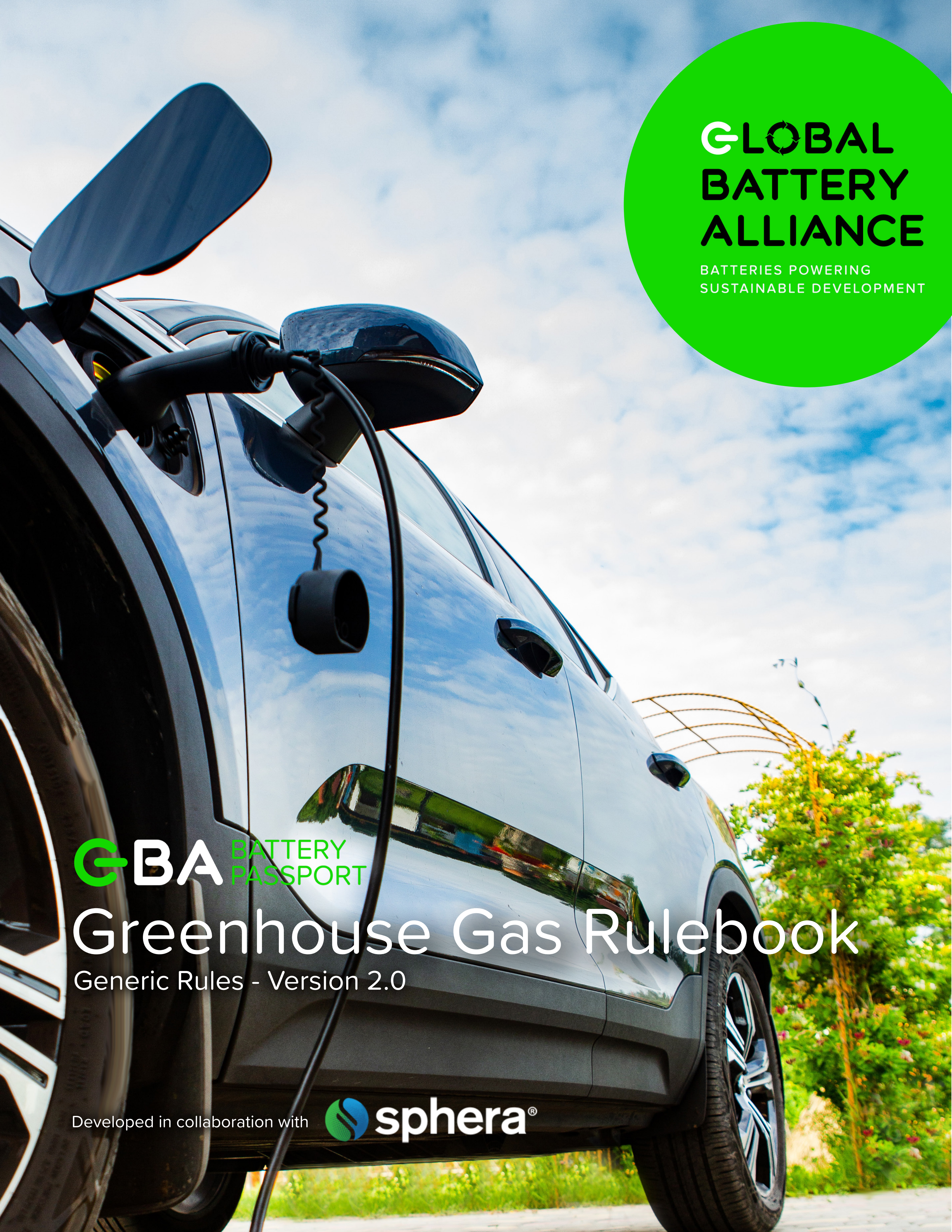

GLOBAL BATTERY ALLIANCE

BATTERIES POWERING
SUSTAINABLE DEVELOPMENT

GBA BATTERY PASSPORT

Greenhouse Gas Rulebook

Generic Rules - Version 2.0

Developed in collaboration with sphera®

Preface

The GBA envisions a global solution to provide transparency, accountability, and circularity in the battery value chain: the Battery Passport. The Battery Passport will both certify compliance with greenhouse gas emission legal and societal expectations and clearly differentiate more valuable batteries in the market based on their sourcing impact and performance.

The specific objectives of this version of the Greenhouse Gas Rulebook are to set globally harmonized rules that make "cradle-to-gate plus recycling" Battery Carbon Footprints transparent; and to allow decisions to be driven by reliable, accessible, and trusted data. The Rulebook aims to provide a sound method by which process-specific data is generated and collected in a homogeneous way and Battery Carbon Footprints across vendors in the battery value chain are comparable.

Development of this Rulebook has been overseen by the GBA's Greenhouse Gas Work Group, which was set up to define what stakeholders likely expect, and to set the high-level principles and operating rules upon which the Battery Carbon Footprint of the GBA Battery Passport is to be developed.

The services of Sphera Solutions GmbH were retained to:

- identify all the necessary parameters to be captured in order to calculate, in an understandable, standardized, accurate, differentiating, auditable and comparable way[1], the GHG footprint of given units of output across facilities,
- recommend, after consulting industry, civil society and governmental members of the GBA GHG Work Group, preferred feasible measurement options, and
- deliver a set of step-specific data collection templates with explanatory documentation.

The GBA's GHG Work Group comprised approximately 45 individuals from 41 GBA members representing activities across the full EV-battery value-chain (80%), civil society (12%), and government bodies (7%). Proportionate representation was ensured throughout the process.

About this Rulebook

In proposing this first public version of the GBA GHG Rulebook (v1.5), GBA members debated several key issues amongst themselves and proposed rules of least resistance – rather than rules that reflect unanimous positions. For example, GBA members have sought to balance transparency and progressive reduction of greenhouse gas emissions from cradle-to-gate production and recycling of batteries; incentivisation of rapid GHG emission reductions in wider electricity markets; and avoidance of double counting of renewable or low-carbon attributes of electricity (see Chapter 5.2.2). The Rulebook has now been revisited following GBA's engagement with external stakeholders, with a view to incorporating the feedback received.

Data calculation, sharing and transfer rules & tools (including decision mechanisms, data access protection, permission-based access, rule definition, calculation and operationalisation) are not in the scope of this Rulebook. These are being developed by other GBA Work Groups.

GBA experts recognise that further progress will require:

- Demonstrating practical applicability across relevant operations of the value chain.
- Ensuring the GHG Rulebook can be understandable for Small & Medium Enterprises
- Consistency across global battery carbon footprint standards (See Chapter 2)
- Regular verification/validation and revisions of Battery Passport (See Chapters 7 & 8)

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[1] Dubbed USADAC principles by the GBA's Greenhouse Gas Work Group

GBA BATTERY PASSPORT

Greenhouse Gas Rulebook

Generic Rules - Version 2.0

Developed in collaboration with Sphera

End-of-life rules developed in collaboration with Battery Pass

Facilitated by Drielsma Resources Europe

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List of Acronyms

BCF	Battery Carbon Footprint
BEV	Battery Electric Vehicle
BMS	Battery Management System
CAM	Cathode Active Material
CF	Carbon Footprint
dLUC	direct Land Use Change
DMS	Dense Media Separation
EF	Emission Factor
EoL	End-of-Life
EV	Electric Vehicle
GBA	Global Battery Alliance
GHG	Greenhouse Gas
GWP	Global Warming Potential
HMS	Heavy Media Separation
ILCD	International Cycle Data System
iLUC	indirect Land Use Change
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LFP	Lithium Iron Phosphate
LIB	Lithium-Ion Battery
MSP	Mixed Sulfidic Precipitate
NCA	Nickel Cobalt Aluminium
NMC	Nickel Manganese Cobalt
OEM	Original Equipment Manufacturer
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PGM	Platinum Group Metals
pCAM	Precursor Cathode Active Material
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute

Terms & Definitions

Active material
"Battery material directly linked to the electrochemical performance: includes the cathode, anode, electrolyte and separator" (Recharge, 2018)

Allocation
"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

By-product
"One of two or more products coming from the same unit process or product system. An output with an economic value above zero, for which demand at the specific production site is available, and evidence can be given that the by- product is used as intended. This term is used to distinguish from waste."

Co-product
"One of two or more products coming from the same unit process or product system. An output with an economic value above zero, for which demand at the specific production site is available, and evidence can be given that the co- product is used as intended. This term is used to distinguish from a main product."

Cut-off criteria
"Specification of the amount of material or energy flow or the level of significance of GHG emissions associated with unit processes or the product system to be excluded from a PCF study" (ISO 14067:2018, section 3)

Electric vehicles (EVs)
"All vehicles containing one or more Li-ion batteries that are specifically designed to provide electric power for traction (e.g., EV, HEV, PHEV, e-trucks, e-buses)".

End-of-life waste (post-consumer material or waste)
"Material recovered from waste generated by households or by commercial, industrial and institutional facilities in their role as end-users of a finished product" (CEN, 2020).

Functional Unit
"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20)

Hotspot
A hotspot in this Rulebook is defined as:

- A process input / output that has a high (≈>5%) impact on the overall GHG impact of the material, battery cell or battery for which the GHG emissions are calculated (e.g., impact of anode material graphite on the total GHG impact of a NMC LIB).
- A factor, parameter, driver of variation that has, due to existing variability, a high (≈>5%) impact on the overall GHG impact of the material, battery cell or battery for which the GHG emissions are calculated (such as the location of the electricity supply and / or the share between electricity and heat supply).

Indirect Land Use Change (iLUC)
"Occurs when a demand for a certain land use leads to changes, outside the system boundary, i.e., in other land use types. These indirect effects may be mainly assessed by means of economic modelling of the demand for land or by modelling the relocation of activities on a global scale." (European Commission, 2021)

Life Cycle
A view of a product system as "consecutive and interlinked stages related to a product, from raw material acquisition or generation from natural resources to end-of-life treatment " (ISO 14067:2018, section 3.1).

Life Cycle Assessment (LCA)
"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)
"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)
"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product"
(ISO 14040:2006, section 3.4)
(ISO 14044:2006, section 4.3.4.3.3)

Load factor
The load factor of a production facility is defined as the ratio between the actual volume produced by a production facility for a specific period and the designed capacity in terms of production output of the same production facility and period.

Passive material
"Battery material not directly producing the electrochemical performance: cell casing, battery casing and OEM parts" (Recharge, 2018)

Primary Data
"Data pertaining to a specific product or activity within a company's value chain. Such data may take the form of activity data, emissions or emission factors. Primary data is site-specific, company-specific (if there are multiple sites for the same product) or supply chain–specific. Primary data may be obtained through meter readings, purchase records, utility bills, engineering models, direct monitoring, material or product balances, stoichiometry or other methods for obtaining data from specific processes in the value chain of the company." (WBCSD, 2021)

Pre-consumer waste
Material diverted from the manufacturing process that cannot be reclaimed/reverted within the process that generated it. This includes, but is not limited to, ingots, grindings, sludges and residues. It excludes reutilized materials such as rework, regrind or process revert that are capable of being reclaimed within the same process (adapted from ISO, 2016).

Product system
"Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product" (ISO 14040:2006, section 3)

Recycled content
The proportion of material in the input to the production that has been recycled from a previous system.

Reference flow
"Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit" (ISO 14040:2006, section 3)

Secondary Data
"Data that is not from specific activities within a company's value chain but from databases, based on averages, scientific reports or other sources". (WBCSD, 2021). In this Rulebook secondary data are any data that are not primary data, i.e., all kind of data not directly measured or gathered from company owned information systems. Secondary data include e.g., life cycle inventory data from a third party, emission factors from inventory guidebooks, data from scientific papers and other kind of literature. (Note that data sourced from information systems or engineering models that collect or obtain data directly from specific processes in the value chain of the company (e.g., the International Material Data System [IMDS] of the automotive industry, shall be considered primary data).

Secondary Material
Input material that has been recovered from previous use or waste from another product system, e.g., recycled scrap metal, crushed concrete, glass cullet, recycled wood chips, recycled plastic granulate. Secondary material is measured at the point where the secondary material enters the product system from another product system (ISO 21930:2017, section 3.6.4).

1. Introduction

Cobalt

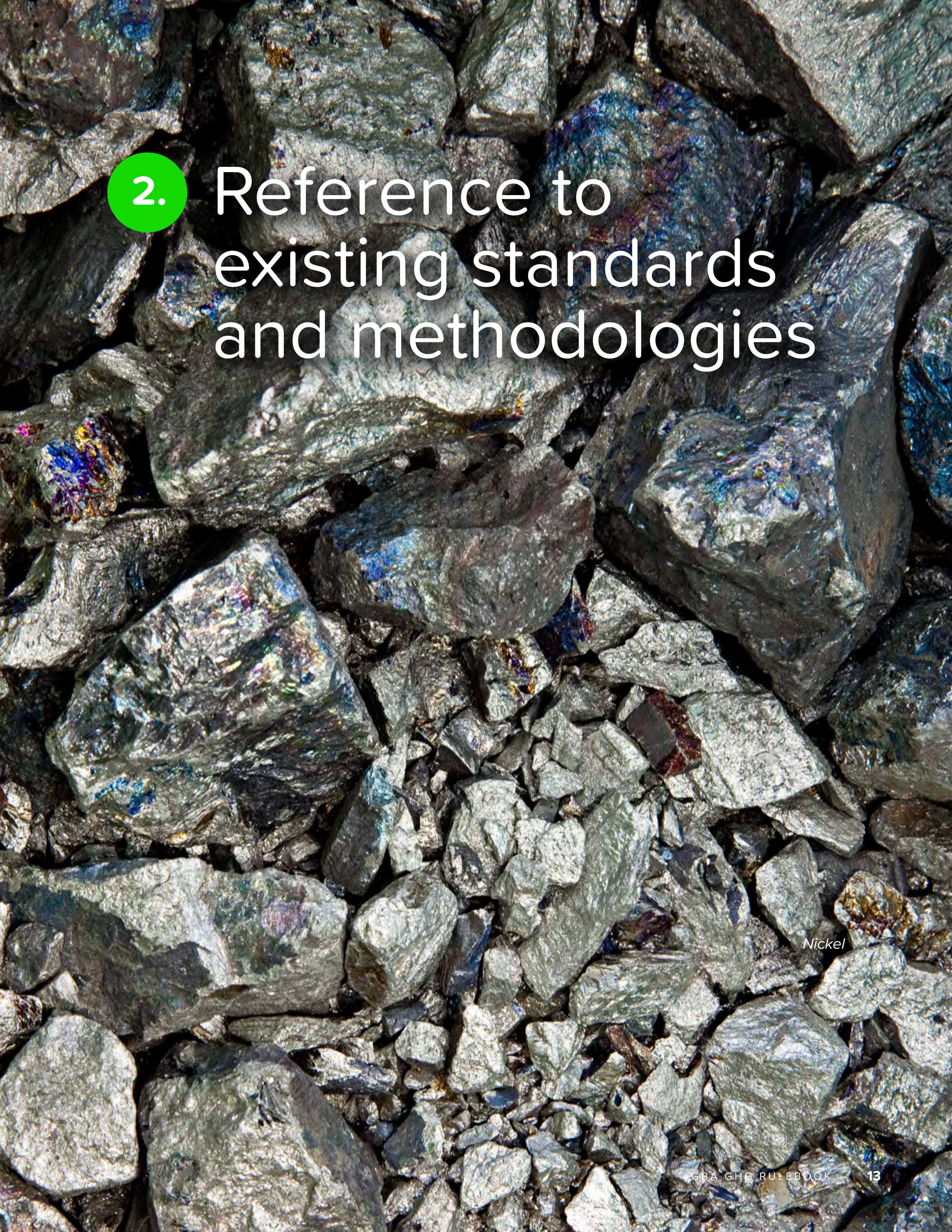
The principal goal behind the Global Battery Alliance (GBA) Greenhouse Gas (GHG) Rulebook is to provide guidance to facilitate the calculation of comparable greenhouse gas (GHG) footprints of lithium-ion batteries (LIB) for electric vehicles (EVs) by users of the (GBA) Battery Passport. The GBA GHG Rulebook can be applied to all kinds of LIB chemistries as well as raw materials, active or passive materials, and components across the value chain of LIB for electric vehicles. The development of the Rulebook was done by analysing widely used LIB chemistries, as examples in terms of the supply chain, hot spots, primary data to be collected, secondary data demand, etc.

The calculation of GHG footprints for commercially newly introduced chemistries in the future, such as Lithium Iron Manganese Phosphate (LFMP) or solid-state batteries, is ideally accompanied by an analysis to identify possible additions or changes (hot spots in the supply chain, secondary data demand, chemistry specific rules, etc.) in an updated version of the rulebook.

The focus of the Rulebook is on the GHG footprint of the manufacturing and end-of-life stages of raw materials, active and passive materials or the battery itself to provide a GHG footprint that can be used in the subsequent production step to calculate the GHG footprint or in general for communication purposes to various stakeholders (manufacturer, OEM, customer, etc.). At this point in time, the use stage of LIBs is not considered in the Rulebook as the use cases for LIBs can be different even for the same battery product (location of use, mileage, lifetime, consumption of a vehicle, etc.). That said, the use phase might be covered in a future version of the Rulebook to provide a set of rules that allow for a consistent and homogenous comparison of LIB use in electric vehicles.

The Rulebook does not cover any offsetting mechanisms in the GHG footprint calculations of the LIB or raw materials, active and passive materials or components across the value chain of LIB covered in this Rulebook. The same holds true for any source of secondary data (e.g., life cycle inventory data for the supply of materials or energy) used for the GHG calculation.

2. Reference to existing standards and methodologies



Nickel

Several standards and guidance documents for the calculation of product carbon footprints or environmental footprints have been analysed. They were considered as a basis for the development of the GBA GHG Rulebook, especially since this first version underlines:

- The GHG calculations of identified raw materials, active or passive materials and production processes across the value chain of LIBs, and
- The rules for the GHG calculations with a significant influence (hotspots) on the overall GHG emissions of raw materials and active or passive materials as well as battery cells and batteries themselves.

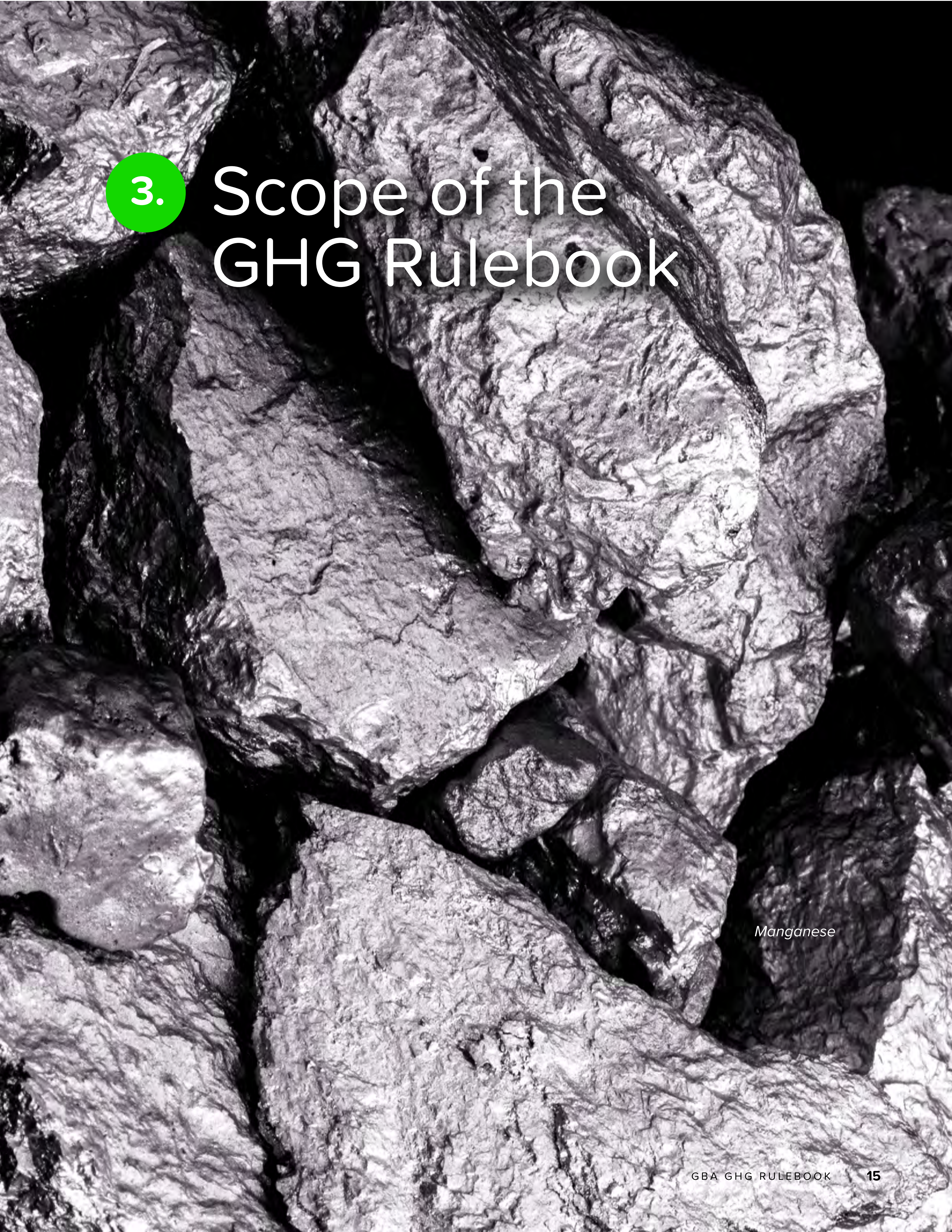
For methodological aspects of GHG calculation, so far not defined in this Rulebook, please refer to the most recent versions of the following standards and guidance documents:

- ISO 14040: 2006 – Environmental - management – Life cycle assessment - Principles and framework (ISO, 2006a)
- ISO 14044: 2006 - Environmental management - Life cycle assessment - Requirements and guidelines (ISO, 2006b)
- ISO 14067: 2018 - Greenhouse gases – Carbon footprint of products - Requirements and guidelines for quantification (ISO, 2018)
- European Commission PEFCR Guidance document (V.6.3) (European Commission, 2018)

In addition to the above-listed standards and guidance documents, the following documents have been used to develop the Rulebook or direct reference to definitions and rules in these documents is made within the Rulebook:

- EN 45557: General method for assessing the proportion of recycled material content in energy-related products (CEN, 2020)
- European Commission – Joint Research Centre: Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods (Fazio, et al., 2018)
- European Union. Regulation (EU) 2023/1542 of the European Parliament and the Council concerning batteries and waste batteries (European Union, 2023)
- Greenhouse Gas Protocol
  - Product Life Cycle Accounting and Reporting Standard (WRI, 2011a)
  - Corporate Value Chain (Scope 3) Accounting and Reporting Standard (WRI, 2011b)
  - GHG Protocol Scope 2 Guidance (WRI, 2015)
- ISO 14025: Environmental labels and declarations - Type III environmental declarations - Principles and procedures (ISO, 2006c)
- ISO 14049: Environmental management - Life cycle assessment - Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis (ISO, 2012)
- International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance (JRC, 2010)

3. Scope of the GHG Rulebook



Manganese

The following Chapters describe the products and materials covered under this GHG Rulebook, corresponding functional units and reference flows, as well as system boundaries and cut-off criteria, to be applied.

3.1. Production definition

The focus of the GHG Rulebook is on rechargeable Lithium-ion batteries (LIBs) used in electric vehicles and is applicable for the battery itself (battery pack including thermal management and battery management system) or single battery cells as well as for raw materials, active or passive materials and components of the battery.

Manufacturing processes across the value chain of LIBs, as visualised in Figure 3-1, have been summarized in several clusters based on the production of NMC and LFP Lithium-ion batteries. The following clusters that summarise manufacturing processes have been defined:

- Mining & refining
- pCAM & CAM manufacturing
- Electrode & cell manufacturing
- Module & battery assembly
- Recycling

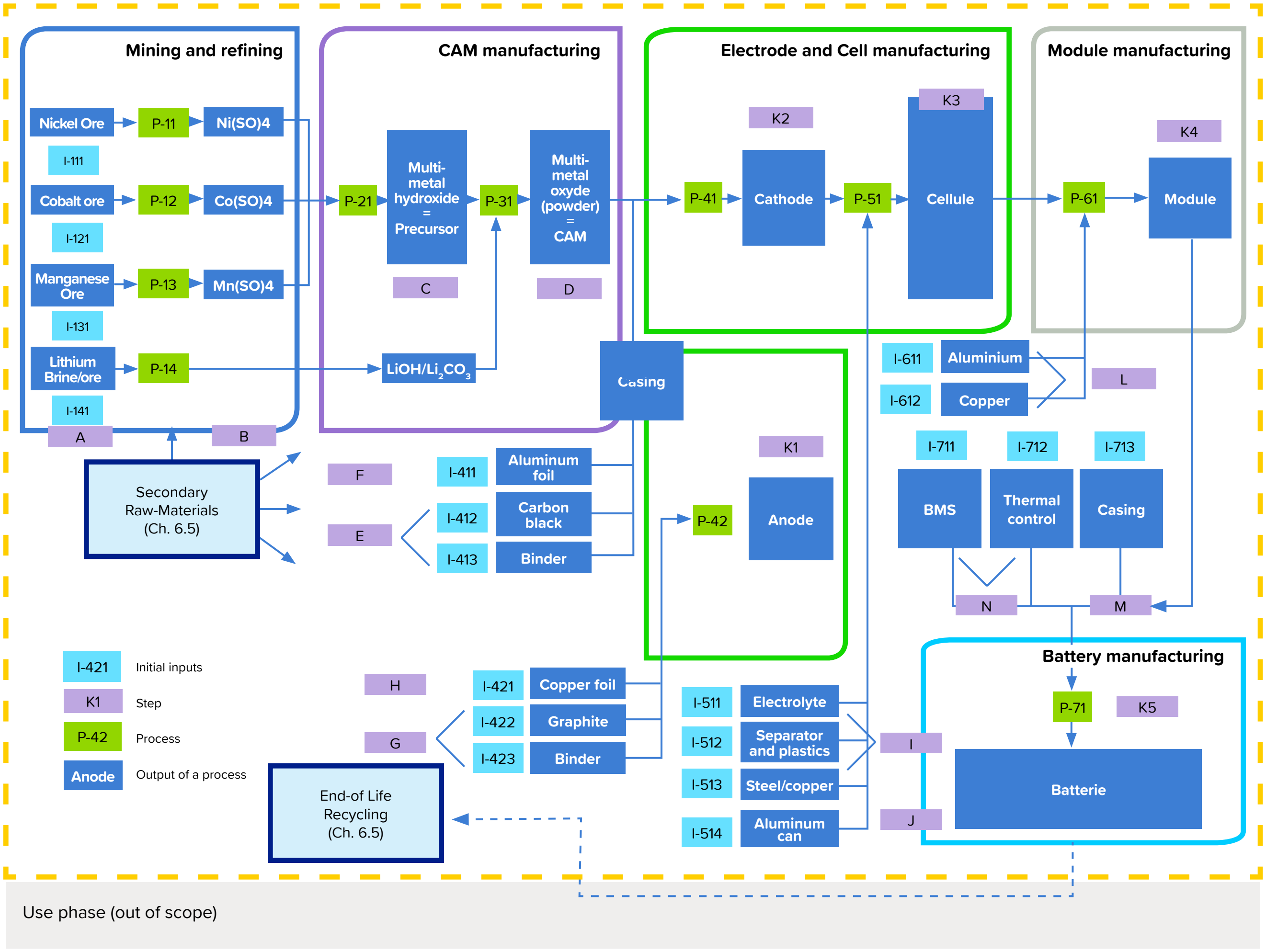
The clusters might be further split in an updated version of the Rulebook to increase the granularity in terms of specific rules for identified manufacturing processes or initial inputs.

For each cluster, cluster-specific rules for the GHG calculation, such as requirements for primary data collection, functional units, etc., are defined in Chapter 6. In the following subchapter, and in Chapter 5, the generic rules for the GHG calculation are defined.

In this first version of the Rulebook the focus is on identified hotspots across the battery value chain:

- Metal compounds (Nickel & Cobalt)
- Lithium carbonate and hydroxide
- Lithium Hexafluorophosphate ($LiPF_6$)
- Lithium metal
- Iron phosphate
- pCAM & CAM manufacturing
- Electrode and cell manufacturing
- Graphite
- Module & battery assembly

FIGURE 3-1: Manufacturing Process and Product System Boundary of a Li-ion battery for Electric Vehicles



3.2. Functional unit / reference flow

Functional Unit

The functional unit shall refer to the supply and end-of-life recycling of a LIB battery to be used in electric vehicles or any raw material, active or passive material or battery component that is traded within the value chain of the covered LIB chemistries in this Rulebook. The functional unit and reference flow need to be in accordance with the goal and scope of the Rulebook, i.e., it should provide the necessary specification of the product to be able to use the provided GHG value in further GHG calculations or assessments (e.g., metal concentration).

The functional unit shall therefore define the function(s) and quantify the characteristics and/or performance of the product (raw material like metal sulfate, CAM, cell, battery) clearly. For example, for metal sulfates or lithium carbonate, CAM or components, these could be quality grade, composition, etc. For battery cells, the functional unit should include specifications such as weight and capacity per cell, energy density, chemistry, peak and continuous power. For an entire battery, the specifications could be the total capacity, weight, chemistry and energy density of cells. Further definitions on which specification per cluster should be used are given in Chapter 6.

Reference flow
The reference flow for raw materials, active and passive materials, or battery components shall refer to the material/component itself and not to the battery in which they are potentially used. Ideally, the reference flows reflect the usual units in which the materials are traded between supplier and user. The generic reference flow shall be in mass, i.e., 1kg or 1t of material, or if more commonly used, 1kg or 1t of a specific element contained in a compound (together with its concentration, e.g., 1 kg Nickel in $NiSO_4$ $6H_2O$; 22.3% Nickel).

Exceptions from the defined reference flow shall only be considered if the standard unit in which the material/component is traded is not mass, e.g., volume (1m3) or surface (1 m2) or for complex components (electronics, several materials) piece might be more appropriate (1 piece). For all exceptions, information to convert the chosen reference flow to mass of the material/component itself shall be disclosed (e.g., share of element in compound, density, weight per m2 or weight per piece).

The reference flow for battery cells and batteries shall refer to one piece, i.e., one cell or one entire battery. The user shall also report the nominal & usable capacity, weight and/or energy density to allow conversion into alternative reference flows, e.g., 1 kg cell / battery or one kWh of nominal or usable capacity. Chapter 6 gives an overview of specific reference flows for materials, components or products manufactured in the defined clusters.

General information about the selection of functional units and reference flows can be found e.g., in ISO 14049 (ISO, 2012).

3.3. System boundaries & Cut-off criteria

3.3.1. System boundaries

In general, the system boundaries of the carbon footprint / GHG calculations shall cover all the GHG emissions associated with the production of the raw material, active or passive material, battery component or battery under investigation until the gate of the factory which has produced it, plus a consideration of the end-of-life phase. Nonetheless, it is common practice in LCAs and carbon footprints to exclude certain aspects (service, material, and energy flows that do not directly affect the studied product during its lifecycle) from the system boundaries, such as employee commuting or research and development activities, for which representative data cannot be easily collected or because other LCA studies have shown the insignificance of the overall GHG impacts of the product.

For the purposes of this Rulebook, the following service, materials and energy flows may be excluded from the product system boundary:

- Overhead operations whose stoppage does not affect the quality or quantity of the reference flows produced (e.g., office lighting, office heating, or office air conditioning)

For the purposes of this Rulebook, the following service, materials and energy flows shall be excluded from the product system boundary:

- Capital goods (e.g., machinery, trucks, infrastructure)
- Corporate activities and services (e.g., research and development, administrative functions, company sales and marketing)
- Transport of employees to and from works

In case some overhead operations are not tracked as such and cannot easily be excluded, an allocation shall be conducted using an appropriate allocation key (see Chapters 4.1.2 and 6.4 for examples).

3.3.2. Cut-off criteria

As general cut-off criteria, the cut-off rule from the Commission Recommendation on the use of the Environmental Footprint (European Commission, 2021) has been adopted for the CF calculations. A maximum of 3% of greenhouse gas emissions may be excluded across the processes (cumulatively over all processes) for which primary data has to be collected referring to the overall CF of the product for which the CF is calculated. The exclusion shall also not exclude more than 3% of material or energy input or outputs cumulatively over the included processes.

The use of cut-off criteria comes with the challenge of deciding if material-specific greenhouse gas emissions, whether known or unavailable, fall under the defined cut-off criteria or not. Note that systematic exclusion of known inputs or impacts just because they fall under the cut-off criteria is not appropriate and should not be done. The possible cut-off in secondary datasets is not included in the 3% cut-off criteria for a process for which primary data is collected. Therefore, a general cut-off of input and output process should be avoided. In case the specific GHG emissions of an input / output are not available / known, the user shall analyse and document the possible impact by the usage of an appropriate proxy that ideally overestimates the GHG impact. As a systematic exclusion, only packaging is excluded (The production of packaging materials shall be excluded from the battery supply chain, as the contribution to the overall impact has been estimated to be negligible according to the European Union’s Product Environmental Footprint Category Rules for batteries)(Recharge, 2018).

4. Generic Rules

Manganese

The following Chapters describe the allocation rules to be applied, requirements for primary and secondary data to be fulfilled and guidance on the data collection itself to perform a carbon footprint under this rulebook.

4.1. Allocation

In this chapter, the generic allocation rules are described for

- Multi-Output Allocation
- End-of-Life Allocation
- Consumption data allocation on production lines (during data collection)

It gives guidance on how to approach the different cases during the calculation of carbon footprints. The user shall document transparently which allocation rules, considering the general guidance given below, were applied if a carbon footprint of a product from a multi-output process is reported.

4.1.1. Multi-output Allocation

In case a process has several valuable outputs, i.e., several co-products are produced with economic value at the gate of the production facility, the GHG emissions associated with the Li-ion EV battery production shall be partitioned between them.

A by-product under the GHG Rulebook is defined as an output with an economic value above zero, for which demand at the specific production site is available, and evidence can be given that the by-product is used as intended. In case the price is only paid for the transportation, or the price is zero, but the by-product is used as input to another product system, processes to treat that output may be excluded from the CF calculation, but no partitioning of GHG emissions to that output shall be performed. In all cases, a third party shall verify the economic value of the claimed by-product with specific properties (e.g., purity/grade, net calorific value, water content, etc.) at the facility gate, as well as the share of the by-product for which the price is paid. If no economic value of the output can be proven, the output shall be considered a waste.

In general, waste shall be modelled by attributing the waste burdens (e.g., from incineration or landfilling) to the process output products for which the carbon emissions are collected and calculated. The emissions from treating manufacturing waste, shall also be included with the burdens in the current life cycle. First, the collected activity data shall be classified in terms of whether the process output is waste or a co-product. In addition to the definition of co-product provided in this Rulebook, the distinction between waste and co-products shall be in alignment with prevailing legislation. Second, if the classification yields that the output is waste, the treatment process shall be identified. Third, as a general rule, process emissions shall be allocated to the process output products in the current lifecycle. Fourth, emissions data for the identified process shall be multiplied with the collected activity data.

Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2 (ISO, 2006b). Therefore, whenever possible, allocation shall be avoided by:

a) Subdivision of a unit process into several sub-processes
b) System expansion by eliminating the co-product from the product system for which the CF shall be calculated by subtracting the GHG emissions of a well-characterised functional equivalent. (Santero & Hendry, 2016)

Unfortunately, it is not always possible to avoid allocation. If a multi-output process cannot be further subdivided, an alternative production route with a well-characterised representative process is needed to implement system expansion. In this context, well-characterised processes are those that don't themselves require allocation amongst co-products, or for which allocation amongst co-products is clear and consistent on a global basis (e.g., the chlor-alkali process for co-production of chlorine and sodium hydroxide). In this context, representative processes are those that are preponderant (of superior weight, influence or prevalence) in the market. In most cases, metals are produced together with several others from the same or different ore deposits. System expansion is therefore not recommended for most metals as alternative production routes that are well-characterised and representative are not available (Santero & Hendry, 2016).

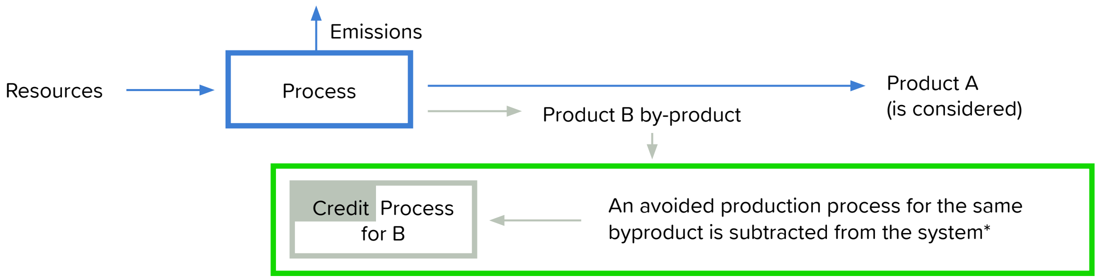
Therefore, for the purposes of this Rulebook, the partitioning of GHG emissions between product and co-product(s) shall be done by allocation for graphite and metals and by system expansion for other materials. In case system expansion is not possible due to a lack of a well characterised and representative alternative production route, allocation may be used, but the rationale for deviation shall be justified within the verification.

System expansion

Chapter 6 of this Rulebook requires system expansion for partitioning of GHG emissions to, for example, sulfuric acid, ammonium sulfate, sodium sulfate, and chlorine by-products.

System expansion is done in a way that the by-product, which is used in other processes and therefore replacing another material, is credited with the carbon footprint of the replaced material. This can be, for instance, if sulfuric acid from processing of sulfidic ore replaces sulfuric acid from the oil & gas industry; or when inert slag is used to replace gravel in the cement industry. Evidence shall be given in the verification of the GHG footprint (e.g., by contracts) that material assumed to be substituted is technically appropriate and the by-product is actually used for the intended application (e.g., if, in reality, the inert slag substitutes gravel in the cement industry, the GHG footprint of gravel shall be used to calculate the credit by system expansion, and not that of clinker). The appropriateness of the selection of the product from the alternative production route shall be verified for each carbon footprint. System expansion shall be applied only at the process step where the separation occurs.

FIGURE 4-1: Generic example for system expansion



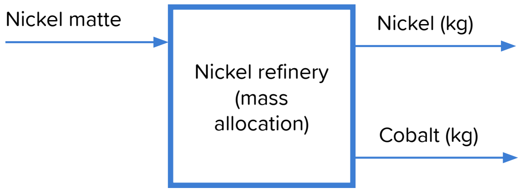
(Note: *as system expansion is about comparing specifically cradle-to-gate production processes, the subtracted impact should not include transport emissions)

Mass allocation between co-products

Chapter 6 of this Rulebook requires mass allocation for partitioning of GHG emissions between metal products in cases where no precious metals or platinum group metals (PGM) are part of the multi-output process; and between salt co-products produced from brine. For instance, in a base metal refinery where nickel and cobalt are produced, a mass allocation between the two metals shall be applied. Mass allocation shall be applied only at the process step where the separation occurs. In any case, mass allocation between co-products shall only be applied if the ratio of their economic values is less than or equal to four (≤4)(Santero & Hendry, 2016)(see following Chapter).

Figure 4-2 shows the calculation of a mass allocation factor. This factor is applied to all input and output streams of the considered process and therefore allocates shares of the overall GHG emissions of the process to the different co-products arising from the process.

FIGURE 4-2: Mass allocation factor calculation



$$\text{Ni Allocation factor} = \frac{\text{Ni kg}}{(\text{Ni kg} + \text{Co kg})}$$

In the following table, mass allocation factors are calculated based on a fictive production volume in a refinery example. When applying mass allocation, the sum of allocation factors shall be equal to 1.

