INDUSTRIAL STRATEGY | UK Research and Innovation

Faraday Battery Challenge: funded projects to date

September 2019

Contents

What is the Faraday Battery Challenge?

The Faraday Battery Challenge is part of the Industrial Strategy Challenge Fund (ISCF), designed to ensure that research and innovation take centre stage in the government's Industrial Strategy.

With an investment of £274 million between 2017-2021, the challenge aims to support a world class scientific, technology development and manufacturing scale-up capability for batteries in the UK. The challenge is focused on developing cost-effective, high-performance, durable, safe and recyclable batteries to capture a growing market.

Initially addressing 8 present-day limitations of automotive battery technology, the challenge will allow the UK to realise its commitment to move to full electrification and zero-emissions vehicles. The challenge is expected to translate into other sectors including aerospace and rail.

The challenge comprises 3 stages to market: Research, Innovation and Scale-up.

Research

Funded through the Engineering and Physical Sciences Research Council (EPSRC), part of UK Research & Innovation, the Faraday Institution is a £78 million research institute that will accelerate the fundamental research needed for future battery development. It will bring together expertise from universities and industry to support research, training and analysis into electrochemical energy storage science and technology.

Innovation

Delivered by Innovate UK, part of UK Research & Innovation, £88 million of funding is available for businesses to lead feasibility studies and collaborative research and development projects in battery technologies.

Scale-up

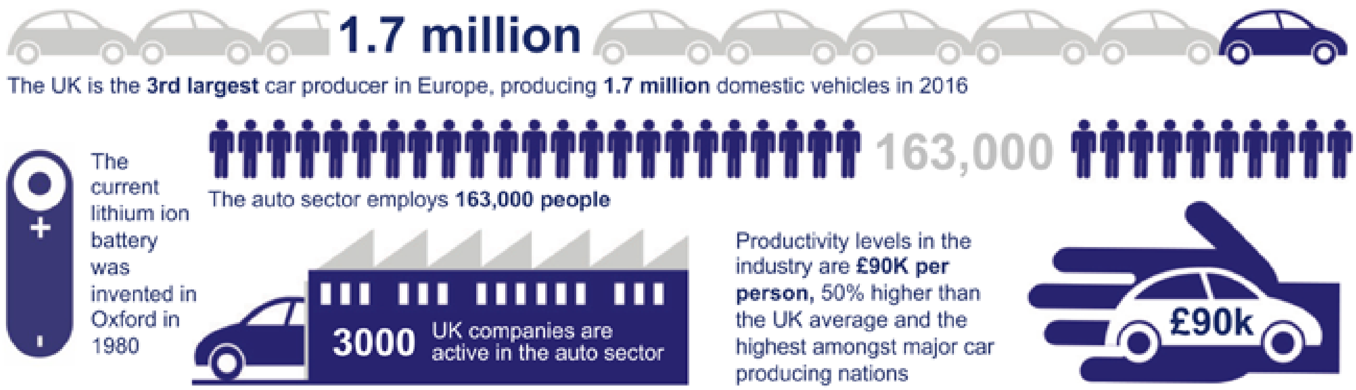
delivered by the Advanced Propulsion Centre (APC), the £108 million UK Battery Industrialisation Centre (UKBIC) will enable companies of all sizes to develop manufacturing capabilities for battery technologies to get them to market quickly.

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

"The Faraday Battery Challenge is a pioneering programme under the government's Industrial Strategy focused on making the UK the go-to place for the research, development, scale-up and industrialisation of cutting-edge battery technology. Two years into the programme, this brochure illustrates the breadth and depth of cutting-edge research, innovation and scale-up activities coming from our research and industrial base, and reinforces why the UK is a world-leader in battery technology development."

Tony Harper, Faraday Battery Challenge Director

The opportunity: why does the UK want to be world-class in automotive battery technology?



The technical gaps

Cost

2017: $130/kWh (cell)
$280/kWh (pack)
2035: $50/kWh (cell)
$100/kWh (pack)

Energy Density

2017: 700Wh/l,
250Wh/kg(cell)
2035: 1400Wh/l,
500Wh/kg(cell)

1st Life

2017: 8 years (pack)
2035: 15 years (pack)

Temperature

2017: -20° to +60°C (cell)
2035: -40° to +80°C (cell)

Power Density/ Fast Charging

2017:
3 kW/kg (pack)
2035:
12 kW/kg (pack)

Safety

2035:
Eliminate thermal runaway at pack level to reduce pack complexity

Predictability

2035:
Full predictive models for performance and ageing of battery

Recyclability

2017:
10-50% (pack)
2035:
95% (pack)

Research

The Faraday Institution: powering Britain's battery revolution

The Faraday Institution is powering one of the most exciting scientific 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 the fundamental research needed for future battery development to power the automotive and energy revolution for the UK.

A £78 million research institute located at the Harwell Science and Innovation Campus, the Faraday Institution brings together experts in science, business, and policy to help make the UK the world leader in battery technology. By helping to focus battery research around key industrial challenges, the Faraday Institution will enable the creation of new jobs, new industries, and develop tomorrow's technologies. The UK's independent institute for electrochemical energy storage science and technology, the Faraday Institution was established in 2017 as part of the government's £274 million investment in battery technology through the ISCF Faraday Battery Challenge by UK Research & Innovation.

A Critical Need for an electrified and "United" Kingdom

Battery technology is the future. And the Faraday Institution wants to ensure that this future thrives in Britain.

Despite recent developments in energy storage, battery technology is still far from its potential. Shortcomings in battery life, power density, and energy efficiency impede the introduction of next-generation batteries to the marketplace. The high cost of raw materials, materials processing, cell and module packaging, and manufacturing also hold us back.

Large scale energy storage is a cornerstone to the Government's green energy strategy. Science in the UK needs to be up-scaled, so that the UK can stay ahead of the curve and that manufacturers, designers and inventors can be supported.

To meet these challenges, the Faraday Institution aims to unify energy storage research across the UK and set leading university battery researchers to these challenges. The Faraday Institution is investing funds in collaborative research to reduce battery cost, weight, and volume; improve performance, efficiency, and reliability; develop scalable designs; improve manufacturing abilities; develop whole-life strategies; and accelerate commercialisation.

Energy storage can reduce carbon emissions, increase energy efficiency, and accelerate deployment of renewable electricity on the national grid, lowering energy costs. Safe, efficient, and dependable energy storage could spur changes in transportation, electric power, and buildings. To enhance chances of success, the Faraday Institution is funding excellence competitively, working with industry to solve great challenges, and proceeding pragmatically using every tool available to the UK.

The power of collaboration

The Faraday Institution represents a new way of working. It brings together the best scientific minds in the field, draws on others from different disciplines, and links intimately with industry, innovators and government to ensure the UK keeps the pipeline of fundamental science to innovation flowing. The core strength of the Faraday Institution is in harnessing the power of collaboration, enabling science, industry and government to work together.

The value of the Faraday Institution is the delivery of focused, substantial and managed research projects in areas defined by industry and delivered by consortia of businesses and universities.

Empowering the next generation of scientists

Because next-generation energy storage technologies will come from the next generation of scientists and engineers, the Faraday Institution is committed to developing a pipeline of talent. The organisation plays an active role in encouraging young people, particularly those from groups historically underrepresented in STEM (science, technology, engineering and maths), to consider such a career. It is building the talent pool at a number of levels, including at undergraduate level, developing enriching PhD programmes to enhance researchers' skills, knowledge and aspirations, and providing continuing professional development opportunities for early career scientists and engineers.

Faraday Institution's research portfolio

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

Because of the current level of commercialisation of different technologies and the UK's need to deliver improvements in EVs over a range of timescales, the Faraday Institution is pursuing a portfolio of projects. Five research areas focus on optimising 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 (delivering benefits to EV owners) within 3-4 years. Its three other projects are higher risk, higher reward projects, that could facilitate the longer-term commercialisation of next-generation battery technologies that still require considerable research in the areas of materials discovery and optimisation.

The Faraday Institution's portfolio of projects was selected after consultation with academic and industrial stakeholders across the country, with due consideration of the potential impact they could make to the UK. The institution's four initial projects were launched in 2018, engaging over 200 researchers from 20 universities and over 30 industry partners. The further five projects will be launched in the second half of 2019. Research areas are as follows:

Optimising performance of lithium-ion technologies:

- Extending battery life
- Multi-scale modelling
- Battery recycling and reuse
- Electrode manufacturing
- Next generation lithium-ion cathode materials

Making step changes in battery performance beyond lithium-ion:

- Next generation solid-state batteries
- Next generation sodium-ion batteries
- Next generation lithium-sulfur batteries

The biggest performance gains in the near-term optimisation of lithium-ion batteries are likely to arise from changing the chemistry of the cathode. There are significant scientific and commercial challenges to achieving better cathode design, discovering new materials and developing a deeper understanding of the scientific field. And there are multiple ways in which research into this field could be approached. If commercialised, the improvements in battery lifetime, range and cost would be significant to EV owners and could potentially accelerate the rate of uptake of EVs. Speed of discovery in this area is particularly important – researchers around the globe are racing towards breakthroughs that could be commercialised by their country's industrial base. Because the potential research scope and the prizes for success are so large and the need to make breakthroughs is so acute, the Faraday Institution is funding two project consortia in the area of next-generation Li-ion cathode materials.

In addition, three smaller projects to develop battery-focused characterisation and analytical techniques will also begin in the second half of 2019. These awards will provide UK battery researchers with world-leading tools to accelerate the development of their understanding of battery materials.

Faraday Insights

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

The Faraday Institution also commissions deeper studies to inform policy. For example, the organisation published a study produced with individuals from McKinsey Energy Insights and the University of Oxford into the UK's electric vehicle and battery production potential to 2040.

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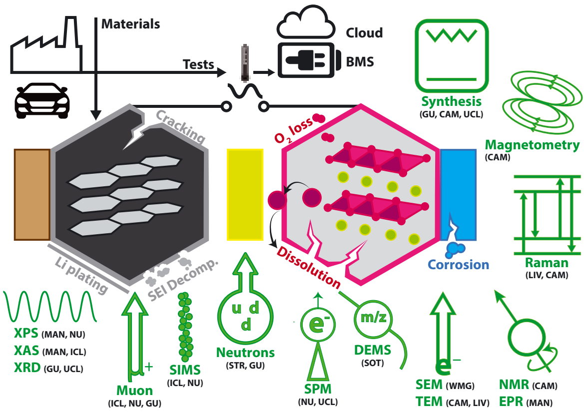
Extending battery life

Optimising battery materials and cells to extend life, reduce cost and enhance safety

Project costs

Grant contribution: £11,202,037



Executive summary

This project will examine 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), reduce battery costs, and enhance battery safety.

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

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

Timeline with milestones and deliverables (February 2021):

- 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 operating battery pack.
- demonstration of an advanced battery management system (BMS), which uses cloud computing and big data management to allow the BMS to identify signals that indicate degradation and mitigate for them.

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 low lifetime in 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 Liverpool
University of Manchester
University of Southampton
University of Sheffield
University of Warwick
10 industrial collaborators

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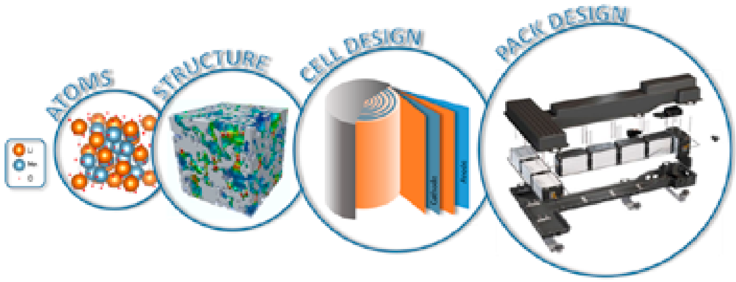
Multi-scale modelling

From atoms to structure to cell, module and pack design

Project costs

Grant contribution: £12,171,430



Executive summary

The Multi-scale modelling project brings together world-leading battery experts with a broad set of skills at every level to build the critical bridge between science and engineering, working alongside UK industry to ensure that the work is innovative and delivers high impact. This consortium uniquely blends theoreticians with modellers, mathematicians and experimentalists, ensuring that the models developed are scientifically rigorous, computationally efficient and experimentally validated, to maintain a high degree of usefulness and accuracy.

To simulate an EV battery pack, we need to consider a range of length scales, from the nanoscale, where atoms interact, right up to the macroscale of a complete pack and its electronic control strategies. In addition, a variety of time scales need to be considered, in order to assess atomic processes at the nanosecond through to long-term degradation occurring over years. Battery simulations and design tools exist at each length- and time-scale, but they are not linked together and often lack the accuracy required for understanding the unique phenomena occurring within batteries.

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

Timeline with milestones and deliverables (February 2021):

- A rational materials by design exercise for low temperature operation.
- Improved cell design capabilities for prolonged life.
- Demonstration of hybrid pack configurations using mass parameterisation.
- Advanced control algorithms to extend lifetime of complete battery packs.
- Enhanced models of the solid electrolyte interface along with mechanical fatigue.

Project innovations

Accurate simulations of batteries will give us the ability to design advanced batteries without the cost of creating numerous prototypes to test every new material, or new type and configuration of the cells which make up a pack. Simulations also offer valuable insight into how existing materials work, enabling us to identify the limiting processes and develop rational strategies to overcome them or design new materials, leading to significant improvements of battery performance and lifetime. Models for control will also enable us to extend the lifetime and/or performance and reduce the cost of existing and future packs. The first challenges to be tackled include low temperature operation and thermal management of cells within battery packs.

Partners

Imperial College London (lead)
Lancaster University
University College London
University of Bath
University of Birmingham
University of Oxford
University of Southampton
University of Warwick
University of Portsmouth
17 industrial partners

THE FARADAY INSTITUTION

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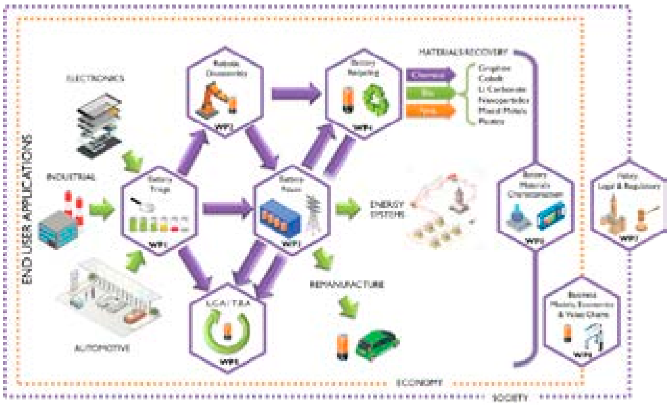
Recycling and reuse (ReLiB)

Determining the ways in which spent lithium batteries can be recycled

Project costs

Grant contribution: £10,060,130



Executive summary

With the aim to recycle 100% of the battery, the project will look how to reuse the batteries and their materials, to make better use of global resources, and ultimately increase the impact of batteries in improving air quality and decarbonisation. The aim of the ReLiB project is to establish the technological, economic and legal infrastructure to make the recycling of close to 100% of the materials contained in lithium-ion batteries from the automotive sector possible.

The ReLiB team will tackle the most demanding technical challenges in sensing, gateway testing, robotic sorting, re-use, recycling and characterisation. The processes developed will be quantitatively assessed by specialists in lifecycle, technical and economic assessment. New business models and regulatory frameworks will be examined in the context of the complete, full-cycle value chain.

Timeline with milestones and deliverables

- A ‘triage’ system for used battery assessment (February 2021).
- Fully autonomous gateway testing and robotic sorting (February 2021).
- The development of recycling technologies to segregate and purify the different materials into a useful form for reuse in batteries or other applications, including, life cycle analysis and techno-economic assessment of each recycling route developed (Various).
- Development of new business models to promote the collection and sorting of batteries (Various).
- A review of the regulatory framework for battery recycling in the UK and analysis of which EU waste laws should be retained law in the UK after Brexit (February 2019).

Project innovations

Introducing robotics into the waste and recycling sector will boost productivity, stabilise the existing jobs market and could also draw jobs into the UK by providing valuable raw materials to feed in further up manufacturing supply chains. The ReLiB project will have a significant impact on the safety, economics and efficiency of battery recycling while minimising the environmental impact of these processes.

