THE FARADAY INSTITUTION

Powering Britain's Battery Revolution

ANNUAL REPORT

2020/2021

FutureCat Post Doctoral Researcher, Dr Beth Johnston (University of Sheffield). Photo by Timm Cleasby Photography.

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Annual Report 2020/2021

*Battery researcher,
WMG at the University of Warwick*

Contents

The trustees and strategic report and the statement of financial activities including the income and expenditure account can be found at http://www.faraday.ac.uk/2020-21-annual-report

Outcomes and Impacts

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

An internationally recognised research powerhouse

10 large-scale research projects
3 characterisation projects
3 emerging economies projects

273 high-quality scientific publications to date with 911 authors across 190 institutions and 6 continents

90.1% in the top quartile journals

62.7% in the top 10% of journals

46.2% in the top 10% most cited publications worldwide

49.6% include international collaborators

Growing community of 470+ battery researchers

45% new to battery research

Across 24 UK universities

Including 4 of the world's top 20 ranked universities (Oxford, Cambridge, Imperial, UCL)

1,000+ academic and industry researchers registered for our Annual Conference

Commercially relevant impacts

50+ industrial partners
8 spin-out companies
26 separate inventions identified

3 have had patents granted and a further 13 are in the patent process

7 leading UK organisations collaborating in a consortium

to develop solid-state battery prototypes and led by the Faraday Institution

11 industrial fellowships

7 industrial sprints

THE FARADAY INSTITUTION

Impact to policy makers

3 presentations to All Party Parliamentary Groups

Participation in 5 national policy consultations

12 Faraday Insights
10 reports / joint reports

Public engagement

130 pieces of coverage

in the 2020-21 financial year with substantial top tier coverage, representing hundreds of thousands of views

BBC, The Telegraph, Reuters, Bloomberg, The Times, The Guardian and The Financial Times

Over 250k online views

from the Royal Institution series of lectures on batteries

Next generation of talent

150 undergraduate interns and 10 Faraday Scholars

10,000+ young people engaged

through the Fully Charged Battery Box programme across the UK

55 PhD researchers in doctoral training programme

with an additional 82 affiliated with our battery projects

'Collectively, we are shaping the energy landscape of the UK'

Statement from the Chair

Professor Peter B. Littlewood FRS, Chair

It is with great pleasure that I present to you the Faraday Institution's Annual Report 2020 / 2021, a year that has seen remarkable achievements amid a continuing global pandemic. Embracing challenges, whilst adapting to change, has become a notable virtue of the Faraday Institution and its community.

Collectively, we are shaping the energy landscape of the UK. Close to 500 experts across UK universities are focused on solving the most significant technical challenges in energy storage. The UK Battery Industrialisation Centre, our partner in the Faraday Battery Challenge, opened its doors in 2021 and brought its first customers into the pioneering production facility. Announcements from Envision AESC and new entrant Britishvolt will create thousands of new jobs in battery manufacturing in the North East bringing production at a gigascale to the UK.

I am mindful that we set out just a few short years ago to bring together four pillars to ensure the energy storage research community made real our promises for the UK: excellence in research, a robust training programme, evidence-based market insights, and a focus on early-stage commercialisation. This work, we knew, would contribute to the UK's economic prosperity, usher in the green industrial revolution, create new industries and secure high-quality jobs.

Led by our chief executive Professor Pam Thomas, today the Faraday Institution research community is thriving – working collaboratively across 10 major programme areas – and delivering ground-breaking research to improve battery performance as this report will attest. Under her leadership, in April, we announced an additional £22.6m commitment to build on the momentum in four research challenges and launched a new project on the science of battery safety, an area of international importance where the Faraday Institution can lead the way. This ongoing investment in research will ensure battery technologies fit into the larger energy picture so that the UK can succeed in the energy transition.

Much important work lies in front of us to realise the promise and full potential of battery technologies, including by optimising current lithium-ion batteries so that they charge faster, last longer, propel us further, so that we understand why they fail, and ensure they are truly safe, sustainable and fully recyclable. But we know that lithium-ion batteries alone cannot fulfil the electrochemical energy storage demands of the future economy across multiple sectors. As a result, we are investing in the next generation of battery chemistries that will need sit alongside existing technologies by the end of this decade. Progress on all these fronts is highlighted in this report.

The reputation of the Faraday Institution as a world-leader in battery research continues to grow stronger. Over 1,000 delegates, across the UK and from around the world, registered for our annual research conference to learn about the high quality, high impact science and engineering undertaken by our community. This is a testament to the interest in our research and the impact we are making in a sustainable future.

To help us navigate down the right path, the Faraday Institution greatly benefits from its advisors, and this year we welcomed three new trustees to bring valuable insight, perspective and energy to our board: battery industry leader, Isobel Sheldon OBE, who is the Chief Strategy Officer of Britishvolt; Mark Newman, the Chief Commercial Officer and Head of Strategy for pioneering battery company Nyobolt and long-time advocate for clean technology solutions, and Cordi O'Hara, who is Chief Operating Officer for US Gas Business for National Grid.

Finally, I would like to recognise the commitment and dedication of our executive team and staff, our trustees, the Faraday Institution research community, our supporters and advisers in government, and our many new partners as we continue with our exciting and important work.

Statement from the CEO

Professor Pam Thomas FInstP, CPhys, Chief Executive Officer

The Annual Report offers me an opportunity to reflect on my first full year as CEO. I remain deeply honoured to lead the Faraday Institution and wish to restate my commitment to working alongside our community to do our utmost to meet two global challenges of our time – decarbonisation and electrification. While the evolving demands of the coronavirus pandemic have impacted all of us this year, I am inspired by the adaptability of our community to find new ways to work together and to deliver impactful research. While this has been an exceptionally challenging period, it remains an exciting moment for British science – as exemplified by the development of the vaccine from Oxford University.

I recognise that what we understood in 2018 when we launched our research programmes has become even more clear today: for the UK to meet Net Zero commitments and transition to an electrified future – from transport and aviation to power generation and distribution – will require many types of batteries, some as yet to be imagined, with varied and different performance characteristics.

In these pages, we highlight Faraday Institution breakthrough research such as the invention of a faster, greener technique from the University of Leicester to improve the recycling process for EV batteries. As another example, Oxford researchers have made a step forward in the mechanistic understanding of oxygen-redox processes in Li-rich battery cathodes as a way of informing practical strategies towards higher energy density batteries.

We have welcomed a number of new staff this year in building the senior team for our expanded portfolio of research projects and commercialisation. James Gaade has joined us as Head of Programme Management to guide and shape our research portfolio with the principal investigators and their academic teams. Nick Smailes has also joined us as Head of Commercialisation to lead in fulfilling the early-stage commercialisation activity that has been part of our mission since our inception. Within the whole Faraday Institution HQ team, we have made appointments in project management, education and engagement and administration to support our burgeoning activity, and a number of specialist consultants focus on our commercialisation portfolio.

Across the spectrum of our research, 26 inventions have been identified, several promising spin outs have launched and our industrial programmes continue to drive innovation.

In this report, we outline how we are targeting a series of commercially relevant impacts where industrial and academic partnerships are being forged. One prime example is a solid-state battery consortium that has the aim of building a prototyping capability in the UK, which includes leading UK-based organisations at each point in the value chain.

We continue to inform our government partners of the need for batteries that are more sustainable, lower cost, higher performing and fit for application. At a House of Lords Science and Technology Select Committee inquiry many leaders from our community answered questions on what is needed to ensure batteries researched, developed and manufactured in the UK fulfil their expected role in making Net Zero a reality.

Our next generation of researchers – from undergraduate FUSE interns to PhD and early career researchers – are continuing to impress and are delivering excellent results, publishing significant papers and being involved in start-ups. Our education and training programmes and outreach activities stand as exemplars of how to bring new thinking, energy and diversity into the UK's workforce.

In a year with inclusivity and wellbeing firmly at the top of society's agenda, we reaffirmed our commitment to equality, diversity and inclusion in science through publishing an EDI charter and through a range of focused career development and wellbeing programmes for members of the UK battery research community. We know that through interdisciplinary collaboration and by celebrating a diversity of people, ideas and knowledge, research excellence flourishes.

To our vibrant research community for the resilience, commitment and dedication you continue to demonstrate on a daily basis: thank you. I wish to express my gratitude to our excellent staff in headquarters, our trustees and expert panel who provide robust advice and guidance, and our funders in the Faraday Battery Challenge and UKRI-EPSRC for their ongoing support.

As we focus on the year to come and face the known and unforeseen challenges ahead, I am sure that the strength in breadth and depth we are building as a community will stand us in good stead and that we will emerge as an even stronger institution as a result.

'I am inspired by the adaptability of our community to find new ways to work together and to deliver impactful research'

Pam Thomas

About the Faraday Institution

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

Quad 1 at Harwell Science and Innovation Campus, where the Faraday Institution is head-quartered

What We Do

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

The UK Government has entrusted the Faraday Institution as a key delivery partner for the Faraday Battery Challenge to bring forward bold and transformational change in application-inspired energy storage research.

The Faraday Institution was designed to be the national focus for energy storage research, market analysis, early-stage commercialisation and training. Funded through EPSRC-UKRI, it serves as the UK's flagship battery research programme to build and manage focused, substantial and impactful research projects in areas of fundamental science and engineering that have significant commercial relevance and potential, defined at a high level by industry and delivered by consortia of universities and businesses. The Faraday Institution delivers training to the next generation of battery scientists and engineers, who will go on to work in both academia and industry and be responsible for facilitating the transition of new technologies to market.

Headquartered at the Harwell Science and Innovation Campus, the Faraday Institution is a registered charity with an independent board of trustees.

Engineering and Physical Sciences Research Council

Faraday Battery Challenge

Our Research Community

In 2017, the Faraday Institution embarked on assembling a unique community — dedicated university researchers from a multitude of fields and UK universities, committed industry partners, technology business development specialists and a new generation of students. Together they bring a diversity of perspectives and are united in their efforts to overcome tough scientific challenges: to reduce battery cost, weight, and volume; improve performance, efficiency, and reliability; develop scalable designs; improve manufacturing abilities; develop whole-life strategies; and accelerate the outputs towards commercial outcomes.

Today this research community is a powerhouse – 470-strong from across 24 universities – working with the direction and guidance of UK industrial partners.

The Faraday Institution has combined the strengths of highly competitive university research groups across the UK to work as active collaborators, marking an important moment of change for the research community and building a new model for how nationally important strategic research is conducted. The Faraday Institution's long-term vision to develop future generations of energy storage scientists and engineers is coming to fruition. 55 PhD researchers are directly supported through the Faraday Institution's doctoral training programme, with an additional 82 working across our partner universities on our battery projects.

University of Cambridge PhD researchers Victor Riesgo Gonzalez (left) and Haydn Francis (right) discuss research data

The Faraday Institution Annual Conference 2021

The fifth Faraday Institution research dissemination conference was held successfully online in November 2021 and this year had the theme of **Battery Research and Innovation for a Sustainable Future**. As part of the Institution's objectives of being the trusted national convener for battery science and building a broader community of battery researchers in the UK, the virtual conference doors were once again opened to UK-based academics working external to current Faraday Institution projects, to UK industry and policy makers in the battery space and to selected overseas partners.

The conference showcased project progress and impact and the additionality that the Faraday Institution brings – for example around market analysis and early-stage commercialisation. Delegates benefitted from the wisdom and insight of three keynote speakers Professor Stan Whittingham (Nobel Prize Winner and Director, Northeastern Center for Chemical Energy Storage), Robert Llewellyn (Founder and Joint CEO, The Fully Charged Show) and Baroness Brown of Cambridge (Member of the Committee for Climate Change, Chair of the Carbon Trust and the Henry Royce Institute).

Conference delegates took a deep dive across four cross-cutting themes into some of the best research from around our projects and beyond in the following areas:

- Towards sustainable batteries
- Discovery and design towards higher performing, lower cost batteries
- Data – challenges and opportunities
- Safety and performance from sensing, prediction, and characterisation

The breakthroughs in scientific knowledge towards the commercialisation of new battery technologies being made by industry fellows, entrepreneurial fellows, industry sprints, and projects developing batteries for emerging economies (funded by the Foreign, Commonwealth and Development Office) were highlighted through over 60 flashtalks.

The conference included an Early Career Researcher Day, which provided a supportive environment in which 4 PhD researchers and 12 Faraday Institution research fellows shared their research and identified opportunities for future collaboration. Around 20 PhD researchers, 30 research fellows and 50 undergraduate FUSE interns also presented scientific posters in online poster sessions.

Over 100 expressions of interest were received from Faraday Institution researchers to speak and present posters at the conference, demonstrating the appetite of researchers to speak at the event.

110
speakers, chairs and project video contributors; over 1,000 individual registrations

220+
participants (average) for sessions in main conference; 160+ at early career researcher day sessions

16,000+
conference website page views

24
Zoom sessions over 3 days

92
pre-recorded videos with over 3800 video views

740+
people engaging on Slack collaboration workspace

> **'This has been a phenomenal event. You have provided a model for others on how to run a conference well, how to engage outsiders, and how to facilitate connections. I am so grateful to be able to join [as a Faraday Institution partner] from the USA. If some time in the future I find myself at a UK institution, this event will be no small reason why.'**
>
> Attendee of the Faraday Institution 2020 Annual Conference

Promoting Equality, Diversity and Inclusion (EDI)

The Faraday Institution is committed to creating and sustaining a diverse and inclusive environment as it seeks to build and support a world-class energy storage research community. Through interdisciplinary collaboration and by celebrating a diversity of ideas, opinions, knowledge and people it is acknowledged that research excellence will continue to flourish. Beyond research disciplines, diversity within this community takes many other forms including career stage, age, race, ethnicity, gender, sexual orientation, gender identity, disability, national origin and religion. In recognition of this, the Faraday Institution aspires to maintain an inclusive environment where all individuals can thrive, feel they belong, and have a voice.

The organisation published its Equality, Diversity and Inclusion (EDI) Charter in June 2021, which outlines the EDI responsibilities that all members of the Faraday community share. Specifically, it encourages engagement with the types of everyday actions that contribute to building the welcoming, supportive, diverse and productive UK battery research community it seeks to create:

- Actively promoting inclusion
- Advocating for others
- Adopting practices that support fairness and equal opportunities for all
- Embracing and championing diversity in all its forms
- Following best practice chargers and initiatives within your own institution
- Challenging non-professional and inappropriate behaviour

The Faraday Institution continues to evaluate its EDI policies and look for ways to incorporate best practice as outlined by experts in the field.

EDI Working Group

The Faraday Institution EDI Working Group is chaired by Chief Operating Officer Susan Robertson and includes Education and Training Lead Fran Long and EDI champions representing the research community, who together inform Faraday Institution policy and practice and embed best EDI practice within the projects. Researchers are encouraged to engage with their EDI champion to further build an inclusive community.

Amir Amiri
Multi-scale Modelling Project Administrator
Imperial College London

Dr Rebecca Boston
NEXGENNa and FutureCat Co-Investigator
University of Sheffield

Neil Cadman
SOLBAT Project Manager
University of Oxford

Dr Eddie Cussen
FutureCat Work Package Lead
University of Sheffield

Dr Laura Driscoll
CATMAT Postdoctoral Researcher
University of Birmingham

Dr Mona Faraji Niri
Senior Research Fellow for the Nextrode project
University of Warwick

Dr Alex Kersting
Degradation Project Programme Manager
University of Cambridge

Yashraj Tripathy
Principal Engineer, SafeBatt project
University of Warwick

Dr Darren Walsh
LiSTAR Co-Investigator
University of Nottingham

EDI best practice

Community training on inclusion, behaviour, intersectionality, psychological safety and wellbeing sought to focus on actions that individuals could take to apply best practice to their own situations. The Faraday Institution has launched an EMPOWER Women programme led by Skills4, as part of its 2020 focus on gender diversity priorities in the community. In 2021, it introduced a THRIVE positive action career development programme for Black, Asian and minority ethnic individuals in the Faraday community, which included four sessions and one-on-one coaching. A three-part programme on wellbeing led by a men's mental health specialist also rounded out the year.

EMPOWER participants reported that as a result of the programme:

- 100% increased in confidence, self-belief
- 44% taken on more responsibility
- 33% taken on new role, received promotion

'It has been a huge boost to my confidence and opened my eyes to a new way of looking at my career.'

'Gives you a toolbox for re-assessing yourself, your aspirations and your career pathway'

'This is a very supportive and amazing group and community! I believe this programme will benefit workplace culture.'

The Faraday Institution's membership in WISE, a campaign for gender balance in science, technology and engineering, enables collaboration with a wider network of experts who are championing best practice in this area.

The momentum built from these efforts will carry the community forward and will make us collectively stronger.

Read the case study from WISE highlighting the Faraday Institution's commitment to attracting, recruiting and empowering women in STEM careers.

Download report

University of Cambridge PhD researcher Greta Thompson

Our Partners

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

Government partners

Across the UK Government, the Faraday Institution regularly provides evidence-based insights into topics related to energy storage, electric vehicles, materials supply chain and recycling. It participates in both formal and informal knowledge exchanges with Number 10, the Cabinet Office, Department for Business, Energy and Industrial Strategy (BEIS), Foreign, Commonwealth and Development Office, Department for International Trade, UK Research and Innovation, the Government Office of Science, the Department for Transport, the Office for Zero Emissions Vehicles, and both Houses of Parliament.

UKRI

The Faraday Institution engages across the most relevant parts of the UKRI research and innovation landscape to accelerate its mission, ensuring access to world-class facilities and building beneficial partnerships with other institutes and challenges. The Henry Royce Institute, for example, has provided state-of-the-art equipment and training to Faraday Institution research teams, including those at Oxford, Manchester and Cambridge. The National Physical Laboratory (NPL) directly supports several of the Faraday Institution research projects through materials and cell testing.

The Faraday research community actively benefits from access to the nation's world-class STFC-UKRI facilities at Harwell Science and Innovation Campus, such as Diamond Light Source and ISIS Neutron and Muon Source as well as from active engagement with other delivery partners from the Faraday Battery Challenge. This year, five discoveries from the Faraday Institution's research programmes have moved on to the next stage of commercialisation, receiving Innovate UK competitive awards for collaborative research and development follow-on work.

Industrial partners

The Faraday Institution has developed strong and significant collaborative links with a wide range of industrial partners, including both established and emerging volume and specialist vehicle manufacturers, automotive and aerospace engineering companies and suppliers, battery manufacturers and the companies in the chemicals and materials sector.

This engagement continues to both grow and deepen as Faraday Institution research matures, ensuring research directions remain commercially relevant and to increase the probability of success. Industry Sprints, Industry Fellowships, and other collaborative opportunities are flourishing and demonstrating value.

More than 50 companies from the UK – including leading corporations in the FTSE 100 index – along with several international research organisations provide financial and non-financial support to the Faraday Institution's research programmes.

Prime Minister Boris Johnson tours the newly opened UK Battery Industrialisation Centre, a key delivery partner of the Faraday Battery Challenge.

'The Faraday Institution is quite an incredible body. It's based at Harwell in Oxfordshire but it links together the universities that are conducting research into batteries... We need these batteries, there is absolutely no question. What we also need to do is make sure that the value in those batteries comes from the UK as well...and to make sure this country retains its lead in devising ever cleaner, ever greener and more beautiful technology. '

Prime Minister Boris Johnson, 15 July 2021, UKBIC opening

University partners

A large-scale endeavour of this significance necessitates an extensive national reach. The Faraday Institution draws its strength from 24 UK universities, from St Andrews to Southampton, including world-leading universities Oxford, Cambridge, Imperial and University College London.

Roadmaps

To guide academia, industry and funding bodies on emerging next generation battery technologies, Faraday Institution researchers have published the following series of roadmaps and research techniques:

2020 Roadmap on Solid-state Batteries

This publication provides an overview of the fundamental challenges impeding the development of SSBs, the advances in science and technology necessary to understand the underlying science, and the multidisciplinary approach being taken by SOLBAT researchers in facing these challenges.
Download roadmap

2021 Roadmap on Sodium-ion Batteries

This roadmap by members of the NEXGENNA research team provides an extensive review of the current state of the art in 2021 and the different research directions and strategies currently underway to improve the performance of sodium-ion batteries. The aim is to provide an opinion with respect to the current challenges and opportunities, from fundamental properties to practical applications.
Download roadmap

2021 Roadmap on Lithium-Sulfur Batteries

To aid the development of the wider Li–S research community, this roadmap highlights the outstanding issues in a rapidly developing research space that must be addressed to advance the commercial prospects of the technology and provide an insight into the pathways towards solving them adopted by the LiSTAR consortium.
Download roadmap

Neutron Studies of Na-ion Battery Materials

Increased understanding of the electrochemical storage mechanisms and kinetics is vital for the development of current and novel materials to realise the commercial Na-ion battery.

This paper reviews this use of powerful and penetrating neutron techniques for the investigation of Na-ion electrode materials and highlights an opportunity for research to elucidate the operating mechanisms within Na-ion materials that are under much debate at present.
Download roadmap

Perspective for Next Generation Lithium-ion Battery Cathode Materials

The researchers from FutureCat and Degradation projects created together a comprehensive road map for the field to improve on technology and techniques geared towards identifying new cathode materials. This paper sets out the direction of research in cathode materials as well as it identifies the benchmarks for different cathode chemistries.
Download roadmap

Regional engagement and levelling up

Recognising the importance of the North East region as a burgeoning centre of battery research, innovation, skills and production, in October 2021 the Faraday Institution opened a regional office in the city of Newcastle. Known as Faraday Institution North East (FINE), the office is based in Newcastle University and led by Professor Colin Herron CBE.

In establishing FINE, the Faraday Institution is keen to build on its credentials as a national research institution both supporting and benefitting from the particular strengths in the UK's regions.

FINE will bring together multiple bodies in the battery innovation ecosystem in the North East. These include research and innovation centres, education and skills organisations, regional and national government and policy representatives, and battery cell manufacturers and associated supply chain partners to ensure collaborative working, identifying and acting upon prospects to accelerate innovation. The success of this pilot will enable the Faraday Institution to explore opportunities to strengthen regional engagement with energy storage initiatives in other parts of the UK.

The Faraday Institution's membership on the Automotive Council Skills Working Group is enabling the sector to anticipate and deliver the skills needed in the North East and the West Midlands to fully electrify auto production and serves as a model for other sectors, such as aero and grid. Working with the Automotive Council, in 2021 the Faraday Institution, WMG and the High Value Manufacturing Catapult, published a seminal report *The Opportunity for a National Electrification Skills Framework and Forum* in September 2021 to ensure quality training is delivered at the right time and at the place of need. This effort was highlighted as a case study in the independent Green Jobs Taskforce report, published in July.

International engagement

The Faraday Institution benefits from relationships with US research organisations like the Joint Centre for Energy Storage Research, Argonne National Laboratory, and the National Renewable Energy Laboratory. In Canada, it is forging ties with centres of excellence and councils such as the National Research Council Canada. In Europe, the Faraday Institution is a supporting organisation of Battery 2030+, a large-scale and long-term European research initiative with the vision of inventing the sustainable batteries of the future, and the Interreg North-West Europe (NWE) STEPS programme of the European Regional Development Fund to strengthen the competitiveness of NWE innovative storage providers.

STEM outreach partners

To ensure the public has the best information on the opportunities and challenges of energy storage, and that future generations of scientists and engineers from all backgrounds are inspired to pursue promising STEM careers, the Faraday Institution has engaged delivery partners including the Royal Institution, the Royal Society of Chemistry, Curiosity Box, the Primary Science Teaching Trust (PSTT), SEO London, the Smallpeice Trust and WISE.

In 2021, the Faraday Institution launched a STEM committee to enable its research community to leverage best practice and pool resources across our partners to raise aspirations of school children as they pursue future careers.

STEPS

The first stage of the STEPS programme provides support for technical studies and the second stage provides testing for prototypes. Under this programme, the Faraday Institution has partnered with Cambridge Clean Tech and universities from the northwest Europe region to provide SMEs with market/technology research reports to advance their prototype products to market. The successful UK applicants for the first stage across two calls, one in 2020 and one in spring 2021, were:

Aceleron
battery pack systems and pack assembly

AMTE Power
battery cell manufacture

Brill Power
BMS systems

Starke Energy
energy buying/sales modelling

Cumulus Energy Storage
Cu/Zn based battery technology

Energineering
thermal energy storage technology

OXTO
flywheel storage technology

Powerquad
novel battery solutions for niche markets

The second stage of the programme will support the installation of working prototypes. The Faraday Institution is partnering with Harwell Campus as the testbed site for one of these.

Newcastle University is the site of Faraday Institution North East (FINE).

