UK Research and Innovation

Faraday Battery Challenge: funded projects to date

September 2021



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What is the Faraday Battery Challenge?

The Faraday Battery Challenge is run by UK Research and Innovation on behalf of the UK government. With an investment of £330 million between 2017 and 2022, the challenge aims to support development of world-class science, technology and manufacturing scale-up capability for batteries in the UK. The challenge is focused on developing cost-effective, high-performance, durable, safe and recyclable batteries to capture a growing market.

Initially addressing eight present-day limitations of automotive battery technology, the challenge allows the UK to realise its commitment to move to full electrification and zero-emissions vehicles. The challenge is also looking to address other sectors including aerospace and rail. It comprises three stages to market: research, innovation and scale-up.

This booklet describes the projects funded to date within the research, innovation and scale-up elements of the Faraday Battery Challenge. Content is provided by the Faraday Institution, UK Battery Industrialisation Centre and the innovation project partners.

Research

The £108 million Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis and early-stage commercialisation.

It brings together research scientists and industry partners on projects with commercial potential that will reduce battery cost, weight, and volume, improve performance and reliability and develop whole-life strategies including recycling and reuse.

Innovation

Delivered by Innovate UK, part of UK Research & Innovation, over £90 million of funding has been made available for businesses to lead feasibility studies and collaborative research and development projects in battery technologies.

Scale-up

The >£130 million UK Battery Industrialisation Centre (UKBIC) opened in 2021 and enables companies of all sizes to develop manufacturing capabilities for battery technologies to get them to market quickly.

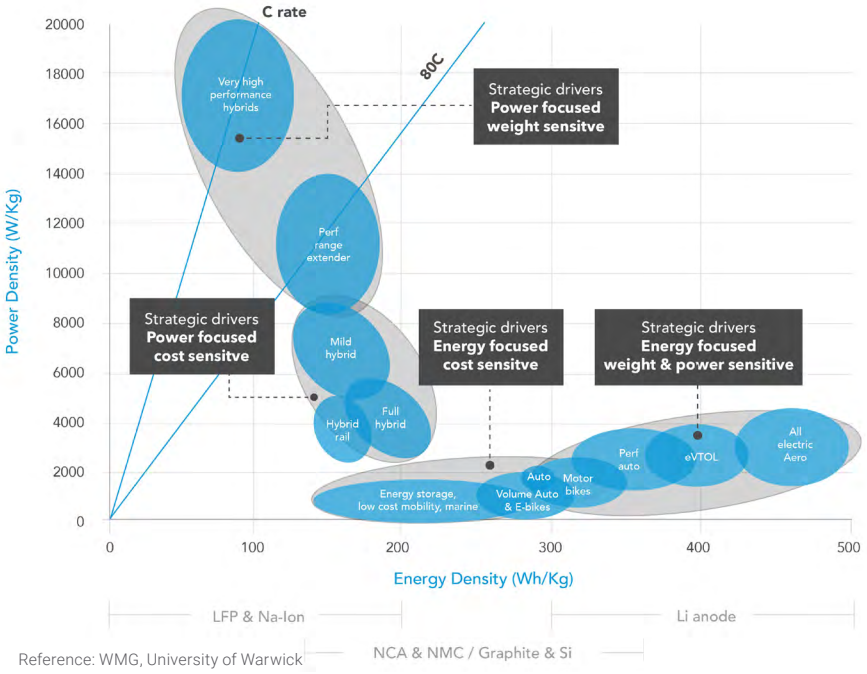
"The Faraday Battery Challenge is a pioneering programme focused on making the UK the go-to place for the research, development, scale-up and industrialisation of cutting-edge battery technology.

Four years into the programme, this brochure illustrates the breadth and depth of cutting-edge research, innovation and scale-up activities coming from our research and industrial base and reinforces why the UK is a world-leader in battery technology development."

Tony Harper, Faraday Battery Challenge Director

Cross-Sector Electrification for Net Zero

Electrification of transport will play a key role in enabling the UK to achieve its Net Zero ambitions. To accelerate this transition, we need to understand where the most significant challenges lie for the electrification of different applications as well as the opportunities for collaboration that can help drive forward innovations. The cross-sector battery targets work has sought to identify the strategic priorities for these different sectors and the performance targets needed to enable economically viable electrification – a complex and challenging landscape.



Reference: WMG, University of Warwick

- **Power focused but weight sensitive:**
  Cost and volumetric density will still be factors
- **Energy focused but cost sensitive:**
  Applications which may be willing to trade attributes e.g. worse volumetric density to achieve cost targets
- **Energy focused but weight and power sensitive:**
  Energy hungry but still need power at a weight limit
- **Power focused but cost sensitive:**
  Supports volume hybridisation of powertrains.

Within each of the four clusters, individual transport applications will have differing performance characteristic priorities, some critical and others able to be traded off to ensure the required performance gains.

You can find the full report and further material at: www.ukbatteriesnetwork.org

Technical priorities

Future battery developments such as those showcased in this booklet will enable significant penetration of electrification across a wide variety of sectors, helping the UK in achieving Net Nero by 2050.

The viability of the sector to grow is dependent on those targets.

Improvements to current technology may be beneficial to the sector but not at the expense of higher priorities.

		Power Density	Energy Density	Cost	1st Life	Safety	Temperature	Predictability / Modeling	Recyclability
Energy Focused Cost Sensitive	Energy Storage	Low	Low	Critical (whole life cost)	High	Medium	Low	Medium	High
	Volume Automotive	Medium	Medium	Critical	Low	Medium	Low	Medium	High
	Low Cost, Efficient Mobility	Low	Low	Critical	Low	Medium	Low	Medium	High
	e-Motorbikes	High	High	High	Low	Medium	Low	Medium	High
	Light Goods Vehicle	Low	Medium	Critical	Medium	Medium	Low	Medium	High
	Heavy Goods Vehicle	Low	Medium	Critical	High	Medium	Low	Medium	High
	Hybrid Rail	High	Medium	Medium	High	Critial	Low	Medium	High
	Marine	High	Medium	Critical	Low	High	Low	Medium	High
Energy Focused Weight and Power Sensitive	Performance Auto	High	High	Medium	Low	Medium	Low	Medium	High
	All Electric Aero	High	Critical	Low	Medium	Critical	Medium	Critical	High
	eVTOL	High	Critical	Medium	Low	Critical	Medium	Critical	High
Power Focused Weight Sensitive	Very High Performance Hybrids	High	Medium	Medium	Low	Medium	Low	Medium	High
	Range Extender Hybrids	High	Medium	High	Low	Medium	Low	Medium	High
Power Focused Cost Sensitive	Hybrid-Rail	Medium	Low	Medium	High	High	Low	Medium	High
	Full Hybrid & Mild Hybrid	High	Medium	Critical	Low	Medium	Low	Medium	High



Research

The Faraday Institution: powering Britain's battery revolution

Executive Summary

The Faraday Institution is powering one of the most exciting technological developments of the 21st century – Britain's battery revolution. As the world competes to define the future of energy and automation, the Faraday Institution is accelerating commercially-relevant research needed for future battery development to power the transport and energy revolution for the UK.

Funded through EPSRC-UKRI, it serves as the UK's flagship battery research programme to build and manage focused, substantial and impactful research projects in areas of fundamental science and engineering that have significant commercial relevance and potential, defined at a high level by industry and delivered by consortia of universities and businesses. The Faraday Institution delivers training to the next generation of battery scientists and engineers, who will go on to work in both academia and industry and be responsible for facilitating the transition of new technologies to market. Headquartered at the Harwell Science and Innovation Campus, the Faraday Institution is a registered charity with an independent board of trustees.

Mission

The Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis and early-stage commercialisation. It brings together research scientists and 50 industry partners to work on projects with commercial potential that will reduce battery cost, weight, and volume; improve performance and reliability; and develop whole-life strategies including safety, recycling and reuse.

Research Community

A large-scale endeavour of this significance necessitates an extensive national reach. The Faraday Institution draws its strength from over 20 UK universities, from St Andrews to Southampton, including world-leading universities Oxford, Cambridge, Imperial and University College London. The Faraday Institution has combined the strengths of highly competitive university research groups across the UK to work as active collaborators, marking a sea change for the research community and representing a new model for conducting commercially-relevant research. This research community is a powerhouse – 450-strong from a multitude of fields – working with the direction and guidance of UK industrial partners.



Photo courtesy of WMG

Empowering the Next Generation

Aware that next-generation energy storage technologies will come from future scientists and engineers, the Faraday Institution is committed to developing a dynamic and diverse pool of talent. The organisation plays an active role in inspiring and attracting young people, particularly those from groups historically underrepresented in STEM (science, technology, engineering and maths), to consider careers in the field. It is building the talent pool at a number of levels, including at undergraduate level through quality internships, developing a bespoke PhD programme to enhance researchers' skills, knowledge and aspirations, equipping them for future careers in academia, industry or policy making. It also provides a range of continuing professional development opportunities for early career scientists and engineers as they build their researcher identity and forge their career pathways.

Partners

From industry to academia, from regional government to international partnerships, the Faraday Institution is part of a growing innovation network that seeks to transform the world we live in through electrification and energy storage. To successfully deliver the UK's mission for a fully electrified economy, the Faraday Institution is convening a range of UK and international organisations to engage with one another, efficiently collaborate and effectively partner.

Faraday Institution's Research Portfolio

In the near term, accelerating the drive towards electric vehicles (EVs) requires the optimisation of lithium-ion battery technology. While there is still room for improvements to Li-ion, there are fundamental limits to the performance improvements that can be expected from its deployment. So, in the medium to long term, step changes in EV cost, range and safety will have to rely on the commercialisation of new battery chemistries such as all-solid-state batteries, sodium-ion and lithium-sulfur.

Because of the current level of commercialisation of different technologies and the UK's need to deliver improvements in EVs over a range of timescales, the Faraday Institution is pursuing a portfolio of projects. The research programme spans 10 major research projects:

- Six focus areas aim to optimise current generation lithium-ion-based batteries where there are still considerable gains to be made and where research breakthroughs could start to be realised in commercial batteries within three to four years.
- Three focus areas are higher risk, higher reward, and could facilitate the long-term commercialisation of next-generation battery technology that still requires considerable research in the areas of materials discovery and optimisation.
- One focussed on the recycling and reuse of batteries and supporting the principles of the circular economy.

This large scale, research programme is multidisciplinary, highly collaborative, and draws together the best of UK university research groups and industrial partners.

Research topics are selected after consultation with academic and industrial stakeholders across the country, with due consideration of the potential impact they could make to the UK.

The Faraday Institution's portfolio also includes:

- Three shorter-term projects to develop battery-focused characterisation and analytical techniques to provide UK researchers with world-leading tools to accelerate their understanding of battery materials and their performance.
- Industry Sprints, comprising small, focused teams of researchers to solve a commercially-relevant research opportunity identified from within the research programme and prioritised by an industrial partner.
- Entrepreneurial Fellowships, supporting researchers across the UK looking to create new businesses and commercialise battery technologies.
- Industry Fellowships, a programme to strengthen ties between battery researchers working in industry and academia.

Informing Policy

The Faraday Institution regularly advises a range of audiences on the UK's transition to energy storage technologies to ensure that members of the public, public bodies, policy makers and public institutions are well-informed. Representing a national effort for energy storage, the Faraday Institution is committed to being a voice to help guide government, industrial and financial communities.

Through its concise "Faraday Insights" briefings, the Faraday Institution provides independent, evidence-based understanding of battery economics, societal issues, capabilities and competitive position. The organisation brings together industry, trade groups, government and academia, bridging knowledge gaps and informing policy makers and regulatory bodies on the energy transition.

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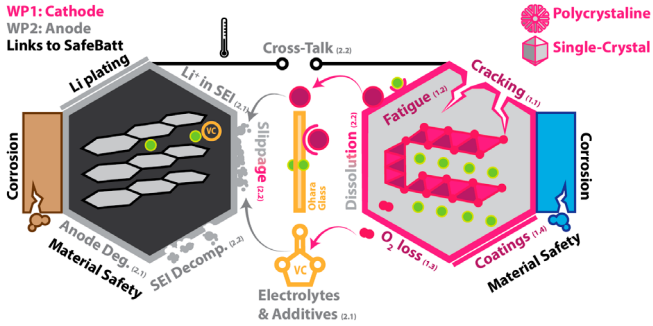
https://twitter.com/FaradayInst

www.linkedin.com/company/thefaradayinstitution/

Extending battery life

Using a suite of advanced modelling and characterisation techniques, the project aims to understand the mechanisms of degradation of lithium-ion batteries containing high Ni-content NMC and graphite.

Grant contribution: £16,000,000



Executive summary

This project is examining how environmental and internal battery stresses (such as high temperatures, charging and discharging rates) degrade electric vehicle (EV) batteries over time. Results will include the optimisation of battery materials and cells to extend battery life (and hence EV range) and reduce battery costs.

Despite the recent reduction in cost of lithium-ion batteries driven by mass manufacture, the widespread adoption of battery electrical vehicles is still hindered by cost and durability, with the lifetimes of the batteries falling below the consumer expectation for long-term applications such as transport.

Additionally, fast charging of battery electric vehicles is crucial to help assuage range anxiety and provide the operational convenience required for mass adoption of the technology. Fast charging, however, can rapidly accelerate degradation and even trigger degradation mechanisms that are not present in 'normal' operating conditions. A key goal for the automotive industry is to better understand the causes and mechanisms of degradation to enable improved control and prediction of the state-of-health of battery systems.

The goal of the project is to create accurate models for use by the automotive industry to extend lifetime and performance, especially at low temperatures.

Timeline with milestone/deliverables (March 2023)

- Identify the key stress-induced degradation processes and kinetics that occur in cells.
- Link the electrical signatures of degradation with specific chemical and materials processes so that they can be identified in an operating battery pack.
- Examine and understand the physicochemical mechanisms of degradation in high-nickel positive electrode materials.
- Examine and understand the physicochemical mechanisms of degradation of graphite electrode materials. Emphasis is being placed on the interaction, or 'cross-talk', effects of high-nickel positive electrode materials on causing or accelerating these pathways at the electrode-electrolyte interface.

Project innovations

This project will provide a more complete understanding of the signatures of degradation, lead to increased lifetime and better prediction of failure, and accelerate the development of new battery chemistries through the holistic and coordinated efforts of the research. An ability to fully understand the causes of limited lifetime of lithium-ion batteries will place the UK at the forefront of the next generation of battery electric vehicle technology.

Partners

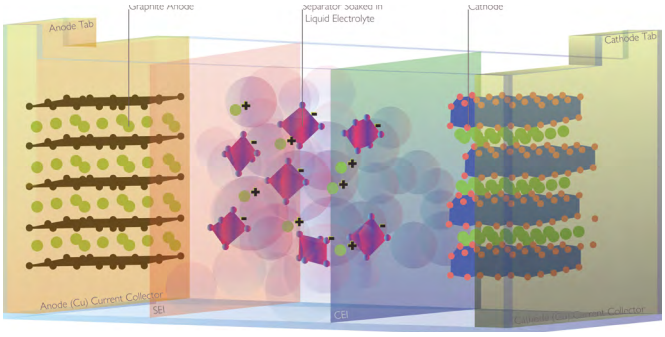
University of Cambridge (Lead)
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National Physical Laboratory (NPL)
Imperial College London
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University of Warwick
University of Oxford
University of Southampton
University of Sheffield
+8 Industrial Partners

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Multiscale modelling of lithium-ion batteries

Bringing together a world-leading, multidisciplinary team to develop fast, highly accurate models, advancing the development of true digital twins to speed up battery development.

Grant contribution: £17,900,000



Executive summary

Accurate simulations of batteries will enable battery makers to improve designs and performance without creating expensive prototypes to test every new material, or new type and configuration of the cells. The project considers a range of length scales, from the nanoscale – where atoms interact – up to the macroscale of a complete pack and its electronic control mechanisms. A variety of timescales are also being considered to assess atomic processes at the nanosecond, through to long-term degradation occurring over years. Battery simulations and design tools exist at each length and timescale, but they have previously often lacked the accuracy required for understanding the phenomena occurring within batteries.

The project's world-leading research bridges science and engineering, working innovatively alongside UK industry to deliver impact. Its internationally recognised experts are developing new digital and experimental techniques for understanding battery behaviour at the atomistic, continuum and system scales. Fast, accurate models, incorporating the most complete physics and advanced mathematical techniques, are being developed to be directly usable for industry, enabling digital twinning of whole cells and packs. Atomistic accuracy will parameterise higher level models and tackle key challenges, such as the complex interactions and activity at the electrolyte-electrode interface. Rapid experimental parameterisation methods are being developed, greatly reducing the time and cost of customising models for particular applications.

Timeline with milestone/deliverables (March 2023)

- Implement multiple, advanced degradation mechanisms in in PyBaMM (Python Battery Mathematical Modelling).
- Improve the physics in PyBaMM and DandeLiion, to incorporate thermodynamics and mechanics.
- Launch DandeLiion as a commercial service.
- Establish a standard method for parameterising models rapidly.
- Develop advanced techniques for diagnostics.
- Develop holistic models to assess whole life cycle sustainability and cost.
- Implement models for advanced state estimation and control.
- Develop digital twins as design tools for new cell and pack configurations.

Project innovations

During the first three years of the project, a common coding framework – PyBaMM – was established, and rigorous, standardised techniques developed. The primary aim of this framework is to be easy to use, providing a "sandpit" for the global battery community to explore the mathematical theories, with a minimum of coding effort. However, the flexibility of this approach does not always support rapid computational speed. Therefore, in parallel, an ultrafast solver called DandeLiion has been developed, which is optimised for speed and incorporates many of the state-of-the-art models developed by the project.

Partners

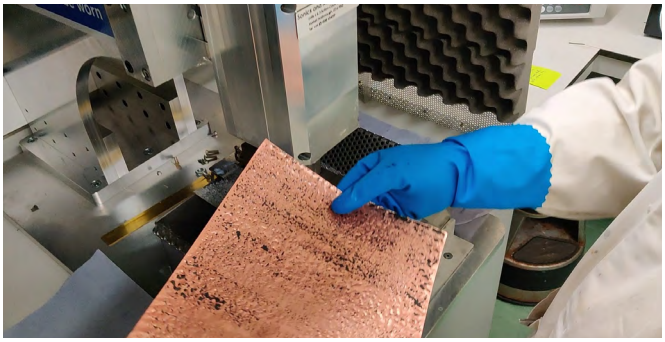
Imperial College London (Lead)
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University of Oxford
University of Birmingham
University of Bath
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University of Portsmouth
University College London
University of Warwick
+15 Industry Partners

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ReLiB – Recycling of EV lithium-ion batteries

Determining the most efficient ways to recycle lithium-ion batteries

Grant contribution: £14,100,000



A faster, greener technique using ultrasonic waves invented by researchers at the Universities of Leicester and Birmingham to improve EV battery recycling processes by returning high purity materials to new battery manufacture.

Executive summary

The transition to electric vehicles (EVs) has the potential to reduce carbon emissions and air pollution, but also brings challenges and opportunities associated with the need to manage projected volumes of around 16,500 tonnes of EV lithium-ion batteries reaching end-of-life by 2028. To cope effectively with these volumes, vast improvements in the speed, environmental footprint and the economics of recycling processes will be required.

ReLiB aims to devise and develop alternative recycling routes that could provide UK businesses with a competitive advantage. At the heart of the ReLiB approach is fast, efficient pack dismantling – facilitated by the implementation of automated disassembly, testing and sorting – and a blend of physical, chemical and biological techniques, targeted at recycling up to 100% of the EV battery efficiently and economically for the full range of battery compositions currently in use.

Objectives are:

- Stripping down the whole battery more safely and much faster than present techniques allow.
- Reducing environmental impact by minimising the use of chemicals.
- Minimising human intervention by automating as many processes as possible.
- Recovering a high proportion of the original materials in a reusable form.cycling.

Timeline with milestone/deliverables (March 2023)

- Demonstration of automated in-line disassembly and safety testing tasks on EV battery packs at multiple scales.
- Development of a cell-dismantling route for recovery of materials from end-of-life EV battery cells as an alternative to shred and sort.
- Routes for short loop and/or direct recycling of common cathode materials, including upcycling.
- Evaluation of optimum methodology for recovery and reconditioning of current and future anode materials.
- Scale up of selective metal bioleaching processes using natural and bioengineered bacterial strains.
- Production of remanufactured cells from recycled materials for long-term cycling and investigation of causes of failure.

Project innovations

Unlocking safe, cheap and environmentally-benign routes for the separation, recovery, remanufacture and recycling of all materials contained within EV batteries is critical to the success of the EV revolution and the sustainability of manufacturing supply chains. This will be achieved through direct targeting of fast, efficient dismantling processes such as implementation of automated disassembly, testing and sorting, and fast electrode delamination, to boost productivity and safety within the waste and recycling sector. This will provide high-purity and high-value recovered material streams, maximising the environmental gains of the transition to EVs.

Partners

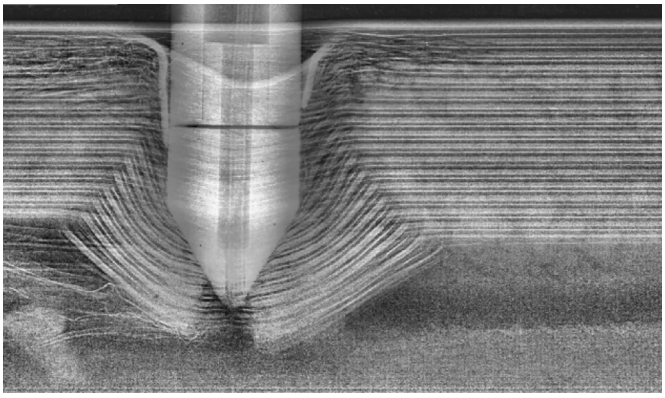
University of Birmingham (Lead)
University of Leicester
Newcastle University
University of Edinburgh
University College London
+ 12 industrial collaborators

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SafeBatt – The science of battery safety

Improving the fundamental understanding of the root causes of cell failure, mechanisms of failure propagation and processes occurring during real world failure.

Grant contribution: £1,520,000



Executive summary

Whilst battery fires are rare, they can occur under various conditions of mechanical, thermal or electrical stress or abuse. As the use of lithium-ion batteries (LiBs) expands into automotive, stationary storage, aerospace and other sectors, there is a need to further decrease the risk associated with battery usage to enable the optimisation of safety systems.

This project will improve the fundamental understanding of the root causes of cell failure and the mechanisms of failure propagation. Working closely with industry partners, a multi-scale approach is being taken, from the material to the cell and module scale. Whilst the nucleation of failure may be a microscopic event, the propagation of failure, in particular cell-to-cell propagation, is macroscopic. Research spans time frames from the degradation of materials over hundreds of charging cycles, down to the nucleation and propagation of thermal runaway with characteristically sub-second events.

The project is also developing an improved understanding of processes occurring during real world failure, including the environmental consequences of LiB fires, which will inform the further development of fire sensing and protection systems for battery energy storage systems and help inform first responders.

Timeline with milestone/deliverables (March 2023)

- Identify the safety signatures of Li-ion cells and how they change over cell lifetime and degradation.
- Investigate the effect of fast charging and operation under extreme conditions on cell ageing and safety.
- Understand how cell failure modes translate to multi-cell modules. Identify the minimum cell count representative of a module.
- Develop an advanced model to infer reactions, kinetics and off-gas release behaviour during failure.
- Improve understanding of dynamic processes during real-world failure to provide best practices and knowledge to first responders, recycling and storage facilities.
- Assess the efficacy and environmental consequences of LiB fire extinguishing systems.

Project innovations

SafeBatt employs state-of-the-art, high-resolution, high-speed characterisation techniques to understand the causes of cell failure and how degradation affects safety. Experiments performed in bespoke safety/abuse testing facilities study the propagation of failure in modules under different operational variables.

By improving the understanding of the dynamic processes occurring during real-world failure, the output from this project will provide best practices and knowledge to first responders, as well as recycling facilities, and domestic and industrial energy storage facilities.

Furthermore, by working closely with industry, first responders and other stake holders, SafeBatt aims to influence relevant British and international standards.

Partners

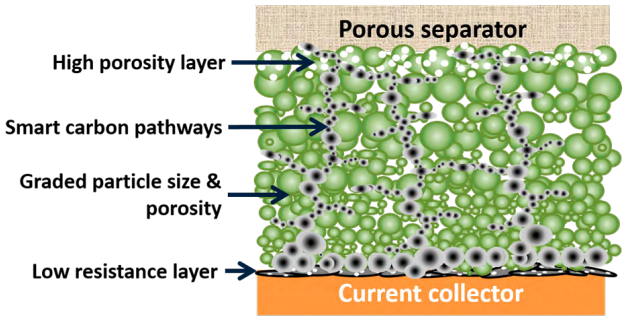
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Nextrode – Next generation electrode manufacturing

Battery performance improvements through smarter electrode manufacturing.

Grant contribution: £12,000,000



Schematic cross-section of a Li-ion battery electrode showing some of the smart manufacturing possibilities being investigated by Nextrode.

Executive summary

Substantial benefits in battery performance can be realised by smarter assembly of the different materials that comprise the electrodes used in rechargeable batteries. These benefits apply equally to mature material systems already used commercially and to new emerging high performance battery systems. Nextrode is focused on researching, understanding and quantifying the potential of smart electrodes to improve energy storage devices, and developing new practical manufacturing innovations that can scale smart electrode benefits to the industrial scale.

Nextrode is investigating how to engineer a new generation of battery electrode structures. Novel developments in electrode structuring are being explored by applying improved scientific understanding of the phenomena involved in the slurry casting of Li-ion battery electrodes. The project is:

- exploiting techniques that give more control over the dynamics of particle coating and electrode formation to ensure a final structure that best realises the intrinsic properties of the electrode materials.
- developing new models and using predictive simulations to suggest the optimum arrangement of materials in an electrode and inventing processes that allow these structures to be realised in practice.
- using 3D characterisation techniques to quantify designer structures and to relate their structural features to the electrochemical performance of electrodes.

Nextrode supports UK manufacturers and energy storage supply chain companies via increased cell performance, added value in electrode processing, and improved safety and sustainability.

Timeline with milestone/deliverables (September 2023)

- Develop manufacturing processes, including high speed additive manufacturing, and analytical tools to give flexible control over particle and binder arrangements within electrodes.
- Develop new approaches to slurry casting to produce electrodes with superior performance.
- Link imaging 3D techniques – using X-rays and electrons – to predict and design optimal microstructures.
- Develop new methods of quantifying and optimising electrode manufacture using simulation and data science.

Project innovations

Two of the three UK-based organisations involved in R&D/niche volume electrode manufacturing, together with UKBIC and the UK's largest cell assembler, are contributing partners to Nextrode. These organisations, along with other partners that are major players in the materials supply chain and the automotive industry, are focusing the project towards developments that have the most potential for industrial impact (at a low volume/niche through to gigafactory scale), including at UKBIC. They are taking an active role in discovery exploitation and dissemination. Where distinct and protectable research breakthroughs occur, the project will secure intellectual property and look for opportunities to form spin-out companies.

Partners

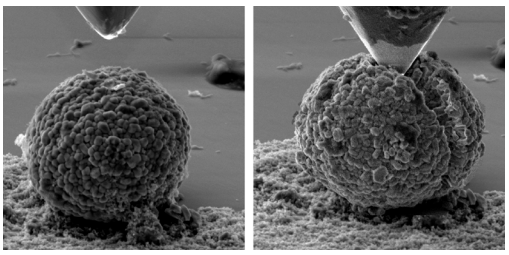
University of Oxford (Lead)
University of Southampton
University of Birmingham
University of Warwick
University College London
University of Sheffield
+ 12 industry collaborators

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FutureCat – Next generation lithium-ion cathode materials

Novel approaches to cathode design to improve lifetime and range, enable fast-charging, and reduce cost and reliance on cobalt.

Grant contribution: £9,900,000



In-situ SEM compression testing of high-nickel NMC particles – investigating the mechanical integrity of future cathode materials. From research by Arron Bird and Dr Laura Wheatcroft at the Sheffield NanoLAB.

Executive summary

Delivering improved EV performance demands high energy density batteries to improve range, high power densities for fast charging, longer lifetimes, and lower cost through reduced reliance on expensive metals. This requires fundamental materials discovery and characterisation to deepen understanding of underpinning mechanisms and mechanics and push performance limits in a sustainable manner.

FutureCat addresses these challenges through five integrated work-streams researching near- and next-generation cathodes, from high-capacity/high-voltage oxides to sustainable alternatives avoiding supply-chain at-risk elements.

The advances the project is targeting represent significant commercial opportunities. Partnering with NPL, FutureCat is developing standardised protocols to validate discoveries. The project is joined by industry partners across the battery supply chain, with three Industry Fellows scaling-up manufacture, optimising performance through local structure manipulation and delivering technoeconomic knowhow on new cathode chemistries.

Timeline with milestone/deliverables (September 2023)

FutureCat is targeting three transformative step-changes:

- Novel approaches to morphologies and microstructures, delivering new electrode topologies highly resistant to fracture; extending battery first-life.
- New protective coatings, dopants and electrolyte additives to increase power densities though faster interfacial ion transport and to prevent active-material erosion; improving power densities, extending lifetime and reducing costs.
- Discovery of new cathode chemistries through a coordinated computational-plus-experimental design approach with increased application of earth-abundant elements; improving energy densities and reducing costs.

FutureCat will deliver cathode materials and fabrication methodologies that deliver enhanced energy density, cycle-life, power output and reduced costs, empowering British battery manufacturing.

Project innovations

FutureCat sets ambitious targets to make fundamental cathode breakthroughs that deliver significant improvements in energy/power density, cost and first life:

- Electrochemical step-changes through strategic synthesis of doped-cathode variants exhibiting controlled morphology, where novel additives/interfaces promote fast-ion conduction; fundamental scientific enquiry of underpinning synthesis–structure–property relationship governing performance.
- Establishing design principles for durable cathodes informed by mechanochemical properties; developing new mechanical-testing methods informing synthetic design process.
- Determining new methodologies for assessing disorder in high-capacity cathodes, fast-tracking theory-meeting-experiment to inform-then-realise new target chemistries.

This innovation pathway also considers material/method scalability and lean-manufacturing techniques to smooth the path from laboratory to commercialisation.

Partners

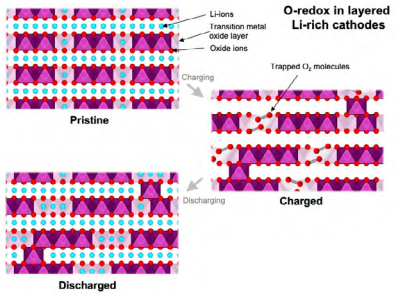
University of Sheffield (Lead)
Lancaster University
University of Cambridge
University of Warwick
University College London
Science and Technology Facilities Council
University of Oxford
National Physical Laboratory
10 Industry Partners

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CATMAT – Next generation lithium-ion cathode materials

Targeting a near-term improvement in lithium-ion battery lifespan and EV range through understanding current limitations of nickel-rich cathodes, the fundamental electrochemistry of lithium-rich oxygen redox cathodes and developing novel solutions.

Grant contribution: £11,000,000



The structure of a Li-rich cathode in a pristine, charged and discharged state showing how molecular O_2 takes part in the energy storage mechanism of an O-redox material (Nature Energy).