TABLE 4-1: Exemplary calculated allocation factors by mass

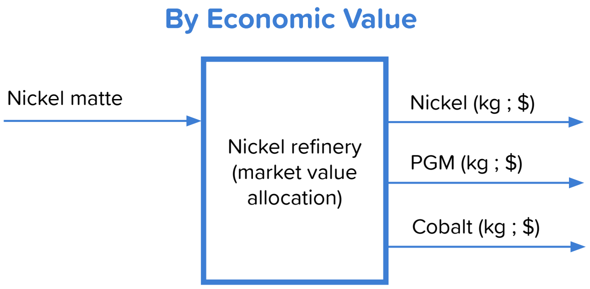
Product	Volume of product produced	Mass allocation factor
Nickel	1 kg Ni	0.91
Cobalt	0.1 kg Co	0.09

Economic allocation between co-products

Chapter 6 of this Rulebook requires economic allocation for partitioning of GHG emissions between base metal products and precious or platinum group metal products; and between battery-grade graphite products and lower-grade graphite products.

The relative economic value of co-products should be calculated on the basis of stable market prices. For metals, 10-year average global market prices, e.g., as published by the World Bank (The World Bank, 2022) shall be applied as recommended by Santero & Hendry (2016) to avoid the impact of high price-volatility in global markets. The used market prices shall reflect the specific conditions in terms of e.g., purity or other properties which have an impact on the global market price. In any case, economic allocation between co-products shall only be applied if the ratio of their economic values is greater than four (>4)(Santero & Hendry, 2016). The calculation method of the economic allocation factor is shown in Figure 4-3.

FIGURE 4-3: Economic allocation factor calculation



$$\text{Ni Allocation factor} = \frac{\text{Ni kg} * \text{Ni \$}}{(\text{Ni kg} * \text{Ni \$} + \text{PGM kg} * \text{PGM \$} + \text{Co kg} * \text{Co \$})}$$

In the following table, economic allocation factors are calculated based on a fictive production volume in a refinery example. Here again, the sum of allocation factors shall equal to 1.

TABLE 4-2: Exemplary calculated allocation factors by economic value

Product	Volume of product produced	Price €/kg	Value €	Allocation factor
Nickel	1 kg Ni	17	17	0.49
Cobalt	0.1 kg Co	28	2.8	0.08
PGM	0.0005 kg PGM	29,500	14.8	0.43

4.1.2. Energy consumption data allocation on production lines

If there is a primary data collection for energy consumption taking place within the value chain where more than the considered product is produced in a plant and only one energy meter (e.g., for electricity) for several production lines is available, it is important to install a metering point per production line. If not enough individual meters are installed, partitioning of energy consumption between products becomes necessary. Considering the overall capital intensity of the Li-ion battery value chain, the most accurate way to determine the energy consumption per production line is a detailed metering system. Therefore, if not already available, a metering point per production line shall be installed by 31 Dec 2024.

In case several products are produced over the most recent available 12m period on one line, the energy consumption shall be measured for the individual time periods in which the specific products are produced.

In case the measured energy consumption is not available per line / product the following hierarchy of methods shall be applied:

- expert judgement (e.g., production engineer does allocation to the production lines according to their experience)
- calculation of energy consumption using the installed capacity
- allocation of energy to the products produced by mass or other physical properties

Expert judgement
In this way of allocation, the experience of the production engineer, for instance, is the basis for the allocation. Throughout their working time the expert can say which line consumes what amount of energy based on the knowledge about the processes within each production line.

The engineer allocates the energy consumption to the different production lines and explains the reasoning for the allocation.

Calculation of energy consumption
In this approach, the installed capacity is used per process step to calculate the energy consumption along the production line.

Every installed capacity in kW (or similar) needs to be collected, and a usage factor (percent of time it is actually used) shall be assumed and documented to calculate the energy consumption per process. In the end, the energy consumption of all processes can be aggregated. A possible downside is that the load of each consumer can be different during the production.

Allocation of energy to the products by mass or other physical property
This is the easiest way if different products are produced within the plant or even on the production line but with the highest uncertainty.

Shared energy consumer
A special case can occur if several production lines are operated, and the energy consumption of a non-volume related energy consumer needs to be split up between the lines. An example would be a dry room for cell production in which several production lines (each with a different product) with different load factors are running. The user of the Rulebook may split up the energy consumption between the lines with a meaningful allocation factor (e.g., capacity of line, surface of line) before the energy consumption per line is related to the products.

In all cases, the selected method of energy consumption allocation shall be reported and documented, including the reasoning why the approach was taken, especially the rationale behind the expert judgement needs a clear justification. In all cases, the sum of the allocation shall equal the total energy consumption (measured). The same approach is valid for all consumables which do not end up in the product (energy, auxiliaries, water, etc.).

4.1.3. End-of-Life Allocation

In this Rulebook, only the carbon footprint for cradle-to-grate plus end-of-life is described. Clarifying the End-of-Life allocation is essential for calculating the carbon footprint of input into certain processes of the battery value chain, for instance, waste into aluminium remelting and casting / extruding of battery trays and for the generation of pre-consumer wastes.

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3. Such allocation approaches address the question of how to assign impacts from virgin production processes to material that is recycled and used in future product systems.

Whereas two main approaches are commonly used in LCA studies to account for end-of-life recycling and recycled content (See Figure 4-4), for the purposes of this Rulebook, the cut-off approach shall be applied since it is the more transparent approach:

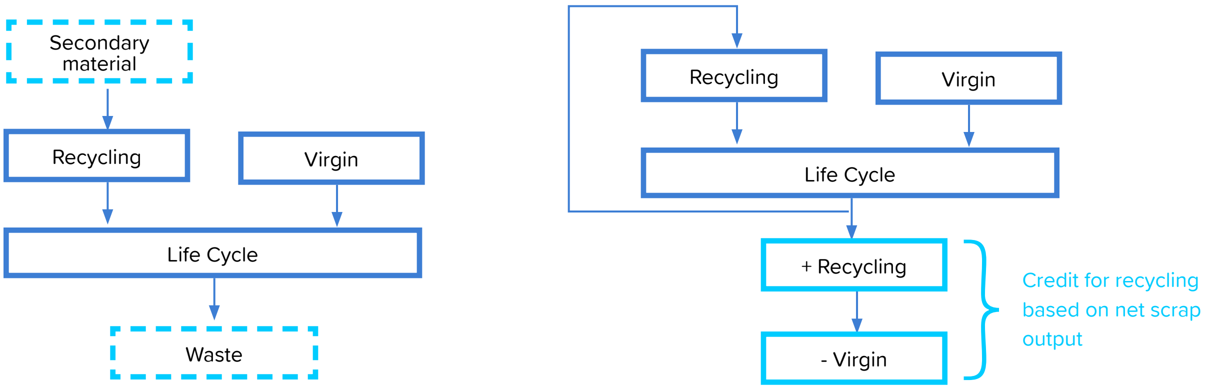
- Cut-off approach (also known as 100:0 or recycled content approach) – burdens or credits associated with material from previous or subsequent life cycles are not considered (i.e., are "cut-off"). Therefore, secondary material input to the production process is considered to be free of burdens, but equally, no credit is received for waste available for recycling at the end of life. This approach rewards the use of recycled content but does not reward end-of-life recycling.

This contrasts to the substitution approach which may be subsequently applied in certain jurisdictions or for different purposes (e.g., to comply with EU legislation). To enable battery producers to calculate recycled content, primary data on secondary material share at the input side of a process / product shall also be collected:

- Substitution approach (also known as 0:100, closed-loop approximation, recyclability substitution or end of life approach) – this approach is based on the perspective that material that is recycled into secondary material at the end of life will substitute for an equivalent amount of virgin material. Hence a credit is given to account for this material substitution. However, this also means that burdens equivalent to this credit should be assigned to secondary material used as an input to the production process, with the overall result that the impact of recycled material is the same as the impact of virgin material. This approach rewards end-of-life recycling but does not reward the use of recycled content.

In the EU, a Circular Footprint Formula has been proposed, which represents a mix of the two approaches described above. To enable battery producers to calculate results of a Circular Footprint Formula, further primary data rules are described in Annex B.

FIGURE 4-4: Schematic representations of the cut-off and substitution approaches



(i) Cut-off approach (secondary material inputs and outputs are not considered)

(ii) Substitution approach (credit given for net scrap arising)

In general, the cut-off approach is recommended since it is the most transparent End-of-Life allocation approach. The recommended way is to report the scrap share on the input side of a process / product to enable the battery producer to calculate the recycled content of his battery. The amount of secondary material shall be reported in two categories as follows:

- Pre-consumer waste (manufacturing waste, excluding process revert)
- Post-consumer waste (end of life waste batteries)

Further details on how to treat scrap input, recovered materials and energy are described in Chapter 6.5.

4.2. Recycled content of materials

Recycled content may only be derived from pre-consumer waste and end-of-life waste and shall be expressed in percentage of the product weight.

The recycled content of a product considers all secondary material (produced from waste) within the final product. It is therefore defined as the ratio between the mass of recycled or secondary materials and the mass of the product itself. The user of secondary material shall report which type of secondary material is used.

In all cases, a mass-balance shall be performed to demonstrate that assumed recycled content is reconciled with received secondary inputs.

Pre-consumer waste in a production facility shall not be included in the calculation of the recycled content.
To calculate the recycled content for a LIB, it is important to consider that only the secondary materials that end up in the final product are relevant. The calculation of the recycled content in the GBA GHG Rulebook is limited to the following components: housing, cables, printed circuit boards, anodes, cathodes and electrolytes.

It is essential that over the entire supply chain, the information about the recycled content within a raw material (e.g., metal sulfate), the pCAM or CAM and the cell are handed over to the next process step / manufacturer with regard to the final battery product, e.g., the CAM manufacturer needs to know the share of recycled cobalt, nickel, manganese or iron and phosphate and lithium carbonate / hydroxide used in the CAM production and submit this information to the cell manufacturer. Then, a transparent recycled content of the active materials can be calculated. The user of the Rulebook shall therefore calculate the recycled content of the six components: housing, cables, printed circuit boards, anodes, cathodes and electrolytes in relation to the relevant reference unit and submit this information together with the GHG impact.

The user should calculate an additional recycled content value that includes all recycled materials within its product.

4.3. Impact assessment

The only impact category addressed by the current version of the rulebook is Global Warming Potential (GWP), also referred to as Climate Change.

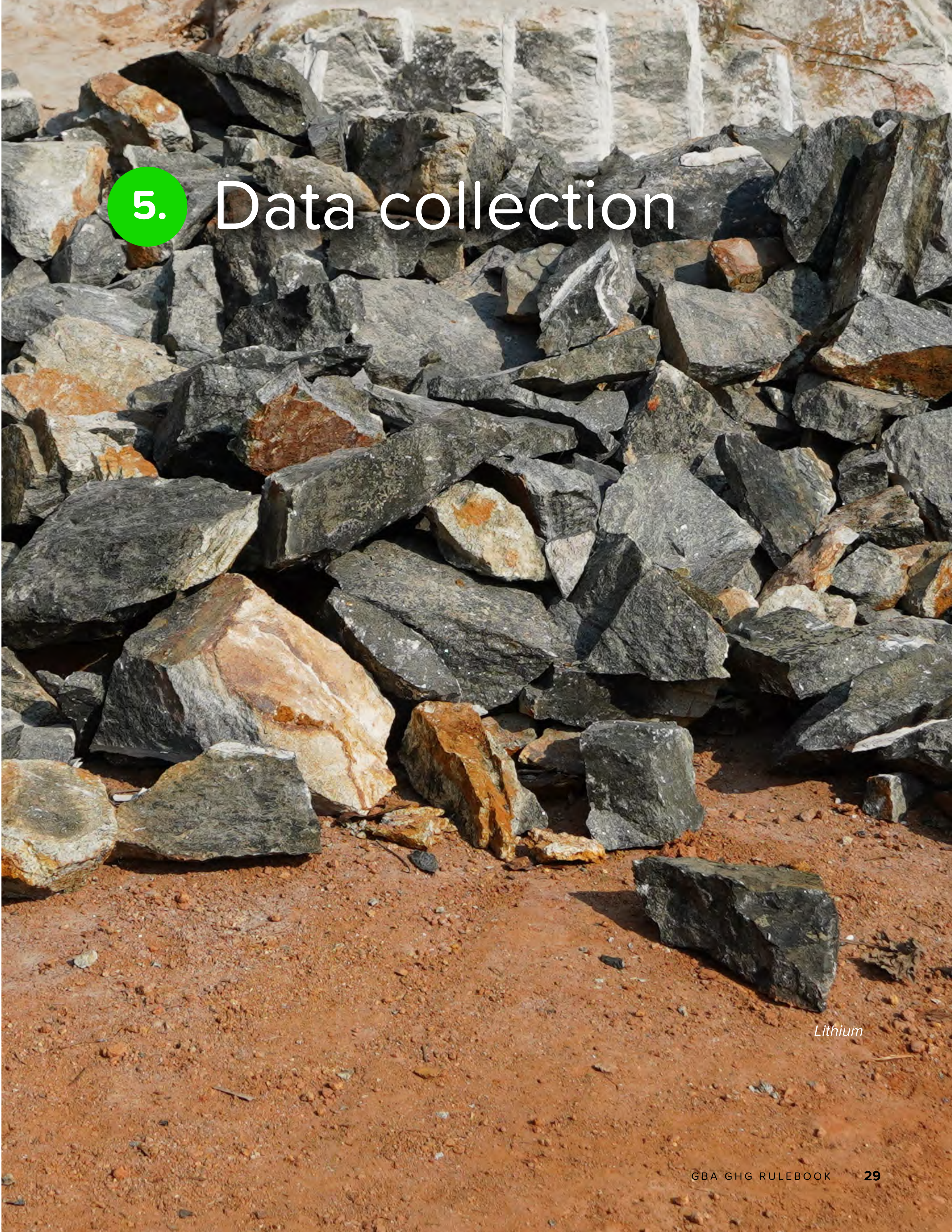
In this version of the GHG Rulebook, the GWP impact category is assessed based on the IPCC GWP factors published in the 5th Assessment Report (IPCC, 2013) in table 8.7 and table 8.A.1. GWP factors are available for a 20 year and 100-year timeframe. Although there is no scientific justification for selecting a specific time frame over other timeframes, the 100-year timeframe (GWP-100) is used as this is currently the most commonly used metric for carbon footprints and life cycle assessment.

As required in ISO 14067 (ISO, 2018), the used GWP factors of every single GHG from the Assessment Report shall include climate-carbon feedbacks (GHG emissions from or due to permafrost, risk of wildfires, CO_2 absorption by oceans etc. as a result of increasing temperature), which are also applied in the EU PEF Climate change indicator (Fazio, et al., 2018) under the PEFCR Guidance (European Commission, 2018).

The calculated GHG emissions under this Rulebook shall also include GHG emissions from direct land use changes, as covered under the EU PEF methodology for climate change. Indirect land use changes (iLUC) are excluded from the GHG calculations due to a lack of a reliable methodology.

Although removals and emissions of biogenic CO_2 from or to the atmosphere have no impact in the EU PEF methodology, biogenic CO_2 emissions shall be included in the primary data collection to perform a proper mass or carbon balance. Finally, the biogenic removals and emissions should be calculated separately as well in case the methodology for the impact assessment is revised.

5. Data collection



Lithium

First, it is important to make clear that all relevant GHG emissions as defined under chapter 4.3 need to be collected and used for the calculation of the GHG footprint. Nevertheless, the major emissions to be included in the collection are shown in Table 5-1.

TABLE 5-1: Selection of major Greenhouse Gases

GHG	Chemical Formula	Examples within primary data collection
Carbon dioxide (fossil)	CO_2	Fuel combustion, use of carbon containing reductants, chemical reactions, thermal treatment of volatile organic matter
Carbon dioxide (biogenic)	CO_2	Biomass combustion or use of biomass as reductant
Methane (fossil)	CH_4	Leakage from natural gas pipes, methane slips from gas motors, combustion emissions
Methane (biogenic)	CH_4	Same as for fossil methane if biomethane is used, leakage from biogas production at side, waste treatment at site
Nitrous oxide	N_2O	Fuel combustion, cultivation of agricultural products
GHG Relevant refrigerants, e.g., R134a	CH_2FCF_3	Leakage from air conditioning

5.1. Primary data collection

Period / start of data collection

The primary data collection shall be done on an annual basis (either the most recent available calendar year or the most recent available financial year) to avoid specific situations in the production process. The advantage is that annual data shows the average production during one year covering typical annual habits like maintenance cycles or seasonal cycles or, in general, fluctuating load factors. In the case that the product for which the carbon footprint is calculated is produced for less than 12 months or not the full year, the data shall be collected for the time period in which the product is manufactured or from the beginning of the most recent available 12-month period until the stop of production.

Data itself

The process steps and the primary data to be collected are defined in the cluster-specific data collection tables. All these primary data points defined in the data collection tables need to be collected for the respective battery value chain members. This is necessary to make the GHG result at the end of the day comparable.

In general, the following types of data need to be collected:

- Inputs
  - Material inputs that end up in the product, such as minerals, semi-finished materials, chemical feedstocks etc.
  - Energy, e.g., fuels, electricity, steam, thermal energy
  - Auxiliaries, e.g., chemicals, cleaning material, lubricants, refrigerants etc.
  - Water

- Outputs
  - Products and co-products
  - Waste, wastewater and all kind of recovered materials
  - Direct process emissions, e.g., CO_2 from the use of reductants
  - Combustion emissions

Especially for the cell and battery production and other complex components, the primary data collection shall include cutting, machining and scrappage rates, i.e., the yield between input and output shall be considered in the data.

In addition, the emissions associated with the recycled content for materials listed under chapter 4.2, need to be collected for the ingoing materials to calculate following the rules laid out in Chapter 6.5.

During the data collection, the data collector needs to perform data quality checks. This shall include, as applicable, checks for completeness, mass balance, energy contents, water balance, carbon balance, metallurgical balance, and other similar balance checks.

The goal of this first quality check is to confirm the data's fitness-for-use in the context of GHG calculation as well as to identify primary data gaps and inconsistencies that would need to be addressed before proceeding (see Chapter 5.2.5). This quality check by the owner of the primary data shall be reported and made available to the verifier because the final data quality checks shall be done by a neutral verifier (see Chapter 7). Chapter 6 and the developed data collection sheets provide more information about the primary data to be collected.

5.2. Secondary data

As described under Terms & Definitions, secondary data includes all kinds of data that is not directly measured or gathered from company-owned information systems. Different types of secondary data are usually needed for the calculation of a carbon footprint:

- GHG data referring to the supply of a specific unit of material, fuel or electricity which is neither produced by the company itself nor subject to cluster-specific rules in this Rulebook (e.g., because its GHG impact is below the cumulative threshold of 3% of the Battery Carbon Footprint).
- Secondary data taken from literature or databases representing the GHG impacts for material or energy supply should be representative in terms of geographical, technological, and time representativeness. In case the representativeness of the data is limited, e.g., data refers to European conditions, but the material is imported from Asia, and the GHG impact of the material or energy is

above the cumulative threshold of 3% of the Battery Carbon Footprint related to the overall GHG emissions of the product for which the CF is done, the user of the Rulebook but also the third party doing the verification shall inform GBA. Based on the feedback, GBA will analyse the relevance, possible alternative sources for secondary data and/or possibly set up a new cluster for which primary data collection could become mandatory in a future version of the rulebook.

- Conversion factors / emission factors needed to convert fuel consumption from a primary data collection into GHG emissions, e.g., to convert natural gas consumption of a boiler into GHG emissions.
- GHG data referring to the transportation of materials, fuels or products by different means of transport.
- Gap filling within primary data (e.g., leakage of GHG relevant substances, like methane or refrigerants within the facility) or data for processes which are not controlled by the company.

In the following Chapters, the different secondary data categories covered in the Rulebook are addressed.

5.2.1. GHG data for supply of materials & energy and waste treatment

In general, the use of secondary data from different sources can lead to different results in the carbon footprint calculation due to different methodology, system boundaries or coverage of GHG emissions between the different data sources. Therefore, the latest EF compliant data sets published under the EF node (https://eplca.jrc.ec.europa.eu/LCDN/contactListEF.xhtml), (European Commission, 2022) shall be used, transparently noting that these datasets contain underestimates due to their use of the EU's Circular Footprint Formula. The combined effect of such underestimates shall be limited by maximising provision of primary data. Older versions of EF compliant data sets under the EF Node may be used if the process (energy or material supply, waste treatment etc.) is not available in the latest version.

In the case of incineration, the CO2 emissions calculated based on the Carbon content of the waste shall be prioritised over the use of secondary datasets.

If a certain input material is not adequately represented by an EF compliant data set under the EF Node (European Commission, 2022), the user may use commercial or other available datasets respecting the following hierarchy, and report in a transparent way:

1. Select the most representative EF-compliant dataset available from the EU's Life Cycle Data Network (LCDN).
2. Select the most representative EF-compliant dataset from any other source
3. Select the most representative dataset developed in agreement with the International Reference Life-cycle Data System (ILCD) Data Network - Compliance rules and entry-level requirements - either from the LCDN or from any other source.

Please see chapter 5.2.5 on gap filling.

5.2.2. Electricity: Two sets of calculation rules

Rule Set 1: Harmonized Market Approach (HMA)
The underlying philosophy of this approach is to guarantee as well as possible the uniqueness of claims. The market-based mechanisms allow electricity consumers that have entered into agreements in which the ownership of bundled or unbundled electricity attributes is transferred to these entities, to fully claim (under the criteria set below) the benefits of these attributes. Although the physical plausibility is

weaker than in Rule Set 2 (PMA), Rule Set 1 (HMA) guarantees better the uniqueness of the claims. Where residual grid mixes are not available, the GBA calls for local governments to introduce this concept in order to guarantee everywhere the uniqueness of the claims.

In this approach, three electricity supply cases are considered.

Case A: Electricity is supplied from a production asset connected to the energy using plant by means of a direct and dedicated connection:

Context:
This case covers *inter alia* the following situations: production of electricity by means of a diesel generator, a renewable energy generation asset such as a PV system or a windmill, or any other production asset, usually located within the premises of the energy using plant or in its close vicinity and connected to it via a direct and dedicated connection (downstream or upstream of the grid meter, if there is such a device in place).

Remote electricity production assets are usually not connected to an energy using plant by means of a direct and dedicated connection, but rather through the electrical grid, and therefore do not usually fall under this case.

The use of the specific Emission Factor (EmF) of such an electricity production asset may only be used for the fraction of energy generated by the contracted and/or connected assets for which no environmental attributes have been sold to a third party.

The quantity of energy generated from such an asset is taken into consideration for a given reporting period (no longer than one year) up to the amount of electricity consumed by the site for that reporting period.

The energy generated during the previous year can be taken into consideration if it can be demonstrated that a corresponding physical quantity of energy has been charged into an electricity storage device and discharged for use during the reporting period.

Case B: Energy attributes instruments are contracted by means of a Power Purchase Agreement or an Energy Attribute Purchase Agreement entered directly or through intermediaries with a remote production asset injecting the underlying electrical energy produced into the grid.

Context:

Electricity using companies may enter directly or through intermediaries into Power Purchase Agreements with low carbon energy producers. In such contractual arrangements, energy using companies may secure ownership of energy attributes instruments such as Guarantees of Origin (GoOs), Renewable Energy Certificates (RECs) or local variations thereof.

Likewise, electricity using companies can enter into agreements for the sole purpose of acquiring RECs or GoOs without any provisions for the supply of energy.

Consideration of such energy attributes instruments, including their relevant Emission Factor (EmF) for the product carbon footprint calculation of the product, shall be subject to the following conditions:

- A traceability system shall ensure the uniqueness of such instruments. Only instruments sourced tracked, redeemed, cancelled, or retired by or on behalf of the energy using company shall be considered, subject to an audit of the contract and its implementation, third party certification or, if handled automatically, through other disclosure mechanisms such as registries,

- Attribute tracking instruments taken into consideration for a given calendar year shall be restricted to instruments corresponding to energy produced within the prior 12 months, and their quantity shall be limited by the quantity of electricity consumed by the site for that year minus the quantity of electricity acknowledged under case A for that same year[1]. Energy generated before the prior 12 months, can be considered if it can be demonstrated that an energy storage asset is attached to this electricity production asset and provides a time-shifting service.

The attribute tracking instrument shall refer to an electricity production asset located in the same regional market (within which a synchronous interconnection can be proven).

Where contractual instruments do not meet the minimum criteria listed above, case C applies.

Case C: Energy is supplied from the grid, with no consideration of attribute tracking instruments. Residual grid mix emission factors are used for countries where a reliable system exists. For other countries, country-specific or grid-specific consumption mixes are to be used.

Context:

Electricity using companies may enter into supply contracts with electricity distributors without consideration of attribute tracking instruments.

The quantity of electricity taken into consideration for a given calendar year under this case shall be the quantity consumed by the site during that same calendar year minus the quantity of electricity acknowledged under case A and case B.

Internationally recognized data sources shall be preferred. Amongst such well recognized data sources is the International Energy Agency (IEA) grid emission factors yearly publication.

In the case of very large countries such as the USA, Canada, Russia and China, in which several electrical grids operate, the grid specific residual mix (if available) or the country-specific consumption Emission Factor (EmF) (if available) shall be used. Preference shall be given to internationally recognized data providers. For the USA, the EPA eGrid data shall be preferred.

In order to ensure accuracy and comparability, electricity transport and distribution losses (or a reliable estimate thereof) shall be taken into consideration.

Rule Set 2: Physically Modelled Approach (PMA)

The underlying philosophy of this approach is to reflect the physical plausibility as well as possible. Additionally, the efforts undertaken by electricity users to support the investment in low carbon production assets are still acknowledged by allowing electricity users to claim the benefits generated by bundled electricity attributes meeting strict criteria. Although Rule Set 2 (PMA) includes some risk of double counting of low carbon electricity claimed under other legally accepted accounting systems, the physical plausibility is higher compared to Rule Set 1 (HMA).

In this approach, three electricity supply cases are considered.

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[1] The GBA shall reconsider this 12-month time period no later than December 31, 2025.

Case A: Electricity is supplied from a production asset connected to the energy using plant by means of a direct and dedicated connection:

Context:

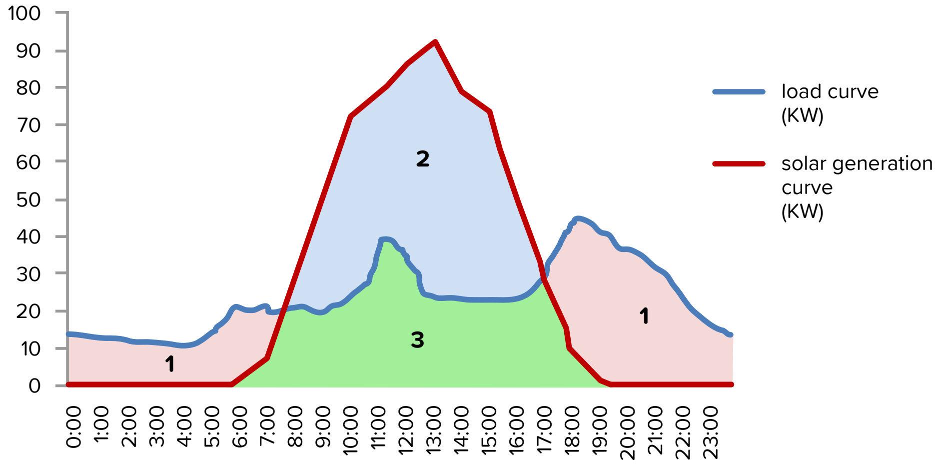
This case covers inter alia the following situations: production of electricity by means of a diesel generator, a renewable energy generation asset such as a PV system or a windmill, or any other production asset, usually located within the premises of the energy using plant or in its close vicinity and connected to it via a direct and dedicated connection (downstream or upstream of the grid meter, if there is such a device in place).

Remote electricity production assets are usually not connected to a specific energy using plant by means of a direct and dedicated connection, but rather through the electrical grid, and therefore do not usually fall under this case.

The use of the specific Emission Factor (EmF) of such an electricity production asset shall be subject to the following conditions:

- Only the fraction of energy generated by the electricity production asset demonstrated to lie below the load curve of the energy using site (as measured in hourly intervals) shall be taken into consideration for use of the asset specific emission factor,
- Consideration of energy generated by the electricity production asset that lies above the load curve of the energy using site can only be contemplated if it can be demonstrated that an energy storage asset is attached to this electricity production asset and provides a time-shifting service which displaces energy otherwise accounted for in area 2 (see below) to area 1 (see below).

FIGURE 5-1: Typical daily solar generation curve and load curve



In this chart, only “area 3” energy can be counted as used by the site, with the asset specific EmF. The energy present in “area 2” is either wasted or injected into the grid, and cannot be associated with the site consumption

The energy present in “area 1” is supplied from the grid and is considered using the appropriate grid characteristics (see case C below)

Case B: Energy attributes instruments are contracted by means of a Power Purchase Agreement entered into directly or through intermediaries with a remote production asset injecting the underlying electrical energy produced into the grid.

Context:

Electricity using companies may enter directly or through intermediaries into Power Purchase Agreements with low carbon energy producers. In such contractual arrangements, energy using companies may secure ownership of energy attributes instruments such as Guarantees of Origin (GoOs), Renewable Energy Certificates (RECs) or local variations thereof.

Consideration of such energy attributes instruments including the relevant Emission Factor (EmF) for the product carbon footprint calculation of the product, shall be subject to the following conditions:

- The generating asset must be additional, that is the majority of the financing of its construction and operation is derived from the PPA, until the implementation of Article 27(3) of EU renewable energy Directive[2] whereby applicable definitions of the Directive shall be used. Where differing additionality requirements are implemented, e.g., countries outside of the EU, the stricter definition of additionality shall be applied,
- The contracted asset and the energy using facility shall be located in the same country. If the contracted asset and the energy using facility are located in two different countries, they need to be located in adjacent bidding areas with a physical synchronous interconnection. For very large countries (e.g., 1,000,000 km^2, i.e., Russia, Canada, China, Brazil and others) that have several bidding areas (or similar supply/demand matching areas), the contracted asset and the energy using facility shall be located in the same bidding area or within an adjacent bidding area with which there is a physical synchronous interconnection,
- A traceability system shall ensure the uniqueness of such instruments. Only instruments sourced tracked, redeemed, cancelled or retired by or on behalf of the energy using company shall be considered, subject to an audit of the contract, third party certification or, if handled automatically, through other disclosure mechanisms such as registries,
- Only the fraction of energy injected into the grid by the contracted asset demonstrated to lie below the load curve of the energy using facility, as demonstrated on an hourly basis by the date/time stamp of each instrument, shall be taken into consideration. Generated energy that lies above the load curve, can be considered if it can be demonstrated that an energy storage asset is attached to this electricity production asset and provides a time-shifting service.

Where contractual instruments do not meet the minimum criteria listed above, case C applies.

Case B of Rule Set 2 will not apply until 1st January 2027 to provide companies with the opportunity to adjust their supply arrangements and establish the required information streams to demonstrate hourly matching through the recording of instrument date/time stamps.

In the meantime, Rule Set 2 Cases A and C shall remain in effect.

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[2] Directive (EU) 2018/2001of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, OJ L 328, 21.12.2018, p. 82–209

Case C: Energy supplied from the grid, with no consideration of attribute tracking instruments.

Context:

This case provides an incentive to develop residual mix emission factors for countries where they do not yet exist.

Electricity using companies may enter into supply contracts with electricity distributors without consideration of attribute tracking instruments.

In this case, the Emission Factor (EmF) of the consumption grid mix of the country (which takes into consideration imports and exports into and from the country) for the most recent calendar year or financial year shall be applied to assess the emissions generated to produce the purchased electricity. Internationally recognized data sources shall be preferred. Amongst such well recognized data sources is the International Energy Agency (IEA) grid emission factors yearly publication.

In the case of very large countries such as the USA, Canada, Russia and China, in which several electrical grids operate, the grid specific consumption Emission Factor (EmF) (if available) shall be used. Preference shall be given to internationally recognized data providers. For the USA, the EPA eGrid data shall be preferred.

The Greenhouse Gas Protocol - GHG Protocol Scope 2 Guidance (WRI, 2015) proposes an alternative methodology for this case, which is based on the use of the country residual mix. However, since most countries do not have central registries in place to capture the generation, transfer and cancellation of attribute tracking instruments, reliable residual mix EmF cannot be calculated in those countries.

Therefore, for comparability purposes, residual mix EmF shall not be used for this case (Rule Set 2, Case C).

In order to ensure accuracy and comparability, electricity transport and distribution losses (or a reliable estimate thereof) shall be taken into consideration.

5.2.2.1 Communication of the product carbon footprint calculation results

Product Footprint calculation results shall consist of the dual, synchronous communication of both Rule Set 1 and Rule Set 2 results with the relevant methodological identifiers (HMA and PMA).
Battery Carbon Footprint data included in communication to third parties with reference to the GBA standard shall meet the following format:

> ***GBA battery carbon footprint of the product is XX kg CO_{2eq} according to the harmonized market approach (rule set #1) and YY kg CO_{2eq} according to the physically modelled approach (rule set #2) as described in the GBA rulebook version 2.0.***

Members of the GBA shall actively refrain from accepting from vendors of their supply chain, and communicating to their downstream prospects or customers, a product carbon footprint calculation based on only one set of the two mandatory Rule Sets.

5.2.3. Combustion emissions

The calculation of greenhouse gas emissions from the combustion of fossil fuels, used within the processes operated by the user of this Rulebook and included in the product system shall be done by the use of specific carbon content when available, or when not available, by default emission factors /

conversion factors provided by the 2006 IPCC Guidelines (IPCC, 2006) or alternatively provided by a national environmental protection agency (EPA) and used for the national GHG reporting under UNFCCC (e.g., National Inventory Report). A list of default emission factors for stationary combustion of fuels in manufacturing industries from the IPCC Guidelines is given in Annex A.

5.2.4. Transportation

The calculation of GHG emissions related to transportation shall be done with one of three approaches, requiring different input data, in the following order of priority:

The **first priority approach** requires the amount of consumed fuel, e.g., the diesel consumption of a company- owned truck fleet in a mine. To calculate the GHG emissions, the diesel consumption is multiplied with the CF for the supply of the fuel (see chapter 5.2.1) and is multiplied with emission factors from e.g., the 2006 IPCC Guidelines for mobile combustion (IPCC, 2006).

The **second priority approach** is based on driven mileage of a known and defined means of transport (e.g., articulated truck > 33t, with 50% or 100% load) that is entirely used to transport specific goods for which the user of this Rulebook wants to calculate the GHG emissions related to transport. Emission factors for this approach shall be taken from the PEF database if available (https://eplca.jrc.ec.europa.eu/LCDN/contactListEF.xhtml), or Modules 1-3 of the Global Logistics Emissions Council (GLEC) framework (https://www.smartfreightcentre.org/en/our-programs/global-logistics-emissions-council/calculate-report-glec-framework/) and multiplied with the distance to obtain the GHG emissions for the mass of goods transported by the defined means of transport.

The **third priority approach** applies if only the start and destination are known, but no further information is available. In this case, the user shall estimate the distances based on a simplified logistic chain (e.g., 40t truck from location of origin to a possible harbour, ship transport to a possible harbour in the vicinity of the destination and a final truck transport). Distances for the different transport sections may be calculated based on web calculators, such as www.sea-distances.org or Google Maps. Finally, a multiplication of distance and mass results in a mass-distance unit, such as tonne-kilometre (tKm) which shall be taken from the PEF database if available or Modules 1-3 of the Global Logistics Emissions Council (GLEC) framework (https://www.smartfreightcentre.org/en/our-programs/global-logistics-emissions-council/calculate-report-glec-framework/).

These approaches can be used to calculate company-specific distribution emissions if required (e.g., in the EU context). For further information refer to Annex B.

5.2.5. Gap filling (secondary data)

Gap filling of missing secondary data is important, especially if new input materials to a specific process in the value chain are required but no Emission Factor is available.

The user of the GBA GHG Rulebook is requested to fill the data gaps based on appropriate data from

- literature,
- scientific papers,
- emission inventory guidebooks (e.g., (IPCC, 2013) (EMEP/EEA, 2019))

or

- other information sources. An overview of commercial and public databases can be found on the GHG Protocol website (https://ghgprotocol.org/life-cycle-databases)(WRI & WBCSD, 2023).

The user shall transparently document how the GHG emission factor was derived and is required to perform a sensitivity analysis of the possible influence of the closed data gap on the overall GHG footprint of the respective step in the battery value chain. The user of the Rulebook but also the third party doing the verification shall inform GBA if the estimated GHG impact of the material or energy is above the cumulative threshold of 3% of the Battery Carbon Footprint related to the overall GHG emissions of the product or if the share of the missing material supply is above the cumulative threshold of 3% of the Battery Carbon Footprint of the overall mass inputs remaining in the product. GBA will analyse the relevance, alternative sources for secondary data and/or set up a new cluster for which primary data collection could become mandatory in a future version of the rulebook.

5.3. Data and Data Quality Requirements

In addition to the primary data listed in Chapter 6, sources of emission factor data for all inputs and outputs must be referenced. As much as possible, these should be based on primary data. The data used to create the carbon footprint shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the Rulebook. This chapter gives generic guidance of data quality requirements, further specification is given for each cluster in Chapter 6.

A minimum requirement of data quality checks needs to be carried out for cross-checks and shall be reported:

- Overall mass and carbon balance of the process
- Metal content balance (assay data) in case of metal production
- Minimum data per cluster shall be collected

Further data quality requirements:

- The requirement of this Rulebook is that primary data be used for material inputs and product and waste outputs, energy consumption, direct CO_2 emissions, etc. Gaps in primary data, e.g., methane or GHG relevant refrigerant leakage, may be filled with literature data but need to be verified by a third party and are limited to direct emissions, which cannot be calculated based on the mass balance, auxiliary materials, and waste treatment. Primary data covers site or company-specific activity or emission factors that can be obtained by different means:
  - Measured data, e.g., electricity consumption of a production line obtained from a metering system installed in the facility
  - Material inputs and outputs obtained via the information system of the company (e.g., purchase records, utility bills, sales numbers, waste fees, stock inventories, etc.)
  - A bill of material listing e.g., the materials or components within a specific battery cell for which the CF is done, including yields or scrappage rates.
  - Calculated data, based on activity data, e.g.,
    - CO_2 emissions calculated based on fuel consumption (primary data) and GHG emission factors for the combustion of fuels from literature.
    - Stoichiometric calculation of direct GHG process emissions, e.g., use of carbon-containing reductants or use of lithium carbonate within CAM production.
  - Primary data might also be obtained via engineering models, material or product balances, stoichiometry or other methods for obtaining data from specific processes in the value chain of the company, provided they are site-specific, company-specific, or supply chain– specific and not merely horizontal aggregates, averages, or guidance values.

  - In this context, data sourced from information systems or engineering models that collect or obtain data directly from specific processes in the value chain of the company (e.g., the International Material Data System [IMDS] of the automotive industry), shall be considered primary data.
  - For transportation see Chapter 5.2.4

- Supply-chain specific data shall be at least used for the following material or components used as inputs for production of pCAM, CAM, battery cells, battery modules, or the final battery:
  - Nickel sulfate (or other) and cobalt sulfate (or other)
  - Lithium carbonate and lithium hydroxide
  - Lithium Hexafluorophosphate ($LiPF_6$)
  - Lithium metal
  - Natural or synthetic graphite
  - Silicon
  - pCAM & CAM
  - Battery cells and battery modules

For purchased components and semi-finished materials not covered above, the GHG calculation ideally includes supplier-specific data for material, auxiliary, and energy consumption, including yields and / or scrappage, as well as waste and emission data. In case data from the supplier is not available, the user of the GHG Rulebook shall add to the material amounts in the components / semi-finished material generic processing steps used to produce the parts (e.g., aluminium die-cast, injection moulding of polymers, machining of steel or aluminium, etc.), covering, for example, energy and auxiliary consumption as well as yields.

