CPI Battery Capability and Case Studies

Robert Mitchell

Principal Scientist – Energy Materials

We help companies to develop, prove, scale-up and commercialise new products and processes

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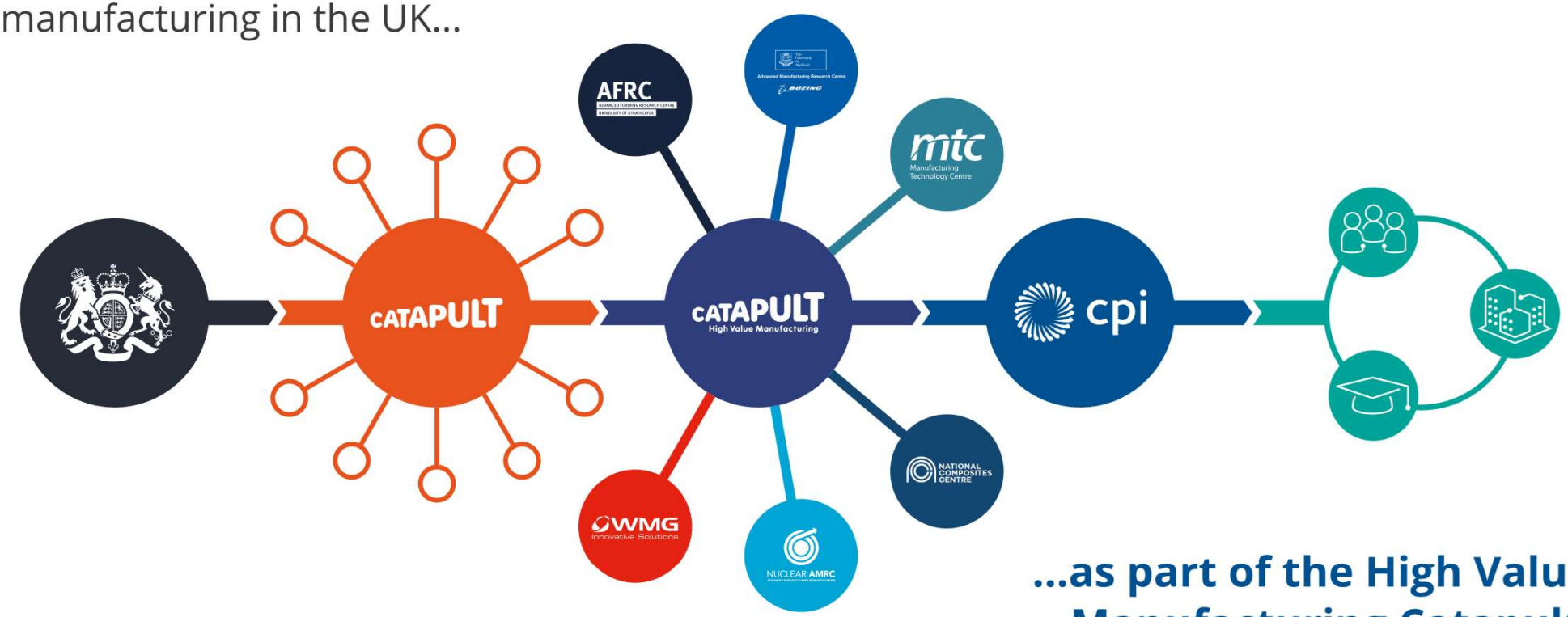
Supporting the growth and development of advanced manufacturing in the UK...



...as part of the High Value Manufacturing Catapult

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We help deliver, de-risk and accelerate...

...your concepts into successful products

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...using our integrated innovation services

Industry relevant expertise and assets

Delivering product development, proof of concept, and scale-up services.

Expertise in securing funding for partners and clients

Enabling the right partnerships, connections, and funding routes at the right time.

Knowledge and application of innovation processes

Business services and consultancy to reduce risk and speed up time to market.

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Fee for service

- **One-to-one** project with CPI
- **Flexible scope** and project size
- **Rapid initiation** of projects
- Can encompass a range of services including business and innovation support, consultancy, and lab-based projects

Offers flexibility and speed

Collaborative projects

- **One-to-one** with CPI or together with a **larger consortium**
- Projects initiate after completion of a **detailed funding protocol**
- We offer a bespoke service for **bid development** and **grant landscape navigation**

Best option for highly innovative projects you can't fully fund yourself

Funded SME support

- Smaller projects may qualify for **total funding** status from ERDF programmes
- **Regional limitations** can apply to supporting SMEs

Great mechanism for an initial engagement with us

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Proof of concept and scale-up

to prove the feasibility of your new ideas before approaching investors, stakeholders, or funding programmes

Reduce risk

by helping prove and refine your novel technologies before investing further in new facilities and equipment

Decreasing time to market

by providing access to proven demonstration assets and industry expertise

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Battery Materials Capabilities at CPI

