MARKET INTELLIGENCE REPORT

COBRA

KEY TECHNICAL, POLICY AND MARKET DEVELOPMENTS INFLUENCING THE ELECTRIC VEHICLE BATTERY LANDSCAPE

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ENVIRONMENTAL AND SOCIAL IMPACTS OF LI-ION BATTERIES

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INTRODUCTION

Electric vehicles do not directly emit CO2. However, the generation of electricity to charge their Li-ion batteries does. More importantly, though, the manufacturing of Li-ion batteries has considerable environmental and societal impact. On one hand, manufacturing processes are highly energy-intensive, which leads to CO2 emissions and negative environmental impacts. On the other hand, batteries contain raw materials such as cobalt, lithium, manganese, graphite, and nickel, of which the mining and processing entail a negative impact on both local societies and ecosystems. Mining operations for cobalt in the Democratic Republic of Congo have often been accused of using artisanal miners and child labour, while leaks of toxic chemicals from lithium mines in Tibet have caused the deterioration of local fauna. Considering the global increase in battery demand, these issues are only expected to increase, should nothing change. Solutions are being developed. Pyro, hydro, and other, innovative recycling processes are being further developed and upscaled, which could partly replace raw material mining. Although up to now just around 5% of all Li-ion batteries (from smaller devices such as laptops or cell phones) are recycled or reused, the volume of larger EV batteries that is expected to reach their end of life in the next few years is expected to change this trend, as recycling of larger batteries – with higher content in valuable materials – is predicted to make recycling financially attractive. In addition, new battery technologies with low or no content of “troublesome” raw materials are being developed, such as the cobalt-free battery developed in COBRA. This market intelligence report aims to highlight the main environmental and social impacts of Li-ion batteries, as well as technologies and measures to reduce them.

> **“Make a material impact on sustainability, at an industrial scale.”**
> *JEFFREY BRIAN STRAUBEL, TESLA CO-FOUNDER & CEO AT REDWOOD MATERIALS*

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TECHNICAL DEVELOPMENTS ON ENVIRONMENTAL AND SOCIAL IMPACTS OF LI-ION BATTERIES

FOREWORD BY IREC REPRESENTING COBRA, AND LLUC CANALS:

Background

Emissions from transport have increased over the last years. In 2020, these emissions represented more than a quarter of total greenhouse gas emissions in the EU [9]. This is the main reason why forced by legislation, the automotive sector is facing a revolutionary scenario to contribute significantly to one of the most challenging situations of current society: reducing harmful emissions causing climate change and air pollution, especially in cities where particulate matter (PM) and nitrogen dioxide (NO2), are damaging human health and the environment. One of the main technologies used to reduce these emissions in the transport sector is electric vehicles compared to the traditionally used internal combustion engine vehicles. Despite the enormous advances in sustainable performance within the automotive industry, the dependency of the EV industry on the electricity sector to power the batteries heavily influences their impact. At the same time, Li-ion battery technology is based on raw materials, such as lithium, cobalt, nickel, manganese, and graphite, most of which are categorised as critical materials and associated with several environmental and social impacts throughout their supply chain, reinforcing the urgency to address their entire lifecycle to be able to assess the sustainability of EVs towards achieving the industry's sustainability goals [1].

Impacts/challenges

Critical materials in batteries, mostly found in electrodes (cathode and anode) and electrolytes, can also present significant issues associated with resource availability apart from other environmental and social issues. Even though lithium, manganese, nickel, and natural graphite have moderate reserves to cover the expected 10% share of electric vehicles in the global fleet in the next years, they are not enough to cover the expected increase in demand, pushing up market prices. Moreover, considering an extreme scenario for 100% electrification of the world's vehicle fleet, under continuous growth conditions, having enough reserves of cobalt and potentially lithium is unlikely [2, 3]. Nowadays, the sustainability and not-so-long-term availability of Li-ion batteries can be affected by cobalt. This metal is extracted mainly from the Democratic Republic of the Congo, a region historically characterized by political instability and social impacts in the mining sector, such as child work, safety mining conditions (with many illegal extractions and uncountable deaths) [2]. Availability is not the only issue related to these materials. For instance, cheap lithium mining requires withdrawing high amounts of water from locations where water is scarce, which has environmental implications [3].

