The ranging impact of materials used in EV batteries

Zemo automotive LCA webinar series
Insights into EV battery life cycle analysis

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Quantifying environmental impacts

Internationally recognised approach

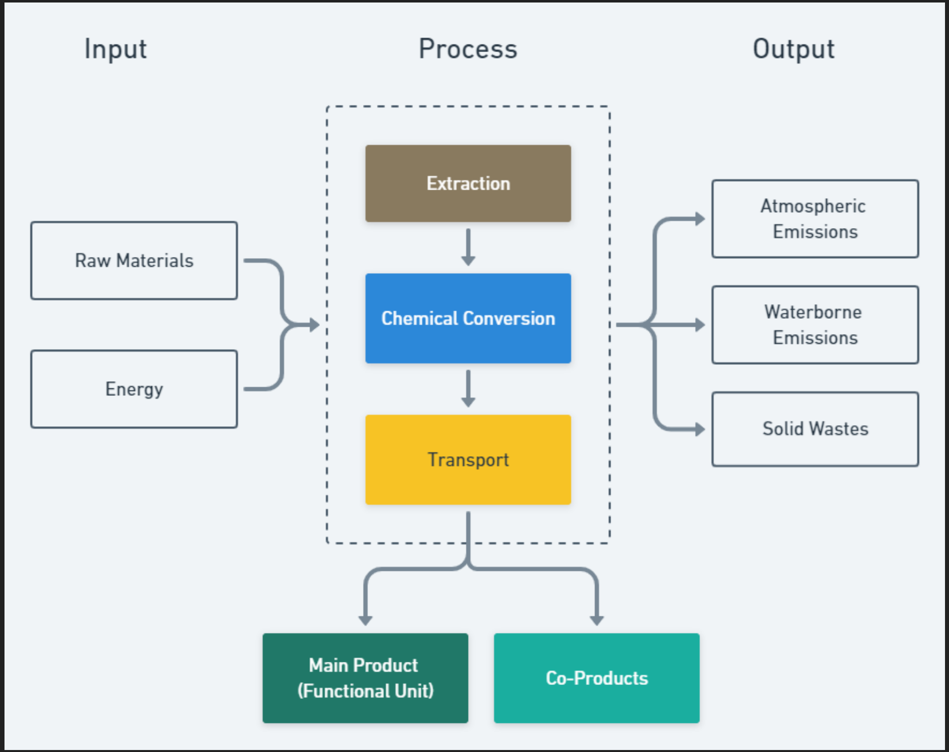
What is a life cycle assessment?

Minviro's Life Cycle Assessment service is an inventory of environmental impacts tailored for mining, mineral processing and refining projects.

The LCA models a range of environmental impacts, ranging from CO_2 intensity to water use and particulate matter formation, and complying with ISO 14040-14044 standards. ISO 14067 follows the same guidelines, only reporting on the climate change impact category.

Minviro's approach makes the environmental impacts of resource projects and operations clear and transparent through quantification.

Environmental hotspots are identified, providing insights into suitable mitigation strategies, ensuring that the raw materials for the low-carbon economy are sourced at minimum environmental impact.

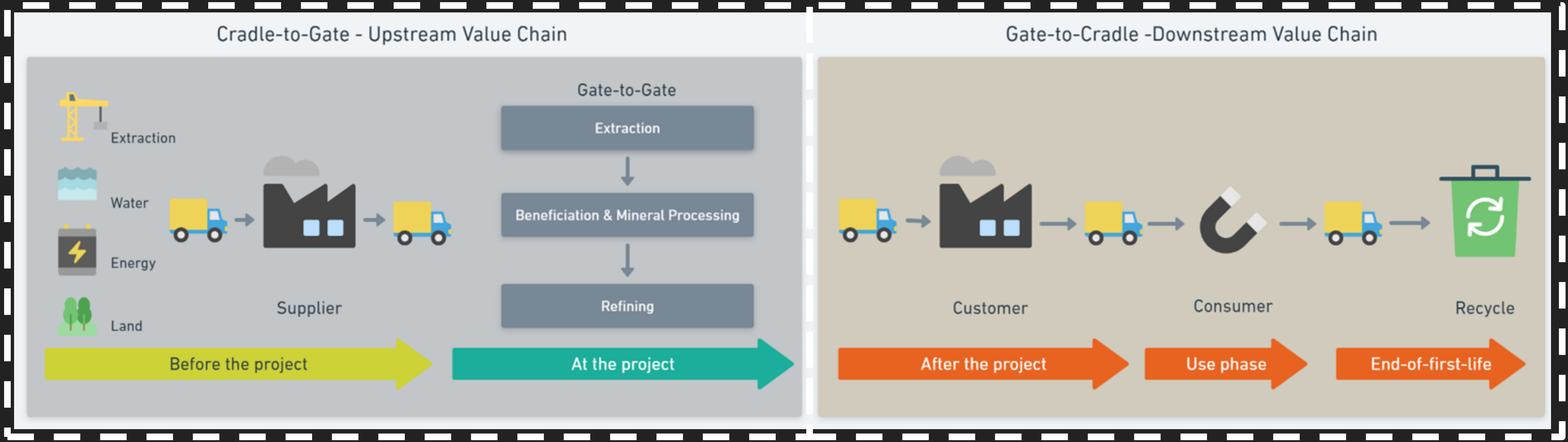


Climate Change is one of many impact categories

Global Warming Potential (kg CO_2 eq. per kg product)

Mining industry commonly reports on foreground processes:

- Scope 1 emissions: represents direct combustion of fuel and energy sources on site
- Scope 2 emissions: represent embodied emissions of consumed electricity
- Scope 3 emissions (upstream) represents embodied emissions of other consumables (eg. reagents)



Scope 1, 2 and upstream scope 3 impact is responsibility of miner.