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We can accelerate Battery Technology development

Materials

- Development support in scalable processes for existing and next-generation electrode materials, including solid-state batteries and the recovery of high-value battery electrode materials
- Surface engineering of materials and structures to maximise performance

Formulation

- Utilise high-throughput experimentation to screen and optimise new and existing chemistries
- Processing with a wide range of mixing technologies to maximise performance from grams to kilograms
- Optimise the evaporation and drying of slurries

Coating and Stucturing

- Wet coating and vacuum coating process development and optimisation (e.g. slot die, ALD)
- Photonic and plasma processing for improved surface adhesion and increased efficiency
- Optimisation of electronic structures and interfaces to obtain the maximum benefits in electrode performance

Sensors

- Developing Integrated and multifunctional smart sensors for high-value battery management solutions
- Distributed solutions to enable individual cell monitoring
- Embedding intelligent sensors in cells to better inform second-life applications

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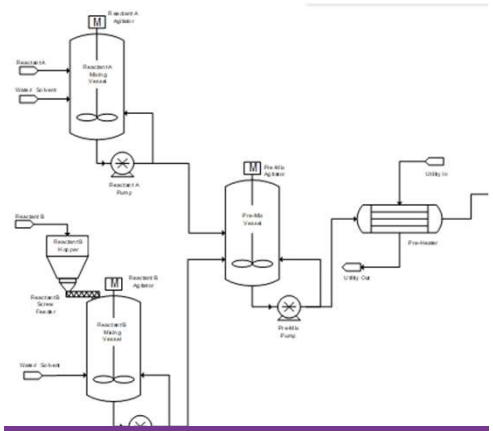
Scale Up Evaluation

Scale-up Development and Validation

- Understand process chemistry
- Make lab scale process more robust, scalable, safer
- Investigate batch to continuous processing

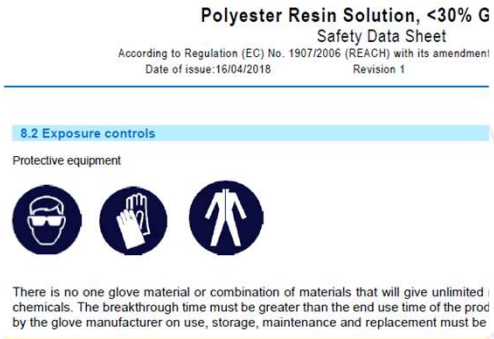
Process Analytical Techniques (PAT)

- Understand key process parameters
- Generate lab data to inform plant design
- Understand and control product quality
- Soft sensor development



Preliminary Commercial Plant Design

- Process Flow Diagram
- Mass and Energy Balance
- Key risks identified with suggested mitigations
- Process Economics (Capex, Opex)



Polyester Resin Solution, <30% G
Safety Data Sheet
According to Regulation (EC) No. 1907/2006 (REACH) with its amendment
Date of issue:16/04/2018 Revision 1

8.2 Exposure controls

Protective equipment

There is no one glove material or combination of materials that will give unlimited
chemicals. The breakthrough time must be greater than the end use time of the prod
by the glove manufacturer on use, storage, maintenance and replacement must be

Safety and Sustainability

- Chemical Safety (COSHH, CHA, MSDS etc)
- Process Safety (HS2, HAZOP etc)
- Life Cycle Analysis

CPI Battery capabilities and respective TRL

- Support CPI can offer partners to develop battery processes
- Dates where listed indicate when likely to come online

Increasing technology readiness level

Synthesis

Formulation

Cells

Analytical

Surface Engineering

Recycling

Process engineering

Digital

Small scale materials processing and synthesis

10 kg pilot scale Materials Synthesis and processing

AMBIC Jan 25

Automated materials screening: 5-20 g scale slurry preparation

Slurry mixing scale 1-5 litre scale

Preparation of electrodes for coin and pouch cells

Analytical screening of materials and performance

Coin cell testing (battery/supercapacitor)

Single Layer Pouch cell testing

Slot die/ALD-PVD-TE coating/plasma treatment/surface structuring by laser

ICP –MS metal content

Sensor design and roll to roll printing

Battery recycling methodologies

Process engineering support: Technoeconomic assessment, Plant/process design, Process safety, Sustainability/CO2 assessment, Life cycle assessment LCA, Material flow analysis MFA

PAT tools

10 kg pilot PAT tools

AMBIC Jan 25

Data Foundry

Key:

Current

Future

Themes:

Synthesis/Formulation

Process engineering

Analytical

Surface Engineering

PAT/Digital

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CPI Formulation system

Automated preparation of battery slurries & syringe transfer into suitable format for drawdown – ambient conditions

Safe handling of toxic and nanomaterial powders ensured *via* a dedicated, HEPA filtered glove box enclosure, which links into main robot system

20-40 + formulations per day at 10-40 g scale.

