The UK chemicals and process supply chain for battery manufacture

An analysis of strengths and opportunities

A report prepared for the UK Advanced Propulsion Centre
Electrical Energy Storage Spoke
June 2018
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1. Introduction
2. EV battery technology
3. Battery supply chain opportunity
4. Potential UK battery supply chain
5. Conclusions and recommendations
6. Appendix
This report is the output of a project that combined automotive battery and chemicals industries in UK.

This work represents a collaboration between the automotive battery industry and chemicals industry, working in the context of UK Industrial Strategy.

- The work was sponsored and managed by the UK Advanced Propulsion Centre Electrical Energy Storage Spoke (WMG, University of Warwick).
- The work was closely supported by the UK Chemistry Growth Partnership and Innovate UK Knowledge Transfer Network.
- The consultancy work and this report were executed by E4tech.
- The Centre for Process Innovation provided input and review, especially on UK suppliers of relevant chemicals and processes.
- 67 other organisations, listed in the appendix, took part in the interviews and workshop informing this work.
- The work took place between March and May 2018, following a process described in the appendix.
This work provides an initial assessment of the EV battery supply opportunity for the UK chemicals and process industry.

There is an opportunity to grow a UK battery industry and related supply chain

- The 2017 UK Industrial Strategy identified four initial Grand Challenges to coalesce industrial activity upon high growth opportunities. Battery development and manufacture is one of these, delivered through the Faraday Challenge.

- Battery pack manufacturing for electric vehicles (EVs) will logically take place close to the point of vehicle assembly since packs are hard to transport. This in turn implies that the battery cells which make up the packs will best be manufactured in (or close to) the UK. This could also mitigate the loss of vehicle engine production in the future.

- For cell production to occur in the UK, the supply chains of chemicals would need to be reconfigured, since most cell production and chemicals supply is currently in Asia. Whilst such inputs could be imported, to capture the most value, cell production and the related chemical and process equipment supply would need to come from UK suppliers.

The automotive battery and chemicals industries have not been well connected

- The emerging EV battery industry in UK would like to understand the potential for the UK chemicals and process industry to supply future requirements.

- Despite growth ambitions, the UK chemicals industry generally has limited information about the battery opportunity and requires clarity about specifications, timing and certainty of needs.

This work describes future battery chemicals and process needs, quantifies the supply opportunity, and provides an inventory and assessment of the potential supply chain in the UK.
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Passenger cars are set to feature growing levels of electrification as regulatory and other drivers tighten.

Passenger car propulsion roadmap (developed by consensus amongst industry and research experts)

https://www.apcuk.co.uk/app/uploads/2018/02/PasCar_Full_Pack.pdf
Significant improvements in battery cost and performance will be required

Battery technology targets (developed by consensus amongst industry and research experts)

**Cost**
- **Now** $130/kWh (cell)
- **2035** $50/kWh (cell)
- **Now** $280/kWh (pack)
- **2035** $100/kWh (pack)

**Energy Density**
- **Now** 700Wh/l, 250Wh/kg (cell)
- **2035** 1400Wh/l, 500Wh/kg (cell)

**Power Density**
- **Now** 3 kW/kg (pack)
- **2035** 12 kW/kg (pack)

**Safety**
- **2035** eliminate thermal runaway at pack level to reduce pack complexity

**1st Life**
- **Now** 8 years (pack)
- **2035** 15 years (pack)

**Temperature**
- **Now** -20° to +60°C (cell)
- **2035** -40° to +80°C (cell)

**Predictability**
- **2035** full predictive models for performance and aging of battery

**Recyclability**
- **Now** 10-50% (pack)
- **2035** 95% (pack)

Source: WMG 2018
Battery technology will continue to develop, with important changes predicted in the 2025-2030 period

Battery technology roadmap (developed by consensus amongst industry and research experts)

**TECHNOLOGY ROADMAP 2017: ELECTRICAL ENERGY STORAGE**

**DRIVERS**
- xEV uptake, CO₂ limits, air quality regulation, ULEZs, charging access
- Very low CO₂, zero emission zones, LCA, materials security, rapid/opportunity charging infrastructure

**TARGETS**
- Current status: 280 $/kWh, 280 Wh/l, 3 kW/kg
- 2025 targets: 150 $/kWh, 550 Wh/l, 7.5 kW/kg
- 2035 targets: 100 $/kWh, 1000 Wh/l, 12 kW/kg