Partners

University of Birmingham (lead)
Cardiff University
Diamond Light Source
Newcastle University
Oxford Brookes University
University of Edinburgh
University of Leicester
University of Liverpool
14 industrial collaborators

THE FARADAY INSTITUTION

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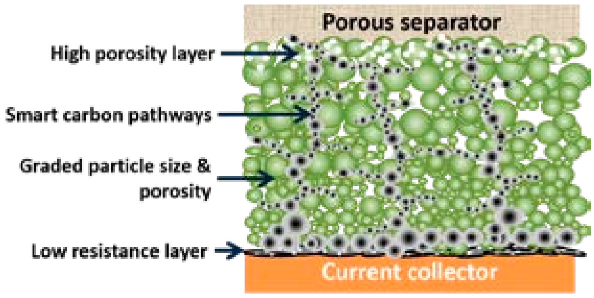
Nextrode – Next generation electrode manufacturing

Battery performance improvements through smarter electrode manufacturing

Project costs

Grant contribution: Around £12m



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

Executive summary

Today, all electrodes for mass market lithium-ion batteries are made by slurry casting. The process involves mixing electrochemically active materials, additives and binders, and produces electrodes with randomly distributed pores and materials, in what is a quick and productive process. However, recent research at the laboratory scale has demonstrated that new manufacturing methods can produce "smart" electrodes with 30% more capacity and 50% lower degradation rates, which could enable EVs with longer range and batteries that are more durable. Even bigger benefits could be achieved once more is understood about the science of smart electrodes and how to scale up production for industry. The Nextrode project has been formed to do just that – to research new methods for manufacturing smarter electrodes and to put them onto the path to commercialisation.

The Nextrode consortium will address a range of crucial scientific and industrial challenges. It will investigate what happens to constituent materials as electrodes are formed, and how this can be controlled; it will be a test bed for radical new manufacturing methods; and it will pioneer new ways, based on data science, to translate small-volume, lab-scale manufacturing into high-volume environments.

The project insights will be transferred directly to existing manufacturers across many sectors, from car and off-road vehicles to aerospace and marine, who continue to push for breakthroughs in performance and cost to enable greater electrification.

Timeline with milestones and deliverables (February 2021):

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

Project innovations

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

Partners

University of Oxford
University of Birmingham
University College London
University of Sheffield
University of Southampton
University of Warwick
6 industrial collaborators

THE FARADAY INSTITUTION

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FutureCat – Next generation lithium-ion cathode materials

Towards a near-term step change in lithium-ion battery energy density and lifespan

Project costs

Grant contribution: Around £11m

Executive summary

Accelerating the drive towards electric vehicles requires a substantial change in lithium-ion battery technology. The next generation of Li-ion batteries must have longer lifespans and increased energy density to increase the range of electric vehicles. The biggest performance gains are likely to arise from changes to the cathode chemistry. And crucially – because of the cost, sustainability and ethical concerns surrounding cobalt – battery technology must be based around alternatives to the traditional cobalt containing cathodes.

Overcoming the significant scientific and commercial challenges to reaching these goals will require better cathode design, new materials and a deeper understanding. The prizes for doing so are both significant and could be realised in commercial products in the relatively near-term.

Some of the areas of research that FutureCat is particularly investigating are materials with controlled or ordered structures (that enable use of otherwise unstable materials, provide mechanical stability, increase battery durability or open new pathways for development) and synthesis methods that may be a route to new materials through inexpensive processes (reducing battery prices).

Timeline with milestones and deliverables (to September 2023):

- Coordinated cathode chemistry design, development and discovery to deliver architectures better suited to withstand prolonged cycling and promote ion mobility (increasing power and acceleration of the EV).
- Develop a holistic understanding of complex structural, mechanical and dynamical transformations in battery cathodes that affect performance.
- Prolong lifetime of Li-ion cathodes through tailored protective coatings, designer interfaces and engineered heterogeneity.

Project innovations

With industry partners, the FutureCat project has set ambitious targets to make fundamental breakthroughs that would put on the path to commercialisation a battery with significant improvements to energy and power density, cost and first life. For example, it is targeting nearly doubling the theoretically possible power density (at pack level) by 2023, through researching high voltage lithium nickel manganese spinels and their dopant counterparts (e.g. Cu, Fe ions), novel additives, coatings and designer interfaces to promote fast ion conduction in the protected electrode. The FutureCat team will concentrate on scalable materials and methods, smoothing the path from laboratory to manufacturing and keeping in mind lean manufacturing techniques to cut manufacturing costs once commercialised.

Partners

University of Sheffield
University of Cambridge
University College London
Lancaster University
University of Oxford
Science and Technology Facilities Council
9 industrial collaborators

THE FARADAY INSTITUTION

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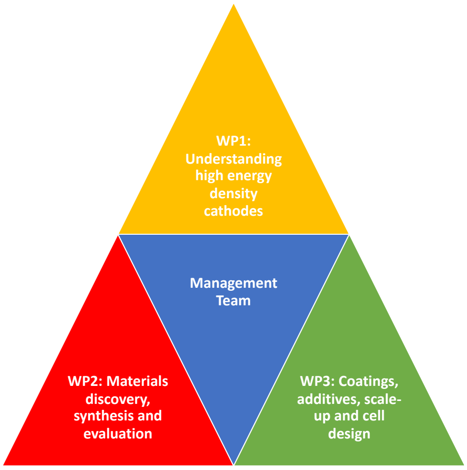
CATMAT - Next generation lithium-ion cathode materials

Targeting a near-term improvement in lithium-ion battery lifespan and EV range

Project costs

Grant contribution:
Around £12m



The interlinking work packages of the CATMAT project.

Executive summary

Over the coming few years automakers will be looking to integrate Li-ion batteries with significantly improved performance into new EV models. They are looking to the research community to develop ways to improve Li-ion cell chemistry that would boost battery life, store greater energy to improve range, reduce battery cost, increase the power available to the EV during acceleration, and remove the reliance on a supply chain for cobalt over which there are significant ethical concerns. The biggest improvements in performance are likely to arise from refinements to the chemistry of the cathode.

Developing a new generation of Li-ion cathodes that meet performance requirements presents a major scientific and commercial challenge, but the benefits to automakers and their supply chain are both large and near-term. The CATMAT project represents a fresh approach to meeting these challenges.

CATMAT will place considerable emphasis on understanding the fundamental mechanisms at work within novel cathodes that currently prevent the use of nickel-rich cathodes (with low or no cobalt) and plans to exploit this new knowledge to inform the discovery of novel cathode materials with enhanced properties. It will identify the most promising new cathode materials, scaling up their synthesis and assimilating them into full battery cells to demonstrate performance.

Timeline with milestones and deliverables (to September 2023):

- Discover and develop enhanced performance cathodes.
- Develop the fundamental understanding of the properties of cathodes.
- Use experiment, modelling, processing and cell performance evaluation to establish feedback between understanding from model systems and the properties of new materials to optimise cathode performance.
- Exploit new knowledge to inform the discovery of novel oxide and mixed-anion cathode materials that could increase battery capacity (potentially increasing EV range).
- Understand instability at the electrode/electrolyte interface and reduce performance losses using coatings or additives.
- Scale up the synthesis of the most promising technologies, demonstrating their performance in real devices.

Project innovations

CATMAT'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 opportunities and technology transfer will be woven throughout the project. The project team is committed to nurturing entrepreneurship and supporting potential spin-out activity. UKBIC could potentially take forward CATMAT's research into commercial scale demonstration, to expedite the commercialisation of promising candidates and maximise industrial impact to the UK.

Partners

University of Bath
University of Birmingham
University of Cambridge
Diamond Light Source
University of Liverpool
University of Oxford
University College London
12 industrial collaborators

THE FARADAY INSTITUTION

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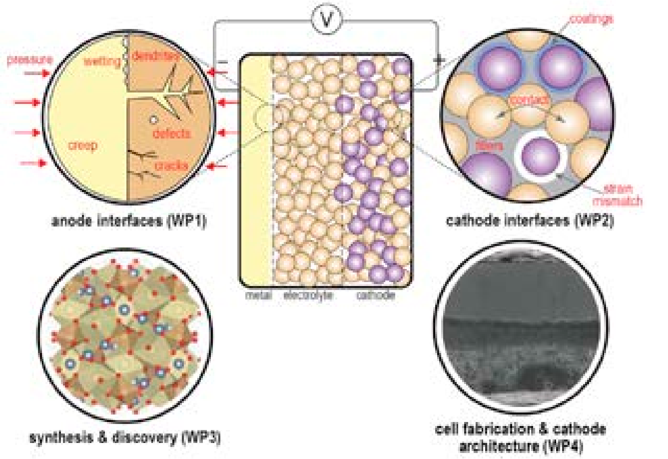
Next generation solid-state batteries (SOLBAT)

Enabling the progression to market of lighter and safer solid-state batteries

Project costs

Grant contribution: £10,692,278



Executive summary

The ambition of this project 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 as well as having a major impact in the consumer electronics and aerospace sectors.

The successful implementation of an alkali 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 of the battery and address the safety concerns. The development of an understanding of the fundamental processes taking place in these devices would accelerate the efforts to commercialise such batteries currently being undertaken worldwide. We have identified the four major barriers facing all-solid-state batteries where a lack of fundamental understanding is blocking progress.

Timeline with milestones and deliverables (February 2021):

- Understand the fundamental science underpinning the problems of solid-state batteries and develop solutions to barriers hindering progress.
- Discover new solid electrolytes.
- Develop smarter cathode structures based on electrolyte scaffolds.
- Integration solid-state electrolytes in full cell architectures.

Project innovations

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

Partners

University of Oxford (lead)
University College London
University of Cambridge
University of Liverpool
University of Sheffield
University of St. Andrews
9 industrial collaborators

THE FARADAY INSTITUTION

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Next generation sodium-ion batteries

Delivering a revolution in cost-competitive battery technologies

Project costs

Grant contribution: Around £12m

Executive summary

Most current generation rechargeable batteries for transportation are based on the use of lithium. However, the relatively high cost, the somewhat limited global abundance of lithium, and environmental concerns around the sourcing of lithium mean that there is demand for a lower cost alternative that would increase the uptake of energy storage technologies in a number of sectors. Sodium-based batteries could be such an option, particularly for static storage, where cost is a more important factor than weight or performance.

This project will accelerate the development of sodium-ion battery technology by taking a multi-disciplinary approach incorporating fundamental chemistry right through to scale-up and cell manufacturing. Its aim is to put on the path to commercialisation a sodium-ion battery with high performance, low cost, that has a long cycle life and is safe.

Many models of future grid networks based on renewable energy incorporate storage on a local or domestic level for increased network resilience and to ensure efficiency of small-scale renewable sources. The widespread use of commercial Na-ion batteries, that this project will facilitate, would aid the realisation of these models, and also fulfil the need for low-cost electric transport options in the highly polluted and densely populated conurbations in developing economies.

Timeline with milestones and deliverables (February 2021):

- Discover and develop innovative electrode materials for higher performance, lower cost Na-ion batteries.
- Discover and develop next-generation electrolyte materials, giving higher sodium mobility and therefore higher power.
- Refine the test and characterisation methods most applicable for materials for Na-ion batteries.

Project innovations

This 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 the cutting-edge science is readily exploited and successfully deployed, making the UK a leader in this technology for stationary and low-cost transportation applications.

Partners

To be selected in August 2019.

THE FARADAY INSTITUTION

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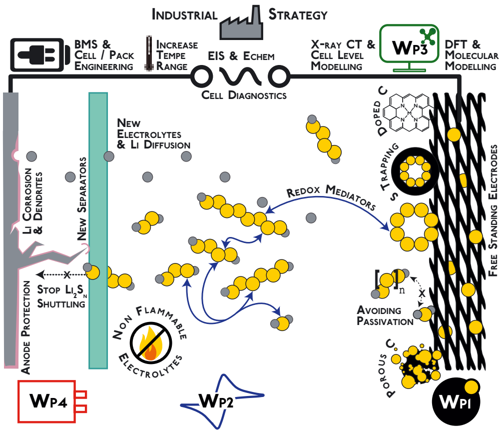
LiSTAR - Lithium-sulfur technology accelerator

Extending battery performance past the theoretical limits of Li-ion technologies

Project costs

Grant contribution: Around £8m



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

Executive summary

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

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

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

Timeline with milestones and deliverables (all September 2023):

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

Project innovations

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

Partners

University College London
Imperial College London
University of Cambridge
University of Nottingham
University of Oxford
University of Southampton
University of Surrey
7 industrial collaborators

THE FARADAY INSTITUTION

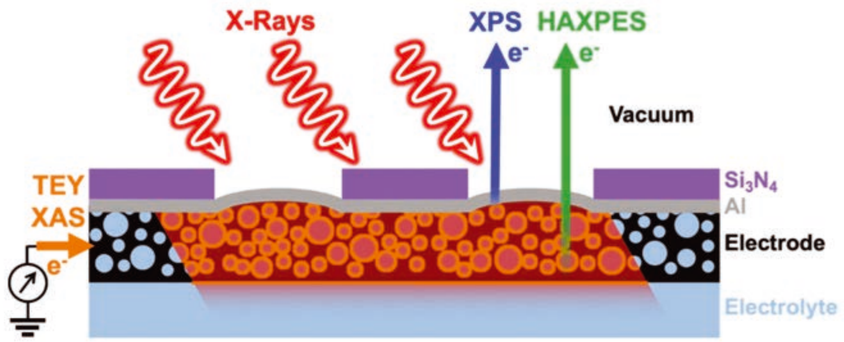
Contact:
Professor Paul Shearing, University College London **Email:** p.shearing@ucl.ac.uk **Web:** www.faraday.ac.uk/research/lithium-sulfur

Battery characterisation

Three projects to develop new tools and battery characterisation techniques for UK researchers

Project costs

Grant contribution:
£2,000,000



Cross-section of operando cell to be developed by the "Exploring Buried Interfaces" project. Diagram shows aluminium windows on Si_3N_4 support with porous electrode behind. X-ray photoelectron spectroscopy (XPS) originates from ~10nm depth, hard X-ray photoelectron spectroscopy (HAXPES) from ~50nm and total electron yield x-ray absorption spectroscopy (TEY-XAS) from all illuminated interfaces.

Executive summary

Three UK-based consortia will develop innovative battery-focused characterisation and analytical techniques to provide UK battery researchers with world-leading tools to accelerate the development of their understanding of battery materials. These technical advances will help the UK develop next-generation batteries and will ultimately improve the performance of electric vehicles.

The projects will develop various cutting edge microscopic, spectroscopic and diffraction techniques, that will enhance the ability of UK researchers to, for example, see deep inside batteries while operating in real time, which will allow researchers to better understand the mechanisms and reactions occurring within them. The tools developed will support the structural and mechanistic understanding of a wide range of battery chemistries, not limited to those currently being investigated by the Faraday Institution.

Timeline with milestones and deliverables (Q2 2021):

- **Multi Modal Analysis, University of Liverpool:**
  - Define a framework that can connect state-of-the-art imaging and analytical methods across different length and time scales.
  - Machine learning to inform experimental design.
  - Develop a clear view of how altering the structure, shape and chemistry of a battery material leads to a change in its function.
- **High Resolution Optical Microscopies, University of Cambridge:**
  - Build upon characterisation methods developed for semiconducting materials to provide a greater understanding of how electrode materials function.
  - Use high speed imaging to capture the incorporation of lithium ions into an electrode.
  - Demonstrate a type of microscopy to track ion diffusion in real time.
  - Refine a new technique to track local changes in magnetic properties in an operating cell.
- **Exploring Buried Interfaces, University of Manchester and Diamond Light Source:**
  - Produce platforms for analysis of in-situ and operating ('operando') cell interfaces.
  - Develop a method to preserve cell interfaces for further analysis.
  - Correlate results from X-ray and mass spectroscopy techniques to understand the complementary information each provides.
  - Make use of new capabilities at Diamond Light Source and the Henry Royce Institute.

Project innovations

- To advance battery-specific characterisation techniques, and quickly share these amongst the research community.
- To set up facilities to allow other researchers access to facilities and the knowledge to run them accurately.

Partners

University of Liverpool
University of Cambridge
University of Oxford
University of Manchester
Diamond Light Source
University College London

University of Birmingham
University of Bath
University of Warwick
9 industrial and academic partners

THE FARADAY INSTITUTION

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Dr Sian Dutton, University of Cambridge Email: sed33@cam.ac.uk
Dr Robert Weatherup, University of Manchester Email: nick.russel@denchipower.com

Innovation

ABLE (Advance battery life extension)

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

Project costs

Total project costs: £427,522

Grant contribution: £290,864

Executive summary

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

The techno-economic study completed in this project shows that currently cost of remanufacturing is dominated by labour. Costs per kWh shows that 2nd life repurposing only become interesting if whole modules or large cells are used specially due to the resource intensive testing/sorting process. Preliminary results are promising for DTV to be used as a factory re-acceptance tool, however this needs to be confirmed with further research.

