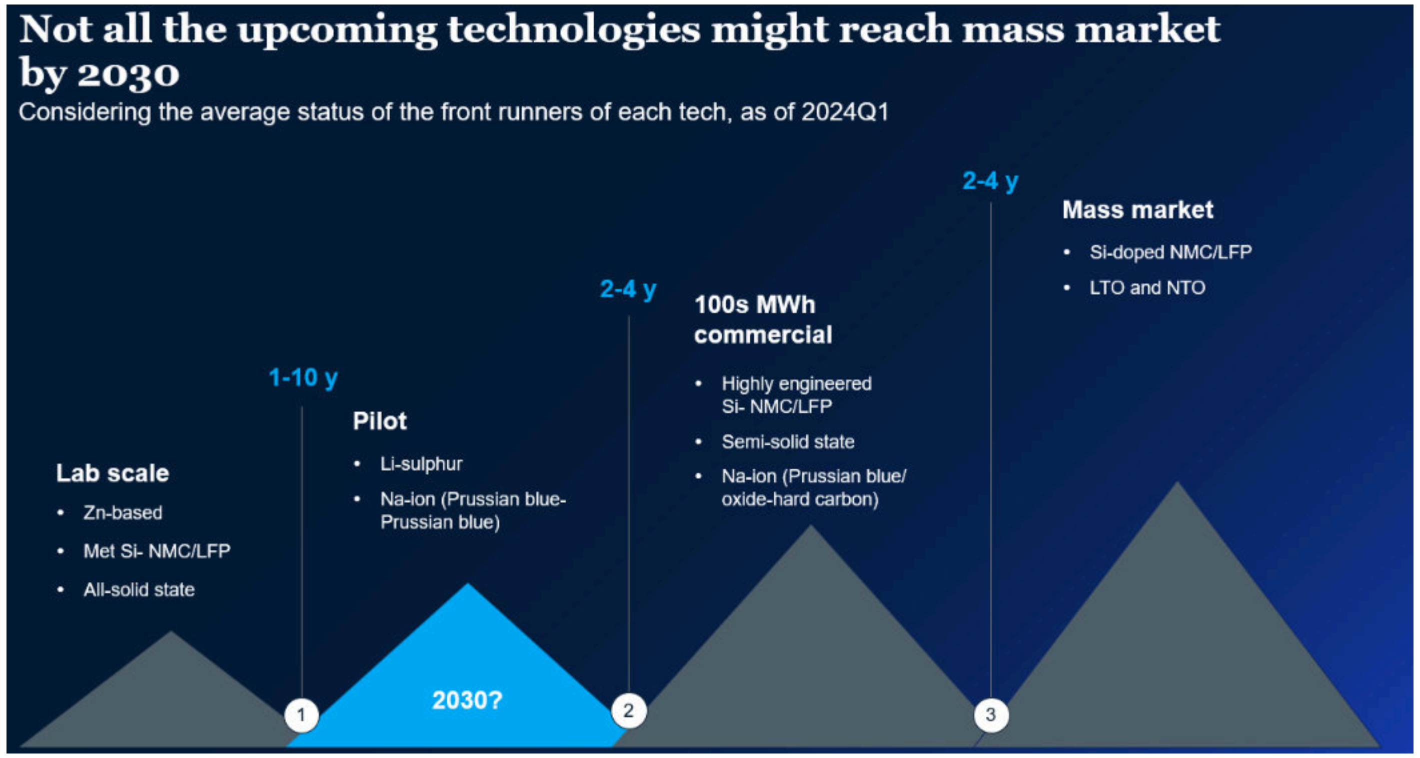
Nicolo Campagnol, PhD, Solution Manager, Battery Insights, McKinsey & Co.

This talk aims to create more clarity about next-generation Li-ion chemistries in terms of what they are and what their industrialisation status is. Nicolo is the manager and co-founder of Battery Insights, a McKinsey Solution (subsidiary) dedicated to the battery industry. Before joining McKinsey, Nicolo earned his PhD in electrochemistry studying at the Massachusetts Institute of Technology, in the USA, and the KU Leuven, in Belgium

In the field of battery technology, significant attention is drawn to two key factors: energy density and cost. Recent advancements of "traditional" Li-ion cells not degrading in 4 years of operation, and/or with cost below 60 USD/kWh, as well as with energy densities potentially allowing 1000 km of range, should prompt (and have prompted) reflection on the necessity for disruptive innovation.

Looking ahead to 2030, the equilibrium in terms of demand by market is poised for shift, with several end markets reaching 100+ GWh, the same order of magnitude as the entire battery market when the first gigafactories were built. Each of these markets will come with different requirements and while so far they leveraged a lot of the innovation driven by passenger vehicles, going forward they might need different specs.

The timing for these step-change innovations varies a lot, with some already deployed in niche markets, and others still at lab scale. Moreover, the pace of innovation is intricately tied to funding, and securing adequate financing remains a formidable obstacle, particularly for startups with very innovative technologies seeking modest investments.



Not all the upcoming technologies might reach mass market by 2030

Considering the average status of the front runners of each tech, as of 2024Q1

Lab scale
- Zn-based
- Met Si- NMC/LFP
- All-solid state

① 1-10 y

Pilot
- Li-sulphur
- Na-ion (Prussian blue-Prussian blue)

2030?

② 2-4 y

100s MWh commercial
- Highly engineered Si- NMC/LFP
- Semi-solid state
- Na-ion (Prussian blue/oxide-hard carbon)

③ 2-4 y

Mass market
- Si-doped NMC/LFP
- LTO and NTO

New technologies: not a winner takes it all but rather a chance for product differentiation

Performance of commercial or delivered samples as of 2024Q1, in comparison with "average" NMC/LFP-graphite

Commercial
- LTO and NTO
- Semi-solid state ①
- Highly engineered Si-NMC/LFP ②
- Na-ion (Prussian blue/oxide-hard carbon)
- Na-ion (Prussian blue-Prussian blue)
- Si-doped NMC/LFP ②
- Zn-based
- Molten salt

Non commercial
- All-solid state ①
- Li- sulphur ③
- Met Si- NMC/LFP ②

Three step change technologies have been attracting a lot of attention for their promises: solid state electrolyte, silicon anode, and lithium-sulphur batteries.

Solid-state batteries

A very important distinction must be made between different types of solid-state chemistries. Semi-solid cells are much more advanced in development stage (actually already in the market in some forms), are not very disruptive in respect to current production methods, yet still suffer drawbacks in cycle life and fast charging. All solid state batteries (ASSB) on the other hand promise similar if not higher energy densities, good cycle life and fast charging, yet might come at a higher cost and with a much different production line needed.

Semi-solid has been fast developing in the West by several startups, but in the last two years Chinese companies have spearheaded advancements with announcements doubling from 2022 to 2024. While 2024 holds promise for semi-solid batteries, with three vehicles potentially hitting the road (all in China), delays in mass production timelines have surfaced among certain next-gen players. Meanwhile, all-solid-state batteries are progressing steadily but require additional time to be ready for the market.

Silicon anode

Silicon can be used either in the form of metallurgical silicon or as highly engineered one (eg nanowires or nanospheres), and can either be used in a blend with graphite in low percentages (between 5 and 20%) or in majority silicon structures. Blending silicon with graphite represents a pivotal strategy for enhancing current lithium-ion technology, increasing energy density and lowering the cost, at the expenses of cycle life. On the other hand, the majority silicon products are just now entering the market, and mostly in the form of highly engineered silicon.

Lithium-Sulphur

Lastly, lithium-sulphur batteries present a promising avenue for achieving higher energy density at potentially reduced costs compared to traditional lithium-ion counterparts. Several players have transitioned beyond the laboratory phase, and are now facing the challenges of scaling up production to meet commercial demands.

In conclusion, the battery technology landscape is characterised by ongoing innovation and diversification, coupled with persistent challenges. Despite financial hurdles and technical complexities, the industry stands on the brink of significant growth and evolution.

Amionx SafeCore – battery safety from the inside-out

Dan Squiller, CEO Amionx

Amionx' presentation at AABC Europe will describe in detail the activation mechanism, abuse test results, and production readiness of the technology.

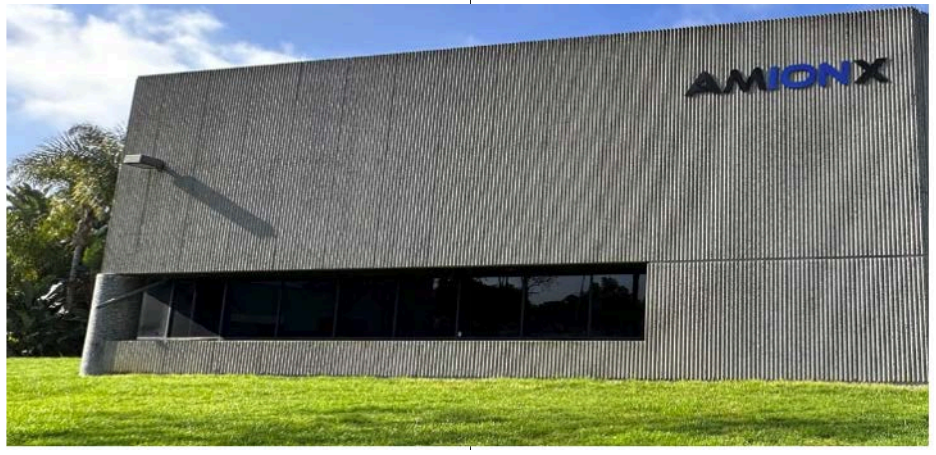
Li-ion Battery Safety Landscape
The proliferation of consumer devices and EVs has resulted in increased demand for batteries with higher energy density and power. Moreover, as devices increase in functionality and buyers of EVs expect longer ranges, the need for more power will continue to be the driving factor in Li-ion battery research. Such batteries are being realised through advancements in cell chemistries and architectures, however, efforts to safeguard these high-power batteries have had only limited success. While the battery industry has made significant investments in improving safety, the number of safety incidences continues to rise. The battery industry and regulatory agencies around the world have gone to great lengths and tremendous investment to improve Li-ion battery safety. Yet, batteries continue to fail in the presence of high voltage, high current, high temperature, high pressure, manufacturing defects, and other conditions. These failures often result in catastrophic fires and explosions that cause injury, loss of property and even death.

Why do Li-ion Batteries Fail?
There are three root causes of battery failure modes: overcharge, internal short, and high temperature.

- Overcharge occurs when the battery is charged beyond a safe voltage and is often due to the failure of protection circuits in the charger or battery management system (BMS). They can also be caused by a faulty cell, which shifts more demand to other cells in the pack to compensate. These failures can take place at the cell or pack level.

- Internal shorting occurs within the battery when there is an electronically conductive pathway between the electrodes. Internal shorts can be due to external conditions including a puncture or crush or can result from a pre-existing manufacturing defect. They can also be formed over cycles as lithium metal is deposited in needle-like structures, called dendrites, that grow and eventually bridge the electrodes creating a short circuit.

- Thermal runaway is an uncontrolled cyclic reaction in which heat causes materials within the cell to decompose and generate increasingly more heat until the cell eventually combusts. The electrolyte, a flammable organic liquid with a low flash point, is often complicit in thermal runaway. Because thermal runaway is cyclic in nature, there is no way to stop it once it has started. In a multi-cell battery, an occurrence in one cell will likely propagate to neighboring cells until the whole battery pack is consumed. Thermal runaway can be activated directly by a heat source or can be a byproduct of heat generated by overcharge or internal short.



SafeCore™: Bullet Proof

Due to the severity of these failures, Li-ion batteries have not been suitable for certain applications and roughly a third of the cost and weight of current batteries comprises protection and packaging. In EV applications, where crashes and impacts can subject the battery pack to major trauma, packaging and safety devices account for more than half of the total pack weight. A fault tolerant and safer battery, therefore, has the potential to significantly extend EV range by eliminating the weight and space taken up by structural components.

Amionx SafeCore
Amionx is a spinout from American Lithium Energy Corporation (ALE), that has been designing, manufacturing, and supplying batteries to the Department of Defence for over ten years. ALE began working on Li-ion safety technology (SafeCore) for military applications which resulted in batteries that could be penetrated by a bullet without risk of fire or explosion. The harsh environments experienced in the military were an optimal proving ground for SafeCore and this heritage is critical to its high tolerance to hazards in commercial markets. The mission of Amionx is to further develop and deploy this technology in EV and other commercial applications.

SafeCore was designed to combat the major hazards associated with batteries including overcharge, internal short, and high temperature. It is a layer within the cell that creates a high impedance electrode layer when triggered by a temperature, voltage, or current threshold. Because it works at the core of the battery, it is the final line of defence when other security measures fail.

SafeCore technology has been transferred into high volume manufacturing and Amionx has licensing and manufacturing agreements spanning markets including EVs, power tools, and consumer electronics companies.

Dan Squiller is the CEO of Amionx, and he has a long tenure in CleanTech. Previously, he has held CEO and C-level positions at Aquam Corporation, Verengo Solar, GT Advanced Technologies, PowerGenix, Invensys plc, St. Bernard Software, and Scientific Atlanta. A graduate of Ohio University with a BS in Electrical Engineering and an MA in Communication, he also completed the Executive Institute program at Stanford University.

Battery design revealed – why battery cells are built the way they are

Dr.-Ing. Michael Schönleber, CTO and co-founder of Batemo GmbH, Karlsruhe

Batemo specialises in the development of lithium-ion simulation software. Based on Batemo's ever-growing toolbox and library of battery data and validated simulation models, Dr. Schönleber will discuss performance targets of battery cells and how these are affected by material choice and cell design. In the talk, cell design trends of the 2024 battery market will be revealed, and principles for target-oriented battery cell design will be derived.

As requirements in the various applications of batteries are highly diverse, there exists a large variety of lithium-ion battery cells with different form factors, chemistries, tab configurations and housings. Clearly, there is not the one battery that fits into all applications, and to transfer cell design parameters to performance targets and vice versa requires great expertise and know-how. Thin electrodes or thick electrodes? One tab, multiple tabs or tabless? Pouch, prismatic or cylindrical? Silicon or pure graphite? Why are batteries built the way they are?

The database: A library of battery cell data and models

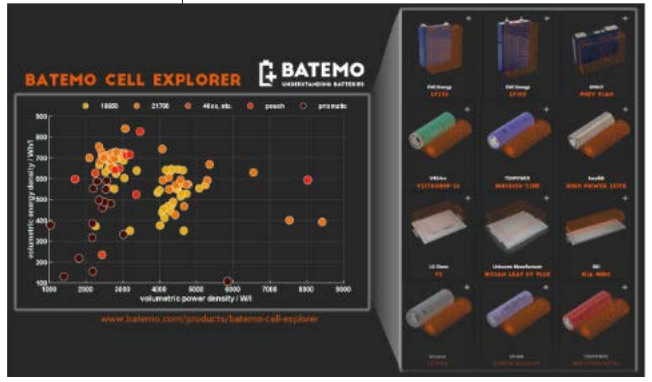
Over the last years since 2017, Batemo GmbH in Karlsruhe has opened, characterised, and modelled hundreds of lithium-ion battery cells. In 2020, Batemo introduced the Batemo Cell Explorer, an ever-growing library of high-precision battery cell models to the market. As shown in the figure, this catalogue includes all formats, ranging from highest power to highest energy designs and containing all the different active materials from LFP over NMC to NCA, from LTO over graphite to silicon. Thereby Batemo gained a profound knowledge and a comprehensive pool of data on how battery cells are internally built. This is exactly how Batemo is able to reveal general cell design trends of the 2024 battery market.

Some of the knowledge that is useful for the community will be presented in the talk given by Michael Schönleber, co-founder and CTO of Batemo GmbH at this year's AABC Europe in Strassbourg. The audience will learn about some fundamental design principles and design trends of battery cells, which are employed in the market, and learn how to direct the cell performance towards desired performance targets.

The tool: A simulation model for cell design

Batemo's close cooperation with battery cell manufacturers resulted in the Batemo Cell Designer, the ultimate tool for battery cell design. The underlying idea of the process is to never start from scratch but with a given cell, electrode, electrolyte or material. Using the tool, battery cell design parameters can be varied, and the dynamic performance under all conditions can be predicted. This is how the link between cell design changes and performance targets can be quantified.

The second part of the talk is dedicated to employing and validating such a digital design and re-design process. Starting from a high-energy cell, cell design variations are applied to transfer it to a high-power cell. Subsequently, the cell design variation study will be validated by cross-checking the simulation model with experimental results from a battery teardown. Thereby, the universality and practical usefulness of the tool to design a battery cell on target will be discussed.



Performing micro-scale simulations of long-term SEI growth in Li-ion batteries

Falco Schneider, PhD, Scientist, Flow and Material Simulation, Fraunhofer ITWM

Li-ion batteries are exposed to a variety of degradation effects, causing cell aging over time. One major contributor to capacity and power fade of the cell is growth of the solid electrolyte interphase (SEI). In this talk we will discuss how the long-term growth behaviour of the SEI can be captured with fully coupled electrochemical simulations. Furthermore, we present numerical methods to enable long-term aging studies of such detailed models.

Growth of the solid electrolyte interphase (SEI) plays an important role for aging of Li-ion batteries. The SEI is the result of irreversible reduction reactions of lithium and electrolyte components at the anode surface during high states of charge, see Fig. 1. This is caused by common anode materials such as graphite since they achieve voltages below the stability window of commercially used electrolytes during battery operation. While this helps to stabilise the system through passivation of the anode surface and enables safe operation of the battery, it comes with the trade-off of permanent capacity fade and power loss, which keeps increasing as growth continues. Gaining a detailed understanding of the SEI growth dynamics and its dependencies on cell operation, cell design and overall cell chemistry facilitates development of novel cells with increased energy efficiency and cycle life.