**EVOLUTIONARY TECHNOLOGY**
- **CELLS**
- Optimised liquid electrolytes for Li-ion (e.g. additives and high voltage)
- Liquid electrolytes for new chemistries (e.g. Na-ion, Mg-ion, Li-S)
- Separators with reduced thickness and cost, oxidation resistance, heat dissipation
- Next gen. separators (e.g. phase change, auxetic structures)
- Solvent replacements for NMP (e.g. N-Acetyl-P)
- Next gen. binders (e.g. hybrid, self-healing)
- Binderless systems

**Anodes and cathodes**
- Optimised Li-ion anode materials and structures (e.g. Silicon, LTO, hard carbon)
- Next gen. anodes (e.g. transition metal oxides, metallic anodes and novel additives)

**Formats and casings**
- Optimised Li-ion cathode materials and structures (e.g. LFP, NMC, NCA, LMO)
- Cathode materials for new chemistries (e.g. Na-ion, Mg-ion, Li-S)
- Embedded sensors in cells
- Cells that eliminate thermal runaway
- Cross-OEM standardisation of cell formats

**MODULES, PACKS AND BATTERY MANAGEMENT SYSTEMS**
- Advanced pack designs for performance and manif.
- Mixed cell packs (high energy and power)
- New cell-module-pack concepts
- Smart and connected BMS enabling accurate SOC and SOH monitoring and life prediction
- Distributed BMS enabling individual cell monitoring
- Advanced thermal management strategies (e.g. integrated with vehicle cooling)
- Passive thermal management (e.g. phase change materials)

**RECYCLING AND LIFE CYCLE MANAGEMENT**
- Pack designs that extend 1st life and enable 2nd life
- Deployment of 2nd life batteries with flexible applicability
- Processes for end-of-life recovery of cell materials/electrode
- Industrial scale up of high efficiency recycling processes

**Roadmap developed by the Automotive Council and the Advanced Propulsion Centre**

The current EV battery technology supply chain (expected to be stable for at least 8 years) comprises many materials and processes.

**Materials**
- Copper
- Graphite
- NMP/aqueous solvents
- PVDF/CMC/SBR binders
- Dispersants
- High conductivity carbon
- Cobalt, Nickel, Manganese
- Lithium carbonate
- PF₆⁻ and other salts
- Organic carbonates
- Additives
- Insulating polymer
- Microporous polymer
- Al₂O₃ and other ceramic material
- Binder
- Nickel

**Cell component materials**
- Copper foil
- Rolling
- Anode active material (Graphite)
- Milling
- Anode coating solvent mix
- Formulation and mixing
- Cathode coating solvent mix
- Formulation and mixing
- Cathode active material (LiNMC)*
- Formulation, milling and mixing
- Aluminium foil
- Rolling
- Insulating polymer film
- Thin film coating
- Separator film
- Thin film coating
- Separator ceramic coating mix
- Formulation and mixing
- Tabs
- Rolling

**Battery pack components**
- Battery cell
- Battery cell assembly
- Electrolyte solution
- Cathode film
- Slurry mixing and coating
- Anode film
- Slurry mixing and coating
- Cathode active material
- Cathode coating solvent mix
- Formulation and mixing
- Anode coating solvent mix
- Formulation and mixing

**Battery pack components**
- Module case and connectors
- Pack case and connectors
- Thermal management system
- BMS hardware
- BMS software
- Module and pack assembly

**Battery cell components**
- Battery cell
- Cathode film
- Slurry mixing and coating
- Anode film
- Slurry mixing and coating
- Cathode active material

**Process**
- Extraction
- Production
- Extraction/recycling
- Extraction
- Production
- Production
- Production
- Production
- Production
- Extraction
- Extraction
- Production
- Production
- Production
- Production
- Extraction
- Extraction
- Production

**Key**
- Component / material
- Process / formulation

*Current technology assumed to apply until 2025-30
* Other options are: LFP, NCA, LMO
** For pouch cells only. Cylindrical use coated steel or aluminium shells
The future EV battery technology supply chain could see some materials and processes replaced, once proven to be viable.
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The current UK battery industry features only a few companies, just two of which manufacture in volume

