Delivered by
Innovate UK

Faraday Battery Challenge Projects

Electrifying the UK's future

September 2024

Contents

What is the Faraday Battery Challenge?

The world is undergoing a transition to a low-carbon future, but transport remains the largest source of carbon dioxide emissions in the UK, accounting for 29% of emissions[1]. Developing low-cost, reliable and long-range electric vehicles is the key to reducing these emissions, with batteries playing a crucial role, not only in the automotive sector but in applications across aerospace, rail, marine, off-highway vehicles and static storage. The UK and the EU have established clear end dates for the sale of petrol and diesel vehicles, which is driving the demand for battery-powered electric vehicles. This transition to an electrified future will require many types of batteries, with some yet to be imagined. Therefore, the next generation of battery technology must be developed, along with exploration and de-risking of new production processes that ensure long-term UK success in battery manufacturing and car-making.

This is the reason the Faraday Battery Challenge exists. It is a £610 million investment from the UK government in battery technology. The mission-led programme coordinates and manages applied research, business-led innovation and national scale-up infrastructure in support of the UK's transition to electrification. Delivered by Innovate UK, on behalf of UK Research and Innovation (UKRI), the Faraday Battery Challenge supports the development of sustainable batteries that are cost- effective, high -performance, durable, safe and recyclable.

The Challenge has positioned the UK as a leading scientific, technological, and industrial player in the development of batteries. The significant investment has not only contributed to the growth of UK companies, but also signaled to investors that the UK is an attractive opportunity for innovation and production in the battery sector. This initiative has promoted innovation and collaboration among researchers, businesses, and other stakeholders, which has enhanced the UK's credibility in this sector. The support provided by the Faraday Battery Challenge extends far beyond the automotive industry and encompasses cross-sector activities in skills development, policy, regulations, and more.

The Challenge is designed to support innovation from early-stage, university-led research through to near-commercial scale facilities to test manufacturing, providing the UK with a world-beating innovation landscape to commercialise battery technology. It is focused on three pillars: research, business-led innovation and scale-up. The Challenge draws together these pillars to accelerate the delivery of a pipeline of activity, and has built a globally competitive scientific capability at scale, harnessing our best talent toward solving the challenges for battery technology.

This document highlights the UK's battery electric transition in action, with the cutting-edge projects of the Faraday Battery Challenge. These projects are blazing a trail towards a cleaner, more sustainable future, backed by groundbreaking research and innovative technology that are the driving force behind the UK's electrifying transition to a battery-powered future. As you will see through these projects, the UK is well -positioned to thrive in the emerging low-carbon economy, with robust infrastructure, a skilled workforce, and a strong innovation ecosystem in place to drive the transition to electrification.

Tony Harper, Faraday Battery Challenge Director

"The Faraday Battery Challenge is a pioneering 'lab to factory' programme focused on delivering the research, business-led innovation, infrastructure and people required for the UK to prosper from the unprecedented opportunities arising from the mass transition to electrification.

Just over six years into the programme, this brochure illustrates the breadth and depth of cutting-edge capability that has been built and reinforces why the UK is amongst the very best in the world in battery technology development."

1 Transport and Environment Statistics 2021 Annual report.

Faraday Battery Challenge

Innovate UK | The Faraday Institution | UK Battery Industrialisation Centre

Scaling high tech business | **Building a Science Superpower** | **Open access scale up with Gigafactory capability**

Research

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 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.

Business-led Innovation

The Faraday Battery Challenge Innovation programme is supporting UK businesses to push the boundaries of battery innovation and grow the UK battery supply chain. £130m of funding from Innovate UK for UKRI has been invested for businesses to lead feasibility studies, and collaborative research and development projects across the battery value chain, in collaboration with the UK's world leading academics and research technology organisations.

Scale-up

The UK Battery Industrialisation Centre (UKBIC), the first facility of its kind in Europe, opened in 2021 and enables companies of all sizes to develop manufacturing capabilities for battery technologies to get them to market quickly.

Contact

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Faraday Battery Challenge Programme timeline

2017

Initiated 2017

July
Launch of the programme by Secretary of State – Greg Clark

October
The Faraday Institution (FI) opens

November
UK Battery Industrialisation Centre (UKBIC) announced by Secretary of State – Greg Clark

2018

March
First four Faraday Institution research projects commence

August
1st round of 25 collaborative projects commences

2019

January
2nd round of 12 collaborative projects commences

May
UK Battery Industrialisation Center ground-breaking event

September
3rd round of 26 collaborative projects commences

2020

September
Six further major FI research projects commence

2021

July
- UK Battery Industrialisation Center official opening by Prime Minister – Boris Johnson
- 4th round of 17 collaborative projects commences

2022

March
Phase 1 Collaborative R&D projects closes (Rd 1, 2 & 3)

June
- 14 Faraday Institution seed project begins, expanding research scope
- 1st cohort of Faraday Institution PhD researchers graduates
- 200th Faraday Institution undergraduate Internship initiated

October
Official announcement of Phase 2 of Faraday battery challenge

2023

February
SME Credit Round 1 competition opens
–
5th round of 17 collaborative projects commences

March
- Investor readiness programme opens
  –
  Investor partnership programme opens
- Reshaping of 10 major FI research projects for maximum impact
  –
  8th Faraday Institution entrepreneurial fellowship (Spin outs), 16th industry fellowship and 11th industry sprint awarded

April
Talent and skills full scale

May
Round 6 collaborative R&D opens
–
Phase 1 completion report
–
Material scale-up opens

October
Round 4 Collaborative R&D projects close

2024

Ongoing phase activities – SME credit projects round 1, with Round 5 and 6 Collaborative R&D running

Impacts of Faraday Battery Challenge Programme by delivery partners

Impact of Innovate UK's Faraday Battery Challenge

£130m of Faraday Battery Challenge (FBC) grant funding through our collaboration research and development (CR&D) portfolio has unlocked:

Over **£800m** of further private investment into UK businesses

197 organisations across the UK

Support for **118** high-tech projects across the battery value chain, with >80% led by SMEs

38% collaborations between SMEs and large businesses

Over **1,000** highly skilled jobs created and secured

80% of projects include academic institutions

Opportunities for SMEs to connect and collaborate with international players in Australia, Japan, South Korea and the US

Further Programme Impact

£3.2m of dedicated skills funding providing opportunities to re-skill, upskill and grow new skills in battery manufacturing and innovation across the UK

£2.6m FBC funding through the Investor Partnership Programme has leveraged **£4.9m** of upfront private investment at point of grant

500 organisations connected through the Cross-Sector Battery Systems (CSBS) Innovation Network

£12m investment for establishing the first open-access battery material scale-up facility in the UK

6 years of high-quality impacts in energy storage

The Faraday Institution has generated a great return on the UK's investment from a standing start in 2018

10
major research programmes, lead across 27 UK universities and research partners and 120+ industrial partners

777+
scientific papers published, 64.6% in top 10% journals, 47.5% in top 10% most cited, 44.1% with international collaborators

40
inventions identified, 18 patents filed and 7 published

500+
researchers united in a community, 45% new to field, to solve battery challenges through breakthrough science

14
entrepreneurial spin-outs, supported 17 industry fellows and 17 industry sprints

20
Faraday insights, 13 major reports, 12 national consultations, numerous briefings including House of Commons and House of Lord enquiries

85
PhDs receiving bespoke training for UK industrial and academic careers, and an additional 100+ affiliated with our projects

International collaboration
DSIT funded US UK joint battery research on recycling and cathole materials

6
Royal Institution events hosted, attracting 300,000+ online viewers

UK Battery Industrialisation Centre

35

companies on more than 70 contracts to support the growth in cell scale-up, and module and pack development and manufacturing

1,986

hours of external training delivered since 2023, across lineside bespoke training and publicly available bookable training courses

More than

£2m

CR&D funding for 6 major projects

140

employees (as of June 2024), with many more moving back into the UK supply chain

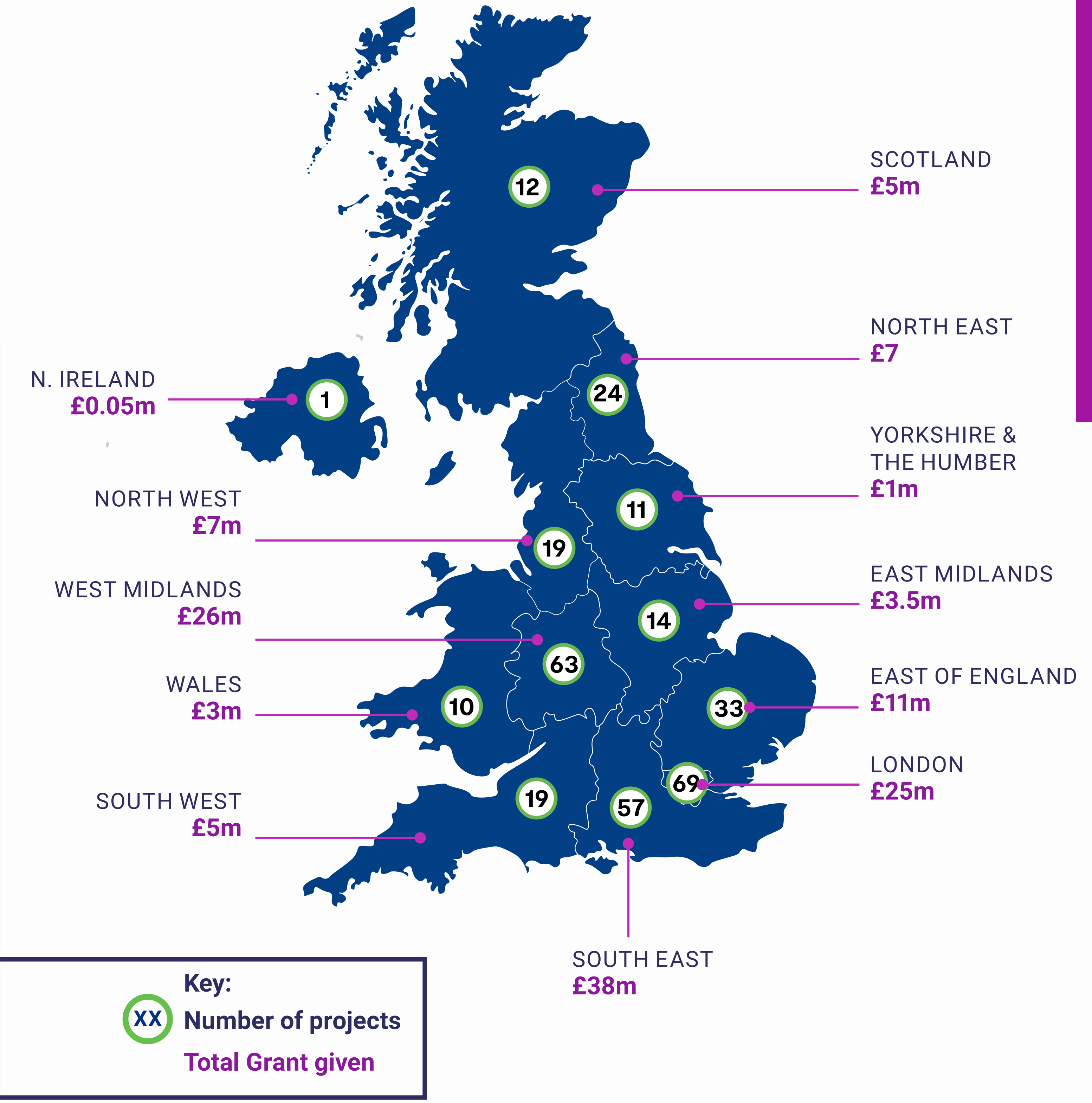
An active conference and events programme at UKBIC, elsewhere in the UK, and overseas. Participated in Cenex Expo (previously, Low Carbon Vehicle conference), the Battery Cells & Systems Expo, The Battery Tech Expo (Silverstone), The Battery Tech Sweden, The Battery Show USA, The Battery Show (Stuttgart), JSAE, and other key events

Almost

500

visits from a range of organisations, including 30 international delegations from the USA, Canada, Japan, Australia, Germany, Singapore, Sweden, China, Thailand, and others

Funded organisations by region in business-led innovation collaborative R&D



Faraday Institution academic and industry partners

Key:
- ● Academics partners
- ▲ Industry partners

Research

THE FARADAY INSTITUTION

The Faraday Institution: powering Britain's battery revolution

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.

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 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.

The organisation serves as the UK's flagship energy storage 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 academia, industry and policy, 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, and a key delivery partner of the Faraday Battery Challenge.

Making an Impact

The Faraday Institution continues to deliver excellent scientific and industry-relevant impacts since the launch of its research programmes in 2018, including:

"The Faraday Institution is harnessing the UK's strengths in energy storage science research and innovation. Propelled by the efforts of its talented and collaborative community of 500 researchers, the organisation is positioning the UK as one of the global leaders in battery research. We remain committed to identifying and investing in the most promising and impactful battery research initiatives.

Our focused portfolio of research, analysis, skills, and commercialisation activities will ensure that the UK can fully seize its potential to maximise the societal, environmental, and economic impacts that energy storage brings."

James Gaade, Faraday Institution

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Research

In the near term, accelerating the drive towards electric vehicles (EVs) requires the optimisation of lithium-ion (Li-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 research, development and commercialisation of new battery chemistries.

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 10 major research projects:

- Seven projects aim to optimise current generation Li-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 on building core knowledge, understanding and capability in battery degradation, modelling and safety.
- Two on processing, electrode manufacturing and recycling.
- Two on next-generation cathode materials.
- The remaining three projects' 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 in solid-state, sodium-ion and lithium-sulfur batteries.

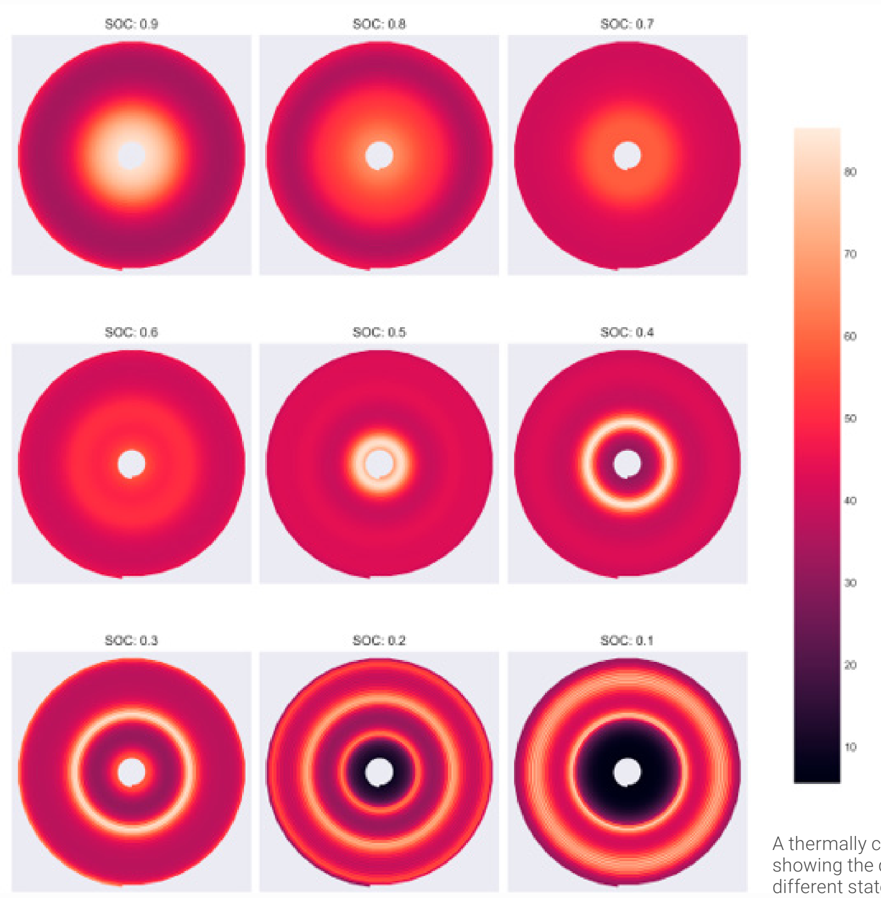
THE FARADAY INSTITUTION

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.

Research Excellence

Research from the Faraday Institution's programme is internationally recognised as a mark of excellence. Scientific discoveries have led to highly cited publications, a suite of patents, and commercial spin outs. To October 2023 the Faraday Institution has contributed over 777 publications to the scientific literature, more than 85 of which represent collaborative work across its research projects.

The following statistical data derives from the SciVal record from April 2018 to October 2023, which recognises 733 papers and 2,228 authors. 90.2% of publications are in open access journals, with 17.3% categorised as gold open access. 45 papers were published in collaboration with an industry partner. Almost half (44.1%) of the published research coming out of the Faraday Institution has international collaborators, spanning over 391 institutions, 39 countries and six continents. Key countries that collaborate most frequently with the Faraday Institution include the USA, China, Germany, France, Sweden, South Korea and Spain in that order.

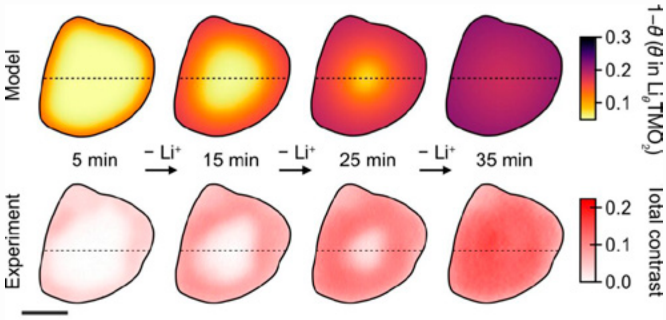


A thermally coupled electrochemical model produced in PyBaMM, showing the density variations that develop in a cylindrical cell at different states of charge.

Extending battery life

Understanding the mechanisms of degradation of lithium-ion batteries.

Grant contribution: £22,700,000



Comparison of simulation and experimental imaging results, both conducted at a delithiation rate of C/3. The predicted degree of delithiation (1-θ) on the basal plane of the particle at various times during the charge.

Executive summary

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, cobalt-free cathodes and a range of anode chemistries from graphite, graphite/SiOx composites and anode-free.

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 the cost of lithium-ion batteries driven by mass manufacture, the widespread adoption of battery EVs 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 EVs 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 understand more fully 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.

Timeline with milestone/deliverables (March 2025)

- 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 and colbalt-free positive electrode materials.
- Examine and understand the physicochemical mechanisms of degradation of graphite and anode free electrode materials. Emphasis is being placed on the interaction, or 'cross-talk', effects of 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 EV technology.

Partners

University of Cambridge (co- lead)
University of Warwick (co-lead)
Imperial College London
Newcastle University
University College London
University of Birmingham
University of Oxford
University of Sheffield
University of Southampton
National Physical Laboratory (NPL)
+ 8 Industrial Partners

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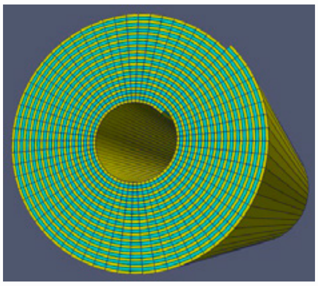
Multi-scale Modelling

Bringing together a multidisciplinary team to develop fast, highly accurate models to speed up battery development and ensure safe operation for longer battery life.

Grant contribution: £22,900,000



Cylindrical cell geometry discretisation example in 2D (approximately 2000 modelling cells). Each finite volume is simulated as an individual Newman model.

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 or configuration of 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 systems. A range of timescales are also considered from the movements of atoms 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 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 specific applications.

Timeline with milestone/deliverables (March 2025)

- Expand on the physics and degradation models in PyBaMM (Python Battery Mathematical Modelling).
- Establish a similar common code base for equivalent circuit models (ECMs), called PRISM.
- Examine the processes that occur during the formation cycles of a newly manufactured battery and how this can set the trajectory for its performance and lifetime.
- Develop physics-based models for lithium iron phosphate (LFP) battery chemistries.
- Develop a data set on long-term cell ageing, using rigorously controlled experiments.
- Implement models for advanced state estimation and control.
- Develop digital twins as design tools for new cell and pack configurations.

Project innovations

A common coding framework – PyBaMM – has been established and multiple degradation mechanisms added. It is an open-source model, which is easy to use and provides a high-quality resource for the battery community to explore the mathematical theories with a minimum of coding effort. The PyBaMM community continues to grow, with users and developers from industry and academia around the world.

Rigorous, standardised parameterisation techniques have been developed and the spin-out About:Energy was formed to provide parameterised models as a service to increase access for industry.

Improvements to atomistic modelling were released as part of ONETEP and an ultrafast solver, DandeLiion, has also been developed, which is optimised for speed. The physical models in both PyBaMM and DandeLiion now incorporate thermodynamics, mechanics and long-term ageing.

Partners

Imperial College London (Lead)
University of Birmingham
University of Oxford
University of Bristol
University of Portsmouth
University of Southampton
University of Warwick
UK Battery Industrialisation Centre (UKBIC)
+ 17 Industrial Partners

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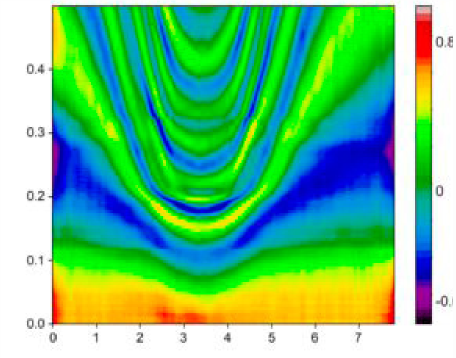
SafeBatt – the science of battery safety

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

Grant contribution: £4,300,000



2D spatiotemporal cross-correlation mapping as a quantitative technique to track failure propagation; this image shows the spatiotemporal map where a ball compresses the electrode structure. The map indicates that the centre of the ball, x ≈ 3.45 mm, starts displacing the electrodes from t ≈ 0.04 s, where the extent of displacement reduces radially due to the circular profile of the ball.

Executive summary

While lithium-ion cell fires are rare, they can occur under various conditions of mechanical, thermal or electrical stress or abuse. As the use of lithium-ion batteries 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 is improving 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 lithium-ion battery fires. This will inform the further development of fire sensing and protection systems for lithium-ion battery energy storage systems and help inform first responders.

Timeline with milestone/deliverables (March 2025)

- Investigate materials driven safety issues, detecting early signatures of failure and how these may change as the cell ages.
- Investigate the effect of fast charging and operation under extreme conditions on the safety response at a cell level.
- Understand cell failure modes and how they translate to multi-cell clusters and modules, using advanced instrumentation and high-speed characterisation and imaging techniques.
- Develop and demonstrate detection methods and mitigation strategies to prevent thermal runaway and propagation.
- Develop a model to infer reaction kinetics and predict thermal runaway, simulating the external flow of gas, heat and ejecta during failure.
- Conduct tests in larger format cells and at module level to help industry and other stakeholders understand how EV and micro-mobility battery packs and static energy storage systems fail in real-world scenarios.
- Continue international dissemination activities, providing a central point of access for industry, government bodies and fire services seeking knowledge on safety related battery issues.

Project innovations

Large scale experiments at module level include further investigating fire extinguisher efficacy and the toxicity of fumes and run-off. Previous large-scale work has been instrumental in highlighting the potential explosion hazard of the vapour cloud, which is produced by cells under certain failure conditions. This ground-breaking work is informing best practice and providing knowledge to numerous stakeholders internationally (including first responders and government working groups) on real-world lithium-ion battery failure hazards in EVs and micro-mobility devices, recycling facilities, and domestic and industrial energy storage facilities. This knowledge is being used to influence British and international standards, and produce safe practices for storing and charging devices such as e-scooters and e-bikes.

Partners

University College London (Lead)
University of Oxford
University of Cambridge
King's College London
Newcastle University
University of Sheffield
University of Warwick
+ 2 Industry Partners

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ReLiB – recycling and reuse of EV lithium-ion batteries

Providing a UK EV battery recycling industry with a pipeline of scalable technologies.

Grant contribution: £18,500,000

Coins cells being tested to understand their performance after remanufacture from recycled material via the organic selective phased leaching technology.

Executive summary

The transition to electric vehicles (EVs) brings challenges and opportunities associated with the need to manage projected volumes of around 28,000 tonnes of EV lithium-ion batteries needing recycling by 2030, rising to 235,500 tonnes in 2040. To cope effectively with these volumes, vast improvements in the speed, environmental footprint and the economics of recycling processes will be required, not least as the security of supply of critical materials is becoming an ever-increasing priority for Government. To this end ReLiB is developing recycling technologies that will put the UK at the cutting edge of research & development whilst also building the industrial capacity to underpin the transition to EVs.

ReLiB's vision is to provide a UK EV battery recycling industry with a pipeline of scalable technologies that are responsive to regulatory drivers, new battery designs and chemistries, and the opportunities afforded by Industry 4.0.

Over the next two years to March 2025 the project aims to develop – and scale – the following technologies:

- Cathode leaching to industrial level;
- Upcycled electrode materials used in new cells;
- Binder recovery (where there is an economic or regulatory rationale to do so);
- Biorecovery of materials, e.g., metals from plastic EV battery waste, from secondary waste solutions – 'zero waste' concept;
- Data informed recycling routes based on digital diagnostic tools that can interface seamlessly with battery data passports to assess the batteries key recycling indicators;
- Batteries designed and manufactured with consideration for recycling;

and

- Identification of new research topics that fit with changing battery design and chemistry systems and regulatory drivers.

Timeline with milestone/deliverables (March 2025)

- Demonstration of effective leaching from generation one end-of-life EV batteries.
- Development of a cell-dismantling route for recovery of materials from end-of-life 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 materials contained within EV batteries is critical to the success of the EV revolution and the sustainability of manufacturing supply chains. The project will achieve this through direct targeting of fast, efficient dismantling processes 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 College London
University of Edinburgh
University of Leicester
Newcastle University
Imperial College London
+20 Industry Partners

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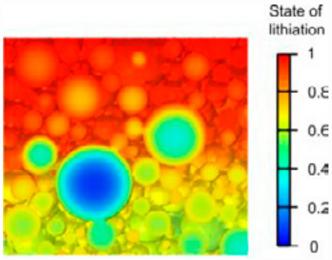
Nextrode – next generation electrode manufacturing

Battery performance improvements through smarter electrode manufacturing.

Grant contribution: £17,900,000



An electrochemical simulation of active material utilisation within a realistic, X-ray CT-based, NMC622 electrode microstructure

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 in both traditional slurry cast electrodes and novel low or no solvent electrodes.

The project is:

- Exploring and exploiting sensor integration and metrology, modelling and data analytics at all stages of electrode manufacture to lay the foundations for future closed loop process control, leading to higher yield, higher productivity and greater flexibility.
- Developing new models and using predictive simulations to suggest the optimum arrangement of materials in electrodes and realising these in practice through prototypes.
- Expanding its research on low and no solvent processing End investigating smart anodes and manufacturing scale-up as well as continuing work on smart cathodes.
- Using 3D characterisation techniques to quantify and assure our bespoke designs and to relate electrode structural features to electrochemical performance.

Nextrode aims to support UK manufacturers and energy storage supply chain companies by showing how to increase cell performance, add value in electrode processing, and improve safety and sustainability.

Timeline with milestone/deliverables (September 2025)

- Provide the critical underpinning manufacturing science to alleviate constraints in electrode manufacturing through engineering particle design and improved understanding of the relationship between powder properties and deposition/calendering techniques.
- Design manufacturing process steps and utilise advanced in-line measurements to enable slurry casting to produce more reproducible electrodes with improved property balance.
- Manufacture new arrangements of anode and cathode materials and identify conditions where benefits are maximised and develop cells that expand the energy-power-lifetime design space.
- Link correlative imaging, quantification and image-based modelling to design optimal microstructures to inform manufacturing development.
- Create and validate data-driven predictive models of electrode manufacturing driving improvements in production efficiency and flexibility.

Project innovations

The project's industry partners, including UKBIC, major players in the materials supply chain and the automotive industry, and organisations involved in R&D/niche volume electrode manufacturing, are focusing the project towards developments that have the most potential for industrial impact (at a low volume/niche through to gigafactory scale). 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)
Imperial College London
University of Birmingham
University College London
University of Sheffield
University of Southampton
University of Warwick
UK Battery Industrialisation Centre (UKBIC)
+ 14 Industry Partners

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FutureCat – high nickel content, high performance cathode materials

Grant contribution: £13,400,000

FutureCat researcher loading a coin cell onto an instrument for electrochemical characterisation.

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 researcher's understanding of the underpinning mechanisms and mechanics, and push performance limits in a sustainable manner.

FutureCat addresses these challenges through three integrated research themes for designing and developing near- and next-generation cathodes, with a focus on high-capacity, high-performance Ni-rich oxide cathodes, but also considering sustainable alternatives that avoid supply-chain at-risk elements.

The advances the project is targeting represent significant commercial opportunities. FutureCat, in collaboration with WMG, University of Warwick, is well positioned to develop scalable solutions for next-generation cathodes towards industry relevant battery formats such as pouch cells. The project is joined by industry partners across the battery supply chain. Three new partners join the consortium in Phase Two working on material lifetime extension via atomic layer coatings, new advanced electrolytes to maximise cathode performance, and advanced X-ray tomography characterisation methods to look inside batteries as they operate.

Timeline with milestone/deliverables (September 2025)

- FutureCat is targeting three transformative step-changes:
- Novel redox processes: understanding novel redox processes and delivering new high-energy/power cathodes exploiting new knowledge.
- Scalable designer morphologies: longer lifetime, high-energy/power through concentration gradient, single crystal and thin coatings.
- Materials delivery: scaling-up industrially relevant Ni-rich and down-selected active materials based on earth-abundant elements.
- FutureCat will deliver cathode materials and fabrication methodologies that provide enhanced energy density, cycle-life, power output and reduced costs, empowering UK 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; including cation-plus-anion redox active materials, gaining a fundamental understanding of anion redox processes to harness and stabilise additional capacity; fundamental scientific enquiry of the underpinning synthesis–structure–property relationship governing performance.
- Establishing design principles for durable cathodes informed by mechanochemical properties; developing new mechanical-testing methods informing the 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 Warwick (Lead)
University of Sheffield
University of Cambridge
Lancaster University
Imperial College London
University of Birmingham
University of Nottingham
Diamond Light Source
ISIS Neutron and Muon Source
+ 8 Industry Partners

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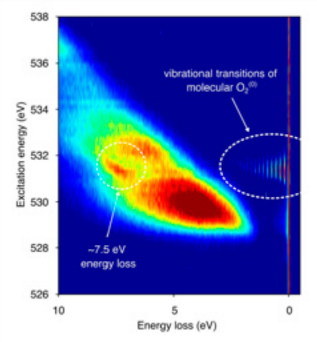
CATMAT – High energy-density, sustainable cathode materials

Grant contribution: £14,300,000



High-resolution resonant inelastic X-ray scattering (RIXS) map of $Li_{2-x}MnO_2F$ charged to 5.0 V, showing the vibrational features corresponding to molecular O2 only, and an energy loss feature at ˜7.5 eV (McColl, House, Islam et al., Nature Comms, 2022).

Executive summary

The CATMAT project is focused on targeting improvements in lithium-ion battery energy density and electric vehicle (EV) range through an understanding of the critical properties and limitations of lithium-rich oxygen-redox cathodes and novel anion-chemistry cathodes, and developing scalable synthesis routes for these materials.

The cathode represents one of the greatest barriers to increasing the energy density of lithium-ion batteries for EV applications. Changes to the chemistry of the cathode are likely to give the greatest improvements in future battery performance: by boosting battery life, storing greater energy to improve range, by reducing battery cost and increasing the power available to the EV during acceleration. Developing a new generation of lithium-ion cathodes is therefore a major scientific and commercial challenge as well as a huge opportunity.

The CATMAT project is focussed on understanding and mitigating the current limitations lithium-rich oxygen redox cathodes, and of developing cathodes with novel or complex anion chemistries. Alongside this progression in fundamental understanding of the electrochemistry of these cathodes, the project is developing scalable synthesis routes for the most promising identified materials. Once synthesised at larger scale, these materials will then be integrated 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 2025)

- Develop a deeper understanding of lithium-rich cathode materials with high energy densities and develop solutions to issues hindering major advances.
- Exploit new knowledge to inform the discovery of novel cathode materials for high energy density batteries (to increase EV range) while reducing reliance on critical materials in the supply chain.
- Use experimental, modelling, and cell performance evaluation to down-select novel materials for further synthetic and scale-up work.
- 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.

As the UK establishes its own lithium-ion battery manufacturing base, the potential for CATMAT to bring important innovations in cathode chemistry to commercial fruition is increasing considerably while the importance of inventing chemistries that boost the resilience of an ethical supply chain and improve recyclability is paramount.

Partners

University of Oxford (Lead)
University of Bath
University of Birmingham
University of Cambridge
University of Liverpool
University College London
CPI
Diamond Light Source (STFC)
UK Battery Industrialisation Centre (UKBIC)
+ 12 Industrial Partners

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

Addressing fundamental research challenges facing the realisation of solid-state batteries in automotive applications.

Grant contribution: £21,800,000

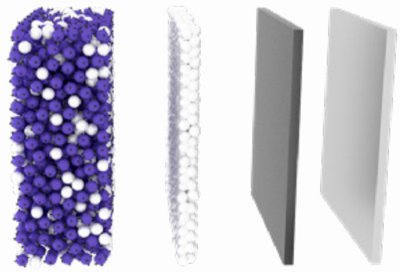

Image representation of solid-state battery structure

Executive summary

The ambition of SOLBAT is to demonstrate the feasibility of a solid-state battery with performance superior to lithium-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 lithium-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. SOLBAT is now using this fundamental understanding to provide solutions to these challenges.

Organised around three research areas, namely anode, cathode and electrolyte, with cross-cutting characterisation and modelling activities, the project aims to prevent dendrites and voiding, minimise operating pressure and facilitate scaling.

Timeline with milestone/deliverables

Anode

- Investigate structural changes during alloying and interfacial stability (March 2024).
- Understand the effect of interlayers on plating, stripping and critical current density (March 2024).
- Prepare and test new alloys and interlayers (March 2025).
- Clarify the effect of the current collector, interlayers and formation cycle in Li-less cells (March 2025).

Cathode (March 2025)

- Synthesise polymers with targeted electrochemo-mechanical properties for use as binders and coatings for use in composite cathodes.
- Demonstrate effect of composite cathode microstructure on performance and optimisation.

Electrolyte (March 2025)

- Investigate effect of particle size, processing and secondary phases on densification, microstructure, mechanical properties and supressing dendrites.
- Understand how the ceramic microstructure, density, grain size, shape, and particle surface composition affect the grain boundary resistances.
- Determine degradation mechanism of sulfide solid electrolytes in air and develop mitigation strategies to reduce moisture sensitivity.
- Develop models at the particle, component and cell level to guide materials research and microstructural design.

Project innovations

SOLBAT will tackle the barriers to realising solid-state batteries that are at the research level. New intellectual property will be developed and ideally converted into viable businesses by industrial partners and/or newly created commercialisation vehicles. Ultimately, a long-term effort in developing a strong and substantial core knowledge will provide a strong foundation for the commercialisation of this technology.

Partners

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

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Professor Mauro Pasta Email: mauro.pasta@materials.ox.ac.uk Web: www.solbat-faraday.org

NEXGENNA – sodium-ion batteries

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

Grant contribution: £13,900,000

St Andrews facility

Executive summary

NEXGENNA will develop the NEXt GENeration of Na-ion batteries. Its mission is to surpass LFP-graphite by improving the energy storage, power, and lifetime of sodium-ion while maintaining sustainability, safety, and cost advantages.

Sodium-ion batteries (NIBs) are an emerging battery technology, on the cusp of commercialisation, with promising cost, safety, sustainability and performance benefits when compared to lithium-ion batteries. They use widely available and inexpensive raw materials and existing lithium-ion production methods, promising rapid scalability. 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. Increasingly NIBs have characteristics comparable to lithium iron phosphate (LFP), suggesting that even mid-range automotive applications are possible.

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 the 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 2025)

- 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.
- Optimise key industry-relevant materials for scale-up.
- Demonstrate nascent NEXGENNA technology in pouch cells.
- Improve the industrial state-of-the-art by delivering a novel medium power, lost-cost sustainable or energy pouch-cell design.

Project innovations

The project benefits from strong academic-industrial links across the value chain, where 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 batteries for transportation applications.

Partners

University of St Andrews (Lead)
Imperial College London
University of Cambridge
Imperial College London
Lancaster University
University of Birmingham
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.

An optical microscope image showing the formation of Li-metal dendrites during Li-S cell cycling captured by Faraday Institution Research Fellow Rhodri Owen, UCL

Grant contribution: £12,900,000

Executive summary

There is a need to develop batteries which supersede the practical capabilities of lithium-ion batteries to enable the electrification of applications including aerospace and heavier electric vehicles (EVs). While there are several realistic candidates, the Li-S chemistry combines relative technical maturity with a practical limit that places the technology in a unique position to facilitate commercialisation.

Compared with conventional 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. However, 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 could unlock their use and see their translation from research into prototypes and industry.