Executive summary

The cathode represents one of the greatest barriers to increasing the energy density of lithium-ion batteries for electric vehicle (EV) applications, with changes to the chemistry of the cathode likely to give the greatest improvements in future battery performance – boosting battery life, storing greater energy to improve range, reducing battery cost and increasing the power available to the EV during acceleration. Developing a new generation of lithium-ion cathodes therefore presents a major scientific and commercial challenge and opportunity.

The CATMAT project is placing considerable emphasis on understanding and mitigating the current limitations of nickel-rich cathodes (with low or no cobalt) and to understand the fundamental electrochemistry of lithium-rich oxygen redox cathodes. The project is exploiting this new knowledge to develop solutions to issues that at present are hindering major advances, and to discover novel cathode materials with enhanced properties. The most promising materials will be identified, before scaling up their synthesis and integrating them in full battery cells to demonstrate practical performance. This project will support the accelerated development of new cathode materials and will build on industrial partnerships to deliver technological applications.

Timeline with milestone/deliverables (September 2023)

- Develop a deeper understanding of nickel-rich and lithium-rich cathode materials with high energy densities and develop solutions to issues hindering major advances.
- Use experimental, modelling, and cell performance evaluation to establish feedback between current systems and new materials.
- Exploit new knowledge to inform the discovery of novel cathode materials for high energy density batteries (to increase EV range).
- Connect basic science to the manufacturing process, with promising cathodes taken forward to synthesis at scale and cell testing, thereby demonstrating their performance for applications.
- Build on industrial partnerships for pathways to deliver technological impact.

Project innovations

CATMAT is developing a substantial core of knowledge that will lead to the development of the lithium-ion cathode chemistries of the future. The project's advances in high performance cathodes will be taken forward to innovation and potential commercialisation through its industrial partners, which will provide important pathways to technological impact. Partners include leading players in the chemical, materials, cell manufacturing and automotive sectors. Their perspectives on commercialisation and technology transfer are being woven throughout the project. UKBIC could potentially take forward CATMAT's research into commercial scale demonstration, to expedite the commercialisation of promising candidates and maximise industrial impact to the UK.

Partners

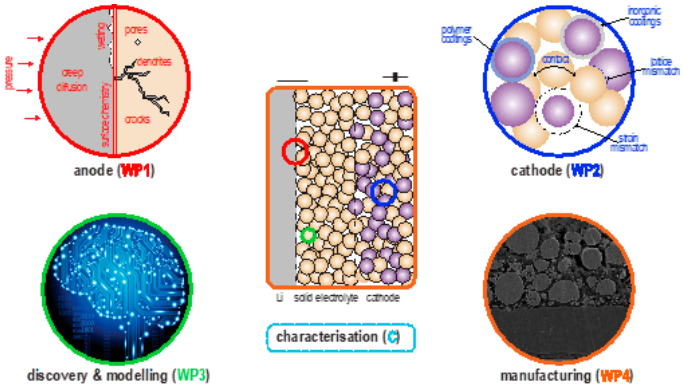
University of Bath (Lead)
Diamond Light Source
University of Birmingham
University of Liverpool
University of Cambridge
University of Oxford (lead from Jan 2022)
University College London
+ 12 Industrial Partners

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SOLBAT – All-solid-state lithium-metal anode batteries

Understanding the fundamental challenges facing the construction of solid-state batteries, using that knowledge to develop solutions, and demonstrate scalability to a commercially competitive product.

Grant contribution: £15,300,000



Executive summary

The ambition of SOLBAT is to demonstrate the feasibility of a solid-state battery with performance superior to Li-ion in electric vehicle (EV) applications. An all-solid-state battery would revolutionise the EVs of the future and profoundly impact the consumer electronics and aerospace sectors. The successful implementation of a lithium metal negative electrode and the replacement of the flammable organic liquid electrolytes currently used in Li-ion batteries with a solid would increase the range, decrease the charging time, and address safety concerns.

SOLBAT was established to address fundamental research challenges facing the realisation of solid-state batteries. Significant progress has been made including: understanding the role of voiding at the lithium-solid electrolyte interface on discharge, and the mechanism of lithium dendrite ingress and crack propagation/short circuit on charge; developing and implementing of a new method of solid electrolyte materials discovery; and understanding the effect of volume change in composite cathodes.

Organised around four research areas, namely anode, cathode, discovery & modelling and manufacturing.

The project aims to address remaining research challenges and accelerate the efforts to commercialise solid-state batteries.

Timeline with milestone/deliverables

Anode
- Identify optimised lithium-alloy anodes (December 2021)
- Demonstrate composite solid electrolyte with optimised mechanical properties and conductivity (March 2022)
- Combine alloy anode with composite solid electrolyte (March 2023)

Cathode
- Demonstrate polymer-coated particles with best combination of mechanical and electrochemical properties (June 2022)
- Demonstrate optimised polymer-coated cathode particles in composite cathode (June 2022)
- Identify zero/low strain and low-cost cathode materials (March 2023)

Discovery and modelling
- Electro-chemo-mechanics model and technoeconomic analysis (March 2023)
- Identify and demonstrate new best-performing solid electrolytes (March 2023)

Manufacturing
- Develop thin solid electrolyte separator processing (March 2022)
- Assist in establishing a solid-state battery prototyping facility (March 2022)

Project innovations

New intellectual property will be developed and ideally converted into viable businesses by industrial partners and/or newly created commercialisation vehicles. Ultimately, a serious, long-term effort in developing a strong and substantial core knowledge will result in either the development of the battery chemistry of the future, or will inform the viability of a solid-state battery on a commercial, scalable level.

Partners

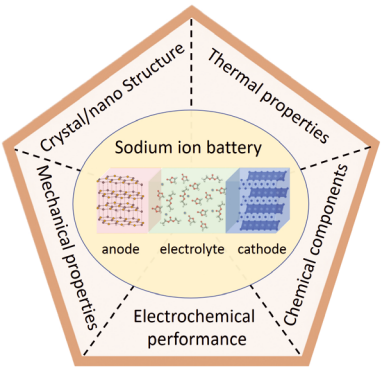
University of Oxford (Lead)
University College London
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University of Sheffield
University of Warwick
+ 3 Industry partners

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NEXGENNA – The next generation in sodium-ion batteries

Improving the energy storage, power and lifetime of sodium-ion batteries while maintaining safety and cost advantages.

Grant contribution: £11,500,000



Executive summary

Sodium-ion batteries (NIBs) are an emerging battery technology with promising cost, safety, sustainability and performance benefits compared to lithium-ion batteries. Key advantages include widely available and inexpensive raw materials and rapidly scalable technology using existing lithium-ion production methods. NIBs are an attractive prospect in meeting global demand for carbon-neutral energy storage, where lifetime operational cost, not weight or volume, is the overriding factor. NEXGENNA will develop the NEXt GENeration of Na-ion batteries. Its mission is to improve NIB energy storage, power, and lifetime while maintaining sustainability, safety and cost advantages.

NEXGENNA is taking a multi-disciplinary approach incorporating fundamental chemistry through scale-up and cell manufacturing. Many models of future renewable networks encompass storage for increased network resilience and to ensure efficiency of small-scale renewable sources. The widespread use of commercial NIBs that this project will facilitate, would aid the realisation of these models, and fulfil the need for low-cost electric transport options in the densely populated and polluted conurbations of developing economies.

Timeline with milestone/deliverables (September 2023)

- Discover and develop innovative electrode materials for higher performance, lower cost NIBs.
- Discover and develop next-generation electrolyte materials, giving higher sodium mobility and therefore higher power.
- Develop the understanding of interface formation and cell degradation to extend cycle life.
- Refine the test and characterisation methods most applicable for materials for NIBs.
- Improve the state-of-the-art cells produced by industrial partners by delivering a novel medium power or energy pouch-cell design.

Project innovations

The project benefits from strong academic-industrial links across the value chain. Industry partners bring strengths in terms of materials, cell fabrication and electrode manufacturing. By working closely with these partners, the project team will ensure that it readily exploits and successfully deploys cutting-edge science, making the UK a leader in this technology for stationary and low-cost transportation applications

Partners

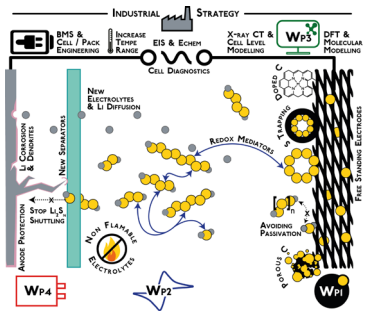
University of St Andrews (Lead)
University of Cambridge
University College London
Lancaster University
University of Sheffield
ISIS Neutron and Muon Source (STFC)
+ 3 Industry Partners

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LiSTAR – The lithium sulfur technology accelerator

Developing commercially relevant lithium-sulfur batteries that surpass the capabilities of existing Li-ion technology, increasing the applications that can be electrified and cementing the UK's capabilities beyond Li-ion.

Grant contribution: £7,500,000



Schematic illustrating Li-S challenges and LiSTAR's technical approach for overcoming them.

Executive summary

To deliver fundamental changes in battery performance in the medium to long term, industry must look to chemistries beyond Li-ion. Of these, lithium-sulfur (Li-S) represents one of the most promising and mature technologies available.

Compared with Li-ion batteries, Li-S cells store more energy per unit weight and can operate in a wider operating temperature range. They may also offer safety and cost improvements. Yet the widespread use of Li-S faces major hurdles that stem from sulfur's insulating nature, migration of discharge products leading to the loss of active material, and degradation of the metallic lithium anode. Scientists and engineers need to know more about how the system performs and degrades in order to overcome current limitations in the power density and lifespan of Li-S cells that could unlock their use.

LiSTAR is designed to address these challenges. The consortium is generating new knowledge, materials and engineering solutions, thanks to its dual focus on fundamental research at material and cell level, and an improved approach to system engineering. The project is addressing four key areas of research: cathodes; electrolytes; modelling platforms; and device engineering. In doing so, the consortium is seeking to enable rapid improvements in Li-S technologies, with the aim of securing the UK as the global hub for the research, development and deployment of this emergent technology.

Timeline with milestone/deliverables (September 2023)

- Enhance the sulfur loading and substantially increase the thickness of electrodes, making battery subcomponents that are significantly more representative of real-world requirements for multiple sectors.
- Improve safety via implementation of non-flammable electrolytes.
- Demonstrate new electrode and electrolyte approaches in a technologically relevant cell to establish confidence in scale-up activities.
- Demonstrate a battery management system to maximise performance.
- Develop bespoke advanced cell monitoring and diagnostic techniques from the outset of the chemistry's commercialisation.

In doing so, the project aims to pave the way for a Li-S cell with significantly improved operating temperature window, power and energy densities, and cycle life.

Project innovations

LiSTAR is tracking the technical requirements for Li-S batteries in strategic markets with near term opportunities such as aerospace and military applications. The project anticipates that the first viable commercial products will be for niche markets, which will subsequently stimulate others (including automotive). The consortium's industry partners, which include leaders in the battery chemicals supply chain and developers of battery management systems, are actively participating in the project. Alongside the research partners, they have the capability to fast-track research to higher technology readiness levels and efficiently provide proof-of-concept manufacture of the new developments.

Partners

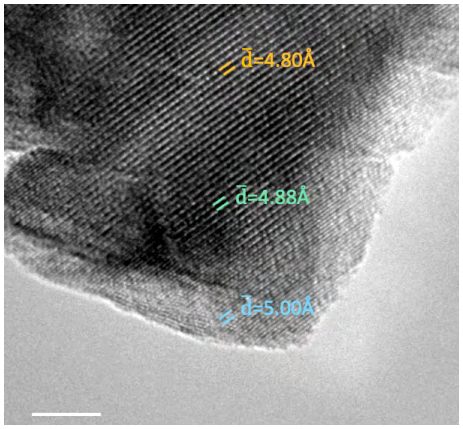
University College London (Lead)
University of Oxford
Imperial College London
University of Southampton
University of Birmingham
University of Surrey
University of Cambridge
University of Nottingham
+ 7 Industrial collaborators

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Characterisation Liverpool – Imaging dynamic electrochemical interfaces

Synergistic advances in *operando* characterisation methods to establish a robust, correlated multi-scale scientific framework for quantifying battery function.

Grant contribution: £1,000,000



Executive summary

The project aims to take the most advanced characterisation capabilities at leading research universities and national facilities in the UK and enhance them to address the pressing materials challenges associated with the development of new batteries with enhanced performance. By emphasising calibration meta-data to accompany each individual method, artificial intelligence (AI) is being used to advance the achievable correlated temporal precision, chemical sensitivity and spatial resolution across the vital length/time scales for battery performance.

The project is focusing on two critical aspects of energy storage: Researchers are identifying how the structure/composition of the electrode/electrolyte interface controls the initial stages of ion transfer (i.e., the charge/discharge process). The second area of interest is to observe the evolution of both performance-degrading stable phases and metal dendrites during extended battery cycling.

By expanding the number of methods that provide key performance indicators, this project is increasing characterisation options for businesses working in the battery supply chain, speeding up the establishment of new IP and the development of new products.

Timeline with milestone/deliverables (October 2021)

- Optimum acquisition for correlated data measurements SECCM-FIB-STEM-Raman to quantify atomic scale kinetics during first 3 cycles.
- AI methods for correlated multi-scale 3-D datasets over extended cycling.
- Dissemination of new methods to battery researchers in the UK.

Project innovations

This project is devising an optimal approach to specimen preparation that will permit reproducible, artefact-free *operando* battery component characterisation across multiple length and time scales. Such methods will enable rapid and quantifiable insights into both existing and future battery technologies, allowing the fundamental structural/chemical parameters controlling electrochemical performance to be ascertained. This unique capability will place the UK at the forefront of developing new battery technologies for electric vehicles and other applications.

Partners

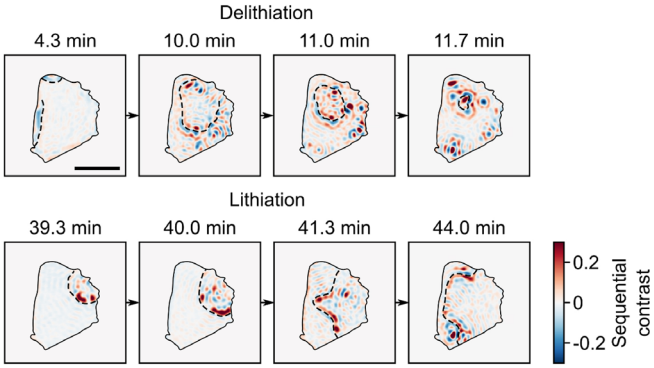
University of Liverpool (Lead)
University of Bath
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University of Manchester
University College London
University of Warwick
+3 Industrial Partners

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Characterisation Cambridge – The development of high-resolution optical microscopies

The development of high-resolution optical microscopies to evaluate structural transformations and dynamics in battery electrodes.

Grant contribution: £500,000



Executive summary

This characterisation project is exploring the use of high-resolution optical microscopies for studying battery systems. Building upon recent breakthroughs in characterisation methods developed for semiconducting materials, the project is aiming to provide a greater understanding of how electrode materials function at the single particle level and at shorter timescales than is currently available.

Understanding the mechanisms by which and the rates that lithium ions move in battery electrode materials is vital to developing higher performing battery materials with improved energy storage capacity.

The team is developing methods that can tackle crucial questions such as: how fast do the lithium-ions move, do electrodes transform via two or single-phase reactions, are electron and ion transport correlated, and what are the obstacles for transport caused by grain boundaries, defects or coatings? These world-leading methods will open a new window for the battery research community to investigate these materials and provide the fundamental science underpinning the next generation of high-performance materials.

Timeline with milestone/deliverables (September 2021)

- Develop a generic and easy-to-implement microelectrochemical cell platform that provides access for super-resolution optical and nitrogen vacancy (NV) centre probes.
- Develop and demonstrate high-speed hyper-spectral reflectance imaging to image lithiation of battery electrodes.
- Develop and demonstrate time-resolved super-resolution interferometric light scattering microscopy as a tool to track ion diffusion within single particles in real time.
- Demonstrate NVs as a local probe to track changes in magnetic properties within an electrode, and develop tools to enable the use of NV centres in an *operando* optical cell.
- Promote and disseminate the new techniques.

Project innovations

The project has developed a new technique – iScat – to observe ion dynamics in solid-state materials that can be used to study most battery materials. Observation of the movement of phase boundaries allows for improved mechanistic understanding of processes at high charge rates. The high throughput methodology allows many particles to be sampled across the electrode and, moving forward, will enable further exploration of what happens when batteries fail and how to prevent them from doing so.

Partners

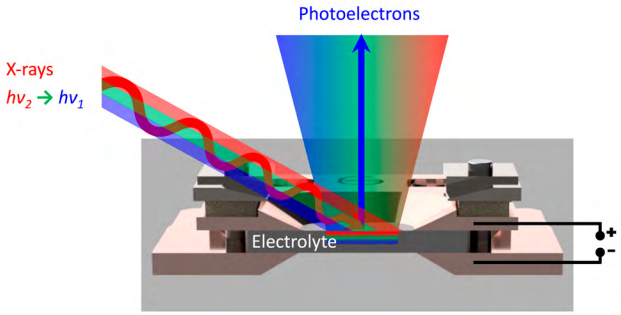
University of Cambridge (Lead)

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Characterisation Oxford – What lies beneath? Probing buried interfaces in working batteries

Development of *in-situ* and *operando* cells for probing buried interfaces in working batteries, portable across different characterisation instruments and applicable to a broad range of battery architectures/chemistries.

Grant contribution: £500,000



Executive summary

The interfaces between the active components in rechargeable batteries play a pivotal role in determining performance. This is where electrons and ions transfer between the electrodes and electrolyte during charging and discharging, and where many of the undesirable reactions that limit battery lifetime take place. Understanding how the structure and chemistry of these interfaces changes during operation is critical to developing higher capacity battery materials, fast charging protocols, and models to predict when batteries need replacing.

However, these interfaces are buried within the battery, making it extremely challenging to extract information without interference from the surrounding materials. This project investigates adapting powerful interface-sensitive methods, typically limited to vacuum conditions, so that they are compatible with battery measurements. The focus is on techniques that provide quantifiable, depth-resolved information on the chemical environment close to buried interfaces and includes X-ray photoelectron and absorption spectroscopies (XAS/XPS), second ion mass spectrometry (SIMS), and electron microscopy.

The project is pursuing both *in situ* cells that can be repeatedly disassembled and reassembled without breaking vacuum to allow measurement of each battery component at specific stages of cycling, and *operando* cells based on X-ray and electron transparent windows that allow measurement of interfaces during cycling.

Timeline with milestone/deliverables (December 2021)

- Develop and demonstrate an *in-situ* cell where each battery component can be removed, measured and the battery subsequently reassembled.
- Develop and demonstrate an *operando* cell where the interfaces between components can be observed while the battery is charging/discharging.
- Develop a new approach to preserving cell interfaces for further analysis.
- Demonstrate measurement across multiple characterisation tools (including hard X-ray photoelectron spectroscopy (HAXPES), SIMS, scanning electron microscopy (SEM), and X-ray diffraction (XRD).

Project innovations

The new techniques developed for studying buried interfaces are being made available to the wider research community through close interaction with Diamond Light Source and the Henry Royce Institute. The project is working closely with other Faraday Institution research programmes, as well as collaborating with industrial partners to help answer their materials problems. The *in-situ* and *operando* capabilities developed are expected to substantially improve researchers' understanding of interfacial behaviour in a wide variety of different battery chemistries.

Partners

University of Oxford (Lead)
University of Manchester
Diamond Light Source
+ 3 Industry Partners

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Industry sprints

Sprints dedicate small, focused teams of researchers to solve a commercially relevant research opportunity identified from within the research programme and prioritised by an industrial partner. Over a period of 6 to 15 months, researchers work closely on the challenge, meeting frequently to review progress and hone plans. Sprints give early career researchers an opportunity to lead a focused team across multiple institutions, and to connect with leaders from industry and academia.

Sprint Title	Description
Off Gases and Detonation Behaviour	UCL worked closely with an industry partner to combine multiple techniques to describe the mechanism and results of cell failure in an aerospace context. Clearly the implication of cell failure in an aerospace environment is significant, and the work here to establish the evolution of gases under various conditions provides results that can then begin to form models and design rules for pack development, increasing safety whilst limiting the destructive testing of multiple expensive test articles. Along with some research from the Degradation and Recycling projects, and on the recommendation of an international review panel, the safety work in the Faraday Institution portfolio has now been combined into a project in its own right (SafeBatt), increasing the scope and visibility of this important work.
Materials for Thermal Transfer	The University of Oxford and Williams Advanced Engineering (WAE) joined forces to look at the development of nanomaterial composites to limit thermal transfer between adjacent battery cells in a pack, improving safety during thermal runaway events. The material developed looks extremely promising in both its thermal performance and low mass, and is likely to be the subject of IP protection in the near future. The results from material tests at Oxford and physical tests at WAE will be supplied to the Multi-Scale Modelling project to assess performance on a larger scale within a virtual environment.
Cell Degradation	An industrial partner indicated evidence of degradation in high nickel cathode material when stored at specific states of charge for long durations. The mechanism behind this effect is being investigated by a combination of Degradation and Multi-Scale Modelling project teams at the Universities of Warwick, Cambridge and UCL, and research staff from the industrial partner. The data collected is comprehensive, assessing many cells stored at different conditions and testing them periodically using multiple methods. Cells will be tested at national facilities to establish the mechanism for degradation as a basis for investigating mitigation strategies.
TOPBAT - Optimising Pack Design for Thermal Management	Members of the Multi-Scale Modelling project at Imperial College London working with AMTE Power have been investigating the potential in changing the physical make up of pouch cells to improve their ability to reject heat more efficiently and hence allow for higher performance and lighter pack designs. AMTE Power made cells with current collector tabs of various thicknesses, which were then tested at Imperial College London alongside modelling work, which, once validated, would enable an optimal solution to be predicted. Whilst cooling cells via the tabs proved problematic, a significant reduction in degradation was observed leading to the potential for further work to understand how to apply this result elsewhere.

Entrepreneurial fellowships and spin-outs

The Faraday Institution Entrepreneurial Fellowship programme supports researchers across the UK looking to create new businesses and commercialise battery technologies. These fellowships have been set up to facilitate the creation of new business opportunities that have emerged from Faraday Institution research programmes and elsewhere from the broader UK battery research community. The programme provides seed funding, business support and mentoring to maximise the potential of success and accelerate the spin-out process.

Breathe Battery Technologies

www.breathe.technology/

Description
Breathe is targeting a step reduction in the charging time of batteries by replacing widely used static charging algorithms used in existing battery management systems. By adapting the charging process to the unique, evolving health of every battery, the researchers believe they can unlock substantial latent performance. Health-adaptive charging could also potentially increase battery lifetime and decrease battery cost.

Outcomes
Following the company's incorporation and award of a Faraday Institution Entrepreneurial Fellowship in 2019, Breathe has achieved important technical and commercial milestones as it asserts itself in a growing market for intelligent battery management software. In 2020 the company, led by Drs Yan Zhao, Ian Campbell & Greg Offer (Multi-scale Modelling project Principal Investigator), filed a patent application to secure intellectual property that has been demonstrated to enhance battery lifetime and manage vehicle fast charging. Breathe is now engaged in battery charge management trials with a global consumer electronics OEM, setting in motion activities that support their roadmap to mainstream deployment in electric vehicles. Breathe has additionally expanded its focus to include the grid battery storage market and is now developing solutions with the support of Innovate UK and project partners.

In the last 12 months the company has also garnered support from the European Regional Development Fund and CTO Dr Yan Zhao was awarded a Royal Academy of Engineering Enterprise Fellowship. Attracting talent has been instrumental in the company's progress and, in addition to attracting full-time engineering talent from Porsche, Breathe has hosted several undergraduate interns from the Faraday Institution FUSE programme. With a pre-seed investment round completed, the company is aiming to expand its partnerships in the automotive market in 2021.

Cognition Energy

Description
Cognition Energy is taking a physics-based approach to developing high performance batteries with a particular focus on thermal management to extend life and reduce ownership cost. Its concept solution includes an innovative thermal management system, a custom battery management system, improved safety, and a design that is both easy to manufacture and recycle. Target markets include commercial robotics, with a longer-term aim to expand to the vehicle and grid sectors.

Outcomes
Following an award of a Faraday Institution Entrepreneurial Fellowship in 2019 to help fund development of a thermally managed 5kWh battery prototype, Cognition Energy took on its first full-time staff member. Today it employs six FTEs and two part-time employees, not counting its founders from Imperial College London. It has taken on customer-funded work to adapt the 5kWh prototype design for a robotics application, and a second to develop a prototype battery charge station. In 2020, the company won an Innovate UK grant with Imperial College London to develop a cell rapid characterisation toolset: Advanced Cell Test (ACT) Feasibility Study. It has established a dedicated headquarters in Oxfordshire, moving out of university labs that had been closed during the COVID-19 lockdown. It plans to commercialise its 5kWh prototype over the coming year and explore other commercialisable technology in development. In July 2020, Cognition Energy successfully completed a funding round valued at £200k.

Solveteq

https://solveteq.co.uk/

Description
Solveteq is developing a sustainable technology for recycling of lead acid automotive batteries, whilst significantly reducing the environmental impact of the lead recycling process. The green, low-temperature and solvent-based technology will enable recycling companies to significantly reduce their expenditure on energy and environmental control, and produce lead and lead oxides that can be directly used in the production of new batteries. The research originates from RELAB, an EPSRC-UKRI-funded research project based at Imperial College London. Proof of concept has been established at the lab scale, and the intellectual property has been captured by two patents (1 granted and 1 pending).

Outcomes
The Entrepreneurial Fellowship enabled Solveteq to scale up its successful lab-scale process into an intermediate-scale continuous-operation prototype, designed to recycle 1kg/h of lead paste from used batteries. Life cycle and economic analyses have been conducted to optimise the process and position Solveteq at the forefront of lead recycling innovation.

During the fellowship Solveteq also established strategic relationships with international industrial partners and future customers, who are actively collaborating with Solveteq and contributing to its technology and commercial development. With the Fellowship's support, Solveteq was incorporated by IP co-inventors, Dr Ola Hekselman and Prof. David Payne and is now investment-ready, seeking to raise a pre-seed funding round. Solveteq received additional validation of its potential by securing funding from the European Regional Development Fund and Innovate UK to further develop and scale its technology.

Qdot

www.qdot.tech/

Description
Qdot is a University of Oxford spin-out developing cutting edge heat transfer technology to solve some of the world's most challenging thermal engineering problems. Applied to EVs, Qdot aims to increase the re-charge rate from 6 miles/min to over 15 miles/min. Qdot's heat transfer technology was originally developed for applications in a nuclear fusion tokamak, where heat loads can be in excess of 10 MW per square metre and the temperatures are over 100 million Kelvin.

Outcomes
The Entrepreneurial Fellowship provided Qdot the resources to develop and validate a prototype thermal management system to achieve extremely fast charging at the battery cell level. Follow-on technology development funding has been successfully secured through the Harwell Cross-Cluster Proof-of-Concept Fund, the UK Innovation & Science Seed Fund and Innovate UK Accelerator Programme, and the Innovate UK and Office for Low Emission Vehicles Catalysing Green Innovation – Securing the Future of ZEV funding competition. Future research will expand the technology to a battery module, and then pack, level. Qdot is initially looking to market its technology for vertical take-off and landing (eVTOL) applications that need very high-power density battery packs able to deliver high peak power during take-off and landing and that can be charged quickly between flights.

Gaussion Ltd

Description
Dr Tom Heenan, UCL, along with co-inventors Dr Chun Tan, Professor Paul Shearing and Professor Dan Brett have patented a charging-enhancement 'MagLiB' technology that uses a dynamic magnetic field to accelerate the fast charging of lithium-ion batteries. MagLiB has already demonstrated charge time reductions of over 60% in commercial cells. The Fellowship has propelled the technology into commercial battery applications, from cordless power tools to electric vehicles and battery manufacturing.

Outcomes
The MagLiB technology, developed at the Electrochemical Innovation Lab at UCL and now being commercialised by Gaussion Ltd, allows a higher average electrical current to be used during charging, which reduces the charging time whilst maintaining the cell's energy and power density (and hence EV range and acceleration) and battery lifetime. The technology is ready for real-world proof-of-concept projects. Early-stage discussions are underway with commercial entities, including a major consumer power tool company. In that sector, Gaussion Ltd is currently seeking seed funding for a technology demonstration, which it aims to have in place by the end of 2021. It hopes to have license agreements in place for this market in 2023. The company is currently seeking to establish initial development partnerships to access the cell manufacturing market, with a technology demonstration targeted in 2023. Accessing the EV market is a longer-term goal.

Altelium

https://altelium.com/

Description
A team at Lancaster University, led by Professor Harry Hoster and brought together through the Faraday Institution Multi-Scale Modelling project, recognised that data about battery history, state-of-health and future performance was crucial to the future economic viability of the EV battery market for both first- and second-life applications. After building diagnostic models on chemistry-related battery failure and securing interest from the insurance sector, they founded Altelium Limited, which today offers a non-intrusive diagnostic toolkit that enables the insurance industry to warranty batteries.

Outcomes
Today, Altelium is a trusted warranty partner delivering information for the electric vehicle and stationary battery storage market to underpin sound product development, investment and insurance decisions. Altelium's data service gives customers the information and peace of mind they need to invest and profit from the green energy revolution. The Altelium information platform combines real-time reporting from built-in battery transmissions with AI self-learning and reporting. Channelled through a secure Cloud-based system, this gives vital information through a secure portal, measured in line with National Measurement Institute standards from the National Physical Laboratory. Altelium currently employs 24 people and has received follow-on funding from Innovate UK.

Industry fellowships

The Faraday Institution awarded its first Industry Fellowships in 2020, a programme to strengthen ties between battery researchers working in industry and academia. Each fellowship enables academics and industrialists to undertake a mutually-beneficial, electrochemical energy storage research project that aims to solve a critical industrial problem and that has the potential for near- and longer-term benefit to the wider UK battery industry. Several of the projects are enabling early career academics to gain valuable career development experience in industry. The personal and corporate links established by the fellows are likely to seed longer-term collaborations between the two sectors.

Fellowship	Highlight
Coventry University with Nyobolt	Dr Alexander Roberts at Coventry University is working with Nyobolt to prototype their niobium-based anode materials into working battery cells. The collaboration is proving highly successful for both parties involved, with prototype cells confirming performance potential that supported a recent funding round for Nyobolt. Dr Roberts benefits from career development opportunities from interacting with the technical and commercial teams at Nyobolt as they head towards larger scale production. The success of the programme has led to a second Fellowship being awarded in 2021.
Imperial College London with Ilika Technologies	Dr Greg Offer and Dr Ganesh Madabattula at Imperial College London are partnering with Ilika to utilise the modelling tools developed by the Multi-Scale Modelling project and begin to apply them to solid-state batteries. This modelling of the fundamental physics governing solid-state batteries is allowing Ilika to rapidly trial various modifications to both the chemistry and physical make up of their designs, without having to commit to the cost and time involved in producing and then testing a large number of physical prototypes. This project is initially focussed on the modelling of the high-capacity silicon anode material used by Ilika.
University of Strathclyde with CDO2	Dr Terry Dyer at the University of Strathclyde is working with CDO2 on the miniaturisation of quantum magnetometry sensors. By taking sensitive magnetometer readings, CDO2 can visualise and monitor the current flow within battery cells and packs, with obvious implications for development of both cell and pack designs without the complications of invasive sensing technologies. The fellowship is working towards a new sensor design that has the potential to have superior size, accuracy and cost characteristics than existing technology and allow a significant number of sensors to be embedded in either prototype or serial application designs.
Cranfield University with Delta Motorsport	Dr Abbas Fotouhi at Cranfield University is working with Delta Motorsports to explore potential applications of artificial intelligence to develop novel temperature prediction techniques that improve the performance of battery thermal management systems, bringing possible benefits to battery performance and lifespan.
University of Sheffield with TFP Hydrogen Products	Prof Serena Cussen and Dr Glen Murray of the University of Sheffield are working with TFP Hydrogen Products to develop processes to control particle morphology and size for next-generation high-nickel cathode materials in a continuous manufacturing process, as part of a long-term aim of maximising battery performance and reducing manufacturing costs.
University of Sussex with CDO2	Prof Peter Kruger and Dr Christopher Abel of the University of Sussex are working with CDO2 to characterise and understand the capability of a newly developed device based on quantum magnetometer technology that could potentially be used to improve the prediction of state-of-health and state-of-charge on-board electric vehicles.
The University of Birmingham with Echion Technologies Ltd	Prof Peter Slater of the University of Birmingham is working with Echion Technologies to identify new mixed metal niobium oxide phases for possible use as anode materials, assess them for performance and thereafter take promising materials into Echion's product development cycle with the aim of improving lithium-ion battery energy densities and charge times.