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery technology</th>
<th>Material / Process</th>
<th>Firms</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery pack / cell</td>
<td>Current / future</td>
<td>Battery cell manufacture and pack assembly</td>
<td>Nissan/AESC</td>
<td>Volume supply of automotive battery cell assembly and pack manufacturing. Small volume ‘powder-to-power’ cell manufacturing and supply of battery packs for niche applications</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AMTE/AGM</td>
<td></td>
</tr>
<tr>
<td>Future</td>
<td></td>
<td></td>
<td>Faradion Oxis Energy ZapGo</td>
<td>Development and manufacturing / licencing of lithium sulfur, sodium ion and carbon ion cells in low volume</td>
</tr>
</tbody>
</table>

- Currently there is one large scale battery cell and pack manufacturer in the UK, which imports most cell components (including electrode and separator rolls) from Asia
- There is only one ‘powder-to-power’ cell manufacturer, with medium scale production facilities
- There are a number of firms developing new battery technologies and looking to either manufacture or license both inside and outside the UK
- There are parallel efforts to attract a major cell manufacturer to establish a plant in UK
UK battery manufacturers and technology developers do not rely on a UK supply chain but would welcome its development

- UK battery manufacturers find that sourcing process equipment from outside the UK is not a problem but sourcing materials, especially those used for conventional lithium ion batteries, poses supply security issues.
- UK battery technology developers are currently sourcing their materials from outside the UK and are not facing particular challenges from a supply chain point of view, given the small scales and novel materials.
- Technology developers are conducting collaborative R&D on next gen products with UK chemical companies.
- Note that the views of potential major battery company inward investors are not known with regard to which materials are must-have vs nice-to-have from UK sources.

Materials today can be manufactured anywhere and shipped around the world, however achieving substantial cost reductions means that in future local suppliers may become more attractive.

Our business model does not rely on UK suppliers however we would welcome working with suitable ones as this would allow joint development work.

UK firms have a role to play in supplying active materials for advanced chemistries. We find that smaller chemical companies are keen to get involved.
Battery companies believe that UK chemical and process companies have strong potential to supply the battery industry

• Conducting joint R&D with technology developers could be a way into the battery supply chain for UK chemical companies, provided they can supply battery-grade materials at scale

• Technology developers are already sourcing some lab and pilot scale process equipment from UK suppliers and think there is more potential

In current development projects we source ~50% of the materials from the UK. In future new chemistry cells we could source 100% of active materials from the UK, or ~70% of all cell materials

We qualify our suppliers through joint R&D work, so working with UK chemical companies on InnovateUK projects can lead to adding them to the list of our suppliers

We believe the potential is there for UK process equipment manufacturers to supply the battery industry, however they would need to be educated on our requirements
The volume and value of the UK EV battery supply chain opportunity can be estimated based on assumptions

- The UK manufactured 1.7m cars in 2016, around 80% of which were exported (SMMT 2017). Assuming that the manufacturing volume stays constant and that 50% of the vehicles manufactured in ~2030 are EVs, the UK would be manufacturing 850k EVs per year.

- The volume and value of the battery supply chain for the 850k EVs is a function of battery price per kWh and average size of battery per EV.

- EV battery price per kWh has been decreasing rapidly in recent years and the extent to which it will further decline by 2030 depends, *inter alia*, on progress in battery technology.

- For the purpose of this assessment we assume that the current chemistry based on NMC cathodes and graphite anodes will still be used in 2030, however thanks to optimisation and volume manufacturing, the battery price at pack level will decrease to approximately $150/kWh.

- In the next two slides an estimate of the value and volume of the EV battery supply chain is provided, broken down by main component, based on the above assumptions.

- This is purely indicative and only representative of the specific chemistry considered, because:
  - As chemistries evolve, so does the volume and value of each of the battery components.
  - Even for the same chemistry, relative volumes will depend on cell size and design.
  - Note that manufacturing of batteries for vehicles other than cars and export of chemicals to non-UK battery production plants offer significant upside to these estimates.
The supply of battery cell materials for UK car manufacturing could be worth £2.7bn per year, or £3,200 per car

Key assumptions:
- 850k EVs manufactured per year (~2030)
- 50 kWh average pack size (UK Automotive Council)
- Current Graphite/Nickel Manganese Cobalt chemistry
- 150 $/kWh pack price
- Argonne National Lab BatPac model results for 100k packs/year

Average value of cell materials per car: £3,200 (battery only, excluding vehicle)

Typical value of chemicals in internal combustion engine cars is £800-1,000 (including vehicle)
The corresponding volumes of each category of material would be substantial

