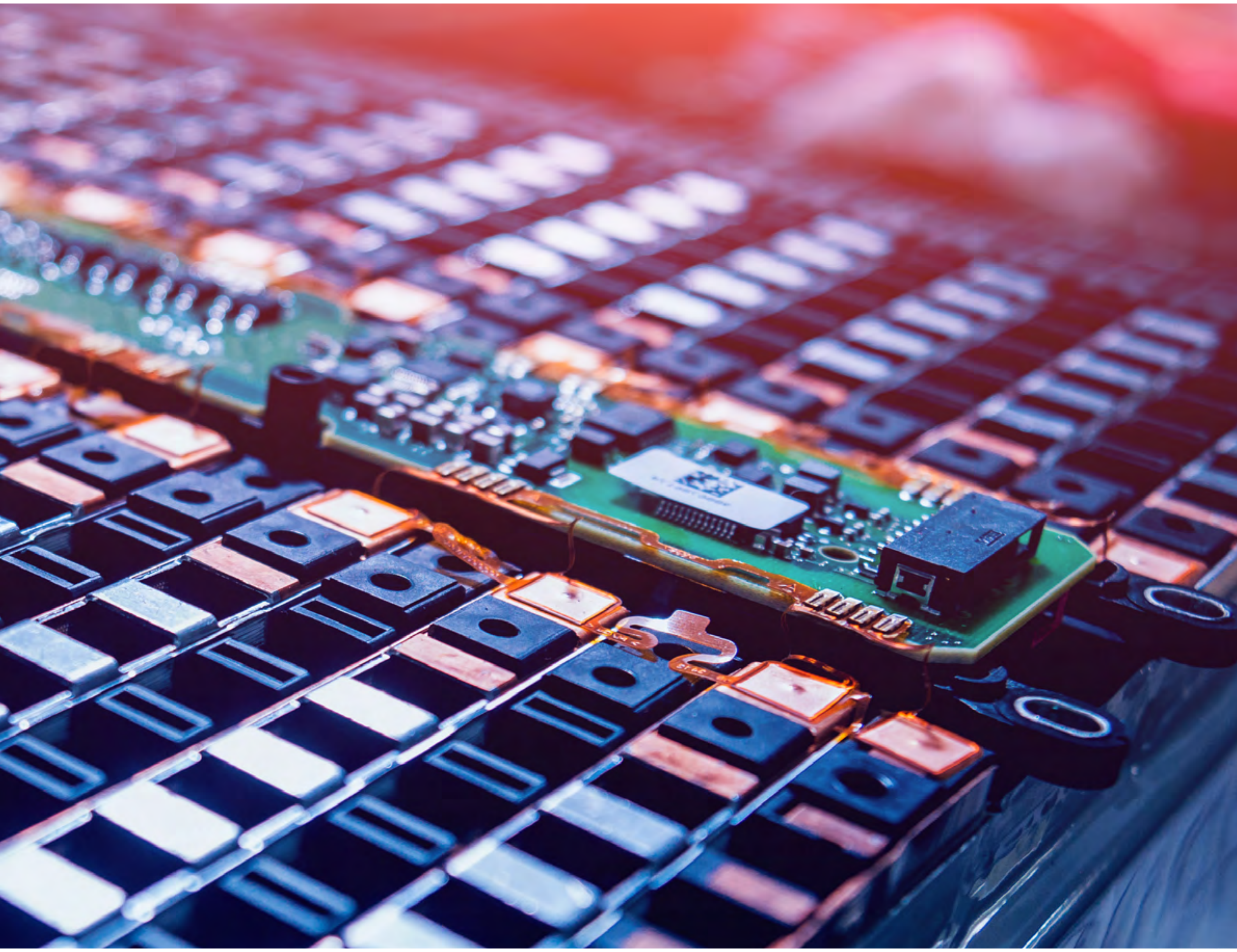
UK Research and Innovation

Faraday Battery Challenge Projects

Electrifying the UK's future



September 2023

Contents

What is the Faraday Battery Challenge? 2

RESEARCH

The Faraday Institution: powering Britain's battery revolution 7
Extending battery life 9
Multi-scale Modelling 10
SafeBatt – the science of battery safety 11
Nextrode – next generation electrode manufacturing 12
FutureCat – high nickel content, high performance cathode materials 13
CATMAT – sustainable, low-cost cathode materials 14
ReLiB – recycling and reuse of EV lithium-ion batteries 15
SOLBAT – all-solid-state lithium-metal anode batteries 16
NEXGENNA – sodium-ion batteries 17
LiSTAR – the lithium-sulfur technology accelerator 18
Seed projects 19
Industry sprints 20
Entrepreneurial fellowships and spin-outs 22
Industry fellowships 25

INNOVATION

Cells and material innovation projects
CatContiCryst – Manufacture of Li-ion Battery Cathode Materials Using Continuous Crystalliser Technology 30
Cathode and Anode Supply Chain for Advanced Demonstrator (CASCADE) 31
Coated current collector for battery performance improvement (CONTACT) 32
CONDUCTOR – thin and lightweight current collector for lithium-ion battery 33
CONstruction of Smart Three-dimensional ELectrode Lithium-ion bATteries via Industrial prOcesses and staNdards (CONSTELLATION) 34
Current collector for improved battery performance (COATED) 35
Digital Twin Technology for Quality and Yield Improvement of Battery GigaFactories 36
Enhanced CNTs for High Power Electrodes (EC-HiPE) 37
Enhanced-lifespan Saggars for Battery Material Production Scale Up (SAGGAR-LIFE) 38
EXtrAPower – Enabling Xtreme Automotive Power 39
GENESIS – Generating Energetic Novel Cells and System Inspired by Software 40
High-powered anodes for fast charging buses 41
IDMBAT – Intelligent enterprise Data Management platform for BATtery manufacturing 42
MAT2BAT: a holistic battery design tool – from materials to packs 43
New Biomass Anode Technology and Silicon Electrodes with high Energy Density (New BATSEED) 44
Next generation LFP cathode material (NEXLFP) 45
Novel Carbon Allotrope for Lithium-Ion Batteries (CALIB) 46
Power-Up (Power Cell Upscaling project) 47
Realising the UK Value-chain in Graphene Composite Battery Materials (GRAVITY) 48
Silicon Anode Battery for Rapid Electrification (SABRE) 49
SAFEVOLT Safe High Voltage EV battery materials 50
Scalable Ultra-Power ElectRic-vehicle Batteries (SUPErB) 51
Scale-up Supply Chain Accelerator for Li-ion Electrode Materials in UK 52
Scaling-up the production of Graphene-Metal Oxide Composites as Li-ion Battery Materials (GRAMOX) 53
Securing domestic lithium supply chain for UK (Li4UK) 54
Silicon Product Improvement through Coating Enhancement (SPICE) 55
Smart Three-dimensional ELectrode Lithium-ion batteries with Automated Robotics (STELLAR) for Battery Scale-up 56
Spraycoat 57
SUNRISE 58
Synergy 59
The Voltt: Optimizing EV Battery Lifetime with Advanced Modelling Technologies 60
UK – GIGAWATT Hour Cell Manufacturing Facility Feasibility (Giga Factory) 61
UK – Niche Vehicle Battery Cell Supply Chain 62

Modules, packs and battery management systems innovation projects
Advanced battery thermal control and thermal run-away cascading prevention system 64
AMPLiFII-2 65
Assessment and development of the novel 'i-BMS' Battery Management System 66
Automotive Technology Transfer Energy Storage Thermal Strategies (ATTESTS) 67
BAFTA (Battery Advances for Future Transport Applications) 68
Battery management control system for Advanced Battery Engineering (BABE) 69
Battery thermal management and diagnostics for heavy duty vehicles – BATMAN 70
COBRA – Cloud/On-board Battery Remaining useful life Algorithm 71

Conceptual feasibility of a heat pipe as a structural and thermal member in an automotive battery pack design 72
CoRuBa 73
Current density imaging in EV battery modules 74
Developing the Isothermal Control Platform (ICP) as the basis of new proposed standards for the testing of lithium batteries for use in electric vehicles 75
EB-Bat – Electron Beam Battery Welding 76
High-integrity busbars for electric vehicle battery systems 77
High-power and high-energy battery systems with integrated structural thermal management for heavy-duty applications 78
Hybrid Battery Optimisation (HBO) 79
i-CoBat: Immersion Cooling of Battery Modules with a synthetic ester dielectric liquid 80
IMPACT – IMProving Battery Cooling Technologies 81
Multi-Bat – innovative power electronics for electric truck batteries 82
Novel lithium battery management and monitoring system for automotive 83
Novel self-regulating CHIP (Cooling or Heating Integrated Pipe) for BTMS 84
PreLIBS: Preliminary Feasibility Study of Lithium-Ion Battery Safety 85
Printed sensors for EV battery current density imaging 86
Printed temperature sensors for use in battery monitoring systems working within the cells/batteries 87
Project Detain 88
Project Gamma 89
Project LIBRIS – Lithium-Ion Battery Research In Safety 90
SAMBA – Smart automotive managed battery algorithms 91
TECHNO – Temperature monitoring, Cooling and Heating during Normal Operation 92
The development of an Isothermal Control Platform (ICP) for the precise regulation of battery temperatures using multiple zone control 93
WIZer Batteries 94

Second life and recycling innovation projects
ABLE (Advance Battery Life Extension) 96
CALIBRE: Custom Automotive Lithium-Ion Battery REcycling 97
CAM-EV 98
Faraday precision ageing laboratory 99
Project: R2LiB 100
REBLEND 101
Second life lithium-ion: recovery, reconfiguration and re-use (Li.2) 102
VALUABLE: Value Chain and Battery Lifecycle Exploitation 103

Beyond Li-ion Projects
Accelerated Na-ion battery technology development through machine learning, modelling, and digitalisation (AccelerateSIB) 105
Advanced metamaterials for sodium-ion battery anodes – a scalability and economic feasibility study 106
Cathodes, Anodes, and Solid-state Electrolytes for Lithium-Ion Batteries (CASE LIBs) 107
Developing commercially viable Quasi-Solid-State Li-S batteries for the Automotive market 108
Development of 3D porous Lithium electrode for new generation electric vehicle batteries 109
LiNa-Power – Development of 1 kWh sodium nickel chloride battery system and associated manufacturing processes 110
Feasibility project to dramatically extend 1st life via next generation battery management systems (HESS) 111
Feasibility research into composite carbon electrodes for sodium-ion batteries 112
Field Enhanced Sintering of Beta Alumina for Electric Vehicle Battery Applications (FESBEV) 113
Gii-Cap supercapacitor in all-terrain vehicles 114
Granite – passenger car solid state battery 115
HIPERCARB – High Performance Carbon Composites for Sodium-ion 116
Innovative Carbons for Electrodes in Batteries (ICE-Batt) 117
LIFE: Lithium Innovation for Future Electric Vehicles 118
LiMHiT - Lithium Metal electrode High Throughput screening 119
LiNaMan – Sodium Battery 120
LiS:FAB - Lithium Sulfur: Future Automotive Battery 121
Low-cost, scalable and agile synthesis routes for sodium-ion battery materials 122
MoSESS: Multi optimal Solutions for Energy Storage Systems 123
Rapid manufacture of solid-state battery structures by additive manufacturing and Flash sintering 124
Sodium-ion batteries for automotive power applications 125
The HIgh Silicon content anOdes for a solid state batteRY Project 126
The PowerDrive Line 127

SCALE-UP
UK Battery Industrialisation Centre (UKBIC) 129

Index of Innovation Project Partners 131

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 27% of emissions[1]. Urgent solutions are required to reduce this figure. The UK is leading the way in the fight against climate change with ambitious targets for achieving net zero emissions, but this goal can only be reached through rapid and pervasive technological change in the way people, goods and services are moved.

The UK and the EU have established clear end dates for the sale of non zero emission vehicles, which is driving the demand for battery powered electric vehicles. Batteries are crucial for decarbonisating transportation, not only in the automotive sector but with applications across sectors such as aerospace, rail, marine, off-highway vehicles and static storage. The transition to an electrified future will require many types of batteries, with some yet to be imagined. The next generation of battery technology must be explored to ensure long-term UK success, in line with development and de-risking of production processes.

The Faraday Battery Challenge is a game-changing initiative for UK battery technology, supported by a £541 million investment from the UK government. It is a mission-led, investment programme that coordinates and manages applied research, business-led innovation and national scale-up infrastructure that has increased the likelihood of the UK successfully transitioning 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 Faraday Battery 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 signalled 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 Faraday Battery Challenge comprises 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.

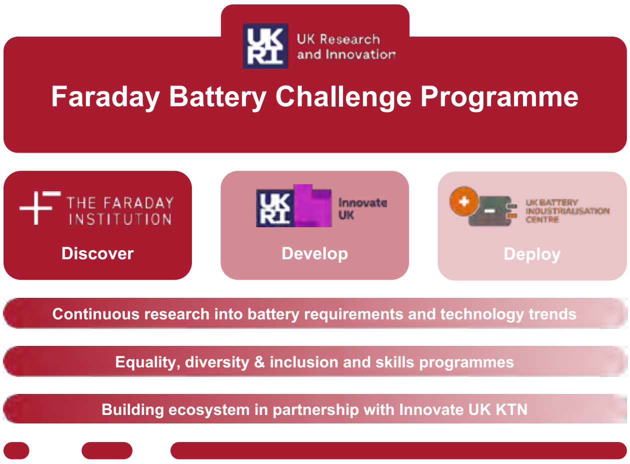
This document highlights the UK's battery electric transition in action, with the cutting-edge projects of the Faraday Battery Challenge. These projects are blazing a trail towards a cleaner, more sustainable future, and they're backed by groundbreaking research and innovative technology that are the 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, skilled workforce, and 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 five 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.*



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. Over £115m 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

Faraday Battery Challenge
Innovate UK

Dr Matt Stock
Head of Battery Technology

E: faradaybatterychallenge@iuk.ukri.org

https://linktr.ee/faradaybatterychallenge

Faraday Battery Challenge Programme timeline

Initiated 2017

July: Launch of the programme by Secretary of State.

October Faraday Institution (FI) opens.

November: UK Battery Industrialisation Centre (UKBIC) announced by Secretary of State.

2018

March: First 4 Faraday Institution (FI) research projects commence.

August: 1st round of 25 collaborative R&D projects commence.

2019

January: 2nd round of 12 collaborative R&D projects commence.

May: UK Battery Industrialisation Centre (UKBIC) Site Ground-breaking event.

September: 3rd round of 26 collaborative R&D projects commence.

2020

September: Six further major FI research projects commence.

2021

July: UK Battery Industrialisation Centre (UKBIC) official opening by Prime Minister.

4th round of 17 collaborative R&D projects start.

2022

March: Three rounds (Rd 1, 2 & 3) of Collaboration research and development project completed.

June: 14 Faraday Institution (FI) seed projects begin, expanding research scope.

First cohort of 13 Faraday Institution (FI) PhD researchers graduate.

200th Faraday Institution (FI) undergraduate internship facilitated.

October: Phase 2 official announcement by Business, Energy and Industrial Strategy (BEIS).

2023

February: UK Battery Industrialisation Centre (UKBIC) SME Credit Round 1 Competition open.

5th round of 17 collaborative R&D projects commence.

March: Investor Readiness competition opens.

Reshaping of 10 major Faraday Institution (FI) projects to maximise impact.

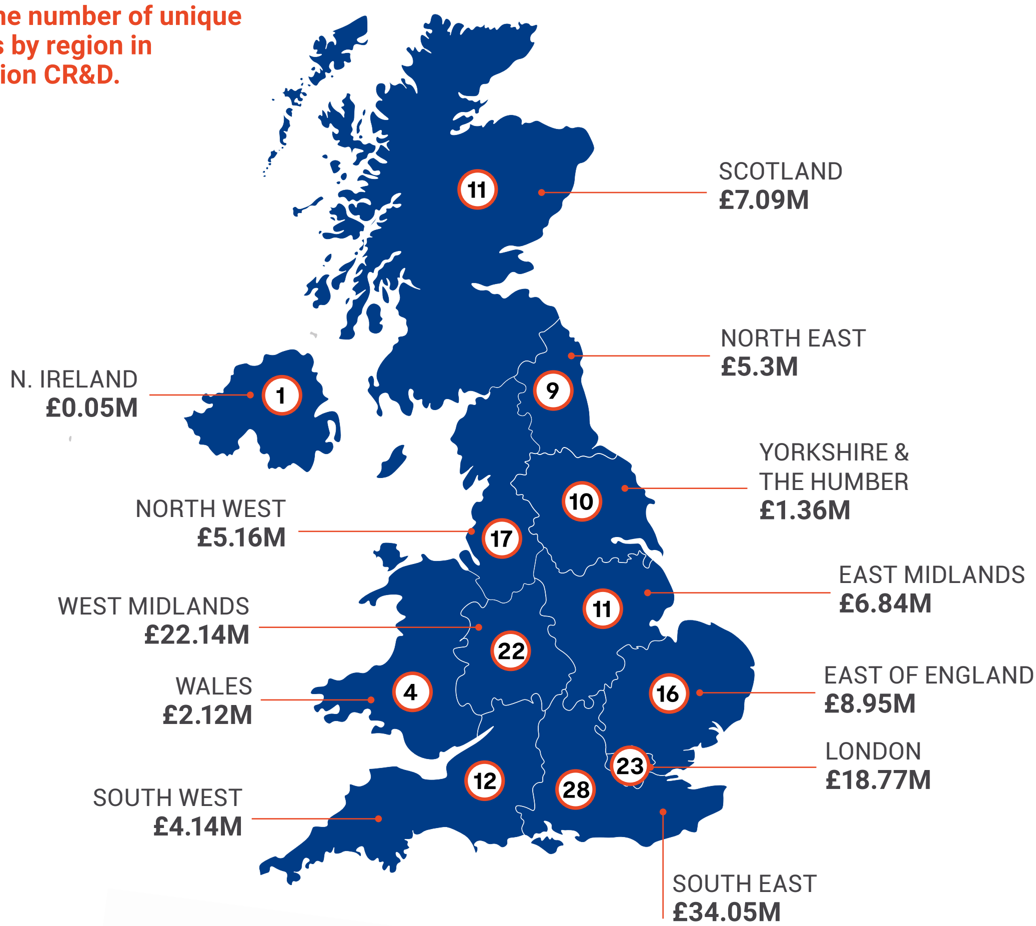
8th Faraday Institution (FI) Entrepreneurial Fellowship (spin out), 16th Industry Fellowship and 11th Industry Sprint awarded.

April: HVMC UK cross sector direct award competition opens

Talent & Skills. Full stage competition opens.

October: Round 4 Collaboration research and development projects completed.

This map indicates the number of unique funded organisations by region in business-led Innovation CR&D.



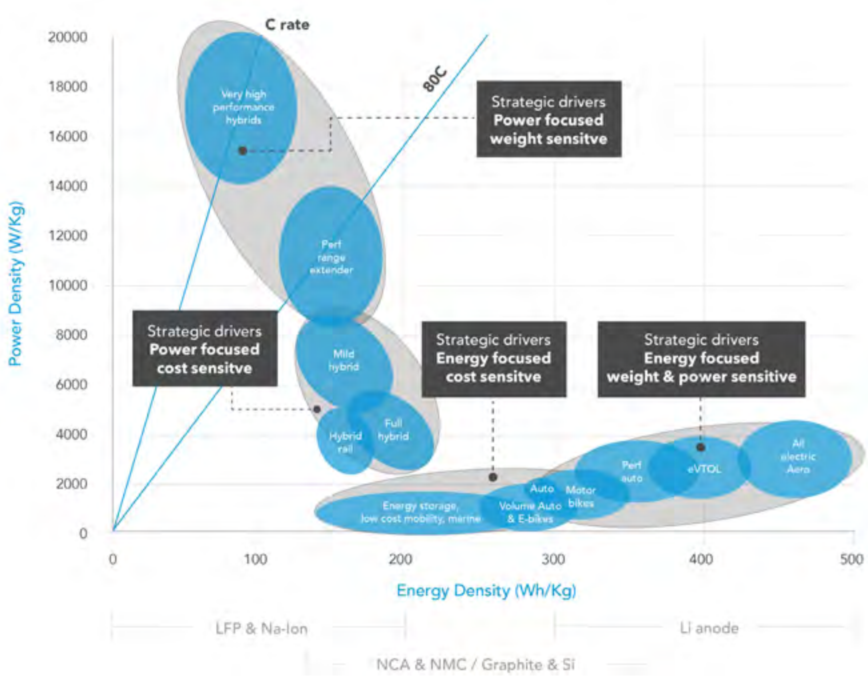
Faraday Institution research and industry partners.