Studying the SEI in detail is impeded by a prominent contrast in spatial and temporal time scales which must be considered to investigate long-term aging behaviour. Common SEI layer thicknesses range from a few up to hundreds of nanometers, demanding significantly higher spatial resolutions than the micrometer sized active particles to resolve its structure and to get a deeper understanding of its morphology and chemical composition. At the same time, extensive operation periods of hundreds to thousands of cycles need to be considered to capture the full aging characteristics of a battery during its life cycle.

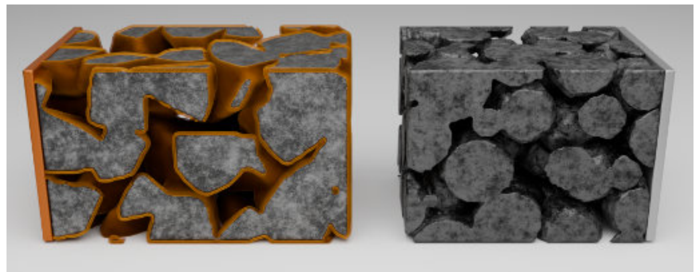


Fig. 1. Visualisation of an anode (left) and cathode (right) microstructure in a Li-ion battery cell. Through formation the SEI is generated as a passivating interphase layer on the anode surface which continues to grow during operation and leads to cell aging over time.

This contrast in scales poses significant challenges for analysing the SEI by experimental observations, where the requirements for spatial resolution limit methods for in-situ observations to specific cell setups and small sub-regions, while detailed post-mortem analysis only provides a destructive method of characterising the SEI, preventing further use and consecutive measurements across the cell's lifetime. Furthermore, the deconstructed cells are highly reactive, such that special care must be taken during disassembly to prevent contamination of samples. Another important factor are the significant energy costs that are associated with these extensive cycling experiments, especially if the cells are conditioned by using climate chambers.

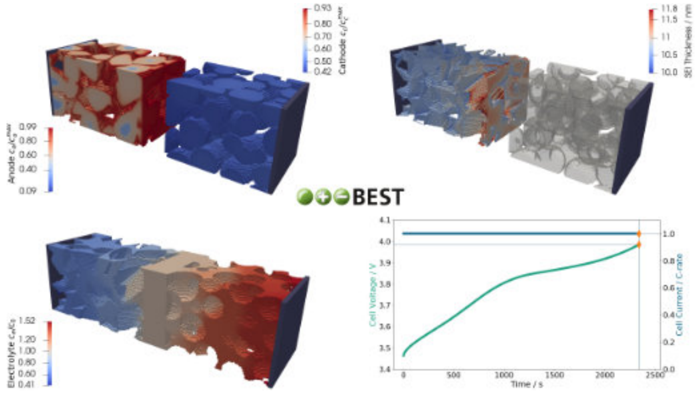


Fig2. Micro-scale simulation of a graphite-NMC cell during constant current charging with 1C in BEST. Top left: Individual electrode states of charge provided as normalised Li-ion concentration. Bottom left: Electrolyte Li-ion concentration normalised by initial salt concentration. Top right: SEI thickness profile. Bottom right: Applied current and resulting cell voltage. The snapshot is recorded at the very end of the simulation, as indicated by the orange markers in the plot.

Due to the aforementioned challenges, physical models can provide a suitable supplementary tool to experimental observations to get a better understanding of cell aging and reduce the number of experiments that need to be performed by providing data and visualisation of internal processes. In our talk we will present a micro-scale electrochemical model which couples the fundamental transport processes on the spatially resolved electrode microstructures of a Li-ion battery with an SEI-growth model. The cell dynamics are characterised by computing the internal Li-ion concentration and electric potential profiles in space and time. Simultaneously, the model captures the SEI thickness profile along the active surface of the anode microstructure, see Fig. 2. Hence, the simulation is able to track the potentially inhomogeneous SEI profile over time, while also accounting for the associated consumption of Li-ions and increase in interface resistance, causing capacity loss and power fade, respectively.

The numerical systems resulting from this type of model feature a complex structure which can impede performance of numerical cell aging simulations. We address this issue by deploying a custom solution scheme in our simulation software Battery and Electrochemistry Simulation Tool (BEST), which specifically takes care of the additional equations of the SEI model. This allows us to increase the robustness of these type of simulations and significantly reduce the computational cost associated with the inclusion of the SEI model.

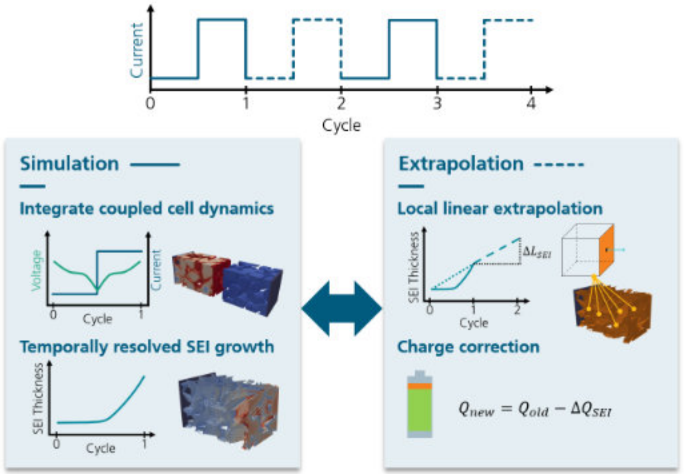


Fig3. Illustration of the deployed cyclic extrapolation scheme to accelerate long-term aging simulations. The simulation alternates between fully resolved simulation of operation cycles and an extrapolation of SEI growth for the next batch of cycles. The extrapolation is performed locally in the microstructure and takes into account the different growth rates from the previous simulation. Finally, the method accounts for the capacity fade caused by the extrapolated SEI.

While the considered class of micro-scale models has the benefit of providing detailed insights into the local transport processes and how they are affected by the microstructure, it comes with the drawback of a substantial computational effort. Hence, fully resolving the large time scales of long-term aging studies featuring hundreds to thousands of operation cycles by continuous simulations is currently not applicable.

In order to address this issue, we propose a cyclic extrapolation scheme which alternates between continuous simulation of full cycles of the operation protocol and a subsequent estimation of SEI growth by extrapolation, see Fig.3. This is motivated by a similar type of schemes, which are commonly used in the field of mechanical engineering when performing long-term fatigue assessment studies of a component under cyclic mechanical load, a problem of very similar structure to cyclic operation of batteries.

Deploying this type of extrapolation technique allows us to significantly reduce the number of cycles that need to be simulated. As an example, we consider a representative volume element of a graphite-NMC cell which is cycled over 500 discharge-charge cycles.

We observe an error of around 5% in the predicted SEI layer thickness, when using an adaptive extrapolation, simulating only seven of the 500 cycles compared to a reference solution which simulates every tenth cycle, which allows to reduce the runtime by 86.9%.

The developed numerical methods allow for detailed micro-scale simulations of long-term cell aging through growth of the SEI. This enables users to study the impact of factors like the cyclic operation protocol, but also the morphology of the microstructure, on the SEI thickness profile and the general aging criteria of capacity fade and power loss.

Charging forward: how to make sustainable battery manufacturing a reality

David Verner, Director of Energy Strategy, Gresham Smith & Partners

The shift in the automotive landscape towards electric vehicles took a defining turn when the GMC Hummer EV emerged. The transformation of an iconic gas-guzzler into an EV muscle car heralded a meaningful change in the market. However, to realise the environmental aspirations of EVs, a comprehensive evaluation of the battery supply chain, from sourcing raw materials to recycling is imperative.

When looking at sustainable battery manufacturing, there are four key steps:

1. Take a holistic view of sustainability
2. Be honest in your approach
3. Consider the overall battery ecosystem and lifecycle
4. Factor in all of the cost structures—economic, environmental and social

Taking a Holistic View

To be truly sustainable, it's necessary to take a holistic viewpoint. Everything has a cost whether it's economic (Euro's), environmental (deforestation) or social (community impacts). Solutions aren't sustainable if you drive down economic costs at the expense of significant environmental damage or negative social impacts. Conversely, it's not sustainable if you prioritize environmental or social results at exorbitant economic costs.

Being Honest

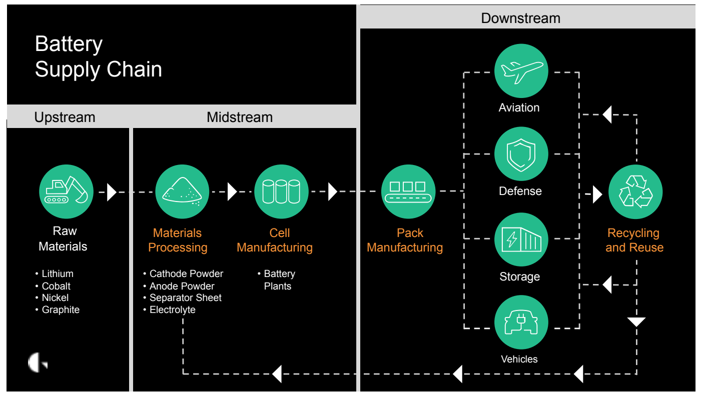
Be open about the realities of the current situation. For example, at the time of manufacturing, studies have shown that EVs have twice the negative environmental impact of a comparable internal combustion vehicle. EVs don't begin to reach a break-even point until they're being driven. Even then, the source for charging determines how quickly the break-even point is reached, and it can range from 9,000 miles when charged with 100% renewable energy to almost 90,000 miles when charged by a coal fired plant.

Considering the Entire Battery Ecosystem

The battery ecosystem has many places where we can improve sustainability whether it is mining, material processing, cell manufacturing, applications, recycling, reuse or disposal. It's up to industry leaders to understand the value chain and drive sustainable practices and encourage others to do the same.

Examining Cost Structures

To identify where the greatest impact can be made, consider all of the cost structures. These costs may not always be monetary, but for the purposes of this discussion we'll use reducing costs as a proxy for increased sustainability.



The cost of the battery is a significant cost of the overall EV. The two largest drivers of that cost are cathode active materials (CAM) (51%) and manufacturing (24%), which together make up 75% of the total cost of the battery.

CAM (51%)

Three improvement areas that will reduce the costs and increase sustainability of CAM are:

1. Localizing material processing
2. Improving extraction practices
3. Better battery chemistry (The Holy Grail)

There is a lot of activity in both North America and Europe that will bring the production of CAM closer to it point use. There are many CAM projects that are either underway or in the planning process in North America that will allow companies to shorten the supply chain and produce CAM using more sustainable energy sources and under stricter environmental regulation.

Ideally, CAM can be extracted near existing production facilities. If that's not possible, then the industry must support sustainable mining practices in other parts of the world.

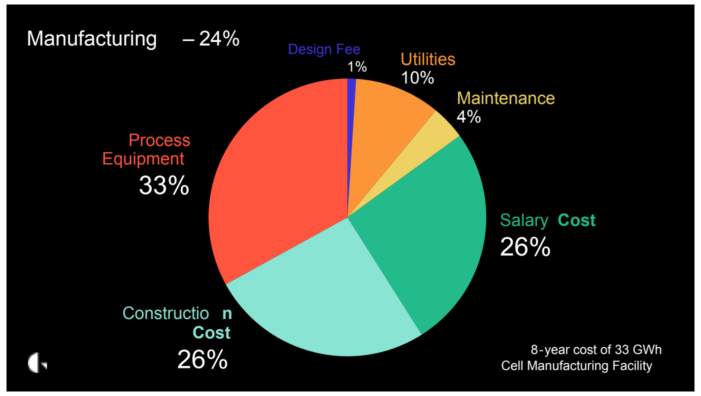
Finally, it's important to acknowledge that current batteries are simply not good enough. The Holy Grail for CAM is to move away from rare earth metals altogether and develop chemistries that use common earth metals.

Manufacturing (24%)

The next largest piece of a battery's cost is manufacturing at 24%. Looking at projected data over an eight-year period for a 33 gigawatt hours (GWh) cell manufacturing operation, we see that more than one-third of the total cost is related to construction and utilities (see graphic above). There are several strategies to improve both these costs and drive long-term efficiency in the plant operation. These include:

1. Identifying key sustainable impact areas at the start
2. Streamlining project flow
3. Prefabrication and standardization
4. Benchmarking and lessons learned

Making battery manufacturing more sustainable requires early planning, coordination and goal-setting at the beginning of the project. Some sustainability strategies are straight-forward items, such as using a highly efficient chiller plant, while others, such as waste heat capture and re-use from charge/discharge, can have a large impact if the return on investment (ROI) problem can be solved.



An overlooked piece of the sustainability puzzle occurs during the design phase of a project. Oftentimes, the design and facility team operate as two separate organizations with separate budgets, and they don't communicate well. This leads to increased costs, schedule overruns and reduced operational efficiency. Use of a variety of tools to enhance communication, such as 3D modeling, virtual white boards and team-building exercises, is critical.

Early planning allows the team to drive down costs and improve outcomes. Use "pull planning" with the entire team and start with end in mind, then work backwards by building milestones to develop a clear, well-defined workflow, which drives efficiency. Establish "stage gates" with critical milestones that a project must go through before proceeding. This establishes buy-in from the overall team, including senior leadership, which reduces the potential for future rework.

Incorporate prefabrication because it allows for major components of a plant to be built in an off-site controlled environment that dramatically increases efficiency and quality. Use virtual design and construction tools, such as 3D BIM technology, to build the plant virtually so that it will come together simply and seamlessly in the field.

Finally, make time for benchmarking and lessons learned. Use benchmarking to question the overall scale, utility demands and environmental data before design begins. Gather data on all projects and develop tools to contrast and compare different operations. Use it to compare the construction cost/GWh across different plants to see if it varies. Evaluate how efficient a plant is by comparing the total area required to produce 1 GWh of capacity. Incorporating lessons learned leads to continuous improvement, which is inherently sustainable.

Battery technology is incredibly exciting and will continue to change the world. But, to be truly sustainable, we have to do better. The good news is that evolving chemistries, improving technologies and shortening supply chains are helping us get better.

Introduction to Beff's initiatives and Beff platform

Beff, founded in 2023 by Shunsuke Amagai (left) and Kodai Nagano (right), is a startup that has garnered significant acclaim by providing technical solutions for the development and production of lithium-ion batteries to numerous clients since its inception.

Driven by a mission to eliminate inefficiencies in the world and achieve a prosperous society for the next generation, we relentlessly explore new technologies and undertake challenges for the betterment of humanity and the planet. Through these endeavors, our aim is to inherit and pass on a beautiful and thriving future to coming generations, leaving behind a responsible legacy.

In terms of market scale, global battery production is projected to increase nearly tenfold over the next decade. Thus, the key to enhancing the competitiveness of battery manufacturers lies in efficiently advancing development, nurturing talent, and early realization of mass production.

Our team comprises specialists who have been involved in the development and production technology of lithium-ion batteries for decades. One recurring observation in this industry is:

1. Manufacturing technology is predominantly concentrated in specific countries in East Asia, leading to information asymmetry between East Asia and Europe/US.

2. Competent production technology engineers are in high demand, creating a bottleneck for the expansion of battery businesses.

3. The significant differences in battery manufacturing difficulty between lab-level and scaled-up production facilities are not deeply understood.

How do we address these challenges? We will now elucidate our initiatives based on these considerations.

One major obstacle to establishing high-yield manufacturing lines is the scarcity of experienced process engineers, industrialization engineers, and operators, coupled with the extensive time required for skill acquisition. This relates to the aforementioned points 1 and 2. The commercialization of lithium-ion batteries originated in Japan and spread across East Asia, resulting in a concentration of experienced talent in the region. Acquiring such talent for regions like Europe and the US poses difficulties due to geographical, cultural, and linguistic differences. Additionally, given the anticipated surge in lithium-ion battery production over the next decade, merely securing experienced talent is inadequate. It is crucial to significantly enhance the development efficiency per engineer and promptly professionalize operators.

Addressing these issues necessitates proposing disruptive and scalable strategies in talent acquisition and education. As a solution, we propose ultra-efficient development of engineers through AI and rapid skill acquisition for operators.

We are developing a software called the Virtual Factory Platform (VFP), which provides a chat-based solution where all stakeholders involved in lithium-ion batteries can easily access desired information. This platform serves various purposes, from answering basic questions about lithium-ion batteries to efficiently exploring cutting-edge technologies, accessing top-tier companies, and conducting benchmark analyses.

VFP (Virtual Factory Platform)

- Strategic and efficient investigation
- Professional expertise and in-depth insights
- Identifying potential partners

By centralizing these functions into a chat interface, users can swiftly find desired answers, dramatically reducing the time required for information retrieval. Additionally, the VFP allows interaction with our experts, enabling direct consultation with specialists.

Another significant challenge in constructing high-yield manufacturing lines is the insufficient development of production process for yield improvement before equipment investment. This is related to the aforementioned point 3.