To analyse the environmental impact in all phases of the product development (materials' extraction, manufacturing, and recycling or disposal impacts at the end-of-life), the Life Cycle Assessment (LCA) is the most used methodology. This tool allows highlighting 'hotspots' of potential environmental pressures, while also providing a general picture of overall environmental performance [1]. However, there is no consensus on a unique LCA methodology, metrics, and indicators, and the existing studies are performed with a Cradle-to-Grave approach which, depending on the LCA study, does not necessarily include the recycling of the battery.

What is an LCA?

The LCA is a holistic methodology internationally recognised and supported by the ISO 14040 series to evaluate the environmental impacts through the life cycle of products or services. There are 4 iterative phases to conduct an LCA: Goal and Scope Definition, Life Cycle Inventory, Life Cycle Impact Assessment and, Interpretation. The first LCA studies of batteries were focused on cell/module production phase and battery assembly (called "LCA cradle-to-gate approach"). However, the expected growth of the battery market in the next 10-20 years encourages us to enlarge the scope covering all life cycle stages, including end-of-life. These studies should show alignment with the circular economy with

2nd life applications and/or treatments to recover materials. Hence, the cradle-to-grave approach *(check ISO 140044)* needs proper definition and consensus on how repurposing batteries with 2nd life and recycling can exploit the energy and economics invested in battery production while reducing the environmental impacts of battery waste landfilling. Unfortunately, the **lack of standardisation** in environmental allocations and the **difficulty in data collection** complicates the obtention of reliable results and depend on the quality and the chosen database, generating different results and uncertainty.

The EU Environment DG together with the JRC developed a method - the Product Environmental Footprint (PEF), to harmonise the methodology for the environmental footprint of products. The method is largely in line with the LCA principles since it was based on standards (ISO14040 and the ILCD Handbook). In addition, the recent Product Environmental Footprint Category Rules (PEFCR) applicable for rechargeable single cells or/and batteries used in e-mobility – excluding charging unit, provide guidance that contributes to more consistent, robust, and reproducible LCA aligned with the PEF method.

Existing LCA studies on Li-ion batteries show that particularly cobalt and nickel (used in the cathode) increase significantly the environmental footprint, as e.g. toxic substances can leak from mine tailings [2]. Some substances used in electrolytes can also have negative impacts, such as carbonate-based solvents and the lithium salt (LiPF6). This latter can be decomposed to form hydrogen fluoride (HF), which is highly corrosive and toxic to the atmosphere. The above environmental concerns involve the active materials of the Li-ion batteries. However, there are “inactive” electrode materials that do not contribute to the energy storage capacity, but they fulfill varied crucial tasks within the battery cell, such as binders to hold the components of the battery together. These exhibit environmental impacts since they are typically made of fluorinated substances, which production is energy-intensive and generates substances that cause ozone depletion.

Additionally, Li-ion batteries involve complicated manufacturing processes that demand high amounts of energy, including cell assembly, carried out in severe dry room conditions. Therefore, the electricity mix of the region where these batteries are manufactured plays an important role in the global warming potential category impact that measures the battery’s CO2 eq emissions. Li-ion batteries are usually manufactured in Asian countries, which have a different electricity mix than most European countries. In particular, China dominates the battery production with 93 “gigafactories” that manufacture Li-ion cells, vs. only four in the United States. China’s electricity mix, dominated by coal, contributes largely to global warming, which is blocking reaching the sustainability targets. Even though batteries are a product on their own, they alone can do nothing else than to store and transfer energy through time to other products and are used in diverse goods. This makes it hard to do an LCA on batteries alone, so these studies are either performed on the product that contains these or end-up just after the manufacturing phase, ignoring the use and end-of-life phases, known as cradle-to-gate analysis [1].

Regarding the use phase, the amount of energy coming out during the discharge of a Li-ion battery, compared with how much was put in to charge it (battery efficiency), should be as high as possible. Reducing energy losses lowers the environmental impacts associated with the electricity production used to charge them, such as GHG emissions from fossil fuel combustion. Li-ion batteries are very efficient (around 97%), however, when including the chargers and other equipment needed to use them, the overall efficiency decreases to around 90%. Thus, considering the battery’s lifetime, a 10% loss is still responsible for some significant environmental impacts associated with the electricity mix used to charge batteries (which can alter the EV global warming potential [10]).