LiSTAR is designed to address these challenges. The consortium is generating new knowledge, materials and engineering solutions, thanks to its application-guided approach, with dual focus on fundamental research at material and cell level, and an improved approach to system engineering. The project is addressing five key areas of research: cathodes and cathode interfaces; electrolytes and electrochemistry; anodes and new cell concepts; cell and system engineering; and Li-S characterisation. 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 commercialisation of this emergent technology.

Timeline with milestone/deliverables (March 2025)

- Identify and develop routes for ultra-high energy cells and improve their durability.
- Improve safety via implementation of non-flammable electrolytes.
- Overcome key remaining commercialisation barriers for Li-S batteries, particularly the use of $LiNO_3$ to expand the operating temperature window.
- Demonstrate the scalability of components and feasibility of the technology at relevant scales.
- Understand and mitigate the anode-dominated degradation routes of Li-S cells.
- Demonstrate a battery management system to maximise performance.
- Develop bespoke advanced cell monitoring and diagnostic techniques from the outset of the chemistry's commercialisation.

The project aims to pave the way for multiple Li-S cell concepts: an 'energy' and 'lifetime' 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 applications. The project anticipates that the first viable commercial products will be for niche markets that place a premium on energy density, which will subsequently stimulate others (including automotive). Alongside the research partners, the consortium's industry partners 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 of Oxford (Lead)
University College London
University of Cambridge
Coventry University
Cranfield University
University of Birmingham
Imperial College London
University of Nottingham
University of Southampton
University of Surrey
Aerospace Technology Institute
+ 5 Industry Partners

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Research Community

Convening the UK battery community at the Faraday Institution Conference 2023

Since its inception, the Faraday Institution has been actively building a unique and dedicated community. It consists of university researchers from various fields, committed industry partners, technology business development specialists, and a new generation of students. Together, they bring a diversity of perspectives and are united in their determination to overcome challenging scientific obstacles.

The research community is a powerhouse, comprising over 500 researchers from across 27 universities. Collaboration with international research groups and UK industrial partners ensures research directions remain commercially relevant and the likelihood of success is maximised. By combining the strengths of highly competitive university research groups across the UK, the Faraday Institution has marked a significant moment of change for the research community, establishing a new model for conducting nationally important strategic research.

Community building initiatives undertaken by the Faraday Institution, alongside training partner Skills 4, include the provision of Inclusion Ally workshops - providing practical ways for the community to improve inclusivity - and a THRIVE career development programme for a cohort of researchers who identify as being in a minority in their work environment. The Faraday Institution Community Awards are a way to celebrate successes and reward members of the community who demonstrate excellence and behaviours in line with the organisation's mission and values – and who go above and beyond what would normally be expected.

The Faraday Institution Conference, held in September 2023 with the theme of driving towards sustainable electrification of the UK, served as a resounding endorsement from the community. As part of the Institution's objectives of being the trusted national convener for battery science and building a broader community of battery researchers, the conference doors were opened to academics working within and beyond Faraday Institution projects, to UK industry and policy makers in the battery space, and to overseas partners. 52% of delegates were academics already working within the Faraday Institution community, 27% were from other UK academic institutions, 13% from industry and 7% from government. It was a pleasure to convene this thriving and diverse community for three days of science dissemination and networking. The buzz in the room and sense of community was palpable, and we look forward to creating a similar atmosphere at the 2024 Conference hosted by Newcastle University from 10-12 September.

2023 Conference success metrics:

- 530 delegates
- 71 speakers
- 9 themed sessions
- 160 posters
- 21 exhibiting companies
- 150 organisations represented of which 55 were industry or government
- 231 expressions of interest to speak or present posters

The thriving academic field of battery research and the collaborative community that is being built offer a wealth of opportunities for researchers at every level to grow their careers in the UK battery sector, be it in academia, industry or policy, with a significant proportion of the community receiving external recognition and promotions.

The 2023 Community Awards winners

Early-Stage Commercialisation

The Faraday Institution has a mission to not only sponsor fundamental, world-class battery research, but to develop resulting discoveries into technologies with significant impacts on the competitive advantage of the British manufacturing industry.

The Institution does this by actively promoting novel means of translating the results of university battery research into technological advancements, undertaking activities that go well beyond the remit of a standard research organisation. See, for example, the support for UK-based start-up OXLiD, which has led to a successful acquisition by Gelion, and retained a significant lithium-sulfur battery IP portfolio for the UK.

The Faraday Institution has developed collaborative links with more than 122 industrial partners in the automotive, aerospace, battery, and materials sectors, working in collaborative relationships that help to identify application needs as the organisation continues to reshape its research programmes.

TSCAN Methodology

The Faraday Institution has developed an analytical methodology to assess early-stage commercialisation potential for each of its research projects. The assessment results in a bespoke approach to commercialisation tailored to each project, the prioritisation of limited resources and the development of consortia that are investment ready. The process has substantial input and support of the academic research teams and industrial partners (where relevant). The assessment is made up of the five components: Technology, Significance, Competition, Action and Investment. The methodology continues to change and develop.

Commercialising Modelling Research

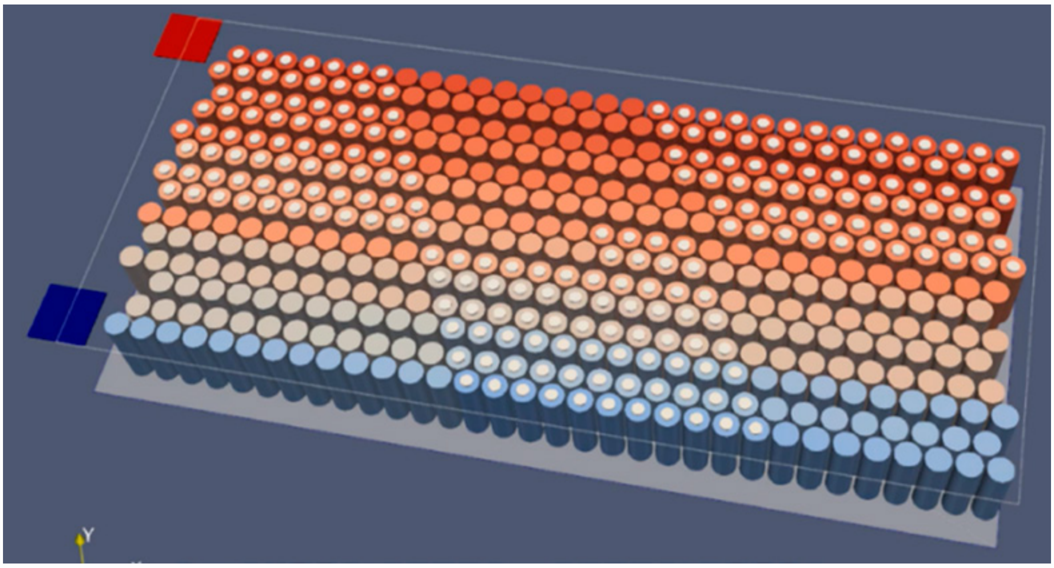
As an example of the innovative routes the commercialisation team is pursuing, the Faraday Institution has launched the Battery Parameter eXchange (BPX). It is an open standard to support the wider adoption of 'industrial strength' physics-based modelling by the battery industry globally. BPX is 'usage driven' and is delivering Faraday-funded research in a form directly useable day-to-day by engineers in industry organisations who are developing batteries.

The standard has been downloaded by over 100 organisations, with. 70% of these from industrial users across a range of battery industry sectors. The feedback from industry, especially OEMs, is that BPX has been very useful in stimulating thinking and discussion, and has helped to highlight many common challenges in industrial battery modelling. Industry organisations have provided strong encouragement to further develop the BPX standard, with various companies being collectively engaged in the process and with the Faraday Institution acting as the convening entity. The commercialisation team believes this standards-based approach of delivering research value directly to engineers based in industry is a valuable supplement to other Faraday Institution research dissemination paths, and one that is more immediately relevant and that can drive further industrial engagement.

Commercialisation project portfolio

The Faraday Institution's commercialisation portfolio also includes (as of March 2024):

- 16 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.
- 14 Entrepreneurial Fellowships, supporting researchers across the UK looking to create new businesses and commercialise battery technologies.
- 18 Industry Fellowships, a programme to strengthen ties between battery researchers working in industry and academia.



Thermal modelling of a Tesla battery pack

Industry sprints

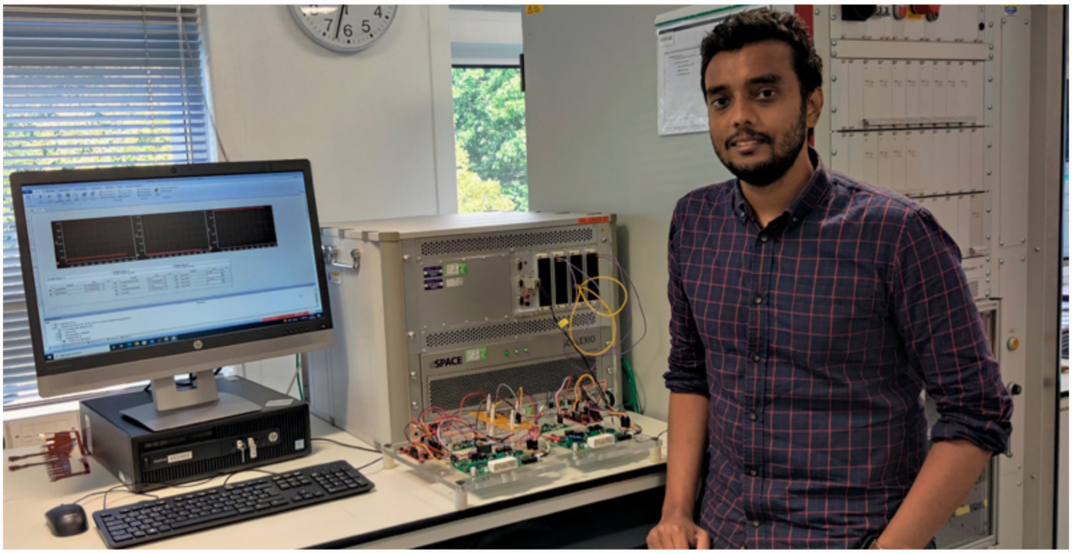
Sprints dedicate small, focused teams of researchers to solve a commercially relevant research opportunity identified from within the research programme and prioritised by an industrial partner. Over a period of 6 to 15 months, researchers work closely on the challenge, meeting frequently to review progress 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	Description
Off Gases and Detonation Behaviour	Researchers at 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 this Sprint to establish the evolution of gases under various conditions provided results that allowed researchers to begin to form models and design rules for pack development, increasing safety whilst limiting the destructive testing of multiple expensive test articles. The battery safety research in the Faraday Institution portfolio has since been combined into a project in its own right (SafeBatt), increasing the scope and visibility of this important work.
Materials for Thermal Transfer	Thermal control of a battery pack is vitally important to its performance and longevity. Higher performance thermal materials could usefully improve both, by transferring heat efficiently from the cells to the cooling system, and by isolating cells from their neighbours in cases where an individual cell is going into thermal runaway. This Sprint involving the University of Oxford and WAE and aligned to the Multi-scale Modelling project is looking at the development of nanomaterials composites, phase change materials and functional scaffold materials to meet these aims, then both model and experimentally validate them.
Cell Degradation	An EV manufacturer had evidence that some battery chemistries were experiencing faster capacity fade when stored at a specific state of charge (SOC). The Sprint, involving WMG, UCL, the University of Leicester and the industry partner, and aligned to the Degradation and Modelling projects, has completed a comprehensive study of calendar aging of commercial cylindrical cells as a function of SOC and temperature to resolve the specific conditions for accelerated aging. The team performed forensic characterisation to determine the root causes of the specific degradation mechanisms, distinguishing contributions from the anode and cathode individually and because of crosstalk using a range of post-mortem and operando methods. The project is enabling the automaker to develop protocols and strategies to suppress the potential degradation mechanism(s).
Optimising Pack Design for Thermal Management (TOPBAT)	Members of the Multi-Scale Modelling project at Imperial College London, working with AMTE Power, investigated 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 alongside modelling work, which once validated enabled 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.
Processing of Oxide Solid-State Batteries	Solid-state batteries allow safe utilisation of metallic lithium electrodes and hence can greatly extend driving range of vehicles. Oxide ceramics offer a highly promising route to solid-state batteries that is facile to process at low cost. Researchers at the University of St Andrews are working with Morgan Advanced Materials and in collaboration with Ilika, in an Industry Sprint project of immediate interest to an automaker. The project, which complements the scope of SOLBAT, is seeking to develop and optimise the process of making supported thin, dense films. Fine-tuning the support would help to mitigate limited conductivity and optimise performance and cyclability.

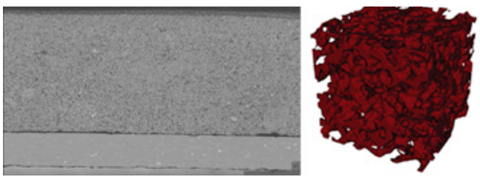
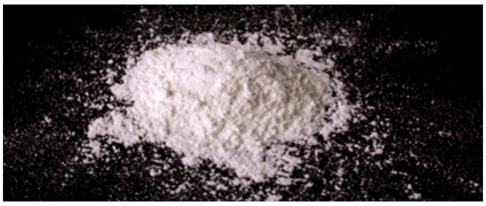
Solid-state battery pouch cell testing at Ilika.

Photo courtesy of Ilika.

Sprint	Description
Screening of ELectrode Manufacturing for All-Solid-State Batteries (ELMASS)	WMG is comparing different coating techniques to determine the performance of the resulting morphologies under different cycling conditions. A key deliverable of the project is the demonstration of the coatings in the type of solid-state batteries being investigated by the SOLBAT project
Li-ion Conducting Fibre for Composite Solid-state Electrolytes (ZEST)	This Sprint is targeting the development of a lithium-ion conducting fibre material for use in a composite solid-state electrolyte for next-generation batteries. A subsidiary of Morgan Advanced Materials has provided raw materials to the Novel Glass Group at Southampton University to develop a continuous, shot-free, single-step fabrication process to manufacture specialist ultrathin fibres of a patented composition to a tight tolerance with high yield. Hundreds of kilometres of fibre have been successfully fabricated and the potential of this novel technique is being explored. The industry partner is engaged with a leading battery producer with a view to supplying the material commercially if the project is successful.
Developing Commercially Viable Quasi Solid-State Lithium-Sulfur Cells	This Sprint focused on the development of quasi-solid-state lithium-sulfur (Li-S) batteries that have the potential to significantly enhance the number of times Li-S batteries can be charged before they reach end of life, the energy they can store per unit volume and the temperature range over which they can operate. Aligned to the LiSTAR project, it combines the expertise of start-up OxLiD and UCL. Researchers were testing and screening potential cathode materials and developing suitable electrolytes for a quasi-solid-state format. The project demonstrated the best cathode materials for this system in combination with suitable electrolytes and evaluated the maximum potential performance of quasi-solid-state Li-S materials to guide future commercialisation.
Dry Printing Technology Accelerator – (Xerode)	Xerode aims to overcome limitations of the current electrode manufacturing process by building a prototype device using a previously untested technique that would print dry, formulated electrode directly onto a moving current collector and give positional and compositional printing control for advanced customer-driven designed electrodes. If successful, this innovation will enable large-scale, rapid, and completely dry electrode manufacturing, reducing manufacturing cost and potentially increasing energy/power density of batteries. The University of Sheffield is leading this Sprint, which is aligned with the Nextrode project.
Validated and Integrated Platform for battEry Remaining life (VIPER)	A recently completed Faraday Battery Challenge collaborative R&D project – COBRA – involving WMG, University of Warwick and Eatron Technologies, proved the feasibility of a hybrid approach to predict remaining useful life (RUL) that combines machine learning and physical models. However, further improvement in the physical models were needed to increase the accuracy required for commercial applications. This follow-on Sprint project, aligned to the Multi-scale Modelling project, extended the collaboration. It accelerated the development of a working demonstrator/prototype of the RUL prediction system, integrating it into Eatron's battery management system, validating models with experimental data, and developing an understanding of Cloud model capabilities/limitations.



Lead researcher Dhammika Widanalage at the labs at WMG.

Sprint	Description
Accelerating commercialisation of new scalable and sustainable manufacturing methods for silicon anodes	The University of Sheffield and WMG at the University of Warwick are seeking to develop the first commercially viable, large-scale process for the bulk manufacture of porous silicon for use in lithium-ion battery anodes. The team are extensively testing silicon anodes produced from their proprietary ultra-low temperature, low-cost, and intrinsically scalable production method, generating commercially relevant data on capacity, stability, and cell life, with the aim of validating the commercial impact of the technology. The project is also undertaking market and customer discovery, and techno-economic analysis, to enable the pitching of the process to potential investors and customers, and embark on the formation of a spin-out to commercialise the technology.
High voltage oxide cathodes for sodium-ion batteries Li-ion Conducting Fibre for Composite Solid-state Electrolytes (ZEST)	In a Sprint complementary to the NEXGENNA project, the University of Oxford is leading a fast-paced, materials discovery programme to identify new oxygen-redox sodium-ion positive electrode materials. The project aims to identify the most promising candidates in terms of cycle life, energy density, stability and rate performance (that use primarily earth-abundant elements) to take forward for scale-up. The team will make single layer pouch-format full cells to demonstrate electrochemical performance and illustrate commercial potential.
NextCell – Next Generation Cell Design	TWMG at the University of Warwick and Agratas have identified that significant innovation opportunities exist around new cell formats and architectures that improve performance and life while concurrently reducing manufacturing cost and end-of-life management. NextCell is adopting a systems-engineering methodology to enhance the outcomes and efficiency of cell design, manufacturability, and through-life sustainability. This sprint aims to co-create a strategy for the design and manufacture of next-generation cell concepts, that meet the fundamental electro-thermal-mechanical challenges that arise from the introduction of novel cell formats and achieve even greater levels of cell-to-pack efficiency, through life sustainability and system safety. The outcome of this project will be the creation of a generic roadmap to support the further development of a sovereign cell design capability for the UK.
Understanding safety for next generation battery technologies	Building upon the significant experience of the SafeBatt project, researchers at the University of Oxford and University College London are partnering with Ilika to establish thought leadership in safety protocols for next-generation batteries and are undertaking physical safety testing on prototype cells to inform industrial design and deployment.
Microstructural design of LMFP cathodes through machine learning assisted manufacturing optimisation	The aims of this Sprint, led by WMG at the University of Warwick, are to: (1) utilise Polaron's AI tools to design enhanced lithium manganese iron phosphate (LMFP) electrode manufacturing processes to improve cell performance, addressing challenges identified by the Degradation project (2) deepen the understanding of LMFP electrode manufacturing (3) demonstrate the commercial value of Polaron's process optimisation tool, validating the company's cell design approach to enable further application across the battery industry.  SEM image of LMFP electrode manufactured in WMG alongside its AI reconstruction using Polaron's AI tools
Niobium oxide recycling and development of industrial capabilities (NORDIC)	The Sprint, led by the University of Birmingham, aims to define a high-yield recovery process for Echion Technologies' mixed niobium-oxide anode active materials XNO® obtained from coated electrodes (scrapped during development or production) and from discharged cells. It is assessing total processing costs for each process stream and conducting a detailed benchmark characterisation of pristine material, production waste material and recovered material to determine performance post-recovery. The project represents a step towards Echion integrating XNO® recovery into an open- or closed-loop recycling process.  Echion's XNO® material

Entrepreneurial fellowships and spin-outs

The Faraday Institution Entrepreneurial Fellowship programme supports UK researchers in establishing new businesses and commercialising 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.

The entrepreneurial fellowship scheme stands as one of the Faraday Institution's most successful programmes, one that is seeding future success for the organisations involved. Companies in receipt of past Entrepreneurial Fellowships, without exception, continue to grow, thrive and make an impact to the UK battery sector and beyond, underscoring the Faraday Institution's ability to identify and support successful ventures. Examples of continued success include scale up of prototypes, securing follow-on funding, growing teams and securing new premises.

Completed Fellowships

Breathe Battery Technologies	Breathe Battery Technologies, a spin-out from Imperial College London, concentrates on battery system health, charging, cycle life and range. Collaborating with global manufacturers in automotive, robotics and electronics, it will provide the latest version of its charging software for use on Volvo Cars' new-generation fully electric cars. It has partnered with VARTA to enhance their Easy Blade battery series, cutting charge time by 27%. Another collaboration with smartphone maker OPPO aims to double the life of Reno8 Series batteries. As of December 2023, Breathe has expanded to 34 team members.
Cognition Energy	Cognition Energy specialises in thermal management and cell testing to improve battery life and ownership costs. The firm employs eight full-time and three part-time employees, and offers an extensive battery cell testing service that assists clients in gathering crucial data for the design and validation of their cells and packs. It has also developed a proprietary CellPod testing product, which is a micro thermal chamber specifically aimed at accurate control of cell temperature during tests.
Gaussion	Gaussion, a spin out from UCL, is developing its proprietary MagLiB technology that utilises a dynamic magnetic field to accelerate lithium-ion battery charging and extend lifetime. The technology has shown over 60% reduction in charge time in commercial cells while preserving energy and power density. The company is actively seeking commercial partnerships, has raised £2.85 million, grown its headcount to 10 and set up a 3,700 square foot R&D HQ in London.
Solveteq	Solveteq is a spin-out from Imperial College London, focused on the recycling of lead-acid batteries. The firm's patented low-temperature process aims to cut energy and environmental costs for recycling companies. Solveteq's technology enhances lead-acid battery recycling by removing high-temperature smelting, reducing energy consumption and emissions. Solveteq is testing a 6m3, 1kg/h prototype with plans to scale its technology to a 25kg/h pilot demonstrator.
Qdot	Qdot Technology is a University of Oxford spin-out that focuses on developing scalable and modular propulsion systems for hybrid-electric aircraft. Initially targeting heavyweight drones and small passenger aircraft, Qdot's products incorporate a patented thermal management technology that enhances battery efficiency and lifespan, and scalable and modular propulsion systems that will reduce overall operating costs. The company has raised over £1.6M in pre-seed funding, over £2.6M in grant funding, and £700,000 from consulting to develop its core technologies. Their team has grown to nine.
About:Energy	About:Energy is a joint spin out from Imperial College London and the University of Birmingham. It was set up in January 2022 to help commercialise the battery modelling capability developed by the Faraday Institution's Multi-Scale Modelling project. The company aims to facilitate the use of battery modelling by UK industry, increasing the speed of battery prototype development and giving the organisations it works with a competitive advantage. The company closed a pre-seed funding round in June 2022, employs 14 full-time members of staff, and collaborates with six research affiliates.
Illumion	Illumion is commercialising charge photometry, a bench-top optical microscopy technique for examining the internal structures and dynamics of batteries during their operation. The technology aims to simplify and reduce the cost of identifying defects within batteries, as well as speed up the development of new materials. Developed by researchers at the University of Cambridge, illumion's solution is agnostic to the underlying battery chemistry and is projected to be about four times less expensive than existing solutions, making it appealing for start-ups in battery development.

Ongoing Fellowships

Ionworks

Ionworks is a battery modelling software startup built around the physics-based modelling software PyBaMM (Python Battery Mathematical Modelling), a core part of the Faraday Institution's Multi-Scale Modelling project.

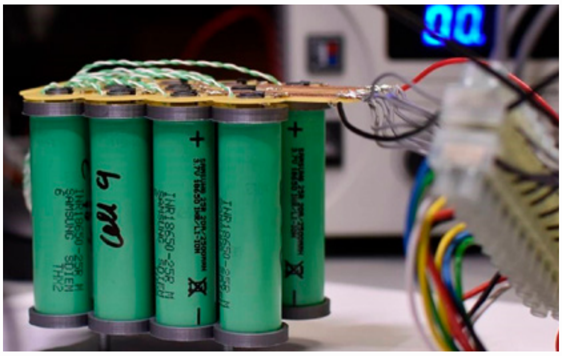
PyBaMM started in academia but is gaining greater adoption in industry, and Ionworks aims to supercharge this growth, unlocking the benefits of accurate battery models based on actual physical phenomena for use by industry. Ionworks' founders include members of PyBaMM's core development team, but are independent from PyBaMM's steering council and so are uniquely positioned to achieve this, while also retaining the independence, credibility and sustainability of the open-source platform and fostering the wider community.

The Entrepreneurial Fellowship will enable Ionworks to ramp up development of professional interfaces to transform their prototypes into attractive, widely usable products. It will also enable the organisation to roll out their software platform to UK clients within the next year.

The grant will allow the founders to focus on business development and consultancy style projects with key clients to gain further understanding of their specific modelling challenges, and develop the software accordingly. This will help Ionworks build a comprehensive battery analysis framework that can be used to run large-scale simulations in the cloud with data analysis to improve battery design through optimisation and materials discovery. The modelling solutions being developed by Ionworks compliment cell libraries being built by other companies, including previous Entrepreneurial Fellows, About:Energy.

Sention Technologies

Start-up Sention has developed a sensitive mapping technique that monitors reflected pulses of ultrasound to evaluate the physical properties of batteries with high special resolution. It can be used to rapidly assess the state of health (SOH) of cells with very limited power and space requirements – significant advantages over incumbent electrochemical techniques.



Cell testing at Sention

The Entrepreneurial Fellowship, led Dr Rhodri Owen of UCL, is allowing Sention to build a demonstration unit that will improve on the existing lab-based setup. This will include the development of a software back-end interface with the ability to automatically assess cells and increase throughput.

The data obtained from additional tests on new and aged cells will allow a detailed and statistically significant relationship between acoustic signature and the cell's SOH to be established. It will also provide data that can be used to inform ultrasound-based quality control systems by correlating the performance of the cells during cycling and their changing acoustic maps, allowing the team to predict which cells are likely to perform poorly.

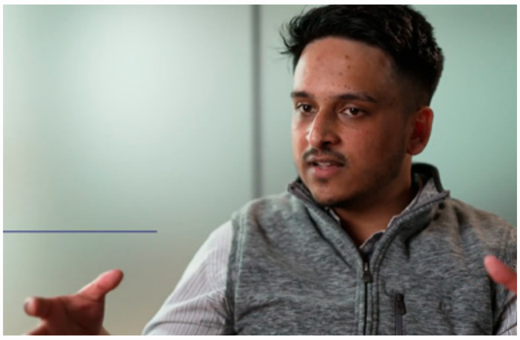
A number of development companies and automakers already have an interest in the technology. With a demonstration unit constructed and a statistically significant data set, the team aims to prove the technology's effectiveness and application to real-world scenarios and exploit these relationships.

Sention's technology has potential applications through the entire battery value chain, including:

- as a low-cost and rapid quality control check during cell manufacturing – identifying defects early in the cell production process, reducing production costs and scrap;
- as an acoustic battery management system to improve SOH (and state-of-charge) prediction; and
- as a high-throughput screening technique to assess the SOH cells at the end of life to determine their suitability for reuse.

Ongoing Fellowships

Recovolt


Mahfuz Kamal, Recovolt Founder

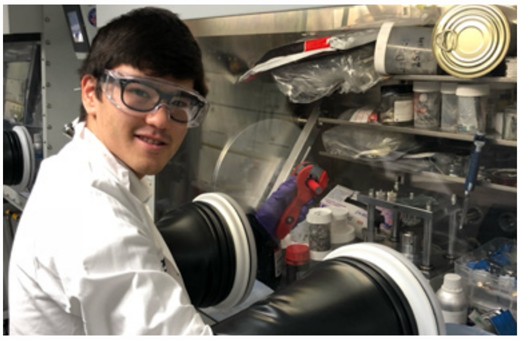
Recovolt is developing a cutting-edge battery discharge system that is deployed on lithium-ion batteries at their end of life to ready them for battery recycling. By leveraging advanced power electronics and intelligent algorithms, the technology can discharge multiple batteries simultaneously – addressing a productivity area that the recycling industry has identified as needing urgent action. The technology not only addresses fire risks, but also captures residual energy, turning a hazard into an asset that can be used to power facilities, offsetting operational costs. The innovation also has potential use by scrap yards and insurance companies by ensuring safe storage, faster transport and value generation from assessing written-off vehicle batteries for reuse.

The team has developed a prototype, and integrated and tested subsystems in a controlled laboratory environment. It has also developed a business model, informed by taking part in ICURe and Conception X incubator programmes, and an Impact Accelerator Award.

The aim of the entrepreneurial fellowship is to facilitate the development of a scaled prototype, which will provide future validation and unlock future feasibility studies with potential customers. Besides providing business mentoring, the fellowship will pay for staff salaries, materials and manufacturing of the prototype, lab costs, test equipment and engagement with a consultancy to further refine the value proposition.

Founder Mahfuz Kamal is a recent graduate of Newcastle University and was a member of the first cohort of Faraday Institution PhD researchers. The technology originated from Mahfuz's PhD thesis: "Energy management techniques to discharge lithium-ion batteries prior to recycling," which he completed as part of the ReLiB project.

TaiSan Energy


Sanzhar Taizhan, founder of TaiSan Energy

TaiSan Energy is pursuing the development of a quasi-solid-state sodium-ion battery, based on an innovative gel polymer electrolyte and a sodium metal anode, to achieve best-in-class energy density and industry-standard room-temperature ionic conductivity.

The concept eliminates the use of a flammable liquid, potentially further enhancing the safety profile of sodium-ion batteries. The team uses a novel polymerisation method to enable an ideal interface between electrolyte-electrode and that removes the need for a high cell stacking pressure. Early indications show that this process approach will be scalable using over 70% of existing lithium-ion battery production lines. The concept retains the low-cost benefits of sodium-ion cells, making it suitable for price-sensitive applications.

The aim of the Entrepreneurial Fellowship is to advance its product development, which would allow the company to pursue agreements with battery OEMs to license its technology. At the end of the Fellowship, prototype battery cells will be supplied to customers to conduct preliminary independent cell tests. Besides providing business mentoring, the Fellowship will pay for staff salaries, raw material purchases, and manufacturing of electrodes, custom electrolyte, and the assembly of coin and monolayer/multi-layer small pouch cells. These activities will be carried out by TaiSan's in-house lab with support from Coventry University, and cell performance will be characterised after cycling to validate modelling predictions of cell cycle life.

Ongoing Fellowships

Ionetic

IONETIC is a start-up specialising in battery pack technology, which aims to leverage its state-of-the-art design platform and production strategy to manufacture optimised and cost-effective battery pack solutions. The company works with niche vehicle-makers and automotive OEMs to overcome some of the challenges of electrification. Its approach manages the end-to-end development process, from initial conceptualisation to final production, streamlining the time and costs required to bring a battery pack from vision, through design, test and manufacture, to an optimised, vehicle-ready product.

Its design platform and vertical integration adds efficiencies during each step of battery pack development. Capital expenditure of battery pack development has shown to be reduced by up to 90%, while increasing energy density up to 36%, and adding up to 110% more range.

The Entrepreneurial Fellowship will help IONETIC by funding labour and materials costs, as well as subcontracting fees, as the company builds a secondl generation battery module prototype. It will enable IONETIC to improve the current design and test parameters such as busbar design, material selection, welding parameters, and safety features, as a step towards scaling its hardware to a full- size battery pack safely and efficiently. The Faraday Institution team will also provide IONETC with business advice, mentorship, networking opportunities, and further development of its IP strategy.

Molyon

Ismail Sami, a Faraday Institution Research Fellow, previously won first prize in Cambridge Enterprise's Chris Abell Postdoc Business Plan Competition 2023

Lithium-sulfur is a lightweight battery technology of potential interest to the aerospace industries. As part of the LiSTAR project, researchers at the University of Cambridge have demonstrated the use of innovative lithiated metallic molybdenum disulfide nanosheets to increase the energy density of lithium-sulfur batteries. The team has manufactured prototype pouch cells with the highest reported volumetric energy density for this cell chemistry (735 Wh/L) that also demonstrate excellent cycling stability. The IP-protected cathode material consists of earth abundant and inexpensive raw materials. Spin-out Molyon has been set up to commercialise the technology.

The Entrepreneurial Fellowship will help Molyon by providing salary, equipment, and consumables as the team develops the know-how and processes to scale up the manufacture of the cathode material. The Faraday Institution will also help the team develop industrial partnerships and provide business support and mentoring. The Fellowship's ultimate aim is to demonstrate the feasibility of scalable, sustainable, and economic manufacture of the material, which will enable future prototype testing with customers, bringing the team a step closer to investment-readiness.

Molyon is the second spin-out from the LiSTAR project.

Enough Energy

Many electric vehicle (EV) fleet operators have a greater charging demand than their facilities allow. Solutions such as grid upgrades, battery-buffered chargers, and use of public chargers do exist. However, they can be very costly and/or slow to deploy. A new company has a solution.

Enough Energy is leveraging modular multilevel converter technology with batteries to develop a battery buffered EV charger capable of both AC and DC charging. The benefits of the technology approach include:

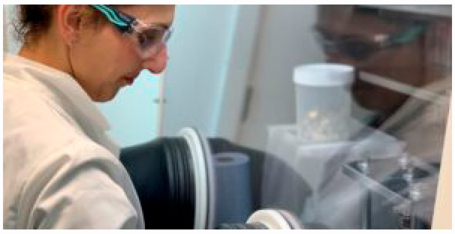
- a significant reduction in the system cost due to elimination of traditional power conversion hardware.
- increased fault tolerance through the ability to bypass weak modules.
- the ability to integrate second life cells with active module-to-module load balancing.

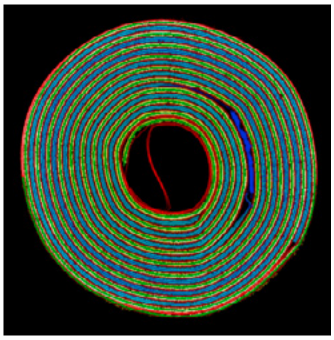
The solution will benefit EV fleet operators by allowing them to access rapid EV charging on site without needing a high-power grid connection. Load management capabilities of the system also have the potential of stabilising grid demand and maximising input from renewable generators. Enough Energy is also exploring off-grid applications for portable EV charging and are working on their first pilot project with a customer for a prototype inverter.

The fellowship will fund the production of a technology demonstrator at full scale and pay the founders wages to allow them to maintain full focus on product development. The outcome of the fellowship will be the demonstration of DC fast charging directly from the demonstrator. Understanding the performance capabilities of the product will be a precursor to external testing and certification, and a pilot programme with potential customers.

Industry fellowships

The Faraday Institution Industry Fellowships 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	Description
Coventry University with Nyobolt	Prof Alex Roberts and Dr Ageta Greszta at Coventry University partnered with Nyobolt to prototype their niobium-based anode materials into working battery cells. The collaboration proved highly successful for both parties involved, with prototype cells confirming performance potential that supported a recent funding round for Nyobolt. Both researchers have benefited from career development opportunities from interacting with the technical and commercial teams at Nyobolt as they head towards larger scale production.  The cell fabrication facilities at Coventry University have greatly benefited Nyobolt as well as bringing new capabilities to the LiSTAR consortium.
Imperial College London with Ilika Technologies	Prof Greg Offer and Dr Ganesh Madabattula at Imperial College London partnered with Ilika to apply the modelling tools developed by the Multi-scale Modelling project to solid-state batteries. This modelling of the fundamental physics governing solid-state batteries allowed 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.
University of Strathclyde with CDO2	The fellowship's goal was to establish UK capability in fluxgate magnetometers at the sub-picoTesla level and optimise their application in EV battery management with commercial partner CDO2. By taking sensitive magnetometer readings, CDO2 can visualise and monitor the current flow within battery cells and packs, with implications for the development of cell and pack designs without the complications of invasive sensing technologies. A fluxgate magnetometer with performance comparable to commercially available products was developed by Dr Terry Dyer, which has several competitive advantages, including lower cost, small form factor, digital readout and WiFi connectivity. In a follow-on fellowship, a 2D array of magnetometers was developed and fabricated for direct implementation in CDO2's EV battery current imaging application.
Cranfield University with Delta Cosworth	Dr Abbas Fotouhi at Cranfield University worked with Delta Cosworth to explore potential applications of artificial intelligence to develop novel temperature prediction and estimation techniques that improve the performance of battery thermal management systems, bringing possible benefits to battery performance and lifespan. A combination of fuzzy systems and neural networks was used to develop novel models, which act as a "soft sensor" inside a battery pack to reduce the measurement costs as well as improve safety by predicting the battery temperature in a finite time horizon.
University of Sheffield with TFP Hydrogen Products	Prof Serena Cussen and Dr Glen Murray of the University of Sheffield worked 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 worked 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 EVs.