Shared solutions for the electrification of transport: an opportunity for the UK battery community

Work carried out by WMG has investigated the requirements of battery technology to be widely adopted across different mobility sectors, producing the Ragone plot and table shown here.

The Ragone plot shows power density on the Y axis plotted against energy density on the X axis, and illustrates the needs of different mobility sectors, and how they can be grouped into clusters with different strategic drivers.

The table highlights the priorities of different characteristics for different mobility sectors.



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

Reference: WMG, University of Warwick

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

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

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

Research

THE FARADAY INSTITUTION

The Faraday Institution: powering Britain’s battery revolution

Executive Summary

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

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.

Mission

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

Research Community

A large-scale endeavour of this significance necessitates an extensive national reach. The Faraday Institution draws its strength from its 27 UK universities, from St Andrews to Southampton, including world-leading universities Oxford, Cambridge, Imperial and University College London. The Faraday Institution has combined the strengths of highly competitive university research groups across the UK to work as active collaborators, marking a sea change for the research community and representing a new model for conducting commercially relevant research. This research community is a powerhouse – 500-strong from a multitude of fields – working with the direction and guidance of its 85 UK industrial partners.

Empowering the Next Generation

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

Partners

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

Faraday Institution's Research Portfolio

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

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

- Seven aim to optimise current generation lithium-ion based batteries where there are still considerable gains to be made and where research breakthroughs could start to be realised in commercial batteries within 3-4 years.
  - Three building core knowledge, understanding, capability in: battery degradation, modelling and safety.
  - Two on processing: electrode manufacturing and recycling.
  - Two on next-generation cathode materials.
- Three focus areas are higher risk, higher reward, and could facilitate the long-term commercialisation of next-generation battery technology that still requires considerable research in the areas of materials discovery and optimisation in solid-state, sodium-ion and lithium-sulfur batteries.

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.

Additionally, in June 2022, the Faraday Institution initiated a number of small, fast-paced, focused projects in areas not covered within its existing battery research portfolio. In doing so it widened its research scope, and set of university partners, in an initiative that will inform future research priorities. The new seed projects, in the areas of anodes, electrolytes, cathodes, next generation technologies, applications, and data management, aim to deliver transformative results that may lead to a second stage of collaborative research beyond the initial exploratory work.

Early-Stage Commercialisation

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 organisation actively promotes novel means of translating the results of university battery research into technological advance, undertaking activities that go well beyond the remit of a standard research organisation. A bespoke analytical methodology is used to assess early-stage commercialisation potential for each of its research projects that results in an approach to commercialisation tailored to each project, the prioritisation of limited resources, and the development of consortia that are investment ready.

The Faraday Institution's commercialisation portfolio also includes (as of April 2023):

- 11 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.
- 8 Entrepreneurial Fellowships, supporting researchers across the UK looking to create new businesses and commercialise battery technologies.
- 15 Industry Fellowships, a programme to strengthen ties between battery researchers working in industry and academia.

Informing Policy

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

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

Contact

James Gaade
Head of Programme Management

+44 (0)1235 425123 office
+44 (0)7387 790493 mobile

opportunities@faraday.ac.uk

www.faraday.ac.uk

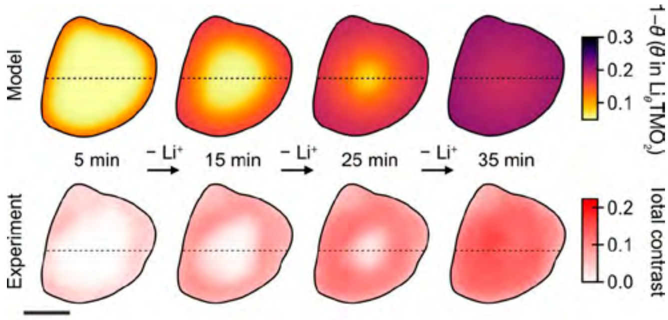
https://twitter.com/FaradayInst

www.linkedin.com/company/thefaradayinstitution

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

Additionally, fast charging of battery electric vehicles is crucial to help assuage range anxiety and provide the operational convenience required for mass adoption of the technology. Fast charging, however, can rapidly accelerate degradation and even trigger degradation mechanisms that are not present in ‘normal’ operating conditions. A key goal for the automotive industry is to 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 electric vehicle technology.

Partners

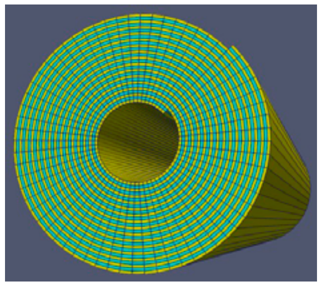
University of Cambridge (Lead)
Imperial College London
Newcastle University
University College London
University of Birmingham
University of Oxford
University of Sheffield
University of Southampton
University of Warwick
National Physical Laboratory (NPL)
+ 8 Industrial Partners

Contact:
Professor Clare Grey Email: cpg27@cam.ac.uk
Professor Louis Piper Email: Louis.Piper@warwick.ac.uk
Web: https://degradationproject.com/

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

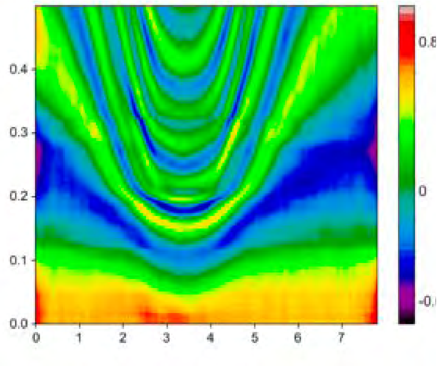
Imperial College London (Lead)
University of Birmingham
University of Oxford
University of Bristol
University of Portsmouth
University of Southampton
University of Warwick
UK Battery Industrialisation Centre (UKBIC)
+ 17 Industrial Partners

Contact:
Professor Gregory Offer Email: gregory.offer@imperial.ac.uk Web: http://batterymodel.co.uk

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, $x \approx 3.45$ mm, starts displacing the electrodes from $t \approx 0.04$ s, where the extent of displacement reduces radially due to the circular profile of the ball.

Executive summary

Whilst 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

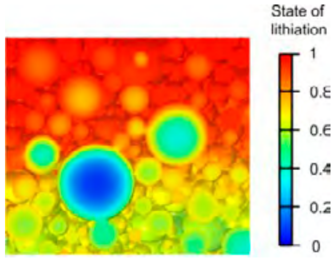
University College London (Lead)
University of Cambridge
King's College London
Newcastle University
University of Sheffield
University of Warwick
+ 2 Industry Partners

Contact:
Professor Paul Shearing Email: p.shearing@ucl.ac.uk Web: www.safebatt.ac.uk

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 and 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.

**At the time of print (May 2023) the exact scope of this project beyond September 2023 is in the process of being defined but is expected to be as described here.*

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

Contact:
Professor Patrick Grant Email: patrick.grant@materials.ox.ac.uk Web: https://nextrode.web.ox.ac.uk

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 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 2 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 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.

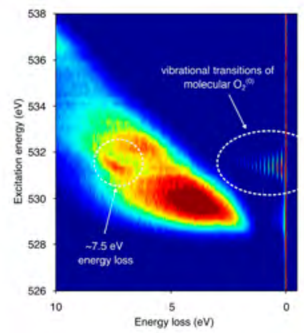
Partners

University of Sheffield (Lead)
University of Cambridge
Lancaster University
Imperial College London
University of Warwick
University of Birmingham
University of Nottingham
Diamond Light Source
ISIS Neutron and Muon Source
+ 8 Industry Partners

Contact:
Professor Serena Cussen Email: s.cussen@sheffield.ac.uk Web: https://futurecat.ac.uk

CATMAT – sustainable, low-cost 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 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: boosting battery life, storing greater energy to improve range, reducing battery cost and increasing the power available to the EV during acceleration. Developing a new generation of lithium-ion cathodes 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 Li-ion battery manufacturing base, the potential for CATMAT to bring important innovations in cathode chemistry to commercial fruition is increasing considerably whilst the importance of inventing chemistries that both 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

Contact:
Professor Saiful Islam Email: saiful.islam@materials.ox.ac.uk Web: https://catmatproject.com/

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.
- 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 1 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

Contact:
Professor Paul Anderson Email: p.a.anderson@bham.ac.uk Web: https://relib.org.uk

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

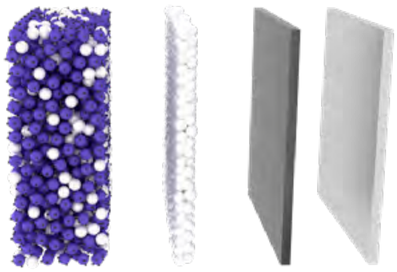


Image representation of solid-state battery structure

Executive summary

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

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

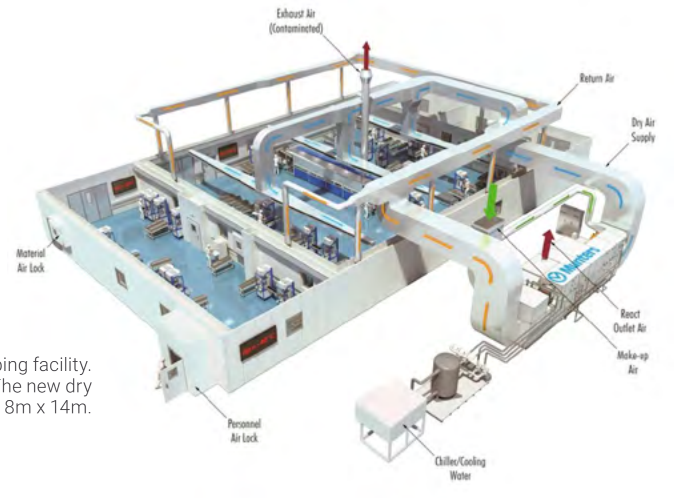
University of Oxford (Lead)
Newcastle University
Diamond Light Source
+ 3 Industry Partners

Contact:
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



Schematic of a prototyping facility. Image courtesy of Munters. The new dry room at St Andrews is 8m x 14m.

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 batteries 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 sodium-ion batteries.
- 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. 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

Contact:
Professor John T S Irvine   Email: jtsi@st-andrews.ac.uk   Web: www.nexgenna.org

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. 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. Yet the widespread use of Li-S faces major hurdles that stem from sulfur's insulating nature, migration of discharge products leading to the loss of active material, and degradation of the metallic lithium anode. Scientists and engineers need to know more about how the system performs and degrades in order to overcome current limitations in the power density and lifespan of Li-S cells that could unlock their use 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

In doing so, 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 College London (Lead)
University of Cambridge
Coventry University
Cranfield University
University of Birmingham
Imperial College London
University of Nottingham
University of Oxford
University of Southampton
University of Surrey
Aerospace Technology Institute
National Physical Laboratory
+ 5 Industry Partners

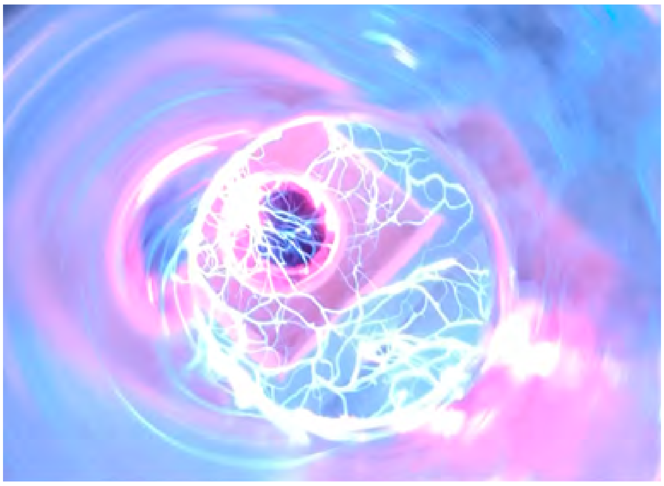
Contact:
Professor Paul Shearing   Email: p.shearing@ucl.ac.uk   Web: www.listar.ac.uk

Seed projects

In June 2022, the Faraday Institution initiated 16 small, fast-paced, focused projects in areas not covered within its existing battery research portfolio. In doing so it widened its research scope, and set of university partners, in an initiative that will inform future research priorities. The new seed projects aim to deliver transformative results that may lead to a second stage of collaborative research beyond the initial exploratory work. The projects are:

Anodes

- The University of Sheffield is seeking to develop the first commercially viable large-scale process for the bulk manufacture of porous silicon for graphite anodes with high silicon content.
- UCL will further develop the relatively new technique of pair-distribution-function computed tomography, which facilitates atomic mapping of working cells at a microscopic scale.
- Loughborough University aims to deliver silicon-carbon composite anodes with optimised porosity and surface area by designing a fast, energy efficient microwave processing pathway.
- UCL, with guidance from Nexeon, will apply X-ray computed tomography to quantify volume expansion in silicon-based anodes and link morphological evolution to performance.



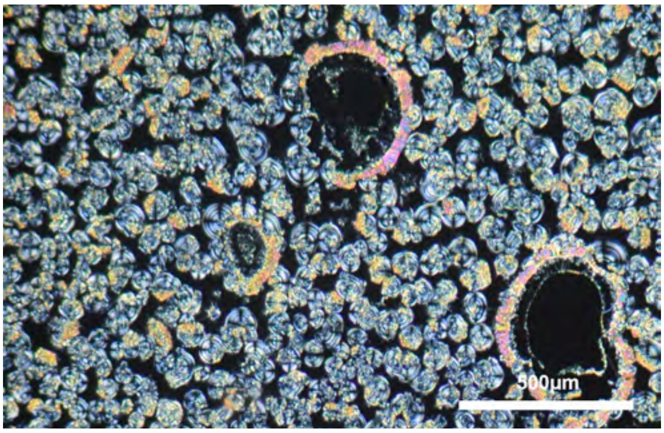
Photograph of the occurrence of arcing upon microwave irradiation of annealed graphene oxide based materials: This allows selective and ultra-rapid heating rates to be achieved leading to significant reduction in processing time.

Cathodes

- The Universities of York and Birmingham will develop novel green solvent-binder systems to provide a low cost and low environmental impact route for manufacturing and recycling of Li-ion electrodes.
- UCL, with QinetiQ, will demonstrate a new energy-efficient scale-up route to synthesise two ceramic powders used in cathodes, benchmarking electrochemical performance in large format pouch cells.

Electrolytes

- The University of Leicester will explore five novel classes of electrolytes, aiming to deliver solutions that improve cycling performance and interfacial stabilisation of both the cathode and anode.
- The University of York will investigate a new class of organic solid-state electrolytes that show promise as lightweight, flexible and manufacturable alternatives.



A polarised optical microscope of the liquid crystalline phase of electrolytes being developed by McGonigal et al.

Next-generation technologies

- The Universities of Strathclyde and Sheffield with NPL will explore the potential use of magnesium as a more sustainable, cheaper alternative to lithium in rechargeable high energy density batteries.
- The Universities of Nottingham and Oxford will explore the use of gas diffusion polymers as a route to increasing the capacity and rate of lithium-air batteries, of particular interest to aerospace.
- The University of Surrey, with NPL, aims to tackle the limiting factors of Li-CO_2 battery performance using their on-chip Li-CO_2 batteries platform for electrocatalyst screening.

Applications and data management

- Imperial College London, with WAE, will bridge the gap between thermofluid science and electrochemistry by developing a multiphase model of battery failure via thermal runaway.
- The University of Birmingham will demonstrate the feasibility of a hybrid technology combining batteries and supercapacitors in a single device, enabling both high power and energy density.
- The Universities of Edinburgh and Oxford will deliver a proof of concept “minimal viable product” for a Battery Data Hub, improving the efficiency of scientific discovery and supporting access to data.

Industry sprints

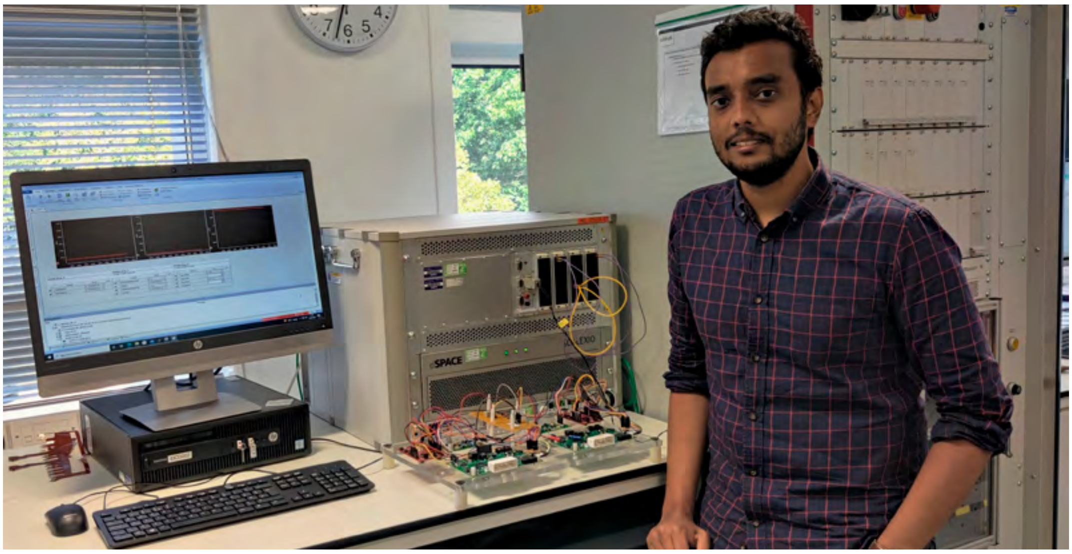
Sprints dedicate small, focused teams of researchers to solve a commercially relevant research opportunity identified from within the research programme and prioritised by an industrial partner. Over a period of 6 to 15 months, researchers work closely on the challenge, meeting frequently to review progress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

Sprint Title	Description
Off Gases and Detonation Behaviour	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 select 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 is performing 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 expected to enable 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 Title	Description
Screening of ELectrode Manufacturing for All-Solid-State Batteries (ELMASS)	WMG, University of Warwick, Jaguar Land Rover and a third partner are working together on an Industry Sprint to unlock a path to scale up the type of solid-state batteries being investigated by the SOLBAT project. The key outputs will be a cost/performance assessment of an electrode manufacturing technique led by end-user requirements.
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 focuses 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 are testing and screening potential cathode materials and developing suitable electrolytes for a quasi-solid-state format. The project will demonstrate the best cathode materials in commercially relevant high-capacity pouch cells and evaluate 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 are needed to increase the accuracy required for commercial applications. This follow-on Sprint project, aligned to the Multi-scale Modelling project, extends the successful collaboration. It aims to accelerate 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.

