Circular Economy perspectives for the management of batteries used in electric vehicles

Summary of the Stakeholder Consultation Workshop

Brussels, 4 February 2019
This meeting summary was developed by the Joint Research Centre of the European Commission with the support of Ricardo Energy & Environment.

The information and views set out in these minutes are those of the authors and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in these minutes. Neither the Commission nor any person acting on the Commission’s behalf may be held responsible for the use which may be made of the information contained therein.

© European Union, June 2019
Reproduction is authorised provided the source is acknowledged.

Contents

Foreword ........................................................................................................................................... 1
Acknowledgements .......................................................................................................................... 1
1 Introduction.................................................................................................................................... 2
2 Presentation of the study: background and outputs ................................................................. 2
   2.1 Global context .......................................................................................................................... 2
   2.2 Policy context ........................................................................................................................ 2
   2.3 Key research questions ......................................................................................................... 3
   2.4 Research outputs .................................................................................................................. 3
3 Summary of stakeholder consultation workshop .................................................................... 4
   3.1 Presentations and discussions ............................................................................................... 4
       3.1.1 Session 1: Key findings from the research .............................................................. 4
           3.1.1.1 Value chain ............................................................................................................. 4
           3.1.1.2 Industrial techniques and processes ................................................................. 4
           3.1.1.3 Lifecycle analysis (LCA) .................................................................................. 5
           3.1.1.4 Fleet impacts of EV uptake (modelling) .......................................................... 5
           3.1.1.5 Key conclusions and comments from the research ....................................... 5
           3.1.1.6 Feedback received on session 1 ........................................................................ 6
       3.1.2 Session 2: Circular economy value chain and business models ......................... 8
           3.1.2.1 Presentation of results ....................................................................................... 8
           3.1.2.2 Feedback received on session 2 ......................................................................... 8
       3.1.3 Session 3: SWOT analysis and proposed policy alternatives ......................... 9
   3.2 Key feedback on policy alternatives .................................................................................. 10
4 Conclusions and next steps ....................................................................................................... 11
List of abbreviations and definitions ......................................................................................... 12
Annexes ......................................................................................................................................... 13
   Annex 1. Participants ............................................................................................................... 13
   Annex 2. Meeting agenda ....................................................................................................... 1
   Annex 3. Presentations .............................................................................................................. 2
Foreword
The following document presents a brief summary of the stakeholder consultation workshop held on 4 February 2019 in Brussels to collect feedback and input on the project led by the European Commission’s Joint Research Centre (JRC) on the Circular Economy perspectives for the management of batteries used in electric vehicles, with support from Ricardo Energy & Environment. The account presented below is not intended to be an exhaustive or a chronological rendition of the discussions held, but simply to capture the key elements of the project presented and of the feedback received from stakeholders from a variety of different backgrounds, (and possibly differing opinions) and draw some trends and outputs from the debates. Discussions were held under the ‘Chatham House Rule’ and therefore comments are not attributed to specific participants (apart from the organisers / presenters where this concerns the material presented).

Where appropriate, comments were collated, synthesised or mentioned in a more relevant section, while attempting to preserve their pertinence and the consistency of the summary.

Acknowledgements
The authors would like to acknowledge the work of Ricardo Energy & Environment, which formed the basis of the discussions held at the workshop. The authors of the background report are Nikolas Hill, Dan Clarke, Laura Blair and Hetty Menadue.

The authors would like to thank all the participants of the workshop (listed in Annex 2) for their involvement and contribution to the discussions and to the project in general where their feedback has been instrumental.

Authors (this report)
Gaudillat, PF
Antonopoulos, IS
Paraskevas, D
1 Introduction

The JRC is carrying out a project on the Circular Economy perspectives for the management of batteries used in electric vehicles (EV), with the aim to further the Commission’s understanding and evidence base, develop expertise, and explore potential policy interventions to help minimise the negative environmental impacts of EV batteries and maximise the value/benefits to the European economy.

The output of this work will be available to inform future European policy work in this area relevant to the Circular Economy. In order to sense-check the preliminary conclusions from this work, developed with support from Ricardo Energy & Environment\(^1\), and provide robust factual findings, the JRC has involved a number of key experts and stakeholders from the sector in order to obtain views, experiences, feedback and other relevant information.

Throughout the preparation of the background Report\(^2\), Ricardo consulted, interviewed and sought feedback from stakeholders; a draft Report was prepared at the end of 2018, which was then disseminated for review and a stakeholder consultation workshop was held on 4 February 2019 in Brussels. Feedback on the report was also collected from experts who could not attend.

This workshop focussed on exploring the key research questions defined for the work (among others: what are the perspectives for developing a sustainable value chain for EV batteries in the EU? what are the strengths and weaknesses of the EU economy for dealing with the lifecycle of traction batteries in the perspective of road transport electrification?), and discussing with a diverse group of stakeholders and experts the policy proposals emerging from the project to steer the battery value chain in the EU towards a more circular economic model.

During the workshop, the draft results of this project were presented to a number of key experts and stakeholders; their views and perspectives will be reflected in the final version of the Report to be published in H1 2019.

2 Presentation of the project: background and outputs

2.1 Global context

The deployment of EVs is a promising approach for the decarbonisation of the global transport sector, which will contribute to the EU’s greenhouse gas (GHG) emissions reduction targets for 2020, 2030 and 2050, supporting EU countries in their effort to reach their Paris agreement commitments. In addition, many countries globally encourage the deployment of EVs for their potential to improve local air quality or reduce oil dependency.

For EVs, the manufacturing stage and the end-of-life of the vehicle, and of the traction battery in particular, constitute a significantly larger share of the full life cycle impacts, compared to conventional vehicles. With EV take-up anticipated to accelerate significantly in the years to come, the importance of consideration and minimisation of these impacts will be critical.

2.2 Policy context

The EU has been ramping up support for EV deployment through several policy initiatives. For instance, the Strategy for Low-Emission Mobility emphasised the need to speed up the electrification of transport and set out a range of measures to support this

\(^1\) Henceforth shortened to Ricardo.

\(^2\) Henceforth, unless otherwise mentioned, ‘the Report’ refers not to this summary but to the project Report by Ricardo Energy and Environment for the JRC: ‘Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles – Report for the European Commission, Joint Research Centre’ (Contract Ref. 934476-2017 A08 UK), in either Draft or Final (published) format.

transition. This has been further accentuated by the Clean Mobility package including car CO₂ targets and clean vehicle definitions favourable to EVs.

In parallel, the EU has strong Circular Economy initiatives that tie in with the overarching objectives on climate and energy and it has also presented proposals to amend two pieces of legislation that help to set the regulatory environment for vehicle batteries: the End-of-Life Vehicles (ELV) Directive (2000/53/EC) and the Batteries Directive (2006/66/EC).

In addition, the strategic action plan on batteries, launched to accompany the European Battery Alliance, is a comprehensive set of concrete measures to develop an innovative, sustainable and competitive battery ‘ecosystem’ in Europe; it includes planned requirements on the performance and sustainability of batteries.

The JRC project discussed in this workshop, on the Circular Economy perspectives for the management of batteries used in electric vehicles, was launched to further the expertise of the Commission on the topics related to the above policy initiatives, to be able to better support future policymaking in these areas.

It is important to note however that this research is a JRC project not directly linked to a policy support initiative for any specific policy instrument, but rather aimed at expanding the understanding and the knowledge base of the Commission in general for these issues; the expertise gained may later be used to inform specific policy processes (with their own objectives and timelines), including further stakeholder consultations.

2.3 Key research questions

In addition to considering the institutional and policy perspective, this project also aims to promote an understanding of how technological developments, industry business models and subsequent environmental impacts of industrial activity respond to this institutional environment and what further EU policies might be promoted to fill any identified gaps hindering the achievement of EU recycling targets for EV traction batteries.