Timeline with milestones and deliverables

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

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

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

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

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

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

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

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

Project innovations

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

Partners

M-KOPA SOLAR MAENDELEO NI LEO

DENCHI POWER

Imperial College London

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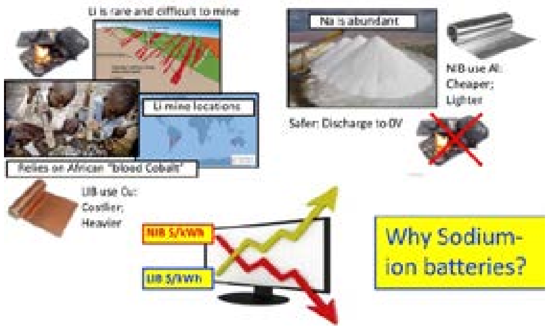
Advanced metamaterials for sodium-ion battery anodes – a scalability and economic feasibility study

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. NIB are safer, thermal runaway is slower than LIB 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
- May 2020 – Experiment vs theory. Comparison of longlist materials.
- July 2020 – 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+ "high-fidelity" ideal metamaterials for NIB electrodes
- Development of "low fidelity" metamaterials forqualitative validation of theory
- Proof-of-principle development of advanced material synthesis techniques to fabricate "medium-fidelity" materials
- PCPI to assess economic and technical challenges to Manufacture at scale – inform process routes at an early stage

Partners

Deregallera

University of Southampton

University of Exeter

cpi

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

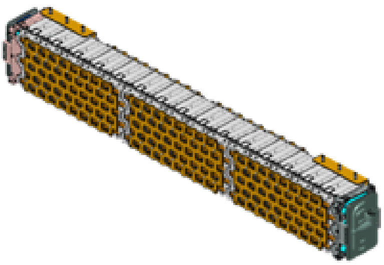
AMPLiFII-2

Design, development, application & implementation of a modular, scalable, flexible battery module & pack architecture.

Project costs

Total project costs:
£10,246,742

Grant contribution:
£7,665,322



Executive summary

AMPLiFII-2 will further develop the successful implementation of scalable, flexible, modular battery module and pack architectures within the previous AMPLiFII project. These designs will be targeted at 4 applications, each represented by an OEM partner (niche automotive, mainstream automotive, bus and off-highway).

Developments include a focus on cooling system performance for high discharge power & fast charging solutions, cost-down exercises on part costs & manufacturing methodologies and adaptations to accommodate the emerging 21700 cell format. by Potenza, supported by Trackwise.

The project will result in packs installed in demonstrator vehicles, a pilot battery module & pack production facility based at Delta Motorsport (with learning from the implementation of WMG's pilot line within AMPLiFII) and a production capable BMS by Potenza, supported by 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
- Q1 2020 – OEM testing complete on prototype battery packs

Project innovations

AMPLiFII-2 will develop innovations such as:

- BMS software over the air updates (SOTA)
- Modules for 18650 & 21700 cylindrical cell formats
- A low-cost, lightweight battery module thermal management system
- Battery solutions to suit 800V vehicle architectures
- Investigations into ASIL D BMS requirements
- A production-capable flexi-PCB BMS solution

Partners

WMG THE UNIVERSITY OF WARWICK
JAGUAR
LAND ROVER
JCB
ALEXANDER DENNIS
POTENZA
delta motorsport
ARIEL
TRACKWISE CONNECTING TECHNOLOGY

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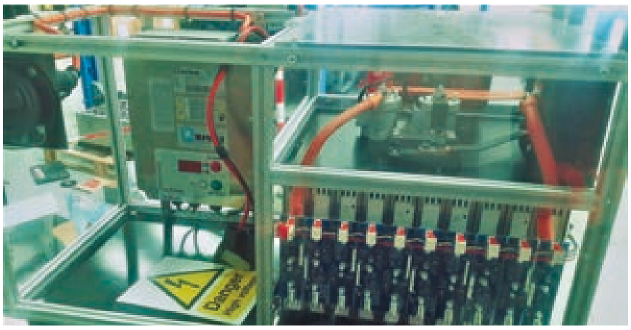
Assessment and development of the novel "i-BMS" Battery Management System

To evaluate the i-BMS using a novel physical-virtual simulation platform developed by WMG; and to explore and develop the i-BMS' potential for improved fault detection and economic second-life battery applications.

Project costs

Total project costs: £319,846

Grant contribution: £245,461



Executive summary

This project is a continuation of two previous funded projects to develop a radically novel battery management system (the "i-BMS") for electric vehicles and other power applications.

Laboratory trials and on-road testing currently under way have demonstrated the effectiveness of the i-BMS, which departs fundamentally from established technologies by eliminating routine cell balancing. Intercal and Indra are now working with WMG to simulate a wide range of conditions and issues, to fully characterise the performance of the i-BMS and further confirm its efficacy in the laboratory and in real-life applications. This will involve the application of a novel hybrid physical-virtual battery simulation platform developed by WMG.

The project is also exploring the scope of the i-BMS to facilitate more economic cell reuse for second-life batteries, exploiting the simplified battery pack assembly made possible by the elimination of complex and fault-prone wiring looms that are required by conventional BMS technology.

In addition, software is being developed to exploit the proven early fault detection capabilities of the i-BMS in reducing or eliminating spontaneous lithium battery fires.

Towards the conclusion of the project, the partners plan a programme of beta testing, to be delivered by invitation to selected manufacturers.

Timeline with milestones and deliverables

The project commenced in July 2019 and will continue for 12 months. Deliverables consist of:

- Characterising and evaluating performance of the i-BMS using the WMG hybrid physical virtual simulation platform,augmented by laboratory testing;
- Laboratory trials to evaluate the i-BMS performance alongside a conventional BMS;
- Construction and testing of a second-life battery using cells removed from an end-of-life OEM EV;
- Installation and testing of a refined pre-prototype i-BMS in an on-road vehicle
- A structured programme of beta-testing by invitation to third party manufacturers; and
- Dissemination of project results through at least one high-quality published paper.

Project innovations

- the i-BMS introduces a novel method of charging and battery
- management that does not require the automated cell charge
- balancing technology that has hitherto been considered essential for lithium batteries. This greatly simplifies battery design and assembly and facilitates maintenance and second-life applications.

Partners

INDRA

INTERCAL BATTERY MANAGEMENT SYSTEMS

WMG THE UNIVERSITY OF WARWICK

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Ben Kelsey, Programme Manager Email: ben.kelsey@indra.co.uk

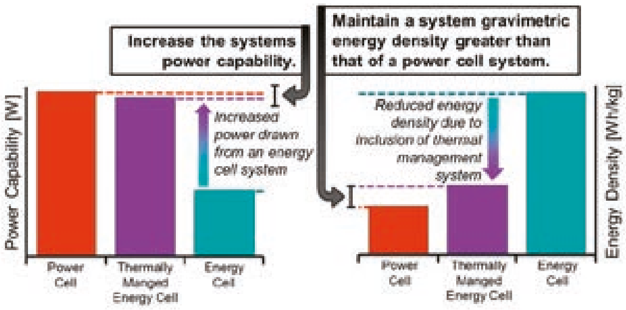
Automotive technology transfer energy storage thermal strategies (ATTESTS)

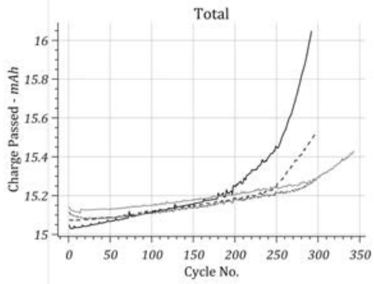
Assessing the feasibility of increased cycle life and power density of low C-rate, energy dense automotive cells through improved thermal management at cell level

Project costs

Total project costs:
£328,419

Grant contribution:
£246,037





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 **Phone:** 01332 248667 **Web:** http://www.imperial.ac.uk/electrochem-sci-eng

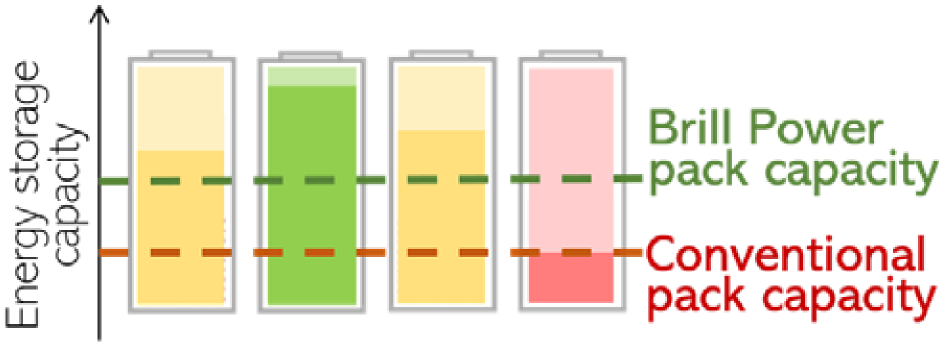
Battery management control system for advanced battery engineering (BABE)

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

Project costs

Total project costs:
£211,593

Grant contribution:
£136,105



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.

Key achievements of this project include 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
Project Milestones:

- 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
- 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

Brill Power

ecar A Europcar Company

sustainable ventures

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Christoph Birkl, Brill Power **Email:** christoph.birkl@brillpower.com **Web:** www.brillpower.com www.ecarclub.co.uk
Web: www.sustainableventures.co.uk

Battery thermal management and diagnostics for heavy duty vehicles – BATMAN

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.

Project costs

Total project costs: £2,813,226

Grant contribution: £2,004,438

Objective

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

Challenges

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

Key objectives

- 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

Highlights

- Down selection from 5 different cell technologies down to 2 for detailed life characterisation work – representing 2 different use cases
- BAUMA 2019 CAT 906 EV concept machine showcased
- Cell to full system model controls integration work underway

Partners

CATERPILLAR®

AVID technology

Imperial College London

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BAFTA (Battery advances for future transport applications)

Project costs

Total project costs: £3,066,817

Grant contribution: £2,217,721

Executive summary

Aston Martin Lagonda is collaborating with Dukosi and Imperial College London on the ‘Battery Advances for Future Transport Applications’ (BAFTA) project which aims to develop a framework that enables optimised performance and system longevity for battery packs. AML’s new battery pack design tool, which optimises pack configurations through cell screening and conceptual vehicle architecture requirement selection, is undergoing validation through data gathered from Valkyrie and Rapide E test vehicles.

One of the core interests in the modelling efforts of the BAFTA project 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 programmatically 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 also being developed for the project.

Dukosi’s dedicated new BAFTA lab is well underway, with state-of-the-art module cyclers and thermal chambers scheduled to arrive in Q3. In the meantime, they are undertaking individual cell characterisation tests on their existing lab equipment to allow AML to select the optimum cell(s) for the project; this is also allowing testing of the new high-current BAFTA cell jigs. Dukosi is showcasing the BAFTA project at numerous upcoming conferences, and has already presented it at the Europe Battery Show in Stuttgart.

Project start
Q3 2018

Battery pack design tools
Q1 2019

Demonstration of hardware
Q3 2019

1st experimental results
Q4 2019

Thermal simulation tools
Q1 2020

Merging of thermal and battery pack tools
Q3 2020

Tools validation
Q3 2020

Project end
Q2 2021

Project innovations

The 3 key pillars of this project are:

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

Partners

ASTON MARTIN

DUKOSI

Imperial College London

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CALIBRE: Custom automotive lithium-ion battery recycling

Project costs

Total project costs: £3,192,157

Grant contribution: £2,205,168

Executive summary

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

Key objectives

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

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Project lead: Emma Schofield **Email:** Emma.Schofield@matthey.com
Project Manager: Michelle Heer **Email:** Michelle.Heer@matthey.com

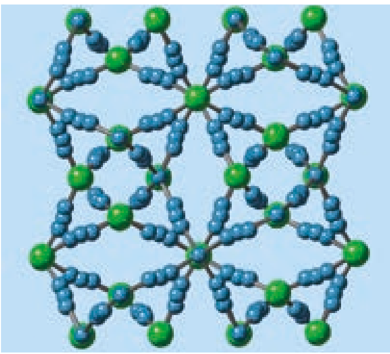
Cathodes, anodes, and solid-state electrolytes for lithium-ion batteries (CASE LIBs)

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

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 aims to address 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 will run from 1st July 2019 to 30th June 2020 and is made up of 4 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.
- Manufacture 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

- Solid-state electrolytes with improved performance.
- Scalable routes to solid-state electrolytes.
- Composite layers of solid-state electrolytes with both cathodes and anodes with an improved understanding of the material interfaces and Compatibilities.
- Novel methodologies for processing and sintering solid-state electrolytes.

Partners

JM Johnson Matthey Inspiring science, enhancing life

The University Of Sheffield.

talga Talga Technologies Ltd

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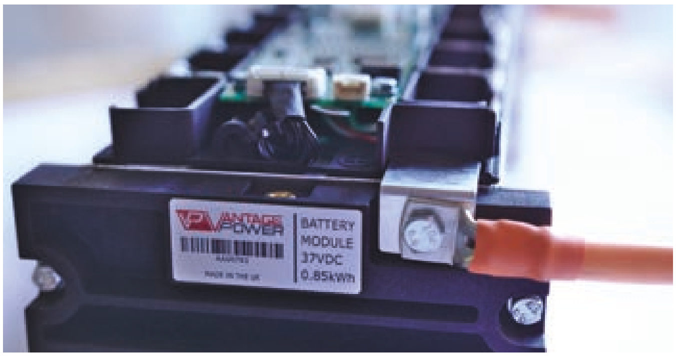
Conceptual feasibility of a heat pipe as a structural and thermal member in an automotive battery pack design

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

Project costs

Total project costs: £505,137

Grant contribution: £385,605



Executive summary

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

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

Proof-of-concept battery modules where 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

Vantage Power

Flint Engineering

Brunel University London

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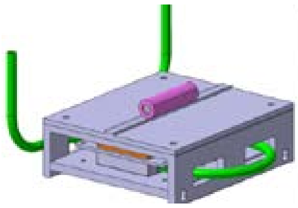
CoRuBa

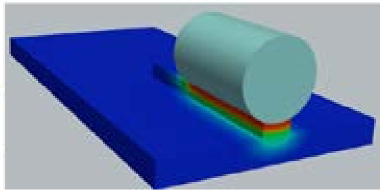
Next generation thermal interface materials to enhance cell life and enable rapid charging

Project costs

Total project costs: £378,583

Grant contribution: £301,521





Executive summary

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

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

Timeline with milestones and deliverables

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

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

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

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

Project innovations

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

Partners

FERGUSSON ADVANCED COMPOSITES TECHNOLOGY

Imperial College London

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Current density imaging in EV battery modules

This project is developing new sensors to image the current flow within EV batteries and incorporate this data within a demonstrator battery management system

Project costs

Total project costs: £455,273

Grant contribution: £382,846

Executive summary

This project has developed novel sensor technology into integrated devices capable of externally monitoring EV battery modules. These sensors have been demonstrated to provide detailed characteristics of the current flow within production EV cells during operation that can lead to new insight in cell design and efficiency. The sensor modules have been integrated into an experimental BMS via a standard CAN bus interface to allow the development of new data processing systems to assess battery performance and improve the usage of the battery pack.

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 being used to validate electrochemical models and improve understanding of battery cell mechanisms.

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
- Implemented real-time current density imaging modules with demonstrator BMS
- Developed novel quantum sensors capable of ultra-sensitive measurement of current flow
- Introduced new technique for analysing and optimising battery cell operation
- Introduced new technique for validating electrochemical models of battery cells

Partners

cdo²

inex microtechnology

University of Sussex

Queen Mary University of London

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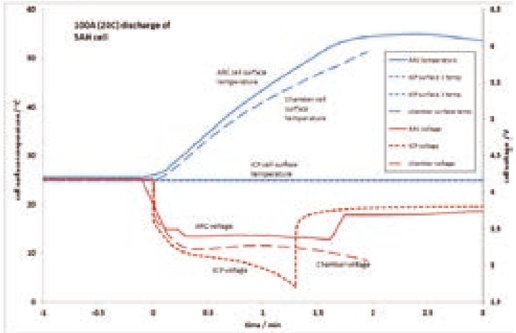
Developing the Isothermal Control Platform (ICP) as the basis of new proposed standards for the testing of lithium batteries for use in electric vehicles

The ICP will form the basis of new proposed standards for the testing of lithium-ion batteries for use in electric vehicles.