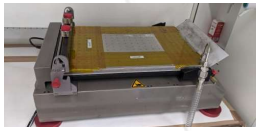
Increase in throughput and reproducibility vs manual preparation.

Supporting equipment (Process)

High throughput experimentation: Battery formulation, Materials compatibility testing, screening leachates for hydrometallurgy processes

Comminution: Milling/grinding and sieving of materials. Dry or wet and options for inert milling.

Pyrolysis: Moderate temperature processing (1200 °C). In air or inert atmosphere.



Electrode (Re)manufacturing: Slurry mixing (centrifugal/three roll mill/silverson/ultra turrax/double planetary), drawdown, calendaring

Stirred tank reactors: Scalable processing and synthesis of materials. Handling black mass for hydrometallurgical processing and extraction of materials

Argon glovebox: Inert handling of materials

Battery materials and electrode testing

Physical properties: Powder bulk density analyser, nitrogen sorption (BET) inverse gas chromatography (IGC), force tensiometer, particle size analysis, UV-Vis, dynamic vapour sorption (DVS)

Chemical properties: X-ray diffraction (XRD), Raman, FTIR with hot stage, EDX, MP-AES, Triple Quad ICP-MS

Electrical and Electrochemical testing: Potentiostats/battery cyclers for electrochemical testing of cells, 4 point probe, powder resistivity, impedance analyser

Microscopy: Materials characterisation. Field-emission scanning electron microscopy (FE-SEM), atomic force microscopy (AFM), optical microscopy with hot stage, confocal, white light interferometry, cross-sectioning

Thermal: Thermogravimetric analysis (TGA) and differential scanning colorimetry (DSC)

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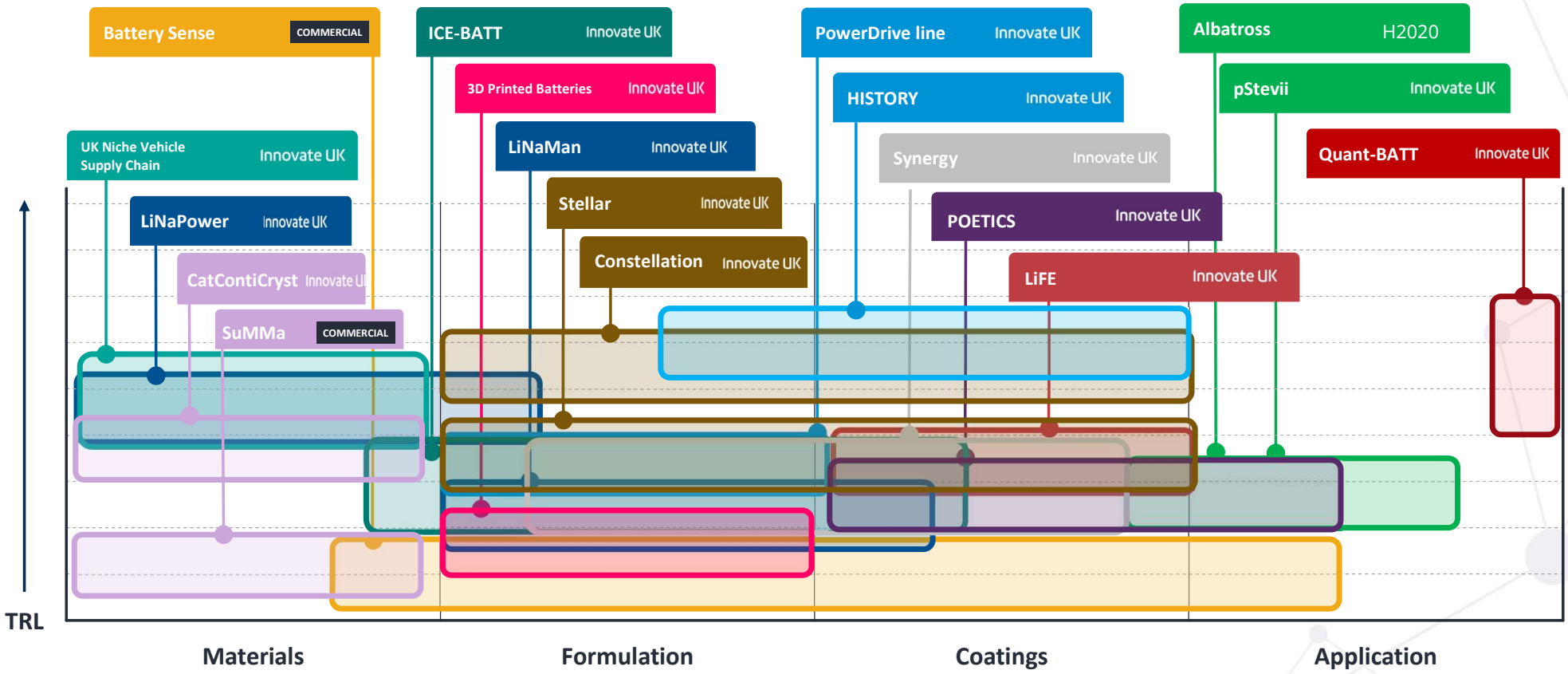
Mapping of Relevant Projects



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Case studies (Approved by partners)

Scale-up evaluation of materials

Developing a niche vehicle battery cell supply chain

Building a supply chain to exploit a gap in niche EV development, hampered in the UK by a lack of availability and supply security of suitable battery cells and materials

Collaborative R&D | 2 years | £4.3 million

HOW CPI HELPED

CPI worked on the 24-month project as an academic partner to speciality chemicals and advanced materials manufacturer William Blythe Limited, supporting process development and scale-up work.