<table>
<thead>
<tr>
<th>Cell material</th>
<th>Annual UK value (£ million)</th>
<th>Annual UK volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode active material</td>
<td>1,040</td>
<td>69,000 t</td>
</tr>
<tr>
<td>Anode active material</td>
<td>538</td>
<td>48,000 t</td>
</tr>
<tr>
<td>Separator</td>
<td>394</td>
<td>263 million m²</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>359</td>
<td>27,000 t</td>
</tr>
<tr>
<td>Anode copper foil</td>
<td>215</td>
<td>18,000 t</td>
</tr>
<tr>
<td>Electrode binders, solvents and additives</td>
<td>72</td>
<td>10,000 t</td>
</tr>
<tr>
<td>Cathode aluminium foil</td>
<td>72</td>
<td>10,000 t</td>
</tr>
</tbody>
</table>

**Key assumptions:**

- 850k EVs manufactured per year (~2030)
- 50 kWh average pack size (UK Automotive Council)
- Current Graphite/Nickel Manganese Cobalt chemistry
- Bill of materials from NREL 2015 and ITRI 2015
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   • Presence of suppliers
   • Specific capabilities of suppliers
   • Views of suppliers
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The presence of UK chemical and process industry suppliers was mapped for current and future battery technologies

• The maps on the next slides illustrate where, if a UK battery industry existed, UK chemical and process companies could play

• Circles provide an indication of the number of UK firms with capabilities relevant to a particular material or process and whether they are already supplying the battery industry. They do not however indicate the size of the firm and the scale at which it supplies or could supply

• In most cases the capability is latent as few companies are currently supplying the battery industry or offering the exact same material/process that would be required. More detail on current vs latent capability and scale of manufacturing is provided later in the report

• A firm offering more than one material or process is represented on each one of the relevant boxes

• Firms that have materials that could potentially be used in combination with new battery concepts that are still to be developed or that are being developed but not disclosed are not represented

• **Note:** E4tech’s assessment is based on a review of 100+ chemical and process companies in the UK, and validated through interviews, a workshop and review by relevant stakeholders. However we are aware that the picture we provide is inevitably not entirely complete and accurate. Further input is encouraged and should be addressed to the APC Electrical Energy Storage Spoke at WMG: APC_EES@warwick.ac.uk
Several UK companies have the potential to supply current+ EV battery technology.

*Current* technology assumed to apply until 2025-30

*Other options are: LFP, NCA, LMO

**For pouch cells only. Cylindrical use coated steel or aluminium shells

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**Battery pack components**

- Battery cell
  - Battery cell assembly
- Battery cell components
  - Cathode film
    - Slurry mixing and coating
- Cell components
  - Anode film
    - Slurry mixing and coating
  - Cathode film
    - Slurry mixing and coating
- Cell component materials
  - Anode coating solvent mix
    - Formulation and mixing
  - Cathode coating solvent mix
    - Formulation and mixing
- Materials
  - Copper foil
    - Rolling
  - Anode active material (Graphite)
    - Milling
  - Anode coating solvent mix
    - Formulation and mixing
  - Cathode active material (LiNMC)*
    - Formulation, milling and mixing
  - Cathode coating solvent mix
    - Formulation and mixing
  - Electrolyte solution
    - Formulation and mixing
- Module and pack assembly
  - Module case and connectors
  - Pack case and connectors
  - Thermal management system
  - BMS hardware
  - BMS software
  - Battery cell assembly
- Automotive battery pack
  - Module and pack assembly

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Knowledge Transfer Network

Innovate UK
EPSRC
ADVANCED PROPULSION CENTRE UK
ELECTRICAL ENERGY STORAGE SPOKE

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Several UK companies have the potential to supply future EV battery technology.
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4. Potential UK battery supply chain
   • Presence of suppliers
   • Specific capabilities of suppliers
   • Views of suppliers
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### Capabilities of UK chemical and process industry suppliers to supply the battery industry (1/6)