The objective of the project is to provide a strong factual base and well-documented techno-economic analysis to address the following six key research questions:

1. What are the current available and emerging techniques in the manufacturing, reuse and recycling of traction batteries for EVs? How are end-of-life batteries currently processed and what plans are emerging for the future?

2. What is the current environmental impact of traction batteries for EVs across the whole life cycle? What are the current environmental hotspots and how are they addressed?

3. What will the potential environmental impacts and hotspots of traction batteries over their whole life cycle be if electric vehicles are deployed on a large scale and/or in accordance with current trends, in the near, medium and long term?

4. What are the current strengths and weaknesses of the EU economy (industry, infrastructure, policy framework…) for dealing with the life cycle of traction batteries from the perspective of road transport electrification?

5. What are the perspectives for developing a sustainable value chain for EV batteries in the EU?

6. What public policies could be envisaged to ensure truly circular life cycles for traction batteries, and to harness the opportunities for growth and jobs in the EU?

2.4 Research outputs

In addition to the present report summarising the discussions held with experts at the stakeholder consultation workshop, the final background Report of the project prepared
3 Summary of stakeholder consultation workshop

NB. The slides presented are available in Annex 3.

3.1 Presentations and discussions

Ricardo presented some of the highlights from the Report and the preparatory project work. The Draft Report had been disseminated ahead of time to the participants. While the Report contains a wealth of information on many aspects relevant to the key Research Questions, the presentations at the workshop only focussed on some of the most remarkable, novel or controversial aspects in order to focus the feedback on those issues where most of the remaining knowledge gaps were still outstanding for the finalisation of the Report.

3.1.1 Session 1: Key findings from the research

The presentations given by Ricardo focussed on four key aspects for EV batteries, where a variety of lithium ion (Li-ion) battery chemistries now predominate:

- Value chain
- Industrial techniques and processes
- Life cycle analysis (LCA)
- Fleet impacts of EV uptake

3.1.1.1 Value chain

- Whilst the front end of the Li-ion traction battery value chain is relatively well characterised/understood, the fate of end-of-life (EoL) batteries is less well known.
- Raw materials represent ~10% of the battery (pack) value; many of the key materials are sourced outside Europe. Cell component manufacturing also represents a small proportion of the value, and European activity in this area is almost non-existent. Cell manufacturing stands for a large share of the value added. Pack assembly remains a competence that original equipment manufacturers (OEMs) prefer to keep in-house.
- EoL: In some cases, batteries from end-of-life EVs can be reused in EVs following assessment/grading, repair or remanufacturing, or find a second use in less demanding applications (such as stationary energy storage). Europe is a world leader in battery recycling; however, lithium ion battery recycling is complex and largely uneconomic at present.

3.1.1.2 Industrial techniques and processes

- Li-ion batteries come in a range of chemistries / forms with different strengths and weaknesses; technical progress continues to be rapid. Battery manufacturing is complex and highly energy-intensive; future cost improvements are likely to also reduce the environmental impact.
- Processes for handling the repair of EV batteries or batteries from end-of-life vehicles (ELVs) are still evolving; they will need to be scaled rapidly with volumes. Common processes for reuse/repurposing largely depend on battery pack construction. Repurposing economics are uncertain.
- Current industrial Li-ion battery recycling focuses on hybrid pyrometallurgical / hydrometallurgical processes; novel processes such as direct cathode recycling potentially offer enhanced recovery. Improvements in EV battery design, coupled with
general scale-up and process optimisation, will facilitate recycling improvements; some examples already exist.

### 3.1.1.3 Life cycle analysis (LCA)

- EV battery manufacturing is relatively well characterised in LCA, but results are highly variable; end-of-life processes are less well analysed. Impacts of battery recycling depend on different LCA method approaches; future benefits are also uncertain but likely to increase. Recent analysis suggests significant lifecycle benefits from second life used for renewable electricity storage, however LCA consideration of second and/or tertiary use is still developing.

- Impacts from EV battery production are significant in comparison to other powertrains, but small versus operational energy benefits. Global and European decarbonisation objectives are likely to significantly reduce the impacts of battery materials and manufacturing impacts on GHG emissions.

### 3.1.1.4 Fleet impacts of EV uptake (modelling)

- The potential benefits of a Sustainable Value Chain (SVC) for EV batteries were explored for alternative EV uptake in the EU road vehicle fleet. The SULTAN model was used to assess vehicle fleet emissions and battery stock, with post-processing to calculate other impacts. The demand for EV batteries is projected to increase dramatically to 2030 and beyond: GWh dominated by cars, numbers by eBikes.

- For EVs: The use phase impacts dominate over the battery life cycle components. Significant reductions for batteries are possible in a "Sustainable Value Chain" scenario. All EV scenarios lead to significant net reductions in air quality pollutants; there is a 43% reduction in battery emissions for SVC vs Base case.

- EV uptake is likely to significantly increase critical material demand – particularly for lithium, with the 2050 demand set to be over three times the current global production. Recycling and repurposing lead to a significant reduction in primary material demand, and significant value is derived from recovered materials.

### 3.1.1.5 Key conclusions and comments from the research

Dr Billy Wu (Imperial College, expert reviewer for the Ricardo team) presented some highlights from the Report and additional thoughts, to complement the earlier presentations:

- Lithium nickel manganese cobalt oxide (NMC) chemistry is likely to dominate in the near future; technological developments are very fast-moving and much of the literature is already out of date.

- There is a need to assess potential changes due to the new battery chemistries proposed.

- There is significant value in cell and pack production.

- EV battery technology is rapidly improving and this means unit costs (EUR/kWh) are rapidly decreasing, faster than industrial analysis indicates.

- Most projections of sales do not go beyond 2025, but having some longer-term predictions will be instrumental for making plans now to develop effective second-use and recycling capabilities.

- Furthermore, as the EV market develops, installed battery energy capacity (in kWh) is likely to increase as the technology develops and costs reduce. This has implications for the volume of used automotive batteries that will arise in the future and that need to be taken into account in the analysis.

- Currently there is limited cell component production capability within the EU with significant uncertainty with regards to the supply of key raw materials.
• Whilst manufacturing of cells is dominated by the Japanese, Koreans and Chinese, there is an opportunity for recycling for Europe.

• New business models have a key role to play in innovation (e.g. V2G for fleet operators).

• Hydro, pyro, mechanical and hybrid techniques have been proposed but there is no dominant recycling technology yet. The diversity of chemistries makes recycling challenging.

• Collaboration with manufacturers is required to make batteries more suitable for recycling/second use. There is still uncertainty around the economics of second-life batteries and public perception.

• The logistics of moving decentralised resources around is still a major issue; the matter of traceability of materials is challenging, and standards for material purity uncertain.

• Lack of regulation leads to uncertainty around liability for second-life batteries.

3.1.1.6 Feedback received on Session 1

Definitions:

- It is important to follow existing definitions and to clarify those that are unclear to reduce uncertainty in the sector: e.g. battery vs battery pack; whether the battery management system (BMS) is part of the battery / pack or not.

- Waste vs not waste/product: This distinction is crucial under current legislation and can massively impact economic decisions. Under the Extended Producer Responsibility (EPR) scheme, the responsibility / liability aspects limit second-life options.

- Certification standards: It is necessary to clarify what modifications to an existing battery (hardware/software) would need recertification

Raw materials:

- Cobalt (Co) is being reduced, but not eliminated altogether in novel technologies.

- As the Co content is reduced (and nickel (Ni) and other valuable materials), the economics of recycling becomes less attractive.

- Nickel (grade A) may become the first material with supply issues.

- Exporting batteries represents a loss of materials for the EU economy and uncertainty on how the battery will be dealt with; it may just be disposed of, with a large environmental impact.