Entrepreneurial fellowships and spin-outs

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

Breathe Battery Technologies

www.breathe.technology

Description

Through continuous research and development, Breathe Battery Technologies is pioneering new ways to use battery systems and enhance their health, charging, cycle life and range. The organisation works in partnership with global OEMs in the automotive, robotics and consumer electronics industries to deliver advanced battery system performance and experiences. They are developers of the world's first health adaptive battery charging software

Outcomes

Breathe was founded in 2019 by Drs Yan Zhao, Ian Campbell & Professor Greg Offer (Faraday Institution Multi-scale Modelling project Principal Investigator) and was awarded a Faraday Institution Entrepreneurial Fellowship in the same year. The company continues to grow strongly on the back of increasing demand for battery system performance and it has released news of two new high-profile customers for its products. VARTA, the battery specialist and manufacturer, licensed Breathe Charge for their Easy Blade battery series, reducing the battery charging time by 27%. Further, global smartphone brand, OPPO, has partnered with the company, licensing Breathe Life to double the battery lifetime of its latest Reno8 Series of smartphones, which is now shipping globally. In December 2021 the company raised £1.5m of seed investment led by pan-European VC Speedinvest. The investment was supported by the Faraday Battery Challenge's Investment Readiness Programme, which is aiding Breathe in on-boarding new clients around the world in its target markets. As of March 2023, the organisation has 25 team members and is recruiting into a further eight roles.

Cognition Energy

www.cognition.energy

Description

Cognition has two distinct business offerings, a cell testing service for third parties and CellPods; innovative micro-thermal thermal chambers that enable better testing of cells. The cell testing service is aimed at organisations that either want to develop their own cell chemistries, or want to evaluate cells as part of pack development programmes. CellPods are currently aimed at anyone testing coin or small cylindrical cells. Cognition was founded by Tom Cleaver, Greg Offer and two other academics from Imperial and Neil Morris, former CEO of the Faraday Institution, who joined as a non-executive director.

Outcomes

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

Cognition Energy's CellPods.

Solveteq

https://solveteq.co.uk

Description

Solveteq is developing a sustainable technology for recycling of lead-acid batteries, whilst significantly reducing the environmental impact of the lead recycling process. The green, low-temperature and solvent-based technology will enable recycling companies to significantly reduce their expenditure on energy and environmental control. Originating as an Imperial College London spin-out, Solveteq is working with some of the world's leading lead recyclers and manufacturers to demonstrate the technology and help them to pre-emptively adapt to a challenging, more restrictive future. Intellectual property has been captured by two granted patents.

Outcomes

The Entrepreneurial Fellowship supported IP co-inventors, Dr Ola Hekselman and Prof. David Payne in the spin-out process and in fundraising of Solveteq's pre-seed round in 2021. The funding enabled Solveteq to build its first prototype and scale up from lab-scale experiments to intermediate-scale and closed-loop operations with processing capacity of 1kg of spent battery paste per hour. During the Fellowship, Solveteq also established strategic relationships with leading battery recyclers, who continue to actively collaborate and contribute to Solveteq's technology and commercial development. More recently Solveteq's team is focused on technology trials and validation. The company aims to scale its technology to a 25kg/h pilot demonstrator and to deploy it in real-life conditions in late 2023. The technology development is being further supported by Innovate UK and Energy Catalyst and the team is preparing for their next investment round scheduled for 2023.

Co-founder Ola Hekselman with an early prototype.

Qdot

www.qdot.tech

Description

Qdot Technology's vision is to enable clean flight through the development of electrified aircraft propulsion systems. It is a spin-out from the University of Oxford, founded by colleagues from the Oxford Thermofluids Institute, which has a rich history in solving challenges in aircraft propulsion.

Its focus is on scalable and modular propulsion systems for hybrid-electric aircraft that will drastically reduce overall operating costs for the user. Initially, the organisation is targeting its systems at heavyweight drones and small passenger aircraft.

Outcomes

The Entrepreneurial Fellowship provided Qdot with the resources to develop and validate a prototype thermal management system to achieve extremely fast charging/discharging at the battery cell level. Follow-on funding to further develop the technology has been successfully secured from a range of Government agencies, including a successful application to the BEIS Energy Entrepreneurs Fund. This project will see Qdot deploy the technology in a pack for application in a heavyweight drone platform, with testing due in 2023.

Gaussion Ltd

www.gaussion.com

Description

Dr Tom Heenan, UCL, along with co-inventors Dr Chun Tan, Prof Paul Shearing and Prof Dan Brett have filed for the patent of a charging-enhancement 'MagLiB' technology that uses a dynamic magnetic field to accelerate the fast charging of lithium-ion batteries. MagLiB has already demonstrated charge time reductions of over 60% in commercial cells. The Fellowship has propelled the technology into commercial battery applications, from battery manufacturing to EV recharging to second life.

Outcomes

The MagLiB technology, developed in the Electrochemical Innovation Lab at UCL and now being commercialised by Gaussion, allows a higher average electrical current to be used during charging, which reduces the charging time whilst maintaining the cell's energy and power density (and hence EV range and acceleration) and battery lifetime. The technology is ready for real-world proof-of-concept projects. Early-stage discussions are underway with commercial entities. In 2022 Gaussion concentrated on producing a technology demonstration and it is targeting market-entry in 2023. The company is currently seeking to establish initial development partnerships to access the EV recharging and cell manufacturing markets, with a technology demonstrator targeted in 2023. In 2021, the MagLiB fast-charging battery solution won the Royal Society of Chemistry Emerging Technologies Competition in the Energy and Environment category, as well as being awarded the Autocar Drivers of Change technology award. In 2022, Gaussion joined the Advanced Propulsion Centre's Technology Development Accelerator Programme (TDAP).

About:Energy

www.aboutenergy.io

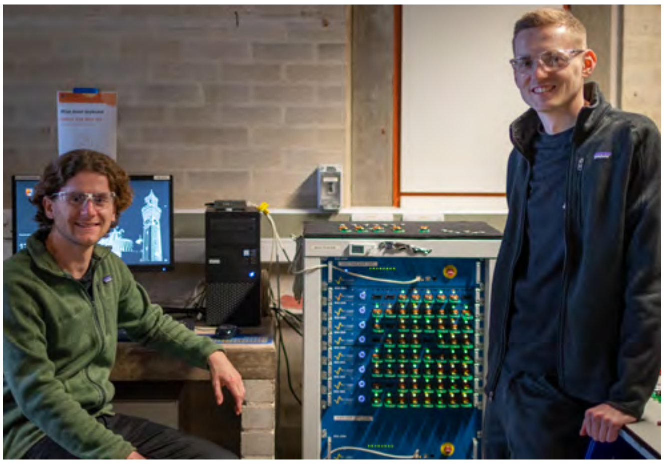
Description

About:Energy is a joint spin out from Imperial College London and the University of Birmingham, which 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 two founding universities have expertise in extracting the experimental data required to construct battery models, an activity known as parameterisation. About:Energy has extensive knowhow in this area as well as a bespoke, patented measurement method.

Outcomes

Since being awarded The Faraday Entrepreneurial Fellowship in 2022, About:Energy has developed commercial relationships with companies in the automotive, manufacturing, and next-generation battery industries. The company is receiving grant support from the Advanced Propulsion Centre through TDAP. This programme has helped shape the core technologies and business model to be able to deliver value to companies through a proprietary software platform. 'The Voltt' is a secure database that contains parameters for commercial and bespoke cell chemistries and formats, providing a tool for cell selection, system development, and battery prediction.

About:Energy is collaborating with the PyBaMM, DandeLiion and Faraday Institution commercialisation teams under the 'Battery Parameterisation eXchange (BPX)' initiative and the associated formation of an associated Battery Modelling Standards Forum (an industry-led organisation that will own and maintain the standard and build a clear technical, commercially informed roadmap for its development). The development of a standardised way of building and sharing parameter sets has the aim of overcoming a number of technical barriers companies face in using battery models in-house. This will enable wider adoption of state-of-the art models within industry to improve the sustainability, cost, and performance of new battery technologies.



About:Energy are reducing the technical barriers that hinder industry achieving full value from battery modelling.

Illumion

www.illumion.io

Description

Illumion is commercialising a novel, low-cost, technique for looking inside lithium-ion batteries and pinpointing potential defects, which could help speed up the development of promising new battery materials.

Outcomes

Developed by scientists at the University of Cambridge's Cavendish Laboratory and Yusuf Hamied Chemistry Department, as an output of a Faraday Institution battery characterisation project, this optical microscopy technique could prove a vital tool for battery research. Currently, studying the behaviour of lithium ions and how they enter a battery's active material is time-consuming and expensive. Illumion's technology promises to offer a much simpler and non-intrusive way to look inside a battery, observe how active particles are behaving, and spot any problems. It is likely to be four to five times cheaper than anything currently on the market, making it an attractive proposition for start-ups developing new batteries. The Fellowship is supporting the company's co-founders as they work with partners in industry and academia to bring this technology to market.

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	Highlight
Coventry University with Nyobolt	Prof Alex Roberts and Dr Ageta Greszta at Coventry University are working with Nyobolt to prototype their niobium-based anode materials into working battery cells. The collaboration is proving highly successful for both parties involved, with prototype cells confirming performance potential that supported a recent funding round for Nyobolt. 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.
Imperial College London with Ilika Technologies	Prof Greg Offer and Dr Ganesh Madabattula at Imperial College London are partnering 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 is allowing Ilika to rapidly trial various modifications to both the chemistry and physical make up of their designs, without having to commit to the cost and time involved in producing and then testing a large number of physical prototypes. The project is initially focussed on the modelling of the high-capacity silicon anode material used by Ilika.
University of Strathclyde with CDO2	The fellowship's goal is 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 has been 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 is being 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 is working 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 is 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 are working with TFP Hydrogen Products to develop processes to control particle morphology and size for next-generation high-nickel cathode materials in a continuous manufacturing process, as part of a long-term aim of maximising battery performance and reducing manufacturing costs.
University of Sussex with CDO2	Prof Peter Kruger and Dr Christopher Abel of the University of Sussex are working with CDO2 to characterise and understand the capability of a newly developed device based on quantum magnetometer technology that could potentially be used to improve the prediction of state-of-health and state-of-charge on-board EVs.

The cell fabrication facilities at Coventry University have greatly benefited Nyobolt as well as bringing new capabilities to the LiSTAR consortium.

Fellowship	Highlight
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 Technologies 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.
The University of Sheffield with Finden	Prof Serena Cussen and Dr Sam Booth at the University of Sheffield are working with Dr Stephen Price at Finden to deepen the understanding of new cathode materials and mitigate deleterious behaviour. Through the application of X-ray diffraction computed tomography methods, the team is uncovering spatially resolved quantitative structural information that is guiding synthetic approaches to next-generation cathodes. The aim is to fast track the best-performing high energy density cathodes to aid their early adoption by UK industry and to inform future cathode protection strategies to prolong battery life.
The University of St Andrews with AMTE Power	Prof John Irvine, Dr Rob Armstrong and Dr Paul Connor of the University of St Andrews are working with AMTE Power to strengthen the pathway from laboratory to cell production. The partnership is focusing on taking newly developed sodium-ion materials from the laboratory to fully functioning pouch cells as an exemplar technology allowing the building of combined capability. The fellowship is strengthening the industry partner's awareness and capability in battery research and enhancing the university partner's capability to transition cells to full scale.
University of Sheffield with Exawatt	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.

Fellowship	Highlight
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.
Bristol University with Thermal Hazard Technology	Dr Alastair Hales of University of Bristol and Prof Gregory Offer of Imperial College London are partnering with Thermal Hazard Technology (THT) to develop a common testing framework to improve the parameterisation of battery models. The testing framework will provide improved tools and methods for a more efficient product development processes and learnings will be 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 performance of sodium-ion batteries based around researching the potential of carbon and phosphorous as anode-materials. The project will aim to improve the capacity of these materials by investigating the porous carbon hosts for the phosphorisation process and improve first cycle capacity loss by using electrolyte additives. The team will work towards improving the performance of these low-cost, high safety alternatives to lithium-ion based batteries, and to capitalise the UK's position as a global leader in sodium-ion battery research to accelerate the commercialisation of these technologies.

Innovation

UKRI Innovate UK

Cells and material innovation projects

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 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 aims to validate the performance of a COBC system configured specifically for this reaction process, with the conversion of a typical batch process as the first step. Process optimisation will then be carried out and produced materials will be performance tested following production of appropriate cell formats. Manipulation of the form of particles produced via adjustment of relevant process variables will aim to increase end-use performance of materials produced.

Timeline with milestones and deliverables

January 2024 – end date

- 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.
- Optimise the COBC process conditions for production of NMC precursor materials and define an appropriate operating window.
- Synthesise a range of NMC-type precursor materials using, including materials suitable for single crystal cathodes.
- Prepare coin cell format to test the performance of COBC synthesised materials and benchmark performance against relevant standards.
- Utilise optimised process conditions to define an industrially relevant scale-up COBC system.

Project innovations

Validation of the technical feasibility of continuous processing (COBC) to manufacture NMC precursor material is the core innovation target. As a follow-on, an optimised process is sought with necessary adjustments to the system configuration defined. Process parameters required for scale-up will also be determined. Process control requirements to ensure production of high-quality product and related product performance will also be defined. Increased end-use performance of produced precursor materials is the final target.

Partners

The University Of Sheffield.
cpi
NiTech Solutions

Contact:
Professor Dr Will Davies Email: will.davies@nitechsolutions.co.uk Web: nitechsolutions.co.uk

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

Contact:
Dr Sarah Stevenson   Email: sarah.stevenson@echiontech.com   Web: www.echiontech.com

Coated current collector for battery performance improvement (CONTACT)

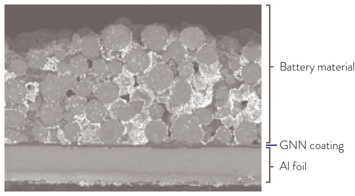
Demonstrate improved rate capability and useful life with a novel high performance current collector in a commercially relevant cylindrical cell.

Project costs

Total project costs: £1,152,264

Grant contribution: £869,273

Proprietary roll-to-roll equipment designed to produce GNN's coated current collector



SEM image illustrating how GNN's thin and uniform coating interfaces directly with active material particles

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 a 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

Contact:
Ravi Daswani Email: ravi@globalnano.network Web: www.globalnano.network
Prof. John Low Email: C.T.J.Low@warwick.ac.uk Web: www.warwick.ac.uk

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 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 lithium-ion batteries, 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 lithium-ion batteries 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

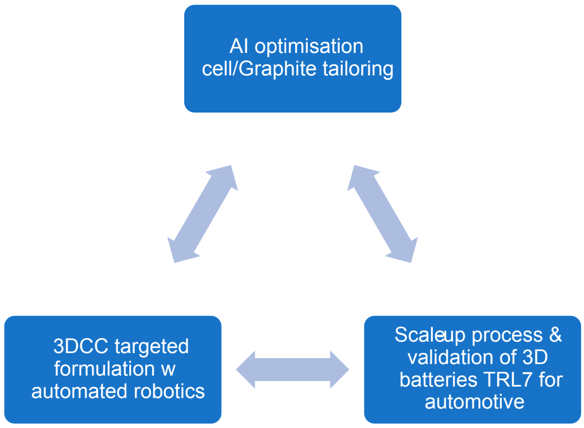
euriscus
GRAPHENE STAR
GLOBAL NANO NETWORK
Rapid Powders
WMG THE UNIVERSITY OF WARWICK

Contact:

Dr David J. Field	Email: david.field@rapidpowders.com	Web: www.rapidpowders.com
Dr John Low	Email: C.T.J.Low@warwick.ac.uk	Web: www.warwick.ac.uk
Graham Bennett	Email: graham.bennett@euriscus.co.uk	Web: www.euriscus.co.uk
Marina Starkova	Email: marina.starkova@graphene-star.com	Web: www.graphene-star.com
Dr Ravi Daswani	Email: ravi@globalnano.network	Web: www.globalnano.network

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

Improve EV battery cells by current collectors designed through Artificial Intelligence; accelerated formulation of customised electrodes using UK-produced graphite and coating in roll to roll systems.



Project costs

Total project costs: £3,796,973

Grant contribution: £2,955,915

Executive summary

The UK needs innovative solutions to meet the target of banning combustion-engine sales by 2030 and maintain competitiveness in a global EV market. Project CONSTELLATION is aimed at enhancing the performance of EV battery cells, improve the competitiveness of the UK battery supply chain and take technology already developed to TRL7 ready towards full commercialisation. Key objectives for this project include developing new verticals in cells manufacturing through improvements to the performance, process efficiency, and environmental profile of cells optimised for the automotive market. Rapid prototyping in Addionics novel 3D current collectors design will be achieved utilizing artificial intelligence routines, with accelerated formulation of slurries to achieve consistent coating using CPI's high throughput robotic formulation platform. WMG will use roll to roll coating and automated pouch cell production line to accelerate battery development. Additionally, we will also incorporate graphitic carbon produced in the UK by James Durrans Group.

Timeline with milestones and deliverables

This is a 24-month long project. Firstly, the specification of materials will be the starting point followed by design and modelling throughout the project led by Addionics. James Durrans will develop the graphite for the anode beyond the first half of the project while simultaneously CPI will work on the formulation development. After the first 6 months, the roll to roll and cell fabrication will start and will be carried out by WMG. Addionics will lead on the exploitation, dissemination and project management.

Project innovations

Volume manufacture of novel AI-assisted optimised 3DCC/cell design; high electrode loading of pouch-cell prototypes for EVs, extending cycle life and power output. Validation of scale-up of custom-tailored graphite anode; Customised anode/cathode ink formulation through advanced robotics tailored for 3DCCs. Roll-to-Roll production with demonstrator batteries utilising new technology in existing lines.

Partners

James Durrans Group

WMG The University of Warwick

cpi

Addionics

Contact:
Marcelo Machado
Email: marcelo@addionics.com
Web: addionics.com

Current collector for improved battery performance (COATED)

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

Project costs
Total project costs: £756,308
Grant contribution: £573,244

Executive summary

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

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

Timeline with milestones and deliverables

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

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

Project innovations

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

Partners

DuPont Teijin Films – Innovation | Partnerships | Sustainability

dzp TECHNOLOGIES – Printed electronics innovator

PLASMA APP

WMG – THE UNIVERSITY OF WARWICK

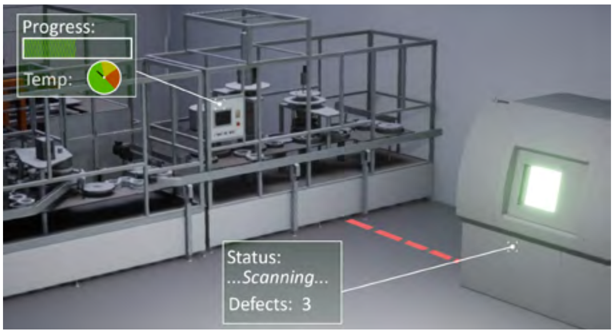
Contact:
Dr Zlatka Stoeva Email: zlatka.stoeva@dzptechnologies.com Web: www.dzptechnologies.com

Digital Twin Technology for Quality and Yield Improvement of Battery GigaFactories

The project will demonstrate 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 utilized to evaluate and optimize 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 will be to validate the yield improvements based on the changing specific parameters in the production flow. To develop and validate an AI-based automated defect recognition (ADR) tool to be used for analysing the industrial computed tomography (CT) scanner data.

Timeline with milestones and deliverables

- Active project for 2023 only as a feasibility study
- 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.

