# METHODOLOGY FOR REDUCTION IN GHG EMISSIONS FROM METAL PRODUCTION USING METAL BEARING WASTES

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| **Title** | Methodology for Reduction in GHG Emissions from Metal Production Using Metal Bearing Waste |
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# Relationship to Approved or Pending Methodologies

Approved and pending methodologies under the VCS Program and approved GHG programs, that fall under the same sectoral scopes were reviewed to determine whether an existing methodology could be reasonably revised to meet the objective of this proposed methodology. No methodologies were identified for reasonable revision to meet the objectives of this proposed methodology.

# CONTENTS

# 1 SOURCES

This methodology was informed primarily by CDM methodology AMS-III.BA, *Recovery and recycling of materials from E-Waste*, VCS Methodology VM0030, *Methodology for Pavement Application using Sulphur Substitute, Version 1.0* and VCS Methodology VM0040, *Methodology for Greenhouse Gas Capture and Utilization in Plastic Materials*, Version 1.0.

# 2 SUMMARY DESCRIPTION OF THE METHODOLOGY

| Additionality and Crediting Method | |
|---|---|
| Additionality | Performance Method |
| Crediting Baseline | Performance Method |

This methodology is globally applicable and quantifies the greenhouse gas (GHG) emission reductions resulting from secondary manufacturing processes which produce metals, metal oxides or alloys from metal bearing waste streams. Secondary metal manufacturing processes are less energy intensive and produce lower amounts of GHG emissions compared to primary metals manufacturing.

For the purposes of this methodology, the GHG emissions produced by the following manufacturing processes are being compared.

- Primary Metals Manufacturing: includes the mining, extraction, and processing of virgin metal ores as the raw material to manufacture metals, metal oxides or alloys.
- Secondary Metals Manufacturing: includes processes that use metal bearing waste streams to reclaim metal constituents for use as a raw material to manufacture metals, metal oxides or alloys.

# 3 DEFINITIONS

In addition to the definitions set out in VCS document *Program Definitions,* the following definitions apply to this methodology.

**Calcination**
A thermal treatment process, in presence of air or oxygen, applied to ores and other solid materials to bring about a thermal decomposition, phase transition, or removal of a volatile fraction.

**Electric Arc Furnace**
A furnace that heats charged material by means of an electric arc.

**Environmental Pollution Controls**
Process controls and equipment used to prevent or reduce the amount of pollutants generated from industrial operations from entering the environment through air, water, or land.

**Extractive Metallurgy**
The practice of removing valuable metal from materials and refining the extracted metals into a purer form.

**Ferroalloy**
An alloy of iron (less than 50 percent) and one or more other metals, important as a source of various metallic elements in the production of alloy steels.

**Gasification**

A technological process that can convert any carbonaceous (carbon-based) raw material such as coal into fuel gas, also known as synthesis gas (syngas for short).

**Hydrometallurgy**

A technique within the field of extractive metallurgy involving the use of aqueous chemistry for the recovery of metals from ores, concentrates, and recycled or residual materials.

**Life Cycle Assessment (LCA)**

A multi-step procedure for calculating the lifetime environmental impact of a product or service. The complete process of LCA includes goal and scope definition, inventory analysis, impact assessment, and interpretation.

**Life Cycle Inventory (LCI)**

The data collection portion of LCA. LCI is the straight-forward accounting of everything involved in the “system” of interest. It consists of detailed tracking of all the flows in and out of the product system, including raw resources or materials, energy by type, water, and emissions to air, water and land by specific substance.

**Pyrometallurgy**

A technique within the field of extractive metallurgy consisting of the thermal treatment of minerals, metallurgical ores and concentrates to bring about physical and chemical transformations in the materials to enable recovery of metals.

**Residue Upgrading Catalyst**
Catalyst that has been used in the upgrading of residuum from the oil refinery distillation process.

**Thermite Reaction**

An exothermic reaction which involves a metal reacting with a metallic or non-metallic oxide to form a more stable oxide and the corresponding metal or nonmetal of the reactant.

# 4 APPLICABILITY CONDITIONS

This methodology is applicable to secondary metals manufacturing activities.