Fellowship	Description
The University of Birmingham with Echion Technologies Ltd	Prof Peter Slater of the University of Birmingham is working closely with the R&D team of Echion echnologies to identify new mixed niobium oxide (XNO®) phases for use as high-performance anode active materials in Li-ion batteries – focused on high safety, long-life (>10,000 cycles), and ultra-fast charge (2-10 mins full charge). This includes assessment of their performance and in-depth materials characterisation. So far, two new classes of XNO® materials have been taken as new potential products into Echion's new product development cycle, where they are being assessed for commercial viability and manufacturability.  A researcher making coin cells in the Echion laboratory. Photo courtesy of Echion
The University of Sheffield with Finden	A successful collaboration between Prof Serena Cussen, University of Sheffield and Dr Stephen Price of Finden Ltd, which has been developing a characterisation technique that aims to inform strategies to mitigate deleterious behaviour in high nickel-content cathodes, has been extended with a follow-on Industry Fellowship. The first phase of the fellowship pushed X-ray diffraction computed tomography (XRD-CT) to the nanoscale, providing insights into the FutureCAT materials' crystallite orientation and informing understanding of lithium diffusion pathways, mechanical strength and aging behaviour (of importance to designing materials capable of fast charging). The second phase aims to deliver standardised in-situ capabilities for the use of XRD-CT to determine how Ni-rich cathodes respond to different charge/discharge conditions. The new in-situ capabilities will be used to characterise pouch cells incorporating promising new materials developed by the FutureCAT project.  Overlaid XRD-CT image of cell components identified in the AAA pristine battery cell: red – separator, yellow – anode (LiC12), green – copper current collector, cyan – cathode (primary NMC532), dark blue – aluminium current collector
The University of St Andrews with AMTE Power	Prof John Irvine, Dr Rob Armstrong and Dr Paul Connor of the University of St Andrews collaborated with AMTE Power to strengthened the pathway from laboratory to cell production. The partnership focused 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 strengthened 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	FutureCat and Exawatt have partnered to determine how cathode active material can be manufactured in the UK in a cost-competitive manner. Dr Usama Mohamed at the University of Sheffield has translated laboratory-scale techniques into an industrial process model to estimate a cost of goods sold. The model identifies the optimal set of manufacturing parameters that maximise the yield of cathode precursor. Judiciously selecting unit operations that transform the precursor into a lithiated cathode material, the capital and operating costs of the chemical plant are minimised. The model has been validated using data from Chinese large-scale producers and has shown the viability of UK-based manufacturing and identified the cost drivers that must receive most significant focus.  Simon Price, CEO Exawatt, with the team at the University of Sheffield
Imperial College London with WAE	Dr Billy Wu and Dr Haijun Ruan of Imperial College London have been working with WAE on translating knowledge from the Multi-scale Modelling project towards understanding the impact of battery derating techniques. These approaches are informed by on-vehicle diagnostic techniques with the aim of extending cell lifetime. A machine learning based approach for extracting key battery states has been implemented and used to define dynamic operating limits that change with aging. This has resulted in better understanding around the benefits of the approach as well as a holistic review of derating approaches for lifetime extension.

Fellowship	Description
Bristol University with Thermal Hazard Technology	Dr Alastair Hales, University of Bristol and Prof Gregory Offer of Imperial College London partnered with Thermal Hazard Technology (THT) to develop a common testing framework to improve the parameterisation of battery models. The testing framework has provided improved tools and methods for a more efficient product development processes and learnings are being incorporated into THT's market-leading thermal control apparatus used for battery testing. The Fellowship marks a transfer of knowledge from the Multi-scale Modelling project and the TOPBAT Industry Sprint to a commercial product of a new UK-based industry partner.
Imperial College with Hitachi High-Tech Europe	Dr Ann Huang from Imperial College London is partnering with Hitachi High-Tech Europe to develop, refine and commercialise innovative electrode manufacturing equipment. This will facilitate the pathway from laboratory to electrode production with bespoke microstructure at large scale. The work is part of a long-term aim of optimising ion diffusivity and increasing energy densities at fast charging for both Li-ion and solid-state batteries. The fellowship is working towards a new equipment design that has the potential to increase production speed and reduce costs, and to aid early adoption by UK industry.
Coventry University with Breathe Battery Technologies	Dr Tazdin Amietszajew of Coventry University is collaborating with Breathe Battery Technologies to advance battery management systems and cell behaviour tracking capabilities. Previously unfeasible to monitor battery internal operating conditions are being tracked, supporting the validation and development of new battery management and control approaches. The collaboration is expanding bespoke in-situ thermodynamic monitoring techniques that allow for deeper and clearer insights into commercial cells operating conditions. Insights support Breathe Battery Technologies' continued development of battery management solutions, which the company offers as compatible with today's embedded systems in cars and electronics, where only standard temperature, voltage and current sensors are available.  Members of the Coventry University/ Breathe Battery Technologies Fellowship
Imperial College with Deregallera	Dr Nuria Tapia-Ruiz of Imperial College London is partnering with Deregallera to improve the processing of high-performance hard carbons for sodium-ion batteries. The project aims to use MgO templates to produce high-capacity hard carbons (>350 mAh/g). The team is working towards improving and optimising the templating process for industrial applications, through the use of mild acids, to regenerate MgO templates with the aim of eliminating hazardous HCl waste, providing renewable feedstocks and thus reducing disposal and bill-of-material costs
Coventry University with FEV UK	Dr Joe Fleming of Coventry University is collaborating with FEV Group to enhance cell monitoring of battery modules. The aim is to achieve efficient and reliable monitoring, control, and communication within battery modules, while minimising complexity and external wiring. The project is developing a novel approach that integrates multiple powerline communication sensor nodes directly within the battery modules at a cell-to-cell level. Powerline communication enables the simultaneous transmission of both data and power within the same conductor. The distributed battery management system developed will be cell and chemistry agnostic, making it suitable for all types of battery technology.
The University of Birmingham with the UKBIC	An industry fellowship between UK Battery Industrialisation Centre (UKBIC) and the University of Birmingham, led by Prof Emma Kendrick and Dr Carl Reynolds, is facilitating the sharing of knowledge on electrode slurry characterisation and modelling. It is improving the ability to predict the rheology of electrode slurries as they are scaled up from lab-scale to production scales, so reducing coating line dial-in times and scrap rates and improving product quality. The fellowship aims to further develop the understanding of how formulation impacts slurry and coating processability, and provides rheological parameters as inputs to computational fluid dynamics models that can be used to predict slurry coat-ability and inform initial process parameters for production.  Carl Reynolds and Emma Kendrick with the coater at the University of Birmingham

Inspiring and Training the Next Generation

The growing national need for energy storage researchers is evident, in order to support research and development for a UK domestic battery manufacturing industry. 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 for the sector. The organisation plays an active role in inspiring, attracting and retaining young people, particularly those from groups historically underrepresented in STEM (science, technology, engineering and maths), to consider careers in the field. This involves nurturing a diverse talent pool at various stages.

Researcher Professional Development

With 75% of Faraday Institution researchers aged below 40, a significant portion of the battery community comprises early-career researchers who are actively seeking opportunities to advance their careers. The organisation provides a range of continuing professional development opportunities for early-career scientists and engineers as they build their researcher identities. The Early Career Researcher (ECR) Committee creates and delivers high-quality training opportunities and events, including the ECR Conference and Training Event and annual Faraday Career Week. Researchers and project managers receive a training budget of £2,000 each year dedicated to their professional development.

PhD Training Programme

Since its inception in 2018, the Faraday Institution PhD Training Programme has supported 85 studentships. Collaborating across partner universities to provide a bespoke curriculum that encompasses technical, commercial, and transferable skills, the programme's primary goal is to nurture the next generation of battery experts, empowering them to emerge as successful leaders in their respective fields.

To ensure the proficiency of PhD researchers, the programme offers networking opportunities and specialised battery-related courses taught by academic and industry experts. These equip researchers with comprehensive knowledge and essential skills to maximise the potential of their research projects. Moreover, the organisation partners with expert training providers to deliver sessions such as presentation skills, project management, negotiation skills, as well as thesis and grant writing workshops. 100% of the first cohort of researchers have now secured permanent positions in the battery sector.

A further 100+ affiliated PhD researchers are valued members of Faraday Institution research projects. The organisation encourages PhD researchers to undertake three-month internships to explore opportunities that further their skills, grow their networks and/or showcase future battery-related careers, and enhance their projects.

Undergraduate Attraction

A range of initiatives attract and inspire undergraduates toward energy storage careers and showcase the opportunities the battery sector has to offer. To date, the Faraday Institution has funded 300+ Faraday Undergraduate Summer Experience (FUSE) internships, giving undergraduate students the opportunity to undertake paid eight-week placements with battery researchers at member universities. Alongside the research, FUSE interns have a series of cohort calls. The FUSE internship programme is also proving an effective feeder programme for the organisation's PhD Training Programme, while other initiatives include careers webinars on Battery Day and sponsorship of Formula Student.

FUSE undergraduate interns at the University of Oxford

STEM Outreach

The Faraday Institution has trained over 85 PhD researchers as STEM Ambassadors who are now adept at delivering presentations about their research in a manner that is relatable, engaging, and creative, effectively reaching diverse audiences. The organisation makes available a wealth of battery-related STEM outreach resources and over 13,000 young people have had the opportunity to learn about batteries through engaging with the "Faraday Fully Charged Battery Box."

Faraday Institution PhD researchers at WMG Battery School 2023

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 and industrial communities.

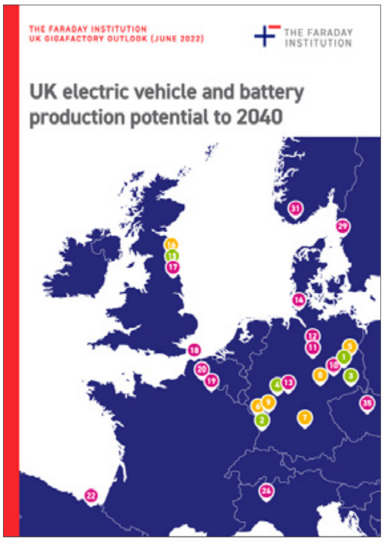
Faraday Insights

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.

19 Faraday Insights have been published, including most recently:

- Powering the Skies: The Rise of Electric and Low-Carbon Aircraft.
- Developments in Lithium-Ion Battery Cathodes.
- Improving the Safety of Lithium-ion Battery Cells.
- The Micromobility Revolution Gathers Momentum.
- The Value of Modelling for Battery Development and Use.
- The Importance of Charging Infrastructure to the Electric Vehicle Revolution.

Micromobility Insight report



EV report

Faraday Reports

The Faraday Institution's report 'UK Electric Vehicle and Battery Production Potential to 2040' continues to be the definitive resource on the demand for UK-based gigafactories. The Faraday Institution predicts that there will be demand for ten UK-based gigafactories by 2040, each producing 20 GWh per year of batteries. The report has had 250+ media citations since it was first published in 2019, and was cited in the UK Government's announcement in July 2023 that Tata Group is to invest over £4 billion in UK gigafactory, creating thousands of jobs.

As an example of another in-depth report commissioned by the Faraday Institution, a report was published in April 2023 analysing how hydrogen and battery technologies are likely to be used in different sectors within the UK, including transportation, manufacturing, the built environment, and power, to 2050. Both technologies are anticipated to play an increasingly vital role as the UK transitions to a low-carbon future to address critical concerns of climate change and energy security. Batteries and hydrogen have distinct characteristics and should largely be viewed as complementary rather than competing technologies. Both will require significant technological advance and extensive scale up of manufacturing and deployment if the UK is to meet its obligation to reach net zero by 2050.

Input into Inquiries and Consultations

The Faraday Institution provides detailed written and oral responses to government inquiries and consultations to inform the UK's transition to energy storage technologies.

Recent examples include:

- House of Commons Business and Trade Committee Inquiry into Batteries for EV Manufacturing.
- House of Lords Science and Technology Committee Inquiry into Long-duration Energy Storage for Net Zero.
- House of Lords Environment and Climate Change Committee Inquiry on Electric Vehicles.

Innovation

Innovate UK

Cells and material innovation projects

This section contains innovations in cells and battery materials for lithium-ion chemistries.

The advancements presented here are on novel production methods of state-of-art active and inactive battery materials, such as current collectors for high-power applications. Projects will also showcase new materials to enhance battery power and energy density as high-energy anode materials, and the use of digital tools for material discovery, digital twins, modelling, and simulation.

Just some of the UK funded organisations

- ABOUT:ENERGY
- BREATHE
- altilium clean technology
- WMG The University of Warwick
- Global Nano Network
- James Durrans Group
- Fortescue
- LiNa Energy
- exawatt
- E+R Group
- Waygate Technologies (a Baker Hughes business)
- cdo2
- University of Sussex
- Echion Technologies
- Coventry University
- Anaphite
- ilika
- Batri
- Cellmine
- RSB Battery Recycling
- Ricardo
- nexeon
- JLR
- Integrals Power
- Immersion Cooling Liquids
- Cornish Lithium
- nyobolt
- Addionics
- FluoRok (Reinventing Fluorination)
- Imperial College London

ACT-SYS: Rapid, edge analytics driven, multi-point, inline inspection solution for assessment of pouch cell battery quality during manufacture

Introduce a rapid, multi-point cell inspection tool for gigafactories (HyLite) to enhance quality control, reduce waste, and empower production personnel. Project activities include customer discovery, POC development, and industry demonstrations.

Project costs
Total project costs: £258,617
Grant contribution: £204,198

Executive summary

The lithium-ion battery (LIB) market is growing exponentially, fuelled by growing demand for electric vehicle and energy storage revolutions. However, scaling up production is plagued by high scrappage rates of potentially as high as 30%, and slow, inefficient inspection processes. To achieve a sustainable battery future, tighter quality control is essential.

Hy-Met, a UK-based deep-tech startup, is tackling this challenge with their "Hyper Measurement Platform." The first product that uses this platform is a breakthrough rapid/non-contact battery inspection solution called "HyLite" (currently at TRL4) that can perform 100% cell inspection for early manufacturing defect detection, inline and instantaneously. This innovative system combines proprietary sensors, electronics, and software to provide real-time insights into LIB cell production. Unlike traditional methods, it offers complete traceability and helps reduce waste in large-scale factories.

Hy-Met has joined forces with the Manufacturing Technology Centre (MTC) and the UK Battery Industrialisation Centre (UKBIC) for a feasibility study aimed at overcoming the limitations of current battery production monitoring methods. This collaboration will also focus on creating functional prototypes for lab testing and validation by both UKBIC and an international advisory board, setting the stage for transformative improvements in battery manufacturing and a more sustainable future.

Timeline with milestones and deliverables

The key milestones in this project include completion of detailed requirements captured from the battery manufacturing process via UKBIC (by Q1), design of POC prototypes for two measurement nodes (by Q2), and possibly testing one node inline in UKBIC (by Q3).

We also aim to promote the solution in key battery shows (at least one) during this project, and partner with an early adopter (one in India and one in the UK) to do field trials at the end of this project.

Project innovations

We embark on a visionary project to revolutionise battery manufacturing. Our mission is to develop/demonstrate Hy-Met's rapid multi-point battery tester (HyLite), to swiftly assesses cell quality during manufacture, surpassing existing methods.

By harnessing our proprietary sensors and edge analytics software algorithms to measure the condition of a battery within seconds, we hope to transform quality control, detecting defective cells early, curbing waste, rework, and costs. Our user-friendly interface and reporting system, particularly the fitness score provided for each cell, empowers production personnel with clear and actionable insights, ensuring effortless operation.

Partners

mtc Manufacturing Technology Centre

Hy-Met

UK Battery Industrialisation Centre

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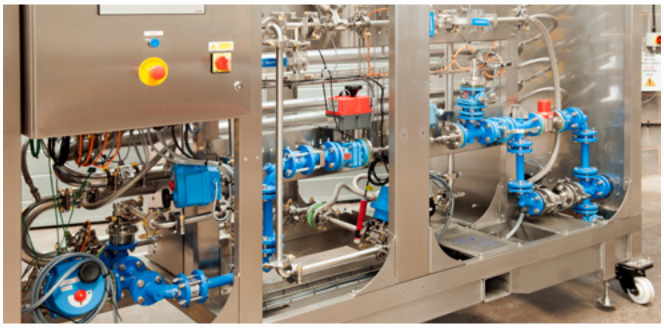
CatContiCryst – Manufacture of Li-ion Battery Cathode Materials Using Continuous Crystalliser Technology

Step change in production efficiency, cost, and end-use performance of NMC-type cathode materials via development of continuous manufacturing process – utilising Continuous Oscillating Baffled Crystallizer (COBC) technology.

Project costs
Total project costs: £194,058
Grant contribution: £149,374



Executive summary

Current production processes for NMC-type precursor materials commonly employ batch systems. Such systems (pCAM) are inherently inefficient and can involve very long batch times leading to low production rates even for sizeable assets. In addition, scale-up in batch systems can lead to process control limitations, which in turn limits control on critical quality parameters. This can lead to suboptimal design and performance of the precursor materials produced.

Continuous production using COBC technology is designed to overcome many of the disadvantages of current production technology. Increased efficiency and high throughputs are possible via modest process residence times. Continuous process monitoring and control using in-line process control systems facilitate the production of high quality, high performance materials.

The project has shown that a continuous method of NMC 811 pCAM is feasible using a COBC system. The material synthesised has the desired crystallographic structure, with low levels of cation mixing. The synthesis process was optimised by modifying mechanical variables (mixing, temperature, etc.) and chemical variables (reactant ratios and concentrations) to yield materials with high specific discharge capacities and good capacity retention

Timeline with milestones and deliverables

February 2023 – January 2024

- June 2023: Design and build continuous processing system, based on COBC technology, specifically configured to facilitate the conversion of mixed metal sulphate salts to cathode precursor materials.
- June–December 2023: Synthesised a range of NMC-type precursor materials using different processing conditions.
- December 2023: Optimisation of the COBC process conditions for production of NMC precursor materials and defined an appropriate operating window.
- January 2024: Coin cell testing to determine the performance of COBC synthesised materials and benchmark against relevant standards.

Project innovations

Proved technical feasibility of using continuous processing (COBC) to manufacture NMC precursor materials. Optimisation of continuous process with necessary adjustments to the system configuration defined. Process parameters required for scale-up have been determined. Critical process control parameters to ensure production of high-quality product and related product performance have been defined. Comparable electrochemical discharge capacity and capacity retention to conventionally manufactured pCAM.

Partners

The University Of Sheffield.
cpi
NiTech SOLUTIONS

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Cathode and Anode Supply Chain for Advanced Demonstrator (CASCADE)

The objective for this project was to bring 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

During the project the four partners were reduced to two. JM withdrew in 2022 meaning that alternative cathode materials were used to produce the demonstrator cells. In January 2023, British Volt also had to withdraw when the company was placed in administration. This changed the original intention to use their testing facility. It also weakened the 'Best of British' aim of the original project objective.

While these withdrawals presented challenges, but they also provided a real-world dynamic to the project. Relationships with partners and suppliers will, by their very nature, change and evolve, and the ability to react and still achieve credible, actionable results has been part of the knowledge growth for Echion.

This project achieved its primary objective to 'accelerate the development of next-generation, ultra-high power battery material cell systems for automotive applications.' Echion was able to complete the production of 4690 demonstrator cells, with cell manufacturer EAS in Germany and pouch cells with China based LiFun.

We were able to use the pouch cells to pass the UN 38.3 Safety test benchmarks. This was not a primary target of the project but gives XNO® product credibility and on a practical note allows for the safe transport of products using XNO®.

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.
- Sept '22 & March '23: 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

These different cell types delivered some specific, measurable and market ready results:

- Development 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.
- A customer-facing design tool to demonstrate benefits / trade-offs in Energy vs. Power vs. Cycle Life vs. Cost vs. Carbon Footprint.
- The energy from raw material to cell is lower in XNO® than other anode materials.
- UN38.3 certification of sample demonstrator cells achieved.

Partners

Echion Technologies

JM

UCL

BRITISHVOLT

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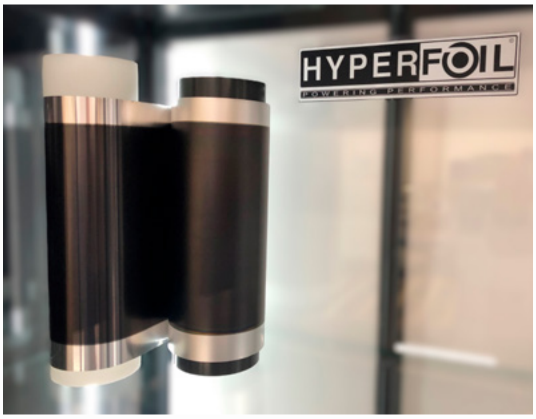
Coated current collector for battery performance improvement (CONTACT)

Demonstrate improved rate capability and useful life with a novel high performance current collector in a commercially relevant cylindrical cell formats.



Project costs
Total project costs: £1,152,264
Grant contribution: £869,273

Executive summary

Global Nano Network (GNN) has developed a conductive coating that acts as an interface between the current collector and battery materials, improving contact and increasing capacity extraction at higher discharge rates.

Current collectors are a critical component of a battery that directly impact the charge and discharge rate capability, battery capacity and the useful lifespan of the cell. Existing current collectors exhibit multiple inefficiencies including:

- Poor adhesion
- High degradation
- Severe corrosion issues
- Increased contact resistance

These limitations are more prominent in high power applications such as performance automotive and haulage. For these applications charging and discharging rates and cell degradation create a significant barrier for the transition to electrification.

Project CONTACT will demonstrate performance improvements that can be achieved with the inclusion of a novel coated current collector in commercially relevant cylindrical cells.

The project will increase GNN's manufacturing readiness level through the development of a proprietary roll-to-roll system that can produce a coil of coated current collector to be used in cylindrical cells for performance validation.

This project promotes the adoption of a cost-sensitive, high-power premium LFP battery that delivers performance advantage. This technology is designed to be chemistry agnostic and compatible with other battery materials including LMFP and LNMO.

Timeline with milestones and deliverables

Project start date: 1 Feb 2023
Project completion date: 31 Jan 2025

- Increase GNN's coating production process from lab to pre-industrial scale.
- Development of roll-to-roll coating reactor.
- Production of ~20kg roll of coated current collector.
- Material testing and characterisation.
- Production of industry relevant cylindrical cells.
- Cell characterisation, testing and reporting.
- Data modelling for use in a commercial application.
- Techno-economic assessment and exploitation Plan.

Project innovations

- A highly conductive, environmentally friendly sub-micron coating that is battery chemistry agnostic and improves cell performance.
- A low carbon, high value rapid roll-to-roll reactor for producing GNN's coated current collector.

Partners

GLOBAL NANO NETWORK
BRIDGNORTH ALUMINIUM LIMITED
cemco
WMG THE UNIVERSITY OF WARWICK
WAE A Fortescue Company

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CONDUCTOR – thin and lightweight current collector for lithium-ion battery

CONDUCTOR will develop lightweight, low-cost and electrically conductive polymer current collectors to replace the incumbent aluminium and copper foils used in lithium-ion batteries.

Project costs
Total project costs: £639,025
Grant contribution: £525,561

Executive summary

Lithium-ion batteries (LIBs) use copper and aluminium foil current collectors; however, they are bulky and comprise a significant portion of the total battery weight, considerably reducing the battery gravimetric energy and power density. Our vision is to develop a lightweight and low-cost polymer current collector, that is electrically conductive, to save up to 4kg weight in a 50kg automotive battery pack. The project involves an expanded supply chain consortium to develop and innovate the new current collector technology combining conductive carbonaceous fillers in polymers using a variety of fabrication techniques (laser sintering, extrusion of composite powders). The project focus is to optimise the formulations for conductivity and processability, and to test candidate materials in electrochemical technologies. The most promising current collectors will be optimised and selected for future development, including LIBs, flow batteries, fuel cells and electrolysers.

Timeline with milestones and deliverables

The first deliverables for this 12-month project are to create an experimental matrix and manufacture a range of materials and create components for the first iteration of conductivity testing to be completed by Q2 (July 2023). Parallel cell testing and electrochemical characterisation will have taken place at this milestone. The current collectors will be refined during a second iteration of formulation and fabrication, and the refined collectors evaluated for upscaling in optimised cells along with their technology advantage by Q4 (Jan 2024). The performance of these materials will also be evaluated as current collectors for fuel/flow cells.

Project innovations

Our project innovations are in the replacement of metal foil conductors with conductive lightweight polymers to reduce the weight of LIBs by up to 4kg for a 50kg automotive battery thereby improving its energy density by some 12%. Our other innovations are in the selection and preparation of conductive carbonaceous materials including graphene and how they are dispersed within the polymer matrix in addition to the fabrication of these materials as thin films.

Partners

euriscus
Graphene Star
Global Nano Network
Rapid Powders
WMG The University of Warwick

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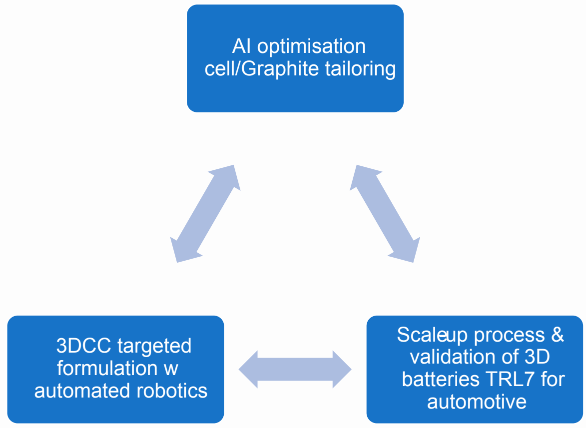
CONstruction of Smart Three-dimensional ELectrode Lithium-ion bATteries via Industrial prOcesses and staNdards (CONSTELLATION)

Revolutionize EV battery cells with AI-designed current collectors, harnessing UK-made graphite for rapid custom electrode creation.



Project costs
Total project costs: £3,796,973
Grant contribution: £2,955,915

Executive summary

Project CONSTELLATION was defined as a strategic response to the UK's plan to phase out combustion-engine vehicles, aiming to secure a leading role in the global electric vehicle (EV) market. This collaborative effort among four companies promises tailored and scalable solutions for electrode materials, ink slurries, and cell manufacturing, aimed at improving the performance and sustainability of cells. The newly developed cell materials are compatible with existing manufacturing lines, and thus the project offers an optimised solution to battery performance ready for giga-factory adoption, and without additional manufacturing costs.

CONSTELLATION combines the power of artificial intelligence to spearhead Addionics' revolutionary 3D current collectors. The first stage of this project saw the integration of 3D current collectors into roll-to-roll coating systems for the fabrication of pouch cells.

This achievement, backed by CPI's and WMG's expertise in accelerated slurry formulation and cell assembly processes, signifies a revolutionary breakthrough in EV battery technology. The use of graphitic carbon from James Durrans Group demonstrates the efforts of the consortium to boosting sustainability and supporting UK-based local industry.

Timeline with milestones and deliverables

The project is running as initially scheduled, with Addionics leading the design and fabrication of new three-dimensional current collectors. James Durrans is progressing towards the development of graphite and CPI is developing improved formulations for anode slurries that incorporate James Durran's graphite. Pouch-cell fabrication is done at WMG's roll-to-roll line, with the first set of cells already cycling vs reference cells. Addionics leads exploitation, dissemination, and project management throughout.

Project innovations

Achieving volume production of an AI-optimised 3D current collector (3DCC) and cell design is pivotal, particularly in maximising electrode loading for pouch-cell prototypes destined for EVs. This approach extends cycle life and enhances power output significantly. Additionally, the validation of custom-tailored graphite anode materials is crucial. Customising anode/cathode ink formulation through advanced robotics tailored for 3DCCs further refines the process. Integrating roll-to-roll production methods with demonstrator batteries showcase the application of new technologies within existing production lines, ensuring seamless adoption and scalability.

Partners

James Durrans Group, WMG The University of Warwick, cpi, Addionics

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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
DZP Technologies
Plasma App
WMG, The University of Warwick

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DANCER (Designing Advanced Niobium anode Cells for Expedited Commercial Rollout)

Project DANCER targets the development of a unique cell design package in an R&D project aimed at meeting key commercial performance metrics to enable the fast-track electrification of automotive applications

Project costs
Total project costs: £1,846,458
Grant contribution: £1,457,341

Executive summary

Project DANCER (Designing Advanced Niobium anode Cells for Expedited Commercial Rollout) brings together battery materials technology supplier Echion Technologies ('Echion') and experts at the Warwick Manufacturing Group ('WMG') in an R&D project to formulate a cell design package that will target key commercial performance metrics. This will fast-track the electrification of automotive applications, including on and off-highway vehicles such as mine haul trucks, as well as buses, lorries and passenger vehicles, including taxis, through the development of a high-value UK supply chain.

Project DANCER partners anticipate the development of a unique cell design aimed to meet increased life cycle and high-temperature performance specifications as provided by Echion's customers. This will be in an end-user design that meets their requirements and surpasses the techno-commercial requirements of the 2025+ automotive market, advancing the UK towards its net zero commitment through automotive electrification. Developing this cell design package will increase the competitiveness of Echion's XNO® material in more technically challenging applications by proving the concept in 'Pre-A' prototype cells.

Timeline with milestones and deliverables

Project Dancer will run from January 2024 to March 2025, over which teams from Echion and WMG will work together to deliver a robust study across six key work packages, including:

- Cathode screening – Identifying commercially relevant cathode materials capable of achieving 10,000 cycles, Q1 to Q3.
- Formulation development – Optimising XNO® electrode formulation to support the target energy density (>280 Wh/L at 7C rate), identifying the optimum formulation by mid Q3.
- Electrolyte development – Development and validation of electrolyte formulations specifically to support long cycle life and minimised gas formation, includes large- scale pouch cell builds, by Q5.
- FA&T – Design and validation of cell formation protocols to achieve enhanced ageing performance, Q1-5.
- Degradation – Application of advances post-mortem techniques to determine the primary causes of cell aging, Q2-5.

Project innovations

The speed of charge of standard commercial lithium-ion batteries is severely limited by the negative terminal material which is used to store electricity upon charge, called the anode. Echion is a high-growth company who spun-out of Cambridge University in 2017 to commercialise proprietary fast-charging battery materials based on niobium, called XNO®. XNO® enables a unique combination of fast charge (down to six minutes for a full charge), high power density, long cycle life, a large optimum temperature range and improved safety, without sacrificing energy density. The DANCER project aims to lift the performance limitations of standard lithium-ion batteries thanks to XNO® technology.

Partners

WMG
THE UNIVERSITY OF WARWICK

ECHION
TECHNOLOGIES

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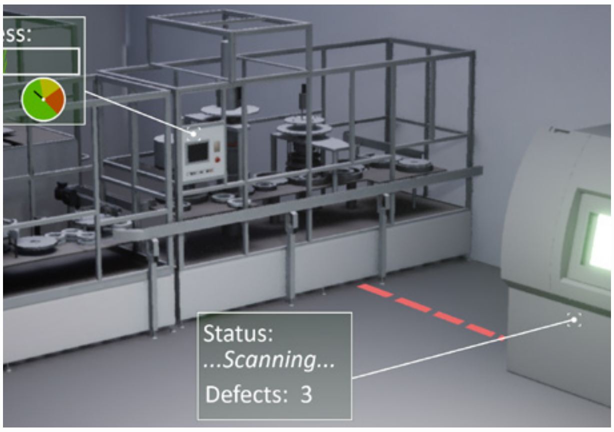
Digital Twin Technology for Quality and Yield Improvement of Battery GigaFactories

The project demonstrated that digital twin technology improves battery factory yield. By leveraging the data from different quality gates e.g., industrial computed tomography (CT) and process parameters/logs, a digital twin provides insights to deliver enhanced productivity.

Project costs
Total project costs: £441,677
Grant contribution: £265,676



Executive summary

The initial part of the project will be a feasibility study (2023), which will demonstrate the benefit and value of the points mentioned below. The building blocks for the next stages, however, will also be defined.

The project aims to reduce waste in battery manufacturing with an approach that leverages quality data from multiple inspection and testing points from across the battery production flow to create a digital twin of the process. This digital twin uses advanced analytics to detect manufacturing flaws and process deviations early for tight quality control.

Key indicators for process improvement are identified throughout the study. Improved data fusion and a reliable IS infrastructure and IT architecture are utilised to evaluate and optimise process parameters' relationships. First data is ingested and streamlined into the digital twin. It then provides a platform for interrogation and monitoring in real-time.

The project challenges were to validate the yield improvements based on the changing specific parameters in the production flow. Advances in development and validation of an AI-based automated defect recognition (ADR) tool were made which is used for analysing the industrial computed tomography (CT) scanner data.

Timeline with milestones and deliverables

- Active project for 2023 only as a feasibility study.
- Process and data mapping (2023 Q1).
- Initial milestones completed Q1 2023 – Process and data mapping.
- Installation and inspection via industrial computed tomography (CT) leveraging Waygate Technologies' Phoenix V|tome|x M300 Metrology Edition system.
- Developing data analytics and adapting automated defect recognition for battery scanning to increase battery cell yield, powered by Waygate Technologies' Inspection Works platform.
- Digital twin software – back end and concept for full process digital twin ingestion of multi-modal inspection data and process parameters. After data fusion then to also link with simulations. (2023 Q2-Q3)

Project innovations

- Greater insights and understanding of production trends during manufacturing through analytical Artificial Intelligence (AI, e.g., CNNs) powered by Statistical Process Control (SPC). Data Fusion, tagging & labelling.
- Industrial CT inspection applying data fusion to automate component analysis by passing the resultant image into processes such as machine vision assisted AI and machine learning algorithms; significantly reducing production waste.
- Digital twin: Simultaneously mixing and streaming both real world data from the Data Lake alongside internal simulation data into a 3D environment. Dynamic switching between real and simulated data while allowing to dynamically alter simulation parameters.

Partners

Waygate Technologies
a Baker Hughes business

UK BATTERY INDUSTRIALISATION CENTRE

PXL ICE

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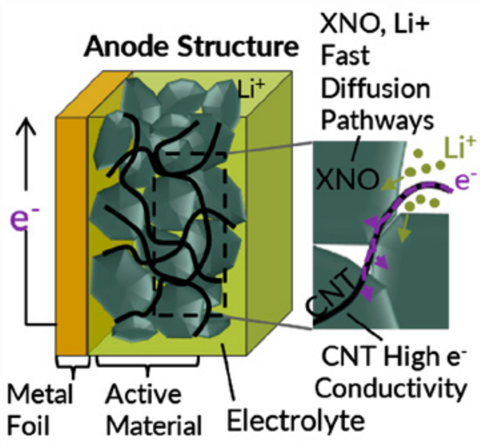
Enhanced CNTs for High Power Electrodes (EC-HiPE)

Ultra-long carbon nanotubes will be used to make highly conductive niobium oxide anodes, facilitating faster charging and longer life. Scalable methods for manufacturing the nanotube-enhanced anode slurries will be developed.



Project costs
Total project costs: £738,650
Grant contribution: £546,886

Executive summary

High-power electrodes require an electrical conductivity far above that provided by the oxide particles within them that store and release lithium. This necessitates the addition of a conductive additive. Carbon black with particle size below 100nm is often combined with a polymer binder to provide electrical connectivity during manufacture and over the cell lifetime: together they must occupy a minimal volume within an electrode for it to have the greatest capacity. An increase in conductive additive performance is required to develop faster charging, higher capacity anodes.

This project seeks to enhance conductivity by using ultra-long carbon nanotubes (UL-CNTs) as the conductive additive. The tubes of up to 1 mm in length are anticipated to provide efficient electron conduction and mechanical reinforcement. UL-CNTs manufactured by project partner Q-Flo will be combined with mixed niobium oxide (XNO) material made by partnering anode manufacturer Echion to create fast-charging anodes with high capacity and long life. Effective dispersion of the nanotubes within the slurry from which the anode is cast is key: here new and existing expertise developed the De Volder and Boies research groups at the University of Cambridge will leveraged to develop scalable methods for the manufacture and processing of UL-CNT/XNO slurries.

Timeline with milestones and deliverables

D1: Complete business exploration plan.
D2: Formulate technologies for the manufacture and processing of UL-CNT dispersions.
D3: Create cell design for testing.
D4: Establish metrics for CNT and XNO materials.
D5: Establish metrics for anode and full-cell performance.
D6: Determine CNT and XNO specifications that provide a high energy density, power density and cycle life.
D7: Create technical datasheet for battery manufacturers to incorporate XNO and UL-CNTs.
M1: Determine the primary CNT material for study and start of full cell tests (Month 6).
M2: Determine the primary UL-CNT/XNO formulations for continued tests (Month 9).

Project innovations

The UL-CNT manufacturing process developed by Q-FLO and the University of Cambridge will be tailored to produce CNTs of the desired length and diameter for electrodes. Methods of manufacturing CNT dispersions and electrode slurries at scale will be invented and developed by investigating the capability of established and new techniques, e.g., shear mixing, continuous-flow homogenisation, liquid-based plasmas and surfactants. The emphasis is to develop anodes with Echion's XNO® anode material that should be fast charging as half-cells (circa 20C) and combine successfully with widely used cathode materials such as NMC to give cells with life exceeding 1,000 cycles.

Partners

Echion Technologies
UNIVERSITY OF CAMBRIDGE
Q-FLO CNT Innovation

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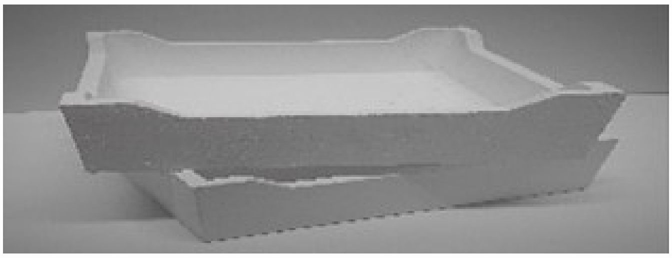
Professor Adam M. Boies Email: amb233@cam.ac.uk Web: https://cambridgenanoaerosol.com/

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 lithium-ion batteries (LIBs) market by late 2020.

Project innovations

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

Partners

LUCIDEON Materials Development and Commercialization

JM Johnson Matthey Inspiring science, enhancing life

Vulcan

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EXtrAPower – Enabling Xtreme Automotive Power

EXtrAPower is addressing a critical market failure for high power, long cycle life automotive applications.