- In case the CF is calculated for a product from the mining & refining cluster, and the producing company is not responsible for the entire supply chain, e.g., is purchasing metal concentrates, supply-chain specific data shall be used for the supply of these major input materials.
- Completeness is defined within the clusters and is based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The capture of all relevant data is defined by the cluster.
- Consistency refers to data sources. The importance is to ensure that differences in the carbon footprint reflect actual differences between product systems and are not due to inconsistencies in calculations, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the carbon footprint based on the information contained in the short description of the calculation done by the user. It is a must to provide transparency with the calculation so that third party verifiers are able to approximate the results.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements. The aim is to use the most representative primary data for all processes and the most representative industry-average data as well as GLEC data for transportation and IPCC emission factors or national emission factors under the UNFCCC GHG reporting for fuel combustion. Whenever such data are not available (e.g., no industry-average data available for a certain country), best-available proxy data need to be used and transparently reported (e.g., from a commercial database).

5.3.1. Primary Data Share

To create visibility on the share of primary data in the CF calculations, the Primary Data Share (PDS) in each data set shall be determined and exchanged across the value chain. This shall be done by calculating the proportion (percentage) of the total GHG emissions (CO_2e) that is derived using primary data:

$$PDS_{PCF} = \frac{Part\ of\ PCF\ based\ on\ primary\ data\ [kg\ C0_2e]}{\text{Total PCF}\ [kg\ C0_2e]}$$

$$PDS = \frac{(\sum |PCF_i| \cdot PDS)}{\sum |PCF_i|}$$

For example, calculations, refer to WBCSD (2021) and Together for Sustainability Initiative (2022).

5.3.2. Data quality rating

During data collection, companies shall assess the data quality of direct emissions data, activity data and emission factors used from secondary data sources. The data quality of each dataset and the CF results shall be calculated and reported.

Data Quality Ratings shall be based on the following formula with three criteria:

$$DQR = \frac{TeR\ +\ GeR\ +\ Tri}{3}$$

Where *TeR* is the Technological-Representativeness, *GeR* is the Geographical-Representativeness, and TiR is the Time-Representativeness.

To rate the data quality of each dataset, calculate the absolute value of the carbon footprint of each process by multiplying the absolute carbon footprint of the dataset by the corresponding activity data. Then, calculate the carbon footprint contribution (in %) of each process and the data quality rating of the BCF as a weighted mean using the following formula:

$$DQR_{total} = \frac{\sum (DQR_i x\ |CF_i|)}{\sum |CF_i|}$$

Where CF is the carbon footprint contribution of process *i*.

Values for the DQR criteria (TeR, GeR, TiR) for each dataset, shall be expressed as one of five categories from 1 ‘Excellent’, 2 ‘Very good’, 3 ‘Good’, 4 ‘Fair’, and 5 ‘Poor’ using the following Table:

TABLE 5-2: How to assign TeR, GeR, and TiR values to DQR criteria (adapted from JRC(2023))

Data Quality Rating	1 – Excellent	2 – Very Good	3 – Good	4 – Fair	5 – Poor
Technology (Ter)	The modelled technology is exactly the same as the one in scope of the dataset/BCF.	The modelled technologies are included in the mix of technologies in scope of the dataset/BCF.	The modelled technologies are only partly included in the scope of the dataset/BCF.	The modelled technologies are similar (i.e., technological proxy) to those included in the scope of the dataset/BCF.	The modelled technologies are different from those included in the scope of the dataset/BCF.
Geography (Ger)	The modelled process takes place in the country for which the dataset/BCF is valid.	The modelled process takes place in the geographical region (e.g., Europe, Asia, North America, Africa) for which the dataset/BCF is valid.	The modelled process takes place in one of the geographical regions for which the dataset/BCF is valid, or the dataset covers several regions (e.g., global - GLO).	The modelled process takes place in a country that is not included in the geographical region(s) for which the dataset/BCF is valid, but it is estimated that there are sufficient similarities based on expert judgement.	The modelled process takes place in a different country than the one for which the dataset/BCF is valid.
Time (Tir)	The "reference year" of the dataset/BCF falls within the time validity of the secondary dataset	The "reference year" of the dataset/BCF dataset is maximum 2 years beyond the time validity of the secondary dataset	The "reference year" of the dataset/BCF is maximum 3 years beyond the time validity of the secondary dataset.	The "reference year" of the dataset/BCF is maximum 4 years beyond the time validity of the secondary dataset.	The "reference year" of the dataset/BCF is more than 4 years beyond the time validity of the secondary dataset.

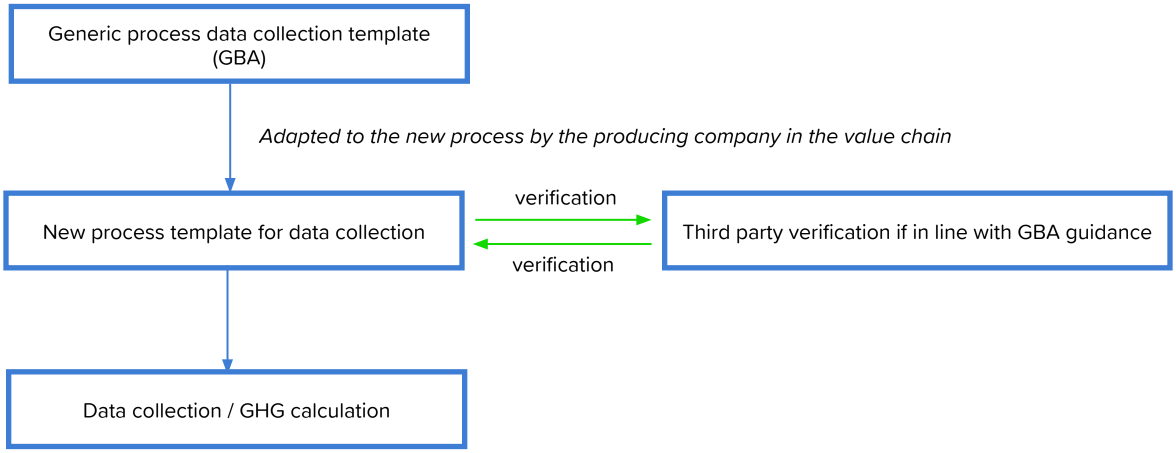
6. Cluster specific rules

Aluminum

In the following chapters, material supply specific rules, and guidance for primary data collection and carbon footprint calculation is given for the different clusters. In addition to the GHG Rulebook, primary data collection sheets have been developed for the process chain of the materials / products covered in Chapter 6. The data collection sheets are developed to give guidance to the user of this Rulebook in terms of which primary data is needed for the CF calculation and which additional information is required / helpful to facilitate the calculation. The data collection sheets make no claim to completeness with regard to processes or inputs and outputs. Missing processes or inputs and outputs in the data collection sheets shall not be seen as an invitation to exclude them from the CF calculation. Conversely, they should be added to the data collection sheets and included in the CF calculation.

In principle, the user is free to adapt the data collection sheets to their needs as shown in Figure 6-1, i.e., by adding inputs and outputs or by adding additional process steps according to the specific production process (e.g., once additional recycled inputs come into use). In case no data collection sheet is available for a process or for the entire material production route for which the CF is to be calculated, the user will find in each of the specific cluster templates a generic data collection template as guidance for the production process where no specific template exists. In such a situation the reporting company needs to describe why a specific input or output flow from the generic templates is excluded so that the verifier can judge if all important input and output parameters for the new production process are reported and used for the calculation.

FIGURE 6-1: Workflow for new process template development



To further improve and update the data collection sheets, the user should communicate possible improvements (missing inputs / outputs, missing processes, new independently verified process templates for data collection, or usability of data collection sheets) that cover not only the specific situations of the user, but are valid for a majority of the supplier to the GBA to be included, if meaningful, in further versions of this Rulebook. The GBA may also ask verifiers to collect and summarize possible improvements for the data collection sheet, as the verifiers might have a better overview of frequently required adaptations by the user in the data collection sheets or usability issues.

6.1. Mining and refining

The following Mining and refining specific chapter is subdivided into the different metals under consideration in this rulebook. In the first part of the specific chapter, generic rules valid for all subchapters are described.

Functional Unit: for all metals and minerals in this mining and refining chapter, the functional unit is 1 kg of metal contained in the respective material. Only for graphite, the functional unit is 1 kg of synthetic or natural graphite. The concentration of the metal in the final product shall be specified as well (for instance 1 kg Nickel in NiSO4 6H2O; 22.3% Nickel).

Cut off rules: As a reminder, the cut off definition is *"the specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be "safely excluded" from the study"*.

The cut-off rules are specified in the generic part of the rule book and shall be considered within this specific mining and refining cluster as well as all other clusters. It is recommended to collect as much of the production process relevant data as possible. So regular maintenance of equipment shall be included and is typically included in Life Cycle Assessment according to ISO 14040 / 44 (e.g., lubricants, grease, etc.)

Cement, which is required within the production of the base metal, shall be accounted for in the data collection and carbon footprint calculation (e.g., cement used for backfilling tailings into a mine).

Data collection period: the period for data collection is annual. This can be either the most recent available calendar year or the most recent available financial year, as long as the selected period is mentioned in the data collection sheet.

The specific production processes / technologies of each metal shall be assigned to the following "umbrella" processes charts:

- Mining
- Beneficiation / ore processing (from ore to concentrate)
- Primary extraction (pyrometallurgical or hydrometallurgical)
- Refining

Each of the above-mentioned generic production stages must have a reference to which all inputs and outputs are referred, as shown generically in the following Figure 6-2, Figure 6-3, Figure 6-4, and Figure 6-5. The green highlighted process displays the primary activity data of the production process, and the blue boxes show secondary data of the purchased goods and services. In the case of supplier-specific data, it is important to gather all scopes of the supplier, including scope 1, 2 and 3.

FIGURE 6-2: Generic mining process

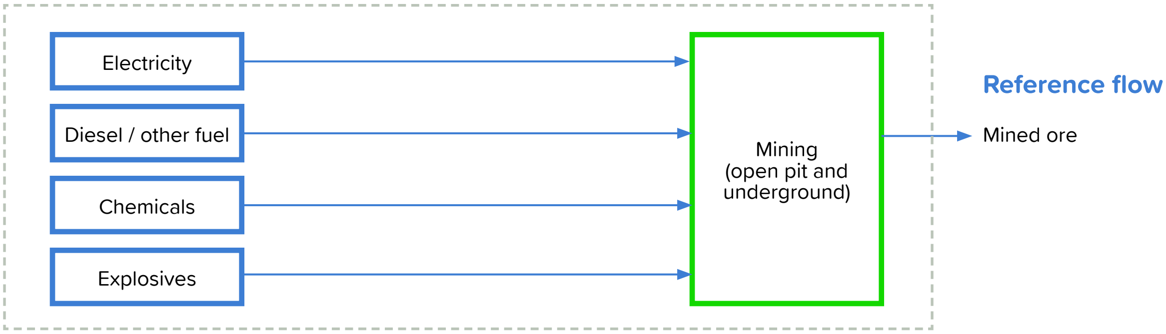


FIGURE 6-3: Generic beneficiation / ore processing process

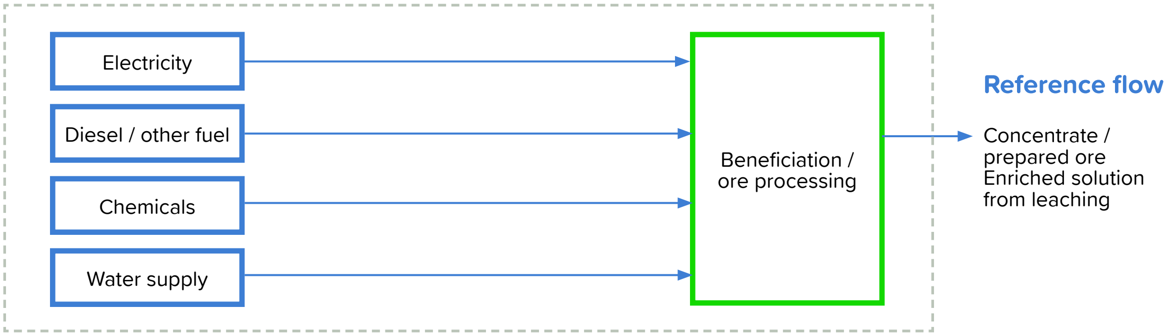


FIGURE 6-4: Generic primary metallurgical extraction process

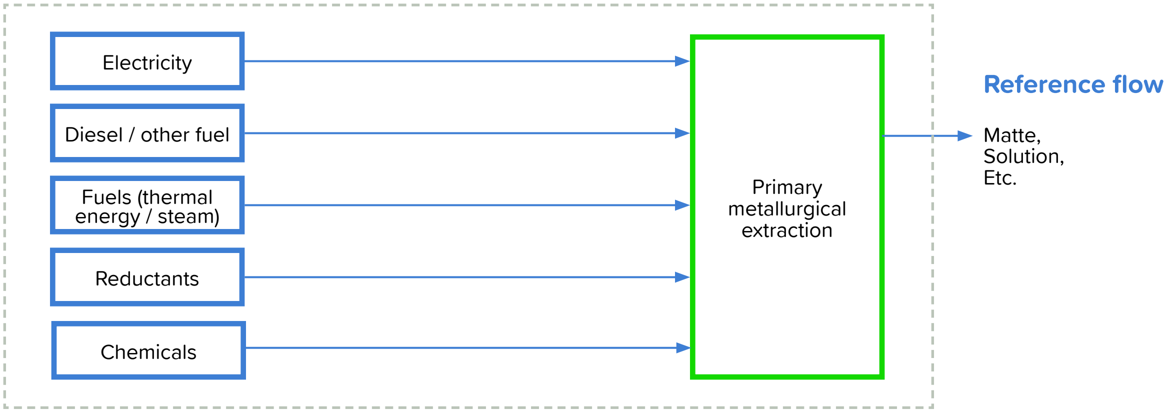
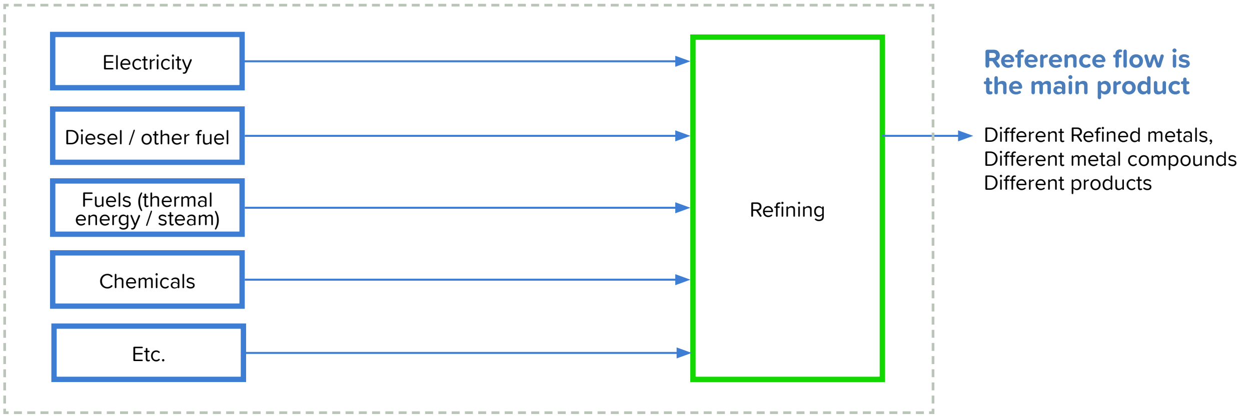


FIGURE 6-5: Generic refining process

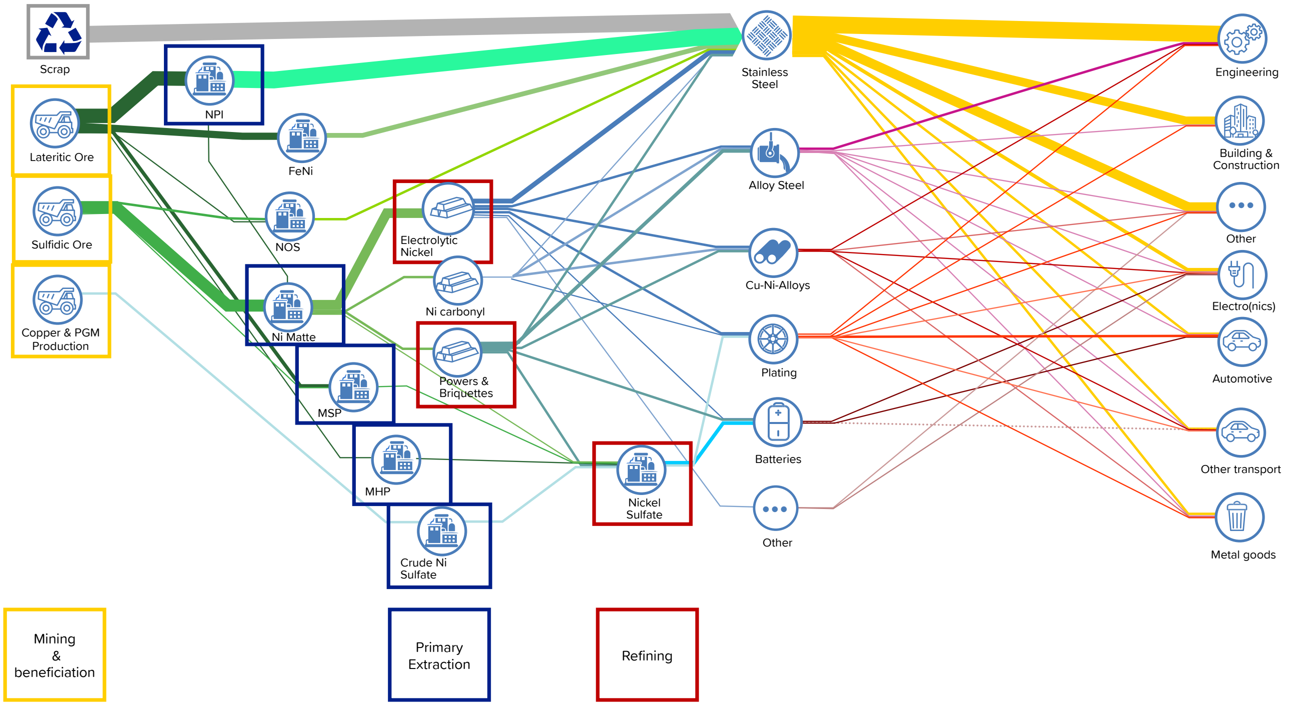


It is very important that for the main reference flows, the specific assay data on Nickel and other elements included are reported with the reference flows to allow a proper mass balance check.

6.1.1. Nickel Sulfate Hexahydrate ($NiSO_4$ $6H_2O$)

There are different routes to produce $NiSO_4$ $6H_2O$ for the battery value chain. The major routings are displayed in the following Figure 6-6. Secondary raw-materials inputs from recyclers can also feature at several places along the production chain. In case a $NiSO_4$ $6H_2O$ producer cannot find its route in this figure, generic data collection templates are provided to include new processes and routings into the value chain of batteries.

FIGURE 6-6: Material flow of nickel into different applications (Roskill, 2019)

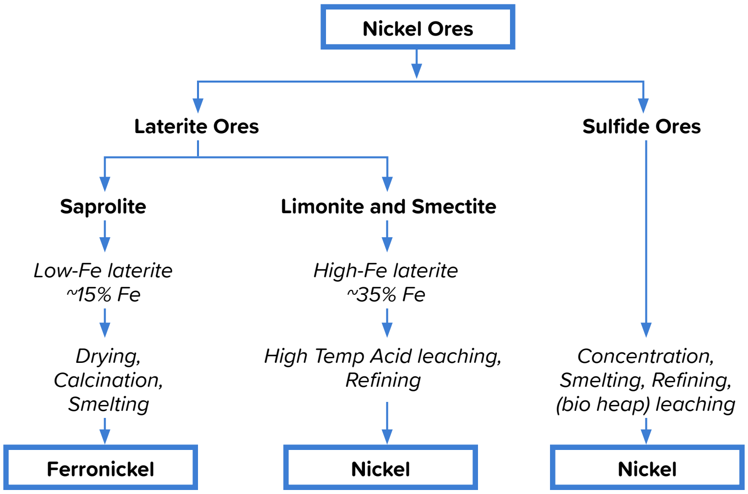


There are two types of nickel ore used to produce $NiSO_4$ $6H_2O$:

- Sulfidic ore
- Lateritic ore

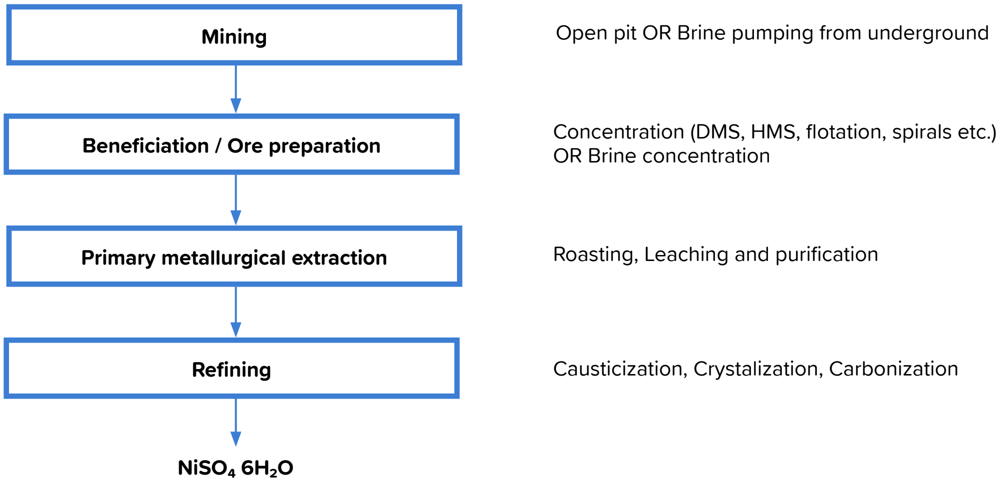
The ores go through different production routes as shown in the following Figure 6-7.

FIGURE 6-7: Process flow chart of different ore types (Crundwell, 2011)



In Figure 6-8, the “umbrella” process steps are shown, as well as the selection of specific processes allocated to these.

FIGURE 6-8: Umbrella process steps and the allocation of specific process steps



In the following Chapter, the generic data collection templates for the major process steps for both routes are shown and described. This is the guide to what data needs to be collected.

Mining (underground and open pit) for sulfidic and lateritic ores
There are two types of mining operation underground and open pit. The data collection shall cover all related operational processes during the mining to receive at the end the ore to be sent to the beneficiation / ore processing step. That includes electricity consumption for hoisting, cooling, lighting, etc., for under-ground mines, as well as fuel consumption for excavators and haul road trucks, and explosives for breaking the rock.

In the following table, the minimum list of input and output parameters is shown. The data collector must state the exact unit, as well as give additional information in the specification field for instance conversion from natural gas in m^3 to kWh or MJ. This is important since the emission factors for fuels are typically given in CO_2 per TJ (terajoule).

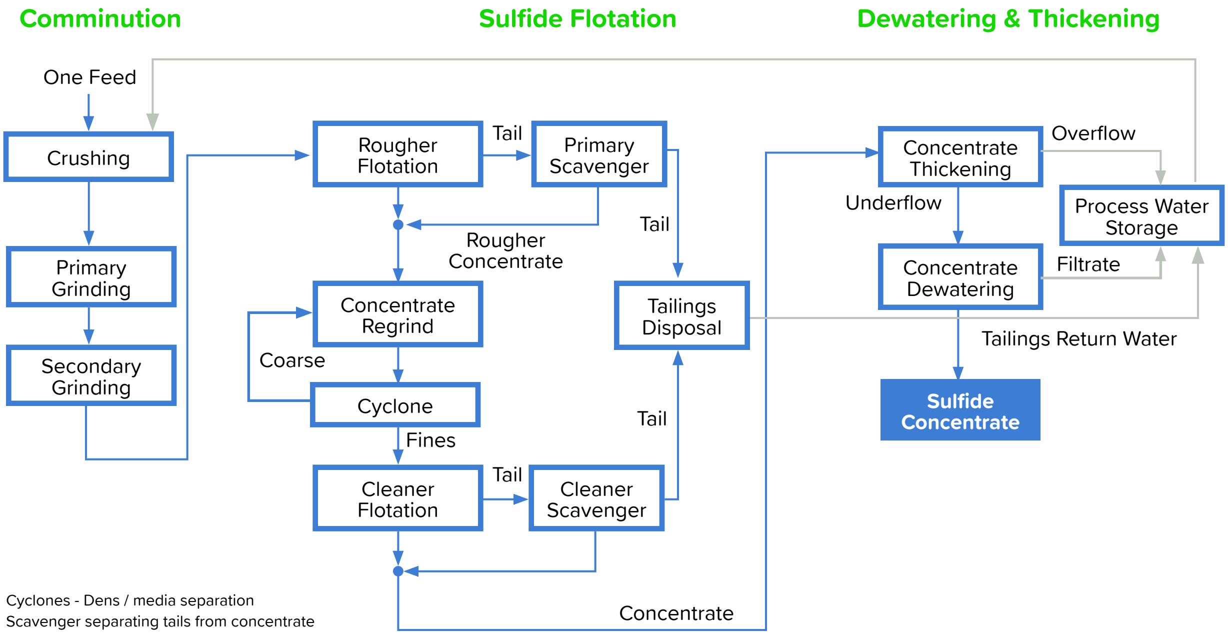
A important specification to be stated is the nickel, as well as the other metals content in the ore. This is an important factor for cross-checking the nickel balance over the whole value chain to the final product, the $NiSO_4$ $6H_2O$.

TABLE 6-1: Generic data collection template for underground and open pit mining

Material	Unit	Data	Specification
Input			
Electricity			
Fuels (e.g. Diesel / LNG / Hydrogen)			conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased			
Explosives			
Cement (for production)			
Tires			
Output			
Ore mined			Assay data
Overburden			
Waste Rock			
CO_2 (fossil)			Based on Fuels & Explosives

Beneficiation / ore processing for sulfidic and lateritic ores
The beneficiation / ore processing step usually has many different process steps, as shown as an example in the following Figure 6-9. It starts with Comminution (crushing and grinding), then goes into the flotation circuit before it ends with the dewatering and thickening to receive the concentrate. All these steps are captured in the generic questionnaire in Table 6-2.

FIGURE 6-9: Process steps in a typical beneficiation of sulfidic ores (Zanin, 2019)



Many chemicals are typically used but not necessarily for each chemical a carbon factor would be available. To avoid some of the chemicals being excluded because of no carbon factor, it is recommended to group the chemicals in the frother, dispersants, and flocculants and take the biggest contributor (mass) as a proxy for all categorised chemicals. Other bulk chemicals or auxiliaries like neutralizer (e.g., quicklime (CaO)) need to be collected separately, as shown in Table 6-2. The grinding media shall be collected even if it might fall under the cut-off criteria.

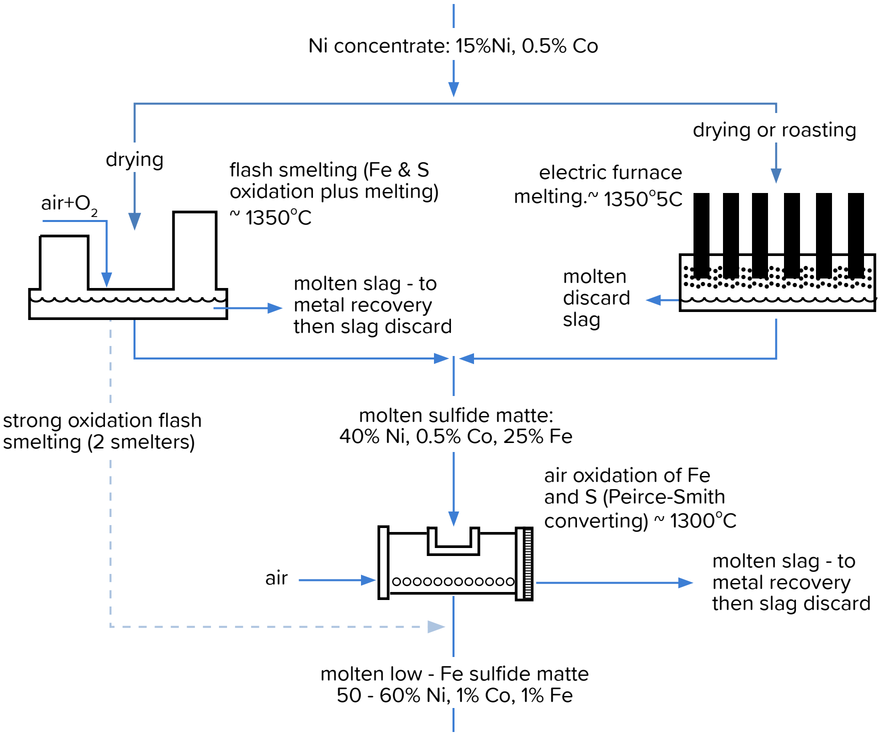
TABLE 6-2: Generic data collection template for beneficiation / ore processing

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Ore mined					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					Flocculants, Frother, Dispersant, bulk chemicals like H2SO4, CuS
Quick lime					
Grinding media *(maybe above threshold for low concentrate ore)*					Steel balls / rods (high Cr steel ~10% and low Cr steel ~1 -3 %)
Output					
Concentrate / Upgrade ore					Assay data
Tailings					Assay data

Primary Metallurgical Extraction

The primary extraction for sulfidic ores typically covers the processes shown in Figure 5-10. Either way, the flash furnace or roasting and smelting is used, followed by using a converter. The SO_2 emissions are captured and transported to the sulphuric acid plant to produce H_2SO_4. The following generic questionnaires cover these processes but can also be used for new processes as a basic questionnaire.

FIGURE 6-10: Process steps in a typical primary extraction from sulfidic ores (Wang, 2016)



Primary Metallurgical Extraction (sulfidic ores) incl. H_2SO_4 plant (pyrometallurgical)

The primary metallurgical extraction is, out of experience, one of the major contributors to the carbon footprint of metals and their compounds. Therefore, it is important to collect all input and output parameters causing the carbon emissions. Table 6-3 shows the main input parameters like reductants (fossil or biogenic), where the CO_2 process emissions need to be calculated using the carbon content of the reductant and the stoichiometry to calculate the process emissions per reductant. The same is valid for the consumption of electrodes. If there are bio-reductants like charcoal consumed, then the biogenic CO_2 factor shall be reported separately from the fossil-based reductants.

In case hydrogen is used, it is important to verify whether the production of hydrogen is via steam reforming or electrolysis using renewable energy.

It is also important to consider the oxygen used in case it is not produced onsite but purchased from a supplier.

In the case of external heat and steam supply, it is important to get the right carbon factors from the supplier, including scope 3 emissions of the supply of the fuels otherwise use CF data from PEF database (https://eplca.jrc.ec.europa.eu/LCDN/contactListEF.xhtml).

It is important to also collect the SO_2 emissions which are then converted to sulfuric acid as described in the next process step.

TABLE 6-3: Generic data collection template for primary (metallurgical) extraction (sulfidic ore furnace)

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Concentrate					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Electrodes					C-content
Reductants (fossil or / and biogenic)					C-content and type of reductant
Oxygen					Can be produced by subcontractor The type (gas/liquid) should be specified
Output					
Nickel Matte					Assay data
CO_2 (fossil)					Calculated based on Electrodes and reductants (based on stoichiometry)
CO_2 (biogenic)					Calculated based on biogenic reductants
SO_2					Capture to H_2SO_4 plant (system expansion according to Santero & Hendry [2016] if by product)
Waste heat recovery					e.g. for district heating

The following Table 5-4 shows the generic questionnaire for a sulfuric acid plant. This is important to be considered within the carbon footprint calculation since it is an essential part of the production process to avoid the acidification of the surroundings of the plant.

The produced and sold sulphuric acid shall be allocated by using system expansion according to Santero & Hendry (2016).

TABLE 6-4: Generic data collection template for sulfuric acid plants

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
SO2					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Lime					
Output					
H_2SO_4 (sold)					
H_2SO_4 (waste)					
CO_2 (fossil)					Calculated based on fuels

Primary Extraction (sulfidic ores) (hydrometallurgical)
In the hydrometallurgical extraction, there is no smelting operation, but the concentrates are dissolved with chemicals. Therefore, it is important (similar to the beneficiation) to report on bulk chemicals and group by mass with minor contributing chemicals together. It is important in the case of precipitation steps where no quicklime, but limestone is used that the process CO_2 emissions through the reaction of $CaCO_3$ with the acid solutions are calculated accordingly.

Primary Metallurgical Extraction (Bio Heap Leaching)
After mining, crushing and heap stacking, the nickel containing ores are irrigated by an aqueous solution and oxidized by aeration, i.e., undergoing a leaching process. Nickel as well as other possibly contained metals such as cobalt are leached from the crushed ore. The enriched solution then undergoes metals extraction resulting in a mixed sulfidic precipitate (MSP).

TABLE 6-5: Generic data collection template for hydrometallurgical extraction from ore or concentrates

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Ore or Concentrate					Assay data
Electricity					Including Oxygen, nitrogen, hydrogen production onsite
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					
Lime, limestone, etc.					Assay data (purity and reactivity)
Oxygen, Nitrogen, Hydrogen					In case it is produced by subcontractor
Output					
MSP					Assay data
CO_2 (fossil)					
CO_2 (process)					Reaction between CaCO3 and acid solution

Primary Metallurgical Extraction (from lateritic ores)

This is an energy and CO_2-intensive process. Therefore, the fuels used to generate steam for the HPAL (Hot Pressure Acid Leaching) process are an important parameter, as well as the sulfuric acid and the limestone for neutralization. In that neutralization step, process-specific CO_2 emissions are generated in the reaction of $CaCO_3$ (limestone) with the acid solution. Here, it can be assumed (stoichiometric) that 44% of the limestone weight on the input side will be CO_2 emissions. It is also important, if one produced his own H_2S onsite that, of course, the CO_2 factor for the sulphur on the input side is taken into account as scope 3.

TABLE 6-6: Generic data collection template for primary metallurgical extraction from lateritic ores

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Upgraded ore					Assay data, for transport use wet weight and not dry matter
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Limestone, Lime (CaO, etc.), NaOH, MgO					Assay data (purity and reactivity)
Sulfur / H_2S					
H_2SO_4					Important to define the CO_2 factor
Flocculants					
Output					
Mixed Sulfides					Assay data
CO_2 (fossil)					Calculated based on combustion
CO_2 (process)					Process emission: reaction of H_2SO_4 & limestone considering purity and reactivity
Tailings					Assay data

A further primary metallurgical extraction process besides the HPAL process is the route via Nickel Pig Iron (NPI) which is mainly used in China. The NPI process is also a high-energy intensive process using a rotary kiln for the low nickel-containing ores before smelting in an Electric Arc Furnace (EAF). The output is a low nickel-containing NPI between 10 and 15% nickel content. These two process steps are covered within the following generic questionnaire (Table 6-7). This low nickel-containing NPI is in the next step via a pyrometallurgical process step processed to a nickel matte with approx. 75% nickel content (Table 6-8).

TABLE 6-7: Generic data collection template for NPI primary metallurgical extraction from lateritic ores

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Concentrate					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Electrodes					C-content
Reductants (fossil)					C-content and type of reductant
Lime					
Other fluxes					
Output					
NPI					Assay data
CO_2 (fossil)					Calculated based on combustion, electrodes and reductants

TABLE 6-8: Generic data collection template for NPI to nickel matte conversion

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
NPI					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Sulphur					For treatment to get to high Nickel containing matte
Fluxes					
Output					
Nickel matte					Assay data (provide the exact Ni%, typically ≈ Ni 75% content)
CO_2 (fossil)					Calculated based on combustion, electrodes and reductants

Refining to $NiSO_4$ $6H_2O$

In the final process step to produce NiSO4 6H2O, the nickel matte is dissolved, or the mixed sulfides and hydroxides or oxides are refined. Therefore, it is important to collect all bulk chemicals, as well as the auxiliary materials listed in Table 6-9. It is important to know the exact assay data of all output and input materials, especially on the output side. Those are prerequisites to carry out the allocation of the carbon footprint to the different products. As stated in chapter 4.1, a mass allocation between the products shall be done according to the metal content if no PGM's are produced in the same process. But in case PGM's are also produced in the same process, an economic allocation is required.

TABLE 6-9: Generic data collection template for $NiSO_4$ $6H_2O$ refining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Matte / Mixed Sulfides / Mixed Hydroxide / Oxides					Assay data
Secondary sources of Nickel					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Chemicals (mainly bulk chemicals)					
External supply (Heat & Steam respective of fuel) purchased					
Oxygen, Hydrogen, Nitrogen					In case it is produced by subcontractor
Output					
Nickel					
$NiSO_4$ $6H_2O$					
Cobalt					
$CoSO_4$ $7H_2O$					
Copper					
PGM					Assay data
CO_2 (fossil)					Calculated based on combustion
By-products like ammonium sulfate					System expansion (See Chapter 4.1.1)

Summary on $NiSO_4$ $6H_2O$ production

Following the above data collection guidelines, a reliable and most accurate carbon footprint of $NiSO_4$ $6H_2O$ can be calculated. It is recommended to consider all input and outputs related to the production process and to group the chemicals according to their purpose (e.g., flocculants, frother, dispersants, etc.) and use the major chemicals as proxy for all chemicals consumed.

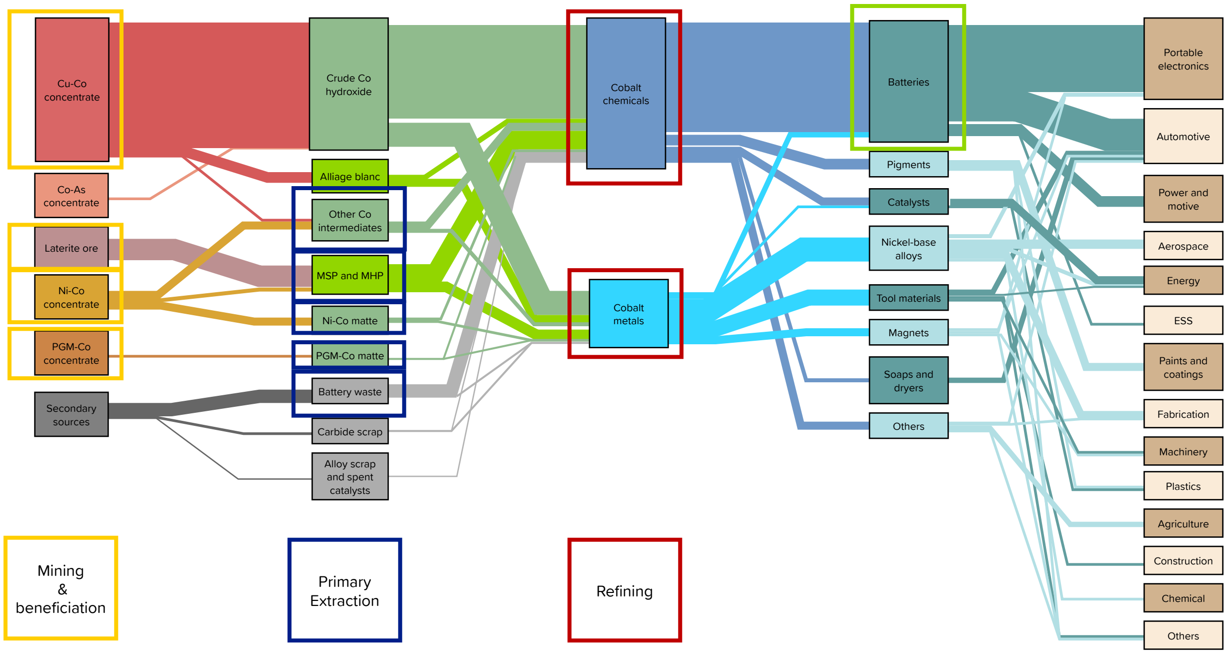
Furthermore, it is important to not forget to calculate process emissions like during the reduction process in the pyrometallurgical process or the CO_2 process emissions in the hydrometallurgical process where limestone is used for neutralization and $CaCO_3$ is reacting with acid solution and generating CO_2 emissions.

It is also important to calculate the transport between the different processes up to the final product with the respective transport means, which is described in 4.2.4.