This methodology is applicable under the following conditions:

- Secondary manufacturing process is the conversion of metal constituents contained in waste streams such as: refinery residue upgrading catalyst, gasification ashes, power plant slags and fly ash, residues, sludges, slurries, or other metal bearing waste streams.
- The project activity utilizes metal processing technologies including pyrometallurgy, hydrometallurgy and remelting.
- Project activities must be compared to baseline activities which manufacture the same type(s) of metal, metal oxide or alloy as the Project.
- Project activities can be undertaken at either a new facility (greenfield site) or existing facility (brownfield site).
- This methodology is not applicable to the recovery and recycling of electrical and electronic equipment (i.e., large and small household appliances; IT and telecommunications equipment; consumer equipment; lighting equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; and automatic dispensers, etc.) for the reclamation of metals.
- This methodology is not applicable to scrap metal (ferrous and non-ferrous) recycling which includes the recovery and processing of scrap metal from end-of-life products or structures, as well as from manufacturing scrap, so that it can be introduced as a raw material in the production of new goods. Examples of common types of scrap metal include: insulated copper wire, copper tubing, sheet aluminum, light iron, aluminum cans, cast iron, bare bright wire, electric motors, scrap cars, plumbing brass, appliances, cooking pots and pans, non-magnetic stainless steel, aluminum siding, lead, aluminum car/truck rims, aluminum/copper radiators, cast aluminum, transformers, copper scrap.

# 5 PROJECT BOUNDARY

The project boundary includes primary and secondary metals manufacturing processes and the GHG emissions related to the electricity and fuel used to operate equipment, machinery, and on-site environmental pollution control equipment to produce metals, metal oxides or alloys.

The baseline, primary metals manufacturing of refined ore, requires additional processing (i.e. electric arc, thermite, etc.) to manufacture metals, metal oxides and alloys.  Processing may occur at the same location where the ores are mined, for integrated operations or require shipment to remote processing plants. Emissions associated with equipment, machinery, and on-site operation of environmental pollution control equipment at either onsite or offsite processing locations are included in this methodology.

Sources, sinks and reservoirs (SSRs) included in the project and baseline quantification include those that are within the project and baseline operational and processing boundaries. A generalized process flow diagram of a typical baseline and project are presented below in Figures 1 and 2, respectively.