With all these aspects in mind, the complexity of the overall environmental and social impact of Li-ion batteries becomes clear. Therefore, it is important to make a detailed LCA of Li-ion batteries to compare their sustainability aspects to other types of transport such as internal combustion engine vehicles. At the same time, the LCA methodology can point out where the biggest improvements in terms of impact can be made.

	ENVIRONMENTAL IMPACTS	SOCIAL IMPACTS
SOURCING	○ Release of toxic chemicals harms communities and ecosystems. ○ Water, soil and air contamination. ○ Large groundwater usage. ○ High toxicity of materials used for extraction, which can leak into local ecosystems. ○ Significant GHG emissions/component.	○ Use and contamination of (the scarce) water sources from local communities. ○ Human health risks. ○ Child labour, improper work conditions. ○ Illegal extractions and countless deaths. ⚠
PRODUCTION	○ Binders' water pollution and (ozone-)depletion. ○ Release of toxic chemicals harms communities and ecosystems. ○ Soil and air contamination. ○ Significant GHG emissions. ○ Highly energy-intensive manufacturing and assembly processes. ⚠	○ Air pollution harming human health. ○ Use of toxic materials, risk for leaks.
USE	○ Emissions from EV charging (depending on electricity mix).	○ Human exposure to flammable materials.
DISPOSE	○ Release of toxic chemicals harms communities and ecosystems. water, soil and air contamination.	○ Air pollution harming human health.

Table 1. Environmental and social impacts of Li-ion batteries on each phase.

FURTHER CHALLENGES
○ Raw material scarcity. ○ Establishing a standardised LCA process. ○ Uncertainty of new battery designs and 2nd-life batteries impacts and performance. ○ High cost and lower performance, therefore questionable adoption of novel eco-design battery concepts.

Table 2. Main challenges encountered by state-of-the-art Li-ion batteries.

SUGGESTED SOLUTIONS
○ Decarbonisation of energy sources. ○ Use of cleaner or renewable raw materials. ○ Highly abundant and easily accessible material compositions. ○ Expand the battery lifespan (2nd life applications). ○ Recycling of critical raw materials.

Table 3. Suggested solutions for the industry's challenges.

Potential solutions/Future research areas

Based on the above, it is evident that to achieve the holistic sustainability of Li-ion batteries, the environmental impacts through their life cycle should be drastically reduced by means of decarbonised energy sources and sustainably sourced materials. Battery manufacturers typically rely on the grid providers for the energy mix, and therefore related emissions. Luckily, the decarbonisation of the energy sector is gaining ground. Likewise, research on less critical and more sustainably sourced materials, as well as battery recycling technologies is ongoing **[1, 5].** In addition, strategies focused on new component designs are based on the use of a material composition that contains materials that are highly abundant and ensure easy accessibility or production possibilities based on renewable raw materials, which can alleviate cobalt demand and provide performance advantages **[1, 5].** However, these strategies are a great challenge, since reaching current Li-ion cell performance with these novel designs is rather difficult. This is because the materials selected for the new sustainable developments should meet the high requirements of the electrochemical processes. Up to now, the green alternatives show one or more drawbacks inherent to the new materials, influencing the energy density, cycle life, or other key electrochemical parameters, and are often not cost-competitive. If not adequately addressed, innovations may lead to a greater upstream environmental impact in the pursuit of greater performances.

Other strategies increasing the sustainability of Li-ion batteries are extending the battery lifespan, prolonged battery cell usage in 2nd life applications, and increased recyclability. The joint coordination of these strategies has been focused recently on research in circular economy principles to guide sustainable management of the Li-ion batteries at the end-of-life. Second life batteries following a cascading reuse approach of batteries in stationary energy storage applications are the final hope for car manufacturers, who, at the same time can create additional revenue streams from the battery re-use and for electricity utilities that can adopt other energy uses (such as Peak-shaving, Time-of-Use management, Transmission Deferral, Energy arbitrage, etc.) in the pursuit of low-cost batteries to make their business profitable **[11].**

The suitable choice of the 2nd life application depends on variable states of health and residual capacity after use in electric vehicles. This can generate many complex scenarios from an LCA point of view to evaluate how the second life concepts can “dilute” the carbon footprint of the battery production over more years of usage. On the one hand, the LCA study needs to define a functional unit to provide environmental results comparable to other studies. Hence, there is no clear consensus on it when including 2nd life applications, although the kWh of energy exchanged seems to be appropriate in many cases.