Battery operations at the UK Battery Industrialisation Centre

The Faraday Battery Challenge

The Faraday Battery Challenge is run by UK Research and Innovation on behalf of the UK government. With an investment of £330 million between 2017 and 2022, the challenge aims to support 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 through three key elements:

Research

Funded at over £100 million through the Engineering and Physical Sciences Research Council (EPSRC), part of UK Research and Innovation, the Faraday Institution is the UK's independent institute for electrochemical energy storage research, skills development, market analysis and early-stage commercialisation.

Innovation

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

Scale-up

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

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

Ground-breaking Research to Improve Battery Performance

Established to overcome key industrial challenges in energy storage technology, the Faraday Institution research programme spans ten major research projects in lithium-ion and beyond lithium-ion technologies. During March 2021, the Faraday Institution announced an additional £22.6m commitment to build on the momentum in four research challenges and launched a new project on battery safety.

Research Stream 1: **Lithium-ion**

Projects optimising the current generation lithium-ion based batteries where there are still considerable gains to be made and where research breakthroughs could start to be realised in commercial batteries within 3-4 years. This includes a project on recycling and reuse of batteries and another on battery safety.

Research Stream 2: **Beyond Lithium-ion**

Projects that are higher risk, higher reward and could facilitate the long-term commercialisation of next-generation battery technology that still require considerable research in the areas of materials discovery and optimisation.

Research Stream 3: **Battery Characterisation**

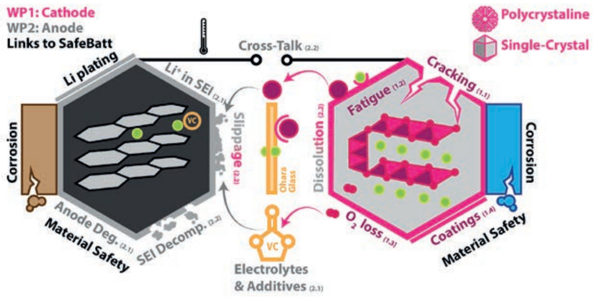
Shorter-term projects to develop battery-focused characterisation and analytical techniques will provide UK researchers with world-leading tools to accelerate their understanding of battery materials and their performance. The two-year projects concluded in September 2021 with a major dissemination event.

Research Stream 4: **Batteries for Emerging Economies**

Shorter-term focusing on reducing the cost and improving the performance of battery technologies for use in developing countries and emerging economies.

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

The Faraday Institution benefits from the UK's world-class research and innovation infrastructure, capabilities and facilities, primarily in the physical sciences and engineering sector, the energy sector, and large-scale multi-sector facilities. These include world-class STFC-UKRI facilities at Harwell Science and Innovation Campus, such as Diamond Light Source (left), ISIS Neutron and Muon Source, and the Royce Institute.



The main modes of degradation in NMC811/graphite systems and the key questions being probed by the project in each sub-work package.

Extending Battery Life

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

Duration 1 March 2018 – 31 March 2023
Funding £16,000,000

Lead Institution UNIVERSITY OF CAMBRIDGE

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

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

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

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

Milestone/deliverables (March 2023)

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

Project innovations

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

Principal Investigator
Professor Clare Grey
University of Cambridge

Project Leaders
Dr Rhodri Jervis
University College London

Dr David Hall
University of Cambridge

University Partners
University of Cambridge (Lead)
Imperial College London
University of Birmingham
University College London
University of Liverpool
University of Oxford
University of Sheffield
University of Southampton
University of Warwick

Research Organisations, Facilities and Institutes
National Physical Laboratory (NPL)

+ 8 Industrial Partners

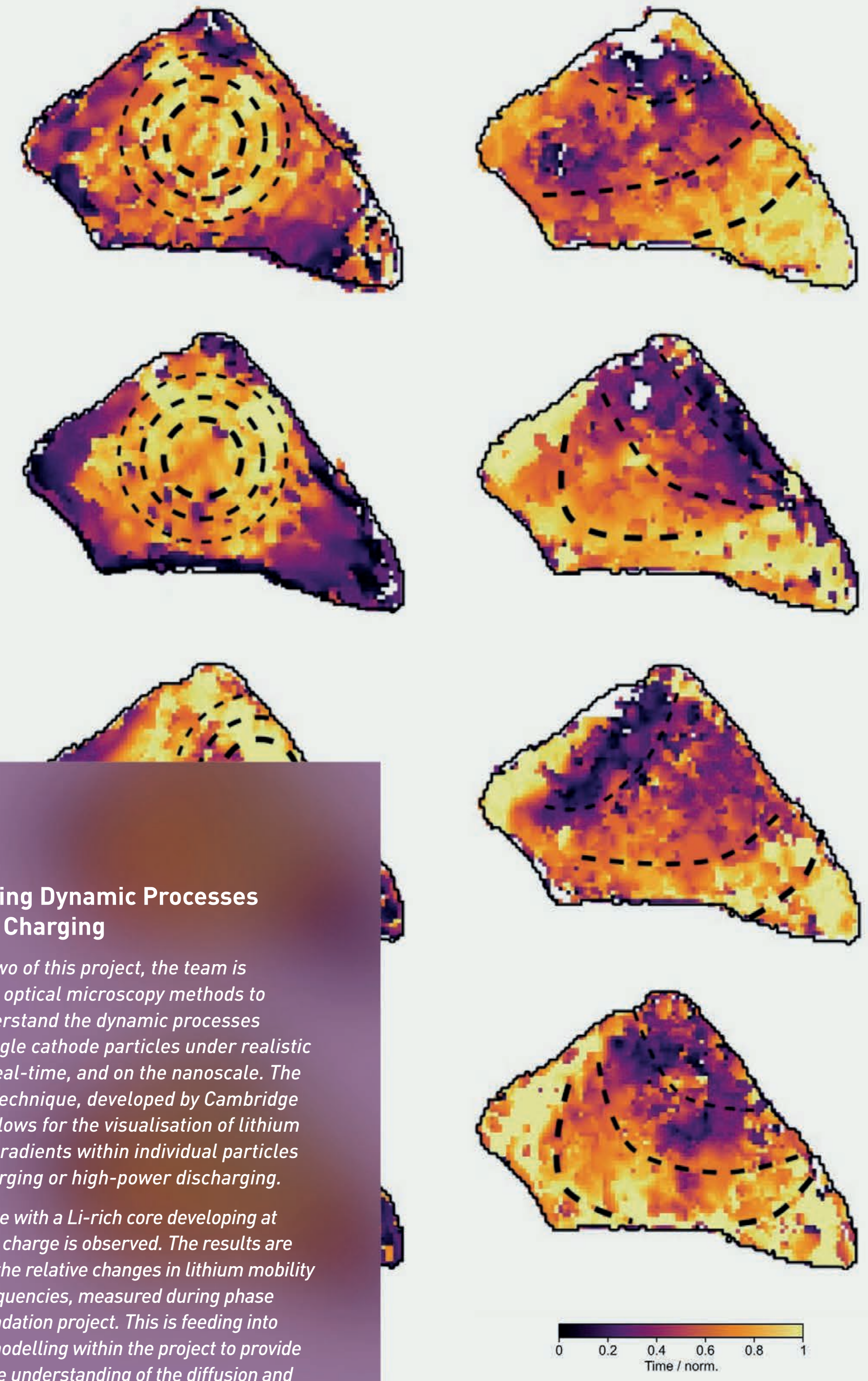
Website

Case Study: Understanding Dynamic Processes During Fast Charging

New to phase two of this project, the team is using advanced optical microscopy methods to follow and understand the dynamic processes occurring in single cathode particles under realistic conditions, in real-time, and on the nanoscale. The measurement technique, developed by Cambridge researchers, allows for the visualisation of lithium concentration gradients within individual particles during fast-charging or high-power discharging.

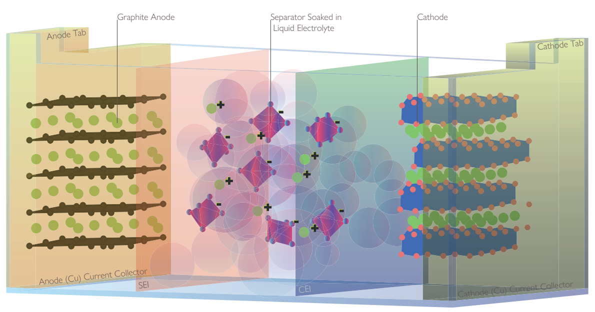
A Li-poor surface with a Li-rich core developing at the beginning of charge is observed. The results are explained from the relative changes in lithium mobility and hopping frequencies, measured during phase one of the Degradation project. This is feeding into finite element modelling within the project to provide a comprehensive understanding of the diffusion and localised state-of-charge dependence of structural and mechanical properties of the crystals.

As with most of the streams of work in the project in phase two, the comparison between polycrystalline and single crystal materials will help researchers elucidate the origins of the extended cycle lifetimes of the latter. Significantly, the results may lead to the development of more advanced materials that are tailored for specific applications.



Behaviour of biphasic phase transitions at various C-rates applied. Progression of the phase boundary through the active particle during the biphasic transition, for delithiation and lithiation. The colour scale represents the time at which each pixel experienced the phase boundary, as a fraction of the total duration of the biphasic transition. Solid black lines clarify the observed outline of the particle. Black dashed circles and lines are a guide to the eye to visualise the progression of the phase boundary. Scale bar (for all images), 2 μm.

For more details please refer to the published work: Merryweather, A.J., Schnedermann, C., Jacquet, Q. et al. Operando optical tracking of single-particle ion dynamics in batteries. Nature 594, 522–528 (2021).



A single cell of a conventional lithium-ion battery, showing its complex internal structure. The active material of both electrodes is in contact with a current collector and a separator keeps the electrodes electrically isolated from each other. The electrode surfaces and the separator are immersed in a liquid electrolyte, which enables Li+ ions to move between the electrodes for charging and discharging the cell, as indicated by the arrows. Reprinted with permission from Imperial College London.

Multi-scale Modelling

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

Duration 1 March 2018 – 31 March 2023
Funding £17,900,000

Lead Institution Imperial College London

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

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

Milestone/deliverables (March 2023)

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

Project innovations

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

Principal Investigator
Professor Gregory Offer
Imperial College London

Project Leader
Dr Jacqueline Edge
Imperial College London

University Partners
Imperial College London (Lead)
University of Birmingham
University of Bath
University College London
Lancaster University
University of Oxford
University of Portsmouth
University of Southampton
University of Warwick

Research Organisations, Facilities and Institutes
UK Battery Industrialisation Centre (UKBIC)

+ 15 Industrial Partners

Website

Case Study: Taking Research to Innovation

Two separate projects build on the success of researchers at Imperial College London working on the Multi-scale Modelling project and its subsequent Industry Sprint TOPBAT. They successfully won follow-on funding from Innovate UK's Collaborative R&D competition in July 2021 to take their research to the next stage of collaboration with industry, a key example of how the Faraday Battery Challenge is taking research to innovation. The team has previously demonstrated significant opportunities for improvements in energy density at pack level, lifetime and cost optimising cell design for thermal management rather than exclusively for cell-level energy density, as is current industry practice.

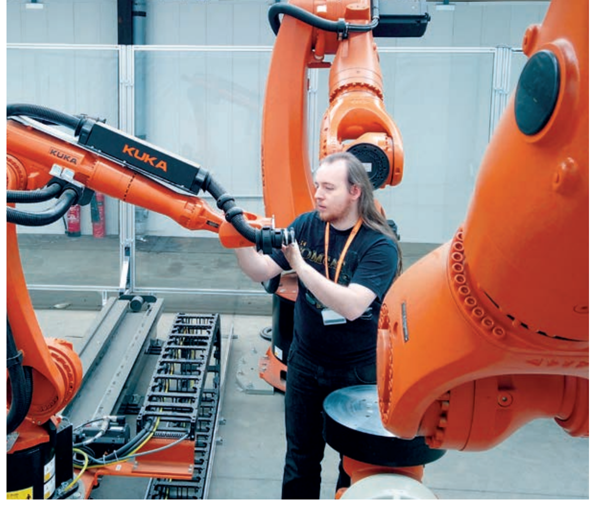
The Power-Up project

The Power-Up project will establish the feasibility of manufacturing AMTE Power's Ultra High Power cells in the UK, at volume. The aim is to have an automotive format cell ready for production at UKBIC by the end of the 12-month project. AMTE will engage with potential UK customers for these cells, providing them early mover advantage. The project aligns with UKBIC's ambition to develop the capacity for high power pouch cell manufacturing for its customer base.

GENESIS

GENESIS (Generating Energetic Novel cells and Systems Inspired by Software) is a collaboration led by Gigaplant developer Britishvolt that aims to design and demonstrate a large format lithium-ion pouch cell. It will be optimised to deliver both high energy density and sustain fast charging to the automotive sector technical requirements and use-case specifications, provided by an automaker. Prototype cells will be fabricated to refine and validate the modelling undertaken at Imperial.

The Power-Up project will establish the necessary volume manufacturing process for the Ultra High-Power cell through the UK Battery Industrialisation Centre (UKBIC)



ReLiB is working to demonstrate robotic battery disassembly for EV battery packs at multiple scales. Courtesy of University of Birmingham.

ReLiB: Recycling and Reuse of EV Lithium-ion Batteries

Determining the most efficient ways to recycle lithium-ion batteries.

Duration 1 March 2018 – 31 March 2023
Funding £14,100,000

Lead Institution UNIVERSITY OF BIRMINGHAM

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

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

Objectives are:

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

Milestone/deliverables (March 2023)

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

Project innovations

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

This will provide high-purity and high-value recovered material streams, maximising the environmental gains of the transition to EVs.

Principal Investigator
Professor Paul Anderson
University of Birmingham

Project Manager
Paul Cornick
University of Birmingham

University Partners
University of Birmingham (Lead)
University College London
University of Edinburgh
University of Leicester
Newcastle University

Research Organisations, Facilities and Institutes
Diamond Light Source (STFC)
UK Battery Industrialisation Centre (UKBIC)

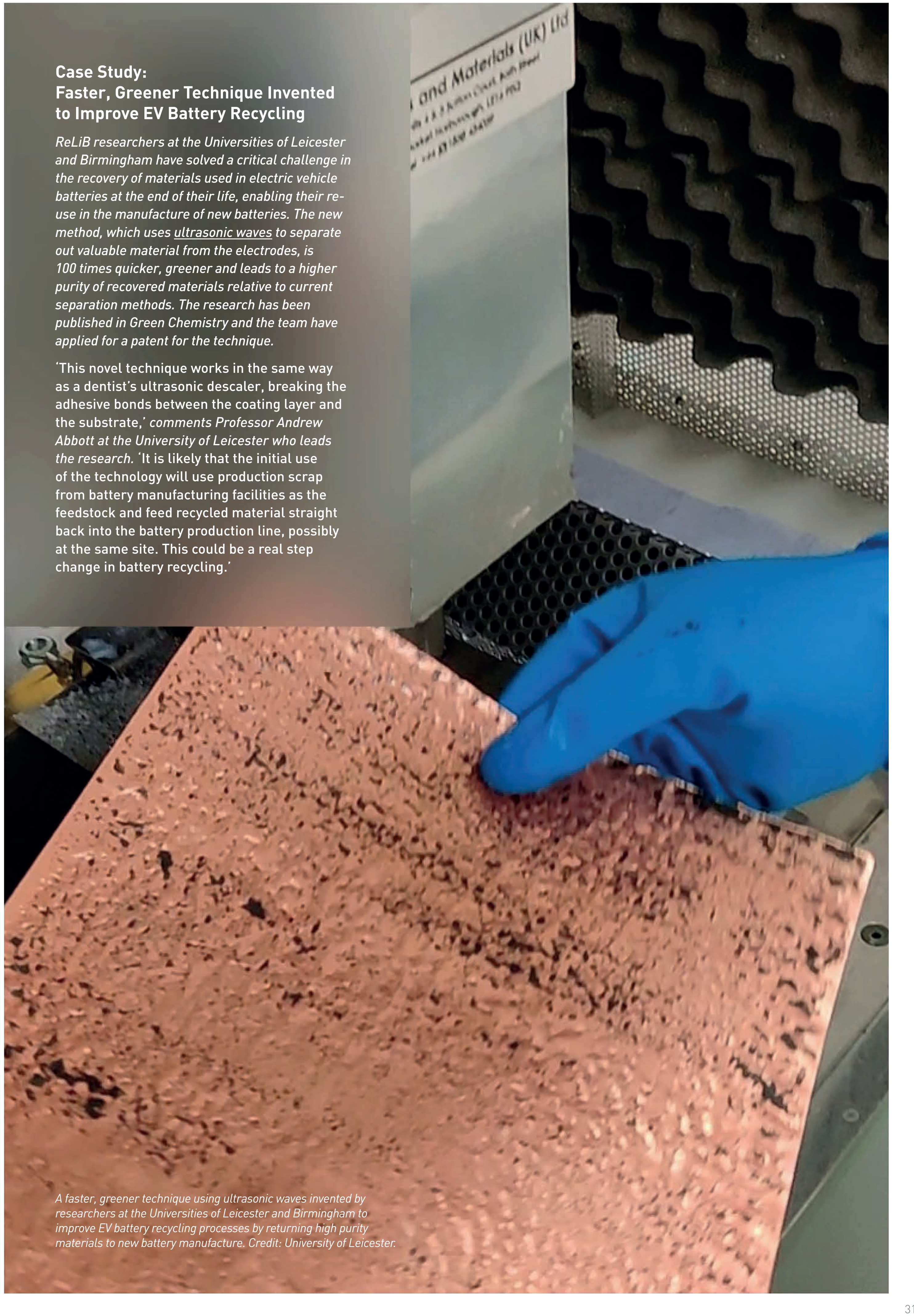
+ 12 Industrial Partners

Website

Case Study: Faster, Greener Technique Invented to Improve EV Battery Recycling

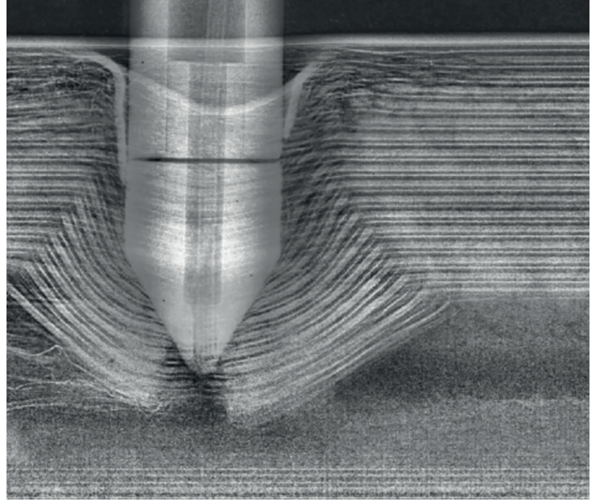
ReLiB researchers at the Universities of Leicester and Birmingham have solved a critical challenge in the recovery of materials used in electric vehicle batteries at the end of their life, enabling their re-use in the manufacture of new batteries. The new method, which uses ultrasonic waves to separate out valuable material from the electrodes, is 100 times quicker, greener and leads to a higher purity of recovered materials relative to current separation methods. The research has been published in Green Chemistry and the team have applied for a patent for the technique.

'This novel technique works in the same way as a dentist's ultrasonic descaler, breaking the adhesive bonds between the coating layer and the substrate,' *comments Professor Andrew Abbott at the University of Leicester who leads the research.* 'It is likely that the initial use of the technology will use production scrap from battery manufacturing facilities as the feedstock and feed recycled material straight back into the battery production line, possibly at the same site. This could be a real step change in battery recycling.'



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

Research Stream 1
Lithium Ion



State-of-the-art high speed X-ray imaging allows researchers to see inside a cell in real time as it fails during abuse tests, providing in-depth understanding of battery safety.

SafeBatt – The Science of Battery Safety

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

Duration 1 April 2021 – 31 March 2023
Funding £1,520,000

Lead Institution UCL

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

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

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

Milestone/deliverables (March 2023)

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

Project innovations

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

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

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

Principal Investigator
Professor Paul Shearing
University College London

Project Leader
Dr Julia Weaving
University College London

University Partners
University College London (Lead)
University of Cambridge
Imperial College London
Newcastle University
University of Sheffield
University of Warwick

+ 2 Industrial Partners

Website

Case Study: Improving Battery Safety for Aerospace Applications

Working with a leading aerospace company, Faraday Institution researchers have developed a better fundamental understanding around potential battery safety issues, which will enable significant advances in modelling capability leading to a faster, cheaper, more efficient battery pack development process.

Researchers at UCL's Electrochemical Innovation Lab have used calorimetry combined with mass spectrometry to provide data to the industry partner on mechanism of failure, heat release and gas composition under a range of conditions. X-ray computed tomography (X-ray CT, a non-destructive technique, similar to that used in medical applications) has been used to show internal structural differences after failure. The use of specialist instrumentation at Diamond Light Source has allowed the capture of high-speed videos of the internal components of a cell during failure using X-ray radiography.

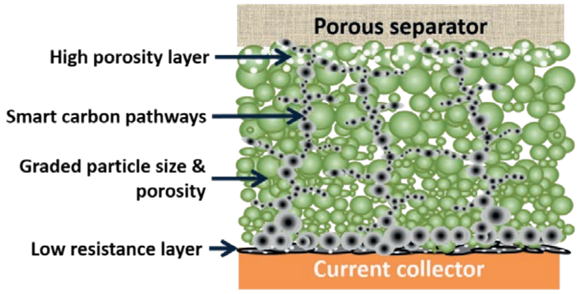
Longer term the success of this programme could lead to a joined-up approach to battery safety research and validation in the UK, strongly linking academia in the UK and overseas with industry and government bodies such as the Health and Safety Executive and the National Physical Laboratory. It has the potential of making the UK a leader in the development of standards for aviation battery safety.

State-of-the-art high speed X-ray imaging allows researchers to see inside a cell in real time as it fails during abuse tests, providing in-depth understanding of battery safety.

Tracking Internal Temperature and Structural Dynamics during Nail Penetration of Lithium-Ion Cells, Donal P. Finegan et al 2017 J. Electrochem. Soc. 164 A3285 (DOI: 10.1149/2.1501713jes)

Nextrode – Next Generation Electrode Manufacturing

Battery performance improvements through smarter electrode manufacturing.



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

Duration 1 October 2019 – 30 September 2023
Funding £12,000,000

Lead Institution University of Oxford

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

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

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

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

Milestone/deliverables (September 2023)

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

Project innovations

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

Principal Investigator
Professor Patrick Grant
University of Oxford

Project Leader
Dr Denis Cumming
University of Sheffield

University Partners
University of Oxford (Lead)
University of Birmingham
University College London
University of Sheffield
University of Southampton
University of Warwick

Research Organisations, Facilities and Institutes
UK Battery Industrialisation Centre (UKBIC)

+ 12 Industrial Partners

Website

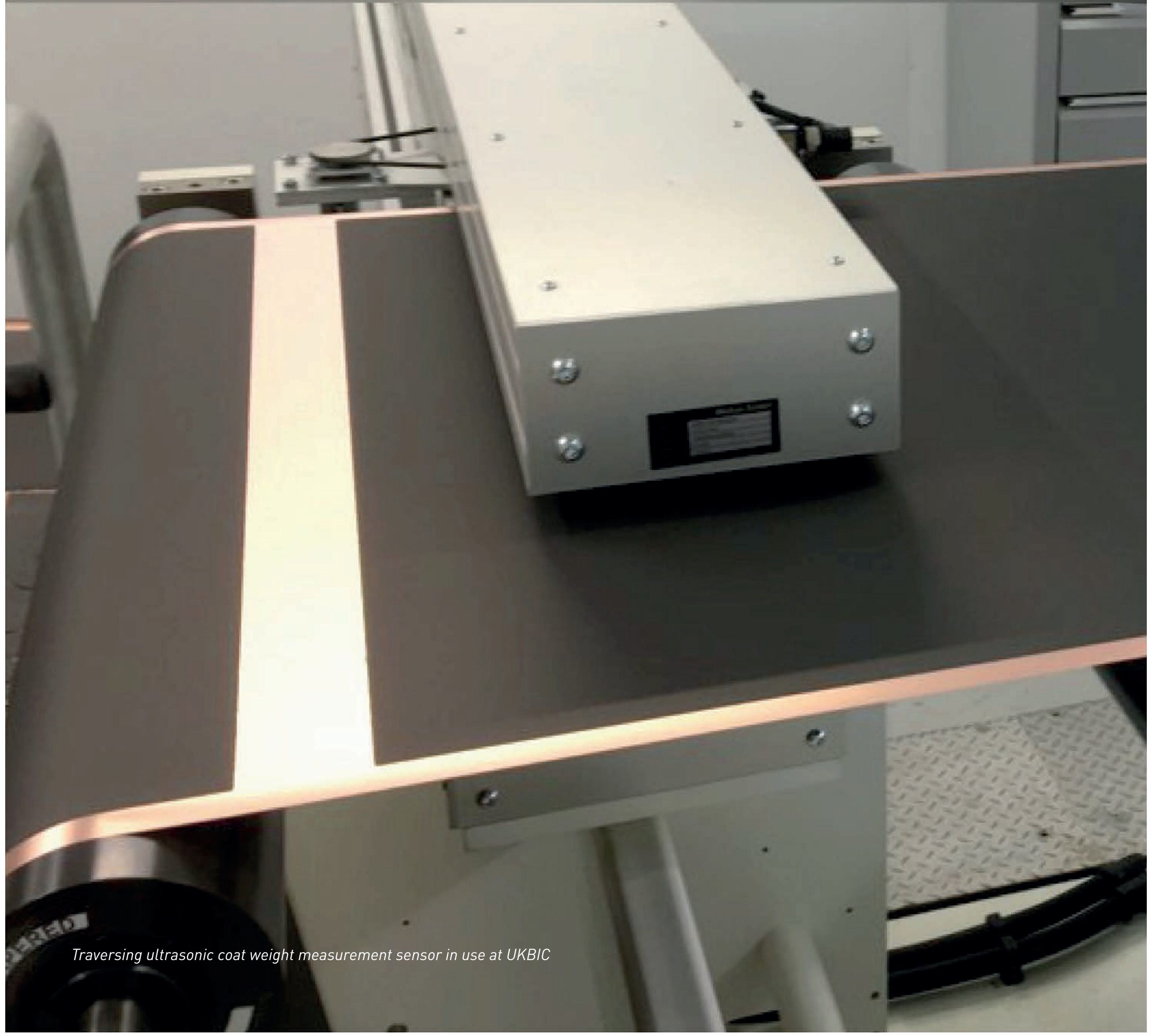
Case Study: Nextrode and UKBIC Collaboration to Improve Electrode Manufacture

The Nextrode project is helping UKBIC to quantify and visualise the quality of their electrode coatings and to 'scale-up' analytical methods developed as part of Nextrode to suit industrial applications.