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

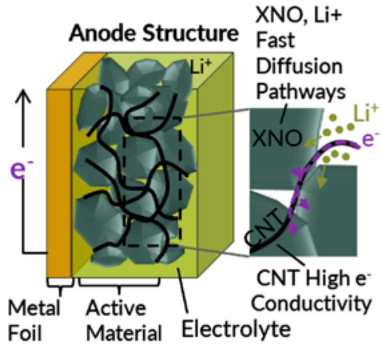
UK BATTERY INDUSTRIALISATION CENTRE

PXL ICE

Contact:
Paul Perera Email: paul.perera@bakerhughes.com Web: www.waygate-tech.com

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. These anodes 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

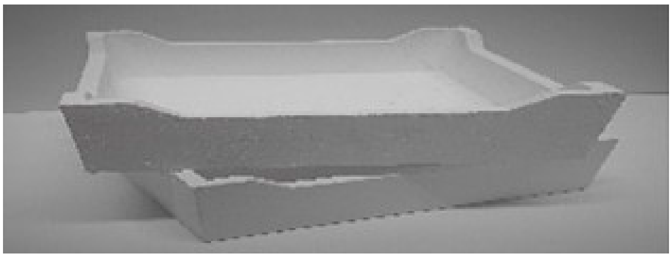
Echion Technologies
University of Cambridge
Q-FLO CNT Innovation

Contact:
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 Li-ion battery market by late 2020.

Project innovations

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

Partners

LUCIDEON
Materials Development and Commercialization

JM Johnson Matthey
Inspiring science, enhancing life

Vulcan

Contact:
Kris McCabe — Email: kristopher.mccabe@matthey.com — Web: www.matthey.com
Stuart Handley — Email: stuart.handley@vulcanrefactories.com — Web: vulcanrefractories.com
Stuart Maclachlan — Email: stuart.maclachlan@lucideon.com — Web: www.lucideon.com

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 (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 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
Q4 2023: Last mile delivery battery design complete
Q2 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

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

GENESIS – Generating Energetic Novel Cells and System Inspired by Software

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

Project costs
Total project costs: £1,390,526
Grant contribution: £1,019,831

Executive summary

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

Imperial will utilise physics-based modelling techniques, developed as part of a Faraday Institution project, to optimise cell design, from material selection to physical cell design. Imperial will also develop innovative multi-objective optimisation tools to rapidly optimise the cell design. JM will characterise and provide their innovative high energy cathodes. ENTEK will investigate advanced microporous separator composites using nano/micro-structured ceramics and mixed fluoropolymers. 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

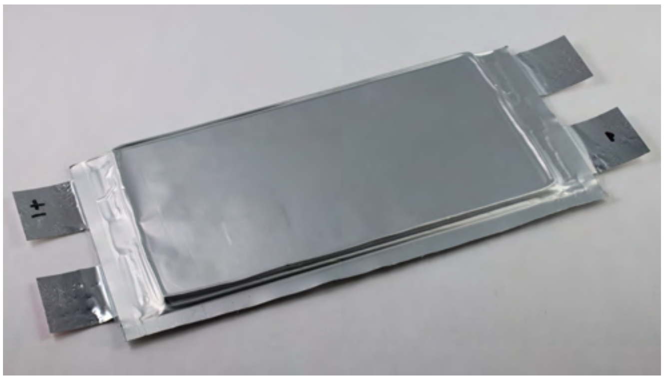
ENTEK

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

Contact:
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 LIB, developing new methodologies and consolidating existing
- New measurement methodologies for LIB manufacturing

Partners

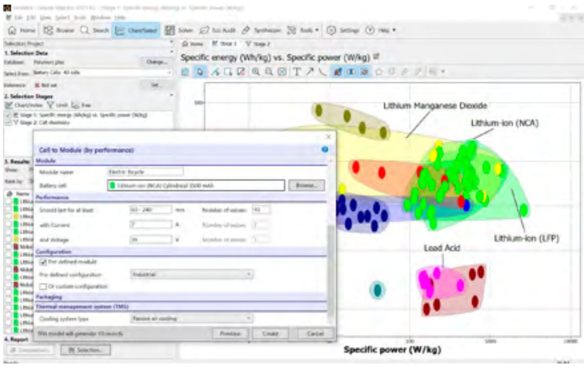
Ansys
University of Birmingham
Intellegens

Contact:

Alex Cazacu	Email: alex.cazacu@ansys.com	Web: www.grantadesign.com
Ben Pellegrini	Email: ben@intellegens.co.uk	Web: www.intellegens.ai
Emma Kendrick	Email: e.kendrick@bham.ac.uk	Web: www.birmingham.ac.uk

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

Contact:
Alex Cazacu Email: alex.cazacu@grantadesign.com
Billy Wu Email: billy.wu@imperial.ac.uk
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 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 via various techniques the structural analysis of cycled full Li-ion cells.

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 & 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 & 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

Contact:
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 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 LIB 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 & material consumption
- Up to 3 times more capacity in extreme temperatures @10C discharge rate
- Safety & reliability
- Security of supply
- Lower cost

Partners

Cranfield University

INTEGRALS POWER

Contact:
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 Li-ion battery anode based on a novel form of carbon material - Carbon Allotrope for Lithium-Ion Batteries (CALIB).

Project costs
Total project costs: £506,000
Grant contribution: £371,400

Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

PLASMA APP

UNIVERSITY OF CAMBRIDGE

Johnson Matthey
Inspiring science, enhancing life

Contact:
Dmitry Yarmolich | Email: dmitry@plasma-app.com | Web: http://plasma-app.com

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 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

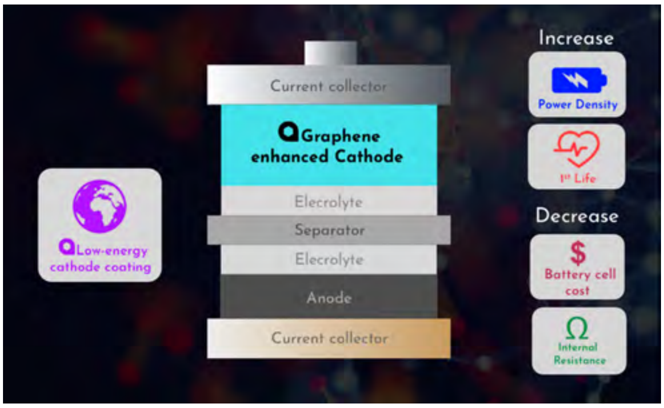
UK BATTERY INDUSTRIALISATION CENTRE

Imperial College London

Contact:
Fergal Harrington-Beatty Email: Fergal.hb@amtepower.com Web: https://amtepower.com

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

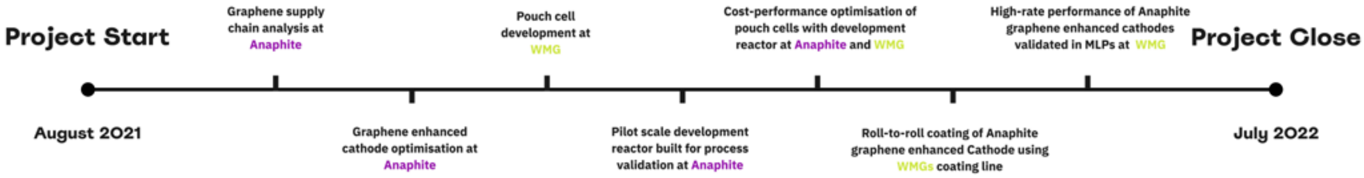
Executive summary

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 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 & 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:
Anaphite: Alexander Hewitt Email: alex@anaphite.com Web: www.anaphite.com
WMG: Dr John Low Email: c.t.j.low@warwick.ac.uk Web: https://warwick.ac.uk/fac/sci/wmg/

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 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 & electrode characterisation
3. High-capacity anode electrode and cell designs
4. 21700 cell assembly & 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

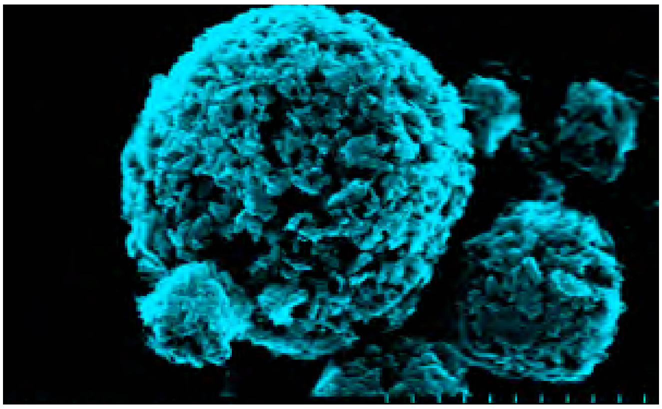
nexeon

UCL

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

SAFEVOLT Safe High Voltage EV battery materials

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



Project costs

Total project costs: £528,887

Grant contribution: £421,207

Executive summary

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

Timeline with milestones and deliverables

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

Milestones/deliverables of the project were:

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

M10 high energy density anode/cathode synthesis

M11 material selection for prototype based on performance

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

Project innovations

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

Partners

talga

TWI

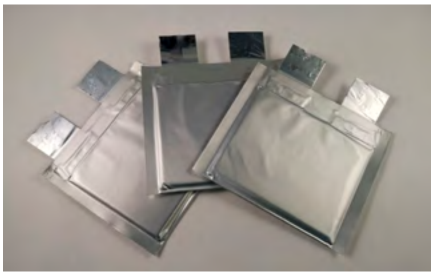
JM Johnson Matthey
Inspiring science, enhancing life

UNIVERSITY OF CAMBRIDGE

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: £1,875,174
Grant contribution: £1,390,435

Executive summary

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

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

Timeline with milestones and deliverables

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

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

Project innovations

The following key innovations were delivered by the SUPErB project:

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

Partners

UCL
University of Birmingham
Echion Technologies
williamblythe – Excellence in chemistry – A Synthomer Group Company
QinetiQ

Contact:
Gary Mepsted Email: GOMEPSTED@qinetiq.com

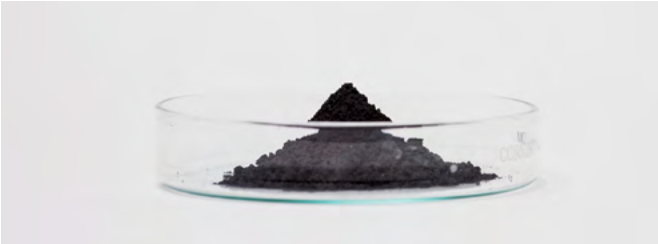
Scale-up Supply Chain Accelerator for Li-ion Electrode Materials in UK

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

Project costs

Total project costs: £1,223,380

Grant contribution: £956,423



Executive summary

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

Timeline with milestones and deliverables

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

Q4 (March 2019):

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

Q5 (June 2019)

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

Q7 (September 2019)

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

Q8 (February 2020, extended to August 2020)

- Material validation in long-term testing completed

Project innovations

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

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

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

Partners

talga

UNIVERSITY OF BIRMINGHAM

WMG THE UNIVERSITY OF WARWICK

TFP HYDROGEN PRODUCTS LTD

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

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

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

Project costs

Total project costs: £499,683
Grant contribution: £394,664

Executive summary

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

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

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

Timeline with milestones and deliverables

- **Project start** August 2019
- Multiple graphene enhanced electrode materials produced at lab-scale via **Anaphite's** process
- Lab-scale electrode materials cell performance analysed by **WMG**
- **Anaphite** develop scaled up process valiation system
- **Anaphite** screen materials in coin cells before long-term testing at **WMG**
- Lab-scale electrode materials characterised by **NPL**
- New low energy coating process discovered at **Anaphite**
- **Project end** January 2021

Project innovations

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

Project innovations include:

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

Partners

Anaphite

WMG
THE UNIVERSITY OF WARWICK

Contact:
Alexander Hewitt Email: alex@anaphite.com Web: www.anaphite.com
Dr John Low Email: c.t.j.low@warwick.ac.uk Web: https://warwick.ac.uk/fac/sci/wmg/

Securing domestic lithium supply chain for UK (Li4UK)

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

Project costs

Total project costs: £475,744

Grant contribution: £358,566

Executive summary

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

Timeline with milestones and deliverables

Project start May 2019	
Sept 2019	UK hard rock sampling
Dec 2019	Processing test work of bulk samples
Aug 2020	Samples analysed/ characterised
Sept 2020	Critical economic assessment
June 2020	Production of lithium carbonate from UK source
Project end Oct 2020	Delivery of feasibility study

Project innovations

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

Partners

wardell armstrong

Natural History Museum

Cornish Lithium

Contact:

Christine Blackmore	Email: cblackmore@wardell-armstrong.com	Web: www.wardell-armstrong.com
Reimar Seltmann	Email: r.seltmann@nhm.ac.uk	Web: www.nhm.ac.uk
Jeremy Wrathall	Email: j.wrathall@ccornishlithium.com	Web: www.cornishlithium.com

Silicon Product Improvement through Coating Enhancement (SPICE)

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

Project costs

Total project costs: £3,300,000
Grant contribution: £2,400,000

Executive summary

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

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

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

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

Timeline with milestones and deliverables

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

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

Project innovations

Innovation is focused in three main areas:

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

Partners

AMTE POWER

nexeon

Phoenix Scientific Industries Ltd
Advanced Process Solutions

University of Oxford

Contact:
Dr Scott Brown — Email: scott.brown@nexeon.co.uk — Web: www.nexeon.co.uk
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 EV market to reach $68bn in 2022; the UK urgently needs innovative solutions to meet these targets.

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

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

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

Project innovations

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

Partners

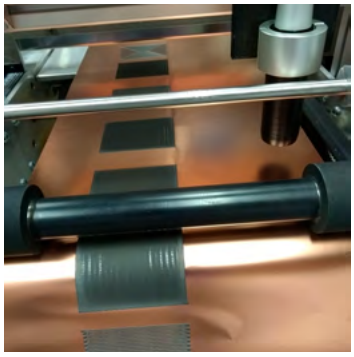
cpi

ADDIONICS

Contact:
Farid Tariq Email: farid@addionics.com

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

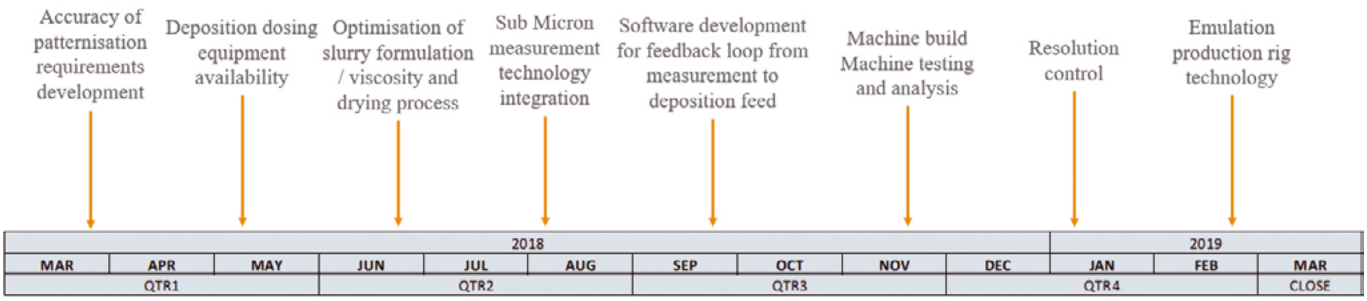
Executive summary

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
KWSP KW Special Projects Ltd
WMG The University of Warwick

Contact:
Emma Kendrick — Email: e.kendrick@bham.ac.uk — Web: www.birmingham.ac.uk
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 Li-ion battery.

Project costs

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

Executive summary

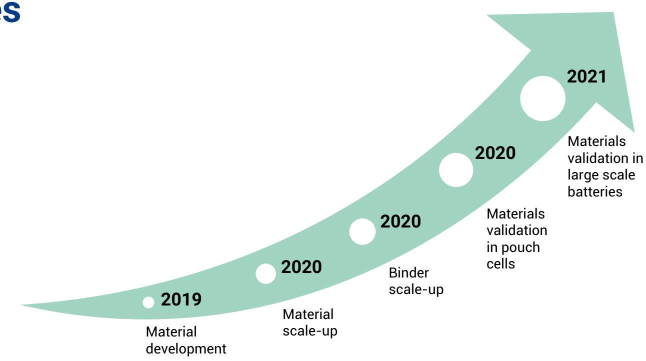
The SUNRISE project will deliver a novel silicon anode system for advanced lithium-ion batteries.

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

Timeline with milestones and deliverables

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

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



Project innovations

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

Partners

synthomer

nexeon

UCL

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

Synergy

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

Project costs

Total project costs: £958,687
Grant contribution: £698,815

Executive summary

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

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

synthomer

williamblythe
Excellence in chemistry
A Synthomer Group Company synthomer

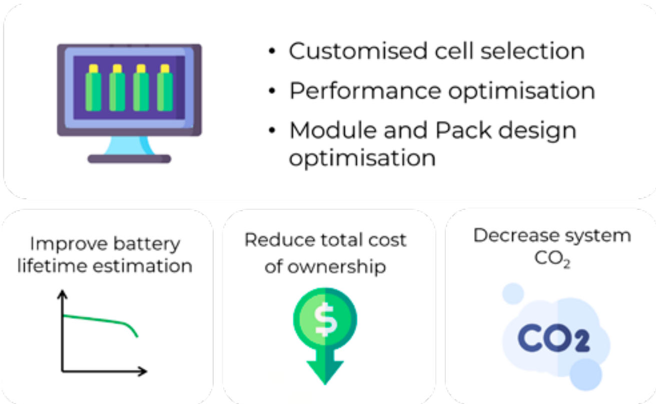
amte power

cpi

Contact:
Becky Pennington
Email: becky.pennington@synthomer.com
Web: www.synthomer.com

The Voltt: Optimizing EV Battery Lifetime with Advanced Modelling Technologies

By better predicting the aging of lithium-ion batteries used in electric vehicles, 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, Imperial College London, and Arrival are collaborating on "The Voltt" project to develop technologies that optimize the lifetime of batteries in electric vehicles. 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 Arrival's commercial vehicle fleet.