Downstream scope 3.

The cradle-to-gate impact of NMC-811 battery production

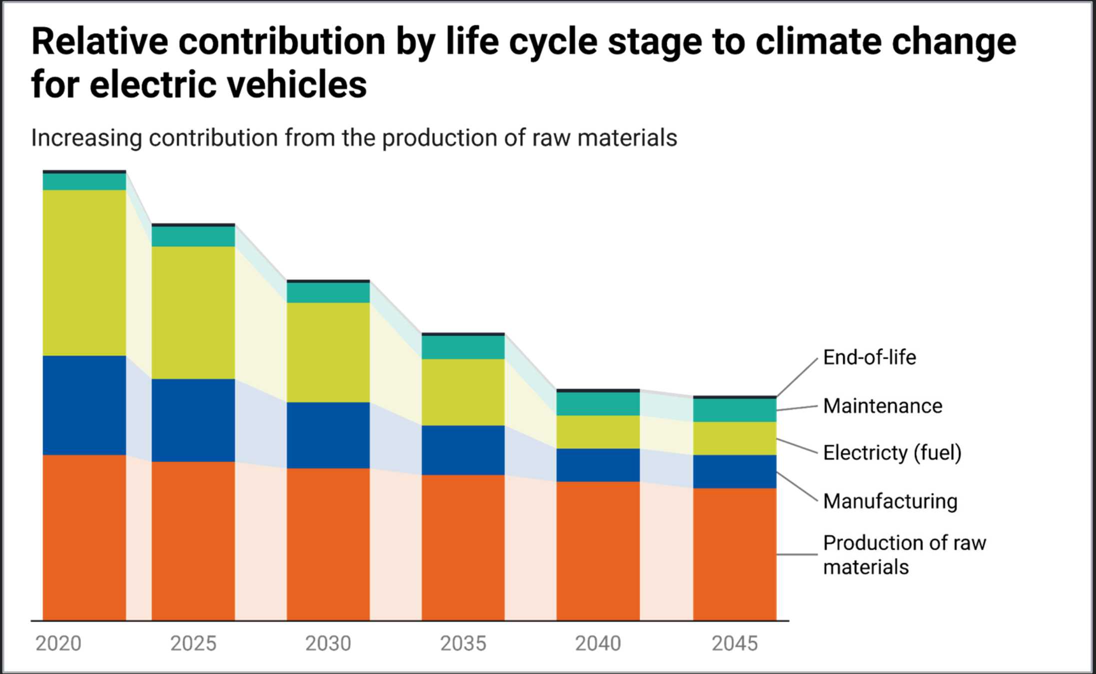
What are the LCA impacts of battery production

Impacts associated with EV battery production over time

Trend for impacts for battery production

In the coming years, many regions will see increased renewable energy & lower CO_2 per kWh of power generated.

This will cut environmental impacts during the manufacturing and use phase of batteries and EVs, but the relative contribution to produce the raw materials will increase.



Production of NMC-811

System boundary

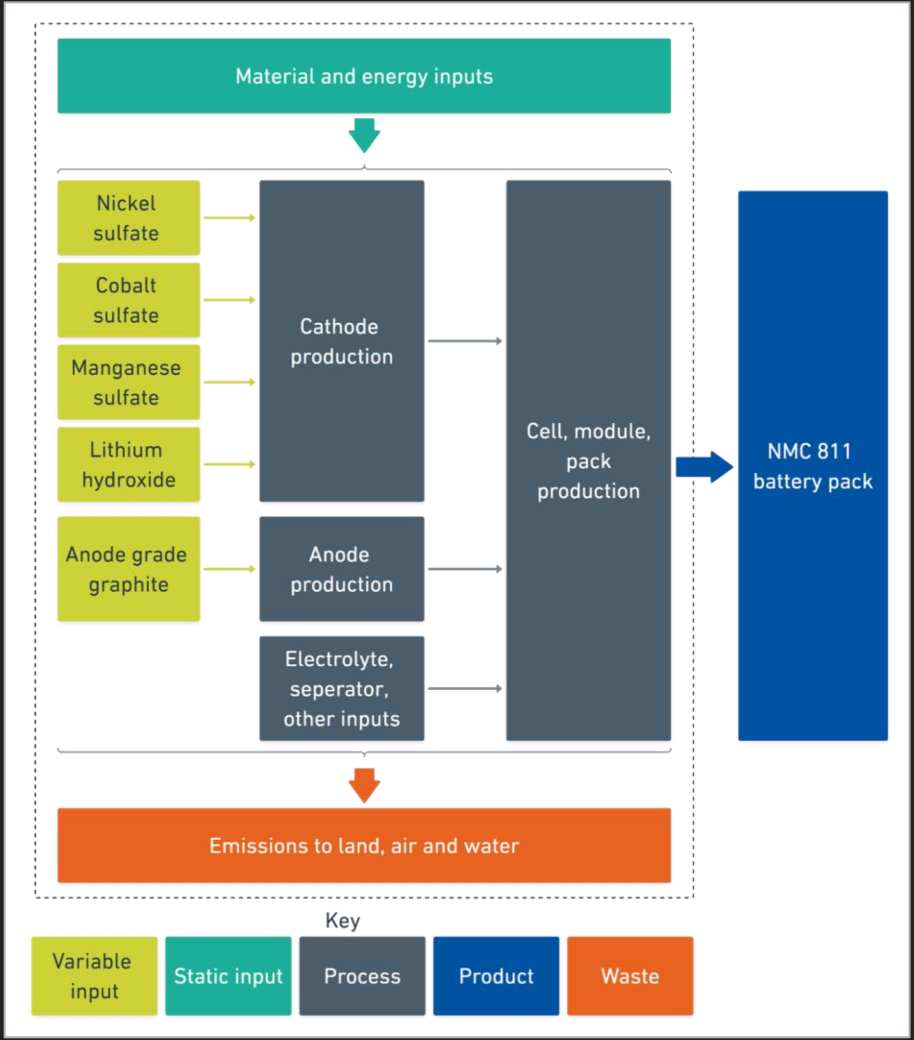
Functional unit - 1 kWh NMC-811 battery pack

Cradle-to-gate study - no use phase

Production of nickel sulfate, cobalt sulfate, manganese sulfate, lithium hydroxide, and anode grade graphite from different production routes.