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery technology</th>
<th>Material / Process</th>
<th>Firms</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode active materials</td>
<td>Current / future</td>
<td>Graphite</td>
<td>Phillips66, Talga Technologies Ltd</td>
<td>Volume supply of Pet-coke for synthetic graphite. Development of large reserves of natural graphite</td>
</tr>
<tr>
<td></td>
<td>Future</td>
<td>Graphene</td>
<td>C-Tech Innovation, DZP Technologies Ltd, Graphion, Talga Technologies Ltd, Thomas Swan &amp; Co Ltd, William Blythe Ltd</td>
<td>Collaborative development with industrial partners, but also contract manufacturing of powders and dispersions</td>
</tr>
<tr>
<td>Si nanoparticles / alloys</td>
<td></td>
<td></td>
<td>Nexeon, PQ Corporation, William Rowland Ltd</td>
<td>Development and supply of Si-based anode mixes, advanced nanomaterials and alloys</td>
</tr>
<tr>
<td>New materials / electrode concepts</td>
<td></td>
<td></td>
<td>Epivalence Ltd, Metalysis, PV3 technologies</td>
<td>Collaborative development and supply of materials for new electrode concepts</td>
</tr>
<tr>
<td>Anode additives</td>
<td></td>
<td></td>
<td>3M</td>
<td></td>
</tr>
</tbody>
</table>
## Capabilities of UK chemical and process industry suppliers to supply the battery industry (2/6)

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery technology</th>
<th>Material / Process</th>
<th>Firms</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cathode active materials</strong></td>
<td>Current / future</td>
<td>Metal oxides</td>
<td>BASF, Cornish Lithium, ICoNiChem Widnes Ltd, Johnson Matthey, Oxkem Ltd, William Blythe Ltd, William Rowland Ltd</td>
<td>Volume supply of cathode mixed metal oxides from imported reserves based on current formulations. Exploring domestic reserves. Can develop and supply advanced formulations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lithium salts</td>
<td>Cornish Lithium, Green Lithium, Leverton Lithium</td>
<td>Volume supply of lithium salts from imported reserves. Exploring domestic reserves</td>
</tr>
<tr>
<td></td>
<td>Future</td>
<td>Additives</td>
<td>Talga Technologies Ltd</td>
<td>Volume supply of conductive carbon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Advanced metal oxides</td>
<td>Johnson Matthey, PV3 Technologies</td>
<td>Development and supply of advanced NMC and LNO cathodes</td>
</tr>
</tbody>
</table>

*green* = already supplying into the battery industry from the UK  
*blue* = already supplying but not from the UK, though with strong UK presence  
*black* = UK company with relevant capabilities, but not yet supplying
## Capabilities of UK chemical and process industry suppliers to supply the battery industry (3/6)

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery technology</th>
<th>Material / Process</th>
<th>Firms</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrode coating</strong></td>
<td>Current / Future</td>
<td>Binders</td>
<td>3M Ashland Specialties Ltd, Lubrizol, Synthomer</td>
<td>Volume supply of PVDF, CMC and SBR binders. Development of binders for future chemistries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ashland Specialties Ltd, Lubrizol, Synthomer</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BYK Additives, Circa Sustainable Chemicals, Croda, Eastman Fine Organics Ltd, Lubrizol, Thermo Fisher Scientific, Thomas Swan &amp; Co Ltd</td>
<td>Volume supply of NMP and water-based solvents and dispersants. In-house and collaborative development and supply, as well as contract manufacturing, of novel dispersants and additives for current and future battery chemistries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Engie Fabricom, Glacier Energy Services, Labman Automation</td>
<td>Design and manufacturing of automated coating formulation and process systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DZP Technologies Ltd, Lubrizol</td>
<td>Development of thin-film printing technology for future electrodes</td>
</tr>
</tbody>
</table>

*green = already supplying into the battery industry from the UK*
*blue = already supplying but not from the UK, though with strong UK presence*
*black = UK company with relevant capabilities, but not yet supplying*
## Capabilities of UK chemical and process industry suppliers to supply the battery industry (4/6)

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery technology</th>
<th>Material / Process</th>
<th>Firms</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrolyte</strong></td>
<td>Current / future</td>
<td>Lithium salts</td>
<td>Leverton Lithium Green Lithium Cornish Lithium Oxkem Ltd Thermo Fischer Scientific</td>
<td>Volume supply of lithium salts from imported resources. Exploring domestic resources. Collaborative development and contract manufacturing of salts for new chemistries</td>
</tr>
<tr>
<td><strong>Organic Solvents</strong></td>
<td></td>
<td></td>
<td>Mitsubishi Chemical Corp Fine Organics Ltd</td>
<td>Volume supply for electrolyte solvents for current chemistries. Contract manufacturing of formulations for future chemistries</td>
</tr>
<tr>
<td><strong>Electrolyte additives</strong></td>
<td></td>
<td></td>
<td>3M Mitsubishi Chemical Corp Fine Organics Ltd Lubrizol Thermo Fischer Scientific</td>
<td>Volume supply of additives for current chemistries. Collaborative development and contract manufacturing for future chemistries</td>
</tr>
</tbody>
</table>