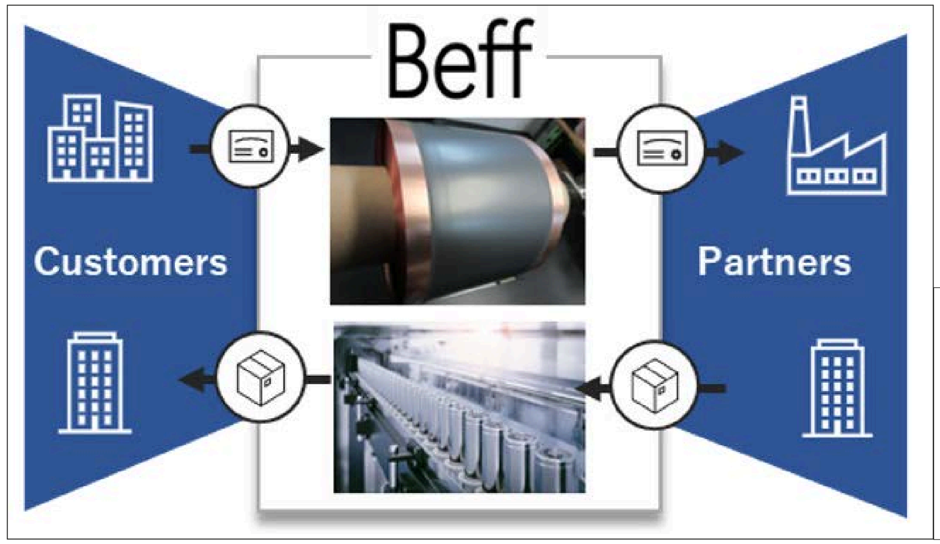
Many might have experienced the discrepancy between successful results obtained with handcrafted small-scale cells in the lab and the performance issues encountered when upscaling to large-scale cells. This difficulty escalates when transitioning to mass production facilities. To efficiently produce competitive cells at low cost, it is essential to balance material and process design and maximize manufacturing speed. Trial and error by each engineer and operator is necessary in this process, underscoring the necessity of acquiring experienced talent.

We offer a service called the Real Factory Platform (RFP), which facilitates seamless development from prototyping with small-scale lines to mass production. As mentioned earlier, designing robust cells with productivity in mind at the R&D stage is essential. Altering materials or processes after equipment installation becomes exceedingly challenging.

Through the RFP, we are collaborating with numerous clients on joint development projects. For example, we support electrode manufacturing, which is one of the difficult processes in cell production, as well as material selection and equipment development to improve yield during mass production. Additionally, we provide clients with large electrode rolls as part of these joint development efforts.

We hope this overview provides insight into Beff's endeavors. At AABC, we not only present detailed presentations on the businesses introduced in this article but also have a booth set up.

We welcome you to visit us, and look forward to meeting you in Strasbourg.

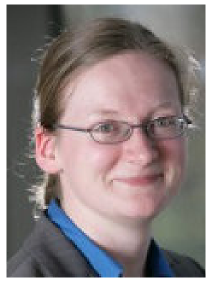


RFP (Real Factory Platform)

- Cutting-edge electrode and cell development
- Environmentally-friendly electrode production
- Prototyping for all cell formats

Addressing scale-up challenges in battery materials

Keri Goodwin, PhD, Chief Technologist, Formulation, CPI



Presentation will detail CPI's work in supporting the main challenges faced by innovators in battery materials development, including supporting the transition from lab scale to commercial validation in industrially relevant cell formats.

CPI is a technology innovation catalyst and part of the UK's High Value Manufacturing Catapult. Established in 2004 and now with 750 staff and £78m turnover, CPI collaborates with universities, SMEs and large corporates to help them overcome innovation challenges and develop next-generation products and processes. We also connect academia, businesses, investors and funders to bring bright ideas and research into the marketplace. CPI has £170m of development and prototyping facilities with five dedicated innovation centres), which underpin innovation in major markets such as energy, materials, FMCGs, agrifoodtech, HealthTech, pharmaceuticals and electronics.

These state-of-the-art, digitally enabled open access facilities are available for CPI's partners to use in the proofing, development and commercialisation of their new products or processes. We have industry-relevant expertise relating to materials scale-up (including process engineering support), high-throughput formulation (to rapidly develop formulation space for new or existing materials sets), and coating capabilities (bench top to R2R). All are supported by an extensive characterisation capability, including electrochemical testing.

CPI has a substantial track record of supporting the battery industry with common challenges relating to supply chain validation and scale-up of materials. Recent funding awarded by Innovate UK's Faraday Battery Challenge has enabled CPI to invest in significant capabilities relating to materials synthesis scale-up.

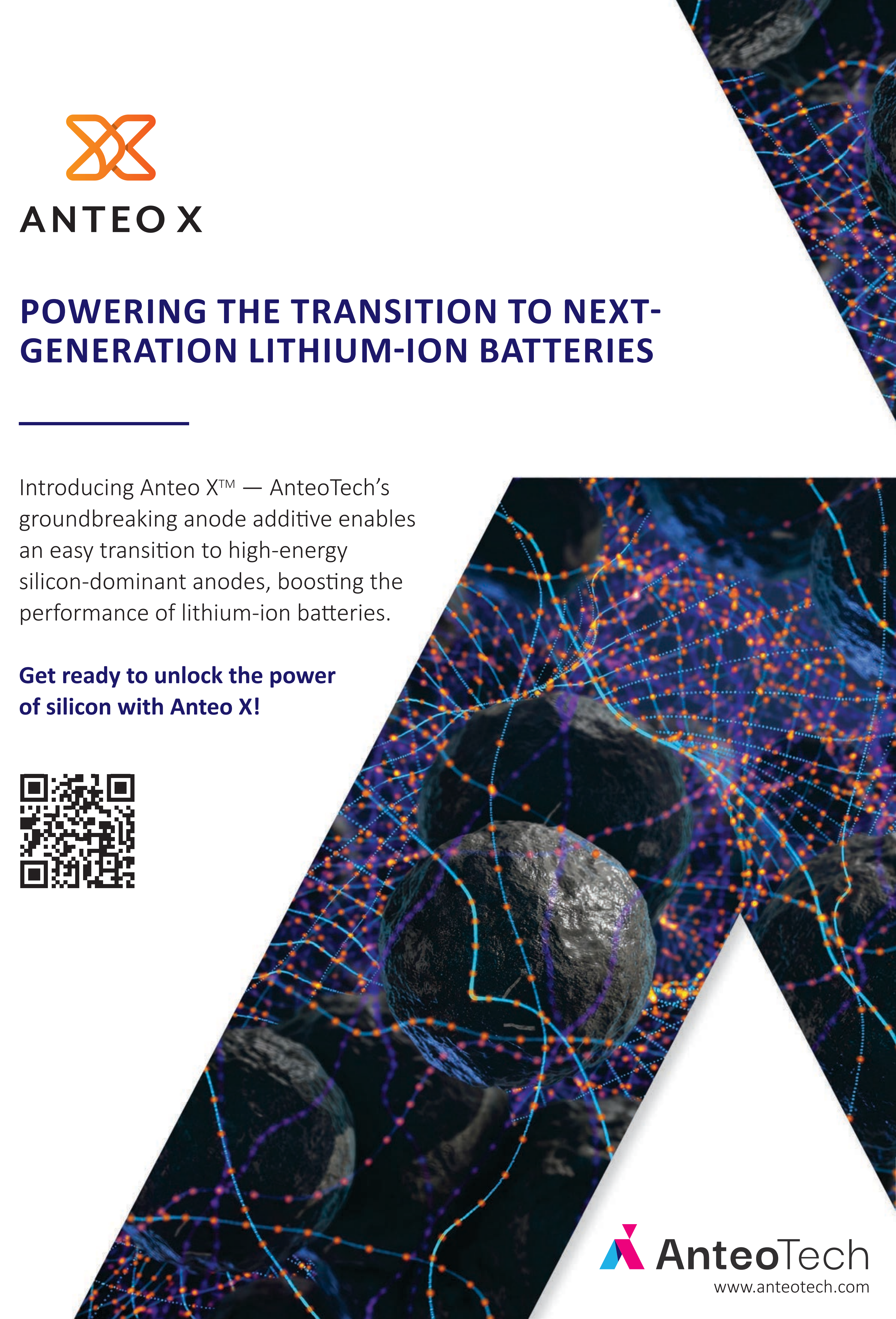
As a result of this funding CPI will have the capability to produce 10+ kg of battery active materials. The synthesised battery active materials can then be processed by WMG into industry-relevant electrodes using scalable slurry mixing, roll-to-roll electrode coating and calendaring to manufacture 10s-100 prototype development cells including 46800 cylindrical. AMBIC is just part of an ecosystem that's being developed to fuel Britain's electric battery aspirations.

The focus of the materials synthesis equipment housed at CPI will be on unit operations that allow a broad range of chemistries to be investigated. Activities such as co-precipitation, dry milling, wet milling, powder drying, powder mixing, calcination and powder coating will be available for materials development for batches of 10+ kg. The technical specification of the equipment will be targeting cathode active materials for current Li-ion (e.g. Ni-rich NMCs, LFP, LMFPs), Na-ion, solid-state electrolytes (excluding sulfides) and some anode materials (e.g. niobium based).

Equipment will also be specified to allow for digital process control development, allowing users to better understand reaction progress. Digital upgrades (e.g., sensors, higher-spec HMIs, enhanced connectivity) for each asset will form the foundation for future data analytical applications and real-time monitoring and control of processes.Computational fluid dynamics (CFD) modelling can further enhance process understanding. CPI has successfully used this to model the slurry mixing process and allow for scale-up considerations when moving between mixing technologies, e.g., from planetary to Eirich mixer.

With the combination of materials synthesis at scale and the ability to model and ideally predict process conditions for new materials, the AMBIC facility will be well-placed to support the scale-up of existing and future generations of battery technologies.

Let's innovate together www.uk-cpi.c



Sustainable battery material production at a fraction of the cost

Wyatt Olson is a Senior Program Manager at 6K Energy responsible for product development and commercial programs. He started his career in chemical R&D at Moses Lake Industries (MLI), spending ten years developing and launching electroplating products at global chipmakers. After spending three years on lithium-ion battery products at MLI, Wyatt joined 6K Energy in 2022. He holds B.S. in Chemistry and an MBA from the University of Washington.

Massive societal, economic, and technological shifts are happening globally in response to the increasing threat of climate change. We are seeing a shift to electrification as a more sustainable energy source, causing an increased need for energy storage in the form of batteries. The need for a secure supply of battery material is growing exponentially because of this transition, both for mobility solutions like electric vehicles (EVs) and for stabilising and reinforcing renewable-fed electricity grids.

While battery technology has been constantly iterated and improved, the increased demand coupled with geopolitical instability and a race to secure finite — and rare — resources has hampered affordable and reliable battery production needed to support the mass electrification agenda. Cathode active materials (CAM), the most expensive component of a lithium-ion battery, remain time-consuming and environmentally hazardous to produce. In addition, regulations and incentives are being implemented to encourage the non-use of China-produced battery material.

Leapfrog Technology for Sustainable Production of Battery Material

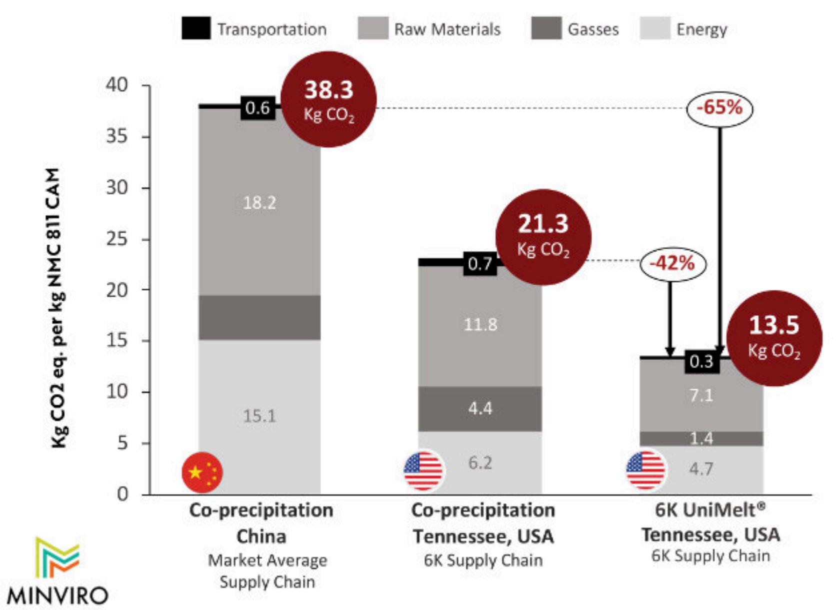
6K's UniMelt® microwave plasma technology is transforming how we produce battery material by collapsing the production process time by 95%, resulting in over 50% reduction in conversion costs.

With 6K's UniMelt technology, we take a multiple-step process down to a one-step, closed-loop process, driving the overall cost of the material down. Our unique technology allows for multiple materials to be produced in the same plant, offering complete flexibility to meet the specific demands of individual customers under one roof. 6K Energy can produce a wide range of battery materials, including NMC, LFP, LLZO, and LMR, all in the same factory. This allows for easy scalability and cost reduction, with a significantly lower environmental impact.

IRA-Compliant NMC and LFP Battery Material

6K Energy's production of lithium-ion cathode active material (CAM) will meet the stringent government mandates for compliance requirements outlined by the Inflation Reduction Act (IRA). 6K Energy is the only company that will offer both LFP and NMC battery materials that will qualify for all the IRA-compliant tax incentives offered for battery material production. These materials will be manufactured at 6K Energy's PlusCAM facility in Jackson, TN.

6K Energy LCA Summary for NMC Battery Material Produced Using the UniMelt® Process



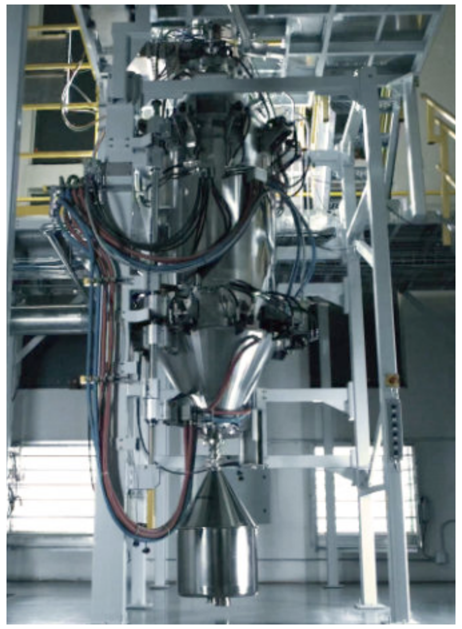
By securing a domestic supply chain of battery material, 6K Energy will significantly reduce dependence on foreign-made battery material and increase domestic supply. Domestic production reduces the national security risk, increases local jobs, and provides significant value in offering sustainably produced battery material at a lower cost. 6K Energy's plan for domestic sourcing of material will decrease the national dependency on raw material suppliers and will ensure a stable, secure source of feedstock for our future electrification needs.

Sustainability of UniMelt Vs. Co-precipitation

The UniMelt process is significantly more sustainable than the current co-precipitation process, creating virtually no waste byproducts. The current co-precipitation process generates large amounts of pollutants, consumes huge amounts of water, and uses energy-intensive processes. By leveraging nitrates versus sulphates, commonly used in conventional processes, the UniMelt process produces zero hazardous waste, a significant reduction in water usage, and two times the reduction in power usage.

Independent Life Cycle Assessment

A recent independent life cycle assessment (LCA) was conducted by Minviro, offering a comparative analysis between 6K Energy's process and conventional production routes for NMC cathode active materials. This LCA highlights the substantial environmental benefits, including significant reductions in greenhouse gas emissions, water pollution, and air pollution.



The 6K Energy process has a significantly lower environmental footprint compared to traditional manufacturing techniques. Key factors in this comparison include raw material sourcing, energy consumption, emissions, and the overall environmental footprint.

The preliminary LCA data underscores the superiority of the 6K Energy process in minimising energy requirements and emissions. Notably, the use of less energy-intensive raw material processing methods contributes significantly to the overall reduction in environmental impact, even factoring in differences in energy supply.

A noteworthy finding of the LCA is the efficient energy use of the 6K Energy's UniMelt platform. Traditional production routes typically involve high energy consumption and substantial emissions, particularly from the use of fossil fuels. On a like-for-like basis, with both traditional and 6K Energy's processes using energy from the same source, the reduction in consumption is marked.

A significant advantage of the 6K Energy process is the use of nitrates as a feedstock, eliminating sodium sulphate waste and creating a closed-loop system to recycle off-gasses back into the process efficiently. Based on this method, 6K Energy's process can significantly reduce core climate change metrics, with the LCA assessment reporting:

- ~65% reduction in climate change impact of producing NMC-811 CAM via 6K Energy's PlusCAM process compared to the conventional China-based co-precipitation process.
- ~43% reduction in the climate change impact of producing NMC-811 via the PlusCAM process compared to the conventional co-precipitation process when the supply chain and manufacturing location are assumed to be the same.

Conclusions

Reducing the cost, securing supply chain instability, and reducing the environmental impact of battery material production are essential to supporting the burgeoning electrification agenda. 6K Energy's UniMelt platform is set to revolutionise the production and recycling of CAM materials for all major battery chemistries in terms of monetary and environmental costs. The ability to establish the processing of materials domestically and close to existing supply chain nodes further improves the benefits.

At 6K Energy, we are setting a new standard for cathode active material production—sustainable, lower cost, domestic, and IRA compliant. To learn more about our process, please visit www.6K-Energy.com.

Sustainable CNT manufacturing to meet global demand for high-performance, low-cost carbon nanotubes

David Arthur, CEO, CHASM Advanced Materials

With Carbon nanotubes (CNTs) becoming critical for today's EV batteries, sustainable, scalable approaches to meet expected global demand are needed, including US and European production. In the past, commercial application has been hindered by the practical obstacles of scaling manufacturing at viable cost. In this talk, we'll present Chasm's unique approach, which produces low-cost, tuneable and high purity CNT materials and we'll share performance results and expansion plans.