The UKBIC coating machine deposits electrode slurry onto foil current collectors and utilises ultrasonic coat weight measuring equipment for in-line monitoring of the slurry coating weight that is coated onto both sides of the foil. The coating weight determines the energy capacity of the electrodes. When manufacturing cylindrical battery cells, gaps are left in the coating for tab welding at a later stage. These coating gaps are incorrectly identified as imperfections in coat-weight data. The challenge was to identify a method by which the gauge data can be processed so that the true average coating weight and tolerances can be quantified without being influenced by the coating gaps. This helps UKBIC to accurately measure process capability and yield, two key metrics for electrode scale-up and industrialisation.

The problem was more challenging than it first may appear, as it's not just a case of ignoring all coat-weight values below a certain level, since you must differentiate these deliberate 'coat weight gaps' with true imperfections in the coatings like streaks, holes, or sloped edges that will have a detrimental impact on battery performance and quality.

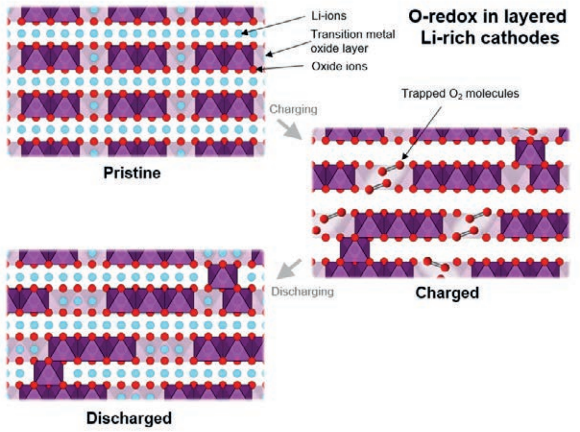
This collaboration between Nextrode researchers and UKBIC, one of the Nextrode project's industrial partners, has helped UKBIC to define the required data management protocol and gain useful process know-how for the Nextrode project. A next stage is to understand how to adapt this analytical method to display the outputs while the electrodes are being manufactured. This will have the potential to significantly change how electrodes are manufactured – simultaneously improving both quality and yield in real-time.



Traversing ultrasonic coat weight measurement sensor in use at UKBIC

CATMAT

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



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

Duration 1 October 2019 – 30 September 2023
Funding £11,000,000

Lead Institution University of Bath

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

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

Milestone/deliverables (September 2023)

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

Project innovations

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

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

Principal Investigator
Professor Saiful Islam
University of Bath

Project Leader
Dr Benjamin Morgan
University of Bath

University Partners
University of Bath (Lead)
University of Birmingham
University of Cambridge
University of Liverpool
University of Oxford
University College London

Research Organisations, Facilities and Institutes
CPI
Diamond Light Source (STFC)
UK Battery Industrialisation Centre (UKBIC)

+ 15 Industrial Partners

Website

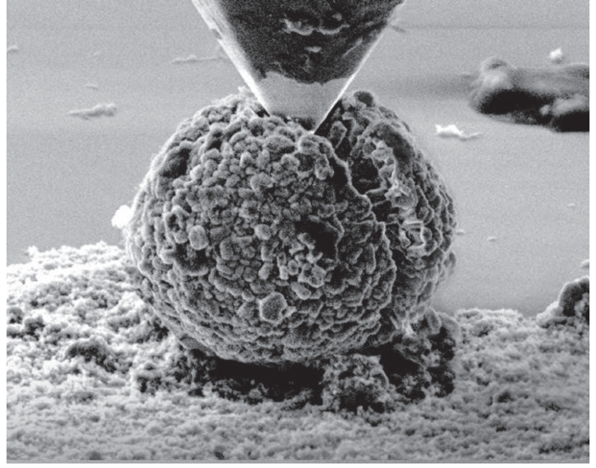
Case Study: Informing Practical Strategies Towards Higher Energy Density Batteries

Scientists based at the Universities of Oxford and Bath researching next-generation cathode materials have made a significant advance in understanding oxygen-redox processes involved in lithium-rich cathode materials. The paper, published in Nature Energy, proposes strategies that offer potential routes to increase the energy density of lithium-ion batteries.

Increasing the range of electric vehicles demands battery materials that can store more charge at higher voltages in order to achieve a higher 'energy density'. There is a limited number of ways to increase the energy density of lithium-ion cathode materials. Most current cathode materials are layered transition metal oxides incorporating, e.g. cobalt, nickel and manganese. One research route involves storing charge on the oxide ions as well as on the transition metal ions.

The breakthrough was enabled by use of state-of-the-art facilities provided by Diamond Light Source and Royce Institute, demonstrating the importance of maintaining the strength of the UK's research infrastructure.

Storage ring sextupole magnet. Copyright, Diamond Light Source Ltd 2020



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

FutureCat

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

Duration 1 October 2019 – 30 September 2023
Funding £9,900,000

Lead Institution The University Of Sheffield.

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

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

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

Milestone/deliverables (September 2023)

FutureCat is targeting three transformative step-changes:

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

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

Project innovations

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

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

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

Principal Investigator

Professor Serena Cussen
University of Sheffield

Project Leaders

Dr Alisyn Nedoma
University of Sheffield

Dr Sam Booth
University of Sheffield

University Partners

University of Sheffield (Lead)
University of Cambridge
University College London
Lancaster University
University of Oxford

Research Organisations, Facilities and Institutes

ISIS Neutron and Muon Source (STFC)

National Physical Laboratory (NPL)

+ 8 Industrial Partners

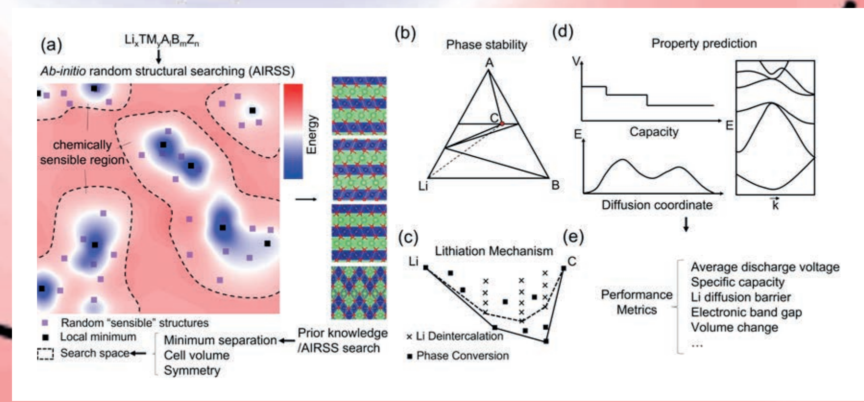
Website

Case Study: Computational Materials Discovery – Expanding the Cathode Space

FutureCat researchers at the University of Cambridge and University College London are using computational modelling to discover brand new materials which show promise as next generation cathodes for lithium-ion batteries. Utilising ab initio random structure searching, the team is making strides in the optimisation of calculations to rapidly and efficiently screen large numbers of possible cathode materials, generating novel structures and selecting for high energy and power density. Through the choice of earth abundant target materials FutureCat is working to not only increase the performance of next generation cathode materials, but to ensure that such materials can supply the predicted battery demand with non-toxic, sustainably sourced and low cost solutions.

Recently published in the Journal of Chemical Physics, the researchers tested and optimised search procedures, successfully generating the known phases for commercial battery cathode materials lithium iron phosphate (LFP) and lithium cobalt oxide (LCO) without a priori information on the structures. Technique refinement when studying LFP, has greatly increased the speed of search for polyanionic materials, successfully biasing towards stable structures. This breakthrough has been highly effective at increasing the application of structural searching to further unknown polyanionic materials. One such example, based on oxalate polyanionic groups, suggests the possibility of anion redox on the oxalate group. Stable anion redox is a key focus of research into next generation cathode materials, as a route to the high energy densities required to take battery performance beyond what is currently achievable.

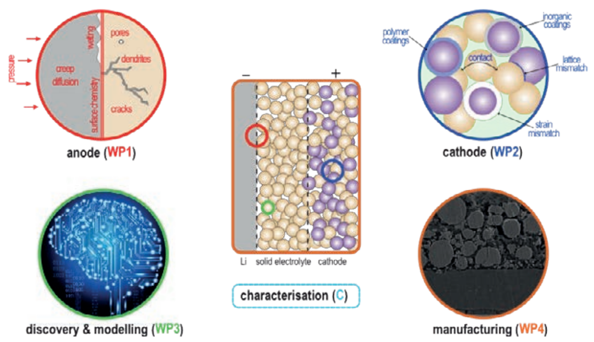
This breakthrough has been made possible by the excellent supercomputer capabilities in the UK such as the Faraday Institution Michael machine.



Schematic of the AIRSS-based framework for the discovery of new battery cathodes: (a) Sampling the potential energy surface with AIRSS, construction of (b) the compositional phase diagram and (c) the pseudo-binary convex hull along the Li-cathode tie line, (d) post-search computation of cathode properties that can be derived from DFT calculations (e.g., voltages, ion diffusion barriers, and electronic bandgaps), and (e) evaluation of performance metrics for battery cathode materials. Reprinted from [Z. Lu, B. Zhu, B. W. B. Shires, D. O. Scanlon, and C. J. Pickard, 'Ab initio random structure searching for battery cathode materials', J. Chem. Phys. 154, 174111 (2021)], with the permission of AIP Publishing.

SOLBAT

All-solid-state lithium-metal anode batteries.



Schematic illustrating the four interconnected work packages of SOLBAT project.

Duration 1 March 2018 – 31 March 2023
Funding £15,300,000

Lead Institution University of Oxford

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

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

Organised around four research areas, namely anode, cathode, discovery and modelling and manufacturing, the project aims to address remaining research challenges and accelerate the efforts to commercialise solid-state batteries.

Milestone/deliverables

Anode

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

Cathode

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

Discovery and modelling

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

Manufacturing

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

Project innovations

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

Principal Investigator
Professor Peter Bruce
University of Oxford

Project Leader
Professor Mauro Pasta
University of Oxford

University Partners
University of Oxford (Lead)
University College London
University of Liverpool
University of Sheffield
University of Warwick

+ 10 Industrial Partners

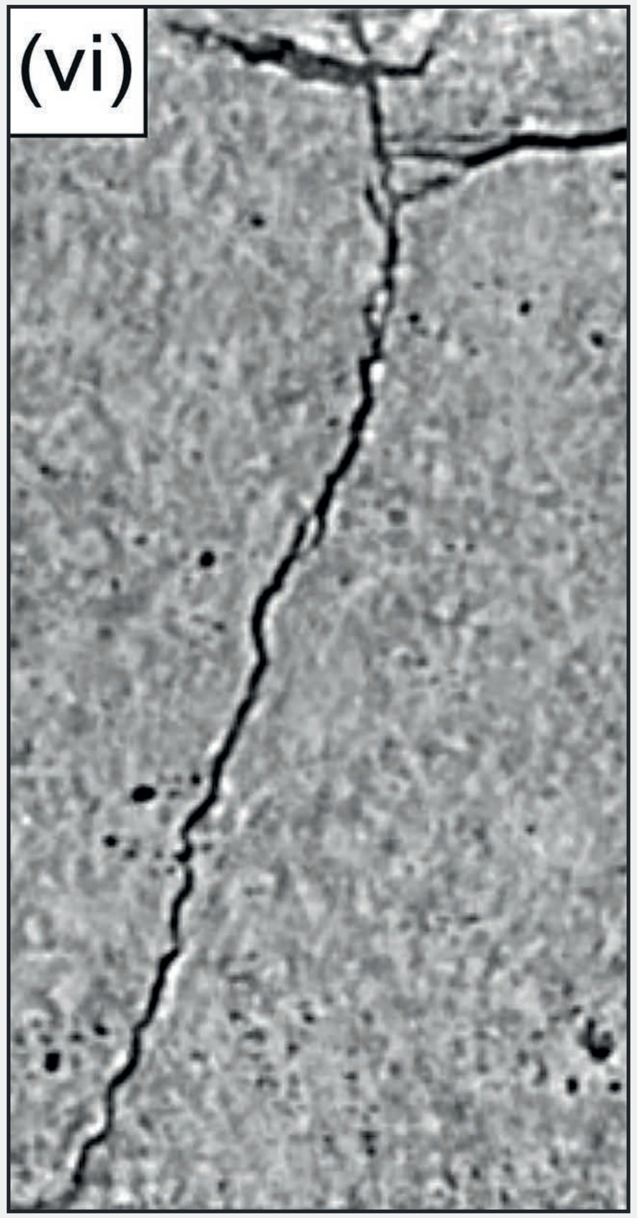
Website

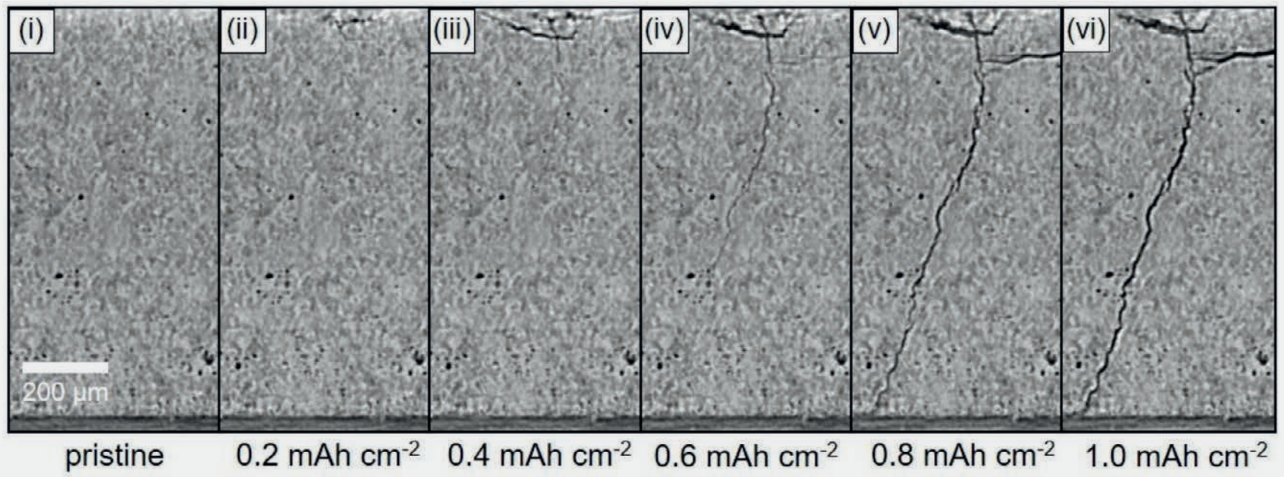
Case Study: Visualising Cracking in Solid State Cells

Scientists at the University of Oxford, in collaboration with Diamond Light Source and the Paul Scherrer Institut, have used advanced imaging techniques to reveal new insights into electrolyte cracking and dendrite formation in solid-state batteries.

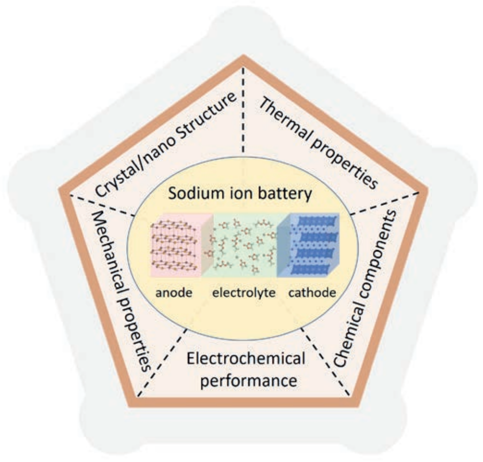
Propagation of lithium dendrites through the solid electrolyte ultimately leads to cell failure and is one of the greatest barriers to the commercialisation of solid-state cells. In a paper published in Nature Materials, the Oxford team used in-situ X-ray computed tomography and spatially mapped X-ray diffraction to track the propagation of cracks and lithium dendrites through the solid electrolyte. Initially pothole-like cracks (spallations) form in the solid electrolyte next to the plated lithium anode and, as more charge is passed, transverse cracks propagate across the electrolyte. Lithium ingress drives the propagation of the crack by widening the crack from the rear, not the crack tip – the crack propagates ahead of the deposited lithium. Only when lithium plates along the full length of the crack does the cell short circuit.

This new mechanistic understanding will inform approaches to avoid cell failure, such as controlling physical properties to prevent dry crack propagation, and accelerate the development of this technology.





Visualising plating-induced cracking in lithium-anode solid-electrolyte cells. From: Ning, Z., Jolly, D.S., Li, G. et al. Nat. Mater. 20, 1121–1129 (2021)



Schematic illustrating the interconnected work packages of the NEXGENNA project.

NEXGENNA – Sodium-ion Batteries

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

Duration 1 October 2019 – 30 September 2023
Funding 11,500,000

Lead Institution University of St Andrews

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

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

Milestone/deliverables (September 2023)

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

Project innovations

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

Principal Investigator
Professor John Irvine
University of St Andrews

Project Leaders
Dr Nuria Tapia Ruiz
Lancaster University

Dr Robert Armstrong
University of St Andrews

University Partners
University of St Andrews (Lead)
University of Cambridge
University College London
Lancaster University
University of Sheffield

Research Organisations, Facilities and Institutes
ISIS Neutron and Muon Source (STFC)

+ 3 Industrial Partners

Case Study: HIPERCARB

Research from the NEXGENNA project has moved on to the next stage of commercialisation having been awarded an Innovate UK collaborative R&D grant for its further development.

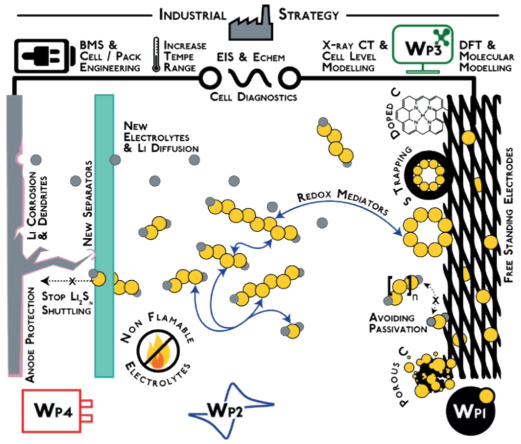
HIPERCARB (High performance hard carbon composites for Na-ion) builds on an existing relationship between the NEXGENNA project and one of its industry partners Deregallera and preliminary data generated by a Faraday Institution cohort PhD researcher at Lancaster University. HIPERCARB will screen composites based on hard carbons manufactured by Deregallera for use as possible anodes for sodium-ion batteries, optimising them to reduce cost and targeting an improvement in cell level energy density of >200Wh/kg, a step beyond current state-of-the-art. The project will be informed by techno-economic assessments carried out by CPI and the final output will be the manufacture and testing of a pouch cell using the most promising anode material.

Scanning Electron Microscopy (SEM) image of a high performance hard carbon composite material. Courtesy of Deregallera.

Research Stream 2
Beyond Lithium Ion

LiSTAR – The Lithium-Sulfur Technology Accelerator

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



Schematic illustrating the complex interactions which occur between the constituent parts of a Li-S cell and the methods adopted by the LiSTAR project to address these.

Duration 1 October 2019 – 30 September 2023
Funding £7,500,000

Lead Institution UCL

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

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

Milestone/deliverables (September 2023)

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

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

Project innovations

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

Principal Investigator
Professor Paul Shearing
University College London

Project Leader
Dr James Robinson
University College London

University Partners
University College London (Lead)
Imperial College London
University of Cambridge
University of Birmingham
University of Nottingham
University of Oxford
University of Southampton
University of Surrey

Research Organisations, Facilities and Institutes
Aerospace Technology Institute
National Physical Laboratory

+ 5 Industrial Partners

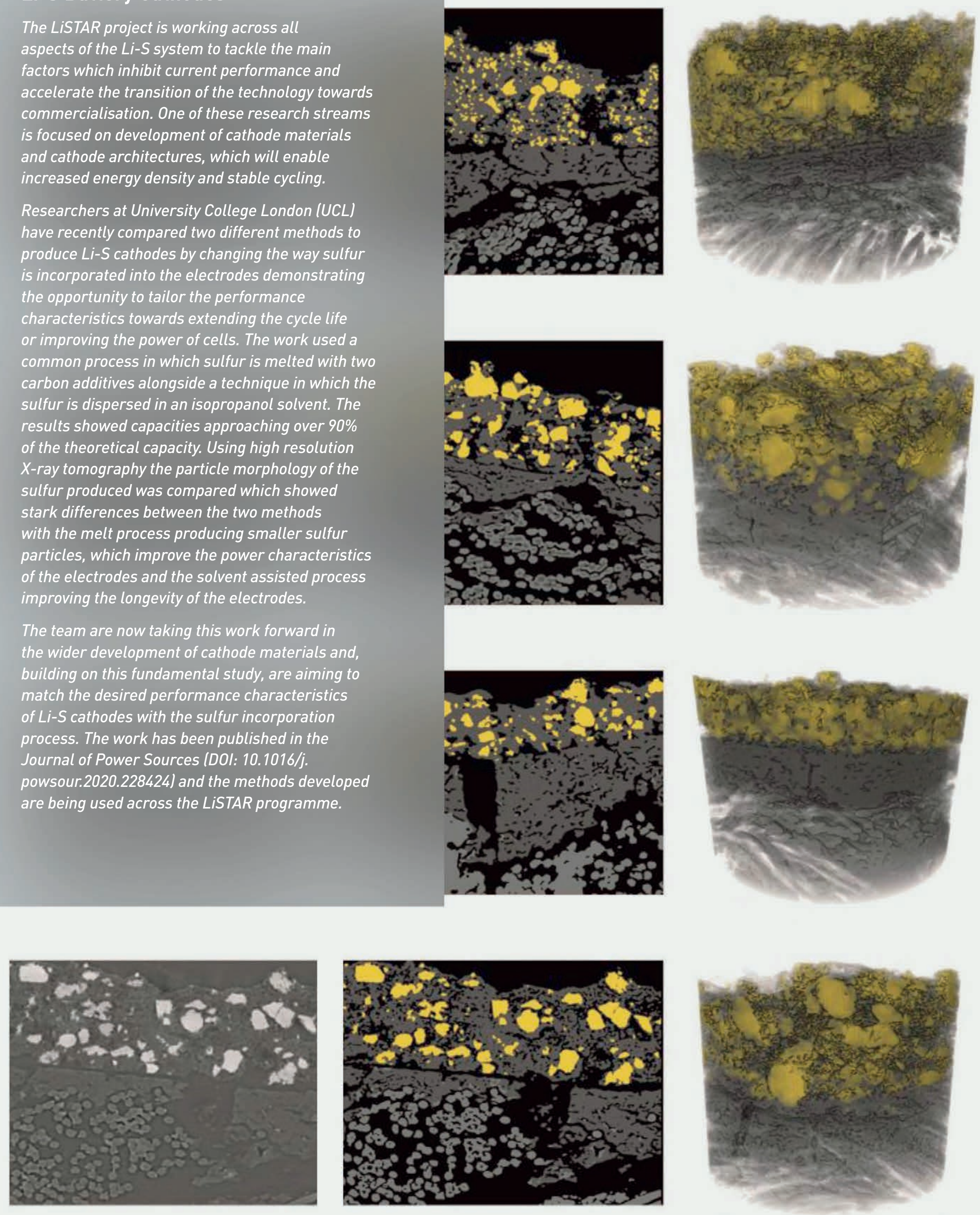
Website

Case Study: Developing New Synthesis Routes for Li-S Battery Cathodes

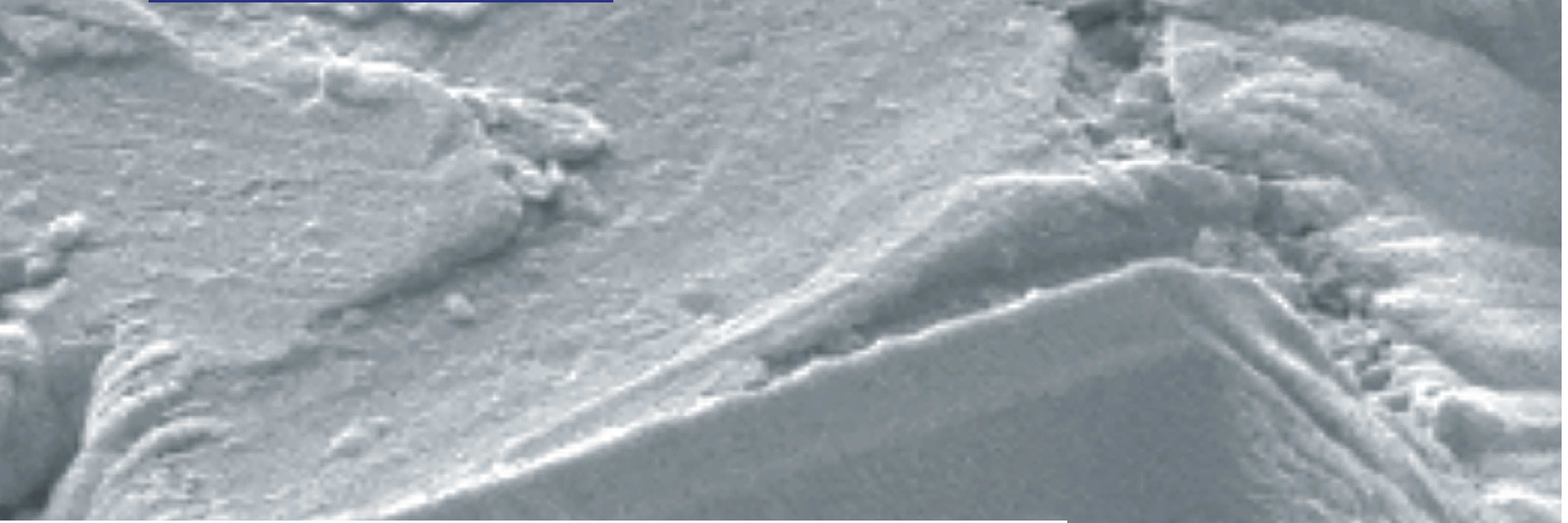
The LiSTAR project is working across all aspects of the Li-S system to tackle the main factors which inhibit current performance and accelerate the transition of the technology towards commercialisation. One of these research streams is focused on development of cathode materials and cathode architectures, which will enable increased energy density and stable cycling.