- If desirable, it is possible to keep the batteries within the EU, e.g. with a tracking number, and a deposit fee to be refunded when returned for recycling.

Cell, battery and EV design and manufacturing:

- Standardisation of battery packs would have benefits for identification in second use and recycling, dismantling, etc.

- At this stage of technology and market development, standards can also stifle business development; in a few years’ time de facto industry practice will probably emerge with common features emerging from the market.

- Regulating pack design could be counterproductive; it may be more efficient to drive from the recycling end.

- Harmonisation of LCA methodologies is needed to allow studies to be comparable. LCA should better consider the projected EoL fate, i.e. not in terms of current market/technologies, but accounting for future evolutions.

Used batteries: collection, transport, reuse, repurposing and remanufacturing:
- Unknown whereabouts of batteries: As is also the case in the ELV (used vehicle) market in general, there is currently a lack of transparency / visibility on the final fate of used batteries. These loopholes should first be closed before any new instrument is introduced; otherwise its efficiency will be compromised.

- Collection and transport costs of used batteries are significant, and a key factor in the logistics of recycling. Costs can actually be higher than recycling processes themselves.

- Hazardous goods/waste legislation varies between MS, in spite of UN (ADR) legislation, and can create obstacles in the internal market.

- Cost challenges for transporting used batteries therefore exist on several levels: regulatory (hazardous waste transport), technical (size, bulk and safety measures for dedicated containers) and logistical (storage and collection of small volumes to be sent over long distances for processing).

- Removal costs of EV batteries are also significant, plus there is a lack of trained personnel in ATFs / garages to safely dismantle high-voltage batteries, and usually little/no information available on dismantling instructions for the batteries.

- Sharing of more detailed information on the state of health of the battery, as well as other usage history (making it accessible to different actors across the value chain) can help maintain the battery as far up the waste hierarchy as possible.

- Reuse / repurposing / remanufacturing is feasible, resource-efficient and makes market sense, and it should be facilitated through clarification of legislation.

- Tax incentives could be used as policy instruments at MS level.

Recycling:

- Batteries degrade gradually; if a battery still has a state of health of typically over 80%, then it could be reused as a traction battery.

- Second life postpones ‘end-of-life’ and reduces the life cycle environmental footprint.

- Second life is important, but ultimately the material remains and will have to be dealt with through recycling, not disposal.

- The waste hierarchy may have to be ‘bypassed’ if it makes more sense from a resource efficiency perspective to recycle (in order to recover materials and use them in more material-efficient, newer technology). This trade-off would have to be assessed from a whole life cycle perspective.

- The Battery Directive sets out a take-back obligation rather than a recycling target, but in practice OEMs have to recycle 50%.

- Recycling technologies: In practice there is no opposition between pyrometallurgy and hydrometallurgy for example; they are used in combination (pyro is used as a pretreatment while hydro is more universal). Technologies also have different kinds of impacts, e.g. energy/GHG for pyro and water use/emissions for hydro.

- Novel methods are also promising, e.g. mechanical pretreatment like shredding which then allows cheaper transportation for further recycling.

- The energy footprint for batteries can be reduced, in particular through deployment of renewable energy (for manufacturing but also recycling processes)
3.1.2 Session 2: Circular Economy value chain and business models

3.1.2.1 Presentation of results
Ricardo presented the analysis of specific business models and concepts that could directly contribute to make the value chain of EV batteries more circular:

1. Integrated value chain
2. Car sharing schemes
3. Battery leasing schemes
4. Battery swapping schemes
5. Vehicle to grid (V2G) energy systems
6. Reuse (complete or partial reuse for the same application)
7. Repurposing (complete or partial reuse for a different application)
8. Extraction of raw materials through recycling (for use in cell manufacturing)
9. Safe handling and treatment of waste

Three different companies active in the sector were also invited to give a brief presentation (<5 minutes) of a specific aspect of their business operations contributing to the circular economy, to provide real-life examples and foster discussion: Tesla, Renault and Spiers New Technologies.

- Tesla: Tesla’s new gigafactory in Nevada is all-electric; no gas is used for thermal processes. It is aiming to become 100% renewable shortly with PV installation and storage. Also, it is currently aiming to design battery packs outlasting the vehicle to avoid the need to replace the pack.

- Renault: Renault has significant experience in leasing batteries and can therefore control the flow of used packs. A modular approach supports second-life use.

- Spiers: It offers a life cycle management service for battery packs to OEMs. Grading (assessment of state of health) is key, achieved through testing and proprietary software, not just relying on BMS information. Logistics represent a very high cost (~50% in the US), therefore locating processes nearby will be key to achieving cost efficiency.

Overall, in all cases, remanufacturing appears the most cost-efficient solution; then the preferability of reuse/second use/recycling can vary depending on many factors.

3.1.2.2 Feedback received on Session 2
- The challenge for ensuring recycling of Li-ion batteries is that there is currently negative/zero value in recycling, unlike Pb or even Ni technologies. Therefore regulation or at least additional incentives will have to be put in place. This will be exacerbated by the reduction in valuable materials currently contained in batteries, e.g. Co, Ni.

- The break-even could also be driven by a reduction in recycling costs (for all major current costs, including dismantling, transport, and recycling itself).

- At scale, it should make more sense to recover materials than mine virgin materials.

- A well-functioning system should also disincentivise leakage of materials, e.g. export to third countries for cheaper but often hazardous disposal. However, it might make economic sense to export for disassembly based for example on labour costs, so regulation needs to take the market phenomena into account.

- The business model for EV battery collection will not be the same as for consumer
electronics, which is much more diffuse – for big battery packs it could make sense to implement a tracking system, and/or a returnable deposit system (but this is difficult to implement for products with a lifetime of 15-20 years).

- Setting the right incentives will also increase collection rates, which is instrumental as a starting point for any Circular Economy model.

3.1.3 Session 3: SWOT analysis and proposed policy alternatives

Ricardo presented the analysis of strengths/weaknesses and opportunities/threats for the EU economy, leading into the final part of the background analysis. The analysis examined all parts of the value chain from an industrial, infrastructure and policy perspective, to highlight the position of the EU in each aspect.

<table>
<thead>
<tr>
<th>EV battery value chain</th>
<th>Industry</th>
<th>Infrastructure</th>
<th>Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td>Weak</td>
<td>Intermediate</td>
<td>Strong</td>
</tr>
<tr>
<td>Cell component manufacturing</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Strong</td>
</tr>
<tr>
<td>Cell manufacturing</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Battery pack manufacturing</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>EV manufacturing</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
</tr>
<tr>
<td>Reuse</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Weak</td>
</tr>
<tr>
<td>Repurposing</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Weak</td>
</tr>
<tr>
<td>Recycling</td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
</tr>
</tbody>
</table>

The methodology followed was to then identify a list of challenges for the EU economy in dealing with EV batteries in a circular manner, and to pinpoint potential policy alternatives that would be adapted to tackle these.

The initial list of policy alternatives which was proposed for discussion at the workshop focussed on the following aspects (NB. these will be amended in the final report to reflect feedback):

- Update critical raw material (CRM) list to include lithium and other raw materials needed for cell component manufacturing;
- Update and streamline existing standards and definitions;
- Establish mandatory reuse and repurposing targets;
- Establish new regulatory requirements to facilitate reuse, repurposing and recycling;
- Establish mandatory certification scheme requiring the use of international standards for manufacturing;
- Establish a mandatory EU life cycle assessment scheme;
- Establish legal reporting requirements for the environmental footprint of the EV battery and battery performance.

These were discussed in detail by all participants in smaller breakout groups, in order to collect more detailed feedback.