Project costs
Total project costs: £3,118,061
Grant contribution: £2,346,777

Executive summary

The EXtrAPower project is delivering high-performance solutions for automotive applications facing a market failure in the availability of batteries with the required combination of high power density, fast charge capability, safe operation over a wide temperature range, and long cycle life.

The collaboration brings together leading expertise in ultra-fast charging, long cycle life battery technology (Nyobolt), advanced automotive engineering and electrification (Fortescue WAE), cell development and optimisation (Prof. Alexander Roberts, Coventry University) and advanced battery research (Dr Israel Temprano, University of Cambridge).

EXtrAPower is optimising the performance of cells with Nyobolt's ultra-fast charging battery technology over an extended operating temperature range with enhanced cycle life. Large format pouch cells are being manufactured at UKBIC to feed module development activities at WAE. WAE and Nyobolt will develop modules for a high performance fuel cell electric vehicle (FCEV) and a last mile delivery application respectively, and will demonstrate the battery performance by testing to the relevant duty cycles.

Timeline with milestones and deliverables

February 2023: Project start
Q2 2023: Preliminary cell build at UKBIC.
Q4 2023: FCEV module design complete.
Q2 2024: Last mile delivery battery design complete.
Q3 2024: Large volume build of optimised cells at UKBIC.
Q4 2024: Performance testing of FCEV and last mile delivery batteries.

Project innovations

- Ultra-fast charging, long cycle life cells optimised for automotive applications.
- Large format pouch cells manufactured using gigafactory scale equipment.
- High power density, high performance module for FCEV.
- Long cycle life, fast charging battery for last mile delivery.

Partners

nyobolt
WAE A Fortescue Company
UNIVERSITY OF CAMBRIDGE
Coventry University

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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 battery electric vehicles (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. The fabrication and demonstration of three iterations of prototype Li-ion cells necessary for experimental model validation and refinement will also be done. 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

JM Johnson Matthey – Inspiring science, enhancing life

Imperial College London

ENTEK

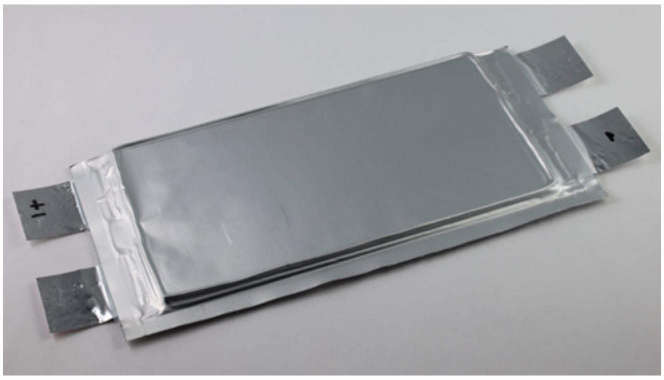
BRITISHVOLT

Contact:
Martina De Marco Email: m.de-marco12@imperial.ac.uk

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

University of Cambridge

Vantage Power

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Dr Sarah Stevenson Email: sarah.stevenson@echiontech.com Web: www.echiontech.com
Toby Schultz Email: toby.schulz@vantage-power.com Web: www.vantage-power.com

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 lithium-ion batteries (LIBs), developing new methodologies and consolidating existing.
- New measurement methodologies for LIB manufacturing.

Partners

Ansys
University of Birmingham
Intellegens

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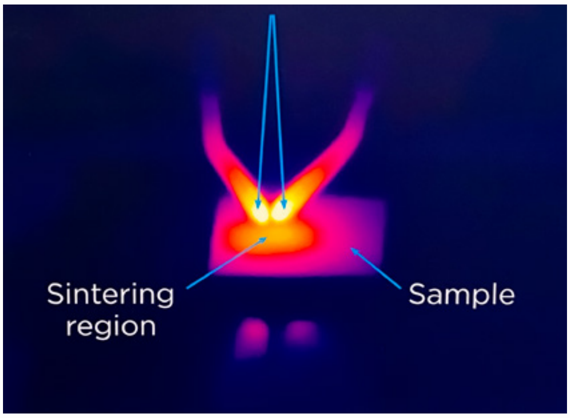
Ben Pellegrini – Email: ben@intellegens.co.uk – Web: www.intellegens.com
Emma Kendrick – Email: e.kendrick@bham.ac.uk – Web: www.birmingham.ac.uk

Investigating the feasibility of flash sintering for battery cathode production

This project will investigate the feasibility of using a novel Flash Sintering synthesis method for Na-ion battery cathode materials as a more effective, more controllable, and lower energy intensity process.

Project costs
Total project costs: £390,465
Grant contribution: £315,683



Executive summary

This innovative project aims to disrupt lithium-iron-phosphate (LFP) dominance by creating a novel sodium-ion battery (SIB), reducing both the cost and environmental impact of electric vehicle (EV) battery manufacturing. By utilising a novel Flash Sintering method for cathode production, this project aims to reduce energy consumption of battery material synthesis and increase cell performance.

This UK-based supply chain improves overall sustainability, and the overreliance and associated environmental impacts of lithium-ion use across the industry. By creating a new sodium-ion battery chemistry using sustainable UK-sourced materials, this pioneering project will pave the way for a new standard of sustainable EV battery technology. This removes the necessity for energy-intensive mining for cobalt and lithium, providing significant carbon savings in line with UK net-zero emissions targets. This advancement into a new technical field also represents significant progress for Flash Sintering to contribute to the UK's growing reputation as a world leader of developing and applying this highly energy efficient process.

Timeline with milestones and deliverables

Feb 2024: Project kick-off

- June 2024: Detailed synthesis protocol and characterisation report established for cathode material synthesised using a conventional solid-state reaction.
- August 2024: Report on cathode performance from half-cell testing synthesised using solid-state.
- October 2024: Detailed synthesis protocol and characterisation report established for cathode material synthesised using a novel reactive Flash Sintering method.
- February 2024: Report on cathode performance from half-cell testing synthesised using Flash Sintering. Report on feasibility and sustainability of adopting reactive Flash Sintering for cathode synthesis, and commercial roadmap to achieve specifications for market entry.

Project innovations

The key innovation in this project is the application of a Flash Sintering method in cathode material synthesis. Flash Sintering is the application of an electric field to a material body which induces rapid internal heating, allowing for much faster heating rates and more efficient energy transfer than conventional heating via convection and radiation. An innovative step has been identified by taking the benefits of Batri's Na-ion technology, combined with Lucideon's expertise in Flash Sintering control, to assess the feasibility for its use in cathode material synthesis and its scale-up adoption into battery manufacturing

Partners

LUCIDEON

Batri

Swansea University Prifysgol Abertawe

Contact:
Dr Stephen Hughes Email: Stephen.hughes@batri.com Web: https://batri.com/

Laser-Assisted Surface Enhancements for Roll-to-roll processing (LASER)

Avocet Battery Materials and The Manufacturing Technology Centre will scale-up a method of treating Al and Ni-plated Cu, for Li-ion pouch cell tabs, replacing the standard Cr(VI) surface treatment used in industry with a chemical-free laser process.

Project costs
Total project costs: £902,000
Grant contribution: £707,000

Executive summary

ABM, Europe's first commercial producer of cell tabs for Li-ion pouch cells, is developing a new laser-processing method for treating Al, Cu and/or Ni-plated Cu for use in their tab production. The current method uses a Cr-based surface treatment, which is regulated in Europe under RoHS. ABM has partnered with The

MTC to develop a conversion layer at the surface of the metal substrate using a laser process. The new laser process provides reliable bonding of the polypropylene to the tab, which is crucial for the performance of the cell. The project will focus on optimising the laser process and developing a high-throughput manufacturing process to validate applicability to commercial- scale production.

The ultimate goal of the project is to replace the current Cr-based surface treatment method, which is environmentally harmful, with a more sustainable, reliable and cost-effective laser processing method and therefore on-shoring of the supply chain for tab manufacture to the UK from Asia. The environmental impact of on-shoring the supply chain will result in a decrease of CO2 emissions caused directly from freight of material and tabs around the world from APAC countries. The development of this technology will benefit the UK battery manufacturing industry by providing a domestically -produced, environmentally -friendly and commercially unique alternative to the current method, enhancing the country's competitiveness in the global market

Timeline with milestones and deliverables

January 2024 – March 2025
Milestone:

- Demonstrator Al tabs to key customers for validation – 05/08/2024.
- Interim report on critical design set-points – 09/09/2024.
- WP4 interim report on edge and laser processing – 21/10/2024.
- WP6 interim report on extraction system performance – 04/11/2024.
- Establish manufacture of new edge profile/s – 03/02/2025.
- Demonstrator Al tabs to key customers for validation – 03/03/2025.

Deliverables:

- Process method for non-destructive leak/adhesion test capability – 30/09/2024.
- Scalable 'Proof of Concept' Al laser treatment process operating at target TAKT time <30 seconds – 30/12/2024.
- Scalable 'Proof of Concept' Cu/NiCu laser treatment process operating at target TAKT time <30 seconds – 03/03/2025.
- Laser xyz-motion path definition – 03/03/2025.
- Full system design and 'Proof of Principle' of critical sub-systems for automated laser treatment line for roll-to-roll tab processing plant – 31/03/2025.

Project innovations

New laser processing parameters for metal substrates.

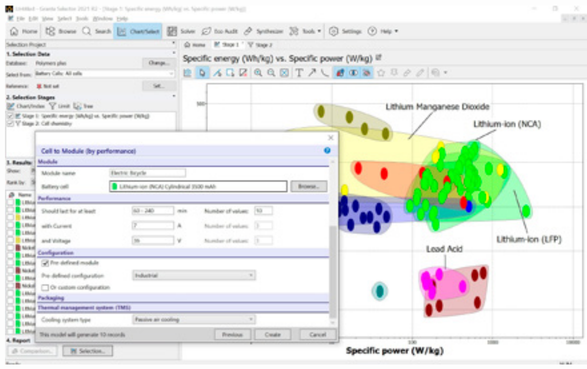
Partners

Contact:
Martyn Brown Email: martyn.brown@avocetbattery.com Web: www.avocetbattery.com

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

Ansys

DenchiGroup

Imperial College London

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Nick Russel Email: nick.russel@denchipower.com

New Biomass Anode Technology and Silicon Electrodes with high Energy Density (New BATSEED)

The introduction of a new lower cost silicon anode material and the development of high silicon content electrode designs for increasing Li-ion cell energy density.

Project costs
Total project costs: £2,950,000
Grant contribution: £2,000,000

Executive summary

The New BATSEED project will focus on high capacity silicon anode materials and high energy density electrode anode designs for next generation automotive electric vehicle (EV) battery cells to deliver increased driving range and for fast charge. Nexeon will develop a new silicon anode material and high silicon content electrodes to enable higher energy density Li-ion cells.

The project will use cell assembly capabilities at Coventry University to fabricate and test silicon containing anodes in multi-layer pouch cells adopting a high nickel content cathode. University College London will perform analysis of silicon containing electrodes and also investigate structural analysis of cycled full Li-ion cells through various techniques.

Timeline with milestones and deliverables

Apr 23: Project kick off.
Oct 23: HE1 high capacity silicon anode electrode design.
Jan 24: HE1 multi-layer Li-ion pouch cells and testing.
Feb 24: POC for new Si anode material.
Apr 24: HE2 high capacity silicon anode electrode design.
Jun 24: Analysis of cycled HE1 pouch cells.
Aug 24: HE2 multi-layer Li-ion pouch cells and testing.
Jan 25: Analysis of cycled HE2 pouch cells.

Project innovations

The New BATSEED project will deliver two innovative developments for next generation automotive EV battery cells and anode materials. Nexeon will develop a new silicon anode material, with increased sustainability, and also two high silicon content electrode designs to enable increased energy density Li-ion cells.

The project partners will also apply their expertise in processing high capacity electrode materials to demonstrate multi-layer Li-ion pouch cells with high silicon content anodes. A suite of state-of-the-art analytical techniques will then be applied by UCL to determine the structure of electrodes and full cells before and after cycle life testing.

Partners

Coventry University
nexeon
UCL

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Bill Macklin Email: bill.macklin@nexeon.co.uk Web: www.nexeon.co.uk

Next generation LFP cathode material (NEXLFP)

NEXLFP is a highly innovative project aiming at scaling up and demonstrating high capacity, high discharge rate and low-cost LFP battery cathode material which will be proven at industrial cell level.

Project costs
Total project costs: £1,224,920
Grant contribution: £924,174

Executive summary

NEXLFP focuses on further development and scale-up of LFP material by demonstrating electric vehicle (EV) battery cells that can overcome technical and economic limitations of conventional alternatives which prevent EVs large adoption. This project aligns with the Faraday Battery Challenge as its main output is high capacity, high power and high discharge rate LFP battery material/cell capable of meeting requirements of EV battery producers and end-users, specifically in extreme temperature. The expected LFP cell demonstrator will be power focused, weight and cost sensitive.

Current Li-ion batteries suffer from low discharge rates, limited capacity, high cost and great environmental footprint. This project will bring to the market innovative battery technology for the propulsion of EVs, significantly boosting EVs adoption with a great benefit for the UK economy and/or national productivity.

Additionally, NEXLFP project will generate process knowledge (advanced materials to improve battery performance), methodologies (e.g. high-current battery cell) and approaches (e.g. novel synthesis method) in developing the battery materials and high-current battery cell. NEXLFP will also mitigate the global dominance of Asian lithium-ion battery cell manufacturers that negatively impact the trade of LIB materials/cells for other regions of the world, resulting in higher costs and negligible role of the UK and EU in the global battery value chain.

Timeline with milestones and deliverables

WP1: Project management, IP and dissemination (Months: 1-24).
WP2: LFP Material Scale-up (Months: 1-22).
WP3: LFP Material development analysis and characterisation (Months: 1-23).
WP4: Development of LFP Pouch Cells (Months: 7-23).
WP5: Cell Testing and Performance Analysis (Months: 5-24).

Project innovations

IPL's approach for scale-up is a novel economical liquid-state method which delivers optimised material at low-cost due to its approach in recycling the by-product and synthesis process difference compared with competitors. IPL's approach offers full control over primary particle sizes which improves the performance of LFP material.

Product value propositions:

- Higher power density and discharge rate
- 20% less weight and material consumption
- Up to three times more capacity in extreme temperatures @10C discharge rate
- Safety and reliability
- Security of supply
- Lower cost

Partners

Cranfield University

INTEGRALS POWER

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Behnam Hormozi Email: b.hormozi@integralspower.co.uk Web: www.integralspower.co.uk

Novel Carbon Allotrope for Lithium-Ion Batteries (CALIB)

The project goal is to develop a new type of Lithium-ion battery (LIB) 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 LIB manufacturing process. Replacing standard graphite electrode with CALIB potentially will allow increase in the specific energy density of the LIB, increase in battery cycle-life, and improve safety especially under stressed high-power operation conditions. Doping of the CALIB anode with a 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 LIBs 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 LIB 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

Contact:
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Power-Up (Power Cell Upscaling project)

The project established the feasibility of manufacturing AMTE's Power cells in the UK, in volume. The power 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 was produced at UKBIC under the project.

Project costs
Total project costs: £999,865
Grant contribution: £849,872

Executive summary

The AMTE 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 a pouch cell manufacturing capability to deliver cells and has a fully commissioned facility using a VDA-standard 300x100x10 (mm) format based on electrodes designed for high-energy-density. These facilities were modified to produce a cell that was optimised for high power density. The Electrochemical Science & Engineering group of Imperial College has a long-term strategy to change the way that the lithium-ion battery (LIB) 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 had already demonstrated the concept through a Faraday Institution funded sprint project, TOPBAT. Working together the partnership created a new generation of best-in-class high power cell with unique features that will help create a thriving UK cell manufacturing industry through local manufacture.

Timeline with milestones and deliverables

Project start date:	01/08/2021
Electrode developed:	30/11/2021
Benchmark cells produced:	30/11/2021
Cell Design Finalised:	31/03/2022
Results electrochemical study:	31/03/2022
Technology Scaled up:	31/05/2022
UK BIC Manufacture cells:	31/07/2022
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 had demonstrated that when tab cooling is used, it can significantly extend cell lifetime. Models and knowledge learnt from previous projects were 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®

UK BATTERY INDUSTRIALISATION CENTRE

Imperial College London

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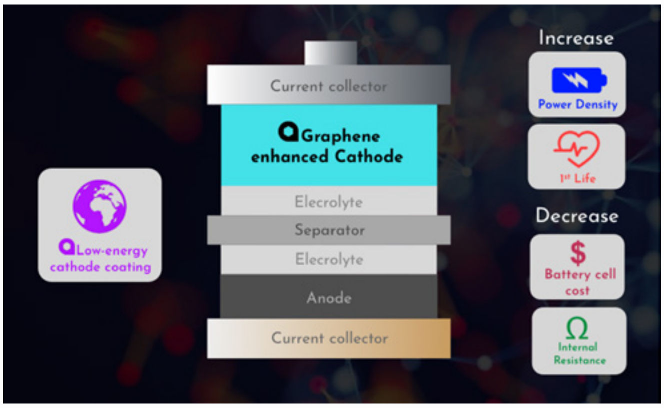
Realising the UK Value-chain in Graphene Composite Battery Materials (GRAVITY)

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

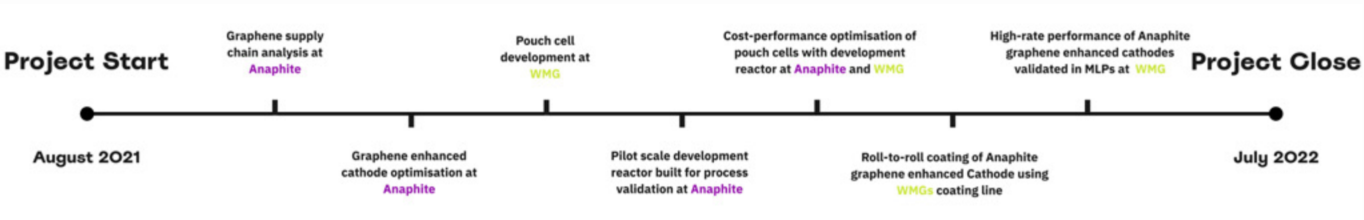
Executive summary

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 also began the development of an improved coating technique to produce battery cathodes using significantly less energy and reducing cost. During GRAVITY we validated 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 enhanced cathode composite materials was explored during the project, with the goal of producing industrially relevant pouch cells optimised for the battery electric vehicle (BEV) market.

A validation-scale development reactor was built for process validation, and from this, accurate cost models were built to motivate further scale-up and development.

Overall, this project allowed Anaphite to showcase the competitive benefits of its graphene enhanced cathodes and low energy coating technologies.



Project innovations

Innovations include:

- Optimisation of improved cathodes utilising graphene.
- Optimisation of cathodes made with an improved low energy, low-cost coating process.
- Justification of scalability and industrial relevance with a graphene supply chain analysis.
- Validation prototype reactor built.
- Multi-layer pouch cells (MLPs) successfully made incorporating Anaphite's graphene enhanced cathode material using WMGs coating line, and high-rate performance validated.

Partners

Anaphite

WMG THE UNIVERSITY OF WARWICK

Contact:
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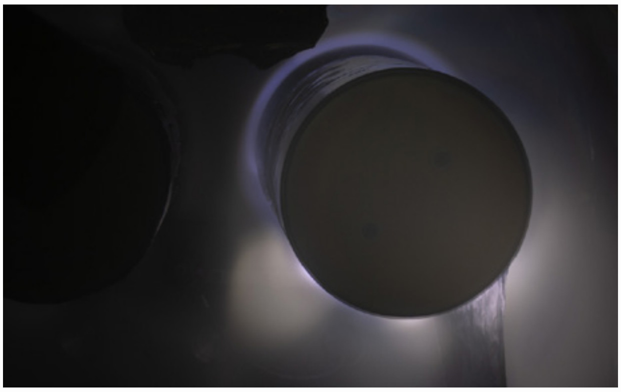
WMG: Dr John Low Email: c.t.j.low@warwick.ac.uk Web: https://warwick.ac.uk/fac/sci/wmg/

SiBAn – Dry silicon-based lithium battery anode structure

Plasma enhanced chemical vapour deposition (PECVD) of a silicon coating as a porous structure on thin copper foils, for use as anodes for lithium-ion cells



Project costs
Total project costs: £496,275
Grant contribution: £419,746

Executive summary

The world is moving toward an all-electric automotive industry and a greater proliferation of electronics, generating a need for batteries that can meet market expectations and to accelerate this proliferation. Lithium-ion batteries (LIBs) dominate the market and a long-standing goal for anode innovation with lithium batteries has been to use silicon as an active material on the lithium anode, creating a lithium-silicon battery. Lithium batteries towards 100% silicon anodes have the potential to hold higher amounts of lithium ions due to silicon's 10 times higher capacity than graphite. This quickly translates in cost parity for electric vehicles (EVs) and creates smaller, better lithium batteries for all electronics and energy storage.

Chemical vapour deposition (CVD) is one of several techniques that could be used to prepare 100% silicon anodes, with one or more gas reacting to produce a solid product. A plasma can be used to increase the rate of reaction, or reduce the reaction temperature, and the process is then termed plasma enhanced (PE).

The anodes produced with high levels of Si (>70%) will be tested in coin cells, and then larger single-layer pouch cells. The tests will measure the capacity and coulombic efficiency of the electrodes, as a function of the PECVD coating conditions. The optimum conditions can then be scaled up to larger coating machines, and fully engineered lithium-ion cells.

Timeline with milestones and deliverables

Deliverables

D1 – Specification document of coating and substrate materials (31/3/24).

D2 – Establish initial PECVD protocol (31/5/24).

D3 – Coatings of SiO_x on copper foil (30/9/24).

D4 – Electrochemical and spectroscopic data on silicon anode materials (30/11/24).

D5 – Material and energy cost feasibility (31/1/25).

D6 – Final project report of all outcomes (27/2/25).

Milestones

M1 – First PECVD deposition system in operation (31/7/24).

M2 – First electrochemical testing of coatings in coin cells (30/11/24).

Project innovations

The project will produce silicon anodes for lithium-ion cells, using plasma enhanced chemical vapour deposition (PECVD). The process will evaluate two reactants, HMDSO (hexamethyl disiloxane, $((CH_3)_3Si)_2O$) and TMS (tetramethyl silane, $Si(CH_3)_4$)) in order to produce a porous SiO_x layer on copper foil. The vacuum coating of the anodes will be carried out at Gencoa, and the batteries will be tested at Warwick Manufacturing Group (WMG), an academic department at the University of Warwick.

Partners

WMG
THE UNIVERSITY OF WARWICK

GENCOA

Contact:
Victor Bellido-Gonzalez   Email: victor@gencoa   Web: https://www.gencoa.com

Silicon Anode Battery for Rapid Electrification (SABRE)

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 electric vehicle (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. The project will apply innovative 21700 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 Coventry University for the fabrication of high energy density 21700 cells to test and validate the new cell design. SABRE assists in establishing Nexeon as key element 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 silicon anode materials to overseas OEMs and cell manufacturers respectively.

Timeline with milestones and deliverables

15-month project, with four key deliverables:

1. Advanced silicon anode material.
2. Material and electrode characterisation.
3. High-capacity anode electrode and cell designs.
4. 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. The project will apply innovation in smart and highly optimised cell design, to enable demonstration of a high energy density 21700 cell via sub-contract with Coventry University 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

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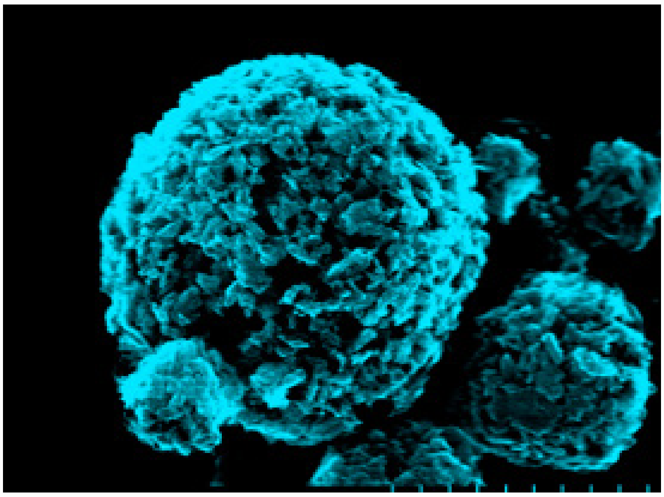
SAFEVOLT Safe High Voltage EV battery materials

Feasibility project for simultaneously improving safety and energy density of electric vehicle (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.

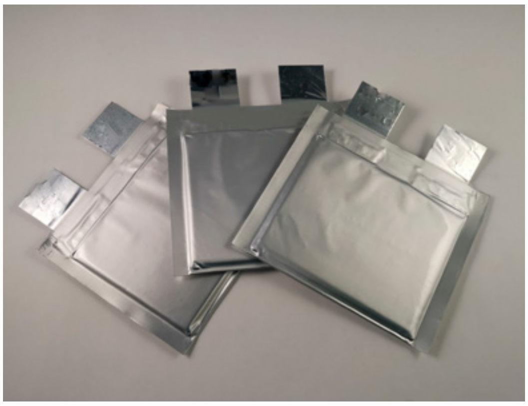
Partners

talga
TWI
JM Johnson Matthey Inspiring science, enhancing life
UNIVERSITY OF CAMBRIDGE

Contact:
Anna Motta Email: anna.motta@talgagroup.com Web: www.talgagroup.com

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: £194,058
Grant contribution: £149,374

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 (EV) 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 and 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
QinetiQ

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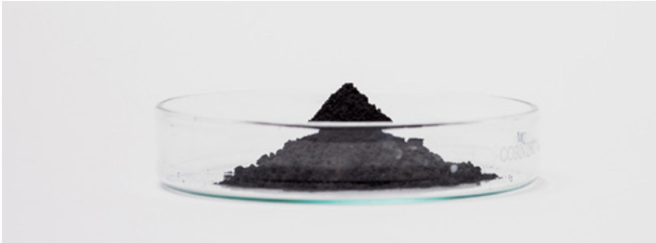
Gary Mepsted Email: GOMEPSTED@qinetiq.com

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 electric vehicle (EV) Lithium-Ion Batteries (LIBs).

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 (LIBs). 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 a 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 (BEVs) and the success of the project will ensure the UK has a role in the supply chain.

Partners

talga
University of Birmingham
WMG The University of Warwick
TFP Hydrogen Products Ltd

Contact:
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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

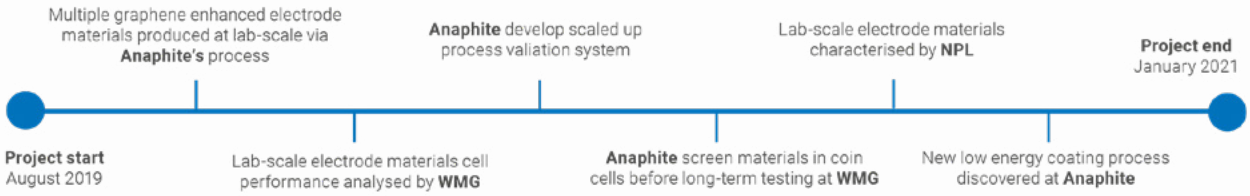
Executive summary

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 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

Anaphite

WMG
THE UNIVERSITY OF WARWICK

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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 direct lithium extraction (DLE) 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 lithium 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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Round 3 competition

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 lithium-ion battery (LIB). 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

nexeon

Phoenix Scientific Industries Ltd
Advanced Process Solutions

University of Oxford

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Terry Nicklin — Email: terry@keynotepr.com

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 electric vehicle (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 (LIBs). New verticals will help reduce time for scaling cell producti on 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 and 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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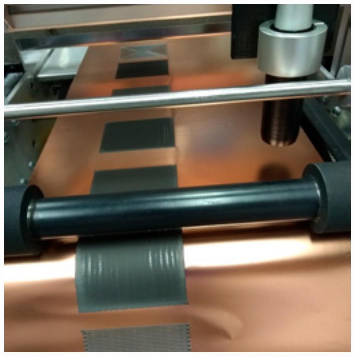
Spraycoat

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



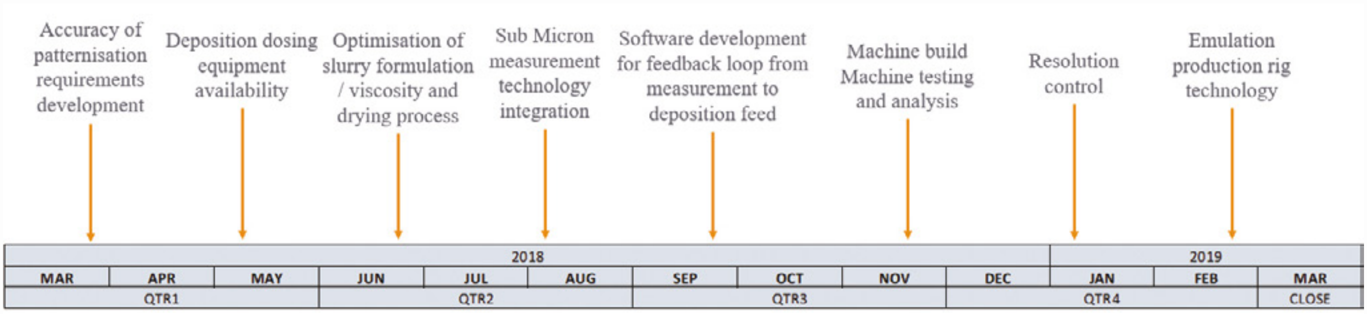
Executive summary

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

University of Birmingham
WSP
WMG The University of Warwick

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Dr Matthew Capener — Email: m.capener@warwick.ac.uk — Web: https://warwick.ac.uk
Kieron Salter — Email: kieron.salter@kwspecialprojects.com — Web: https://kwspecialprojects.com

SUNRISE

Synthomer, UCL & Nexeon rapid improvement in the storage of energy Silicon anode and polymer binder for high energy density lithium-ion battery (LIB).

Project costs
Total project costs: £9,612,706
Grant contribution: £6,989,114

Executive summary

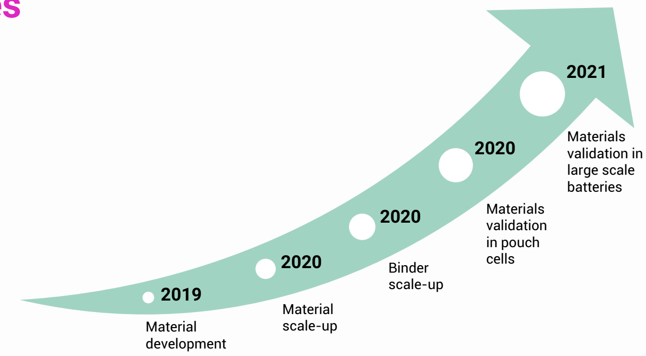
The SUNRISE project will deliver a novel silicon anode system for advanced lithium-ion batteries.

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

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



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 electric vehicle (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

Contact:
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Round 6 competition

Sustainable HF-Free Fluorinations for a UK-Based Li-ion Battery Electrolyte Supply Chain (SUS-FLUOR-BAT)

The project aims to develop UK based manufacturing of battery electrolyte salts (e.g. LiFSI, LiPF6) through development and scale up of FluoRok's novel and disruptive fluorochemical manufacturing technology.

Executive summary

FluoRok's technology, for the first time, enables Lithium-Ion Battery Electrolyte Salts to be manufactured bypassing the use of highly toxic, hazardous and difficult-to-handle hydrogen fluoride (HF). The groundbreaking new process allows direct manufacture of fluorinated materials from raw minerals (fluorite, CaF_2) or fluorinated waste streams to speciality chemicals such as Electrolyte Salts.

Through exploitation of our technology, we will enable vastly improved manufacturing cost, lower carbon emissions and introduce for the first time a cyclic economy for fluorochemicals. Alongside the significant safety benefits of executing our technology on scale, notable barriers such as high capital expenditure, environmental protections, and excessive controls of hazard operations are equally circumvented. With this project, FluoRok will enable the UK economy to compete on the global stage for the manufacture of lithium-ion battery (LIB) cells and build a UK-based supply chain for a key area of the battery industry.

Timeline with milestones and deliverables

FluoRok will transfer their optimised Electrolyte salt manufacturing process to the Centre for Process Innovation (CPI) for scale-up development. CPI will develop key understanding to enable pilot manufacturing of the product. The project includes a detailed techno-economic analysis and sustainability/ life cycle assessment for FluoRok's manufacturing process vs key benchmarks. Alongside this work regulatory, toxicology aspects, and analytical methods will be established. WMG will provide validation of the electrolyte performance in cells. Finally, the project will develop a design, business plan and roadmap towards market entry for the pilot scale manufacturing process developed in this project

Project innovations

FluoRok and its partners the Centre for Process Innovation (CPI) and Warwick Manufacturing Group (WMG) will scale up and industrially validate FluoRok's unique manufacturing technology to develop a new sustainable, low- cost, local supply of critical materials in the battery supply chain.

Through combining FluoRok's deep expertise, innovative technology and knowhow in fluorochemical processes with scale up and chemical manufacturing innovation/expertise at CPI and deep knowhow in battery materials/testing at WMG, the project will enable the industrial utilisation of this new technology and close a key gap in the UK battery supply chain.

Partners

FluoRok — REINVENTING FLUORINATION

cpi

WMG — THE UNIVERSITY OF WARWICK

Contact:
Andrew Schwarz Email: andrew.schwarz@fluorok.com Web: www.fluoRok.com

Synergy

Increasing the performance, manufacturability and environmental profile of lithium-ion battery (LIB) 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 LIBs. 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 (EVs).

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 synthomer
AMTE POWER
cpi

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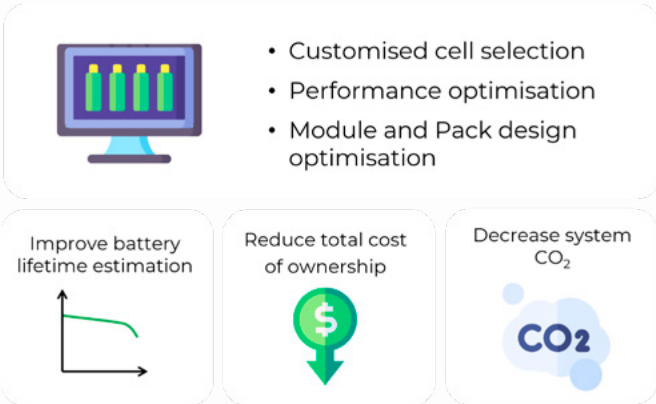
Round 5 competition

The Voltt: Optimizing EV Battery Lifetime with Advanced Modelling Technologies

By better predicting the aging of lithium-ion batteries (LIBs) used in electric vehicles (EVs), this project will reduce the total cost of ownership of systems and improve the sustainability of battery development.



Project costs
Total project costs: £950,152
Grant contribution: £745,808

Executive summary

About:Energy and Imperial College London are collaborating on "The Voltt" project to develop technologies that optimize the lifetime of batteries in EVs. Estimating battery lifetime is crucial to pack design, warranty estimation, and advanced battery management systems. However, collecting data on battery degradation is expensive and time-consuming, making it difficult for new entrants into the industry. The project will develop state-of-the-art ageing datasets and models for commercial lithium-ion batteries, reducing the total cost of ownership of EVs.

Battery modelling and virtual iteration can speed up battery development, but current software platforms lack insights into the underlying physical properties of batteries. The project aims to fill this gap and bring new innovations to market for state-of-the-art and next-generation batteries.

About: Energy has commercialised research developed within Faraday Institution research projects to characterise the electrical, electrochemical, and thermal properties of a battery. The project aims to develop advanced battery ageing testing procedures and models with Imperial College London, centralising bespoke testing methods and reducing the barriers to the adoption of models. This project will contribute to the development of next-generation batteries and reduce the reliance on physical testing and prototyping, making battery development more accessible and cost-effective.

Timeline with milestones and deliverables

- Develop a test plan to create ageing models that provide a significantly lower cost and timeline to predicting battery lifetime. (Month 3)
- Building a cloud-based pipeline and database that can be used by companies to efficiently access real-time ageing data of batteries. (Month 6)
- Create degradation models for five popular commercially available batteries (inc.Samsung, LG and Molicell) used in automtive, motorsports and avaition. (Month 22)

Project innovations

- Translating existing research from Imperial College London relating to degradation into a commercially ready product for industry.
- Understanding how degradation models can be used to optimise system design and automotive battery products for lifetime and carbon footprint.
- Developing a cloud-based database to streamline the development of new battery technologies that rely on ageing data.