Project costs

Total project costs: £566,607

Grant contribution: £447,619



Executive summary

The project aims to build upon the ICP prototype platform developed in partnership with Imperial College during our previous Faraday funded feasibility study.

The ICP offers precise regulation of battery temperatures using specially designed Peltier element modules in direct contact with the cell surface and/or tabs. In addition to the control of the cell surface temperature, the cell internal temperature is predicted via a heat transfer model. 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. Traditional chambers based on air convection are the industry standard thermal control method used in cell characterisation. However, thermal control through air convection alone is not sufficient during vigorous cell cycling. In an environmental chamber, the cell temperature will rise significantly during cell charge/discharge and drive cycle testing. Changes in cell temperature have a significant effect on cell performance.

The data obtained from the ICP will enable the proper design of battery thermal management systems and ultimately translate into significant gains in battery performance, reliability and safety.

Timeline with milestones and deliverables

The 18 month project runs from July 2019 – January 2021
July 2019: The feasibility study has shown the need to establish a new standard requiring ICP precision temperature control.
September 2019: Delivery of ICP pre-production prototype unit to Imperial College London (ICL)
September 2019: ICL to develop ICP testing standards, ICP enhancements
March 2020: THT and Cranfield University (CU) to refine ICP hardware
May 2019: ICL continue to develop thermal model
December 2020: THT thermal model integrated into ICP software control
January 2021: Launch of ICP

Project innovations

The ICP testing framework will allow empirical derivation of a new metric; the cell cooling coefficient (CCC).

The CCC (W.K-1) is independent of cell chemistry format or geometry.

The CCC can revolutionise the cell design industry, with the potential to become a Standard measure on all datasheets aiding cell manufactures and pack designers.

CP method will assist Li battery research groups in cell comparison for EV usage and in design of thermal management.

Partners

THT THERMAL HAZARD TECHNOLOGY

Cranfield University

Imperial College London

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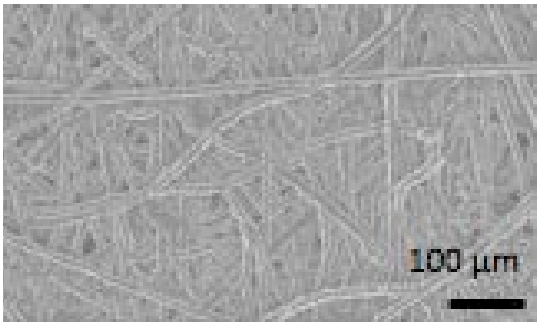
Development of 3D porous lithium electrode for new generation electric vehicle batteries

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

Project costs

Total project costs: £780,700

Grant contribution: £546,500



Executive summary

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

Timeline with milestones and deliverables

1. Commission pilot unit for manufacture of 3D Li anode material (Q6).
2. Demonstrate 3D Li anodes on coin cells and industry acceptable pouch cells (Q7).
3. 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

Sigma Lithium Ltd

Lithium Technologies for Energy Storage

JLS DESIGNS

agm batteries

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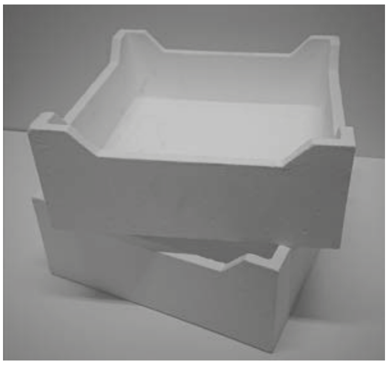
Enhanced-lifespan saggars for battery material production scale-up (SAGGAR-LIFE)

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

Project costs

Total project costs: £1,183,938

Grant contribution: £630,705



Executive summary

The aim of this project is to identify suitable ceramic materials to develop and benchmark saggars with favourable compositions and microstructure to increase saggar lifespan. This will ultimately aid scale-up to commercialise battery material production by reducing saggar volumes. This has benefits in respect to easing saggar logistics, driving OpEx down within a production plant, 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 4 key work packages with distinct deliverables and realistic milestones. The main deliverable will be commercial-scale validation of saggars and establishing a viable UK supply chain for the Li-ion battery market by late 2020.

Project innovations

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

Partners

JM Johnson Matthey Inspiring science, enhancing life

LUCIDEON Materials Development and Commercialization

Vulcan

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Faraday precision ageing laboratory

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

Project costs

Total project costs: £4,079,910

Grant contribution: £3,861,017

Executive summary

The mechanisms that cause lithium-ion battery ageing and degradation are not well understood. There is limited availability of validated data on individual ageing mechanisms and even less data on the inter-dependency of ageing mechanisms and path dependencies.

This is a major threat to the UK battery industry, 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

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

Partner

WMG
THE UNIVERSITY OF WARWICK

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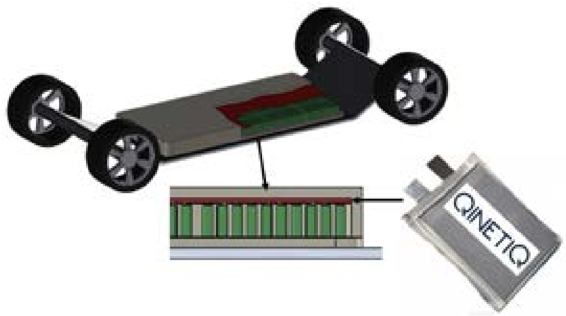
Feasibility project to dramatically extend 1st life via next generation battery management systems (HESS)

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

Project costs

Total project costs: £497,563

Grant contribution: £397,711



Executive summary

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

Timeline with milestones and deliverables

- Jan 2019– Kick-off
- Mar 2019 – HESSv1 hardware complete
- May 2019 – Delivery of high voltage electrolytes from London South Bank University to Deregallera
- July 2019 – Scale-up of Deregallera supercapacitor electrode material complete
- Aug 2019 – HESSv1software and algorithms complete – Delivered to CAPSE (USW) for FTP-72 test cycling
- Sept 2019 – Supercapacitor pouch cell production at QinetiQ complete
- Oct 2019 – HESSv2 iteration complete and delivered to CAPSE (USW) for FTP-72 test cycling
- Dec 2019 – Project end. Definition of cost/benefit analysis, 1st life, range, power vs kg/L/£ penalty of HESS.

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

London South Bank University

University of South Wales Prifysgol De Cymru

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

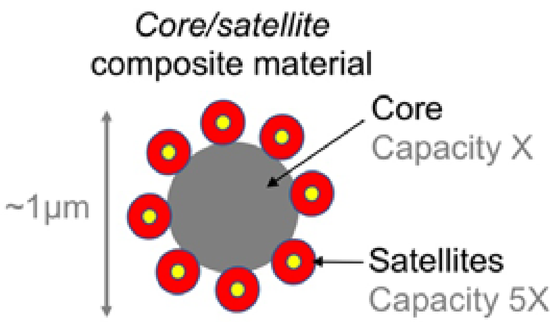
Feasibility research into composite carbon electrodes for sodium-ion batteries

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; low active skin-depth.
- The low-cost, more readily scaleable synthesis process of the core material both undercuts commercial leading materials on price while affording improved opportunity to tune material properties for specific applications.

Partners

Deregallera

University of Southampton

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FESBEV

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

Project costs

Total project costs: £241,225

Grant contribution: £152,186

Executive summary

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

This project assessed the feasibility of using a promising new 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 prospect of greater market acceptability. Additionally success would increase productivity and reduce manufacturing costs.

The project was delivered by two SME's, Ionotec and Lucideon, who brought complementary expertise and capabilities plus 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.

As a result of the feasibility study the partners are considering approaches to develop this unique technology further for exploitation in the UK.

Timeline with milestones and deliverables

The feasibility study ran between May 2018 and April 2019 and demonstrated the 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 Ionotec, Lucideon opportunity to exploit new battery concepts involving thinner walled electrolyte discs and tubes made possible through less distortion on firing.

Partners

LUCIDEON
Materials Development and Commercialization

ionotec
INNOVATION WITH ELECTROCERAMICS

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G-Cap supercapacitor in all-terrain vehicles

This project will deliver a battery pack augmented by RD graphene's supercapacitor G-Cap, validated in an EATV that can be commercialised by the end of this project

Project costs

Total project costs: £2,279,121

Grant contribution: £1,649,097

Executive summary

RD graphene's invention is the only one in the world which manufactures pure graphene foam electrodes on reel-to-reel equipment with seconds cycle times. This enables the manufacture of graphene supercapacitors ("G-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 and the University of Liverpool) will develop the next generation of EV batteries which are augmented by G-Cap to yield high-power and high-energy systems. Our cost and performance models suggest that G-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: G-Cap Supercapacitor Power Pack Build & Env. Testing

M5: Design Finalised

M9: Provide cells to MEP for pack build

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
- G-Cap fast charging power pack at TRL 7
- Scaled to high cell numbers manufacturing MRL 8
- A system-proven, best-in-market supercapacitor
- Novel Battery Management System (BMS) with capabilities to manage the unique characteristics of the G-Cap cells in a workable hybrid architecture
- Innovative Electric All Terrain Vehicle (EATV) architecture with a prototype vehicle showing significant benefits in performance, efficiency, volumetrics, mission duration and fuel economy

Partners

UNIVERSITY OF LIVERPOOL

RD graphene

Agile VEHICLE TECHNOLOGIES

MEP Technologies Battery Systems & Support

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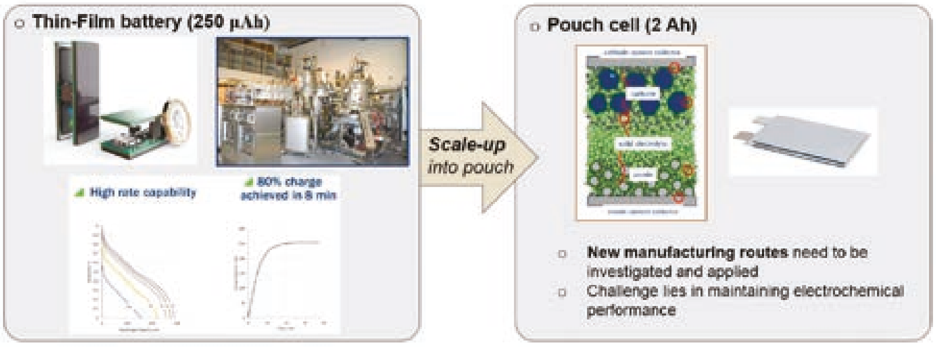
Granite – Passenger car solid-state battery

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

Project costs

Total project costs:
£2,511,652

Grant contribution:
£1,813,671



Executive Summary

Granite brings together an automotive OEM, Jaguar Land Rover (JLR), with technology leadership in battery electric vehicles (Project leader), a technology business with exciting, solid-state battery capability (Ilika), a large-scale lithium-ion battery (LIB) manufacturer (AGM), and academic experts in battery technology at Warwick Manufacturing Group (WMG). Granite is part of an ambitious plan for industrial scale deployment of UK solid-state batteries (SSBs) in JLR electric vehicles (EVs). This will deliver safer and better EVs to consumers and reduce the electricity required to power them. It will reduce range anxiety and the cost of recharging and thus increase speed of uptake of EVs, with all attendant environment benefits. Existing Ilika cells in current JLR battery packs could increase gravimetric and volumetric energy densities, enabling major weight savings and increased vehicle range and performance. Solid-state packs should also permit improved thermal management which could reduce the cost of the cooling system. Granite will focus on adjusting Ilika's SSB cell technology to JLR's target pack concepts, whilst demonstrating potential to massively scale up manufacturing to meet JLR cost targets. The performance of the cells will be tested and the scale-up modelling solution validated. Granite will deliver demonstrator-ready disruptive technology with a clear plan for large scale manufacturing and deployment in JLR vehicles.

Timeline with milestones and deliverables (March'21)

1. Solid-State cell development: Focus on inorganic solid-state electrolyte development
2. Defining the process suitable for industrial scale up of solid-state cell
3. Defining vehicle level requirements and targets
4. Concept design of battery Module and pack
5. Solid-state cell abuse simulation

Project innovations

- Focus on "beyond Li-ion" technologies for better vehicle attributes
    - Better gravimetric & volumetric energy density
    - Cost savings from safety, thermal, weight and cell costs
- Overcome challenges at the fundamental level
    - Material research, Lab scale production and
    - Industrial mass production (modification of conventional Li-ion manufacturing facilities)

Partners

JAGUAR
LAND ROVER
agm batteries
ilika accelerated materials innovation
WMG THE UNIVERSITY OF WARWICK

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High-powered anodes for fast charging buses

Innovations in high power anode materials for Li-ion cells will be industrialised and demonstrated at the automotive module level

Project costs

Total project costs: : £1,353,112

Grant contribution: £1,004,522

Executive summary

This 30-month project joins ambitious partners from academic and industrial backgrounds across the supply chain to bring new materials innovations to the automotive market.

Electric and hybrid buses currently suffer from poor availability of high-power battery packs, inhibiting their widespread uptake as very large and expensive battery packs are required.

This collaborative project will develop a module 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.

Timeline with milestones and deliverables

Project start: 1 Sep 2018 - Project end: 31 Jan 2021

Work Package Key Outcomes

WP1: Kgs/day production of anode material to specification.

WP2: High power pouch full cell design and testing.

WP3: Pilot-scale production and safety certification of cells.

WP4: Manufacture of a module with WP3 cells with thermal management and cell-level electronics.

Project innovations

- High power anode material innovation
- Pilot scale technology with "drop-in" compatibility for both material and cell manufacturing
- Active module thermal management and cell-level electronics

Partners

Echion Technologies

UNIVERSITY OF CAMBRIDGE

VANTAGE POWER

Contact:

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Vantage Power Ltd	**Email:** general@vantage-power.com	**Web:** www.vantage-power.com

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: £834,011

Executive Summary

This 18-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 Q1 2020

Battery designs finalised – End Q2 2020

System Built – Mid Q3 2020

Testing complete – Q4 2020

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

FERGUSSON ADVANCED COMPOSITES TECHNOLOGY

VANTAGE POWER

flint ENGINEERING

Brunel University London

Contact:
Steven Marchlewski **Email:** steven.marchlewski@vantage-power.com **Web:** vantage-power.com

Hybrid battery optimisation (HBO)

Optimised from start to finish – the HBO project will define the optimal combination of energy storage and deliver a hybrid system that outperforms existing alternatives

Project costs

Total project costs: £2,710,117

Grant contribution: £1,878,934

Executive summary

The Hybrid Battery Optimisation (HBO) project will develop a novel type of high-performance hybrid energy storage system (HESS) with higher power and energy storage capability per weight than existing alternatives.

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 and Aston Martin.

The optimal combination of energy storage devices will be combined into an HESS 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, a novel battery management system (BMS) will be provided by Brill Power, which can combine any type of battery energy storage while maximising performance.

The project will conclude with integration and performance testing in a high-performance Aston Martin vehicle and the development of a commercialisation roadmap.

Timeline with milestones and deliverables

Project start date: 1 July 2019

Planned completion date: 31 December 2020

The HBO Project begins with cell, system, and vehicle level modelling to be completed over the first nine months of the project. HESS system design and BMS development will be initiated in Q3 2019 and ready for integration to a test vehicle at the end of Q3 2020. Performance testing and commercial proposition development will continue to the end of the project on 31 December 2020.

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

Brill Power

delta motorsport

Aston Martin

Imperial College London

Contact:
Carolyn Hicks (Project Manager) **Email:** carolyn.hicks@brillpower.com **Web:** www.brillpower.com
Web: www.astonmartin.com **Web:** www.delta-motorsport.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 will compare cold plate cooling (using ethylene-glycol/water) with an innovative immersion cooled concept based on a synthetic ester dielectric liquid. The project will include both simulation and practical tests to assess the relative cooling performance of these methods. Experimental work will investigate the thermal performance of a battery module when the coolant comes into direct contact with battery cells and busbars. It is hoped the project can prove 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 project will consist of work streams running over 18 months, with dissemination milestones throughout this period. The final deliverable will be the release of test results, simulations and performance improvements - all demonstrating the advantages of direct immersion cooling over cold plate methods.