*green* = already supplying into the battery industry from the UK  
*blue* = already supplying but not from the UK, though with strong UK presence  
*black* = UK company with relevant capabilities, but not yet supplying
### Capabilities of UK chemical and process industry suppliers to supply the battery industry (5/6)

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery technology</th>
<th>Material / Process</th>
<th>Firms</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Separator</strong></td>
<td>Current / Future</td>
<td>Binder for ceramic coating</td>
<td>3M Ashland Specialties Ltd</td>
<td>Volume supply of separators and of binder for ceramic coated separators</td>
</tr>
<tr>
<td></td>
<td>Future</td>
<td>New separator materials / concepts</td>
<td>Unifrax Lauscha Fiberlean Technologies Lubrizol Dupont Teijin Films</td>
<td>Collaborative development and manufacturing of cellulose, ceramic, fiberglass and polymer based separators for future battery concepts</td>
</tr>
<tr>
<td><strong>Current collectors</strong></td>
<td>Current / Future</td>
<td>Copper</td>
<td>William Rowland Ltd Cornish Lithium</td>
<td>Supply of high purity copper from imported resources. Exploring domestic resources</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aluminium</td>
<td>William Rowland Ltd</td>
<td>Supply of high purity aluminium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nickel</td>
<td>William Rowland Ltd ICoNiChem Widnes Ltd</td>
<td>Supply of high purity nickel</td>
</tr>
</tbody>
</table>

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*black* = UK company with relevant capabilities, but not yet supplying
### Capabilities of UK chemical and process industry suppliers to supply the battery industry (6/6)

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery technology</th>
<th>Material / Process</th>
<th>Firms</th>
<th>Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Packaging</strong></td>
<td>Current / future</td>
<td>Laminated metal soft packaging film</td>
<td>Dupont Teijin Films</td>
<td>Supply of insulating polymer film that can be laminated on to aluminium foil</td>
</tr>
<tr>
<td><strong>Battery cell</strong></td>
<td>Current / future</td>
<td>Manufacturing automation equipment</td>
<td>Engie Fabricom</td>
<td>Design and manufacturing of industrial machines, process equipment and electronics</td>
</tr>
<tr>
<td></td>
<td>Current / future</td>
<td>Recycled materials / recycling processes</td>
<td>Aurelius Technologies, Axion, Biffa Waste Services</td>
<td>Development of EV battery recycling processes and supply of recovered materials</td>
</tr>
</tbody>
</table>

*green* = already supplying into the battery industry from the UK  
*blue* = already supplying but not from the UK, though with strong UK presence  
*black* = UK company with relevant capabilities, but not yet supplying
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2. EV battery technology
3. Battery supply chain opportunity
4. Potential UK battery supply chain
   • Presence of suppliers
   • Specific capabilities of suppliers
   • Views of suppliers
5. Conclusions and recommendations
6. Appendix
There is a high level of interest amongst UK chemical and process companies in the EV battery market

• The companies interviewed are all looking at the EV battery market with interest
• A few are already supplying or have supplied the battery industry internationally
• Several are currently working with battery manufacturers / technology developers in the UK through the Faraday Challenge
• Others are either planning to engage with battery manufacturers or considering conducting R&D activities

We are interested in understanding the landscape of new battery chemistry R&D and who in the supply chain to talk to

We are particularly interested in collaborative R&D projects, such as those funded by InnovateUK

We would like to meet potential partners, discuss the challenges ahead and look into possible economies of scope
However there is a need to better understand the requirements of the battery industry

- All companies interviewed believe that they have relevant capabilities
- But a few don’t have a good understanding of how exactly these may fit with current and future battery technologies
- Some companies are learning through collaborative R&D programmes with battery manufacturers / technology developers
- Some companies have broad capabilities and/or can supply chemicals on a contract basis
- Others would need to substantially invest in R&D and production facilities

We still don’t have a good understanding of what we could supply and how EV battery chemistry will evolve over the next 10-20 years

Participating in the Faraday Challenge is helping us better understand the requirements of the battery industry