Partners

ABOUT:ENERGY

Imperial College London

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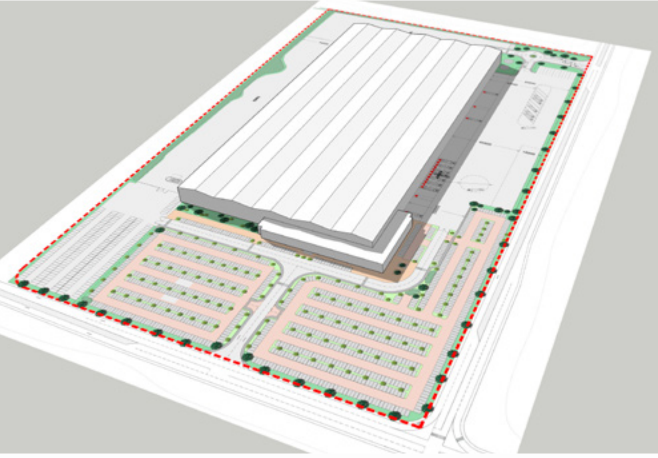
UK – GIGAWATT Hour Cell Manufacturing Facility Feasibility (Giga Factory)

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 decarbonisation 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

williamblythe
Excellence in chemistry
A Synthomer Group Company synthomer

Lancaster University

cpi

delta
A Cosworth Company

WILLIAMS ADVANCED ENGINEERING

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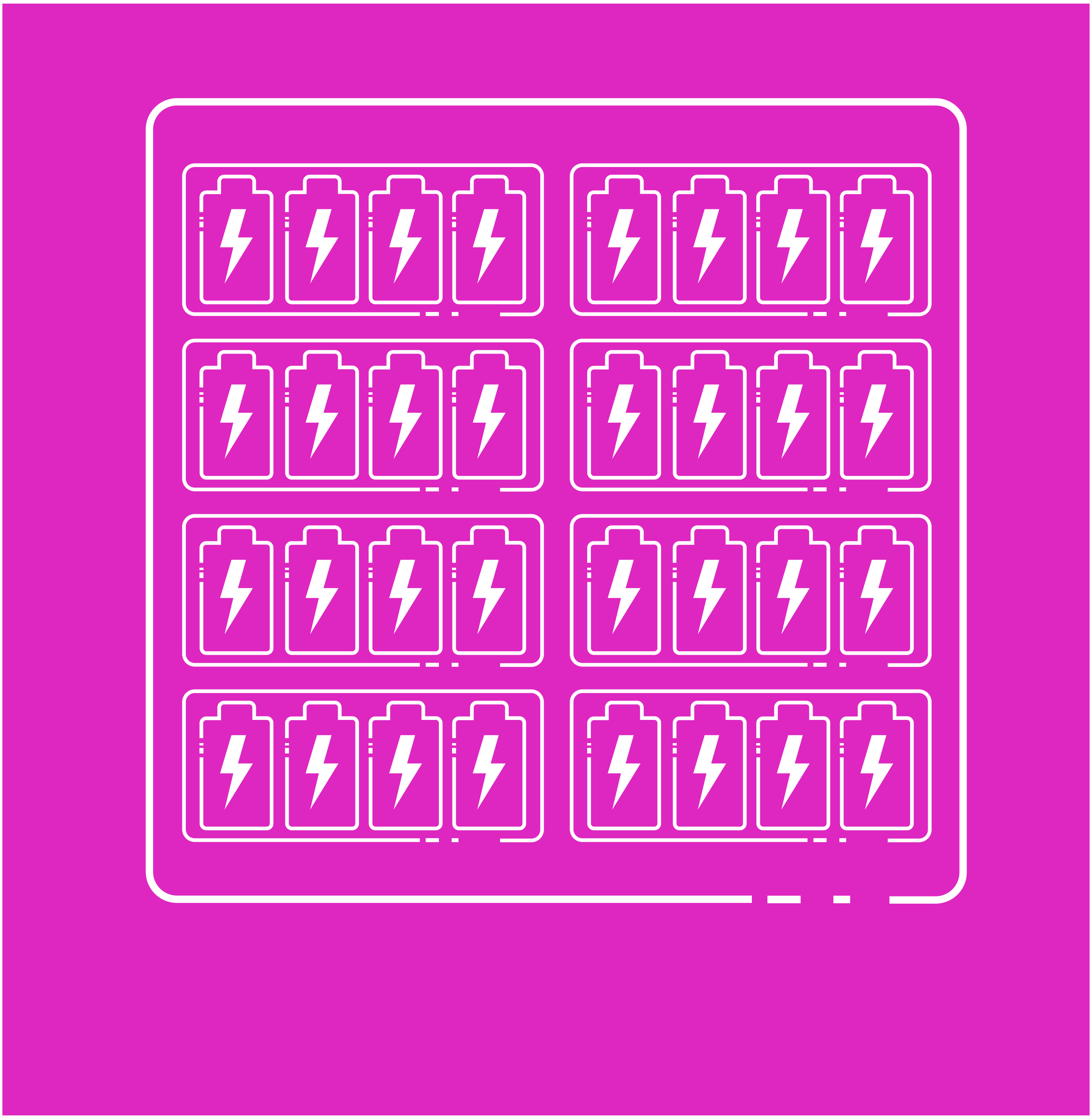
Modules, packs and battery management systems innovation projects

A further step into battery integration on final applications is covered here.

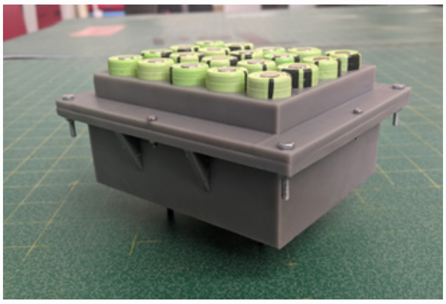
The section presents projects covering key critical design aspects for modules and packs, such as thermal management, packing efficiency and safety. Novel materials and processes to improve safety and diagnostics are also covered. Developments on enhanced battery management systems with improved battery life predictability and accuracy are described.



Round 3 competition

Advanced battery thermal control and 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 202.

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

Queen's University Belfast, ALP technologies ltd, University of Southampton, cpi, University of Exeter, Deregallera

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AEROPROOF: UK produced aerogel Anti-Thermal Propagation pads for EVs

The project consortium of Thermulon, CPI and University of Southampton will be formulating and testing Thermulon's superinsulating aerogel powders in various formats of anti-Thermal Propagation pads

Project costs
Total project costs: £658,166
Grant contribution: £549,531

Executive summary

The energy-dense batteries used for electric vehicles (EVs) are vulnerable to Thermal Runaway (TR): an incident where a cell heats in an uncontrolled manner, breaches a safe operating temperature, and triggers a domino effect of overheating in the rest of the module or pack. The outcome of such incidents can be a fire that leads to damage to the vehicle or even to loss of life. The spread of TR and major incidents can be prevented or mitigated with an effective TR barrier: a thin, lightweight layer of a super-insulating material. Often referred to as an Anti-Thermal Propagation (ATP) Pad.

The aim of this project is to produce a thermal runaway (TR) mitigation solution called AEROPROOF: a thin insulating blanket based on Thermulon's lightweight, superinsulating aerogels. Silica aerogels are fire safe, the most insulating materials known to science, and minimise heat transfer thanks to their nanoporous structure (95%+ air); and thanks to Thermulon's chemical process (continuous, low-temperature, ambient-pressure drying), can be made affordably at scale.

Alongside CPI using their state-of-the-art formulation skills, Thermulon and CPI will formulate new types of TR ATP Pads using Thermulon's aerogels. These will then be tested by the University of Southampton in a destructive test rig between two EV cells to understand performance.

Timeline with milestones and deliverables

- Formulate ATP pad using different matrices and additives with CPI (Months 1–3).
- Make ATP pads (CPI/Thermulon; via two different routes) (Months 3–9).
- In-situ cell testing of ATP pads at UoS (From month 6–12).
- Iterate to output final ATP pad formulation and process ready for external third-party testing with OEM (Months 6–12).

Project innovations

The key innovation in this project is the integration of Thermulon's superinsulating aerogel powders into a useable aerogel ATP barrier pad which can be deployed in electric vehicles globally. This will include formulation of the powder in various formats and matrices to enable the powder to be included into a fibrous mat so it can be cut to size, or integrated into a compression pad for use between cells.

For CPI – there will be secondary innovation in powder formulation using their state-of-the-art iterative equipment to enable large volume testing of hundreds of formulations.

For UoS – there will be secondary innovation in designing and making new battery safety testing rigs for thermal runaway testing.

Partners

THERMULON

University of Southampton

cpi

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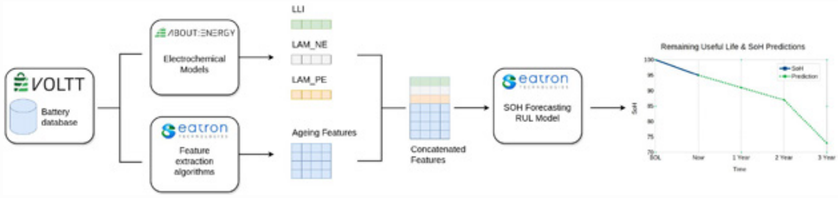
aiMAGINE – Intelligent management of battery-aging with an AI-powered Decision Engine

Development of AI-powered solutions to maximise battery-lifetimes using existing Battery Management Systems (BMS)

Project costs
Total project costs: £884,388
Grant contribution: £619,072



Executive summary

aiMAGINE integrates physical models, cloud analytics, AI, and over-the-air (OTA) updates to enhance battery performance and prevent premature SoH degradation.

AI can enable a battery lifetime revolution via predictive analysis using big data from real-world battery operation combined with high-quality models. However, integrating AI into real Battery Management Systems remains challenging due to limited integration know-how and inadequate data inputs.

aiMAGINE combines two pioneering organisations to deliver a revolutionary AI-powered intelligent battery software layer with industry leading data.

Eatron has developed a unique edge and AI-powered cloud-based platform designed to deliver highly accurate predictions of SoX, SoH alongside a patented Remaining-Useful-Life (RUL) predictive capability. A first-of-its-kind AI-powered decision engine (AI-DE), a new Eatron innovation, will be developed in aiMAGINE to provide optimum Depth-of-Discharge (DoD) and charge limits policies to BMS for each individual battery.

About:Energy has developed a high-fidelity electrochemical model database, offering the industry access to performance battery models and degradation data. This project aims to reduce costs and accelerate the delivery timelines of complex Battery Management System (BMS) products.

Timeline with milestones and deliverables

February 2024 – March 2025

Key Milestones

- Scale up from cell to pack model demonstrated.
- Pack model developed incorporating customer-bespoke cell data.
- Hybrid RUL models validated.
- Synthetic data for customer cells generated.
- Customer-RUL model built.
- Initial Decision-engine model training completed.

Deliverables

- Cell to pack model scale up methodology.
- Cloud-infrastructure with pack-model access.
- Customer cell characterisation completed: beginning of life and degradation.
- Pack model for Eatron customer cell validation report against real-world data.
- ML training with new models and existing Voltt data completed.
- Pack-scale RUL model integrated into Eatron cloud.
- Decision framework and model training for DoD/ charge limit management.
- Showcase material completed and engagement with educators on showcase.

Project innovations

- Develop cloud-based hybrid (AI+model) RUL-model with accuracy of <80 equivalent-cycles.
- Establish transfer-learning methodology leveraging existing modelling data to minimise time and need for degradation testing.
- Develop first-of-its-kind AI-Decision Engine (AI-DE) to close the loop with active RUL-management via adaptive depth-of-discharge (DoD) and charging-current limits to increase first-life by up to 20% (~400 cycles) for aggressive use cases, and increase range up to 10%.
- Develop interfacing protocols between Eatron's AI-IBSL (edge and cloud) and About:Energy's existing 'Voltt' database.
- Develop cloud-platform for scalable (10s-1000s cells) electrochemical models for customer-bespoke packs, demonstrated on e-motorcycle packs (~5 kWh).

Partners

ABOUT:ENERGY

eatron TECHNOLOGIES

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Kieran O'Regan Email: kieran@aboutenergy.co.uk Web: https://www.aboutenergy.io/m

AMPLiFII-2

Design, development, application and 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 and 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) and 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
JLR
POTENZA
TRACKWISE
CONNECTING TECHNOLOGY
WMG
THE UNIVERSITY OF WARWICK

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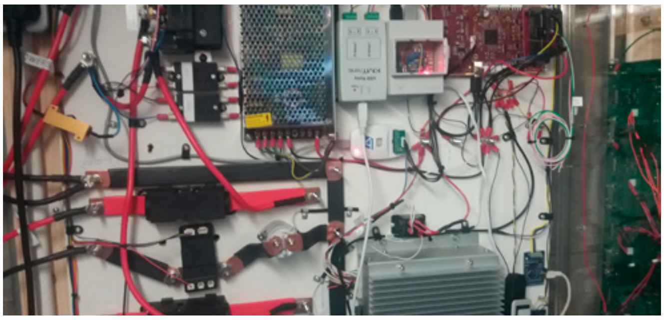
Round 3 competition

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 (EVs), 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 (EVs) 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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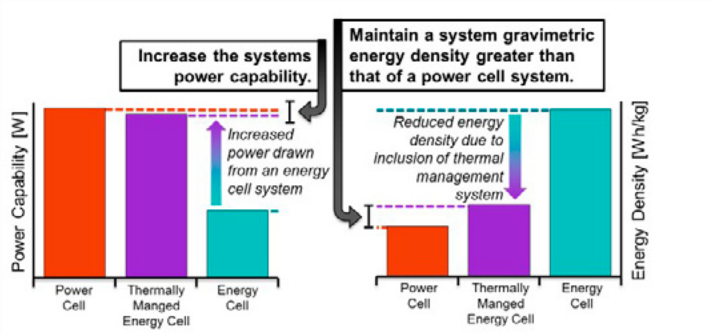
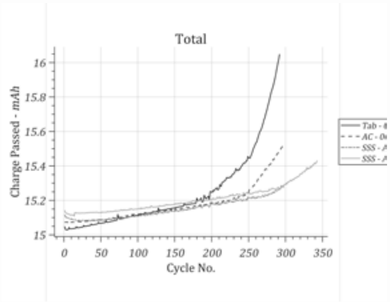
Automotive Technology Transfer Energy Storage Thermal Strategies (ATTESTS)

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 electric vehicle (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 five times 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

Web: www.imperial.ac.uk/electrochem-sci-eng

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

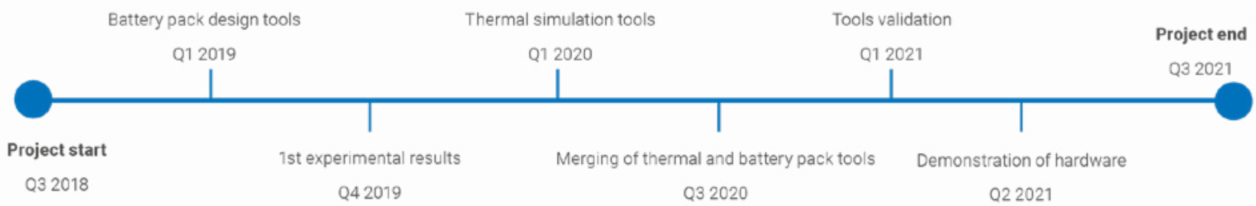
Executive summary

Aston Martin Lagonda (AML) 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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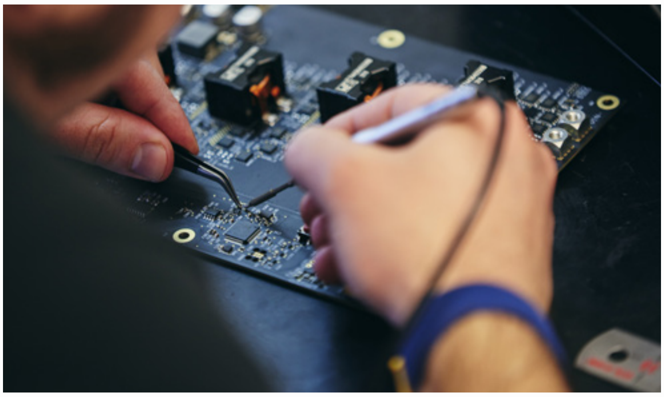
Battery management control system for Advanced Battery Engineering (BABE)

Developing the technical and commercial stages of Brill Power's revolutionary Battery Management Control System in electric vehicle (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 electric vehicles (EVs) 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 EVs 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

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Thomas Kelly Email: Kelly_Thomas_x1@cat.com

BESTBUS: Battery pack life-Enhanced Solutions Tailored for e-BUS

BESTBUS objective is to establish a high-performance battery-pack solution that overcomes the challenges faced by bus manufacturers, from concept to manufacture

Project costs
Total project costs: £1,400,000
Grant contribution: £1,100,000

Executive summary

Electrification presents many challenges for a bus manufacturer such as Alexander Dennis: electrified powertrains double the vehicle cost, the bus powertrain lifetime reduces from 40-years to as little as seven, battery-pack weight must be <2,500kg for double-decker, while achieving 150-200+ miles of range in all weather conditions. Meanwhile, ingress to vehicle cabin usable volume also imposes height and packaging challenges.

The project's objective is to design and manufacture a high-performance battery-pack solution that overcomes these challenges. As a dynamic UK start-up specialising in electric vehicle (EV) battery-pack technology, IONETIC is leveraging its state-of-the-art Arc design and production platform to establish the manufacture of highly optimised and cost-effective battery-pack solutions. This is achieved by modular and flexible battery design software combined with innovative production techniques, allowing the Arc Platform to generate a bespoke battery solution for individual customers.

Responding to e-bus market needs, Imperial College London joins the project to create state-of-the-art degradation mode analysis tools and design of experiments that develops the understanding of degradation states that cells inside the pack experience under real operating conditions. This toolset is used to identify the most valuable opportunities to extend the battery-pack lifetime trough battery design and control. This approach supports the UK's leadership in advanced automotive engineering during the transition to Net-Zero.

Timeline with milestones and deliverables

The project will take place from January 2024 to March 2025.

- It will deliver a battery system solution with significantly improved life, cost, and mass, versus existing market solutions.
- State-of-the-art degradation mode analysis approaches will be developed using experimental, analytical, and modelling-based methods. This will enable rapid evaluation of the state of degradation under real-world scenarios to inform improvements in battery pack design.
- A commercial case will develop to combine degradation data, system design, and supply chain to deliver improved total cost of ownership.

Project innovations

- This project aims to drive several innovations to support the long-term future of the bus sector in the UK.
- Design and manufacture lighter and more compact battery systems to enable higher passenger count and comfort.
- Develop experimental and analytical tools to rapidly carry out and evaluate real-world degradation.
- Identify and implement electrochemically informed opportunities to at least double battery pack life in bus applications through cutting-edge control strategies.
- Reduce total cost of ownership of buses, via optimised design and implementation, using IONETIC's Arc platform.

Partners

IONETIC

ALEXANDER DENNIS

Imperial College London

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Breathe Life: a Physics Enhanced Battery Life Controller

The project aims to develop a physics-based approach to predict electric vehicle battery lifetime, minimising degradation uncertainties and reducing testing time. It will introduce a new battery life-control algorithm for enhanced performance and cost reduction, validated for market entry.

Project costs
Total project costs: £759,000
Grant contribution: £596,857

Executive summary

There is industry demand for more a accurate prediction of electric vehicle (EV) battery lifetime to optimise battery pack design and management. Current challenges to achieving this include EV battery degradation as a result of temperature or battery ageing.

Breathe Battery Technologies, the leading provider of adaptive charging software, focuses its technology on charge time optimisation and degradation reduction.

The objective of this project is to develop a physics-based approach to predict battery lifetime with quantified uncertainties, in a shorter testing timeframe. The project aims to introduce a new battery life-control algorithm to minimise lifetime uncertainties and complement existing charge-control software. It will utilise existing research from Imperial College London to establish a parameterisation framework, reducing time and data requirements for lifetime predictions.

Some of the objectives of the project include:

- Reducing testing time from three to six months, down to four to six weeks
- Extending battery lifetime
- Ensuring battery health remains within +/-5% of target, reducing development test volume by 50%, and extending battery life by over 20% compared to current solutions.
- Prototyping features integrated into existing charge products with further validation in automotive environments for swift market entry post-project completion.

Timeline with milestones and deliverables

The project will last a total of 15 months, with the ultimate objective being to develop a unique approach to predicting and ensuring battery lifetime. This will be achieved by combining physics-based predictions at the development stage with active degradation rate control once EVs are owned by customers.

The project will comprise of seven work packages with their own deliverables and milestones:

1) Project management (15 months).
2) Model and test specification (3 months).
3) Model parameterisation and validation (12 months).
4) Model development (13 months).
5) Life prediction and charge control optimisation (10 months).
6) Battery life controller development (14 months).
7) Commercial development and exploration (3 months).

Project innovations

- Faster predictions to enable longer battery life.
- This includes extending life through optimal charge control at beginning-of-life (BOL) by leveraging physics-based model prediction, creating cell-agnostic modelling and data analysis procedures, predict degradation, quantifying prediction uncertainties and accelerating parameterisation.
- Real-time life control to minimise lifetime uncertainty.
- This innovation includes a life controller which autonomously adjusts charge control throughout vehicle life to ensure battery health is on track to meeting life target, consciously optimising charge control by combining BOL life predictions and real-time estimations of battery health states, minimising life uncertainty from variations in battery packs and usage conditions, and fast integration to the existing Breathe Life product.

Partners

BREATHE

Imperial College London

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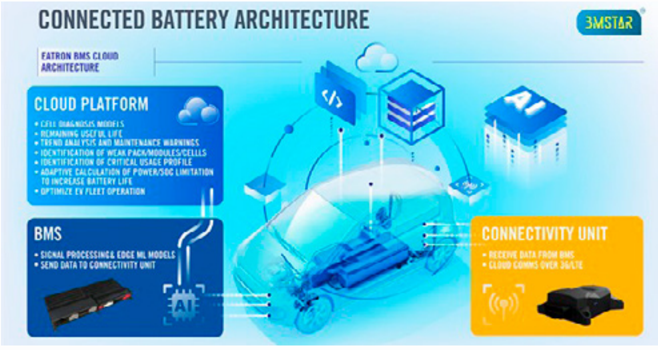
COBRA – Cloud/On-board Battery Remaining useful life Algorithm

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 electric vehcile (EVs) and their uptake on the roads around the world.

Partners

WMG
THE UNIVERSITY OF WARWICK

eatron
TECHNOLOGIES

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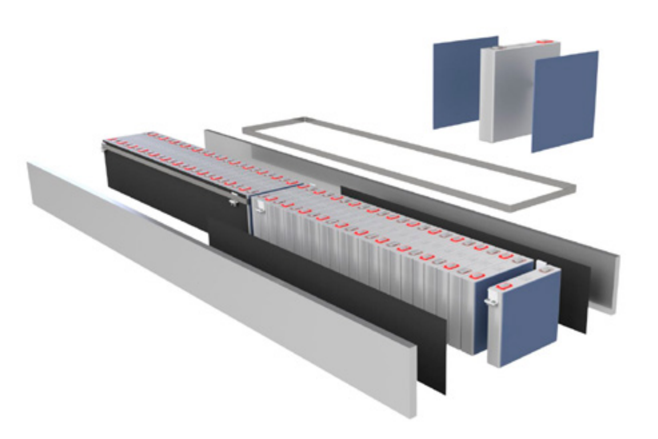
Conceptual feasibility of a heat pipe as a structural and thermal member in an automotive battery pack design

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

Contact:
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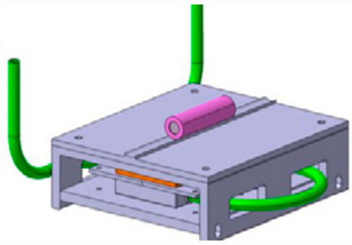
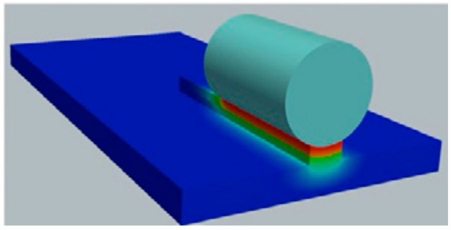
CoRuBa

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.
- A combined experimental-numerical approach to characterise conductive heat losses through individual connections to a cell within a battery was developed by FACT and validated at the cell level.

Partners

Imperial College London

Fergusson Advanced Composites Technology

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Current density imaging in EV battery modules

This project produced new sensors to image the current flow within electric vehicle (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 (LIBs) for use in electric vehicles (EVs).

Project costs
Total project costs: £566,607
Grant contribution: £447,619

Executive summary

The Isothermal Control Platform (ICP) 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 second 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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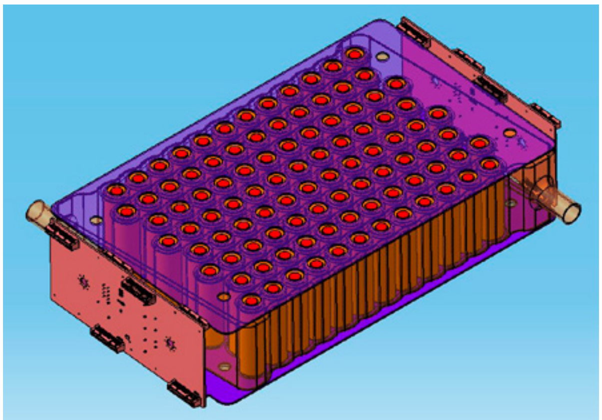
Email: info@thermalhazardtechnology.com Web: www.thermalhazardtechnology.com

DutyCell: Duty Cycle Optimisation at the Cell Level

By implementing pulsed charge and discharge profiles using a smart busbar, we are able to produce a battery module with improved efficiency in rapid-charging and high-power applications.



Project costs
Total project costs: £320,796
Grant contribution: £260,401

Executive summary

Improving battery charge and discharge performance is a key area of battery development. Many charging strategies have been proposed and evaluated, extending beyond the standard CC-CV (Constant Current -- Constant Voltage) profile and adding a range of pulsed charging profiles including relaxation periods and discharge phases. These charging strategies have been shown to improve battery performance but require charge points that can tailor the charging strategy to the battery. In addition, the updated charging profiles are applied at the module or pack level, subjecting all cells to the same charging profile.

This project will move the battery charging algorithms to the battery itself by using a patented 'flexible busbar' to implement the flexible charging profiles internal to the battery, dynamically varying the charge to each cell. This allows the battery to be charged by a conventional charger whilst the charge profile to each cell can be modified.

The project will deliver a prototype battery with integrated pulsed charging to demonstrate the feasibility of this approach.

Timeline with milestones and deliverables

February 2024:	Project start
June 2024:	Cell level benchmarking
October 2024	Prototype battery modules
January 2025:	Module level benchmarking

Project innovations

- Benchmarking of cell pulse charging and discharging strategies.
- Patented cell level control and monitoring in the busbar.
- Implementation of module level pulse charging and discharging strategies within the BMS.
- Benchmarking of integrated module.

Partners

bd blue dolphin

cdo2

US University of Sussex

Contact:
Gary Kendall, CDO2 Email: info@cdo2.com Web: cdo2.com

EB-Bat – Electron Beam Battery Welding

The key objective is to produce a prototype system to prove the key technology concept of electron beam welding of battery packs; to enable manufacturers to this forward to production.

Project costs
Total project costs: £1,428,313
Grant contribution: £900,486

Executive summary

The UK automotive industry is facing the challenge that ICE production is set to decline over the next decade as they are replaced by electric vehicles (EVs) due to the requirement for zero-tailpipe emission, consumer demand and government regulation.

Many car manufacturers are moving towards using cylindrical cells, which offer high energy density and faster charge rates, but a typical EV pack will contain some 12,000 joints, with a production rate of two packs/minute. This presents a unique manufacturing challenge. Conventional welding is slow and multiple parallel stations are needed, adding to costs. More recently, laser welding has been deployed; offering higher production rates, although the materials used for bus bars (copper and aluminium alloys) are difficult to laser weld due to reflectivity, and the speed of scanning is limited. High rejection rates have been experienced with volume laser welding.

EB-Bat will demonstrate battery pack manufacture using a process potentially twenty times faster than laser welding. Electron beams (EBs) can be deflected and refocussed much more rapidly than laser beams, as this is achieved using magnetic fields, without moving parts, as the welds are made. In addition, EBs do not suffer from reflectivity from copper and aluminium, making more consistent and reliable welds.

Timeline with milestones and deliverables

Q1
M1: Requirement’s specification
D6.1 Battery module outline specification
D8.1 Initial risk register

Q2
M2: Equipment and fixturing designed
D3.1 Machine long lead orders placed

Q3
D4.1 Process and QA interim report

Q4
D2.1 Electron optics design simulation complete
D3.2 Machine engineering drawings complete
D8.2 Initial exploitation plan

Q5
D6.2 Design of battery modules
D7.1 Initial test and evaluation report

Q6
D5.1 Equipment and fixture manufactured
M3: Weld process report
M4: Battery pack manufactured

Q7
D4.2 Process and QA final report
D5.3 Battery pack assembled
D6.3 Battery EB manufacture method issued
M5: Battery pack tested

Q8
D8.3 Demonstration Day
D7.2 Final test and evaluation report
M6: Video/equipment description issued

Project innovations

- Wide deflection EB welding equipment.
- In-line process quality assurance.
- Novel battery pack designed for EBW.

Partners

Cambridge Vacuum Engineering
delta – A Cosworth Company
TWI

Contact:
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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 and 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

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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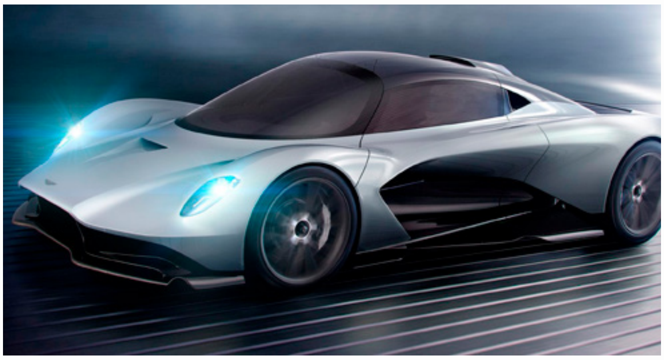
Hybrid Battery Optimisation (HBO)

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), Vantage Power, Aston Martin, Imperial College London, BrillPower

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Web: www.brillpower.com
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

M&I MATERIALS

RICARDO

MIVOLT® LIQUID IMMERSION COOLING

WMG THE UNIVERSITY OF WARWICK

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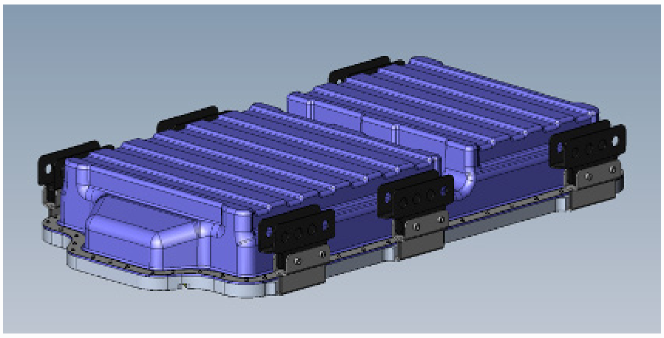
IMPACT – IMProving Battery Cooling Technologies

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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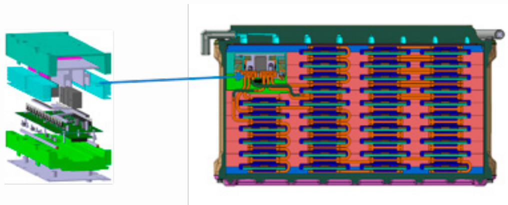
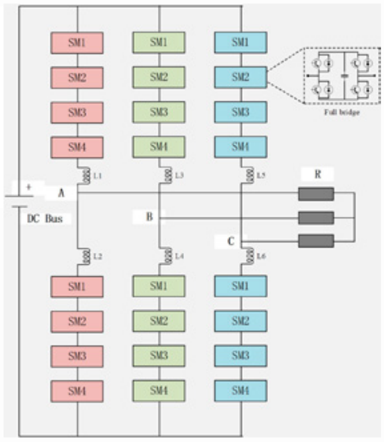
Multi-Bat – innovative power electronics for electric truck batteries

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 of battery and power electronics technologies.





Project costs
Total project costs: £402,968
Grant contribution: £241,909

Executive summary

Multi-Bat project aimed to design a smart battery pack using an innovative multilevel converter topology. The project optimised the number of levels versus power stage cost and efficiency, based on the design requirements for a 44t HGV. The smart control system demonstrated that the topology can achieve both machine drive and SOC management.

The battery pack was designed according to the specific requirements of the project, ensuring high efficiency and low cost. Additionally, thermal and EMC analysis demonstrated the benefits brought by the smart battery pack design and control. A new lab prototype is set up based on the project design. It is currently being used to validate the design and further optimisation on the smart control of modular multilevel converters.

The project successfully developed a highly efficient and cost-effective smart battery pack for use in heavy-duty vehicles, which will have a positive impact on both the environment and the economy.

Timeline with milestones and deliverables

The project run from August 2021 – March 2022.

Project innovations

This project successfully optimised the number of levels and module design, achieving a balanced cost/efficiency for the battery pack. The decoupled control for machine drive and SOC management significantly reduced harmonic distortion, EMI issues, and improved system reliability. The project also integrated an immersive cooling system into the smart battery pack design. This innovative cooling system utilises a dielectric liquid to directly immerse the battery cells, resulting in significantly improved cooling performance and temperature uniformity with the help of control from the multilevel converter topology.

The outcomes of this project provided significant benefits for the heavy-duty vehicle industry. The optimised battery pack design reduces the environmental impact while good efficiency and increasing reliability, ultimately resulting in a more sustainable transportation system.

Partners

RICARDO

UNIVERSITY OF BATH

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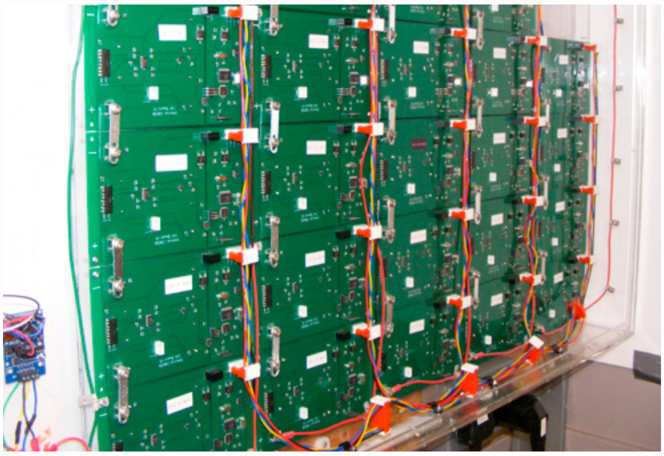
Vincent Zheng, Technical Project Leader UoB — Email address: xz2478@bath.ac.uk

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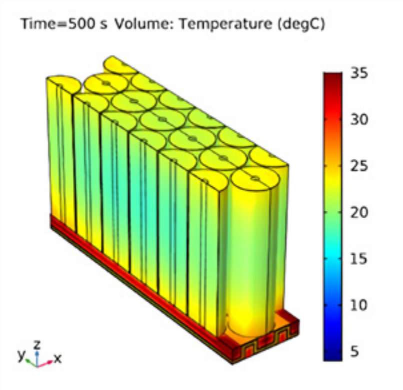
Novel self-regulating CHIP (Cooling or Heating Integrated Pipe) for BTMS

The major objective of this project is to improve the safety and efficiency of current electric vehicle (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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PIC-BATT

Project costs
Total project costs: £471,028
Grant contribution: £349,244

Executive summary

Ultramax Batteries Ltd., in partnership with The University of Bath and MIVOLT (a 'Shell' company), will develop a novel immersive cooling technique for high-energy lithium battery packs, as winners of the Faraday Battery Challenge.

With the greater adoption of electric vehicles (EV's) and ever-increasing applications of lithium-ion batteries (LIBs) in power-hungry applications, battery packs are subjected to elevated operating temperatures due to higher charge and discharge rates. This has a detrimental effect on the battery life span, since lithium-ion cells are highly temperature-dependent and experience reduced lifespan and performance outside the restrictive optimal operating temperature range of 25 °C to 40 °C.

This presents a crucial consideration for engineers tasked with optimising battery performance in diverse applications.

Ultramax along with their partners will conduct research into suitable immersion fluids and develop battery packs with and innovative cooling system that uses a biodegradable fluid. This will help to improve the lifespan of LIB packs considerably. It will also have a significant positive impact on battery pack safety mitigating thermal runaway in the cells under fault conditions or elevated ambient temperatures. ''Whilst creating these battery packs; safety, sustainably better thermal management, cost reduction and commercial scalability have been our top priority'' remarked the Chief Engineer at Ultramax. The project once implemented will massively benefit the LIB industry and allied or dependent industries.

Timeline with milestones and deliverables

The project aims to develop a prototype immersive cooling system for lithium-ion battery packs using a novel dielectric fluid, with a focus on safety, sustainability, cost reduction and commercial scalability. The "PIC-BATT" project is scheduled to run for 12 Months, from February 1, 2024, to January 31, 2025. The project will progress through various development phases, starting with simulating the battery pack in the first phase and developing the hardware in the second phase. The third phase will involve fine tuning the design of the pack and the module through extensive testing, while the fourth phase will focus on improving the manufacturability of the pack for commercial uses.