Project innovations

Faster charging times

- Higher power output
- Battery cell longevity

Partners

MIVOLT LIQUID IMMERSION COOLING

RICARDO

WMG THE UNIVERSITY OF WARWICK

Contact:
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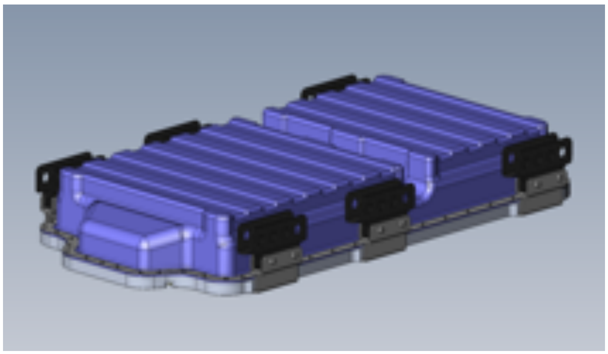
IMPACT

Improving battery cooling technologies

Project costs

Total project costs: £594,290

Grant contribution: £469,141



Executive summary

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

flint ENGINEERING

Imperial College London

REACTION ENGINES

arcola energy

Brunel University London

Contact:
Arcola Energy **Web:** www.arcolaenergy.com

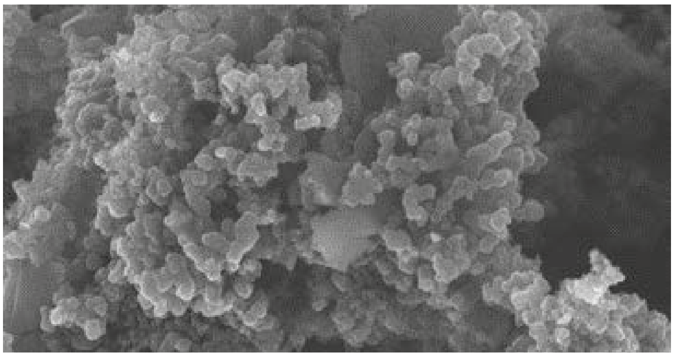
Innovative carbons for electrodes in batteries (ICE-Batt)

Enabling the adoption on next generation Li-ion cathode material components using innovative carbons

Project costs

Total project costs: £809,992

Grant contribution: £543,939



Executive summary

ICE-Batt aims to tailor innovative carbons to optimise the performance of current and next generation battery technologies. Specific materials will be designed for battery applications and utilised at the materials and at the electrode levels. These will be applied within both existing Li-ion cathode materials and for the preparation of cathode chemistries for beyond Li-ion chemistries. Furthermore, enhancing the formulation of materials will improve the sustainability of the process.

The approach that will be undertaken is as follows:

- Develop a specification for the requirement of battery
- Development of nanomaterials and composite materials that can be formulated to develop the electrode
- Formulation and optimisation of the electrode slurry
- Validating the performance of the electrodes in different cell formats

The project has the potential to deliver benefits in key performance parameters, such as increased energy density; increased power density; improved low temperature performance, as well as economic benefits.

Timeline with milestones and deliverables

M1: Battery Specification complete (Oct 2019)
M2: Nanomaterial Development complete for optimum performance (May 2020)
M4: Screening of Electrode slurries complete (June 2020)
M6: Initial electrochemical evaluation (July 2020)
M3: Optimised Nanomaterial scaled-up (Oct 2020)
M5: Scale-up of Electrode slurries complete (Feb 2021)
M7: Electrochemical evaluation of optimised systems (Mar 2021)

Project innovations

- Development of nanomaterials and composite materials tuned forcurrent Li-ion and next generation battery materials
- Optimisation and scale-up of novel carbons enabling maximum value
- Evaluation of improved electrode slurry formulations
- Electrochemical validation of optimised materials and electrodes in multiple cell formats

Partners

Johnson Matthey
Thomas Swan
cpi

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IDMBAT - Intelligent enterprise data management platform for battery manufacturing

IDMBAT is addressing a substantial gap in the market by developing software solutions for battery manufacturers 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: £498,587

Grant contribution: £369,249

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 (M4)
- AI methodology development (M8)
- Intelligent enterprise data management platform, Alpha version (M12)
- Summary of achievements (including quantification of benefits on use cases) and next steps (M12)

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

Partners

ANSYS GRANTA

UNIVERSITY OF BIRMINGHAM

Intellegens

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Ben Pellegrini	**Email:** ben@intellegens.co.uk	**Web:** www.intellegens.ai
Emma Kendrick	**Email:** E.Kendrick@bham.ac.uk	**Web:** www.birmingham.ac.uk

LIBRIS: Lithium-ion battery research in safety

This project aims to understand, detect and inhibit battery thermal events within both transient and stationary applications

Project costs

Total project costs: £6,770,849

Grant contribution: £4,846,466

Executive summary

LIBRIS will survey the current state of the art in Li-ion battery (LIB) safety, analyse real-life hazards encountered in the EV LIB life-cycle and assess test coverage by typical standards & regulations addressing thermal runaway (TR) hazards. The findings will inform a physical testing program from single cell to pack level addressing: cell formats; chemistries; and layouts commonly used in electric vehicles and in energy storage units. The physical test findings will inform characterisation methods for physical mitigation strategy effectiveness, display impact of new materials and packaging solutions, support validation of numerical modelling methods, and allow evaluation of novel sensing methods to support timely interventions. Validated modelling approaches will be 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 inherently safe LIB systems for commercial applications.

Timeline with milestones and deliverables

Start date 1 July 2019, end date 31 December 2020

- 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

Contact:
Philip Richards **Email:** prichard@jaguarlandrover.com

LiNaMan - Sodium battery

Produce a design for manufacture for an innovative sodium battery

Project costs

Total project costs: £234,438

Grant contribution: £198,712

Executive summary

The LiNaMan feasability study will establish the feasibility of the design for a sodium-nickel-chloride battery for automotive and energy storage applications. LiNaMan is a collaboration between three UK organisations: (1) LiNa Energy Ltd - project lead; (2) the Lancaster University; and (3) the Centre for Process Innovation CPI.

The IP at the heart of the project is LiNa Energy's innovative design for a Na-Ni-Cl cell; the first step of patenting the LiNa cell concept is almost complete.

Sodium battery chemistry has many advantages over the lithium-ion cells which currently dominate automotive and stationary energy storage markets: sodium batteries are safer, cheaper and do not need scarce or precious metals, cobalt in particular. However, they have until now been confined to niche markets, largely because developers could not mass produce them cheaply.

In project LiNaMan, the partners will evaluate new cheap nano-engineered ceramics and advances in manufacturing techniques to produce a design for manufacture for its sodium battery. Work will proceed on both the design of the cell, design of the active-layer material, and the design of the process for its mass manufacture. Developments in each of these areas will have knock-effects on the others.

Timeline with milestones and deliverables

The project has a duration of 12 months, finishing on 31 October 2019. At the time of writing, assembly of first prototype LiNa Cell, and initial testing has been achieved. Further work will take place to optimise the prototype and develop manufacturing processes. The final set of deliverables will include technical drawings and manufacturing PFD; analysis of cell performance data; a process economic assessment. The final Milestone will be the demonstration of the Design intent cell.

Project innovations

Innovation in the project is in achieving a novel design for the manufacture for sodium batteries, exploiting new processes and materials, making sodium batteries both commercially and technical viable in automotive and energy storage applications

Partners

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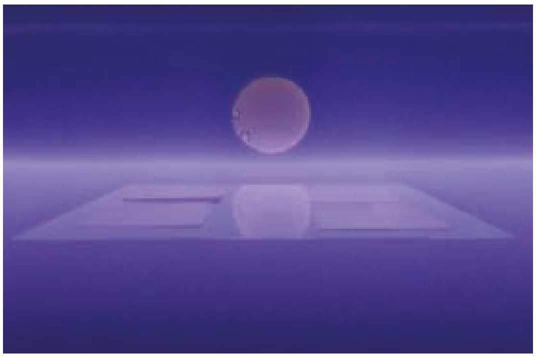
LIFE: Lithium innovation for future electric vehicles

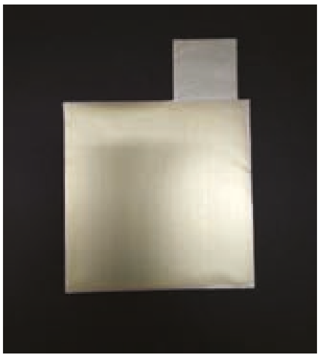
Scaling production of advanced lithium metal anodes

Project costs

Total project costs:
£625,237

Grant contribution:
£498,588





Executive summary

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

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

Timeline with milestones and deliverables

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

Project innovations

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

Partners

oxis ENERGY
Next Generation Battery Technology

cpi

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LiS:FAB - Lithium-sulfur: Future automotive battery

Powering electric buses and trucks with lithium-sulfur batteries

Project costs

Total project costs:
£6,846,916

Grant contribution:
£4,637,075

Executive summary

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

Timeline with milestones and deliverables

Requirements set by steering committee

2008 → 2019 → 2020

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

Project innovations

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

Partners

Contact:
Email: david.ainsworth@oxisenergy.com **Web:** https://oxisenergy.com/oxis-energy-chosen-aerotecs-first-international-investment-2/

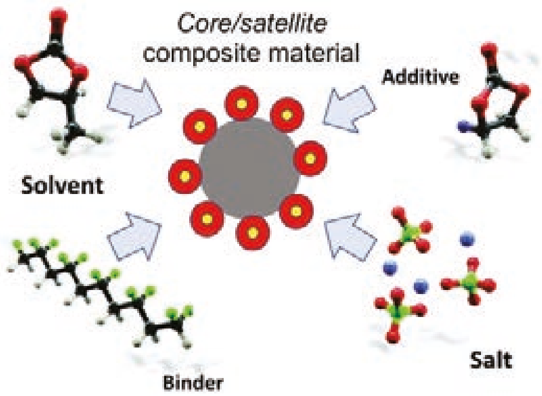
Low-cost, scalable and agile synthesis routes for sodium-ion battery materials

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

July 2019 Project kick-off
Oct 2019 Delivery of Deregallera's prototype positive electrode to Southampton
Dec 2019 Intermediate scale-up of Deregallera's prototype positive and negative materials
Jan 2020 Optimised electrolyte/binder defined composite negative electrode from Southampton
Feb 2020 Production of Deregallera's first prototype full NIB pouch cell
Jun 2020 Production of Deregallera's premium NIB pouch cell
Sept 2020 Conclusion of economic and technical assessments of project materials processes
Dec 2020 – Project close

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
London South Bank University
NPL National Physical Laboratory
University of Southampton

Contact:
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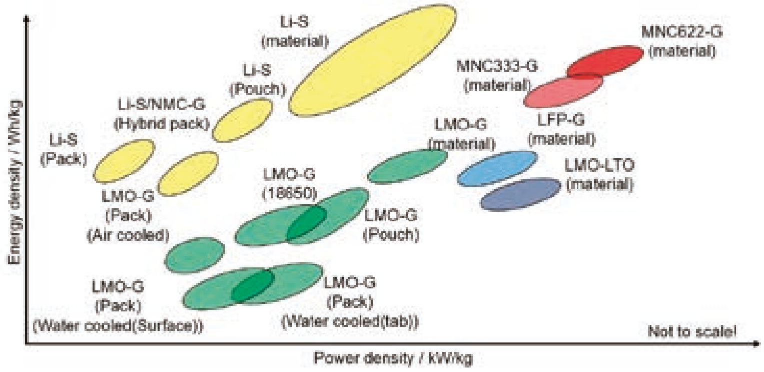
MAT2BAT - A holistic battery design tool from materials to packs

Project costs

Total project costs: : £327,838

Grant contribution: £259,616



Executive summary

The vision of the MAT2BAT project is to develop a holistic battery pack design software tool to accelerate and catalyse innovation for the development of battery packs within a framework which is easy to use. Such a tool would encompass several design domains: material selection (cell database), cell form factor, battery pack design, thermal management systems and material selection for pack construction. From this high-level framework, figures of merit such as energy/power density, cost, embodied energy and recyclability can be quickly explored to find suitable pack designs

Timeline with milestones and deliverables

M2	Software development completed	Month 10
M3	Trials complete and feedback received	Month 12
D1.1	List of materials and battery chemistries for selection, end user requirements (Report)	Month 3
D1.2	Selection criteria and algorithms established (Report)	Month 6
D1.3	Model pack designs summary (Report)	Month 7
D2.1	Database created and populated (Demonstration)	Month 7
D2.2	Back end software development (Demonstration)	Month 10
D2.3	Front end development and UI (Demonstration)	Month 11
D3.1	Trials and further development (Report)	Month 12

Project innovations

- Development of a holistic design tool incorporated in Granta's CES Selector software which considers the impact of designdecisions from chemistry selection to pack design and the materials used to enable more rapid design of battery systems. The relevant battery material property data, detailed cell/pack design frameworks and an intuitive user interface will be created for a holistic and easy to use battery design tool.
- The analytical approach in chemistry selection will enable companies to explore the likely impact of current and future chemistries.

Partners

GRANTA MATERIAL INTELLIGENCE

DENCHI POWER

Imperial College London

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Billy Wu **Email:** billy.wu@imperial.ac.uk
Nick Russel **Email:** nick.russel@denchipower.com

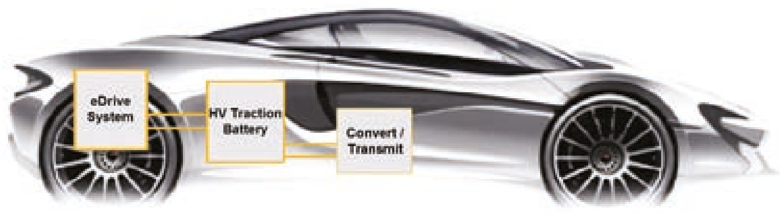
MoSESS: Multi optimal solutions for energy storage systems

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, optimized crash structure for battery, as well as reduced charging time and weight. The project will deliver significant increase in technology and manufacturing readiness levels, together with an innovative modularly designed battery to allow the final integration into a demonstrator. This project will unlock the possibility to deliver a mobility solution that matches the usability provided by conventional vehicles today, and meet consumers' expectation, hence accelerating the uptake of hybrid and electric transport solutions.

Timeline with milestones and deliverables

Q1 2019: Project Kick-Off

Q3 2019: Design and Prototyping

Q2 2020: Validation Results Available

Project innovations

Objectives:

- Next Generation cell technology
- Prototyping and characterisation of cells and packs
- Validation of Energy Storage Systems within a demonstrator

Challenges:

- Cells and Pack to achieve automotive qualification
- Current technology is not mature for the demands of high-performance cars

Partners

McLaren

A123 SYSTEMS

ilika accelerated materials innovation

WMG THE UNIVERSITY OF WARWICK

Contact:
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Novel carbon allotrope for lithium-ion batteries (CALIB)

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

Project costs

Total project costs: £506,143

Grant contribution: £370,946

Executive summary

Plasma App, Cambridge University and Johnson Matthey PLC have explored the new 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.

Project innovations

Active material for EV battery	900 mAh/g retained specific capacity
	Arial capacity of 4.2mAh/cm² of electrode
	Dopants to increase capacity
Electrode macturing method	Deposition process of 20um of CALIB
	CALIB deposition process on separator
	Twofold reduction of anode weight
	Threefold reduction of anode volume
Structure and properties	Identified morphological properties of the CALIB
	Defined reason for capacitance increase
	Polymorphism model

Partners

PLASMA APP

Johnson Matthey
Inspiring science, enhancing life

UNIVERSITY OF CAMBRIDGE

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

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 EU grant in 2014 to 15, were followed by a larger Innovate UK funded project in 2016 to 17 testing the system on a full-scale replica of a civil airliner auxiliary power unit battery. The current project has equipped 3 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 two conventional modern electric vehicle BMS, one OEM and one an off-the-shelf aftermarket. Initial results suggest the test system permits the use of more usable capacity. Testing continues and we intend to evaluate the effect on service life over time

Timeline with milestones and deliverables

The project ended in April 2019. We expect field trials and data recording to continue through 2019 and 2020. The hardware and software have been successfully developed, and will be further refined in the light of the field trials in a follow-on project. This will allow us to offer full scale beta-test kits to OEMs from late 2019, and/or selling production kits to smaller scale users from about late 2020.