Some of the options garnered strong negative or positive feedback, while others need refining on some key aspects, e.g. whether to favour a mandatory or voluntary approach, or the policy instrument to be used.

The main elements of the feedback are summarised in the following section.
3.2 Key feedback on policy alternatives

General comments
- Voluntary vs mandatory instruments: Many stakeholders favoured the introduction of policy orientations initially through the use of voluntary instruments, in order to encourage rather than hamper the development of a rapidly evolving market where many fundamentals are still not settled. This flexibility will allow the emergence of a well-functioning market and allow technologies and business models to compete. If proven to be practicable, these could then evolve into mandatory instruments using the experience from a voluntary phase.
- However, it was also recognised that some market evolutions towards the most environmentally desirable outcome (e.g. development of recycling as the final fate of the batteries) needs some intervention as it is not currently the most economic route.
- To reconcile these constraints in a fair way, it will be important to clearly define responsibilities and align incentives along the value chain.
- The choice of policy instruments can vary as long as they are fit for purpose and create legal certainty for the market to develop.
- At the current stage, volumes are still low but major investments in industrial capacity (for manufacturing, but also recycling) will be made. The policy framework needs to support the desired evolution for economic actors to act accordingly.
- Ultimately the global environmental impact of policies needs to be assessed; this implies that trade-offs have to be considered:
  - avoid leakage of materials / lack of compliance outside the EU;
  - second life (reuse / second use etc.) and recycling should not be in opposition to each other but made to work together.

Specific comments on policy options:
- The CRM list is a specific policy instrument; the criteria should not be manipulated, and it is probably not the most relevant tool for achieving the goals of circularity.
- Standardisation or common definitions for state of health could facilitate resale, repair, remanufacturing, etc.
- ELV handlers (ATFs) may need certification to handle end-of-life EVs.
- ADR (waste transport), a UN regulation, can create barriers as waste classification is not harmonised between Member States.
- Setting targets for reuse and repurposing is counterproductive, especially at such an early stage when markets are emerging. Creating incentives and removing barriers would be more efficient.
- Requirements on the design and manufacture of batteries (and cells/modules) such as:
  - standardisation of interfaces,
  - dismantlability,
  - unique ID / tracking number,
could help foster second-life markets, but there is a cost trade-off for manufacturers.
- Dismantling time could be defined and standardised, with a modulation of the EPR fee based on it. The provision of dismantling instructions could be mandated/encouraged.
- Best Available Techniques for manufacturing could be taken into account.
- Cobalt traceability could be put in place to avoid child labour issues.
- LCA is a complex methodology and difficult to use as a basis for regulation at the
current state of development. If used, it should be applicable to all power trains, not just EVs.

- LCA for greenhouse gases only looks at one environmental aspect; it may not be enough to identify ‘green’ manufacturing. Other environmental aspects such as air pollutants and water consumption should be included.

- Reporting on the environmental footprint of batteries is broad but it could level the playing field. Second life should be factored in.

4 Conclusions and next steps

The workshop provided a unique opportunity to get direct feedback from some of the most relevant stakeholders in industry, academia and civil society on the emerging issues linked to the development of a Circular Economy for the management of batteries used in electric vehicles.

Some of the key points highlighted by the stakeholders for further consideration include:
- the necessity to adapt the level of (mandatory) requirements to the environmental objectives to be attained, while leaving some flexibility to attain objectives;
- the short-term challenges (e.g. collection and transport costs of used batteries; lack of dismantling information and qualified staff to handle high-voltage batteries) and longer-term issues to consider globally (whether to retain materials within the EU, how to ensure the ultimate recycling of batteries);
- the need to establish clear standards and definitions, set responsibilities and align incentives along the value chain, and ensure consistency between policy instruments.

Ultimately, the boundary conditions of the system remain important, i.e. that major leakage of batteries (and therefore materials) is avoided or at least traceable to ensure appropriate treatment; and that, ultimately, recycling is the final step and resource recovery is maximised.

The feedback will be integrated in the finalisation of the background Report for the project, including in particular the latter sections on policy alternatives and the concrete ways to address the challenges identified for the EU economy. This will also include a review of potential policy interventions through existing and new policy instruments.

Furthermore, the workshop conclusions will also enable the JRC to continue to research this topic and to support policy initiatives related to the implementation of its overarching objectives (among others, the revision of the Batteries Directive or the proposed setup of sustainability requirements for batteries) with a stronger evidence base.
## List of abbreviations and definitions

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATF</td>
<td>Authorised Treatment Facility</td>
</tr>
<tr>
<td>BMS</td>
<td>Battery Management System</td>
</tr>
<tr>
<td>CRM</td>
<td>Critical Raw Material</td>
</tr>
<tr>
<td>ELV</td>
<td>End-of-Life Vehicle</td>
</tr>
<tr>
<td>EoL</td>
<td>End-of-Life</td>
</tr>
<tr>
<td>EPR</td>
<td>Extended Producer Responsibility</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EV</td>
<td>Electric Vehicle</td>
</tr>
<tr>
<td>LCA</td>
<td>Lifecycle Analysis</td>
</tr>
<tr>
<td>MS</td>
<td>Member State</td>
</tr>
<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
</tr>
<tr>
<td>SVC</td>
<td>Sustainable Value Chain</td>
</tr>
<tr>
<td>SWOT</td>
<td>Strengths, Weaknesses, Opportunities and Threats</td>
</tr>
<tr>
<td>V2G</td>
<td>Vehicle to Grid</td>
</tr>
</tbody>
</table>
## Annexes

### Annex 1. Participants: organisations represented

<table>
<thead>
<tr>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argonne National Lab</td>
</tr>
<tr>
<td>ARN</td>
</tr>
<tr>
<td>AVERE</td>
</tr>
<tr>
<td>Bellona Europa</td>
</tr>
<tr>
<td>Cummins Inc</td>
</tr>
<tr>
<td>EBRA ivzw (European Battery Recycling Association)</td>
</tr>
<tr>
<td>EcarACCU bv</td>
</tr>
<tr>
<td>ECOS</td>
</tr>
<tr>
<td>EEB</td>
</tr>
<tr>
<td>EGARA</td>
</tr>
<tr>
<td>EMIRI</td>
</tr>
<tr>
<td>Eucobat</td>
</tr>
<tr>
<td>EUROBAT</td>
</tr>
<tr>
<td>European Automobile Manufacturers' Association – ACEA</td>
</tr>
<tr>
<td>European Commission - DG CLIMA</td>
</tr>
<tr>
<td>European Commission - DG ENV</td>
</tr>
<tr>
<td>European Commission - DG GROW</td>
</tr>
<tr>
<td>European Commission - JRC (Petten)</td>
</tr>
<tr>
<td>European Commission - JRC (Sevilla)</td>
</tr>
<tr>
<td>F&amp;R Cawley Ltd</td>
</tr>
<tr>
<td>Ford of Europe</td>
</tr>
<tr>
<td>Greenspire Advisors Ltd</td>
</tr>
<tr>
<td>Imperial College London</td>
</tr>
<tr>
<td>Kompetenznetzwerk Lithium-Ionen Batterien (KLiB e.V.)</td>
</tr>
<tr>
<td>National Physical Laboratory (NPL)</td>
</tr>
<tr>
<td>Peter Ursem</td>
</tr>
<tr>
<td>Piaggio &amp; c SpA</td>
</tr>
<tr>
<td>RECHARGE</td>
</tr>
<tr>
<td>RENAULT</td>
</tr>
<tr>
<td>Ricardo Energy and Environment</td>
</tr>
<tr>
<td>Saft</td>
</tr>
<tr>
<td>Spiers New Technologies</td>
</tr>
<tr>
<td>T&amp;E</td>
</tr>
<tr>
<td>TNO</td>
</tr>
<tr>
<td>Toyota Motor Europe</td>
</tr>
<tr>
<td>Umicore</td>
</tr>
<tr>
<td>University of Birmingham</td>
</tr>
<tr>
<td>University of Birmingham - Faraday Institute</td>
</tr>
<tr>
<td>University of Leicester</td>
</tr>
<tr>
<td>Vito</td>
</tr>
<tr>
<td>Volvo Cars</td>
</tr>
<tr>
<td>Volvo GTT</td>
</tr>
</tbody>
</table>
Annex 2. Meeting agenda