Chasm's Breakthrough Manufacturing Technology Addresses Surging Demand for Carbon Nanotubes (CNTs) in lithium-ion Battery Market for NA and European Market

In the rapidly evolving electric vehicle (EV) market, the quest for more efficient, durable batteries is relentless. At the forefront of this technological advancement is Chasm Advanced Materials, Inc., which is further expanding the production of its NTeC®-E conductive carbon nanotube (CNT) additives, set to transform the lithium-ion battery landscape. Chasm is poised to showcase its innovative solutions and industry leadership at AABC in booth #303. Chasm's CEO and Co-founder, David Arthur, will give a presentation on Thursday, May 16th, at 8:50 AM, titled *'Manufacturing Carbon Nanotubes at Gigafactory Scale in the US and Europe.'*

CNTs have become the go-to conductive additive solutions for lithium-ion EV batteries in both cathodes and anodes to enhance key battery performance metrics such as lower internal resistance, increased energy storage capacity, superior rate capability, and longer cycle life. For example, in cathodes, compared to traditional conductive additives, high-quality CNTs like NTeC-E products enable a 4–8% increase in active materials and 15% or more capacity retention at 2C. In the emerging silicon anode applications, CNTs are used to provide critical structural support to address the significant expansion and contraction issues of silicon anode materials and have been proven to increase conductivity, as silicon materials do not inherently conduct well. According to a recent report by IDTechEx, the demand for CNTs in the lithium-ion battery market is expected to soar to 50,000 metric tons by 2032, a fivefold increase over today's production capabilities. This surge underscores the critical need for scalable, efficient production methods.

Chasm's CNT manufacturing technology

Chasm's new CNT production platform offers the most scalable, cost-efficient and sustainable approach for mass production of high-quality CNTs tailored for lithium-ion batteries. The core technologies behind this innovation include proprietary (iron-free) catalysts plus proprietary (rotary kiln) reactors for CNT synthesis, which are more capital-efficient than traditional fluidised bed reactors used by leading CNT producers.

Chasm's NTeC-E conductive CNT additives are produced at Chasm's manufacturing plant in Norman, Oklahoma. Chasm is currently producing its portfolio of NTeC CNT additives products at pilot-scale (50 metric tons) and aims to complete the construction of the world's largest CNT production reactor with a capacity of 1,500 metric tons by Q4, 2024.

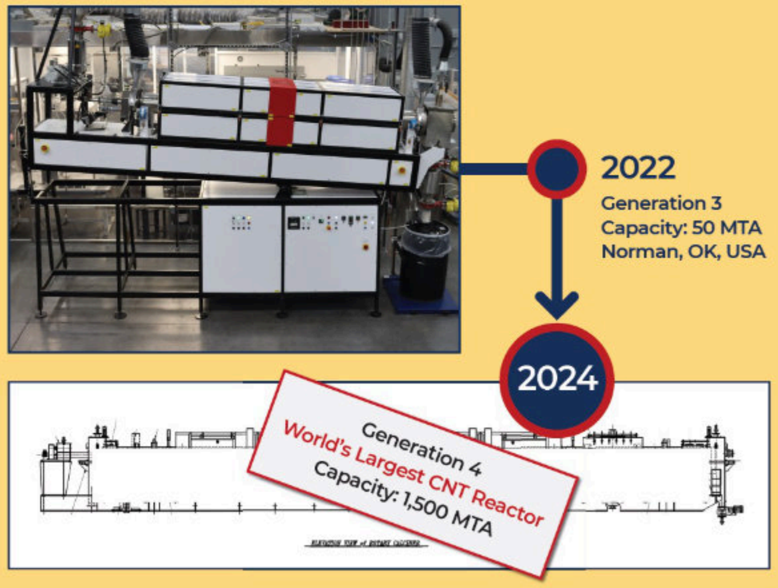
NTeC-E conductive CNT additives validated

Chasm's NTeC-E conductive CNT additives have been validated by various partners and independent third-party laboratories through rigorous testing. These independent test results have consistently shown that NTeC-E conductive CNT additives perform as well as CNTs made by leading producers in Asia. Furthermore, test results suggest that NTeC-E conductive CNT additives are compatible not only with multiple cathode types but also with silicon-anodes and next-generation solid-state batteries.

In addition, Chasm offers its NTeC-E conductive CNT additives in the form of dispersions (or conductive pastes) for easy integration with existing battery industry manufacturing processes. Options include aqueous or solvent-based, with or without polymer binders. Chasm's ability to tailor products for next-generation batteries allows it to meet the evolving needs of the EV battery industry and remain at the forefront of technology. The company also designs its CNT production processes to minimise waste and reduce environmental impact, ensuring both economic and environmental sustainability.

World's Largest CNT Production Platform

- ☑ CNT production in CHASM's manufacturing and R&D center in Norman, OK
- ☑ Pilot-scale rotary kiln reactor in current production
- ☑ Plant expansion planned for H2 2024
- ☑ World's largest CNT reactor with 1,500 MTA capacity planned to be in production by Q1 2025
- ☑ New plant will house two 1,500 MTA reactors for a total capacity of 3,000 MTA, far exceeding the capacity of any other CNT production facility outside Asia



Chasm licensing business model and its partnership with Ingevity

The majority of CNT production facilities are currently based in Asia, so a significant challenge persists as manufacturers seek local CNT production in North America and Europe to meet the surging demand in these markets.

To address this challenge, Chasm and licensed manufacturing partners are positioned to be the lowest-cost and largest-scale producers of CNTs, with local production to serve North America and Europe markets.

A recent collaboration with Ingevity aims to establish a gigafactory-level CNT supply in North America and Europe. With Chasm's leadership in CNT technology and Ingevity's renowned expertise in activated carbon production for the automotive market, this collaboration marks a milestone for Chasm's entry into the EV battery market.

John Fortson, President and CEO of Ingevity, emphasised the strategic significance of the partnership. "Today's announcement represents a pivotal moment in our company's journey, emphasising Ingevity's steadfast commitment to growth and expanding the company's presence in the EV market," said Fortson. "Our strategic partnership with Chasm signifies our intent to diversify into the EV and battery market, granting us access to a critical carbon-based product crucial for enhancing battery performance."

David Arthur, CEO and Co-Founder of Chasm, articulates the significance of these collaborations: "Partnering with industry leaders like Ingevity not only accelerates our production capabilities but also integrates our advancements directly into the heart of the battery industry, ensuring our technologies meet the real-world demands of EV manufacturers."

As Chasm continues to innovate and expand its capabilities, its impact on the EV battery industry is poised to be profound, driving forward a future where electric vehicles are powered by more efficient, sustainable, and high-performing batteries.

Risks to the European battery raw materials supply chain

Alex Laugharne – Principal Consultant, CRU

CRU is a leading independent provider of business intelligence on the global metals, mining and fertilizer industries through market analysis, price assessments, consultancy and events. Alex will be speaking on European battery supply chain risks, with broader coverage across additional key raw materials.

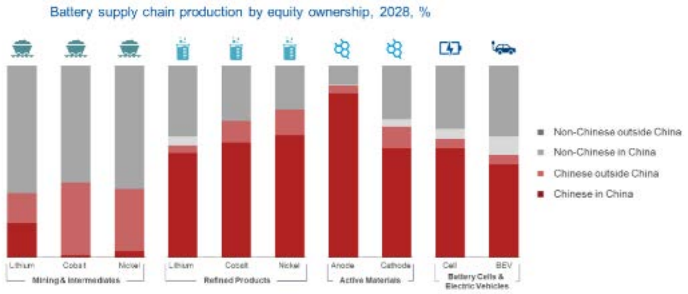
Skyrocketing demand for the batteries needed to power EVs, and for the energy storage systems that will enable greater use of intermittent renewables, has created a drastic increase in raw material requirements to which the mining industry has struggled to respond.

Cathode raw materials such as lithium and nickel, as the largest individual contributors to battery costs, have dominated headlines due to spiking prices and panic over availability, but issues relating to materials sourcing for the battery industry run both broader and deeper than whether we can extract enough of a narrow range of minerals to keep pace with global demand.

Concentration and integration

One of the most important of these issues is the high level of geographical concentration and vertical integration in the raw materials supply chain. China, both domestically and through investment in foreign supply such as cobalt in the DRC and nickel in Indonesia, now dominates the entirety of the value chain for key battery raw materials. This integration provides cost advantages to Chinese cell manufacturers as well as increasing the difficulty in developing mining and midstream projects elsewhere in the world, further entrenching Chinese dominance.

China dominates the battery supply chain from mine to EVs; mitigating its lack of domestic resources by investing in foreign projects.



DATA: CRU. Percentage based on production volumes x ownership equity stake. Owner origin country based on location of company's headquarters.

Relying on a single country for strategic materials poses economic, environmental, and geopolitical risks. The longer Europe takes to build its battery raw materials supply chain, the harder it will be to shift to independency. Once a foreign-dependent supply chain becomes entrenched, alternatives to importing can involve some or all of lower product availability, supplier optionality, or product quality, potentially combined with higher costs.

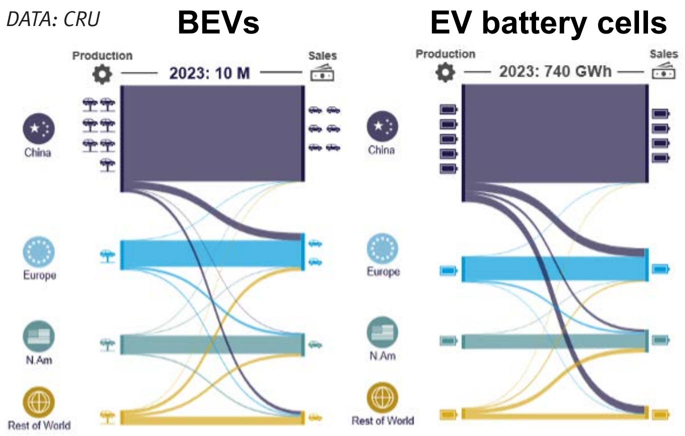
Additionally, if Europe fails to foster investment in a robust local value chain, the region limits its potential to generate a thriving industry with corresponding job opportunities and tax revenues. The region is already importing more than 20% of its cell and BEV requirements, primarily from China.

ESG standards

Compared to other regions, Europe is in general a highly regulated environment that enforces strict ESG standards; foreign producers of imported battery supply chain products or upstream materials may not meet, diminishing the ESG credentials of the final products relative to their potential level were the products and their raw materials all manufactured within Europe. This could make it difficult for e.g. in-region BEV manufacturers to reduce the carbon footprint of their vehicles if they have no control over their upstream supply chains.

Europe is more reliant than other regions on Chinese imports of both BEVs and cells, reducing the size of the industry supporting in-region supply of these products

DATA: CRU



Supply chain risks have become a key area of concern in Western countries following Covid-era disruption, with some of the same automakers that had been badly burned by the critical semiconductor shortage now keenly aware of their lack of control of their upstream battery raw material supply chain in the face of rapidly growing requirements. Concern has been heightened by recent events such as China restricting the export of gallium, germanium, and high-grade graphite, bringing greater attention to the fragility of the EV supply chain and the Western world's dependence on China specifically.

In response, policies and regulations have sought to incentivise investment in local supply chains. The most significant initiative falls under the Inflation Reduction Act (IRA) in the USA. The IRA provides a $7,500 tax credit for plug-in vehicles if said vehicle is independent from supply chain of certain "foreign entities of concern", as well as generous manufacturing tax credits for domestic supply chain projects, and the US government also has a well-funded Department of Energy scheme offering low cost loans for project financing. Since its implementation, the IRA has helped to turbocharge domestic gigafactory capacity; planned projects are targeting a cumulative total of more than 1,000 GWh by 2030.

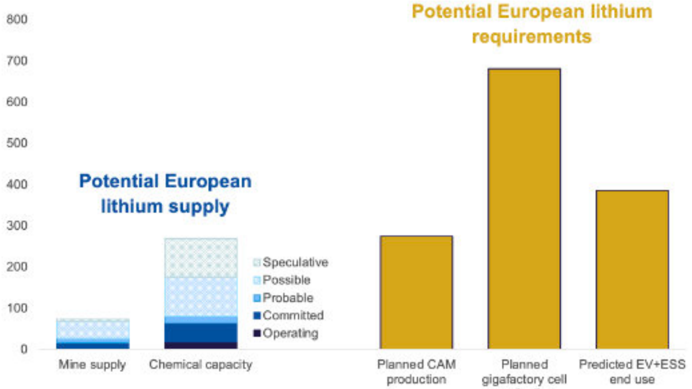
Partly due to regulatory incentives, we are beginning to see more development in the active materials (PCAM and CAM) midstream outside of China. Importantly, these products are highly technical and have relatively high barriers to entry; as a result much of the planned capacity will be spearheaded by Korean and Chinese manufacturers. Conversely, key local producers such as Johnson Mathey have exited this business, unable to secure premium prices or compete on costs with their foreign peers.

Lithium resources

With expanding cathode materials production due to grow in Europe, there will be a growing source of local demand for lithium chemicals, improving the necessity of - and prospects for - lithium refining projects in the region.

European lithium resources are small compared to the major producing regions of South America and Australia. Finnish miner Keliber is expected to be the first operator to bring on an integrated lithium extraction and refining project due to come on stream planned to start in 2025, to be followed by other integrated projects such as those under development by Vulcan Energy Resources in Germany and Infinity Lithium in Spain. However, a greater volume of European lithium capacity will be based on imported raw materials, such as AMG and Rock Tech Lithium's refinery projects, both of which are based in Germany but will process imported raw materials from their mining operations in Brazil and Canada respectively. Nonetheless, the combined capacity from these planned projects is far behind the expected level of midstream and downstream demand.

CRU's forecast for committed European supply of mined and refined lithium is dwarfed by that of midstream requirements, which in turn lags well behind lithium requirements at the application level



DATA: CRU

Other key resources

The analysis above focuses on lithium, but a similar picture can be seen in other key raw materials such as nickel, graphite, cobalt and manganese.

For European gigafactories to compete with incumbent industry players, access to a reliable source of low-cost raw materials is essential; upstream integration currently provides Chinese manufacturers with a huge competitive advantage. With limited reserves within Europe, increasing mining capacity is a challenge, as-is pre-emptively developing raw material refining and midstream output before local gigafactory capacity ramps up. Downstream consumers are fully awake to these risks and are taking steps to invest upstream to secure raw material supply, but still face a host of uncertainties in having to rely on projects that are not as-yet in operation. As shown by the US, government-led initiatives can be a major mitigant of competitive disadvantages at all stages of the supply chain, as well as fast-tracking in-region projects that might otherwise be overlooked in favour of relying on incumbent suppliers; more concerted and better-funded government support may be the critical factor determining how reliant Europe remains on imported BEVs, cells, active and raw materials.

Direct recycle cathode healing, battery neutralisation, and rejuvenation to improve cost and safety of the value chain

Steve Sloop, President, OnTo Technology

Lithium-ion batteries (LIBs) are potentially flammable during life and at end-of-life (EoL). Understanding the fire triangle is essential when assessing the risks associated with LIBs), they inherently contain the three components required for combustion: ignition, fuel, and oxygen *(Figure 1.)*. The widespread production and use of billions of these cells globally amplifies the probability of fire, making safety procedures such as neutralisation critical for electric vehicles and energy storage systems (EVs and ESS).

In LIBs, oxygen can be supplied from cathode-oxides or the surrounding air following a physical or thermal event. The fuel sources include the electrolyte and active/metallic lithium. The ignition can occur through heat or a spark, generated from interactions between active lithium and other battery components, or from external events like mechanical insult, external short circuit, or temperature exposure. The OnTo Technology LLC (OTL) battery neutralisation technology addresses these risks by removing the fuel and the ignition source. This is achieved by fuel removal through electrolyte extraction and ignition prevention through lithium passivation.

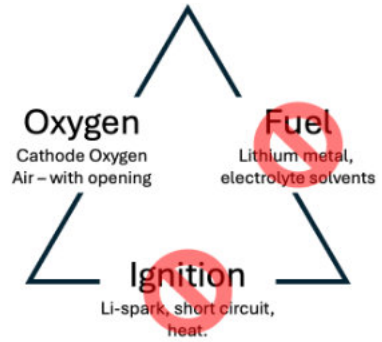


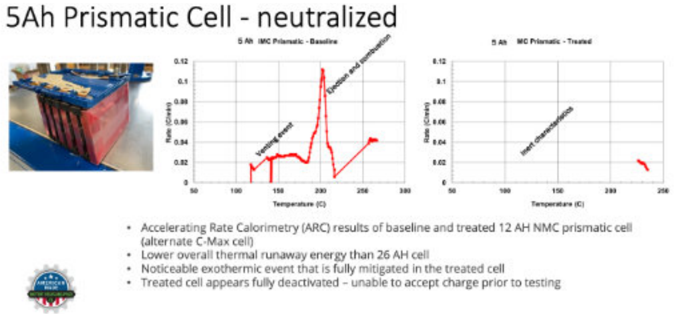
Figure 1. Fire triangle showing the essential components to support combustion. The result of deactivation (shown by the blocking sign) is to remove fuel and ignition, and to make an inert item: battery inertisation.

The recognition of these risks within industrial standards organisations, such as SAE-I, and the Department of Energy highlights the importance of developing robust safety infrastructures to deactivate LIBs at the collection site.

Battery Neutralisation Technology

Battery Neutralisation is a patented process that uses carbon dioxide to passivate lithium and extract electrolyte from small cells or EV battery packs at EoL or whenever necessary.