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

INTERCAL
BATTERY MANAGEMENT SYSTEMS

INDRA

CIA Technology Global

Contact:
Email: admin@intercal.uk.com

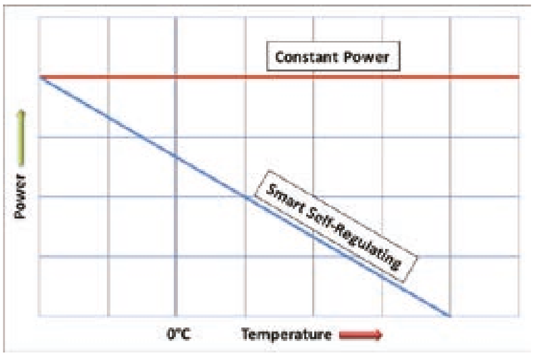
Novel self-regulating CHIP (cooling or heating integrated pipe) for BTMS

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

Project costs

Total project costs: £499,903

Grant contribution: £342,424



Executive summary

Our vision, in this 12-month feasibility study, is the transfer of Heat Trace's aluminium-based polymeric smart self-regulating heating technology into EV BTMS. Self-regulating heaters cannot burn out which will eliminate thermal runaways due to heater design.

Compared to current designs, the CHIP technology has the potential to give significant benefits in 7 of the 8 Faraday targets. The most important potential benefits are improved safety, reduced costs and reduced weight of the EV batteries.

Timeline with milestones and deliverables

1. Development of self-regulating heating prototypes
2. Incorporation of liquid cooling capability
3. Development of a combined heating/cooling module (CHIP)
4. Development of electrical and fluid connectors

Project innovations

The innovative features include:

- The CHIP module can be operated either as a heating module or a cooling module
- The self-regulating polymeric heater improves safety and minimises the variation of cell temperatures
- The aluminium-based design enables flexible geometry and weight reduction. The CHIP module can be customised to any cell type or battery pack configuration

Partners

Nobel Automotive

HEAT TRACE™ SETTING THE STANDARDS LEADING THE WAY

WMG THE UNIVERSITY OF WARWICK

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Abhishek Das Email: A.Das.1@warwick.ac.uk /

PreLIBS

Preliminary Feasibility Study of Lithium Ion Battery Safety. Objective-Safety related to thermal runaway

Project costs

Total project cost: £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)

- Lliterature review
- Single cell failure characteristics
- Mitigation strategies
- Computational modelling

Project innovations

- Understanding of existing and 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 2019 for details

Partners

lifeline® Fire & Safety Systems Ltd

POTENZA

WMG THE UNIVERSITY OF WARWICK

3M

HEALTH & SAFETY LABORATORY

Warwick FIRE Warwick University

JAGUAR

LAND ROVER

Contact:
Email: innovation.uk@mmm.com

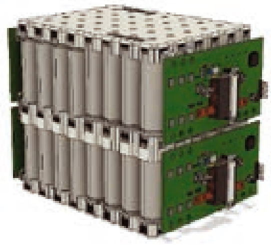
Printed sensors for EV battery current density imaging

This project is developing new sensors using printable electronics to map the current flow of standard cells in an existing battery pack

Project costs

Total project cost: £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 will be integrated into an existing battery pack design manufactured by Aceleron with existing BMS hardware from Brill Power using the CAN bus interface. New software algorithms will be developed to make improved use of cells in the battery pack and improve safety by incorporating the current density imaging measurements.

The resulting demonstrator battery pack will showcase this new sensing technology in a manner capable of being readily incorporated into existing automotive battery pack designs.

Timeline with milestones and deliverables

Project duration: June 2019 – May 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 · peacock Technology ltd · Brill Power · ACELERON · cpi · University of Strathclyde Glasgow · University of Sussex

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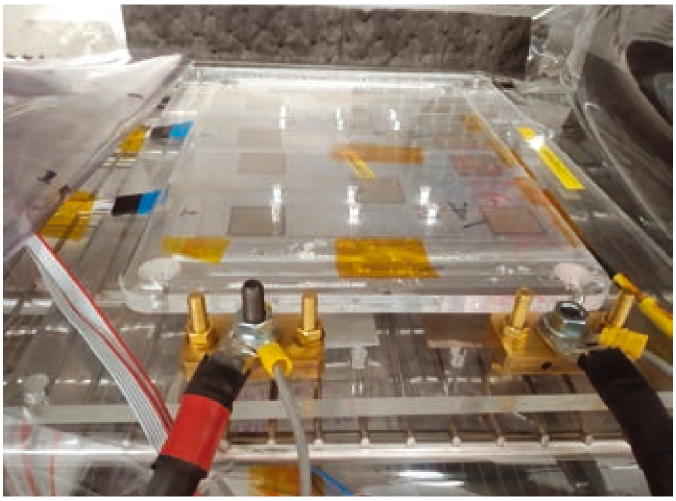
Printed temperature sensors for use in battery monitoring systems working within the cells/batteries

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

Project costs

Total project costs: £235,515

Grant contribution: £199,854



Executive summary

Printed thin film temperature sensor arrays were developed to monitor EV battery systems. Arrays of temperature sensors were placed between heater beds to mimic battery cells and how temperatures would conduct through a stacked cell. The positions of the temperature changes are easily identified in the stack using the sensor arrays.

Timeline with milestones and deliverables

Timeline with Milestones and Deliverables Confirmation of how the charge and discharge of batteries causes temperature variations, as great as 7 degrees, during in rapid cycling can help work towards better battery management and battery life. External partners, WMG Warwick University and Liverpool University, confirmed these results with independent tests. After a 15 minute cycle and a constant 6A current, the temperature increased up to 33 C, then returns to the initial 24 C after ~1 hour after the cycle. This shows the large scale temperature increase over time and the smaller changes that occur during charging

Project innovations

Up-scale for printing the arrays was successfully used on a roll-to-roll machine, printing 150 metres worth of sensor arrays. The printed sensors on the roll were also becoming completed devices with the help of CPI and their specialist equipment. Automotive parts manufacturers have shown interest in this technology to enhance their products.

Partners

PST SENSORS

cpi

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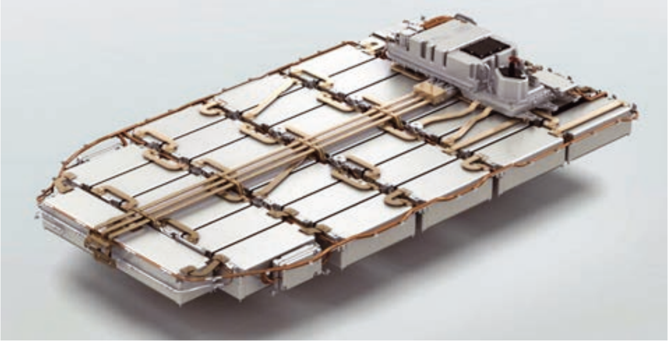
Project DETAIN

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

Project costs

Total project costs: £235,515

Grant contribution: £199,854



Executive summary

Project DETAIN focuses on the supply chain challenge of safely and efficiently storing HV lithium-ion batteries. Current best practice dictates standalone, sacrificial buildings and a 'let it burn' approach to managing thermal runaway events. For small numbers of battery packs, this is acceptable, but isn't at any level of scale.

Timeline with milestones and deliverables

To detect thermal runaway there will be three areas of focus: 1) BMS thermal runaway detection algorithms for next generation hardware, 2) externally mounted (on battery) thermal runaway detection systems, and 3) distributed sensor networks for battery storage facilities.

Project DETAIN's objectives are to:

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

Project innovations

Thermal runaway detection technologies to identify solutions in the short to long term: infrastructure-based sensor networks, sensitive externally mounted battery monitoring equipment, and BMS control strategies combining the electrical and chemical analysis techniques.

Thermal runaway containment technologies, automation and fire suppression individually and in combination.
The requirements for an effective, accepted and scalable solution design

The effects of battery fire contamination and a specification for a battery integrity and thermal runaway test facility (to ensure that the solutions designed can be tested and confirmed to reduce risks).

Partners

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Unipart Logistics **Email:** david.lydiat@unipart.com **Web:** www.unipartlogistics.com

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 cost: £3,520,090

Grant contribution: £2,461,238

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.

Project objective is to reclaim all of the materials and components from end of life LiBs and remanufacture into new battery with comparable performance to those made with primary raw materials.

Key deliverables (30-month project)

Development of laser opening module	end 2019
Development of physical separation processes	mid 2020
Samples of NMC precursors from recycled materials	mid 2020
Synthesis of NMC cathode materials from recycled metals	end 2020
Cell remanufacture and characterisation	early 2021
LCA review of process	early 2021

Project innovations

- Controlled automated laser cutting of battery cells
- Pphysical separation of constituent parts
- Use of novel solvent blend for recovery of PVDF
- Recovery of graphite (not currently a focus for recycling processes)
- Hydrometallurgical process for recovery of Co, Mn, Ni and Li
- Development of cathode materials from recycled metals

Partners

Industrial Partners

PV3 Technologies, IConiChem, circa, M-SOLV Limited

Research Partners

University of York Green Chemistry Centre of Excellence, University of Birmingham, WMG The University of Warwick

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Paul Croft (Operations Director, ICoNiChem Widnes Ltd) **Email:** pcroft@iconichem.com

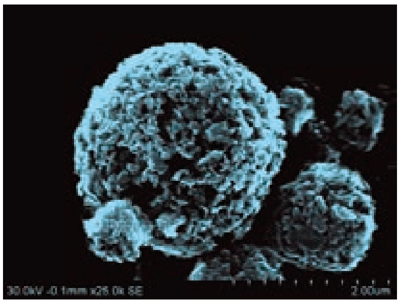
Safe high voltage EV battery materials - SAFEVOLT

Safe and high energy density EV battery materials development via graphene-silicon anode, high voltage cathode and Ionic liquid electrolytes

Project costs

Total project costs: £528,887

Grant contribution: £421,207



Executive summary

Current lithium-Ion battery technologies are facing challenges in terms of safety, efficiency to operate over 4V and are heavy. Within SAFEVOLT project, Johnson Matthey, Talga, University of Cambridge and TWI ltd evaluated the feasibility of improving energy density of the cell by focussing on improvements in electrode materials and addressing safety aspects of the cell by testing alternative electrolyte materials that are non-flammable. The project aims to achieve 60% improved energy density over current technologies on the materials level.

Timeline with milestones and deliverables

3/2018 - 8/2018: Half cell of high energy capacity anode and cathode prepared and tested; Room temperature Ionic Liquid electrolyte initial test completed.

4/2018-12/2018: Anode, cathode and ionic liquid electrolyte optimized.

5/2018 - 1/2019: Best materials selected and work package reported.

12/2018-2/2019: Thermal analysis, NMR studies and full cell evaluation completed.

2/2019 - Project end

Project innovations

- Silicon composite anode with improved cyclability (> 300 cycles @80% retention). Demonstrated compatibility with high voltage electrolytes and stability in full cells.
- Developed alternativ synthesis pathways for high voltage cathodes.
- Further understanding and scaling of a higher energy density material with improved safety over current materials.
- Identification of two Ils as potential electrolytes for silicon-containing Li-ion batteries.
- New insights into high temperature stability in RTILs with silicon anodes (> 55 deg C). Capability to test safe cycling regimes in large format cells at TWI.

Partners

talga

TWI

JM Johnson Matthey Inspiring science, enhancing life

UNIVERSITY OF CAMBRIDGE

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SAMBA: Smart automotive managed battery algorithms

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

Project costs

Total project cost: £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 algorithms learns 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 deliverable that can be retrofitted to other existing dumb chargers, allowing these charges to connect to the cloud-based planning systems which in turn rely on the created AI demand prediction algorithms.

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

Partners

mA milliamp technologies

MIRALIS

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Scalable ultra-power electric-vehicle batteries (SUPErB)

Combining the power and cycle-life benefits of a supercapacitor with the energy benefits of a Li-ion cell

Project costs

Total project costs: £1,194,102

Grant contribution: £514,067

Executive summary

One of the 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 aims to lift this limitation using advanced electrode materials and Li-ion battery engineering. The ultra-high-power cells for electric vehicle batteries that the SUPErB project will develop will have very high peak power handling capability and the SUPErB project will demonstrate, for the first time, 10 kW.kg-1 and 40 Wh.kg-1 at the cell level. This will enable improved peak-power handling in EV main traction batteries. Spin-off applications are numerous with the technology finding use in fast charge stations and transport, UPS and military applications.

The project aims to achieve this at scale using high performance, complementary cathode and anode materials developed on a pilot-plant at University College London (UCL), proprietary, scalable manufacturing processes developed at Echion Technologies Ltd, and high-power cell design and manufacture by QinetiQ. The University of Birmingham (UoB), will optimise ink formulations and electrochemistry fundamentals to improve performance. William Blythe will test and assess the manufacturability of the ultra-high-power materials with a view to scale-up for manufacture. An advisory group composed of automotive manufacturers will provide the end-user requirements, advice and guidance.

Timeline with milestones and deliverables (March 2021)

- Benchmarking state-of-the-art high-power cells and initial formation studies
- Cathode materials development, analysis & down selection; scale-up of CHFS
- Development of new anode materials
- Development of electrodes, inks and test cells using new materials
- Continued formation studies on test cells
- kg scale-up of electrode materials integrating continuous synthesis techniques
- Manufacturability and scale-up assessment of high-throughput materials and processes
- Demonstration of ultra-high-power cells

Project innovations

The SUPErB project will demonstrate, for the first time, 10 kW.kg-1 and 40 Wh.kg-1 at the cell level using high performance complementarity cathode and anode materials, scalable manufacturing, and high-quality commercial grade cells. The project will build on nanostructured materials produced so far by incorporating low-cost conductive additives and coatings, at scale from the outset, and will test optimised materials in cells of intermediate capacity. The project will make use of optimised ink formulations and electrochemistry to improve performance.

Partners

QINETIQ

Echion Technologies

UCL

UNIVERSITY OF BIRMINGHAM

williamblythe Excellence in chemistry

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Gary Mepsted **Email:** GOMEPSTED@qinetiq.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

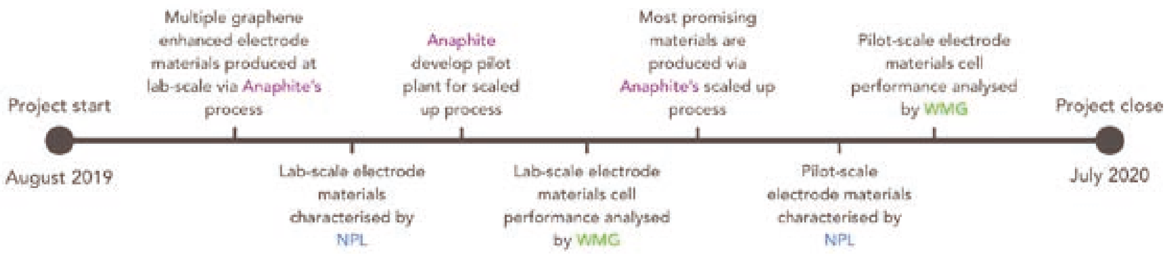
Total project cost: £499,683

Grant contribution: £394,664

Executive summary

Lithium-ion batteries (LIBs) are a key enabler of the move towards electric vehicles and decarbonisation of transport. However, to meet government targets to phase out internal-combustion vehicles, limitations in energy density, power density, safety, and battery lifetime must be addressed. Improved electrode materials can enable these developments. Metal-oxides are a promising class of materials, offering significant advantages in power density, energy density, and cycle stability compared with the current state-of-the-art. Existing metal-oxide electrode materials suffer from poor electrical conductivity and sometimes poor mechanical stability under cycling, which has largely prevented them from being commercialised. 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 explores multiple graphene-metal oxide composites already demonstrated as promising electrode materials (where previous work used graphene oxide). With the Warwick Manufacturing Group (WMG), we will carry out extensive analysis of electrochemical properties, demonstrating technical feasibility of GMO composites formed with Anaphite's process. We will cost-effectively scale-up Anaphite's process via the development of a pilot facility, capable of producing kgs of materials/day, while maintaining quality. This positions us to partner with LIB

Timeline with milestones and deliverables



Project innovations

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

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

Partners

Anaphite

WMG
THE UNIVERSITY OF WARWICK

Contact:
Email: Web:

Second life lithium-ion: Recovery, reconfiguration and reuse (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 (Oct 2019)

Primary objectives:

i) 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;

ii) deepen understanding of Second-Life-Battery characteristics, and determine 'optimal' secondary application;

iii) ascertain/quantify surrounding commercial opportunities (collection; sorting; cell maintenance).

Data gathered on technical performance and economics will be critical for validating the remanufacturing opportunity and guiding post-project exploitation.