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 commercialized research developed within Faraday Institution research projects to characterize 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, centralizing 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 five battery degradation models for commercially available batteries (Month 22)

Project innovations

- Translating existing research from Imperial relating to degradation into a commercially ready product
- 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

Contact:
Kieran O'Regan | Email: kieran@aboutenergy.co.uk | Web: www.aboutenergy.io

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

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

Project costs
Total project costs: £351,099
Grant contribution: £276,186

Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

AMTE POWER

HSSMI

Contact:
John Fox Email: john.fox@amtepower Web: www.amtepower.com

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

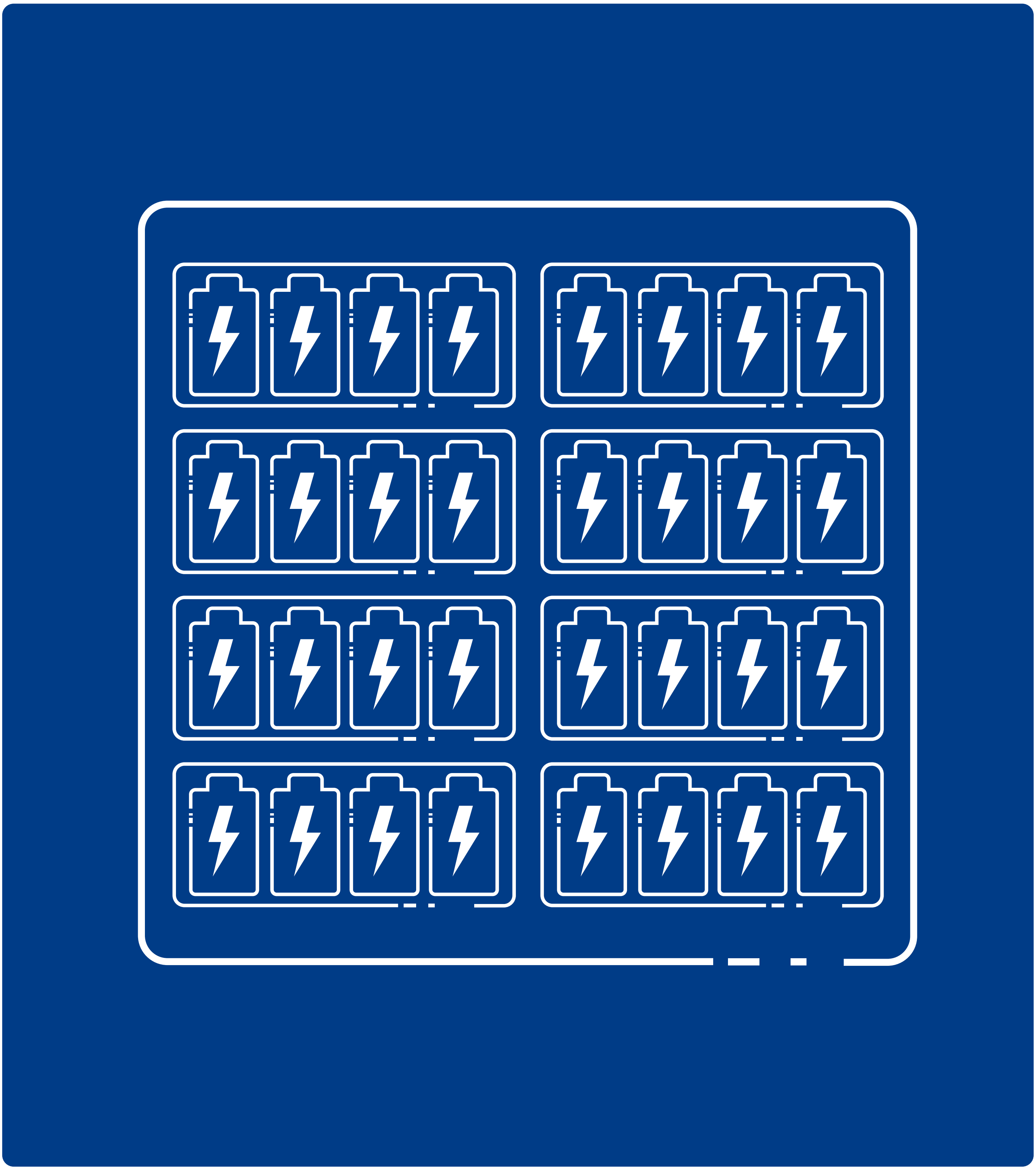
The project produced, using volume production techniques, a state-of-the-art SiOx anode material, coated and analysed it for use in Energy cells. It developed a cell degradation model to provide data for a long-term cell warranty model in collaboration with an insurance company. The project used for 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

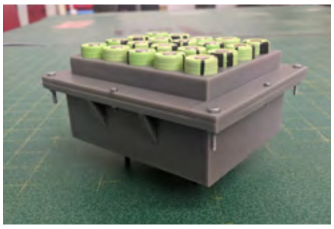
Contact:
Anish Gami Email: anish.gami@amtepower.com Web: www.amtepower.com

Modules, packs and battery management systems innovation projects



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 2020

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

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

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

Project innovations

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

Partners

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

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

AMPLiFII-2

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

Project costs

Total project costs: £10,246,742

Grant contribution: £7,665,322

Executive summary

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

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

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

Timeline with milestones and deliverables

Q1 2018 Implementation of lessons learned from the AMPLiFII project into beta module design

Q4 2018 Initial beta module testing complete

Q1 2019 Pilot production facility installed at Delta Motorsport

Q2 2019 Prototype packs designed

Q4 2019 Prototype packs manufactured

Q2 2020 OEM testing complete on prototype battery packs

Project innovations

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

Partners

ARIEL

ALEXANDER DENNIS

JCB

delta A Cosworth Company

JAGUAR

LAND ROVER

POTENZA

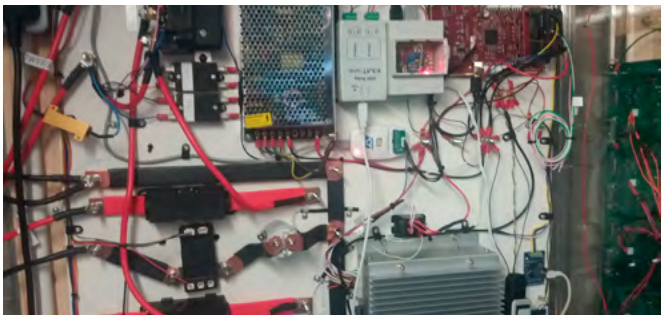
TRACKWISE CONNECTING TECHNOLOGY

WMG THE UNIVERSITY OF WARWICK

Contact:
Scott Herring Email: Scott.Herring@cosworth.com Web: https://delta-cosworth.com/

Assessment and development of the novel 'i-BMS' Battery Management System

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



Project costs
Total project costs: £319,846
Grant contribution: £245,461

Executive summary

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

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

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

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

Timeline with milestones and deliverables

- The funded project ran from July 2019 to December 2020. Deliverables were:
- Improved i-BMS hardware and software successfully tested
- Parallel running of test rigs over more than 1000 charge cycles, enabling thorough assessment of i-BMS baseline performance alongside a conventional BMS
- Detection algorithms for cell faults developed and successfully tested through simulations
- Preparation for field trials using two test EV's completed.
- Feasibility of economic assembly of a small ESS (using new or second-life batteries) demonstrated
- A research paper prepared and submitted for publication
- Preparations made in readiness for third-party beta testing of the technology

Project innovations

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

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

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

Partners

INTERCAL Battery Management Systems

INDRA

WMG The University of Warwick

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

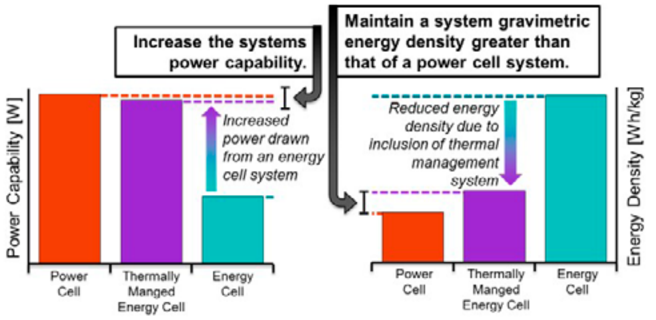
Automotive Technology Transfer Energy Storage Thermal Strategies (ATTESTS)

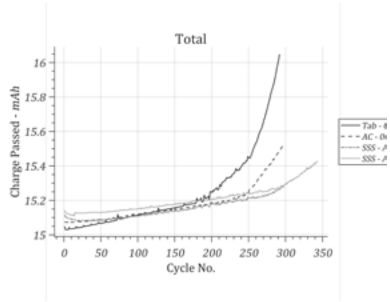
Assessing the feasibility of increased cycle life and power density of low C-rate, energy dense automotive cells through improved thermal management at cell level.

Project costs

Total project costs: £329,000

Grant contribution: £246,000





Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

Rolls Royce

Imperial College London

Contact:
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 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 start
Q3 2018

Battery pack design tools
Q1 2019

1st experimental results
Q4 2019

Thermal simulation tools
Q1 2020

Merging of thermal and battery pack tools
Q3 2020

Tools validation
Q1 2021

Demonstration of hardware
Q2 2021

Project end
Q3 2021

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

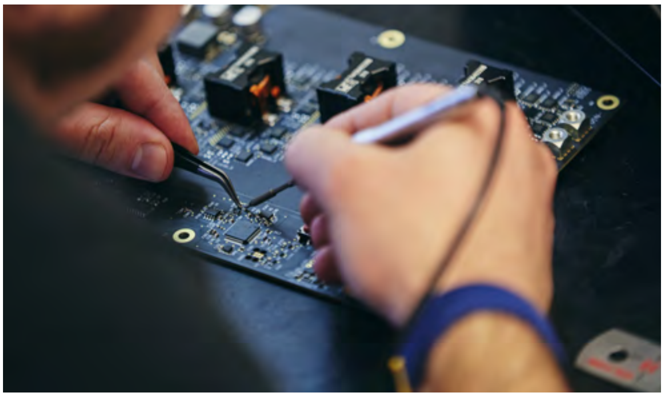
DUKOSI

Imperial College London

Contact:
Javier Castane Email: Javier.castane@astonmartin.com Web: www.astonmartin.com
Joel Sylvester Email: joel@dukosi.com Web: www.dukosi.com
Dr Billy Wu Email: billy.wu@imperial.ac.uk Web: www.imperial.ac.uk

Battery management control system for Advanced Battery Engineering (BABE)

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



Project costs

Total project costs: £209,493
Grant contribution: £129,980

Executive summary

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

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

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

Timeline with milestones and deliverables

Project start date: 01 February 2018

Project completion date: 31 March 2019

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

Project innovations

Three main innovations were developed on this project:

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

Partners

BrillPower

ecar A Europcar Company

sustainable ventures

Contact:
Christoph Birkl
Email: christoph.birkl@brillpower.com
Web: www.brillpower.com
Web: www.ecarclub.co.uk
Web: www.sustainableventures.co.uk

Battery thermal management and diagnostics for heavy duty vehicles – BATMAN

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

Project costs
Total project costs: £2,813,226
Grant contribution: £2,004,438

Executive summary

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

Timeline with milestones and deliverables

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

Challenges:

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

Project innovations

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

Partners

Caterpillar
AVID technology
Imperial College London

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

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

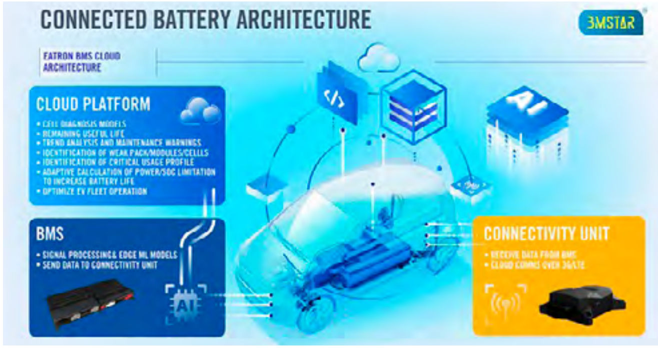
COBRA is focused on three key objectives:

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

Project costs

Total project costs: £168,563

Grant contribution: £126,988



Executive summary

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

The benefits of an accurate RUL algorithm include:

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

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

Timeline with milestones and deliverables

Milestone 1:	Software development complete for RUL model
Milestone 2:	Test and validation of the developed concept is complete
Milestone 3:	Integration of the final software package is complete
Deliverable 1:	A real-time validated Simulink model with ageing
Deliverable 2:	Trained Machine Learning (ML) model and parameter set
Deliverable 3:	Remaining Useful Life (RUL) software package integrated into hardware and cloud platform

Project innovations

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

Partners

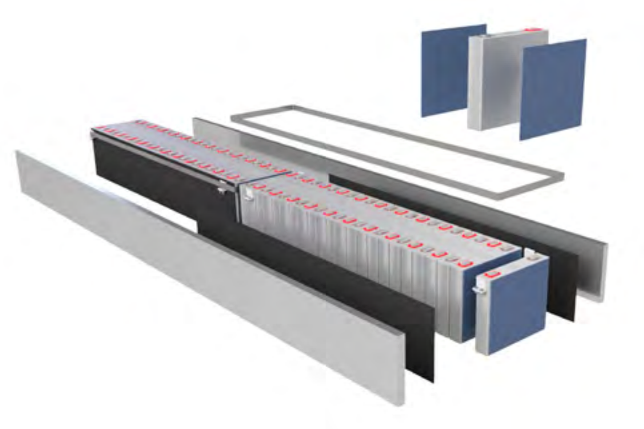
WMG THE UNIVERSITY OF WARWICK

eatron TECHNOLOGIES

Contact:
Krzysztof Slosarczyk Email: krzysztof.slosarczyk@eatron.com Web: www.eatron.com

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

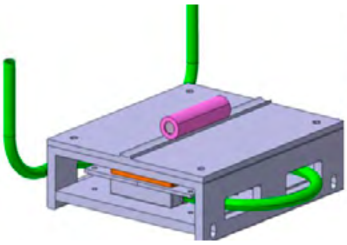
VANTAGE POWER

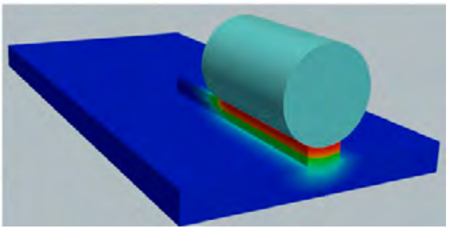
Contact:
Marinda Mantel Email: marinda.mantel@vantage-power.com Web: vantage-power.com

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

Contact:
Dr Alexander Fergusson — Email: alex@factechnology.com — Web: www.factechnology.com
Dr Yatish Patel — Email: yatish.patel@imperial.ac.uk — Web: www.imperial.ac.uk/electrochem-sci-eng

Current density imaging in EV battery modules

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

Project costs

Total project costs: £455,273
Grant contribution: £382,846

Executive summary

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

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

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

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

cdo2

inex microtechnology

Queen Mary University of London

University of Sussex

Contact:
Gary Kendall   Email: info@cdo2.com   Web: www.cdo2.com

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

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

Project costs

Total project costs: £566,607

Grant contribution: £447,619

Executive summary

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

The ICP offers precise regulation of battery temperatures using specially designed Peltier element modules in direct contact with the cell surface and/or tabs. The system is highly thermally stable and provides hitherto unavailable data accuracy and quality from charge, discharge and cycling tests.

Holding the battery at constant temperature in the ICP provides much more usable data for cell modelling and characterisation than offered by traditional climate chambers, where the cell temperature can wonder significantly.

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

Cranfield University

THT THERMAL HAZARD TECHNOLOGY

Imperial College London

Contact:
Email: info@thermalhazardtechnology.com Web: www.thermalhazardtechnology.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 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 2 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 x20 times faster than laser welding. 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

CVE Cambridge Vacuum Engineering
delta A Cosworth Company
TWI

Contact:
Chris Punshon Email: cpunshon@camvaceng.com Web: www.camvaceng.com

High-integrity busbars for electric vehicle battery systems

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

Project costs

Total project costs: £363,966

Grant contribution: £251,621

Executive summary

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

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

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

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

Timeline with milestones and deliverables

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

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

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

WP3 Fluidized bed testing – manufacture/test/validate

WP4 spray testing - manufacture/test/validate

WP5 Create standardise Test Method & Procedure

Project innovations

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

Partners

HV Wooding

The University Of Sheffield. AMRC Advanced Manufacturing Research Centre

Contact:
Paul Allen Email: pallen@hvwooding.co.uk Web: www.hvwooding.co.uk

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:
Marinda Mantel Email: marinda.mantel@vantage-power.com Web: vantage-power.com

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

Contact:
Carolyn Hicks
Web: www.astonmartin.com

Email: carolyn.hicks@brillpower.com
Web: www.delta-motorsport.com

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

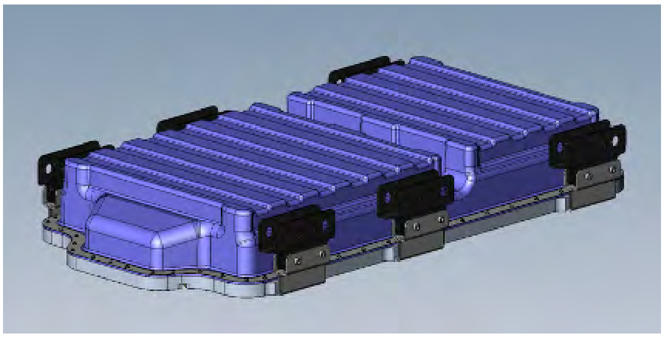
RICARDO

MIVOLT® LIQUID IMMERSION COOLING

WMG THE UNIVERSITY OF WARWICK

Contact:
Mark Lashbrook Email: marklashbrook@mimaterials.com Web: www.mivoltcooling.com

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.

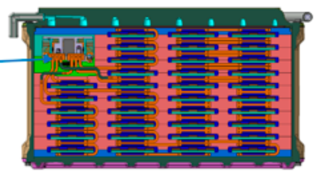
Partners

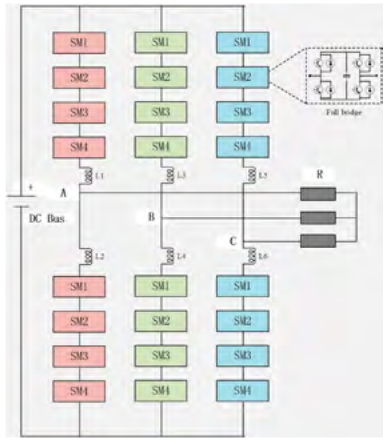
arcola energy
REACTION ENGINES
Brunel University London
flint ENGINEERING
Imperial College London

Contact:
Arcola Energy   Web: www.arcolaenergy.com

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 optimized 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.
- Milestones and Deliverables:

Project innovations

This project successfully optimized 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 utilizes 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 optimized battery pack design reduces the environmental impact while good efficiency and increasing reliability, ultimately resulting in a more sustainable transportation system.