Researchers at University College London (UCL) have recently compared two different methods to produce Li-S cathodes by changing the way sulfur is incorporated into the electrodes demonstrating the opportunity to tailor the performance characteristics towards extending the cycle life or improving the power of cells. The work used a common process in which sulfur is melted with two carbon additives alongside a technique in which the sulfur is dispersed in an isopropanol solvent. The results showed capacities approaching over 90% of the theoretical capacity. Using high resolution X-ray tomography the particle morphology of the sulfur produced was compared which showed stark differences between the two methods with the melt process producing smaller sulfur particles, which improve the power characteristics of the electrodes and the solvent assisted process improving the longevity of the electrodes.

The team are now taking this work forward in the wider development of cathode materials and, building on this fundamental study, are aiming to match the desired performance characteristics of Li-S cathodes with the sulfur incorporation process. The work has been published in the Journal of Power Sources (DOI: 10.1016/j.powsour.2020.228424) and the methods developed are being used across the LiSTAR programme.



X-ray tomography imaging of the four cathode materials produced using the melt and solvent assisted process alongside the impressive cycling results showing early capacities in excess of 90% of the theoretical capacity of sulfur.



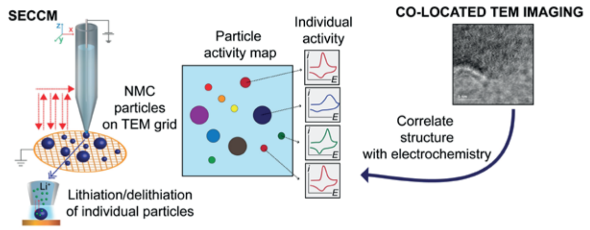
The Faraday Institution awarded a total of £2 million to three UK-based consortia in July 2019 to develop battery-focused characterisation and analytical techniques to provide UK battery researchers with world-leading tools to accelerate the development of their understanding of battery materials and enable scientific breakthroughs that will ultimately improve the performance of electric vehicles (EVs).

These projects build upon the recommendations of a study of scientific facilities available in the UK as commissioned by the Faraday Institution (Identifying Infrastructure and Collaborative Expertise for Electrochemical Energy Storage Application, by Professors Nigel D Browning and Laurence J Hardwick).

The Battery Characterisation projects concluded in September 2021 with multiple community dissemination activities taking place, including a Faraday Masterclass, a Faraday TECH Series and finally a hybrid event at University of Cambridge. The event attracted 114 online delegates from 16 countries and 36 in-person attendees. Moreover, several journal publications have been published with more in preparation stage. These techniques are already being used for material characterisation across the wider Faraday Institution projects including Extending Battery Life (Degradation), CATMAT, FutureCat, SOLBAT and ReLiB.

Imaging Dynamic Electrochemical Interfaces

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



Correlative single particle imaging

Duration 1 July 2019 – 30 September 2021
Funding £1,000,000

Lead Institution University of Liverpool

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

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

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

Milestone/deliverables (October 2021)

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

Project innovations

This project has developed an approach to specimen preparation which permits reproducible, artefact-free operando battery component characterisation across multiple length and time scales. It has developed and demonstrated combined use of chemical reaction and measurement technique with imaging techniques. The project delivered a high-throughput technique which should accelerate characterisation of degradation processes as well as future battery materials and coatings. A negotiation with commercial instrument supplier is taking place regarding the AI software and algorithms. Potential intellectual property from the technique is being evaluated.

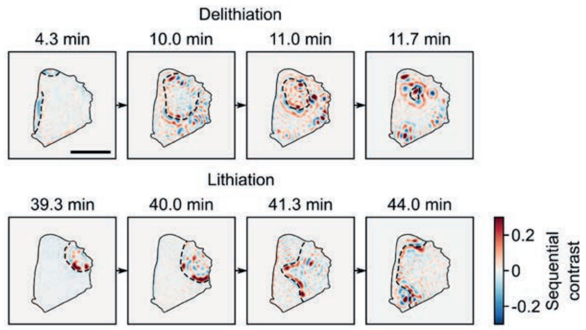
Principal Investigator
Professor Nigel Browning
University of Liverpool

University Partners
University of Liverpool (Lead)
University of Bath
University of Birmingham
University of Manchester
University College London
University of Warwick

+ 3 Industrial Partners

The Development of High-resolution Optical Microscopies

This characterisation project is exploring the use of high-resolution optical microscopies for studying battery systems.



iScat spectroscopy showing lithiation and delithiation of LiCoO2 particle

Duration 1 July 2019 – 30 September 2021
Funding £500,000

Lead Institution University of Cambridge

Building upon recent breakthroughs in characterisation methods developed for semiconducting materials, the project aims to provide a greater understanding of how electrode materials function at the single particle level and at shorter timescales than is currently available.

Understanding the mechanisms by which and the rates that lithium ions move in battery electrode materials is vital to developing high-rate battery materials with reduced capacity fade.

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

Milestone/deliverables (September 2021)

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

Project innovations

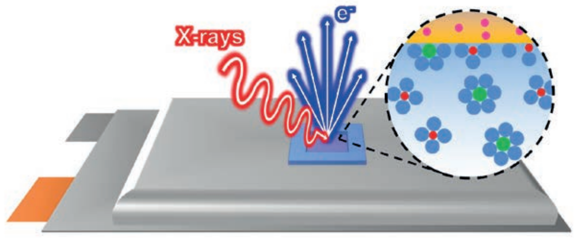
The project has developed a new technique – iScat – to observe ion dynamics in solid-state materials that can be used to study most battery materials. Observation of the movement of phase boundaries allows for improved mechanistic understanding of processes at high charge rates. The high throughput methodology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

Principal Investigator
Dr Siân Dutton
University of Cambridge

University Partners
University of Cambridge

What Lies Beneath? Probing Buried Interfaces in Working Batteries

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



Operando probing of battery interfaces: X-ray and electron transparent windows are used to directly observe chemical changes occurring during battery cycling.

Duration 1 July 2019 – 30 September 2021
Funding £500,000

Lead Institution University of Oxford

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

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

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

Milestone/deliverables (December 2021)

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

Project innovations

Through close interaction with Diamond Light Source and the Henry Royce Institute, the project has developed a new XPS/HAXPES technique that can be used with both lab-based systems and a synchrotron source. This adds new in-situ chemistry capability by providing a new option to react and reliably measure uncontaminated samples. It also offers an offline route for sample verification before national lab instrument beamtime. The in-situ and operando capabilities developed are expected to substantially improve researcher understanding of interfacial behaviour in a wide variety of different battery chemistries.

Principal Investigator
Professor Robert Weatherup
University of Oxford

University Partners
University of Oxford (Lead)
University of Manchester

Research Organisations, Facilities and Institutes
Diamond Light Source

+ 3 Industrial Partners

Funded from a £3 million grant provided to the Faraday Institution from UK Aid as part of its Transforming Energy Access (TEA) programme, two ongoing projects focus on reducing the cost and improving the performance of battery technologies for use in developing countries and emerging economies in order to enable the clean energy transition and reduce reliance on diesel generators. These projects are expected to conclude in 2022.

RELCo-BAT Reclaimed Electrolyte, Low-Cost Flow Battery

Dr Richard Wills from the University of Southampton is leading a team from the Universities of Southampton and Sheffield and the Botswana International University of Science and Technology to develop a low-cost soluble lead flow battery to promote grid stability and a secure, clean supply in off-grid generation with a focus on Botswana and Sierra Leone.

Low-Cost Graphite Polysulphide Single Liquid Flow Battery

Researchers at the University of Strathclyde are working with StorTera to reduce the cost of an innovative graphite polysulphide single liquid flow battery by refining and cost-engineering the system.

UKaid from the British people
Transforming Energy Access

Published in October 2021, the report entitled *Techno-economic Analysis of Battery Energy Storage for Reducing Fossil Fuel Use in Sub-Saharan Africa*, commissioned by the Faraday Institution and carried out by DNV and TFE Africa, explores the potential of battery energy storage solutions BESS to be viable and competitive in sub-Saharan Africa, as a way of offering alternative solutions for resilience and grid independence. If realised, this would enable the integration of more utility-scale renewables and bringing electricity and opportunity to the least developed corners of the continent. The accompanying techno-economic model into BESS, explores their potential to displace fossil-fuel powered generators and increase the uptake of cheaper, cleaner and more reliable energy.

Accelerating Research to Commercial Outcomes

Professor Saiful Islam (left) and Dr Ola Hekselman (right) meet at a Faraday Institution conference. Hekselman is the CEO of start-up Solveteq, which was awarded a Faraday Institution Entrepreneurial Fellowship in 2019.

For energy storage to flourish, breakthroughs in the lab must be identified and protected, and associated commercialisation strategies developed and executed. Early-stage commercialisation of battery technology to deliver UK economic impact is central to the mission of the Faraday Institution.

This year the Faraday Institution has built up its commercialisation capability and started to accelerate research emerging from its projects on their journey into commercial products, services and solutions with the potential to improve battery performance and significantly reduce cost. Researchers are working with the UK's rapidly emerging battery supply chains to provide globally competitive breakthroughs that will support economic growth and create new jobs.

In April 2021, the Faraday Institution added a Head of Commercialisation role to its leadership team and expanded its commercial capability that now comprises four, full-time equivalent, innovation and commercialisation professionals. The team has added an innovative analysis and prioritisation process, T-SCAN, to its operating model that encompasses active research project management and close links with university technology transfer offices.

As the research projects mature, more and more scientific breakthroughs are emerging with commercial potential. T-SCANs are developed in conjunction with project research leaders and provide a way to help prioritise opportunities across the portfolio, and to determine whether there are plausible pathways to UK economic impact where the commercialisation team can add value alongside university technology transfer capabilities.

The Faraday Institution has also continued to develop and build its strong collaborative links with a wide range of industrial partners. Today, more than 50 companies proactively provide support and direction to the research projects. Our projects and commercialisation team maintain active relationships with these companies and leverages their significant expertise and know-how to help accelerate its research breakthroughs towards commercial outcomes.

T-SCAN

T-SCAN is a novel commercialisation methodology proprietary to the Faraday Institution. The analysis includes battery market and application assessment, identification of associated UK stakeholders and supply chain bottlenecks, estimates of scale of economic impact and identification of a plausible pathway to market, including detailed understanding of the initial step and identifying investment to deliver that step.

The impact is already being felt:

This summer of 2021, building on the SOLBAT research project, the Faraday Institution and a consortium of six other UK industry and academic organisations signed a memorandum of understanding to combine their ambitions to develop world-leading prototype solid-state battery technology, targeting automotive applications. Solid-state batteries offer significant potential advantages over conventional lithium-ion batteries and could be transformational in meeting the UK's net zero commitments through the electrification of transport. The successful outcome of the collaboration would be to harness and industrialise UK academic capability to produce cells using highly scalable manufacturing techniques that leapfrog the cost-effectiveness and performance achieved elsewhere.

The solid-state battery consortium comprises the following world-leading organisations in battery research, development and manufacturing:

THE FARADAY INSTITUTION

Faraday Institution – the UK's independent institute for electrochemical energy storage research, which has led the consortium's formation and will lead its development.

WMG THE UNIVERSITY OF WARWICK

WMG, University of Warwick – leaders in battery R&D and initial scale-up capability, as well as academic and apprenticeship skills development.

UNIVERSITY OF OXFORD

Oxford University – that leads the Faraday Institution's solid-state battery project and provides the necessary scientific understanding to the consortium.

JM

Johnson Matthey – a global leader in sustainable technologies.

BRITISHVOLT

Britishvolt – the UK-based Gigaplant developer, with a site in NE England.

UK BATTERY INDUSTRIALISATION CENTRE

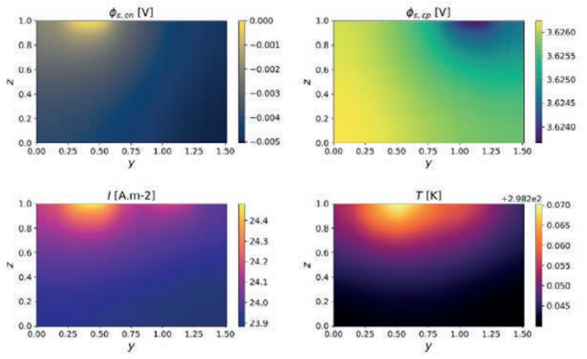
UK Battery Industrialisation Centre – the pioneering battery manufacturing development facility to enable UK battery manufacturing scale-up and facilitate upskilling in the battery sector.

E+R GROUP

E+R (Emerson & Renwick) – a world leading designer of manufacturing equipment.

'Collaboration between industry, government and our world-leading academic institutions is putting the UK at the forefront of global efforts to develop innovative automotive technologies, such as solid-state batteries. It is the work of our internationally-renowned research and development base, like those brought together by this consortium, that will give us the tools needed to forge a strong and sustainable future for the automotive sector and increase our contribution to combatting climate change.'

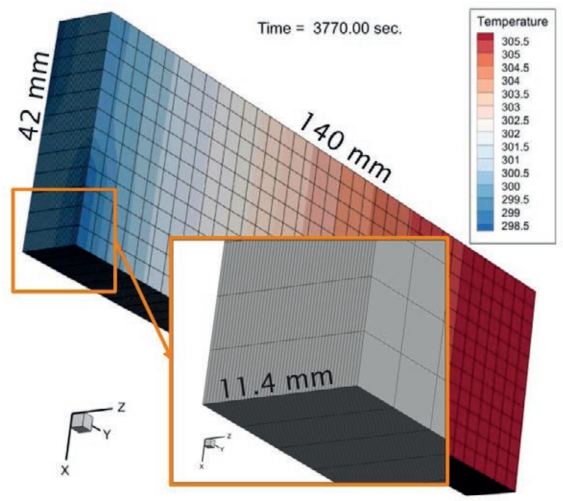
Minister for Investment Lord Grimstone



Plots of current, potential and temperature of a pouch cell created using the PyBaMM modelling tool

The **Multi-scale Modelling** project has been working closely with the Faraday Institution commercialisation team to:

- spinout a joint Imperial College, University of Birmingham company that is already working with automotive OEMs and leading battery engineering design companies to develop global leading capabilities in battery characterisation and model parameterisation.
- develop a standards-based commercialisation strategy for its open source PyBaMM modelling tool of degradation and thermodynamics, linked closely to the accelerated application-specific bespoke cell modelling capabilities of DandeLiion.



Temperature distribution in a 3-D pouch cell created using the DandeLiion modelling tool

Through these developments computer modelling is accelerating battery design and prototyping for UK industry. Projects in applications including the electrification of taxis, buses and municipal vehicles are already underway.

The commercialisation team is also working closely with the:

- lithium-sulfur battery project **(LiSTAR)** and UK supply chain companies that have identified near and medium-term market opportunities in aerospace applications.
- sodium-ion battery project **(NEXGENNA)** and UK supply chain and power grid companies to understand the energy capacity and congestion challenges, and the associated energy storage opportunities, which will need to be addressed with the evolution and reinforcement of the UKs power grid as it evolves to manage the rising demand for power due to an increase in use of EVs and electric heating.

To further accelerate what is often the long journey from research breakthrough to commercial outcome, the Faraday Institution has also introduced several innovation support programmes: Industrial Sprints, Entrepreneurial Fellowships and Industrial Fellowships.

Industrial Sprints

Sprints dedicate small multidisciplinary teams of researchers to solve a commercially relevant research opportunity identified from within the research programme and prioritised by an industrial partner. Over a period of 6 to 18 months, researchers work closely on the challenge, meeting frequently to review progress and hone plans. Sprints give early career researchers an opportunity to lead a focused team across multiple institutions, and to connect with leaders from industry and academia.

Cell Abuse, Off Gas Species and Related Behaviours

Timeframe:
February 2020 – March 2021

Status:
Completed

Projects Involved:
Degradation

Post-Sprint outcome:
Became part of a new Faraday Institution core project *SafeBatt*

Highlight

Industry partners have identified the need to find a better understanding of cell behaviour outside of their specification window. Potentially cells can give off gas and reach high temperatures under thermal, mechanical, or electrical abuse conditions. This needs to be understood to enable a robust design of pack structures especially in safety critical applications such as automotive and aerospace.

In 2021, project researchers at UCL, working closely with an industry partner, combined multiple techniques to describe the mechanism and results of cell failure in an aerospace context. Clearly the implication of cell failure in an aerospace environment is significant, and the work here to establish the evolution of gases under various conditions provided results that can then form models and design rules for pack development, increasing safety whilst limiting the destructive testing of multiple expensive test articles. Along with work from the Degradation project and on the recommendation of an international review panel, the safety work in the Faraday Institution portfolio has now been combined into a project in its own right (SafeBatt), increasing the scope and visibility of this important work.

TOPBAT – Thermally Optimised Battery System

Timeframe:
July 2020 – March 2021

Status:
Completed

Projects Involved:
Multi-scale Modelling

Post-Sprint outcome:
Learning is being taken forward in collaborative Innovate UK R&D projects

Highlight

Imperial College London researchers, in collaboration with AMTE Power, identified the potential for improvements in battery pack and cell design to better control cooling at the cell, module and pack level. This involves the manufacture, modelling and parameterisation of some custom designed cells.

Some of the technical outcomes of this project are as follows: improved equivalent-circuit network (ECN) model, thermally coupled and compatible with pack level models; an insight into tab cooling versus surface cooling; conclusions on feasibility of implementing different thickness tabs into the pouch cell and greater understanding of the implication on tabs welding. In addition, the results of that sprint have successfully been exploited in other newly awarded Innovate UK projects.

Cell Degradation

Timeframe:
September 2019 – Q2 2022

Status:
Ongoing

Projects Involved:
Degradation,
Multi-scale Modelling

Highlight

A major UK company identified an issue whereby some battery chemistries have been shown to suffer from increased capacity fade when stored at a specific state of charge. The aim of this work was to establish the mechanism of the capacity fade and indicate if the issue can be solved by modification to the cell chemistry, or whether battery management system (BMS) strategies need to be employed to minimise residence time at these conditions.

Commercial cells have completed prolonged storage at various conditions (storage duration, SoC, temperature) and electrochemical evaluation of the cells, including impedance spectroscopy, have been performed at WMG. Further in-depth analysis of the cell materials is undertaken at UCL and University of Cambridge, where various characterisation techniques are being deployed, including CT scanning and tests in half cells. Neutron diffraction data have also been collected (Diamond Light Source beamline) and future synchrotron sessions are being planned. The work is still ongoing to fully unveil the issue of capacity fade.

Thermal Interface Materials

Timeframe:
November 2021 – May 2022*

Status:
Ongoing

Projects Involved:
Multi-scale Modelling

Highlight

A leading engineering company was seeking better thermal control of its battery pack as it is vitally important to performance and longevity. Higher performance thermal materials could usefully improve both, by transferring heat efficiently from the cells to the cooling system, and by isolating cells from their neighbours in cases where an individual cell is going into thermal runaway. This sprint aims to develop nanomaterials composites, phase change materials and functional scaffold materials, which will then be validated by models and experimentally. Up-to-date progress led to proof-of-concept model fibres and mechanically stable foams being produced. Preliminary thermal characterisation was conducted. Future work will focus on scaling up and tests of the prototypes. Modelling work is also envisaged.

*originally: February 2020 – December 2020, but restarted with the new schedule

New Approaches to Processing of Oxide Solid State Batteries

Timeframe:
July 2021 – December 2022

Status:
Ongoing

Projects Involved:
SOLBAT

Highlight

Solid state batteries (SSB) allow safe utilisation of metallic lithium electrodes and hence can greatly extend driving range of vehicles. Oxide ceramics offer a highly promising route to solid state batteries that is facile to process at low cost. Researchers at the University of St Andrews began working with Morgan Advanced Materials, in collaboration with Ilika, in the autumn of 2021 in an Industry Sprint project of immediate interest to an automaker. The project, which complements the scope of the longer-term, multi-disciplinary SOLBAT project, is seeking to develop and optimise the process of making supported thin, dense films. Fine-tuning the support would help to mitigate limited conductivity and optimise performance and cyclability.

Screening of Electrode Manufacturing for All-Solid-State Batteries (ELMASS)

Timeframe:
November 2021 – October 2022

Status:
Approved and due to start

Projects Involved:
SOLBAT and solid state battery consortium

Highlight

WMG, University of Warwick, Johnson Matthey, and Jaguar Land Rover are working together on an Industry Sprint to unlock a path to scale up the type of solid-state batteries being investigated by SOLBAT and the recently announced solid-state battery consortium formed by the Faraday Institution. The key outputs will be a cost/performance assessment of an electrode manufacturing technique led by end-user requirements.