**Figure 1: Baseline Process Flow Diagram for Primary Metals Manufacturing**

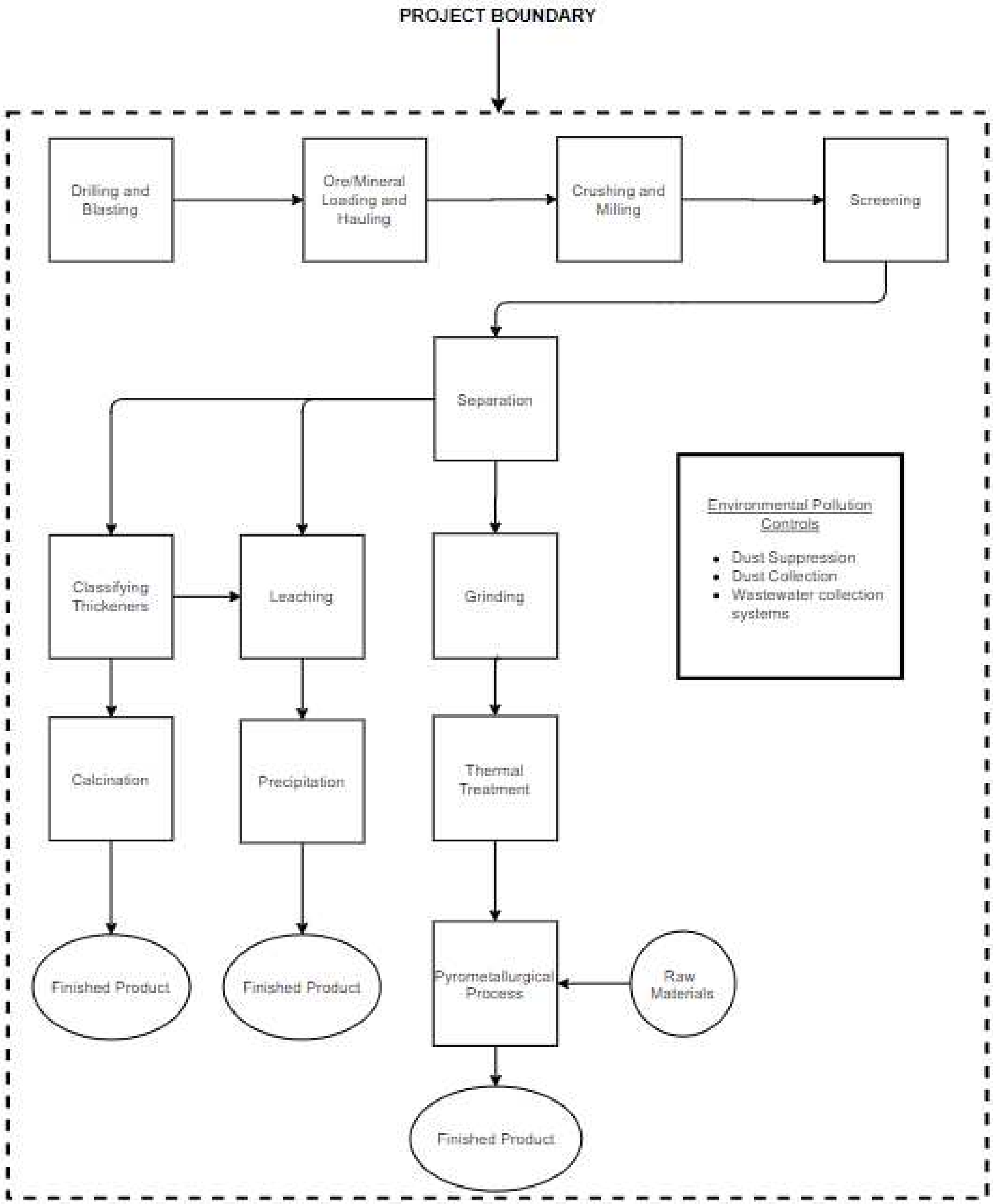

**Figure 2: Project Process Flow Diagram for Secondary Metals Manufacturing**

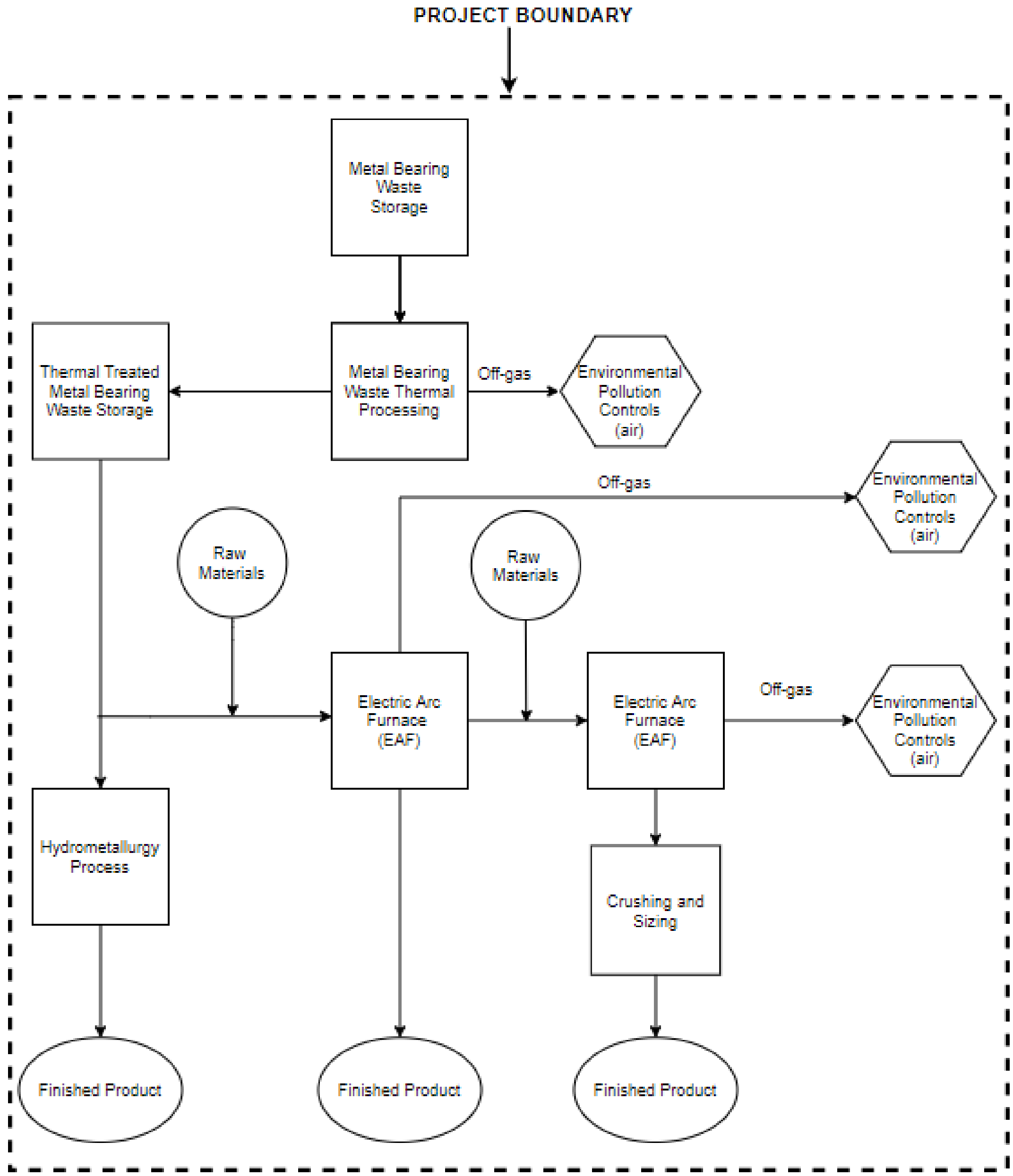

**Table 1: GHG Sources Included in or Excluded From the Project Boundary**

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| Baseline | Drilling | $CO_2$ | Yes | The use and combustion of fossil fuels is the primary energy source. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Blasting | $CO_2$ | No | Emissions are negligible and difficult to measure based on the variation of blasting agents used. |
| | | $CH_4$ | No | |
| | | $N_2O$ | No | |
| | | Other | No | Not applicable. |
| | Ore/Mineral Loading and Hauling | $CO_2$ | Yes | The use and combustion of fossil fuels is the primary energy source. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Crushing and Milling | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Screening | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| | | Other | No | Not applicable. |
| Baseline | Separation | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Grinding | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Classifying Thickeners | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Thermal Treatment | $CO_2$ | Yes | Use of electricity, combusted natural gas or liquid/solid fuels are the primary energy sources that would be used for the operation. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Leaching | $CO_2$ | Yes | Negligible source from electricity usage from pumps, mixers, or stirrers. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| | | Other | No | Not applicable. |
| Baseline | Raw Materials | $CO_2$ | Yes | Emissions from the reaction or melting of raw materials. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Pyrometallurgical Process | $CO_2$ | Yes | Use of electricity and combusted natural gas are the primary energy sources that would be used for the operation. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable |
| | Environmental Pollution Controls | $CO_2$ | Yes | Use of electricity and fossil fuels are the primary energy sources that would be used for the operations. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| Project | Metal Bearing Waste Storage | $CO_2$ | No | Excluded for simplification. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable |
| | Metal Bearing Waste Thermal Treatment | $CO_2$ | Yes | Off-gases from thermal treatment of waste stream, electricity and natural gas are primary sources. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |

| Source | | Gas | Included? | Justification/Explanation |
|---|---|---|---|---|
| Project | Emissions Control System | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Raw Materials | $CO_2$ | Yes | Emissions from the reaction or melting of raw materials in electric arc furnaces. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Electric Arc Furnace | $CO_2$ | Yes | Electricity and the combustion of additives (e.g. coke) are primary sources of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Electric Arc Furnace Baghouse | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |
| | Crushing and Sizing | $CO_2$ | Yes | Use of electricity is the primary energy source and indirect emissions from production may be a material source of emissions. |
| | | $CH_4$ | No | Excluded for simplification. |
| | | $N_2O$ | No | Excluded for simplification. |
| | | Other | No | Not applicable. |

# 6 BASELINE SCENARIO

The baseline scenario is the primary metals manufacturing process which includes the mining and processing of metal ores to produce metals, metal oxides or alloys. This methodology uses the performance method to determine the crediting baseline. See Appendix I for additional detail for establishing benchmark emission values for the baseline scenario.

# 7 ADDITIONALITY

This methodology uses a performance method for the demonstration of additionality. Projects are deemed additional when the total $CO_2$ emissions per metal, metal oxide or alloy of production, using the secondary manufacturing process, meets or exceeds the additionality threshold for the respective product as shown in Table 2.