6.1.2. Cobalt Sulfate Heptahydrate ($CoSO_4$ $7H_2O$)

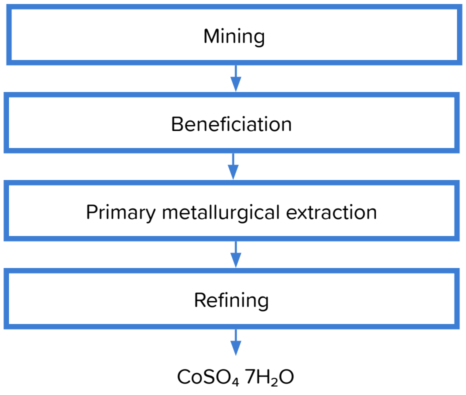
$CoSO_4$ $7H_2O$ is an important compound for the battery industry. The material flow of cobalt is shown in Figure 6-11. It can be seen that there are 4 different ore sources. Two sources are similar to Nickel (sulfidic and lateritic ore route), and one additional is the copper-cobalt route, which is also the biggest reserve of cobalt in the world in the copper belt in the Democratic Republic of Congo (DRC). The primary extraction of the Crude Cobalt Hydroxide is done in a hydrometallurgical process, which is described further below. The other processes are similar to those of $NiSO_4$ H_2O production.

FIGURE 6-11: Material flow of cobalt into different applications (Cobalt Institute, 2021)



In Figure 6-12, the “umbrella” process steps are shown, as well as the selection of specific processes allocated to these.

FIGURE 6-12: Umbrella processes steps and the allocation of specific process steps



Open and underground

Concentration (DMS, HMS, flotation, spirals etc.); from tailings

Flash furnace, Electric Arc Furnace, HPAL (High-pressure acid leach), roasting, SX (solvent extraction Cu/Co ores)

Refinery

Mining (underground and open pit) for sulfidic and lateritic ores

There are two types of mining operation underground and open pit. The data collection shall cover all related operational processes during the mining to receive at the end the ore to be sent to the beneficiation / ore processing step. That includes electricity consumption for hoisting, cooling, lighting, etc., for under-ground mines, as well as fuel consumption for excavators and haul road trucks, and explosives for breaking the rock.

In the following table, the minimum list of input and output parameters is shown. The data collector must state the exact unit, as well as give additional information in the specification field, for instance, conversion from natural gas in m^3 to kWh or MJ. This is important since the emission factors for fuels are typically given in CO_2 per TJ (terajoule).

A very important specification to be stated is the cobalt, as well as the other metals content in the ore. This is an important factor for cross-checking the cobalt balance over the whole value chain to the final product the $CoSO_4$ $7H_2O$.

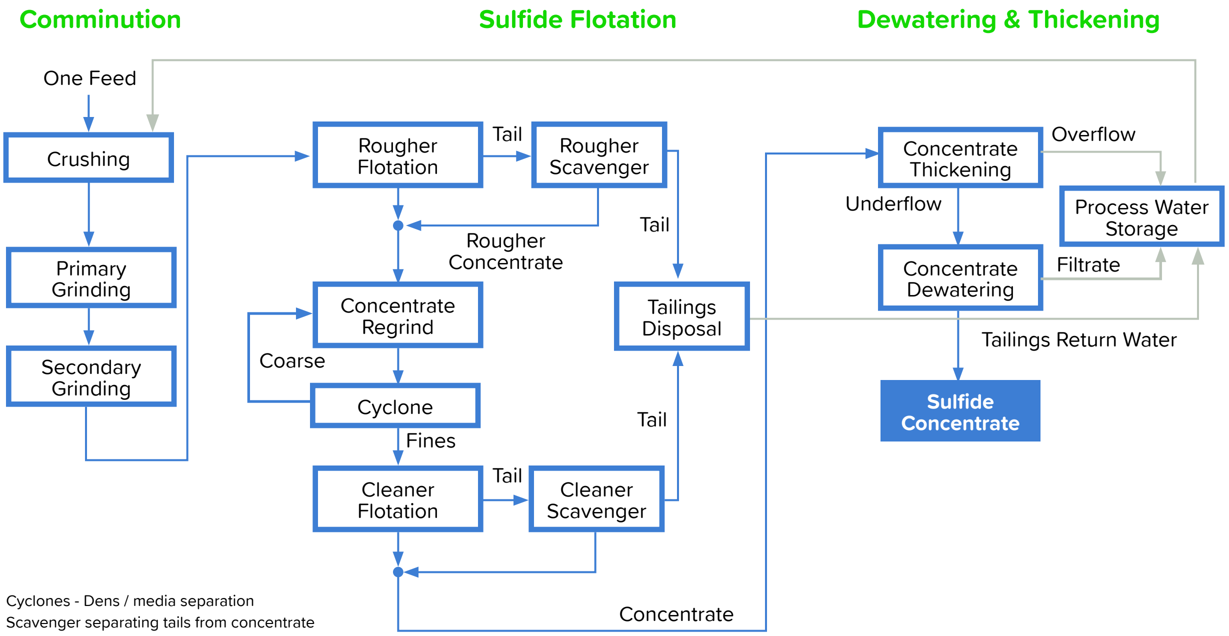
TABLE 6-10: Generic data collection template for underground and open pit mining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Explosives					
Cement (for production)					
Tires					
Output					
Ore mined					Assay data
Overburden					
Waste Rock					
CO_2 (fossil)					Based on Fuels & Explosives

Beneficiation / ore processing for sulfidic and lateritic ores

The beneficiation / ore processing step usually has many different process steps, as shown as an example in the following Figure 6-13. It starts with Comminution (crushing and grinding), then goes into the flotation circuit before it ends with the dewatering and thickening to receive the concentrate. All these steps are captured in the generic questionnaire in Table 6-11.

FIGURE 6-13: Process steps in a typical beneficiation of sulfidic ores (Zanin, 2019)



Cyclones - Dens / media separation
Scavenger separating tails from concentrate

Many chemicals are typically used but not necessarily for each chemical a carbon factor would be available. To avoid some of the chemicals being excluded because of no carbon factor, it is recommended to group the chemicals in the frother, dispersants, and flocculants and take the biggest contributor (mass) as a proxy for all categorised chemicals. Other bulk chemicals or auxiliaries like neutralizer (e.g., quicklime (CaO)), need to be collected separately, as shown in Table 6-11. The grinding media shall be collected even if it might fall under the cut-off criteria.

TABLE 6-11: Generic data collection template for beneficiation / ore processing

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Ore mined					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					Flocculants, Frother, Dispersant, bulk chemicals like H_2SO_4, CuS
Quick lime					
Grinding media *(maybe above threshold for low concentrate ore)*					Steel balls / rods (high Cr steel ~10% and low Cr steel ~1 -3 %)
Output					
Concentrate / Upgrade ore					Assay data
Tailings					Assay data

Primary Extraction (sulfidic ores) incl. H_2SO_4 plant (pyrometallurgical)
The primary metallurgical extraction is, out of experience, one of the major contributors to the carbon footprint of metals and its compounds. Therefore, it is important to collect all input and output parameters causing the carbon emissions. Table 6-12 shows the main input parameters like reductants (fossil or biogenic) where the CO_2 process emissions needs to be calculated using the carbon content of the reductant and the stoichiometry to calculate the process emissions per reductant. The same is valid for the consumption of electrodes. If there are bio-reductants like charcoal consumed, then the biogenic CO_2 factor shall be reported separately from the fossil-based reductants.

In case hydrogen is used, it is important to verify whether the production of hydrogen is via steam reforming or electrolysis using renewable energy.

It is also important to consider the oxygen used in case it is not produced onsite but purchased from a supplier.

In the case of external heat and steam supply, it is important to get the right carbon factors from the supplier, including scope 3 emissions of the supply of the fuels.

It is important to also collect the SO_2 emissions which are then converted to sulfuric acid as described in the next process step.

TABLE 6-12: Generic data collection template for primary (metallurgical) extraction (sulfidic ore furnace)

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Concentrate					Assay data
Electricity					Including Oxygen production onsite
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Electrodes					C-content
Reductants (fossil or / and biogenic)					C-content and type of reductant
Oxygen					In case it is produced by subcontractor
Output					
Nickel Matte					Assay data
CO_2 (fossil)					Calculated based on Electrodes and reductants (based on stoichiometry)
CO_2 (biogenic)					Calculated based on biogenic reductants
SO_2					Split between emissions and capture to H_2SO_4 plant (system expansion according to Santero & Hendry [2016]if by product)
Waste heat recovery					e.g. for district heating

The following Table 6-13 shows the generic questionnaire for a sulfuric acid plant. This is important to be considered within the carbon footprint calculation since it is an essential part of the production process to avoid the acidification of the surroundings of the plant.

The produced and sold sulfuric acid shall be allocated by using system expansion according to Santero & Hendry (2016).

TABLE 6-13: Generic data collection template for sulfuric acid plants

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
SO_2					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Lime					
Output					
H_2SO_4 (sold)					
H_2SO_4 (waste)					
CO_2 (fossil)					Calculated based on fuels

Primary Extraction (from sulfidic ores) (hydrometallurgical)
In the hydrometallurgical extraction, there is no smelting operation, but the concentrates are dissolved with chemicals. Therefore, it is important (similar to the beneficiation) to report on bulk chemicals and group by mass with minor contributing chemicals together. It is important in the case of precipitation steps where no quicklime, but limestone is used that the process CO_2 emissions through the reaction of $CaCO_3$ with the acid solutions are calculated accordingly.

TABLE 6-14: Generic data collection template for hydrometallurgical extraction from concentrates

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Concentrate					Assay data
Electricity					Including Oxygen, nitrogen, hydrogen production onsite
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					
Lime, limestone, etc.					Assay data (purity and reactivity)
Oxygen, Nitrogen, Hydrogen					In case it is produced by subcontractor
Output					
MSP					Assay data
CO_2 (fossil)					
CO_2 (process)					Reaction between CaCO3 and acid solution

Primary Metallurgical Extraction (from lateritic ores)
This is an energy and CO_2-intensive process. Therefore, the fuels used to generate steam for the HPAL (Hot Pressure Acid Leaching) process are an important parameter, as well as the sulfuric acid and the limestone for neutralization. In that neutralization step, process-specific CO_2 emissions are generated in the reaction of $CaCO_3$ (limestone) with the acid solution. Here, it can be assumed (stoichiometric) that 44% of the limestone weight on the input side will be CO_2 emissions. It is also important if one produced his own H_2S onsite that, of course, the CO_2 factor for the sulfur on the input side is taken into account as scope 3.

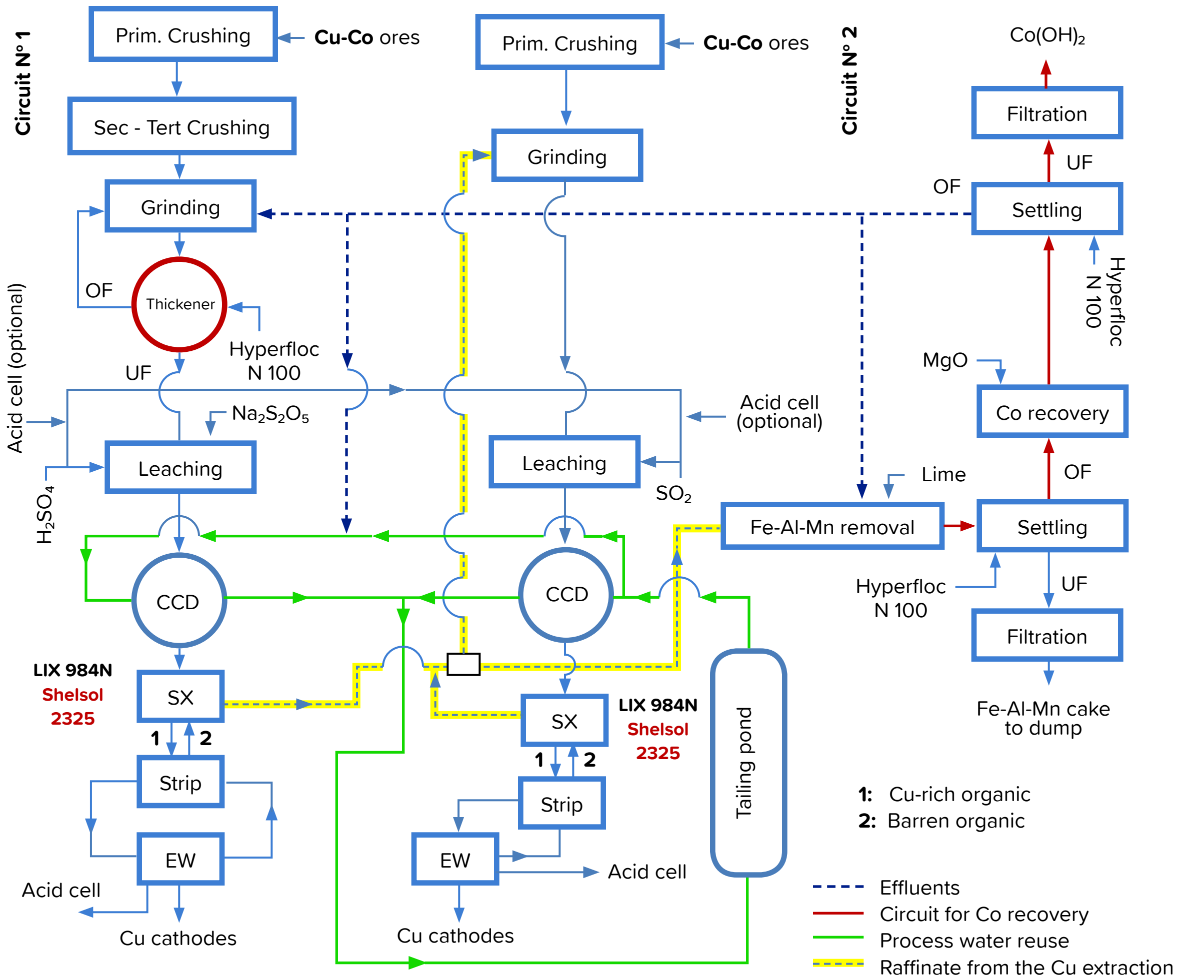
TABLE 6-15: Generic data collection template for primary metallurgical extraction from lateritic ores

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Upgraded ore					Assay data, for transport use wet weight and not dry matter
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Limestone, Lime (CaO, etc.), NaOH, MgO					Assay data (purity and reactivity)
Sulfur / H_2S					
H_2SO_4					Important to define the CO_2 factor
Flocculants					
Output					
Mixed Sulfides					Assay data
CO_2 (fossil)					Calculated based on combustion
CO_2 (process)					Process emission: reaction of H_2SO_4 & limestone considering purity and reactivity
Tailings					Assay data

Primary Extraction from copper-cobalt concentrates (hydrometallurgical)

After mining and beneficiation of the copper-cobalt ore in DRC, the concentrate or tailings (reworked in the hydrometallurgical circuit as well since higher Co content), a roasting step (depending on the ore) might take place before the leaching, solvent extraction processes until the final precipitation process for the crude cobalt hydroxide is carried out. In Figure 6-14, a generic hydrometallurgical process flow for producing Crude Cobalt Hydroxide is shown (note that the roasting step does not feature in this particular example).

FIGURE 6-14: Process steps in a typical hydrometallurgical process flow to produce $Co(OH)_2$ (Lutandula, 2020)



The basis of a reliable process where the consistency of data can be checked is the assay data to be able to check if the mass balance of cobalt is closed. In this hydrometallurgical step again, it is very important to calculate the process emissions as soon as limestone is used for neutralization. Furthermore, it is important to use an allocation between the Crude Cobalt Hydroxide and the copper-containing solution.

TABLE 6-16: Generic data collection template for the roasting of copper -cobalt ores

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Concentrate					Assay data
Electricity					
Diesel					
External supply (Heat & Steam respective of fuel) purchased					
Output					
Roasted Calcine					Assay data
CO_2 (fossil)					Based on Fuels

TABLE 6-17: Generic data collection template for primary hydrometallurgical extraction from copper-cobalt ores

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Concentrate / tailings					Assay data
Electricity					
Fuels					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					Flocculants, H_2SO_4, NaOH
Limestone, Lime (CaO), NaOH, MgO					Assay data (purity and reactivity)
Output					
Crude CoOH					
Cu containing solution					To electrowinning (Assay data)
CO_2 (fossil)					Calculated based on fuels
CO_2 (process)					Reaction of $CaCO_3$ with acid solution

Refining to $CoSO_4$ $7H_2O$

In the final process step to produce $CoSO_4$ $7H_2O$, the nickel matte is dissolved, or the mixed sulfides and hydroxides or oxides are refined. Therefore, it is important to collect all bulk chemicals, as well as the auxiliary materials listed in Table 6-18. It is important to collect the assay data of all output and input materials, especially on the output side. Those are pre-requisites to carry out the allocation of the carbon footprint to the different products. As stated in chapter 4.1.1, a mass allocation between the products shall be done according to the metal content if no PGM's are produced in the same process. But in the case PGMs are also produced in the same process, an economic allocation is required.

TABLE 6-18: Generic data collection template for $CoSO_4$ $7H_2O$ refining via matte

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Matte / Mixed Sulfides / Mixed Hydroxide / Oxides					Assay data
Secondary sources of Cobalt					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Chemicals (mainly bulk chemicals)					
External supply (Heat & Steam respective of fuel) purchased					
Oxygen, Hydrogen, Nitrogen					In case it is produced by subcontractor
Output					
Nickel					
$NiSO_4$ $6H_2O$					
Cobalt					
$CoSO_4$ $7H_2O$					
Copper					
PGM					Assay data
CO_2 (fossil)					Calculated based on combustion
By products like ammonium sulfate					System expansion (See Chapter 4.1.1)

In Table 6-19, the generic questionnaire for the refining step from Crude cobalt hydroxide to either $CoSO_4$ $7H_2O$ or cobalt metal is given. Again, essential is the assay data to be able to do the content-based allocation between cobalt and $CoSO_4$ $7H_2O$ in case the processes cannot be separated.

Here, as in all other questionnaires, it is important to consider the bulk chemicals and group minor chemicals according to their purpose like precipitants, etc., and apply a proxy suing the major contributor to the grouped chemicals.

TABLE 6-19: Generic data collection template for $CoSO_4$ $7H_2O$ refining via crude $Co(OH)_2$

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
CoOH					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Chemicals (mainly bulk chemicals)					
External supply (Heat & Steam respective of fuel) purchased					
Output					
Cobalt					
$CoSO_4$ $7H_2O$					
CO_2 (fossil)					Calculated based on combustion of fuels

Summary on $CoSO_4$ $7H_2O$ production

Following the above data collection guidelines, a reliable and most accurate carbon footprint of $CoSO_4$ $7H_2O$ can be calculated. It is recommended to consider all input and outputs related to the production process and to group the chemicals according to their purpose (e.g., flocculants, frother, dispersants, etc.) and use the major chemicals as proxy for all chemicals consumed.

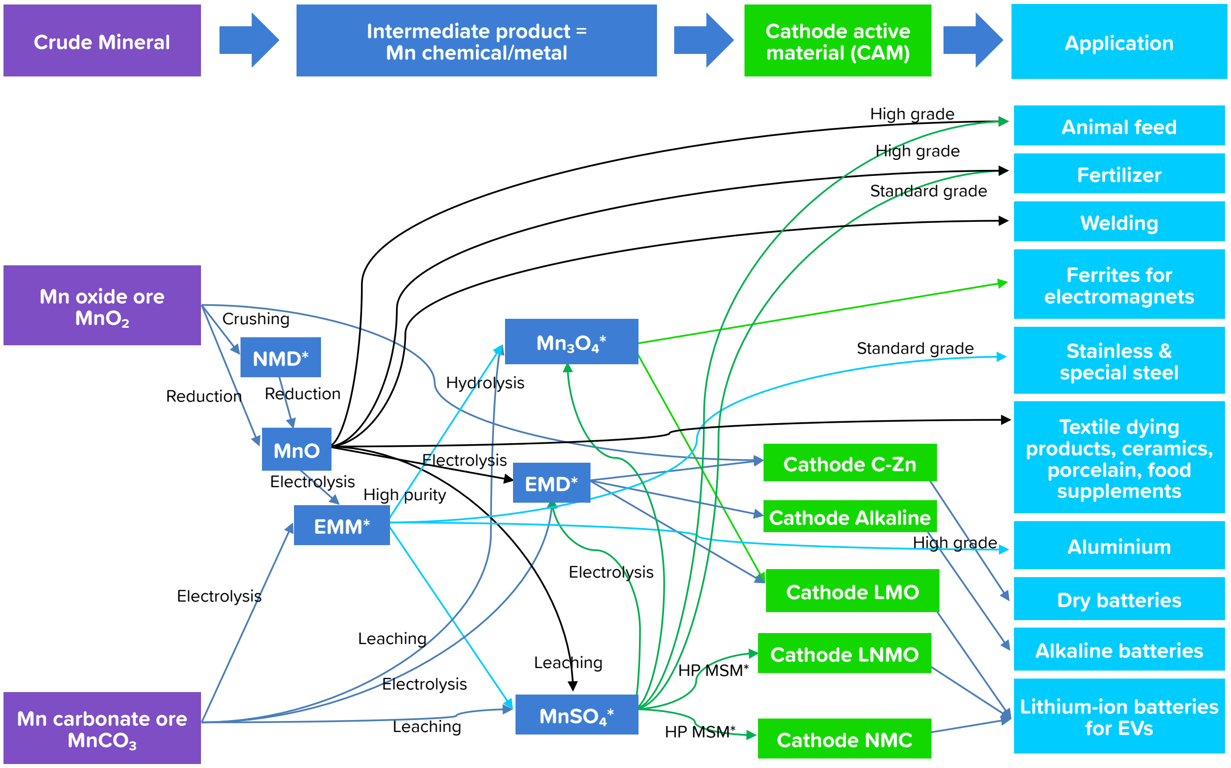
Furthermore, it is important to calculate process emissions during the reduction process in the pyrometallurgical process and the CO_2 process emissions in the hydrometallurgical process where limestone is used for neutralization and $CaCO_3$ is reacting with acid solution and generating CO_2 emissions.

It is also important to calculate the transport between the different processes up to the final product with the respective transport means, which is described in 4.2.4.

6.1.3. Manganese Sulfate Monohydrate ($MnSO_4$ H_2O)

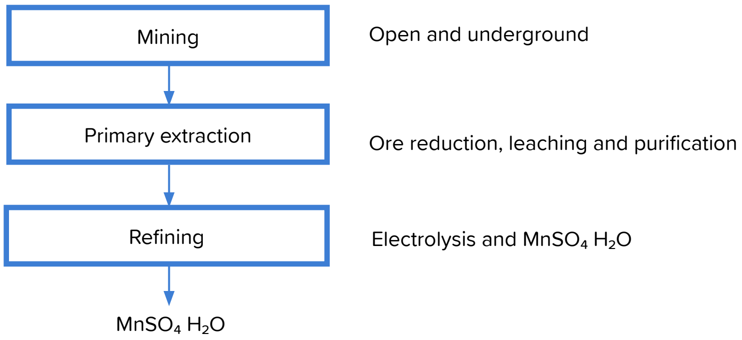
There are different routes to produce $MnSO_4$ H_2O for the battery value chain. The two main raw materials are oxidic ore and carbonate ore. Carbonate ore is mainly found in China and would trigger the Chinese production, whereas ore bodies in Southern Africa and Australia are mainly oxidic ores. The major routings are displayed in Figures 6-15 and 6-16. One main route is the route vial leaching purification and electrolysis to yield $MnSO_4$ H_2O.

FIGURE 6-15: Material flow of manganese into different applications (IMnI, 2022).



* NMD = natural Mn dioxide
* EMD = electrolytic Mn dioxide
*MnO = reduced ore Mn oxide
*Mn3O4 = trimanganese tetraxoide
*MnSO4 = Mn sulfate
*EMM = electrolytic Mn
*HP MSM = high purity Mn sulfate

FIGURE 6-16: Umbrella processes steps and the allocation of specific manganese process steps



Mining (underground and open pit) for oxidic and carbonate ores

There are two types of mining operation underground and open pit. The data collection shall cover all related operational processes during the mining to receive at the end the ore to be sent to the beneficiation / ore processing step. That includes electricity consumption for hoisting, cooling, lighting, etc., for underground mines, as well as fuel consumption for excavators and haul road trucks, and explosives for breaking the rock.

In the following table, the minimum list of input and output parameters is shown. The data collector must state the exact unit, as well as give additional information in the specification field, for instance, conversion from natural gas in m^3 to kWh or MJ. This is important since the emission factors for fuels are typically given in CO_2 per TJ (terajoule).

A very important specification to be stated is the manganese content in the ore. This is an important factor for cross-checking the manganese balance over the whole value chain to the final product the $MnSO_4$ H_2O.

TABLE 6-20: Generic data collection template for underground and open pit mining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Explosives					
Cement (for production)					
Tires					
Output					
Ore mined					Assay data
Overburden					
Waste Rock					
CO_2 (fossil)					Based on Fuels & Explosives

Primary Metallurgical Extraction

The allocated specific process steps to the primary extraction are

- Ore reduction
- Leaching and purification

Ore reduction of oxidic ores

The ore reduction process is required for oxidic manganese ores before they are added to the leaching and purification process. The data collection spreadsheet of this step is displayed in Table 5-21. It is very important to collect the carbon content of the reductants (fossil or biogenic) to be able to calculate the CO_2 process emissions by applying stoichiometry.

TABLE 6-21: Generic data collection template for reduction

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Ore mined					Assay data
Electricity					
Diesel					
External supply (Heat & Steam respective of fuel) purchased					
Reductants (fossil)					C-content and type of reductant
Reductants (biogenic)					C-content and type of reductant
Output					
MnO					Assay data
Waste					Assay data
CO_2 (fossil)					Based on Fuels

For leaching and purification, it is important to collect the chemicals and report the bulk chemicals separately. If a selection of other chemicals is used, a grouping should be done based on the application, like precipitants, etc. If there is a group of chemicals combined, a proxy needs to be identified, which is recommended to be the chemicals with the biggest contribution in terms of weight.

TABLE 6-22: Generic data collection template for leaching and purification

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
MnO / $MnCO_3$					Assay data
Electricity					
Diesel					
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					
Output					
Purified solution					Assay data
CO_2 (fossil)					Based on Fuels

Refining

The refining step consists of two main steps

- Electrolysis
- Refining of $MnSO_4$ H_2O

For the data collection, it is important which type of electrolysis technology is used:

- SO_2 technology type
- SeO_2 technology type

Both have differences in input and output parameters.

TABLE 6-23: Generic data collection template for electrolysis

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Purified solution					Assay data
Electricity					
Fuels					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
SO_2					
SeO_2					
NH3, etc.					
Output					
EMM					Assay data
CO_2 (fossil)					Calculated based on fuels used

The final refining step to produce $MnSO_4$ H_2O can be done using directly reduced manganese ore, as well as manganese carbonate, but the most common routing is via the electrolysis process.

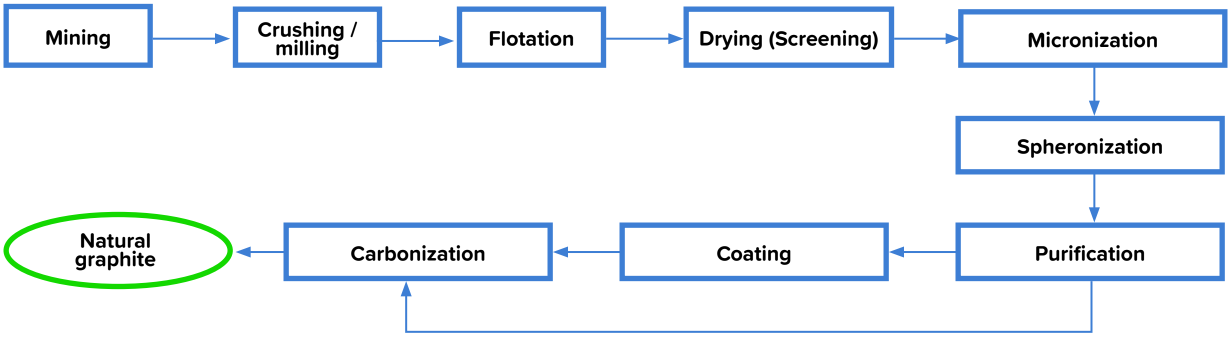
TABLE 6-24: Generic data collection template for $MnSO_4$ H_2O refining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
MnCO3 / MnO / Mn metal					Assay data
Electricity					
Fuels					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
H_2SO_4					
Output					
$MnSO_4$ H_2O					Assay data
CO_2 (fossil)					Calculated based on fuels

6.1.4. Natural Graphite

There is one major route to produce Anode material from natural graphite for the battery value chain. The routing is displayed in the following Figure 6-17. In case a graphite anode material producer cannot find its own route in the figure a generic data collection template is provided to include new processes and routings into the value chain of batteries.

FIGURE 6-17: Material flow of natural graphite anode material production (ECGA, 2022)



In general, it is required to calculate for each process step the carbon balance to be sure that no CO_2 emissions are missing dung the calculation of the carbon footprint of natural graphite for the battery value chain.

Mining (underground and open pit)

There are two type of mining operation underground and open pit. The data collection shall cover all related operational processes during the mining to receive at the end the ore to be sent to the crushing / milling step. That includes electricity consumption for hoisting, cooling, lighting, etc. for underground mines as well as fuel consumption for excavators and haul road trucks. Explosives for breaking the rock.

TABLE 6-25: Generic data collection template for graphite mining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Electricity					Specification where you source your electricity from, and country operation
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Explosives					
Tires					
Output					
Graphite ore					Assay data on graphite
Overburden					
Waste Rock					
CO_2 (fossil)					Based on Fuels & Explosives

Crushing / Milling

This step includes crushers which are breaking the big graphite rocks and mills which are grinding it to fine graphite material which is then sent to the flotation step

TABLE 6-26: Generic data collection template for graphite crushing / milling

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Graphite ore					
Electricity					Specification where you source your electricity from, and country operation
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Grinding media *(maybe above threshold for low concentrate ore)*					
Output					
Crushed graphite ore					Assay data
CO_2 (fossil)					Based on Fuels

Flotation

The crushed and milled graphite is put into flotation cells where the content is increased up to 90% carbon content and tailings are separated and usually put through thickeners before landfilling the tailings.

TABLE 6-27: Generic data collection template for graphite flotation

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Crushed / milled graphite ore					Assay data
Electricity					Specification where you source your electricity from, and country operation
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					Flocculants, Frother, Dispersant, bulk chemicals
Output					
Flotation output to drying					Assay data
Waste streams / By-products					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give assay data
Tailings					
CO_2 (fossil)					Based on Fuels

Drying (Screening)
The drying and screening process step is dominated by the fuels used for drying. The following Table 5-36 is drying and screening activity data together. It is recommended to even report on the evaporated water to be able to check the mass balance for consistency of the data.

TABLE 6-28: Generic data collection template for graphite drying

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Flotation material to drying					
Electricity					Specification where you source your electricity from, and country operation
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Output					
Dried material					Assay data
Waste stream / By-products					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give assay data
Water evaporated					
CO_2 (fossil)					Based on Fuels and Process emissions

Micronization / screening / classification
Micronization is the process of reducing the average diameter of a solid material's particles. Traditional techniques for micronization focus on mechanical means, such as milling and grinding. As it can be seen the major impact for the process is the electricity consumed for the mechanical operation of the process.

TABLE 6-29: Generic data collection template for graphite micronization / screening / classification

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Dried material					
Electricity					Specification where you source your electricity from, and country operation
Grinding media (may be above threshold)					
Output					
Micronized material					Assay data
Waste streams / By-products					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give assay data
Waste stream					
CO_2 (fossil)					Based on Fuels

Spheronization

Spheronization is a sizing and shaping process that micronizes and rounds the vein graphite particles. Spheronization is done to optimize the particle surface area to achieve the highest performance in the anode. In this process a by-product is produced which is sold. At that stage, an economic allocation shall take place between the Spheroids and the sold fines in accordance with the general rules provided in Chapter 4.4.1.

TABLE 6-30: Generic data collection template for graphite Spheronization

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Micronized material					
Electricity					Specification where you source your electricity from, and country operation
Output					
Spheronized material (spheroids)					
By Product - fines					Sold
Waste stream					Specify if incinerated / treatment and energy consumption of treatment
Dust					Specify treatment and specify energy consumption
CO_2 (fossil)					Based on Fuels

Purification

The Spheroids will be purified in this step where bulk chemicals like HF are used. It is important to specify gaseous outputs and if they are reused or sold etc. to be able to apply an allocation to the reused off gasses.

TABLE 6-31: Generic data collection template for graphite purification

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Spheronized material (spheroids)					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					Bulk chemicals HF & Cl gases
Auxiliaries used in waste gas and water treatment					
Output					
Purified material					
Waste water stream					WWT
Waste stream					Specify if incinerated / treatment and energy consumption of treatment
Gas waste streams					Specify treatment and specify energy consumption
CO_2 (fossil)					Based on Fuels and process emissions

The purified Spheroids then can either undergo the coating process or going directly into graphitization to receive the final product for anode manufacturing.

Coating

Pitch is the main material used for the coating of the purified spheroids. Therefore, it is important to also collect the C-content of the pitch from the supplier to be able to calculate the respective process emissions. Off gases need to be reported by their composition as well the respective treatment (reuse or flaring). In case of after burning the CO_2 emissions shall be calculated and included in the carbon footprint.

TABLE 6-32: Generic data collection template for graphite coating

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Purified material					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Pitch					
Output					
Coated material					
Off Gas					If burned CO_2 need to be calculated & otherwise composition of offgas shall be reported
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels and process emission

Graphitization

The purified spheroids can also directly undergo the graphitization process which is a high energy intensive process. Off gases need to be reported by their composition as well the respective treatment (reuse or flaring). Process emissions need to be reported based on the carbon balance.

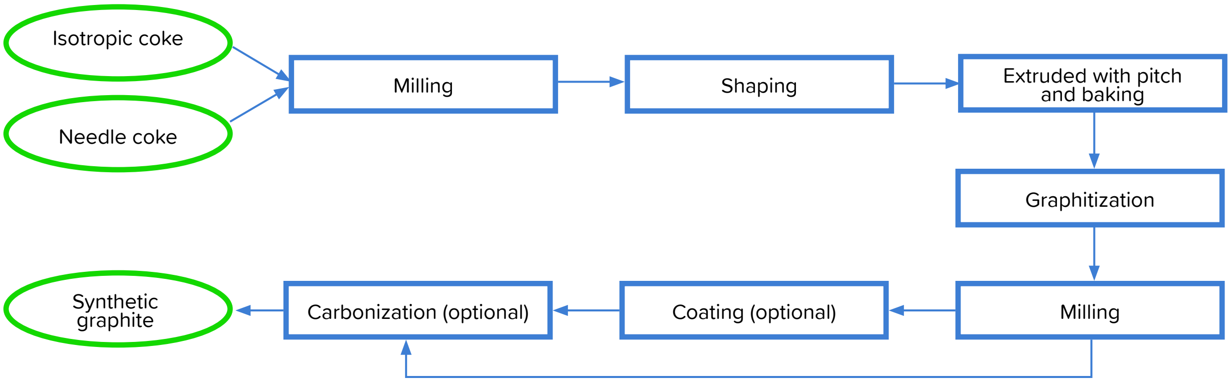
TABLE 6-33: Generic data collection template for graphitization

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Purified material					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Output					
Coated material					
Off Gas					If burned CO_2 need to be calculated & otherwise compsition of offgas shall be reported
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels and process emission

6.1.5. Synthetic graphite

Synthetic graphite is produced from isotropic coke and needle coke (See Figure 6-18). These are the main input materials to produce synthetic graphite. It is important and recommended to collect supplier-specific data for these materials. In case supplier-specific data is not available, the secondary data sources listed in Chapter 5.2.1 shall be used in order of priority.

FIGURE 6-18: Material flow of synthetic graphite anode material production (ECGA, 2022)



In the following the generic questionnaire template for each of the production processes for synthetic graphite are displayed and the important consideration for the data collection and the calculation of the carbon footprint are given.

Milling

The milling process is the first step to mill the coke for the next step the shaping process. The milling process is mainly driven by electricity consumption and to assure the right impact the mass balance shall be checked including waste and by products which are sold or used in different production routes.

TABLE 6-34: Generic data collection template for milling

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Needle coke					C-content
Isotropic coke					C-content
Electricity					
Grinding media					
Output					
Milled coke					C-content
By products (fines)					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give C content data
Waste process					

Shaping

To produce the spheroids the shaping process uses electricity and fuels as shown in the generic questionnaire below.

TABLE 6-35: Generic data collection template for shaping

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Milled material					C-content
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Output					
Spheroids					C-content
By Product - fines					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give C content data
Waste stream					
CO_2 (fossil)					Based on Fuels

Extruding and baking

This process is important for CO_2 calculation therefore the carbon content of the Spheroids as well as for the pitch and the baked material shall be collected to be able to carry out a proper carbon balance to calculate the CO_2 emissions in a reliable way.

Table 6-36 Generic data collection template for extruding with pitch and baking

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Spheroids					C-content
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Pitch					Bulk chemicals for coating - C-content
Output					
Extruded and baked material					C-content
Off gas					Flared (CO_2 calculation) or released off gas composition
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels

Graphitization

The most energy intensive process which is mainly carried out by using electricity. Therefore, it is important to collect all input and output parameters listed in Table-6-37. It is again very important to close the carbon balance to not miss any process CO_2 emissions. Off gas treatment must be considered in form of CO_2 emissions in case there is a flaring taking place.

Table 6-37: Generic data collection template for graphitization

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Extruded and baked material					C-content
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Output					
Graphitized material					C-content
Off gas					Flared (CO_2 calculation) or released off gas composition
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels

Milling of graphitized material

The milling process of the graphitized material is electricity driven and therefore the mass balance of the mill plus electricity consumption are important parameters.

TABLE 6-38: Generic data collection template for milling of graphitized material

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Graphitized material					C-content
Electricity					
Grinding media					
Output					
Milled graphitized material					C-content
By products (fines)					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give C content data
Waste process					

Coating (optional)

This process is done in specific cases and therefore optional. But in case one is using this process step the parameters listed in the generic questionnaire need to be collected.

TABLE 6-39: Generic data collection template for coating (optional)

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Graphitized material					C-content
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Pitch					C-content
Output					
Coated material					C-content
Off Gas					If burned CO_2 need to be calculated & otherwise composition of off gas shall be reported
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels and process emission

Graphitization (optional)

A second graphitization might happen. Graphitization is a high energy intensive process which is mainly carried out by using electricity. Therefore, it is important to collect all input and output parameters listed in Table 6-40. It is again important to close the carbon balance to not miss any process CO_2 emissions. Off gas treatment must be considered in form of CO_2 emissions in case there is a flaring taking place.