On the other hand, the system boundaries should be well defined according to the allocation of the environmental impact of both manufacturing and EoL stages. This means that the allocation of the environmental impact represents an unresolved issue to be addressed at a post-stage, entailing one of the most complex characteristics of the LCA when thinking of a Cradle-to-Cradle approach, since they are different concepts **[1, 12]** . In a repurposing scenario where the lifetime of the battery is extended, not all the impacts of both manufacturing and EoL should be allocated to the second life of the battery, since it already fulfilled the purpose for which it was built Thereby, an allocation system should be defined which is at the discretion of who conducts the study. Nonetheless, different LCA studies considering second life scenarios state that they offer the potential to minimize the magnitude and pace of LIB waste generation while at the same time reducing the life cycle environmental impacts of energy systems.

> **“People underestimate what recycling can do for the electric vehicles industry. This could have a huge impact on raw material prices and output in the future.”**
>
> *CELINA MIKOLAJCZAK*
>
> *LI-ION BATTERY EXECUTIVE AND MEMBER BOARD OF DIRECTORS IN QUANTUMSPACE*

Although the industry must work towards enlarging the life of the battery ensuring a 2nd life, it is important to bear in mind that any life extension will also have some negative environmental implications, even if these are lower than the ones generated by using new batteries. Although being used even in recent studies [13], the comparison on the impact against the use of new batteries is considered to be non-realistic, as new batteries aren't likely to be used for such purposes due to their high economic costs, and thus, this so-called "environmental savings" are difficult to occur in the close future.

The recycling of batteries is currently effective in searching for high-cost elements and materials and discarding much of the other components. For instance, although it is possible to recycle lithium, the cost of recycled lithium is higher than virgin, thus, the process has not been adopted. Cobalt, copper, aluminum, and other elements of the battery are recovered using pyro and hydrometallurgical methods, mixing it all together [8]. However, the gross amount of battery recycling is still coming from small devices such as laptops and mobile phones. Once EV batteries begin to come at high rates, the industry will evolve accordingly. Maybe if batteries were manufactured in a way that they are easier to dismantle or re-use (following eco-design principles) [8], this process would be less expensive and much more interesting from an economic perspective. Nevertheless, arising policies and taxes in carbon pricing and footprint, together with the new technology developments in material reuse and recycle might impact the previous statements.

RELEVANT RECENT ARTICLES ON ENVIRONMENTAL AND SOCIAL IMPACTS OF LI-ION BATTERIES

REVIEW ON GREENER BATTERY CELLS [1]

Cradle-to-cradle, requirements, LCA, sustainability.

Li-ion batteries are among the state-of-the-art technologies able to meet most of the key requirements of the industry at a justifiable cost. However, the industry must not forget to assess the impact these have on the planet and its inhabitants. This review provides a deep cradle-to-cradle life cycle assessment of the battery cell, providing different approaches for the development of "greener" Li-ion batteries. In addition, alternative battery technologies are evaluated regarding their sustainability aspects and competitiveness.

READ MORE

HUMAN RIGHTS ABUSE IN D.R. CONGO IN COBALT EXTRACTION [2]

Social sustainability, cobalt, working conditions, impacts.

This report highlights the harmful conditions in which cobalt miners, including the high number of children, in the Democratic Republic of the Congo work. Using basic low-tech tools, miners dig out rocks from tunnels deep underground under poor safety conditions and minimal protective equipment. Besides, the supply chain and prolonged exposure to such material have fatal health effects on the workers. Thus, the report gives a full overview of all social impacts of the cobalt extraction process.

READ MORE

THE ENVIRONMENTAL AND SOCIAL COSTS OF THE LITHIUM-ION BATTERY INDUSTRY [3]

Extraction, impact, lithium, cobalt, nickel.