All other inputs are static in the model.

https://greet.es.anl.gov/



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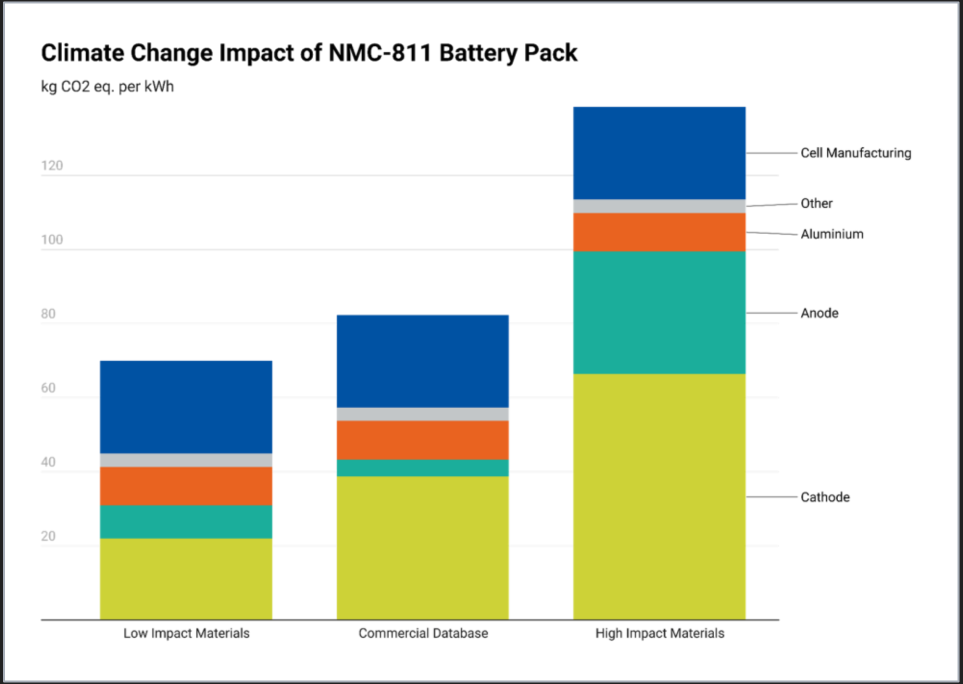
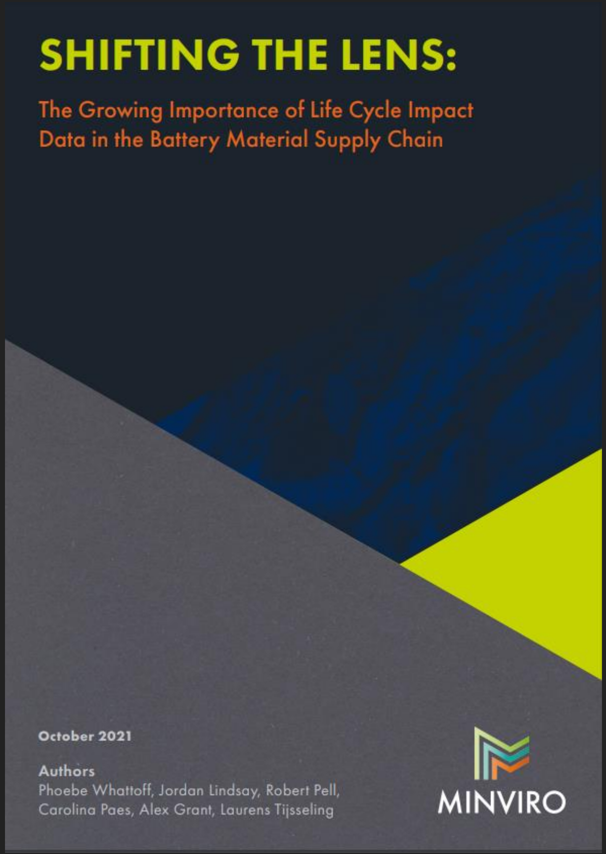
Shifting the lens

LCA of battery raw materials





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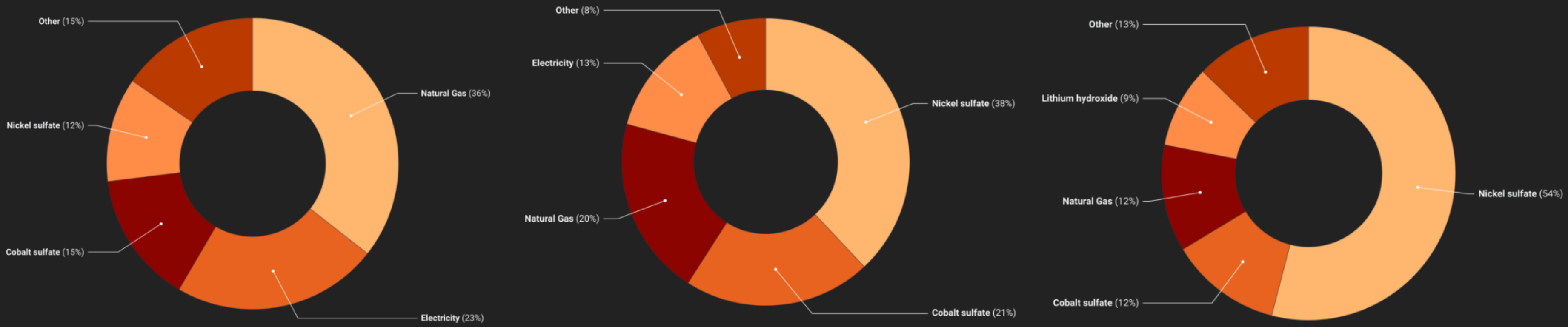
Sourcing scenarios dictates the hotspots