The additionality threshold, expressed as a percentage, is the comparison between the product calculated emissions (t $CO_2e$/ t product) compared to the benchmark value (t $CO_2e$/ t product). The following formula can be used for calculating a product's additionality threshold.

$$\text{Additionality Threshold (\%)} = 1 - \frac{\text{Product Calculated Emission}}{\text{Benchmark Value}}$$

**Table 2 – Benchmark Values and Additionality Thresholds**

| Product | Benchmark Value (t $CO_2e$/ t product) | Additionality Threshold |
|---|---|---|
| Ferronickel | 40 | 30% |
| Ferromolybdenum | 7.68 | 20% |
| Alumina | 3.8 | 25% |
| Vanadium Pentoxide | 6.14 | 15% |
| Ferrovanadium | 11.04 | 20% |

Additional benchmarks may be established for other metals, metal oxides or alloys following the methods described in Appendix I and in accordance with the current VERRA Standard for Methodology Requirements.

# 8 QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

## 8.1 Baseline Emissions

The GHG emissions relevant to this process result from the combustion of fossil fuels as an energy or heat source and the use of electricity generated from combustion of fossil fuels. The GHGs emitted are carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$).

(1)(a) Project proponents must calculate the annual baseline emissions ($BE_x$) for each metal, metal oxide or alloy, within the project boundary, processed from virgin ore to a final product, using the following equation:

$$BE_x = \left( Mining_{Enrg} + RawM_E + Production_{Enrg} \right) / \ Baseline_{Prod}$$

Where:

| | |
|---|---|
| $BE_x$ * | = Annual baseline emissions per unit of metal production ($tCO_2e$/t of final product) |
| $Mining_{Enrg}$ | = Annual baseline emissions from energy usage ($tCO_2e$) |
| $Production_{Enrg}$ | = Annual baseline emissions from various processes ($tCO_2e$) |
| $RawM_E$ | = Annual baseline emissions from raw materials used in the metal production process ($tCO_2e$) |
| $Baseline_{Prod}$ | = Average Annual final product production (t) |
| x | = Value for each metal, metal oxide or alloy |

(1)(b) In the absence of publicly available baseline data of fuel and electricity usage, the project proponent should use the performance method benchmark values found in Appendix I for greenhouse gas emissions reported as $tCO_2e$/t Metal. The benchmark values will replace $BE_x$ in the net emissions reductions and removals calculation in Section 8.4 of this methodology:

$$BE_x = Benchmark\ Value$$

Where:

| | |
|---|---|
| $BE_x$ | = Annual baseline emissions per unit of metal production ($tCO_2e$/t of final product) |

(2) Annual baseline emissions from energy usage for metal ore mining includes all activities required to extract and process raw ore for further conversion (e.g. pyrometallurgy, hydrometallurgy, etc.) of ore to final product, and are calculated using the following equation:

$$\mathrm{Mining_{Enrg}} = \sum_i \left[ \left( F_{base_i} * \ Fef_i \right) + \left( \ E_{base} * \ Eef \right) \right]$$

Where:

| | |
|---|---|
| $\mathrm{Mining_{Enrg}}$ | = Annual baseline emissions from energy usage for metal ore mining ($tCO_2e$) |
| $\mathrm{F_{base}}$ | = Volume of each fuel combusted (l, $m^3$ or other/year) |
| Fef | = Emission Factor for specific fuel combustion ($kgCO_2e/m^3$, $kgCO_2e/l$ or other) |
| $E_{base}$ | = Amount of electricity consumed (kWh, MWh, GWh or other/year) |
| Eef | = Emission Factor for electricity generation ($kgCO_2/MWh$) |
| $i$ | = Value for each fuel type applicable to a project |

(3) Annual baseline emissions from raw materials used in the production of final products are calculated using the following equation:

$$\mathrm{RawM_E} = \sum_i \left[ \left( Material_{base_{in}} * \ C_{in} \ \% \right) * (0.00366) \right] - \sum_i \left[ \left( Material_{base_{out}} * \ C_{out} \ \% \right) * (0.00366) \right]$$

Where:

| | |
|---|---|
| $\mathrm{RawM_E}$ ** | = Annual baseline emission from raw materials ($tCO_2e$) |
| $Material_{base_{in}}$ | = Annual weight of each carbon containing raw material added in process (kg) |
| $\mathrm{C\%_{in,out}}$ | = Percent Carbon (approximate) of each raw material or product out of process |
| 0.00366 | = conversion factor from kg of C to metric ton of $CO_2$ ($tCO_2/kg$ C) |
| $Material_{base_{out}}$ | = Annual weight of each product out of process (kg) |
| $i$ | = Value for each material applicable to project |