The extraction of the materials within Li-ion batteries has a serious impact on the planet. Such is the case that some experts in the field describe the process as invasive, harming the landscape, destroying the water resources, and polluting the earth and the local wells. The following articles provide example cases on the environmental and social impacts of lithium, cobalt, and nickel mining and processing.

READ MORE HERE and HERE

GLOBAL BATTERY ALLIANCE IN THE SEARCH FOR SAFER AND MORE SUSTAINABLE BATTERY SUPPLY CHAINS [4]

The Global Battery Alliance, value chain, investment, costs.

The Global Battery Alliance (GBA) is a public-private collaboration platform of 70 organizations founded in 2017 to help establish a sustainable battery value chain. The transport industry needs to actively react to current supply chains and establish sustainable market conditions while accelerating battery deployment in support of this vision and attract more investment. Batteries also need to become more affordable through lower production costs, lowering emissions, eliminating human rights violations, ensuring safe working conditions across the value chain, and improving repurposing and recycling.

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BIOMASS: A MORE SUSTAINABLE OPTION FOR LI-ION BATTERY ELECTROLYTES [5]

Biomass electrodes, binder, decarbonise, biowaste

Storage of energy still relies on harmful heavy metals in batteries. Therefore, research on biomass-derived electrodes has been taken up by a multitude of researchers worldwide. Considering that electrodes in batteries could be composed of all kinds of carbonised and noncarbonised biomass, biomass-based binders can replace toxic halogenated commercial binders to enable a truly sustainable future of energy storage devices. This report summarises the recent research progress in this rapidly emerging field, with a focus on potentially fully biowaste-derived batteries.

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CRITICAL RAW MATERIALS RESILIENCE: GREATER SECURITY AND SUSTAINABILITY [6]

Material supply, resilience, actions.

European industrial ecosystems must become more resilient and sustainably secure their material supply to scale up clean and digital technologies. Therefore, the European Commission in close partnership with other EU institutions, the European Investment Bank, Member States, regions, the industry, and other key stakeholders are moving forward with the deployment of a sustainable strategic plan by 2022. More details in regards to its strategic priorities and actions can be found in the following article.

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ARE ALL-POLYPEPTIDE BATTERIES THE SOLUTION TO THE CHALLENGES FACED BY CURRENT EV BATTERIES? [7]

Recycling, metal-free, redox-active.

“The rate of recycling Li-ion batteries right now is in the single digits. There is valuable material in the Li-ion battery, but it’s very difficult and energy-intensive to recover,” states Jodie Lutkenhaus, Professor of Chemical Engineering at Texas A&M University. The following article highlights and further explains the benefits of developing metal-free, all-polypeptide organic radical battery composed of redox-active amino-acid macromolecules and how these entail significant progress toward sustainable, recyclable batteries that minimise dependence on strategic metals.

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CHALLENGES IN THE DECONSTRUCTION OF BATTERIES FOR THEIR RECYCLABILITY [8]

Extraction, impact, lithium, cobalt, nickel.

Most of the valuable materials extracted for recycling are found in individual battery cells. However, current EV batteries are designed to increase robustness, which makes disassembly cumbersome. For this reason, today’s recycling methods are still in their infancy. After the battery is discharged and the case is removed, modules are shredded and thrown in a heater. Lighter materials like lithium and manganese burn, leaving behind an alloy slurry that contains higher-value metals like copper, nickel, and cobalt, which can be purified using strong acids. This pyro- and hydrometallurgical recovery require large amounts of energy and produce hazardous gases and waste.

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THE IMPACTS OF THE TRANSPORT INDUSTRY IN EUROPE [9]

Pollution, emissions, impacts, regulations, policies, EU.

The transport industry is among the most impactful sectors contributing to climate change and atmospheric and noise pollution in the EU. Although some other industries such as the energy sector have reduced their emissions since 1990, the ones coming from transport have increased, representing a quarter of the overall GHG emissions in Europe. The following article summarises the different impacts the industry has on the planet and brings up some new regulations and policies coming from the EU.

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SUSTAINABILITY ANALYSIS OF THE ELECTRIC VEHICLE USE IN EUROPE FOR CO2 EMISSIONS REDUCTION [10]

Decarbonisation, emissions, GWP, Europe.