What ‘matters most’ for an NMC811 LIB

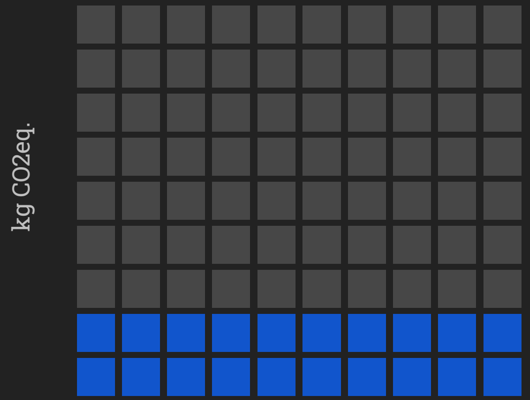


This study of NMC-811 indicates the importance of sourcing low CO_2 nickel sulfate. These impacts only represent currently used production routes, and some future routes could potentially lead to an even broader range of impacts. As conventional technologies expected to be applied to lower grade and less pure resources, environmental impacts will increase alongside increased reagent, material and energy use.

Example of different nickel sulfate LCA impacts

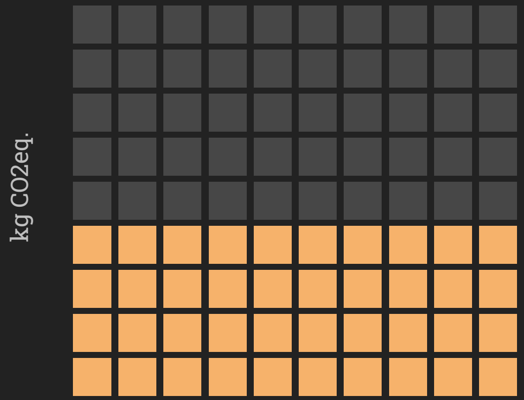
Cradle-to-gate study on $NiSO_4$ production

Terrafame public LCA



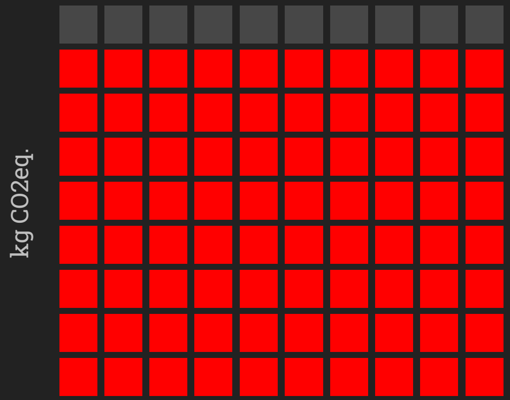
~1.8 kg CO_2 per kg $NiSO_4$

Nickel Institute LCA



~5.4 kg CO_2 per kg $NiSO_4$

Laterite project public data - internal calculations



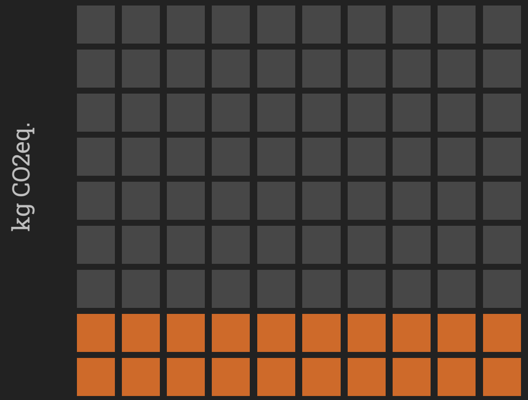
~ 11.1 kg CO_2 per kg $NiSO_4$

The internal LCA calculations should not be considered as equivalent to an ISO compliant LCA and numbers should be interpret as indicative.

The same functional material can have different environmental impacts

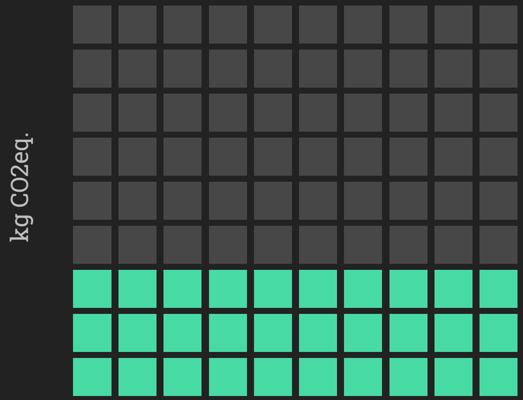
Minviro's study on lithium hydroxide production