Partners

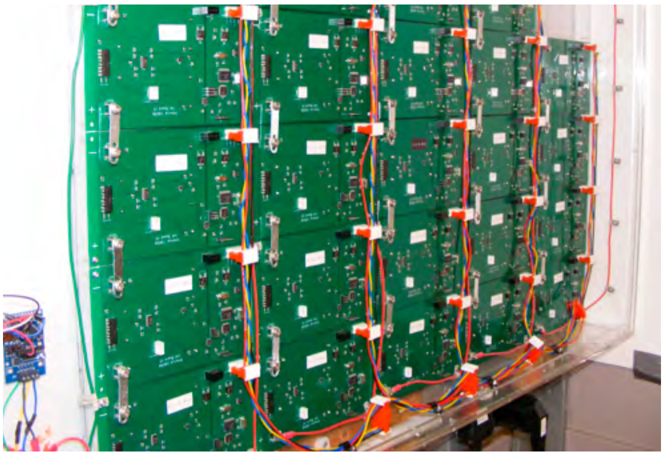
RICARDO

UNIVERSITY OF BATH

Contact:
Jay Al-Tayie, Technical Project Leader Ricardo — Email address: Jay.Al-ayie@ricardo.com
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

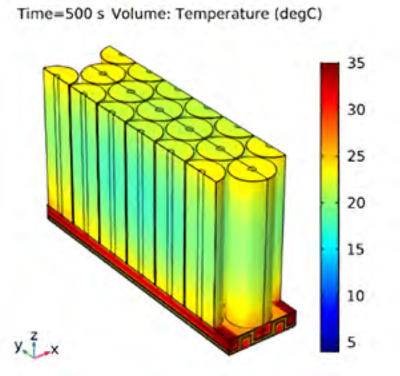
INDRA

INTERCAL Battery Management Systems

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

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

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



Project costs
Total project costs: £499,903
Grant contribution: £342,424

Executive summary

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

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

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

Timeline with milestones and deliverables

- Project Start: 01/09/2019 Project Finish: 26/02/2021
- Heating and cooling specifications confirmed, design evaluations with CFD modelling - January 2020
- Optimal design selected and prototype manufacturing feasibility established – March 2020
- Development and production of prototype heater elements complete - November 2020
- Optimisation of laser welding process for electrical and fluid connections complete - November 2020
- Integration of prototype unit for testing – November 2020
- Scale-up feasibility established – January 2021
- Functional testing completed and data analysed – February 2021

Project innovations

The innovative features include:

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

Partners

HEAT TRACE™ SETTING THE STANDARDS LEADING THE WAY

Nobel Automotive

WMG THE UNIVERSITY OF WARWICK

Contact:
Dr Peter Howe Email: phowe@heat-trace.com Web: www.heat-trace.com

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

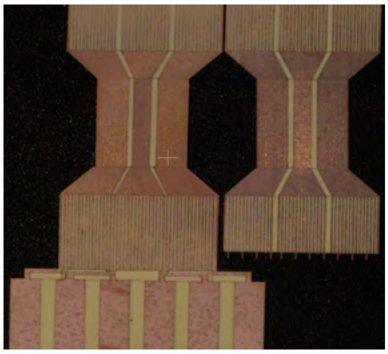
Partners

JAGUAR
LAND ROVER
3M
POTENZA
A Brand of FPT Powertrain Technologies
lifeline Fire & Safety Systems Ltd
BESPOKE RESEARCH AND CONSULTANCY FROM HSE
Warwick FIRE

Contact:
Email: uk.contact.co@mmm.com

Printed sensors for EV battery current density imaging

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



Project costs

Total project costs: £499,606
Grant contribution: £393,015

Executive summary

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

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

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

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

Timeline with milestones and deliverables

Project duration: June 2019 – November 2020

Deliverables:

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

Project innovations

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

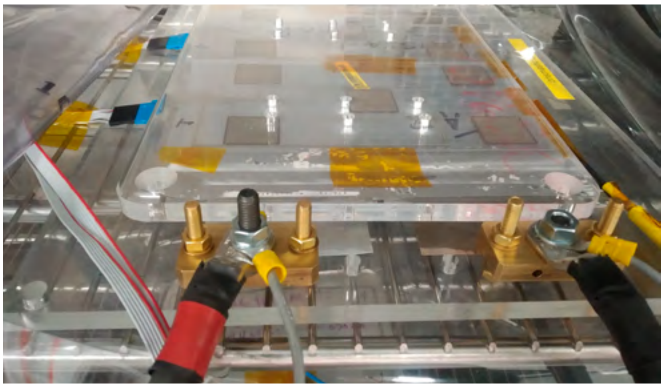
Partners

cdo2
cpi
ACELERON
peacock technology ltd
University of Sussex
University of Strathclyde Glasgow

Contact:
Gary Kendall Email: info@cdo2.com www.cdo2.com

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

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



Project costs

Total project costs: £235,516

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

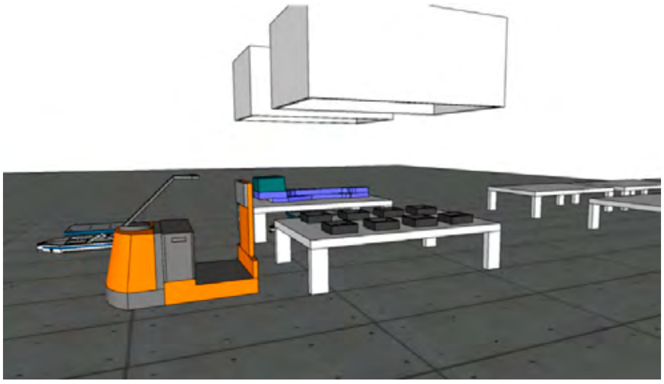
cpi

PST SENSORS

Contact:
David Britton Email: david.britton@pstsensors.com Web: www.pstsensors-europe.com

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

MIRA (A HORIBA COMPANY)
ASPIRE ENGINEERING
instrumentel MEASURING SUCCESS
UNIPART LOGISTICS Experience. Innovation. Advantage.

Contact:
Kathryn Sansbury
Email: Kathryn.sansbury@unipart.com
Web: www.unipartlogistics.com

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 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	Feb 23 – May 23
WP2 – Battery Design – Jaguar Land Rover / Danecca	Feb 23 – Oct 23
WP3 – Computer Aided Engineering – Altair	Feb 23 – Feb 25
WP4 – Vehicle Body Build – Jaguar Land Rover	Apr 24 – Jan 25
WP5 – Battery Build – Danecca	Jan 24 – Mar 24
WP6 - Connected Cells – Jaguar Land Rover	Aug 23 – Jan 24

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

JAGUAR

LAND ROVER

Contact:

Phil Richards	Email address:prichard@jaguarlandrover.com	
Paul Haney	Email: phaney@jaguarlandrover.com	Web: www.jaguarlandrover.com
Danson Joseph	Email: danson.joseph@dnecca.com	Web: www.danecca.com
Jamie Buchanan	Email: buchanan@altair.com	Web: https://altair.com

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

Timeline with milestones and deliverables

Start 1st July 2019, end 31st March 2021

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

Project innovations

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

Partners

Potenza, Denchi Group, Jaguar Land Rover, Lifeline Fire & Safety Systems Ltd, Health & Safety Laboratory, 3M, Tri-Wall, WMG The University of Warwick, Warwick FIRE

Contact:
Philip Richards Email: prichard@jaguarlandrover.com
Brian Cooper Email: bcooper@jaguarlandrover.com

SAMBA – Smart automotive managed battery algorithms

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

Project costs

Total project costs: £166,724
Grant contribution: £116,707

Executive summary

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

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

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

Timeline with milestones and deliverables

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

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

Project innovations

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

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

Partners

mA milliamp technologies

MIRALIS

Contact:
Rich Grant Email: sales@milliamp.co.uk Web: www.milliamp.co.uk
Uschi Maden-Weinberger Email: hello@miralis.co.uk Web: www.miralis.co.uk

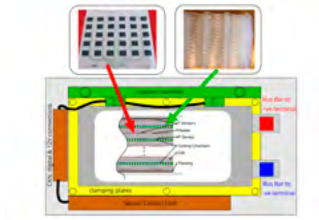
TECHNO – Temperature monitoring, Cooling and Heating during Normal Operation

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

TECHNO is a project to build 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:

- Maintain a uniform temperature within specified limits, depending on the operating requirements.
- Report specific parameters, e.g. minimum/maximum/mean temperatures, to the BMS.
- Send 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, 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 & coding of algorithms (July 2023)
- Completed stack assembly (July 2023)
- Completion of TECHNO module (November 2023)
- Completion of testing and demonstration of TECHNO module (January 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

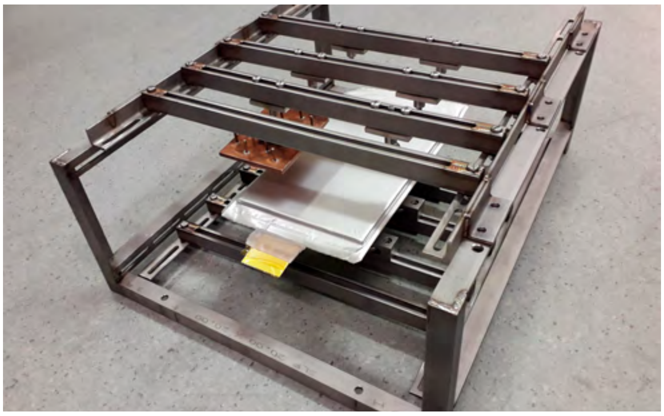
PST SENSORS

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 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

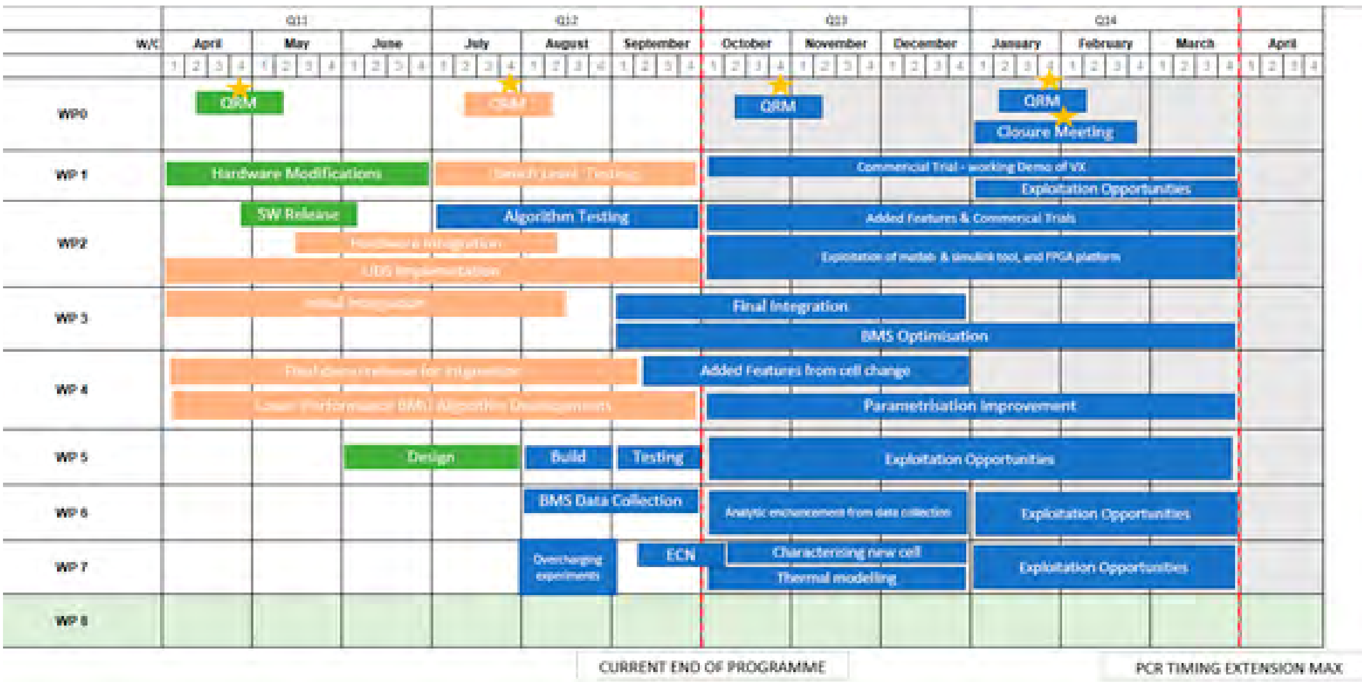
Project costs

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 module design, alongside an end-to-end battery life tracking platform will demonstrate state of the art, disruptive UK technology.

Timeline with milestones and deliverables



Project innovations

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

Partners

Silver Power Systems

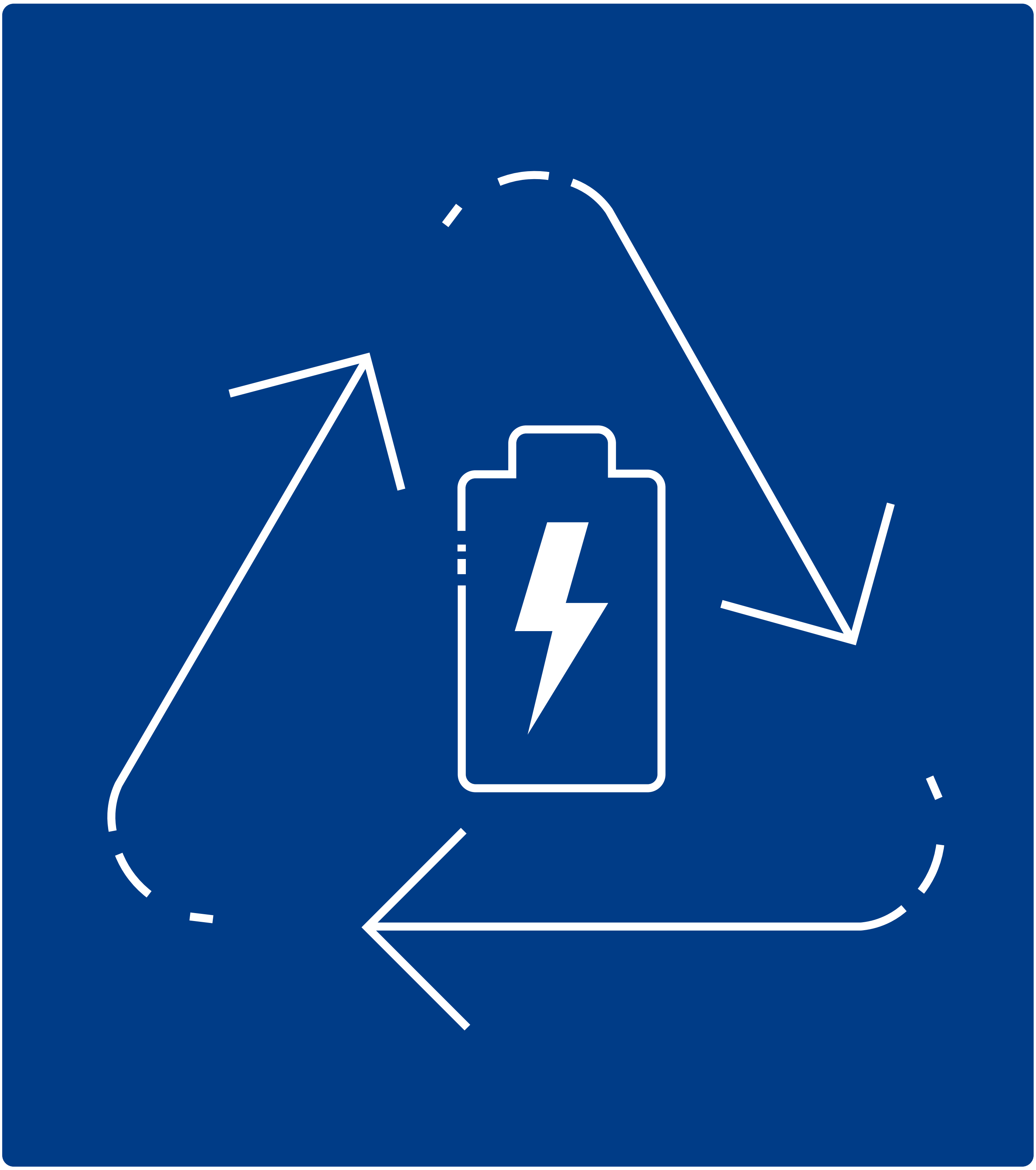
Imperial College London

codeplay

WILLIAMS ADVANCED ENGINEERING

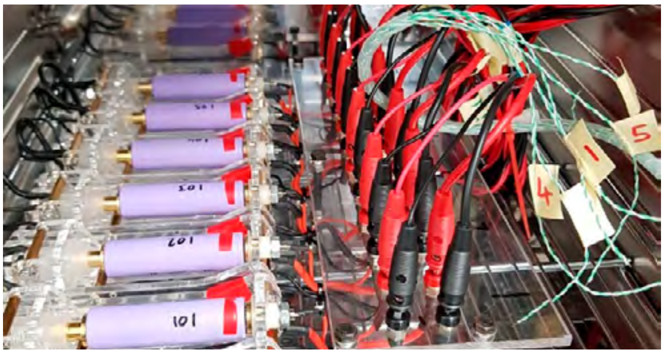
Contact:
Rob Millar Email: Robert.millar@wae.com Web: www.wae.com

Second life and recycling innovation projects



ABLE (Advance Battery Life Extension)

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



Project costs

Total project costs: £427,522

Grant contribution: £290,864

Executive summary

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

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

Timeline with milestones and deliverables

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

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

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

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

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

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

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

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

Project innovations

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

Partners

M-KOPA SOLAR MAENDELEO NI LEO

DENCHI POWER

Imperial College London

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 lithium-ion batteries generating materials suitable for re-manufacture of lithium-ion batteries.

Timeline with milestones and deliverables

Over 36 months the consortium will achieve:

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

Project innovations

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

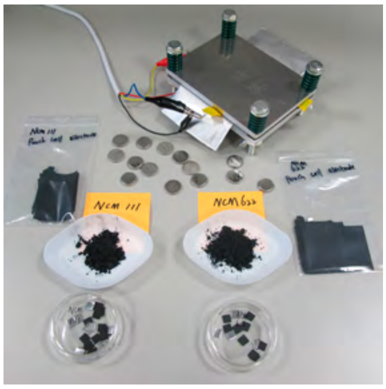
Partners

Benchmark Mineral Intelligence
Autocraft Drivetrain Solutions
Johnson Matthey — Inspiring science, enhancing life
Nissan
Coventry University
Ecobat Battery Technologies

Contact:
Jenny Mash Email: Jenny.Mash@matthey.com

CAM-EV

Development of new processes to recover critical metals from multi-chemistry, end-of-life 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 & qualification of CAM in battery cell samples.
- Technical & Commercial validation of recycling next-gen, 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) cathode-active materials (CAM).

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 Metals

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

Faraday precision ageing laboratory

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

Project costs

Total project costs: £4,079,910
Grant contribution: £3,861,017

Executive summary

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

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

Timeline with milestones and deliverables

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

Deliverables:

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

Project innovations

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

Partners

WMG
THE UNIVERSITY OF WARWICK

Contact:
Helen White Email: h.white.3@warwick.ac.uk Phone: +44 024765 23537

Project: R2LiB

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

Project costs

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

Executive summary

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

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

Timeline with milestones and deliverables

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

Partners

Industrial Partners

RSB RSBruce

IConiChem

circa

TFP HYDROGEN PRODUCTS LTD

M-SOLV Limited

Research Partners

WMG THE UNIVERSITY OF WARWICK

UNIVERSITY OF BIRMINGHAM

UNIVERSITY of York

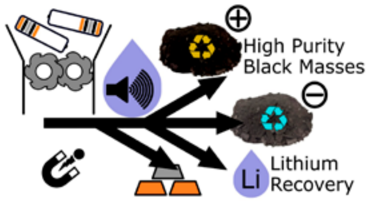
Contact:
Paul Croft Email: pcroft@iconichem.com

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

UK automotive Lithium-Ion Battery (LIB) production industry 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, SotA 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 H&S 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 in one batch.
- 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 10kg 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 (10kg batches).
- 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

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

Project costs

Total project costs: £421,248

Grant contribution: £305,716

Executive summary

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

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

Timeline with milestones and deliverables

Primary objectives:

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

Project innovations

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

Partners

Loughborough University

POWERVAULT

Contact:
Joe Warren Email: joe.warren@powervault.co.uk Web: www.powervault.co.uk
D Strickland Email: d.strickland@lboro.ac.uk Web: www.lboro.ac.uk/research/crest

VALUABLE: Value Chain and Battery Lifecycle Exploitation

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

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

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 Li-ion batteries to support a complete End-of-Life (EoL) supply chain network within the UK.