Assisting William Blythe's in-house expertise, CPI developed a material in collaboration with AGM Batteries Limited, using its plant to produce cells for the project, which also includes Delta Motorsport.

CPI developed a range of cells, bringing together state-of-the-art facilities and industry expertise with customisation and predictive modelling to provide cost-effective solutions.

OUTCOMES AND IMPACT

- Enabling the development and scale-up of batteries for the niche vehicle industry
- Strengthening the UK's chemical industry in producing battery materials
- Help AGM Batteries move towards a Gigafactory

"This project will provide UK-based niche automotive manufactures with a home-grown supply chain option, bringing stability and assurance of product supply."

Steven Farmer
Innovation Director, AGM Batteries

Materials | Formulation | Coating and structuring | Sensors

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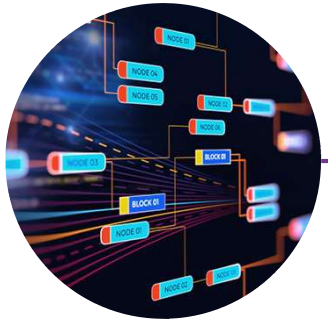
Scale-up evaluation of materials

Development and evaluation of anode material scale-up processes



Evaluation of the manufacture route for anode material

Process development

Material analysis and performance evaluation

Product scale-up and technical transfer

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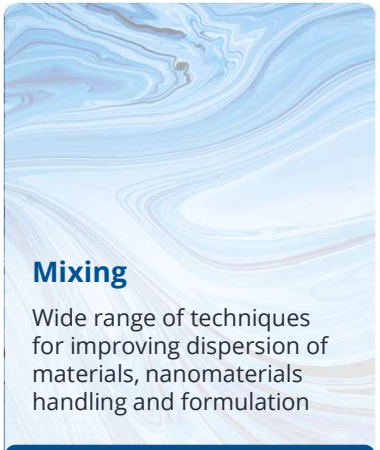
Formulation optimisation and scale-up

Evaluation and incorporation of novel materials to optimise performance in new formulations with a demonstration of scalability



Mixing

Wide range of techniques for improving dispersion of materials, nanomaterials handling and formulation

CAPABILITIES

- Relevant industry techniques such as planetary, high-shear, and centrifugal
- Nanomaterial handling capabilities

Milling

Optimising dispersion via particle size reduction or de-agglomeration

CAPABILITIES

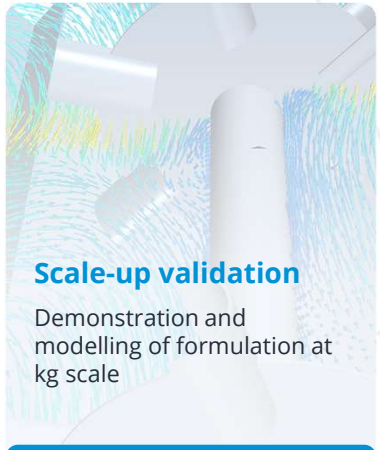
- Bead mills and three-roll mills for improved dispersion
- Ball mills for decreased particle size

Material optimisation

Screening ink and coating properties

CAPABILITIES

- Plasma or wet chemistry functionalisation of powders
- Thermal treatment



Scale-up validation

Demonstration and modelling of formulation at kg scale

CAPABILITIES

- CFD modelling of mix process at industrial scale
- Kilogram-scale mixing and milling options

Formulation optimisation and scale-up

High performance, low cost, and safe energy storage

Demonstration of a novel technology solution, based on sodium nickel chloride, to replace existing lithium-ion batteries in electric vehicles and in grid storage

Collaborative R&D | 1 year | £234,000

HOW CPI HELPED

- Expertise in battery technology
- State-of-the-art facilities
- Innovate UK funding

PROJECT OUTPUTS

- Investigation of processing methods
- Successful proof of concept
- Proven large-scale and low-cost manufacturing
- Na-Ni-Cl battery proved successful in operation

OUTCOMES AND IMPACT

- Advancement of Na-Ni-Cl battery technology
- A prestigious £1million UK grant secured and closure of a significant capital raise
- Grant application for additional funding
- Demonstration of Na-Ni-Cl battery technology

"I am delighted with the outcomes of our collaboration with CPI. To truly enable widescale adoption of electric vehicles, it is accepted that new non-lithium and cobalt battery chemistries are needed. Together, we have demonstrated the incredible potential of LiNa's Na-based technology."