** In the absence available data for completing the calculation, the project proponent should conservatively enter zero for $\mathrm{RawM_E}$

(4) Annual baseline emissions from energy usage for production (e.g. pyrometallurgy, hydrometallurgy, etc.) of each final product is calculated using the following equation:

$$\mathrm{Production_{Enrg}} = \sum_i \left[ \left( F_{prod_i} * \ Fef_i \right) + \left( E_{prod} \ * \ Eef \right) \right]$$

Where:

| | |
|---|---|
| $\mathrm{Production_{Enrg}}$ | = Annual baseline emission from various process ($tCO_2e$) |
| $\mathrm{F_{prod}}$ | = Volume of each fuel combusted (l, $m^3$ or other/year) |
| $\mathrm{Fef}$ | = Emission Factor for each fuel combusted ($kgCO_2e/m^3$, $kgCO_2e/l$ or other) |
| $\mathrm{E_{prod}}$ | = Amount of electricity consumed (kWh, MWh, GWh or other/year) |
| $\mathrm{Eef}$ | = Emission Factor for electricity generation ($kgCO_2/MWh$) |
| $i$ | = Value for each fuel type applicable to a project |

## 8.2 Project Emissions

The Project $CO_2$ emissions are released from the processing of the raw materials plus the $CO_2$ released from the operation's fuel usage minus the total potential $CO_2$ of each product out of the process. The carbon content of the material and the product out of the process were used to find total potential released $CO_2$ mass. This happens when all the carbon from both the material and the product out of the process were to be released.

(5) Project proponents must calculate the annual Project emissions ($PE_x$) for each final product (i.e. metal, metal oxide or alloy), within the project boundary, processed from metal bearing waste stream to a final product, using the following equation:

$$PE_x = \frac{(Total\ Production_E * FC_i)}{Project_{Prod}}$$

Where:

| | |
|---|---|
| $PE_x$ | = Annual project emissions per unit of metal production ($tCO_2e/t$ $Project_{Prod}$ |
| $\mathrm{Total\ Production_E}$ | = Annual total project emissions ($tCO_2e$) |
| $FCi$ | = Approximate % of Total Production emissions allocated to produce each final product within the project boundary. If only one final product is being manufactured, project proponent should enter 1 for 100% of emissions allocation. |
| $Project_{Prod}$ | = Annual metal production for each final product (t) |
| x | = Value for each metal, metal oxide or alloy |

(6) Annual total emissions from the project operations are determined using the following equation:

$$Total\ Production_E = [(RawM_E + Fuel_E + Electricity_E)]$$

Where:

$\text{Total Production}_E$ = Annual total project emissions ($tCO_2e$)
$RawM_E$ = Annual project emission from raw materials ($tCO_2e$)
$Fuel_E$ = Annual project emissions from fuel ($tCO_2e$)
$Electricity_E$ = Annual project emissions from electricity ($tCO_2e$)

(7) Annual project emissions from raw materials used in the production of final products are calculated using the following equation:

$$RawM_E = \sum_i [(Material_{in} * \ C_{in}\ \%) * (0.00366)] - \sum_i [(Material_{out} * \ C_{out}\ \%) * (0.00366)]$$

Where:
$RawM_E$ = Annual project emission from raw materials ($tCO_2e$)
$Material_{in}$ = Annual quantity of each carbon-containing raw material added in process (kg)
$C\%_{in,out}$ = Percent Carbon (approximate) of each raw material or product out of process
$0.00366$ = conversion factor from kg of C to metric ton of $CO_2$ ($tCO_2$/kg C)
$Material_{out}$ = Annual pounds of each product out of process (kg)
i = Value for each material applicable to project

(8) Emissions from electricity usage within project boundary are calculated as follows:

$$Electricity_E = \left(E_{proj} * \ Eef\right)$$

Where:

$Electricity_E$ = Annual emissions from electricity usage ($tCO_2e$)
$E_{proj}$ = Approximate amount of electricity consumed within project boundary (kWh, MWh, GWh or other/year)
$Eef$ = Emission Factor for electricity generation ($kgCO_2$/MWh)

(9) Total emissions from the combustion of fuels used in all activities required to process metal bearing waste streams to final product, and are calculated using the following equation:

$$Fuel_E = \sum_i [(\mathrm{F}_{\mathrm{proj}_i} * \ Fef_i)$$

$Fuel_E$ = Annual project emissions for total fuels combusted ($tCO_2e$)
$F_{proj}$ = Volume of each fuel combusted (l, $m^3$ or other/year)
$Fef$ = Emission Factor for each fuel combusted ($kgCO_2e/m^3$, $kgCO_2e$/l or other)
$i$ = Value for various fuels combusted

## 8.3 Leakage

No sources of leakage have been identified for this project activity.