We can manufacture on a contract basis but the customer would have to pay for any R&D work required
More confidence in the market is required for most companies to be prepared to invest

• Companies are unclear on exactly what products the battery industry will require, on what scale and when

• Auto sector confidence in direction of battery development not matched by the chemical industry, which perceives risks

• This is a potentially big barrier to investing in products that are dedicated to the battery market. Closer engagement needed between auto and chemicals

• Given the uncertainties, chemicals companies are looking at low risk strategies to enter the battery supply chain. These include adapting existing products, developing new products that can have multiple applications, or conducting R&D activities co-funded by public grants

We would need good information on future battery technologies and markets so that we could develop the right products at the right time

We could develop new products but will prioritise finding uses for our existing products so we’ll conduct collaborative R&D with battery developers on this basis

We would prefer to develop products that can be sold to other industries as well
Time is needed to develop new products, scale them up and build the necessary manufacturing capacity

- Only a few UK companies are already supplying the battery industry at scale
- Those who are not will need time, once the business case is made, to develop new products and the necessary production capacity
- Typical time to market for new products in the chemical industry is in the order of 2 years
- Some have multi-purpose production plants that they can use for medium production volumes
- Others though only have pilot production facilities

We would need to launch a development project with stage gates that would last a year or more. This is typically done with the customer

We could replicate existing materials in a year. We could scale up new materials in around three years, but it would take at least four years for these materials to be used in commercial batteries

We cannot currently supply at scale. We could rent facilities for medium-scale production but anything beyond that would be difficult to arrange
The UK chemical industry perceives established suppliers to the current battery industry as hard to compete with

- The general perception is that displacing established suppliers who already work with large battery manufacturers (mostly in Asia) is difficult
- The auto industry’s desire for shorter supply chains is not (yet) felt by most UK chemical suppliers
- Established suppliers benefit from having amortised their production plants and from technological learning
- Some think that playing catch up on current technology is not the right strategy therefore
- Many indicated building close partnerships with developers of new battery technology as their preferred strategy, allowing them time to grow and gain competitive advantage over suppliers to current battery technology manufacturers

Emulating the suppliers to Asian cell manufacturers in the UK would be hard and we would risk being ‘just in time to be too late’

We see becoming suppliers to large battery manufacturers in Asia as very difficult and instead look to team up with UK cell developers for collaborative R&D

We can provide the most value to developers of new battery technology if we become involved in their R&D programmes early on (TRL 2-4). This would also allow us enough time to scale up production
Government’s role in addressing the perceived risks with battery chemicals and processes is viewed as very important

• Certainty in the UK battery market is essential to enable investment in chemical production plants
• In addition to support to EV adoption and battery manufacturing, perceived risk in the development of the chemicals and process supply chain also needs to be addressed
• Any support provided would need to last long enough for the supply chain to reach critical mass

To scale up we need investment, which can only be attracted if the market opportunity is clear enough

Government support on materials is needed because this is not addressed by the BIC. Lack of support so far may be due to the perception that this is low value added

We need a long term support programme, not one that only lasts 2-4 years
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There is a large supply chain opportunity for the chemicals industry, but barriers remain

EV batteries are a large potential opportunity:

- UK auto industry already innovative in vehicles, modules and packs
- Faraday Challenge actively working to develop cell manufacturing in the UK
- Large scale chemical supply opportunity with strong growth fundamentals
- Chemicals supply from nearer sources than Asia is highly desirable for auto battery producers
- Some UK players are already supplying into the global EV battery industry

Important barriers need to be overcome, however:

- Timing and scale of ramp-up unclear to many chemicals suppliers
- Battery chemistries are evolving so specific chemical and process needs are dynamic
- Supply for current battery chemistries is dominated by strong players outside UK so UK suppliers are not yet confident to compete
Overall, the UK chemicals and process industry has a good presence in several higher value areas, plus other opportunities.

<table>
<thead>
<tr>
<th>Stronger</th>
<th>Weaker</th>
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<tbody>
<tr>
<td>* Presence* of relevant UK suppliers</td>
<td>* Value of chemicals and processes in EV batteries</td>
</tr>
<tr>
<td>- Electrode binders, solvents and additives</td>
<td>- Anode active materials for both current and future technologies: graphite, graphene, silicon</td>
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<tr>
<td>- Lithium salts and electrolyte additives</td>
<td>- Future cathode formulations</td>
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<tr>
<td>- Mixing and coating equipment for electrodes and separators</td>
<td>- Future solid electrolytes</td>
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<td></td>
<td>- Current cathode materials</td>
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<td></td>
<td>- Electrode films, electrolyte solvents and separators</td>
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* NB the depth of capability is not analysed here; this would be required to draw full strategic conclusions about UK competitive advantage and areas to focus on.
**Recommendations**: Maintain momentum by building confidence for the chemicals sector and deepening analysis to support this.