This study focuses the analysis on how electric vehicle emissions vary when compared to internal combustion engine vehicles, depending on the energy mix and the efficiency during the use phase. For this to be done, there is a need to calculate the Global Warming Potential (GWP) associated with the electricity generation of the most profitable electric vehicles coming from European countries. Similarly, an electric vehicle’s use-phase energy efficiency is calculated under a wide range of driving conditions using the Monte Carlo method. Finally, the paper highlights which countries have a bigger potential for decarbonisation from the introduction of EVs.

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END OF ELECTRIC VEHICLE BATTERIES: REUSE VS. RECYCLE [11]

Recycling, reusing, circular economy, battery manufacturers, electric vehicle.

The global EV market is significantly increasing and hence battery consumption. The challenge in the market is to find an optimal solution from two options, whether to recycle the battery after its first use in the EV or to re-use it (second life). Looking at the rate at which EVs are deployed in the market and coupling the concepts of reusing and recycling together, strategically this would form a circular economy. Once the infrastructure is developed for battery recovery for EVs, Europe's position can strengthen, and it could become one of the largest battery manufacturers and exporters as well.

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THE MID-POINT BETWEEN CIRCULAR ECONOMY, LCA AND CRADLE-TO-CRADLE [12]

Cradle-to-cradle,, LCA, circular economy, impacts.

Life Cycle Assessment, Circular Economy, and Cradle to Cradle are seen as interchangeable terms by some, and totally separate concepts by others. The following article takes a mid-point perspective for the optimal approach and concluding that, while an LCA study focuses primarily on reducing the negative impact, a product's sustainable performance can be maximized by bringing together the reliable data of quantitative LCA and C2C concepts to inform a wider circular economy.

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EVALUATING THE COST AND CARBON FOOTPRINT OF SECOND-LIFE ELECTRIC VEHICLE BATTERIES [13]

Extraction, impact, lithium, cobalt, nickel.

Most automotive Li-ion batteries are recycled but could be repurposed as second-life batteries since they have 70–80% residual capacity, which can be adequate for stationary applications. Even though second-life Li-ion batteries offer an opportunity to utilize an end-of-life product for energy storage applications, there is still high uncertainty in the quality and on whether these will provide similar cost and carbon emission reduction for the different stationary applications in all locations compared to new Li-ion batteries.

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OTHER TECHNICAL, MARKET AND POLICY DEVELOPMENTS

STRAUBEL IS WORKING ON MINIMISING THE MINING OF CRITICAL RAW WMATERIALS IN BATTERIES.

J. B. Straubel's mission, with the creation of the start-up "Redwood Materials", is to drastically reduce mining of raw materials such as nickel, copper, and cobalt over several decades by building out a circular or "closed-loop" supply chain that recycles and recirculates materials retrieved from end-of-life vehicle and grid storage batteries and cells scrapped during manufacturing. To do so, the organisation will combine pyrometallurgy processes (burning batteries to remove the unwanted materials) and hydrometallurgy (soaking the Li-ion cells in acids to dissolve the metals into a solution).

READ MORE HERE AND HERE

SOLVENT BASED DELAMINATION: AN INNOVATION TO RECOVER GRAPHITE AND LITHIUM FROM BATTERIES.

The supply scarcity and dependency in other geographical locations of the critical raw materials graphite and lithium are accelerating the urgency to recover these from existing batteries, ensuring domestic supply. Solvent-based delamination is a new process that separates active material powders from current collector foils using inexpensive, nontoxic solvents. These do not entail water and/or air pollution, nor damage to active materials and current collectors.

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LITHIUM EXTRACTION PLAN TAKES ROOT IN ARKANSAS: INTERVIEW WITH ROBERT MINTAK.

El Dorado's chemical industry and the state regulatory structure, along with plentiful water and inexpensive electricity, have smoothened the path for Standard Lithium, a technology developer for specialty chemicals and extractive processes. This organisation aims to extract through innovative technology: LiSTR (lithium stir tank reactor). The brine is a chloride matrix brine the reaches the plant at about 70°C, where it's mixed with a lithium-selective absorbent material. Adjusting the pH the technology can recover >90% of the lithium from the brine. The lithium is moved in a slurry through washing and thickening stages until it reaches a toothpaste consistency. Changing the pH again by introducing a diluted hydrochloric acid they obtain a raw lithium chloride solution recovering 90% of the lithium in a high-purity lithium chloride solution in less than a day. Hence, it has a lower footprint, higher recovery, and higher purity. This new technology is expected to reach a commercial scale within two years.