Project innovations

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

Partners

Loughborough University

POWERVAULT

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D Strickland **Email:** d.strickland@lboro.ac.uk **Web:** https://www.lboro.ac.uk/research/crest/

Securing domestic lithium supply chain for UK (Li4UK)

Feasibility Study to examine potential domestic lithium resources; viability of extracting these resources and locating a lithium conversion plant in the UK to create a critical new industry for Britain

Project costs

Total project cost: £475,744

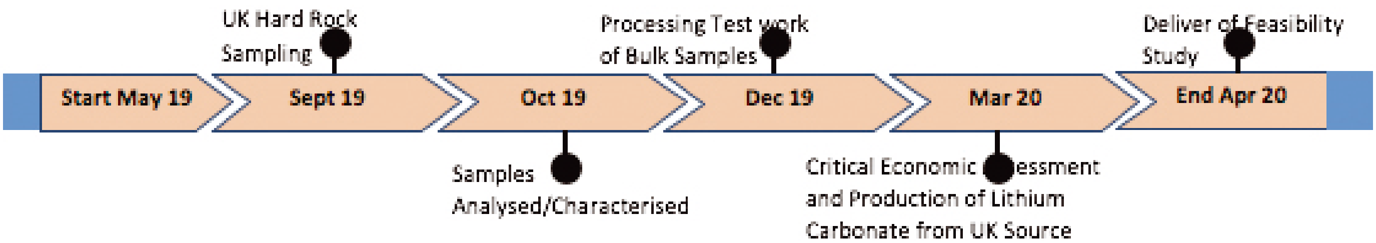
Grant contribution: £358,566

Executive summary

The Li4UK Consortium is will address critical missing links in the UK's battery supply chain, identifying potential UK lithium resources and developing the requisite processing/conversion technologies to ensure lithium can be supplied from UK resources.

This Project is an innovative approach to sourcing a domestic supply chain of lithium. Currently the UK is reliant upon Chinese imports of lithium compounds used in the manufacture of lithium-Ion Batteries. Mineral processing and conversion routes exist for spodumene but currently no commercial mineral processing/conversion flow routes exist to treat lithium bearing mica. Much of the UK lithium is contained in micas. Once technical viability has been established preliminary economic appraisal and identification of the optimum siting of a conversion plant to convert lithium mineral concentrates to lithium carbonate/hydroxide will be considered.

Timeline with milestones and deliverables



Project innovations

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

Partners

wardell armstrong

Natural History Museum

Cornish Lithium

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Jeremy Wrathall, Cornish Lithium Limited — **Email:** j.wrathall@ccornishlithium.com — **Web:** www.cornishlithium.com

Sodium-ion batteries for automotive power applications

The project will develop low-cost sodium-ion technology for 12 V SLI batteries, focusing on the optimisation of rate capability and temperature range, before demonstration of the technology within a vehicle

Project costs

Total project costs: £2,032,490

Grant contribution: £1,506,223

Executive summary

12 V SLI batteries typically use lead acid technology, due to its low cost and specialist requirements (high power, wide temperature range). The six-partner consortium will use its complimentary skills to replace these lead acid batteries with sodium-ion (Na-ion) batteries, a new technology, providing benefits over lead acid including weight, volume and sustainability. Na-ion batteries are a new and exciting technology, and their many similarities to lithium-ion (Li-ion) technology means 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 successful demonstration of Na-ion technology in a 12 V system will lead to the technology being further developed for 48 V MHEV systems, with future aims to trial this technology in BEV systems.

Timeline with milestones and deliverables

This 3-year project runs from March 2018 to February 2021. The deliverables comprise the development of active materials for sodium-ion batteries, along with the optimisation of electrodes and electrolytes for high rate capability. High power pouch and cylindrical cells will be designed, built and tested under the conditions required in the target application. The optimised cells will be integrated into a battery pack, with a BMS, and this will be demonstrated within a vehicle.

Project innovations

Faradion is maximising the power capability of its Na-ion technology. Croda is developing additives to improve electrode performance. Talga is developing anode materials. The University of Birmingham is investigating electrolytes and test methods. WMG is involved in the scale-up, and cell build, using both pouch and cylindrical cell designs. Jaguar Land Rover will design and build a battery pack, develop a BMS and demonstrate the technology in a vehicle.

Partners

FARADION Advanced Energy Storage Solutions

CRODA

UNIVERSITY OF BIRMINGHAM

talga

WMG THE UNIVERSITY OF WARWICK

JAGUAR

LAND ROVER

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Richard Heap **Email:** info@faradion.co.uk **Web:** https://www.faradion.co.uk/

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

18 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 scaleable 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

Phoenix Scientific Industries Ltd
Advanced Process Solutions

University of Oxford

agm batteries

nexeon

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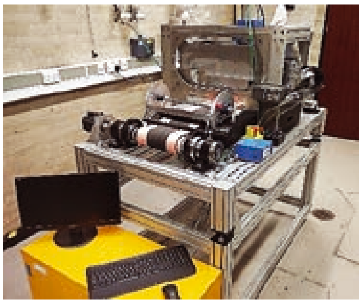
Spraycoat

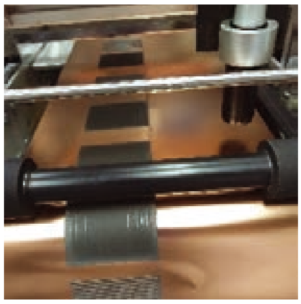
To develop innovative new electrode coating methods which have the potential to revolutionise both unit cost of a battery, its performance and its lifetime

Project costs

Total project cost: £378, 070

Grant contribution: £304,321





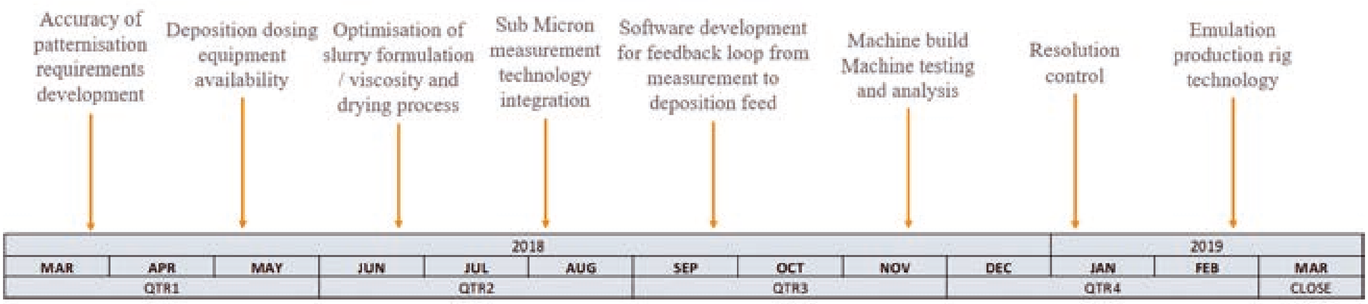
Executive summary

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 1/2 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

KWSP KW SPECIAL PROJECTS LTD

WMG THE UNIVERSITY OF WARWICK

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SUNRISE

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

Project costs

Total project costs: £9,612,706

Grant contribution: £6,989,114

Executive summary

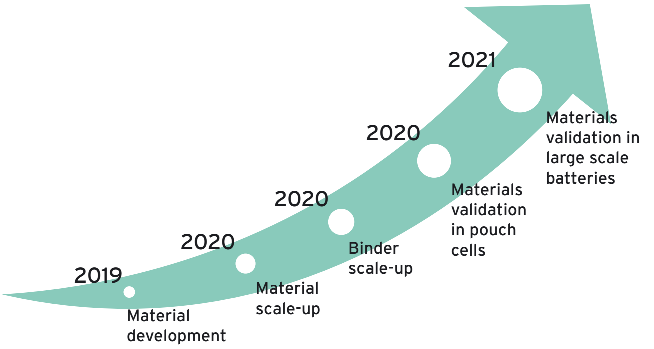
The SUNRISE project will deliver a novel silicon anode system for advanced lithium-ion batteries.

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

Timeline with milestones and deliverables

3-year project, 1 March 2018 to 28 February 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 customer 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

nexeon

synthomer

UCL

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SCALE-Up: Supply chain accelerator for Li-ion electrode materials in UK

Project costs

Total project cost: £1,223,380

Grant contribution: £956,423

Table 1 Automotive Council UK's summary of lithium-ion battery value chain and TRL levels showing Scale-Up's position.

	Material and Electrochemistry	Cell Components	Cell and Cell Manufacture	Module, Pack and BMS	Application Integration	Recycling and 2nd Life
Discovery TRL1-3	1a • Material discovery • Functional material • Degradation/ageing • Material modelling • Synthesis evaluations • Synthesis process design • Material manufacture (<300g)	1b • Rheology and mixing • Electrode compositions • Electrode structures • Electrolytes and additives • Ageing and degradation • Current collections	1c • Cell testing methods • Cell design and form factors • Measurement techniques • Thermal and mechanical designs • Ageing and degradation	• Prognostics and diagnostics • Mechanical and thermal designs, BMS+electronics • BMS alogorithms and architecture	• Real world applications simulations (Hardware in the loop) • Duty cycle and big life testing • Integration design	• Physical and chemical processes of material recovery • Material re-use options • Value modelling and circular economy
Application TRL4-6	2 • Optimisation of material compositions • Synthesis at scale (5kg) • Materials evaluation QC methods • Industrial validations	3 • Synthesis at scale (200m) • Manufacturing technologies • Flexible manufacturing methods • Industrial validation	4 • Cell evaluations • Monitoring and managing degradation • Manufacturing at scale (>0.5Ah)	• Measurements and testing • Joining and electrical contacts • Pack scale thermal management solutions	• Field data analysis • Test processes • Development processes application integration safety and control	• Design for disassembly • BMS and diagnostics for 2nd life • Requirement for remanufacture
Manufacture TRL7-9	• Volume manufacturing • Industrial metrology • Manufacturing methodology • Process parameter control	• Supply chain integration and logistics • Manufacturing process and quality control	• Manufacturing and assembly methods • Testing in integrated environments • Supply chain	• Assembly methods • Manufacturing process and quality control in process testing	• Industrial trial and validations • Designs of manufacturing plants	• End of life logistics and dismantling techniques • Full scale plant and design economics

Executive summary

This project aims to create and accelerate the supply chain development for advanced electrode materials needed to produce next generation EV lithium-Ion batteries in the UK. Talga Technologies Ltd and PV3 Technologies Ltd envision a scale-up of cost effective methods to produce high energy density anode and cathode materials respectively.

WMG the academic partner will support the industrial partners, through investigation of the material electrochemical properties, through cell research and development, and translation through to a validation run at a cell maker.

Timeline with milestones and deliverables

Establish battery materials manufacturing and supply chain for battery materials in the UK:

- March 2019, PV3 Technologies Ltd develop synthesis route for high nickel NMCs, for high tap density and high gravimetric energy density
- March 2019, Talga Technologies Ltd develop synthesis route for high-energy density graphite, through novel exfoliation and purification methodologies
- July 2019, WMG Develop high nickel NMCs/graphite in small coin cells and manufacture small pouch cells (2Ah) for further verification of protocols for cell performance
- December 2019, Talga Technologies Ltd and PV3 Technologies outsource manufacture of large pouch cells (10Ah) to AGM batteries for material, cell and development validation

Project innovations

The main innovation challenge addressed is the manufacturability of these next generation electrode materials at scale.

Demonstrate scalability
Cell cycle life: 2000 cycles at 80% DoD First cycle reversible capacity: <10% Overall energy density: 20% improvement
Cost: comparable with existing materials.

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

Partners

talga

P|V|3 TECHNOLOGIES

WMG THE UNIVERSITY OF WARWICK

Contact:
Talga Technologies Limited Unit 15-17 Cambridge Science Park Milton Road Cambridge CB4 0FQ United Kingdom
Web: http://www.talga.co.uk/ Email: admin@talgatechnologies.com Phone: +44 1223420416

Synergy

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

Project costs

Total project costs: £1,106,624

Grant contribution: £760,826

Executive summary

Synergy is focused on developing step changes in the performance and environmental friendliness of lithium-ion batteries to meet the needs of electric vehicles. 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 AGM Batteries.

The project will lead to manufacturing and performance improvements in the anode system. It will also focus on 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

18-month project, September 2019 to February 2021:

- First cathode material developments — Q1 2020
- Scale-up of cathode electrode active — Q1 2021
- Scale-up and validation of optimised Binders — Q4 2020
- Screening of electrode slurries — Q2 2020
- Optimised slurry scale-up — Q1 2021
- Pouch cell validation of developments — Q1 2021

Project innovations

- Optimised anode binder & formulations
- Next generation cathode binders
- Water stable cathode active materials

Partners

synthomer

williamblythe
Excellence in chemistry

agm batteries

cpi

Contact:
Tom Castle **Email:** tom.castle@synthomer.com

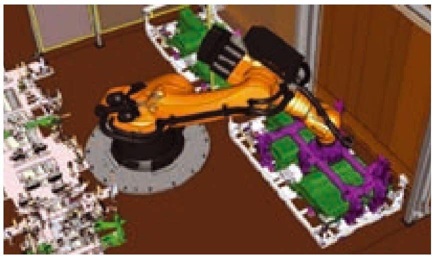
Technical feasibility study (TFS) of battery remanufacturing for electric vehicles (BATREV)

The primary aims of the BATREV Project are to determine how robots could be used as a de-risking process to protect people from the risks of disassembly of high voltage batteries, which is required to support 'End of Life Vehicles Directive'; and to provide a clear understanding of the processes needed to scale-up these processes to account for high levels of component variability.

Project costs

Total project costs: £433,895

Grant contribution: £292,277



Executive summary

The main motivation of BATREV Technology Feasibility Study (TFS) addresses the need for remanufacturing warranty-return & damaged/worn/EoL Electric Vehicle Batteries (EVBs), which are increasing exponentially as EV manufacturers compete fiercely. The main state-of-the art address high-volume/low-variety EVB-remanufacturing markets. BATREV outputs will be at virtual-demonstrator-level, i.e.: (1) TFSPLAN & TFSSIM database tools of RRE simulation assets enabling (i) creation & visualisation of RRE-scenarios, (ii) RRE mechanical-characteristics, (iii) end-effector motions, (iv) scalability and manufacturability data-collection & output to TFS. (2) TFSOPT AI-enabled tool for optimised RRE Planning & QCDE characteristics. The BATREV project will undertake a feasibility study to identify the scalability, manufacturability and capability of using autonomous robots and autonomous operations planning systems to undertake the remanufacturing of EVBs. Providing understanding of processes needed, de-risking scaling-up of Robot Remanufacturing Engineering (RRE) technology and autonomous operations planning, making scaling-up faster and less costly with a greater effect on UK competitiveness.

Timeline with milestones and deliverables

Technical Deliverable & Milestone1: Detailed & validated requirement specifications report for BATREV (HAL) occurs end of Month 2 & witnessed by BATREV requirement specifications report. Technical Deliverable & Milestone2: Detailed & validated TFSPLAN and TFS-build plans occurs end of Month 4 & witnessed by TFSPLAN & TFS-build study plans. Technical Deliverable & Milestone3: Detailed & validated TFSSIM & simulation/animation models and simulation data extraction links occurs end Month 6 & witnessed by TFSSIM & sim models & data extraction links. Technical Deliverable & Milestone 4 occurs end Month 9 & witnessed by detailed & validated AI-software tool. Technical Deliverable & Milestone 5: (TD5) occurs end Month 11 and witnessed by report detailing BATREV TFS. Technical Deliverable & Milestone 6: (TD5) occurs end Month 11 and witnessed by report detailing BATREV TFS and use of TFSOPT to optimise BATREV QCDE optimisation RRE scale-up scenarios.

Project innovations

Main motivation for BATREV is addressing the technical needs required for innovative applications of (A) Existing robot disassembly and reassembly technologies in new 'EVB high variety/small batch' areas using innovative autonomous functionality, (B) Disruptive technology involving new robot fitness-for-purpose strategies and AI-enabled operations -planning processes. IP for disruptive technologies in (A) will be developed-&-owned by user partners, in (B) by HAL. Hence, BATREV will have complete operational freedom. TRL3 'Experimental Proof-of-Concept', (EPoC), analytical and laboratory-based studies & validations have been undertaken for (A) & (B) using commercial simulation & AI-development systems to model RRE scale- up planning scenarios.