09:30 – 10:00 | Arrival and registration of participants

10:00 – 10:15 | Introduction, project background

Objectives of the workshop and expected outcomes

10:15 – 12:15 | Key findings and outputs of the research and how they relate to the sustainable value chain

- Value chain
- Industrial techniques and processes
- Life cycle analysis
- Electric vehicle fleets

12:15 – 12:30 | Key conclusions of the draft report and morning session’s discussions

12:30 – 13:30 | Lunch break

13:30 – 14:30 | Circular economy value chain and discussion of business models

14:30 – 15:00 | Outcome of the SWOT analysis and the methodology used for prioritisation of policy options

(Coffee break)

15:15 – 16:30 | Break out session to discuss the shortlist of policy options

N.B. This session is designed to discuss the direction of travel the policy options will take, not to finalise the details of the policy options presented

16:30 – 17:15 | Presentation of the main breakout session outcomes, next steps and wrap-up
Annex 3. Presentations

Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles

- General context
  - Climate change: decarbonisation of transport system
  - Potential contribution of electrification
  - Resource efficiency and circularity
  - Raw materials availability
  - Environmental / social / security impact
  - EU competitiveness
    - opportunity to implement a circular economy model

CEBEV: Key research questions

1. What are the current available and emerging techniques in the manufacturing, reuse and recycling of traction batteries for electric vehicles? How are end-of-life batteries currently processed and what are emerging plans for the future?
2. What is the current environmental impact of traction batteries for electric vehicles across the whole life cycle? What are the current environmental hotspots and how are they addressed?
3. What will the potential environmental impacts and hotspots of traction batteries over their whole life cycle be if electric vehicles are deployed at large scale and in accordance with current trends, in the near, medium and long terms?
4. What are the current strengths and weaknesses of the European industry (infrastructure, policy framework) for dealing with the lifecycle of traction batteries in the perspective of road transport electrification?
5. What are the perspectives for developing a sustainable value chain for electric vehicle batteries in the EU?
6. What public policies could be envisaged to ensure truly circular lifecycles for traction batteries, and to harness the opportunities for growth and jobs in the EU?

Workshop objectives

- Formulate a vision of circular economy of EV batteries in the EU
- Techno-economic understanding of logistic options
- Pathways and policy support
- Collect feedback on analysis presented in draft report
- Evidence base
- Projections
- Discuss and assess policy options
- Draft an outline of a roadmap to novel suggestions

Sustainable Product Policy

- All products on the market
- Low sustainability of products
- High sustainability of products
- European market
- Global market
- Low sustainability
- High sustainability
- Product and material transparency
- Transparency in product and material supply chain
- Life cycle assessment
- Environmental impact
- Economic impact
- Social impact
- Energy label
- Ecotag
- Environmental impact
- Economic impact
- Social impact
- Life cycle assessment
- Transparency in product and material supply chain
- Product and material transparency
- Low sustainability
- High sustainability

Thanks!

Any questions?
Introduction, background and objectives of the workshop [10:00]

- Key findings and outputs of the research [10:30]
  - Value chain
  - Industrial techniques and processes
  - Lifecycle analysis (LCA)
  - Key impacts of EV uptake
- Key conclusions from the research [12:15]
- Lunch [12:30]
- Circular economy value chain and business models [13:30]
- SWOT analysis and policy option prioritisation methodology [14:30]
- Breakout session to discuss the shortlisted policy options [15:15]
- Outcomes from breakouts, wrap-up and close of the day [16:30]

Research Topics

1. Technology assessment
2. Battery life cycle impacts
3. EU SWOT analysis
4. Circular economy approach
5. Policy options

Project overview: the project has involved literature review and a range of stakeholder consultation activities

Research Questions

- Development of a clear and rapid environmental assessment (REA) framework
- Identification, review and synthesis of evidence, identification of key gaps

Consultation Approach

- Project management
- Targeted interviews
- Summative workshop
- Project reporting

Whilst the front end of the Li-ion traction battery value chain is relatively well characterised and understood it is less so for the ESL fate.

Cell materials (Ni: 15%)

- Cell component manufacturing (value: 18%)
- Battery cell production (value: 45%)
- Battery pack production (value: 23%)

- Breakdown of the battery manufacturing value chain is relatively well understood (though relative values/impacts are shifting due to changes in battery technology and scale/market deployment)
- Analysis of development battery chemistry/manufacturing improvements and lifecycle analysis show improvements linked to economic and performance drivers should also reduce largest environmental impacts from production

- In comparison, the value chain is more fragmented and impacts are less understood (a result of the first life of the battery in an electric vehicle is less well understood)
  - More research is still needed to better understand this in particular

The raw cell materials are responsible for ~10% of the value of the battery pack; however few of the key materials are located in Europe.

Cell component manufacturing also has a small share of the battery pack value; Europe only has a share in cathode material production.
Cell manufacturing represents the largest portion of the battery pack value; oversupply has made European manufacturers challenging.

Battery pack assembly is also a valuable step; European OEMs prefer to keep assembly in-house rather than outsourcing.

The automotive value chain currently represents ~1.5% of all EV jobs and is a €90bn net exporter; shift to EVs could have big impacts.

In some cases batteries from end-of-life EVs can be re-used in EVs following assessment, grading, repair or remanufacturing.

Even at 78% remaining capacity, EV batteries can potentially still provide years of useful life in less demanding applications.

Europe is a world leader in battery recycling, however lithium ion batteries are complex as they are recycling processes and economics.

There is a range of outstanding uncertainties and data gaps, mainly around the fate of the battery after its (first) life in an EV.
Li-ion batteries come in a range of chemistries/forms with different strengths and weaknesses; technical progress continues to be rapid.

- Most Li-ion cells now use lithium-ion batteries, with NMC and NCA now the most commonly used cathode materials. LFP cathode is mainly used in Tesla (BYD), China.
- There is still significant improvement potential seen for current chemistries:
  - Advanced chemistry (solid-state, Li-S, Na-ion, etc.): production expected to accelerate beyond 2025 (mainly unreliable for renewable energy recycling and reuse by 2040)
- Batteries come in a number of form-factors: prismatic, pouch and cylindrical.

Battery manufacturing is complex and highly energy intensive; future cost improvements likely to also reduce environmental impact.

- The greatest future cost reductions are expected to be in cell and pack manufacturing.
- Improvements likely to reduce whole life costs: some are also likely to have a significant impact on other aspects, such as: manufacturing decoupling – i.e. cathode materials and anode processes.
- One of the biggest challenges is how to standardise (e.g. MOP, MOPPy) recycling and reuse during the manufacturing process. Hence, there is significant interest in exploiting new chemistries.

A wide range of manufacturing improvements were identified, but there is little available information on advanced battery improvements.

- Little information available on relative levels of research and industry activity in the three main stages of battery manufacturing in EU vs other regions:
  - Raw materials and cell manufacturing
  - Packaging and assembly
  - Battery end-of-life recycling.

Common processes for reuse/repurposing depend strongly on battery pack construction. Repurposing economics are uncertain.