Gene Lewis
Chief Executive, LiNa Energy

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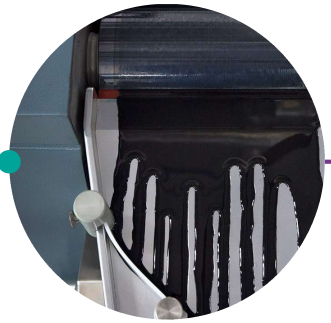
Formulation optimisation and scale-up

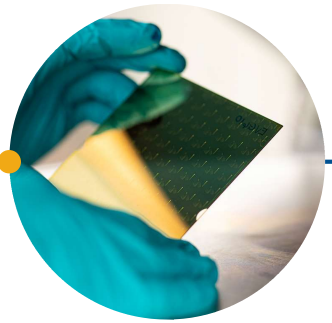
Formulating electrolyte powder into inks for screen printing into a dense electrolyte film

Raw material characterisation

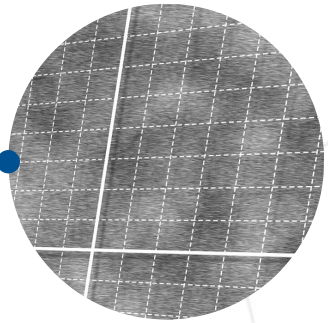


Formulate screen printing ink from electrolytes

Rheology process for the select ion of optimum ink formulations



Screen print to metal surface



Printed film characterisation

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Formulation optimisation and scale-up

Next generation solid-state battery development

Develop a proof of concept pilot line and new scalable processes allowing for the manufacture of solid-state cell materials for plug in hybrid and electric vehicles.

Collaborative R&D | 30 months | £6 million

OUTCOMES AND IMPACT

- Development and scale-up of cost-effective solid-state batteries with high power density and short charge time
- Helping in establishing a pre-pilot prototype cell manufacturing line

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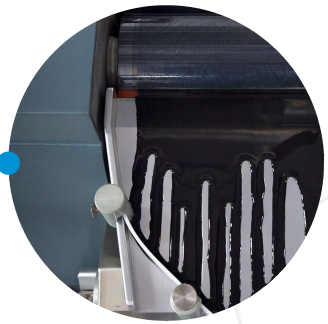
Formulation optimisation and scale-up

Ink development and print support

Commercial and partner materials evaluation

Ink development

Print development support



Ink scale-up

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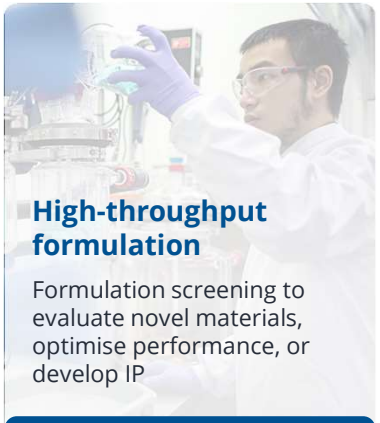
High-throughput formulation evaluation

Rapid evaluation of formulation and coatings to maximise learnings for novel materials and to optimise formulations

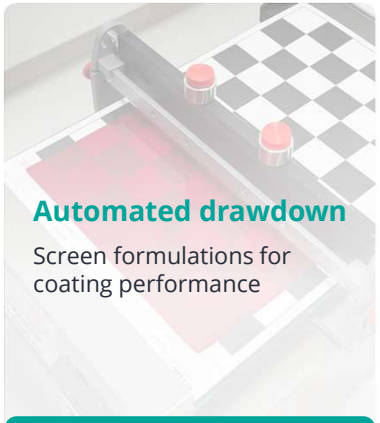


High-throughput formulation

Formulation screening to evaluate novel materials, optimise performance, or develop IP

CAPABILITIES

- A highly skilled team dedicated to robot operations
- Automated dispensing of nanomaterials, solids, liquids, viscous liquids, semi-solids, and pastes



Automated drawdown

Screen formulations for coating performance

CAPABILITIES

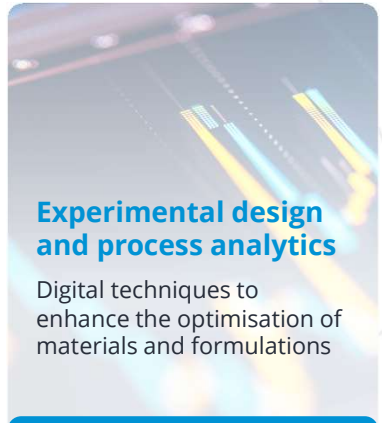
- Doctor blade and slot die heads
- Syringe dispensing

Material property characterisation

Screening ink and coating properties

CAPABILITIES

- Automated DSC, TGA, UV, IR, and gloss-to-screen materials properties
- Material printability using in-line rheology
- Coatings characterisation



Experimental design and process analytics

Digital techniques to enhance the optimisation of materials and formulations

CAPABILITIES

- Design of experiments
- Process analytics such as principle component analysis

High-throughput formulation evaluation

Enhanced cathode materials for optimised battery packs

Optimising existing Li-ion cathode materials, exploring the inclusion of innovative carbon additives such as graphene and alternative solvents in the electrode structure.