**Build confidence** for the UK chemical and process supply industries:

- Continue to build relationships between chemical and auto sectors and link to Faraday Challenge to keep focus
- Include substantial engagement of chemical and process industry in second phase of Faraday Challenge (years 5-10)
- Engage chemicals sector in UK Battery Industrialisation Centre scale-up activities

**Deepen analysis** to ensure that opportunities are clearly understood:

- Understand how important the UK presence or absence of a supply capability is – which are crucial for a battery company to grow in UK, which are nice-to-have?
- Understand the UK’s potential competitive advantage in each supply area versus competitors. Should the UK specialise? What are the implications for attracting a cell manufacturer to UK?
- Assess specific UK supply opportunities for individual companies (e.g. through collaborative research and development) – to prove technical capability and business case

* A list of potential ways to extend this work is included in the appendix
Next steps: this report will guide development of the UK battery and chemicals industries through continued dialogue

Strategic development of the battery industry and chemicals supply chain in UK:

• This work will be used to inform further development of the Faraday Challenge and ongoing efforts to establish EV battery manufacturing in the UK

• Continued strategic engagement is invited through:
  • APC Electrical Energy Storage Spoke at WMG (University of Warwick): Prof David Greenwood, Advanced Propulsion Systems d.greenwood@warwick.ac.uk
  • Chemistry Growth Partnership: Richard J Carter, BASF plc. leading the CGP Supply Chain Group richard.carter@basf.com

Practical support for stronger interaction between battery and chemicals industries:

• Part of this report can form the basis of a supplier directory if updated. To provide comments or corrections please email the APC Electrical Energy Storage Spoke at WMG: APC_EES@warwick.ac.uk
We would like to thank the following organisations for interview and/or workshop participation during this study

<table>
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<th>Organisation</th>
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The project was informed by desk work, 18 interviews and a well-attended workshop.

**Desk research**
- Review of EV and battery technology roadmaps
- Review of EV battery manufacturing cost modelling and bill of materials
- Map of supply chain - materials and processes
- Volume and value of UK EV battery supply chain by component

**Workshop**
- KTN list of 120+ relevant organisations
- Qualitative assessment of strengths and opportunities
- Workshop with ~60 chemical and process industry companies
- Validated qualitative assessment of strengths and weaknesses
- Conclusions & recommendations

**Interviews**
- KTN introduction to selected organisations
- Interviews with 18 battery and chemical / process industry firms
- Analysis of barriers and enablers
E4tech is a strategic consultancy firm working across strategy, energy and sustainability

- International consulting firm, offices in UK and Switzerland
- Focus on sustainable energy, transport, chemicals
- Established 1997, always independent
- Deep expertise in technology, business and strategy, market assessment, techno-economic modelling, policy support...
- A spectrum of clients from start-ups to global corporations. E.g....
This work could be deepened and extended in several ways

**Strategic topics:**

- How important is the presence or absence of a supply capability – which are crucial for a UK battery company to grow in UK, which are nice-to-have?

- What is the UK’s potential competitive advantage in each supply area versus competitors? Should the UK specialise? What are the implications for attracting a cell manufacturer to UK?

- What is needed to reduce uncertainty for the chemicals and process industry?

- What level of collaboration across the supply chain is appropriate?

- What ongoing mechanisms are needed to ensure close collaboration between the battery and chemicals industries (R&D funding, forums, roadmaps etc)?

**Specific analyses:**

- Quantify additional opportunities for export of chemicals and supply to non passenger car applications

- Identify potential production capacities and ramp-up times by supplier / material

- Quantify process equipment opportunities

- Quantify value in terms of margins not sales

- Include the role of facilitators by mapping R&D and technology providers

- Develop employment and other economic multipliers that are specific to the EV battery supply chain

- Monitor the development of the supply chain and the changing perception of chemical and process firms as the education process progresses

- Section 4 of this report could be developed into a full supplier directory