The technology was demonstrated and validated by OTL through support of DOE-EERE in project EE-DE0008475 *“Elimination of Class-9 Hazards in Lithium-ion Recycling”*, and the Phase II Made in America Battery Recycling Prize. Validation experiments with Sandia National Laboratories in *Figure 2* show heating rate change from ›250°C/min for baseline cells to ‹15°C/min for treated cells.


5Ah Prismatic Cell - neutralized

- Accelerating Rate Calorimetry (ARC) results of baseline and treated 12 AH NMC prismatic cell (alternate C-Max cell)
- Lower overall thermal runaway energy than 26 AH cell
- Noticeable exothermic event that is fully mitigated in the treated cell
- Treated cell appears fully deactivated – unable to accept charge prior to testing

Figure 2. Accelerating Rate Calorimetry comparison of a baseline untreated (left) and treated (right) commercial pouch cell. Inertisation treatment resulted in little to no energy release with heating. Such a deactivated cell poses no thermal risk in storage and transportation and, therefore, affords appropriate logistical costs for inert items.

Successful neutralisation of batteries will transform shipping cost from $2/kg to $0.50/kg of EoL or damaged batteries. Successful inertisation has the potential to eliminate the hazardous characteristics and reduce the cost burden to less than 10% of the total cost of recycling, which is critical for the affordability of EVs and large format batteries.

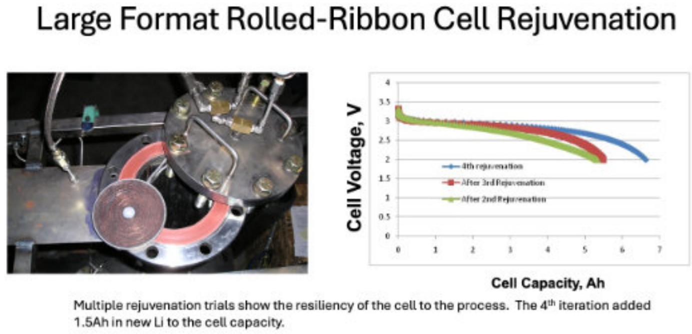
Workers at MEET have observed fluorophosphates decomposition products at moderately high temperatures. The toxicity risk, beyond the flammability risk focused on here, underscores the need for controlled extraction with a CO_2 system.

Rejuvenation Concept

LIB electrolyte decomposition contributes to lifetime degradation. Sloop teaches methods to remove electrolyte and decomposition products using liquid or supercritical CO_2 followed by replacement of the electrolyte.

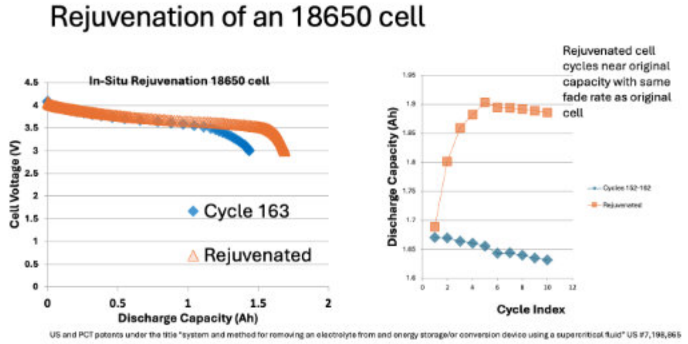
Experimental examples for rejuvenation of cells made from LFP and LCO are shown in *Figures 3 and 4* below.

The process gives an excellent capacity rebound to 1.9Ah after treatment and a few cycles for a common 18650 cell. The continuing cycle fade is consistent with the original testing.


Large Format Rolled-Ribbon Cell Rejuvenation

Multiple rejuvenation trials show the resiliency of the cell to the process. The 4th iteration added 1.5Ah in new Li to the cell capacity.

Figure 3. A large format cell has capacity added using rejuvenation with a LiI additive.


Rejuvenation of an 18650 cell

Rejuvenated cell cycles near original capacity with same fade rate as original cell

US and PCT patents under the title "system and method for removing an electrolyte from and energy storage/or conversion device using a supercritical fluid" US #7,198,865

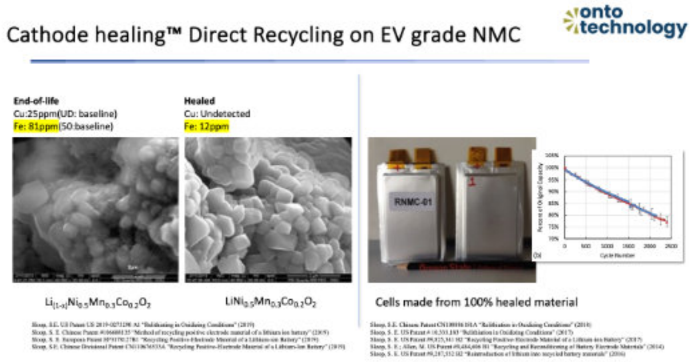
Figure 4. An 18650 LCO cell (with original capacity of 2Ah) is rejuvenated after 163 cycles and returns to of 1.9Ah and continues to cycle.

Rejuvenation impact on affordability is compelling for mass acceptance and affordability of EVs. Current lifetime costs are hurdles for mass adoption, for a state-of-the-art cell with specific energy *ED* (Wh/kg/cycle) is 175–225 and the overall energy delivered during cell lifetime (kWh/kg) is E_T=550. With rejuvenation is E_T›3,000; the improvement in cell lifetime energy cost, LC/$/kWh ‹$0.008, which is transformational in making EV and ESS affordable for everyone.

Direct Recycling Cathode Healing™

Cathode healing™ is a patented direct recycling approach. There are three advantages over other methods. First, it avoids multiple dissolution/precipitation steps to make a PCAM and the final high-temperature treatment CAM. It requires as little as 10% of the energy required for NMC CAM from purified inorganic salts. Second, it reuses the lithium in the cathode. *Figure 5* shows the side-by-side comparison of EV grade cells made by an OEM using pristine and recycled NMC. They have the same capacity fade profiles, but the NMC from cathode healing is 1/10th the cost of the original NMC.

Figure 5. NMC from cathode healing has the same performance as pristine material. The side-by-side comparison shows the ability of end-of-life NMC to be remanufactured into EV grade cells using cathode healing.


Cathode healing™ Direct Recycling on EV grade NMC

onto technology

End-of-life
Cu:25ppm(UD: baseline)
Fe: 81ppm(50:baseline)

Healed
Cu: Undetected
Fe: 12ppm

$Li_{(1-x)}Ni_{0.5}Mn_{0.3}Co_{0.2}O_2$

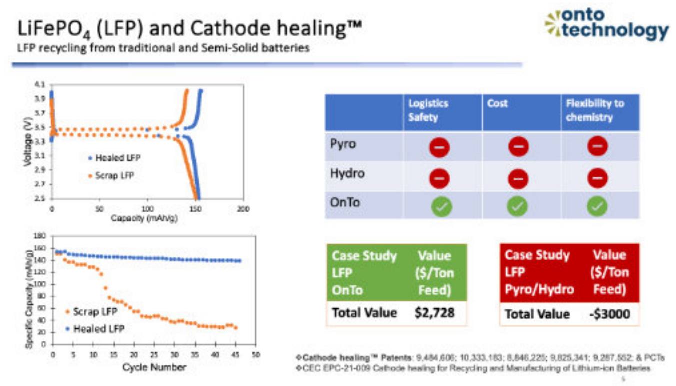
$LiNi_{0.5}Mn_{0.3}Co_{0.2}O_2$

Cells made from 100% healed material

Figure 5. NMC from cathode healing has the same performance as pristine material. The side-by-side comparison shows the ability of end-of-life NMC to be remanufactured into EV grade cells using cathode healing.

Cathode healing is applicable to cobalt/nickel free chemistries such as LFP. *Figure 6* shows LFP from cathode healing with the same performance as pristine material.

Figure 6. Cathode healing™ applied to lithium iron phosphate (LFP) chemistries underscores the need for technical alignment between recycling and advanced batteries. Simply stated, materials recovery and revitalisation is required over elemental salvage and waste disposition.


LiFePO$_4$ (LFP) and Cathode healing™

LFP recycling from traditional and Semi-Solid batteries

onto technology

	Logistics Safety	Cost	Flexibility to chemistry
Pyro	⊖	⊖	⊖
Hydro	⊖	⊖	⊖
OnTo	✓	✓	✓

Case Study LFP OnTo	Value ($/Ton Feed)
Total Value	$2,728

Case Study LFP Pyro/Hydro	Value ($/Ton Feed)
Total Value	-$3000

◆Cathode healing™ Patents: 9,484,606; 10,333,183; 8,846,225; 9,825,341; 9,287,552; & PCTs
◆CEC EPC-21-009 Cathode healing for Recycling and Manufacturing of Lithium-ion Batteries

Figure 6. Cathode healing™ applied to lithium iron phosphate (LFP) chemistries underscores the need for technical alignment between recycling and advanced batteries. Simply stated, materials recovery and revitalization is required over elemental salvage and waste disposition.

Conclusion:

The environmental and economic sustainability of EV and ESS requires innovative lifecycle technologies that address safety and cost. Battery neutralisation, cathode healing™, and battery rejuvenation offer the industry a way to reach affordability of Cell Lifetime Energy Cost, LC / $/kWh ‹$0.008, which is transformational in making EV and ESS affordable for everyone.

Unlocking value from Spent Lithium-ion Batteries: Advanced Recycling with Electrostatic and Magnetic Technologies

Hyeyeon Lee, PhD, Research Fellow, University of Birmingham

While techniques exist for recycling lithium-ion batteries, they predominantly retrieve only high-value metals and elements. To enable greater elemental recovery and less resource waste, a robust pre-treatment technology is required. This study delineates the utilisation of electrostatic and magnetic separation processes across four distinct lithium-ion battery formats and chemistries to maximises the efficiency of materials separation and pre-treatment, which enhances both recovery rates and material purity.

As the world moves towards electrification, the availability of scrap and end-of life Li-ion batteries has increased significantly. The challenge is to extract the greatest value from this feedstock of materials, in the most cost-efficient way, with the fewest emissions to the environment (doi:10.1111/jiec.13157). Pyrometallurgical recycling techniques are viable for batteries with a high Co and Ni value, but as we see in increasing market share from Lithium Iron Phosphate batteries, and a decreasing Co content in EV batteries, this isn't cost-effective in the long-term.

Hydrometallurgical recycling processes are the best-available technology, and is the approach being embraced by many start-ups, and seasoned recycling companies, but environmental and financial costs are dependent on the chemistry of your battery, and the purity of your "black mass".

The black mass is a free flowing black powder with most of the value, and comprises the cathodic active material (Lithium Nickel Manganese Cobalt Oxide, or Lithium Iron Phosphate) and anodic active material (Graphite), and normally contains some Al and Cu contaminants, which lower the value of your black mass, and present a challenge when trying to reuse the material in a new battery.

Other main points to make: direct recycling is where the materials are recovered directly, they keep their crystalline structure and can be potentially reused in a battery, with very little further processing or treatment. This reduce reliant on imports from China. The difference is we're not separating first into the constituent elements. However direct recycling needs really pure materials, so your separation process need to be effective. The use of Magnetic and Electrostatic separation processes offers a chance to separate anode from cathode and reduce contamination. This could bring us closer to an even shorter recycling loop, and give recyclers and opportunity to maximise value from recycling.

The challenge of Battery Waste

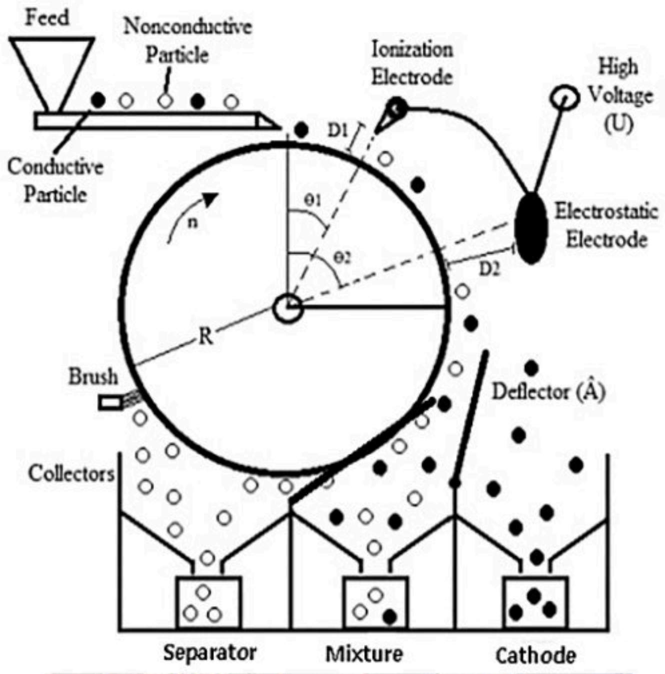
Lithium-ion batteries, while incredibly efficient during their lifespan, pose significant environmental and economic challenges once they are no longer usable. Traditional disposal methods, such as landfilling or incineration, not only contribute to pollution but also squander valuable materials like lithium, cobalt, and nickel – finite resources that are critical for manufacturing new batteries.

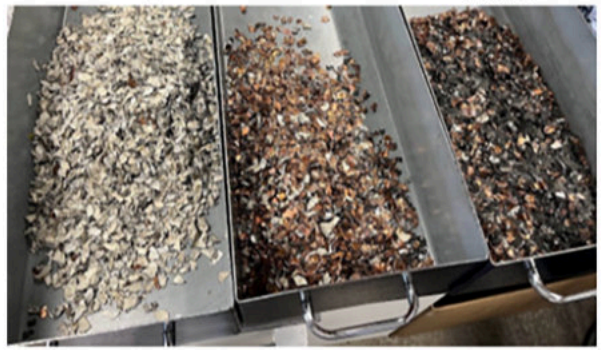
Furthermore, improper disposal can lead to hazardous leaching of heavy metals and toxic chemicals into the environment, posing risks to both human health and ecosystems. It's evident that a more sustainable approach to battery end-of-life management is urgently needed.

Advanced Recycling Technologies

Among the recycling processes, physical separation ensures that feedstocks with high material concentrations can be supplied for subsequent reclamation processing stages. Electrostatic and magnetic technologies offer a promising solution to the problem of spent lithium-ion batteries. By harnessing the principles of electrostatic and magnetic separations, these innovative processes enable the efficient extraction and recovery of valuable battery materials.

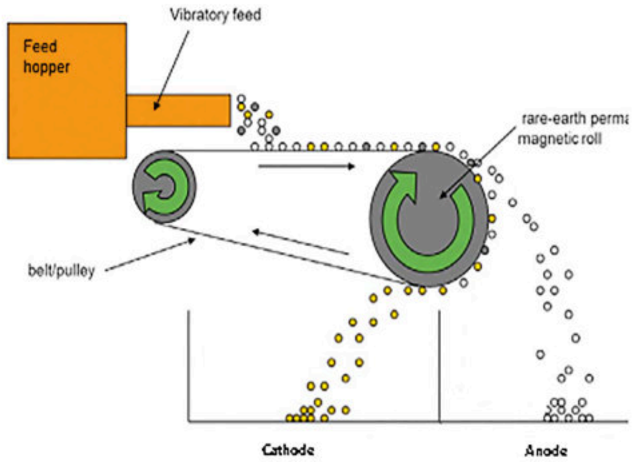
Electrostatic separation:





Electrostatic separation gained traction in mineral processing in the early 1900s until froth flotation emerged. However, more recently, there's been a push for eco-friendly methods that use fewer chemicals. Since many mineral processing plants don't have enough water, there's a growing interest in dry electrostatic separation. Each type of mineral has its own electrical properties, which means they can be separated using an external electrostatic field. Mineral processing sorts of minerals into two groups: conductors and non-conductors (dielectric materials). When we apply an electrostatic field, these minerals react differently, making it possible to separate them. Therefore, it allows the removal of the separator from mixed shredded materials.

Magnetic separation:



Magnetic separation is a widely used and technique for physical separation. Its principle lies in separating magnetically responsive particles or bodies from diamagnetic ones. Removing the separator using electrostatic separation allows the paramagnetic cathode and the diamagnetic anode to be separated. Therefore, the synergistic application of these two separation technologies maximises the efficiency of materials separation, resulting in ensuring high-purity cathode active materials and recovery rate.

Unlocking value and Sustainability

Adopting advanced recycling technologies offers numerous benefits to the environment and the economy. By recovering valuable metals from spent lithium-ion batteries, these processes reduce the need for raw material extraction, lowering the environmental impact associated with mining and refining.

Moreover, recycling batteries through electrostatic and magnetic separation processes conserves energy compared to conventional mining and manufacturing processes and other separation processes. It also mitigates the risk of supply chain disruptions by creating a closed-loop system where materials are continuously reused and recycled.

Conclusion

The transition to a sustainable energy future hinges not only on the development of advanced battery technologies but also on responsible end-of-life management practices. Electrostatic and magnetic recycling technologies offer a promising avenue for unlocking the value inherent in spent lithium-ion batteries while minimising environmental impact and promoting a circular economy.