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

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

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

Timeline with milestones and deliverables

Project start Jan 2018

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

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

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

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

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

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

Project innovations

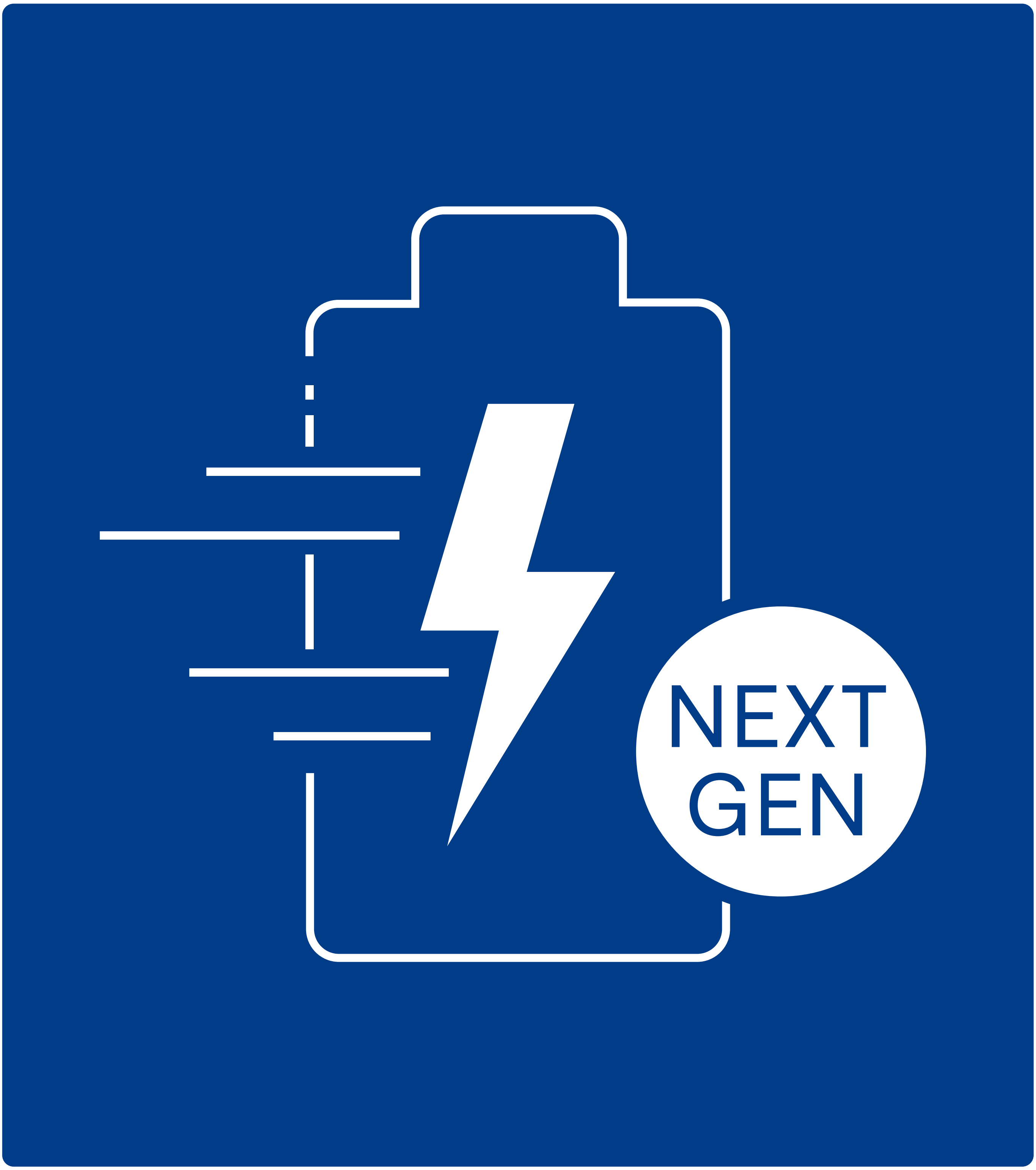
- Development of a UK-based end-of-life battery value chain focusing on reuse, remanufacturing and recycling for second- life automotive Li-ion batteries.
- Quantified recyclability and reuse potential of traction battery packs
- Commercially viable metrology and testing processes
- Battery price evaluation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

Partners

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

Contact:
Robin Foster Email: robin.foster@hssmi.org

Beyond Li-ion Projects



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

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

Project costs

Total project costs: £877,595

Grant contribution: £630,631

Executive summary

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

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

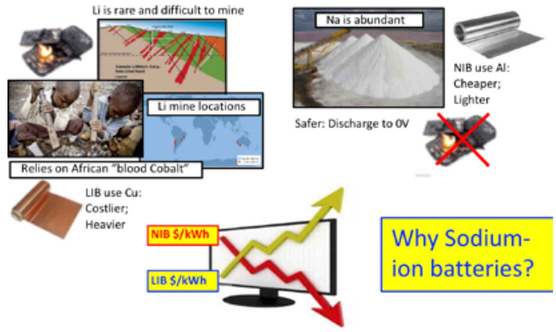
AMTE POWER, Ansys, Deregallera, University of Birmingham, Intellegens

Contact:

Ben Pellegrini	Email: ben@intellegens.co.uk	Web: www.intellegens.ai
Alex Cazacu	Email: alex.cazacu@ansys.com	Web: www.ansys.com/materials
Emma Kendrick	Email: E.Kendrick@bham.ac.uk	Web: www.birmingham.ac.uk
Peter Curran	Email: petercurran@deregallera.com	Web: www.deregallera.com
Fergal Harrington-Beatty	Email: fergal.hb@amtepower.com	Web: www.amtepower.com

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

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



Project costs

Total project costs: £437,143

Grant contribution: £344,686

Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

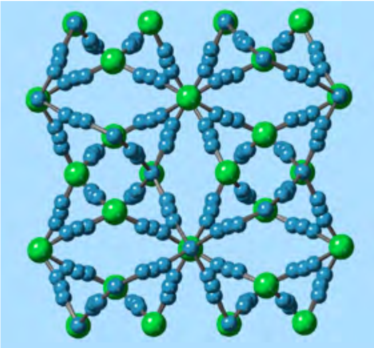
Partners

University of Southampton
Deregallera
cpi
University of Exeter

Contact:
Peter Curran Email: petercurran@deregallera.com Web: www.deregallera.com

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

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



Project costs

Total project costs: £498,703

Grant contribution: £339,636

Executive summary

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

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

Timeline with milestones and deliverables

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

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

Project innovations

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

Partners

Johnson Matthey – Inspiring science, enhancing life

talga – Talga Technologies Ltd

The University Of Sheffield.

Contact:

James Stevens	Email: james.stevens@matthey.com	Web: www.matthey.com
Sai Shivareddy	Email: sai@talgatechnologies.com	Web: www.talgatechnologies.com
Ian Reaney	Email: i.m.reaney@sheffield.ac.uk	Web: www.sheffield.ac.uk

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 600 Wh/L), high gravimetric energy (above 500 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 (>500Wh/kg), extended cycle life, high safety, a broad operating/storage temperature window (-10 to 80°C), and potential for low cost by Q1 2025.

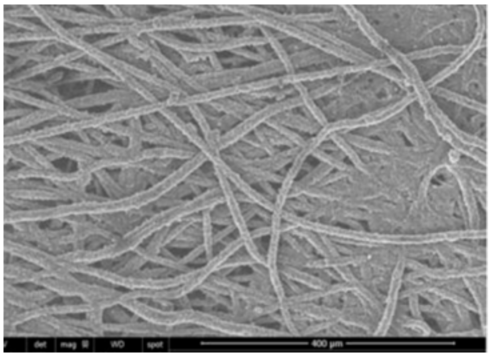
Partners

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 synthomer

Contact:
Adrien Amigues Email: adrien.amigues@oxlid.co.uk

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

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



Project costs

Total project costs: £780,700

Grant contribution: £546,500

Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

AMTE POWER®

Sigma Lithium Ltd

Lithium Technologies for Energy Storage

Contact:
Dr Gleb Ivanov Email: gleb.Ivanov@slithium.com

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 & 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

LiNa Energy

Imperial College London

MEP Technologies Battery Systems

WMG The University of Warwick

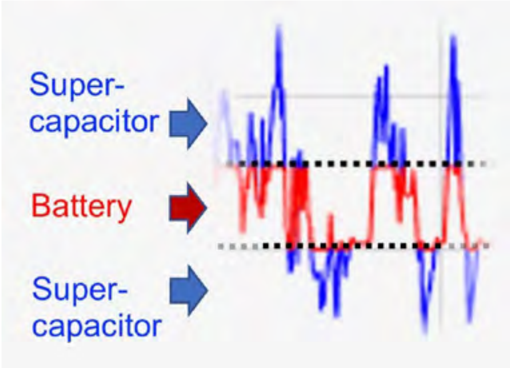
Helical Technology

Lancaster University

Contact:
Mark Boland Email: mboland@lina.energy

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

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



Project costs

Total project costs: £497,563
Grant contribution: £397,711

Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

- System level, by integrating supercaps and batteries into the same pack casing
- Developing high voltage electrolytes
- Developing high capacity electrode materials
- Our power electronics operates at the interface of energy storage systems and utilises recent advances in SiC and GaN devices

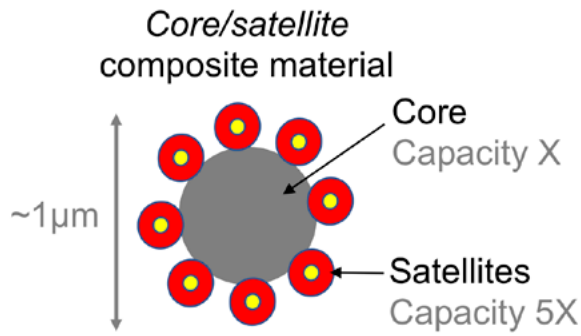
Partners

Deregallera
QINETIQ
University of South Wales Prifysgol De Cymru
London South Bank University

Contact:
Peter Curran Email: petercurran@deregallera.com Web: www.deregallera.com

Feasibility research into composite carbon electrodes for sodium-ion batteries

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



Project costs

Total project costs: £409,410
Grant contribution: £323,507

Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

Deregallera

University of Southampton

Contact:
Peter Curran Email: petercurran@deregallera.com Web: www.deregallera.com

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
- Approaches to sinter larger batches of ceramic components were scoped

Project innovations

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

Partners

LUCIDEON
Materials Development and Commercialization

ionotec
INNOVATION WITH ELECTROCERAMICS

Contact:
Stuart MacLachlan — Email: stuart.maclachlan@lucidoen.com — Web: www.lucideon.com
John Blackburn — Email: john@ionotec.com — Web: www.ionotec.com

Gii-Cap supercapacitor in all-terrain vehicles

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

Project costs

Total project costs: £2,279,121

Grant contribution: £1,649,097

Executive summary

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

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

Timeline with milestones and deliverables

Project start: 1 Sep 2019

M3 Gii-Cap Supercapacitor Build & Test

M5 Design Finalised

M12 Systems developed

M13 Systems Rig Testing Complete

M16 Architecture Validated

M18 Final Report

Project innovations

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

Partners

WMG – The University of Warwick

MEP Technologies Battery Systems

University of Liverpool

Integrated Graphene

Agile Vehicle Technologies

Contact:

Claus Marquordt	Email: cm@rd-groupco.com	Web: www.rd-graphene.com
John May	Email: johnmay@agilevt.com	Web: www.agilevt.com
Stuart Morrison	Email: smorrison@mepcs.co.uk	Web: www.mepcs.co.uk
Laurence Hardwick	Email: Laurence.Hardwick@liverpool.ac.uk	Web: www.liverpool.ac.uk
Mark Copley	Email: Mark.Copley@warwick.ac.uk	Web: www.warwick.ac.uk

Granite – passenger car solid state battery

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

Project costs

Total project costs: £1,974,000
Grant contribution: £1,451,000

Executive summary

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

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

Timeline with milestones and deliverables

Project start: 01 August 2019

Project completion: 30 April 2021

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

Project innovations

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

Partners

AMTE POWER®

ilika accelerated materials innovation

JAGUAR

LAND ROVER

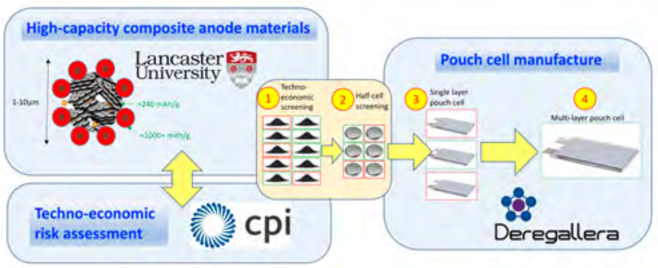
WMG THE UNIVERSITY OF WARWICK

Contact:
Philip Richards Email: prichard@jaguarlandrover.com
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 in: Very-high-capacity/high cost; high-capacity/moderate cost and 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 & 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 4 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

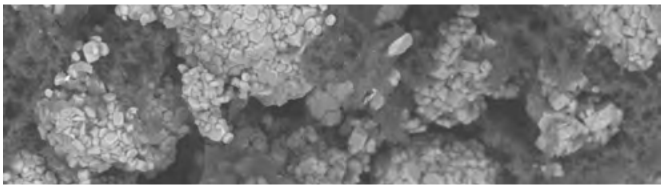
Lancaster University

Contact:
Peter Curran Email: petercurran@deregallera.com Web: www.deregallera.com

Innovative Carbons for Electrodes in Batteries (ICE-Batt)

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

Project costs
Total project costs: £809,992
Grant contribution: £543,939



Executive summary

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

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

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

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

Timeline with milestones and deliverables

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

Project innovations

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

Innovations include:

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

Partners

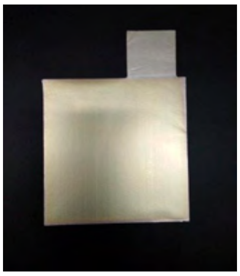
cpi
Thomas Swan – Chemical manufacturing since 1926
JM Johnson Matthey – Inspiring science, enhancing life

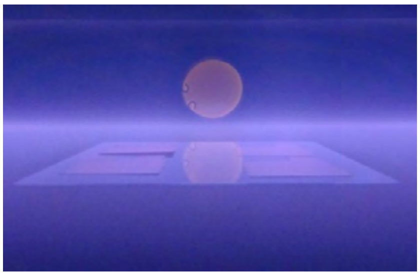
Contact:
Dr Ross Gordon — Email: ross.gordon@matthey.com
Dr Amponsah Kyeremateng — Email: amponsah.kyeremateng@uk-cpi.com
Michael Edwards — Email: MEdwards@thomas-swan.co.uk

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 next generation of high-performance cell technologies for future Electric Vehicles.

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

cpi

OXIS ENERGY
Next Generation Battery Technology

Contact:
Keri Goodwin Email: keri.goodwin@uk-cpi.com

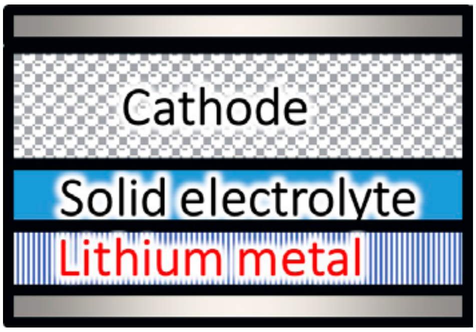
LiMHiT - Lithium Metal electrode High Throughput screening

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

Project costs

Total project costs: £668,339

Grant contribution: £514,551



Executive summary

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

Lithium-metal-based solid state batteries (SSBs) could eliminate the compromise between cost and performance for eVs. Lithium-metal electrodes are needed to guarantee high performance and represent a step-change versus lithium-ion. The Lithium-Metal electrode High Throughput screening (LiMHiT) project aims to address this opportunity by investigating alternative chemistry solutions for batteries whereby reducing processing costs associated with fabrication of negative electrodes for SSB cells. Consequently, the challenge is to reduce overall cost of eV ownership and improve performance for customers, accelerating eV uptake.

Delivery of this would significantly contribute to UK environmental targets and support the creation of new green jobs across the supply chain.

Timeline with milestones and deliverables

The 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 Li 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 set-up of dedicated SSB facilities to increase capabilities/expertise in testing SSB technology and defining new test procedures that will contribute towards future work. Finally, detailed understanding of mechano-chemical characterisation of Li-metal and Li-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. Achieving 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. Successful dissemination demonstrated through publishing of 3 journal articles and proposed perspective article "Realising scalable Li films for battery applications" upon project conclusion.

Partners

NISSAN

UNIVERSITY OF OXFORD

E+R GROUP

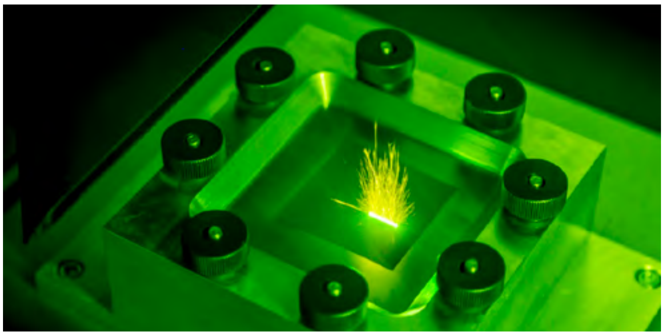
WMG THE UNIVERSITY OF WARWICK

Contact:
Kris McCabe Email: kris.mccabe@ntc-europe.co.uk

LiNaMan – Sodium Battery

The objective of this project is to demonstrate an innovative sodium-nickel-chloride ($NaNiCl_2$) prototype battery system to TRL6 in representative automotive-sector conditions and optimise manufacturing for scale up and recycling.

Project costs
Total project costs: £234,438
Grant contribution: £198,712



Executive summary

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

The Consortium was led by LiNa Energy, who develop the batteries at the heart of this project. Partners are: Centre for Process Innovation Limited (CPI) and Lancaster University.

This partners also prepared for volume production by designing the first processes, adapting modern manufacturing methods and techniques.

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

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

Timeline with milestones and deliverables

Key deliverables:

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

Milestones:

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

Project innovations

The partners applied modern material engineering to successfully produce and test the first planar $NaNiCl_2$ 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

Contact:
Mark Boland Email: mboland@lina.energy

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 QC methods for Li-S production
- Advances on Li-S modules and control systems

Partners

ceetak sealing solutions

williamblythe Excellence in chemistry

Cranfield University

OXIS ENERGY Next Generation Battery Technology

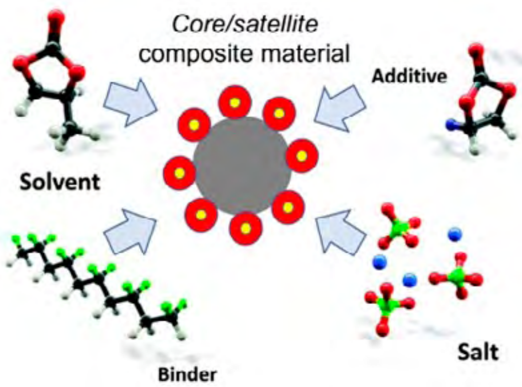
WILLIAMS ADVANCED ENGINEERING

UCL

Contact:
Michael Butler   Email: Michael.butler@williamblythe.com   Web: www.williamblythe.com

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

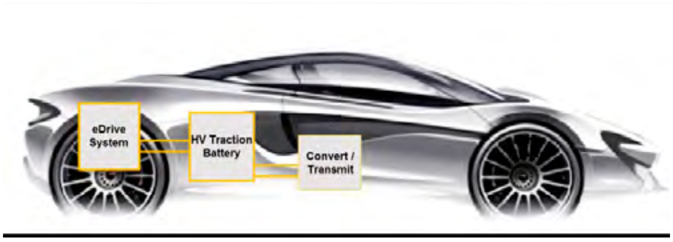
cpi
Deregallera
University of Southampton
NPL National Physical Laboratory
London South Bank University

Contact:
Peter Curran Email: petercurran@deregallera.com Web: www.deregallera.com

MoSESS: Multi optimal Solutions for Energy Storage Systems

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

Project costs
Total project costs: £8,973,835
Grant contribution: £6,020,377



Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

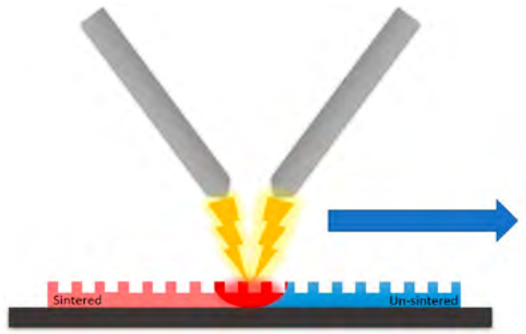
Partners

ilika accelerated materials innovation
WMG THE UNIVERSITY OF WARWICK
McLaren

Contact:
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:

- 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 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

KWSP KW SPECIAL PROJECTS LTD

Contact:
Stuart MacLachlan
Email: stuart.maclachlan@uk.lucideon.com
Web: www.lucideon.com

Sodium-ion batteries for automotive power applications

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

Project costs

Total project costs: £2,032,490

Grant contribution: £1,506,223

Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

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

Partners

University of Birmingham

WMG The University of Warwick

Jaguar Land Rover

faradion

talga Talga Technologies Ltd

CRODA

Contact:
Richard Heap Email: info@faradion.co.uk Web: www.faradion.co.uk

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 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, and St Andrews will be provided to formulate scalable inks from the NSP-2, in-depth characterization of the anode and the creation of a modelling tool for future development up to pack level
- Sustainable manufacturing consultants HSSMI will produce an 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.