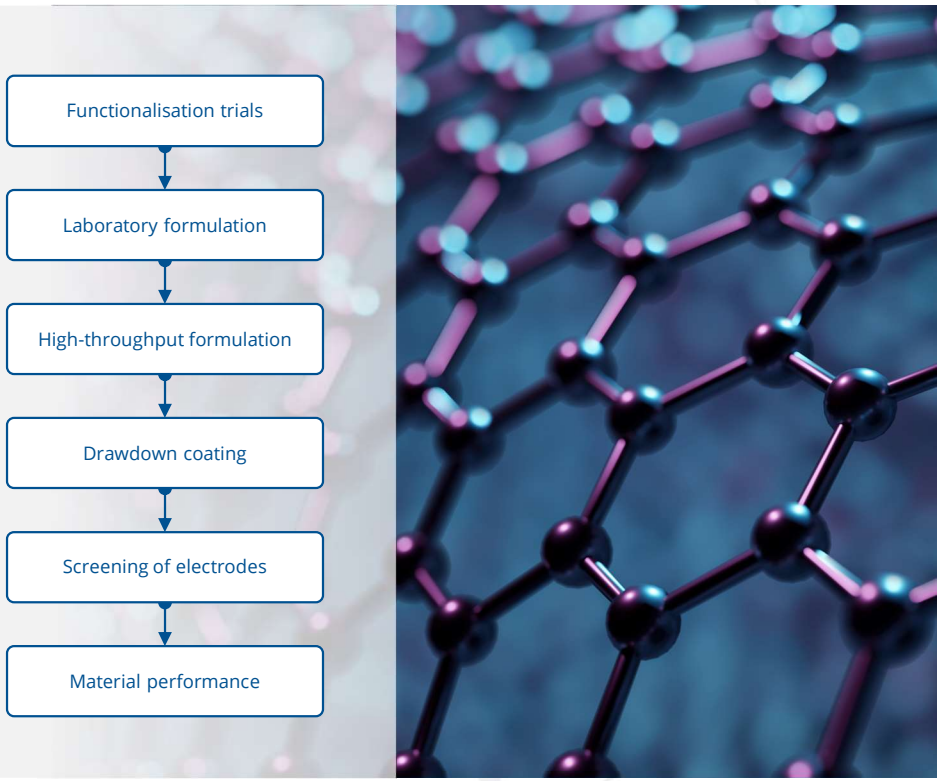
Collaborative R&D | 18 months | £810,000

HOW CPI HELPED

- High-throughput formulation of actives, binders and carbons
- Functionalisation of innovative carbons for optimised dispersion
- Performance evaluation through characterisation

OUTCOMES AND IMPACT

- Developed optimised battery materials and formulations that enhance electrochemical performance and lifetime
- Support the supply chain for innovative cathode battery materials



Materials | **Formulation** | Coating and structuring | Sensors

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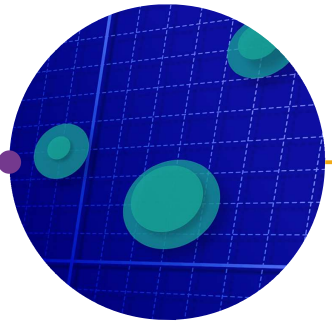
High-throughput formulation evaluation

Solvent and binder replacement for battery electrodes

Collect data on solvent properties

Collect relevant data on a wide range of solvents, such as Hansen solubility parameters and boiling point



Creating solvent maps

Principle component analysis of the solvent parameter space and variability to allow the targeting of a subset of solvents

Design of experiments

Systematic approach to formulation development, reducing the experiments required and accelerating process development for the customer