Fellowship	Highlight
The University of Sheffield with Finden	Prof Serena Cussen at the University of Sheffield is working with Stephen Price at Finden to deepen the understanding of new cathode materials and mitigate deleterious behaviour. The aim is to fast track the best-performing high-energy density cathodes to aid their early adoption by UK industry and to inform future cathode protection strategies to prolong battery life.
The University of St Andrews with AMTE Power	Prof John Irvine, Dr Rob Armstrong and Dr Paul Connor of the University of St Andrews are working with AMTE Power to strengthen the pathway from laboratory to cell production. The partnership is focusing on taking newly developed sodium-ion materials from the laboratory to fully functioning pouch cells as an exemplar technology allowing the building of combined capability. The fellowship is strengthening the industry partner's awareness and capability in battery research and enhancing the university partner's capability to transition cells to full scale.
University of Sheffield with Exawatt	Dr Alisyn Nedoma and Dr Sam Booth from the University of Sheffield will work closely with the team at Exawatt (a key industry partner of the FutureCat project) to develop a techno-economic analysis and forecasting model of the cost of possible novel cathode materials given market raw materials costs and manufacturing methods. The tool will guide cathode research and scale-up options and has potential for use by automakers and to inform policy.
Imperial College London with Williams Advanced Engineering	Dr Billy Wu of Imperial College London will lead a Fellowship with Williams Advanced Engineering (WAE) to accelerate the deployment of advanced physics-based modelling (developed as part of the Multi-scale Modelling Project) to improve the diagnostic and prognostic capability of the WAE battery management system, targeting an extension in battery life.

Innovation

ABLE (Advance Battery Life Extension)

Feasibility study of diagnostic techniques to increase end-of-life reuse in automotive battery packs, and improve second life pack design and manufacturing.

Project costs

Total project costs: £427,522

Grant contribution: £290,864



Executive summary

The ABLE project aim is to 're-juice', reuse and recycle end-of-life (EOL) batteries from the UK-based electric vehicle industry to extract more value from lithium-ion batteries (LIB). Specifically, ABLE 're-juice' discarded packs by filtering useful cells through an innovative diagnostic tool developed by Imperial called Differential Thermal Voltammetry (DTV). It reuses them in second-life applications such as the 'M-KOPA Solar Home System' and recycles them once they've exhausted all useable capacity.

The techno-economic study completed in this project shows that currently cost of remanufacturing is dominated by labour. Costs per kWh shows that second life repurposing only become interesting if whole modules or large cells are used specially, due to the resource intensive testing/sorting process. Preliminary results are promising for DTV to be used as a factory re-acceptance tool, however this needs to be confirmed with further research.

Timeline with milestones and deliverables

M1: Delivery of the techno-economic study (M-KOPA) January 2019

M2: Delivery of all test plans for new and second-life cells/modules (Imperial) July 2018

M3: Second-life cells/modules characterisation completed. Define volume testing plan (Imperial) July 2018

M4: Batched cells/modules returned to Denchi (Imperial) September 2018

M5: Completion of second-life battery pack building (Denchi) November 2018

M6: Delivery to Imperial and M-KOPA of battery packs for further testing (Denchi) November 2018

M7: Comparison study of second-life battery packs and first life packs with Ostrich devices February 2019

M8: Completion of the lab study comparing best case and worse case scenarios for second-life batteries February 2019

Project innovations

- Production of a techno-economic study into the value of using end-of-life batteries for second-life applications in solar home systems.
- Delivery of second-life battery packs with filtered cells/modules using differential thermal voltammetry (DTV) as a novel filtering tool for LIB pack design.
- Demonstration of use of DTV filtered second-life lithium-ion battery (LIB) packs in off-grid solar home applications.

Partners

M-KOPA SOLAR
MAENDELEO NI LEO

DENCHI POWER

Imperial College London

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Web: www.denchipower.com/

Accelerated Na-ion battery technology development through machine learning, modelling, and digitalisation (AccelerateSIB)

Project will develop and demonstrate a digital toolkit for fast advancement of a new battery technology, bringing the technology closer to market while reducing the development time and costs. The project will demonstrate accelerated development of Na-ion battery (NIB) technology for light mobility applications.

Project costs

Total project costs: £877,595

Grant contribution: £630,631

Executive summary

The use of the digital toolkit (Ansys, Intellegens) and advanced materials development for sustainable, low-cost hard carbon optimisation for anodes (Deregallera), will result in the development of new, enhanced NIB cell batches (University of Birmingham), suitable for future mass production and commercialisation (AMTE Power).

The digital toolkit development will include: An intelligent data management software platform based on GRANTA MI software, Machine Learning algorithms based on Alchemite software, Materials Data for Simulation and new NIB cell modelling capability. The development builds upon the feasibility study (IDMBAT - IUK#133855) where an initial platform (alpha) was developed for cell manufacturing parameter traceability at University of Birmingham. The intelligent platform will dramatically shrink the materials synthesis parameter space and reduce the size of the expensive and laboured Design-of-Experiments campaigns. The project will enable the UK supply chain to perform techno-economic assessments of anode materials and revisit the 12+ dimensional material synthesis parameter space to optimise for £/kg and define the cost/performance envelope. The materials will be screened through half-cell, single layer pouch cell, double-sided electrode, multilayer pouch cells and have the ambitious goal of conducting a 20kg scale-up for a cell run at AMTE Power. Deregallera and AMTE will utilise the intelligent platform to optimise cell manufacturing processes on their respective prototype and industrial scale pouch lines.

Timeline with milestones and deliverables

- Data management platform with machine learning capability (Month 10 – June 22)
- Anode materials development and characterisation report (Month 11 – July 22)
- Multi-physics model development and parameterisation (Month 6 – April 22)
- Final report highlighting model quality and validation of approach (Month 12 – August 22)
- Summary of cell materials optimisation (Month 10 – June 22)
- Cell manufacturing data and report, including benchmarking against standard anode materials (Month 12 – August 22)
- Anode materials (Month 12 – August 22)

Project innovations

- Data management platform with integrated machine Learning capability tailored for a new battery technology Development.
- Materials data for NIB simulations & model development.
- Anode optimisation for NIB.
- NIB technology advancements demonstration & scale-up strategy.

Partners

amte power

Ansys

Deregallera

University of Birmingham

Intellegens

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Advanced battery thermal control & thermal run-away cascading prevention system

Our cooling system would make use of a cooling enclosure that enables coolant to pass around a group of 18650 cells, arranged in the format they would be in a BRIC, ALP Technologies' battery storage solution

Project costs

Total project costs: £194,058

Grant contribution: £149,374



Executive summary

The aim of the Faraday project was to design and make a novel liquid cooling system for 18650 lithium-ion batteries. The cooling system would make use of a cooling enclosure that enables coolant to pass around a group of 18650 cells, arranged in the format they would be in a BRIC, ALP Technologies' battery storage solution.

The system also makes use of phase change materials in the form of individual cell wrappings. These act as insulators preventing current running through the coolant. The wrappings also act as a method of heat extraction, as they will absorb energy as they transition to the liquid state at a certain reference temperature.

The work for this project was divided between two organisations. ALP Technologies were responsible for designing, making and testing the cooling enclosure to prove its effectiveness and show how it would perform in a thermal runaway event. Queen's University Belfast would look at testing phase change materials in parallel with this work. This project offers a solution for a low cost and highly efficient thermal

management system for our M-BRIC battery storage solution, the most affordable and smartest in the world.
Within this project it was proven that the cooling system would prevent thermal runaway with the calculations and experimental data collected. It was also proven that this design would work for half a BRIC (we couldn't do a full BRIC because of printer size limitations), but we are confident that this would scale to a full BRIC. The design completed is not ready for mass manufacturable, which was not completed due to time constraints.

Timeline with milestones and deliverables

D1: Completion of electrical Design - July 2020

D2: Improve existing electrical design of the battery and integrate temperature sensors - Sept 2020

D3: Design thermal casing and construct one prototype using thermal phase change materials - April 2021

D4: Thermal management system for the integrated individual cell-level thermal electronics, phase change materials casing and water cooling - June 2021

D5: Produce detailed risk metric table, technical feasibility report and business plan - June 2021

Project innovations

- Predictability: The design of the battery management electrical system can better predict range and battery health due to ability to "drill down" data to individual cells.
- The physical and electrical thermal control system at a cell level can lengthen the li-ion battery pack lifespan by keeping them within optimal operating temperature.
- Dual thermal control and thermal runaway prevention using phase-change material enhances safety significantly using a very targeted approach with material and design innovations of cooling casing.
- No welding/soldering assembly method of design allows rapid assembly that can minimise expenditures (e.g logistics, repair) of battery pack module

Partners

Contact:
James Kong **Email:** j.kong@alp-technologies.com **Web:** www.alp-technologies.com

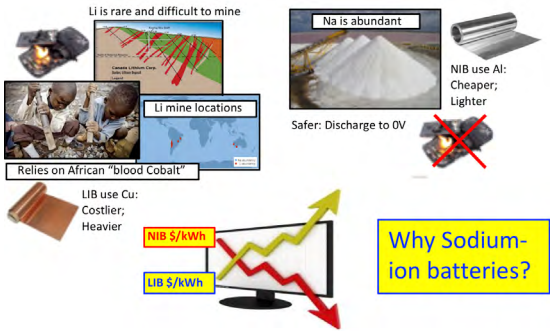
Advanced metamaterials for sodium-ion battery anodes – a scalability and economic feasibility study

Advanced synthesis processes are employed in the search for materials that can propel sodium-ion batteries towards parity with lithium

Project costs

Total project costs: £437,143

Grant contribution: £344,686



Executive summary

Sodium-ion batteries (NIB) are emerging as a viable alternative to lithium (LIB). They rely on more sustainable materials, no 'African blood cobalt', no copper, instead using aluminium on both current collectors, which is 30% cost and 30% mass of copper used in LIB. Today's prototype NIB is 30% lower cost than 30 years mature LIB, with the cost differential poised to diverge significantly over the next 5-10 years. NIBs are safer, thermal runaway is slower than LIBs and they can be transported at 0V, dramatically reducing the fire risk and, crucially, avoiding the increasingly stringent transport regulations (UN3481). NIB materials can "drop-in" to existing LIB production lines affording a rapid route-to-market. The downside, energy density, which is currently reported to be 140Wh/kg at the cell level, in comparison to 240Wh/kg for automotive LIB. This project explores opportunities for an advanced metamaterial to become a premium NIB electrode for automotive applications.

Timeline with milestones and deliverables

Aug 2019	Project kick-off and delivery of metamaterials experimental shortlist from Southampton to Exeter
Nov 2019	Delivery of metamaterials experimental longlist from Deregallera to Exeter
Feb 2020	Theoretical simulations (Exeter) of shortlist informs material choice at Southampton
Jan 2021	Experiment vs theory. Comparison of longlist materials.
Sept 2021	Project close, validation of 100,000+ simulated results via 10s of experimental samples. Feasibility of metamaterial composites established.

Project innovations

- High throughput theoretical screening of 100,000+ ideal metamaterials for NIB electrodes
- Proof-of-principle development of advanced material synthesis process to fabricate materials
- CPI to assess economic and technical challenges to Manufacture at scale – inform process routes at an early stage

Partners

University of Southampton

Deregallera

cpi

University of Exeter

Contact:
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AMPLiFII-2

Design, development, application & implementation of a scalable battery module & pack architecture, including set up and installation of a pilot production facility.

Project costs

Total project costs: £10,246,742

Grant contribution: £7,665,322



Executive summary

AMPLiFII-2 successfully developed a scalable battery module solution in both 18650 and 21700 cylindrical cell formats, integrated with Potenza's BMS and installed within battery pack architectures for the OEM partners. Each OEM partner represented a different sector - niche automotive (Ariel), mainstream automotive (JLR), bus (ADL) and off-highway (JCB). This helped to feed relevant requirements from each sector into the BMS and battery system designs.

The developments within AMPLiFII-2 focused on optimising cooling system performance for high power charging capability, cost-down exercises, and the improvement of manufacturing processes for cell joining, cell instrumentation and BMS hardware.

The project resulted in packs installed in demonstrator vehicles validated by real-world performance testing, a pilot battery module & pack production facility based at Delta's premises (with learning from the implementation of WMG's pilot line within the original AMPLiFII project) and a production capable BMS by Potenza, supported by the manufacturing capability at Trackwise.

Timeline with milestones and deliverables

Q1 2018	Implementation of lessons learned from the AMPLiFII project into beta module design
Q4 2018	Initial beta module testing complete
Q1 2019	Pilot production facility installed at Delta Motorsport
Q2 2019	Prototype packs designed
Q4 2019	Prototype packs manufactured
Q2 2020	OEM testing complete on prototype battery packs

Project innovations

- A BMS capable of Ethernet over Powerline (EoP) & software-over-the-air updates (SOTA)
- Battery modules for 18650 & 21700 cylindrical cell formats
- A low-cost, lightweight battery module thermal management system
- Battery pack solutions to suit 800V vehicle architectures and high-power charging requirements
- Investigations into ASIL D BMS requirements
- A production-capable flexi-PCB BMS solution
- Pilot battery module & pack facility capable of up to 5000 modules/year, including digital-twin model
- Prototype battery-electric vehicle development with 800V system architecture
- Battery system life cycle analysis using data from project developments

Partners

ARIEL

ALEXANDER DENNIS

JCB

delta
A Cosworth Company

JAGUAR

LAND ROVER

POTENZA
A Brand of FPT Powertrain Technologies

TRACKWISE
CONNECTING TECHNOLOGY

WMG
THE UNIVERSITY OF WARWICK

Contact:
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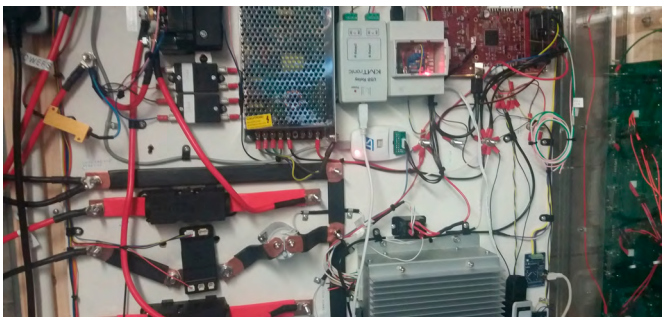
Assessment and development of the novel ‘i-BMS’ Battery Management System

Further evaluation of the i-BMS baseline performance; developing the capability to give early warning of fire risk from internal cell faults; and demonstrating scope for simple second life battery assembly.

Project costs

Total project costs: £319,846

Grant contribution: £245,461



Executive summary

The i-BMS pioneers a unique method of battery management which, by eliminating routine cell voltage balancing, enables very early warning of latent cell faults. Internal short circuits (“ISC”) can develop in a faulty cell over long periods before manifesting suddenly in thermal runaway and fire.

Following successful trials of the i-BMS baseline function, this project developed algorithms to detect very early stage ISC. This was undertaken in parallel testing alongside a commercial BMS over 1000 charge/discharge cycles, supplemented by model simulations.

The i-BMS was shown to have far greater sensitivity at detecting ISCs than any current detection method using a conventional BMS. The tests demonstrated that the detection method can be automated very simply, offering the prospect of routine early detection of potential thermal runaway events long before they reach a critical stage.

As part of the project, the i-BMS hardware and software was refined to pre-production stage. A separate workstream has demonstrated the simplicity of second-life battery assembly. The project has paved the way for economical beta testing of the technology in electric vehicles (“EV’s”), Energy Storage Systems (“ESS”) and other applications. Field trials of two test vehicles are scheduled to commence in the autumn of 2021.

Timeline with milestones and deliverables

The funded project ran from July 2019 to December 2020. Deliverables were:

- Improved i-BMS hardware and software successfully tested
- Parallel running of test rigs over more than 1000 charge cycles, enabling thorough assessment of i-BMS baseline performance alongside a conventional BMS
- Detection algorithms for cell faults developed and successfully tested through simulations
- Preparation for field trials using two test EV’s completed.
- Feasibility of economic assembly of a small ESS (using new or second-life batteries) demonstrated
- A research paper prepared and submitted for publication
- Preparations made in readiness for third-party beta testing of the technology

Project innovations

After proving the baseline performance of the i-BMS, the critical innovation from this project is the successful development and i-BMS partners logos testing of early ISC detection algorithms.

Spontaneous battery fires caused by runaway ISC continue to cause major concerns to Regulators and investors in lithium battery technology.

The current failure to develop effective early warning of ISC in systems using conventional balancing BMS is a direct consequence of the fact that cell balancing masks the very small voltage anomalies that accompany an early-stage ISC. An effective solution based on the i-BMS is now available for evaluation and testing by interested parties.

Partners

INTERCAL
BATTERY MANAGEMENT SYSTEMS

INDRA

WMG
THE UNIVERSITY OF WARWICK

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Peter Hardy **Email:** ph@intercal.uk.com

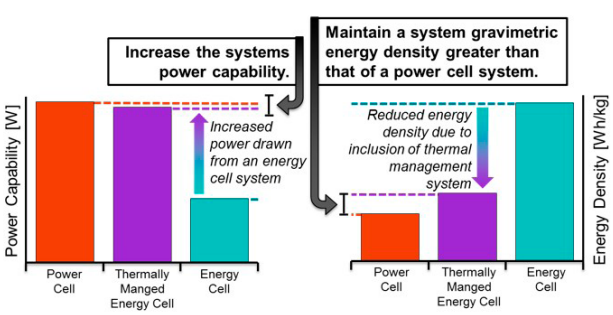
Automotive Technology Transfer Energy Storage Thermal Strategies (ATTESTS)

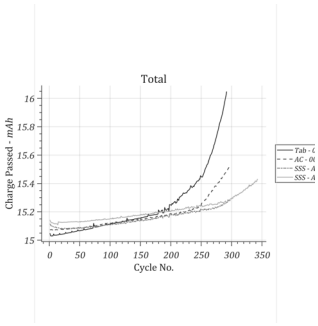
Assessing the feasibility of increased cycle life and power density of low C-rate, energy dense automotive cells through improved thermal management at cell level

Project costs

Total project costs:
£329,000

Grant contribution:
£246,000





Executive summary

ATTESTS is assessing the feasibility of achieving increased cycle life and power density of low C rate, high energy dense automotive cells through improved thermal management at cell level. Enabling use in high C-rate applications as seen in electric ferries, aerospace and EV fast charge.

Timeline with milestones and deliverables

- Baseline high energy density cell characteristics – Oct 2018
- Proposed cell level thermal solutions – Dec 2018
- Final feasibility assessment – May 2019 (Complete)

Project innovations

Investigating Tab and Surface cooling solutions to deliver at least a 5x lifetime and 10% power density improvement on high energy density automotive battery cells across different markets.

Partners

Rolls-Royce

Imperial College London

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Mark Husband

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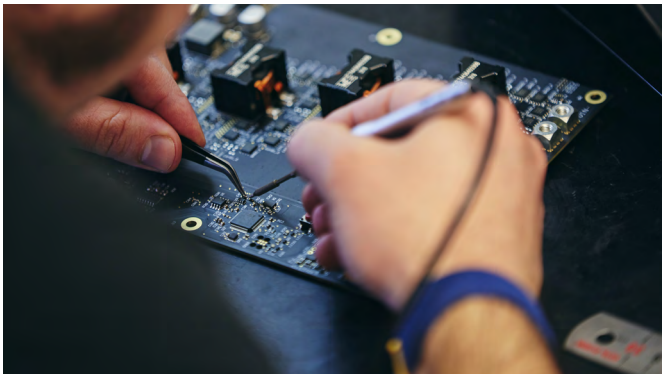
Battery management control system for Advanced Battery Engineering (BABE)

Developing the technical and commercial stages of Brill Power's revolutionary Battery Management Control System in EV fleet applications.

Project costs

Total project costs: £209,493

Grant contribution: £129,980



Executive summary

Battery lifetime is one of the greatest challenges to EV uptake. According to Berenberg Thematics (2019) average expected lifetime of EV batteries is only five years, after which the battery needs replacing. Considering that an EV battery can be around 40% of the vehicle cost, such replacements are financially infeasible.

Brill Power has developed battery management system technology which can extend the lifetime of batteries by up to 60% and used this project to create and test its value proposition for the EV market in collaboration with E-Car and Sustainable Ventures.

The key achievements of this project were an assessment of E-Car's EV battery health data, the design, build and test of a new version of Brill Power's battery management system, value proposition testing with stakeholders in the EV market, a business plan for Brill Power for the EV market, a market and dissemination plan for Brill Power, and a technology strategy plan

Timeline with milestones and deliverables

Project start date: 01 February 2018

Project completion date: 31 March 2019

- Report with summary of current battery performance, warranties, costs and replacement options
- Collection of data on E-Car fleet performance
- Report / Conclusions from Data Analytics
- Building and testing of updated iteration of Brill Power Battery Management System (Brill MS)
- Application of findings to develop value proposition
- Summary of value proposition testing results
- Business plan for EV market
- Technology development roadmap

Project innovations

Three main innovations were developed on this project:

- Analysis of EV battery lifespan using field data
- Development and testing of updated Battery Management System
- Development and testing of Brill Power value proposition

Partners

BrillPower

ecar A Europcar Company

sustainable ventures

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Web: www.ecarclub.co.uk
Web: www.sustainableventures.co.uk

Battery thermal management and diagnostics for heavy duty vehicles – BATMAN

Deliver a breakthrough in owning an operating costs of electrified vehicles through significant improvement in the life of battery pack in real world operation

Project costs

Total project costs: £2,813,226

Grant contribution: £2,004,438



Executive summary

Caterpillar UK, AVID Technology and Imperial College London have joined together to develop a new battery storage system. This will significantly improve battery life through advanced controls, monitoring and thermal management. The consortium will implement this technology breakthrough in a Caterpillar wheel loader. Utilising sophisticated simulation techniques, the team will also demonstrate that integrated powertrain systems utilising battery storage can be commercially viable for Electric and Hybrid vehicles in the commercial on-highway as well as off-highway sectors

Timeline with milestones and deliverables

- Design a modular battery module for aggressive heavy duty vehicle (HDV) applications.
- Develop and validate tools and techniques to perform system specification optimisation and Techo-economic assessment:
  - First cost
  - Full-life owning and operating costs
  - System performance and battery life
  - Real world usage
  - Develop battery management system and supervisory control
- Demonstration through:
  - Physical build of a fully electric production viable construction vehicle
  - Sophisticated vehicle level simulation of Medium Goods Vehicle (MGV)
  - Sophisticated vehicle level simulation of hybrid off-highway machine

Challenges:

- Adapting EV Technology for off-highway requirements
- Leveraging automotive industry supply chain to improve viability of the technical solution

Project innovations

- Down selection from five different cell technologies down to two for detailed life characterisation work – representing two different use cases.
- BAUMA 2019 CAT 906 EV concept machine showcased.
- Cell to full system model controls integration.

Partners

CATERPILLAR®

AVID technology

Imperial College London

Contact:
Thomas Kelly **Email:** : Kelly_Thomas_x1@cat.com

BAFTA (Battery Advances for Future Transport Applications)

The aim is to deliver a toolkit of software, models, and methodologies, implemented on an innovative BMS platform and validated to a statistically significant level.

Project costs

Total project costs: £2,939,405

Grant contribution: £2,215,494



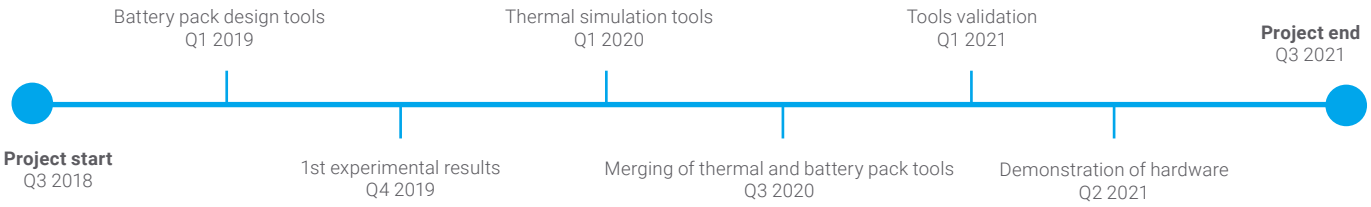
Executive summary

Aston Martin Lagonda is collaborating with Dukosi and Imperial College London to develop a framework that enables optimised performance and system longevity for battery packs. AML's new battery pack design and analysis tool optimises pack configurations through cell screening and vehicle requirement selection.

BAFTA's core interest in the modelling is to expand the cell-level state-of-charge and state-of-available-power predictions to the pack level. ICL's model development extends equivalent circuit modelling of a single cell to the pack level and can include all the resistances, both thermal and electrical, that appear in the pack to investigate different pack and cooling combinations to find the optimum. The online state-of-available-power estimation aims at incorporating the cell temperature as a limiting criterion with the aim of coupling it to the degradation model being developed.

Dukosi's dedicated lab has been built, commissioned, and continues to produce data. Cell characterisation tests have been performed to allow AML to select the optimum cell(s) for the project; The lab allows a diverse combination of cycling conditions (high temperature/high SOC, low temperature/high current etc) designed to accelerate cell degradation. The data is being used to validate the model's ability to track state of health and state of available power.

Timeline with milestones and deliverables



Project innovations

- Model-based thermal management system design that enables prolonged use of the battery system without significant performance de-rating.
- Novel diagnostic techniques that inform more intelligent battery management system enabling the system to be pushed to the limits of its capabilities.
- System packaging modelling design that enables the efficient packaging and layout of the entire system in a way that optimises weight, package size and distribution.

Partners

ASTON MARTIN

DUKOSI

Imperial College London

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CALIBRE: Custom Automotive Lithium-Ion Battery REcycling

Project costs

Total project costs: £3,192,157

Grant contribution: £2,205,168

Executive summary

Laboratory/pilot scale demonstration of end-of-life recycling of electric vehicle lithium-ion batteries generating materials suitable for re-manufacture of lithium-ion batteries.

Timeline with milestones and deliverables

Over 36 months the consortium will achieve:

- Safe disaggregation of modules and supply of cells to consortium
- Installation of mechanical disassembly pilot plant for cells
- Lab-scale validation of proposed routes for chemical recycling
- Synthesis of lithium-ion batteries from recycled feedstocks
- Value estimation of materials recovered
- Lifecycle assessment analysis of proposed supply chain

Project innovations

- 15-year forecast of battery production in EU and recycling market size estimation
- Process for safe pack discharge and disassembly
- Process to recover lithium and electrolyte, aluminium, copper, plastics, graphite, cathode materials
- Lab-scale validation of processes for cathode material upgrade

Partners

BENCHMARK MINERAL INTELLIGENCE

AUTOCRAFT Drivetrain Solutions

JM Johnson Matthey Inspiring science, enhancing life

NISSAN

Coventry University

ECOBAT BATTERY TECHNOLOGIES

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(CASCADE) Cathode and Anode Supply Chain for Advanced DEmonstrator

Bringing together the "Best of British" to accelerate the development of next-generation, ultra-high power battery material cell systems for automotive applications

Project costs

Total project costs: £1,138,909

Grant contribution: £827,624



Executive summary

The speed of charge of standard commercial batteries is severely limited by the negative terminal material which they use to store the electricity upon charge, called the anode. Echion Technologies Ltd has developed a new anode material called Mixed Niobium Oxide (MNO) which enables a unique combination of safe fast charge (down to six minutes for a full charge), high energy and power density, long cycle life and low cost.

JM has developed advanced battery cathode materials which can be matched with the Echion anodes to build battery cells with unprecedented performance characteristics.
These technologies will be demonstrated in commercial-format battery cells which will be comprehensively tested by potential customer British Volt, who will also conduct a scale-up assessment focusing on considerations for giga-scale production. Results of these tests, together with extensive characterisation and modelling performed by the UCL Electrochemical Innovation Lab, will form the basis of a knowledge package which will be used to facilitate business development and accelerate market entry. Finally, JM will develop strategies for recycling and understanding of the system's carbon footprint.

Overall Project CASCADE de-risks a key commercialisation aspect of the technology and will fast-track industrialisation of these advanced battery technologies in the UK.

Timeline with milestones and deliverables

Cell Demonstrator Milestones and Deliverables:

Dec 21:	Active materials shipped to cell manufacturer
Feb 22:	Electrode and cell designs validated at Lab Scale
Apr 22:	Commercial-format Electrodes and Cells manufactured
Jul 22:	Benchmarking of demonstrator cells completed

Characterisation and modelling Milestones and Deliverables:

Feb 22:	Parametric model inputs characterised at Lab Scale
May 22:	Ageing studies completed
Jul 21:	Parametric model validated vs. Demonstrator Cell benchmarking results

Knowledge Database Milestones and Deliverables:

Jun 22:	Technical recommendations re: CASCADE materials system recycling developed
Jun 22:	Manufacturing strategy and Life Cycle Analysis complete
Jul 22:	Customer-facing design tool validated

Project innovations

- Development of the 100's of ultra-high power demonstrator cells, and associated Intellectual Property and Know-How
- Parametric modelling to accelerate future development and optimisation
- Cell Manufacturing and Recycling Studies, including Life Cycle Analysis
- Customer-facing design tool to demonstrate benefits / trade-offs in Energy vs. Power vs. Cycle Life vs. Cost vs. Carbon Footprint

Partners

BRITISHVOLT

JM

Echion Technologies

UCL

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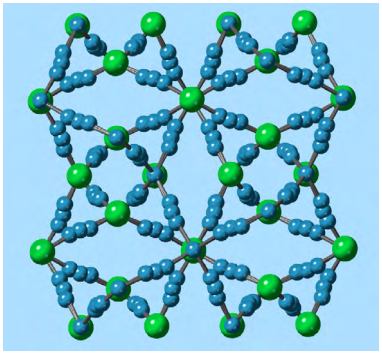
Cathodes, Anodes, and Solid-state Electrolytes for Lithium-Ion Batteries (CASE LIBs)

Feasibility study exploring the synthesis and processing of solid electrolytes and developing our understanding of the compatibility of these materials with active materials.

Project costs

Total project costs: £498,703

Grant contribution: £339,636



Executive summary

All solid-state batteries have the potential to realise significant improvements in key parameters such as energy density (dense material layers) and improved safety (no flammable solvents). Thus far the technology remains at a low technology readiness level and this is in part due to handling, processing, and scaled production of the electrolyte materials. Furthermore, suitable interactions need to be ensured at the electrolyte/active material interface to mitigate persistent issues such as high impedance and mechanical fatigue.