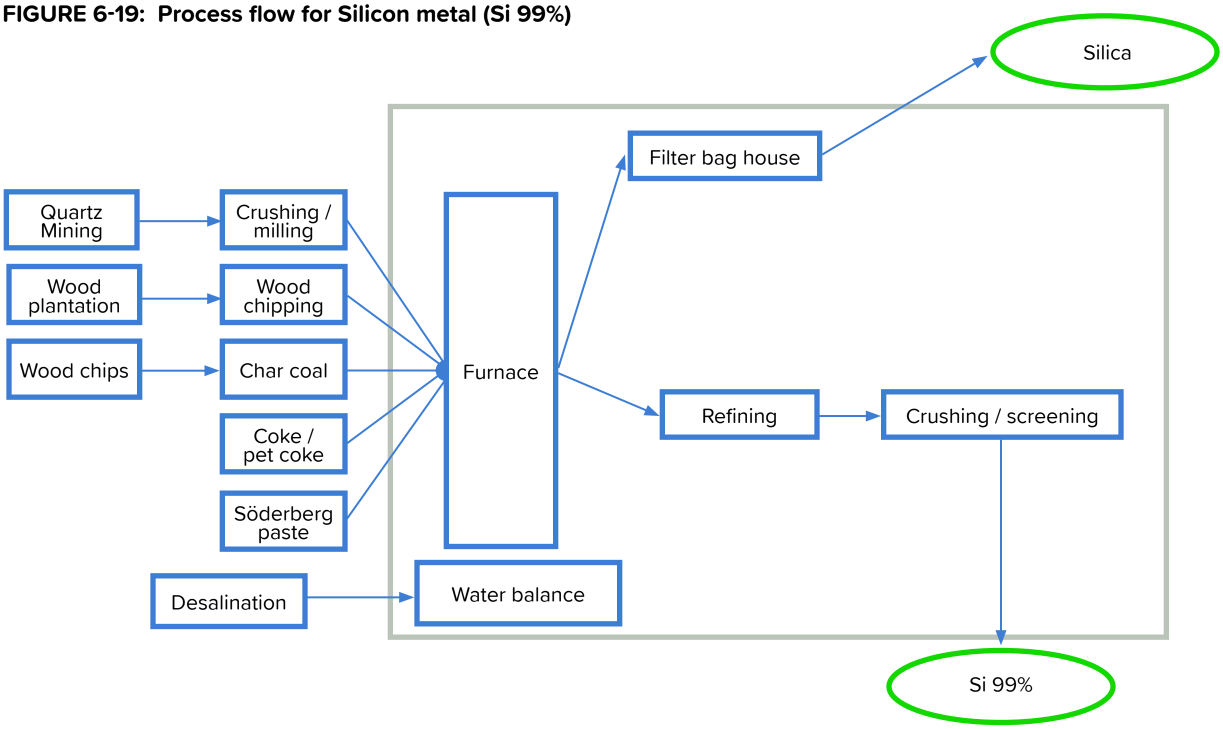
TABLE 6-40: Generic data collection template for graphitization

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Coated material					C-content
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Output					
Coated material					C-content
Off Gas					If burned CO_2 need to be calculated & otherwise composition of off gas shall be reported
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels and process emission

6.1.6. Silicon metal

Silicon metal is another anode material, but we have only the processes until the Silicon metal with 99% and it was not clear if there are further refining steps to high grade like 99,999%. This chapter gives you guidance for data collection up to the silicon metal 99% Si content as shown in Figure 6-19.

FIGURE 6-19: Process flow for Silicon metal (Si 99%)



Mining

The mining of Quartz is mainly driven by fuel consumption and depending on the type of mine on electricity. The generic questionnaire for quartz mining is shown in Table 6-41.

TABLE 6-41: Generic data collection template for Quartz mining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Electricity					Specification where you source your electricity from, and country operation
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Explosives					
Tires					
Output					
Quartz					
Overburden					
Waste Rock					
CO_2 (fossil)					Based on Fuels & Explosives

Crushing / milling

After the mining depending on the size of the mined quartz a crushing and milling take place. This process is driven mainly by electricity consumption or fuel consumption in case of generator use for electricity production.

TABLE 6-42: Generic data collection template for crushing / milling

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Quartz					
Electricity					Specification where you source your electricity from, and country operation
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Grinding media *(maybe above threshold for low concentrate ore)*					
Output					
Crushed Quartz					Assay data
CO_2 (fossil)					Based on Fuels

Smelting / Filter Baghouse

In the smelter the electricity consumption is a main driver of the carbon footprint as long there are fuels used to produce the electricity. Of further importance is the use of wood chips / bars and its biogenic carbon content in the melt which should be from sustainable forestry. Further reductants shall also report on the carbon content. Based on this and the output the carbon balance shall be calculated and displayed for fossil, process and biogenic CO_2 emissions. It is important to report on the by-products like silica fume to perform partitioning of GHG emissions to recovered and sold by-products by allocation supported by 3rd-party verified evidence in accordance with the general approach (see Chapter 4.1.1).

TABLE 6-43: Generic data collection template for melting and filter baghouse

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Crushed / milled Quartz					Assay data
Electricity					Specification where you source your electricity from, and country operation
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Wood chips					C-content (Sustainable forest)
Pet coke, coke, Coal, etc.					C-content
Output					
Silicon 99					Assay data
By-products like Silica					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give assay data
Slag					Landfilled or used in SiMn process?
CO_2 (fossil)					Based on Fuels
CO_2 (process)					Based on reductants
CO_2 (biogenic)					Based on wood and char coal

Refining

The refining step is carried out by blowing oxygen or nitrogen into the ladle.

TABLE 6-44: Generic data collection template for refining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Silicon					
Nitrogen					
Oxygen					
Output					
Refined Silicon 99					
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on process emission

Crushing and screening

The crushing and screening step is mainly driven by electricity consumption and is also the reason for the major impact.

TABLE 6-45: Generic data collection template for crushing and screening

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Refined Silicon 99					
Electricity					Specification where you source your electricity from, and country operation
Output					
Crushed Silicon 99					Assay data
Dust					

In case there is a further refining step necessary to get anode grade silicon please use the following standard questionnaire and check if those input and output parameters are part of the process and report specifically on their consumption.

TABLE 6-46: Generic data collection template for an additional process step

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Silicon 99					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Auxiliaries (e.g., water)					Please specify
Chemicals					Please specify
Output					
Si anode grade					
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels
CO_2 (process)					Process emission

6.1.7 Lithium

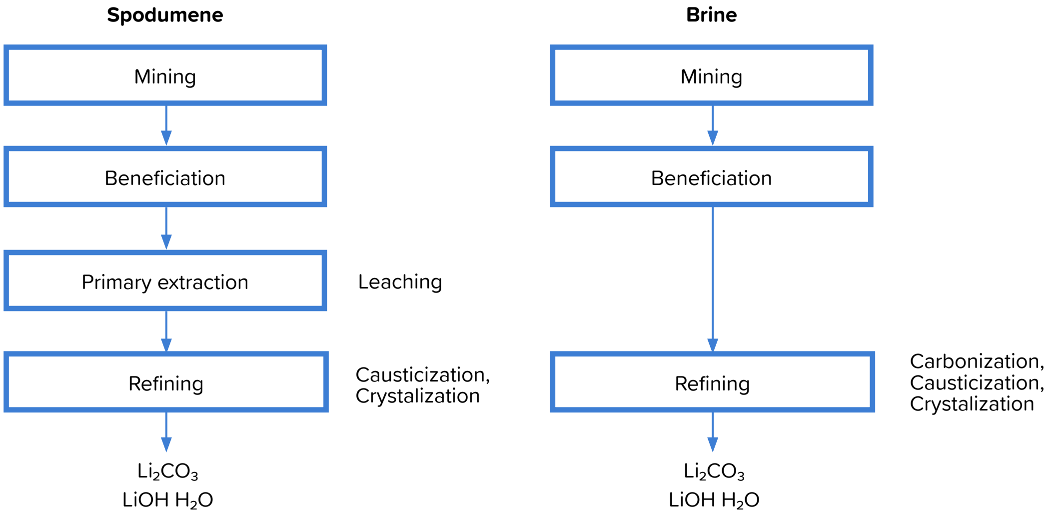
Lithium is produced using two different raw materials:

- Lithium brine
- Spodumene ore

Both sources are used today to produce lithium carbonate and lithium hydroxide, as well as lithium metal. In this chapter, it is described which input and output parameters need to be collected to receive a reliable carbon footprint for lithium according to the ISO 14040 and 44 standards.

In general, the main production steps are shown in Figure 6-20.

FIGURE 6-20: Umbrella production process with allocation of specific processes for brine and spodumene



Mining

There are two routes of mining for lithium. One route is via the spodumene ore, which covers a typical underground or open cast mining of rock containing Lithium. The other mining is rather a brine pumping from underground into ponds where the water is evaporated, and the brine is getting to a higher concentration of Lithium.

In the following Table 6-47, the spodumene mining questionnaire is listed with input and output parameters, which are the minimum requirement to get a reliable carbon footprint.

In Table 6-48, the brine “mining” questionnaire is shown, and the main impacts are electricity and fuel consumption, which need to be collected.

TABLE 6-47: Generic data collection template for spodumene mining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Explosives					
Tires					
Output					
Ore mined					Assay data
Overburden					
Waste Rock					
CO_2 (fossil)					Based on Fuels & Explosives

Table 6-48: Generic data collection template for brine extraction

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Output					
Brine					Assay data
CO_2 (fossil)					Based on Fuels

Beneficiation
The beneficiation process for spodumene ore is like the processing of hard rock ores. The beneficiation of brine is rather a concentration process initiated by solar rays, and only pumping energy is needed to pump the brine from pond to pond for the different concentration stages. In Table 6-49 and Table 6-50, the requirements for data collection are shown.

In the case of the brine concentration, an allocation is required since there is potassium chloride as a co-product produced (See Chapter 4.1.1).

TABLE 6-49: Generic data collection template for brine concentration

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Brine					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Output					
LiCl solution (6% Li)					Assay data
Potassium (by product)					Assay data

TABLE 6-50: Generic data collection template for spodumene beneficiation

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Ore mined					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					Flocculants, Frother, Dispersant, bulk chemicals like H_2SO_4
Grinding media *(maybe above threshold for low concentrate ore)*					Steel balls / rods (high Cr steel ~10% and low Cr steel ~1 -3 %)
Output					
Spodumene concentrate					Assay data
Tailings					Assay data

Primary Metallurgical Extraction from spodumene ore

The primary extraction process from spodumene ore is shown in the following flowchart (Figure 6-21). The main steps are roasting, leaching, and purification before it is sent to the refining of the final products, lithium carbonate or lithium hydroxide..

FIGURE 6-21: Lithium production process from spodumene ore – primary metallurgical extraction (Bishimbayeva, 2018)

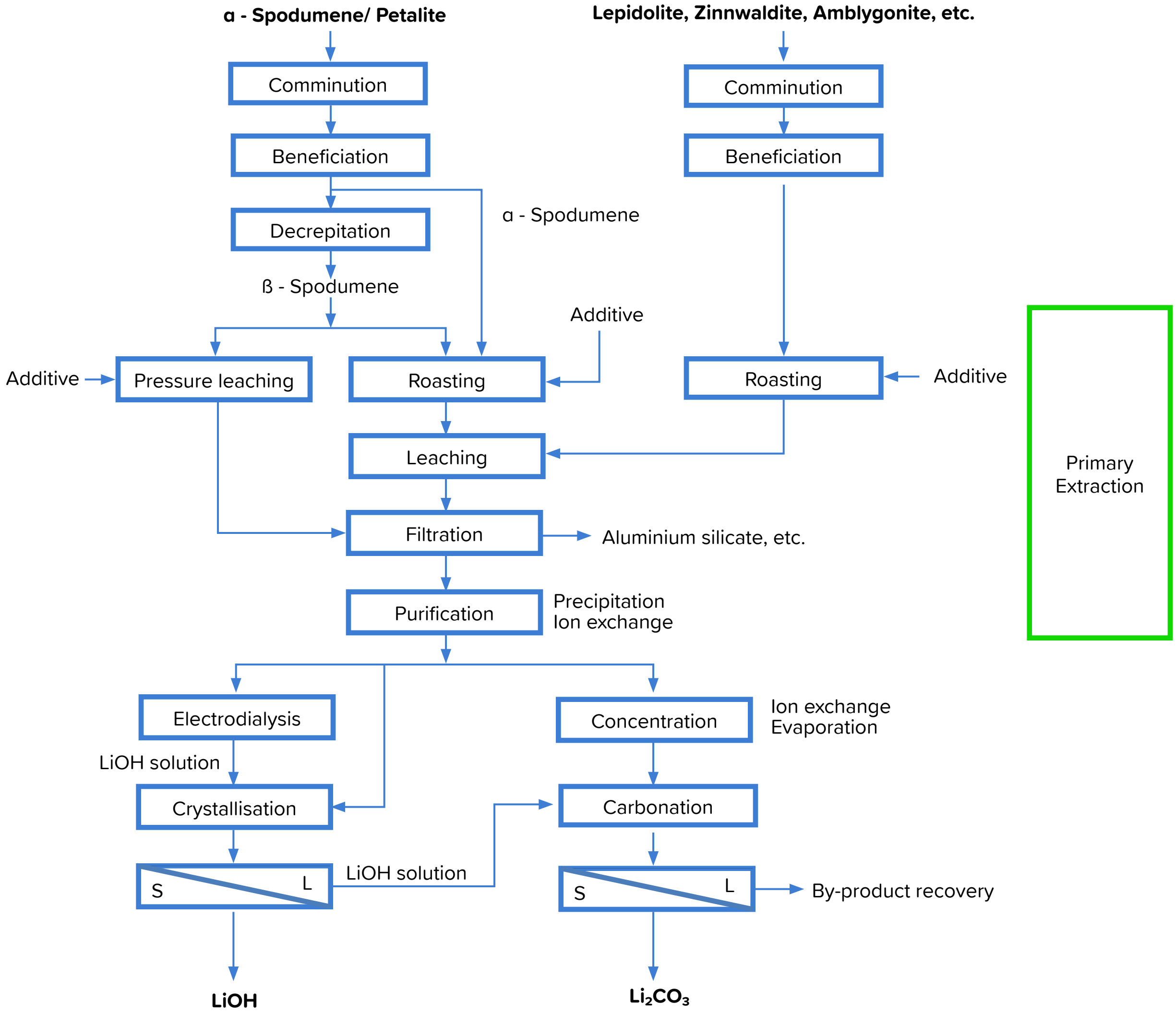


Table 6-51 shows the required input and output parameters for the primary metallurgical extraction from spodumene ore. It is important that the bulk chemicals are collected, and the remaining chemicals are grouped by their application (e.g., precipitants). The reason for this grouping is that today carbon footprint data are not necessarily available for all chemicals, whereas for bulk chemicals, CF data is available.

Following the general approach (see Chapter 4.1.1), any produced and sold calcium carbonate or quicklime shall be allocated by using system expansion according to Santero & Hendry (2016) and supported by 3rd-party verified evidence.

TABLE 6-51: Generic data collection template primary metallurgical extraction from spodumene

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Spodumene Concentrate					Assay data
Electricity					Including Oxygen production onsite
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Chemicals					Bulk Chemicals / specific chemicals
Oxygen					
Output					
Purified solution					Assay data
CO_2 (fossil)					Calculated based on Electrodes and reductants (based on stoichiometry)
Na_2SO_4					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied

Refining

This last step (See Figure 6-22) is refining the brine solution as well as the purified solution from spodumene ore to the final products of Lithium Carbonate (Li_2CO_3) and Lithium Hydroxide (LiOH H_2O).

FIGURE 6-22: Lithium production process from spodumene ore – refining (Bishimbayeva, 2018)

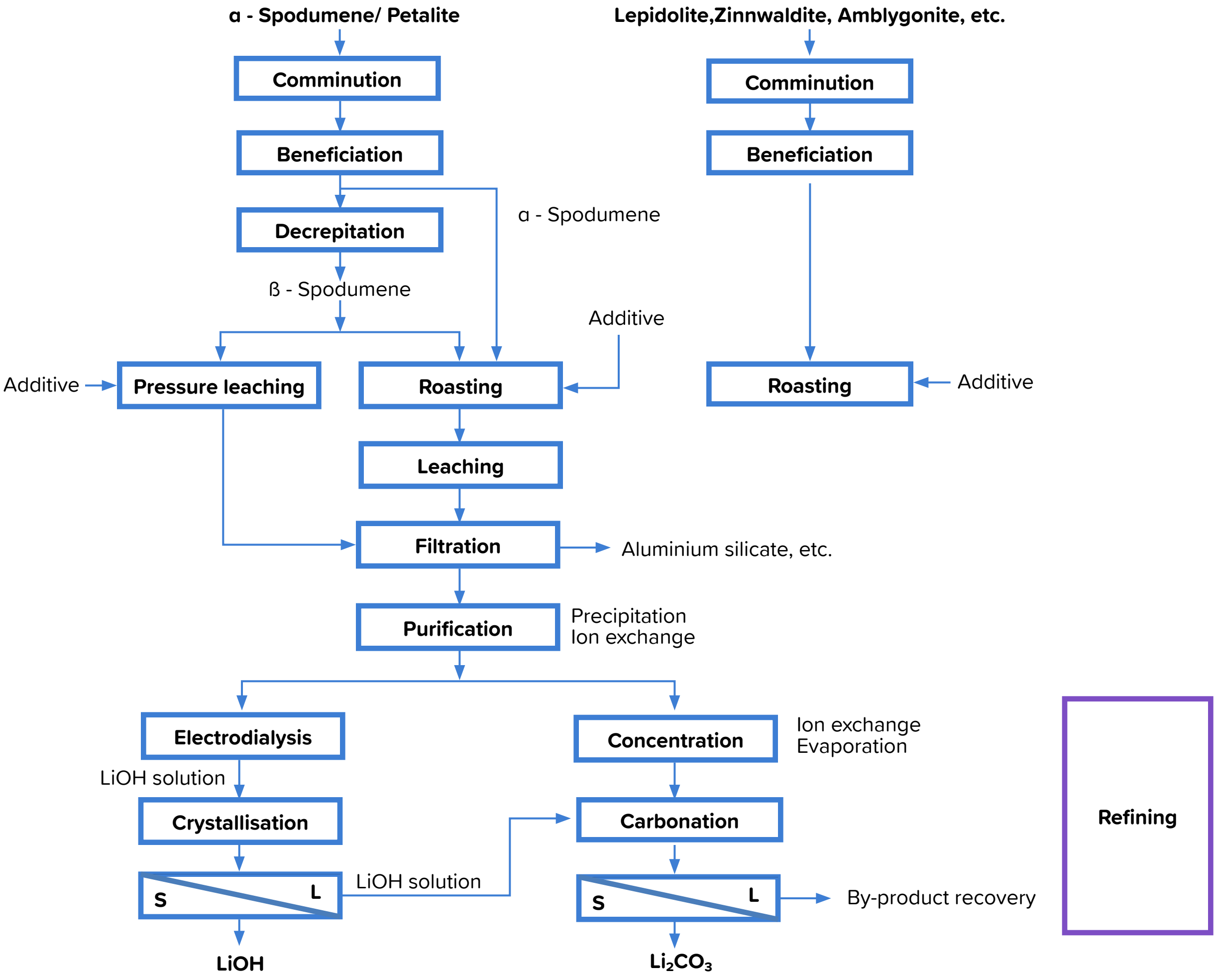


Table 6-52 shows a generic process related to producing either lithium carbonate or lithium hydroxide. The input and output parameters need to be collected for the processes under consideration.

TABLE 6-52: Generic data collection template for spodumene refining

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Purified Solution / concentrated brine					Assay data
Electricity					
Fuels (e.g. Diesel / LNG / Hydrogen)					conversion from m^3 to kWh or MJ
Chemicals (mainly bulk chemicals)					
External supply (Heat & Steam respective of fuel) purchased					
Oxygen, Hydrogen, Nitrogen					Bulk Chemicals / specific chemicals
Output					
Li_2CO_3					
LiOH H_2O					
CO_2 (fossil)					Calculated based on combustion
CO_2 (process)					Process reaction emissions

Summary on Li_2CO_3 and LiOH H_2O production

Following the above data collection guidelines, a reliable and most accurate carbon footprint of Li_2CO_3 and LiOH H_2O can be calculated. It is recommended to consider all input and outputs related to the production process and to group the chemicals according to their purpose (e.g., flocculants, frother, dispersants, etc.) and use the major chemicals as proxy for all chemicals consumed.

Furthermore, it is important to calculate process emissions during the leaching and purification process in case limestone is used for neutralization, and $CaCO_3$ is reacting with acid solution and generating CO_2 emissions.

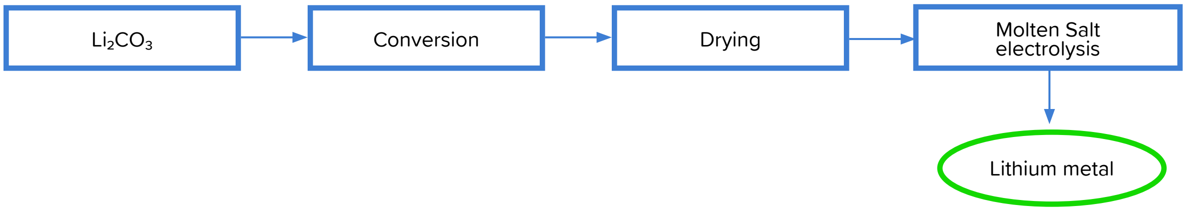
It is also important to calculate the transport between the different processes up to the final product with the respective transport means, which is described in 4.2.4.

6.1.7.1 Lithium metal

Lithium metal is produced using Lithium Carbonate (Li_2CO_3) as basis (See Figure 6-23). The respective questionnaire template can be found in chapter 6.1.7. Or the supplier of Lithium Carbonate provides the lithium metal producer with the specific carbon footprint.

There are 3 process steps to produce Lithium metal.

FIGURE 6-23: Process flow for Lithium metal



Conversion

In the conversion process the carbonate will be transformed into a Chloride which is then the basis for the molten salt electrolysis to produce the lithium metal. It is important to calculate the process specific CO_2 emissions caused by the reaction of the carbonate with the acidic solution.

TABLE 6-53: Generic data collection template for conversion to $LiCL_2$

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Li_2CO_3					
Electricity					
Fuels					conversion from m^3 to kWh or MJ
Hydrochloric acid					Specify concentration of HCI
Chemicals					Specify type and concentration
Output					
$LiCl_2$ solution					
Waste streams / By-products					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied and give assay data
CO_2 (process)					

Drying
In the drying process the mass balance is important as for all other processes but here also the Water evaporated shall be reported to prove a closed mass balance.

TABLE 6-54: Generic data collection template for drying

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
$LiCl_2$ solution					Moisture content
Electricity					
Fuels (e.g. Diesel / LNG /NG /Hydrogen)					conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased					
Output					
$LiCl_2$ solution					
H_2O (water)					Recycled?
Waste streams					
CO_2 (fossil)					Based on Fuels

Molten Salt Electrolysis
The electrolysis is energy intensive and is therefore an important process step. Following the general approach (see Chapter 4.1.1), partitioning of GHG emissions to recovered and sold chlorine shall be by system expansion supported by 3rd-party verified evidence.

TABLE 6-55: Generic data collection template for electrolysis

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
$LiCl_2$ dried					
Electricity					
Fuels (e.g. Diesel / LNG //Hydrogen)					conversion from m^3 to kWh or MJ
Potassium Chloride					
Output					
Lithium metal					
By-Products? (Chlorine)					
Waste stream					Landfilled / incinerated
CO_2 (fossil)					Based on Fuels

6.2. pCAM and CAM manufacturing

The following pCAM and CAM manufacturing-specific chapter covers the production of precursor cathode active material (pCAM) and the final production of the cathode active material (CAM). Rules for production of pCAM and CAM from recycling are included in Chapter 6.5. This cluster covers all kinds of cathode chemistries used for LIB in the electric vehicle sector (e.g., NMC, LFP, NCA). Cluster-specific rules are defined below in addition to the generic rules defined in chapters 4 & 5. As outlined in Chapter 5.3, the used CF for the supply of the following materials shall be supplier-specific:

- Nickel sulfate or other
- Cobalt sulfate or other
- Lithium hydroxide
- Lithium carbonate

Functional unit: The functional unit for the pCAM and CAM manufacturing shall be the supply of one kg or tonne of pCAM or CAM for lithium-ion batteries (e.g., 1kg of 180mAh/g NMC622 CAM).

To enable allocation of electricity consumption where necessary within the downstream cell manufacturing process, the following information shall be given:

- Chemistry (e.g., ratio of respective metals)
- mAh/g CAM

Primary data collection: Data collection shall be specific to the pCAM & CAM manufacturing location. In case the pCAM / CAM is produced in several locations, and the CF shall represent the average product, the data shall be collected for all locations, and a weighted average shall be calculated.

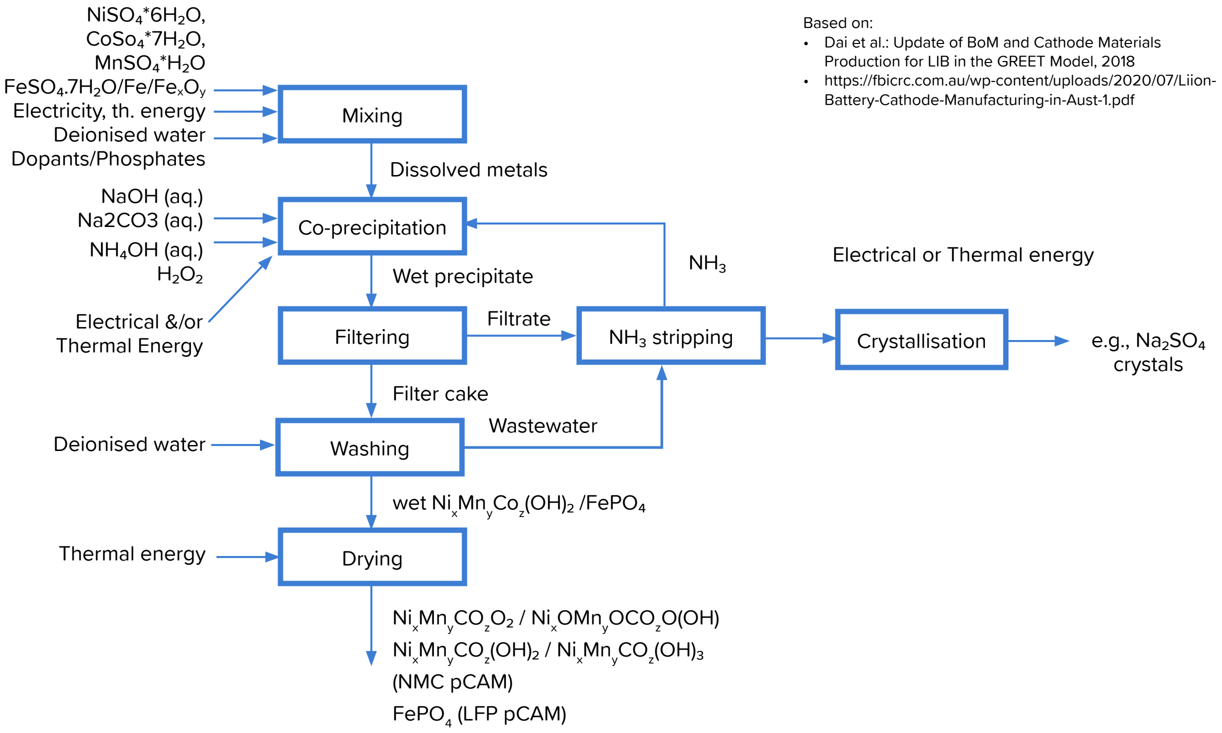
6.2.1. pCAM

The pCAM production is usually done by the co-precipitation process as illustrated in Figure 6-24 (based on (Dai, 2018)) or similar. For the co-precipitation step either sodium hydroxide or sodium carbonate can be used. The use of sodium carbonate results in direct carbon dioxide emissions in the following calcination step.

The supplier-specific carbon footprint of the metal sulfate shall be per 1kg of metal contained. This should be verified with care to guarantee a proper calculation of the CF for the pCAM / CAM. The concentration of the metal in the final product shall be specified as well.

Waste: Depending on local legislation and company policy, the sodium sulfate containing filtrate from the ammonia stripping is either discharged to a water body or needs to be treated, e.g., by evaporation or electrodialysis. The energy and auxiliary materials consumption shall be included when the producer is doing the treatment or is obliged by legislation to do so. Following the general approach (see Chapter 4.1.1), partitioning of GHG emissions to recovered and sold sodium sulfate shall be by system expansion supported by 3rd-party verified evidence.

FIGURE 6-24: Schematic process flow chart of pCAM production



Based on:

- Dai et al.: Update of BoM and Cathode Materials Production for LIB in the GREET Model, 2018
- https://fbicrc.com.au/wp-content/uploads/2020/07/Liion-Battery-Cathode-Manufacturing-in-Aust-1.pdf

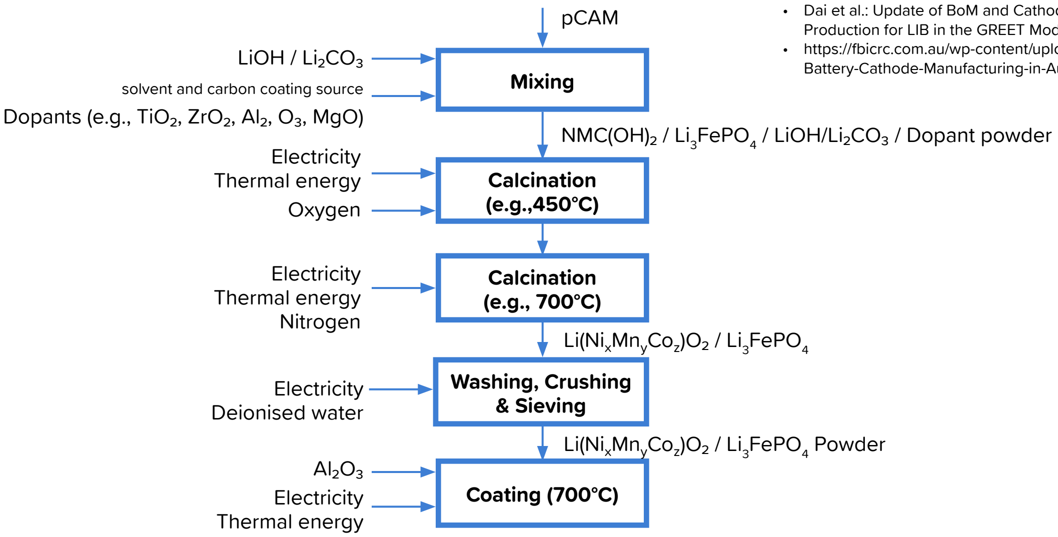
TABLE 6-56: Generic data collection template pCAM production

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
Nickel sulfate ($NiSO_4$ x $6H_2O$)					In case of solution, specify concentration
Secondary sources of Nickel					
Cobalt sulfate ($CoSO_4$ x $7H_2O$)					
Secondary sources of Cobalt					
Manganese sulfate ($MnSO_4$ x H_2O)					
Seconday sources of Manganese					
Sodium hydroxide (NaOH)					Specify concentration
Sodium bicarbonate (Na_2CO_3)					Specify concentration
Ammonia solution (NH_4OH)					If closed-loop recycling of ammonia is in place, reported inputs may be limited to those necessary to make up for losses over time
Auxiliaries (water) and Chemicals (sulfuric acid etc.)					Also for wastewater treatment and production of pCAM from recycled inputs
Electricity / Thermal energy					
External supply (Heat & Steam respective of fuel) purchased					
Fuels					conversion from m^3 to kWh or MJ
Output					
pCAM					e.g. $N_{ix}Mn_yCo_z(OH)_2$ or $N_{ix}Mn_yCo_zCO_3$
Sodium sulfate					
Waste water / filtrate					Specify where discarded as waste, where sold as a by-product (see definition), and any treatment processes applied
Combustion emission					

6.2.2. CAM

For the CAM production (illustrated in Figure 6-25), lithium hydroxide or lithium carbonate can be used as a lithium source. Usually, for CAM with high nickel contents (above NMC 622 or NCA), lithium hydroxide is used. In case nickel manganese cobalt carbonate is used for the CAM production, the calcination processes lead to direct carbon dioxide emissions that need to be included in the CF calculation. The calculation of the direct CO_2 emissions from the calcination should be done via stoichiometry.

FIGURE 6-25: Indicative process flow chart of CAM production



Based on:
- Dai et al.: Update of BoM and Cathode Materials Production for LIB in the GREET Model, 2018
- https://fbicrc.com.au/wp-content/uploads/2020/07/Liion-Battery-Cathode-Manufacturing-in-Aust-1.pdf

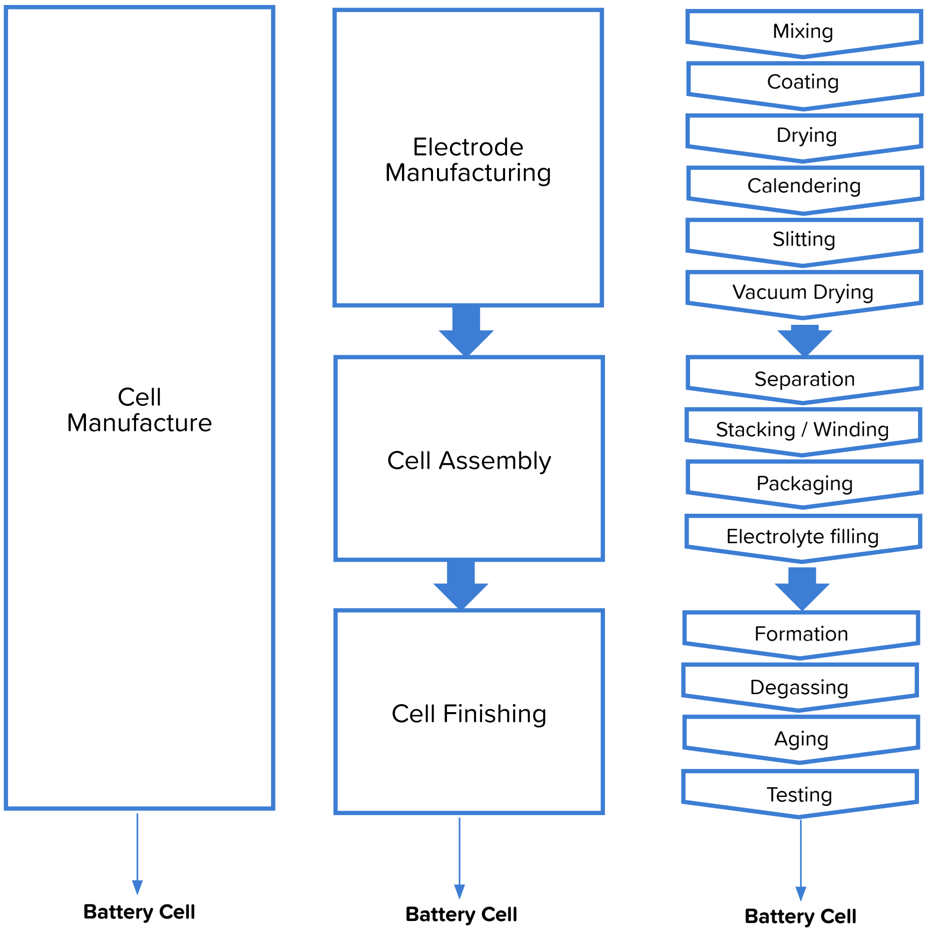
TABLE 6-57: Generic data collection template CAM production

Material	Unit	Amount	Transport distance	Transport type	Specification
Input					
pCAM (e.g., NMC, LFP, NCA)					e.g., $N_{ix}Mn_yCo_z(OH)_2$ or $Ni_xMn_yCo_zCO_3$
Lithium hydroxide (LiOH x H_2O)					Specify concentration
Lithium carbonate (Li_2CO_3)					Specify concentration
Secondary sources of Lithium					Specify concentration
Li_3PO_4					e.g., for LFP
Phosphoric acid					e.g., for LFP
$FePO_4$*$2H_2O$					Specify concentration
$FeSO_4$					e.g., for LFP
$Fe(NO_3)_3$*$9H_20$					Specify concentration
Fe_2O_3					e.g., for LFP
FeOOH					e.g., for LFP
$FeO_4C_4H_6$					e.g., for LFP
Monoammonium phosphate (MAP)					e.g., for LFP
Diammonium phosphate (DAP)					e.g., for LFP
Glucose					e.g., for LFP
Sucrose					e.g., for LFP
Dopants (e.g. TiO_2, ZrO_2, MgO, Al_2O_3)					
Auxiliaries (water) and Chemicals (oxygen, solvents etc.)					Also for production of CAM from recycled inputs
Trays					
Electricity / Thermal energy					
External supply (Heat & Steam respective of fuel) purchased					
Fuels					conversion from m^3 to kWh or MJ
CO/CO_2 mix					For processes requiring an inert atmosphere
Hydrogen					For processes requiring an inert atmosphere
Output					
CAM (e.g., NMC, LFP, NCA)					e.g., $Li(Ni_xMn_yCo_z)O_2$
Direct GHG emissions (CO_2)					e.g., methane, nitrous oxide, CO_2 in case carbonates are used
Waste / waste water / Li_2SO_4					Specify where discarded as waste, where sold as a by-product (see definition), where used for Llithium recovery and any treatment processes applied
Combustion emission					

6.3. Electrode cell and module manufacturing

The *Electrode cell and module manufacturing* Cluster covers the electrode manufacturing, the cell assembly, and the cell finishing, as outlined in Figure 5-26. The data collection may be divided into these three main steps of the cell manufacturing or even further to the individual processes, which is not necessary for the CF calculation (the split-up of the cell manufacturing in single processes in Figure 5-26 is based on (Heimes & Kampker, 2019)). Hence, it is sufficient to collect the primary data for the cell manufacturing as a whole, covering the entire process chain. Nonetheless, the user of the GHG Rulebook shall verify and document that all process steps are covered in the primary data collection.

FIGURE 6-26: Level of aggregation for primary data collection cell manufacturing



A detailed list of potential materials needed for the cell manufacturing is given in Table 6-58.

TABLE 6-58: Generic data collection template for cell manufacturing

Material		Unit	Data	Specification
Input				
Cathode				
CAM	CAM powder	kg/cell		e.g. chemistry like NMC 622 or LFP, energy density etc.
Binder / Additives	Carbon black	kg/cell		
	Polyvinylidene fluoride (PVDF)	kg/cell		
Current collector / Tap	Aluminium foil	kg/cell		e.g. thickness and alloy, share of primary / secondary material
Anode				
Anode active material	Anode powder	kg/cell		e.g. 95% graphite & 5% Silicon
Binder / Additives	Polyvinylidene fluoride (PVDF)	kg/cell		
	Carbon black	kg/cell		
	Carboxymethyl cellulose (CMC)	kg/cell		
	Styrene butadiene rubber (SBR)	kg/cell		
Current collector / Tap	Copper foil	kg/cell		
Separator	Polypropylene (PP), Polyethylene (PE)	kg/cell		Additional coating, usually ceramic
Electrolyte	Dimethyl carbonate, Ethylene carbonate, Propylene carbonate, Vinylene carbonate	kg/cell		Electrolyte materials should be individually reported or when used as a mixture the share of each component in the mixture should be reported
	Lithium salt, e.g., Lithium hexafluorophosphate ($LiPF_6$)	kg/cell		Electrolyte materials should be individually reported or when used as a mixture the share of each component in the mixture should be reported
Housing	Aluminium foil / case	kg/cell		e.g. alloy, thickness, production process e.g. deep drawing
	Steel	kg/cell		e.g. alloy, production process e.g. extrusion / 37% secondary
	Polymers (PP, PE,...)	kg/cell		
Lid	Aluminium	kg/cell		
Solvent	N-Methyl-2-pyrrolidon (NMP)	kg/cell		
	Deionised water	kg/cell		
Auxiliaries (water) and Chemicals		kg/cell		
Electricity / Thermal energy		kWh/cell		
External supply (Heat & Steam respective of fuel) purchased				
Fuels		kg/cell		conversion from m^3 to kWh or MJ
Outputs		kg/cell		
Product	LIB cell	kg / psc		
Waste & scrap	Metal scrap, NMP, scrapped cells, polymers etc	kg/cell		
Waste water		kg/cell		
Combustion emissions		kg/cell		

The required conditions in the dry rooms for the cell manufacturing (dew point down to -30°C for electrode manufacturing and down to -70°C for the cell assembly), as well as the drying of the electrodes, require relevant amounts of energy consumption (electricity and thermal energy). As outlined in Chapter 4.1.2, the energy consumption should be based on an individual and detailed metering system to be able to split the energy consumption of the entire cell manufacturing into lines, products, and time periods. If this is not the case, please refer to Chapter 4.1.2.).

In the following Chapter, cluster-specific rules are defined in addition to the generic rules defined in chapters 4 & 5.

System boundaries: The manufacturing of the electrodes, cell assembly, and cell finishing usually take place at the same location. In case the electrodes are purchased by the cell maker from a supplier, a supplier-specific CF shall be used for the electrodes.