Chilean Brine



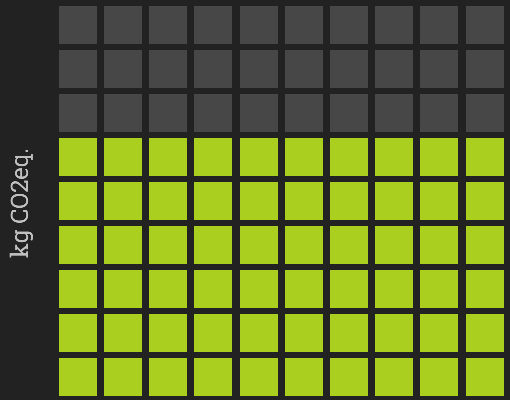
~5 kg CO_2 per kg LiOH

Argentine Brine



~7 kg CO_2 per kg LiOH

Australian Spodumene



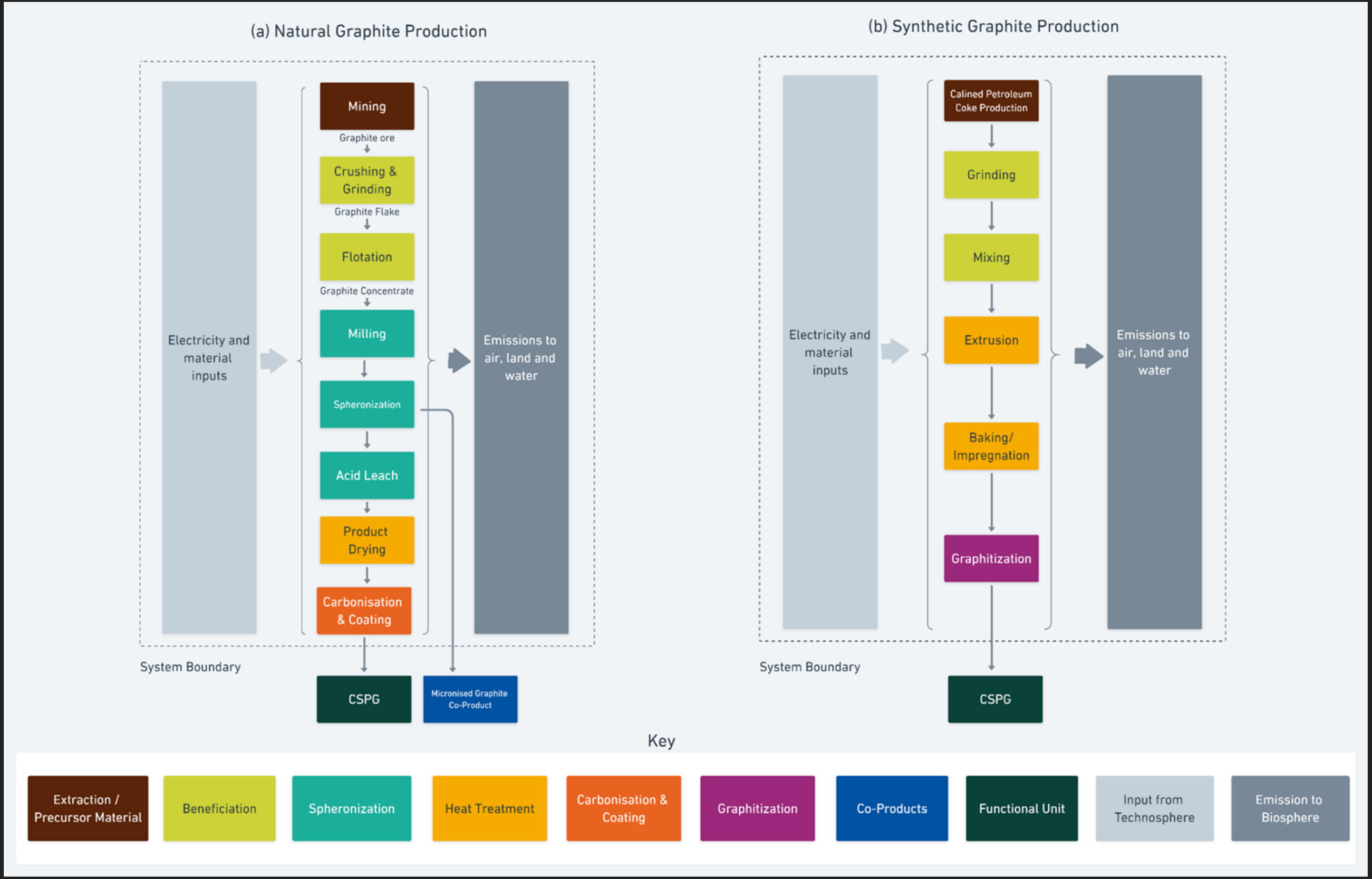
~ 16 kg CO_2 per kg LiOH

See the full whitepaper on this link: The Climate Change Impact of Lithium Hydroxide for the 2020s