- There are common steps in reusing/repurposing batteries: destination of packs/modules/cells from incoming batteries dependent on pack design/assurance:
  - Reuse/repurposing of the whole pack is probable.
  - Processes used for battery re-pack/repair.
  - Recycling required if no reuse is possible.
  - Manufacturing costs are significant.
  - Typically pack SHD: 10%.
  - Repurpose: <0%.
- Economics: uncertain.

Current industrial LIB recycling focus on hybrid pyromet/hydromet. processes; novel processes potentially offer enhanced recovery.

- 4 European large-scale industrial LIB recycling companies: Accurec, Umicore, Recupel, and RRC. Current recycling processes focus on pyromet/hydromet. techniques, complemented with other treatments.

Improvements in EV battery design, coupled with general scale-up and process optimisation will facilitate recycling improvements.

- Battery design:
  - Use of fewer parts or other distinguishing features.
  - Use of a minimum number of different materials.
  - Standardisation of formats and materials.
  - Automation of packaging materials.
  - Designs that allow easy separation of parts (e.g. separable cooling systems, removable pins/exit and bolt Instead of rivets, and avoidance of putting or adhesive compounds to hold cells in place).
- Further process optimisation, automation, improved quality control.

- Pro-treatment:
  - Disassembly by automated processes to recover electrodes for reuse.
  - Discharge of cells to recover residual energy.
- Process optimisation:
  - Recovery of the electrolyte.
  - Development/adaptation of processes for new battery types (e.g. Li-S, solid state, Na-ion, etc.)

Optical classification:
- Recovery of Li from shaft furnace stage and leaching of Li from Li2SO4 (dissolution).
- Electrolyte (Li-salt, e.g. Li2SO4 LiTF7) recovery based on liquid phase extraction (ELBA/MATRIX project).
- Further development of proprietary pyromet/hydromet. techniques, such as direct re-synthesis, electrochemical processes and bio-leaching.

New chemistry agnostic hydrometallurgical processes are being developed, however there is currently no clear roadmap for scale up.
There are already examples of improvements being made to improve battery lifecycle and facilitate reuse/repurposing/recycling.

**Agenda**

- Introduction, background and objectives of the workshop[10:00]
- Key findings and outputs of the research [10:30]
  - Value chain
  - Technical solutions and processes
  - Lifecycle analyses (LCA)
  - Fleet impacts of EV uptake
- Key conclusions from the research [12:15]
- Lunch [12:30]
- Circular economy value chain and business models [13:30]
- SWOT analysis and policy option prioritisation methodology [14:30]
- Break out session to discuss the shortlisted policy options [15:15]
- Outcomes from breakouts, wrap-up and close of the day [16:30]

**EV battery manufacturing is relatively well characterised in LCA, but results are highly variable; end-of-life processes are less analysed**

- EV Li-ion battery manufacture impacts relatively well characterised (but most focus on GHG and energy)
- Knowledge of the scales of lifecycle impacts / hotspots
- Differences in assumptions and the basis of the LCA can make comparability difficult
- Significant variability mainly due to:
  - Electricity mix for manufacturing
  - Battery energy density, and
  - Treatment of end-of-life recycling

**Impacts of battery recycling depend on different LCA method approaches, future benefits also uncertain but likely to increase**

- Impacts from end-of-life recycling are less clear, with most of the evidence base coming out of Argonne National Laboratory / the US GREET LCA model
- Two different methodologies predominated:
  - "Recycled content" often used in manufacturer product declarations
  - "Kovaci border" or hybrid approaches to account for generally higher extensive recycling rates

**Recent analysis suggests significant lifecycle benefits from second life use with renewables, however LCA treatment is still developing**

- Second life applications of EV batteries are still at early stages of investigation and few LCA studies available considering environmental impacts
- Comparison with fossil generation in one study found remanufacturing impacts <10% of a new battery
- Significant overall benefits compared to conventional systems
- Efficiency fade is a significant detracting factor in second use performance
- JRC IASLAB project found second use was only environmentally beneficial when used in conjunction with renewable energy
- More information is needed to establish more clearly the potential benefits
- Options for LCA treatment of second life batteries
- Modelling of separate second life reference systems/technologies for comparison
- Credit based on equivalent fraction of displaced new energy storage battery
- Economic allocation using the value of the used battery at its end-of-life

**Global and European decarbonisation objectives are likely to significantly reduce impacts of battery materials and manufacturing**

- Due to future Global and European decarbonisation objectives:
  - Industrial processes improving
  - Cleaner electricity used in material and battery production
- Overall effect on impacts is likely to be very significant
- EU electricity mix is anticipated to decarbonise by 89.9% by 2050
- Region of manufacture of materials and battery will therefore have an increasing importance in the future
Improvements in battery energy density and the introduction of advanced battery chemistries are expected to reduce impacts/kWh.

- Literature shows higher energy density batteries lead to reduced impacts per kWh.
- Counter-balanced by increases in battery production/energy intensity.
- Few sources consider potential impacts of advanced chemistries. (Li-S, sodium batteries, and Na-air)
- All show substantial reductions, compared to the currently dominant NCA chemistry. In most, all environmental impact categories: 
  - 15-50% reduction in GHG.
  - Up to 90% reduction for other impacts.
- Due to energy density improvements and changes to materials/processing.
- No studies specifically looked at other manufacturing impacts.

There are still a range of outstanding questions, gaps, and uncertainties for battery LCA which require further research.

- Production
  - Lifecycle impacts: How much might the most significant impacts from production change over time as a result of advanced battery chemistry and improved manufacturing technique?
  - What are the trends likely to provide the greatest benefits per kWh?
  - How might future impacts from production be reduced by more simple chemistry (performance improvements)?
  - What is the correlation to improvements in energy density (KWh) benefitting impacts clear?

- End of Life
  - Contribution of optimised recycling processes to overall impacts: What level of key material recovery and impact reduction might future optimised recycling achieve for 2030-2050 period?
  - How should battery second life be credited in lifecycle analysis?
  - To what extent could changes to recycling based battery chemistries affect recycling benefits?
- Advanced battery technologies likely need to be relatively greater, or fewer benefits from recycling?
- Quantified LCA impacts per type of recycling process and battery type are highly variable or uncertain in the literature. Additional information is needed on material recovery rates, impact of battery recycling on the overall LCA result and how this varies by process and battery type.

Agenda

- Introduction, background and objectives of the workshop [16:01]
- Key findings and outputs of the research [16:30]
  - Value chain
  - Industrial techniques and processes
  - Lifecycle analysis (LCA)
  - Impact of E, V uptake
- Key conclusions from the research [12:15]
- Lunch [12:30]
- Circular economy value chain and business models [13:30]
- SWOT analysis and policy option prioritisation methodology [14:30]
- Breakout session to discuss the shortlisted policy options [15:15]
- Outcomes from breakout, wrap-up and close of the day [16:30]

The potential benefits of a Sustainable Value Chain for EV batteries was explored for alternative xEV uptake in the EU road vehicle fleet.

- The objective was to assess impacts on battery lifecycle emissions and critical resource supply for a Base Case versus a Sustainable Value Chain for EV batteries.
- Batteries manufactured are better designed with second life applications in mind and recycling rates, and the recovery of key materials is higher in a for each unit.
- A much higher proportion of battery cells are manufactured within Europe.
- Two alternative levels of xEV uptake for all road transport modes were assessed, with similar assumptions for future trajectory of average new vehicle GHG emissions.

<table>
<thead>
<tr>
<th>xEV uptake scenarios</th>
<th>Value chain scenarios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case (BC)</td>
<td>Sustainable value chain (SVC)</td>
</tr>
<tr>
<td>1 Minimum EV deployment scenario (LoDeV)</td>
<td>1 Base case (BC)</td>
</tr>
<tr>
<td>2 Maximum EV deployment scenario (MiDeV)</td>
<td>2 Base case (BC)</td>
</tr>
<tr>
<td>2 Sustainable value chain (SVC)</td>
<td></td>
</tr>
</tbody>
</table>

- Two main criteria:
  - High battery production emissions
  - Mid-life replacement of BEV batteries for LDVs (default = 0)

The SULTAN model was used to assess vehicle fleet emissions and battery stock, with post-processing to calculate other impacts.