This project explored these industrial and fundamental challenges by bringing together three leading organisations that are at the forefront of battery materials and ceramic processing innovation. Johnson Matthey (one of UKs largest battery companies and a leading global cathode material manufacturer) Talga Technologies (a SME with extensive experience in graphene production and R&D), University of Sheffield (ceramics group with advanced ceramics processing capability).

Timeline with milestones and deliverables

The project ran from July 2019 to June 2020, and is made up of four key work packages:

- Development of solid-state electrolyte which will include the scale-up of electrolytes and their optimisation to improve key properties.
- Manufacture of composite cathodes, including material modification to improve composite manufacture.
- Preparation of composite solid-state anode using carbon-based anodes, including the investigation and improvement of electrolyte-carbon interfaces.
- Novel processing of solid-state electrolytes which will explore low-temperature sintering technologies.

Project innovations

- Preparation of solid-state electrolytes with improved performance via scalable routes
- Composite layers of solid-state electrolytes with both cathodes and anodes with an improved understanding of the material interfaces and compatibilities
- Novel methodologies for processing and sintering solid-state electrolytes

Partners

Johnson Matthey
Inspiring science, enhancing life

talga
Talga Technologies Ltd

The University Of Sheffield.

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COBRA – Cloud/On-board Battery Remaining useful life Algorithm

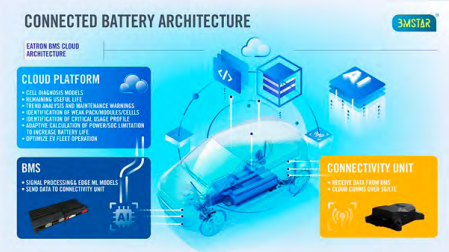
COBRA is focused on three key objectives:

- Development of a unified physics and machine learning based approach for battery Remaining Useful Life (RUL) estimation with high accuracy (\>90%)
- Integration of the developed solution in automotive-grade BMS hardware
- Integration of the solution into cloud-based platforms for fleet operation services

Project costs

Total project costs: £168,563

Grant contribution: £126,988



Executive summary

The COBRA project will deliver brand new, practical, algorithms for predicting the Remaining Useful Life (RUL) of batteries; capable of running directly on the BMS, and in the cloud. Such algorithms are not available in any existing BMS, but will be a core feature of Eatron's new product line, BMSTAR(r). Accurate RUL prediction will increase the value and sustainability of battery packs and there is significant interest in this feature in the industry. To reliably forecast remaining battery life, this project will apply novel simplified battery ageing models, developed by WMG, leveraging physics and Artificial Intelligence (AI) based approaches. This enables the RUL algorithm to account for both predictable key ageing mechanisms and any uncertainties that occur within the long-term operational use of the battery.

The benefits of an accurate RUL algorithm include:

- extending first life of batteries by giving an accurate indication of the remaining life;
- improving second-life applications by reducing the need for expensive testing;
- increasing effective battery power/energy density by allowing safe utilisation of a wider operating window.

Both WMG and Eatron Technologies have the necessary knowledge and resources to deliver this project successfully.

Timeline with milestones and deliverables

Milestone 1: Software development complete for RUL model

Milestone 2: Test and validation of the developed concept is complete

Milestone 3: Integration of the final software package is complete

Deliverable 1: A real-time validated Simulink model with ageing

Deliverable 2: Trained Machine Learning (ML) model and parameter set

Deliverable 3: Remaining Useful Life (RUL) software package integrated into hardware and cloud platform

Project innovations

This project's innovation comes from combining advanced battery ageing models developed by Warwick Manufacturing Group (WMG) with Eatron's Machine Learning based approach to RUL estimation (deriving from existing internal R&D) to a level of usability, reliability and maturity that gives battery manufacturers/integrators/fleet operators the confidence required to enable mass adoption. Realising this combined physics/AI-based approach will enable accurate prediction of RUL and will make the resulting BMS algorithms considerably more market competitive as such routines are currently unavailable. In wider terms, successful adoption of these new BMS features would ultimately also increase the value of the EVs and their uptake on the roads around the world.

Partners

WMG
THE UNIVERSITY OF WARWICK

eatron
TECHNOLOGIES

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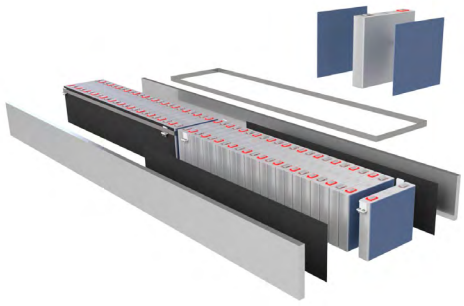
Conceptual feasibility of a heat pipe as a structural and thermal member in an automotive battery pack design

To assess the feasibility of Flint Engineering's innovative heat mat product in application to automotive battery pack design

Project costs

Total project costs: £505,137

Grant contribution: £385,605



Executive summary

This project considered the use of a sealed heat pipe in a mat format as a structural member in an automotive lithium-ion battery pack.

The existing heat mat innovation uses the latent heat of evaporation and condensation of a working fluid in a closed circuit. Through this mechanism the heat mat provides much higher thermal conductivity than an aluminium plate.

Proof-of-concept battery modules were designed and built during the course of the project and used to provide quantitative results for structural integration and thermal effectiveness through bench testing.

This testing showed best-in-class thermal performance when compared to competing thermal management systems and the potential to save weight and complexity at a system level by using one component to combine multiple functions.

Timeline with milestones and deliverables

This project was completed in Dec 2018.

Project innovations

Innovative thermal management system as structural member of battery pack that achieves:

- reduced part count and complexity
- increased safety including resistance to thermal runaway propagation
- decreased peak battery temperature across duty cycle
- minimised pack temperature difference across duty cycle

Partners

flint ENGINEERING

Brunel University London

VANTAGE POWER

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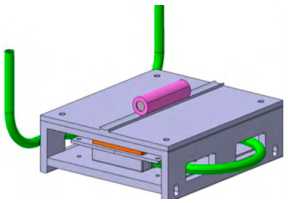
CoRuBa

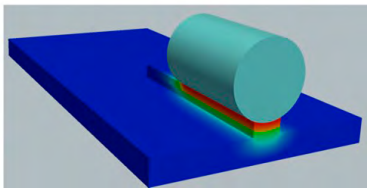
Next generation thermal interface materials to enhance cell life and enable rapid charging

Project costs

Total project costs: £378,583

Grant contribution: £301,521





Executive summary

This project aimed to develop the next generation of thermal interface materials (TIMs), with greatly enhanced thermal conductivities. TIMs that exhibit an order of magnitude increase in thermal conductivity were developed. Experimental development work at Imperial has led to new metric, the Cell Cooling Coefficient, to aid battery designers in down selecting from the vast range of cells available for a given application. As expected, experimental work demonstrated that increasing the thermal conductivity in the interface material between a cell and a heat exchange system leads to a reduced thermal resistance and improved rates of heat rejection from cells. TIMs developed in this project showed the least thermal resistance, illustrating a route to increasing cell life and/or charging at higher C rates whilst remaining within thermal limits of a given cell.

FACT developed a combined numerical-experimental approach to enable more accurate characterisation of the capabilities of different thermal management approaches and systems. Conductive heat transfer rates can be measured and the contributions from electrical connections separated out from those from a heat exchange system. These measurements are decoupled from radiative and convective loses, thus enabling simpler evaluation of thermal management approaches going forward. Existing in-house Multiphysics solvers were further developed for this work and are inherently capable of handling complex, fully 3D geometries. This enables aspects of evaluation of battery and heat exchange systems to be done in-silico. FACT was part of a successful consortium bid in the latest Faraday Challenge round, led by a Tier 1 automotive supplier. The step change in conductivity offered by FACT's TIMs will enable ultra-fast charging in the partner's new EV products. FACT's experimental-numerical approach will be scaled up and validated through combined electrical, thermal and multiaxial mechanical loading to of lithium battery modules in a dedicated and hardened test lab/bunker.

Timeline with milestones and deliverables

Q2: Solid TIMs with thermal conductivities up to 7.4W/mK developed

Q3: Foamed TIMs with conductivities up to 5.4W/mK developed

Q4: POC Experimental setup, along with numerical and physical apparatus calibration, completed

Q5: Final report on effect of thermal interface geometry and TIM properties under transient and steady state initial and boundary conditions

Project innovations

- TIMs with an order of magnitude greater thermal conductivities than current commercial equivalents were produced
- An experimental approach and new battery design metric, the Cell Cooling Coefficient, was developed by Imperial College

Partners

Imperial College London

FERGUSSON ADVANCED COMPOSITES TECHNOLOGY

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Current collector for improved battery performance (COATED)

Demonstrate the techno-economic performance of a novel current collector within commercially viable lithium-ion battery pouch cells

Project costs

Total project costs: £756,308

Grant contribution: £573,244

Executive summary

Current collectors are essential components in lithium-ion batteries (LIBs) and typically consist of either copper or aluminium foil. However, such materials comprise approximately 10-15% of the total battery cell mass and do not actively contribute to the battery capacity. It is therefore possible to achieve considerable battery performance e.g., an improvement in energy and power density, by reducing the current collector mass. In addition, the safety performance and mechanical properties of existing current collectors may also be increased with modifications to formulation and coating processes.

This project aims to validate the use of a novel current collector, which consists of a graphene-coated, double-sided metallised polyester film, for application within representative LIB pouch-cell batteries. The various components of the current collector will be supplied by DZP Technologies Ltd., DuPont Teijin Films UK Ltd., and Plasma App Ltd., with extensive battery testing and evaluation being performed at Warwick Manufacturing Group.

Timeline with milestones and deliverables

The project will commence on 1st August 2021 for 12 months and contains the following deliverables:

- Production of polyester film suitable for LIBs.
- Development of plasma metallisation process.
- Development of conductive coating.
- Testing and evaluation of LIB pouch cells.
- Techno-economic assessment and stakeholder engagement

Project innovations

- Current collector material developments for existing and next generation of LIBs.
- Process development for novel functional coatings
- New cell assembly processes
- Increasing manufacturing readiness level of production facilities for a UK-based supply chain.

Partners

DuPont Teijin Films™
Innovation | Partnerships | Sustainability

DZP Technologies
Delivering printed electronics innovation

WMG
THE UNIVERSITY OF WARWICK

PLASMA APP

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Current density imaging in EV battery modules

This project produced new sensors to image the current flow within EV batteries. They have since been developed into a commercial battery analysis system by CDO2

Project costs

Total project costs: £455,273

Grant contribution: £382,846



Executive summary

This project developed novel sensor technology into integrated devices capable of externally monitoring EV battery modules. It demonstrated that the sensors can provide non-invasive measurements of the current flow within production EV cells during test charge/discharge cycles. This new information can be used to improve cell design and monitor battery cell production.

The sensor modules were developed to produce a live feed of current density information during battery operation. This data was made available via a CAN bus interface to allow the development of new data processing systems to assess battery performance and incorporate the data in a battery monitoring system (BMS).

The commercialisation phase of the project led to the development of a standalone battery testing and analysis system. This has since been deployed in battery production and test facilities across the UK.

The project has also enabled the development of a new type of quantum sensor to provide ultra-sensitive analysis of current flow, capable of detecting small defects and irregularities in production cells. These sensors are now being developed in a separate Innovate UK Quantum Technology project led by AMTE Power to improve the battery formation and ageing process.

Timeline with milestones and deliverables

Project duration:	September 2018 – August 2019
Deliverables:	Small scale current density imaging sensor module
	Full scale current density imaging sensor module
	Quantum sensor demonstrator
	BMS integration demonstrator

Project innovations

- Demonstrated novel non-invasive technique for measuring the current flow distribution in EV battery modules
- Produced prototype integrated sensors that produce a live feed of current density information for analysis
- Demonstrated quantum sensors capable of ultra-sensitive measurement of current flow caused by battery relaxation and self-discharge
- Introduced a new technique for analysing and optimising battery cell operation and validating electrochemical models
- Post-project commercialisation produced battery cell analysis system incorporating sensor technology developed in the project
- Follow-on Innovate UK quantum technology project to develop quantum sensors for end-of-line battery testing led by AMTE Power

Partners

cdo2

inex microtechnology

Queen Mary University of London

University of Sussex

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Developing the Isothermal Control Platform (ICP) as the basis of new proposed standards for the testing of lithium batteries for use in electric vehicles

The ICP enables reduced testing time and improved model parameterisation for lithium-ion batteries for use in electric

Project costs

Total project costs: £566,607

Grant contribution: £447,619



Executive summary

The Isothermal Control Platform has been developed and is available as marketed product for battery characterisation.

The ICP offers precise regulation of battery temperatures using specially designed Peltier element modules in direct contact with the cell surface and/or tabs. The system is highly thermally stable and provides hitherto unavailable data accuracy and quality from charge, discharge and cycling tests. Holding the battery at constant temperature in the ICP provides much more usable data for cell modelling and characterisation than offered by traditional climate chambers, where the cell temperature can wonder significantly.

In addition to maintaining isothermal conditions, the ICP has the ability to programmatically change the temperature of the cell rapidly. This capability has enabled Imperial College to develop test methodologies which dramatically reduce cell characterisation times whilst reducing model error. Additionally, Cranfield University have developed thermal characterisation techniques based on the ICP's temperature step-change feature, allowing insight into the battery's internal temperature

Timeline with milestones and deliverables

July 2019:	The feasibility study has shown the need to establish new cell characterisation procedures requiring ICP precision temperature control.
September 2020:	A 2nd ICP prototype (immersion-based) delivered to Imperial College London
December 2020:	Isothermal Temperature Control for Battery Testing and Battery Model Parameterization (Hales et al. / SAE Int. J. Elect. Veh. / Volume 10, Issue 2, 2021) paper published by Imperial in collaboration with THT and Cranfield.
June 2021:	New ICP prototype (non-immersion) at THT

Project innovations

- Development of an isothermal control platform, with integrated circulator, thermal reservoir and control interface. Capable of handling large pouch cells and multiple smaller cells / cylindrical. Highly stable control of the cell temperature, and rapid controlled change of the cell temperature.
- New cell parametrisation methods developed by Imperial dramatically reducing the cell characterisation time.
- Thermal characterisation techniques utilising the ICP's rapid temperature change features.
- Marketable product available.

Partners

Cranfield University

THT THERMAL HAZARD TECHNOLOGY

Imperial College London

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Development of 1 kWh sodium nickel chloride battery system and associated manufacturing processes – Lina Power

The objective of this project is to demonstrate an innovative sodium-nickel-chloride (NaNiCl2) prototype battery system to TRL6 in representative automotive-sector conditions and optimise manufacturing for scale up and recycling.

Project costs

Total project costs: £1,500,000

Grant contribution: £1,180,004



Executive summary

The Consortium is led by LiNa Energy, who develop the batteries at the heart of this project. Partners are: Centre for Process Innovation Limited (CPI); Helical Technology Ltd; Imperial College London; Lancaster University; MEP Technologies Ltd; and University of Warwick.

This project will demonstrate how LiNa's innovative planar battery design overcomes problems which prevented the original tubular sodium-nickel-chloride batteries achieving mass production.

Cells achieved TRL5 in Feb 2021. In this project, the partners aim to achieve TRL6 at system level (1 kWh). A novel pack will be designed and operated. Modelling and advanced analytical techniques will help refine cell design and optimise performance. System trials in conditions representative of real-world automotive-sector conditions will be validated by an independent third-party expert.

Manufacturing will be upgraded, to increase production from current lab-scale volumes. Processes will be prepared for scale-up and optimised to maximise recycling/re-use. A pilot manufacturing line will be designed to implement the upgraded process and introduce automation.
Legal and commercial preparations for a follow-on demonstration will be completed. The commercialisation strategy for the LiNa-Power system will be upgraded including a refined cost-model.

Timeline with milestones and deliverables

Oct 2021	MS1 System spec defined
Jan 2022	MS2 Proposed process improvements defined
	MS3 Material changes & system defined
Apr 2022	MS4 Designs for prototype completed
July 2022	MS5 Prototype successfully operated and performance evaluated
	MS6 Technology ready for follow-on large-scale demonstration

Key deliverables:

1. Independent validators report
2. Commercialisation strategy, including cost model tool, business plan and spec for follow-on demonstration

Project innovations

Achieving:

- TRL6 for the novel NANiCl2 system, and
- optimised manufacturing processes ready for mass production, and able to achieve theoretical recycling/re-use targets.

Partners

Lancaster University

Imperial College London

MEP Technologies Battery Systems

WMG THE UNIVERSITY OF WARWICK

Helical Technology

cpi

LiNa Energy

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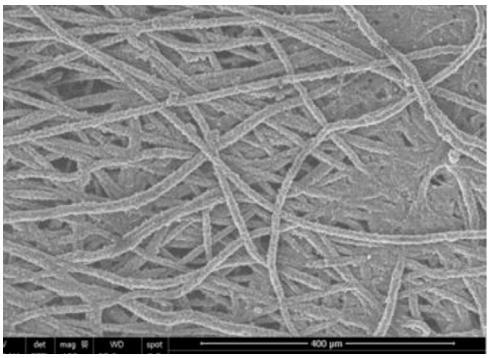
Development of 3D porous Lithium electrode for new generation electric vehicle batteries

Lithium-based 3D anode technology, agnostic to battery chemistry and delivering increased power and energy density at high stability to dendrite formation

Project costs

Total project costs: £780,700

Grant contribution: £546,500



Executive summary

This 24-month industrial research project develops and validates a proprietary 3D metallic Lithium anode material and manufacturing solution to overcome power, safety and performance problems of state-of the-art Li-ion batteries and emerging metallic lithium electrochemistries.

Timeline with milestones and deliverables

- Commission pilot unit for manufacture of 3D Li anode material (Q6)
- Demonstrate 3D Li anodes on coin cells and industry acceptable pouch cells (Q7)
- Independent validation of 3D Li battery prototypes with battery manufacturers and end users

Project innovations

- Increase in power achieved at high battery energy density;
- Better safety due to inherent stability of 3D Li anode to dendrite formation
- Longer battery cycle life

Partners

amte power

Sigma Lithium Ltd
Lithium Technologies for Energy Storage

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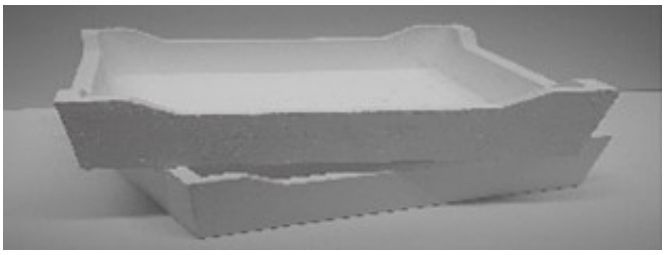
Enhanced-lifespan Saggars for Battery Material Production Scale Up (SAGGAR-LIFE)

Innovative ceramic materials research for scaling production of Li-ion battery material

Project costs

Total project costs: £1,183,938

Grant contribution: £630,705



Executive summary

The aim of this project is to identify suitable ceramic materials to develop and benchmark saggars with favourable compositions and microstructure to increase saggar lifespan. This will ultimately aid scale-up to commercialise battery material production by reducing saggar volumes. This has benefits in respect to easing saggar logistics, driving OpEx down within a production plant, and significant sustainability factors by reducing the volumes of new saggars to be manufactured and amount of waste generated at saggar end-of-life.

Timeline with milestones and deliverables

The project will run for 18 months, working through four key work packages with distinct deliverables and realistic milestones. The main deliverable will be commercial-scale validation of saggars and establishing a viable UK supply chain for the Li-ion battery market by late 2020.

Project innovations

- Development of novel test programmes and characterisation to define chemical compatibility between ceramics and Li-ion battery materials
- Delivery of UK supply chain for commercially viable saggars compatible for Li-ion battery materials
- Reducing OpEx costs in production of Li-ion battery materials

Partners

JM Johnson Matthey
Inspiring science, enhancing life

LUCIDEON
Materials Development and Commercialization

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Faraday precision ageing laboratory

Delivering fully factored, long-term cell ageing & degradation studies – on a scale not previously achieved before

Project costs

Total project costs: £4,079,910

Grant contribution: £3,861,017



Executive summary

The mechanisms that cause lithium-ion battery ageing and degradation are not well understood. There is limited availability of validated data on individual ageing mechanisms and even less data on the inter-dependency of ageing mechanisms and path dependencies. This is a major threat to the UK battery industry, as current state-of the-art ageing and degradation models cannot provide the required level of precision. Through Faraday Battery Challenge funding, a unique UK facility has been established specifically to address this threat to the UK battery industry. The Faraday Precision Ageing laboratory is dedicated to large-scale, long-term cell ageing & degradation studies – on a scale not previously achieved before. There are three main objectives:

1. The creation of a UK depository of battery ageing and degradation datasets. These datasets will help to support and accelerate the development of machine learning and Artificial Intelligence (AI) battery ageing algorithms.
2. The development of new fully validated and parameterised, high accuracy ageing and degradation models. As the data depository expands over time, models will be available for different cell chemistries, use-cases and form factors.
3. The generation of new knowledge and a better understanding of electrochemical ageing mechanisms through forensic autopsy and physical validation of ageing mechanisms.

Timeline with milestones and deliverables

November 2017	Project Start (funding awarded):
December 2017	Equipment ordering:
March to August 2018	Equipment deliveries and commissioning:
March 2019	First experimental rigs completed
April 2019	Facility first tests started:

Deliverables:

- 1,344 cell level cycler channels – 0-6V, 10A intended for long-term ageing.
- 48 high-power cell cycler channels – 0-6V, 200A intended for periodic cell characterisation.
- 64 channel (expandable) Electrical Impedance Spectroscopy (EIS) Equipment (for in-situ testing)
- 31 recirculating heater/chiller units – to support high-precision, fully immersed thermal management test rigs
- (EUCAR Level 6) climatic test chambers – intended for high-power cell testing
- 10 thermal storage chambers – intended for long-term calendar ageing
- Dedicated IT Infrastructure – secure, access controlled, replicated data storage and networking
- Experimental rig design(s) - high-precision, fully immersed thermal management rigs for accurate management of cell temperature during long-term ageing experiments.

Project innovations

- First ever comprehensive, fully factored, long-term ageing & degradation study
- Market leading high channel density cell cycler technology.
- Unique experimental rig design with fully immersed thermal management

Partners

WMG
THE UNIVERSITY OF WARWICK

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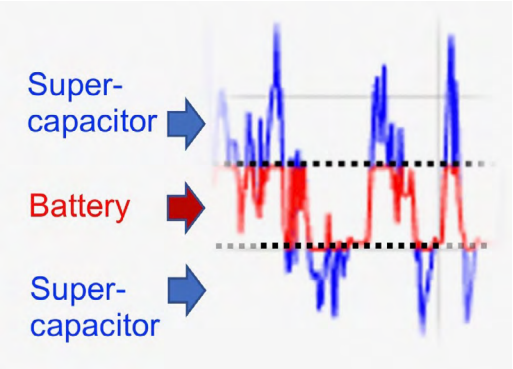
Feasibility project to dramatically extend 1st life via next generation battery management systems (HESS)

A feasibility study to define the benefits of HESS versus penalty increase in mass, volume and cost of integrating supercapacitors and power electronics with lithium-ion batteries at the system level.

Project costs

Total project costs: £497,563

Grant contribution: £397,711



Executive summary

HESS addresses three of the eight central tenets of the Faraday Battery Challenge: Extending battery life (target +50%), increasing pack range (TBC) and increasing power density (+300%). The high-power density of supercapacitors, inherent to electrostatic forms of energy storage, complements the high energy density electrochemical energy storage of the battery. Not only does it boost the available power density, the supercaps shave the peaks off the most damaging high-power acceleration and deacceleration events, shielding the battery from otherwise harmful events, and extending the battery life.

Timeline with milestones and deliverables

- Prototype HESS hardware and software developed along with legacy testing facility.
- Demonstrated against OEM duty cycles for 48V Mild Hybrid and 48V Light Mobility cases
- Screen NMC Li-ion battery from events greater than 0.5C (1 every 12 seconds) with a system that is 80% the size and mass of LFP Li-ion.
- Deregallera supercapacitor material raised from TRL3 to 4, demonstrating 50% higher capacity than market leader in single-layer pouch cells.

Project innovations

Increasing supercapacitor energy density is a key enabler of HESS. We approach this from three directions:

- System level, by integrating supercaps and batteries into the same pack casing
- Developing high voltage electrolytes
- Developing high capacity electrode materials

Our power electronics operates at the interface of energy storage systems and utilises recent advances in SiC and GaN devices

Partners

Deregallera

QINETIQ

University of South Wales Prifysgol De Cymru

London South Bank University

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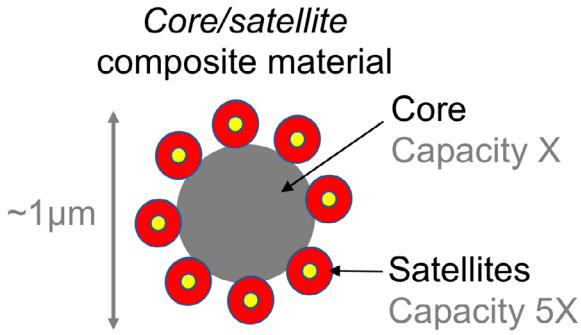
Feasibility research into composite carbon electrodes for sodium-ion batteries

After 30 years of neglect, sodium-ion batteries are emerging as a lower cost, safer, more sustainable alternative to lithium-ion, if suitably high energy density electrode materials can be discovered.

Project costs

Total project costs: £409,410

Grant contribution: £323,507



Executive summary

The long-term future of lithium-ion batteries is shrouded in uncertainty. They rely on geographically constrained and relatively scarce deposits of lithium, unethically sourced "African blood cobalt" and pose a serious fire risk that is only belatedly being acknowledged by increasingly stringent transport regulations. Sodium-ion based technology solves all of these problems with lower cost and more sustainable materials that can "drop-in" to existing lithium-ion manufacturing lines. All this comes at the cost of energy density. In 2019, state-of-the-art prototype sodium-ion batteries are reported to be 50% bigger and heavier than their lithium counterparts. This proof-of-principle demonstration, proved the feasibility of a high energy density composite electrode material, doubling the specific capacity of leading commercial sodium negative electrode materials and taking significant steps towards realising parity with lithium-ion batteries.

Timeline with milestones and deliverables

- Successfully completing in March 2019, with an average Innovate UK score of 4.5 out of 5, this project successfully demonstrated the feasibility of our composite material, while simultaneously developing a suite of materials spanning a cost-to-synthesise/capacity trade-off. The lower cost materials are earmarked for demonstration in stationary energy storage applications.
- Follow-on research to optimise the electrolyte (salt/solvent/additives) and binder synergy with our materials, while developing and integrating Deregallera's own layered oxide positive electrode materials, commences in July 2019 for 18 months (105308).

Project innovations

- The core/satellite particle nano-architecture solves three issues that prevent the high capacity "satellite" material from being used on its own: Excessive volume expansion; low conductivity; and low active skin-depth.
- The low-cost, more readily scalable synthesis process of the core material both undercuts commercial leading materials on price, while affording improved opportunity to tune material properties for specific applications.

Partners

Deregallera

UNIVERSITY OF Southampton

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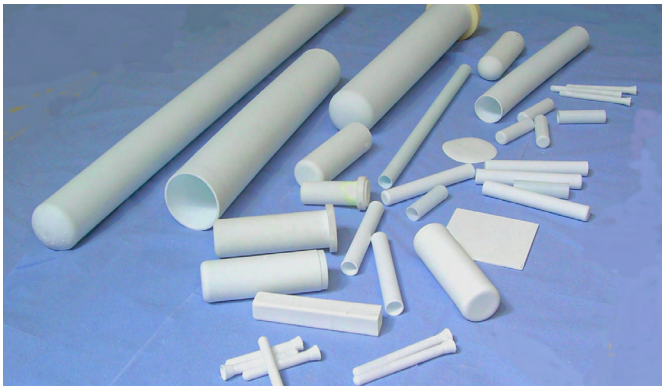
FESBEV

Assessing Field Enhanced Sintering, a novel sintering method, of beta-alumina solid electrolytes, a critical part of sodium batteries, for enhanced properties and productivity

Project costs

Total project costs: £241,225

Grant contribution: £152,186



Executive summary

Sodium batteries are a key technology to replace current lithium-ion technology.

This project assessed the feasibility of an energy efficient firing technique, Field Enhanced Sintering (FES), to process beta-alumina solid electrolytes, a critical component of sodium batteries. By controlled application of an electric field to the ceramic body during sintering, the peak temperature can be significantly lower and the process cycle quicker.

The challenge was to apply FES to beta-alumina sintering whilst retaining its distinctive sodium-ion conducting properties essential for use in batteries.

A step change in ceramic processing would revolutionise sodium battery technology, opening opportunities for new cell concepts with lower operating temperatures, improved safety and the prospect of greater market acceptability. Additionally, success would increase productivity and reduce manufacturing costs.

The project was delivered by two SMEs, Ionotec and Lucideon, who brought complementary expertise, capabilities and market presence. Ionotec is a leader in solid electrolyte manufacture and sodium battery development, working with global clients. Lucideon is a leading developer of FES technology, working with many ceramic manufacturers and researchers.

Following the feasibility study, Lucideon has continued to develop FES processing of battery components and the partners are considering approaches to develop and exploit this unique technology further.

Timeline with milestones and deliverables

The feasibility study ran between May 2018 and April 2019 and demonstrated five key parameters:

- Flash sintering of tubes and discs was possible at lower peak temperature
- Sintering conditions were controlled to avoid locally high currents and give uniform microstructure and properties- The density of sintered bodies was close to the target but further optimisation is needed for full density and target strength
- Conversion to the beta'' phase was achieved, but again requires optimisation for target conductivity
- Approaches to sinter larger batches of ceramic components were scoped

Project innovations

Flash sintering lowers the furnace temperature to process beta alumina shapes giving potential for a three times increase in productivity and longer furnace lives and opens opportunity to exploit new battery concepts involving thinner walled electrolyte discs and tubes made possible through less distortion on firing.

Partners

LUCIDEON
Materials Development and Commercialization

ionotec
INNOVATION WITH ELECTROCERAMICS

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Gii-Cap supercapacitor in all-terrain vehicles

This project will deliver an advanced battery pack augmented by a Gii-Cap® supercapacitor, demonstrated in an EATV. The project will also demonstrate the manufacturing scalability of Integrated Graphene's Gii-Cap® for future commercialisation

Project costs

Total project costs: £2,279,121

Grant contribution: £1,649,097



Executive summary

Integrated Graphene's invention is the only one in the world which manufactures pure graphene foam electrodes scalable to reel-to-reel equipment with seconds cycle times. This will enable the manufacture of graphene supercapacitors ("Gii-Cap") with highest-in-class energy and power density, but at significantly reduced weight and cost due to its innovative design-for-manufacture process.

Our collaboration with experienced commercial battery systems and EV design companies (MEP Technologies, Agile Vehicle Technologies, the University of Liverpool, and Warwick Manufacturing Group) will develop the next generation of EV batteries which are augmented by Gii-Cap to yield high-power and high-energy systems. Our cost and performance models suggest that Gii-Cap can even replace lithium-ion batteries for certain products in the near future.