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REPORT ON U.S. 2019 BATTERY R&D ADVANCES.

America's Energy Department is leading the charge in curtailing U.S. dependence on critical materials, by reducing the amount of these in the battery production and recycling the materials that are already in use, while cutting down the costs for both, consumers and businesses. The following report shows the extensive battery research and development performed by this department in 2019.

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BIDEN ANNOUNCES ITS AMBITION TO REALLOCATE EXTRACTION PLANTS TO THE US.

"DOE will release a National Blueprint for Lithium Batteries that will codify the findings of the battery supply chain review in a 10-year, whole-of-government plan to urgently develop a domestic lithium battery supply chain." The blueprint from these will be discussed at a roundtable with various experts from the battery supply chain this month. Moreover, DOE is about to leverage "$17 billion from the Advanced Technology Vehicles Manufacturing Loan Program to support the domestic battery supply chain" by e.g.: incentivising manufacturers of advanced battery cells and packs to expand or reallocate their manufacturing sites in the U.S.

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IREC’S REFLECTION ON DEVELOPMENTS IN COMPARISON WITH COBRA

Victor José Ferreira Ferreira

Senior researcher at IREC

Professional background

Victor is a chemical engineer with a PhD in the matter from the University of Porto (2013). Currently, he works as a Senior researcher at IREC applying Life Cycle Assessment and cost methodologies to support the Circular Economy and Eco-designs of energy technologies.

Relation to/ Role in COBRA

Within COBRA, Victor works optimising materials, processes, energy consumption and treatment at the end of life considering the useful life of products, processes and services from the environmental, economic and social point of view.

The work performed in COBRA will contribute to overcoming challenges to solve several problems highlighted in the previous sections. In particular, our research addresses one of the main issues involving environmental and social implications in the battery value chain, as it is developing new cobalt-free battery generations, based on LNMO chemistry for their cathodes. The project is also in the direction to reduce the dependence of CRM without neglecting to fulfill requirements in terms of cell energy, rate-capability, and life cycle. The project is focused on the design of anodes based on silicon and graphite as active particles to increase the anode performance when compared with pure graphite. However, to avoid the additional incorporation of environmental burdens associated with silicon, the project considers the use of recycled silicon from waste streams, which is in line with the circular economy principles. Additionally, other novel components are being used in the development of new electrolyte solutions, and more sustainable and energy-efficient battery-pack manufacturing. At the moment, the COBRA consortium is working on the design of the battery system at all levels (material, component, cell, module, and battery pack). The environmental, economic, and social performance from an LCA perspective of these innovations will be evaluated for the different alternatives to provide guidelines in the design of greener batteries and an easier management in end-of-life scenarios involving recycling technologies and 2nd life usages, which will reduce the use of material resources and consequently their environmental impacts.

INTERVIEW WITH VICTOR JOSÉ FERREIRA FERREIRA

Q1: How would you personally tackle the issue of not being able to assess and perform an LCA of the battery on its own?

I would seek support from experts to help me applying the LCA methodology, in particular in the battery field. This is a methodology that despite being standardized, each researcher or technician can consider different criteria, scopes, and objectives. It implies collaborative work with other researchers dedicated to the battery LCA studies. While conducting the LCA, we must pay attention to the data collection process, since the battery value chain involves complex processes, especially in the production phase. Data for the foreground processes must be of quality, thereby, we should seek close collaboration with the manufacturers and entities dedicated to recycling processes. In addition, we must have recognized and updated databases for the background processes (raw material extraction and energy sources). These can be private and public databases, for example, those that we public databases, for example, those that we can find in the European Platform on Life Cycle Assessment. On the other hand, we have to be careful when making an environmental comparison between products using the LCA approach, since different results can be found in literature. I would look for the latest trends, methods or recommendations for the application of LCA when having to evaluate a new generation of batteries being developed with respect to other conventional ones to report a reliable LCA.