Optimisation of formulation

High-throughput experimentation to rapidly produce and characterise formulations

High-throughput formulation evaluation

synthomer

williamblythe
Chemistry for tomorrow

amte

UKRI Innovate UK

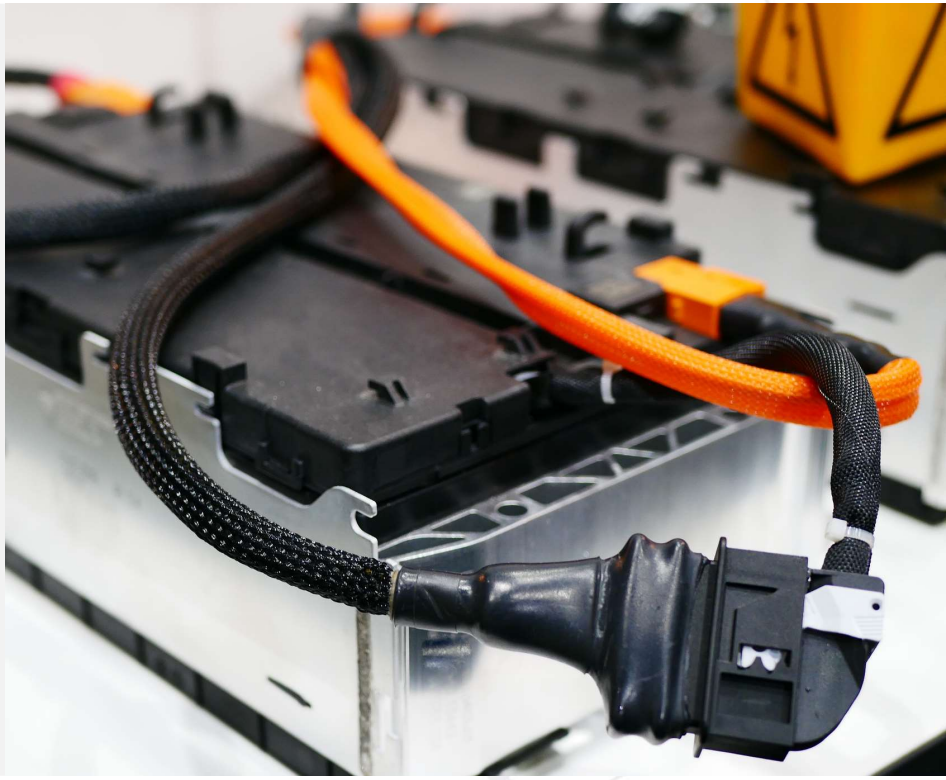
Improving the performance of battery cell components

Demonstrating the improvements to the manufacturing efficiency, performance and environmental profile of cells optimised for the automotive market.

Collaborative R&D | 18 months | £1.1 million

OUTCOMES AND IMPACT

- Improvements in raw materials and the formulation of anode and cathode systems used in lithium ion batteries
- Support the supply chain for the scale-up of innovative cathode and anode battery materials and cells



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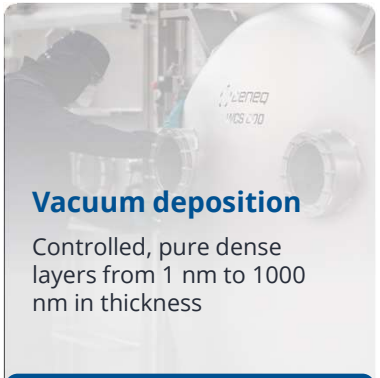
Coating and structuring

Optimisation of electrode structures through the controlled wet coating and vacuum deposition of novel materials



Vacuum deposition

Controlled, pure dense layers from 1 nm to 1000 nm in thickness

CAPABILITIES

- Batch systems for proof of concept
- R2R systems for scale-up and manufacture
- Atomic and molecular layer deposition, evaporation and sputtering

Wet coating

Dispersion and formulation layer deposits from 100 nm to 40 µm in thickness

CAPABILITIES

- Wet coating techniques, including wire bar, spin coat, slot die, and screen printing
- Small and large area R2R
- Multiple pass processes
- Range of oven, IR, and UV drying techniques

Patterning

Etching and ablation to pattern films from 1 nm to 1000 µm

CAPABILITIES

- Full suite of photo-lithographic tools
- Photoresist coating and developing
- Batch and stepper exposure tools
- R2R Femto second laser ablation capability

Surface engineering

Photonic, thermal, and plasma modification of surface properties and interface enhancement

CAPABILITIES

- Full suite of surface treatment processes
- Plasma O_2,Ar, CF_4, N_2
- Photonic treatments

Coating and structuring

Extending the lifetime of novel lithium-sulphur batteries

Assessing scalable processes for coating lithium foil, for next-generation manufacturing of lithium-metal batteries; increasing battery cycle lifetime and energy density for EVs.

Collaborative R&D | 1 year | £625,000

OUTCOMES AND IMPACT

- Demonstrate the handling, storage and processing of lithium foils
- Developing processes for surface engineering, coating scale-up, and low temperature ALD recipes for ceramic and organo-metallic coatings on lithium foils

Materials | Formulation | **Coating and structuring** | Sensors

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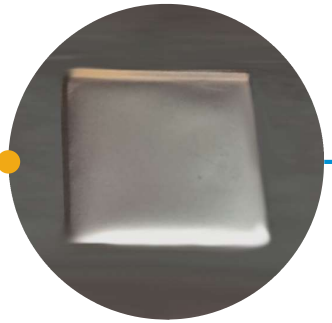
Coating and structuring