WP	Activity name	Q1 - 2024	Q2 - 2024	Q3 - 2024	Q4 - 2024	Jan-25
WP1	Project Management			Mid-project report		Project close report
WP2	Concept and Detailed Design		Extended market research report			
WP3	Simulation modelling			Simulation analysis results		
WP4	Dielectric Fluid			Fluid testing results		
WP5	HW manufacture/procurement			Proof of concept batt.modules		
WP6	Batttery testing				Battery testing report	
WP7	Manufacturability					Manufacturing feasibility report
WP8	Exploitation and Dissemination					Exploitation plan

Project innovations

The project will leverage on latest advances in immersion cooling technology by using biodegradable ester fluids with high dielectric strength. The battery packs will be designed using LFP cells which will be fully submerged in the fluid to allow rapid heat transfer to the medium. This technique has potential to deploy LFP cells in applications requiring higher C rates. The aim of the project will be to reduce the volume of fluid used and trade off with performance though the use of bespoke manifolds and novel fluid flow paths.

Partners

ULTRAMAX®
ULTRA QUALITY MAX POWER

IMMERSION COOLING LIQUIDS

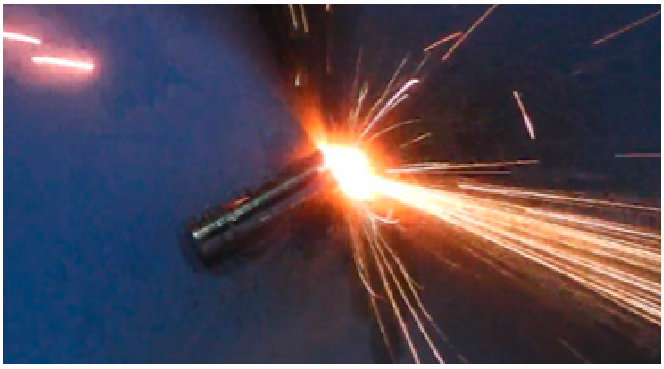
IAAPS
ADVANCING PROPULSION

UNIVERSITY OF BATH

PreLIBS: Preliminary Feasibility Study of Lithium-Ion Battery Safety

Objective-Safety related to thermal runaway.

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

JLR
3M
Potenza
Lifeline Fire & Safety Systems Ltd
Bespoke Research and Consultancy from HSE
Warwick FIRE

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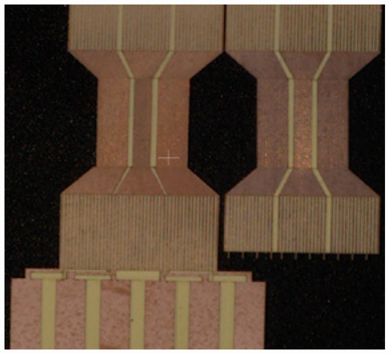
Round 3 competition

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 electric vehicle (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 looking 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, peacock technology ltd, University of Sussex, University of Strathclyde Glasgow

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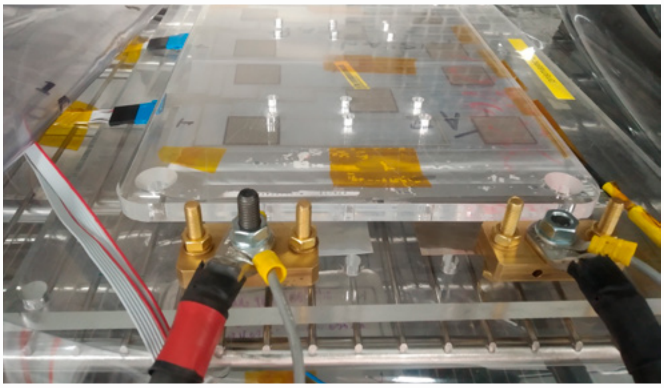
Printed temperature sensors for use in battery monitoring systems working within the cells/batteries

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



Project costs
Total project costs: £235,516
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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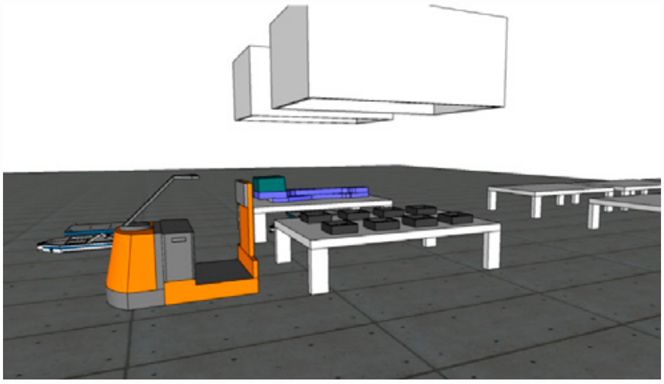
Project Detain

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

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Project Gamma

The project focuses on developing an integrated structural battery pack and wireless communicating battery cells to allow increased efficiency, reliability, and sustainability of automotive batteries.

Project costs
Total project costs: £8,575,000
Grant contribution: £4,701,000

PROJECT GAMMA Y

Executive summary

The project will create an integrated structural battery pack to utilise the battery more effectively in the vehicle than current products. This will be achieved by optimising and combining component functions to deliver improved system energy density.

The partners bring valuable expertise in technology, manufacturing process and simulation areas to maximise the project benefits:

- Grow UK R&D battery expertise.
- Deliver advanced technology solutions for integrated structural batteries with wireless communicating cells.
- Improved battery characteristics: through reducing mass, increasing range, improving structural rigidity, reducing part count, more efficient packaging, simpler manufacturing and therefore reduced CO2e.
- Validated modelling techniques offering accelerated programme delivery and attributes.
- Create new UK battery supply chain opportunities.
- Grow JLR electrified vehicle sales by introducing more competitive vehicles enabled by higher efficiency and improved sustainability.

Project Gamma has been conceived in conjunction with the partners as a significant step to accelerate the growth of advanced battery technologies in the UK – aligned with the Faraday Battery Challenge's aims and supporting the UK Net Zero Strategy.

Timeline with milestones and deliverables

Deliverables are, a comprehensive technology benchmarking report, an integrated battery demonstration vehicle, cut-away exhibit and a wireless battery demonstrator. Development, build and test of these will give all partners improved knowledge, processes, products and services.

Work packages are:

WP1 – Technology Trend Assessment and Target Setting.

WP2 – Battery Design.

WP3 – Computer Aided Engineering.

WP4 – Vehicle Body Build.

WP5 – Battery Build.

WP6 – Connected Cells.

Project innovations

Project Gamma will target innovation in battery design by improved integration to vehicle, supported by optimisation modelling techniques:

- Structural integration of the battery pack; with the objectives of reducing mass, increasing range, improving structural rigidity, reducing part count, more efficient packaging and simpler manufacturing.
- Creation of validated modelling and optimisation techniques offering accelerated programme delivery and improved attributes.

Partners

ALTAIR

danecca

JLR

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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

Executive summary

LIBRIS surveyed the state-of-the-art in lithium-ion battery (LIB) 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 LIB 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, JLR, Lifeline Fire & Safety Systems Ltd, Health & Safety Laboratory, 3M, Tri-Wall, WMG The University of Warwick, Warwick FIRE

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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 EV, while optimising the sources of electricity, either cost driven or charge time 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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SHIELD – State of Health Including Evaluating Longevity Determination of batteries

Developing cost effective and practical implementation of improved State-of-Health monitoring in batteries and improved second-life battery grading

Project costs
Total project costs: £224,401
Grant contribution: £187,075

Executive summary

Lithium Ion with its growing popularity for automotive application, is now facing the ever-increasing demand and challenge for end-of-life disposal. As lithium-ion recycling is still in its infancy, repurposing and second-life applications as a way to extend a batteries useful life, is gaining ground. Unfortunately, many repurposed battery modules are running a higher risk of catastrophic failure as the battery cells are taken to deeper end-of-life limits, or first-life usage has stressed and degraded the cells for which knowledge or data on the stressing is unavailable.

A battery subjected to frequent cold charging, fast charging or long periods of storage fully charged in elevated temperatures, will each have a significant impact on the State of Health or State of Failure of the battery

Project SHIELD incorporates the benefits of (Lab-Based) Electrochemical-Impedance-Spectroscopy (EIS) State-of-Health approach into a BMS adaptable solution, using novel hardware and software algorithms. By tracking cell degradation over its life cycle and monitoring performance changes in use, SHIELD aims to identify critical failure risk in advance and safely shut down the module before a failure occurs. The project builds on UTE's Weld-free technology for ease of remanufacture, and supports the next stage into second life.

Timeline with milestones and deliverables

- Benchmark cells using current lab-based methods to characterise battery models for referencing test cells.
- Develop simulations based on modelled parameters and the electronics approach being developed. Concept and test circuits to be produced in conjunction with simulated results.
- Using approaches to stress test cells, such as; fast charging, low-temperature charging, elevated temperature and high-state-of-charge storage and cycling. Monitoring of cell characteristic changes periodically through testing using lab techniques.
- Validate and build test electronics mountable within a battery module for State-of-Health determination of the test cells.
- Compare readings and results from lab-based degradation monitoring and project electronics monitoring.

Project innovations

The project aims to incorporate an effective method of degradation tracking and State-of-Failure determination within a battery module, such that advanced indication of failure can be more reliably ascertained. Understanding of key degradation mechanisms and measurable characteristics that may be used to evaluate a cell as goes through its useable life has current challenges with technology that can be incorporated at battery level, which this project aims to address. In addition, the project also aims to provide better grading of batteries destined for second-life application, as well as more reliable projections of useful battery life.

Partners

Cranfield University

CHIMERA ENERGY
AN UPGRADE TECHNOLOGY ENGINEERING COMPANY

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Web: www.chimera-energy.com

TECHNO – Temperature monitoring, Cooling and Heating during Normal Operation

TECHNO is a demonstration/concept pouch cell module with differential thermal control overcoming the limitations of current global control by keeping the temperature throughout the pack uniformly in its optimal range.

Project costs
Total project costs: £662,895
Grant contribution: £558,419

Executive summary

The TECHNO project has successfully built a demonstration/concept module with integrated differential thermal management incorporating state-of-the-art UK developed predictive monitoring, differential cell heating and cooling. It is connected to a liquid coolant/refrigerant supply and communicates with an external BMS. The functions of the autonomous system are:

- Maintaining a uniform temperature within specified limits, depending on the operating requirements.
- Reporting specific parameters, e.g. minimum/maximum/mean temperatures, to the BMS.
- Sending alerts to the BMS in case of impending risk.

Operating at optimum temperature has three main advantages: faster charging, higher energy density, and longer life. Charging rates above 5C and doubling of the useful lifetime are possible, (with 3C demonstrated before project close), but the optimal operating temperature depends heavily on the charge/discharge rate. Temperature uniformity is essential to keep all parts of the cells operating under the same conditions.

TECHNO combines two scalable printed sensing technologies, for temperature and pressure, with novel computational approaches for real-time monitoring and control. Tomographic reconstruction, producing a full 3D temperature map, is combined with predictive monitoring and adaptive control algorithms. Thermal control is maintained by a combination of low power printed resistive heaters and indirect liquid cooling through a unique structured polymer heat exchanger, both positioned between the cells.

Timeline with milestones and deliverables

- Specification of TECHNO cells, module and BMS (April 2023).
- Design of appropriate printed temperature sensors and resistive heaters (April 2023).
- Algorithms for thermal tomography and predictive monitoring and control (April 2023).
- Design of cell cooling units (May 2023).
- Design of appropriate printed pressure sensors (June 2023).
- Modelling and design of manifolds and fluid flow system (July 2023).
- Completion of internal BTMS hardware and coding of algorithms (January 2024).
- Completed stack assembly (December 2023).
- Completion of TECHNO module (March 2023).
- Completion of testing and demonstration of TECHNO module (April 2024).

Project innovations

- Integrated module level autonomous battery thermal management system.
- Maintains uniform optimum temperature within the cell stack and in individual cells.
- Full 3D temperature profile using thin printed sensors and reconstruction algorithms.
- Cell level pressure sensing using thin printed sensors.
- Predictive monitoring and adaptive control.
- Intra-cell heating using thin printed resistive heaters.
- Individual cell indirect liquid cooling/heating using structured polymer heat exchangers.
- Scalable, modular solution.
- Hierarchical communication with external battery management system.
- Connects directly to external fluid cooling system.

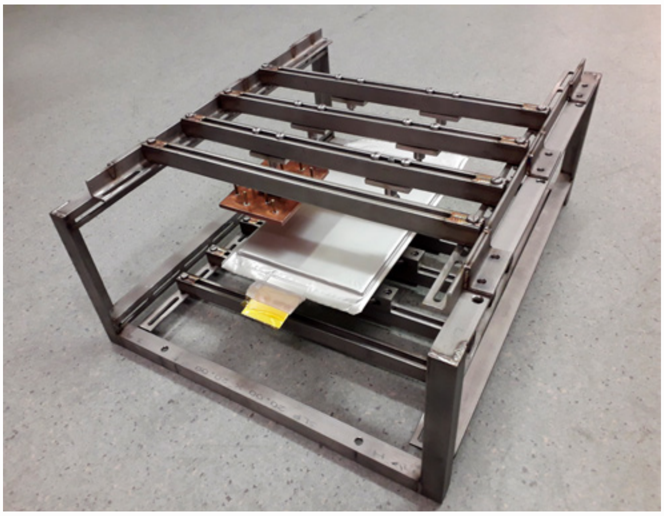
Partners

cpi
PAK Engineering
PST SENSORS
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Contact:
David Britton Email: david.britton@pstsensors.com Web: www.techno-ect.co.uk

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 (LIB) 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

Contact:
Email: info@thermalhazardtechnology.com Web: www.thermalhazardtechnology.com

WIZer Batteries

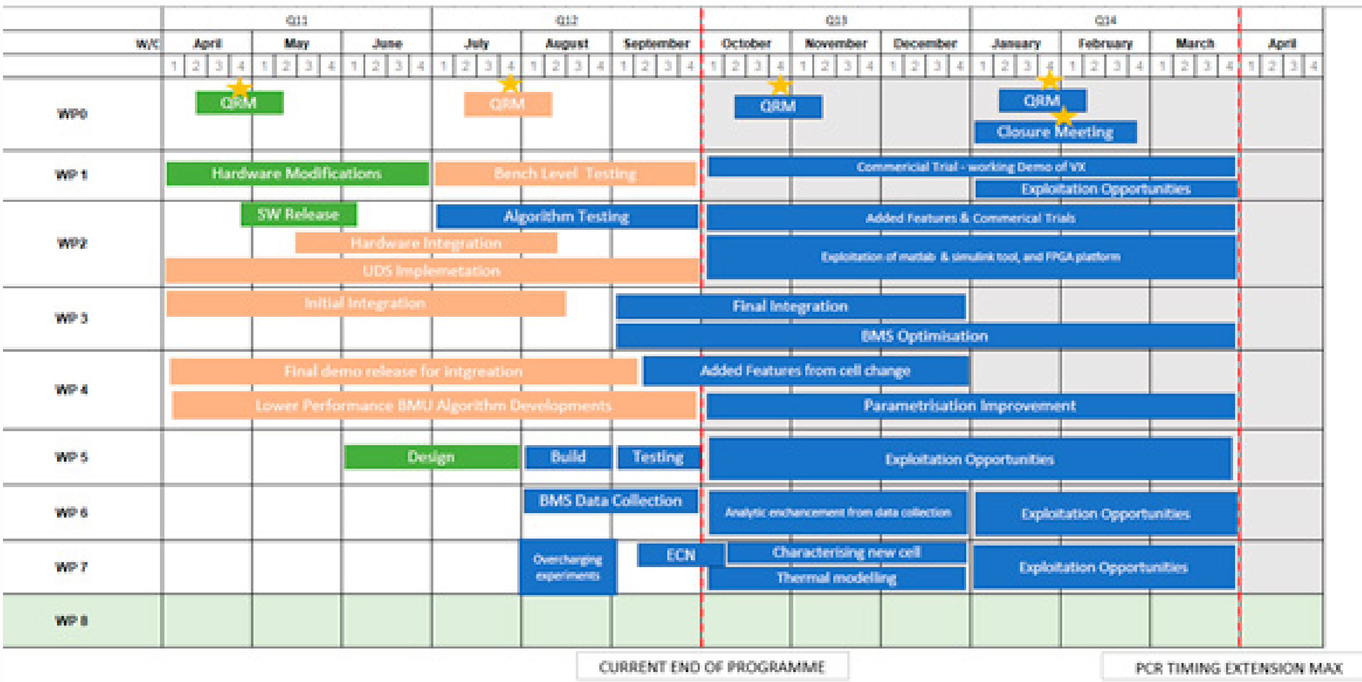
WIZer Batteries will deliver a number of disruptive linked technologies in the field of energy storage

Project costs
Total project costs: £7,564,215
Grant contribution: £5,801,698

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 (LIB) 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

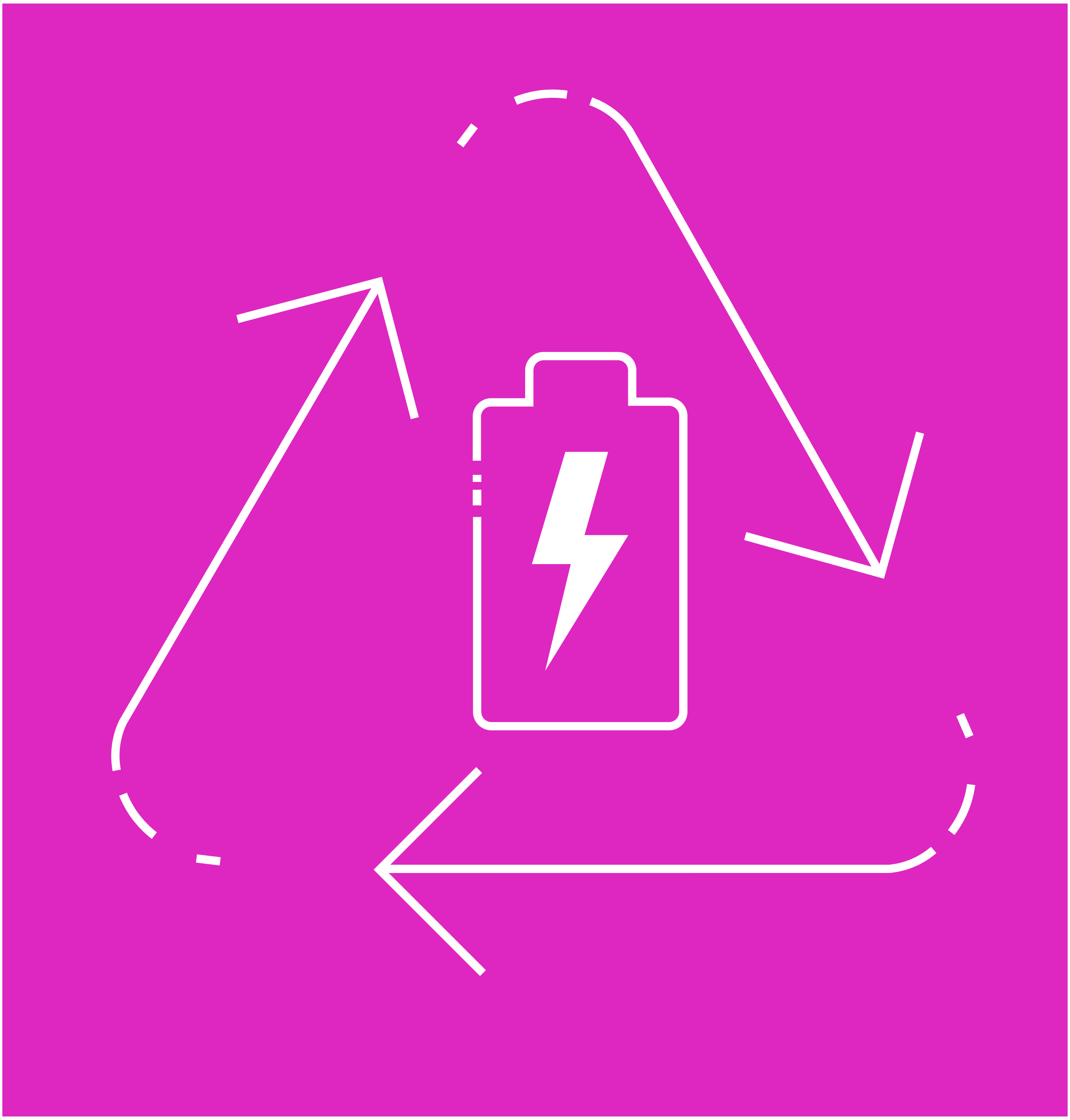
Silver Power Systems
Imperial College London
codeplay
Fortescue WAE

Contact:
Rob Millar Email: Robert.millar@wae.com Web: www.wae.com

Second life and recycling innovation projects

An important factor for minimising the environmental impact of batteries is to extend their use and lately recover not only the critical minerals from the active materials, but also recycle all components.

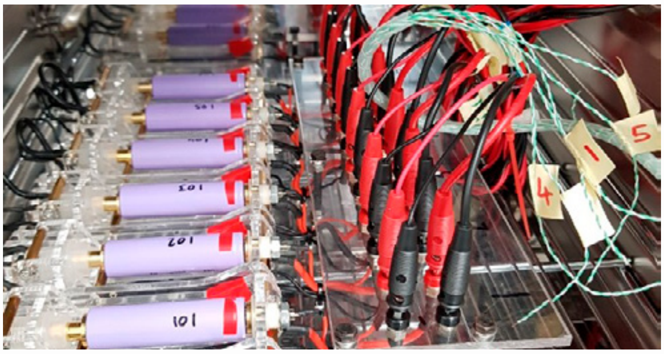
This section presents innovations in diagnostics and applications for second-life batteries, technologies for recycling and critical metals recovering of end-of-life cells and life-cycle analysis. Topics on recycling will cover, for instance, direct recycling, hydrometallurgical, shredding, and separation process for black mass.



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 (EV) 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 LIB packs in off-grid solar home applications.

Partners

M-KOPA SOLAR (MAENDELEO NI LEO)
DENCHI POWER
Imperial College London

Contact:
Billy Wu — Email: billy.wu@imperial.ac.uk — Web: www.imperial.ac.uk/design-engineering
Nick Russel — Email: nick.russel@denchigroup.com — Web: www.denchipower.com

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 (EV) lithium-ion batteries (LIBs) generating materials suitable for re-manufacture.

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 LIBs 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
Johnson Matthey
Nissan
Coventry University
Ecobat Battery Technologies

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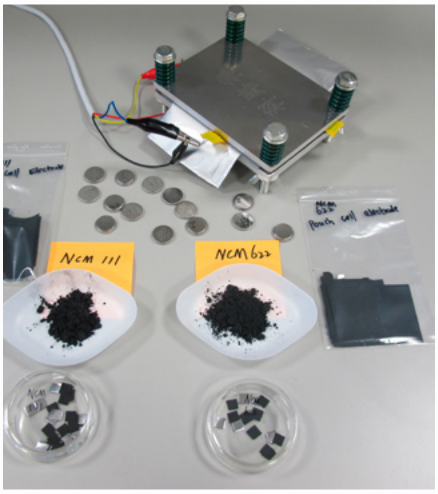
CAM-EV

Development of new processes to recover critical metals from multi-chemistry, end-of-life electric vehicle (EV) batteries and convert them into tailored cathode-active materials.



Project costs
Total project costs: £1,289,443
Grant contribution: £1,018,629

Executive summary

The global electric vehicle (EV) revolution could create more than 11 million tons of battery waste annually by 2040, enough to fill Wembley Stadium almost 20 times every year. Fortunately, this mountain of battery waste can be avoided by taking a circular economy approach.

In January 2022, UK BEIS established the Critical Minerals Expert Committee; in July, they produced a policy paper that confirmed a key objective as being “accelerating a circular economy of critical minerals in the UK, increasing recovery, reuse, and recycling rates and resource efficiency, to alleviate pressure on primary supply”.

In addition, researchers alongside battery EV manufacturers have started to switch their focus to battery chemistries that are less reliant on scare materials. Examples include Tesla with lithium ferrophosphate (LFP) batteries, which are still reliant on nickel and cobalt, and CATL with (Sodium) Na-ion batteries.

This 24-month collaborative R&D programme between Altilium Metals and Imperial College London’s Department of Chemical Engineering, is focussed on optimising Altilium Metals novel hydrometallurgical method to process black mass containing multiple end-of-life battery chemistries (i.e. NMC+NCA+LCO+LFP) to recover the critical metals and, from which, ensure the consistent production of a high-quality, tailored cathode-active material (CAM).

Imperial will test and qualify the CAM material in silo, before using it to manufacture cathodes in battery cells for further performance qualification. Furthermore, the consortium will perform a technical and commercial viability assessment regarding the processing of next-generation sodium ion batteries.

Timeline with milestones and deliverables

- Independently validated, TRL6 hydrometallurgical and CAM production processes from mixed-stream black mass containing LFP chemistry.
- Demonstration and qualification of CAM in battery cell samples.
- Technical and commercial validation of recycling next-generation, sodium-ion chemistry.
- Independently audited Carbon Impact Assessment of Recycling Materials versus Mining.

Project innovations

The project focuses on the development and demonstration of two key, novel processes:

1. Recycling methods to recover 95%+ critical metals from black mass containing diverse lithium-ion battery chemistries (NMC+NCA+LCO+LFP).
2. Manufacturing of the recovered materials into tailored (e.g. NMC) CAMs.

ICL will electrochemically test and validate the CAM before using it to manufacture cathodes in battery cell samples for performance qualification. Imperial College will test capacity, DCR-Impedance, Rate-Capability, Self-Discharge, Cycle-Trend and Recovery-Efficiency.

Partners

Imperial College London

altilium clean technology

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Christian Marston Email address: cm@altilium-metals.com Web: www.altilium-metals.com

Faraday precision ageing laboratory

Delivering fully factored, long-term cell ageing and 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 (LIB) 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 and 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 and 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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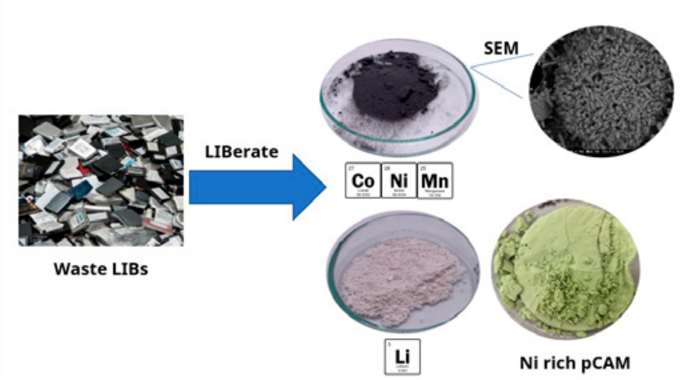
LIBerate- A novel method for black mass extraction from used Lithium-Ion cells and refining the material to go back into new cells

Developing scalable and economically feasible process to produce high performance cathode precursors from end-of-life lithium-ion batteries (LIBs)

Project costs
Total project costs: £665,030
Grant contribution: £525,307



Executive summary

LIBerate addresses the urgent global need for efficient battery recycling methods at a time when demand for electric vehicles (EVs) and battery storage is rapidly increasing. It supports the circular economy of battery materials, reduces environmental impact, decreases greenhouse gas emissions, and lessens dependency on raw material mining by recovering and recycling the precious cathode material. As the EV market expands and the call for renewable energy storage grows, LIBerate aims to deliver a resilient supply chain of secondary battery critical minerals in the UK.

Project LIBerate promises not only to redefine the landscape of battery recycling, but also supports the UK's transition to a low-carbon economy and bolsters its standing in the global battery production sector. With a strategic focus on rapid commercialisation and market integration, LIBerate plans to move quickly from pilot demonstrations to broader market rollout, collaborating with industry leaders. CellMine's patent pending process isolates and purifies critical metals such as lithium, cobalt, manganese, and nickel. The refined metals not only meet but surpass the performance standards of virgin materials, providing a sustainable alternative to traditional mining practices. This ensures that refined secondary materials are reintegrated directly into the battery manufacturing process, allowing manufacturers to comply with incoming regulations.

Timeline with milestones and deliverables

- Develop and refine an advanced method for black mass extraction from used lithium-ion cells.
- Implement CellMine technology for refining the isolated metals into high-quality cathode materials that surpass the performance of virgin equivalents.
- Optimise the recycling process to improve operational efficiency, reduce energy consumption, and lower the environmental impact, making the technology scalable and economically viable.
- Design a pilot-scale facility to demonstrate the practical application of the LIBerate process in an industrial setting.
- Demonstrate the integration of recycled cathode materials in new battery cells, showcasing their performance in comparison to conventional materials, and establishing benchmarks for industry acceptance.

Project innovations

Project LIBerate focuses on developing safe, cost-effective, and environmentally friendly methods for extracting and refining materials from spent LIBs —a key step in enhancing the sustainability of battery supply chains. This project targets innovative purification techniques for black mass, ensuring high productivity and safety in recycling operations. CellMine not only enhances the performance of cathode materials derived from recycled content, but also can be applied to virgin feedstocks, greatly expanding its utility within the supply chain. This approach promises to yield high-purity, high-value materials, thereby maximising the environmental benefits of electric vehicles and supporting a robust circular economy in battery manufacturing

Partners

CELLMINE

RSB Battery Recycling

University of St Andrews

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Simon Rathbone
Email address: simon@cellmine.co.uk
Web: www.cellmine.co.uk

Project: R2LiB

The challenge is to identify and prove an economically viable process for the recycling and reclamation of materials from end-of-life lithium-ion batteries (LiBs).

Project costs
Total project costs: £2,200,000
Grant contribution: £1,600,000

Executive summary

Predicted sales of ultra-low-emission vehicles (ULEVs) in the UK will generate large volumes of end-of-life LIBs. There is no current recycling supply chain for LIB in the UK currently, and 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 polyvinylidene fluoride (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 LIB 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 Limited

Research Partners

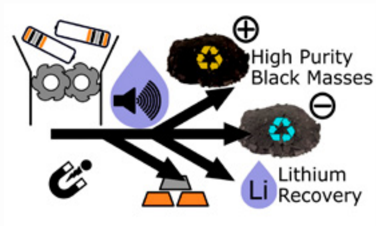
WMG The University of Warwick
University of Birmingham
University of York

Contact:
Paul Croft Email: pcroft@iconichem.com

REBLEND

Recovering battery-grade materials from upgraded black mass to enable remanufacturing of automotive battery products in the UK.

Project costs
Total project costs: £2,337,600
Grant contribution: £1,816,418



Executive summary

The UKs automotive lithium-Ion Battery (LIB) production industrsy faces two existential threats:

- LIBs require vast amounts of critical raw materials, especially the Cathode Active Materials (CAMs) cobalt, nickel and lithium. CAMs are all sourced from overseas, creating critical security of supply issues.
- OEMs and LIB manufacturers who are responsible for end-of-life (EoL) batteries lack LIB recycling infrastructure. Consequently, there is a growing mountain of automotive LIB waste (~6.6Mt by 2030) that must be exported.

Automotive LIBs can be reused or recycled to deal responsibly with battery-waste and provide a source of battery-grade materials. However, commercial, state-of-the-art recycling processes are inefficient and costly, do not produce raw materials of sufficient quality for reuse in automotive batteries, and are only available overseas.

REBLEND will demonstrate three processes for recovering the most expensive CAMs, cobalt, nickel and lithium through:

1. Combining novel delamination, magnetic, electrostatic and membrane separation techniques to produce separated and pure anodic and cathodic black masses from shredded EoL LIBs enabling battery-grade CAM recovery.
2. Direct cathode reclamation from production scrap removing the need for hydro-metallurgy and enabling direct reuse in new cells.
3. Processing coarse shredded material using electrostatic and magnetic separation, preventing carcinogenic dust formation, significantly reducing health and safety risks for workers.

Timeline with milestones and deliverables

Two-year project with the following milestones:

- Optimum safe shredding parameters (State of charge, kg/hr).
- Demonstrate recovery of >90% NMC and Li salts from a minimum of 1kg black mass.
- Demonstrate zero liquid discharge capability on liquid wate stream(s) through membrane treatment.
- Pilot line design & build.
- Complete life-cycle impact assessment for the base process route.
- Production of sufficient black mass feedstock for pilot-line operations to project-end.
- Validation of pilot line to produce batches of purified black mass.
- Separation and relithiation of 100g of active material.
- Complete environmentally optimised supply chain and production process option catalogue and tool.

Project innovations

Key areas of innovation in the project are:

- Optimisation of LIB shredding parameters to reduce undesirable reactions that limit recovery of materials.
- Use of world-leading polymeric nanocomposite membrane technology to achieve zero process waste and extract lithium.
- Optimisation of innovative electrostatic and magnetic separation techniques and (for the first time) delamination of electrode and current-collector to enable cost-effective recovery of high-purity CAM recyclates at pilot-scale.
- Direct recycling techniques for cathode reclamation.

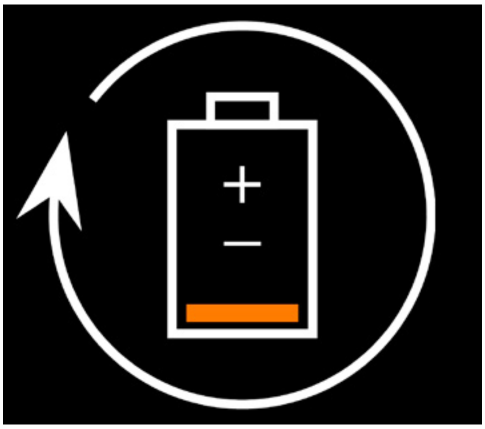
Partners

University of Birmingham
ecoshred
ICoNiChem
Watercycle Technologies
ecolamp recycling solutions
Cornish Lithium
University of Leicester
MINVIRO

Contact:
Anthony Hulmes Email: anthony.hulmes@ecoshreduk.com

ReLIGHT

Development of a rapid, charge photometry-based scanning and classification system to evaluate the lithium content in black mass to empower industrial direct recycling approaches



Project costs
Total project costs: £397,824
Grant contribution: £331,832

Executive summary

Direct recycling offers significantly improved sustainability, lower greenhouse emissions and could lead to cost savings of up to 43%. However, a major challenge to enable a direct recycling industry lies in the efficient classification of the lithiation content in the spent active materials. Knowledge of this quantity will determine the amount of re-lithiation required and sets the value of the spent material.

ReLIGHT will demonstrate the feasibility of a low-cost, high-throughput methodology for the classification of the lithiation content in automotive black mass. The technology will build on illumion's charge photometry technique for characterising the amount of charge stored in battery materials using light. Black mass will be extracted from spent automotive batteries utilising the state-of-the-art recycling techniques established at the University of Birmingham, and then used to develop charge photometry for the high-speed identification of lithium content.

Timeline with milestones and deliverables

This is a 12-month project, commencing on 1 February 2024. It's key deliverables and milestones are:

- Production of black mass with known lithium content from two cell chemistry types (NMC & LFP).
- Development of charge photometric determination of lithiation content in black mass.
- Conduction of relithiation trials on NMC and LFP cells for direct recycling.
- Comparison of lithium loss between different stages of the recycling process.
- Development of a business case on how to integrate the methodology into industrial processes.

Project innovations

Our innovation is the development of a rapid and non-invasive quality control platform to accelerate the classification of lithium content in the direct recycling process of automotive battery electrodes. Existing technology used for determining lithium content in black mass is destructive and too slow to allow for in-line assessment of lithium content, curtailing the scalability of the direct recycling process. Our innovation will thus provide a viable technological alternative to expensive and energy intensive hydro-/pyro-metallurgical techniques, enabling industry to adopt a more sustainable direct recycling approach.

Partners

illumion

UNIVERSITY OF BIRMINGHAM

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Cathryn Langley Email: c.langley@illumion.io Web: www.illumion.io

ReNEW

ReNew is focused on increasing recyclability at the cell level, both at end-of-life and during manufacture, by developing processes for the direct recovery of NWO

Project costs
Total project costs: £496,832
Grant contribution: £326,196

Executive summary

Through the ReNEW feasibility study, Nyobolt and Coventry University will investigate and develop innovative methods for direct recovery and recycling of Nyobolt's NWO anode material from cell manufacturing scrap and end-of-life cells.

Sustainability and reducing environmental impact are key drivers for Nyobolt in bringing NWO to market. NWO addresses a market failure in the availability of batteries for applications which require fast charging, long cycle life and high power density. NWO already offers environmental benefits to customers by enabling smaller batteries to be used, therefore, reducing the resource burden for production, and through the long cycle life of over 10,000 cycles.

Alongside performance requirements, OEMs and operators require environmentally sustainable solutions when adopting zero emission technologies to meet regulations and customer expectations. Nyobolt's technology can meet upcoming EU requirements regarding recycled content without direct recovery of the anode, however, direct recovery of the anode enables a local source of NWO and further enhances the sustainability of the technology.

ReNEW will enable Nyobolt, working with Coventry University, to fully understand and further reduce the environmental impact of Nyobolt's technology. This feasibility study will assess the viability, both technically and commercially, of the direct recovery of NWO.

Timeline with milestones and deliverables

February 2024: Project start
- **Q2 2024:** NWO recovery methodology and scale up processes defined.
- **Q3 2024:** Regulatory report finalised.
- **Q1 2025:** Technical and commercial viability report finalised.

Project innovations

Current state-of-the-art battery recycling technology involves shredding of whole modules and packs to produce "black mass" as a major product. This is generally sold to processors as a wet paste mixture of water, cathode and anode, for further refining. Further process steps include pyrometallurgical, hydrometallurgical or direct recycling. These processes are usually outsourced outside the UK.

In ReNEW, Nyobolt aims to examine how state-of-the art battery recycling technology might be adapted for the unique qualities of NWO, and whether alternative methodologies need to be adopted.