Functional unit: The functional unit for the cell manufacturing shall be one cell (one piece). The reference flow can be given in one piece or mass per piece. In case a piece is chosen as reference flow, the weight per piece shall be given. The use of the carbon footprint results for reporting, or any kind of analysis defined later by GBA might require alternative reference flows. The carbon footprint of the cell shall therefore contain the necessary information to convert the CF results from one piece to other reference flows, as well as additional technical specifications to better understand the possible use cases of the cells:

- Cell design (pouch, prismatic, cylindrical) plus additional common information about size (e.g., cylindrical 18650).
- Capacity (usable & overall) & voltage
- Weight
- Chemistry of cell
- Number of cycles / fading curves
- C-rate

Primary data collection: Data collection shall be specific to the cell manufacturing location. In case the specific battery cell is produced in several locations, and the CF shall represent the average product, the data shall be collected for all locations, and a weighted average shall be calculated.

Material inputs

- In case activity data for material inputs (e.g., from a management system) are not available for a specific cell (only available aggregated for several cell products), the user of this Rulebook may use a bill-of-material (BoM) to compile the material inputs. The BoM shall include yields, e.g., cuttings or individual scrap rates for a process to be included.
- In case a BoM is used, possible scrappage of entire cells at the end of line testing shall be included in the data collection.
- For the scrappage rate after cell assembly, a facility-specific value should be used, e.g., calculated and verified based on waste streams. If not available, a default 30% shall be applied.
- As outlined in Chapter 5.3, the used CF for the supply of the CAM and anode active material shall be supplier-specific.

Energy consumption

- In case the energy consumption (as well as auxiliaries, e.g., process water, compressed air, etc.) cannot directly be related to a specific product (e.g., several products produced in a facility, but energy consumption data is not always available per specific product), the data shall be collected as specific as possible, e.g., split up of energy consumption for *electrode manufacturing, cell assembly, cell finishing,* as well as climatization of clean / dry rooms. In case the energy consumption can be directly related to a specific process (e.g., electrode manufacturing), this data shall be used, in case the energy consumption data is only available for several cell products (e.g., individual meters for cell assembly lines, but only one meter for a dry room, in which several assembly lines produce different cells), the energy consumption data shall be split up by allocation. Hierarchy for allocation:
  - In case all cell products have the same geometry (pouch, cylindrical or prismatic) and the same size (e.g., cylindrical 18650), the allocation shall be done by number of cells.
  - Allocation by capacity (kWh or Ah)

Solvents (other than water)

- In case organic solvents, such as N-Methyl-2-pyrrolidone (NMP), are used and the captured solvent vapour is thermally treated after the drying, the resulting carbon dioxide emissions shall be included in the CF calculation based on the carbon content of the solvent.
- In case the solvent vapour is collected for recycling and the recovered solvent is internally used, the net consumption should be used (difference between needed solvent for the cell manufacturing and recovered solvent) under the condition that the energy and material consumption for the solvent recycling is covered in the carbon footprint calculation (i.e., primary data from cell manufacturer for internal recycling or data from external solvent recycler).
- In case no evidence can be given that the treatment of the captured solvent results in a product that can be reused as a solvent with the same properties or the CF for the external treatment is not available, the entire solvent consumption shall be considered in the CF.
- Collected solvent that is consumed for cleaning purposes shall be deducted from the collected and recycled amount.

Start-up period of new facilities

- A start-up period for a new facility (new location, extension of capacity or exchange of entire production line) of maximum six months may be used to exclude non-representative energy consumption due to low utilization rates (e.g., load-independent energy consumers directly connected to the studied product, like dry room climatization).
- No exclusion of a data period shall be done in case a new product is produced on an existing line.

6.4. Battery assembly

The battery assembly cluster covers the assembly of the battery module and the assembly of the battery itself. For both processes or assembly steps, primary data shall be collected. In case the cell-to-pack technology is used, only data for the battery assembly need to be collected. A summary list of materials possibly needed for the cell manufacturing is given in Table 6-59. A detailed overview of components and possible materials needed for the module and battery assembly is given in the GBA data collection sheet “Battery Assembly”.

TABLE 6-59: Generic data collection template for battery assembly

Material		Unit	Data	Specification
Input				
Cells / Modules		kg or psc/ battery		e.g. chemistry like NMC 622 or LFP, energy density etc.
Housing	Aluminium	kg/battery		e.g. deep drawn aluminium sheet / primary
	Steel	kg/battery		
	Polyamid GF	kg/battery		e.g. 30% glass fibre
Gap filler	Aluminium foil	kg/battery		
Brackets / covers / structural elements	Steel, Aluminium			
Cooling plate / heat exchanger	Aluminum, Steel PA 6.6	kg/battery		e.g. grade 304 or 1.4301 / sheets / secondary
Cables LV (harness)	Copper / PVC	kg/battery		
Cables HV (harness)	Copper / PVC	kg/battery		
Busbars / terminals	Aluminium, Copper + Insulation Polymer or tapeing	kg/battery		
Connectors (HV, Charger etc.)		kg/battery		
Fixation (screws, nuts, bolts, clips etc.)	Steel	kg/battery		
Insulation	Mica, glue, tape etc.	kg/battery		
Fixation (screws, nuts, bolts, clips etc.)	Steel	kg/battery		
Coolant	Glycol / Water Other fluids possible	kg/battery		
BMS	1 Master board + 1 Module board per module	kg/battery		
Electronic components	Sensors, relay, fuse, contactors, resistors etc.	kg/battery		
Auxiliaries (water) and Chemicals		kg/battery		
Electricity / Thermal energy		kWh/battery		
External supply (Heat & Steam respective of fuel) purchased				
Fuels		kg/battery		conversion from m^3 to kWh or MJ
Output				
Product	Battery	kg / psc		e.g. chemistry like NMC 622 or LFP, energy density etc.
Waste & Scrap	Metal scrap, NMP, scrapped cells, polymers etc.	kg/battery		
Waste water		kg/battery		
Combustion emissions		kg/battery		

In the following, cluster-specific rules are defined in addition to the generic rules defined in chapters 4 & 5.

System boundaries: The manufacturing of battery modules and pack do not necessarily take place at the same company or location. Data for module and battery assembly should be therefore collected separately to increase transparency in the data collection process and increase flexibility for result display and comparison.

If a possible integration of battery components into the vehicle (e.g., housing of battery is partly/completely removed and passive safety of battery provided by vehicle body) or a function of the other vehicle components is added to the battery (e.g., battery casing is designed to hold modules and integrate cooling, but also to support the structure of the vehicle itself) this may lead to different system boundaries between LIB for which carbon footprints are calculated under this Rulebook.

One of the reasons to calculate the CF of the entire LIB but also for raw materials, active or passive materials, and other components across the value chain is to provide the CF to the next step in the value chain and to enable the purchaser to calculate the CF of its own product. In the case of the entire LIB, the CF information would be supplied, together with the LIB, to the OEM and would support the OEM to calculate the CF of the entire vehicle. Another possible use of the CF information might be a direct comparison of LIBs in terms of GHG emissions during manufacturing including the GHG emissions for the supply of all materials or components.

First, the CF shall be therefore calculated for one battery pack as it is sold to the OEM or produced by the OEM for the vehicle assembly. Second, in an updated version of the rulebook the use phase may be covered, enabling the user of this Rulebook also to calculate the CF *“for one kWh of the total energy provided over the expected service life by the battery system”* allowing a comparison between batteries, as required under the proposed battery regulation (European Commission, 2020) and the PEFCR for batteries (Recharge, 2018). The influence on the GHG Rulebook is detailed below separately for the two different use applications of CF results.

In case the CF is calculated for the module, the functional unit is the supply of one LIB module, with the system boundary covering everything needed to produce a module as it is used for the battery pack assembly. The reference flow can be in piece or kg, and the weight per piece shall be given to convert piece to kg or vice versa. In addition, the carbon footprint of the battery module shall therefore contain the necessary information to convert the CF results from one piece to other reference flows, e.g., kWh.

A) CF result of LIB used by OEM to calculate CF of entire vehicle

Functional Unit:
The functional unit covers the supply of one lithium-ion battery pack for electric vehicles as it is supplied to the OEM or produced by the OEM for the vehicle assembly. The reference flow can be in piece or in kg per piece and the weight per piece shall be given to convert piece to kg. The carbon footprint of the battery pack shall therefore contain the necessary information, e.g., mass of battery in kg.

System boundaries:
The CF shall include all components of the battery pack as it is delivered to the OEM or produced by the OEM for the vehicle assembly, e.g., in case the battery does not include the housing, because it is integrated within the chassis / vehicle body, the CF shall exclude the housing and no further correction shall be done. In case the battery fulfils additional functions to the one of supplying electricity to the motor, e.g., in case the housing has also the function of supporting the torsional stiffness of the vehicle, no correction shall be done.

B) CF result used for comparison of LIB

A direct comparison of CF results of different LIBs is subject to several challenges:

- A comparison of LIB with different use applications, e.g., batteries for hybrids or city buses (opportunity charging) with a need for high C-rates vs. vehicles for which a high driving range is needed will have limited informative power, as active materials and energy densities can be a lot different.
- A comparison of absolute GHG emissions of batteries with different capacities will by nature lead to CF results which can be hardly compared.
- A comparison of CF results of different LIB, by relating the CF results to the capacity, i.e., CO_2eq./kWh of capacity is only partly solving the problem above, as this could lead to an unjustified preference of batteries with larger capacities (impact from housing, BMS or thermal management probably lower per kWh of capacity with increasing battery capacity), although it is unclear if these larger battery capacities are needed without considering the specific use case of the BEV in which the battery is going to be installed.

Functional Unit:
To overcome at least partly the challenges listed above, the GBA GHG Rulebook has adopted the methodology from the PEFCR for batteries (Recharge, 2018) and the battery regulation of the EU (European Commission, 2023)

The functional unit is defined as *"one kWh of the total energy provided over the expected service life by the battery system"* (European Commission, 2020) (Recharge, 2018). The reference flow is the calculated amount of battery (in mass or pieces) needed to provide one kWh. All information and battery specifications needed to convert the CF of one battery to the CF of one kWh of delivered energy shall be documented in a transparent manner (weight, capacity, kWh delivered energy over the expected service life, etc.).

System boundaries:
All components that belong to the battery pack, also those which might be added during the vehicle assembly, e.g., coolant (volume of coolant inside the battery) or manual service-interrupter, shall be included under battery pack assembly. Nonetheless, the integration of battery components within the rest of the vehicle or vice versa could lead to some distortion when comparing LIBs, if at least one battery provides an additional function (e.g., increase torsional stiffness of the vehicle) or a component of one battery is integrated in the vehicle (e.g., parts of the housing).

In the currently updated PEFCR for batteries, an approach for a fair comparison of the batteries is currently under development. The approach defines a set of mandatory functions a battery shall fulfil. For all these functions, the necessary components shall be included in the CF. As an example, the battery shall be able to support or hold the cells or modules of the battery. In case the battery cannot fulfil this function, because parts or the entire housing is integrated into the chassis / vehicle body, a virtual housing (JRC, 2023) shall be included in the CF calculations. On the other side, in case the battery housing provides an additional function, e.g., increase of torsional stiffness, ideally a partitioning of impacts between the function of the housing and the additional function is done (e.g., the incremental amount of material in the new design of a battery is allocated to the additional function and can be excluded from the system boundaries of the battery). In case a partitioning of impacts is not possible, a virtual housing approach shall be modelled (i.e., the size of the housing shall be re-calculated according to the size of the battery and a reference thickness for each material).

The virtual housing shall be modelled as:

a) The size of the housing will be re-calculated according to the size of the battery. Based on the actual Length (L), the Width (W) and the Hight (H) of the battery housing, the Area of the virtual housing shall be calculated as:

$$Area = (L \cdot W) \cdot 2 + (W \cdot H) \cdot 2 + (L \cdot H) \cdot 2$$

b) The materials to model the virtual housing shall be the same as used in the real housing. In addition:
   i. If only one material is used in the real housing, the virtual housing shall be considered as made of such material.
   ii. If more than one material is used in the real housing, only those materials accounting for at least 95% of the weight of the real housing shall be considered. Those materials shall be selected in decreasing order of importance, from the material contributing most to the material contributing the least in terms of weight, until the minimum threshold of 95% is reached. Once the materials are selected, the mass of the different materials shall be normalized to 100%.

c) The “Weight” of each material in the virtual housing shall be calculated as:

$$Weight_{mat\,i} = Area \cdot Percentage_{mati} \cdot t_{mati} \cdot pmat\ i$$

Where:

- Area: total area of the virtual housing, as calculated in point (a) above
- Percentage$_{mati}$: proportion of material i, as calculated in point (b)
- t_{mati}: reference thickness of material i
- p_{mati}: density of material i

The following reference thickness values for different materials shall be considered: aluminium (2.5 mm); steel (1.75 mm); carbon fibre based material (2.02 mm). The user of this Rulebook may prove that a different thickness would be more appropriate for the considered battery housing of other materials (e.g., when other innovative materials are used).

Primary data collection: Data collection shall be specific to the assembly location. In case the specific battery module / pack is produced in several locations, and the CF shall represent the average product, the data shall be collected for all locations, and a weighted average shall be calculated.

Material inputs

- In case activity data for material inputs (e.g., from a management system) are not available for a specific battery module or pack (only available aggregated for several battery module / pack products or data of assembly is included in overall vehicle assembly), the GHG Rulebook user may use a bill-of-material (BoM) to compile the material inputs.
- In case a BoM is used, and final products (module / pack) that do not pass the end-of-line test are disassembled, and the different components are in general reused in the assembly line, scrappage of single components is supposed to be neglectable, and scrappage may be left out to calculate the material inputs as well as waste / scrap outputs.
- As outlined in Chapter 5.3, the used CF for the supply of the battery cells or battery modules shall be supplier-specific.

Energy consumption

- Although energy consumption for module / pack assembly is less important than for cell manufacturing, the energy consumption shall be included. In case the energy consumption cannot directly be related to a specific product (several products produced on an assembly a partitioning of the energy data to the different products is needed (see Chapter 4.1.2).

6.5. Recycling (recycled content emissions)

The Recycling cluster covers the recycling of post-consumer waste batteries and pre-consumer battery manufacturing waste through a combination of processes spanning from dismantling, pyrolysis (pre-treatment), mechanical/shredding treatment, pyrometallurgical treatment to hydrometallurgical treatment. It is subdivided into the different recycling process steps that recover the battery metals and minerals. The Recycling cluster covers the modelling of EOL and recycling life cycle stage as well as guidance on calculating the process-specific GHG emissions. The EOL allocation is described, as are functional unit, system boundaries, and data collection requirements, including the process-specific allocation.

The following EOL and recycling cluster rules are specified under the cut-off EOL allocation method. The rules are primarily addressed to companies running recycling operations (i.e. recycling providers) such that recycling process emissions can be calculated based on primary activity data. Additionally, the rules are addressed to companies having to declare carbon footprints for the EOL and recycling life cycle stage based on waste collection and disposal emissions. The consumer receiving the recycled content shall report supplier-specific data for the recycled content used, based on the data collection processes provided in the subsequent Chapters. Specifically, the recycled pCAM/CAM and anode materials shall include the supplier-specific GHG footprint based on the general rules and primary data collection as set out in the following Chapters. For all other recycled materials (i.e. other than pCAM/CAM and anode materials) used in the production process, also supplier-specific data shall be used where available.

Chapter 6.5.6.8 provides a general approach for the data collection for other recycled materials while the general rules of this document shall apply. The current focus is on Li-ion/NMC batteries, but the general rules apply to all technologies and corresponding input/output tables for primary activity data collection can be extended by applicants.

In the context of the EU Battery Regulation CF declaration, the CFF will likely be demanded by the EU Battery Regulation via reference to the PEF/PEFCR. Defining the primary data collection through the cut-off approach however yields the first part of the CFF and can be subsequently complemented. A separate chapter addition is provided in the ‘EU module’ in Annex B.

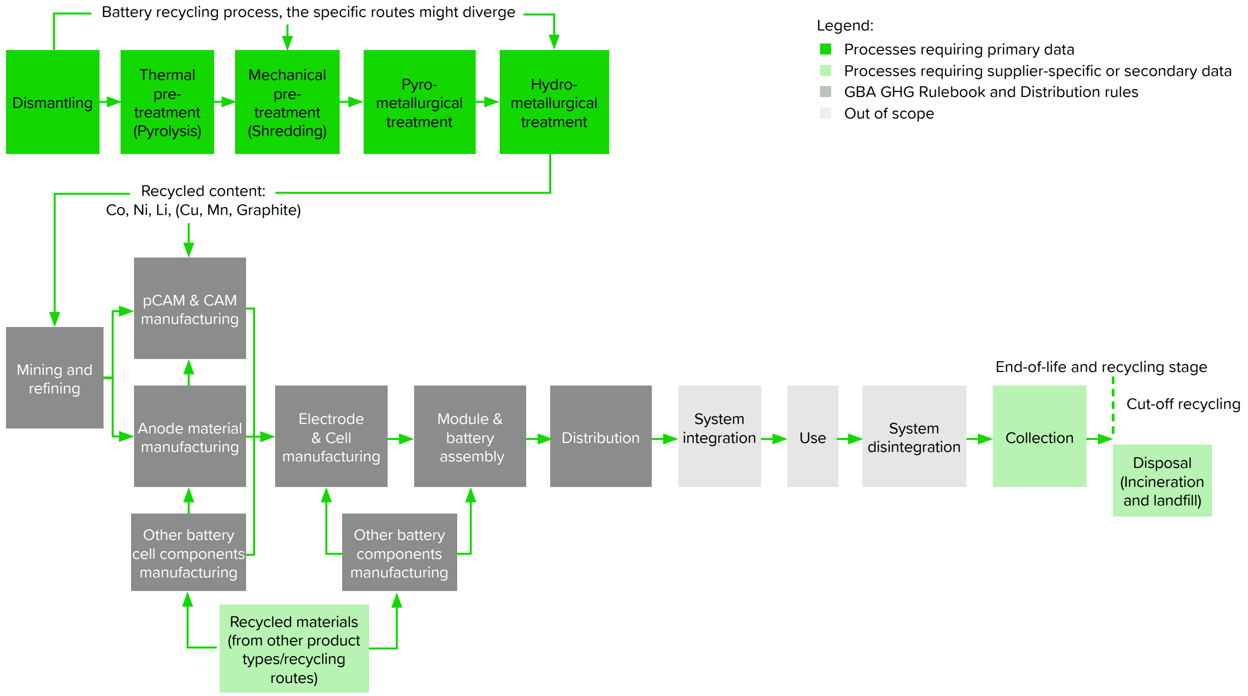
6.5.1. End of life and recycling allocation via the cut-off approach

Following the cut-off approach, the processing and recycling emissions of the considered product system (battery) are allocated to subsequent product systems and not considered at EOL – only recycled content on the input side of production bears recycling emissions. Therefore, recycling emissions are accounted for as emissions associated with the recycled content in production processes. No burdens or credits are associated with the material from the previous lifecycle, i.e. are set to zero before entering the recycling process. The 'End of life and recycling' life cycle stage includes, besides recycling treatment, the EOL collection as well the waste incineration and landfilling processes following the polluter-pays-principle based on a recyclability assessment or statement of the materials (see Figure 6-27).

The share of recycled materials shall be reported on the input side of a process or product to enable the producer to calculate the recycled content of the battery. Per Chapter 4.1.3, the amount of secondary material shall be reported in two categories as follows:

- Pre-consumer waste (manufacturing waste, excluding process revert)
- Post-consumer waste (end of life waste batteries)

FIGURE 6-27: End of life and recycling allocation in the cut-off approach



6.5.2. Functional unit and reference flow of battery recycling processes

The recycling process requires unit flows that relate the recycling outputs to the individual cell composition, incorporating the yields of the respective recycling process. The Functional Unit for the individual recycling process steps shall be specified such that it refers to the characteristics of the respective process output (e.g., dismantled modules, black mass, secondary battery grade materials). The reference flow is the amount of product needed per process step to fulfil the function (measured in kilograms).

For the complete battery recycling process:

- **the functional unit shall be one kg of battery-grade material** (recovered from the needed mass of pre- or post-consumer battery packs/modules/cells for all metals and minerals in the recycling process). Battery-grade thereby is defined as the quality of the material complying to the material specifications for reutilization in batteries. For instance, the functional unit refers to the production of 1 kg NiSO4.6H2O battery grade. The GHG emissions (in CO2eq) are calculated per the defined functional unit.
- the reference flow shall be in kg of treated packs/modules/cells in the recycling process.

6.5.3. Recycling-related system boundaries and processes

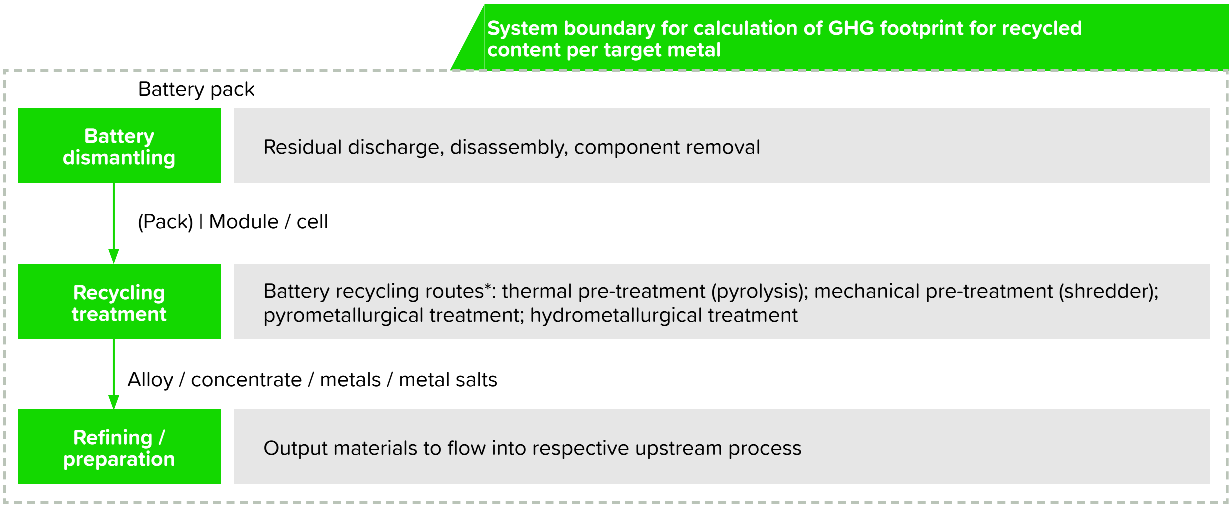
The carbon footprint calculation requires defining the system boundary for the ‘End of life and recycling’ process (ISO 14044:2006). The ‘End of life and recycling’ stage consists of the end of life collection (Chapter 6.5.5.), recycling treatment (Chapter 6.5.6) and disposal of unrecyclable fractions (Chapter 6.5.7). The system boundaries of recycling are commonly set after the waste batteries are collected (CEID 2020). Following the cut-off approach where the recycling treatment is allocated as recycled content on the input side of production, the ‘End of life and recycling’ stage only consists of the emissions associated with the collection of waste batteries as well as potential emissions from waste disposal (incineration and landfilling) since recycling emissions are accounted in the upstream production emissions. EOL collection is modelled as described in Chapter 6.5.5. Disposal emissions that should be associated with the unrecyclable fraction of the considered battery are described in Chapter 6.5.7.

The following umbrella process chart (Figure 5-28) shows the generalized process for recycled battery metals in the cut-off approach. The GHG footprint system boundary of the recycled content thus starts with battery dismantling, and via the respective recycling treatment flows into the refining or preparation of the output materials.

The specific recycling treatment processes shall follow the general umbrella process:

1) Battery dismantling
2) Recycling treatment (pre-treatment and main treatment)
3) Refining / preparation (to battery-grade recycled materials)

FIGURE 6-28: System boundaries of battery recycling as umbrella process chart



*The battery recycling routes vary per recycling provider. Batteries are usually dismantled into modules before mechanical treatment is applied. However, some providers mechanically treat entire battery packs. If pyrolysis is applied, it will be followed by or used in combination with mechanical treatment. Pyrolysis, mechanical and pyrometallurgical treatments are optional, but all routes usually end with hydrometallurgical treatment.

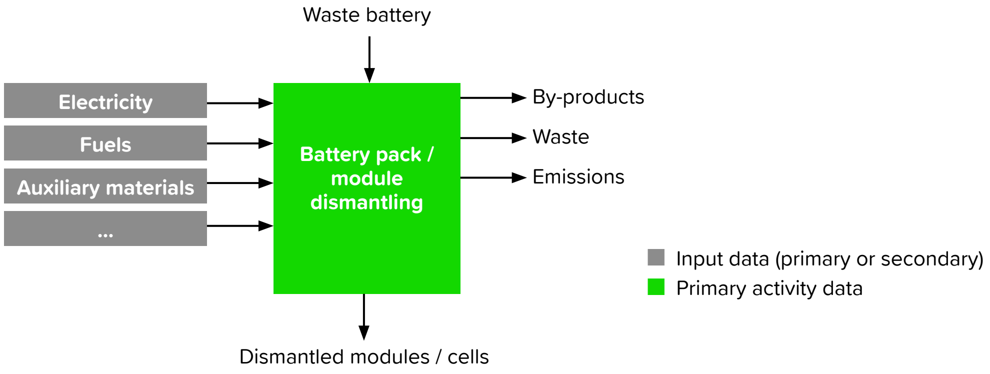
The recycling treatment process system boundaries focus on the recovery of CAM and anode materials. The system boundaries for other recycled materials, for instance in cell and pack components, are defined in Chapter 6.5.6.8 Figure 6-33.

Consistency requires the end of life cut-off being made at a point which harmonizes with the input data used for the secondary raw materials in the production stage, i.e., the recycled content needs to account for the emissions associated with the processes starting with discharging and disassembly. The resulting emissions are included at the substitution point in the relevant upstream processes.

Each of the above-mentioned generic recycling stages must have a reference to which all inputs and outputs are referred to, as shown in the respective following generalized flow charts (Figure 6-29, Figure 6-30, Figure 6-31).

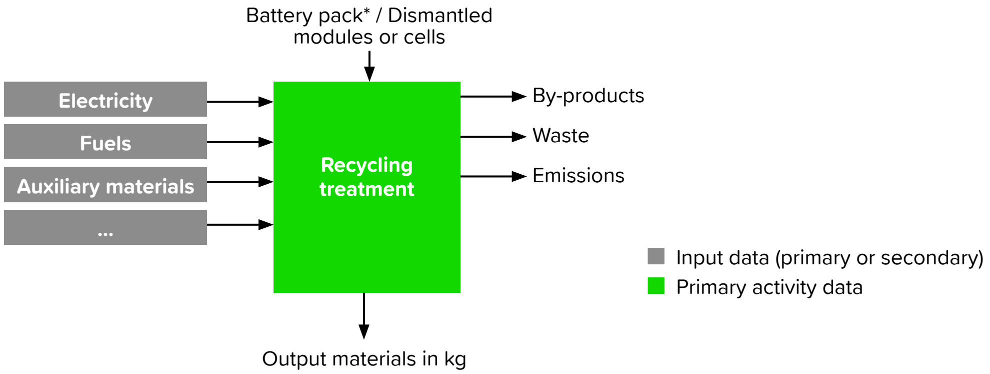
Dismantling

FIGURE 6-29: Generalized dismantling reference flow chart



Recycling treatment (including potential pre-treatment steps)

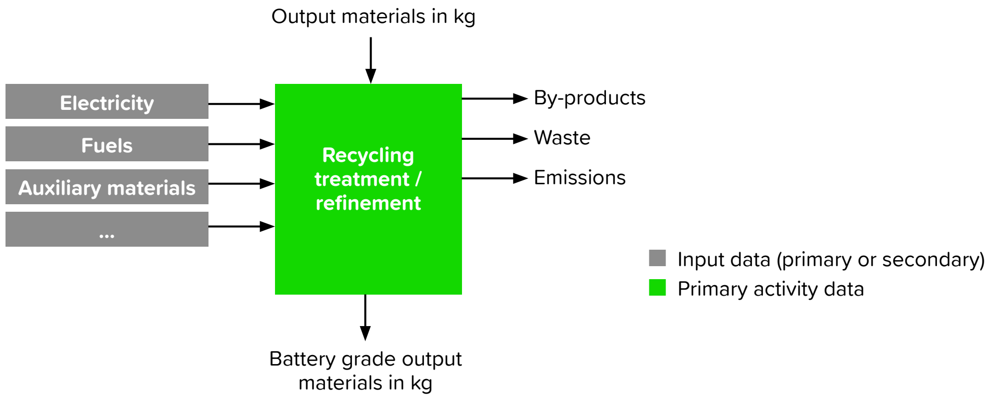
FIGURE 6-30: Generalized recycling treatment reference flow chart



*Note: Battery pack, if no dismantling is performed prior to the recycling (pre-)treatment

Further refinement (if recycling does not yield battery grade materials)

FIGURE 6-31: Generalized refinement treatment reference flow chart



6.5.4. Data collection requirements

The emissions arising in recycling processes vary depending on the specific cell chemistries as well as recycling routes and technologies employed (Mohr et al. 2020). Therefore, the user (i.e. recycler) shall collect activity data for each of these steps and calculate the carbon footprint on this basis using associated GHG emissions factors and GWP conversion factors.

The calculation of the recycling process emissions shall be based on a detailed modelling of input-output flows with company-specific activity data for the recycled battery grade materials. Only the resulting carbon footprint per material should be provided to the recipient of the recycled content. Main treatment emissions (i.e. pyro- and/or hydrometallurgical treatments or further refinement to battery grade) shall always be based on company-specific activity data. In case recyclers performing the main treatment do not operate the entire recycling processes, supplier-specific data shall be used for the steps not operated.

Guidance for modelling passive components (e.g., cell casing, Battery Management System, separator) and other components that potentially include recycled materials is not provided in the same detail. Nevertheless, manufacturers using recycled materials other than secondary battery-grade materials shall include supplier-specific carbon footprint values as much as possible. As such, it is generally recommended to collect supplier-specific data for all materials and components, but particularly required for the pCAM/CAM and anode materials.

The data quality requirements as specified in Chapter 5.3 shall apply.

The period for data collection is annual per default. This can be either calendar year or fiscal year. Which time period was used, shall be indicated in the data collection sheet.

Data collection and the footprint calculation shall be site-specific per default. In case the battery module or pack is recycled in several locations (i.e. the recycling process chain is performed in several locations), and the carbon footprint shall represent the average product, the data shall be collected for all locations, and a weighted average shall be calculated.

If the recycling provider using these rules to calculate company-specific carbon footprints can prove that the use of site-specific footprints leads to negative environmental consequences overall, the provider may use a mass balance across plants and locations to provide a representative average over manufacturing plants. In this case, justification shall be provided. An example is that recycled materials are ordered from different world regions due to lower local footprint, effectively increasing transport emissions to the consumer. Proof shall be provided that this leads to overall negative impacts.

The input/output tables in the subsequent process-specific Chapters shall serve as guidance for the users of these rules and applies the data collection requirements to the processes. Data collection templates are developed to give more detailed guidance to the user in terms of which primary activity data is needed for the CF calculation and which additional information is required to facilitate the calculation.

The data collection tables and templates do not claim to be complete regarding processes or inputs and outputs and shall be amended if additional processes or inputs and outputs are required for the carbon footprint calculation.

6.5.5. End of life collection

The carbon footprint shall include the EOL collection of waste batteries. Related emissions are associated to the EOL and recycling life cycle stage. The emissions result from the transport from a collection place where the spent battery is disassembled from the used system to the end of life treatment.

For modelling the transport-related emissions to the recycling treatment, the user of the rules shall specify the transport and vehicle type as well as transport distance and utilisation ratio. The data collection and partitioning of EOL transport-related emissions follows the approach as outlined in Chapter 5.2.4 on transportation and Annex B.2 on Distribution.

In case company-specific values are not available, the following values shall be used (Recharge 2018):

- **Transport to the EOL recycling**

  Intracontinental supply chain: 200 km by truck (28-32 t, EURO 5; UUID 0aa65e8b-70c8-4b7f-b1d7-91a6403d2b5a) with utilisation ratio 64%

The transport from the collection place to the EOL treatment for unrecyclable fractions is included in the landfill and incineration EF-compliant datasets (see Chapter 6.5.7).

6.5.6. Recycling treatment processes – data collection guidance

Today, most battery recycling processes consist of a combination of pyrometallurgical and/or hydrometallurgical processes including pre-treatment such as dismantling and/or pyrolysis and mechanical shredding (Wagner-Wenz et al. 2022)). Battery pack dismantling includes the electrical deactivation of the spent battery as well as the disassembly of the battery pack into modules or cells. Alternatively, pyrolysis (high temperature treatment >200°C) could be applied to deactivate the battery. Subsequently, three process technology types are commonly applied, which are combined in varying steps: mechanical, pyrometallurgical, and hydrometallurgical processes. Current industrial recycling treatment processes for lithium-ion batteries involve pyrometallurgical (high temperature) and/or hydrometallurgical (chemical) separation methods for the contained metals. However, these routes vary strongly depending on the recycling provider (see Figure 6-32). In the following sub-Chapters, the generic data collection and allocation requirements for the major process steps of these routes are described.

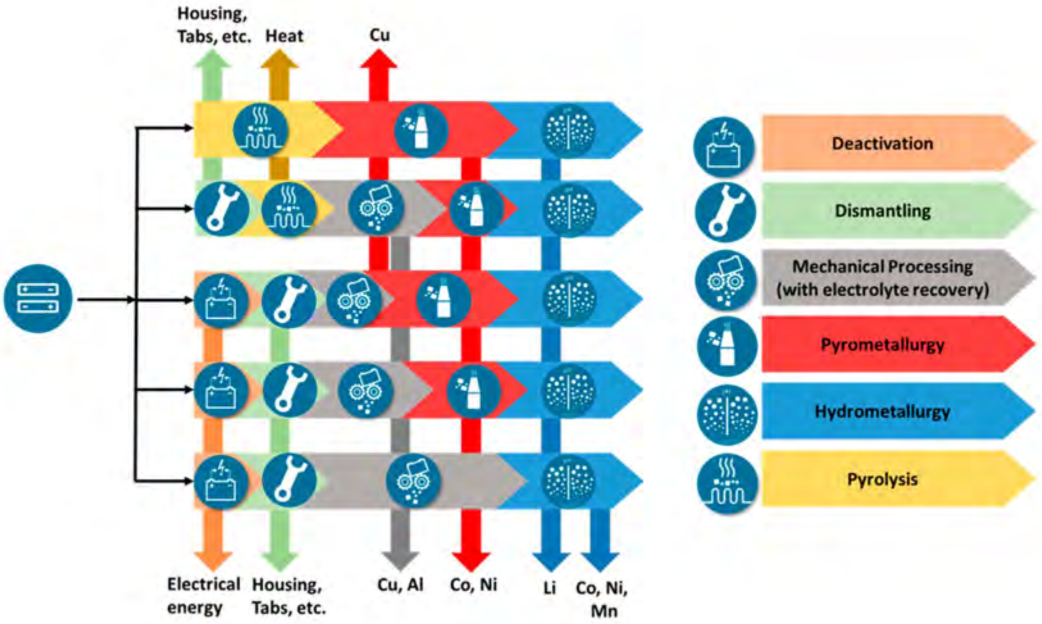
The user of these rules shall include each step of the recycling process chain applicable to the respective operation that leads to recycled battery materials in line with the system boundaries (Chapter 6.5.3). The user shall outline the process route operated in the documentation. In case a battery recycling provider follows a different route than displayed in Figure 6-32, the generic data collection shall be extended to include new processes and routes into the recycling value chain. Co-production is a special case being discussed in Chapter 6.5.7.

Depending on the specific route and combination of treatment processes, the recycled output materials and their quality differ as the various metallurgical recycling steps may not entirely cover refining to battery-grade materials. Additional refining steps should be modelled and documented to represent the functional unit. Waste occurring in the recycling treatment process chain needs to be accounted for in the respective step.

The recycling provider (i.e. recycled content provider) using these rules to calculate the recycling emissions shall include all relevant process steps and calculate the carbon footprint for the respective steps separately, which on an aggregated level form the overall carbon footprint of the recycling process. Additionally, the user shall report overall recycling efficiencies of the process.

Furthermore, the respective user shall calculate the transport between the different process steps up to the recycled material that flows into the upstream production process with the respective transport means, which is described in the rules on transport-related emissions for distribution (please refer to Annex B).

FIGURE 6-32: Different recycling process routes for spent batteries (Doose et al. 2021)



6.5.6.1. Discharge and dismantling (if required)

Process description
Usually, the first process step includes the deactivation of the spent battery system having been dismantled from the final product (if applicable). The dismantling from the final product is not included in the system boundary. The deactivation of the battery is followed (but not compulsory) by dismantling the battery system to modules or, rarely, to individual cells.

The deactivation frequently proceeds by full electrical discharge and subsequent short circuiting or by pyrolysis of the battery systems. If pyrolysis is the first processing step, refer to Chapter 6.5.6.2. Discharge is vital prior to disassembly to guarantee stabilization and security as the energy content in the battery can cause adverse chemical reactions (e.g., short circuiting) and due to safety reasons in currently mostly manual dismantling processes. Electrical discharge is followed by a dismantling procedure, where passive components such as casing, connection and sealing materials of the battery pack are removed before further treatment and the battery pack is separated into modules (and in some cases even cells). The removed components are typically introduced to conventional recycling methods for aluminum, iron, copper, polymers, and others.

Data collection requirements
The user of this rulebook shall make reference to which inputs and outputs are referred to, as shown generally in Figure 6-29. No emissions credits shall be given for the discharged electricity in the deactivation process. If it is demonstrated that the electricity is reutilized in the same production site and therefore replaces procured electricity, this may be reflected in the electricity input for the CF calculation (i.e. only newly procured/produced energy is accounted for).

The data collection shall cover all related operational processes during the discharging and dismantling (prior to further treatment) to obtain at the end the dismantled modules or cells to be sent to the recycling treatment process steps. The following table includes a generalized minimum list of input and output parameters the use of these rules shall collect. The user shall state the exact unit, as well as give additional information in the specification field (for instance for the conversion of unit metrics).

Allocation

In the dismantling process, economically valuable components are dismantled from the battery (e.g., BMS, casing, connectors). If the conditions for system expansion are not met (alternative well-characterized and representative routes), allocation shall be applied. As it is considered that the economic value at end of life of some of these components is significantly higher than other co-products, economic allocation as presented in Chapter 4.1 may be required (See Chapter 4.1.1). The user of this Rulebook shall assess the applicability of economic allocation taking the price of the components as the basis. Only if these are not available, the value of the embedded materials may be used.

For modelling electricity, please refer to the Chapter 5.2.2.

TABLE 6-60: General input-output table for dismantling process

Material	Unit	Data	Specification
Input			
Spent battery	kg		
Electricity	kWh		
Fuels	kg		conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased			
Chemicals	kg		
Water	l		
Output			
Modules/cells	kg		
Co-products	kg		
Waste	kg		e.g. glues
Direct GHG emissions	kg		

6.5.6.2. Thermal pre-treatment – pyrolysis (if required)

Process description
Thermal pre-treatment offers a controlled deactivation, discharge and decomposition to remove carbon and organic components (Makuza et al. 2021). Pyrolysis is the process of heating the battery material above its decomposition temperature in an oxygen-free environment to facilitate the thermal decomposition of organic compounds, which can be used as fuel or chemical feedstock. The active cathode material can withstand the pyrolysis temperature and remains as a solid residue, which is then further processed during the subsequent recycling steps.

Data collection requirements
The data collection shall cover all related operational processes during thermal pre-treatment required to reach the next recycling treatment process step. Combined thermal-mechanical pre-treatment processes exist, yielding pyrolyzed black mass. Both pre-treatments as described in these rules may be modelled in combination using the relevant input-output tables. A separate data collection sheet provides a combined data template. Off-gas treatment shall be accounted for in the process activity footprint calculation. The same applies to wastewater treatment. Where electrolytes and graphite evaporate in the thermal pre- treatment, direct emissions need to be included. The same applies to graphite.