Timeline with milestones and deliverables

Project start: 1 Sep 2019

M3	Gii-Cap Supercapacitor Build & Test
M5	Design Finalised
M12	Systems developed
M13	Systems Rig Testing Complete
M16	Architecture Validated
M18	Final Report

Project innovations

- Patent pending graphene manufacturing process for pure 3D graphene foam electrodes in seconds.
- Gii-Cap fast charging at TRL 7.
- Scaling ability to high cell numbers, manufacturing MRL 8.
- Novel Battery Management System (BMS) with capabilities to manage the unique characteristics of the supercapacitor cells for a workable hybrid architecture.
- Innovative Electric All-Terrain Vehicle (EATV) architecture with a prototype vehicle showing significant benefits in performance and efficiency.

Partners

WMG THE UNIVERSITY OF WARWICK

MEP Technologies Battery Systems

UNIVERSITY OF LIVERPOOL

Integrated Graphene

Agile VEHICLE TECHNOLOGIES

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GENESIS – Generating Energetic Novel Cells and System Inspired by Software

To optimise system level performance via multi-scale modelling from cell to vehicle, driving informed cell design choices.

Project costs

Total project costs: £1,390,526

Grant contribution: £1,019,831



Executive summary

The GENESIS project will be the beginning of a new generation of highly optimised large form factor automotive pouch cells for BEVs which will be capable of delivering both high energy density and at the same time high-power, fast charging within 20 minutes. Thermal management will be made easier, by minimising heat generation and maximising heat rejection to reduce the system level mass and volume.

Imperial will utilise physics-based modelling techniques, developed as part of a Faraday Institution project, to optimise cell design, from material selection to physical cell design. Imperial will also develop innovative multi-objective optimisation tools to rapidly optimise the cell design. JM will characterise and provide their innovative high energy cathodes. ENTEK will investigate advanced microporous separator composites using nano/micro-structured ceramics and mixed fluoropolymers. Britishvolt will lead the fabrication and demonstration of three iterations of prototype li-ion cells necessary for experimental model validation and refinement. An external contractor will be used to provide pack and vehicle models to analyse the influence of the resulting cell designs on system level and vehicle platform attributes, in order to validate the holistic approach to optimise the cell design for the system, and not the spec sheet.

Timeline with milestones and deliverables

This is a 12-month project, with the final deliverables being a software toolset incorporating degradation effects, validated via the building and testing of large format pouch cells optimised for system-level performance. To get there, we will characterise and parameterise our cell components, and iteratively refine both the design and model via three prototyping stages. These results will be incorporated into vehicle-level simulations to drive the cell design to best suit the high-performance attributes required for the premium vehicle market we are targeting. Additionally, we will review and report on the commercialisation and IPR opportunities presented by the project.

Project innovations

The key innovation in GENESIS comes from the linking of battery cell design choices all the way through to vehicle-level performance. This will enable a level of optimisation beyond that which is available currently. Is it more efficient to design for maximum energy density at a cell level, or better to back off on the energy density in preference of another attribute? If so, how do you best achieve this, and what are the impacts on vehicle performance, cell life, etc. There are a wide range of questions that can be answered through this work.

Partners

BRITISHVOLT

JM Johnson Matthey
Inspiring science, enhancing life

Imperial College London

ENTEK

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Granite – passenger car solid state battery

To develop a scale-up strategy for a passenger vehicle solid-state battery.
To power overall vehicle cost by utilising cell cost, thermal, safety and weight advantages.

Project costs

Total project costs: £1,974,000

Grant contribution: £1,451,000

Executive summary

Granite brought together Jaguar Land Rover, Ilika (solid-state cell developer), AMTE Power (cell manufacturing experts), and Warwick Manufacturing Group (cell abuse test and simulation experts), to develop and apply solid-state cell and vehicle battery pack technology for use in passenger vehicles.

It is hoped that solid-state batteries will yield improvements in several aspects of electric vehicles; including improving efficiency, extending range, reducing charge time and reducing cost.

Timeline with milestones and deliverables

Project start: 01 August 2019

Project completion: 30 April 2021

- Solid-state cell development, with a focus on inorganic solid-state electrolyte
- Develop a process for industrial scale up of manufacturing solid-state cells
- Vehicle level requirements and targets
- Vehicle battery pack concept
- Solid-state cell abuse simulation

Project innovations

- Ilika moved the Goliath solid-state battery technology forward, with multiple advances in knowledge, particularly in regard to scale up, mechanical understanding and the battery management system.
- AMTE delivered manufacturing process flow mapping and a cost model that will be invaluable for the next stage of manufacturing process development.
- WMG delivered a new conventional Li-Ion cell abuse model and generated structural data that will be helpful in the application to solid-state batteries.
- JLR identified how to maximise the benefits of solid-state batteries, whilst mitigating the low temperature and resistance challenges.

Partners

amte power

ilika accelerated materials innovation

JAGUAR

LAND ROVER

WMG THE UNIVERSITY OF WARWICK

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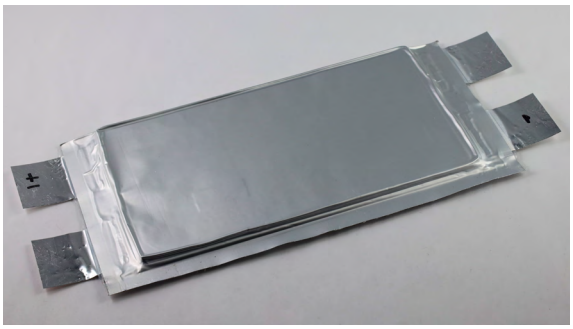
High powered anodes for fast charging buses

Innovative high-power anode technology using next-generation Mixed-Niobium Oxides has been developed into commercially relevant cells and verified against electric bus and automotive requirements.

Project costs

Total project costs: £1,290,000

Grant contribution: £830,000



Executive summary

The power density performance of electric and hybrid buses is currently limited, inhibiting their widespread uptake as very large and expensive battery packs are required. This collaborative project has developed prototype cells for a high-power bus battery pack, demonstrating new Li-ion cell technology that can enable more efficient regenerative braking and opportunity charging for hybrid and electric buses. The performance of these cells was tested to ascertain benefits at module level for electric and hybrid bus applications.

Timeline with milestones and deliverables

Project Start: 01 September 2018

Project End: 31 March 2021

Deliverables:

WP1: Kgs/day production of anode material to specification

WP2: High power pouch full cell design and testing

WP3: Demonstration production and safety certification of cells.

WP4: Performance testing of WP3 cells with thermal management and cell-level electronics modelling

Project innovations

Significant anode material production innovations, with the project overachieving to MRL 3 in the production and supply of material required for subcontractors.

Development of 12.5Ah demonstrator cells – Echion's largest formats to date, including significant know-how gained from two production runs and testing which confirmed high performance and high safety.

High efficiency, fast-charging performance (10C, ~76% energy efficiency) demonstrated by Vantage power, "setting Echion demonstrator cells above any competitor."

Partners

Echion Technologies

Vantage Power

University of Cambridge

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High-integrity busbars for electric vehicle battery systems

Our project focuses on busbars, which are battery pack or module power distributors, essential for driving propulsion in electric vehicles with additional charging station and energy storage applications. Leading busbar supplier HV Wooding Ltd will partner with experts in materials, automation, manufacturing and testing from The University of Sheffield to improve and standardise the manufacture of insulated busbars. This will result in a high-integrity product capable of meeting higher voltage requirements for battery module assembly and operation.

Project costs

Total project costs: £363,966

Grant contribution: £251,621



Executive summary

Reliable electric and low-emission vehicles are key to the UK meeting its Net Zero transport goals, and their rapid development is particularly pertinent given the Government's recent announcement to bring forward the ban of new petrol and diesel cars to 2030. By investing in innovative battery technologies, the Faraday Battery Challenge will directly enable this transition.

Our project focusses on busbars, which are battery pack or module power distributors. Epoxy powder is the preferred busbar insulation method, having superior chemical, corrosion and heat resistance, along with excellent electrical insulating properties. It also makes the busbar less susceptible to in-service mechanical challenges in automotive, rail, and aerospace applications including flexing, shock, or vibration.

High-integrity epoxy powder coated busbars will facilitate a move towards compact battery designs due to superior dielectric performance and are easily re-used and recycled to reduce environmental impact.

The project will improve and upgrade the powder coating process with advanced fluidised and spraying methods followed by a standardised test procedure for quality assurance. This is something severely lacking across the industry, with high product fallout rates through defects causing tension between manufacturers and customers. This standardisation is critical for the UK to maintain and grow its competitiveness within this fast-growing market. The project will also investigate automation options to increase volume production in line with future demand.

Timeline with milestones and deliverables

This is a 12-month project commencing 01/08/21, key deliverables/WP:

WP1 materials and process review and down selection – select a range of base materials & epoxy coatings

WP2 sample and equipment preparation – procure materials, equipment, build test cell

WP3 Fluidized bed testing – manufacture/test/validate

WP4 spray testing - manufacture/test/validate

WP5 Create standardise Test Method & Procedure

Project innovations

The enabling technologies developed in the project will facilitate efficient design, development, and manufacturing of busbars. Powder-coated insulated busbars are safer than heat shrink sleeved alternatives. They have better thermal and electrical performance, alongside other benefits in compact battery design, e.g., saving up to 10% clearance and creepage distance. Powder-coated busbars can be re-purposed or the material reused after service. If the innovative and optimised epoxy powder coating process is implemented by HV Wooding Ltd, it not only grows the business revenue to £3.5 million by 2024 and creates 27 more jobs in the local region, but increases the commercial opportunity for the busbar supply chain such as chemical production, metal, tooling and service across the country. The successful project will support the overall goal of the Faraday Battery Challenge and scale-up British busbar manufacturing for battery modules and packs in accordance with the UK's Ten Point Plan for a green industrial revolution.

Partners

HV Wooding

The University Of Sheffield. AMRC Advanced Manufacturing Research Centre

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High-power and high-energy battery systems with integrated structural thermal management for heavy-duty applications

This project will use the latest in integrated structural and thermal innovations to reduce part count, complexity and cost, whilst improving thermal performance of heavy-duty battery packs.

Project costs

Total project costs: £1,341,121

Grant contribution: £834,010.50



Executive summary

This 27-month project will take forward two innovations from previous Faraday projects and incorporate them into demonstrator battery systems for commercial on and off-highway vehicles with the aim of improving heat transfer from the cells within a battery, while also reducing part count and complexity. By achieving this, packs with higher overall specific energy and power densities can be built, whilst enabling applications that previously required prohibitively costly and complex cooling.

The first of these innovations is the use of heat pipes as an integrated structural and thermal member of a battery pack. This concept has been demonstrated in 2018 by the partners Vantage Power, Flint Engineering and Brunel University through testing at a module level. This showed class-leading cooling under fast opportunity charge duty cycles and the ability to reduce complexity, part count and the energy needed to cool the battery.

The second innovation is the development of FAC Technology's structural adhesive, which can act as both a cell clamping method as well as the thermal interface material, thus integrating these two functions. This again allows a complexity, weight and part reduction while performing as a class-leading thermal interface material.

Timeline with milestones and deliverables

- Product definition complete: End Q4 2019
- Fatigue testing of thermal/structural material: End Q3 2020
- Battery designs finalised: End Q2 2020
- System Built: Mid Q3 2021
- Testing complete: Beg Q4 2021

Project innovations

Increase in battery lifetime and performance combined with reductions in cost and weight via:

- Scaled heat pipe technology acting as structural and thermal member
- A Structural and thermal adhesive material that acts as both a thermal interface material and a structural element

Partners

VANTAGE POWER

flint ENGINEERING

FERGUSSON ADVANCED COMPOSITES TECHNOLOGY

Brunel University London

Contact:
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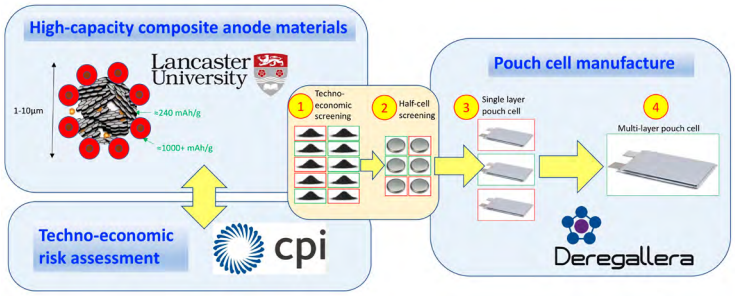
HIPERCARB - High performance hard carbon composites for Na-ion

Screening high-capacity composite anode materials and processes from TRL2 to TRL5 in a 12-month Feasibility Study. Seeking to pave the way for sodium-ion cells in excess of 200Wh/kg

Project costs

Total project costs: £408,000

Grant contribution: £338,000



Executive summary

Sodium-ion is emerging as a rival chemistry to the ubiquitous lithium-ion owing to its sustainability, lower cost and increased safety. Today, UK based Faradion and AMTE Power are manufacturing sodium-ion cells in the region of 140Wh/kg seeking to encroach on the 48V light mobility market alongside 12V SLI (starting/lighting/ignition) lead acid replacement. This project's vision is to explore opening up sodium-ion to the high voltage full-EV market by developing a high-capacity anode material in excess of 500mAh/g, with a goal of modelled cell level energy density exceeding 200Wh/kg. The Centre for Process Innovation will screen processes and materials for techno-economics at TRL2.

Nuria Tapia-Ruiz at the University of Lancaster identifies promising candidates in half cells at TRL3. These are progressed into single-layer pouch cells (TRL4) manufactured at Deregallera. Finally, the best material is tested in double-sided electrode multilayer pouch cells in a size and format guided by the Automotive end-users (TRL5). The National Physical Laboratory supports with their latest operando techniques to lift the fog of empirical analysis during material discovery process development and directly elucidate the electrochemical reaction pathways.

Timeline with milestones and deliverables

M1 – Month 0 – Process information exchange between the CPI and Lancaster

M2 – Month 3 – Techno-economic "first-pass" complete by CPI.

M3 – Month 6 – First composites passed to Deregallera for SLP manufacture.

M4 – Month 9 – One composite material is scaled to 100g for MLP manufacture.

M5 – Month12 – Demonstrator cell showcased to Advisory Board.

Project innovations

High-capacity battery materials often follow conversion and/or alloy reaction pathways that come with inescapable drawbacks:

- Massive volume expansion during cycling limits life
- Reactions occur to a shallow "skin-depth" in bulk material
- Low intrinsic conductivity often limits power density
- Prohibitive cost.

We target these four issues by controlling particle morphology to synthesise nanoparticles supported on a hard carbon core. The nanosized microstructure gives room for the crystal lattice to "breathe" during cycling, the large surface area affords the whole particle to be accessed electrochemically. The proximity to a carbon support aids conductivity and the ability to tune the amount of conversion/alloy material enables fine tuning of cost/performance trade-offs.

Partners

cpi

Deregallera

Lancaster University

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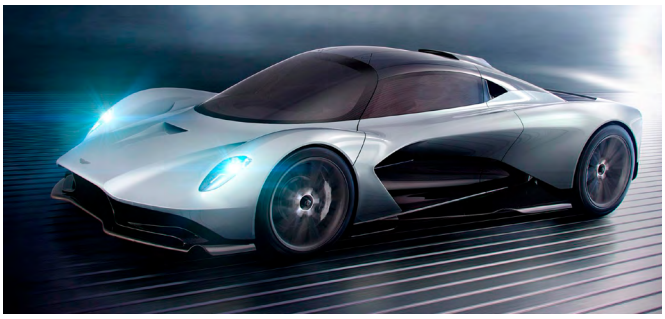
Hybrid Battery Optimisation (HBO)

Optimised from start to finish – the HBO project will explore optimal combinations of energy storage types for automotive applications and develop novel hybrid systems for high-performance use.

Project costs

Total project costs: £2,362,435

Grant contribution: £1,792,391



Executive summary

The Hybrid Battery Optimisation (HBO) project has developed a novel type of high-performance hybrid energy storage system (HESS) combining different types of available energy storage devices.

The HBO project will screen commercially available high-quality devices, such as lithium-ion batteries and supercapacitors, and select a combination of devices to optimise for both energy and power capability. The HESS will be designed through a new method of optimal system design, which involves a holistic modelling approach - from cell to vehicle. This modelling approach will be developed in collaboration between Imperial College London, Delta Motorsport, Brill Power, and Aston Martin Lagonda.

Once the optimal combination of energy storage devices is chosen, the HESS is designed and built by Delta Motorsport, a specialist provider of high-performance automotive electrical energy storage systems.

To combine the different energy storage devices into a single system, Brill Power's novel battery management system (BMS) will be applied for the first time into a split-chemistry system.

Three energy storage systems will be built - one split-chem system with the Brill Power BMS, one split-chem system with a dc/dc converter, and one single-chem benchmark system. These systems will be tested to confirm the compliance of the HESS with the high-performance requirements defined by Aston Martin.

Timeline with milestones and deliverables

Project start date: 01 July 2019

Planned completion date: 31 August 2021

The HBO Project begins with an assessment and selection of available devices. In parallel, the development of a high-fidelity cell model will be completed by ICL and the design of a new Battery Management System completed by Brill Power. Initial testing of the control strategy with a partial pack will be completed by Delta Motorsport and Brill Power. Performance testing will be completed on the three energy storage systems built for this project. The project will conclude in August 2021 with an assessment of the opportunities generated by using a split-chemistry approach to energy storage.

Project innovations

Two key innovations will be developed on this project. The first is the methodology and toolkit for optimal HESS design and simulation, taking a holistic view of the system – from cell-to-vehicle in order to optimise for target objectives. The second is the delivery of the hybrid system, using state-of-the art HESS design and a battery management system that can best manage the combination of storage devices.

Partners

delta A Cosworth Company

Imperial College London

ASTON MARTIN

BrillPower

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Web: www.imperial.ac.uk/mechanical-engineering

i-CoBat: Immersion Cooling of Battery Modules with a synthetic ester dielectric liquid

Development of an immersion cooled battery module for PHEVs and BEVs

Project costs

Total project costs: £726,251

Grant contribution: £471,251



Executive summary

Project i-CoBat compared cold plate cooling (using ethylene-glycol/water) with an innovative immersion-cooled concept based on a synthetic ester dielectric liquid. The project included both simulation and practical tests to assess the relative cooling performance of these methods. Experimental work investigated the thermal performance of a battery module when the coolant comes into direct contact with battery cells and busbars. This project concluded that immersion cooling with a synthetic ester can improve the following metrics: Power density (W/l) +20-30%, Volumetric Energy Density (Wh/l) +20-30%, Weight Energy Density (Wh/kg) +10-20%, Battery Ageing (Years) +5-10% - whilst also enabling ultra-fast charging technology.

Timeline with milestones and deliverables

The consisted of work streams running over 18 months, with dissemination milestones throughout this period. A summary of the test results, simulations and performance improvements - all demonstrating the advantages of direct immersion cooling over cold plate methods - are available on request.

Project innovations

- Faster charging times
- Higher power output
- Battery cell longevity

Partners

MIVOLT® LIQUID IMMERSION COOLING

WMG THE UNIVERSITY OF WARWICK

RICARDO

Contact:
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IDMBAT - Intelligent enterprise Data Management platform for BATtery manufacturing

IDMBAT aim is to reduce fabrication and development costs while improving key batteries metrics. This aim will be achieved by combining the proven benefits of a systematic, enterprise approach to materials information, with new AI capabilities for predicting optimum process parameters from complex interdependencies between materials, processes, and function.

Project costs

Total project costs: £498,000

Grant contribution: £369,000

Executive summary

The project endeavours to:

- De-risk scaling up innovative technologies across the battery manufacturing value chain (cell materials, manufacturing processes) through intelligent, systematic information data management
- Remove some technical and commercial barriers to cell manufacture in the UK (advancement in battery metrics improvement, reduced costs of trials and experimentation).
- Support the overall goal of the Faraday Battery Challenge to make the UK the go-to place for the research, development, scale up and industrialisation of cutting-edge battery

Timeline with milestones and deliverables

- Cells manufactured and tested for inputting into the data platform (Month 6 – Feb 2020)
- AI methodology development (Month 8 – April 2020)
- Software development completed (Month 12 – August 2020)
- Testing and validation on selected use cases (Month 16 – Dec 2020)
- Intelligent enterprise data management platform, Alpha version (Month 18 – Feb 2021)
- Summary of achievements (including quantification of benefits on use cases) and next steps (M18 – Feb 2021)

Project innovations

- Creation of a battery manufacturing data management module
- Data measurement techniques development, fully connected to digital platform
- AI models for optimised cell building
- Parameterisation of manufacturing protocols in LIB, developing new methodologies and consolidating existing
- New measurement methodologies for LIB manufacturing

Partners

Ansys

UNIVERSITY OF BIRMINGHAM

Intellegens

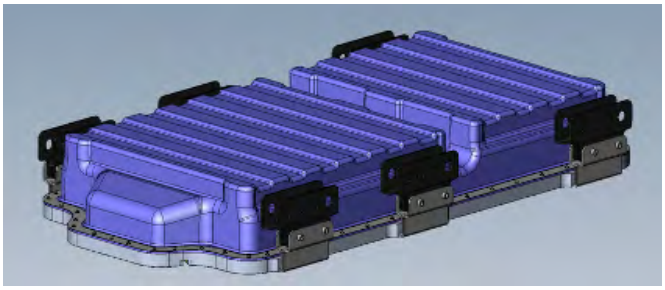
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IMPACT – IMProving Battery Cooling Technologies

Project costs

Total project costs: £594,290

Grant contribution: £469,141



Executive summary

The IMPACT project will explore the technical feasibility of integrating innovative thermal management technologies into modules and packs to improve the power-density of batteries for low and zero emission hybrid powertrains, as well as assessing the commercial viability of the approaches.

Timeline with milestones and deliverables

This is a 12-month project aiming to test prototype modules with innovative cooling technologies to verify performance. Key milestones to achieve this include module design, development of prototype cooling systems and integration into modules for testing.

Project innovations

The objective is to find cost effective ways to improve battery power density through thermal management. Novel thermal management approaches, two applicable at cell level and one at module and pack level, will be explored.

Partners

arcola energy

REACTION ENGINES

Brunel University London

flint ENGINEERING

Imperial College London

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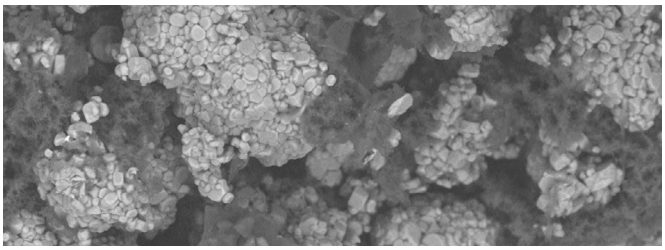
Innovative Carbons for Electrodes in Batteries (ICE-Batt)

Tailoring innovative carbons to optimise performance in current and next generation battery technologies

Project costs

Total project costs: £809,992

Grant contribution: £543,939



Executive summary

Johnson Matthey (JM), a global leader in sustainable technologies, has teamed up with CPI, an independent technology innovation centre, and Thomas Swan, one of the UK's leading independent chemical manufacturers, to explore how to best optimise battery technology.

ICE-Batt will combine Thomas Swan's innovative graphene nanoplatelet (GNP) technology and CPI's formulation expertise to explore how together they can help realise the full potential from Johnson Matthey's high-performance battery materials.

The ICE-Batt project aims to overcome limitations of lithium-ion batteries, including energy density, power density and low-temperature performance through the application of innovative carbons. ICE-Batt will fine tune these novel carbon structures produced at an industrial scale by Thomas Swan and demonstrate how they can be best applied to enhance the overall performance of traditional lithium-ion and next generation batteries such as Johnson Matthey's family of nickel-rich advanced cathode materials eLNO® and Life Power® LFP.

CPI will provide formulation optimisation through integration, iteration and evaluation. CPI's high throughput capabilities offer a rapid route towards improved, safer and more-sustainable technologies in the production of battery cathodes. This will support the shift away from the commonly used – but toxic and now regulated – solvents, improving sustainability and the potential for widespread adoption.

Timeline with milestones and deliverables

M1 Battery specification complete (Oct 2019)
M2 Initial electrochemical evaluation (Nov 2020)
M3 Screening of electrode slurries complete (Jan 2021)
M4 Nanomaterial development complete for optimum performance (Jun 2021)
M5 Optimised nanomaterial scaled-up (Jul 2021)
M6 Scale-up of electrode slurries complete (Jul 2021)
M7 Electrochemical evaluation of optimised systems (Aug 2021)

Project innovations

Fine-tuning the existing cathode formulations and introducing advanced carbon nano-materials into them may result in a longer life-span for Lithium-ion batteries, which will have widespread economic benefits to society. In this way the ICE-Batt project will help pave the way for the next generation of high-performance, sustainable battery technology. Innovations include:

- Optimisation and scale-up of novel carbons enabling maximum value
- Development of nanomaterials and composite materials tuned for current Li-ion and next generation battery materials
- Evaluation of improved electrode slurry formulations

Partners

cpi

Thomas Swan
Chemical manufacturing since 1926

JM Johnson Matthey
Inspiring science, enhancing life

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Michael Edwards **Email:** MEdwards@thomas-swan.co.uk

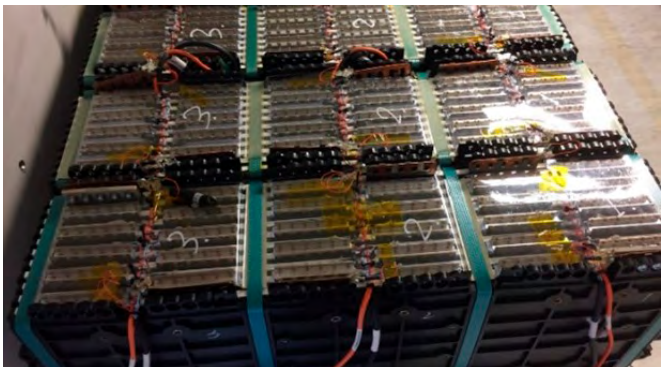
Innovative discharging technologies for recycling and transportation of lithium-ion batteries

To develop discharge technologies that are safe, fast, cheap, efficient, and smart, and that can act as a common front-end platform to a variety of downstream processing steps

Project costs

Total project costs: £777,348

Grant contribution: £611,106



Executive summary

Currently the UK has no industrial capacity for Lithium-ion battery (LIB) recycling; spent batteries are shipped to mainland Europe – a process which is carbon-intensive and expensive. Because the UK has no existing legacy processes (e.g. pyrometallurgy) for LIBs, we have a unique opportunity to develop next-generation, environmentally sensible LIB recycling facilities.

Numerous private and publicly-funded projects have focused on the establishment of LIB recycling facilities in the UK, but technical hurdles remain. Chief amongst these is pre-treatment of the battery packs prior to processing. The flammable and explosive nature of LIBs means they must be discharged and then dismantled before downstream recycling. This is both dangerous and expensive, with current (mainly manual) methods accounting for around 15% of the total cost of recycling.

Our project brings together a battery recycler (Ever Resource, ER), an electrical engineering company (Advanced Electronics and Logistics, AEL) and a research-led organisation (WMG) to develop the underpinning technologies (BMS communication; cell discharging) for enabling LIB recycling (the DISCOVERY platform). Our objective is to develop discharge technologies that are scalable, safe and efficient, and that can act as a common front-end platform for downstream recycling. DISCOVERY will catalyse the development of LIB recycling in the UK.

Timeline with milestones and deliverables

The project commenced on 1st August 2021 and will continue for 12 months. Deliverables consist of:

- Acquire and disassemble FIA Formula E battery packs and O.E.M battery packs.
- Reverse engineer EV BMS battery communications and develop hardware and software to allow full discharge of Lithium-ion Battery.
- Develop and demonstrate standard operating procedures for battery discharging and capturing the discharged energy.

Project innovations

DISCOVERY will achieve the following innovations.

- Progress towards developing a BMS communication system (hardware and software) that will allow communication with common EV battery packs on the market, allowing for pack discharge without prior dismantling.
- Develop safe and efficient discharging protocols meeting the application requirements of the BMS communication system.
- Demonstrate proof of concept by discharging LIB cells, modules and an OEM battery pack.

Partners

ever resource

Advanced Electronics & Logistics

WMG
THE UNIVERSITY OF WARWICK

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Dr Athan Fox — **Email:** a.fox@ever-resource.com — **Web:** www.ever-resource.com

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Project LIBRIS: Lithium-Ion Battery Research In Safety

The project aim was to understand, detect and inhibit battery thermal events, in vehicles and stationary applications

Project costs

Total project costs: £6,137,000

Grant contribution: £4,512,000

LIBRIS

Executive summary

LIBRIS surveyed the state-of-the-art in lithium-ion battery safety, analysed real-life hazards encountered in the battery lifecycle and assessed test coverage by typical standards and regulations for thermal runaway. The findings informed a testing program, from single-cell to vehicle battery pack levels, which addressed cell formats, chemistries and layouts used in electric vehicles and in stationary energy storage units. The test findings informed characterisation methods for mitigation strategies; assessed the impact of new materials and packaging solutions; supported validation of numerical modelling methods; and evaluated novel sensing methods. Validated modelling approaches were used within the project to help reduce the number of large-scale tests required, and beyond the project, to permit cost-effective evaluation of different interventions and assist in the development of lithium-ion battery systems for commercial applications.

Timeline with milestones and deliverables

Start 1st July 2019, end 31st March 2021

- Hazard mapping
- Abuse characterisation
- Sensing methods
- Mitigation solutions
- Packaging solutions
- Modelling
- Validation

Project innovations

- Better understanding of thermal events
- Thermal runaway detection and early sensing
- Active and passive mitigation methods
- Safe battery packaging solutions
- Modelling of thermal events

Partners

Potenza

DenchiGroup

Jaguar

Land Rover

Lifeline Fire & Safety Systems Ltd

Health & Safety Laboratory

3M

Tri-Wall

WMG The University of Warwick

Warwick Fire

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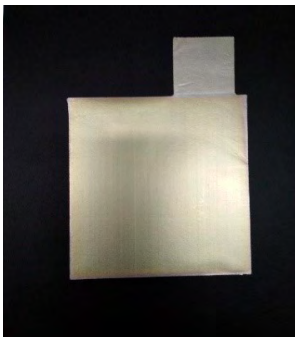
LIFE: Lithium Innovation for Future Electric Vehicles

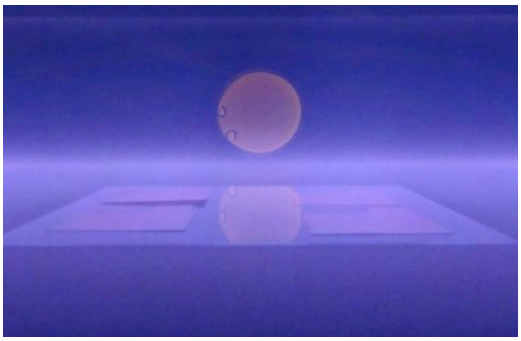
Scaling production of advanced lithium metal anodes

Project costs

Total project costs: £625,237

Grant contribution: £498,588





Executive summary

Via the LIFE project, OXIS Energy Ltd. and the Centre for Process Innovation (CPI) have successfully completed a feasibility study into the full end-to-end processing of advanced protected lithium metal electrodes for use in next generation lithium metal batteries. A scalable process to produce advanced protected lithium metal electrodes is an essential requirement to enable the mass production of next generation of high-performance cell technologies for future Electric Vehicles.

The key success of the project was the development of design requirements for each process stage within a pilot production line, this was accomplished via insight into industrially relevant equipment and processes specifications.