System boundary

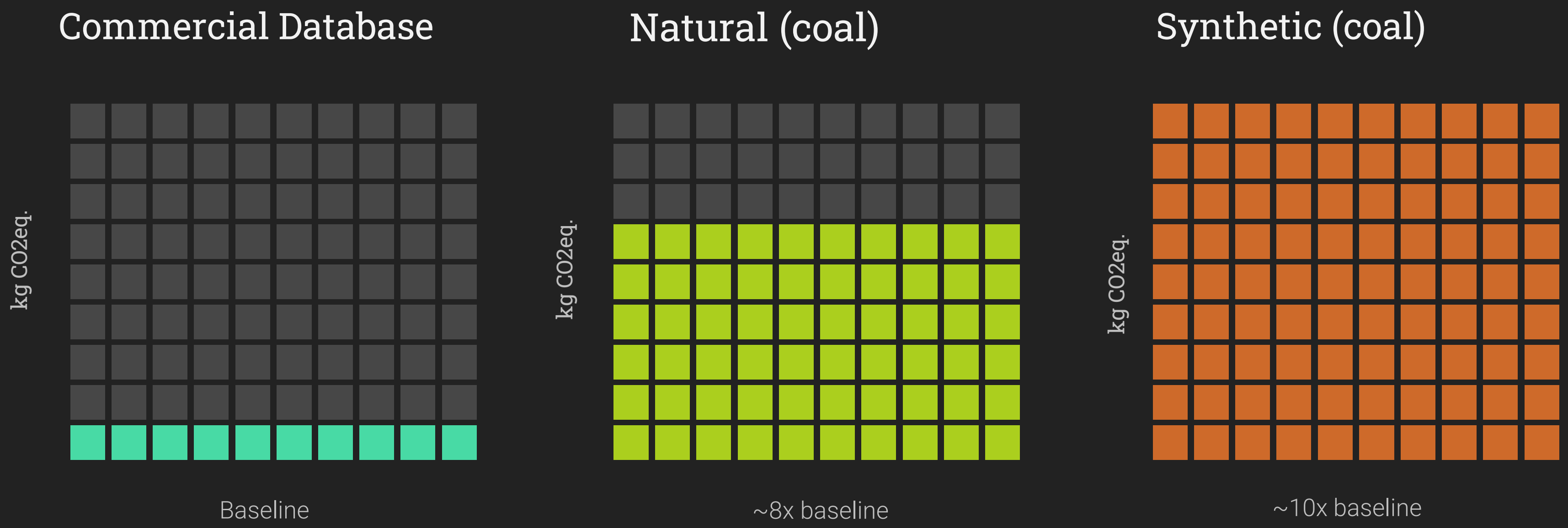
LCA of Anode Graphite Material

The same functional material can have different environmental impacts



The same functional material can have different environmental impacts

Cradle-to-gate study on battery grade graphite production



See the full whitepaper on this link: **The Climate Change Impact of Graphite Production**

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nature reviews earth & environment

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BGS British Geological Survey

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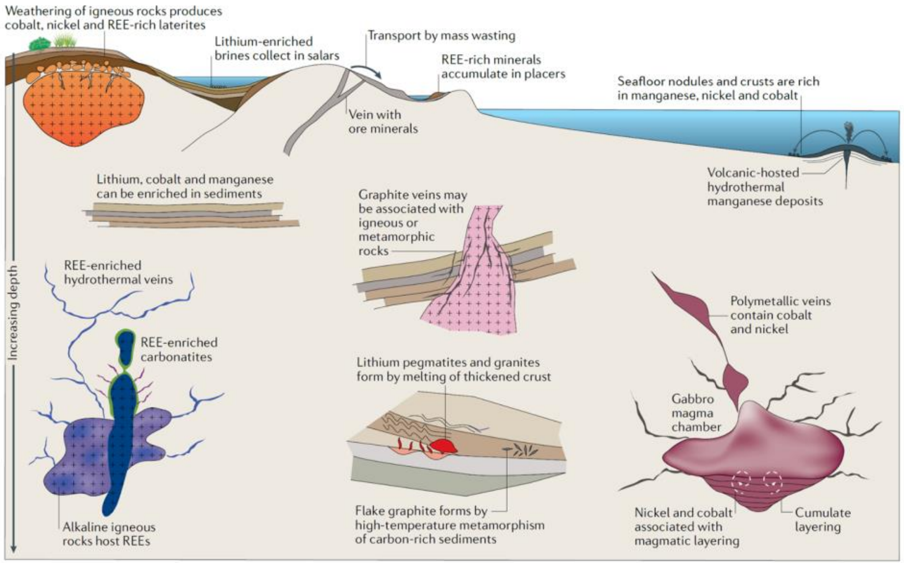
GTK



REVIEWS

Check for updates

Towards sustainable extraction of technology materials through integrated approaches

Robert Pell[1,2], Laurens Tijsseling[2], Kathryn Goodenough[3], Frances Wall[1], Quentin Dehaine[4], Alex Grant[2], David Deak[2], Xiaoyu Yan[5] and Phoebe Whattoff[2]

Abstract | The transition to a low-carbon economy will be material-intensive. Production of these materials (from mining to manufacturing) incurs environmental costs that vary widely, depending on the geology, mineralogy, extraction routes, type of product, purity of product, background system or manufacturing infrastructure. Understanding the impacts of the raw materials underpinning the low-carbon economy is essential for eliminating any dissonance between the benefits of renewable technologies and the impacts associated with the production of the raw materials. In this Review, we propose an integrated life cycle assessment and geometallurgical approach to optimize the technical performance and reduce the environmental impact of raw material extraction. Life cycle assessments are an effective way of understanding the system-wide impacts associated with material production, from ore in the ground to a refined chemical product ready to be used in advanced technologies such as batteries. In the geometallurgy approach, geologists select exploration targets with resource characteristics that lend themselves to lower environmental impacts, often considering factors throughout the exploration and development process. Combining these two approaches allows for more accurate and dynamic optimization of technology materials resource efficiency, based on in situ ore properties and process simulations. By applying these approaches at the development phase of projects, a future low-carbon economy can be achieved that is built from ingredients with a lower environmental impact.

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The transition to renewable energy, especially the electrification of transportation systems, will require a notable quantity of technology metals and materials[1,2]. The transition from internal combustion engine vehicles to electric vehicles (EVs), along with the deployment of solar photovoltaic and wind power, are considered three major technologies for decarbonization[3] (FIG. 1). Access to raw materials that enable these technologies, termed here as 'technology materials', is critical to the energy transition. However, the systems that deliver these engineered materials come with local and global pressures on the environment. These impacts need to be quantified and, wherever possible, mitigated[4]. It is also essential that the environmental impact of extracting, processing, refining and embedding these raw materials in the low-carbon economy does not limit the impact reduction of the technology itself or substantially displace impacts to other regions or impact categories. The social and governance issues for the production of these raw materials can also be significant and can be challenging to resolve[5,6].

There is a strong consensus that the demand for technology materials required for the energy transition will increase substantially in the 2020s. For example, between 2015 and 2050, global EV stock is estimated to increase from 1.2 million to 965 million passenger cars, and battery storage capacity will increase from 0.5 gigawatt-hours to 12,380 gigawatt-hours[7]. Some have claimed that the extractive industry will face challenges adapting to this rapid increase in demand[8–11]. Therefore, it is vital to understand how mineral deposit characteristics can influence environmental impacts as new projects advance over the coming decades[12].