Zero-Shot Tower (ZeST)

Timeframe:
December 2021 – November 2022

Status:
Approved and due to start

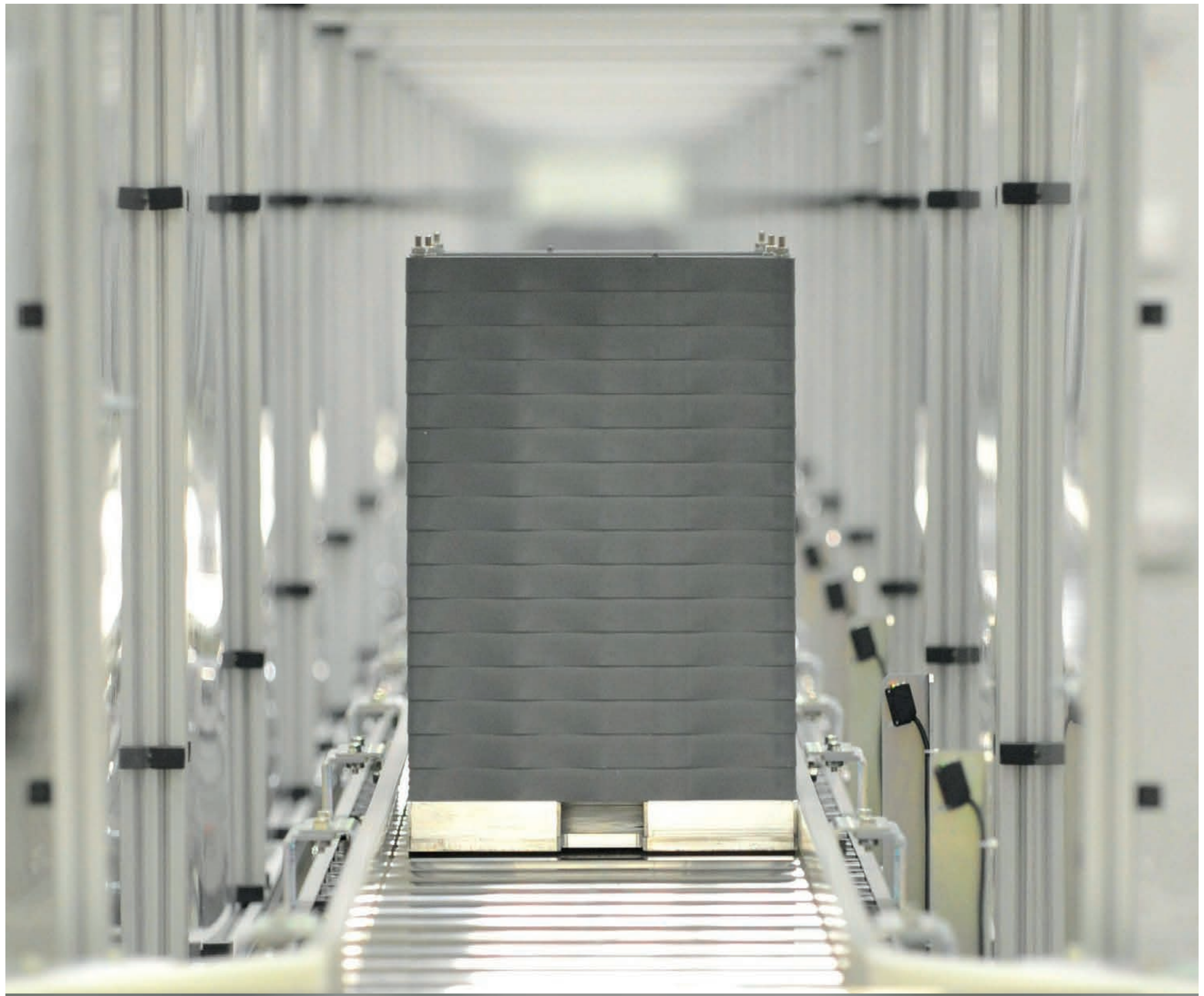
Projects Involved:
SOLBAT

Highlight

Initial studies have indicated that a composite material using lithium-ion conducting fibres can be an effective solid-state electrolyte. The ZeST project is targeting the development of a lithium-ion conducting fibre material for use in a composite solid-state electrolyte for next-generation batteries.

Thermal Ceramics UK Ltd, a subsidiary of Morgan Advanced Materials, will work with the novel glass group at Southampton University to develop a process to manufacture specialist fibres of a new composition to a tight tolerance with high yield.

The University of Southampton is contributing world leading experience and equipment, in the drawing of novel glasses into fibre form, to the project, which is targeting early commercial scale-up using greener and more efficient processes. The industry partner is engaged with a leading battery producer with a view to supplying the material commercially if the project is successful.



Faraday Institution industrial partners

AGM Batteries
AMTE Power
Arcola Energy
Axion Group
BBOXX
Benchmark Mineral Intelligence
BenovolentAI
Breathe Battery Technologies
BMW Group
Britishvolt
British Metal Recycling Association
cap hpi
Carl Zeiss Microscopy
Caterpillar
Claytex Services
Continental
Connected Energy
CDO2
CPI
Delta – a Cosworth Company
Denchi Power
Deregallera
Echion Technologies
Eco-bat Technologies
Envision AESC
Exawatt
Faradion
Finden
Horiba Mira
Huntsman Corporation
Ilika Technologies
Imerys Minerals
Intelligens
Jaguar Land Rover
Johnson Matthey
KU Leuven
KUKA Robotics
Lancaster Materials Analysis Ltd
Less Common Metals
LG Chemical Investment
Lianhetech
McLaren Automotive
Morgan Advanced Materials
Nexeon
Nissan
Nyobolt
nVIDIA
Omicron Nano Technology
Potenza Technology
Prismatic
QinetiQ
Qdot
Rolls-Royce
Samsung
Shell International Exploration and Production
Shell Research UK
SHIELD Investment Management
Siemens
Silson
Stortera
Talga Technologies
TFP Hydrogen Products
Thatcham Research
Thermo Fisher Scientific
Toyota Motor Europe
William Blythe
Williams Advanced Engineering

Entrepreneurial Fellowships and Spin-Outs

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

Breathe Battery Technologies team

Breathe Battery Technologies

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

Website

Outcomes

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

In the last 12 months the company has also garnered support from the European Regional Development Fund and CTO Dr Yan Zhao was awarded a Royal Academy of Engineering Enterprise Fellowship. Attracting talent has been instrumental in the company's progress and, in addition to attracting full-time engineering talent from Porsche, Breathe has hosted several undergraduate interns from the Faraday Institution FUSE programme. In December 2021 Breathe announced it had completed a £1.5m fundraise led by Speedinvest – an early-stage venture capital firm – that will enable it to scale up and accelerate deployment of its technology in electric vehicles and consumer electronics.

The Cognition team at their facility in Oxfordshire (Photo by Natalie Jezzard)

Cognition Energy

Headquartered in Oxfordshire, Cognition Energy's expertise in thermal management, its cell testing service and novel CellPod testing product are being used to extend battery life and reduce ownership costs. The company was founded in October 2018 by Tom Cleaver, Greg Offer (who leads the Faraday Institution Multi-scale Modelling project) and two other academics from Imperial to test cells more accurately and thus develop better batteries. Cognition offers external organisations with a high-quality cell testing service. A large number of cell test channels are available at the organisation's premises that replicate the thermal conditions that cells would experience in a pack.

Outcomes

Following an award of a Faraday Institution Entrepreneurial Fellowship in 2019 to help fund development of a thermally managed 5kWh battery prototype, Cognition Energy took on its first full time staff member. Today it employs 6 FTEs and two part time employees, not counting its founders from Imperial College London. The company has filed one patent related to novel battery electrical design that will reduce cost and increase recyclability.

Based on Cognition's original battery development activities and an Innovate UK Advanced Cell Test (ACT) study, the organisation has developed both a cell testing service and a novel cell testing product, CellPods. There is significant interest in the product from industry and academia, both in the UK and Europe. Its design means it could be used by major pack manufacturers targeting all sectors. The company plans to launch the product before the end of 2021 and begin deliveries to customers by early 2022. Cognition already has one major UK based customer for its testing service and is in discussions with others that recognise Cognition's expertise in thermal management as an enabler to accelerate their battery development and extend battery life and reduce ownership costs.

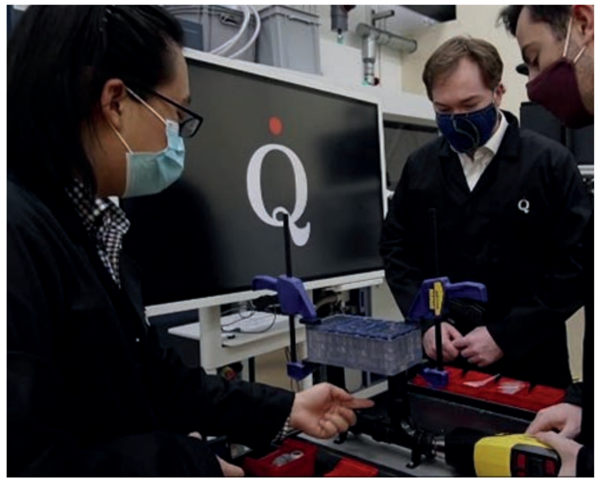
Solveteq's technology replaces the most energy-intensive and polluting steps in the lead-acid battery recycling process with a low-temperature, solvent-based method.

Solveteq

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

Outcomes

The Entrepreneurial Fellowship enabled Solveteq to scale up its successful lab-scale process into an intermediate-scale continuous-operation prototype, designed to recycle 1kg/h of lead paste from used batteries. Life cycle and economic analyses have been conducted to optimise the process and position Solveteq at the forefront of lead recycling innovation. During the fellowship Solveteq also established strategic relationships with international industrial partners and future customers, who are actively collaborating with Solveteq and contributing to its technology and commercial development. With the Fellowship's support, Solveteq was incorporated by IP co-inventors, Dr Ola Hekselman and Prof. David Payne and is now investment-ready, seeking to raise a pre-seed funding round. Solveteq received additional validation of its potential by securing funding from the European Regional Development Fund and Innovate UK to further develop and scale its technology.



The Qdot team based at Harwell Campus

Qdot

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

Website

Outcomes

The Entrepreneurial Fellowship provided Qdot the resources to develop and validate a prototype thermal management system to achieve extremely fast charging at the battery cell level. Follow-on technology development funding has been successfully secured through the Harwell Cross-Cluster Proof-of-Concept Fund, the UK Innovation and Science Seed Fund and Innovate UK Accelerator Programme, and the Innovate UK and Office for Low Emission Vehicles Catalysing Green Innovation – Securing the Future of ZEV funding competition. Future research will expand the technology to a battery module, and then pack, level. Qdot is initially looking to market its technology for vertical take-off and landing (eVTOL) applications that need very high-power density battery packs able to deliver high peak power during take-off and landing and that can be charged quickly between flights. In 2020, Qdot Technology on battery uniform tab cooling to enable clearn flight was awarded a Department for Transport, Transport-Technology Research and Innovation Grants (T-TRIG).

Tom Heenan, Gaussion Ltd

Gaussion Ltd

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

Outcomes

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

The MagLiB fast-charging battery solution won the Royal Society of Chemistry's Emerging Technologies Competition 2021 for the Energy and Environment category. It was also awarded the Autocar Drivers of Change 2021 technology award.

Hand-held Altelium device

Altelium

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

Website

Outcomes

Today, Altelium is a trusted warranty partner delivering information for the electric vehicle and stationary battery storage market to underpin sound product development, investment and insurance decisions. Its information platform combines real-time reporting from built-in battery transmissions with AI self-learning and reporting, channelled through a secure Cloud-based system, giving vital information to customers. Altelium's data service gives customers the information and peace of mind they need to invest and profit from the green energy revolution. The Altelium information platform combines real-time reporting from built-in battery transmissions with AI self-learning and reporting. Channelled through a secure Cloud-based system, this gives vital information through a secure portal, measured in line with National Measurement Institute standards from the National Physical Laboratory. Altelium currently employs 26 people and has received follow-on funding from Innovate UK.

Industrial Fellowships

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

University of Strathclyde with CDO2

Dr Terry Dyer at the University of Strathclyde is working with CDO2 on the miniaturisation of quantum magnetometry sensors. By taking sensitive magnetometer readings, CDO2 can visualise and monitor the current flow within battery cells and packs, with obvious implications for development of both cell and pack designs without the complications of invasive sensing technologies. The fellowship is working towards a new sensor design that has the potential to have superior cost, size, accuracy and cost characteristics than existing technology and allow a significant number of sensors to be embedded in either prototype or serial application designs.

Imperial College London with Ilika Technologies

Prof Greg Offer and Dr Ganesh Madabattula at Imperial College London are partnering with Ilika to utilise the modelling tools developed by the Multi-Scale Modelling project and begin to apply them to solid-state batteries. This modelling of the fundamental physics governing solid-state batteries is allowing Ilika to rapidly trial various modifications to both the chemistry and physical make up of their designs, without having to commit to the cost and time involved in producing and then testing a large number of physical prototypes. This project is initially focussed on the modelling of the high-capacity silicon anode material used by Ilika.

The University of Birmingham with Echion Technologies Ltd

Prof Peter Slater of the University of Birmingham is working with Echion Technologies to identify new mixed metal niobium oxide phases for possible use as anode materials, assess them for performance and thereafter take promising materials into Echion's product development cycle with the aim of improving lithium-ion battery energy densities and charge times.

Cranfield University with Delta Motorsport

Dr Abbas Fotouhi at Cranfield University is working with Delta Motorsports to explore potential applications of artificial intelligence to develop novel temperature prediction techniques that improve the performance of battery thermal management systems, bringing possible benefits to battery performance and lifespan.

University of Sheffield with TFP Hydrogen Products

Prof Serena Cussen and Dr Glen Murray of the University of Sheffield are working with TFP Hydrogen Products to develop processes to control particle morphology and size for next-generation high-nickel cathode materials in a continuous manufacturing process, as part of a long-term aim of maximising battery performance and reducing manufacturing costs.

University of Sussex with CDO2

Prof Peter Kruger and Dr Christopher Abel of the University of Sussex are working with CDO2 to characterise and understand the capability of a newly developed device based on quantum magnetometer technology that could potentially be used to improve the prediction of state-of-health and state-of-charge on-board electric vehicles.

The University of Sheffield with Finden

Prof Serena Cussen at the University of Sheffield is working with Stephen Price at Finden to deepen the understanding of new cathode materials and mitigate deleterious behaviour. The aim is to fast track the best-performing high energy density cathodes to aid their early adoption by UK industry and to inform future cathode protection strategies to prolong battery life.

Imperial College London with Williams Advanced Engineering

Dr Billy Wu of Imperial College London will lead a Fellowship with Williams Advanced Engineering (WAE) to accelerate the deployment of advanced physics-based modelling (developed as part of the Multi-scale Modelling Project) to improve the diagnostic and prognostic capability of the WAE battery management system, targeting an extension in battery life.

The University of St Andrews with AMTE Power

Prof John Irvine, Dr Rob Armstrong and Dr Paul Connor of the University of St Andrews are working with AMTE Power to strengthen the pathway from laboratory to cell production. The partnership is focusing on taking newly developed sodium-ion materials from the laboratory to fully functioning pouch cells as an exemplar technology allowing the building of combined capability. The fellowship is strengthening the industry partner's awareness and capability in battery research and enhancing the university partner's capability to transition cells to full scale.

University of Sheffield with Exawatt

Dr Alisyn Nedoma and Dr Sam Booth from the University of Sheffield will work closely with the team at Exawatt (a key industry partner of the FutureCat project) to develop a techno-economic analysis and forecasting model of the cost of possible novel cathode materials given market raw materials costs and manufacturing methods. The tool will guide cathode research and scale-up options and has potential for use by automakers and to inform policy.

The success of the first Coventry University, Nyobolt collaboration has lead to the awarding of a second fellowship. Agata Greszta is pictured here.

Coventry University with Nyobolt

Dr Alexander Roberts at Coventry University is working with Nyobolt to prototype their niobium-based anode materials into working battery cells. The collaboration is proving highly successful for both parties involved, with prototype cells confirming performance potential that supported a recent funding round for Nyobolt. Dr Roberts benefits from career development opportunities from interacting with the technical and commercial teams at Nyobolt as they head towards larger scale production. The success of the programme has led to a second Fellowship being awarded in 2021.

'Lithium-ion battery cells with unparalleled fast charging capabilities are being scaled up through a Coventry University – Nyobolt Ltd collaboration.'

Associate Professor Alex Roberts, Coventry University

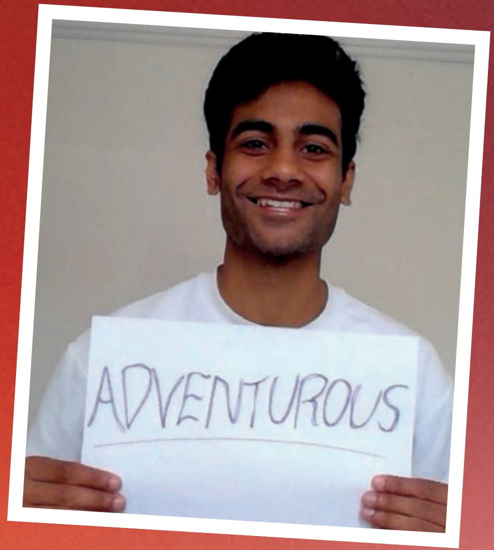
Case Study: Coventry and Nyobolt

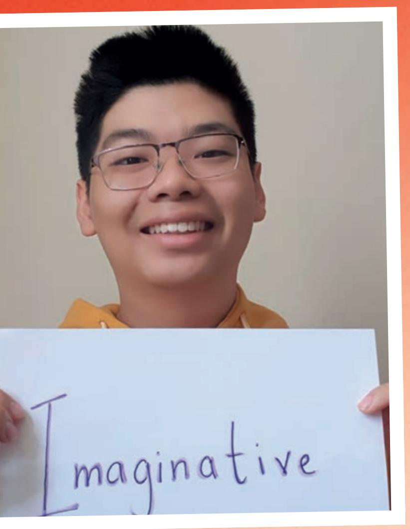
Fast Charging Battery Success

Current lithium-ion batteries can take several hours to recharge, and even the fast-charging of EVs takes over 30 minutes. The materials being developed by Nyobolt have the potential to offer a step change in fast charge capabilities. Through this Faraday Institution supported collaboration between Nyobolt and Coventry University, battery cells with unparalleled fast charging capabilities are being scaled up. Around 100 industry-relevant cylindrical cells have been manufactured, capable of full charge in under 5 minutes, compared to an average of 30 minutes for fast charging to 80% charge for current EV batteries. The prototype devices developed under this programme were essential to demonstrate the potential of Nyobolt's technology and, in so doing, helped secure a £8m Series A investment for Nyobolt early in 2021.

Developing battery prototypes at the Centre for Advanced Low Carbon Propulsion Systems

Inspiring and Training the Next Generation





FUSE interns hold signs with words that describe themselves

Aware that next-generation energy storage technologies will come from future scientists and engineers, the Faraday Institution is committed to developing a dynamic and diverse pool of talent.

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

The Growing Impact of Faraday Institution Educational Programmes

470+ researcher community
with professional career development prioritised to include 9 Faraday Masterclasses with experts in 2021

55 PhD Researchers
from 16 universities receiving training through our doctoral programme

150 undergraduate interns
50 in 2021

10 undergraduate Faraday Scholars
supported to diversify researcher pipeline

10,000+ young people engaged
through the Fully Charged Battery Box programme, spanning all parts of the UK

Undergraduate Attraction

Each summer, the Faraday Institution funds up to 50 undergraduate internships in partner universities. These 8-week, competitive internships give students access to leading scientists, unique facilities, hands-on and online research experiences and inspires them about future STEM careers. A number of graduates from this programme have since gone on to pursue PhDs in energy storage related disciplines, further internships, work in battery development for UK industry and to join a Faraday Institution spin out.

Faraday Undergraduate Summer Experience (FUSE)

A success story from 2021 was the adaption of the Faraday Undergraduate Summer Experience (FUSE) programme to create bespoke virtual internships for the online environment again for a second summer. Successfully widening reach and participation, the scheme was highly competitive with over 950+ applications. A dynamic and diverse pool of talent was drawn from over 18 universities.

Supplementing the work experience, the Faraday Institution hosted a programme of career shaping events to give interns greater insight into the field and potential opportunities. Guest speakers presented on a day in the life of a battery researcher, what PhD research entails, and a glimpse into launching an entrepreneurial spin-out. Rounding out the career development aspects of the programme, interns presented research posters at the Faraday Institution Annual Conference.

950+
applications

participants from
18
universities

FUSE supervisor quotations from 2021:

'I think the FUSE students really appreciated the direct contact with the FutureCat researchers. For our PhDs it was their first supervisory experience, and for the postdocs it gave them the opportunity to get involved in an outreach project, using their science expertise.'

'The programme offers a mutually beneficial situation for both intern and academic, with the student able to learn new cutting-edge techniques and science while offering the opportunity to make focussed progress on a specific project.'

'The FUSE program offers students the opportunity to conduct real research at the frontier of battery innovation.'

'We produced a high impact paper in a new topic for the group. It led to a fully funded MPhil project with a new industrial collaboration.'

'The summer intern brought a fresh perspective and a jolt of positive energy to my group that was much needed after a long tough year.'

'We had an outstanding intern who carried out an in-depth review with 250 references and produced the bulk of a critical review which was submitted to Green Chemistry. An amazing result from an 8-week project.'

'Our experience was so positive that we would be very keen to host similar secondments from the Faraday Institution in the future.'

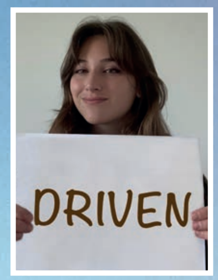
FUSE intern feedback

Catie Kohler
Materials science and engineering undergraduate at University of Sheffield, FUSE intern with FutureCat project at the University of Sheffield.

'It's been a great opportunity to speak to PhD students and post Docs in the field to learn more about their experiences.'

James Swift
Mechanical engineering undergraduate at University of Warwick, FUSE intern with ReLiB project at Newcastle University

'The Faraday Undergraduate Summer Experience is not only an exciting and rewarding paid research placement but also a fantastic addition to the portfolio of anyone pursuing a career in the energy storage industry.'



Beatrice Ricci
Natural sciences undergraduate at the University of Cambridge, FUSE intern with the Degradation project at the University of Cambridge.

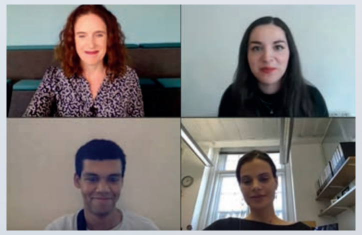
'It gave me a unique opportunity to understand the actual work atmosphere, daily life and responsibilities of someone working in a research group, which is far beyond anything that could have been gained simply from my university course. It also gave me a chance to see how the science I study could be applied to real-world problems, and the type of work that one can do.'

Irene Salvadori
Chemistry undergraduate at the University of Edinburgh, FUSE intern with the Degradation project at the University of Cambridge.

'Making the poster has certainly been a key moment of the internship. Being able to summarise for a wider audience all I learnt during the 8 weeks has given me a great confidence boost, making me realise I am actually becoming a real scientist! Being a FUSE intern has been an amazing experience which not only gave me the chance to widen my knowledge, but also to be part of the dynamic Faraday community and gain an insight into academia and research.'

Chemistry careers webinar

With the Royal Society of Chemistry, Faraday Institution Education and Training Lead Fran Long moderated a webinar about chemistry careers, featuring Dr Beth Johnston (FutureCat researcher, University of Sheffield), Haydn Francis (PhD researcher, University of Cambridge) and Dr Ola Hekselman (CEO and co-founder of Faraday Institution spin-out Solveteq). In the lead up to COP26, this was aimed at undergraduate students and early career researchers, highlighting exciting career pathways that can positively contribute towards building a sustainable future.



ROYAL SOCIETY OF CHEMISTRY

Routes to success

Isabella Stephens

Chemistry undergraduate at University of Oxford

FUSE internship 2019

Investigating ceramic solid electrolyte / polymer composite cathode interfaces in all solid-state lithium and sodium batteries with Professor Peter Bruce's group at Oxford Materials.

Poster winner Faraday Institution Annual Conference.

Northvolt intern 2021

Faraday Institution PhD Researcher

Working on CATMAT at University of Birmingham in Professor Emma Kendrick's group, starting October 2021.

Greta Thompson

Materials science undergraduate at University of Oxford

FUSE internship 2019

Investigating the surface roughness of solid electrolyte material LLZTO with Mauro Pasta's group at Oxford Materials

Intern Breathe Battery Technologies (a Faraday Institution spin-out)

Master's project on degradation in lithium-ion batteries

Working with Robert Weatherup's group at University of Oxford.

PhD position at the University of Cambridge

Working in redox-flow batteries under Professor Clare Grey and Professor Michael de Volder, starting October 2021

'I always wanted to go into the energy sector which I see as the key way to tackle the climate crisis. The FUSE internship really opened my eyes to the unique opportunity of battery technology. It connected me to the dynamic Faraday researcher community and I was really interested in the work that I read and heard about. That experience and the people I worked with were crucial to me joining the Faraday Institution PhD Training programme. I'm looking forward to studying the science in depth, whilst maintaining strong industry relevance and connections. I think the programme will also enable me to continue to grow my professional network and enhance my career. The sustainable future is coming, and I am so excited to be a part of the battery community finding those innovative solutions.'