Timeline with milestones and deliverables

Apr 2018 Project Kick-Off
Oct 2018 Fully defined Lithium Foil Specifications
Mar 2019 Lithium Pre-Processing Specifications
Mar 2019 Lithium Processing Specifications
May 2019 Lithium Post-Processing Specifications
Jun 2019 Project Completion

Project innovations

- Optimised, scalable pre-processing methods
- Optimised lithium protection coating process
- Optimised handling processes for protected lithium
- New Intellectual Property will be developed and exploited by both partners

Partners

cpi

OXIS ENERGY
Next Generation Battery Technology

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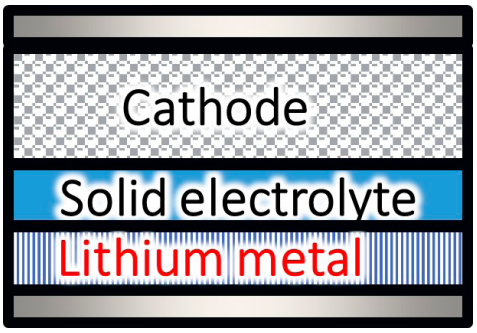
LiMHiT - Lithium Metal electrode High Throughput screening

LiMHiT brings together four industrial and academic partners to investigate the processing costs associated with fabrication of thin dense, lithium/(-alloy)-based thermally evaporated negative electrodes for lithium-metal, sulphide-based, all-solid-state battery cells

Project costs

Total project costs: £668,339

Grant contribution: £514,551



Executive summary

The UK Government 10-point plan has committed the UK to ending the sale of petrol and diesel cars from 2030 and all hybrids by 2035. Delivery of these targets can only be achieved by significant customer uptake of electric vehicles (EVs). Mass adoption of EVs is dependent on the development of affordable, sustainable batteries that meet technical requirements of end-users. Currently, OEMs must choose between "high performance" or "low cost", forcing a compromise between range, power and battery life when choosing an EV.

Lithium-metal-based solid-state batteries (SSBs) could eliminate the compromise between cost and performance for EVs. Lithium-metal electrodes are needed to guarantee high performance and represent a step-change versus lithium-ion. The Lithium-Metal electrode High Throughput screening (LiMHiT) project aims to address this opportunity by investigating alternative chemistry solutions for batteries whereby reducing processing costs associated with fabrication of negative electrodes for SSB cells. Consequently, the challenge is to reduce overall cost of EV ownership and improve performance for customers, accelerating EV uptake. Delivery of this would significantly contribute to UK environmental targets and support the creation of new green jobs across the supply chain.

Timeline with milestones and deliverables

- The main output will be a realistic cost/performance assessment for Li electrode fabrication led by end-use requirements.
- A scale up of test panels will be achieved and witnessed at the manufacturing partner as well as mechano-chemical characterisation of Li-metal and Li-alloys with the solid electrolyte
- The feasibility project will start in September 2021 and run for 12 months, consisting of four technical work packages each managed by the partners. Both physical and simulation testing will be carried out periodically during the project

Project innovations

A key output would be establishing effective partnerships and knowledge to develop a UK-based all-solid-state prototyping facility and ultimately deliver a world class SSB mass-manufactured by 2027. LiMHiT will investigate processing of thin (20-30um, 4-5 mAh cm-2), dense lithium/(-alloy)-based thermally evaporated negative electrodes for lithium-metal, sulphide-based, all-solid-state battery (SSB) cells. Sulphide-SSB cell technology is closest to exploitation with 2-20Ah prototypes publicly demonstrated by Samsung and Solid Power. However, high temperature requirements, > 60°C, and pressure for operation mean these cannot be integrated with EV systems. However, further development could deliver a paradigm shift to e-powertrain design.

Partners

NISSAN

E-R GROUP

WMG THE UNIVERSITY OF WARWICK

UNIVERSITY OF OXFORD

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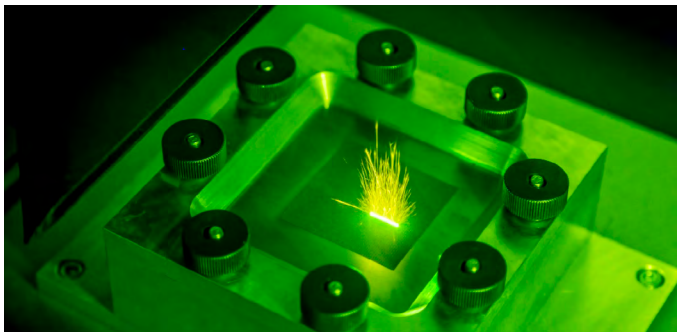
LiNaMan – Sodium Battery

The objective of this project is to demonstrate an innovative sodium-nickel-chloride (NaNiCl2) prototype battery system to TRL6 in representative automotive-sector conditions and optimise manufacturing for scale up and recycling

Project costs

Total project costs: £234,438

Grant contribution: £198,712



Executive summary

In this project, the partners achieved proof of concept for the novel (patent filed Oct 2017) sodium metal chloride planar cell, demonstrating the high power/energy density potential of the established sodium battery chemistry, applying modern material engineering techniques to in LiNa's innovative planar design.

The Consortium was led by LiNa Energy, who develop the batteries at the heart of this project. Partners are: Centre for Process Innovation Limited (CPI) and Lancaster University. This partners also prepared for volume production by designing the first processes, adapting modern manufacturing methods and techniques.

Key Project Tasks: Completed design and process specification for a single unit pouch cell, the single unit cell from which automotive battery packs can be built.
Produced key electrolyte on a metallic support.
Operated cell to demonstrate the electrolyte delivers good performance at 160-300°C.

Adapted screen-printing process to manufacture the scaled-up primary electrolyte to allow incorporation into design intent unit pouch cell.

Timeline with milestones and deliverables

Key deliverables:

- Design drawings and materials specifications for the cell;
- Process specifications for cell manufacture.
- Witnessed performance data demonstrating the Na-Ni-Cl battery's technical viability
- A robust, detailed cost-model for use as a planning tool

Milestones:

- MS1- Apr 2019 Impermeable electrolyte layer formed at product-intent scale
- MS2- Oct 2019 Successful demonstration of the design-intent cell
- Both Milestones were achieved on time and within budget.

Project innovations

The partners applied modern material engineering to successfully produce and test the first planar NaNiCl2 cell made to LiNa's design. To achieve this, they densified a sodium-conducting separator on a planar metallic support. The partners also designed the first manufacturing processes for the cell, and undertook LCA for the future system.

Partners

cpi

LiNa Energy

Lancaster University

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LiS:FAB - Lithium Sulfur: Future Automotive Battery

Powering electric buses and trucks with Lithium-Sulfur batteries

Project costs

Total project costs: £6,846,916

Grant contribution: £4,637,075

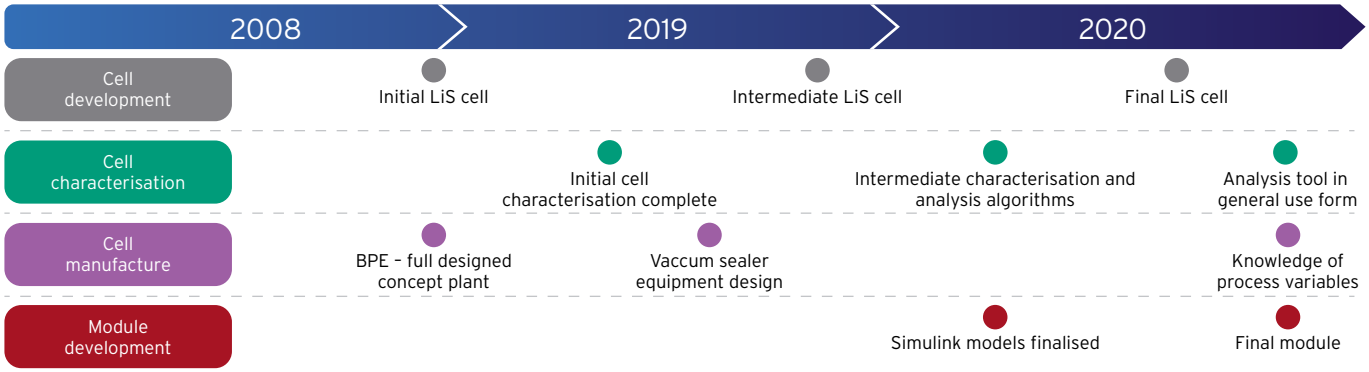


Executive summary

LiS:FAB will transform electric mobility thanks to a new lithium battery technology: lithium-sulfur. The project will develop a next generation cell and module suitable for large electric vehicles, such as trucks and buses. Li-S cells have already achieved over 400 Wh/kg and are targeting 500 Wh/kg by the end of 2019. The project will build on this success to deliver a high-energy cell with improved power and cycle life to suit EV applications. This cell will be thoroughly characterised and brought to mass production level. Strings of cells will also be tested, and modules will be built, incorporating an Li-S specific BMS.

Timeline with milestones and deliverables

Requirements set by steering committee



Project innovations

- A Li-S cell achieving 400 + Wh/kg and capable of cycling reversibly over 300 times
- A production line for that cell from the materials to the finished cell capable of building millions of cells per annum
- Reliable QC methods for Li-S production
- Advances on Li-S modules and control systems

Partners

ceetak sealing solutions

williamblythe Excellence in chemistry

A Synthomer Group Company

Cranfield University

OXIS ENERGY Next Generation Battery Technology

WILLIAMS ADVANCED ENGINEERING

UCL

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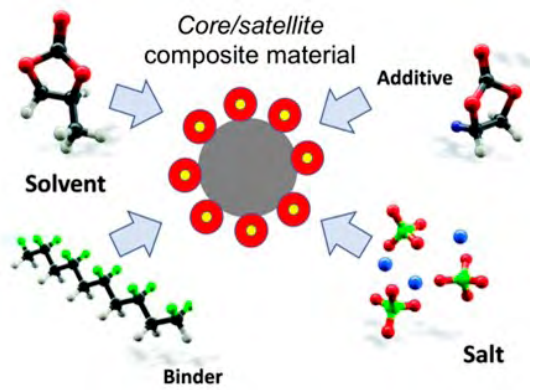
Low-cost, scalable and agile synthesis routes for sodium-ion battery materials

Building on the composite negative electrode material developed under 133370, this project now optimises the electrolyte (salt/solvent/additives) and binder, while also incorporating Deregallera's positive electrode into full pouch cells.

Project costs

Total project costs: £953,114

Grant contribution: £752,846



Executive summary

The composite electrode material developed under R1 feasibility study (133370) doubled the specific capacity of leading commercially available material. Now efforts turn to optimising the electrolyte/material synergy to realise further gains in capacity, while stabilising long-term cyclability (Southampton). Deregallera's positive electrode material also enters the system, culminating in the manufacture of commercially relevant full-pouch cells. NPL bring measurement expertise and advanced in-situ analysis techniques to accelerate the optimisation of the full system. The Centre for Process Innovation assess project materials synthesis processes for economic and technical challenges to manufacture at scale, preparing Deregallera for moving to manufacture.

Timeline with milestones and deliverables

- Patent filing on composite anode material commenced in the final quarter
- Developed a hard carbon anode from a sustainable precursor with equivalent technical performance to market leader and develop the UK-based contacts for route-to-scale
- Techno-economic assessment of hard carbon synthesis identified cost pain-points and directly defined 2021 follow-on activity to achieve economic competitiveness
- Deregallera first full Nai-ion cell manufactured in Qinetiq. Prototype pouch cell line commissioned at Deragellara with first cells off the line in the final quarter.
- Composite development lessons seed a Round 4 project- HIPERCARB

Project innovations

- LSBU develop a low-cost, agile synthesis route for NIB positive materials – moving away from conventional batch furnaces
- Deregallera develop a low-cost, agile synthesis route for NIB negative materials – moving away from conventional batch furnaces
- Southampton develop a high-capacity composite negative material propelling energy densities towards lithium-ion
- CPI assess and steer materials synthesis processes at early stage of development

Partners

London South Bank University

Deregallera

University of Southampton

NPL National Physical Laboratory

cpi

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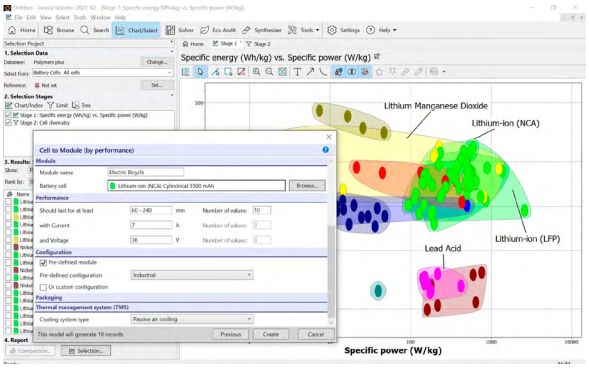
MAT2BAT: a holistic battery design tool – from materials to packs

The MAT2BAT project provided powerful capabilities to teach and train new engineers in the key concepts of cell/module selection and design as well as giving industry the tools to rapidly explore multiple different design configurations and compare them easily.

Project costs

Total project costs: £327,838

Grant contribution: £259,616



Executive summary

Electrification is a strong driver of industry world-wide, particularly in automotive, consumer goods and aerospace. However, battery cells, modules and packs are complex systems with multiple interdependencies, materials and components challenges. Future engineers need to be able to design better tools and battery solutions.

A new holistic design tool integrated in Ansys Granta Selector and EduPack software packages has been developed to quickly explore the growing battery design space, to understand the design and selection process and learn about how cells are integrated into modules and packs for the application requirements. The tool will be ideally suited for the preliminary design phase, enabling fast iterations of multiple design alternatives to assess performance using cell selection methodology and module design for a battery pack specification. Imperial College have developed the design methodology, Ansys Granta developed the software tool and database, and Denchi Group have provided input to industrial models and end user feedback.

Timeline with milestones and deliverables

• Software development completed for prototype	Month 10 (Sept 2019)
• Trials complete and feedback received	Month 12 (Nov 2019)
• List of materials and battery chemistries for selection, end user requirements	Month 3 (Nov 2018)
• Cell selection criteria and algorithms established,	Month 6 (Feb 2019)
• Cells Database created and populated,	Month 7 (March 2019)
• Software development completed,	Month 10 (Sept 2019)
• Trials and further development planning	Month 12 (Nov 2019)
• Post project development to commercialisation	Dec 2019 - Dec 2020
• Product launch (Software release)	January 2021

Project innovations

Development of a holistic battery design tool and associated cells database incorporated in Ansys Granta's software which will consider relevant battery material property data, detailed cell/pack design frameworks and an intuitive user interface. The analytical approach in chemistry selection brought to the project by Imperial College enable companies to explore the likely impact of current and future battery capacity.

Partners

Imperial College London

DenchiGroup

Ansys

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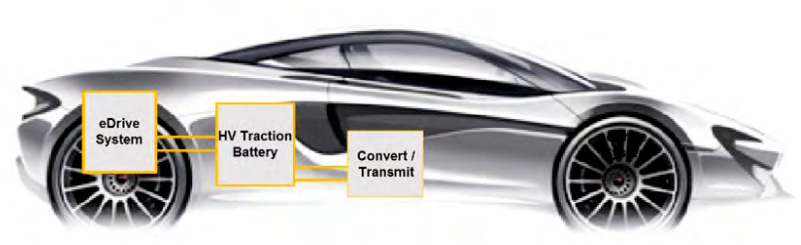
MoSESS: Multi optimal Solutions for Energy Storage Systems

A highly integrated battery system that aims to provide a unique optimal battery system for high-performance automotive applications.

Project costs

Total project costs: £8,973,835

Grant contribution: £6,020,377



Executive summary

This project aims at developing and integrating within a vehicle a fast-charging and high-power battery system based on an advanced cell technology, to deliver a solution with simpler cooling system, optimised crash structure for battery, as well as reduced charging time and weight. The project aimed to deliver significant increase in technology and manufacturing readiness levels, together with an innovative modularly designed battery to allow the final integration into a demonstrator.

Timeline with milestones and deliverables

Q1 2019: Project Kick-Off
Q3 2019: Requirements engineering, cell & concept pack design and cell prototyping
Q2 2020: Virtual test rig and cell validation results available
Q1 2021: Solid-state cell benchmark testing
Q2 2021: Pack design Improved performance of solid-state batter technology
Q2 2021: Project ends

Project innovations

- Novel Compact Battery Pack Design
- Solid-State Cell development
- Solid-State Cell benchmarking
- Virtual Test Rig

Partners

ilika
accelerated materials innovation

WMG
THE UNIVERSITY OF WARWICK

McLaren

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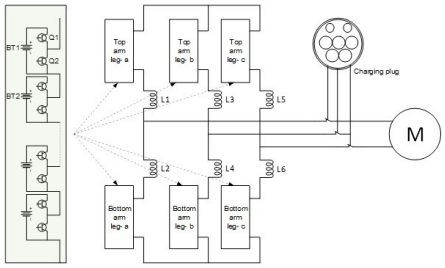
Multi-Bat: innovative power electronics for electric truck batteries

Multi-bat is a novel technology project to assess the benefits of integrating power electronic converters into a battery pack to drive cost out of future electric commercial vehicles and to facilitate a multi-function design.

Project costs

Total project costs: £402,968

Grant contribution: £241,909



Executive summary

Multi-Bat is a novel research and development programme to develop a multi-functional, modular battery pack which will enable reduced cost electric vehicles in sectors with lower production volumes. The primary objective is to assess the feasibility and benefits of a battery pack with an integrated power converter in an electrified commercial vehicle (ECV) application.

The battery will combine the functionality of the inverter and on-board charger into the existing battery management system (BMS) using a distributed converter topology integrated into the battery pack, thus enabling modular solutions to be created for a range of applications.
There are four main areas of focus: development of a viable electronic layout to perform the required functions; development of the thermal concept to mitigate adverse effects that the power converter integration could have on the battery; assessment of the mechanical feasibility for the installation of the distributed converter into a commercial vehicle battery pack; and finally, the impact of the distributed converter layout on electromagnetic emissions.

If successful, the project will deliver efficiency improvement, will reduce the mass of the vehicle leading to lower charging requirements, and will provide £1500-£2000 savings per vehicle – all to help to accelerate the wider-scale adoption of electrified commercial vehicles.

Timeline with milestones and deliverables

D1.1 Initial system specification and targets
D1.2 Initial concept design report
D1.3 Final concept design report
D1.4 Final commercial and technical feasibility assessment
D2.1 Distributed battery management system specification report
D2.2 Converter topology report
D2.3 Converter control simulation report
D2.4 Converter efficiency and quality evaluation report
D3.1 1-D thermal concept selection report
D3.2 3-D thermal analysis report
D4.2 Mechanical analysis report
D5.1 Revolutionary electric vehicle battery electromagnetic compatibility validation report
D5.2 Multi-Bat EMC simulation report
M1.1 3D battery geometry available for analysis
M1.2 Modular multi-level converter feasibility assessment complete
M2.1 Converter topology defined
M3.1 Thermal concept selected
M4.1 Battery module loads generated
M5.1 Revolutionary electric vehicle battery electromagnetic compatibility baseline simulation complete

Project innovations

The battery pack will combine the functionality of the inverter and on-board charger into the existing battery management system using a distributed converter topology integrated into the battery pack to enable modular solutions to be created for a range of applications. Using multi-level converter topology in automotive applications to provide both power inverting and battery charging is an innovative technology to reduce cost and mass of the vehicle.

Additionally, as electric commercial vehicles already operate at 600-800V, this layout is a cost-effective method of power conversion that can be readily adapted for future electrified road systems, which could operate at 1200V.

Partners

UNIVERSITY OF BATH

RICARDO

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Novel Carbon Allotrope for Lithium-Ion Batteries (CALIB)

The project goal is to develop a new type of Li-ion battery anode based on a novel form of carbon material - Carbon Allotrope for Lithium-Ion Batteries (CALIB).

Project costs

Total project costs: £506,000

Grant contribution: £371,400



Executive summary

Plasma App, Cambridge University and Johnson Matthey PLC have explored the new carbon-based material with the goal to develop the functional electrode to be integrated within the standard Li-Ion battery manufacturing process. Replacing standard graphite electrode with CALIB potentially will allow increase in the specific energy density of the Li-ion battery, increase in battery cycle-life, and improve safety especially under stressed high-power operation conditions. Doping of the CALIB anode with small percentage of Si (~ 5 wt%) makes it feasible for application in generation-3b batteries which are in the focus of the EU policy on establishing LIB manufacturing capacity in Europe in near terms.

Timeline with milestones and deliverables

The project was completed in early 2019. The novel Carbon active material for Li Ion batteries was investigated for the morphological properties and the battery performance. The results of were published at Nano Energy 83 (2021) 105816. We have developed a prototype of Li-Ion Battery anode with Virtual Cathode Deposition technology. The anode was exhaustively tested for the battery performance in the coin cell configuration and demonstrated as feasible large area electrode for pouch cell manufacturing.

Project innovations

The anode manufacturing process allows deposition of active material directly on the standard battery separator, followed by the deposition of variety of metal (e.g., copper) current collectors. The process eliminates binder and current collector foil that enables twofold decrease in the anode weight and threefold decrease in the anode volume. The carbon active material demonstrated 900mAh/g long term retained capacity.

Partners

PLASMA APP

UNIVERSITY OF CAMBRIDGE

Johnson Matthey
Inspiring science, enhancing life

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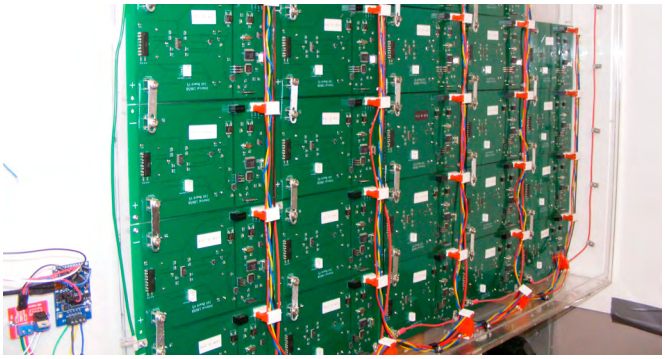
Novel lithium battery management and monitoring system for automotive

A project moving from successful laboratory trials towards road use.

Project costs

Total project costs: £325,984

Grant contribution: £228,188



Executive summary

This project continued a development pathway, previously part-funded by Innovate UK, to develop and test a wholly new and patented operational platform for lithium-ion battery management systems (BMS) in power applications. Initial laboratory tests of the Intercal BMS, funded with an EU grant in 2014 to 2015, were followed by a larger Innovate UK-funded project in 2016 to 2017 for testing the system on a full-scale replica of a civil airliner auxiliary power unit battery. The current project has equipped three road-going test vehicles with 72V, 120V and 360V powertrains for field trials. This is being supplemented with comparative laboratory testing and evaluation of a 360V test rig alongside a conventional modern electric vehicle BMS. Results to date suggest the test system permits effective use of full usable capacity. Testing continues.

Timeline with milestones and deliverables

The funded project ended in April 2019. Field trials and data recording continued through 2019 and 2020 and the hardware and software were further refined in the light of the field trials in the follow-on project "Assessment and Development of the novel "i-BMS" Battery Management System".

Project innovations

This is the first fully functional BMS to eliminate the need for automated cell balancing, relying instead on the very stable behaviour of lithium-ion cells. As well as dispensing with complex and fault-prone cell balancing circuitry, the Intercal BMS has demonstrated unprecedented effectiveness in the early detection of cell faults, including those leading to cell failure and thermal runaway. These innovations offer major potential benefits for automotive and other applications.

Partners

INDRA

INTERCAL
Battery Management Systems

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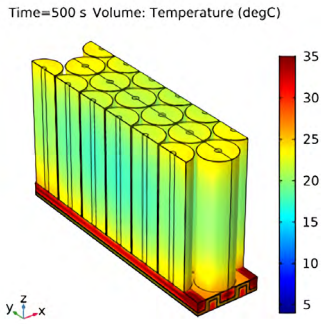
Novel self-regulating CHIP (Cooling or Heating Integrated Pipe) for BTMS

The major objective of this project is to improve the safety and efficiency of current EV batteries by the incorporation of smart self-regulating heating technology and optimised cooling

Project costs

Total project costs: £499,903

Grant contribution: £342,424



Executive summary

This feasibility study has demonstrated the utility of using Heat Trace's aluminium/polymer heating technology in EV BTMS. These inherently temperature-safe self-regulating heaters cannot overheat under their own power. Compared to traditional PTC, the direct application of these heaters to the cells enables significant enhancements in efficiency. In tests, the energy required to raise the module temperature from -30 to +20°C reduced by up to 71%, and the time required reduced by 25%.

This exceptional heating performance is integrated with extruded aluminium coolant channels, to enable the system to operate efficiently in heating, cooling or temperature maintenance modes. There is potential for the integrated thermal management system to form part of the structure of the module, further contributing to mass reduction.

Compared to current designs, the CHIP technology has the potential to give significant benefits in seven of the eight Faraday targets. The most important potential benefits are improved safety, reduced costs and reduced mass of the modules and pack.

Timeline with milestones and deliverables

Project Start: 01/09/2019 Project Finish: 26/02/2021

- Heating and cooling specifications confirmed, design evaluations with CFD modelling - January 2020
- Optimal design selected and prototype manufacturing feasibility established – March 2020
- Development and production of prototype heater elements complete - November 2020
- Optimisation of laser welding process for electrical and fluid connections complete - November 2020
- Integration of prototype unit for testing – November 2020
- Scale-up feasibility established – January 2021
- Functional testing completed and data analysed – February 2021

Project innovations

The innovative features include:

- The CHIP module can be operated either as a heating module or a cooling module.
- The inherently temperature-safe polymeric heater improves safety and minimises the variation of cell temperatures.
- The direct application of heat to the cells enables significant energy and time or power savings.
- The aluminium-based design enables flexible geometry and mass reduction.
- Due to the direct application of heat to the cells, the thermal efficiency and heating rate is substantially improved.
- The use of high-precision laser welding for fluidic and electrical interfaces results in high reliability
- The CHIP module can be customised to any cell type or battery pack configuration

Partners

HEAT TRACE™ SETTING THE STANDARDS LEADING THE WAY

Nobel Automotive

WMG THE UNIVERSITY OF WARWICK

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Power-Up (Power cell Upscaling project)

The project will establish the feasibility of manufacturing AMTE's Ultra Power (UP) cells in the UK, in volume. The UP cell has high energy density for a power cell, with excellent heat rejection capability using tab cooling, preventing cell overheating during continuous aggressive cycling or fast charging, and extending lifetime, in an automotive format that is ready for production by UKBIC by the end of the project.

Project costs

Total project costs: £999,873

Grant contribution: £849,880



Executive summary

The Ultra Power cell was initially designed within the UK - Niche Vehicle Battery Cell Supply Chain project to a custom format based on the requirements of a group of special vehicle manufacturers. UKBIC has the ambition to provide power pouch cell technology for its customer base and has commissioned its facility with a VDA-standard 300x100x10 (mm) pouch cell based on electrodes designed for high energy density. The Electrochemical Science & Engineering group of Imperial College has a long-term strategy to change the way that the lithium-ion battery industry designs their cells, in particular, to take a holistic approach to performance and particularly the interaction between the cells and the thermal management at the system level. They have already demonstrated the concept through a Faraday Institution funded sprint project, TOPBAT. Working together, the partnership will help create a new generation of best-in-class high energy / high power cell with unique selling points that will help create a thriving and profitable UK cell manufacturing industry.

Timeline with milestones and deliverables

Project start date:	01/08/2021	Results electrochemical study:	31/03/2022
Electrode developed:	30/11/2021	Technology Scaled up:	31/05/2022
Benchmark cells produced:	30/11/2021	UK BIC Manufacture cells:	31/07/2022
Cell Design Finalised:	31/03/2022	Project completion:	31/07/2022

Project innovations

Typical power pouch cells are designed for surface cooling, which has a dramatic impact on useable energy and lifetime. Previously published research on a 20Ah pouch power cell saw a 12% reduction in energy density at 3C for surface cooling compared to tab cooling. Other previous work has demonstrated that when tab cooling can be used, it can significantly extend cell lifetime. Models and knowledge learnt from previous projects will be used to optimise the power cell design for tab cooling and optimise the trade-off between energy, power, heat generation and rejection.

Partners

amte power

Imperial College London

UK BATTERY INDUSTRIALISATION CENTRE

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PreLIBS: Preliminary Feasibility Study of Lithium-Ion Battery Safety

Project costs

Total project costs: £503, 304

Grant contribution: £404, 996



Executive summary

PreLIBS' aims were to develop an understanding of key areas linked to thermal runaway:

- Thermal runaway /resultant thermal propagation of the typical energy release magnitude and direction
- Standardised test methods around which mitigation strategies can be designed, and products developed
- Guidance on navigating and evidence to inform the standards
- Analysis of sensing and detection methods
- Evaluation of material effects in thermal runaway
- Cell and cell group data to inform modelling and material design
- The project findings have been an invaluable input to the Faraday R3 project LIBRIS

Timeline with milestones and deliverables

Project now completed (1st September 2018-30th May 2019)

- Literature Review
- Single Cell Failure Characteristics
- Mitigation Strategies
- Computational Modelling

Project innovations

- Understanding of existing & Emerging Standards
- Thermal runaway detection
- Early sensing and mitigation for improved public safety
- Developed a basis for future research priorities – Project LIBRIS
- Several publications are now available-see us at CENEX 2021 for details

Partners

JAGUAR

LAND ROVER

POTENZA

3M

BESPOKE RESEARCH AND CONSULTANCY FROM HSE

Lifeline Fire & Safety Systems Ltd

WMG THE UNIVERSITY OF WARWICK

Warwick FIRE

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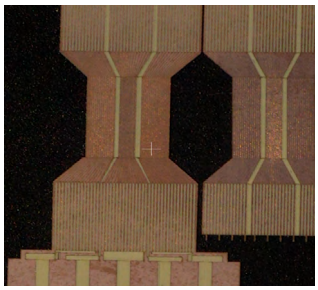
Printed sensors for EV battery current density imaging

This project developed a system using printed sensors to measure the current in every cell of an existing battery module and feed that information to the battery management system (BMS)

Project costs

Total project costs: £499,606

Grant contribution: £393,015



Executive summary

This project builds on existing work done by CDO2 and the University of Sussex to demonstrate the feasibility of using current density imaging to monitor EV battery modules. This consortium adds additional expertise from the University of Strathclyde and Peacock Technology to design sensors capable of being manufactured using printable electronics by CPI to reduce the size, weight, power and cost of the technology.

The printed sensors were incorporated into the busbar of the Aceleron battery pack and data analysis by CDO2 to produce a calculation of the current in each cell was sent over a CAN bus interface to the Brill Power battery management system, in order to optimise cell performance.

The project demonstrated that individual cells discharge at different rates and co-exist with different states of charge, even when the voltages are held together in a parallel configuration.

The resulting battery pack demonstrator led to post-project development activities by CDO2 in the SmartBat project to produce a battery pack which integrates current sensors and cell control into the busbar, which was funded by the Office of Zero Emission Vehicles (OZEV).