1. Clear review goal/scope definition
2. Critical review of references
3. Identify significant parameters
4. Harmonise parameters
5. Statistical supportive analysis
6. Results and discussion

Q2: As all the assessment options discussed throughout the paper are mainly based on analysing the environmental and economic sustainability of the different phases, what do you consider the best option to monitor or assess the social impacts of batteries? How is this done currently within the industry?

Most battery sustainability studies are focused on economic and environmental aspects. Battery manufacturers have given little attention to the social implications, probably due to the difficulty of assessing quantitatively the social impacts of batteries following the LCA methodology because of current sources of data and social categories. However, researchers are developing new methods for quantification. From my point of view, to provide a picture of social impacts related to batteries, the supply chain from mining companies to battery manufactures should be monitored, as the activities associated with the raw material extraction generate considerable impacts around the local communities where these are mined. Moreover, in order to close the loop and enhance the circular economy of batteries, the effect of recycling/re-use of batteries should be taken into account. Battery recycling offers an opportunity to maximize the use of materials before their eventual disposal to reduce the raw material extraction and the energy involved. The second-life of EV batteries is also a very promising pathway for reducing the cumulative social impacts of batteries and a new opportunity to generate new business models. Under this context, battery researchers and manufacturers have a moral responsibility to analyse where the social conflicts, risks or opportunities, within their activities occur.

Q3: Considering there are different LCA templates and indicators, which one is the one chosen by COBRA for the project and why?

The COBRA project's LCA indicators are based on recognised standards and guidelines for the proper evaluation of products and systems (that can be found in the COBRA report. For the environmental performance description, several metrics are selected around energy consumption, climate change effects, and primary energy demand. The economic aspects are assessed through analysis of CAPEX and OPEX variables and, also, the end-of-life evaluation on the total economic impact of the battery pack. While the social evaluation, performed by an experienced external partner, includes the analysis of potential labour abuse-related risks and safety and health risks derived from the use of the developed technology. We can find all chosen indicators in the following COBRA report.

Q4: What are the differences and similarities between COBRA's approach and the market's/industry's general approach when addressing the impacts of state-of-the-art Li-ion batteries?

The LCA methodology in use is similar to the one generally chosen in the market, which is focused on the production stage. However, the COBRA project also addresses the impacts from the early stages of cobalt-free battery development/design. The analysis of the environmental, economic, and social impacts, considering all lifecycle phases, will provide insights of the different developments at the material, component, cell, module, and battery pack level. In addition, recyclability and eco-design concepts are also considered to achieve the targeted sustainability performance of the new generation battery technology.

Second life applications and recyclability are expected to aid in reaching a more sustainable value chain, considering all three pillars: environmental, social, and economic.

Q5: How does the project contribute to solutions that encourage the recycling and repurposing of batteries?

COBRA project contributes to this taking a cradle-to-grave perspective in its LCA to provide the environmental benefits of full solutions, including their second life application and recyclability to reduce the consumption of raw materials. In contrast to the most common methods for recycling and recovery of metals (hydrometallurgical and pyrometallurgical processes), which have large environmental impacts, the COBRA project is developing a bioleaching method to recover materials, which is expected to have lower impacts. In addition, design aspects are being considered in the development of new battery generation to enhance the 2nd life applications based on their needs and requirements.

Q6: How do you foresee the future scenario of sustainable batteries and how will COBRA's outcome contribute to it?

I think that the future for sustainable batteries will be focused on considerable efforts to minimise the material and manufacturing impacts of Li-ion batteries, in particular new electrode designs and alternate materials that alleviate cobalt demand and provide performance advantages, such as higher energy and power density or longer lifetime. In addition, the new designs will include increasingly the circular economy principles that can guide sustainable management of the growing stream of end-of-life batteries considering recovery through hierarchy pathways, i.e., direct reuse of used batteries in vehicle applications, cascading reuse in less demanding energy storage applications, material recovery through recycling processes with lower impacts, and sending a minimum amount of material to downstream disposal. The COBRA project hence contributing to the design of new cobalt-free batteries, high energy density, and rate of self-discharge including 2nd life aspects and recyclability with a holistic LCA assessing the three pillars of sustainability: environmental, economic, and social.

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