Isabella Stephens

Sanzhar Taizhan

FUSE internship 2018

Generated Neural Network Deep Learning for coin cell batteries to predict future failure points with WMG Energy Storage Group.

Poster winner Faraday Institution Annual Conference.

Founder of start-ups Warwick Hyperloop, Warwick Boring and Taisan Motors

Advisor to the Minister for Industry, Infrastructure and Development

in native Republic of Kazakhstan 2020.

Forbes 30 under 30 Kazakhstan

Finalist in Elon Musk's *Not-a-Boring Tunnel Competition*

Charlotte Hyde

FUSE internship in 2020 with the ReLiB project

2021 Published her first journal article in Resources, Conservation and Recycling

2021 Process engineer for SPTS Technologies

Doctoral Training

The Faraday Institution doctoral training programme is the sole UK programme in energy storage and addresses both a skills shortage and specialist industry needs. It leverages partner universities and encompasses technical, commercial and transferable skills with the aim of training the next generation of battery experts to become successful leaders in their fields. Graduates will become 'agents of change' in their careers, working to reduce barriers and being able to professionally bridge many divides.

Now in its fourth year, the Faraday Institution offers a comprehensive PhD training programme, supporting 55 PhD researchers from 16 UK universities. Faraday Institution PhD cohorts have access to networking opportunities, industry visits, mentorship, internships, as well as other quality experiences that will further develop knowledge, skills and aspirations. In 2021, the Faraday Institution established a Faraday Student Committee to capture student voice and feedback to continuously improve future programming.

The Faraday Institution offers a programme of bespoke battery-related courses, delivered by experts in the field, to ensure students are equipped with the in-depth knowledge and skills needed to maximise the potential of their research projects. The programme includes week-long training residentials with Newcastle University, Imperial College London and WMG's Battery School in Warwick. In addition, the Faraday Institution brings in expertise from training partners – such as BodyTalk, Kindred, IMECHE and Skillfluence – to prepare PhD researchers with skills that will transfer to future industrial and academic roles in areas ranging from dynamic presenter training, project management, negotiations, and thesis and grant writing. Adapting to the pandemic, these programmes were delivered in a combination of virtual and in-person residentials.

'I have had a great experience participating in the Faraday PhD Cohort for the past three years. The Faraday Institution has put great effort in building a course that was engaging, diverse, and valuable. The training has been critical in my professional development and influenced my career aspirations to outside a career in academia. It has helped shape the most important output of the battery research community: people.'

Kieran O'Regan, University of Birmingham

Over the course of his Faraday Institution PhD, researcher Kieran O'Regan has published 8 journal articles, interned at Benchmark Materials Intelligence and co-launched a spin-out.

PhD impact

Metrics from the first PhD cohort demonstrates that the students are having an impact: 45 academic publications (several as first author), 92% presenting research at academic conferences, 31% delivered scientific posters, 38% organising academic events, 38% setting up labs and purchasing new equipment. 85% are involved with undergraduate attraction, teaching and mentoring. In 2021, nearly all were awarded industrial or policy internships in firms including:

- AMTE Power
- Benchmark Mineral Intelligence
- Exawatt
- Jaguar Land Rover
- Lambda Energy
- OSIP (the Open Space Innovation Platform) of the European Space Agency
- Parliamentary Office for Science and Technology
- Rho Motion
- UKRI Policy Internship at the House of Commons – Environment, Food and Rural Affairs (DEFRA) Select Committee.

'My experience working at JLR has been invaluable, as I've had an insight as to how the battery industry works and how important it is working as part of a big team. I've really enjoyed my time here and have learned about the thought processes behind setting up a new lab and commissioning new equipment. The team I worked in has been really friendly and welcoming and have given me lots of insight into the business and their future plans for the company. I'm really thankful for the opportunity and hope to work with them again in the future.'

Dana Thompson, University of Leicester, intern at Jaguar Land Rover

'The impact of the internship on my career was massive because I see myself (be it in academia or in a policy setting) wanting to make a real-life difference.'

Louis Dawson, University of Birmingham, intern at DEFRA Select Committee

'I feel like I can make a much better decision choosing between academia and industry having experienced them both ... I know what challenges I could face and the benefits versus just staying in the lab'

Aaron Wade, UCL, intern at Exawatt

'Meeting people who have been involved in start-ups for 5-10 years has given me a different perspective from academic research; you have to consider the economics. Gave me the experience of working with businesspeople and economists.'

Victor Riesgo-Gonzalez, University of Cambridge, intern at Lambda Energy

Year 2 PhD researchers

The Faraday Institution programme of battery-related courses, delivered by experts in the field from our university and industrial partners, ensures students are equipped with the in-depth knowledge and skills needed to maximise the potential of their research projects.

Download guide

Early Career Development

Over 180 Post-Doctoral Research Assistants (PDRAs) in the Faraday Institution community are supported through annual career development reviews with supervisors, a training budget, access to a Training Champion and multiple professional learning opportunities.

The Faraday Institution is committed to the continuing professional development of UK-based battery researchers. It has selected a range of CPD, residential and short courses from its partner university and other reputable providers for members of the UK research community, other academics and industrial partners to further develop and enhance their abilities. The majority of these are offered as online courses.

Faraday Masterclass series

Now in its second year, the Faraday Institution – working with leaders from our industrial and research community – presented a virtual masterclass series to offer valuable insights from experts in the field to early career researchers. Masterclasses are one-hour interactive discussions around science, state-of-the-art techniques, and professional development, While the training focuses on early-career researchers, the broader researcher community have benefited from the series.

Early Career Researcher Day

The Faraday Institution Annual Conference includes an Early Career Researcher Day, which this year provided a supportive environment in which 4 PhD Researchers and 12 Faraday Institution Research Fellows shared their research results and identified opportunities for future collaboration. Around 20 PhD Researchers, 30 research fellows and 50 undergraduate FUSE interns also presented scientific posters in on-line poster sessions. The Faraday Early Career Researcher Committee was established in 2021 to capture the voices of ECR and to develop ongoing programming for the community.

Faraday Masterclass Series
Battery Research Materials at Johnson Matthey: An Industrial Perspective James Cookson, Johnson Matthey
Britishvolt Gigafactory: Producing Lithium-ion Batteries at Scale Isobel Sheldon, Chief Strategic Officer, Britishvolt
Laser and Focused Ion Bean Techniques for TEM-prep and Serial Sectioning Tomograph Professor Phil Withers, Henry Royce Institute, University of Manchester Matthew Curd, University of Manchester
More SEI than CSI… Associate Professor Melanie Loveridge, WMG
An Industrial Perspective on Applied Research; Nissan Solid-state Battery Case Study Dr Ulderico Ulissi, Nissan
Stress and the New 'Normal': Recharging, Not Just Enduring Andy Elwood
Exploring the Safety Challenges Lithium-ion Batteries Present Professor Paul Christensen, Newcastle University, SafeBatt project
Bridging the Gap: From Lab to Gigafactory George Hull, Operations Director, UKBIC
Career Stories from the Battery Sector Professor Emma Kendrick, University of Birmingham Dr Alex Groombridge, Echion Technologies

Faraday Institution Community Awards 2021

In 2021, new Community Awards were launched to celebrate the successes of Faraday Institution researchers who demonstrate excellence and behaviours in line with the institution's mission and values – and who go above and beyond what would normally be expected.

Collaboration Award

Recognising outstanding examples of innovation and progress through teamwork and multi-university, multi-disciplinary and/or academic-industry collaboration.

Winner: The PyBaMM Contributing Community
Led by Robert Timms, Ferran Brosa Planella and Tom Tranter of the Multi-scale Modelling project as well as Valentin Sulzer with a significant contribution from Simon O'Kane and Toby Kirk. The development of PyBaMM – a valuable tool with a global userbase across academia and industry – highlights the world-leading nature of the Faraday Institution's work to a global audience and was only possible through wide-reaching collaboration involving 38 contributors, including around 14 from the Multi-scale Modelling project.

Highly Commended: The ReLiB Project Team
The ReLiB project team that developed a pioneering method for delaminating electrodes as part of a faster, greener recycling process using high-powered, focussed ultrasound, and the associated patenting, paper publication and publicity. The success of the project was due to very strong collaboration involving several universities and a range of researchers at different career stages, coordinated under testing circumstances during the Covid pandemic by excellent leadership from Faraday Institution Research Fellow Dr Chunhong Lei at the University of Leicester. Researchers on the team across Birmingham, Leicester and Swansea include: Dana Thompson, Jason Terreblanche, Rob Sommerville, Anton Zorin, Iain Aldous, Rowan Hansen, Sean Scott, Gavin Harper, Jack Allen, and Jennifer Hartley.

Public Engagement / STEM Outreach Award

In recognition of an individual's or team's outstanding contribution to the local or national community in relation to science communication or the promotion of STEM careers.

Winner: Elizabeth Driscoll, University of Birmingham

A PhD researcher working on the CATMAT project. Lizzie is recognised for a consistently outstanding contribution to STEM outreach via involvement in a variety of events, developing YouTube resources and podcasts, and working with a variety of partners, including the Royal Society of Chemistry, to reach a wide audience and to inspire the next generation of battery researchers.

Highly Commended: Dr Gavin Harper, University of Birmingham

Gavin has conducted outstanding public engagement work for the ReLiB project, with 70 media engagements over a two-year period, that has gone a long way to position the project as an authority on battery recycling. His work has clearly progressed public understanding of battery science.

Researcher Development Champion

In recognition of an individual who goes the extra mile in the role of supervisor, mentor or training champion (in a formal or informal capacity) to guide early career researchers and inform career paths.

Winner: Professor Emma Kendrick, University of Birmingham

Emma is recognised for her outstanding mentorship and commitment to progressing the prospects of early career researchers, both in her group and beyond. Emma sets an example within academia as an outstanding scientist, role model and advocate for early career researchers, and is highly deserving of the award.

Highly Commended: The FutureCat Training Committee
Led by Dr John Griffin of Lancaster University for their innovative and supportive activities for FutureCAT PDRAs to network during the pandemic.

The FutureCat Training Committee has demonstrated an impressive commitment to researcher training, organising a range of accessible events during the Covid pandemic. Steering group members included Sam Booth, Anita Blakeston, Elinor Noble and Abby Haworth. Also recognised are the impactful contributions of Kirstie McCombie, Beth Johnston, Laura Wheatcroft, Gabriel Perez and Alisyn Nedoma.

STEM Outreach

The Faraday Institution is actively committed to STEM outreach through training and equipping STEM Ambassadors to inspire future generations about careers in energy storage and battery technology. STEM Ambassador training is at the heart of the PhD training programme, with over 50 researchers trained to date on how to present their research in creative, age-appropriate ways to pupils.

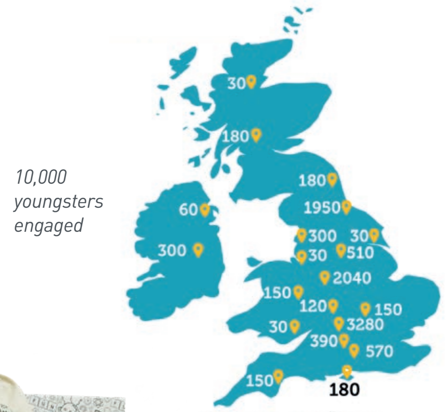
Fully Charged Battery Box

To inspire young people across the UK about STEM careers, the Faraday Institution, in collaboration with the Curiosity Box, launched its bespoke, curriculum-linked Fully Charged Battery Box to foster curiosity amongst pupils aged 7-11+ about battery technology and STEM careers.

The resource provides teachers, researchers and STEM Ambassadors with everything they need to deliver high quality key stage 2 sessions that build science capital through exploring batteries and electricity, stimulating discussion about challenges and opportunities of the UK's electric future. To date, over 10,000 young people have been engaged with hundreds of boxes being deployed across the UK.

GKN Automotive funded the supply of 50 Fully Charged Battery Boxes to schools in and around Abingdon as part of ATOM Science Festival. The Fully Charged Battery STEM Day in a Box provides schools with all the resources they need to run a series of activities that explore electricity, the chemistry and engineering of batteries and their application in electric vehicles. Through this project 1620 pupils engaged in hands-on STEM and the feedback has been overwhelmingly positive. Students were encouraged to explore and gain a greater understanding of electric vehicles and the impact of electrification on a more sustainable future.

100+ Fully Charged Nano Boxes went to families in January as part of the Curiosity Box Lockdown Survival Subscription. The Faraday Institution funded 50 eco racer kits for the Great Big Green Week.



'Fully Charged Battery Box made my Y4 class's learning about circuits so much fun! Lemon batteries galore powering digital timers and cards with light-up LED eyes made using copper tape. Gave one girl her chance to really shine in STEM'

Robin James, Primary Science Teaching Trust Fellow

Battery Zone

In partnership with the Royal Society of Chemistry, the Faraday Institution has sponsored and supported a month long *Battery Zone* with the *I'm a Scientist* team which connects pupils with our scientists who are working to make the world a more sustainable place.

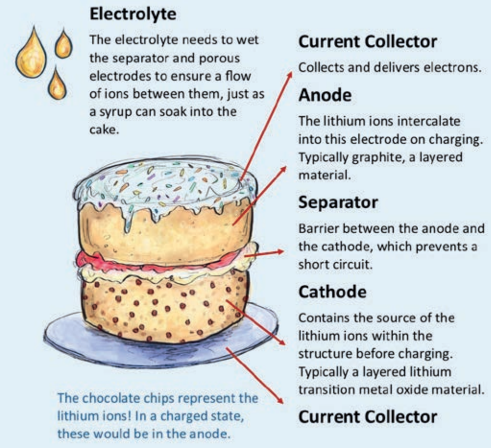
Big Bang Digital 2021

9,885 young people learnt out about battery technology careers through the Big Bang Digital event and Faraday Institution video.

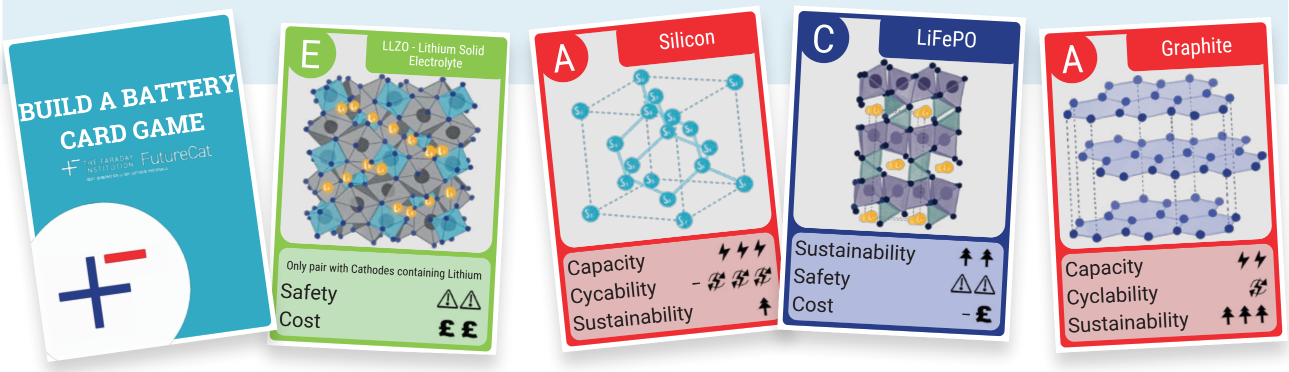
Promoting science careers

All Faraday Institution researchers are encouraged to take part in public engagement with research activities as one way of boosting their researcher identity and promoting science careers.

In May 2021, the Faraday Institution launched a Faraday STEM Network to build a community of researchers active in the space to share ideas, resources and best practice. Faraday PhD researchers have additionally been using their outreach skills to engage with the public, such as the STEM outreach activity, Crunchie Bar Batteries by Beatrice Browning and Rosie Madge, and Elizabeth Driscoll's work on Battery Jenga, all from the University of Birmingham. Driscoll has also produced Through the Lab Specs, a video series on researchers working in the battery field. Researchers in our FutureCat programme have created resources for primary and secondary school and beyond.



Battery cake – Sophia Constantinou
Battery card game – Catie Kohler



smallpeice

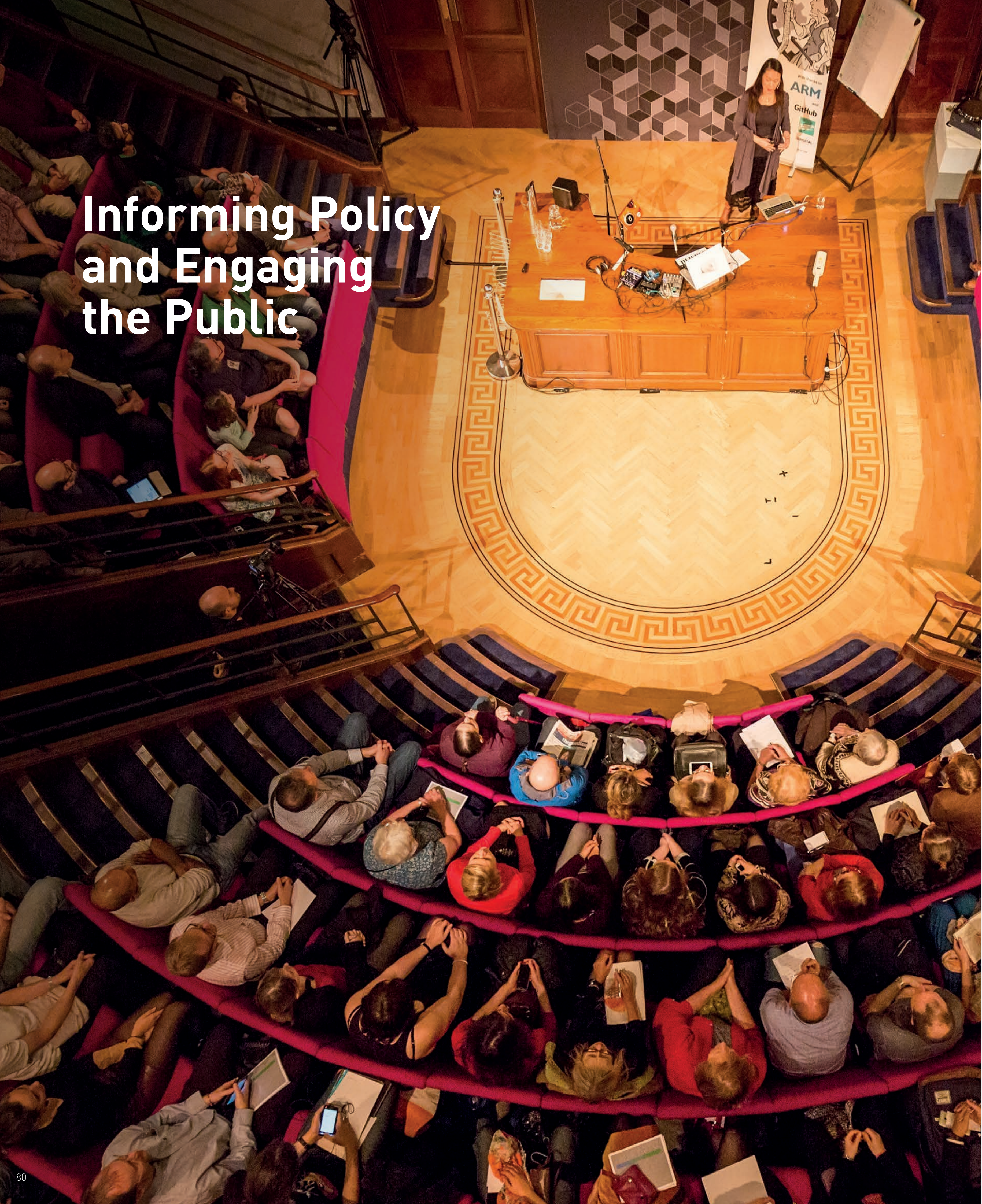
Smallpeice Trust

In August 2021, 39 Year 11 pupils attended the *Fully Electric Challenge Online Course*, created with the aim of inspiring the next generation of engineers invested in the creation of a cleaner future for transportation. Led by WMG, with support and sponsorship from the Faraday Institution, a combination of inspiring talks from experts and practical 'hands-on' challenges led to an engaging week, where battery technology careers were showcased.

Website

'I enjoyed building the car kit the most as it allowed lots of creativity and helped us to get hands on and generate more ideas about our car brand.'

'It was interactive and extremely informative. I am specifically interested in the environmental science and this course involved an expansive outlook on electric cars and future dilemmas we will face.'



Informing Policy and Engaging the Public

The Faraday Institution advises a range of audiences on the UK's transition to energy storage technologies to ensure that members of the public, public bodies, policy makers and public institutions are well-informed.

Representing a national effort for energy storage, the Faraday Institution is committed to being a voice to help guide government, industrial and financial communities. The Faraday Institution Chief Executive Professor Pam Thomas and Chief Economist Stephen Gifford regularly present to government departments and in 2021 submitted written evidence and appeared in front of multiple parliamentary inquiries, including the:

- House of Lords Science and Technology Select Committee Inquiry on the *Role of batteries and fuel cells in achieving Net Zero*, resulting in the publication of Battery strategy goes flat: Net-zero target at risk.
- Environmental Audit Committee Inquiry on *Technological Innovations and Climate Change: Supply Chain for Battery Electric Vehicles*, which led to the committee reporting out that gigafactories for electric vehicle batteries need more Government support.

A previous Faraday Institution report on the need for a domestic supply of batteries *UK Electric Vehicle and Battery Production Potential to 2040* was evidenced by government to support the establishment of the government's £1 billion fund, created to enable large-scale industrialisation in developing a high-value end-to-end electrified automotive supply chain in the UK. The fund is an important mechanism to reach targets in the UK Government's 10-point plan for a green industrial revolution and its recent Transport Decarbonisation Plan.

Analysis based on an updated Faraday Insight on global and UK demand and supply of raw materials, as a result of the new policy to end the sales of petrol and diesel vehicles by 2030, led to a seminar for the Chief Scientists of the Department of Business, Energy and Industrial Strategy and Department for Transport and their teams on EV demand for raw minerals and the potential resilience of the UK supply chain.

House of Lords inquiry

Alongside government ministers and senior civil servants from the Department for Business, Energy and Industry and the Department for Transport, Professor Pam Thomas, CEO of the Faraday Institution, joined leading investigators from our research community, and members of the Faraday Institution Board of Trustees and Expert Panel, to respond to the Select Committee investigation on the role of battery and fuel cell technologies in achieving the UK's ambition to reach net-zero greenhouse gas emissions by 2050. Oral evidence was provided by challenge director Tony Harper, Professor Paul Shearing of UCL, Professor John Irvine of St Andrews University, Associate Professor Mauro Pasta of Oxford University and Associate Professor Mel Loveridge of the University of Warwick. Additionally, University of Cambridge Professor Clare Gray served as the chief scientific advisor for the Lords Select Committee inquiry.

House of Lords, Science and Technology Select Committee, 1st Report of Session 2021-22
Battery strategy goes flat: Net-zero target at risk
HL Paper 53

The Committee calls for 'long-term commitments to give the UK a future competitive advantage in fuel cells and next-generation batteries' and which would 'allow the UK to leapfrog its competitors and gain an advantage for future manufacture of batteries and vehicles.' Further, it calls for 'widening the scope of battery innovation to include batteries for stationary applications on electricity grids, to help balance supply and demand whilst making better use of renewable generation.'

Faraday Insights

The Faraday Institution continues to publish Faraday Insights, evidence-based assessments of the market, economics, technology and capabilities for energy storage technologies and the transition to a fully electric UK. The insights are concise briefings that aim to help bridge knowledge gaps across industry, academia and government.

The UK: A Low Carbon Location to Manufacture, Drive and Recycle Electric Vehicles

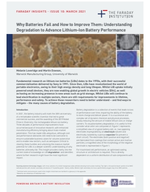
Electric vehicles (EVs) have much lower lifetime carbon emissions than petrol and diesel internal combustion engines (ICE), with carbon emissions over the EV life cycle falling fast as the UK electricity grid is decarbonised and the UK moves towards Net Zero. Total life cycle carbon emissions of a medium-sized battery EV will be about one-third of a petrol car sold in 2025, with UK-manufactured EV batteries 12% greener than the European average.

Download

Sodium-ion Batteries: Inexpensive and Sustainable Energy Storage

Sodium-ion batteries are an emerging battery technology with promising cost, safety, sustainability and performance advantages over current commercialised lithium-ion batteries. Key advantages include the use of widely available and inexpensive raw materials and a rapidly scalable technology based around existing lithium-ion production methods. These properties make sodium-ion batteries especially important in meeting global demand for carbon-neutral energy storage solutions.