The following table includes a generalized minimum list of input and output parameters the use of these rules shall collect. The user shall state the exact unit, as well as give additional information in the specification field (for instance for the conversion of unit metrics).

Allocation
Mechanical pre-treatment separates battery materials into black mass and several other co-products. Typically, metal fractions are produced as co-products. As a first step, it shall be assessed whether process subdivision can be applied at the points of separation for the respective co-products, in line with Chapter 4.1.1. As a second step, it shall be evaluated whether system expansion applies for eliminating co-products from the system boundary. Since there is likely no well-characterized and representative alternative for metals, metal fraction co-products shall be allocated either economically or via mass, depending on the price differential. For other materials such as polymer flakes, graphite or electrolytes, these co-products shall be given system expansion credits if the conditions of the allocation rules in Chapter 4.1 are met (particularly alternative well-characterized and representative routes, verification of economic value). If these alternative routes cannot be identified, economic or mass allocation applies (See Chapter 4.1.1). When the price ratio between all process output products exceeds four, economic allocation shall be applied. This is likely the case but depends on the composition of the treated battery, which is why the user of this Rulebook shall assess the applicability of economic allocation in line with the allocation requirements (See Chapter 4.1.1).

For modelling electricity, please refer to the Chapter 5.2.2.

TABLE 6-61: General input-output table for thermal pre-treatment

Material	Unit	Data	Specification
Input			
Spent battery / dismantled modules	kg		
Electricity	kWh		
Fuels	kg		conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased			
Chemicals	kg		
Industrial gases	m^3		
Water	l		
Output			
Solid battery residue	kg		(for further treatment)
Co-products - Metal fractions	kg		
Co-products - Other	kg		
Off-gases for further treatment	kg		
Waste	kg		
Direct GHG emissions	kg		Graphite and electrolyte, if thermally lost

6.6.6.3. Mechanical pre-treatment / shredding (if required)

Process description

Mechanical treatment includes mechanically crushing/shredding (potentially with gas treatment under iMechanical treatment includes mechanically crushing/shredding (potentially with gas treatment under inert atmosphere) dismantled battery modules or cells, followed by air classification, sieving and magnetic separation. This yields black mass and, through segregation processes, other co-products such as polymer flakes from separators, aluminium and copper fractions from foils or ferrous/non-ferrous metal fractions from the casing. Additionally, one possible route for graphite treatment might be separation before the black mass is produced (see the example of graphite treatment in the box below which shall serve as the basis for deciding on treating co-products). Drying can be a part of the mechanical treatment, yielding electrolyte as a co-product. The electrolyte treatment processes (especially if thermally treated) could lead to direct carbon dioxide emissions that need to be included in the CF calculation. The off-gas emerging in this process step is cleaned via condensing and an activated carbon filter which needs to be replaced and reprocessed periodically (Mohr et al. 2020). The degree of mechanical processing varies and thus determines the amount of recovered materials as the amount and quality of recovered materials increases with more complex mechanical treatment. Subsequently, the black mass is pyrometallurgically processed before it goes into a final hydrometallurgical step or directly introduced into hydrometallurgical treatment.

Potentially, entire battery packs are mechanically processed. This yields additional by-products such the fractions from the battery/cell casing and wiring.

Example graphite treatment: The example of graphite highlights that battery recycling process outputs can vary strongly depending on the technical design. It shall serve as basis for classifying and accounting for typical co-products/waste from the respective recycling process steps (such as electrolyte). The recovery of graphite can follow four routes:

1) **Separated in mechanical pre-treatment:** Graphite might be separated before the black mass is produced in the mechanical pre-treatment. Depending on the economic value (potentially as energy carrier substitute) and local waste legislation, the user of these rules shall determine whether graphite is to be treated as a co-product or waste.
    a. Sold as co-product: If the net economic value of graphite removed in the mechanical pre-treatment is above zero and local legislation does not classify it as waste, the allocation hierarchy in Chapter 4.1.1 applies.
    b. Incinerated (as waste): If the classification yields that the removed graphite is waste, the waste modelling approach in Chapter 4.1.1 applies and burdens of further treatment shall be allocated to the output products of the mechanical pre-treatment step.
2) **Thermally lost in pyrometallurgical or thermal pre-treatment:** The according carbon emissions from thermal treatment shall be accounted as direct process emissions with the carbon content of the graphite.
3) **Recovered in hydrometallurgical treatment:** If black mass still contains graphite, it can be recovered through leaching in hydrometallurgical treatment. The rules in Chapter 4.1.1 apply to recovered graphite as a co-product in the hydrometallurgical treatment. For all described routes, the quality of outgoing graphite shall be documented in the data collection as it is important for accounting associated emissions.

Data collection requirements

Depending on the overall process design (i.e. no thermal pre-treatment prior to mechanical pre-treatment), the black mass might require pyrolysis/thermal treatment (e.g., roasting) prior to hydrometallurgical processes to remove the organic components and to concentrate the metal content (Brückner et al. 2020). In this case, please refer to and adapt accordingly the data collection in Chapter 6.5.6.2. Combined thermal-mechanical pre-treatment processes exist, yielding pyrolyzed black mass. Both pre-treatments as described in these rules may be modelled in combination using the relevant input-output tables. A separate data collection sheet provides a combined data template.

It is important to calculate GHG-relevant process emissions such as during the off-gas treatment. In case off-gases occur, their treatment needs to be accounted for in the process activity footprint calculation. This applies to other processes might be required during mechanical pre-treatment.

Allocation

Mechanical pre-treatment separates battery materials into black mass as main product and several co-products. Typically, metal fractions are produced as co-products. As there is likely no well-characterized and representative alternative for metals, metal fraction co-products shall be allocated either economically or via mass, depending on the price differential (See Chapter 4.1.1). For other materials such as polymer flakes, graphite or electrolytes, these co-products shall be given system expansion credits if the conditions of the rules in Chapter 4.1 are met (particularly well-characterized and representative alternative routes, verification of economic value). If these alternative routes cannot be identified, economic or mass allocation applies.

For modelling electricity, please refer to the Chapter 5.2.2.

TABLE 6-62: General input-output table for mechanical pre-treatment / shredding

Material	Unit	Data	Specification
Input			
Dismantled modules/cells | Battery pack	kg		
Electricity	kWh		
Fuels	kg		conversion from m^3 to kWh or MJ
Chemicals	kg		
Industrial gases	m^3		
Water	l		
Output			
Black mass	kg		
Co-products - Metal fractions	kg		E.g., Copper, Aluminium, steel
Co-products – Other	kg		E.g., polymer flakes, electrolyte, graphite
Off-gases for further treatment	kg		
Waste	kg		
Direct GHG emissions	kg		

6.6.6.4. Pyrometallurgical treatment (if required)

Process description

Pyrometallurgical processes (e.g., smelting in blast furnace or electric arc furnace) are well established for extracting materials from metal fractions and can achieve high recovery yields for cobalt, nickel, and copper. These extract metal by heating the battery/module/cell scrap with products of a metallic alloy, slag and gases in the processes. However, challenges regarding the recovery of other materials exist as lithium, manganese, and graphite are lost into the slag depending on the battery composition (Rinne et al. 2021). To be able to recover lithium and manganese, pyrometallurgical processes have to be combined with hydrometallurgical processes for recovering the lithium- and -manganese-containing slag or cobalt-, nickel-, copper-containing alloy/matte. Overall, a relatively small total recovery of the battery materials can be expected in this case due to graphite, polymers, and electrolyte being burned, although a very high recovery of nickel, cobalt, and copper is possible.

Pyrometallurgy includes high-temperature processes such as roasting or smelting for recovering and refining metals. Roasting describes processes that include a gas–solid reaction (oxidizing roasting) to purify the ore or secondary material. Smelting describes processes that extract a metal from an ore or secondary material using heat and a chemical reducing agent to decompose the secondary material. This drives off other elements as off-gases or slag and leaves the metal base as alloy/matte for further processing and refinement (Brückner et al. 2020). The reducing agent is commonly a source of carbon, potentially originating from the battery itself. In this process, untreated battery modules/cells can be directly fed into the furnace. After the reduction smelting process, the metals are concentrated into a molten alloy (Makuza et al. 2021).

The pyrometallurgical process yields a cobalt, copper, and nickel-containing alloy (metallic phase) or matte (sulfidic phase). Additionally, an aluminium-, manganese- and lithium-containing slag (oxidic phase) as well as a fly ash are produced. These processes often only produce intermediates that require further hydrometallurgical refining. Thus, to recover the individual metals, the alloy is introduced to hydrometallurgical processes. The fly ash is usually used as an outlet for undesirable elements such as fluorine and hence, it is disposed of (Brückner et al. 2020).

Data collection requirements

The data collection shall cover all related operational processes during the pyrometallurgical process required to reach the next recycling treatment process step. It is important to calculate GHG-relevant process emissions such as during the reduction process. In case cokes or graphite is used as reducing agent, these can be very important contributions to the carbon footprint. Furthermore, off-gas treatment shall be accounted for in the process activity footprint calculation. The same applies to wastewater treatment. An additional important specification to be stated is the quality of output metals and the yield. This is an important factor for cross-checking the recycling balance over the whole process chain. The grade/purity level of the output metals shall be reported (assay data) as well as the recycling yield.

Allocation

In case recycling providers co-produce with primary materials, sulphuric acid from SO2 scrubbing and recovered heat (as steam or thermal energy) are co-products from the process. In case the conditions of the rules in Chapter 4.1 are met (particularly well-characterized and representative alternative route as well as verification of economic value), these shall be allocated via system expansion credits. The credits for co-products shall be calculated only after accounting for emissions from transport to the processing site and further treatment. For including transport emissions, the respective buyer-specific transport distances shall be applied. The user of these rules shall clearly classify co-products and provide justification in the technical documentation. If system expansion is not applicable, economic or mass allocation shall be applied depending on the price differential of the co-products (See Chapter 4.1.1).

For modelling electricity, please refer to the Chapter 5.2.2.

TABLE 6-63: General input-output table for pyrometallurgical treatment

Material	Unit	Data	Specification
Input			
Black mass/ solid battery residue	kg		
Reducing agents	kg		C content and type of reductant
Chemicals / Additives	kg		e.g., limestone, sand
Bulk chemicals	kg		e.g., NaOH, Na2SO4, NaCl
Electricity	kWh		
Fuels	kg		conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased			
Water	l		
Output			
Slag or alloy/ Matte for further treatment in hydro	kg		Assay data for metal fractions and quality (% of metal content), including recycling yield
Co-products - Other	kg		e.g., sulphuric acid from SO2 scrubbing; recovered heat (as steam or thermal energy)
Chemical waste	kg		e.g., SO2, Cl
Wastewater	l		
Off-gases for further treatment	kg		
Solid waste	kg		e.g., fly ash
Direct GHG emissions	kg		Calculated based on reductants (stoichiometry, graphite carbon content)

6.6.6.5. Hydrometallurgical treatment

Process description

The flowsheets of hydrometallurgical processes can vary significantly. Yet, in general, hydrometallurgical treatment uses chemical solutions to leach and extract target metals from battery waste and proceeds in three steps: (1) Leaching, (2) purification as well as (3) precipitation (Mn, Li) and crystallization (Co, Ni) or electrowinning in some cases (Liu et al. 2019).

In leaching, the metals in the slag or black mass are dissolved using a leaching media (salt, base or acid e.g., sulfuric acid solution). In the purification step, metals are separated and purified through selective chemical reactions such as solid-liquid (ion exchange) and liquid-liquid (e.g., solvent extraction) reactions. The third step consists of recovering the metals from the solution into solid products in the form of metals, metal salts or compounds through crystallization or ionic precipitation (Brückner et al. 2020). Cobalt and nickel can be recovered in solvent-based reactions, as well as crystallized to CoSO4 and NiSO4 via water evaporation under vacuum. Manganese is oxidatively precipitated as MnO2. Lithium is subsequently recovered as a lithium compound (e.g. Li2CO3). The lithium filtrate may also be crystallized (LiOH) while producing sodium sulphate (Na2SO4). The wash waters and effluents are neutralized to produce neutral wastewater and to precipitate the remaining metals as hydroxides (Rinne et al. 2021).

Depending on the specific flowsheets and input materials used, different product compositions can occur.

A distinction can be made between three routes.

(1) The first includes complex hydrometallurgical flowsheets and results in the recovery of battery grade materials, i.e., $NiSO_4$, $CoSO_4$, $MnSO_4$, $LiOH/Li_2CO_3$. For the calculation of the process carbon footprint, the input/ouput Table 5-64 applies.

(2) The second is the production of intermediates by leaching and precipitation with the aim of producing cobalt and nickel and a separate lithium product for further processing in existing refineries. For instance, MHP, which requires further treatment and refinement to achieve battery grade. If a recycling provider follows this route, the provider shall adapt Table 5-64 for calculating the GHG emissions of the intermediate production and include the refinement process in the calculation as described in Chapter 6.5.6.6.

(3) The third is a combination of (1) and (2) where battery grade materials ($NiSO_4$ and $CoSO_4$) and non-battery grade intermediates ($MnCO_3$ and Li_2SO_4) are produced as co- products. Table 6-64 can be applied with the specification that MnCO3 and Li2SO4 are to be classified as co-products in the data collection. If the co-products are further treated to battery grade materials, the refinement process shall be included in the carbon footprint calculation.

Data collection requirements

Table 5-64 presents a generalized input output table which shall be extended by the user to accommodate the complexities of the recycling process at hand. The user shall adapt this to match the complexities of the respective flowsheets.

The data collection shall cover all related operational processes during the hydrometallurgical process required to reach the final recycling treatment process step (or additional refinement step). It is important to consider process emissions in the hydrometallurgical process where limestone is used for neutralization and $CaCO_3$ is reacting with acid solution generating GHG emissions. All relevant process emissions shall be included, for example potential sodium sulphate crystallization as well as wastewater treatment which shall be accounted for in the process activity footprint calculation (see input/output Table 5-64). In case lithium is recovered in a separate process step compared to the other battery metals, the user may collect the data for this process step separately as displayed in Table 5-65. Burdens of this separate process shall be attributed to the lithium product, which shall bear its share of emissions from the previous process step (allocated via final product mass to the main products).

Chemical inputs and outputs shall include supplier-specific CF data as far as possible. Where this is not possible, EF-compliant databases shall be used. As for many chemicals a carbon factor is not available, proxies per categorization as follows shall be used. To avoid some of the chemicals being excluded because a carbon factor not being available, it is recommended to group the chemicals according to their purpose in frothers, dispersants, and flocculants and take the biggest contributor (mass) as a proxy for all categorized chemicals in case no supplier-specific or EF-compliant carbon footprint as available for these. Other bulk chemicals or auxiliaries like neutralizer (e.g., quicklime (CaO)), need to be collected separately.

For all hydrometallurgical flowsheets, the grade/purity level of the output metals shall be reported (assay data) as well as the recycling yield. This is an important factor for cross-checking the recycling balance over the whole process chain.

Allocation

Recycling processes are multi-output processes, i.e., having several valuable and functional outputs. For multi-output processes, the GHG emissions associated with the process shall be partitioned between the co-product(s) in a consistent way as per the multi-output allocation hierarchy in Chapter 4.1.1. Hydrometallurgical treatment yields a variety of co-products which varies depending on the complexity of the respective flowsheet.

In battery recycling, the target process output products are generally battery-grade nickel, cobalt, manganese and lithium compounds. Typically, sodium sulfate crystals, copper and graphite/carbon filter cake are produced as co-products. Following the multi-output allocation hierarchy in Chapter 4.1.1, if sub-division can be applied, hydrometallurgical processes shall be further sub-divided into sub-process level under the conditions and guidance set out in Chapter 4.1.1. Where sub-division is not applicable, system expansion shall be investigated. Where this is not applicable, allocation shall be applied.

For co-products where the appropriate conditions of Chapter 4.1.1 apply, system expansion shall be applied (e.g., sodium sulfate). The credits for sodium sulphate – and other co-products – should be calculated only after accounting for emissions from transport to the processing site and further treatment. To include transport emissions, the respective buyer-specific transport distances shall be applied.
The user of this Rulebook shall clearly classify co-products and provide justification in the technical documentation.

Even though nickel, cobalt, copper, manganese and lithium compounds have alternative production routes, these are not representative of a dominant route on the market producing these materials (see for instance Chapter 6.1.1. and 6.1.2.)[3] and, therefore, allocation shall be applied. If the price differential between output products surpasses four – as is likely in this case – economic allocation shall be applied. Only if the price differential is below four, shall mass allocation be applied for these outputs of recycling. The user of this Rulebook shall determine the price differential based on the specific outputs of the process. Allocation shall always be done at the point of separation. If this proves difficult, the applicability of subdivision or system expansion should be checked again.

For modelling electricity, please refer to the Chapter 5.2.2.

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[3] Note that the identification of well-characterized and representative alternative routes for the applicability of system expansion requires knowledge of production processes that yield materials of the same quality and composition as those of the recycled product. It is recommended to refer to the relevant Chapters for the upstream processes in this rulebook

TABLE 6-64: General input-output table for hydrometallurgical treatment

Material	Unit	Data	Specification
Input			
Black mass | slag | alloy | matte	kg		
Electricity	kWh		
Fuels	kg		e.g., coke, conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased			
Water	l		
Bulk Chemicals	kg		e.g., H2SO4, SO2, NaOH, Na2CO3, diluents etc.
Auxiliary gases	Nm^3		e.g. compressed air, oxygen, nitrogen
Reagents / additives / auxiliaries	kg		e.g. Lime (CaO), limestone, carbon activated carbon filter, silica sand
Output			
Cobalt compound (CoSO4)	kg		Assay data
Nickel compound (NiSO4)	kg		Assay data
Manganese compound (MnSO4)	kg		Depending on complexity of process flow, Assay data
Lithium compound (LiOH / Li2CO3)	kg		Assay data
Electrolyte	kg		Depending on complexity of process flow and if not removed in mechanical pre-treatment
Co-products - Metal fractions	kg		e.g., MnCO3 or Li2SO4 (if not battery grade), copper, graphite/carbon filter cake (depending on complexity of the flowsheet), Assay data required
Co-products - Other	kg		e.g., sodium sulfate (crystals), electrolyte, graphite
Material content in water for further treatment	kg		e.g. lithium content - if lithium is extracted in aggregated process and no further materials can be recovered, this can be neglected. If lithium is extracted in separate process, the lithium content in waster is required for the allocation and shall be stated
Wastewater	l		Incl. solid suspension, fluoride, other emissions to water
Waste	kg		e.g., inert waste residue for landfill, waste gypsum, chemical waste
Direct GHG emissions	kg		

TABLE 6-65: Lithium recovery in case of separate process step

Material	Unit	Data	Specification
Input			
Lithium contained in water for further processing	kg		Lithium content in water
Electricity	kWh		
Fuels	kg		e.g., coke, conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased			
Water	l		
Bulk Chemicals	kg		e.g., H2SO4, HCl, NaOH, NaCO3, CA(OH)2, CaCl2 etc.
Auxiliary gases	Nm^3		e.g. compressed air, oxygen, nitrogen
Output			
Lithium hydroxide (LiOH) Crystals	kg		Assay data
Lithium Carbonate (Li2CO3)	kg		Assay data
Co-products - Other	kg		e.g., Sodium chloride (NaCl) crystals
Wastewater	l		Incl. solid suspension, fluoride, other emissions to water
Waste	kg		e.g., inert waste residue for landfill, waste gypsum
Direct GHG emissions	kg		

6.5.6.6. Refining / preparation to battery grade (if required)

The recovered recycled material quality must comply with quality/ grade requirements for each battery input. In case the battery recycling process does not yield recycled materials of sufficient quality (i.e., battery grade), further refinement or preparation to battery grade materials is required. The respective activities shall be included in the Carbon Footprint calculation. Hydrometallurgical unit operations often occur as refining steps at the end of a process chain because of their ability to produce high-quality products (Brückner et al. 2020). In case additional hydrometallurgical steps are added for intermediates, please refer to Chapter 6.5.6.5. In case pyrometallurgical roasting is applied to purify the secondary material alongside primary materials, please refer to Chapter 6.5.6.4. Additionally, please refer to the respective Chapters in the cluster-specific rules on refinement of primary Nickel, Cobalt and Manganese sulfate as well as lithium carbonate/hydroxide (see refining in Chapters 6.1.1.-6.1.4.). Fundamentally, the displayed refinement processes are similar for refining intermediate metals that originate from the hydrometallurgical treatment in battery recycling.

6.5.6.7. Co-production of primary and secondary materials

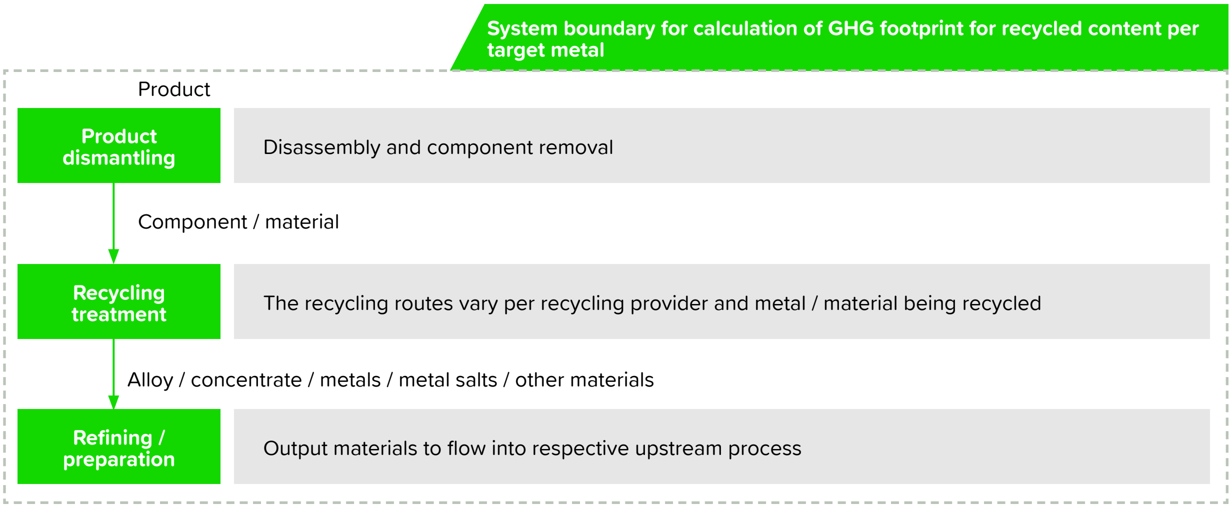
Co-production of primary and secondary materials is applied in industry. Pre-processed waste materials are refined together with primary materials. In this process, pre-processed waste materials are refined together with primary materials. For calculating the carbon footprint of such processes, the steps from waste collection to the pre-processed waste material (i.e., black mass) shall be accounted for, including steps that clean or scrub the pre-processed materials. The user of these rules shall identify the point of substitution where the secondary materials replace primary materials. The secondary materials bearing the emissions from collection, dismantling and pre-processing are included at the respective point of substitution. This corresponds to further refining as outlined above, where secondary materials are included in the refinement steps in Chapters 6.1.1.-6.1.4.

If users operate co-production processes, the recycled content entering the production shall be identified and associated with the burdens of previous processing steps. Company-specific data shall be used for the pre-processing steps if the user operates these. If not, supply chain-specific data shall be used where available. In each case, all steps of the recycling system boundaries until the point of substitution shall be considered. This requires identifying the amount of recycled content that is introduced into the refinement process. In case secondary materials are introduced in several refinement steps, a correct mass balance shall be provided for the share of recycled content.

6.5.6.8. Other recycling processes: generalized data collection sheet

For all materials other than pCAM/CAM and anode materials or different products systems and recycling processes, the user of this rulebook shall collect supplier-specific data from the respective recycling routes where the recycled material is procured. A generalized recycling process chart is given in Figure 5-33. Each of these generic recycling stages must have a reference to which all inputs and outputs are referred to.

FIGURE 6-33: System boundaries of general recycling as umbrella process chart



*The battery recycling routes vary per recycling provider. Batteries are usually dismantled into modules before mechanical treatment is applied. However, some providers mechanically treat entire battery packs. If pyrolysis is applied, it will be followed by or used in combination with mechanical treatment. Pyrolysis, mechanical and pyrometallurgical treatments are optional, but all routes usually end with hydrometallurgical treatment.

As the recycling processes vary significantly within types of materials but even more so between types of materials (e.g., polymers and steel), the generalized data collection sheet shall be extended and applied by the recycled material provider under the general described in Chapter 6.5 under consideration of the sub-Chapters for battery materials recycling in 6.5.6.

The following general data collection sheet shall be used and extended to collect primary activity data and calculate the GHG footprint of the recycled material that is used on the input side of the battery production. The general rules shall apply.

For modelling electricity, please refer to the Chapter 5.2.2.

TABLE 6-66: Input-output table for other recycling processes - generalized data collection

Material	Unit	Data	Specification
Input			
Product waste	kg		e.g., end of life steel, aluminium, polymers etc.
Electricity	kWh		
Fuels	kg		conversion from m^3 to kWh or MJ
External supply (Heat & Steam respective of fuel) purchased			
Auxiliaries (water)	kg		
Reductants	kg		
Bulk chemicals	kg		
Output			
Recycled material	kg		e.g., recycled polymers, recycled steel, recycled aluminium etc.
Waste	kg		
Co-products	kg		
Direct emissions	kg		

6.5.7. Disposal emissions based on recyclability (as End of life and recycling emissions)

While the recycling emissions of previous batteries are associated on the input side, the emissions related to the disposal of the considered battery are assigned to the respective system boundary as emissions for the End of life and recycling stage. Hence, the system boundary of the considered product includes the waste incineration and landfilling processes following the polluter-pays-principle. This requires assumptions on the EOL treatment of the battery (e.g., information on collection rate and future recycling flowsheets and efficiencies).

The user of this rulebook shall indicate if unrecyclable materials are included in the battery and the respective destination as of current EOL processing. This means that unrecyclable fractions shall be reported with the respective amount and whether these are landfilled or incinerated. Thereby, recyclability is defined as the ability of component parts, materials or both that can be diverted from an end of life stream to be recycled (ISO 22628:2002). For these rules, this shall refer to recycling technologies and processes available on the market at the point of calculating the carbon footprint. This means that no future recycling technologies shall be taken into account. Additionally, the available recycling processes shall be dominant, i.e. indicating that these are generally economically beneficial. Therefore, if no recycling process is dominantly available on the market for certain materials, these shall be classified as unrecyclable.

In the EU context, an evaluation for recyclability of the material in the battery is required and a statement on the recyclability of the materials/products shall be provided (Recharge 2018). The statement on and evaluation of the recyclability shall follow the three criteria (as described by ISO 14021:1999, section 7.7.4) and requirements as per the PEFCR (Recharge 2018):

1. The collection, sorting and delivery systems to transfer the materials from the source to the recycling facility are conveniently available to a reasonable proportion of the purchasers, potential purchasers and users of the product;
2. The recycling facilities are available to accommodate the collected materials;
3. Evidence is available that the product for which recyclability is claimed is being collected and recycled.

As these fractions and resulting EOL emissions are likely non-significant, EF-compliant secondary datasets for heating values and landfill emissions may be used: if waste incineration occurs, materials are to be linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. No credits for power or heat production as well as material recovery are assigned. If materials are sent to landfills, they are to be linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring versus power production).

7. GHG Calculation

Post collection of activity data and selecting suitable emission factor either from secondary sources or supplier-specific sources the carbon dioxide equivalent is calculated using the formula as specified below.

$$CO_2e = \sum_i ActivityData * EmissionFactor_i * GWP$$

QQuantities of GHG emissions are expressed as tons of **CO_2e** (Carbon Dioxide Equivalents) using the globalwarming potentials (GWP) from the IPCC. The time horizon is 100 years.

Direct emissions sources are expressed as both **CO_2e**, including the GWP (Global Warming Potential) value.

The Intergovernmental Panel on Climate Change (IPCC) regularly publishes 100-year global warming potentials (GWPs) for different greenhouse gases. These values shall be used to convert life cycle inventory results to an expression in units of climate change impact (kg CO2eq) as follows:

- As a priority, GWP-100 characterization factors shall be sourced from Table 7.15 of Chapter 7 of the IPCC's Sixth Assessment Report Climate Change 2021 Physical Science Basis (IPCC, 2021a).
- Additional factors shall be sourced from Table 7.SM.7 in Chapter 7 Supplementary Materials of the IPCC's Sixth Assessment Report Climate Change 2021 Physical Science Basis (IPCC, 2021a).
- Additional factors shall be sourced from the IPCC's Fifth Assessment Report, Appendix 8.A (IPCC, 2013).

All other GWP factors can be accessed on the JRC webpage (https://eplca.jrc. ec.europa.eu/LCDN/contactListEF.xhtml).

8. Verification/Review

The GHG calculation from each member along the value chain shall be reviewed and verified in accordance with the GBA scheme for Battery Passport data verification.

The verification/validation body will at least verify the

- primary data collected,
- the selection of GHG emission factors
- the calculation method and documentation of the result
- recycled content (calculation and documentation of recycled content from supplier)

Disclaimer:
The GHG Rulebook is the first publication in a series of rulebooks to be developed as part of the Global Battery Alliance Battery Passport framework. As such, it includes only elements of data verification and assurance guidance that will ultimately be evolved and be applicable across the entire indicator framework and that are not specific to GHG emissions data collection and aggregation.

To make the GBA GHG rulebook a helpful freestanding tool in the medium-term, while accompanying rulebooks and guidance documents for the Battery Passport are being finalized in parallel, any future version of the rulebook should describe both processes of **intra**-company data collection and **inter**-company data aggregation and related data verification and aggregation requirements, to support correct calculation and aggregation into the battery carbon footprint.

Guidance for these cross-cutting data validation and verification processes may be provided in a dedicated document or rulebook covering data aggregation, verification, and validation in the future, which will be applicable across the entire spectrum of GBA battery passport rulebooks.

The GBA adheres to principles of independent verification and intends to reference globally recognized standards as the basis for this upcoming document. To ensure participation in the GBA Battery Passport serves to demonstrate compliance with regulatory requirements, any future GBA guidance on data validation or verification will build on, mirror or even enhance data verification protocols set out be relevant regulators in the future.

9. Outlook

For different reasons, the following aspects have not been covered or need further specification in the next version of the GHG Rulebook:

- Use phase
- Biogenic carbon content (Needed to be able to calculate correct CO_2 emissions during the end-of-life stage)
- Additional cathode chemistries e.g., solid state
- Specific primary data collection rules for other materials e.g., copper, aluminium, Lithium Hexafluorophosphate ($LiPF_6$)

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Annex A:

Annex A1: Emission factors

Default GHG emission factors for fuel combustion from 2006 IPCC Guidelines

FIGURE A-1: Emission factors from 2006 IPCC Guidelines I (IPCC, 2006)

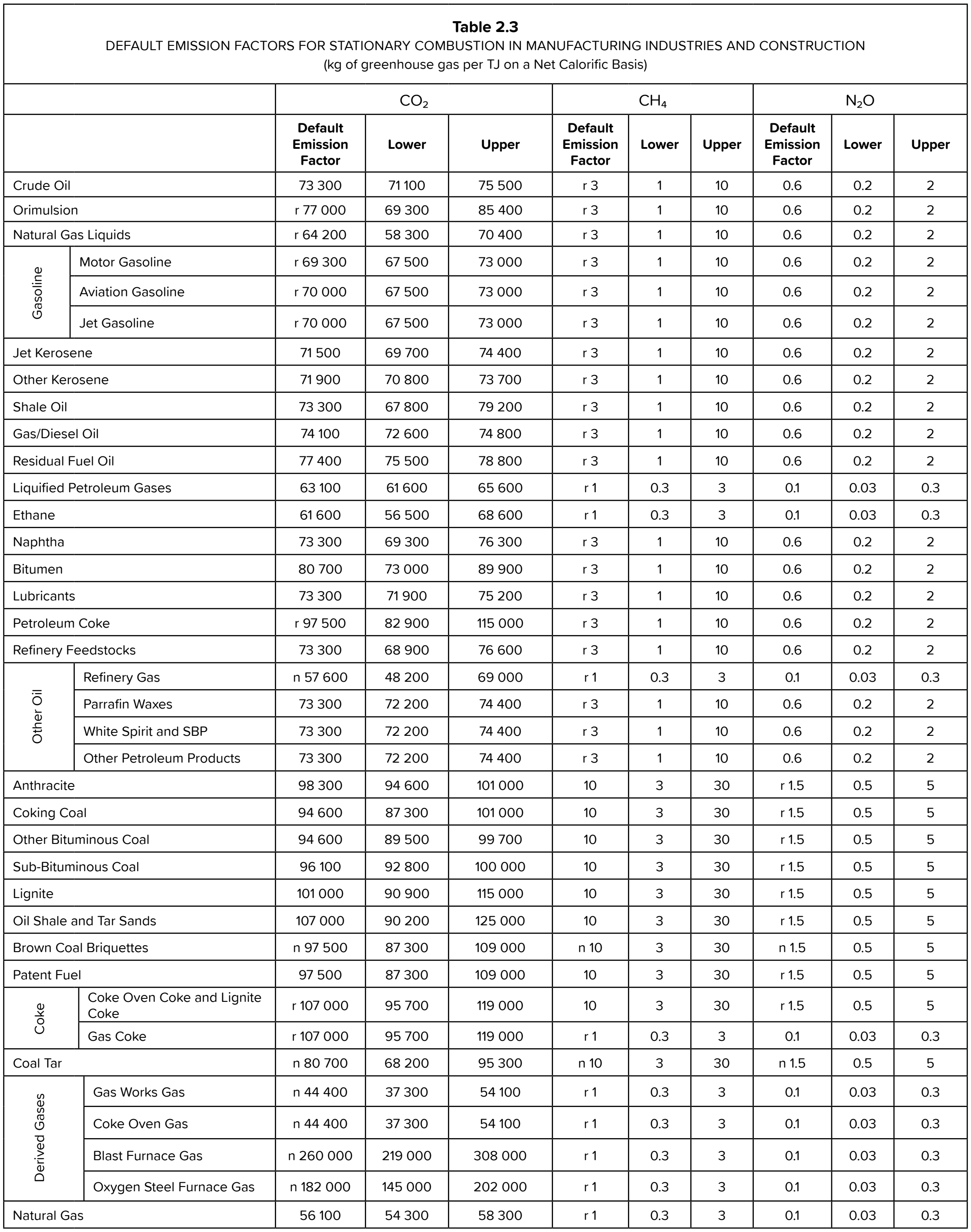


Table 2.3

DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN MANUFACTURING INDUSTRIES AND CONSTRUCTION

(kg of greenhouse gas per TJ on a Net Calorific Basis)

		CO_2			CH_4			N_2O		
		Default Emission Factor	**Lower**	**Upper**	**Default Emission Factor**	**Lower**	**Upper**	**Default Emission Factor**	**Lower**	**Upper**
Crude Oil		73 300	71 100	75 500	r 3	1	10	0.6	0.2	2
Orimulsion		r 77 000	69 300	85 400	r 3	1	10	0.6	0.2	2
Natural Gas Liquids		r 64 200	58 300	70 400	r 3	1	10	0.6	0.2	2
Gasoline	Motor Gasoline	r 69 300	67 500	73 000	r 3	1	10	0.6	0.2	2
	Aviation Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
	Jet Gasoline	r 70 000	67 500	73 000	r 3	1	10	0.6	0.2	2
Jet Kerosene		71 500	69 700	74 400	r 3	1	10	0.6	0.2	2
Other Kerosene		71 900	70 800	73 700	r 3	1	10	0.6	0.2	2
Shale Oil		73 300	67 800	79 200	r 3	1	10	0.6	0.2	2
Gas/Diesel Oil		74 100	72 600	74 800	r 3	1	10	0.6	0.2	2
Residual Fuel Oil		77 400	75 500	78 800	r 3	1	10	0.6	0.2	2
Liquified Petroleum Gases		63 100	61 600	65 600	r 1	0.3	3	0.1	0.03	0.3
Ethane		61 600	56 500	68 600	r 1	0.3	3	0.1	0.03	0.3
Naphtha		73 300	69 300	76 300	r 3	1	10	0.6	0.2	2
Bitumen		80 700	73 000	89 900	r 3	1	10	0.6	0.2	2
Lubricants		73 300	71 900	75 200	r 3	1	10	0.6	0.2	2
Petroleum Coke		r 97 500	82 900	115 000	r 3	1	10	0.6	0.2	2
Refinery Feedstocks		73 300	68 900	76 600	r 3	1	10	0.6	0.2	2
Other Oil	Refinery Gas	n 57 600	48 200	69 000	r 1	0.3	3	0.1	0.03	0.3
	Parrafin Waxes	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
	White Spirit and SBP	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
	Other Petroleum Products	73 300	72 200	74 400	r 3	1	10	0.6	0.2	2
Anthracite		98 300	94 600	101 000	10	3	30	r 1.5	0.5	5
Coking Coal		94 600	87 300	101 000	10	3	30	r 1.5	0.5	5
Other Bituminous Coal		94 600	89 500	99 700	10	3	30	r 1.5	0.5	5
Sub-Bituminous Coal		96 100	92 800	100 000	10	3	30	r 1.5	0.5	5
Lignite		101 000	90 900	115 000	10	3	30	r 1.5	0.5	5
Oil Shale and Tar Sands		107 000	90 200	125 000	10	3	30	r 1.5	0.5	5
Brown Coal Briquettes		n 97 500	87 300	109 000	n 10	3	30	n 1.5	0.5	5
Patent Fuel		97 500	87 300	109 000	10	3	30	r 1.5	0.5	5
Coke	Coke Oven Coke and Lignite Coke	r 107 000	95 700	119 000	10	3	30	r 1.5	0.5	5
	Gas Coke	r 107 000	95 700	119 000	r 1	0.3	3	0.1	0.03	0.3
Coal Tar		n 80 700	68 200	95 300	n 10	3	30	n 1.5	0.5	5
Derived Gases	Gas Works Gas	n 44 400	37 300	54 100	r 1	0.3	3	0.1	0.03	0.3
	Coke Oven Gas	n 44 400	37 300	54 100	r 1	0.3	3	0.1	0.03	0.3
	Blast Furnace Gas	n 260 000	219 000	308 000	r 1	0.3	3	0.1	0.03	0.3
	Oxygen Steel Furnace Gas	n 182 000	145 000	202 000	r 1	0.3	3	0.1	0.03	0.3
Natural Gas		56 100	54 300	58 300	r 1	0.3	3	0.1	0.03	0.3

FIGURE A-2: Emission factors from 2006 IPCC Guidelines II (IPCC, 2006)

Table 2.3 (CONTINUED)
DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN MANUFACTURING INDUSTRIES AND CONSTRUCTION
(kg of greenhouse gas per TJ on a Net Calorific Basis)

		CO_2			CH_4			N_2O		
		Default Emission Factor	**Lower**	**Upper**	**Default Emission Factor**	**Lower**	**Upper**	**Default Emission Factor**	**Lower**	**Upper**
Municipal Wastes (non-biomass fraction)		n 91 700	73 300	121 000	30	10	100	4	1.5	15
Industrial Wastes		n 143 000	110 000	183 000	30	10	100	4	1.5	15
Waste Oils		n 73 300	72 200	74 400	30	10	100	4	1.5	15
Peat		106 000	100 000	108 000	n 2	0.6	6	n 1.5	0.5	5
Solid Biofuel	Wood / Wood Waste	n 112 000	95 000	132 000	30	10	100	4	1.5	15
	Sulphite lyes (Black Liquor)a	n 95 300	80 700	110 000	n 3	1	18	n 2	1	21
	Other Primary Solid Biomass	n 100 000	84 700	117 000	30	10	100	4	1.5	15
	Charcoal	n 112 000	95 000	132 000	200	70	600	4	1.5	15
Liquid Biofuels	Biogasoline	n 70 800	59 800	84 300	r 3	1	10	0.6	0.2	2
	Biodiesels	n 70 800	59 800	84 300	r 3	1	10	0.6	0.2	2
	Other Liquid Biofuels	n 79 600	67 100	95 300	r 3	1	10	0.6	0.2	2
Gas Biomass	Landfill Gas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
	Sludge Gas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
	Other Biogas	n 54 600	46 200	66 000	r 1	0.3	3	0.1	0.03	0.3
Other non-fossil fuels	Municipal Wastes (biomass fraction)	n 100 000	84 700	117 000	30	10	100	4	1.5	15

(a) Includes the biomass-derived CO_2 emitted from the black liquor combustion unit and the biomass-derived CO_2 emitted from the kraft mill lime kiln.
n indicates a new emission factor which was not present in the 1996 Guidelines
r indicates an emission factor that has been revised since the 1996 Guidelines

Annex B:

Annex B: EU module: the Circular Footprint Formula and Distribution

In the context of the EU CF declaration, EU-specific methodologies are required. Based on the defined rules, these requirements can be fulfilled. Detailed guidance on the application of the Circular Footprint Formula (CFF) for the EOL and recycling life cycle stage and the Distribution life cycle stage are provided in this 'EU module'. Thereby, it is described how the data collected under the GBA GHG Rulebook can be used to fulfil the requirements.