Partners

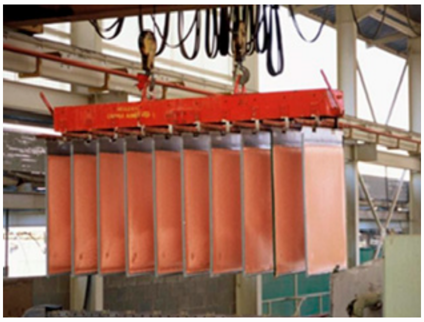
Coventry University

nyobolt

Contact:
Chris Lee
Email: info@nyobolt.com
Web: www.nyobolt.com

ReTail: Proving technical and economic recycling of battery metals from old mine tailings for re-entry into a UK electrified supply chain

ReTail aims to evaluate the feasibility of developing a new source and supply chain for metals that are critical to battery production for electric vehicles (EVs) using old mine tailings.



Project costs
Total project costs: £596,475
Grant contribution: £495,736

Executive summary

Instead of sourcing metals from mining of virgin mineral resources, which are increasingly carbon and resource intensive to extract and refine, ReTail will explore a new opportunity to extract metals by reprocessing mine tailings i.e. waste material left after primary metal mining processing - and provide these in a form that can be utilised by the UK battery supply chain. The project will focus on copper (Cu) and other metals, including Aluminium (Al), Iron (Fe), Titanium (Ti) and Magnesium (Mg), that are present in tailings of old copper mines.

The ReTail project will be led by the UK SME, Altilium Metals Ltd., who will collaborate with CPI on the project. Altilium has exclusive rights to reprocess materials from the largest mine tailing site in Eastern Europe. This site, in Bulgaria, contains approximately 170 million tons of tailings, that have been analysed and shown to have high residual volumes of Cu (estimated as 170 thousand tons), Al (2.9 million tons), Iron (2.9 million tons) and other metals. While others are seeking to recycle Cu from waste, this work is believed to be the first to aim to valorise copper mine tailings in battery supply chains.

Timeline with milestones and deliverables

- Altilium Metal 1/31/2024 SX-EW scale up feasibility study.
- CPI 4/30/2024 Process feasibility demo for Cu concentrate extraction.
- CPI 5/31/2024 TEA and LCA of SX-EW process for Cu recovery.
- CPI 6/30/2024 Outline TEA of Cu concentrate extraction process.
- CPI 7/31/2024 Process feasibility demo for other metal(s) extraction.
- CPI 9/30/2024 Outline TEA of other metal(s) extraction process.
- Altilium 9/30/2024 Market opportunity summary report.
- Altilium 10/31/2024 Final Project Report.

Milestones

- 12/31/2023 Process targets and output requirements agreed.
- 5/31/2024 TEA/LCA of SX-EW and Copper Concentrate processes complete.
- 7/31/2024 Screening study of other metals complete
- 10/31/2024 Business decision based on feasible study outputs
.

Project innovations

The innovative outputs of this project include:

- Cu SX-EW process evaluation and scaling study (TEA/LCA) for EV battery applications.
- Landscaping of metal recovery processes from mixed ores (Cu, Al, Fe, Mg, Ti).
- Reports on hydrometallurgy process development for Cu and other candidates (potential IP).
- Market feasibility validation of mine tailings to battery metals innovation.

These will reduce the technical and business risks, promoting further investment into reprocessing plants, accelerating a new supply of metals battery manufacturers.

Partners

altilium™ clean technology

cpi

Contact:
Christian Marston Email: christian@altilium.tech Web: https://altilium.tech/

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 (EVs), 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 EVs 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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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 lithium-ion batteries (LIBs).

Project costs
Total project costs: £2,617,960
Grant contribution: £2,064,530

VALUABLE

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 LIBs 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 LIBs.
- 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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Beyond Li-ion projects

This section will feature projects on next-gen batteries.

These technologies may have the potential to offer enhanced features compared to current Li-ion cells, for instance higher safety and improved energy density. Innovations are in new materials, cells and applications on different sodium systems, Li-Sulfur and solid-state chemistries. Projects will also present developments in material discovery using digital tools and Li-metal processing.

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 and model development.
- Anode optimisation for NIB.
- NIB technology advancements demonstration and scale-up strategy.

Partners

AMTE POWER, Ansys, Deregallera, University of Birmingham, Intellegens

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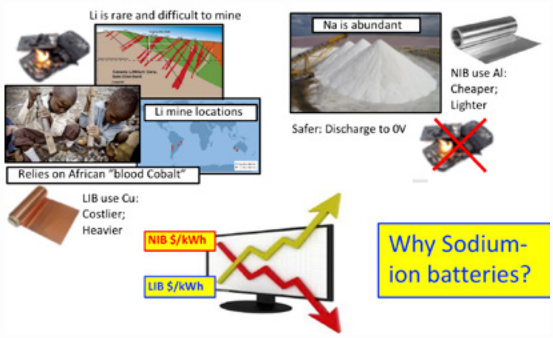
Advanced metamaterials for sodium-ion battery anodes – a scalability and economic feasibility study

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% of the cost and 30% of the mass of the copper used in LIB. Today's prototype of the NIB is 30% lower of the mass cost than the 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

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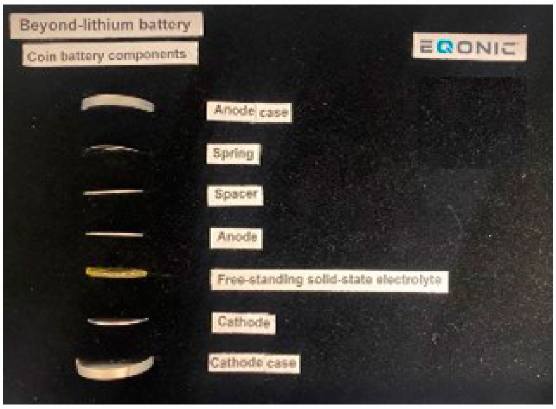
Round 6 competition

Anode and Current Collector Engineering for Lithium-free Batteries (ACORN)

ACORN focuses on improving energy efficiency and cycle life of next-generation lithium-free batteries through development of innovative engineering methods to optimise the surface and interface of anodes and current collectors



Executive summary

High-capacity rechargeable batteries are undeniably fundamental to achieving a net-zero economy. Eqonic is committed to achieving this goal through its cutting-edge R&D activities and generating opportunities our clients to achieve their net-zero objectives.

Existing mainstream battery technologies rely primarily on lithium and other rare-earth materials, which are scarce and unlikely to meet the projected global demand as well as being environmentally damaging to mine. Powered by cutting-edge R&D, our breakthrough innovation is our next-generation lithium-free battery technology which reduces reliance on critical elements while maintaining performance.

ACORN brings together our expert team and leading university academics to achieve this ambition through the advancement of electrolyte compositions along with superior cathodes and anodes, which together offer high-performance products. ACORN aims to improve the energy efficiency and cycle life of lithium-free batteries by developing innovative engineering methods to improve anodes and current collectors. ACORN focuses on cell materials and components of the battery value chain to meet the Faraday Battery Challenge objectives of (a) low-cost solutions with appropriate energy density, (b) high cycle life and reduction of battery degradation, and (c) increase safety by reducing thermal runaway risk.

Timeline with milestones and deliverables

D1– Parameter space mapping for surface engineering of anodes and current collectors (July 2024).

D2–Optimisation of surface engineering processes and development of design rules for long cycle life and high charge/discharge energy efficiency (October 2024).

D3– Battery cell prototyping for lab-scale demonstration and validation of performance to enable further development of the technology beyond ACORN (January 2025).

Project innovations

We pioneer innovative battery technologies that go beyond traditional lithium chemistry. Designed for performance, safety, reliability, and recyclability, our batteries minimise issues with raw material security and environmental impact throughout their lifecycle from sourcing to disposal. Our key innovations are:

- Scalable surface engineering approaches to minimise cell internal resistance and performance degradation of anodes and current collectors.
- Comprehensive design rules for improvement of cell energy density and charge/discharge energy efficiency.
- Novel anode and current collector formulations to achieve hundreds of full charge/discharge cycles.

Partners

Cranfield University

EQONIC

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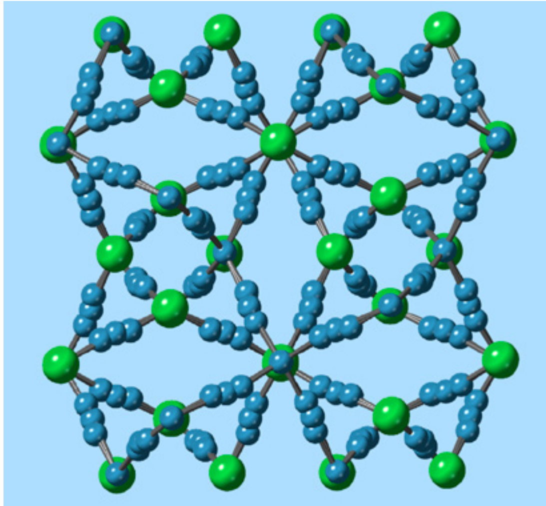
Cathodes, Anodes, and Solid-state Electrolytes for Lithium-Ion Batteries (CASE LIBs)

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. These are 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 and the 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

JM Johnson Matthey
Inspiring science, enhancing life

talga
Talga Technologies Ltd

The University Of Sheffield.

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Developing commercially viable Quasi-Solid-State Li-S batteries for the Automotive market

Project costs
Total project costs: £1,900,000
Grant contribution: £1,430,000

Executive summary

Lithium-sulfur (Li-S) batteries are a promising energy storage technology for application where high performance, lightweight batteries are needed, such as in certain aerospace and electrical vehicle (EV) applications. This project focuses on the development of Li-S batteries that have the potential to significantly enhance the number of times Li-S batteries can be cycled before they reach end of life, the energy they can store per unit volume, and the temperature range over which they can operate.

This project will combine the expertise of a consortium of leading UK industrial and academic partners to accelerate the development, scale-up and commercialisation of Li-S batteries within the aerospace and EV markets, enabling potentially significant economic benefits to the UK and contributing to reaching the national net-zero carbon emission target set for 2050.

The Project Team will develop suitable electrodes, separators, electrolytes, and cell design for a pouch cell Li-S format. The final deliverable will be the demonstration and evaluation of a Li-S pouch cell prototype with combined high volumetric energy density (above 400 Wh/L), high gravimetric energy (above 400 Wh/kg), long cycle life, high safety, and a broad operating/storage temperature window suitable for the EV market.

Timeline with milestones and deliverables

This project aims to deliver a Li-S pouch cell prototype with high specific energy (>400Wh/kg), extended cycle life, high safety, a broad operating/storage temperature window (-10 to 80°C), and potential for low cost by Q1 2025.

Partners

exawatt, E+R Group, Infineum, UCL, University of Nottingham (UK | China | Malaysia), OXLiD, WAE (A Fortescue Company), williamblythe (Excellence in chemistry; A Synthomer Group Company)

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Developing High Voltage Cathodes and Electrolytes for High Power 3D-Li Metal Batteries

Project costs
Total project costs: £434,088
Grant contribution: £343,795

Executive summary

Lithium metal is considered to be the ultimate anode material for next generation Li-batteries as it offers the highest possible energy density. However, reactivity of Li metal and difficulty in manufacturing cost-effective, thin, and battery-grade Li are some of the factors limiting its realisation as the anode in practical rechargeable solid-state, Li-metal and Li-S batteries. Sigma Lithium has developed an advanced 3DLi anode technology which circumvents issues such as dendrite formation and volume expansion. With this technology, Sigma Lithium can manufacture 3DLi anodes on various porous scaffolds with desired thickness of lithium in a cost- and resource-efficient way.

Sigma Lithium is teaming up with the University of Oxford to develop high-energy and high-power rechargeable Li metal batteries. The research team at the University of Oxford, led by Dr Robert House, have extensive practical and fundamental knowledge on cathode materials chemistry, their synthesis, and advanced battery materials characterisation methods. Cells with Sigma Lithium 3DLi anodes, novel in-house high voltage electrolytes and University of Oxford's high-voltage cathodes aim to go beyond usual nominal voltages (from 3.7 V to >4.5 V) and deliver high-energy and high-power densities.

The project is supported by Nissan Motor Manufacturing (UK) Limited as a research topic of interest and will act via an advisory role on the project.

Timeline with milestones and deliverables

This is a 15-month long project, and the following are some of the key milestones and deliverables:

- Initial selection of high voltage cathode and electrolyte combinations.
- Selection of high voltage cathodes and electrolytes for high-energy cells.
- Achieving system high-energy density.
- Selection of high-voltage cathodes and electrolytes for high-power cells.
- Electrode optimisation for high-power cells.
- Achieving system high-power density.

Project innovations

- 3D-Li anode with an optimised structure to deliver high-power/fast-charge discharge.
- High-voltage electrolytes compatible with Li metal.
- High-energy cells with optimised high-voltage cathode formulations.
- A practical rechargeable high-voltage Li-metal battery.

Partners

UNIVERSITY OF OXFORD

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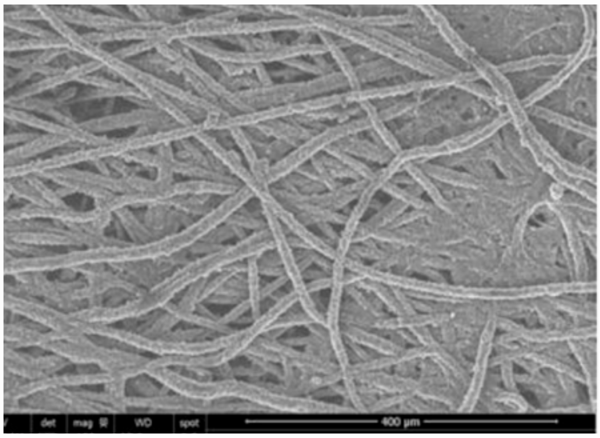
Development of 3D porous Lithium electrode for new generation electric vehicle batteries

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 lithium-ion batteries (LIBs) 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 LIB 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

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

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 demonstrated how LiNa's innovative planar battery design overcomes the problems which prevented the original tubular sodium-nickel-chloride batteries from achieving mass market take-up.

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

Manufacturing processes were upgraded, to increase production from current lab-scale volumes. Processes were prepared for scale-up and optimised to maximise recycling/re-use. A high-level concept for pilot manufacturing was designed, which will implement the upgraded process and introduce automation.

Legal and commercial preparations for a follow-on demonstration were completed. The commercialisation strategy for the LiNa-Power system will be upgraded including a refined cost-model.

Timeline with milestones and deliverables

Milestones

Oct 2021	MS1	System spec defined
Jan 2022	MS2	Proposed process improvements defined Jan 202
	MS3	Material changes and 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 (i) TRL6 for the novel NANiCl2 system, and (ii) optimised manufacturing processes ready for mass production, and able to achieve theoretical recycling/re-use targets.

Partners

cpi
Imperial College London
Helical Technology
LiNa Energy
MEP Technologies Battery Systems
Lancaster University
WMG THE UNIVERSITY OF WARWICK

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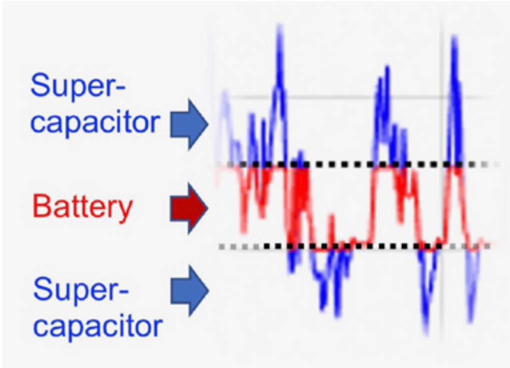
Feasibility project to dramatically extend 1st life via next generation battery management systems (HESS)

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 (LIBs) 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 LIB 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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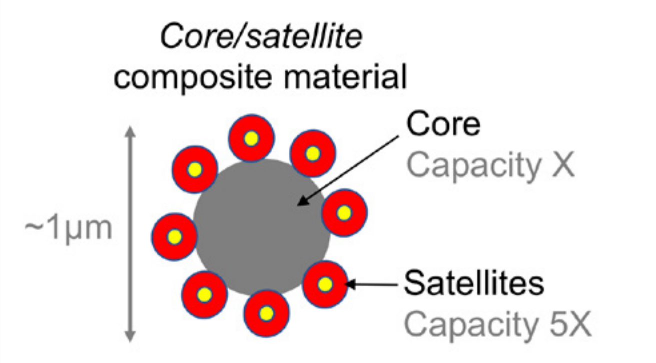
Feasibility research into composite carbon electrodes for sodium-ion batteries

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 (LIBs) 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 LiBs.

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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Round 1 competition

Field Enhanced Sintering of Beta Alumina for Electric Vehicle Battery Applications (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: and
- 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 threefold increase in productivity and longer furnace lives and opens up an 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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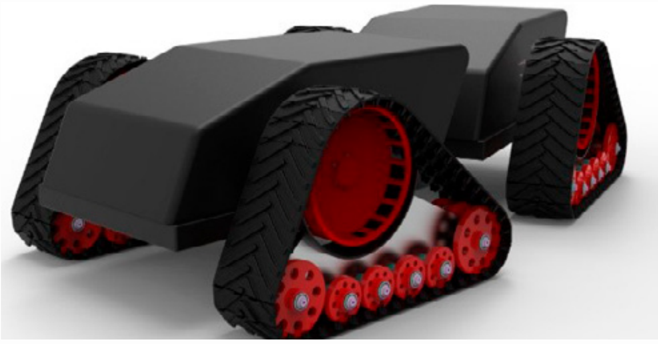
Gii-Cap supercapacitor in all-terrain vehicles

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 cycle times. This will enable the manufacture of graphene supercapacitors of just seconds ("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 electric vehicle (EV) design companies (MEP Technologies, Agile Vehicle Technologies, the University of Liverpool, and Warwick Manufacturing Group) will develop the next generation of electric vehicle (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 (LIBs) 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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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
JLR
WMG THE UNIVERSITY OF WARWICK

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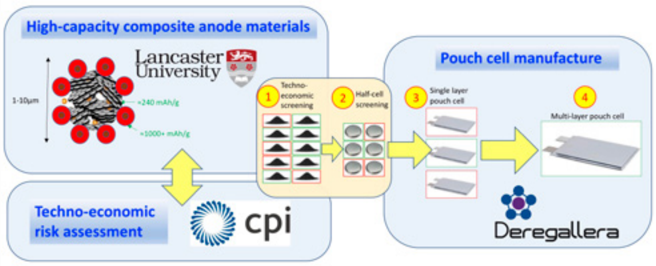
Brian Cooper Email: bcooper@jaguarlandrover.com

HIPERCARB – High Performance Carbon Composites for Sodium-ion

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

Project costs
Total project costs: £408,000
Grant contribution: £338,000



Executive summary

HIPERCARB delivered three exciting composite anode materials to TRL3. The three materials promise to serve distinctly individual applications that are either: very-high-capacity/high cost; high-capacity/moderate cost or moderate capacity/very-low-cost applications. Progress beyond TRL3 was stymied by difficulties encountered during scale-up from 1g to 100g within the project timescale.

However, development of all three materials continues under NEXGENNA. The techno-economic risk assessments conducted by the CPI provided early identification of cost and health and safety issues likely to present at 1000 tonne/year production scale and guided the low TRL process development.

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:

1) Massive volume expansion during cycling limits life.
2) Reactions occur to a shallow “skin-depth” in bulk material.
3) Low intrinsic conductivity often limits power density and,
4) 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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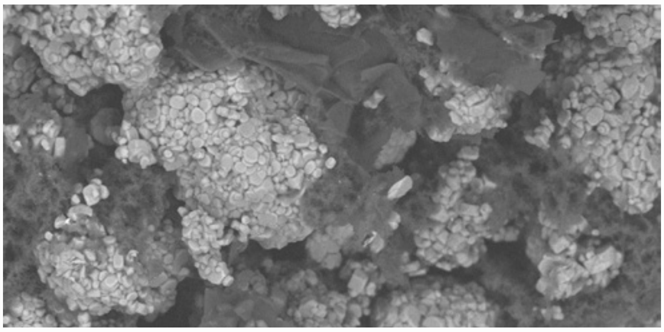
Round 3 competition

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 (LIB) 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 LIBs, 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 LIB 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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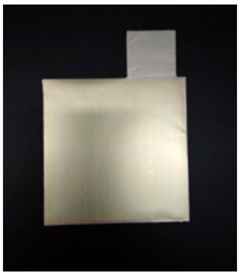
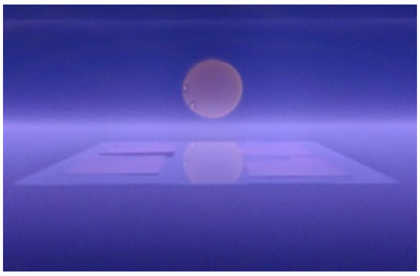
Michael Edwards Email: MEdwards@thomas-swan.co.uk

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 the next generation of high-performance cell technologies for future electric vehicles (EVs).

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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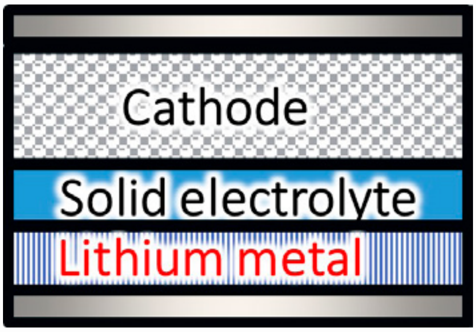
LiMHiT – Lithium Metal electrode High Throughput screening

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, with the aim of 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 feasibility project started in September 2021 and finished on schedule 12 months later. The main deliverables were the successful in-house design and manufacture of lab scale thermal deposition equipment (Emerson & Renwick). This enabled proof of concept and then process optimisation for producing lithium metal anode material. Furthermore, the success of the process technology as a commercial production line was detailed in a feasibility cost report. Extensive electrochemical characterisation was conducted (WMG), as well as the set-up of dedicated SSB facilities to increase capabilities/ expertise as the testing SSB technology and defining new test procedures that will contribute towards future work. Finally, detailed understanding of mechano-chemical characterisation of lithium-metal and lithium-alloys with the solid electrolyte helped to understand favourable surface properties and ways to improve performance (University of Oxford). Upon project completion a continuation of SSB R&D has remained with collaboration between Nissan and the University of Oxford.

Project innovations

LiMHiT successfully optimised production of thin dense lithium/(-alloy)-based thermally evaporated negative electrodes for lithium-metal, sulphide-based, all-solid-state battery (SSB) cells, the project achieved a number of project material KPIs, including coated area and thickness, and current density values; demonstrating throughput of lithium metal samples at production scale capable of up to 10-fold increase and 1/3 of manufacturing cost compared to alternative commercial market technologies and the successful dissemination demonstrated through publishing of three journal articles and proposed perspective article "Realising scalable Li films for battery applications" upon project conclusion.

Partners

NISSAN
UNIVERSITY OF OXFORD
WMG THE UNIVERSITY OF WARWICK
E+R GROUP

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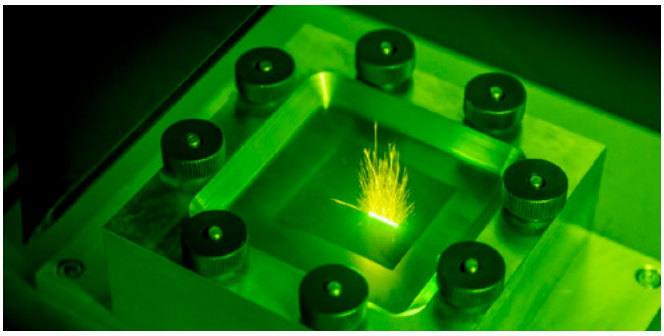
LiNaMan – Sodium Battery

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.

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.

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.

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

2008 → 2019 → 2020

Cell development	Initial LiS cell; Intermediate LiS cell; Final LiS cell
Cell characterisation	Initial cell characterisation complete; Intermediate characterisation and analysis algorithms; Analysis tool in general use form
Cell manufacture	BPE - full designed concept plant; Vaccum sealer equipment design; Knowledge of process variables
Module development	Simulink models finalised; Final module

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 quality control 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 synthomer
Cranfield University
OXIS ENERGY Next Generation Battery Technology
WILLIAMS ADVANCED ENGINEERING
UCL

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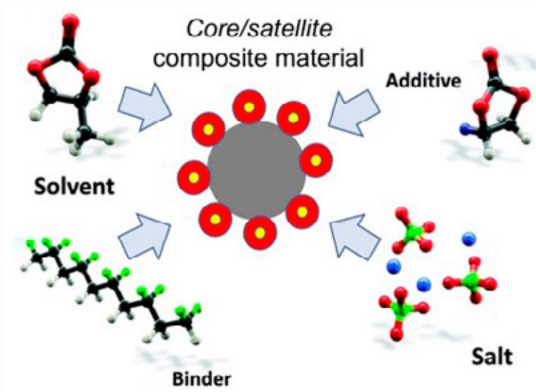
Low-cost, scalable and agile synthesis routes for sodium-ion battery materials

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

cpi
Deregallera
University of Southampton
NPL National Physical Laboratory
London South Bank University

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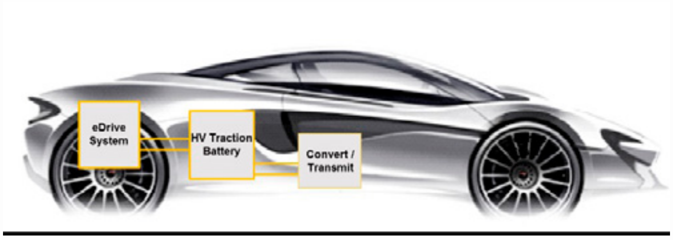
MoSESS: Multi optimal Solutions for Energy Storage Systems

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 a fast-charging and high-power battery system within a vehicle. The system is based on an advanced cell technology, looking to deliver a solution with a vehicle. with simpler cooling system, optimised crash structure for the system is the 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 and 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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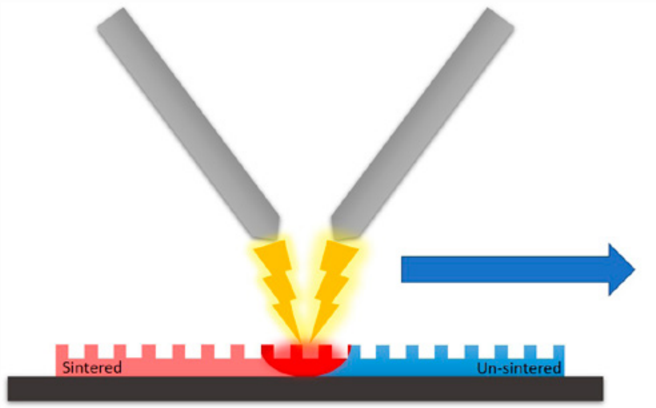
Oliver Gilkes Email: Oliver.Gilkes@McLaren.com

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 assessed 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 simultaneously targeted 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 12-month study completed in July 2022 and demonstrated the feasibility of the approaches concluding that:

- Additive Manufacturing (AM) is capable of producing solid electrolytes for Li-ion and Na-ion batteries.
- Contactless Field Enhanced Sintering (c-Flash) has the potential of being a rapid and energy efficient process to consolidate electrolyte.
- Manufacturing approaches combining AM and c-Flash can be a capable process.

Project innovations

The project significantly progressed innovations in both Additive Manufacturing of battery electrolyte components and Contactless Flash Sintering. Additionally, a thorough design study showed the ability to manufacture battery electrolyte at scale by combining both of these processes.

The partners are now looking to advance these technologies through further development and scale-up investigation. Solid-state batteries made by this route could take significant shares of the electric vehicle (EV) battery market and adoption by the UK battery supply chain would reinforce the UK's ability to grow and compete in this sector.

Partners

Loughborough University

LUCIDEON
Materials Development and Commercialization

WSP

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Round 1 competition

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 batteries (LIBs), 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 lithium-ion technology mean that existing infrastructure can be used for their manufacture. Unlike LIBs, 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 LIB 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
JLR
faradion
talga Technologies Ltd
CRODA

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The HIgh Silicon content anOdes for a solid state batteRY Project

The delivery of a multi-layer, solid state pouch cell with a silicon anode with specifications aligned to the requirements of automotive OEM's and electric vehicle (EV) pack developers.

Project costs
Total project costs: £8,200,000
Grant contribution: £5,600,000

Executive summary

- Ilika will design and fabricate the SSB cell
- Nexeon and CPI will develop a high silicon content electrode based on Nexeon's low expansion NSP-2 material for incorporation into the anode of Ilika's SSB cell
- Academic support from UCL, Imperial, St Andrews and University of Oxford used to provide in-depth characterization of the electrodes and the creation of a modelling tool for future development up to pack level
- Sustainable manufacturing consultants HSSMI will produce a life cycle analysis and an End-of-life White Paper

Timeline with milestones and deliverables

Feb 23: Project kick off.

Apr 23: Nexeon starts delivery of its silicon based anode materials.

Oct 23: Characterisation of SSBs.

Dec 23: First SSB modelling framework complete.

Jan 24: CPI deliver scaled printed anodes.

Feb 24: SSB Performance Report.

May 24: End-of-Life White Paper.

Sep 24: Facility Resource Efficiency White Paper.

Jan 25: Deliver automotive SS pouch cell, Modelling tool, and Supply chain Report .

Project innovations

The consortium will focus on delivering an optimised automotive cell design through increasing active material loading, removing parasitic masses and increasing footprint. Optimisation will involve controlling and fine-tuning the electrode/electrolyte interface interactions, reducing edge effects and tolerances and incorporating Nexeon's silicon into the anode.

The creation of a dynamic EoL and LCA optimisation model will enable us to understand and advance the circular economy opportunities of the SSB.

Partners

BMW GROUP
cpi
HSSMI
ilika accelerated materials innovation
Imperial College London
UCL
nexeon
University of St Andrews

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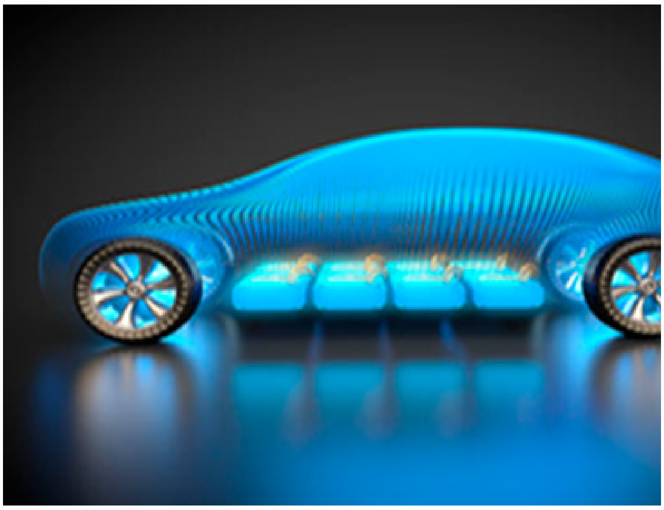
The PowerDrive Line

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



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 (LIBs).

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 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

Contact:
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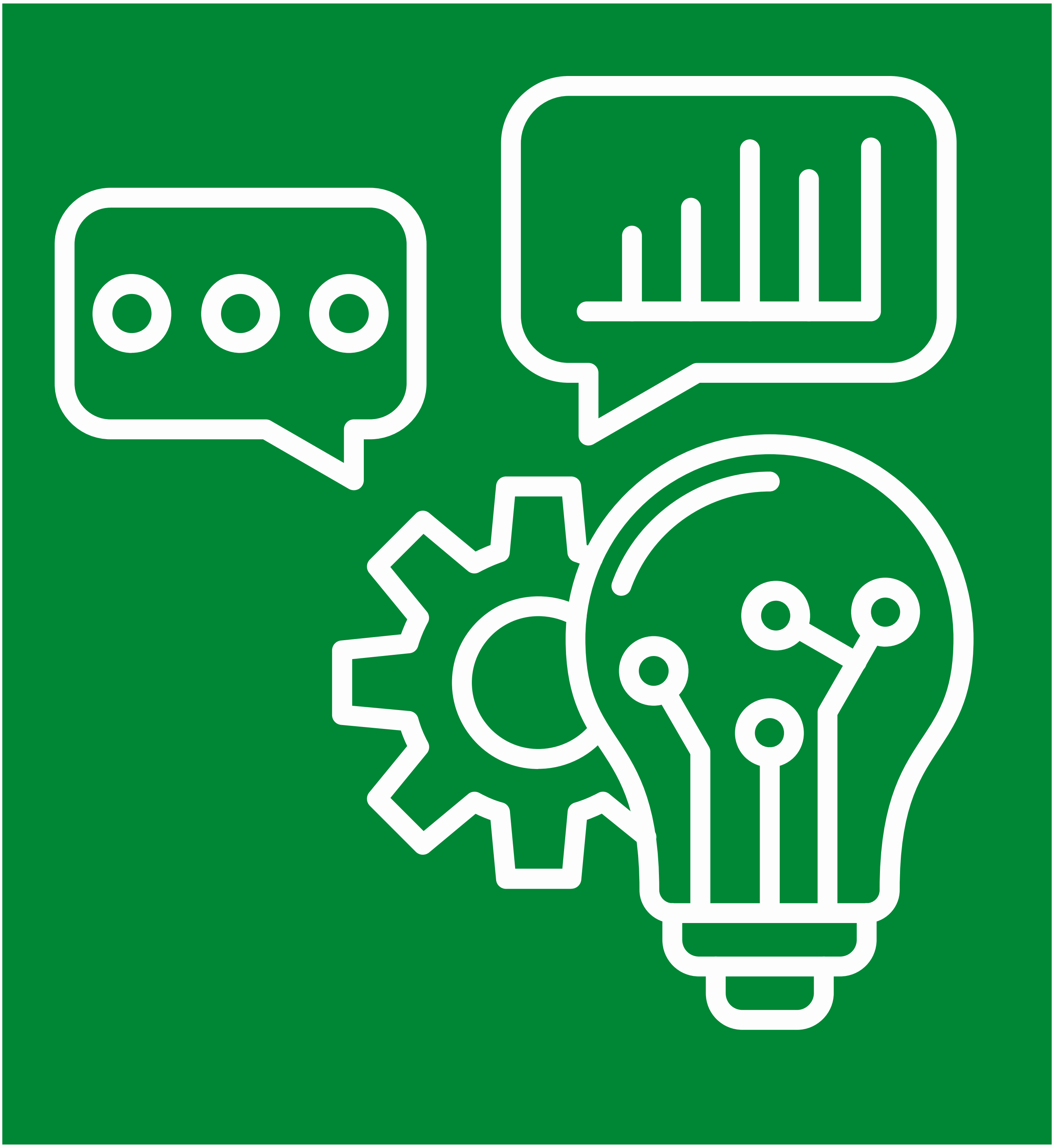
Skills Programme

Unlocking skills opportunities today, for tomorrow's workforce.

It is no secret that the pace of change within the UK battery industry, coupled with the need for trained workers at all skills levels in the coming years, cannot be underestimated. Approximately 270,000 jobs will be needed across the UK battery and electric vehicle (EV) industry by 2040, and ensuring we inspire emerging talent, signpost career changers, and welcome job market returners into the exciting battery sector is vital. To aid skills development across the UK the Faraday Battery Challenge has commissioned a trio of projects to tackle known skills challenges, collaboratively aligning industry and skills providers across the UK through a skills framework, and unlocking training demand in regions linked to industry need.



Digital Enhanced Battery Ubiquitous Training – West Midlands (DEBUT-WM)

Building an inclusive and collaborative 'Battery Community'

Project costs
Total project costs: £1,200,000
Grant contribution: £1,200,000

Executive summary

The University College Birmingham will lead a regional partnership delivering an innovative project to re-skill, upskill and grow new skills in battery manufacturing and innovation.

The project aims to develop and deliver level 2 and 3 battery manufacturing training targeted at assembly, maintenance, logistics and production engineers, to be known as the Digital Enhanced Battery Ubiquitous Training – West Midlands (DEBUT-WM), to grow the region's battery manufacturing workforce. The training will be developed in collaboration with RAVMAC Ltd, Warwick Manufacturing Group and Cranfield University.

The programme will offer an ambitious blend of traditional physical training alongside advanced immersive digital technologies, such as augmented, virtual and mixed reality. Learners will be taught the skills used across battery manufacturing, repairing, recycling and reusing that will support them in employment in a variety of roles - ranging from production, maintenance, quality assurance, to engineering and technical support.

The trainee will have the freedom to explore a topic, practice and rehearse the relevant battery manufacturing skill on the path towards confidence and mastery of a new capability. The immersive training technology provides trainees with an immediate "hands-on" approach to rapidly acquiring new battery manufacturing skills in a realistic virtual environment where they are part of reinforcing the skills they have learned to offer to the modern workplace.

Project commitment

- Convene technologists/industry/education/training partners, and local government as a focal point for the shift to battery electric vehicle (EV) production.
- Collaboratively work with others to curate suitable existing education and training provision.
- Maximise regional engagement through, outreach and equality diversity and inclusion practices.
- Alignment with the Electrification Skills Network (ESN) to support delivery of skills fore-sighting and industrial demand.

Project supporters

Jaguar Land Rover
Delta Cosworth
West Midlands Combined Authority
Greater Birmingham & Solihull Institute of Technology
Microsoft
Zytek
and a growing network of support.