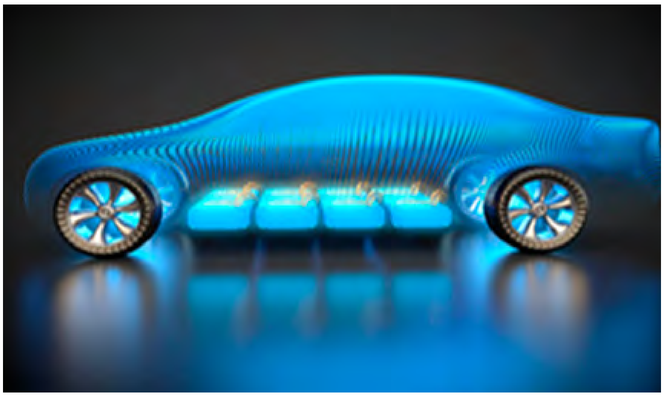
Partners

BMW GROUP, cpi, HSSMI, ilika, Imperial College London, UCL, nexeon, University of St Andrews

Contact:
Dan Walker Email: dan.walker@ilika.com

The PowerDrive Line

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



Project costs

Total project costs: £5,960,773
Grant contribution: £4,383,502

Executive summary

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

The major benefits of solid-state batteries derive from their compatibility with high-energy anode materials and use of non-flammable solid electrolyte, as opposed to the flammable organic solvents used in current lithium-ion batteries.

In terms of performance, solid-state lithium batteries offer the prospect of much faster charging times, increased energy density, increased life cycle of up to 10 years, and extremely low self-discharge.

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

ilika — accelerated materials innovation
cpi
HONDA
RICARDO
UCL

Contact:
Elaine Kent   Email: Elaine.kent@ilika.com   Web: www.ilika.com

Scale-up

UK BATTERY INDUSTRIALISATION CENTRE

UK Battery Industrialisation Centre (UKBIC)

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

Grant contribution: £130,000,000

UK BATTERY INDUSTRIALISATION CENTRE

Executive summary

The UK Battery Industrialisation Centre (UKBIC) is the UK's national battery development facility providing manufacturing scale-up & skills for the battery sector, where businesses can develop their manufacturing processes at the scale they need to move to industrial production.

Opened in July 2021, the unique facility bridges the gap between battery research and successful mass production and helps companies to scale and commercialise their technologies. It's also a working production environment where companies can undergo specialist training in battery manufacturing.

The facility welcomes manufacturers, entrepreneurs, researchers and educators, and can be accessed by any organisation with new or existing Li-ion based or compatible battery technologies.

The pioneering facility – still the only one of its kind anywhere in Europe - is a key part of the UK Government funded Faraday Battery Challenge, which has been delivered by Innovate UK on behalf of UK Research and Innovation, with the aim of building a high-tech, high-value, high-skill battery industry for the UK.

What is UKBIC for

UKBIC is designed to help organisations develop their battery technologies, and to increase confidence in manufacturing plant investment for new battery-related technologies. UKBIC achieves this by providing production-scale facilities and expertise which bridge the gap from product Research & Development to manufacturing at scale, massively reducing the level of risk for investment in new technologies.

We work with customers across the battery value chain, including end users of batteries (propulsion, energy storage, industrial application), battery module and pack developers, cell developers and manufacturers, and supply chain companies (materials, components, and equipment manufacturers).

The facility enables companies to:

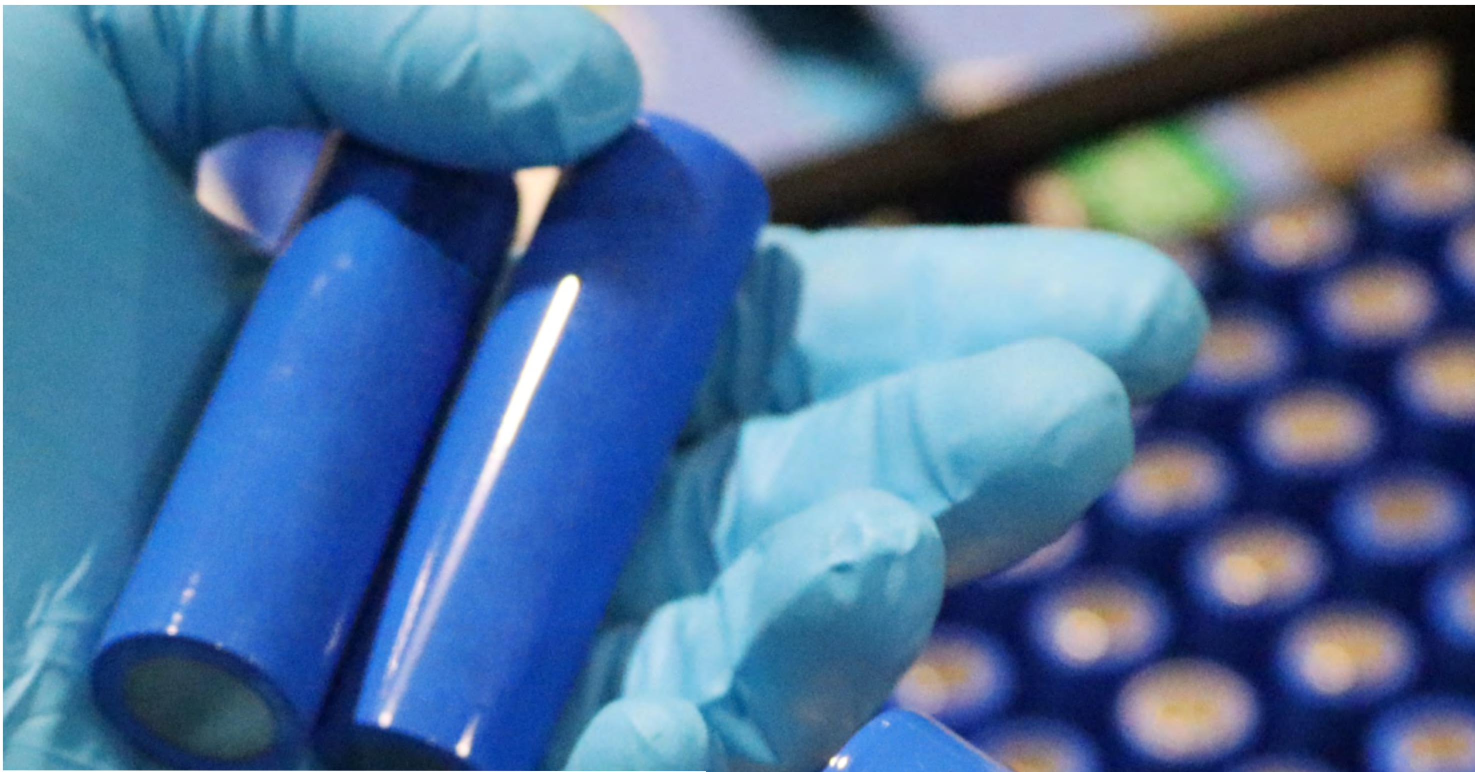
- Prove product manufacture at industrial rates without the need for huge up-front capital investment
- Increase investor or customer confidence in products and processes being demonstrated at scale
- Reduce the level of complexity for mass manufacturing design
- Develop their skills and knowledge in battery production processes
- Gain access to a range of cutting-edge, high tech modular equipment, systems, and facilities not available elsewhere

UKBIC's Giga-scale battery manufacturing equipment

The battery manufacturing equipment installed covers the whole production process from electrode manufacturing, cylindrical and pouch cell assembly, to formation, ageing and testing and battery module and pack assembly. The equipment and environment replicates that found in battery production plants across the globe.

Sectors UKBIC support, include:

- Automotive
- Aerospace
- Off-highway vehicles
- Mass transportation systems
- Marine
- Industrial applications
- Static energy storage (Grid, Commercial, Domestic)



Working together

As a development facility, we can work alongside customer teams throughout the scale up and manufacturing processes so that companies are fully aware and up skilled in each of those processes, enabling the businesses to transfer to full manufacturing stage. Our specialist staff also offer consultancy and advisory support

Examples of a project include:

- Some design assessment and design for manufacture (DFM) – the customer remains the design authority for their product
- Technology transfer work into UKBIC to enable us to scale the product
- A mutually agreed, gated approach to trial build phases
- A,B,C – sample cell phases and initial manufacturing build phase

Training and Skills

In collaboration with industry, the education sector and other providers, UKBIC offers specialist training packages and programmes for those working across the battery sector, either classroom based, online, or ‘on the line’, integrating processes unique to customers’ products temporarily to our facility.

Customer confidentiality

The facility is designed so that several customers can run different projects at the same time in dedicated and security controlled segregated areas. UKBIC’s customers retain full ownership of their own Intellectual Property (IP) developed in UKBIC’s facilities.

Consultancy and Advisory service

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

Flexible Industrialisation Line (FIL)

We’re set to build a £36 million manufacturing line, which will help to bridge the gap between our existing Volume Industrialisation Line (VIL) and existing kilogramme scale demonstrator lines available elsewhere. Construction is set to get underway in September 2023, with the equipment expected to be online by 2025.

Location

Coventry, West Midlands, England.

Get in touch:
Business Development Team: sales@ukbic.co.uk   Training Courses: training@ukbic.co.uk   www.ukbic.co.uk

Index of Innovation Project Partners

Businesses

3M United Kingdom Public Ltd Company 85,90
ABOUT:Energy Ltd 60
Aceleron Ltd 86,103
Addionics Ltd 34, 56
Agile Vehicle Technologies Ltd 113
Alexander Dennis Ltd 65
Alps Technologies Ltd 64
Altair Engineering Ltd 89
Altilium Metals Ltd 98
AMTE Power Ltd 47,55,59,61,62,105,109,115
Anaphite Ltd 48,53
Ansys Ltd 42,43,105
Arcola Energy Ltd 81
Ariel Ltd 65
Aspire Engineering Ltd 88,103
Aston Martin Lagonda Ltd 68,79
Autocraft drivetrain solutions Ltd 97
Avid technology Ltd 70
Baker Hughes Energy Technology Solutions UK Ltd 36
Benchmark Mineral Intelligence Ltd 97
BMW Group 126
Bridgnorth Aluminium Ltd 32
Brill power Ltd 69,79
Britishvolt Ltd 31,40
Cambridge Vacuum Engineering 76
Cdo2 Ltd 74,86
Ceetak Ltd 122
Circa Sustainable Chemicals Ltd 32,100
Codeplay Software Ltd 94
Cornish lithium ltd 54,101
Croda Europe Ltd 126
Delta Cosworth Ltd 76,79
Denchi Power Ltd 43,90,96
Denecca Ltd 89
Deregallera Ltd 64,105,106,111,112,116,122
Dukosi Ltd 68
Dupont Teijin Films UK Ltd 35
DZP Technologies Ltd 35
Eatron Technologies Ltd 71
E-car club Ltd 69
Echion Technologies Ltd 31,37,41,51
Ecolamp Recycling Ltd 101
ECOSHRED LIMITED 101
Emerson & Renwick Ltd 108,119
Entek International Ltd 40
Ecobat 97
Env-aqua Solutions Ltd 103
Euriscus Ltd 33
Exawatt Ltd 108
Faradion Ltd 125
Fergusson's Advanced Composite Technology Ltd 73,78
Flint Engineering ltd 72,78,81
Global Nano Network Ltd 32,33
Graphene Start Ltd 33
H.V. Wooding Ltd 77
Heat Trace Ltd 84
Helical Technology Ltd 110
Honda R& D Europe (UK) Ltd 127
Horiba Mira Ltd 88
Iconichem Widnes Ltd 100,101
Ilika Technologies Ltd 115,123,126,127
Indra Renewable Technologies Ltd 66,83
Inex Microtechnology Ltd 74
Infineum UK Ltd 108
Integrals Power Ltd 45
Instrumentel Ltd 88
Intellegens Ltd 42,105
Intercal (UK) Ltd 66,83
Integrated Graphene Ltd 114
Ionotec ltd 114
J.C.B. Service 65
Jaguar Land Rover Ltd 65, 85,89,90,115,125
James Durrans & Sons Ltd 34
Johnson Matthey Plc 31,38,46,50,97,107,117
KW Special Projects Ltd 57,124
Lifeline Fire and Safety Systems Ltd 85,90
Lina Energy ltd 110,120
Lucideon Ltd 38,113,124
M&I Materials ltd 80
Mclaren Automotive Ltd 123
MEP Technologies ltd 110,114
Milliamp Technologies Ltd 91
Minviro Ltd 101
M-kopa UK Ltd 96
M-solv ltd 101
Nexeon Ltd 44,49,55,58
Nlitech Solutions Ltd 30
Nissan Motor Manufacturing (UK) Ltd 97,119
Nobel Autoparts UK. Ltd 84
NYOBOLT LIMITED 39
OXLID LTD 108

P.A.K Engineering Ltd	92
Peacock Technology Ltd	86
Perkins Engines Company Ltd (Caterpillar UK)	70
Phoenix Scientific Industries Ltd	55
Plasma App Ltd	35,46
Potenza Technology Ltd	65,85,90
Powervault Ltd	102
PST Sensors Europe Ltd	87,92
PXL ICE LIMITED UKBIC	36
Q-FLO LIMITED	37
Qinetiq Ltd	51,111
Rapid Powders Ltd	33
Reaction engines Ltd	81
Ricardo UK Ltd	80,82,127
Rolls-royce plc	67
RSBruce	101
Sigma lithium Ltd	109
Silver power systems Ltd	94
Sustainable Ventures	69
Synthomer (UK) Ltd	58,59
Talga Technologies Ltd	50,52,107,125
Tevva Motors Ltd	103
TFP Hydrogen Product Ltd	52,100
Thermal Hazard Technology Ltd	75,93
Thomas Swan & Co. Ltd	117
Trackwise designs Ltd	65
Tri-wall Europe Ltd	90
Unipart Logistics Ltd	88
Vantage Power Ltd	41,72,78,79
Vulcan	38
Wardell Armstrong international Ltd	54
Watercycle Technologies Ltd	101
William Blythe Ltd	51,59,62,109,121
Williams Advanced Engineering Ltd	32,33,39,62,94,108,121

Research and Technology Organisations (RTO)

HSSMI Ltd	61,103,126
Centre for Processing Innovations Ltd	30,34,56,59,60,62, 64,86,87,92,106,110,116,117, 118,120,122,126,127
NPL Management Ltd	103,122
TWI Ltd	50,76
UK Battery Industrialisation Centre Ltd	36,47

Public Sector Organisations

Health and Safety Executive - Science Div.	85,90
The Natural History Museum	54

Research Organisation

Brunel University London	72,78,81
Cranfield University	45,121
Imperial College London	40,43,47,60,67,68,70,73,75, 79,80,93,94,96,98,110,126
Lancaster University	62,110,116,120
London South Bank University	111,122
Loughborough University	102,124
Queen's University Belfast	64,74
Queen Mary University of London	64
University College London	31,44,49,51,58,103,108, 121,126,127
University of Bath	82
University of Birmingham	42,51,52,57,100,101,105,125
University of Cambridge	37,39,41,46,50
University of Coventry	39,44,97
University of Exeter	64,106
University of Leicester	101
University of Liverpool	114
University of Nottingham	92,108
University Of Oxford	55,119
University Of Sheffield	30,77,107
University of South Wales	111
University of Southampton	64,106,112,122
University of Strathclyde	86
University of St Andrews	126
University of Sussex	74,86
University of Warwick	32,33,34,35,48,52,53,57,65,66, 71,80,84,85,90,99,100,110, 114,115,119,123,125
University Of York	100

UK Research and Innovation

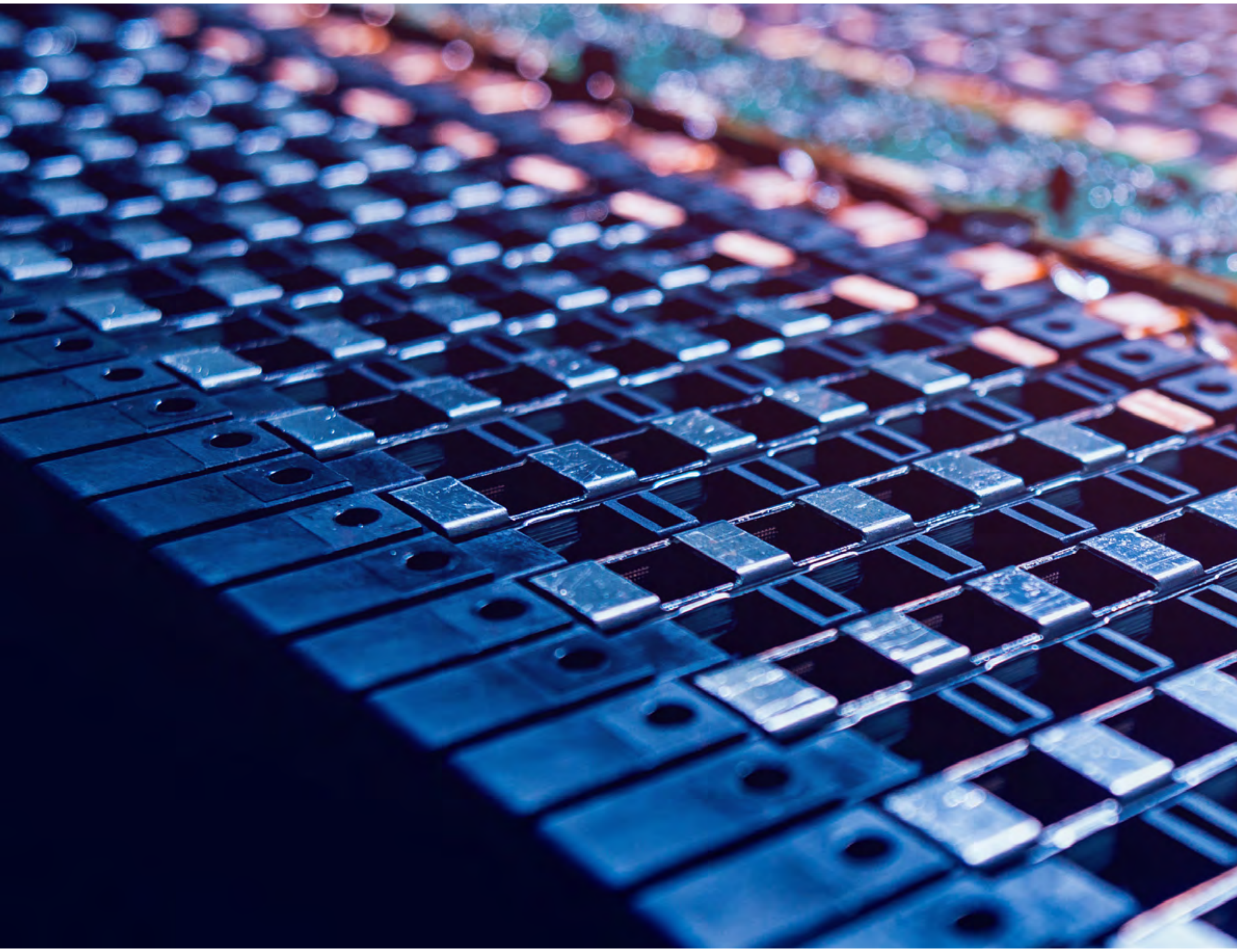
UK Research and Innovation is a new organisation that brings together the UK Research Councils, Innovate UK and Research England into a single organisation to create the best environment for research and innovation to flourish. The vision is to ensure the UK maintains its world-leading position in research and innovation.

Published by UK Research and Innovation

For more information visit www.ukri.org

Follow us

June 2023



8871/06-23