- SULTAN model modified to explicitly track battery stock and weight (Production & End Life), project future battery capacities, post processing analysis to estimate lifecycle impacts:
  - GHG, NiOx/PM, SxOx
  - Flows of key materials: Li / Cu / Ni / Al / Cu / Fe

xEV use phase impacts dominate over battery lifecycle components.

- Significant reduction for battery possible for sustainable value chain.

Lifecycles GHG (and other emissions) are dominated by the use phase, and in both xEV uptake scenarios there are significant improvements in net emissions vs the baseline.

- Sustainable Value Chain scenario result in <25% reduction in net GHG emission impacts from battery production and disposal (P+D) by 2050 for all xEV scenarios.
- Significant credits are scored for reuse/reprocessing and recycling, especially after the emissions resulting from corresponding battery production.
- The two scenarios result in increases of battery P+D GHG emissions by 14-35% by 2050.

The demand for xEV batteries is projected to increase dramatically to 2030 and beyond: GWh dominated by cars, numbers by eBikes.

- Hybrid and xEV battery demand increases to 173-226 GWh by 2030 and 995 GWh by 2050 in the HIndE scenario.
- By 2050, 16% Tesla Gigafactory
- Demand increases by >25% with LDV battery replacement.
- ~100 GWh for LDeV by 2050.

- The numbers of batteries reaching their end of life (End Life) and requiring recycling increase dramatically—mainly due to eBike uptake in earlier years.

All xEV scenarios lead to significant net reductions in air quality pollutants: 43% reduction in battery emissions for SVC vs Base

- NOx/PMx emissions from battery production and disposal (P+D) reach a peak of 2050.
- 2% for NOx
- 5% for PM
- 6% for SOx

- NOx/PMx emissions from battery production and disposal could all be reduced by up to 43% by 2050 with a Sustainable Value Chain (SVC) for batteries (versus Base Case).
Circular Economy Perspectives for the Management of Batteries used in Electric Vehicles

Key conclusions and summary

Dr. Billy Wu
Imperial College London
Senior Lecturer
billywu@imperial.ac.uk

1. Technology aspects

• NMC chemistry likely to dominate in the near future
• Technological developments are very fast-moving and much of the literature is already out of date
• Need to assess potential changes due to new battery chemistries proposed
• Significant value in cell and pack production

Scope and objectives

1. What are the current available and emerging techniques in the mining sector, re-use and recycling of batteries?
2. What is the current understanding of the environmental impact of battery recycling and how are they addressed?
3. What is the potential for energy storage and recycling of batteries and how can they be optimised for the future?
4. What is the current understanding of the environmental impact of battery recycling and how are they addressed?
5. What are the main drivers for developing a sustainable value chain for electric vehicle batteries in the EU?

Research Topics

1. Technology aspects
2. Battery lifecycle impacts
3. 3.4 EU battery impacts
4. 4.5 SWOT analysis
5. Circular Economy aspects
6. Policy options

2. Battery lifecycle impacts

• The LCA definition can be complicated and not necessarily consistent between different studies
• Different assumptions on e.g., emission factors, sourcing of materials, energy, etc. can dramatically change results
• Lots of uncertainty over future chemistries
• Not much work done in LCA of end-of-life cells and recycling
3. EV deployment impacts
   - EV battery technology is rapidly improving and this means unit costs (€/kWh) are rapidly decreasing faster than industrial analysis.
   - Most projections of sales don’t go beyond 2025, but having some longer-term predictions will be instrumental for making plans now to develop effective second-use and recycling capabilities.
   - Furthermore, as the electric vehicle market develops, the installed battery energy capacity (in kWh) is likely to increase as the technology develops and costs reduce. This has implications for the future arisings of used automotive batteries that needs to be taken into account in the analysis.

5. Circular economy aspects
   - Hydro, Pure, Mechanical: Hybrid techniques proposed but no dominate recycling technology as of yet
   - Collaboration with manufacturers required to make batteries more suitable for recycling at use
   - Still uncertainty around economics of 2nd life batteries and public perception
   - Logistics of moving decentralized resources around still a major challenge
   - Traceability of materials challenging
   - Standards for material purity uncertain
   - Lack of regulation leads to uncertainty around liability for 2nd life batteries
   - Diversity of chemistries make recycling challenging

4. EU SWOT analysis
   - Currently limited cell component production capability within the EU with significant uncertainty over supply of key raw materials
   - Whilst manufacturing is dominated by the Japanese, Koreans and Chinese there is an opportunity for recycling
   - New business models have a key role to play in innovation (e.g. V2G for fleet operators)

6. Policy options
   - To ensure a circular approach, the role of public policy is to close the gap between the solutions that will be provided by the market without intervention and the EU goal for where the market should be to minimise environmental externalities.
   - These policies should aim to promote the competitiveness of EU industry for the EV battery value chain and increase employment opportunities in industry.
   - More clarity needed on definitions
   - Recycling and 2nd life not yet economically attractive and thus may need to incentivise

Thoughts for lunch
- What are the practical elements which have not been considered?
- How will recycling be economic in the future as the cobalt levels decrease?
- What new innovative business models are emerging and what can be done to support them?
- What are emergent opportunities and threats?

Agenda
- Introduction, background and objectives of the workshop [10:00]
- Key findings and outputs of the research [10:30]
  - Value chain
    - Industrial techniques and processes
    - Lifecycle analysis (LCA)
  - Fleet impacts of EV uptake
- Key conclusions from the research [12:15]
- Lunch [12:30]
- Circular economy value chain and business models [13:30]
- SWOT analysis and policy option prioritisation methodology [14:30]
- Break out session to discuss the shortlisted policy options [15:15]
- Outcomes from breakouts, wrap-up and close of the day [16:30]

Circular economy value chain and business models [13:30]
Assessment of the circular economy value chain reveals the barriers and opportunities for development

**State of play**
- Existing models for recycling and remanufacturing are insufficient.
- High material losses in disposal stages.
- Limited availability of recycling licenses.

**Barriers**
- High capital required for establishing recycling facilities.
- Low capital required for establishment of reverse logistics and sales networks.
- Limited market for recycled materials.

**Opportunities**
- Increased demand for recycled materials.
- Technological advancements in recycling technologies.
- Government incentives for recycling.

Key insights across the sustainable value chain

**State of play**
- Significant price disparity between new and used batteries.
- Recycling processes vary significantly.

**Barriers**
- High costs associated with recycling.
- Limited availability of high-quality recycled materials.
- Lack of standardization in recycling processes.

**Opportunities**
- Cost savings from using recycled materials.
- Penetration of sustainable value chain.
- Increased demand for sustainable products.