Contact:
Battery Project Team, University College Birmingham
Email: batteryproject@ucb.ac.uk

Electrification Skills Network – Elevating electrification skills for a thriving UK future

The Electrification Skills Network project aims to establish itself as a comprehensive, and collaborative, electrification skills reference point to support the economic growth and success of the UK.

Project costs
Total project costs: £700,000
Grant contribution: £700,000

Executive summary

In summer 2023, Coventry University successfully bid for funding to deliver the National Electrification Skills Framework & Forum (which has subsequently been renamed Electrification Skills Network) from the Faraday Battery Challenge.

Leading a collaboration across a number of influential organisations, including UKBIC, Enginuity and WMG, Coventry University aims to deliver this one-of-a-kind project up to at least the end of March 2025. Throughout this period, the Electrification Skills Network will be committed to developing electrification skills and capabilities within the four nations of the UK, helping industry to address the evolving needs of a skilled workforce across diverse sectors within electrification.

The Electrification Skills Network will work to collaboratively align industry, skills providers and accreditation bodies by facilitating the creation of communities where ideas and challenges can be shared, and initiatives integrated to minimise duplication. This sharing of best practice will help accelerate skills solutions.

Serving as a comprehensive reference point for electrification skills, the Electrification Skills Network will provide the essential connections, guidance and best practices for industry while also contributing to a thriving electrification ecosystem.

The Electrification Skills Network's focus is to build a strong, resilient and agile workforce for today, alongside a pipeline of talent and capability, to support electrification skills provision for the future.

Timeline with milestones and deliverables

Up to March 2025, the Electrification Skills Network will be:

- Continuing to deliver a quarterly national Electrification Skills Forum to all stakeholders;
- Defining and establishing employer and stakeholder sector communities for electrification;
- Implementing a model and method, for supporting the connection of skills need to skills supply;
- Working a framework advisory group and establishing an electrification framework;
- Further establishing the electrification skills provider communities to support understanding and delivery;
- Investigating and proposing a model for future sustainability; and
- Supporting the creation of electrification learning content and solutions.

Project innovations

As part of the project, the Electrification Skills Network will be working with stakeholders across the electrification landscape to shape a clear and dynamic electrification framework for skills. The electrification framework will support the understanding of skills requirements and the availability of solutions across the UK.

The framework also aims to include a mechanism(s) for quality assurance to support industry by improving confidence and clarity in the skills solutions available.

Overall, the framework will help to bring clarity to skills requirements and support skill and capability development within the workforce, empowering industry and skills providers

Partners

ESN – Electrification Skills Network
WMG – The University of Warwick
Coventry University
Enginuity
UK Battery Industrialisation Centre

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Paul Whiteside Email: info@electrificationskillsnetwork.co.uk Web: www.electrificationskillsnetwork.co.uk

The National Battery Training and Skills Academy

The NBTSA is designed to support the UK's growing battery industries and eventually the whole ecosystem, delivering classroom and hands on training to existing and new staff as the industry undergoes a major expansion

Project costs
Total project costs: £1,300,000
Grant contribution: £1,300,000

Executive summary

In the North East of England there is a growing R&D and manufacturing base for lithium-ion batteries (LIBs). A key component of the national drive to greater electrification, batteries will be key to energy storage and transport of the future. The North East has the only Gigafactory and a thriving battery ecosystem which is undergoing rapid growth, leading to a predicted workforce gap.

The NBTSA is leading the response, designed to address the skills gap and ensure that operators and technicians have the skills required now and for the future, supporting the development of a workforce equipped with skills in the manufacture of innovative technologies.

A collaboration between Newcastle University and New College Durham, the academy focuses on level 2 and 3 training and skills. Learners are encouraged to continue their learning beyond the academy, and battery-related CPD courses and degree apprenticeships are available in-region, creating a continuum of skills development.

To attract the workforce of the future, the academy is also working with Newcastle's Discovery Museum. A two-year exhibition called Steam to Green explores the North East of England's journey from its key role in the industrial revolution, to leading today's drive to electrification.

Timeline with milestones and deliverables

To March 2025

Learning and qualifications through the academy covers a range of topics through different experiences, including:

- Industry aligned technical skills;
- Theory and principles with hands-on practical sessions; and
- Tools and equipment training using a scaled-down manufacturing line.

The programmes also draw on the thriving battery ecosystem of the North East of England and expertise of the partnership, including:

- The UK's only gigafactory alongside Nissan's electric vehicle (EV) assembly plant.
- Driving the Electric Revolution Industrialisation Centre North East.
- North East Battery Alliance.
- The Faraday Institution North East.
- World leading expertise in battery safety.

and more.

Project innovations

The project will provide a well-needed boost to the upskilling and reskilling of the existing and the new workforce required to support a growing industry. It will provide an understanding of the battery manufacturing environment and skills needed, while providing an insight into the opportunities that this industry can provide.

Hands-on experience will be delivered on a scaled-down manufacturing line, as well as classroom training, and the inclusion of immersive technologies to support learning, equip individuals with the skills and knowledge they need to be effective in their role, and supporting homegrown talent.

The project also aims to encourage individuals to continue their learning through CPD courses, and will create a pathway to further learning through degree apprenticeships with a focus on battery manufacture.

Partners

Newcastle University

New College Durham

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The Investor Partnerships Programme

Innovate UK launched the Investor Partnerships Programme to provide grant funding for highly innovative micro, small, and medium-sized enterprises (SMEs) who require equity investment at the same time in order to develop their technology and to grow their business.

Innovate UK has a pool of 150 selected investor partners, such as venture capital funds, corporate investors, business angel groups, and social impact investors, from across the UK, Europe, and the US. The programme focuses on specific themes, that include net zero, health and wellbeing, critical circular materials, and batteries. The Faraday Battery Challenge has invested £2.6m.

Better, Lighter, Cheaper: Reinventing the Prismatic Cell

The project aims to demonstrate a new, chemistry agnostic mechanical cell design for a prismatic cell resulting in a dramatic increase energy density and reduction in cost

Project costs
Total project costs: £800,000
Grant contribution: £398,000

Executive summary

Significant leaps forward in performance of lithium-ion cells are difficult to find without alterations in cell chemistry. This project aims to improve the performance and reduce costs of current lithium-ion technology without expensive and time-consuming redevelopment of the chemistry. This will be achieved through radical redesign of the internal connections of a conventional prismatic cell.

The redesigned connections will significantly improve the utilisation of space within the cell, increasing the available room for active electrode. The project will demonstrate a 6% increase in volumetric energy density and 2% reduction in cost on a $/kWh basis when compared to incumbent technology.

Timeline with milestones and deliverables

This is an 18-month project, with the final deliverable being a tested and validated prismatic cell prototype. To get there, the process techniques required to weld the internal cell tabs and bus bars will be developed. Subsequently this learning will be transferred onto full electrode stacks. Once the technology has been proven in full electrode stacks, design intent cell prototypes will be built for test and validation at Celltris' cell prototyping facility in Bristol, UK.

Project innovations

The project focuses on optimising cell mechanical designs, and several innovations will be required to produce validated prototypes. The most significant development will be a new welding methodology of the internal tabbing and busbar structure. In addition, new innovations in cell assembly methodology will be developed to optimise the cost and volumetric energy density of the cell.

Partners

celltris

QANTX

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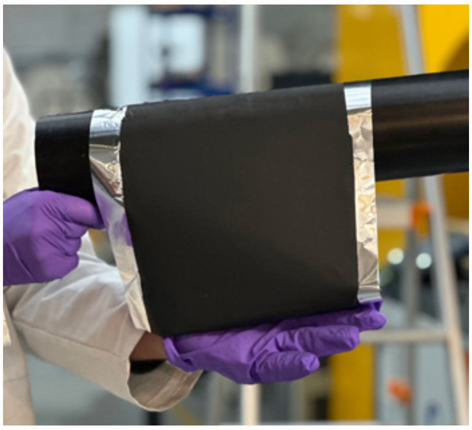
Dry coating of lithium-ion cell cathodes using composite powders

The purpose of this project is to investigate the powder properties, coating techniques and process conditions required for the industrialisation of dry battery electrode coating processes using Anaphite cathode Dry Coating Precursor composites.



Project costs
Total project costs: £978,819
Grant contribution: £685,173

Executive summary

The battery industry is looking to move to new “dry” electrode coating processes that do not use solvents. The major cost and environmental impact of electrode manufacture in existing processes comes from the drying equipment needed to remove the solvent, which includes energy intensive drying ovens up to 100m long. Removing electrode drying has the potential to reduce the process cost of cell manufacturing by up to 50% and reduce energy consumption by up to 30%. Anaphite has proprietary technology to design and manufacture composite powders for the production of cathodes for lithium-ion batteries.

Cathodes made with these composites in standard electrode coating processes have demonstrated higher performance than those made from a mix of components. Anaphite’s composite powders are particularly suited to dry coating. We call these powders Dry Coating Precursors. The purpose of this project is to investigate the processes required for the industrialisation of dry coating processes using Anaphite composites. Our objective is to demonstrate in an automotive relevant cell design that a roll of cathode that matches the performance and properties of standard wet-coated cathode can be made without solvent on industrially viable equipment.

Timeline with milestones and deliverables

- Form industry advisory board to guide project decision making (December 2023).
- Freeze composite formulation for coating trials (February 2024).
- Decision on coating technique (April 2024).
- Coat materials for reference cells (June 2024).
- Build reference cells (September 2024).
- Test reference cells (October 2024).

Project innovations

- Develop advanced, first-of-a-kind cathode formulations containing advanced nanocarbons for dry coating.
- Production of state-of-the-art dry-coated cathode made from Anaphite Dry Coating Precursors in dry-coating hardware.
- Demonstration of Anaphite dry coated cathode performance equivalence to a wet-coated cathode of equivalent formulation.

Partners

Anaphite

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LiNa-Scale

Development of an innovative pilot production line for solid-state sodium batteries in the North of England

Project costs
Total project costs: £1,812,268
Grant contribution: £815,521

Executive summary

LiNa will construct and operate a pilot production line for the manufacture of its solid-state, sodium-nickel-chloride (NamCl2) cells, delivering a forty-fold increase in manufacturing volumes from a current average of 50 to 2025 cells per week. The unit cost of cells produced in the automated pilot line will be less than one quarter the cost of artisan lab-scale production and confirming the trajectory toward a cost of ~40% below lithium-ion solutions, once mass production begins.

Timeline with milestones and deliverables

The project began in February 2024 and will run for 18 months.

- The key project output is a pilot-scale production facility ready to manufacture cells in sufficient volumes for commercial-scale demonstrations.

Key Milestones include:

- Electrolyte equipment operational by month 9.
- Cell assembly equipment operational by month 12.
- Flawless operation of pilot line by month 18.

Project innovations

The key innovations concern the development of processes for the manufacture of solid-state sodium batteries. This project supports LiNa's transition from artisan, lab-scale cell manufacture to commercial-scale automated production.

Partners

LiNa Energy

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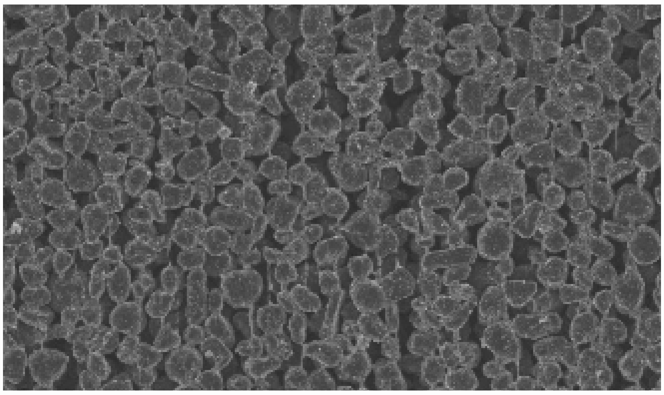
Mark Boland, Company Secretary   Email: mboland@lina.energy   Web: https://www.lina.energy/

Next Generation Battery Electrode Production

The goal of this project is to develop Inition Energy's Electrode Particle Alignment technology to the point of establishing a clear scale up path for commercial exploitation.

Project costs
Total project costs: £1,000,000
Grant contribution: £700,000



Executive summary

INITION has unlocked a hidden potential within batteries. By aligning particles at the anode and cathode, we've achieved a breakthrough using water as a powerful tool. This innovation promises a dramatic leap: batteries with 20% more energy and 24% lower production costs. The secret lies in reducing resistance, the roadblock that hinders power flow in thicker electrodes. Using water as a tool gives us the way to reduce charge transfer resistance by 90%, doubling electrode thickness without losing power capability even with NMC811.

All this is possible with our patented process which reinvents how to mix, coat and dry the electrode.

We are in the process of scaling up to production volume in any anode or cathode chemistry. This project will drive forward our mission to harness the power of water to transform the future of batteries.

Timeline with milestones and deliverables

The project will run for 18 months from February 2024 – July 2025.

Major deliverables along the way will include:

- Full aligned pouch cells produced with Inition technology and benchmarked against industry standard.
- Independent industrial validation.
- Semi-automated alignment process demonstrator.
- Scale up readiness report.
- Cost and energy modelling report on scaled up production.

Project innovations

While work has been done on control of electrode microstructure in university labs, this project will be the first production focused development for commercial cells that aligns both cathode and anode sides of the battery. Inition will produce full cells with aligned cathode and anode technology and bring the process to the point of production readiness with a clear map to scaling. Inition will also demonstrate the energy and cost efficiency of the process through process modelling from pilot production to large-scale manufacturing.

Partners

INITION

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Faraday Battery Challenge Investment Readiness Programme

Sponsored by the Faraday Battery Challenge and led by Innovate UK Business Connect, the Programme has empowered 35 UK-based SMEs in the battery supply chain from 2021-2023. With 90% of participants achieving positive outcomes or raising capital, the 12-week transformative journey includes tailored workshops, one-on-one mentoring, and a live showcase event. Supported by external experts and investors, the cohort hones their investor pitches, refines their value proposition, and develops a defendable understanding of their finances, intellectual property, and future plans. The comprehensive programme fosters a deeper understanding of investment types, empowering companies to craft robust investment strategies and optimise their funding requests. The journey culminates in an investment showcase event where participants pitch to an audience of forward-thinking investors interested in battery technologies, transport solutions, and the energy transition.

2021 Cohort:

You can read more about the 2021 Cohort:
www.iuk.ktn-uk.org/news/the-successful-applicants-in-the-faraday-investment-readiness-programme/

2022 Cohort:

You can read more about the 2022 Cohort:
www.iuk.ktn-uk.org/news/meet-the-successful-applicants-in-the-faraday-battery-investment-readiness-programme-2022/

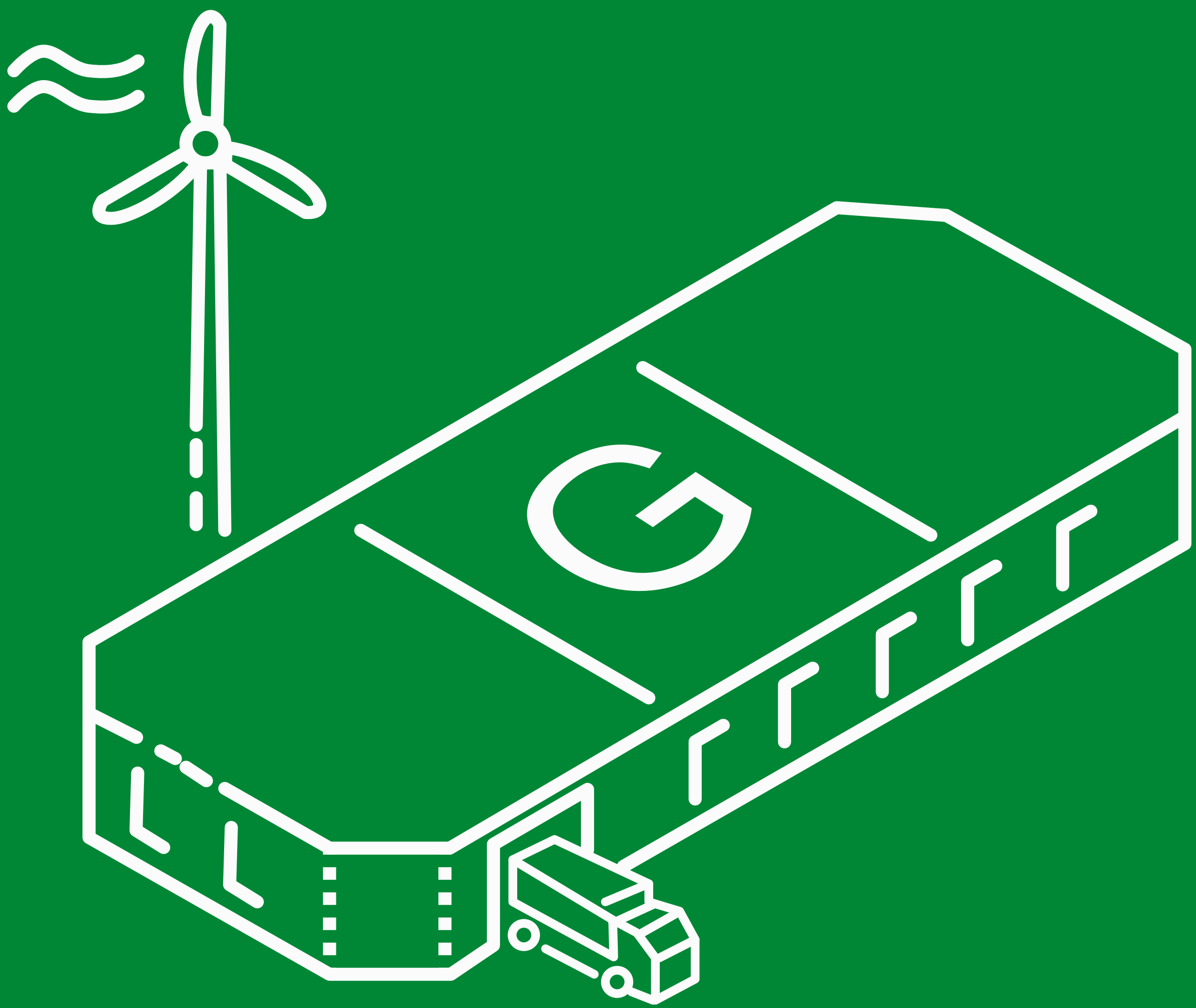
2023 Cohort:

You can read more about the 2023 Cohort:
www.iuk.ktn-uk.org/news/successful-applicants-faraday-battery-challenge-investment-readiness-programme-2023/

SME credit projects

This section supports micro, small or medium-sized enterprises (SME) research and development for the scale-up of battery technologies within the UK.

Its aim is to move UK battery innovations from technological potential towards commercial capability, and help develop and secure material and manufacturing supply chains for battery technologies in the UK.



Giga-scale demonstration of 3d electrodes for automotive applications

Accelerate validation of Addionics' proprietary 3D current collector technology, demonstrating successful adoption at giga-factory scale through collaboration with UKBIC.

Project costs
Total project costs: £1,034,921
Grant contribution: £465,714

Executive summary

This project represents a strategic response to the UK's imperative need to transition away from combustion-engine vehicles, aiming to establish leadership in the global electric vehicle (EV) market. Collaborating with UKBIC, Addionics seeks to evaluate the compatibility of their 3D current collectors within UKBIC's state-of-the-art 'Giga-Factory' facility. This partnership is designed to expedite the validation of Addionics' proprietary technology, demonstrating its successful integration at a giga-factory scale. By accessing UKBIC's facilities, Addionics can seamlessly transition from development to production-standard cells, validating their technology under conditions resembling those of established large-scale processes used by OEMs and cell manufacturers.

Addionics' innovative approach integrates AI software into battery hardware, facilitating intelligent, optimised solutions. Leveraging internal expertise and global partnerships with battery piloting facilities, Addionics has effectively developed and validated a range of battery electrode architectures. The project aims to achieve technology readiness level TRL 7, building upon the current TRL 6 status, to accelerate commercialisation

Timeline with milestones and deliverables

Over eight months, the project assesses Addionics' 3D current collectors at UKBIC's 'Giga-Factory'. Key focuses include validating processing setpoints and characterising current collectors and materials. A significant achievement is the development of a pouch cell model for UKBIC manufacture, with approved technical drawings. Completed milestones include web handling trials, with ongoing optimisation of roll-to-roll coatings and cell testing reporting. Throughout, Addionics takes the lead in project management and dissemination efforts, driving progress towards successful integration and validation of their innovative technology.

Project innovations

Addionics leads a green battery revolution in the UK, aligning with carbon neutrality goals. By enhancing 3D current collectors for seamless integration into mainstream gigafactories, Addionics ensures efficient and scalable production. With tailored drop-in solutions validated in automotive cells, their technology promises better performance. Leveraging patented fabrication devices, Addionics secures freedom to operate, overcoming limitations of single-chemistry competitors. With extensive IP rights and strategic partnerships, Addionics accelerates the deployment of 3DCC technology, poised to redefine battery innovation and address energy storage challenges across diverse sectors, from automotive to consumer electronics.

Partners

ADDIONICS

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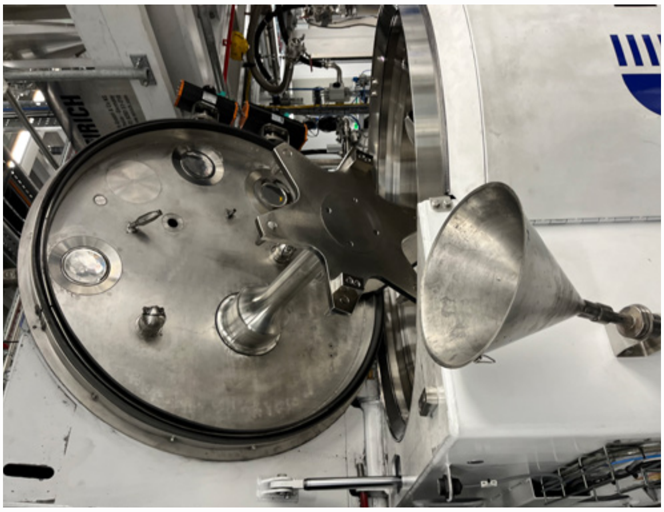
MAC-UK

MAC-UK enables the optimisation of the quality and speed of the giga-scale manufacturing at UKBIC for Nyobolt's electrode material



Project costs
Total project costs: £230,859
Grant contribution: £103,886

Executive summary

MAC-UK focuses on the process transfer and optimisation for speed and quality of the production of Nyobolt's electrode material, to support manufacturing at scale using UKBIC. Nyobolt has produced large quantities of electrode at facilities worldwide, and this project specifically aims to transfer this process to the equipment at UKBIC with the aim of creating a viable manufacturing route within the UK.

Nyobolt will be undertaking a knowledge transfer of a new and novel material to UKBIC to enable further growth in the UK Battery technology development.

Project innovations

Nyobolt is currently focused on scaling the production of cells, optimising the manufacturing process for speed and efficiency as volume is increased volume to GWh scale. Transferring electrode manufacturing process to UKBIC requires optimisation to reach the high quality and speed required for a viable volume manufacturing route.

Partners

nyobolt

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Scale-up

UK BATTERY INDUSTRIALISATION CENTRE

UK Battery Industrialisation Centre (UKBIC)

UKBIC is the UK's national manufacturing battery development facility, providing manufacturing scale-up and skills for the battery sector.

UK BATTERY INDUSTRIALISATION CENTRE

Opened in 2021, UKBIC's construction was part-funded through the West Midlands Combined Authority and was delivered through a consortium of Coventry City Council, Coventry and Warwickshire Local Enterprise Partnership and WMG, at the University of Warwick.

Our purpose-built facility is where businesses come to develop their battery manufacturing processes at the scale they need to move to industrial production. It's also where those working in the industry can develop new skills by joining us on the production line, learning from our specialist teams.

UKBIC is part of the £610m Faraday Battery Challenge, which is delivering a research and innovation programme that covers "Lab to Factory" development, cutting-edge research, national scale-up infrastructure, and skills and training.

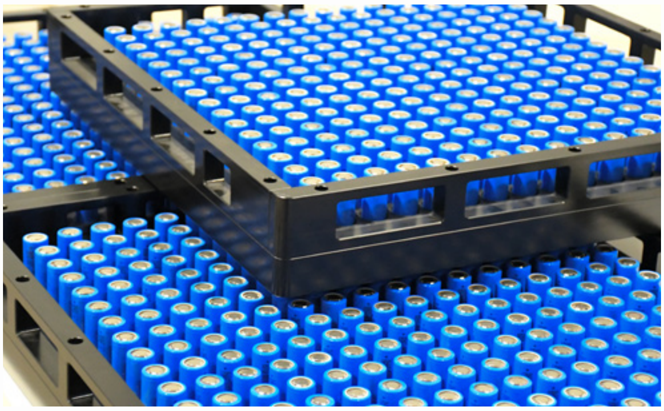
Based in Coventry, the facility can be accessed by organisations with existing or new battery technology, or companies looking at entering the industry. The flexible facilities are designed so that several users can run projects at the same time in dedicated and security-controlled discrete areas. We don't take a share in any customer Intellectual Property (IP) developed through the facility, we're just here to help drive innovation and support the development of new ideas.

New facilities at UKBIC

Created with an initial investment of £130m, an additional £74m from UK Research and Innovation (UKRI) was announced in 2023, and is being used to enhance and expand the facility with a number of new initiatives:

- Our innovative Flexible Pilot Line (FPL) will bridge the gap between the facility's existing Industrial Scale-up Line (ISL) and smaller, kilogram-scale demonstrators available elsewhere. Coming in 2025, the new specialist line will provide developers with a more cost-efficient route to market, helping them move from research and development to large-scale production in more manageable steps. The new FPL features individually controlled rooms, each set from -40°C to ambient dew point on a zonal basis, allowing a controlled environment from room to room.

- Our new Battery Development Laboratory is due to become operational in Autumn 2024, and will boost the facility's capabilities in key areas of battery material characterisation, cell analysis, and forensic activities – all to support manufacturing development. The enhanced laboratory will specialise in the characterisation of raw materials, slurries, coated electrodes, and finished cells, and will also have processing, electrochemistry, forensics and CT scanning capabilities.



- We are also building an innovative, flexible clean room space, the Clean and Dry Zone, which will also become available later in 2024. The research and development zones will offer flexible clean room spaces, providing controlled conditions for equipment testing, temporary equipment installation for manufacturing work, or other research and development projects. Rooms will range from 93m^2 to 256m^2, with the option to extend further by removing interior walls, while one room is also equipped with a higher ceiling to accommodate processes which require additional height. Each room will have individual, card-controlled access to protect customer intellectual property.
- Also coming in 2024 is an area dedicated to Cell Characterisation. The new bespoke cell cyclers and environmental chambers will be housed in a 135m^2 air-conditioned unit inside an existing formation, ageing and testing area. The facility will include extended life-cycle testing, environmental control, and temperature measurement functions.

Supporting SMEs on their scaleup journey

In May 2024, UKRI funded small and medium-sized (SME) battery developers to the tune of £1.5 million to enable them to work with us at UKBIC.

The winners of the second SME Credit competition – Altilium and Nyobolt – will each be given the chance to scale up their projects as they move from technological potential towards commercial capability. In addition, the projects will further enable UK competitiveness across the battery value chain by:

- supporting SME research and development for the scale up Sf battery technologies within the UK;
- Help demonstrate technologies at suitable scales to customers;
- Move UK battery innovations from technological potential towards commercial capability; and
- Develop and secure material and manufacturing supply chains for battery technologies in the UK.

The projects we have supported so far involve cylindrical and pouch cell technologies, and include bringing advanced lithium titanate oxide (LTO) battery technology and a new cathode active material (CAM) to the UK for the first time.

This latest funding builds on an earlier SME Credit competition, which was launched in 2023 and has seen Nyobolt and Addionics already work with UKBIC.

Delivering skills and training

UKBIC also delivers specialist skills and training to the wider industry, both at home and abroad. Companies can send their employees to work with us and learn first-hand from the organisation's team of specialist battery manufacturing trainers.

Our main public access course is Introduction to battery manufacturing, which takes place over two days. The course is designed to provide a basic introduction to battery manufacture and use, covering in detail how to develop and create battery technologies, and offering the chance to experience life on the line at our facility in Coventry.

As a founding member of the Electrification Skills Network, we have also already given comprehensive training to several European and US battery developers.

More specialist training courses we offer include: Introduction to Electrode Processes, Introduction to Cell Assembly, Introduction to Formation, Ageing and Testing Processes, Substance Awareness, Clean and Dry Rooms in Battery Manufacturing, and Fundamentals of Sustainable Manufacturing Processes.

Views on the UKBIC opportunity

Sean Gilgunn, UKBIC's managing director, said:

"As the national manufacturing development facility, we were established to provide manufacturing scale-up and skills for the battery sector – and that remains at the heart of everything we do.

"Our existing high-volume specialist manufacturing equipment is perfect for those organisations in need of representative scale-up, but not necessarily for those organisations at an earlier technology readiness stage of their development. The new facilities now under construction will change all that.

"These new elements will help those organisations looking to scale up their battery technology, as they go from desktop research to the FPL, the ISL, and beyond. The construction of these facilities and their potential impact will be hugely significant for UKBIC and the wider battery industry as it progresses."

Sean Gillgunn, UKBIC's managing director

Customer feedback

Feedback on customers after participation in UKBIC's two day introduction to battery manufacturing, a course designed for anyone interested in gaining practical knowledge about the fundamentals of battery manufacturing process, materials, and technologies.

Lisa Bingley, operations director at the MIRA Technology Institute, said:

"It was great to get an understanding of the whole process of battery manufacturing along with an update on the future of the sector. The tour was especially good, as it linked to the knowledge. obtained during the training course."

Derek Siu, Research Associate, Imperial College London, added:

"The introduction to battery manufacturing was an excellent overview. The mix of theory and factory tour was ideal and unparalleled outside of UKBIC."

Contact

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info@ukbic.co.uk

Case Study: Ilika

Supporting UK battery scale-up: UKBIC's ongoing collaboration with Ilika, pioneers in solid-state battery technology

Executive summary

Project BUS100: The objective of this completed £180,000 Advanced Propulsion Centre-funded feasibility study was to determine whether a MWh-level manufacturing line for Ilika's Goliath solid-state batteries (SSB) could, in principle, be installed economically at UKBIC, utilising some of the existing lithium-ion battery (LIB) manufacturing equipment to supply automotive cells to Ilika's customers at an acceptable price point. Demonstrating cell manufacturing on production-intent equipment, at MWh-scale, is key to Ilika's scale up plans.

Project SiSTEM: This ongoing Automotive Transformation Fund £2.7 million funded project – under the Scale Up Readiness validation (SURV) 2 programme – included consortium members Agratas and MPac. The project aims to develop a 1.5MWh SSB assembly line and undertake physical trials at UKBIC, where UKBIC's formulation and coating lines will be trialled with Ilika's SSB chemistry, in order to verify the expectations from Project BUS100. It's important that the manufacturing of this novel technology can use existing equipment in the LIB industry as much as possible, in order to enable adoption of SSB.

Timeline with milestones and deliverables

Framework agreement signed between ilika and UKBIC: November 2020.

Project BUS100: July 2022 and January 2023.

The deliverables of this feasibility study were:

- To provide a gap analysis of Ilika's requirement vs the existing UKBIC installed equipment;
- To establish how the Ilika and UKBIC manufacturing lines could be integrated;
- To develop a cost model for installing and integrating the Ilika equipment into UKBIC; and
- To establish whether there was a business case for making the required investment to install SSB manufacturing in UKBIC which met Ilika's volume requirements.

Project SiSTEM: October 2023 and is due to last 18 months

- The main deliverable of the project is to establish that it's possible to coat a solid-state electrolyte onto a previously coated anode material using a reel-to-reel manufacturing process.

Project innovations

Project BUS100:

The outcome of BUS100 was generally positive. The study concluded that, subject to physical trials to accommodate Ilika's process and the acquisition of some minor additional equipment, it would be technically possible to utilise part of the existing UKBIC electrode line to manufacture Ilika's SSB cells; and using some of UKBIC's industrial-scale equipment for a large-scale trial, albeit for a smaller part of the year only, could in principle provide sufficient cells to Ilika's customers, and demonstrate production at scales relevant to gigafactories.

Project SiSTEM:

Activities in SiSTEM are currently in the technology transfer stage when it comes to collaborating with UKBIC, with electrode manufacturing trials planned later in the project. The outcomes of the project will be assessed in 2025.

The benefits of working with UKBIC

"UKBIC has always been attentive to our needs and offered solutions to help Ilika move our development forward. They've delivered on cost and in good time and have been flexible to adapt to our developing needs.

"The advantage of collaborating with UKBIC is that we can access UKBIC's GWh-scale equipment, which is important to us given our asset light business model, enabling us to de-risk industrialisation and demonstrate giga-scale production to potential licencees.

"UKBIC helps companies tnegotiate the so-called 'valley of death' stage in their development between pilot and volume-manufacturing, by making industrially relevant facilities available; and we can collaborate with UKBIC's pool of researchers and engineers who have expertise both in LIB R&D and production activities, as much of the process is similar to the SSB process, and that enables an understanding of the link between the two technologies."

Denis Pasero,
ilika's Product Commercialisation Manager

Advanced Materials Battery Industrialisation Centre (AMBIC)

£12m to deliver the UK's national battery materials scale up facility

Photo credit: Centre for Process Innovation (CPI)

"AMBIC will bring together two emerging regions of battery innovation and manufacturing; the North-East and Midlands, under one facility to de-risk and accelerate battery materials scale up in the UK. Through the Faraday Battery Challenge's £12m investment in the High Value Manufacturing Catapult, we will establish a truly world-class facility to support the growth of a battery materials supply chain. With AMBIC and previous investments in UKBIC and the wider ecosystem, the UK will now be in a position to support businesses from "powder to pack" and from lab to commercial scales."

Thomas Bartlett,
Challenge Deputy Director for the Faraday Battery

The Faraday Battery Challenge (FBC) is enhancing battery scale-up support in the UK with a new facility that will give companies access to state-of-the-art materials synthesis and processing equipment. The funding is part of a co-investment strategy between the FBC and the HVM Catapult, aligned to a common strategic vision for the UK battery scale up ecosystem in order to support the development of a battery supply chain in the UK.

The Advanced Materials Battery Industrialisation Centre (AMBIC), which will be delivered by the HVM Catapult, will provide innovation capability for the synthesis and processing of immediate and next-generation battery materials. It adds to the growing open-access scale up capability being delivered by the FBC, which includes the UK Battery Industrialisation Centre and it's new £36m Flexible Industrialisation Line.

The £12m facility will be delivered by CPI and WMG, two of HVM Catapult's seven centres of innovation. CPI's expertise in chemicals processing and WMG's cell development capabilities will be brought together to allow companies and researchers to scale their innovations from the laboratory to commercially relevant scale and enable "powder to cell" support.

AMBIC will help deliver the UK's ambitions in battery materials by:

- Bringing together scalable, commercially relevant equipment into one facility to fast-track battery materials development.
- Helping to stimulate and grow the chemical and materials supply chain to collaborate and invest in the UK, leading to economic growth and jobs, and attract inward investment.
- Aligning to existing cell manufacturing and validation facilities, and supporting the wider UK scale-up ecosystem.
- Having the flexibility to accommodate equipment supplier trials.
- Enabling rapid, cost-effective product and process design.
- Enabling the provision of a skills and training programme complimentary to the National Electrification Skills Framework and Forum and other skills activities being supported by the FBC.

Both facilities at CPI and WMG will be open-access, and activities will typically be project-based and can be funded via CR&D or commercial contracts. CPI and WMG engineers and scientists will operate the equipment to achieve customer requirements for material synthesis and cell processing.

“The next generation of battery technologies are critical to the green energy transition and a major opportunity for UK manufacturing. Realising that potential will require combining our collective expertise and this investment from the Faraday Battery Challenge is a brilliant example of that in action. In CPI and WMG, the Advanced Materials Battery Industrialisation Centre has two centres that are at the very forefront of chemical processing and battery cell development;. Together, they can turbo charge battery materials scale-up.”

Katherine Bennett,
CEO of the High Value
Manufacturing Catapult

At WMG, the advanced cell-prototyping equipment can be accessed directly or through research grants and collaborations. Initial enquiries for access to WMG’s facilities should be routed through WMG’s business development team on WMGBusiness@Warwick.ac.uk.

The facilities are currently being set up at both sites (CPI in the North-East of England and WMG in the West Midlands) and will be fully operational from March 2025. WMG’s advanced cell prototyping line is due for commissioning in March 2025 and will be user ready from May 2025.

“The Advanced Materials Batteries Industrialisation Centre will enhance the UK’s existing competitive advantages in batteries technology, and it stands to become a catalyst for the UK to address some of the biggest challenges we face as a nation. By giving innovators the opportunity to harness our expertise, we can tackle issues such as climate change, while growing a sector that will be vital to the future of the economy.”

Frank Millar,
Chief Executive, CPI

“Cathode and anode active materials make up more than 50% of the value of an automotive battery cell. For the UK to take its great academic research into production, and to capture the billions of pounds of resulting economic value in the UK, we need facilities which allow the UK to scale up and fully evaluate new materials. This investment, alongside the combined skillsets of CPI and WMG will provide that capability for the UK.”

Professor David Greenwood,
CEO WMG

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