Timeline with milestones and deliverables

Project duration: June 2019 – November 2020

Deliverables:

- Printed sensor samples for characterisation
- Battery modules using existing current density imaging sensors
- Battery modules using printed sensors
- Integrated BMS and printed sensor battery pack

Project innovations

- Novel manufacture of printed sensors for current density imaging
- Real-time reporting of current load for each cell in a battery pack
- Detection of defective cells in a battery module
- Degradation reports of cells in a battery module
- Integration into existing BMS capable of optimising use of degraded cells
- Integration into maintainable battery pack suitable for replacing identified defective cells
- Complete battery pack demonstrator showcasing above innovations

Partners

cdo2 cpi ACELERON BrillPower UNIVERSITY OF SUSSEX peacock technology ltd University of Strathclyde Glasgow

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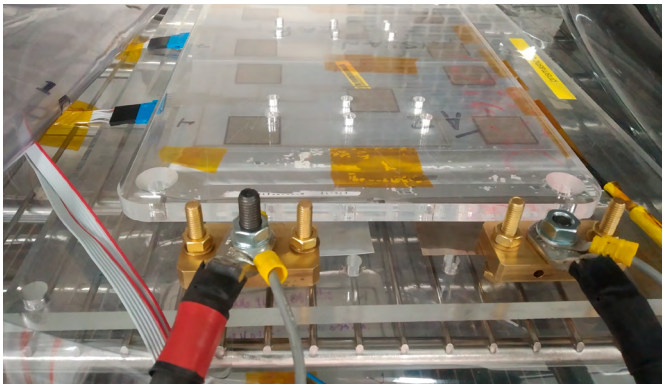
Printed temperature sensors for use in battery monitoring systems working within the cells/batteries

Innovative printed, thin and conformable temperature sensing arrays which offer a unique approach to measuring cell temperatures directly have been developed to monitor EV battery systems.

Project costs

Total project costs: £235,515

Grant contribution: £199,854



Executive summary

In this feasibility study, printed thin film temperature sensor arrays were developed to monitor EV battery systems, and their potential for manufacture at scale by R2R printing was demonstrated. Arrays of temperature sensors were distributed in a stack of thick polymer plates containing embedded printed heating arrays to mimic local heating in a module of pouch cells, and the location of hot spots. This arrangement was used successfully to demonstrate 3D mapping of the temperature profile. External partners, WMG Warwick University and Liverpool University, performed independent tests of the sensors with live cells. These results confirmed the large-scale temperature increase over time, and the smaller changes that occur during the charging cycle. Subsequent to the completion of the project: in late 2019, printed sensors were successfully tested in a HV battery pack, constructed for a separate project, with a Midlands OEM; and the development work is continuing within a large consortium in a Horizon 2020 project, which started in January 2020.

Timeline with milestones and deliverables

The project ran for nine months, achieving all its declared milestones, including:

- Sheet and R2R production of sensor arrays.
- Demonstration of the principles of tomographic reconstruction of temperature profiles.
- Independent confirmation of how the charge and discharge of batteries causes temperature variations during rapid cycling.
- Independent testing of the sensors in a battery and cell environment
- Use of the temperature sensors with live cells

Project innovations

- Successful scale up of printing arrays of sensors on a roll-to-roll machine, printing 150m metres of sensor arrays on a 30cmweb.
- Demonstration of tomographic reconstruction of temperature profiles, now being developed for real-time implementation.
- Interest from automotive parts manufacturers for the technology, and its inclusion in a battery pack being developed in a H2020 project.

Partners

cpi

PST SENSORS

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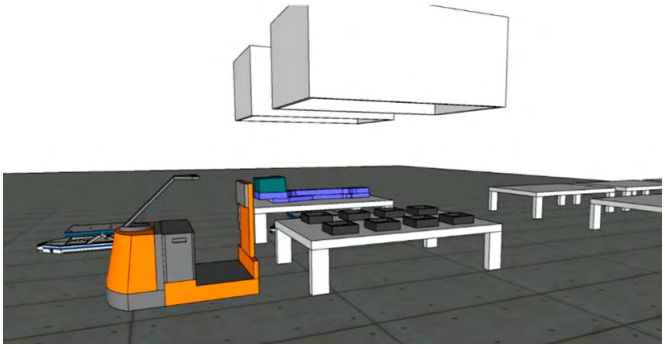
Project Detain

Project DETAIN brings together the expertise of Unipart Logistics, Aspire Engineering, HORIBA MIRA, and Instrumentel, to develop an 'intelligent' high voltage battery storage solution to detect and contain thermal runaway: DETAIN.

Project costs

Total project costs: £456,789

Grant contribution: £247,396



Executive summary

The feasibility study of Project DETAIN designed an 'intelligent' lithium-ion battery storage facility, one that can detect thermal runaway and automate a containment solution to limit damage to a single product and reduce associated risks. Combining the expertise of the consortium, it formed a holistic view of what an intelligent and saleable storage facility requires and identified innovation gaps needed to create it including thermal runaway detection technologies, fire suppression and automated solutions for battery handling.

Timeline with milestones and deliverables

To detect thermal runaway there are three areas of focus:

- BMS thermal runaway detection algorithms for next generation hardware,
- Externally mounted (on battery) thermal runaway detection systems, and
- Distributed sensor networks for battery storage facilities.

Project DETAIN's deliverables:

- Completed a holistic analysis of the state-of-the-art processes, products and technology to detect and contain thermal runaway,
- Predicted how a connected, intelligent storage solution could function in line with safety and insurance requirements,
- Produced a gap analysis to identify further developments required,
- Created a design and plan for the PoC facility,
- Specified the testing facilities required to measure the efficacy of the PoC.

Project innovations

- Thermal runaway detection technologies to identify solutions in the short- to long-term: infrastructure-based sensor networks, sensitive externally mounted battery monitoring equipment, and BMS control strategies combining the electrical and chemical analysis techniques.
- Thermal runaway containment technologies, automation and fire suppression individually and in combination. The requirements for an effective, accepted and scalable solution design.
- The effects of battery fire contamination and a specification for a battery integrity and thermal runaway test facility (to ensure that the solutions designed can be tested and confirmed to reduce risks).

Partners

A HORIBA COMPANY MIRA

ASPIRE ENGINEERING

instrumentel MEASURING SUCCESS

UNIPART LOGISTICS Experience. Innovation. Advantage.

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Project: R2LiB

The challenge is to identify and prove an economically viable process for the recycling and reclamation of materials from end-of-life LiBs

Project costs

Total project costs: £2,200,000

Grant contribution: £1,600,000



Executive summary

Predicted sales of ULEVs in the UK will generate large volumes of end-of-life lithium batteries (LIB). There is no current recycling supply chain for LIB in the UK; currently, 80% of the metals that are separated in the UK are shipped to offshore smelters.

R2LiB is the first example of a remanufactured cathode in the UK from recycled transition metals, showing comparable performance to non-recycled commercially available materials. Life Cycle Analysis indicated global warming potential comparable to industry standard, but energy requirements reduced by 70-90%

Timeline with milestones and deliverables

- A multi-axis laser processing machine has been developed and built in an enclosure allowing testing of laser cutting of battery cells in an inert CO2 environment
- Four green solvents have been identified and proven to show good ability to dissolve PVDF; all have low hazards and are exclusively bio-derived, or can be obtained bio-derived at reasonable cost.
- Methodology for physical separation of components has been developed and demonstrated that 100% of the anode and cathode can be recovered.
- Chemical recovery of the black mass has been proven using solvent extraction, with reduced losses compared to classical methods. The resulting mixed metal solution meets current market specifications and can be converted to NMC materials that perform comparably to those made from virgin materials.
- An industrial pilot scale Li-ion battery recycling facility has been established with scale up to larger quantities planned beyond the project.

Partners

Industrial Partners

RSB RSBruce

ICoNiChem

circa

TFP HYDROGEN PRODUCTS LTD

M-SOLV

Research Partners

WMG THE UNIVERSITY OF WARWICK

UNIVERSITY OF BIRMINGHAM

UNIVERSITY of York

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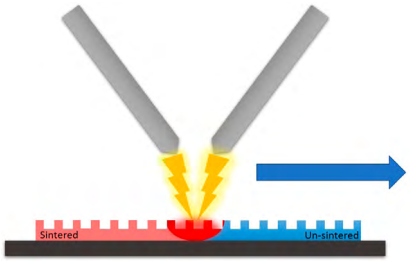
Rapid manufacture of solid-state battery structures by additive manufacturing and Flash sintering

Assessing the possibility of combining two novel and highly efficient technologies, Additive Manufacturing and Contactless Field Enhanced Sintering, to process solid electrolytes for both Li-ion and Na-ion batteries

Project costs

Total project costs: £313,383

Grant contribution: £240,263



Executive summary

With the UK government's mandate to achieve net-zero carbon emissions by 2050, together with the ban on sales of new petrol and diesel cars by 2030, there is no doubt that the battery market is going to experience rapid growth over the next 10 years. Solid-state batteries are a key technology to augment and replace current lithium-ion technology due to their increased safety and potential to achieve much greater energy/power densities.

During this project, the project partners will assess two complementary technologies, Additive Manufacturing (AM) and contactless Field Enhanced Sintering (c-Flash) to manufacture thin, textured/designed films of solid electrolytes for Li-ion and Na-ion batteries. This new method of manufacturing addresses three of the main technological challenges with solid-state batteries: thin film processing, increasing electrolyte/electrode interfacial area, and minimising ion volatilisation.

This project will simultaneously target benefits in resource and energy efficiency, assessing the possibility of combining two novel and highly efficient technologies to exploit the strengths of both systems.

Timeline with milestones and deliverables

The feasibility study will run between August 2021 and July 2022 and demonstrate the below key parameters:

- Additive Manufacturing of thin, textured/designed films of solid electrolytes for Li-ion and Na-ion batteries.
- Contactless Field Enhanced Sintering (c-Flash) of manufactured electrolytes
- Comparison of various properties including composition, microstructure, ionic and electrical conductivity of manufactured films densified via c-flash and conventional flash sintering methods
- Design and development of commercial equipment

Project innovations

- A breakthrough from this project could create a unique technology for exploitation in the UK, allowing the UK to become a leader in low-energy and low-waste manufacturing methods.
- Solid-state batteries made by this route could take significant shares of the EV battery market and adoption by the UK battery supply chain would reinforce the UK's ability to grow and compete in this sector.
- In addition, the project partners will be developing the processes and pilot-scale manufacturing in parallel in order to expedite technology exploitation

Partners

Loughborough University

LUCIDEON
Materials Development and Commercialization

KW SPECIAL PROJECTS LTD

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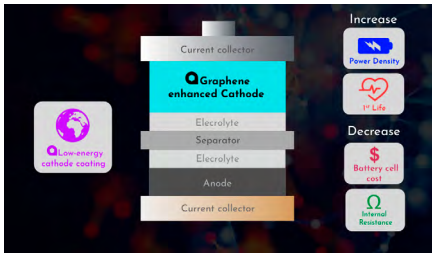
Realising the UK Value-chain in Graphene Composite Battery Materials (GRAVITY)

The scale-up of graphene enhanced cathode materials and a low-energy electrode coating technique for high volume Li-ion battery production.

Project costs

Total project costs: £755,739

Grant contribution: £596,478



Executive summary

Battery cost and performance are becoming the limiting factors in the global shift towards electrification of transport. In our previous Faraday Challenge project, GRAMOX, we showcased graphene's potential as an enabler of high-performance batteries. We have also begun development of an improved coating technique to produce battery electrodes using significantly less energy and reducing cost. This project aims to validate the combined technologies of graphene and improved coating techniques as enablers of low-cost, high-performance batteries that are desperately needed for the electric transport revolution.

Graphene is currently under-utilised as a potent component in modern cathodes. Anaphite's proprietary process to produce graphene-composite materials will be harnessed in this project to produce industrially relevant pouch cells optimised for the BEV market.

The cathode coating steps in Li-ion battery production contributes a surprisingly large portion of the battery cost. Anaphite's new coating techniques will be showcased alongside the graphene composites in pouch cell tests. A pilot-scale development reactor will also be built for process validation. Additionally, it will enable creation of accurate cost models to motivate further scale-up and development. Overall, this project positions Anaphite to showcase the competitive benefits of its graphene enhanced cathodes and low-energy coating technologies.

Timeline with milestones and deliverables

Project start
August 2021

Graphene supply chain analysis at **Anaphite**

Graphene enhanced cathode optimisation at **Anaphite**

Pouch cell development at **WMG**

Pilot scale development reactor built for process validation at **Anaphite**

Cost-performance optimisation of pouch cells with development reactor at **Anaphite** and **WMG**

Roll-to-roll energy coating trials at **Anaphite**

Project end
July 2022

Project innovations

- Optimisation of improved cathodes utilising graphene
- Optimisation of cathodes made with an improved low-energy coating process
- Showcasing of a new coating technology with industrially relevant (roll-to-roll) coating technology
- Justification of scalability & industrial relevance with a graphene supply chain analysis
- Pilot scale reactor built.

Partners

Anaphite

WMG
THE UNIVERSITY OF WARWICK

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SABRE- Silicon Anode Battery for Rapid Electrification

The SABRE project will develop battery cells with higher energy density, combining advanced Li-ion cell design and novel silicon anode material in response to the demand for increased EV driving range.

Project costs

Total project costs: £1,492,774

Grant contribution: £1,135,131



Executive summary

The SABRE project will deliver a combination of advanced Li-ion cell design and novel silicon anode material to achieve higher energy density that support the demand for increased EV driving range. Silicon, with its greater affinity for lithium than graphite, can enable increased cell energy density. Nexeon's silicon material design is highly innovative, achieving a combination of high lithium capacity with low volume change for long cycle life. Britishvolt will apply innovate computer-aided cell design and simulation to accelerate the integration of silicon into the anode design, and with cell design optimisation can also accommodate the increasing demand for fast charging. These tasks will be supported by UCL's Electrochemical Innovation Lab. The project will also utilise the cell assembly capabilities at UKBIC for the fabrication of high energy density 21700 cells to test and validate the new cell design. SABRE establishes Britishvolt and Nexeon as key elements of a dynamic, expanding UK-based automotive battery supply chain capable to support both the growing domestic demand (predicted 100 GWh by 2035) and with the opportunity for exporting both high performance battery cells and advanced anode materials to overseas OEMs and cell manufacturers respectively.

Timeline with milestones and deliverables

12-month project, with four key deliverables:

- Advanced silicon anode material
- Material and electrode characterisation
- High-capacity anode electrode and cell designs
- 21700 cell assembly and performance validation

Project innovations

The SABRE project will utilise Nexeon's novel silicon anode materials and processing to deliver low-expansion and high-capacity anodes to increase cell energy density and cycle life. Britishvolt will apply innovation in smart and highly optimised cell design, leveraging modelling toolchains, to enable demonstration of a high energy density 21700 cell with Nexeon's silicon anode. UCL's expertise in micro-particle level analysis will be applied to silicon materials, anodes and cells enabling the optimum silicon materials and electrode design to be implemented.

Partners

nexeon

UCL

BRITISHVOLT

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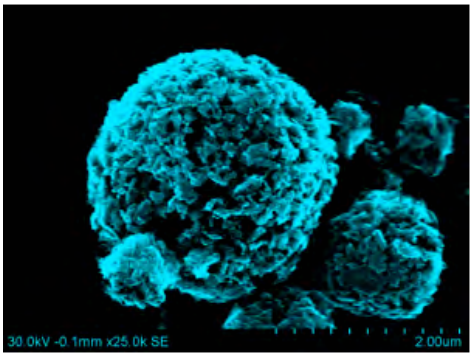
SAFEVOLT Safe High Voltage EV battery materials

Feasibility project for simultaneously improving safety and energy density of EV batteries through material innovations.

Project costs

Total project costs: £528,887

Grant contribution: £421,207



Executive summary

The current EV batteries technologies are facing challenges in terms of safety while efficiently operating over 4V. Within the SAFEVOLT project, Johnson Matthey, Talga, University of Cambridge and TWI Ltd came together to evaluate the feasibility of improving energy density of batteries by focussing simultaneously on material innovations on anode and cathode, and addressing safety by evaluating alternative electrolyte materials.

Timeline with milestones and deliverables

This 12-month feasibility project was carried out from March 2018 to February 2019

Milestones/deliverables of the project were:

M6 coin cell testing for novel anode and cathode, electrolyte selection through NMR stability analysis

M10 high energy density anode/cathode synthesis

M11 material selection for prototype based on performance

M12 Full cell prototype manufacture, testing and thermal stability evaluation.

Project innovations

- The main project innovations related to development and testing of anode, cathode and ionic liquid electrolyte materials for improved safety and higher energy density.
- Novel manufacturing methods were successfully demonstrated for both anode and cathode materials. Suitable electrolytes were proposed based on lithium diffusion and thermal stability testing carried out for a range of ionic liquid electrolytes.

Partners

talga

TWI

JM Johnson Matthey
Inspiring science, enhancing life

UNIVERSITY OF CAMBRIDGE

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SAMBA: Smart automotive managed battery algorithms

Using artificial intelligent algorithms means to schedule and control electric vehicle charging. Ensuring maximum protection for the battery while utilising the most environmentally-friendly electricity sources.

Project costs

Total project costs: £166,724

Grant contribution: £116,707



Executive summary

The SAMBA innovation has tied together the requirement to protect the life of the battery, within an electric vehicle, while optimising the sources of electricity, either cost driven, charge time driven or cost driven.

The smart AI algorithm learns a combination of vehicle and driver movements history from a connection with the vehicle, recording historical, charge amount (KWH), duration of connection to the charger, and odometer readings. This allows the AI algorithm to determine the expected requirement and duration of a charge. Once connected to a SAMBA charger, a charge plan is calculated to protect the battery as much a possible while delivering the excepted amount of charge, rather than charging to capacity.

The charge plan allows for the charge to be taken from multiple sources, including national grid, local generation (wind, solar) or from a locally, maintained battery.

Timeline with milestones and deliverables

The project ran between 1 August 2018 and 31 July 2019. Key deliverables include

- Cloud-based AI customer behaviour algorithm – predicting usage based on historical records
- Cloud-based charging algorithm – producing charge plans based on available knowledge
- Telemetry device for connecting EV to Android App
- SAMBA Charging Unit – complete with smart switching technology
- Android Application – for monitoring and control

Project innovations

The SAMBA project has produced deliverables that can be retrofitted to other existing dumb chargers, allowing these charges to connect to the cloud-based planning systems which, in turn, rely on the created AI demand prediction algorithms.

Using a purpose designed and built telemetry device to connect electric vehicles to an Android application which allows communication of vehicle history with the innovate AI algorithms.

Partners

mA
milliamp technologies

MIRALIS

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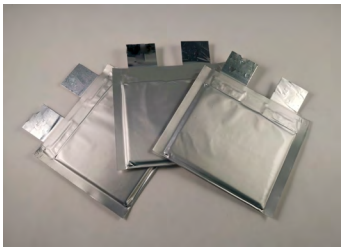
Scalable Ultra-Power ElectRic-vehicle Batteries (SUPErB)

Combining the power and cycle-life benefits of a supercapacitor with the energy benefits of a Li-ion cell to deliver ultra-fast charge and discharge capability.

Project costs

Total project costs: £1,875,174

Grant contribution: £1,390,435



Executive summary

One of the key challenges for electric vehicles is to meet peak power requirements. Existing high-peak-power devices, such as supercapacitors, suffer from low energy densities and the SUPErB project aimed to lift this limitation using advanced electrode materials and Li-ion battery engineering. The ultrahigh-power cells for electric vehicle batteries that this project has developed have very high peak power handling and fast-charge (full recharge in less than 3 minutes) capability. The SUPErB project has demonstrated, for the first time, a combined 7 kW.kg-1 and 88 Wh.kg-1 at the cell level. These cells will enable improved peak-power handling in EV batteries. Spin-off applications are numerous with the technology finding use in fast-charge stations and transport (motorsport, EVTOL), UPS and the military.

The project achieved its aims, at scale, using high-performance, complementary cathode and anode materials with scalable anode manufacturing processes developed at Echion Technologies Ltd for its proprietary anode materials, and high-power cell design and manufacture by QinetiQ. Optimised cell parameters and electrochemistry from the University of Birmingham contributed to extracting maximum performance, University College London developed next-gen nano-particulate cathode material and William Blythe assessed commercial scale manufacture of the electrode materials.

Timeline with milestones and deliverables

The following is a simplified list of key milestones that were achieved in order to deliver the programme:

- Benchmarking state-of-the-art high-power cells and initial formation studies
- Cathode materials development, analysis & down selection
- Development of new anode materials
- Development of electrodes, inks and test cells using new materials
- Generate comprehensive test data on all new materials to support cell design and exploitation plan
- Continued formation studies on test cells
- kg scale-up of anode materials
- Manufacturability and scale-up assessment of high-throughput materials and processes
- Build, test and demonstration of 3Ah ultra-high-power cells

Project innovations

The following key innovations were delivered by the SUPErB project:

- Demonstration of an ultra-high-power cell with 88 Wh/kg and 202 Wh/L, approximately 45% and 100% improvement, respectively on comparable commercial cells
- Demonstration of a cell that can be fully recharged in less than 3 minutes
- Development of the SUPERB Ultra-high-power cell and associated Intellectual Property and Know-How
- Publications of three papers in top journals, related to new research results in cathode material design and production
- Intellectual Property from research work on new material compositions and processes

Partners

UCL

University of Birmingham

Echion Technologies

williamblythe
Excellence in chemistry
A Synthomer Group Company synthomer

QINETIQ

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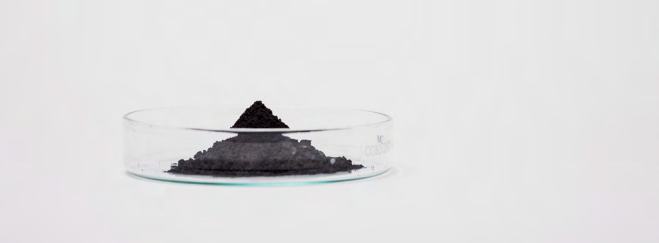
Scale-Up: Supply Chain Accelerator for Li-ion Electrode materials in UK

Develop anode and cathode materials and scale-up their production in the UK for next generation EV Lithium-Ion Batteries

Project costs

Total project costs: £1,223,380

Grant contribution: £956,423



Executive summary

The goal of this project was to create and accelerate the supply chain development in the UK for advanced electrode materials that are needed to produce next generation EV Lithium-Ion batteries. Talga Technologies Ltd and PV3 Technologies Ltd (now TFP Hydrogen Products) developed and scaled up methods to cost-effectively produce high energy density anode and cathode materials, respectively. WMG and University of Birmingham supported the industrial partners with a study of the materials' electrochemical properties, coating/cell manufacturing methods as well as pilot scale manufacturing and long-term testing.

Timeline with milestones and deliverables

The key deliverable was to establish battery materials manufacturing and supply chain for battery materials in the UK. The main milestones were:

Q4 (March 2019):

- Anode development: synthesis route for high energy density graphite;
- Cathode development: synthesis route for high-nickel NMCs.

Q5 (June 2019)

- Electrochemical testing of high-nickel NMC // graphite in small coin cells

Q7 (September 2019)

- Anode and cathode material scaleup
- Pouch cell manufacture for material, cell and development validation

Q8 (February 2020, extended to August 2020)

- Material validation in long-term testing completed

Project innovations

The main innovation challenge addressed in the project was the manufacturability of the next generation electrode materials at scale.

Significant advances were made for next generation electrode material supply. A novel production technology was developed and scaled up for high energy density anode, and low-cost synthesis routes were demonstrated for high capacity NMC cathode materials. Electrode manufacturing methods were successfully demonstrated for the anode and cathode materials.

The availability of high energy capacity materials is expected to have a major impact on the range of battery-EVs and the success of the project will ensure the UK has a role in the supply chain.

Partners

University of Birmingham

WMG, The University of Warwick

talga

TFP Hydrogen Products Ltd

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Scaling-up the production of Graphene-Metal Oxide Composites as Li-ion Battery Materials (GRAMOX)

The development and pilot scale-up of graphene-metal oxide (GMO) materials as next generation Li-ion battery electrode materials.

Project costs

Total project costs: £499,683

Grant contribution: £394,664



Executive summary

Existing cathode electrode materials suffer from poor electrical conductivity, which limit power and energy density. These issues can be addressed by incorporating graphene into these materials, due to its extremely high aspect ratio, electrical conductivity, thermal conductivity, and excellent flexibility.

This project explored multiple graphene-metal oxide composites already demonstrated as promising electrode materials. With the Warwick Manufacturing Group (WMG), we carried out extensive analysis of electrochemical properties, demonstrating technical feasibility of GMO composites formed with Anaphite's process. We cost-effectively scaled-up Anaphite's process via the development of a pre-pilot process validation system. With WMG, we also validated the quality of materials produced with the scaled-up process. NPL provided excellent materials characterisation of graphene materials and also the finished electrodes, substantiating valuable scientific conclusions. During the project, we also discovered a novel low-energy electrode coating process which offers cost savings over conventional techniques. We found that the process offers comparable electrochemical performance to standard techniques.

These findings have positioned us well to partner with battery manufacturers to enable development of next-generation electrodes.

Timeline with milestones and deliverables

Project start
August 2019

Multiple graphene enhanced electrode materials produced at lab-scale via **Anaphite's** process

Lab-scale electrode materials cell performance analysed by **WMG**

Anaphite develop scaled up process valiation system

Anaphite screen materials in coin cells before long-term testing at **WMG**

Lab-scale electrode materials characterised by **NPL**

New low energy coating process discovered at **Anaphite**

Project end
January 2021

Project innovations

Anaphite has developed a commercially feasible process to form stable graphene-metal oxide composites. The process produces these composites orders of magnitude cheaper than the current state-of-the-art, while improving graphene quality and intrinsic material characteristics.

Project innovations include:

- Discovery of promising new graphene-enhanced anode and cathode materials.
- Scale-up of materials produced via Anaphite's process – to enable commercial exploitation.
- Comprehensive graphene quality validation by the National Physical Laboratory (NPL).
- New electrode formulation, production and testing by the Warwick Manufacturing Group (WMG).
- Working toward the production of a drop-in graphene enhanced electrode material for battery manufacturers.

Partners

WMG
THE UNIVERSITY OF WARWICK

Anaphite

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Second life lithium-ion: recovery, reconfiguration and re-use (Li.2)

Project costs

Total project costs: £421,248

Grant contribution: £305,716

Executive summary

Lithium batteries are central to a number of low-carbon technologies such as electric vehicles, consumer electronics, and stationary storage applications, with their load shifting capabilities poised to play a critical role in the dynamic and integrated energy systems of the future. With electric vehicles now generating volume sales (\>1.26m in circulation globally), and the earliest models now approaching end of life, opportunities surrounding secondary applications now merit greater investigation. With high recycling costs, and batteries still retaining 70% capacity post transport application, there are strong economic and environmental reasons to find secondary applications for used lithium batteries.

The 18-month Li.2 project, led by UK SME Powervault and supported by consortium partner Loughborough University, is investigating the processes involved in recovery and reconfiguration of second-life batteries, how these can be scaled to realise maximum efficiencies, and deepen understanding of second-life cells to evaluate potential for new service offerings, new product offerings, and build up remanufacturing expertise on a key commodity.

Timeline with milestones and deliverables

Primary objectives:

- validate the technical feasibility of creating a cell agnostic remanufacturing process, and determine how best to scale this for domestic-storage production so as to maximise system economics;
- deepen understanding of second-life-battery characteristics, and determine 'optimal' secondary application;
- ascertain/quantify surrounding commercial opportunities (collection; sorting; cell maintenance).
- Data gathered on technical performance and economics will be critical for validating the remanufacturing opportunity and guiding post-project exploitation

Project innovations

- New re-manufacturing process with cell agnostic process
- Sweat testing of different secondary applications to understand behaviour.
- Deepened understanding of batteries to guide business strategy

Partners

Loughborough University

POWERVAULT

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Securing domestic lithium supply chain for UK (Li4UK)

Feasibility Study to examine potential domestic lithium resources; viability of extracting the resources and potential location of a domestic lithium conversion plant to create a critical new industry for Britain.

Project costs

Total project costs: £475,744

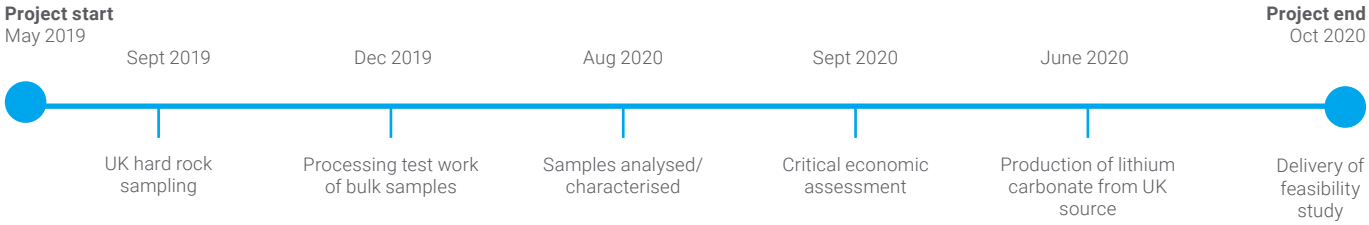
Grant contribution: £358,566



Executive summary

This project aimed to assess the feasibility of extracting lithium from domestic resources; examining the case for locating a lithium conversion plant within the UK; and engaging with end users to determine the optimal configuration of a suitable raw material supply chain. An exploration campaign across England, Scotland, Wales and Northern Ireland showed that several locations could host favourable deposits capable of providing raw lithium material for upgrading. Assay results demonstrated that the highest lithium grades are found in Southwest (Cornwall) and Aberdeenshire. Bulk samples from Cornwall and Scotland were successfully taken and upgraded from a raw material to a lithium compound at bench scale in laboratories in Cornwall. Lifecycle and economic assessments have shown that the most direct route to produce a low-carbon lithium compound for the clean energy transition will come from geothermal style deposits that utilise DLE (direct lithium extraction) and co-energy production technology. The second possibility is to extract lithium from a micaceous source, using lower roasting temperatures than other hard rock deposits and unconventional processing techniques and to thus produce a lithium product. It is projected that utilising both these styles of resources will be required to begin to fulfil the 2030 guidelines the government has set for the electrification of vehicle manufacture within the UK. It is now crucial that such a domestic industry is established given the "Rules of Origin" that come into place over the next five years.

Timeline with milestones and deliverables



Project innovations

- Comprehensive assessment of UK Li potential, including unconventional lithium sources
- Process flow sheet development for mineral processing and conversion routes for unconventional lithium resources, especially those containing lithium mica.
- Production of a UK-sourced lithium carbonate at bench scale

Partners

wardell armstrong

NATURAL HISTORY MUSEUM

Cornish Lithium

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Silicon Product Improvement through Coating Enhancement (SPICE)

Improved Li-ion cell performance through coating of silicon anode material

Project costs

Total project costs: £3,300,000

Grant contribution: £2,400,000



Executive summary

The SPICE project is developing a novel coating technique to improve the surface morphology of silicon used in the anode of a Li-ion battery. This will lead to improved conductivity of the anode material for faster charge rates, and sustained capacity of the battery during charge / discharge cycles. In addition to improved battery cell performance, this work will extend the system compatibility of silicon anode materials, allowing their use with lower-cost electrolyte formulations and hence lower overall battery cell costs.

The project is led by Nexeon Ltd, working with UK-based partners Phoenix Scientific Industries (PSI), AGM Batteries and Oxford University's Department of Materials.

Nexeon's battery materials expertise will be combined with PSI's experience in producing systems for coating powders. AGM will validate the performance of prototype cells incorporating Nexeon's coated silicon anode powder, and provide one of its subsequent routes to market. Oxford University's Department of Materials will provide critical feedback on the coating process outputs and tune the CVD process design parameters.