Download



Why Batteries Fail and How to Improve Them: Understanding Degradation to Advance Lithium-ion Battery Performance

Fundamental research on lithium-ion batteries (LIBs) dates to the 1970s, with their successful commercialisation delivered by Sony in 1991. Since then, LIBs have revolutionised the world of portable electronics, owing to their high energy density and long lifespan. Whilst LIB uptake initially powered small devices, they are now enabling global growth in electric vehicles, as well as having an increasing presence in new areas such as grid storage. Whilst LIBs will continue to lead electrification in multiple sectors, there are still requirements for improvements in lifetime, performance and safety. To achieve these, researchers need to better understand – and find ways to mitigate – the many causes of battery degradation.

Download

In 2021, Faraday Insights and Reports have been included in Government Office for Science's emerging technologies Resource Library, which includes over 300 technology reports available for use by teams across government in order to facilitate knowledge sharing. Previous Insights include:

The Importance of Coherent Regulatory and Policy Strategies for the Recycling of EV Batteries
Download Insight 9

Lithium-Sulfur Batteries: Lightweight Technology for Multiple Sectors
Download Insight 8

Building a Responsible Cobalt Supply Chain
Download Insight 7

Lithium, Cobalt and Nickel: The Gold Rush of the 21st Century
Download Insight 6

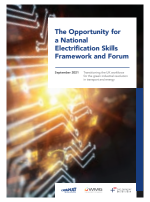
Solid-State Batteries: The Technology of the 2030s but the Research Challenge of the 2020s
Dowload Insight 5

Report: UK Electric Vehicle and Battery Production Potential to 2040
Download

Brexit and Batteries: Rules of Origin

The trade deal and new rules of origin should provide the conditions for the UK automotive industry to succeed. But, to do so, it is now more important than ever that gigafactories are built in the UK, and quickly, and with well-developed local supply chains.

Download



National Electrification Skills Framework and Forum

Together with industrial digitalisation, the UK government's commitment to the electrification revolution represents the largest shift in industrial skills for the UK in a generation. The need to move quickly, and effectively, to re-skill and up-skill the existing workforce, whilst providing newly skilled workers to fill crucial roles, emphasises the need for a unified national skills structure more than ever before.

Written in partnership by the Faraday Institution, WMG and the High Value Manufacturing Catapult, the seminal report **The Opportunity for a National Electrification Skills Framework and Forum** published in September 2021 charts a way forward. Working with industrial partners to identify the key principles and skills needed to make the UK a world leader in battery technology, power electronics, motors and drives, and the clean energy generation, this report and subsequent forums provide an opportunity to map, design and deliver the training needed across multiple regions to supply these skills for the UK's workforce.

Download

Public Engagement

The Faraday Institution has established itself with top tier media outlets as a trusted and reputable source of information regarding energy storage research and technology and EVs. It regularly engages with UK nationals, international publications and trade press via proactive outreach and a rapid response on topics targeted on the following areas:

- **Policy and UK investment**
  CEO Professor Pam Thomas provided comment on Envision AESC's decision to build a gigafactory in Sunderland on BBC One's evening news. Earlier in 2021, the Telegraph published a feature interview with her: *Leading the charge for better batteries to make Britain a world-beater*.
- **Breakthroughs in science and technology**
  The widespread coverage of the ReLiB project's new technique for the recycling of electrode materials led to an invitation to speak at a green investor event.
- **The need for a sustainable supply chain**
  The Fully Charged Show, with its 1 million subscribers, dedicated an episode to the use of cobalt in batteries that featured interviews with Faraday Institution investigators Professor Paul Anderson (below), University of Birmingham and Professor Paul Shearing, UCL (right).

Its media outreach programme led to 130 pieces of coverage in the 2020-21 financial year, with substantial top tier coverage by the BBC, The Telegraph, Reuters, Bloomberg, The Times, The Guardian and The Financial Times. This represents hundreds of thousands of views as the organisation seeks to ensure that the public has access to evidence-based information as the UK transitions to a fully electrified economy.

Royal Institution Battery Engagement Programme

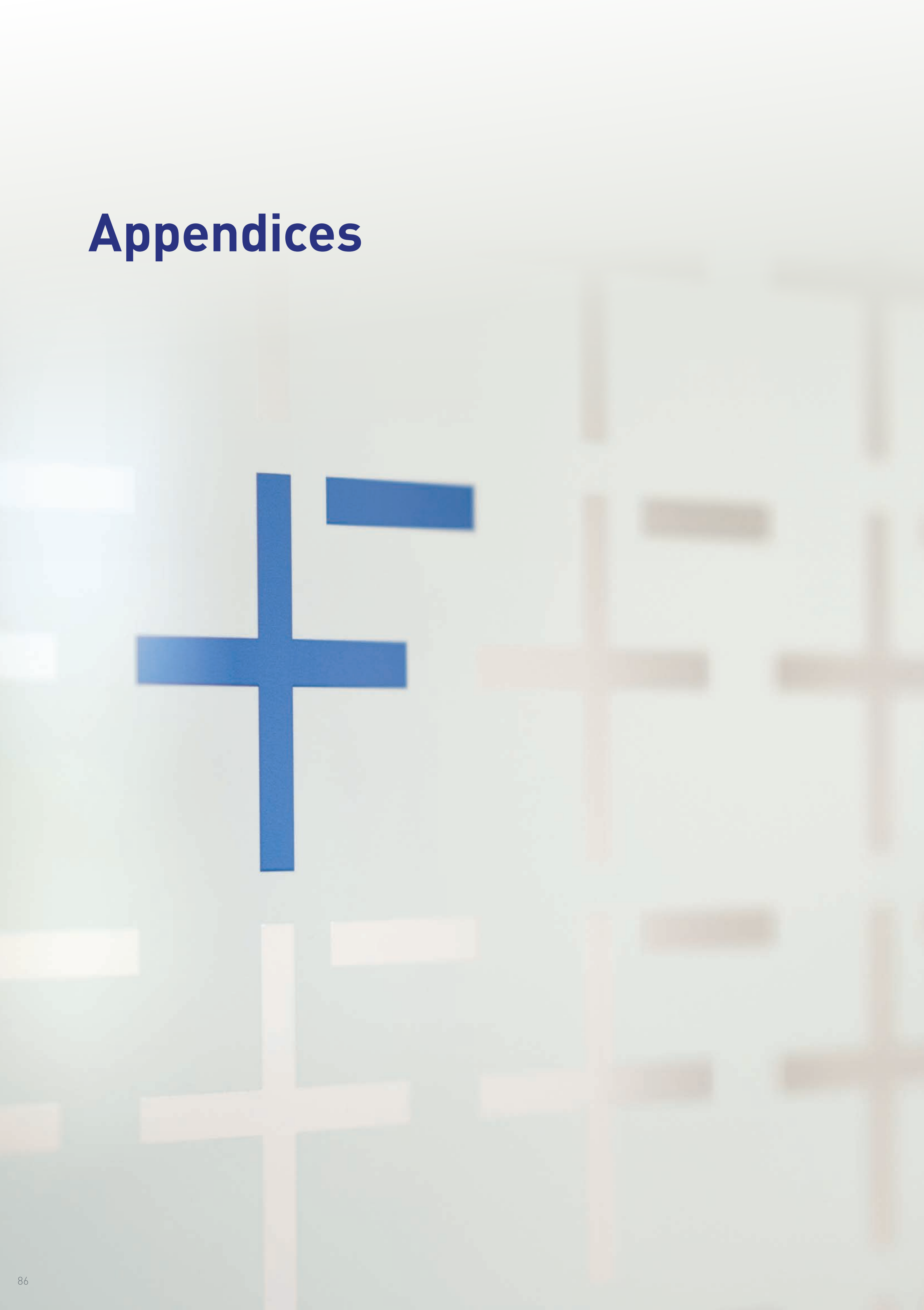
The Faraday Institution has continued its public engagement work with the Royal Institution through the coronavirus lockdowns and beyond – with an ongoing programme both online and in person.

Professor Serena Cussen, University of Sheffield (right) and Principal Investigator of the FutureCat project, presented the *Hunt for New Batteries* at a livestreamed event in October 2020.

In September 2021 in the iconic Royal Institution lecture theatre as part of the Ri's celebration events marking 200 years since Michael Faraday invented the electric motor, Professors Pam Thomas, Faraday Institution CEO, and Saiful Islam, University of Bath, Principal Investigator of the CATMAT project, spoke to the relevance of Faraday's discoveries to the present electrification moment. In October, Professor Paul Shearing, University College London and Principal Investigator of the LiSTAR and SafeBatt projects followed by presenting *From Galvani to gigafactories: how batteries have tamed electricity to power the modern world* at an in-person event.

The battery engagement programme with the Royal Institution has led to over 250,000 views online and continues to grow.

Appendices



Board of Trustees

Peter B. Littlewood, Chair

Peter B. Littlewood FRS is Professor of Physics at the University of Chicago. He served as the 13th Director of the US Department of Energy's Argonne National Laboratory, after having served as the associate laboratory director of its Physical Sciences and Engineering directorate. He spent the previous 14 years at the University of Cambridge, where he last served as the head of the Cavendish Laboratory and the Department of Physics. Littlewood is internationally recognised for his research in a number of areas, including superconductivity, semiconductor optics, and magnetic materials. Littlewood holds a bachelor's degree in natural sciences (physics) and a doctorate in physics, both from the University of Cambridge.

Stephen Heidari-Robinson, Vice-Chair

Stephen Heidari-Robinson is co-founder and Managing Director of Quartz Associates. He served as former UK Prime Minister David Cameron's energy and environment adviser and was one of the architects of the UK's generation strategy and decarbonisation plan. Heidari-Robinson spent nine years as a leader in McKinsey and Company's energy practice and was a vice president of Schlumberger. Heidari-Robinson read history at the University of Oxford, holds an MA in architectural history from the Courtauld Institute, University of London, and studied Farsi at the School of Oriental and African Studies.

Jeff Chamberlain

Dr Jeff Chamberlain is CEO of Volta Energy Technologies, a company that identifies and invests in battery and energy storage technology after performing deep diligence with the support of unparalleled global research institutions. In service both to its strategic corporate investors and to entrepreneurs, Volta identifies and invests in the most promising energy-storage innovations. Chamberlain holds a PhD in physical chemistry from the Georgia Institute of Technology and a BS in Chemistry from Wake Forest University.

Kristina Edström

Professor Edström leads the Ångström Advanced Battery Centre (ÅABC) and she is a professor of Inorganic Chemistry at Uppsala University, Sweden. Her main research interests are lithium-ion batteries for all applications including electric vehicles, 3D microbatteries but beyond lithium batteries (sodium-ion, organic batteries, lithium-sulfur, lithium/sodium-oxygen batteries and solid-state batteries). She also develops photon science and neutron scattering in operando methods for studying dynamic processes in materials and batteries, in addition to having a great interest in teaching and guiding young researchers. She is a member of the Royal Academy of Engineering Sciences.

Board of Trustees

Johney Green

Dr Johney Green Jr. serves as the Associate Laboratory Director for the Mechanical and Thermal Engineering Sciences directorate at the US Department of Energy's National Renewable Energy Laboratory (NREL). Green oversees early-stage and applied research and development in NREL's advanced manufacturing, buildings efficiency, concentrating solar power, geothermal energy, sustainable transportation, water power, and wind energy programs. Green holds a bachelor's degree in mechanical engineering from the University of Memphis and a master's and doctorate in mechanical engineering from the Georgia Institute of Technology.

Mark Newman

Mark Newman is Chief Commercial Officer and Head of Strategy for pioneering battery company Nyobolt, the original founders of ultra-fast charging niobium-based battery technology. Mark previously spent 11 years as Managing Director and Senior Analyst covering technology at Bernstein, where he was lead author of numerous research reports focused on batteries, electric vehicles and semiconductors. Prior to Bernstein, Mark worked at Samsung in Korea for six years in various strategy and business development roles where he was a key driver of several strategic initiatives, venture investments and acquisitions.

Cordi O'Hara

Cordi O'Hara OBE is Chief Operating Officer, US Gas Business for National Grid, where she is accountable for the safe, reliable and affordable operation of National Grid's gas distribution businesses across New York, Massachusetts and Rhode Island. Prior to joining the US business, she ran the UK System Operator for National Grid. Cordi has more than 20 years of experience in the energy industry, managing key relationships with government officials, regulators and customers. Prior to joining National Grid, Cordi worked for Centrica, the largest UK energy retailer, in a variety of commercial and operational roles. She is a fellow of the UK Energy Institute.

Jorge Pikunic

Dr Jorge Pikunic is CEO of Xynteo, a management consultancy that empowers leaders to reinvent growth by transforming their businesses and wider systems. He was formerly Managing Director of Centrica's global Distributed Energy and Power business, established to deliver distributed energy solutions for large energy users as part of a more flexible energy landscape. Born in Venezuela, Pikunic is an engineer and holds a MSc and PhD in Chemical Engineering. He was a research fellow at the University of Oxford before joining McKinsey and Company, where he advised a number of institutions in energy and other sectors.

Isobel Sheldon

Isobel Sheldon OBE is Chief Strategy Officer of Britishvolt, responsible for overall business, manufacturing, technology and customer strategy. She joined Britishvolt from her role as Business Development Director at the UK Battery Industrialisation Centre. She has 20 years of experience in battery design and development, technology and industry, and is a globally renowned automotive battery specialist. Isobel has worked with many of the world's major automotive businesses and suppliers, including Jaguar Land Rover, Lotus, Nissan, Ricardo and Johnson Matthey Battery Systems, helping them advance their battery system solutions.

Mark Spearing

Professor Mark Spearing is the Vice-President, Research and Enterprise at the University of Southampton. Previously he was the Pro Vice-Chancellor (International) and Head of the School of Engineering Sciences, having been appointed as the Professor of Engineering Materials in 2004. He was a faculty member at the Massachusetts Institute of Technology from 1994-2004. His personal research focuses on structural and functional materials. He holds a BA and PhD in Engineering from the University of Cambridge.

Maurits van Tol

Maurits van Tol is Chief Technology Officer at Johnson Matthey. Before joining Johnson Matthey, Maurits was Senior Vice President Innovation and Technology at Borealis, where he was responsible for shaping the circular economy business as well as being part of the company's management board responsible for their plastics business. Maurits has a PhD in Catalysis and an MSc in Physical Chemistry and Catalysis, both from Leiden University, The Netherlands. Parts of his studies were also performed at the University of East Anglia, and UC Berkeley.

Special Advisors

Sir Oliver Letwin
Special Advisor

Sir Oliver served as the Member of Parliament for West Dorset from 1997 to 2019. From 2010, he was the Minister for Government Policy in David Cameron's coalition government and coordinated the push to make the UK a world leader in electric vehicles. He continued to serve as Chancellor of the Duchy of Lancaster, Cabinet Minister in overall charge of the Cabinet Office until July 2016. He was educated at the University of Cambridge, Princeton University, and London Business School. In a varied career, Sir Oliver has been a research fellow at the University of Cambridge, a civil servant, and a bank director.

Robin Grimes
Special Advisor

Professor Robin Grimes is the BCH Steele Chair in Energy Materials, Faculty of Engineering, Department of Materials, Imperial College London. His primary research interest is the application and development of computer simulation techniques to predict structural and dynamic properties of ceramics and metals. Robin has authored over 300 peer-reviewed publications. He is currently a member of the editorial board for Journal of Materials Science. In 2013 he was made a Fellow of the Royal Academy of Engineering, in 2016 Fellow of the Australian Academy of Technology and Engineering and in 2018 a Fellow of the Royal Society.

Faraday Institution Team

Pam Thomas, Chief Executive Officer

Professor Pam Thomas FInstP CPhys became the Chief Executive Officer of the Faraday Institution in September 2020 after a decade in senior management roles at the University of Warwick that culminated in a 5-year period as a Pro Vice Chancellor (Vice President) for Research. Pam is currently also a council-member of the Science Technologies Facilities Council (STFC) and a Fellow of the Clean Growth Leadership Network (CGLN). Retaining her professorial status at the University of Warwick, she chairs the Social Inclusion Committee in her non-executive capacity as an Academic Vice President. Her personal research is in the field of functional ferroelectric materials where she has published more than 160 peer-reviewed journal articles and two patents, one of which became the basis of a spin-out company, Pro KTP, to exploit the invention of a new low-conductivity variant of the nonlinear optical material potassium titanyl phosphate (KTP). She was educated at the University of Oxford, where she took a BA (Hons) in Physics and a DPhil on the subject of Optical Activity in Crystals in the Physical Crystallography Group of the Clarendon Laboratory.

Peter G. Bruce, Chief Scientist

Professor Peter Bruce FRS is a founder and Chief Scientist of the Faraday Institution. He is also leading the research project on solid state batteries and a member of the senior leadership team of the solid-state battery commercialisation initiative. He is the Wolfson Professor of Materials at the University of Oxford as well as Physical Secretary and Vice-President of the Royal Society.

Peter's research interests embrace materials chemistry and electrochemistry, especially lithium and sodium batteries. Recent efforts have focused on the synthesis and understanding of new materials for lithium-ion batteries, on understanding anomalous oxygen redox processes in high capacity Li-ion cathodes, the challenges of the lithium-air battery and the influence of order on the ionic conductivity of polymer electrolytes.

His research has been recognised by a number of awards and fellowships, including from the Royal Society, the Royal Society of Chemistry, the German Chemical Society and The Electrochemical Society. He was elected to the Royal Society (UK Academy of Sciences) in 2007 and the Royal Society of Edinburgh (Scottish Academy of Sciences) in 1994. He has appeared on the Thomson Reuters list of highly cited researchers since 2015.

Sophia Constantinou, Digital and Social Media Co-ordinator

Sophia Constantinou joined the Faraday Institution in June 2021 as the Digital and Social Media Co-ordinator. She is extremely passionate about science communication and education.

Prior to joining the team, she completed a BSc in Chemistry at the University of Edinburgh, with her final year project focused on science education.

Sophia previously worked for the Faraday Institution in 2020 as a FUSE intern, where she created infographics and podcasts to explain lithium-ion battery manufacturing for the Nextrode project. Her academic poster won the award for engagement and communication.

Ian Ellerington, Head of Technology Transfer

Ian joined the Faraday Institution in 2018 after six years in central government where he worked on designing and implementing innovation programmes in the energy sector. He was responsible for the government's energy innovation programme in the Department of Energy and Climate Change and continued in the Department of Business, Energy and Industrial Strategy as Head of Disruptive Energy Technologies and Green Finance Innovation.

Ian is an engineer who graduated from University of Cambridge with an M.Eng. in manufacturing engineering in 1993 and is now an experienced technical manager who has worked with small, medium and large corporates, academia and government. His early career was spent working on gas turbine engines with the Ministry of Defence before moving to project management at QinetiQ where he was responsible for research programme management and delivery of large test programmes. He left QinetiQ to join Meggitt Defence Systems that developed and operated new technical products. As UK General Manager Ian set up and ran a new R&D and manufacturing facility.

Faraday Institution Team

James Gaade, Head of Programme Management

James Gaade joined the Faraday Institution as Head of Programme Management in April 2021, after 2 years as an independent consultant focusing on vehicle electrification for organisations ranging from the UK Battery Industrialisation Centre, the British Standards Institute and the Advanced Propulsion Centre.

Prior to this James worked for Jaguar Land Rover for 20 years, with varied vehicle propulsion and powertrain system roles in product engineering, research and technology and commercially in product marketing, working on projects from research through to vehicle production. His last role was Head of Powertrain Research and Technology, where he led a portfolio of research projects, a team of 80 engineers focused on the next generation of vehicle electrification technologies and internal combustion engine capability for near zero emissions and 2025 CO2 targets.

A Chartered Engineer and Fellow of the Institute of Mechanical Engineering, James graduated from De Montfort University in 1993 with a B.Eng (Hons) in Mechanical Engineering and from Loughborough University in 2003 with an MSc in Automotive Systems Engineering.

Stephen Gifford, Chief Economist

Stephen has over 25 years of economics experience, including as the Chief Economist at Grant Thornton, the Director of Economics at the CBI and as a senior economist at KPMG, Oxford Economics and the Prime Minister's Strategy Unit. Prior to joining the Faraday Institution, Stephen was Head of Economic Regulation at the Civil Aviation Authority, where he focused on the regulation of Heathrow and Gatwick airports, and the development of the new runway at Heathrow. Stephen is currently a Commissioner in the National Infrastructure Commission for Wales.

Stephen brings particular skills and expertise in economic policy, transport economics, infrastructure, market assessment and the role of the public sector. He has a first-class degree in economics from the University of Liverpool and a MSc in econometrics and mathematical economics from the London School of Economics.

Louise Gould, Communications Lead

Louise Gould is a marketing and communications professional who has centred her career around technology-based organisations. She joined the Faraday Institution after five years as Marketing Communications Manager at the renewable fuels company Velocys, where she was responsible for all marketing, communications and brand activities. Her role included formulation of communications strategy with C-suite executives, as well as the operational delivery of projects across messaging development, stakeholder management, PR, annual reporting, events, naming and branding, social media strategy and website development. In her career, she has served as a marketing manager for an equipment manufacturer serving the print industry, a product manager for Oxford Instruments, and a scientific consultant and project manager at AEA Technology.

Louise graduated from the University of Cambridge with a BA in Natural Sciences (Chemistry) and holds an MSc in the Chemistry of Advanced Materials from the University of Manchester Institute of Science and Technology (UMIST).

Alison Green Briggs, Financial Analyst

Alison joined the Faraday Institution from Navitas, a leading global education provider where she helped to set up the European shared services centre and ran the general ledger team. Prior to that she held finance roles in an international paints and coatings company.

Alison has a BA (Hons) in accounting and finance from Leeds Metropolitan University and is currently in the process of completing her accountancy qualification with the Chartered Institute of Management Accountants (CIMA).

Vicki Harper, Executive Assistant and HR Officer

Vicki has over 25 years' experience working in the administrative, HR and office management fields. Most recently Vicki held the position of Office Manager at Oxford Biotrans, a University of Oxford spin-out company developing and commercialising enzymatic process technologies that yield high-value chemical compounds. Prior to that she was at Velocys plc, an AIM-listed renewable fuels company for 11 years, where she was the Office and HR Manager. Vicki holds an advanced diploma in business studies and also a certificate in Human Resource Management. She is an associate member of the Chartered Institute of Personnel and Development (CIPD).

Gareth Hartley, Business Intelligence Manager

Dr Gareth Hartley joined the Faraday Institution in June 2020 as the Business Intelligence Manager. He is interested in UK decarbonisation policy and is passionate about facilitating the commercialisation of sustainable technologies.

Prior to joining the team, he undertook a DPhil in Materials at the University of Oxford under the supervision of Prof Peter Bruce, where his research was primarily focused on solid-state batteries. However, Gareth's research interests extended to many energy production and storage technologies. He previously worked with Prof. Mike Bowker at the UK catalysis hub and with Prof. Thomas Maschmeyer at the University of Sydney on solar technologies and hydrogen production. Gareth has managed several multi-million-pound projects and has experience working within a financial institution.

In 2015, Gareth attained a 1st Class MChem from the University of Sheffield. His Master's project focussed on modelling the properties of semiconductors for solar applications.

Fran Long, Education and Training Lead

Fran is the Education and Training Lead at the Faraday Institution and is working to create a dynamic and diverse pool of talent for the fields of battery technology and energy storage. An innovative educator and award-winning primary science specialist, who has conducted research into raising STEM career aspirations, Fran is committed to boosting professional career development in the STEM sector through developing and leading programmes for early career researchers, PhDs, undergraduate students, young people (through STEM outreach) as well as a host of Equality, Diversity and Inclusion initiatives that widen participation and foster inclusivity.

Fran holds a first-class honours degree in Primary Teacher Education, received a Primary Science Teacher Award (PSTA) endorsed by the Institute of Physics and she is also a Fellow of the Primary Science Teaching Trust (PSTT). Today, talent development for the battery sector is her key focus with leading a bespoke PhD training programme and the Faraday Undergraduate Summer Experience (FUSE) internship programme, central to the role. Both aim to increase the knowledge, skills and aspirations of the next generation.

Susan Robertson, Chief Operating Officer

Susan Robertson joined the Faraday Institution in 2018. Prior to this, Susan was Chief Financial Officer of Velocys, the AIM-listed renewable fuels company, a position she held for 10 years through the company's transformational years from early-stage start-up to the point of having a commercial plant in operation. Previously, she served at the BOC Group (now Linde Group) where she held various senior-level financial management and business development positions in the UK and in Japan. Susan helped to set up and then, from 2003 to 2006, served as Vice President and CFO of Japan Air Gases (JAG), a joint venture between The BOC Group and Air Liquide.

Susan has an honours degree in economics from the University of Cambridge and is a chartered accountant (FCA) having originally trained with Arthur Andersen in London.