Effects of over-discharge on the quality of lithium-ion battery recycling products

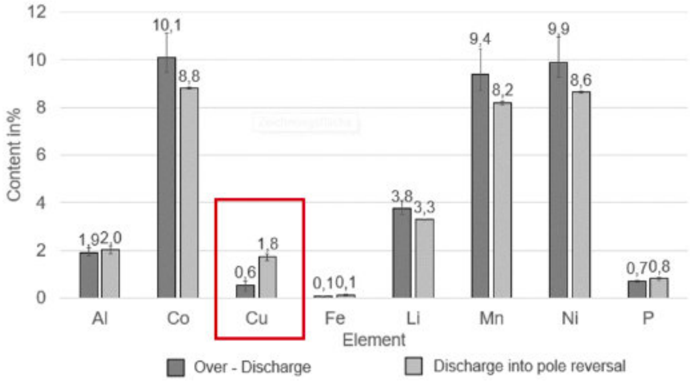
Alexandra Kaas, Research Associate, Mechanical Process Engineering and Mineral Processing, Freiberg University of Mining and Technology

Discharging is performed to ensure safety during a recycling process and can be done to different levels. The effects of over-discharging, e.g., formation of copper on the cathode or coating of the separator, have an influence on the quality of the recycling products, e.g., black mass or metal fractions. Examination of whether the new EU regulations can be met with different chemistries (NMC, NCA, LFP) were investigated.

Lithium-ion batteries are an important tool to achieve the transfer in the transportation sector from combustion to electric based motors. This chemical storage contains critical materials like cobalt, nickel, graphite or copper. A possible way to regain the materials and meet the EU targets is the combination of mechanical recycling and hydrometallurgy. Prior to the recycling the batteries are discharged. This can influence the later mechanical recycling which includes crushing, classification and sorting. By crushing the complex material compound is liberated and afterwards the fine fraction, called black mass, is screened off. Using density separation further components like casing, electrodes and separator can be sorted.

Discharging prior to the crushing is essential to lower hazards like e.g. thermal runaway. Due to internal cell defects, different SoC and SoH in the modules/packs and poor battery design, it can happen, that batteries are over-discharged or even discharged into pole reversal. Due to the large potential difference, copper ions from the anode migrate through the separator and are deposited as metallic copper on the cathode. This results in the formation of copper dendrites. Another phenomenon is the coating of the separator foil with cathode active material. The changes in the material structure affect the recycling of batteries as shown by Kaas et al. Problems occur with the sorting behaviour and the black mass output in the first stage of the mechanical recycling. First results show that the impact of the phenomena depend also on the battery chemistry.

The current research concentrates now on the product qualities of the black mass which scatter regarding yield and content of impurities. Therefore, new challenges are generated in terms of the required recycling rates according to EU regulations. Here, especially the metals of the cathode active material are affected due to the coating of the cathode on the separator foil. Due to the different structure of the components like separator foil and cathode, the contamination of the black mass increases, while the liberation of coating is reduced. Additionally, the recovery of copper is made more difficult by ion migration, so that the metal is now contained in almost all material flows. This makes further processing steps necessary and recovery more costly.



Black mass composition after first classification

The findings of this study underscore the necessity of optimising the mechanical recycling process to ensure stability in handling phenomena associated with greater discharge depths. Due to the new product quality, further challenges arise for subsequence processes such as flotation and hydrometallurg

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Influences on the properties of black mass from mechanical lithium-ion battery recycling

Christian Wilke, Research Associate, TU Bergakademie Freiberg

During mechanical recycling of lithium-ion batteries, a fine fraction, black mass is produced. This fraction consists of the detached coating of the electrodes and small quantities of impurities. Yield and composition of the black mass are influenced by the preceding processing steps. This presentation provides an overview of the process settings that affect the black mass properties and outlines how to optimise yield and quality.

With the increasing use of electric vehicles powered by lithium-ion batteries, there will be a growing number of used batteries in the future. Recycling of these batteries is essential to meet EU recycling targets and to cover the demand for valuable resources, such as lithium, cobalt and nickel. One way to recycle lithium-ion batteries is through mechanical recycling combined with hydrometallurgical treatment.

For the process of the Technical University Freiberg, the batteries are first over-discharged to reduce the risk of short circuits and thermal runaway during the further treatment. The discharged cells are then crushed to liberate the individual components from each other. A subsequent drying step removes the solvents from the electrolyte. The dry material is sieved to remove a fine fraction, the so-called black mass, which can be subjected to further hydrometallurgical treatment. The coarse fraction is further treated by air classification to produce three products: separator, casing and electrodes. The electrode fraction can be further treated to liberate remaining coating and to separate aluminium and copper.

Figure 1: Products of the mechanical recycling process.

The black mass contains the liberated coating materials from anode and cathode. It also contains low volatile solvents and the conductive salt ($LiPF_6$) from the electrolyte, as well as small amounts of metallic impurities (Al, Cu, Fe) originating from the cell casing and the electrode current collector foils. There are several parameters that influence the yield and the composition of the black mass. The factors investigated were the depth of discharge, a thermal pre-treatment, the crusher settings and a pyrolysis after crushing.

The depth of discharge is important for safe crushing. The cells should be discharged to at least 0% State of Charge. The further down, the lower the risk, as the cells can recover some charge if the discharge is stopped. However, the further down the cells are discharged, the more negative the effects. For example, Cu ions from the anode current collector foil start to take over the ion transport. The current collector partially dissolves and the copper precipitates on the cathode coating. When the cathode is then decoated, the copper ends up in the black mass together with the cathode coating.

Thermal pre-treatment prior to crushing has the advantage, that there are no or less emissions and less fire risk during crushing. The temperature applied has an effect on the black mass. A low temperature treatment increases the black mass yield whereas higher temperatures in the range of 80-120°C increase the adhesive strength of the binders which reduces the black mass yield..

At last, the crusher settings also have an effect on the black mass yield and quality. With increasing stress on the electrode foils caused by a smaller crusher grid size, the decoating efficiency is improved. At the same time, the impurity content increases as the current collector foils are also subjected to higher stress.

The presentation will provide an overview of the parameters that affect the black mass yield and quality. It will show some examples and outline how to optimise recovery and quality.

Recycling of Li-ion batteries: empower your understanding of the competitive and technological landscape thanks to patent analysis

Filippo Farina, PhD, Technology & Patent Analyst, Energy, KnowMade

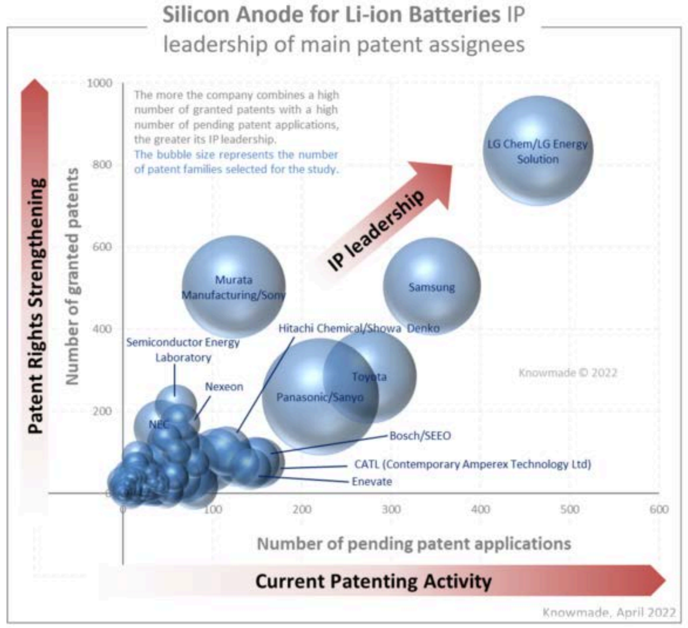
The global growing demand for batteries has led to the increasing interest for lithium-ion batteries recycling. Players on the market need to stay ahead of the technological trends and to understand their competitive environment. In this context, patent landscape analysis is a complementary approach to market research to acquire a deeper knowledge about competitors' strategies. Through patent landscape analysis, we will uncover IP trends and key IP players, with a focus on cathode active materials.

In the 21st century, Lithium-ion batteries have conquered a vast space in currently used electronic devices; more recently, the push for more sustainable technologies has led to the sharp increase of the use of electric vehicles. This success is the result of many technological and industrial combined efforts, still heavily ongoing in current days.

East Asian battery manufacturers started expanding into the western world, building factories to be closer to their OEM customers in the European and North American markets. Being aware and proactive in the intellectual property (IP) space gives companies the much-needed advantages on their competitors in their target markets. Knowing their respective freedom to operate is paramount for protecting their large investments.

New technologies need to be protected by IP rights, to have enough granted patents with valid claims and no overlap with competitors' inventions and geographical protection over the main key regions. Understanding how the market is taking shape and evolving under the light of IP landscape can be a powerful added value to the company strategy, highlighting their strength, weaknesses and potential areas/segments where they could potentially expand.

With the sharp increase of IP protection in the battery space the clash possibilities between companies and patent infringements are expected to increase and it's best to stay updated. A good knowledge of the intellectual property encompasses many patent filings over the course of many decades, geographical areas and languages. Being up-to-date and aware of the competitive environment is the first step, and market research is not the only tool for this purpose. Patent landscape can constitute a fundamental brick in the knowledge of the technological environment, answering questions about who the actors are, what's their intended IP protection and where they tend to protect it.



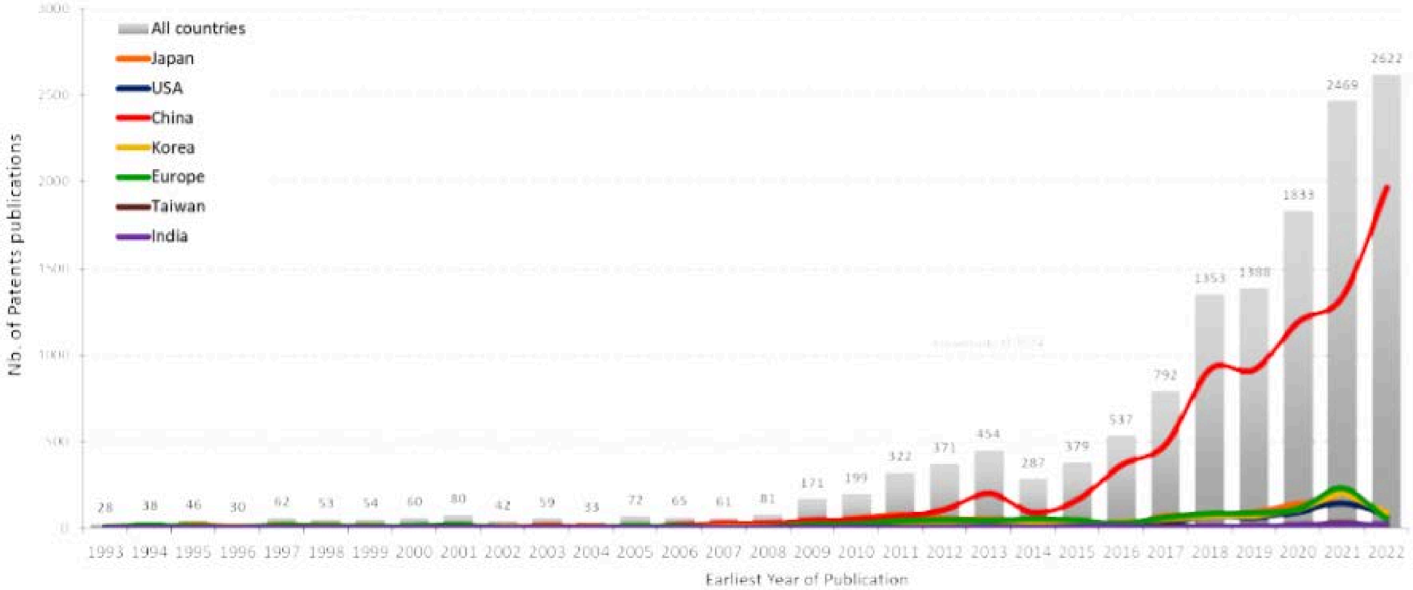


Figure 1: Time evolution of Lithium-ion battery recycling-related patent publications by main application country (1993-2022).

The widespread diffusion of Li-ion batteries brings up more additional challenges in terms of environment, raw materials availability, sustainability, circular economy. Given the abundant presence of these energy storage devices, how is the world dealing with waste and scraps? We are all aware of the need for battery recycling, but how are we organised? What are the most sought-after materials and what are the main recycling methods? Who are the industrial players operating in this space and how are they geographically distributed?

When talking about battery recycling, we mostly think of active materials and battery shells; reality, however, is much more complex than this, as many of the materials and battery components involved need care too. Thinking about carbon/graphite conductive agents, PVDF electrode binders, electrolytes, copper or aluminium electrode substrates or plastic separators is not so intuitive for the common public, and yet they are fully part of the landscape.

This is precisely the scope of Knowmade: painting a broad and general patent landscape view to start delving into more sectorial segments composing that space. Battery recycling is an example of the interesting subjects in the battery space, and it will be the main topic of the presentation of our Technology & IP Analyst Filippo Farina at AABC Europe in Strasbourg. What are the main companies operating in the field? In which segments are they most active? Who are the newcomers? How heavy is the IP activity, and how has it developed over time? Where are the companies seeking IP protection? Those are some of the questions that need answers, especially in a crucial domain like battery recycling.

Dr. Filippo Farina works for KnowMade in the field of energy storage and conversion devices. He's a Materials Chemistry PhD graduate from the University of Montpellier (France) and, after few years spent in industry as a chemical analyst, he has been working in the domain of materials for batteries and fuel cells since 2015 (University of Montpellier, CNRS and CEA-LITEN).

Super EV: Powering the Future with 500-Mile Range and 1,000 Horsepower

Dr. Ionel Stefan, CTO, R&D, Amprius Technologies

Improvements in pure silicon anodes with nanowire structures have enabled LIB energy density and specific energy performance that exceed current state-of-the-art graphite cells by 50-100%, depending on cell size. Commercialised cells have demonstrated 1,300Wh/L and 500Wh/Kg and have achieved 4000W/kg power density with over 400Wh/kg specific energy density, while maintaining cycle life compatible with aerospace, military, and other high-end applications.

In electric vehicles (EVs), the quest for longer-range and faster charging has become the holy grail of innovation. Amprius Technologies, a trailblazer in lithium-ion battery technology, is leading the charge towards achieving these distance and power goals with its groundbreaking silicon anode batteries.

The upcoming presentation, "Super EV: Powering the Future with 500-Mile Range and 1,000 Horsepower," will highlight the potential of Amprius' cells to transform the EV landscape. These cells are engineered to redefine the boundaries of electric mobility, boasting unparalleled characteristics that set them apart in the market.

Exceeding Industry Benchmarks

With a focus on exceeding the rigorous targets set by the US Advanced Battery Consortium (USABC) – an organization that establishes performance and cost goals for advanced battery technologies for electric vehicles – Amprius' cells demonstrate exceptional performance across multiple key metrics. The USABC targets are widely recognized as industry benchmarks for evaluating the capabilities of next-generation battery technologies.

The data presented in the upcoming session showcases Amprius' remarkable achievements in surpassing USABC targets. Amprius' cells exhibit an energy density exceeding the target by 30%, ensuring extended driving ranges for EVs. Moreover, the peak specific discharge power exceeds expectations by over 75%, enabling lightning-fast acceleration and superior road performance.

Rapid Charging Redefined

One of the most impressive features of Amprius' silicon batteries is the fast charge capability. With the ability to achieve a 90% charge in just 15 minutes, Amprius' cells outpace the USABC target by over 10%. This rapid charging capability not only increases convenience for EV owners but also aligns with the industry's push towards faster charging solutions, reducing range anxiety and enabling more efficient long-distance travel.

Addressing Challenges Head-On

While the current performance metrics showcase Amprius' leadership in critical areas, the company acknowledges that there is still room for improvement. "We are actively working to enhance cycle life and calendar life to meet USABC protocols fully," stated Dr. Kang Sun, CEO of Amprius. "Our commitment to continuous innovation and addressing challenges head-on further solidifies our position as a frontrunner in the EV battery market."

Cutting-Edge Silicon Nanowire Technology

Behind these impressive achievements lies Amprius' silicon nanowire technology, which forms the backbone of its innovative battery solutions. This cutting-edge technology unlocks new possibilities in electric mobility, offering fast charging, high power, and long cycle life. From electric flight to compact wearables, Amprius' silicon batteries pave the way for a cleaner, more sustainable future across various industries.

Shaping the Future of Electric Mobility

The upcoming presentation will highlight Amprius' technological prowess and shed light on the company's vision for the future of electric mobility. With plans to release sample cells for customer evaluation in 2024, Amprius is poised to revolutionize the EV market and drive the transition toward a greener, more sustainable transportation ecosystem.

Amprius' silicon batteries represent a groundbreaking advancement in electric mobility, offering unrivaled performance and addressing the industry's demands for more extended range, faster charging, and enhanced sustainability. As the world transitions towards a greener future, Amprius' innovative solutions are poised to drive transformative change in the EV market and beyond.

Ionel Stefan joined Amprius in its early days in 2009 as a Senior Scientist, initially to lead electrochemistry for silicon nanowire anode-based lithium-ion batteries. Dr. Stefan now leads Amprius' development of silicon nanowire electrochemistry, cell technology - including material design, cell design and engineering - and product development.

How to assess feasibility of different HV architectures in early stages of concept development?