Lithium-ion batteries (LIBs) are currently the dominant technology for energy storage in EVs[13]. They can contain a combination of lithium, cobalt, manganese, aluminium, iron and nickel in the cathode and graphite in the anode, as well as aluminium and copper in other pack components (FIG. 1a). A range of competing battery cell chemistries dictate the proportion and form of the materials required. Current estimates indicate that growing demand for LIBs will mean demand for the necessary

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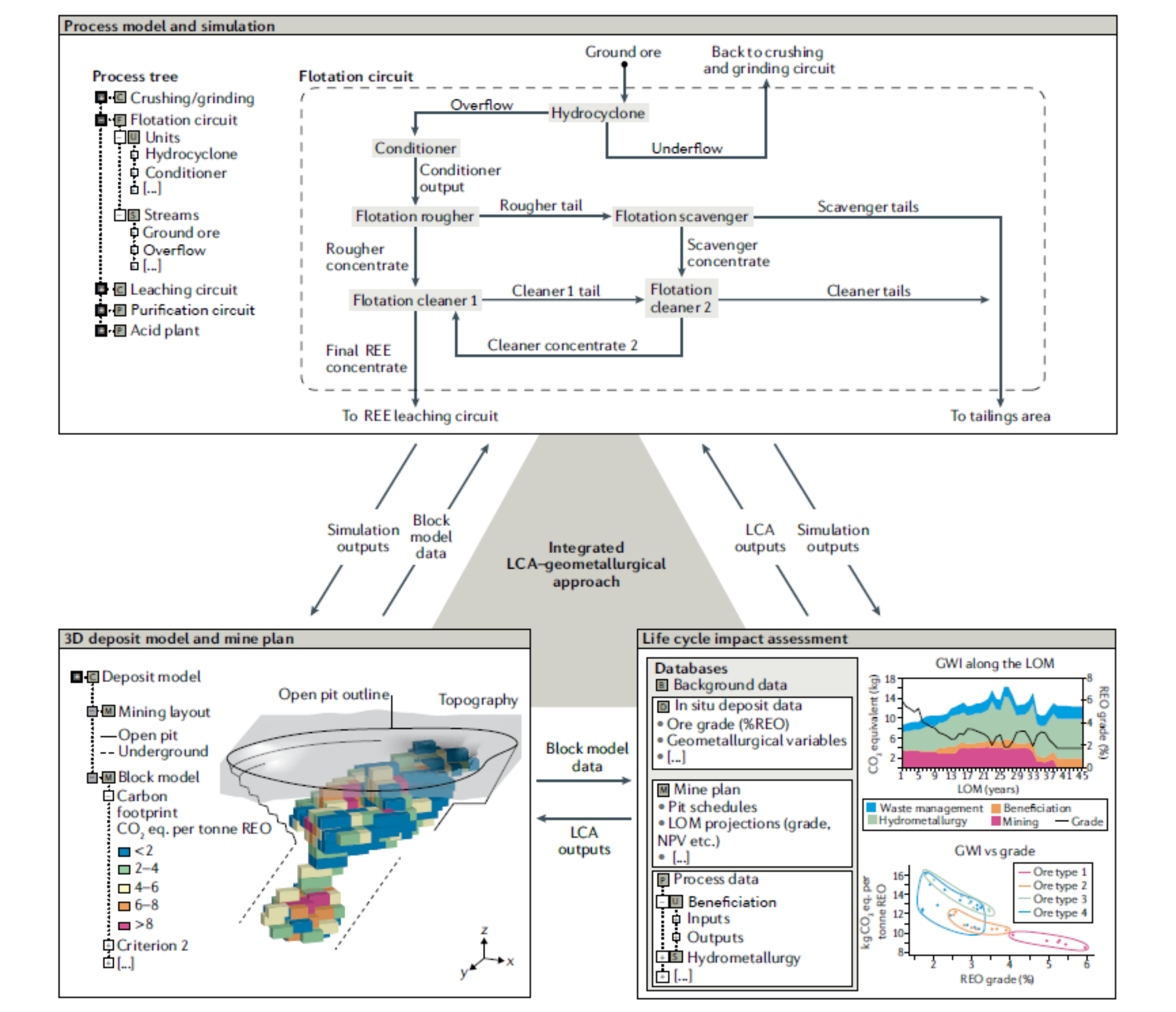


Integrating LCA

Geometallurgy

Geometallurgy and integration with LCA

- Best possible use of mineral raw materials in terms of energy and resource efficiency
- Understanding and measuring geological, mineralogical and metallurgical ore properties & can be integrated into a spatial predictive model for mineral processing design and operation, mine planning and financial analysis of future or existing mines
- Can also be used to promote resource efficiency and reduce the environmental impacts

LCA studies should not be static

A Life of Mine Case Study - Temporally-Explicit LCA

Why static LCA values are not always representative...