Overview of business models included in the report:

- **Recycling**
  - ■■■■■
- **Re-use & re-purposing**
  - ■■■■■
- **Value chain**
  - ■■■■■

An example of the integrated value chain business model

**2nd life battery sales mode**
- **Complete pack**: no modification on original vehicle battery pack
  - Industrial and network applications
    - Large or medium capacity
      - ■■■■■
- **Modular**: new battery pack creation
  - ■■■■■
  - ■■■■■
  - ■■■■■
Renault 2 Life Batteries Overview

- 3 battery types available to date: Ni-MH, Ni-Cd and Ni-Fly
- Modular solutions from 3.3 Wh to 11 kWh
- Competitive pricing
- Additional revenue for Renault, reduced recycling for others
- 100% diagnosis and capacity measurement before second life
- Expected running life span: 8.5 years (depending on application)
- Many new projects/applications/partnerships in progress

Discussion of highlighted and any additional business models in a sustainable value chain

SWOT analysis and policy option prioritization methodology [14-38]

- Agenda
  - Introduction, background and objectives of the workshop [10:00]
  - Key findings and outcomes of the research [10:30]
    - Value chain
    - Industrial techniques and processes
    - Lifecycle analysis (LCA)
    - Fleet impacts of EV uptake
  - Key conclusions from the research [12:15]
  - Lunch [12:30]
  - Circular economy value chain and business models [13:30]
  - SWOT analysis and policy option prioritisation methodology [14:30]
  - Breakout session to discuss the shortlisted policy options [15:15]
  - Outcomes frombreakouts, wrap-up and close of the day [16:30]

The SWOT analysis evaluated each sector of the value chain across three pillars and used RAG to highlight areas of weaknesses

<table>
<thead>
<tr>
<th>EV battery value chain</th>
<th>Industry</th>
<th>Infrastructure</th>
<th>Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td>Weak</td>
<td>Intermediate</td>
<td>Strong</td>
</tr>
<tr>
<td>Cell component manufacturing</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Strong</td>
</tr>
<tr>
<td>Battery pack manufacturing</td>
<td>Strong</td>
<td>Weak</td>
<td>Weak</td>
</tr>
<tr>
<td>Re-use</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Weak</td>
</tr>
<tr>
<td>Re-purposing</td>
<td>Intermediate</td>
<td>Intermediate</td>
<td>Weak</td>
</tr>
<tr>
<td>Recycling</td>
<td>Weak</td>
<td>Weak</td>
<td>Weak</td>
</tr>
</tbody>
</table>

Outcomes of the SWOT analysis identified a series of problems from which an initial list of policy options was devised

<table>
<thead>
<tr>
<th>Problem</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Raw materials missing from CRM list</td>
<td>Legally binding instrument needed to ensure a mandatory and uniform implementation across Member States relating to confidentiality, quality, delivery and reprocessing systems, battery ownership</td>
</tr>
<tr>
<td>2 No definition or standards for re-use or re-purposing</td>
<td>Establish legally binding instrument at EU level, if necessary</td>
</tr>
<tr>
<td>3 End-of-waste criteria for EVs and their components varies between Member States</td>
<td>Use of mandatory targets</td>
</tr>
<tr>
<td>4 No targets for re-use &amp; re-purposing in the Batteries Directive</td>
<td>Use of mandatory targets – need flexibility to respond to market changes</td>
</tr>
<tr>
<td>5 Targets for recycling do not facilitate extraction of raw materials as needed by the industry</td>
<td>Use of mandatory targets – need flexibility to respond to market changes</td>
</tr>
</tbody>
</table>

Outcome of the SWOT and the methodology use for prioritisation of policy options

<table>
<thead>
<tr>
<th>Problem</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 Costly to transport EV battery waste</td>
<td>Define legally binding standards for an EU battery waste collection system, need to avoid risk of environmental degradation</td>
</tr>
<tr>
<td>7 No incentive to factor in re-use, re-purposing or recycling needs in earlier phases of the EV battery value chain</td>
<td>Establish legal requirements via the R&amp;I Directive or the type-approval of motor vehicles with regard to their recyclability, reusability and reproductivity, Directive to regulate re-use, re-purposing and recycling needs in the design and manufacturing phases of the EV battery</td>
</tr>
<tr>
<td>8 Lack of traceability across the manufacturing processes</td>
<td>Establish a mandatory certification scheme for industry operators (across the value chain) to comply with international standards</td>
</tr>
<tr>
<td>9 Conflict between manufacturers relating to producer responsibilities as a result of extending the value chain</td>
<td>Establish a common policy framework that will facilitate industry growth</td>
</tr>
<tr>
<td>10 Low flexibility in industry to respond to changing technologies and consumer demands</td>
<td>Establishing a clearer policy framework will facilitate industry growth</td>
</tr>
<tr>
<td>11 Capital investment needed to meet infrastructure needs</td>
<td>Mandated reporting is considered most appropriate</td>
</tr>
<tr>
<td>12 Larger skilled workforce and technical expertise needed</td>
<td>Information needs relating to the environmental footprint of the EV battery value chain</td>
</tr>
<tr>
<td>13 Information needs relating to the environmental footprint of the EV battery value chain</td>
<td>Information needs relating to battery performance</td>
</tr>
<tr>
<td>14 Information needs relating to battery performance</td>
<td>Impact assessment needed to establish the extent of regulatory intervention required</td>
</tr>
<tr>
<td>15 Lack of policy to regulate emerging circular economy business models, namely VGI</td>
<td>Establishing a common policy framework that will facilitate industry growth</td>
</tr>
<tr>
<td>16 Circular economy business models are emerging at local level with little coordination at national or EU level</td>
<td>Need for ongoing support for R&amp;D and horizon scanning</td>
</tr>
</tbody>
</table>

Agenda

1. Introduction, background and objectives of the workshop [10:00]
2. Key findings and outcomes of the research [10:30]
   - Value chain
   - Industrial techniques and processes
   - Lifecycle analysis (LCA)
   - Fleet impacts of EV uptake
3. Key conclusions from the research [12:15]
4. Lunch [12:30]
5. Circular economy value chain and business models [13:30]
6. SWOT analysis and policy option prioritisation methodology [14:30]
7. Breakout session to discuss the shortlisted policy options [15:15]
8. Outcomes from breakouts, wrap-up and close of the day [16:30]
### Delegation feedback for Policy Option 4: Establish new regulatory requirements to facilitate re-use, re-purposing and recycling

| What is positive about the policy options? | Standardisation helps reverse logistics |
| What is negative about the policy options? | Too early to standardise |
| Any other comments? | Mandate that all recyclers must look at reuse and repurposing first |
| Are there additional or alternative policy options that should be shortlisted, and why? | Best Available Manufacturing Techniques |

### Delegation feedback for Policy Option 5: Establish mandatory cert. scheme requiring the use of international standards for manuf.

| What is positive about the policy options? | To promote sustainability and ethically mined Cobalt traceability is essential |
| What is negative about the policy options? | Standards not needed as it stunts innovation |
| Any other comments? | Need to define what is meant by standardisation |
| Are there additional or alternative policy options that should be shortlisted, and why? | Have traceability number but no information about what is in it, like diamonds |

### Delegation feedback for Policy Option 6: Establish mandatory EU life cycle assessment scheme under reg. on vehicle CO2 standards

| What is positive about the policy options? | Produces a level playing field between technologies |
| What is negative about the policy options? | Might be too variable to enforce |
| Any other comments? | Would require a LCA organisation to standardise |
| Are there additional or alternative policy options that should be shortlisted, and why? | Need to have LCA for all powertrains for a level playing field |

### Delegation feedback for Policy Option 7: Establish legal reporting requirements for ewe, footprint of BV battery and to battery perform.

| What is positive about the policy options? | Grading of 2nd life batteries is needed and better documentation on can create a level playing field |
| What is negative about the policy options? | Standards needs to follow battery chemistry and might become outdated |
| Any other comments? | Definition of use of health needs to be verified |
| Are there additional or alternative policy options that should be shortlisted, and why? | Share information on the BMS |

---

**Nikolas Hill**  
Ricardo Energy & Environment  
The Quintain Building  
Farnham, Godalming  
GU10 5QR  
United Kingdom  
T: +44 (0)1252 753622  
E: nikolas.hill@ricardo.com

**Dan Clarke**  
Ricardo Energy & Environment  
2nd Floor  
30 Euston Terrace  
Paddington, London  
W2 6LA  
United Kingdom  
T: +44 (0)1252 753712  
E: douglas.clarke@ricardo.com