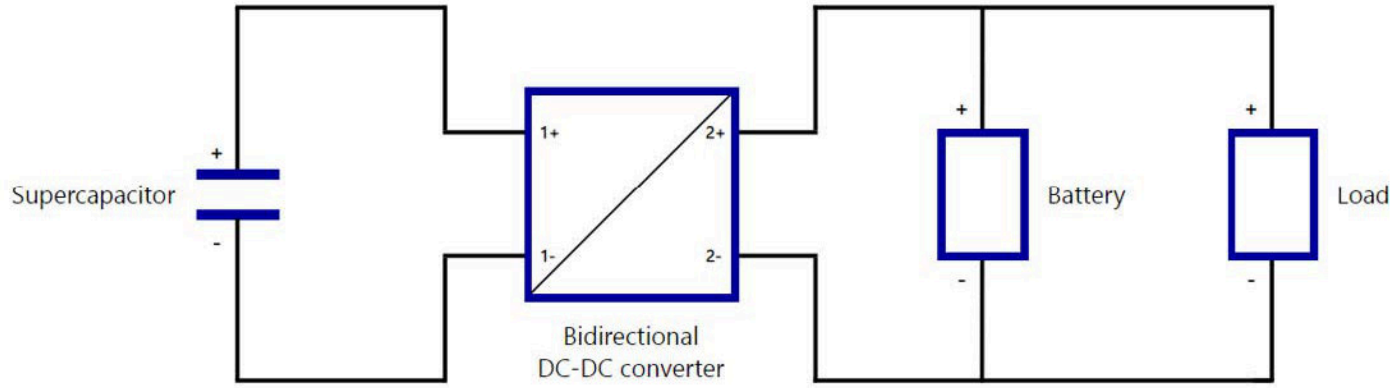
Roman Moedl, development engineer, AVL

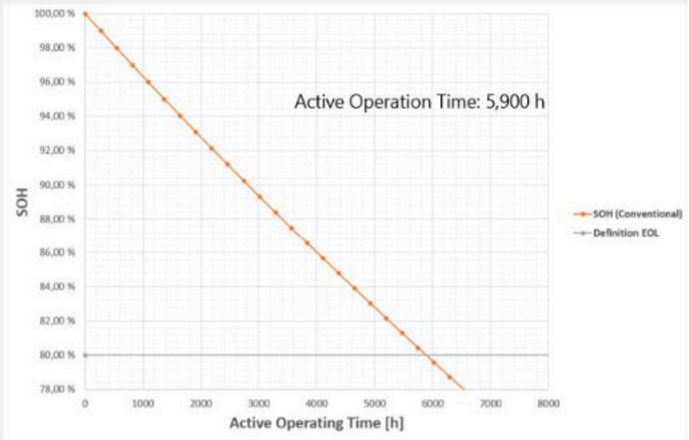
The extension of traction batteries from electric vehicles with supercapacitors is regularly discussed as a possibility to increase the lifetime of lithium-ion batteries as well as the performance of the vehicle drive. The objective of this work was to validate these assumptions by developing a simulation model. A slowdown of the aging effects and thus an improvement of the battery lifetime in the hybrid energy storage system could be clearly demonstrated. Through further technical development, subsidies or the construction of new, highly automated production facilities, supercapacitors will experience a price reduction in the future, which is why electric hybrid energy storage systems can play an important role in the mobility of tomorrow.

In recent years, the electrification of vehicles has gained significant momentum. As we strive for cleaner and more sustainable transportation options, electric vehicles (EVs) have become increasingly popular. However, one of the key challenges in EV technology is the limited capacity and lifespan of lithium-ion batteries – the primary energy storage solution in most electric cars. One promising way to improve battery performance and extend battery life is to integrate supercapacitors into traditional high-voltage traction batteries. Supercapacitors offer several advantages over conventional batteries. They have a higher power density, rapid charge and discharge capabilities, and excellent cycle life.

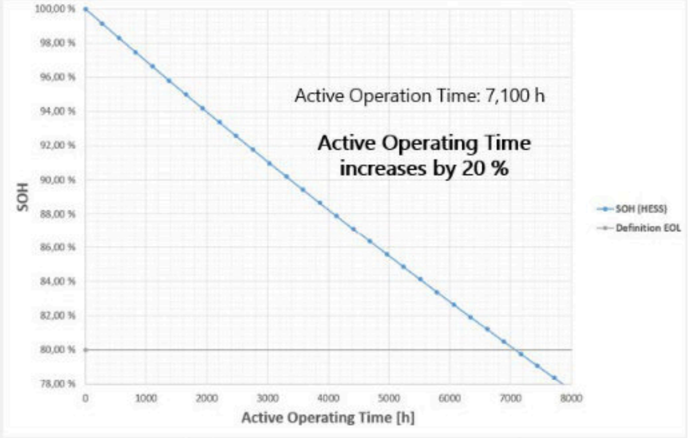
Within the R&D project SukoBa, carried out by AVL together with the project partners Fraunhofer Institute for Energy Economics and Energy System Technology (IEE) and Skeleton Technologies, the strengths of both technologies were combined to create a hybrid energy storage system (HESS). Therefore, the spotlight was set on the following characteristics:

- Assessment of different system topologies
- Definition of application-specific load profiles for different use cases
- Development of a control strategy with focus on slowing down the aging effects of the battery cells (patent pending)
- Definition of suitable evaluation parameters
- Battery lifetime simulation





Conventional Battery System: Mining Truck



Hybrid Energy Storage System: Mining Truck

The virtual modelling of the system was carried out in the AVL CRUISE™M software, which offers the possibility of predictive analysis of battery electric vehicles and battery systems, including their aging behaviour. The open system framework enabled the implementation of supercapacitors and thus, the comparison of the hybrid system with a conventional battery system. During initial simulations, a semi-active topology for the HESS proved to be the best possible topology, with convincing technical advantages and cost benefits.

To ensure comprehensive and representative simulation results, several use cases in different power categories were investigated. For this purpose, AVL internal measurement data from real vehicles was used to carry out simulations as close to reality as possible. Furthermore, the control strategy was designed to relieve the battery from transient load peaks – and thus, from high electrical and thermal energy flows. The focus was set on effective peak shaving and systematic use of the recuperation phases. As an evaluation parameter for the simulation the state-of-health (SoH) is used with a limit value of 80% residual capacity (in relation to the available nominal capacity at the start). Simulations with the HESS demonstrated a technical advantage of up to 20% in the form of a slowdown in battery aging and thus an extension of battery life.

In order to qualitatively classify the technical advantage of the HESS topology, an economic analysis follows. For this purpose, an evaluation factor is defined:

$$\text{Factor} = \frac{\text{charges battery system x lifetime extension [\%]}}{\text{charges supercapacitor}}$$

Factor ‹ 1: Not cost-efficient

Factor › 1: Cost-efficient

Use-case specific simulation results

While the technical benefits are evident, the practical adoption of electric hybrid systems remains uncertain. The cost of supercapacitors is a significant barrier. However, there is hope for the future:

- Continued technical advancements may lead to cost reductions.
- Government subsidies or investments in automated production facilities could make supercapacitors more affordable

In conclusion, electric HESS has the potential to revolutionise the mobility sector. As we work toward sustainable transportation solutions, collaboration between battery and supercapacitor technologies will play a crucial role in shaping the vehicles of tomorrow. The project results now provide AVL with a tool that can be used to quickly assess whether hybrid energy storage architectures are suitable in the early offer or concept phase and which priorities need to be considered in further development.

	Technical Advantage (Lifetime Extension)	Factor	Additional Costs
Passenger car	20.0 %	0.10	67.3 %
Telehandler	9.5 %	0.15	38.1 %
Excavator	5.5 %	0.20	21.4 %
Mining Truck	20.3 %	1.71	10.6 %

Analysing the growing need for energy storage in industrial applications: implications for sustainability, resilience, and technological advancements

Bernhard Riegel, Director, R&D, HOPPECKE Batterien GmbH & Co. KG

The presentation illuminates the overall technological maturity of industrial energy storage, focusing on their main application areas in terms of sustainability and circular economy. It discusses approaches for developing new technologies and the electrochemical storage technologies that are expected to dominate in 2030, aiming to achieve the goal of climate neutrality by 2050. The sustainability of batteries must be ensured throughout their entire life cycle. Batteries that are sustainable over their entire life cycle are crucial for achieving the central goals of the European Green Deal—climate neutrality, sustainable competitiveness of the industry, green transportation, and clean energy.

According to the Net-Zero pathway until 2050, there is an increasing need for electrochemical storage systems for the conversion of the (still) fossil dominated market in an electrified energy market. Only a handful electrochemical storage systems will achieve full maturity in 2030.

According to a forecast of the International Energy Agency (IEA), electric the car sales will rise strongly in 2024 despite economic headwinds in some markets.

The forecasted demand for electrochemical storage systems is estimated to be higher than 6.2 TWh in 2030 and up to 12.9 TWh in 2050. In 2030, 60% of the global electric car sales are expected to reach between 4.7 and 4.9 TWh in agreement with the global predicted production capacities of lithium-ion in 2030 *(McKinsey Battery Insights)*.

In the case of stationary storage, which is estimated to be the fastest growing market with a Compound Annual Growth Rate (CAGR) of about 30 - 44% (2020-2030), the demand in 2030 could reach 500 - 850GWh (Roland Berger) and 1 TWh in 2050 (as forecasted by BNEF NZS).

Lead-acid and lithium-ion will remain the dominant technologies until 2030. A significant market growth of up to 200 GWh is expected for sodium-ion at room temperature (Na RT). Sodium-ion batteries (Na RT) are seen as an alternative technology to lithium iron phosphate (LFP) due to their similar performance and potentially lower material costs. However, the further development and market penetration of organic electrolyte sodium-ion (Na RT) will depend very much on the price of lithium carbonate which has strongly affected the cost of LFP batteries in the past. The sodium-ion storage technology is not yet cost-competitive against Li-ion due to its still underdeveloped supply chain infrastructure for battery raw materials.

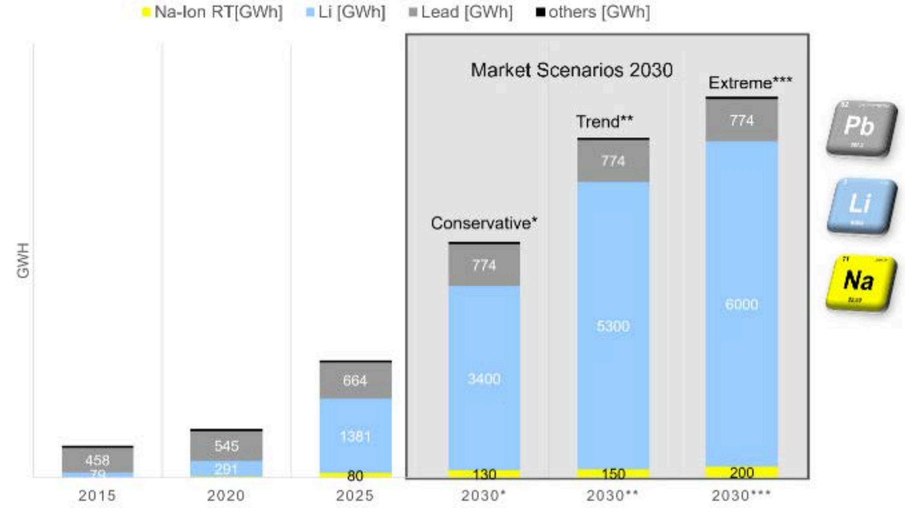


Fig. 2. Global Battery Demand: Data Source HOPPECKE, EUROBAT, Fraunhofer ISI, Avicenne, Roland Berger, McKinsey.

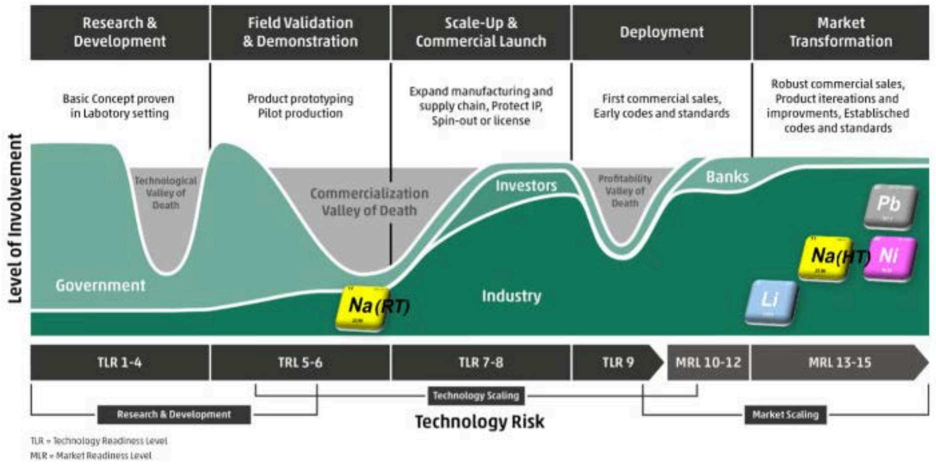


Fig. 2. Source: U.S.Department of Energy DOE Technology-to-Market (T2M) Process.*
*Tech-to Market Process: Technology readiness is commonly measured on a nine-point scale referred to as Technology Readiness Level (TRL). TRLs are used to consistently identify technology development stages across technology types. Market Readiness Levels (MRLs) refer to the readiness of a market to accept and adopt a new technology.

While lithium-ion remains the favored technology for Batterie Energy Storage System (BESS) applications, the expected global shortage in lithium-ion batteries, coupled with the rising demand for electric vehicles, could potentially result in limitations in the availability of lithium batteries for stationary energy storage. However, for the transition to pure electric driving in transportation, lithium-ion systems remain the only suitable technology.

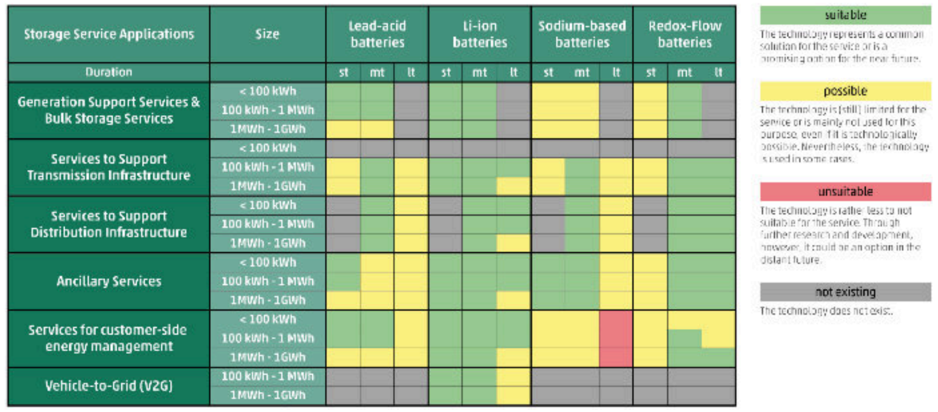
To address the potential shortage of lithium-ion batteries for meeting the demand in stationary storage, it is crucial to explore alternative electrochemical storage systems with a Market Readiness Level (MRL) of 13 to 15 by 2030 (Fig.2).

Technologies assigned to MRL 13 -15 includes lithium-ion, lead-acid, high-temperature NaNiCl and NaS, nickel-based systems (NiX) as well as redox flow systems.

According to McKinsey´s 2023 (Battery Energy Storage System) BESS Customer Survey, for German customers the most important criteria for BESS are “price and performance” followed by “safety and warranty”.

There are a multitude of storage service applications for BESS, based on different performance and storage duration criteria (ST: short-term, MT: midterm, LT: long-term).

In addition to high-temperature sodium batteries and redox flow batteries, lead-acid batteries could serve as a suitable alternative for certain BESS services. This is owing to their cost advantages, resilience in terms of raw materials, and well-established circular economy.



Storage Service Applications	Size	Lead-acid batteries			Li-ion batteries			Sodium-based batteries			Redox-Flow batteries		
Duration		st	mt	lt	st	mt	lt	st	mt	lt	st	mt	lt
Generation Support Services & Bulk Storage Services	< 100 kWh	🟩	🟩	⬜	🟩	🟩	⬜	🟨	🟨	⬜	🟨	🟩	⬜
	100 kWh - 1 MWh	🟩	🟩	⬜	🟩	🟩	⬜	🟨	🟨	⬜	🟨	🟩	⬜
	1MWh - 1GWh	🟨	🟨	⬜	🟩	🟩	⬜	🟨	🟨	⬜	🟨	🟩	⬜
Services to Support Transmission Infrastructure	< 100 kWh	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
	100 kWh - 1 MWh	🟨	🟩	🟨	🟩	🟩	🟩	🟨	🟩	🟨	🟨	🟩	🟩
	1MWh - 1GWh	🟨	🟩	🟨	🟩	🟩	🟨	🟨	🟩	🟨	🟨	🟩	🟩
Services to Support Distribution Infrastructure	< 100 kWh	⬜	🟩	🟨	⬜	🟩	🟩	⬜	🟩	🟨	⬜	🟩	🟩
	100 kWh - 1 MWh	⬜	🟩	🟨	⬜	🟩	🟩	⬜	🟩	🟨	⬜	🟩	🟩
	1MWh - 1GWh	⬜	🟩	🟨	⬜	🟩	🟨	⬜	🟩	🟨	⬜	🟩	🟩
Ancillary Services	< 100 kWh	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩
	100 kWh - 1 MWh	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩
	1MWh - 1GWh	🟨	🟨	🟨	🟩	🟩	🟨	🟩	🟩	🟨	🟨	🟩	🟩
Services for customer-side energy management	< 100 kWh	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟥	🟨	🟨	🟨
	100 kWh - 1 MWh	🟩	🟩	🟨	🟩	🟩	🟩	🟨	🟨	🟥	🟨	🟩	🟨
	1MWh - 1GWh	🟨	🟨	🟨	🟩	🟩	🟨	🟨	🟨	🟥	🟨	🟩	🟩
Vehicle-to-Grid (V2G)	100 kWh - 1 MWh	⬜	⬜	⬜	🟩	🟩	🟨	⬜	⬜	⬜	⬜	⬜	⬜
	1MWh - 1GWh	⬜	⬜	⬜	🟩	🟩	🟨	⬜	⬜	⬜	⬜	⬜	⬜

🟩 suitable
The technology represents a common solution for the service or is a promising option for the near future.