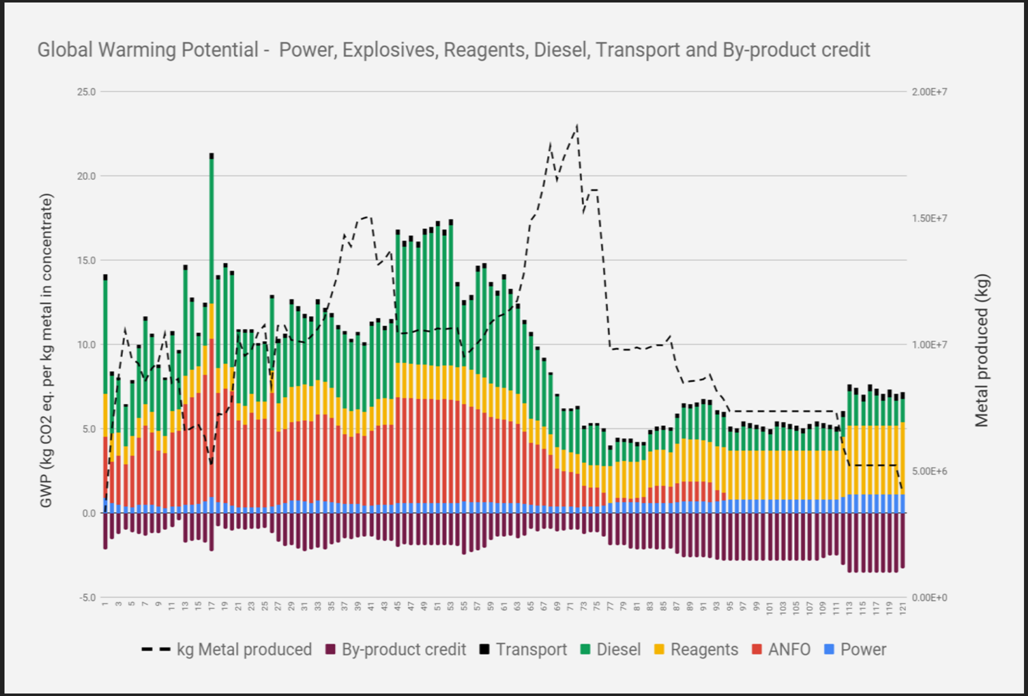
- Average GWP: 9.4 kg CO_2 eq.
- Maximum GWP: 21.0 kg CO_2 eq.
- Minimum GWP: 4.0 kg CO_2 eq.

Results in all cases cover scope 1, 2 and upstream scope 3 emissions.

Embodied emissions (upstream scope 3) of ANFO, the largest contributor, followed by direct emissions of diesel combustion.

Negative values for carbon sequestration potential of tailings.

This is based on a metal in concentrate case study.



Minviro Services - Software

MineLCA User Features

Features:

- LCA at any level of user expertise for consultancy-quality results
- Functionality for operations and developments
- Simple interface with streamlined input process - no jargon
- Access to vast LCA database for >>10,000 material and energy inputs
- Specific mining/mineral processing focus - no other tool on market
- Environmental impacts beyond CO_2 output (see next slide)
- *Mitigation feature for high impactors*
- *API connection for automated data entry from ESG*

A team of mining, mineral processing and chemical engineers

Minviro's Team

Robert Pell PhD.

Founder & Director

Robert founded Minviro after completing his PhD at Camborne School of Mines & Tsinghua. He is a specialist in REE.

Laurens Tijsseling

Sustainability Manager

Laurens is Sustainability Manager at Minviro. He previously worked as a Process Engineer in Sibelco Group.

Phoebe Whattoff

Sustainability Analyst

Phoebe is Sustainability Analyst at Minviro. She is a geologist by training and has previously studied the carbon sequestration potential of minerals.

Alex Grant

Snr. Lithium Expert

Alex is Principal at Jade Cove Partners & co-founder of Lilac Solutions, a Silicon Valley direct lithium extraction technology company.

David Deak PhD.

Snr. Lithium Expert

David obtained his PhD at the University of Oxford. His experience includes Tesla, Lithium Americas and currently works with Azimuth Capital Management

A team of mining, mineral processing and chemical engineers

Minviro's team

Conor Hickey

Snr Full Stack Developer

Conor has completed a undergraduate and masters in software development. He has extensive experience developing both front and back end having previously worked with Ericsson.

Feruzjon Majidov

Junior Developer

Feruzjon recently completed undergrad studies in software development.

Jordan Lindsay

Sustainability Analyst

Jordan recently completed his PhD at Camborne School of Mines and has experience in mining engineering. His PhD was focussed on PGM geology.

Carolina Paes

Sustainability Analyst

Carolina is MSc in Sustainable and Innovative Natural Resources Management with knowledge on LCA for Lithium and Cobalt.

Prof. Frances Wall

Academic Advisor

Frances has extensive experience in rare earth geology and has worked on a number of sustainability focused research projects.

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Thank you

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More than carbon accounting

Life Cycle Impact Categories

1

Global Warming Potential

(kg CO_2 eq)

Radiative forcing as Global Warming Potential (GWP100)

2

Ozone depletion

(kg CFC-11 eq)

Steady-state ozone depletion potential

3

Human Toxicity

(CTUe)

Comparative toxic unit for humans as provided in the USEtox 2.1.

4

Particulate Matter

(Disease incidence)

Human health effects associated with exposure to PM2.5 from the PM method recommended by UNEP

5

Ionising Radiation

(kBq U)

Human exposure efficiency relative to U235 using the Human health model as developed by Dreicer et al 1995

6

Photochemical ozone formation

(kg NMVOC)

Tropospheric ozone concentration increases from LOTOS-EUROS as applied in ReCiPe 2008

Internationally accepted and best practice

Life Cycle Impact Categories

7

Acidification

(Mol H+ eq)

Accumulated Exceedance

8

Eutrophication

(Mol N eq)

Accumulated Exceedance

9

Ecotoxicity freshwater

(CTUe)

Comparative toxic units for ecosystems derived from USEtox 2.1.derived from the HC20 instead of the HC50.

10

Land Use

(Dimensionless)

Soil quality index (biotic production, erosion resistance, mechanical filtration and groundwater replenishment) based on LANCA

11

Water Use

(kg world eq. deprived)

User deprivation potential (deprivation-weighted water consumption) from the AWARE method

12

Resource Use

(MJ)

Abiotic resource depletion from fossil fuels using CML