B.1 The Circular Footprint Formula for EOL and recycling allocation

Background and regulatory requirement

The EU Battery Regulation's Carbon Footprint Declaration will require the Circular Footprint Formula (CFF) as EOL allocation method as per reference to the PEF/PEFCR in Annex II (European Commission, 2023). The Circular Footprint Formula proposed by the European Product Environmental Footprint method combines usage of recycled materials as well as benefits and burdens associated with recycling, energy recovery and disposal at the End of life (EOL) (European Commission, 2019).

Additionally, the CFF is required for production waste modelling. This is mandatory for all waste occurring in the Manufacturing life cycle stage (mandatory primary activity data) and all processes where primary data are used.

To be able to fulfil the legal requirement in the European context, this chapter provides guidance on using the CFF as well as detailed rules on the calculation for batteries building on the Battery Pass rules for EOL and recycling and on the GBA GHG rulebook for upstream emissions.

The Circular Footprint Formula: an overview

In comparison to other allocation methods, that focus either on ingoing (cut-off) or outgoing (substitution) secondary materials, the CFF aims at considering both by accounting for the recycled content on the input side as well as recyclability at the EOL. Therefore, fulfilling the CFF specifications requires data collection for a wider range of parameters including, e.g., the change in material quality between life cycle stages as well as allocation factors for recycling and energy recovery processes. Furthermore, the formula refers to different life cycle stages and involves the calculation for each material.

The parameters need to be clearly defined and specified such that comparability of Carbon Footprints (CF) is ensured and no overestimation of credits is possible. This is particularly important as recovered materials from the EOL generally yield favorable credits that decrease the battery CF.

The CFF consists of three parts: material recovery, energy recovery and waste disposal. It is composed as follows with the parameters described below (European Commission, 2021):

Material $(1\text{-}R_1)E_V + R_1 \times (A \times E_{recycled} + (1\text{-}A)E_V \times Q_{Sin}/Q_p) + (1\text{-}A)R_2 \times (E_{recyclingEOL} - E^*_V \times Q_{Sout}/Q_p) +$

Energy $(1\text{-}B)R_3 \times (E_{ER}\text{-}LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec}) +$

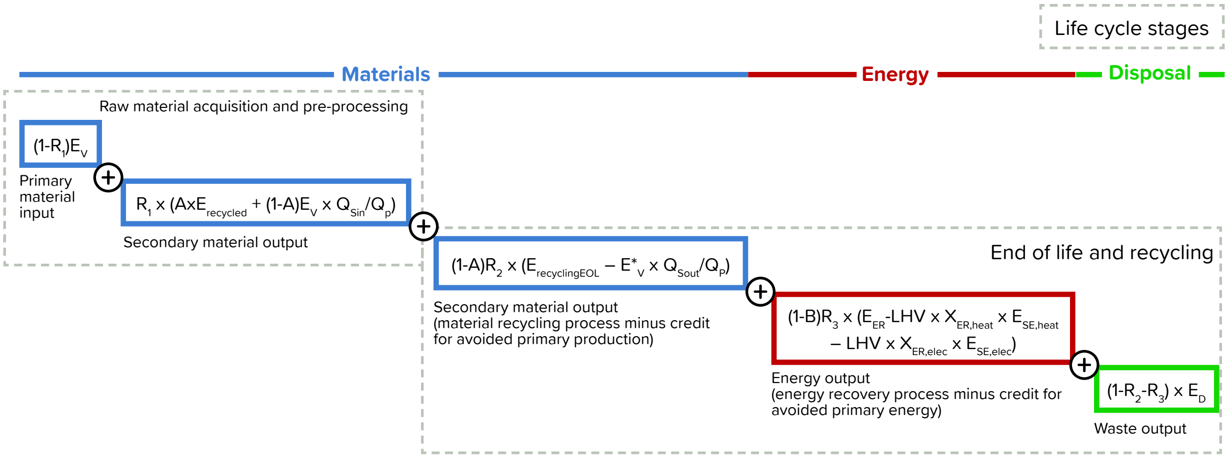
Disposal $(1\text{-}R_2\text{-}R_3) \times E_D$

Description of the CFF parameters as per PEF / PEFCR guidance:

- **A:** allocation factor of burdens and credits between supplier and user of recycled materials.
- **B:** allocation factor of energy recovery processes: it applies both to burdens and credits.
- **Q_{sin}:** quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.
- **Q_{sout}:** quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.
- **Q_p:** quality of the primary material, i.e. quality of the virgin material.
- **R_1:** it is the proportion of material in the input to the production that has been recycled from a previous system.
- **R_2:** it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.
- **R_3:** it is the proportion of the material in the product that is used for energy recovery at EoL.
- **$E_{recycled}$ (E_{rec}):** specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.
- **$E_{recyclingEoL}$ (E_{recEoL}):** specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process.
- **E_v:** specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.
- **E^*_v:** specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.
- **E_{ER}:** specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, …).
- **$E^{SE,heat}$ and $E_{SE,elec}$:** specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.
- **E_D:** specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.
- **$X^{ER,heat}$ and $X_{ER,elec}$:** the efficiency of the energy recovery process for both heat and electricity.
- **LHV:** Lower Heating Value of the material in the product that is used for energy recovery

The CFF combines different life cycle stages (see Figure B-1). It accounts for the emissions of the primary and secondary material input, referred to as the “Raw material acquisition and pre-processing” lifecycle stage as well as the secondary material output, energy output and waste output, referred to as the “End of life and recycling” life cycle stage.

FIGURE B-1: The elements of the Circular Footprint Formula (own illustration based on (European Commission, 2019)



Rules for calculating the Circular Footprint Formula

Modelling approach for the CFF

In the context of the CF Declaration accompanying the battery's placement on the EU market, production waste (in production processes where primary data are used)[1] and the EOL shall be modelled using the Circular Footprint Formula and the accompanying rules described in the following Chapters. These rules are primarily addressed to economic operators / manufacturers placing the battery on the market and having to declare the CF under the PEF / PEFCR rules (for the EOL modelling) as well as companies reporting primary data for their respective production processes (for waste modelling).

In general, the PEF and CFF take a single actor Life Cycle Assessment (LCA) perspective, i.e. the calculation is performed by one actor at a specific point in time. Applied to the CF calculation as required by the Battery Regulation, this implies that the economic operator placing the battery on the market or putting it into service is responsible to collect data and perform the calculation. Thereby, data of the upstream processes needs to be collected 'retrospectively' and for the downstream processes, i.e. the EOL taking place in the future depending on the useful life of the battery, 'prospectively' (see Figure B-2).

The parameters can be clustered into actual "Emissions values", which are calculated by multiplying the mass of a specific process producing a material with the respective emissions factors. This results in a carbon footprint of a specific amount of CO_2e. All "Other parameters" refer to a rate or percentage and therefore range between 0 and 1 without a unit (see Figure B-2).

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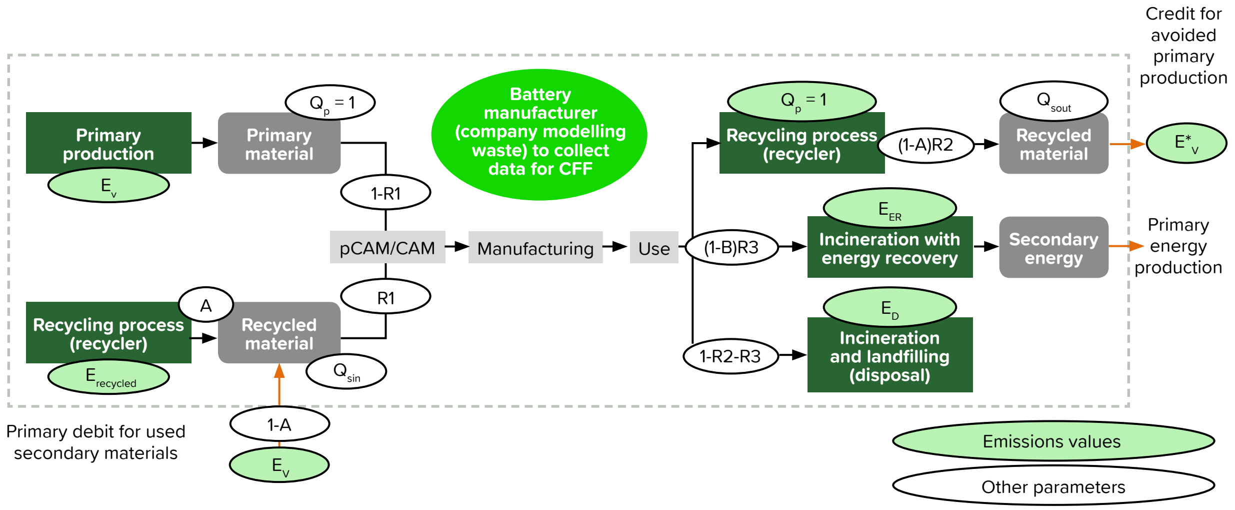
[1] Note that the topic of pre-consumer waste modelling and allocation needs to be resolved for the GBA GHG rulebook version 3.0. As the current discussion on waste modelling via CFF are still ongoing, this topic has not yet been considered in the current version.

FIGURE B-2: CFF life cycle view with data to be collected from the supply chain (refer to the Chapter specifying the parameters below)



The battery manufacturer placing the battery on the market (CF declarant) shall apply the CFF for the EOL and recycling allocation. As per PEF/PEFCR, the user of these rules declaring the CFF values shall calculate these per material contained in the battery system boundary. Therefore, an inventory with emissions values and parameters needs to be compiled for each material (aggregated per component, see PEFCR) including the following steps:

1. Mapping of Bill of Materials (BoM) including mass of materials;
2. Definition of “Other parameters” and calculation of “Emissions values” per material;
3. Calculation of CF as sum of CFs per material, in accordance with the CFF requirements.

Thereby, the cut-off threshold applies to the BoM. Processes cumulatively contributing less than 3% in terms of their greenhouse gas emissions impact may be excluded across the processes (cumulatively over all processes), referring to the overall CF of the product for which the CF is calculated as defined in this rulebook.

As according to the EU Battery Regulation, the CF shall be “differentiated per life cycle stage” (Battery Regulation *Article 7(1)(e)*), it is important to consider which part of the formula relates to which life cycle stage (see Figure B-2) and report the respective calculated values separately.

The parameters of the Circular Footprint Formula

TABLE B-1: Overview of default parameters for the CFF

Parameter	Recommended specifications as of November 2023 (Joint Research Center, 2023) (Replace with specifications of the EU's Batteries Regulation once adopted)
A	0.2 for metals 0.5 for plastics
B	0
Q_{Sin}/Q_P	See PEF Annex C
Q_{Sout}/Q_P	See PEF Annex C
R_1	0 per default When using company specific R1 values other than 0 traceability throughout the supply chain is necessary
R_2	0.95 for nickel, cobalt, manganese 0 for iron and titanate 0 for lithium (and lithium organics) 0 for graphite, hard carbon, silicon etc. 0.95 for other metals (e.g. aluminium, steel, copper) 0.5 for plastic, polymers For other materials see PEF Annex C, for all other materials 0 shall be assumed
R_3	See PEF Annex C (only for packaging and municipal solid waste)
$E_{recycled}$	EF-compliant default datasets Primary data allowed under specific conditions
$E_{recyclingEOL}$	EF-compliant default datasets (as not available yet, default recycling scenarios provided by JRC and PEFCR) Primary data allowed under specific conditions
E_v	EF-compliant default datasets
E_{v*}	EF-compliant default datasets
E_{ER}	EF-compliant default datasets
$E_{SE,heat}$ and $E_{SE,elec}$	EF-compliant default datasets
E_D	EF-compliant default datasets
$X_{ER,heat}$ and $X_{ER,elec}$	EF-compliant default datasets
LHV	EF-compliant default datasets

Under the EU requirements, the CFF per default uses secondary data, but allows for primary data. The GBA intends to collect primary data for identified hotspots. Therefore, in the GBA, these primary data shall be collected.

The specifications of the GBA GHG rulebook for Cradle-to-Gate emissions and EOL and recycling can be applied to calculate certain parameters required for the CFF, particularly E_v and R_1, $E_{recycled}$ and Q_{sin}/Q_p. Yet, additional parameters are needed to fulfil the CFF requirements.

In this Chapter, each parameter of the formula is explained and rules for the definition and calculation are provided. In practice, these parameters need to be specified per material contained in the battery.

Emissions values

Figure B-3 provides an overview on the emissions values including which data sources to use.
The EF-compliant datasets can be accessed via
https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml.

The most relevant processes are processes identified as hotspots under the GBA GHG Rulebook where primary data shall be collected.

FIGURE B-3: Data sources for CFF emissions values

Emissions values [in CO2 eq.]	Primary data	vs.	secondary data
E_v: emissions from acquisition and pre-processing of virgin/primary material	GBA GHG Rulebook		EF-compliant datasets
E^*_v: emissions from acquisition and pre-processing of virgin/primary material assumed to be substituted by secondary materials output	EF-compliant datasets		
$E_{recycled}$: emissions caused by recycling process of secondary materials input/recycled content	GBA GHG Rulebook		
$E_{recyclingEOL}$: emissions of recycling process at EOL	GBA GHG Rulebook[1] EF-compliant datasets		
E_{ER}: emissions from the energy recovery process	EF-compliant datasets		
$E_{SE,heat}$ and $E_{SE,elec}$: emissions from specific energy source, heat and electricity respectively, assumed to be substituted by recovered Energy			
E_D: emissions from disposal of waste material at the EoL			

[1] If primary data are available and physical and contractual links can be proven, this factor must be representative as of today. This reflects a conservative approach under the assumption that processes become more efficient and less emissive in the future.

E_v

“E_v“ indicates the specific CO2e emissions caused by the acquisition and pre-processing of virgin/primary materials.

Primary data shall be used for the retrospective calculation following the GBA GHG rulebook. When calculating the CFF, these values are available from the cradle-to-gate calculation. EF-compliant datasets can be used, unless primary data are available.

E*v

“E^*_v ” indicates the specific CO_2e emissions caused by the acquisition and pre-processing of virgin/primary materials assumed to be substituted by recycled/secondary materials.

EF-compliant secondary datasets shall always be used for the prospective calculation to ensure better comparability. A common specification of the dataset to use is crucial as this parameter reflects a future process. Hence, it cannot be reliably demonstrated which material will be substituted, i.e. how it is produced. As the secondary material is assumed to be provided in the EU, the geographical scope of the EF-compliant dataset for E^*_v shall be EU-specific.

$E_{recycled}$ (E_{rec})

“$E_{recycled}$“ indicates the specific CO_2e emissions caused by the recycling process of the recycled material, including collection, sorting and transportation process. These emissions value can be provided by recycled content suppliers.

Primary data shall be used for the retrospective calculation following the rules in Chapter 6.5.
EF-compliant datasets shall be used, unless primary data are available.

$E_{recyclingEoL}$ (E_{recEoL})

“$E_{recyclingEoL}$” or in short “E_{recEoL}” indicates the specific CO_2e emissions caused by the recycling process at the EOL of the battery. The recycling process shall cover the collection, sorting and transportation steps, and the conversion to recycled material accounting for specific material inputs and energy demand of the recycling process.

EF-compliant secondary datasets shall be used for the prospective calculation to ensure better comparability as the economic operator will likely have a network of recyclers and it cannot be reliably demonstrated how the material will be recycled, e.g. at which recycling plant. The EF-compliant dataset used shall cover the geography “EU-28+EFTA” and be specific per material. If no dataset is available for a specific recycling process per material, datasets covering components or product groups can be used.

The ongoing discussions in EU institutions (JRC and PEFCR) indicate that primary data may be used under strict conditions. The criteria under which primary data may be used are still under development. The GBA recommends using the same EF-compliant datasets to increase comparability of EOL credits given. In the case of battery recycling, there is no EF compliant dataset yet. Default scenarios will be provided by JRC and PEFCR.

The EU rules (currently still in development) propose using primary data under the following specification: “company-specific activity data or company-specific datasets may be used for the waste batteries being recycled within the own premises or via a specific-recycling process if the corresponding evidence is provided in the CFB supporting study.”

The corresponding PEFCR update (still being developed) includes the condition that, if proof exists that the batteries go to a certain recycling process (contractual and physical links shown) and also access to the related data is prevalent, primary data shall be used for End-of-Life collection and processing. If not, EF-compliant dataset to represent those processes must be used.

Default recycling scenarios containing default activity data that shall be used to model recycling emissions are provided by JRC. Additionally, PEFCR includes representative data for the recycling process that shall be used in the context of the PEFCR.

E_{ER}-LHV x $X_{ER,heat}$ x $E_{SE,heat}$ – LHV x $X_{ER,elec}$ x $E_{SE,elec}$

This part of the formula equals the environmental impact of incineration and credits for recovered energy and is supposed to be available as combined impact in an EF secondary data set per material. In case the respective materials are not treated by incineration with energy recovery, i.e. when $R_3 = 0$, this part of the formula does not need to be calculated.

The user of the rulebook shall use these datasets for the prospective calculation, but make sure that heating values of the material used and the selected secondary data set are similar or comparable.

Note that, in addition, remaining waste after energy recovery is to be modelled as disposal (unless used, e.g. as ash for cement making); EF waste-to-energy datasets consider this generally already.

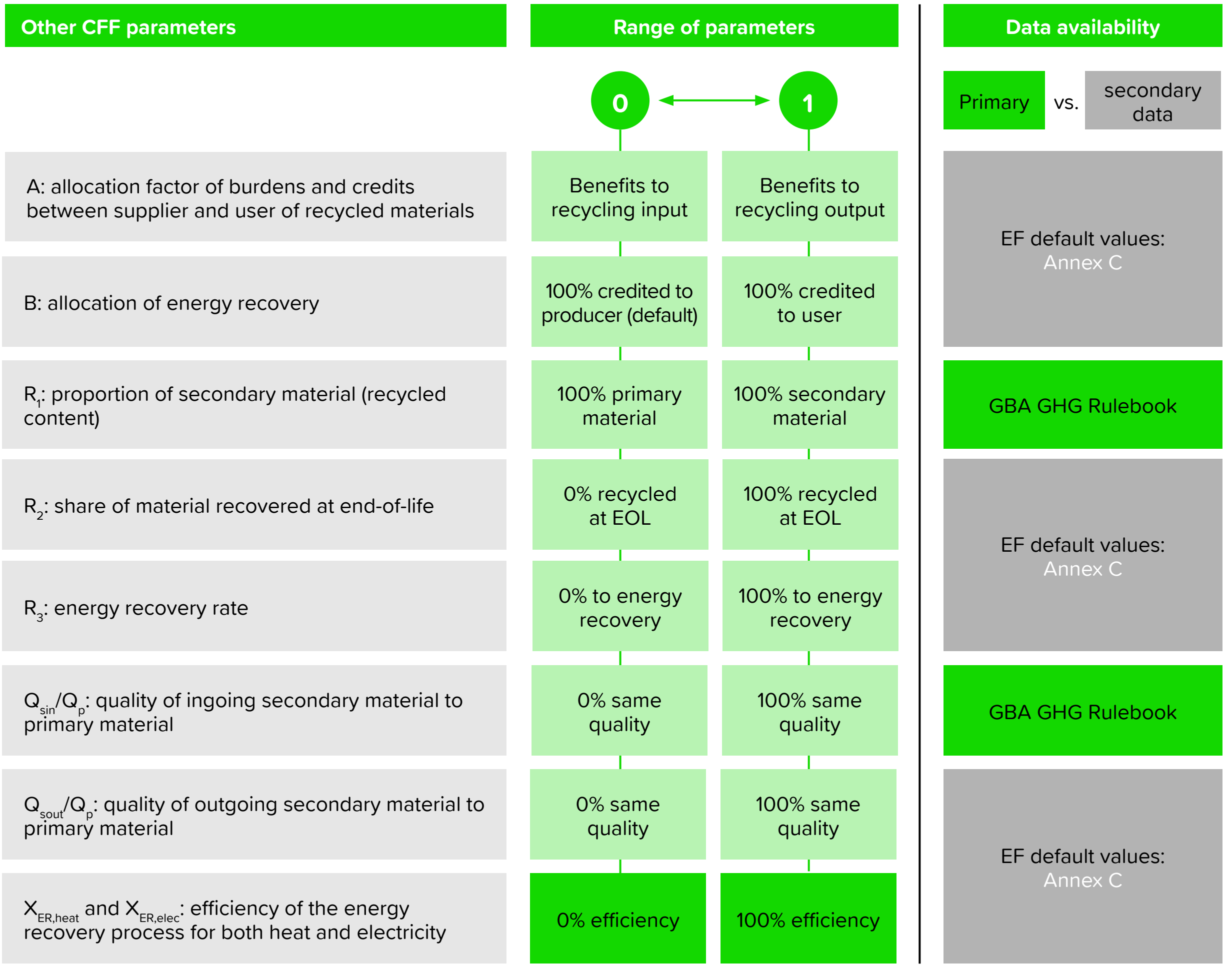
E_D

“E_D ” indicates the specific CO2e emissions caused by disposal of waste material at the EOL of the analysed product. This includes landfill and incineration without energy recovery.

Following Chapter 6.5.7, the recyclability of the battery shall be evaluated (please refer to detailed description for parameter R_2). For the unrecyclable fraction(s), the user shall indicate which fractions are disposed (see also R_3). In case, there is no disposal, E_D equals 0 for the respective material. EF-compliant secondary datasets shall be used for the prospective calculation of E_D to ensure better comparability.

Other parameters

FIGURE B-4: Meaning, unit, range and data sources for CFF parameters



Other CFF parameters	Range of parameters		Data availability
	0	1	Primary vs. secondary data
A: allocation factor of burdens and credits between supplier and user of recycled materials	Benefits to recycling input	Benefits to recycling output	EF default values: Annex C
B: allocation of energy recovery	100% credited to producer (default)	100% credited to user	
R_1: proportion of secondary material (recycled content)	100% primary material	100% secondary material	GBA GHG Rulebook
R_2: share of material recovered at end-of-life	0% recycled at EOL	100% recycled at EOL	EF default values: Annex C
R_3: energy recovery rate	0% to energy recovery	100% to energy recovery	
Q_{sin}/Q_p: quality of ingoing secondary material to primary material	0% same quality	100% same quality	GBA GHG Rulebook
Q_{sout}/Q_p: quality of outgoing secondary material to primary material	0% same quality	100% same quality	EF default values: Annex C
$X_{ER,heat}$ and $X_{ER,elec}$: efficiency of the energy recovery process for both heat and electricity	0% efficiency	100% efficiency	

A

"A" allocates between burdens/benefits of recycled content and End of life recycling therefore is similar to either one of the other allocation procedures depending on the material and the market situation of the material. Hypothetically, if A is set to 1, the CFF approximates the cut-off approach. Similarly, if A is set to 0, the CFF approximates the substitution approach. The PEF methodology defines an A value of 0.2 for high quality secondary materials (i.e. metals), which are more demanded than produced. Thereby, the PEF A value implies that their market price is close to or the same as the one for primary materials, which is the case for many metals. For materials, where the opposite is the case and the market price is low compared to primary materials, an A value of 0.8 is defined by by PEF as default. Where the market situation is more balanced or unknown the A value should be set to 0.5 (e.g. plastics).

For better comparability of carbon footprints, the user of this Rulebook shall use the values indicated in the applicable PEFCR or PEF Annex C (European Commission, 2020). In case these are updated, the updated factors shall be used.

The specification of default A values for the calculation of the battery carbon footprint is still under discussion in the European Institutions.

B

“B” allocates between burdens and benefits of energy recovery processes. The parameter is equal to 0 per default, which indicates that 100% of generated and externally used energy is credited to the producer and debited to the user of the secondary energy. This means that there are both waste-to-energy burdens and avoided primary production benefits. Guidance on calculating or defining a B factor different than 0 could not be found. Therefore, as indicated in the PEF Annex C, the B factor shall be set to 0 per default.

R_1

“R_1“ indicates the share of the respective material in the input to the production that has been recycled from a previous system, i.e. the recycled content per material employed.

Primary data shall be used at least for the share of secondary nickel, cobalt, lithium and lead in active components, as this is reporting requirement as per the Battery Regulation. Additionally, verification for these values shall be provided. For all other materials, users may use primary data, if verification is provided. If no primary data is available or verifiable R1 shall be 0 per default.

Ongoing discussion might lead to changes in the default values of the parameters.

R_2

“R_2” indicates the share of the respective material in the product that will be recycled (or reused) in a subsequent system, i.e. recycling rate per material. As this parameter significantly determines the credits for material recovered at the future EOL, it needs to be defined and specified diligently.
The user of the rulebook shall follow the PEF/PEFCR requirement to evaluate the recyclability of the material and provide evidence, before selecting the appropriate R^2 value. The statement on the recyclability shall be provided together with an evaluation for recyclability that includes evidence per material for the following three criteria (as described by ISO 14021:1999, section 'Evaluation methodology') (Recharge, 2018):

1. The collection, sorting and delivery systems to transfer the materials from the source to the recycling facility are conveniently available to a reasonable proportion of the purchasers, potential purchasers and users of the product;
2. The recycling facilities are available to accommodate the collected materials;
3. Evidence is available that the product for which recyclability is claimed is being collected and recycled.

As per the PEFCR, Point 1 and 3 can be proven by recycling statistics (country specific) derived from industry associations or national bodies. Approximation to evidence at point 3 can be provided by applying for example the design for recyclability evaluation outlined in EN 13430 Material recycling (Annexes A and B) or other sector-specific recyclability guidelines if available.

Ongoing discussion might lead to changes in the default values of the parameters. Therefore, the specification in this chapter might change.

R_2 values shall be calculated by multiplying the statistical collection rate of batteries (e.g. PEFCR assumes 95% for EVs) with the material recovery yield (e.g. 90% of cobalt per battery as per Battery Regulation by likely 2027) and excluding exports.

The material recovery yield shall be based on primary data if available (i.e. when contracts with recyclers are already in place). The value must be representative as of the day of calculation taking the conservative approach under the assumption that processes become more efficient in the future.

Thereby the R2 shall consider inefficiencies in the collection and be measured at the output of the recycling plant (EC 2021).

- If no company-specific values are available and the criteria for the evaluation of recyclability are fulfilled, application-specific R_2 values from Annex C shall be used [to be listed by PEFCR]
- If an R_2 value is not available for a specific country, then the European average shall be used;
- If an R_2 value is not available for a specific application, the R2 values of the material shall be used (e.g. materials' average);
- In case no R_2 values are available, R_2 shall be set equal to 0.

R_3

R3 indicates the share of the respective material in the product that will be used for energy recovery at EOL. The difference (1-R2-R3) will yield the share of fraction being disposed of.

For better comparability of carbon footprints, the user of the rulebook shall use the default values. As the default values provided by PEF Annex C are currently only applicable to Municipal Solid Waste, R_3 should be calculated using official statistics for share of waste incinerated versus landfilled. EUROSTAT provides data on energy recovery for batteries & accumulators.

Q_{sin}/ Q_p

"Q_{sin}/ Q_p" indicates the quality ratio of the ingoing secondary material. These shall be determined at the point of substitution per application or material and be based on either economic aspects or physical aspects.

As all secondary materials used in the battery need to be battery grade materials, it shall be assumed that the quality of the ingoing secondary materials is equal to the quality of primary materials. Therefore, the ratio shall be set to 1 per default.

Q_{sout}/ Q_p

"Qsout/ Qp" indicates the quality ratio of the outgoing secondary material. Equally to "Qsin/ Qp", these shall be determine at the point of substitution per application or material and be based on either economic aspects or physical aspects.

As this is unknown at the point of time when calculating the CF, EF default values indicated in Annex C (European Commission, 2020) shall be used for better comparability.

B.2 Distribution

The Distribution cluster covers the transport-related emissions that occur in the life cycle stage 'Distribution'. It follows the calculation logic for transportation-related emissions based on company-specific data as provided in Chapter 5.2.4. Where this is not feasible, default scenarios provided by the Product Environmental Footprint (PEF) standard may be used.

The Distribution stage comprises the transport of the battery from the manufacturing site to the final use site (or to a reference entry point into the market). The final client is generally defined as the user of the battery (use phase). This means that the following scenarios need to be included in the Distribution stage:

- transport from battery supplier to manufacturer placing the battery on the market (='Original Equipment Manufacturer (OEM)') factory (if battery assembly is not performed by the economic operator placing the battery on the market).
- from manufacturer placing the battery on the market (='OEM' factory to user (use phase)

Additionally, the EOL collection (to be accounted for in End of life and recycling stage) follows the same principles and approaches as the Distribution stage.

The manufacturer placing the battery on the market for its intended use (carbon footprint declarant as per the EU Battery Regulation) is set equal to OEM in this document. The Distribution cluster covers the transport from OEM factory to final user. If the battery assembly does not take place at the OEM factory but at the supplier, the step from battery supplier to OEM needs to be included as well (otherwise accounted for under the respective upstream process step). It sets general rules for the respective outlined scenarios and specifies primary data collection guidance as well as, in case specific data are not available, default scenarios and values.

The final user needs to be clarified by the applicant of the rulebook. As the battery carbon footprint declaration is tied to the placement of the market, the user shall be the final client (use phase). As the PECFR for batteries has shown that the Distribution life cycle stage has a negligible impact on the battery carbon footprint, by default, there is no waste of products during the distribution lifecycle stage and storage emissions may be omitted (Recharge 2018).

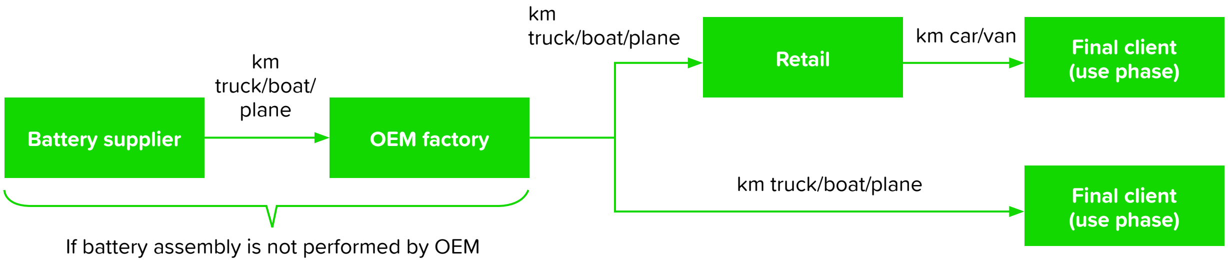
B.2.1 System boundaries and processes

As generally the battery assembly and system integration takes place at the Original Equipment Manufacturer (OEM) placing the battery on the market, transport from battery supplier to OEM factory is to be accounted for in the respective upstream production process. If this is not the case, the transport must be accordingly modelled. In the general case, this means that the following scenario needs to be included in the Distribution stage:

- Only required if battery assembly does not take place at OEM level: transport from battery supplier to OEM factory[2]
- from OEM factory to user (use phase)

The distribution might take place directly or via retailers (see Figure B-5). For each of these, the respective transport distance, vehicle type, transport type and utilization ratio need to be specified. If this is not possible, default scenarios may be applied (refer to Chapter B.2.2.3).

FIGURE B-5: Transport scenarios for the Distribution lifecycle stage



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[2] In case final battery assembly takes place at the OEM placing the battery on the market, the transport emissions from supplier to OEM factory need to be accounted for under the respective production process step (i.e. battery assembly).

B.2.2 Functional unit and reference flow

The distribution transport process requires partitioning related emissions to the specific battery model per battery manufacturing plant. The functional unit and reference flow for the distribution processes shall be:

- For final product production/OEM factory to final user: the transport of one final (integrated) battery pack/module placed on the market

The reference flow can be in piece or kg and the weight per piece shall be given to convert piece to kg or vice versa. The carbon footprint of the battery pack shall contain the necessary information, e.g., the nominal or usable capacity of the battery pack in kWh, to translate the carbon footprint as calculated as kg of carbon dioxide equivalent per one kWh of the total energy provided by the battery over its expected service life.

B.2.2.1 Data collection requirements

The GHG emissions related to the distribution lifecycle stage usually have a negligible contribution to the total environmental impacts over the battery life cycle (Recharge 2018). Nevertheless, the battery carbon footprint shall consider the transport from battery assembly to the client (including consumer transport). Supply-chain-specific information (primary data) shall be prioritized and used for the calculation of GHG emissions related to the Distribution stage using three approaches as per Chapter 5.2.4. For further details please refer to Chapter B.2.2.5.

The applicant of the rulebook shall use specific transport data and related EF compliant datasets to calculate the carbon footprint. In case a specific detailed assessment based on primary data cannot be documented, the default scenarios and standard transport distances provided by the PEFCR guidance version 6.3 shall be used (EC 2018). The user may apply tools that are in line with accepted industry standards, such as the GLEC framework (e.g. EcoTransIT World[3]).

The period for data collection is annual per default. This can be either calendar year or fiscal year. Which time period was used, shall be indicated in the data collection sheet.

B.2.2.2 Allocation of distribution transport burdens

To allocate the impacts from transport to the battery product system, emission factors per transported mass should be coupled with transport distances and vehicle types. Hence, values shall be nominated in tkm (tonne*km) expressing the environmental impact for 1 tonne (t) of product that is transported for 1 kilometre (km), for instance in a truck, average freight train or shipping container with a certain load (EC 2018). The transport emissions are allocated based on the transported battery mass, resulting in emissions being partitioned to the mass share of the battery. For example, a truck of 28-32 t has a maximum mass allowed (i.e. payload) of 22 t. In case the product is 0.5 t, the share of emissions is 0.5/22 of the truck's full emissions. When a full freight's mass is lower than the truck's load capacity (e.g. 10 t), the transport of the product may be considered volume limited. In this case, the environmental impact shall be calculated using the real mass loaded (EC 2018).

The transport payload should be modelled in a parameterised way through the utilisation ratio. The utilisation ratio is calculated as the mass of the real load divided by the mass of the (maximum) payload and shall be adjusted when the dataset is used. For instance, in case the truck is fully loaded for delivery

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[3] EcoTransIT: https://www.ecotransit.org/en/

but half empty upon its return, the utilisation ratio is: 22 t real load / 22 t payload * 50% km + 11 t real load / 22 t payload * 50% km = 75%.

The user of these rules shall specify the utilisation ratio to be used for each transport modelled, as well as clearly indicate whether the utilisation ratio includes empty return trips. If the load is mass limited, a default utilisation ratio of 64% shall be used in line with the current PECFR guidance (EC 2018). This utilisation ratio includes empty return trips and thus shall not be modelled separately.

B.2.2.3 Distribution – data collection guidance

Supply chain-specific transport modelling
Primary data shall be prioritized and used for the calculation of GHG emissions related to the Distribution stage. To model transport, see Chapter 5.2.4.

The following inputs and outputs shall be specified (see Table B-2).

TABLE B-2: Input-output table for supply-chain specific transport

Material	Unit	Data	Specification
Input			
Battery placed on market	kg		
Vehicle type			e.g. lorry (28-32 t)
Transport type			e.g. truck transport, plane, boat
Transport distance	km		
Payload / utilisation ratio	%		If load mass is limited, use default 64%
GHG emissions factors	kg		Per fuel type
Output			
GHG emissions per transported battery	kg		Allocation based on payload and mass-transport distance

Default scenarios as per PEF recommendation
In case the above mentioned supply specific data are not available, the following default scenarios from the PEF recommendation may be applied. The applicant shall specify why these default scenarios were used. Within the respective EF-compliant datasets concerning transport-related emissions, the fuel production, the fuel consumption by the transport vehicle, the infrastructure needed and the amount of additional resources and tools needed for logistic operations (e.g. cranes and transporters) are included. To allocate the impacts from transport to the product, secondary datasets using emission factors per transported mass are coupled with transport distances and vehicle types. Hence, EF-compliant datasets for truck transport are nominated in tkm (tonne*km) expressing the environmental impact for 1 tonne (t) of product that is transported for 1km in a truck with a certain load. The respective weight of the transported battery shall be used to calculate the respective emissions.

Only in case battery pack assembly does not take place at the OEM level:
From supplier to OEM factory

A) For suppliers located within Europe (utilisation ratio 64%)

- 130 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio; and
- 240 km by train (average freight train; UUID 02e87631-6d70-48ce-affd-1975dc36f5be); and
- 270 km by ship (barge; UUID 4cfacea0-cce4-4b4d-bd2b-223c8d4c90ae).

B) For all suppliers located outside Europe (utilisation ratio 64%)

- 1,000 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), for the sum of distances from harbour/airport to factory outside and inside Europe. PEFCR specific utilisation ratio; and
- 18,000 km by ship (transoceanic container; UUID 6ca61112-1d5b-473c-abfa-4accc66a8a63) or 10,000 km by plane (cargo; UUID 1cc5d465-a12a-43da-aa86-a9c6383c78ac).

If producers country (origin) is known: the adequate distance for ship and airplane should be determined using online sources[4]. The user of these rules shall state which transport type is typically used. In case it is unknown whether the supplier is located within or outside Europe, the transport shall be modelled as the supplier being located outside Europe.

From OEM factory to final client (use phase):
In case no supply-chain-specific transport scenario is available, the default scenarios outlined below (see also Figure B-5) shall be used as a basis in combination with a number of specific values (e.g. utilization ratio if available):

- Ratio (X%) between products sold through retail and **directly to the final client;**
- **For OEM factory to final client:** Ratio (X%) between local, intracontinental and international supply chains;
- **For OEM factory to retail:** distribution (X%) between intracontinental and international supply chains;

A) X% (PEFCR specific) from **OEM factory to final client:**

- X% (PEFCR specific) local supply chain: 1'200 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio.
- X% (PEFCR specific) intracontinental supply chain: 3'500 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio
- X% (PEFCR specific) international supply chain: 1'000 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio and 18'000 km by ship (transoceanic container; UUID 6ca61112-1d5b-473c-abfa-4accc66a8a63).

Note that for specific cases, plane or train may be used instead of ship. The user of these rules shall state which transport type is typically used.

B) X% (PEFCR specific) **from OEM factory to retail:**

- X% (PEFCR specific) local supply chain: 1'200 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio.

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[4] The PEFCR guidance proposes http://www.searates.com/services/routes-explorer or https://co2.myclimate.org/en/flight_calcula tors/new

- X% (PEFCR specific) intracontinental supply chain: 3'500 km by truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57) (Eurostat 2014), PEFCR specific utilisation ratio.
- X% (PEFCR specific) international supply chain: 1'000 km truck (>32 t, EURO 4; UUID 938d5ba6-17e4-4f0d-bef0-481608681f57), PEFCR specific utilisation ratio and 18’000 km by ship (transoceanic container; UUID 6ca61112-1d5b-473c-abfa-4accc66a8a63).

Note that for specific cases, plane or train may be used instead of ship.

C) X% (PEFCR specific) **from retail to final client:**

- 62%: 5 km, by passenger car (average; UUID 1ead35dd-fc71-4b0c-9410-7e39da95c7dc), PEFCR-specific allocation
- 5%: 5 km round trip, by van (lorry <7.5t, EURO 3 with utilisation ratio of 20%; UUID aea613ae-573b-443a-aba2-6a69900ca2ff)

33%: no impact modelled

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