🟨 possible
The technology is (still) limited for the service or is mainly not used for this purpose, even if it is technologically possible. Nevertheless, the technology is used in some cases.

🟥 unsuitable
The technology is rather less to not suitable for the service. Through further research and development, however, it could be an option in the distant future.

⬜ not existing
The technology does not exist.

Tab. 1. Suitability of mature (MRL 13-15) electrochemical storage systems for various BESS services based on graph by Fraunhofer ISE.

In the future, alongside meeting customer needs, the sustainability of electrochemical storage systems and the resilience of supply chains will be crucial. For instance, the EU Battery Regulation, a key part of the European Green Deal, aims to enhance the circular economy, optimize resource utilization and efficiency, and ensure that batteries will contribute to climate neutrality and environmental protection throughout their lifecycle.

The efficient storage of electrical energy is a crucial component of future energy policy and a prerequisite for the transition to sustainable energy.

The Critical Raw Materials Act (CRM Act) as part of The Green Deal Industrial Plan will ensure EU access to a secure and sustainable supply of critical raw materials, enabling Europe to meet its 2030 climate and digital objectives.

Given the diverse requirements for energy storage systems and the specific needs of various applications, a potential shortage of lithium-ion batteries for BESS could be addressed by the alternative technologies that have already reached considerable market maturity.

How innovations in battery technology will support greater grid-scale battery storage deployments in Europe

Iola is Head of Research at Rho Motion working across the EV & Battery research team and has been with the company since its inception. Her work spans across the battery demand sectors, from electric vehicle to stationary storage forecasting, managing the team's view of battery demand and chemistry, and considering the influence of key variables from legislation to OEM strategy and technology roadmaps.

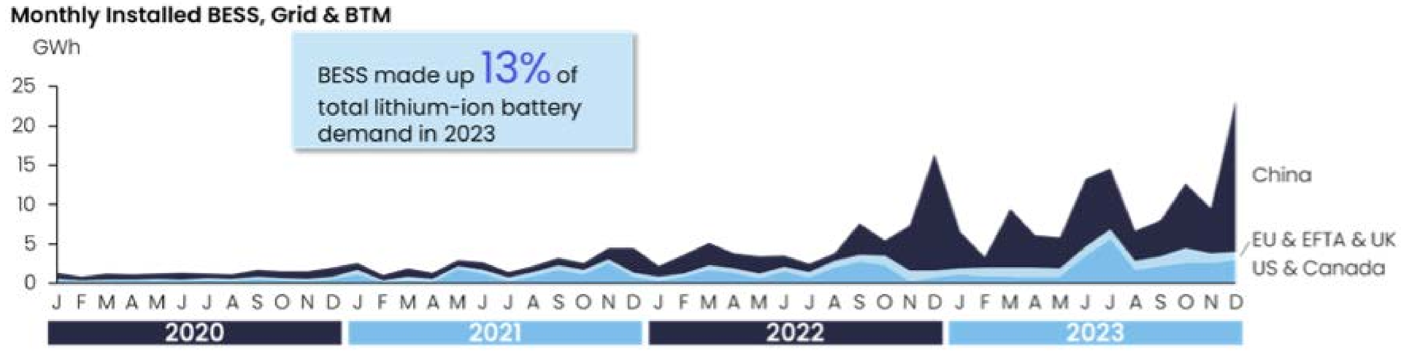
The battery energy stationary storage (BESS) market has undergone rapid growth in recent years, reaching ~100GWh of new grid-scale storage installed in 2023 – compared to less than 10GWh in 2020. This unprecedented growth was driven largely by two key markets: China, which accounted for 70% of new installations, and the US (namely California and Texas) that contributed 20% of new installations. Grid-storage market growth in Europe to date, excluding the UK, has been lack lustre by comparison. This is a result of a weaker regulatory environment, poor support mechanisms and in some cases prohibitive policy that has made the economics of storage challenging.

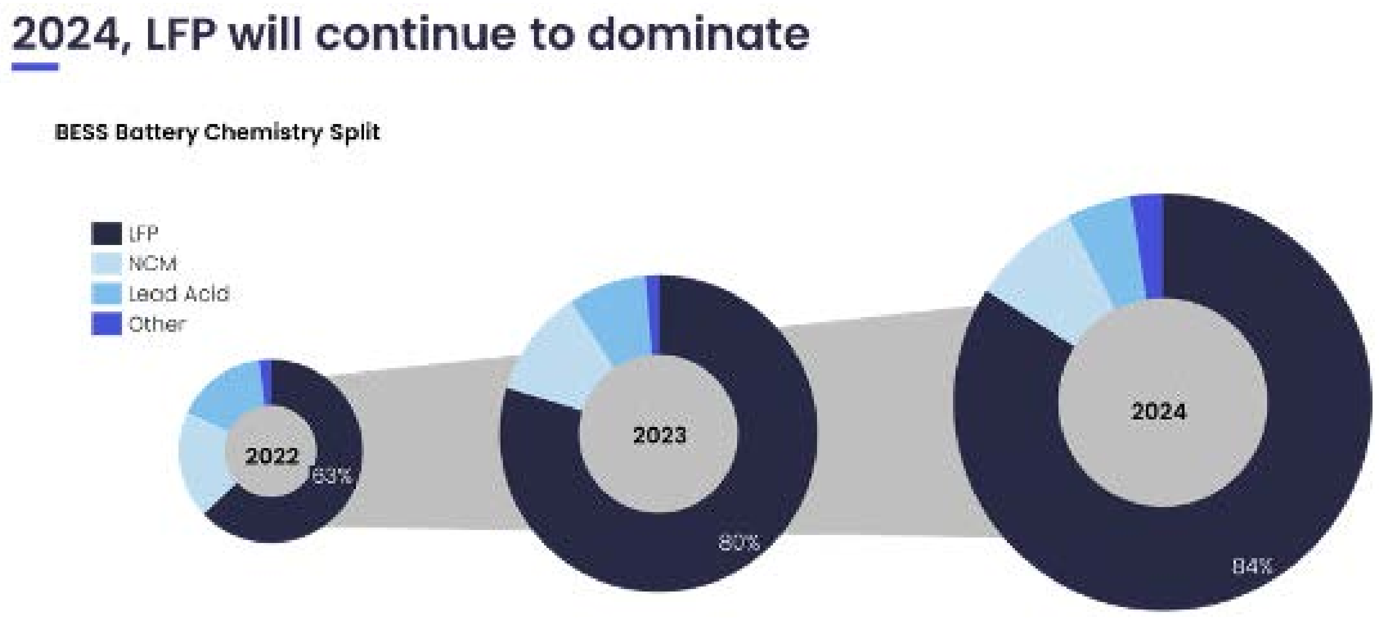
A changing EU landscape

The pipeline for the European grid-storage market is improving, with over 60GWh of projects announced to come online over the next three years - an impressive step change compared to the 3.4GWh installed across the region in 2023 This growth has been closely linked to the growing deployment of and increasing support for renewables in the region. Policy changes at the supra-national level such as the reform of the EUelectricity market design will see member states now required to submit flexibility assessments in accordance with their Nationally Determined Contributions (NDCs) to mitigate greenhouse gas emissions. Whilst some national governments have already included energy storage targets, forecasts and support mechanisms in their domestic policy, the Electricity Market Design Reform has now made energy storage targets a requirement across the bloc. National government policy agendas are also beginning to pay more attention to energy storage development, with strong opportunities emerging in the Germany and Italy, as well as the existing base in the UK and Ireland.

A battery market of its own right

When it comes to battery technology used in storage, this market has benefited from investment and R&D in the EV space. Until recently, the market for energy storage cells was one of surplus from the EV cell industry, which significantly outweighed demand for BESS. In 2023, global battery demand was just under 1TWh across all end use markets, with over 70% of this from the EV space. The BESS market accounted for 13%of battery demand. While this proportion sounds relatively inconsequential this impressive increase from less than 2% of battery demand in 2020 is indicative of the direction of travel in the BESS cell market's expansion This growing market share has allowed cell manufacturers to invest in and develop storage-specific cells, no longer viewing storage as a surplus market.





LFP is no longer just LFP

The storage market is now dominated by LFP technology, in particular in the grid market, where 2023 saw its market share surpass 90% globally for the first time (over 80% across grid & BTM – chart below), compared to less than 50% in 2020. This switch to LFP was driven by the need to match technology to application, with low cost, cycle life and safety being key factors when it comes to stationary storage. Over the last 18 months we have witnessed significant developments to improve LFP cells, further refining the technology to suit the needs of the storage market.

The new standard when it comes to a single LFP cell capacity is now over 300Ah, compared to a typical ~180Ah cell used in the EV space. These larger cells bring a number of BESS specific benefits such as longer cycle life, higher volumetric energy density and lower cost. Cycle life is a key consideration when it comes to storage defining the lifetime cost of an asset which ultimately drives the economic case of storage projects.

Outside of LFP, advancements in alternative technologies such as sodium ion in the past year have the potential to bring a further low cost technology to the storage market. Sodium ion has the benefit of sodium's abundance, potential low cost, full depth of discharge and a low operating temperature. Despite most activity focused in China to date, there have been several announcements in recent months that look to bring a sodium ion supply chain to Europe, such as Northvolt-Altris and Tiamat. These players have the potential to bring a battery supply chain to Europe that is not reliant on China. However, significant work is still needed in the sodium ion space, with cycle life and cost not yet competitive with Chinese LFP cells.

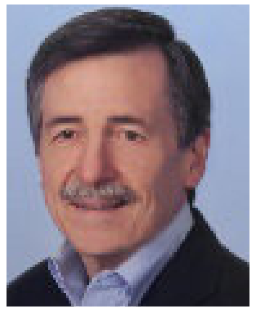
The role of grid-scale storage is the EU is increasingly clear as member states bolster renewable targets and net-zero ambitions. Continued developments to both reduce cost and improve cycle life of BESS cells will lead to a strong upside for the market globally.

Rho Motion, based in London, offers comprehensive and well-informed forecasts and analysis for the energy transition. Our core assessments, databases and outlooks provide actionable intelligence on the development of electric vehicle, battery, charging and infrastructure markets.

Extreme fast-charge batteries for heavy-duty applications

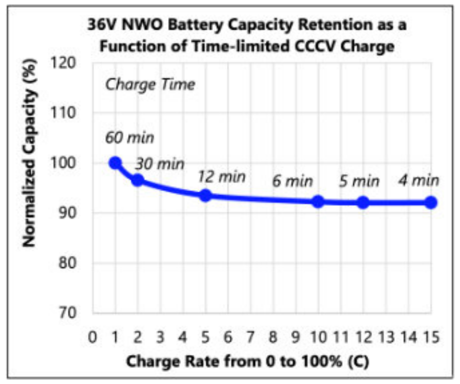
Dr. Brian Barnett, CTO, Nyobolt

To learn more about Nyobolt's battery technology, join us during the session "Innovation in Heavy-Duty Applications".



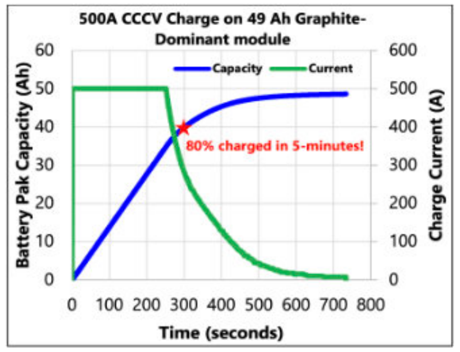
As the material handling industry drives inexorably towards multi-shift (16-hour) and even 24/7 operation, and ever higher levels of electrification, heavy-duty vehicles using batteries that require multi-hour recharge times represent a significant barrier towards operational productivity. It's simply not acceptable to have these vehicles spend hours out of service while on a charger. This inefficiency, combined with the limited cycle-life of conventional Li-ion technologies, represents a substantial challenge for commercial battery electric vehicle (BEV) adoption for materials handling applications such as warehouses, mining, drayage, and port cargo applications. New batteries capable of remarkably fast charging and extended cycle life, such as those recently developed by Nyobolt, can dramatically improve efficiency and up-time for materials handling applications.

At the upcoming Advanced Automotive Battery Conference (AABC) in Strasbourg, France, Nyobolt will present performance characteristics for its two battery technologies, both capable of charging in less than 5–10 minutes with extended low impedance-growth cycling. These batteries resolve bottleneck and critical inefficiency pain-points for the heavy-duty, logistics industry. Nyobolt's Niobium Tungsten Oxide (NWO) technology maintains ›90% capacity retention at ‹5-minute charge rates for tens of thousands of 0– 100% SoC charge-discharge cycles, meeting demands for high-power applications with stringent safety requirements and continuous battery operation. Nyobolt's Graphite-Dominant technology is designed for applications requiring high energy density with fast-charge as a premium, differentiating factor. Both chemistries have been implemented in cells with remarkably low impedance, achieving high rates and low thermal signatures.



Operating in stealth mode since being founded out of the University of Cambridge in 2019, Nyobolt has rapidly scaled both technologies into high-capacity, low impedance cells, up to 32Ah, and high voltage, thermally optimised battery packs, up to 800V and has already entered into customer supply contracts in materials handling applications.

NWO battery packs deployed in autonomous mobile robots enable extremely high uptime, maximising metrics such as boxes-moved-per-hour over a multi-year lifetime requirement. This technology is being implemented from the warehouse to the mine, to power 200-ton hybrid haulage trucks with 45kWh sub-packs. Independent studies have confirmed that the fast charge enabled by NWO batteries not only greatly increases efficiency and up-time, it also can significantly reduce the number of full BEVs required to move the same tonnage of ore in a 24-hour period by 15%, thereby sizeably decreasing system level costs.



As an example, Graphite-Dominant battery packs built into 26.4V, 49Ah modules charge 80% of battery capacity in five minutes using a 500A charger. These modules, part of the 35kWh battery pack in the Nyobolt EV, deliver 250km of range with a 6-minute charge over more than 2,000 fast charge cycles with minimal degradation. In heavy-duty and medium-duty middle mile and last mile delivery trucks, these batteries can be recharged in minutes, e.g., faster than it takes to re-load the delivery vehicle. The result can be reduced fleet size and charging queues.

The alternative, conventional Li-ion batteries with charge times of even an hour or two, require extra vehicles to fill in for vehicles being charged. Furthermore, Nyobolt batteries can be partially charged in a get-the-job-done mode to finish the last route at the end of a workday – recharging 50% in a few minutes – equivalent to diesel refuelling.

Use of recycled materials in a heavy duty lithium-ion battery application

In the evolving world of electric vehicles (EV) and the lithium-ion battery (LIB) supply chain, a great misconception exists. Many believe cathode active material (CAM) from recycled materials requires a compromise on battery performance vs. using virgin materials. A new, recycled NCM grade cathode material tailored for heavy duty electrification applications developed by Ascend Elements and XALT Energy of Freudenberg e-Power Systems proves that theory wrong.

Picture this: Two players from different parts of the EV battery supply chain come together to provide a unique and sustainable solution to deliver heavy duty performance. They create a custom-engineered cathode active material to a customer specification – relying on both partner's expertise to create a new product.

At AABC EU this year, Ian Braime, Chief Commercial Officer at Ascend Elements, will present for the first time on the Heavy Duty track in partnership with Kevin Dahlberg, PhD., VP of Cell Technology with Freudenberg e-Power Systems on the successful, real-world use of engineered cathode material (made from recycled materials) in high performance cell designs for marine, fuel cell hybrid, heavy duty commercial transportation and other specialty electrification applications.

The audience can expect an introduction to both companies as the foundation to this real-world case study on high performing batteries using recycled materials. Ascend Elements is an engineered battery materials company producing sustainable, high-performance precursor (pCAM) and cathode active material (CAM), using the most efficient closed-loop recycling technology. XALT Energy, a part of Freudenberg e-Power Systems, is an innovator in energy storage technologies focused on the growing demand for high-tech storage solutions in marine, commercial transportation, and specialty applications.

Compared to passenger EVs, the performance requirements for heavy duty electrification markets are discussed far less but carry equal importance. Heavy duty applications have particularly high-performance requirements for lifetime, charge time and safety. Freudenberg's cell and pack roadmap specifically addressing the heavy duty market is outlined, followed by the development of NCM-523 cathode materials with high cycle life and thermal stability. Combining Freudenberg's expertise in battery cell pack and system solutions for applications with high performance requirements with Ascend Elements' innovative battery recycling process and patented cathode engineering technology resulted in strong performance vs. benchmark materials. This strong cell performance at both the prototype and large format production scale pouch cells demonstrates sustainability does not equate to compromised performance.

Not only does the sustainable cathode product meet high performance requirements, including exceptional cycle life and safety results, but using Ascend Elements' patented Hydro-to-Cathode® with recycled feedstock process provides significant economic and carbon-reduction benefits.

The presentation both educates the audience on the critical performance requirements for heavy duty electrification markets and demonstrates the technological readiness of cathode active material (CAM) derived from LIB recycling.

To keep pace with growing demands and to overcome challenges within the LIB supply chain, a significant contribution of recycled metals to the cathode supply chain will be essential. This joint project between Ascend Elements and Freudenberg e-Power Systems represents a major milestone in the journey toward net zero carbon emissions in the heavy duty market.

Also be sure to stop by Booth 208 to learn more about AE Elemental™; a newly formed joint venture in Poland and Germany between Ascend Elements and Elemental Strategic Metals.

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