Faraday Institution Team

Matthew Howard, Chief Strategy Officer

Matt Howard joined the Faraday Institution in 2018 and is responsible for working with the CEO and the Executive Team to drive the organisation's overall strategic direction. He oversees a portfolio that includes developing and stewarding new strategic partnerships and relationships that build the Faraday Institution's impact, visibility, value, thought leadership and longevity.

He most recently served as the Chief Communications Officer and director of the communications, education and public affairs division for the US Department of Energy's Argonne National Laboratory, where he was responsible for communicating the distinctive scientific culture and the groundbreaking innovations and impacts of one of the largest science and engineering research laboratories in the US.

He holds an MBA from the University of Chicago Booth School of Business, a master's degree from Miami University, and a bachelor's degree from the University of Rochester.

Michelle Liddiard, Training Co-ordinator

Michelle joined the Faraday Institution in August 2021 as Training Co-ordinator. She is passionate about education and training as well as pushing for change in industry for a sustainable future.

Prior to joining the team, she spent over 10 years supporting and facilitating learning in primary, secondary, college and special education settings and completed a BA Hons in Education and Lifelong Learning at Oxford Brookes University. In her final year, she focussed on pupil re-engagement in core lessons such as science, maths, english and IT by providing a diverse and inclusive curriculum.

As an experienced co-ordinator, Michelle enjoys being involved with projects from implementation to conclusion thriving on complex situations and remaining solution focussed throughout.

Nick Smailes, Head of Commercialisation

Nick joined the Faraday Institution as of Head of Commercialisation in April 2021. In 2015 Nick set up the Energy Systems Catapult on behalf of UK Government. He was an Executive Director there for 5 years, helping to build it into a £20m, 200 staff organisation. His achievements included enabling the Catapult to leverage and acquire the Energy Technologies Institute's 10-year legacy including its Strategic Analysis capabilities and the Smart Systems and Heat Programme and also supporting the origination of the Industrial Strategy PFER programme.

In 2008 Nick co-founded and was CEO of PowerOasis Ltd, a spin-out from Motorola, which developed energy solutions for telecoms networks in parts of the works where the electricity grid is unreliable or unavailable. Nick built the company into a micro multinational with business in Asia, Africa, Europe and the US before exiting after securing a large round of venture capital investment to further grow the company.

In 2002 Nick co-founded and was MD of SETsquared, the leading global technology accelerator that works with the Universities of Bath, Bristol, Cardiff, Exeter, Southampton and Surrey. SETsquared has supported over 4,000 entrepreneurs and helped raise over £1.8bn of venture investment.

Andrea Strange, Compliance and Contracts

Andrea joined the Faraday Institution in September 2021 in the new role of Contracts and Compliance Administrator.

She has over 30 years' experience working in a wide range of secretarial and administrative support roles within large scientific research facilities. Andrea joined the Faraday Institution after spending 20 years at Diamond Light Source where she most recently held the position of Student Engagement Coordinator. Prior to working at Diamond, she spent 13 years at the energy and environmental consultancy AEA Technology plc.

Andrea particularly enjoys finding herself in new positions where she can use her breadth of skills and experience to adapt to suit the needs of the role.

Sylwia Waluś, Research Project Manager

Sylwia joined the Faraday Institution as Research Project Manager in June 2021. She works closely with the Head of Program Management and is responsible for managing the portfolio of the main Faraday Institution research projects as well as supporting the team with her scientific background in battery technologies.

In the past she has been involved in various next-generation battery projects, both commercially and government funded. In particular, lithium-sulfur technology is her field of expertise.

Prior to joining the Faraday Institution, Sylwia gained industrial experience at OXIS Energy, working on development of Li-S technology in various roles (Senior Scientist and Product Manager), as well as in Jaguar Land Rover as a Project Engineer, sharing her responsibilities between Research and Advanced Engineering teams.

Before moving to the UK, Sylwia obtained her PhD in Li-S batteries at CEA and Université Grenoble Alpes in France. She obtained her MSc degree through a European programme, part of the Alistore-ERI consortium, dedicated to Materials for Energy Storage and Conversion (MESC), during which she was a student in various European universities: Marseille, Cordoba, Uppsala and Warsaw. She obtained her BSc degree in Chemical Technology at Warsaw University of Technology in Poland, where she is originally from.

Principal Investigators

Paul Anderson, ReLiB

Paul Anderson is Professor of Strategic Elements and Materials Sustainability in the School of Chemistry at the University of Birmingham, and Co-Director of the Birmingham Centre for Strategic Elements and Critical Materials.

The synthesis and development of improved materials for energy applications has been a major theme of his research for over two decades, with particular interests in porous framework materials, ion mobility in hydrogen storage materials and related Li+ and H+ electrolyte systems, and the efficient husbandry of the earth's elemental resources.

Paul has published 130+ research papers in scientific journals as well as reviews, book chapters and patents in the fields of porous framework materials, nanowires and nanoparticles, and hydrogen storage materials. He has received major research grants from the Royal Society, the Engineering and Physical Sciences Research Council, the European Union, Innovate UK and Advantage West Midlands.

Peter Bruce, SOLBAT

See Faraday Institution Team

Serena Cussen, FutureCat

Professor Serena Cussen FRSC is Chair of Functional Nanomaterials and Head of Department of Materials Science and Engineering at the University of Sheffield. Recipient of multiple awards from learned societies, her research breaks new ground in the design and synthesis of functional materials, deepening our understanding of the synthesis-structure-property interplay. She leads multi-institutional, interdisciplinary research activities, including the UK Faraday Institution FutureCat project, a consortium of 55+ researchers delivering next-generation Li-ion battery cathodes.

Director of Research and Innovation for her department, Serena was recently appointed to the RSC Materials Division Council and co-chaired the successful international MC15 conference. Her significant research contributions are regularly highlighted (e.g. Top Women in Materials) and her public engagement activities have had global reach (e.g. her Royal Institution lectures garnering over 140K views). She is deeply committed to career sustainability, ECR mentoring, and the promotion of women in STEM. She sits on the Faraday Institution Training and Diversity Panel, EPSRC Materials Working Group, RSC's Equity in Publishing group (contributing to their recent *Is publishing in chemistry gender biased?* report) and featured in the recent *The Chemical Ladies* report. In response to the Covid pandemic, she founded The Recharge Network to support those working in academia with caring responsibilities. She is associate editor of IOP Progress in Energy and editorial board member of J.Mater.Chem.A, Nanoscale and Chemistry of Materials.

Patrick Grant, Nextrode

Patrick Grant FREng is the Vesuvius Professor of Materials and Pro-Vice-Chancellor for Research at the University of Oxford. His research takes place at the interface between advanced materials and manufacturing. Particular applications include electrodes for energy storage and advanced metallics for power generation. Many of his research projects are concerned with solidification behaviour in complex alloys, and/or the use of liquid metal, ceramic or polymer droplet and powder sprays to create unusual materials. All the research work involves close collaboration with industry.

Clare P. Grey, Degradation Project

Clare P. Grey, FRS is a Royal Society Research Professor, Geoffrey Moorhouse-Gibson Professor of Chemistry at the University of Cambridge and a Fellow of Pembroke College Cambridge. She received a BA and D. Phil. (1991) in Chemistry from the University of Oxford. Her current research interests include the use of solid-state NMR and diffraction-based methods to determine structure-function relationships in materials for energy storage (batteries and supercapacitors), conversion (fuel cells) and carbon capture.

Recent honours and awards include Honorary PhD Degrees from the Universities of Orleans (2012) and Lancaster (2013), the Research Award from the International Battery Association (2013), the Royal Society Davy Award (2014), the Arfvedson-Schlenk-Preis from the German Chemical Society (2015), the Société Chimique de France, French-British Prize (2017), the Solid State Ionics Galvani-Nernst-Wagner Mid-Career Award (2017), the Eastern Analytical Symposium Award for Outstanding Achievements in Magnetic Resonance (2018), the Sacconi Medal from the Italian Chemical Society (2018), the Charles Hatchett Award, Institute of Materials, Minerals and Mining (2019), the RSC John Goodenough Award (2019) and The Körber European Science Prize (2021). She is a foreign member of the American Academy of Arts and Sciences, and a Fellow of the Electrochemical Society and the International Society of Magnetic Resonance.

John Irvine, NEXGENNA

John Irvine is a professor at School of Chemistry, University of St Andrews. He has established a significant international research grouping investigating fundamental electrochemistry, solid state chemistry, and materials science addressing critical energy problems. This research has ranged from detailed fundamental to strategic and applied science and has had major impact across academia, industry and government.

The quality and impact of Prof Irvine's research has been recognised by a number of national and international awards, including the Hughes Medal from the Royal Society in 2021, the Lord Kelvin Medal from the Royal Society of Edinburgh in 2018, the Schönbeim gold medal from the European Fuel Cell Forum in 2016, the RSC Sustainable Energy Award in 2015, with earlier RSC recognition via Materials Chemistry, Bacon and Beilby awards/medals. Irvine has almost 500 publications and has an WoS h-index of 75. He has strong international standing having held senior visiting appointments in the US, Australia and China.

Saiful Islam, CATMAT

Saiful Islam is Professor of Materials Modelling at the University of Oxford. He grew up in London and obtained his Chemistry degree and PhD from University College London (with Richard Catlow FRS), followed by a Postdoctoral Fellowship at the Eastman Kodak Labs in New York. He returned to the UK to the University of Surrey followed by a Professorship at the University of Bath before joining Oxford in 2022. His research interests include structural, transport and computational studies of new materials for lithium-ion batteries and perovskite solar cells. He has presented more than 95 invited conference talks and has over 230 publications.

Prof Islam is the recipient of several awards including the 2020 ACS Award in Energy Chemistry, 2017 RSC Peter Day Award for Materials Chemistry and 2013 Royal Society Wolfson Merit award. He also presented the 2016 Royal Institution Christmas Lectures for BBC TV, entitled 'Supercharged: Fuelling the Future.'

Gregory Offer, Multi-Scale Modelling

Gregory Offer is Professor in Electrochemical Engineering, Faculty of Engineering, Department of Mechanical Engineering, Imperial College London and leads the Electrochemical Science and Engineering Group in Mechanical Engineering. Since starting his group in 2010 he has worked with multiple industry partners on projects worth over £42.8 million. Greg has also worked as a management consultant and a government advisor.

Professor Offer's research is at the interface between the science and engineering of electrochemical devices. Having trained as an electrochemist before moving to engineering, his research portfolio focuses on understanding the limits of operation, degradation mechanisms and failure modes of batteries, supercapacitors and fuel cells in real world applications, and the impacts and consequences on system design, integration and control. He has published multiple peer reviewed journal papers, patents, technical reports and books. Greg is also a co-founder of three battery related start-ups, Cognition Energy Ltd, Breathe Battery Technologies Ltd and About:Energy Ltd.

Paul Shearing, LiSTAR and SafeBatt

Paul Shearing is a Professor of Chemical Engineering at UCL, where he holds the RAEng Chair in Emerging Battery Technologies which recognises 'global research visionaries'. He is co-director (alongside Dan Brett) of the Electrochemical Innovation Lab (EIL), the UK's largest electrochemical engineering laboratory. His work focuses on the development of next generation battery materials (the subject of his RAEng Chair) with work on Li-S batteries including the first application of 4D-imaging tools and the first use of image-based modelling to describe electrode behaviour. He has worked extensively with industry to translate this understanding of Li-S electrodes to commercial environments. He is a Fellow of the IChemE, leads the UK's STFC Batteries Network, and chairs the Faraday Institution's Training and Diversity Panel.

Expert Panel

The Expert Panel, led by the Faraday Institution Chief Scientist, Peter Bruce, and joined by the Faraday Institution Principal Investigators, brings the UK's best battery experts together across academia and industry in one organisation. The Expert Panel is the engine of the Faraday Institution, acting formally in an advisory role to the Faraday Institution Chair and Board.

Jerry Barker

Jerry Barker runs an independent consultancy specialising in advanced batteries and energy storage technology. He is a world-renowned battery scientist, having set up and managed battery research facilities in the US and the UK. Over the course of his career, he has gained a wealth of knowledge and experience in the field of battery technology, from the active materials to their scale up and integration into battery systems. Founder and former chief technology officer at Faradion and former chief scientist at Valence Technology Inc., Dr Barker is an inventor on over 90 issued and ~ 50 pending US battery patents. Some noteworthy examples of his inventions include the well-known Li-ion materials $LiVPO_4F$, $Li_3V_2(PO_4)_3$, $LiMSO_4F$, $Li_2MP_2O_7$, $LiFe(Mg)PO_4$ along with the carbothermal reduction (CTR) manufacturing method. As a result of Dr Barker's impressive track record in this field, he was presented with the International Battery Materials Association Technology Award 2012, for his contributions to identifying new secondary battery cathode materials and related materials.

Nigel Brandon

Professor Nigel Brandon OBE is Dean of Engineering at Imperial College London, Director of the UK Hydrogen and Fuel Cell SUPERGEN Hub, Co-Director of the UK SUPERGEN Energy Storage Hub, and Chair of Imperials' Sustainable Gas Institute. His research is focused on electrochemical devices for energy applications, with a particular focus on fuel cells, flow cells, electrolysers, and batteries. He was the founding Director of the Energy Futures Lab at Imperial College, a founder of Ceres Power, an AIM listed fuel cell company spun out from Imperial College in 2000, and a founder of RFC Power, a flow battery company spun out from Imperial College in 2018. He was awarded the Royal Academy of Engineering Silver Medal in 2007, the Institution of Civil Engineers Baker Medal in 2011, and the ASME Francis Bacon Medal in 2014. He is a Fellow of the Royal Academy of Engineering, the Institute of Materials, Minerals and Mining, and the Energy Institute.

Dan Brett

Dan Brett is Professor of Electrochemical Engineering at UCL, where he is a director of the Electrochemical Innovation Lab (EIL) and Advanced Propulsion Lab (APL). He received his PhD in Physical Chemistry from Imperial College London in 2000. Prof Brett's research encompasses a broad range of electrochemical technology, with a particular focus on fuel cells, batteries, supercapacitors, electrolysers, and redox flow batteries. His research has been recognised through the 2009 De Nora Prize for Applied Electrochemistry (International Society of Electrochemistry), the Baker Medal in 2011 (Inst. Civil Engineers), and The Engineer Collaborate to Innovate Award for lithium-ion battery safety research in 2017. His research has been commercialised through the spin-out companies Amalyst (advanced electrochemical materials) and Bramble Energy (fuel cell stacks and systems), where he is the Director of Innovation.

Anthony Burrell

Anthony K. Burrell is chief technologist for energy storage at the US Department of Energy's National Renewal Energy Laboratory (NREL). He has been working in the areas of energy science and technology since the early 1990s with a specific focus on energy storage. Recently, he was the department head for electrochemical energy storage at Argonne National Laboratory. He holds a PhD in chemistry from the University of Auckland, New Zealand.

Valentina Gentili

Dr Valentina Gentili is Senior Technical Specialist for the Battery Collaboration Projects and Head of the Electrochemistry and Cell team at Jaguar Land Rover.

Having over 15 years of experience across a wide range of disciplines within the lithium-ion advanced materials and automotive battery research and development field, Valentina leads the delivery of electrified vehicle battery cell technology in support of the product cycle plan, as well as formulating and delivering next generation cell technology strategies at JLR.

Valentina obtained her PhD in Chemistry from the University of St Andrews with a thesis on 'Nano-materials for use as anodes in lithium-ion batteries' under the supervision of Prof Peter G. Bruce.

David Greenwood

David Greenwood is the CEO of the WMG centre High Value Manufacturing (HVM) Catapult at the University of Warwick, where he is also Professor of Advanced Propulsion Systems. His research spans batteries, electric motors, power electronics, and the integration and control of these for propulsion and energy applications. He joined WMG in 2014 from engineering consultancy Ricardo UK Ltd where he was Head of Hybrid and Electric Systems leading advanced technology projects for OEM and Tier 1 customers in passenger cars, defence, motorsport and the clean energy markets. Professor Greenwood holds advisory and board positions for the Advanced Propulsion Centre, and Innovate UK (Faraday Challenge and IDP), EPSRC (Energy). He is head of the Advanced Propulsion Centre's Electrical Energy Storage Spoke.

A Robert Hillman

Robert Hillman was educated at Imperial College London (BSc, 1976) and the University of Oxford (DPhil, 1979). After postdoctoral research at Imperial College, he was appointed to a Lectureship at the University of Bristol (1983), to the Chair of Physical Chemistry at the University of Leicester (1992), and as Dean of the Faculty of Science (2003-2009). He was Scientific Editor of Faraday Transactions and Faraday Discussions (1994-1997) and has been Editor in Chief of Electrochimica Acta since 2014. Prof Hillman has served the International Society of Electrochemistry as UK National Secretary (1994-1998), Secretary General (1999-2005), Chair of the Scientific Meetings Committee (2006-07) and President (2009-2010), and the Electrochemical Society through its Sensor Division and Education Committees. He is an elected Fellow of the International Society of Electrochemistry and of the Electrochemical Society.

His research interests in electrochemistry have involved surface modification, electrodeposition, interfacial characterisation, materials science and interfacial analysis and imaging. He has pioneered the development of a number of acoustic wave, optical, spectroscopic, neutron reflectivity and surface analytical techniques for in situ interfacial characterisation. These works are represented in over 230 publications.

Robert Millar

Rob Millar is the Head of Electrical for Williams Advanced Engineering, the technology and engineering services business of the Williams Group.

He has been involved with vehicle electrification since 2004 when he founded his own company developing electronic systems for Modec, Tata, JLR and Daimler vehicles amongst others. Having first worked with Williams in 2010, when he was part of the team who delivered the Jaguar C-X75 programme, he joined the company as a full-time employee in 2016 to head up the company's battery and electronics programmes.

John Owen

John Owen is an Emeritus Professor in the Southampton Electrochemistry Group. After his early studies on lithium anodes, polymer electrolytes and composite electrodes at Imperial College, London in 1979 he began an academic career at Salford in 1984 then Southampton since 1991, training students and postdoctoral researchers in batteries, supercapacitors and simple models of their energy and power limitations. His research has mainly comprised the characterisation of electrochemical materials, e.g. ceramic, glass, polymer, gel and liquid nonaqueous electrolytes, electron conducting polymers, nanocomposites, redox mediators and their applications in batteries, particularly lithium-ion, lithium-air and lithium sulfur.

Andrea Russell

Andrea Russell is Professor of Physical Electrochemistry at the University of Southampton. Her research interests are mainly in the application of spectroscopic methods to study the electrode/electrolyte interface, with particular emphasis on electrocatalysts and electrode materials for batteries including metal-air systems, fuel cells and electrolysers as well as gas sensors. Prof Russell received her PhD from the University of Utah and then proceeded to hold an NRC Postdoctoral Research Fellowship at the US Naval Research Laboratory. She came to the UK in 1991, first holding lectureships at the Universities of Liverpool, Newcastle and the University of Southampton before being appointed to her current position in 2007. She is the author or co-author of 70+ refereed papers and is Chair of the Physical Electrochemistry Division of the International Society of Electrochemistry.

Julia Rowe

Julia Rowe is Sustainability Manager for Johnson Matthey (JM), a position she has he held for over a decade. In this role, she ensures the corporate sustainability strategy is incorporated into all aspects of its business, from the way decisions are made on R&D projects and capital investments to the way manufacturing plants are run globally. Her current focus is developing JM's corporate Net Zero strategy, enhancing its global responsible sourcing strategy and building up its product life cycle assessment capability. Over the last few years, she has been working with JM's Battery Materials business to ensure sustainability is integral to the design of its first cathode manufacturing plant, currently under construction in Poland, and all its supply chains. In prior positions over her 25-year career at JM, she has managed technical projects in the area of hydrogen generation and hydrogen PEM fuel cell technology and as served as Technology Commercialisation Manager for JM's first membrane electrode assembly plant. Julia has an MA (Oxon) in chemistry and a PhD in catalysis with surface science.

Nigel Taylor

Nigel Taylor is the Senior Manager, Energy Storage and Consumption at Jaguar Land Rover, where he has worked for over 30 years in a number of areas including as a technical specialist in acoustics, winning an award for time domain route tracking. The move to hybrid and electric vehicles came about in 2008 with Limo Green, a range extended electric Jaguar XJ. From here Nigel moved to technical lead for Jaguar Land Rover, WMG and TMETC on the HVM Catapult Energy Storage project, this team based on the Warwick University campus developed a number of the fundamental measurement techniques and knowledge around cell to pack design of a battery. Nigel is now the senior manager for the concept battery team who are responsible for everything from fundamental battery research to concept pack design.

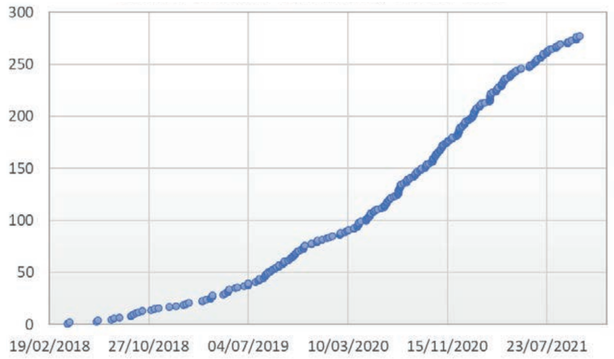
Scientific Publications

Research from the Faraday Institution's programme is internationally recognised as a mark of excellence. Scientific discoveries have led to highly cited publications, a suite of patents, and commercial spin outs – growing evidence that the work the organisation is doing is hitting its mark.

Since its inception, the Faraday Institution has contributed over 270 publications to the scientific literature. Almost half of the published research coming out of the Faraday Institution has international collaborators, spanning over 190 institutions and six continents. Key countries that collaborate most frequently with the Faraday Institution include the USA, France, Germany, China and Sweden, in that order.

Faraday Institution publications are of measurably high quality and are bringing up the UK average Field-Weighted Citation Impact (FWCI) in the research domains in which the Faraday Institution operates (chemistry, materials science, energy, physics, chemical engineering, engineering, environmental science). In the UK, research in 2021 carries a FWCI of 1.56. Faraday Institution research is on target to be ahead of this with a FWCI of 2.53.

As of October 2021, papers published by Faraday Institution researchers are as follows.



The below list contains all the articles published by the Faraday Institution projects. The name of a first author is included. For more details on each article please follow the DOI or link provided.

Lithium Ion

Battery Degradation

In-Situ Electrochemical SHINERS Investigation of SEI Composition on Carbon-Coated Zn0.9Fe0.1O Anode for Lithium-Ion Batteries, Cabo-Fernandez, L., Batteries and Supercaps, (Sep 2018), DOI:10.1002/batt.201800063
https://onlinelibrary.wiley.com/doi/abs/10.1002/batt.201800063

Evolution of Electrochemical Cell Designs for In-Situ and Operando 3D Characterization, Tan C., Materials, (Nov 2018), DOI:10.3390/ma11112157
https://www.ncbi.nlm.nih.gov/pubmed/30388856

4D Visualisation of In-situ Nano-compression of Li-ion Cathode Materials to Mimic Early Stage Calendering, Daemi, S.R., Materials Horizons, (Dec 2018), DOI:10.1039/C8MH01533C
https://pubs.rsc.org/en/content/articlelanding/2019/MH/C8MH01533C (See also Multi-scale Modelling)

Evolution of Structure and Lithium Dynamics in LiNi0.8Mn0.1Co0.1O2(NMC811) Cathodes during Electrochemical Cycling, Märker, K., Chemistry of Materials, (Mar 2019), DOI:10.1021/acs.chemmater.9b00140
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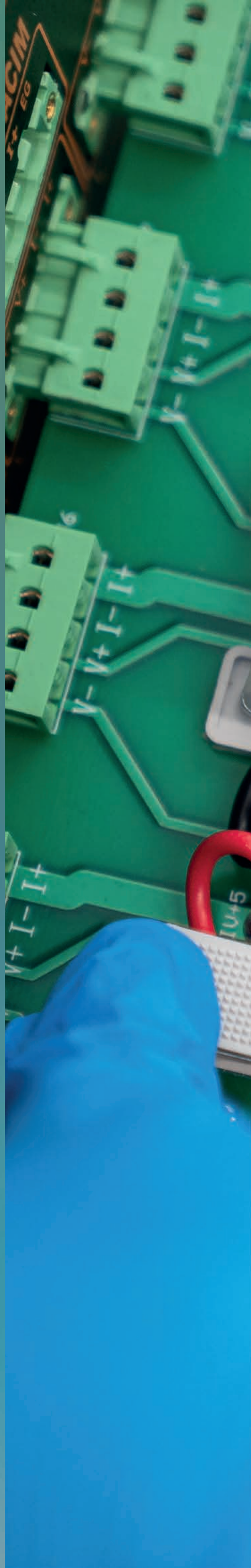

Battery cycling (University of Sheffield).
Photo by Timm Cleasby Photography