Partners

JDW

recoturbo
remanufacturers & stockists of turbochargers

ASPIRE ENGINEERING

HAL

Contact:
Professor David Stockton and Professor Riham Khalil
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Emails: support@ha-ltd.org **support@ha-ltd.org**
Web: www.homeodynamicautonomy.co.uk

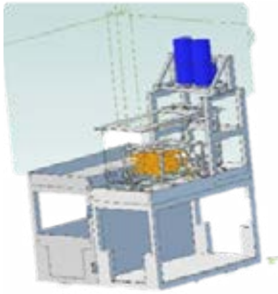
The development of an Isothermal Control Platform (ICP) for the precise regulation of battery temperatures using multiple zone control

The ICP will 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



Prototype ICP CAD Drawing

Executive summary

The ICP will provide a thermally stable basis for characterising lithium cells and their chemistries. It is intended to overcome the limitations that currently affect almost every such test, resulting 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 THT and a second unit is due for delivery at Imperial College London. 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 will be further developed in a new Faraday project (Innovation R&D Studies Round 3) in partnership with Imperial College and Cranfield University.

Project innovations

High precision control of temperature of Lithium batteries using real-time Scalable thermal battery models during cycling and load testing. The ICP will significantly improve the quality of quantitative data from such tests

Partners

THT
THERMAL HAZARD TECHNOLOGY

Imperial College London

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

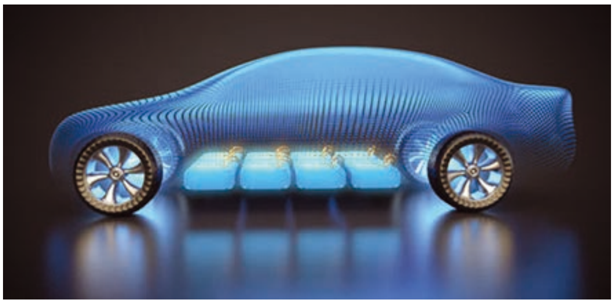
The PowerDrive line

Development of a solid-state battery pre-pilot line, battery management system and materials supply chain for plug-in hybrid and battery electric vehicles. This project will develop a lithium based solid-state battery for plug in hybrid and electric vehicles, establish a pre-pilot line for solid-state battery cell technology and develop processes for a solid-state materials supply chain. The innovative solid-state technology will enable safer, more energy and power dense cells that will facilitate ultra-fast charging (enabling PHEV or BEV drivers to charge their cars in under 25 minutes)

Project costs

Total project cost: £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 use of non-flammable solid electrolyte as opposed to the organic solvent used in current lithium-ion batteries, which is both flammable and has a relatively short useful life. 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 30-month project started on the 1st October 2018 and has just completed Q3. The project Deliverables and Milestones are on track. Upon completion the consortium will have delivered a pre-pilot production line for solid-state batteries, defined a materials supply chain and produced a demonstration battery pack.

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

UCL

ilika

cpi

HONDA

RICARDO

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

UK - GIGAWATT Hour cell manufacturing facility feasibility (Giga Factory)

This project aims to enhance the UK's battery cell manufacturing capability to meet growing demand, helping work towards a greener more sustainable future.

Project costs

Total project cost: £351,099

Grant contribution: £276,186

Executive summary

This collaborative innovation project is 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 is 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 will result in the delivery of a business case and manufacturing blueprint for the proposed Giga Factory that will enable AMTE Power to advance their production and supply chain readiness of their battery cells towards the level of capability, scale and cost per kWh required by the UK's burgeoning EV sector and it's global demand.

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
- 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

This project will assess the feasibility of increasing the UK's battery cell manufacturing capability providing significant benefits to the economy and reshoring the supply chain and skills ensuring a self-sustaining UK green energy sector. The facility will incorporate the concepts of Circular from its conception to ensure environmental impacts are minimised while still remaining competitive in the market.

Partners

amte power

A Manufacturing Innovation Institute

Contact:
eve Farmer **Email:** steven.farmer@agmbatteries.co.uk

UK - Niche vehicle battery cell supply chain

The project is designing, developing and manufacturing power (pouch) and energy (cylindrical) Li-ion cells to suit the UK Niche Vehicle Manufacturers with warranties and at acceptable cost

Project costs

Total project costs: £4,279,693

Grant contribution: £3,224,493

Executive summary

Scale-up will be via AGM's existing Li-ion facility, through the UKBIC to the AMTE Giga Factory in the UK. The consortium has identified a sustainable market, of smaller but still substantial size automotive manufacturers which is ideally suited to its strengths in the form of the 'niche' vehicle design, development and manufacture. They are global companies based in the UK producing; special-car, sportscar, off-highway, bus, marine and emergency/special vehicles. They are however starting to be being impeded by the difficulty in obtaining suitable quantities of battery cells from the global suppliers. After consultation with 27 of these companies Williams, Delta and AGM have determined a requirement for a power cell in a pouch format and energy cell in a cylindrical format. These cells have been designed and materials, with subsequent supply chains, down selected to allow the manufacture of A models for initial evaluation. In parallel William Blythe and CPI have synthesized both anode and cathode material samples, based on the cell designs , which are being fully characterized before scale-up. Lancaster University have been evaluating cell degradation modes at different SOC and C rates ncluding; SEI growth, Lithium plating and Calendar aging to support warranty provision.

Timeline with milestones and deliverables

Project started	Complete
Power and Energy cell requirements agreed	Complete
Anode & cathode materials produced by William Blythe & CPI	Complete
A model prototype cells delivered	24/09/19
B model final cells delivered at TRL 7	21/04/20
Project completion	31/07/20

Project innovations

- UK volume production of state-of-the-art anode and cathode materials.
- Cell degradation modelled to provide long product warranties.
- Ethical UK sourced cell materials and components.
- Environmentally friendly electrode materials and processing techniques.
- Duty cycle configurable cell lifetime model

Partners

Contact:
Ian Whiting, BD AGM Batteries **Web:** www.agmbatteries.com

VALUABLE

Building a complete end of life supply chain network within the UK by developing sustainable reuse, remanufacturing and recycling routes for 2nd life automotive Li-ion batteries

Project costs

Total project cost: £2,617,960

Grant contribution: £2,064,530

Executive summary

Project VALUABLE's key objectives are to increase the added value of the UK battery supply chain, while decreasing its environmental impact. To achieve this, project partners are developing commercially viable metrology and test processes, optimising battery design for 2nd life applications and establishing new supply chain concepts for recycling, reuse and remanufacturing of automotive Li-ion batteries to create a complete End-of-Life (EoL) supply chain network within the UK. The project brings 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 is 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 is 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. In addition, feedback from the members will ensure that the project outputs are relevant to industry needs and that the public investment results in a maximum return for the UK.

Timeline with milestones and deliverables

Work Package	January 2018	June 2018	January 2019	June 2019	January 2020	June 2020	Dec 2020
WP2	Developing Value chain	Legislation review	Guidance for Compliance	Compliance tool		Economic, Environmental and Social assessment	
WP3	Design for end of life	Design suggestions	Battery teardowns	Battery cost tool & design guidelines			Tool to support 2nd life
WP4	Metrology & Battery analysis		Scanning techniques report	Correlated acoustic and XCT	Report on rapid scanning	Integrated in-line testing	Demonstration
WP5	Battery reuse			EoL battery analysis report			Blueprint for reuse
WP6	Remanufacture	Remanufacturing strategy	H&S strategy	Remanufacturing pilot line plans	Reverse logistics strategy		
WP7	Recycling & Material recovery	Recycling infrastructure review	Black Mass opportunities	Guidelines for waste battery treatment			Guidance document
WP8	Exploitation & Dissemination	Establishment of Industrial Advisory board	High level publications. Speak at relevant events	International Outreach (Global Battery Alliance, EU battery Show)	Insight for Industrial advisory board	Publication of "VALUABLE – A circular Economy for the automotive supply chain"	Launch of toolbox & services

Project innovations

- Development of a UK-based end of life battery value chain focusing on reuse, remanufacturing and recycling for 2nd life automotive Li-ion batteries.
- Industry-wide support represented by an Industrial Advisory Board.
- Increase recyclability and reuse potential of traction battery packs.
- Commercially viable metrology and testing processes.
- Battery evaluation tool to support recycling and 2nd life opportunities.
- Legal and regulatory support tools.

Partners

ACELERON

ASPIRE ENGINEERING

TEVVA MOTORS

NPL National Physical Laboratory

EnvAqua Solutions

UCL

HSSMI A Manufacturing Innovation Institute

Contact:
Alberto Minguela Email: alberto.minguela@hssmi.org Web: www.valuablebatteries.co.uk Twitter: @valuable_uk

WIZer Batteries

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

Project costs

Total project costs: £7,668,057

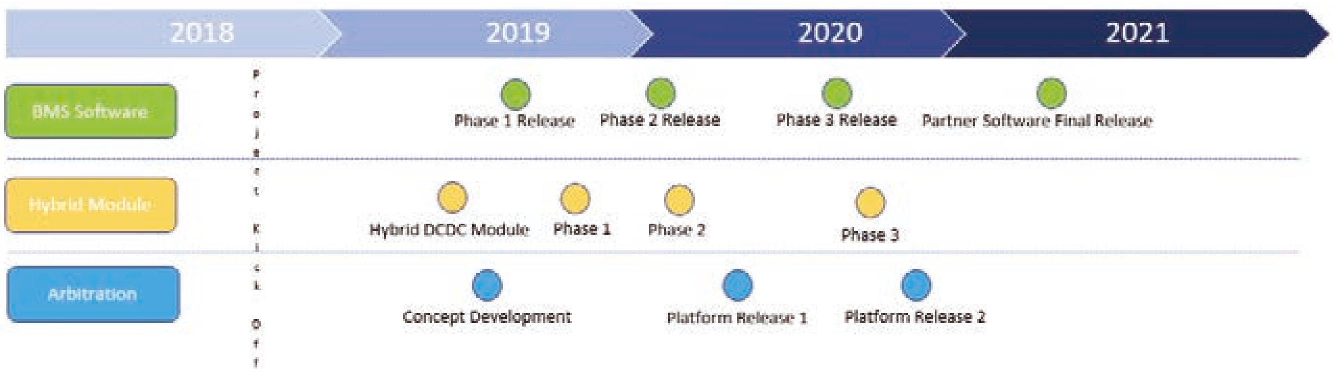
Grant contribution: £5,337,325

WIZer

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, plus faster charge times and greater life than today's competing technologies. The integration of this to a hybrid supercapacitor and lithium-ion battery module design, alongside an end to end battery life tracking platform will demonstrate the state of the art, disruptive UK technology.

Timeline with milestones and deliverables



Project innovations

- A BMS system based on completely new control method delivering better control and fidelity incorporating high-power processing capabilities
- A hybrid battery module design, modelling and control technology
- Unique carbon ion supercapacitor 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

WILLIAMS ADVANCED ENGINEERING

Imperial College London

codeplay

ZAP&GO

Silver Power Systems

Contact:
Email: robert.millar@williamsf1.com **Web:** www.wae.com

Notes

Scale-up

UK Battery Industrialisation Centre (UKBIC)

Enabling the development of UK battery manufacturing for the production of electric vehicles

Project costs

Grant contribution: £108m

Executive summary

A 20,000m² facility on the outskirts of Coventry opening in early 2020, UKBIC will provide open access facilities and expertise to support UK industrial R&D and skills development across electrode, cell, module and pack production processes. UKBIC offers a production realistic environment for trial, validation and short volume manufacture of battery components to allow organisations to reduce risk of investment in new technology and production techniques and enable growth of commercial opportunities in the battery industry.

UKBIC purpose

UKBIC aims to be 'the place to go' for battery industrialisation in order to fulfil its role in helping to accelerate the pace of commercialisation of new battery technologies in the UK. It will enable industry, via open access to its facilities and expertise, to scale-up advanced technologies which will be central to the development and commercialisation of advanced batteries. It will provide an essential bridge from technology research and innovation into proving that products can be produced at an industrially-relevant scale, speed and quality. The result of this will be increased opportunities for industry and its investors to reduce risk and increase confidence in technology production prior to investment in expensive full-scale commercial facilities of their own.

UKBIC facilities

UKBIC will be a 20,000m² 'learning factory' environment for the UK to enable the development of battery components (electrodes, cells, modules and/or packs) used for the trial, validation and short volume demonstration of:

- New manufacturing processes
- New/improved battery materials/chemistries
- New/improved cell formats
- New/improved module and/or pack structures

UKBIC's operations will cover all standard industrial processes from mixing of materials for electrode manufacturing, through to assembly of battery cells, modules and packs for integration into vehicles and other platforms.

Open access
UKBIC facilities will be available to UK organisations of all sizes and sectors interested in developing high volume / high speed production processes for battery technology scale-up. It can accommodate groups of organisations undertaking collaborative R&D projects or individual organisations. The facilities can be utilised to support the specific needs of R&D campaigns or training and skills development for a growing UK battery industry.

Confidentiality for users
UKBIC will offer a confidential and secure environment for user organisations to develop their own IP in products and manufacturing techniques. Any IP results will be generated and owned by the users of the facility for them to take forward and commercialise.

Location and timescales
Located centrally on the outskirts of Coventry, UKBIC will benefit from excellent national and international transport links and proximity to an established automotive supply chain in the West Midlands.

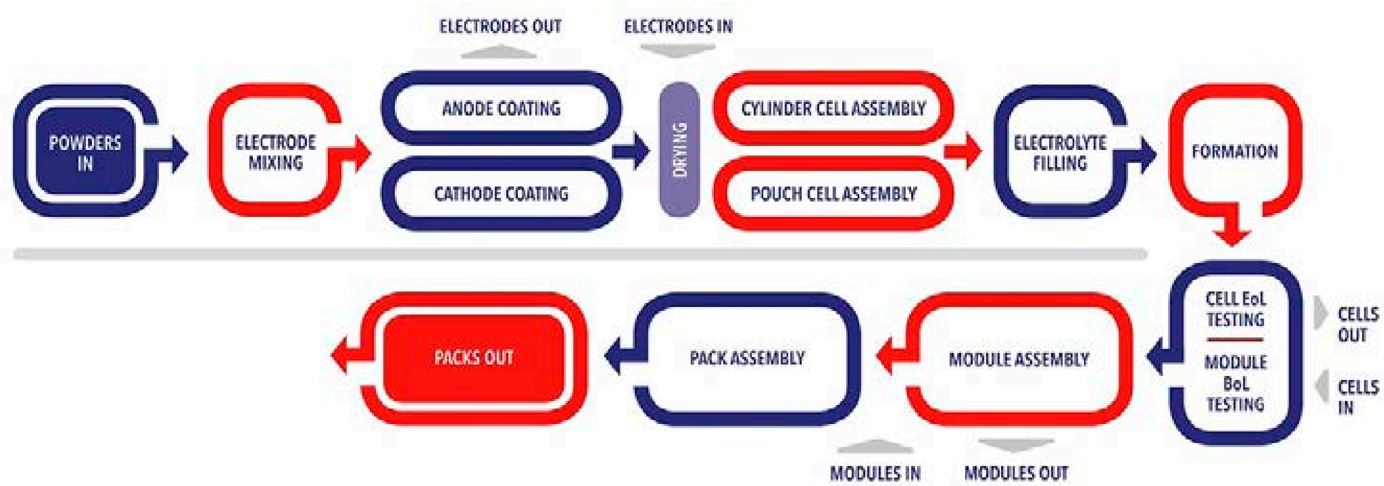
UKBIC is currently under construction and is planned to be open for business in early 2020.

Contact:
Email: info@ukbic.co.uk Web: www.ukbic.co.uk

Example UKBIC Uses

	Organisation Type	Potential Interest
Industry Scale-up	Material suppliers	Improve product/process; test market feasibility to join the supply chain
	Component suppliers	Test and validate products for new supply chain opportunities
	Cell manufacturers	New market opportunities – work with supply chains or OEMs; improve product/process
	Low Volume OEM	Validate and develop modules and packs – direct or with Tier 1
	High Volume OEM	Prototype volumes; develop high volume production processes for in-house investment
	Production Equipment Suppliers	New market opportunities; test and validation of new equipment
Education/ Research	Universities/research organisations	Path to market for new technologies; industrial data for research
	Apprenticeships/employers	Production skills development for emerging battery production industry
	Schools/Public Engagement	Educational & fact finding visits; STEM participation

UKBIC Process Plan



Index of Innovation project partners

Businesses

Research and Technology Organisations (RTO)

Public Sector Organisations

Research Organisations

Notes

Notes

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. For more information visit www.ukri.org

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