Surface engineering, ceramic and organo-metallic coatings of lithium foils

Tools modification to operate in non-dry room with an argon atmosphere

High energy radiation surface engineering



Scale-up of ceramic coatings

Low temperature ALD of ceramic and organometallic coatings

Sensors and embedded electronics

Enabling the cell-level monitoring of automotive battery systems through the integration of sensors, and systems, and with large area or embedded electronics

Design and development

Designing proof of concept sensor systems including sensors and electronic systems

CAPABILITIES

- Sensor design and layout
- Electronic circuit design software suite
- Software development systems for multiple target platforms

Device manufacturing

Batch and R2R printing capability for scale up of sensor technology

CAPABILITIES

- Clean room capability to create sensors
- Roll-to-roll and batch scale manufacture
- Range of sensor types including temperature, pressure, and strain

Roll-to-roll integration

New electronic form factors for BMS by combining sensors, circuitry, energy, processing, and methods of communications

CAPABILITIES

- Pick and place capability
- ICA and ACA dispensing systems
- Thermode / oven curing
- Glob top protection
- R2R convertor system

Characterisation

Comprehensive set of test and characterisation tools for both batch and continuous processes

CAPABILITIES

- Roll-to-roll tester for device and process characterisation
- Electrical test laboratory
- Temperature and humidity characterisation and life testing

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Sensors and embedded electronics

Printed sensors for monitoring battery life

Evaluate new types of sensors to feed data into a battery management system (BMS) enabling responses to battery health and charge, and to improve operational safety.

Collaborative R&D | 12 months | £500,000

HOW CPI HELPED

Development for the project used CPI's state-of-the-art electronics capabilities and expertise at our dedicated national centre. Developing the novel print techniques, resulted in a process for the production of printed induction coils on a large area substrate with integrated pick and place components.

The process is capable of scale-up on to CPI's roll-to-roll printing equipment.

PROJECT OUTPUTS

- Demonstrating low cost device that will provide a richer more accurate picture of battery dynamics at cell level
- Reduced ageing time for batteries, saving costs.

"We are delighted to be collaborating with CPI and a number of organisations to further our aim of improving the range, health and safety of electric vehicle batteries. It is fascinating to see how innovative manufacturing processes can bring our technology closer to being deployed on the road"

Gary Kendall
Director, CDO2

Materials | Formulation | Coating and structuring | **Sensors**

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Sensors and embedded electronics

PST SENSORS

UKRI Innovate UK

Printed temperature sensors for monitoring battery cells

Develop, demonstrate and validate processes to print temperature sensors for use in BMS that will be able to react to the changing state of battery health and charge and improve operational safety.

Collaborative R&D | 9 months | £236,000

PROJECT OUTPUTS

- Demonstrate sensors that improve operational safety and allow for improved monitoring of the batteries
- Enabling longer life and increased range without altering the current design of EV, reducing environmental impact

Materials | Formulation | Coating and structuring | **Sensors**

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CASE STUDY

Recovering metals from electronic waste

Process development and scale-up – Deep Eutectic Solvent recovery of precious metals from e-waste

Literature review and evaluation

Developed understanding of current state of knowledge for all process steps, determining key areas of risk.

Valuable metal reclamation

Chemical extraction of valuable metals, including inductively coupled plasma mass spectrometry analysis.

Recycle stream development

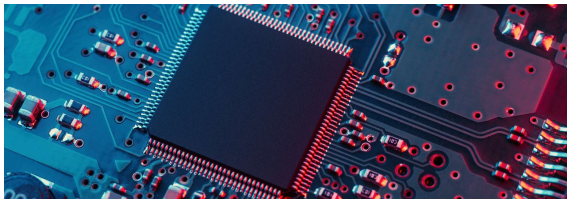
Developing a process to recycle deep eutectic solvents (DES) after metal recovery.

Process scale up to pilot plant

Scaling up to 10 L, with future potential of scaling up to true pilot plant.

Engineering assessments

Assessing mass flow, heat flow and cost analysis of the process.



Commercial

2 years

DESCYCLE
metals made new

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Sustainable batteries

HM Government

LITHIUM SALVAGE (UK) LTD

Materials Processing Institute

Improving Lithium-ion battery recycling

Understanding and improving Lithium-ion battery recycling methodology for the extraction of precious materials. With exponentially increasing demand for portable energy storage devices arising from vehicle electrification, it is imperative to recycle end-of-life devices to ensure sustainability and to achieve net-zero.

Community Renewal Fund

150 hours

cpi

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Where are we unique?

- **Chemistry agnostic** formulation and materials process development
- **High-throughput formulation expertise** allowing rapid development of understanding
- Combination of **vacuum and solution-based** deposition processes
- **Scalable evaluation** of material synthesis, formulation and printing. From desk-based to R2R exemplification.
- **Connections** into supply-chain from raw material producers to cell manufacturers

- **Toll manufacturer** of materials
- **High volume** cell manufacturer

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Thank you

For more information visit **www.uk-cpi.com**

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