Importantly, SPICE will further strengthen the case for adoption of silicon anode technology by OEMs and battery makers globally.

Timeline with milestones and deliverables

24-month project, with three stages of scale-up:

1. Optimisation of process chemistry at lab and pilot scale
2. Design, installation and commissioning of a prototype reactor with a semi-continuous process
3. Mass production design for a fully automated and continuous process

Project innovations

Innovation is focused in three main areas:

- development of a process to produce a thin, uniform, well-bonded coating layer on an irregular silicon-based anode material;
- development of a high-yield scalable process that can operate continuously at full production volumes, without the drawbacks of current solutions in the industry;
- use of OU Department of Materials high-resolution electron microscopes, X-ray diffraction etc. to provide micro-level analysis of a cell during electrochemical cycling, extending the boundaries of UK electrochemistry knowledge.

Partners

amte power

UNIVERSITY OF OXFORD

nexeon

Phoenix Scientific Industries Ltd
Advanced Process Solutions

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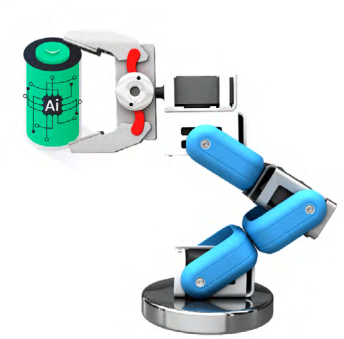
Web: www.nexeon.co.uk

Smart Three-dimensional ELectrode Lithium-ion batteries with Automated Robotics (STELLAR) for Battery Scale-up

Project costs

Total project costs: £563,000

Grant contribution: £449,000



Executive summary

With the UK's aim to ban combustion-engines by 2030, achieve carbon neutrality by 2050 and maintain global competitiveness in an EV market to reach $68bn in 2022; the UK urgently needs innovative solutions to meet these targets.

Project Stellar will improve the performance of EV batteries by bringing together the expertise of competitiveness of the UK battery supply chain. Key objectives include new verticals in cell manufacture through improvements to the manufacturing efficiency, performance and environmental profile of cells optimised for the automotive market. These will be achieved through improvements in novel current collectors designed by the adoption of Addionics Artificial Intelligence (AI) and the formulation of customised electrodes in lithium-ion batteries. New verticals will help reduce time for scaling cell production resulting in lower cost for manufacturing and cost of ownership for the end-user.

The partners are uniquely well placed to deliver the project. Addionics technology for 3D current collector fabrication that has shown significant battery performance improvements. AI algorithms and modelling will be used to help design 3D current collector geometries to address the thermal, energy density and mechanical issues that plague state-of-the-art batteries. We will demonstrate significant improvement of batteries in charging, thermal loads, energy density, mechanical loads and lifetime – this is also applicable to solid-state batteries.

This enables integration into the cell manufacturing process through tailoring batteries for specific type of vehicles: fast charging times, increased energy density and power density can then all be engineered before fabrication. CPI will enable vertical integration of successful current collector designs and ink formulations for commercial applications using state-of-the-art Automated Robots.

Project innovations

Current collectors (CC) are critical to batteries, remained unchanged for 30 years and development overlooked. The UK lacks CC adequate CC metal fabrication for cells and new innovations will be highly significant for emerging battery technology. The planar configurations limit areal capacity (<6mAh/cm2). Higher energy requires greater areal capacity that is easily achievable through 3D electrode(3DE) collectors. Addionics has successfully developed patent-protected processes and technology develop 3DE. The novelty lies in utilisation of scalable electrochemical processes combined with Artificial Intelligence & novel coatings through automation. Issues of life-cycle, charging, capacity, and thermal management will be addressed while enabling vertical integration into manufacturing facilities with minimum disruption.

Partners

cpi

ADDIONICS

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Sodium-ion batteries for automotive power applications

Development and demonstration of low-cost sodium-ion (Na-ion) technology for 12 V SLI batteries, focusing on the optimisation of rate capability and temperature range.

Project costs

Total project costs: £2,032,490

Grant contribution: £1,506,223



Executive summary

Na-ion batteries are similar to lithium-ion (Li-ion) batteries, but with advantages in terms of cost, safety and sustainability. The target application for this project was 12 V SLI batteries, which typically use lead-acid technology, due to its low-cost, high-power capability and wide temperature range. In order to meet these demanding requirements, the power density and operational temperature range were maximised, while maintaining Na-ion's sustainability and cost advantages. Na-ion batteries have been proven to provide benefits over lead-acid, including weight, volume and sustainability. Their many similarities to Li-ion technology mean that existing infrastructure can be used for their manufacture. Unlike Li-ion batteries, however, Na-ion batteries use more sustainable raw materials, without the need for cobalt, lithium or copper, resulting in a cost reduction of 30 % in terms of $/kWh. In addition, unlike Li-ion technology, the ability to deep discharge Na-ion batteries to 0 V will allow safer shipping of these batteries. The positive results achieved in this project will lead to the technology being further developed for a wider range of automotive applications.

Timeline with milestones and deliverables

The project ran from March 2018 to May 2021. The deliverables included the development of active materials for Na-ion batteries, along with the optimisation of electrodes and electrolytes for high-rate capability. High-power pouch and cylindrical cells were designed, built and tested to industry standards.

Project innovations

Improvements were made to electrode conductivity via developments in electrode formulation, and through the introduction of low-cost additives. New anode materials were developed, and sustainable water-based mixing technology was introduced. Novel electrolytes were also developed, widening the operational temperature range and enhancing cycle-life. Formation techniques were developed, which improve performance and reduce manufacturing costs.

High-precision electrodes were produced, using novel mixing techniques that reduce processing time and increase conductivity. High-quality 5 Ah pouch cells were manufactured and tested against automotive standards, the results of which provide confidence that this low-cost technology is suitable for a range of automotive applications

Partners

University of Birmingham

WMG, The University of Warwick

Jaguar Land Rover

faradion

talga

CRODA

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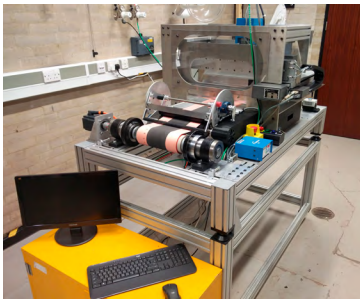
Spraycoat

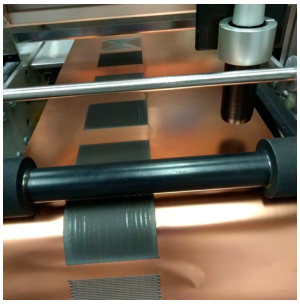
To develop innovative new electrode coating methods which have the potential to revolutionise both unit cost of a battery, its performance and its lifetime.

Project costs

Total project costs: £378,070

Grant contribution: £304,321





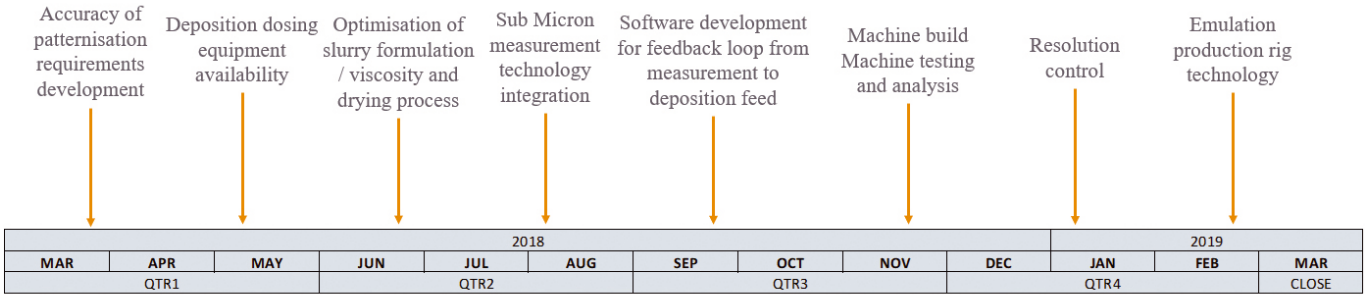
Executive summary

The Spraycoat project developed a novel digital deposition method for anode and cathode slurries, to ensure consistency, reproducibility and accuracy of material placement (patterning). Through the use of this new and innovative process, the Spraycoat project demonstrated an improvement in the reliability, homogeneity, consistency and performance of electrode coatings. The Spraycoat project also developed a closed loop measurement and feedback system to monitor the characteristics of the deposited layer and alter the parameters of the deposition to maintain consistency and accuracy.

The Spraycoat project researched, tested and carefully selected appropriate deposition technologies and measurement / process inspection equipment and integrated them into a near commercially ready Lab printer for the characterisation and testing of new anode and cathode inks and the potential benefits of anode and cathode patternisation.

The Spraycoat project optimised ink slurries for the deposition process(es) including the formulation, rheology, particle morphology and size and optimisation of slurry formulation /viscosity and drying process. The project tested the electrochemical performance of electrode coatings in ½ and full cells. (Coin and pouch).

Timeline with milestones and deliverables



Project innovations

- Digital placement of Anode and Cathode materials
- Closed loop feedback metrology
- On the fly parameter updates
- Anode and Cathode patternisation

Partners

WMG
THE UNIVERSITY OF WARWICK

KW SPECIAL PROJECTS LTD

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SUNRISE

Synthomer, UCL & Nexeon rapid improvement in the storage of energy Silicon anode and polymer binder for high energy density Li-ion battery

Project costs

Total project costs: £9,612,706

Grant contribution: £6,989,114



Executive summary

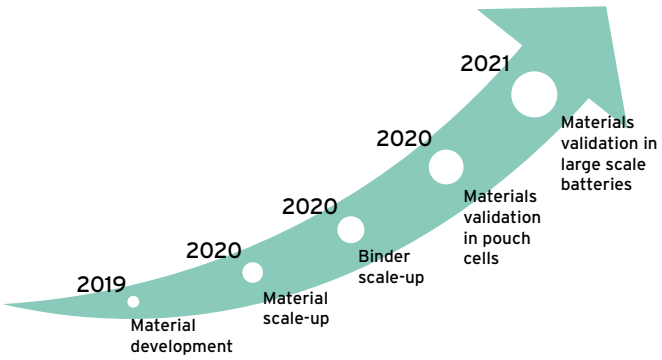
The SUNRISE project will deliver a novel silicon anode system for advanced lithium-ion batteries.

Silicon has a great affinity for lithium and can (in theory) deliver up to 9x the energy density of graphite on a gravimetric basis. Nexeon is developing a highly innovative anode active material, which, in conjunction with Synthomer's polymer binder technology, will turn this potential into reality. With support from UCL's Electrochemical Innovation Lab, this project will identify the optimum system to give the highest energy density, lowest first-cycle loss, lowest volume change and best capacity retention during use. The project will utilise new infrastructure in the UK Battery Industrialisation Centre to build batches of automotive Li-ion cells for testing in conjunction with material sampling direct to automotive OEMs and leading cell manufacturers

Timeline with milestones and deliverables

42-month project, 1st March 2018 – 31st August 2021

- Next generation silicon anode material and anode binder development **Q1 Y2**
- First phase of the material scaling up (silicon anode material and anode binder) **Q4 Y2**
- Validation in pouch and 18650 cell configurations **Q4 Y2**
- Second phase of the material scaling up (silicon anode material and anode binder) **Q2 Y3**
- Validation in large automotive designed batteries (following customers' specifications) **Q4 Y3**



Project innovations

- Silicon-based materials that do not suffer excessive volume changes during use
- Binders that are optimised to work with silicon
- New analytical and characterisation techniques for better understanding of cell failure modes
- Higher energy density anodes with high-capacity retention and improved safety
- Anodes optimised for EV applications, including high rate and temperature operation
- Validation in EV pouch and cylindrical cells
- Demonstration of scalable and economically viable processes for material manufacturing

Partners

synthomer

nexeon

UCL

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Synergy

Increasing the performance, manufacturability and environmental profile of lithium-ion battery cells through improved electrode raw materials

Project costs

Total project costs: £958,687

Grant contribution: £698,815



Executive summary

Synergy is focused on developing step changes in the performance and sustainability of lithium-ion batteries. It brings together the raw material, formulation, electrochemical knowledge and cell manufacture capabilities of Synthomer (including Synthomer's polymer binder and William Blythe active material development teams), CPI and AMTE Power.

The project will lead to manufacturing and performance improvements in the anode system. It is also examining methods to improve the safety and environmental profile of cathode systems. The combined improvements are expected to reduce the costs of cell manufacture and help to realise the range and power output needed for the next generation of electric vehicles.

Timeline with milestones and deliverables

Anode slurry optimisation	**Q1 2021**
NMP free cathode slurry formulation complete	**Q2 2021**
Selection of cathode binder prototype	**Q2 2021**
Next gen anode binder prototype selection	**Q3 2021**
Anode validation in pouch cells	**Q4 2021**

Project innovations

- Optimised anode binder technology to maximise cell performance and lifetime
- Replacement of n-methyl-2-pyrrolidone cathode solvent with more environmentally-friendly alternative
- Potential next generation cathode binder system
- Feasibility study on water stable cathode active materials

Partners

synthomer

williamblythe
Excellence in chemistry
A Synthomer Group Company

amte power

cpi

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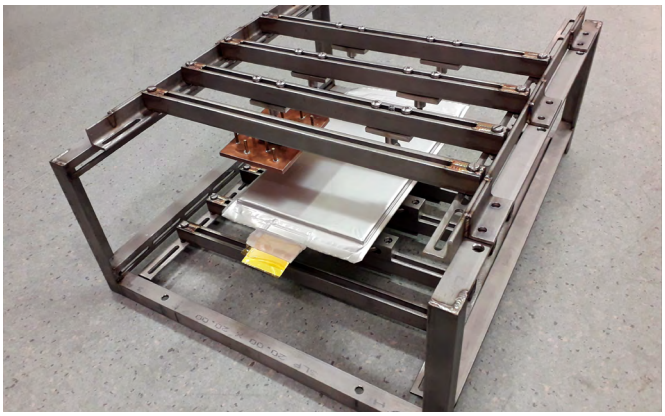
The development of an Isothermal Control Platform (ICP) for the precise regulation of battery temperatures using multiple zone control

The ICP was developed to improve the industry's understanding of lithium-ion battery chemistries and better characterise the temperature-based limitations on battery and vehicle performance.

Project costs

Total project costs: £293,106

Grant contribution: £249,033



Executive summary

The ICP provides a thermally stable basis for characterising lithium cells and their chemistries. It is intended to overcome the limitations that currently affect characterisation tests in environmental chambers, which can result in significant errors and gross overestimation of battery performance.

Timeline with milestones and deliverables

- This project ran from April 2018 to March 2019. Two prototypes were built: one is operational at Imperial College, and the other is due to be loaned to one of the collaborator universities.
- The THT prototype has been used successfully to maintain the cell surface temperature to within +/- 0.1°C of the setpoint during discharges up to 30C of a Kokam 5Ah pouch cell.
- The ICP was further developed in a second Faraday project (Innovation R&D Studies Round 3) in partnership with Imperial College and Cranfield University.

Partners

THT THERMAL HAZARD TECHNOLOGY

Imperial College London

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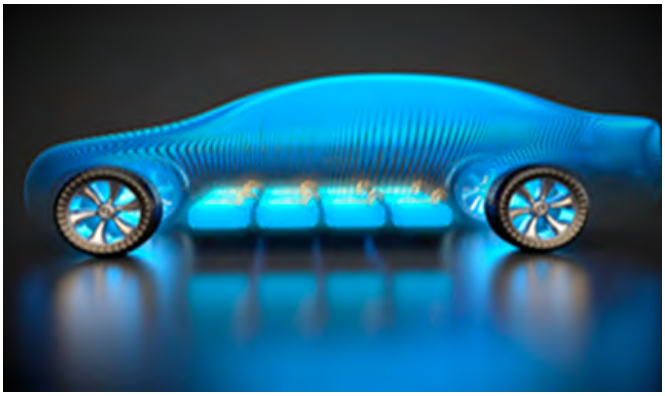
The PowerDrive Line

Development of a solid-state battery pre-pilot line, battery management system and materials supply chain for plug-in hybrid and battery electric vehicles

Project costs

Total project costs: £5,960,773

Grant contribution: £4,383,502



Executive summary

Solid-state lithium battery technology is widely seen as having the potential to transform the performance and safety of electric and plug-in hybrid electric vehicles (EVs and PHEVs).

The major benefits of solid-state batteries derive from their compatibility with high-energy anode materials and use of non-flammable solid electrolyte, as opposed to the flammable organic solvents used in current lithium-ion batteries.
In terms of performance, solid-state lithium batteries offer the prospect of much faster charging times, increased energy density, increased life cycle of up to 10 years, and extremely low self-discharge.

The innovative solid-state battery technology will enable safer, more energy and power dense cells that will facilitate ultra-fast charging (enable a PHEV or BEV driver to charge their car in 15 to 25 minutes) and put the UK on a path to produce materials for the manufacture of solid-state battery cells and packs and in a world leading position to exploit the technology globally.

Timeline with milestones and deliverables

This 33-month project started on the 1st October 2018 and has reached a successful conclusion in June 2021. The project delivered a 1kWh per week pre pilot line for developing and manufacturing solid-state batteries, defined a solid-state materials supply chain and designed a BMS for solid state batteries

Project innovations

- Solid-state battery development
- A scalable UK based capability for the reproducible manufacture of solid-state electrolyte feed powders
- Development of an ultra-fast charging battery module and battery management system in a prototype package
- Commissioning of a solid-state battery pilot line

Partners

ilika accelerated materials innovation

cpi

HONDA

RICARDO

UCL

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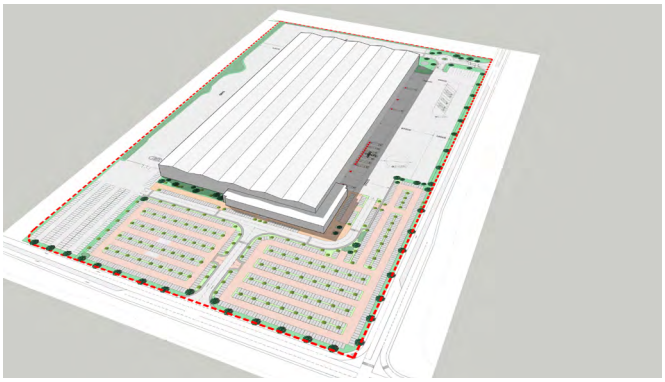
UK – GIGAWATT Hour Cell Manufacturing Facility Feasibility (Giga Factory)

This project was aimed at enhancing the UK's battery cell manufacturing capability to meet growing demand from the automotive sector and allow the UK to achieve decarbonization towards net zero.

Project costs

Total project costs: £351,099

Grant contribution: £276,186



Executive summary

This collaborative innovation project focused on assessing the commercial feasibility of establishing a scalable Battery Cell Manufacturing Facility in the UK, with the capability to ramp up to a Gigawatt hour worth of cell production (35m units) by the year 2024. This was driven by the strategic need to establish the UK as a global leader in the development and manufacture of battery cells for electric vehicles. This project resulted in the delivery of a business case and manufacturing blueprint for a proposed Giga Factory that will enable AMTE Power PLC to prepare their production and supply chain readiness at a level of capability, scale and cost per kWh that is required by the UK's specialist EV sector.

Timeline with milestones and deliverables

May 2019:	Project Kick Off
October 2019:	Facility Specification - final requirements for successfully producing battery cells at volume
December 2019:	Completion of Equipment and Process Specification – ensuring production costs and waste are kept to a minimum
December 2019:	Site Down Selection – Establishment of the best location for the facility. Down selected to two sites from initial five.
January 2019:	Digital VR Representation of Future Facility – Allowing potential investors to experience the facility before ever breaking ground
March 2020:	Economic Summary Report – Detailed analysis of the socio-economic impacts of the facility
April 2020:	Final Feasibility Study Report

Project innovations

The project developed a toolkit to support future manufacturing decisions for GWh/y production of a mix of cells with different chemistries and formats. The toolkit allowed the cell producer to determine what products it should be producing, the production volumes of these products, the total output capacity of the plant, what manufacturing equipment should be used, and how it should be financed.

Partners

amte power

HSSMI

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UK – Niche Vehicle Battery Cell Supply Chain

The project designed, developed and manufactured, partially in UKBIC; Power (pouch), High Power (pouch) and Energy (cylindrical) Li-ion cells to match the requirements of UK low volume vehicle manufacturers with warranties and at acceptable cost.

Project costs

Total project costs: £4,171,000

Grant contribution: £3.224,000



Executive summary

The consortium identified a sustainable market of smaller, but still substantial-sized automotive manufacturers, which is ideally suited to its strengths. They are global companies based in the UK, producing; special-car, sportscar, off-highway, bus, marine and emergency/special vehicles. They are, however, being impeded by the difficulty in obtaining suitable quantities of battery cells from the global suppliers. After consultation with 27 of these companies, Williams, Advanced Engineering, Delta – A Cosworth Company and AMTE Power determined a requirement for a power cell in a pouch format and energy cell in a cylindrical format. Later in the project, a third high power cell was also added. These cells were designed with subsequent supply chains, down selected to allow the manufacture of A & B models for evaluation by Williams and Delta. In parallel William Blythe and CPI synthesised both anode and cathode materials, based on the cell chemistries, which were fully characterised prior to scale up in the UK. Lancaster University evaluated cell degradation models at different SOC and C rates including; SEI growth, Lithium plating and Calendar aging to support warranty provision. Scale up was via AMTE Powers existing Li-ion facility in Thurso and partially in UKBIC.

Timeline with milestones and deliverables

Project started	**01/08/2018**
Power and Energy cell requirements agreed	**23/12/2018**
A model prototype cells produced	**24/09/2019**
Anode & cathode materials produced by William Blythe & CPI	**01/08/2020**
B model cells produced	**21/12/2020**
Project completion	**31/06/2021**

Project innovations

The project produced, using volume production techniques, a state-of-the-art SiOx anode material, coated and analysed it for use in Energy cells. It developed a cell degradation model to provide data for a long-term cell warranty model in collaboration with an insurance company. The project used for the first time, in volume production in the UK, environmentally-friendly electrode material processing techniques and binder systems. Three cell variants were produced that had some components scaled at Giga pace through UKBIC.

Partners

amte power

cpi

WMG THE UNIVERSITY OF WARWICK

Lancaster University

williamblythe Excellence in chemistry
A Synthomer Group Company synthomer

delta A Cosworth Company

WILLIAMS ADVANCED ENGINEERING

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VALUABLE: Value Chain and Battery Lifecycle Exploitation

Building a complete end of life supply chain network within the UK by developing sustainable reuse, remanufacturing and recycling routes for second-life automotive Li-ion batteries.

Project costs

Total project costs: £2,617,960

Grant contribution: £2,064,530

Executive summary

Project VALUABLE's key objectives were to increase the added value of the UK battery supply chain, while decreasing its environmental impact. To achieve this, project partners developed commercially viable end of life metrology and test processes (acoustic, dimensional and XCT), optimised battery design for second-life applications and established new supply chain concepts for recycling, reuse and remanufacturing of automotive Li-ion batteries to support a complete End-of-Life (EoL) supply chain network within the UK.

The project brought together partners across the supply chain and has industry-wide support represented by an Industrial Advisory Board. The project consortium has been meeting with the Industrial Advisory Board on a quarterly basis since July 2018.

The Advisory Board comprised of key stakeholders from the automotive industry and beyond with an interest in battery end of life, from established automakers to recyclers, from innovation companies to trade associations.

The purpose of the Advisory Board was for its members to have early access to project information and for the project to disseminate this knowledge into the wider industry, ensuring the network takes advantage of the solutions developed within the project.

Timeline with milestones and deliverables

Project start
Jan 2018

June 2018
- Legislative review
- Design for second-life guidelines
- Remanufacturing strategy
- UK recycling infrastructure review
- Establishment of industrial advisory board

Jan 2019
- Compliance guidance
- Battery teardown analysis
- EoL scanning technique report
- High voltage H&S report
- Black mass recycling opportunities report

June 2019
- Compliance toolbox draft
- Battery recycle valuation tool
- Correlated acoutic & XCT cell analysis
- Remanufacturing pilot line feasibility
- International outreach (Global Battery Alliance, EU battery show)

Jan 2020
- Reverse logistics strategy
- Insights from Industrial Advisory Board and transnational outreach

June 2020
- Blueprint for cell testing and reuse
- Publication of 'VALUABLE – A circular economy for the automotive supply chain'
- XCT Cell virtual unrolling Analysis

Project end
March 2021
- Second life cost estimation service development
- Correlated and demonstrated results for inline dimensional and acoustic testing
- Launch of toolbox and services

Project innovations

- Development of a UK-based end-of-life battery value chain focusing on reuse, remanufacturing and recycling for second- life automotive Li-ion batteries.
- Quantified recyclability and reuse potential of traction battery packs
- Commercially viable metrology and testing processes
- Battery price evaluation tool to quantify and validate recycling and second- life opportunities
- Legal and regulatory support tools
- Industry-wide support represented by an Industrial Advisory Board

Partners

ASPIRE ENGINEERING
ACELERON
Envaqua Research
HSSMI
NPL National Physical Laboratory
TEVVA
UCL

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WIZer Batteries

WIZer Batteries will deliver a number of disruptive linked technologies in the field of energy storage

Project costs

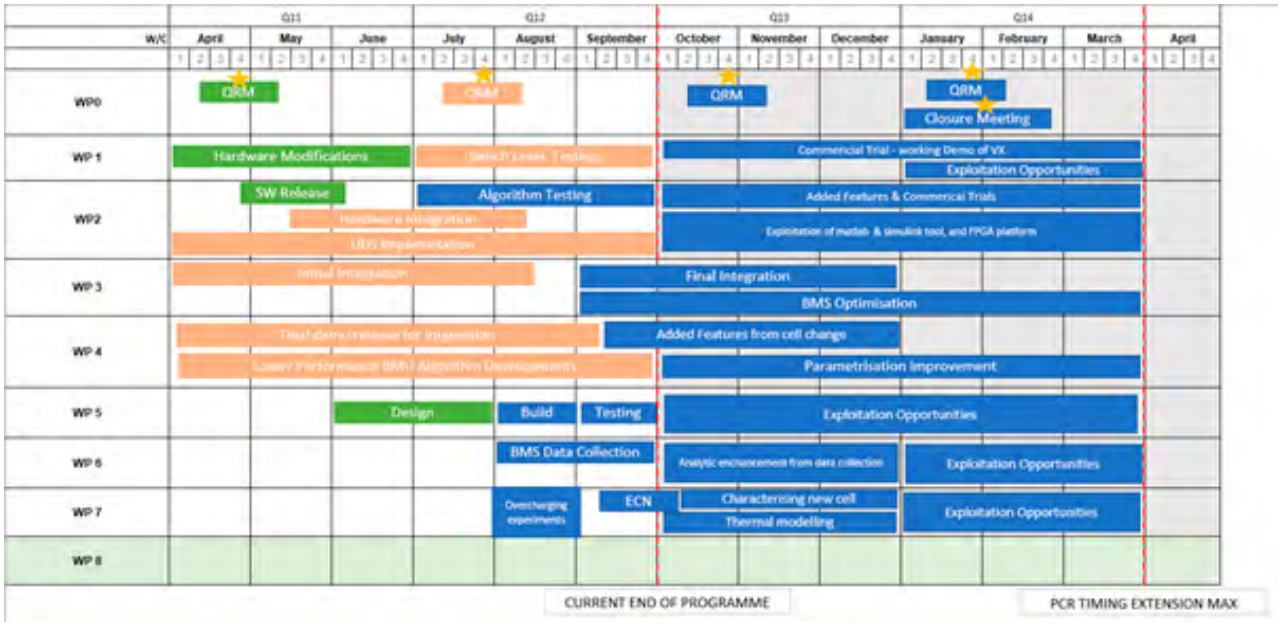
Total project costs: £7,564,215

Grant contribution: £5,801,698.40

Executive summary

WIZer Batteries, led by Williams Advanced Engineering, will deliver a revolutionary approach to battery management systems (BMS) capable of using fewer cells, while delivering more energy and power, faster charge times and greater life than today's competing technologies. The integration of this to a hybrid lithium-ion battery module design, alongside an end-to-end battery life tracking platform will demonstrate state of the art, disruptive UK technology.

Timeline with milestones and deliverables



Project innovations

- A BMS system based on completely new control methods delivering better control and fidelity incorporating high-power processing capabilities
- A hybrid battery module design, modelling and control technology
- New developments in cell modelling with the highest possible fidelity in real life situations
- An accelerated and adaptive computing platform allowing more precise analysis and delivering greater performance in model adaptation, alongside the application of artificial intelligence within the battery
- A software platform delivering life tracking of battery condition and status

Partners

Silver Power Systems

Imperial College London

codeplay

WILLIAMS ADVANCED ENGINEERING

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Notes

Scale-up

UK Battery Industrialisation Centre (UKBIC)

National battery manufacturing development facility providing UK battery manufacturing scale-up and to facilitate upskilling in the battery sector.

Project costs

Grant contribution: £130m

Executive summary

The UK Battery Industrialisation Centre, which was opened by the Rt Hon Boris Johnson, the Prime Minister in July 2021, is a national battery manufacturing development facility providing battery manufacturing scale-up and facilitating upskilling in the battery sector. The publicly-funded facility welcomes manufacturers, entrepreneurs, researchers and educators, and can be accessed by any organisation looking to scale battery technologies – if that technology will bring green jobs and prosperity to the UK.

The state-of-the-art facility – described by the Prime Minister as "a beacon of innovation and ingenuity" - has been developed to support UK industry with development of battery technologies for future electrification.

UKBIC's purpose

UKBIC can be used by any organisation working on batteries for, amongst others, electric vehicles, rail, aerospace, industrial and domestic equipment and static energy storage, who can benefit from finding out whether their advanced technologies can be scaled up successfully before committing to the huge investment required for mass production.

The open access facility - which is housed in a 18,500 square metre building - allows organisations in the UK to prove whether their promising technologies (from electrode and cell materials through to battery modules and packs) can be manufactured at the required volume, speed, performance and cost to be commercially successful.

We can also help them build bespoke production lines at UKBIC to enable them to prove higher throughput production in early stages whilst they prove their business cases or build their own production lines.



UKBIC's specialist equipment

The battery manufacturing equipment installed in the facility covers the whole production process from electrode manufacturing, cylindrical and pouch cell assembly, to formation ageing and testing and battery modules and packs. The equipment installed is exactly what you would find in Gigafactories now under construction across the globe.

Training

As the sale of new petrol and diesel cars/vans ends in 2030, five years earlier than previously planned, we all know that there will be a seismic shift as the internal combustion engine powered by diesel and petrol are replaced with cars/vans powered by batteries. This growth means that there will be a need for reskilling across the battery sector. Therefore, in tandem with industry, the education sector and Government, UKBIC is looking to develop specialist training programmes for those working across the battery sector.

Customers can also bring their own employees in to work and be trained on our process equipment.

Customer confidentially: The highly flexible facilities, which have both physical and digital firewalling as norm, are designed so that several users can run projects at the same time in dedicated and security controlled discrete areas. UKBIC does not exist to own IP but to enable industry users to develop their own.

Advisory support: Using our own first-hand experience of setting up a battery facility, we can also offer consultancy and advisory support for a wide range of organisations.

Location: UKBIC is located in Coventry in the West Midlands, home to an established automotive supply chain, and a city that is steeped in the automotive sector.

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