## 8.4 Net GHG Emission Reductions and Removals

Net GHG emission reductions and removals are calculated as follows:

$$ER_y = BE_x - PE_y - LE_y \quad (1)$$

Where:

$ER_Y$ = Net GHG emissions reductions and removals in year y ($tCO_2e$)
$BE_X$ = Baseline emissions in year y ($tCO_2e$)
$PE_y$ = Project emissions in year y ($tCO_2e$)
$LE_y$ = Leakage in year y ($tCO_2e$)

# 9 MONITORING

## 9.1 Data and Parameters Available at Validation

The following data must be made available at validation by the project proponent. Default values may vary according to the physical location of the project activity. The project proponent must provide evidence and justification that the values presented here are applicable to the project or provide and justify project-specific values as needed.

| Data / Parameter | $Baseline_{Prod}$ |
|---|---|
| Data unit | t |
| Description | Annual production of each specific final product (e.g. metal, metal oxide or alloy) |
| Equations | 1 |
| Source of data | Private industry public disclosures, industry groups and associations |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | Due to the limited publication of private industry data, project proponents may be required to rely on industry data of annual production or average production for a specified period |
| Purpose of Data | Calculations of baseline emissions |

| | |
|---|---|
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | Fef |
| Data unit | $kgCO_2e/m^3$, $kgCO_2e/l$ or other |
| Description | Emission factor for fuel combustion |
| Equations | 2, 4, 9 |
| Source of data | The emission factor must be obtained or calculated from relevant industry data according to the most conservative and regionally appropriate approach possible. In the absence of local or regional data, reference values must be obtained from the most recent version of the IPCC guidelines for National Greenhouse Gas Inventories. |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | National emissions factors, or emissions factors created by local industry using internationally accepted procedures should be used preferentially. Regional emissions factors may be used if national or local emissions factors are unavailable. International emissions factors may be used if regional emissions factors are unavailable. In the absence of local or regional data, reference values must be obtained from the most recent version of the IPCC guidelines for National Greenhouse Gas Inventories. |
| Purpose of Data | Calculation of baseline emissions<br>Calculation of project emissions |
| Comments | Project proponents must ensure that all fuel sources are accounted for in the equation and the appropriate emission factor applied. Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to project specifics. This parameter may be updated over the course of the crediting period (as a project description deviation) due to the availability of more recent information. |

| | |
|---|---|
| Data / Parameter | Eef |
| Data unit | $kgCO_2/MWh$ |
| Description | Emission factor for electricity |
| Equations | 2, 4, 8 |

| | |
|---|---|
| Source of data | Reference values must be obtained from the relevant national GHG inventory. The value used should be consistent with the source of generation. In the absence of local or regional data, reference values may be obtained from the most recent version of the IPCC guidelines for National Greenhouse Gas Inventories. |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | Review of best practice guidance and accepted standards. Reference values are generally available |
| Purpose of Data | Calculation of baseline emissions<br>Calculation of project emissions |
| Comments | Default values must be sourced from recognized, credible sources and be geographically and temporally relevant to project specifics. This parameter may be updated over the course of the crediting period (as a project description deviation) due to the availability of more recent information. |

| | |
|---|---|
| Data / Parameter | $F_{base}$ |
| Data unit | L, $m^3$ or other/year |
| Description | Volume of each fuel combusted by equipment within the project boundary for metal ore mining including all activities required to extract and process raw ore for further conversion |
| Equations | 2 |
| Source of data | Private industry public disclosures, industry groups and associations |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Due to the limited publication of private industry data, project proponents may be required to rely on industry data of average typical fuel consumption for mining operations |
| Purpose of Data | Calculations of baseline emissions |
| Comments | N/A |

| Data / Parameter | $F_{prod}$ |
|---|---|
| Data unit | L, $m^3$ or other/year |
| Description | Volume of each fuel combusted by equipment within the project boundary for the production (e.g. pyrometallurgy, hydrometallurgy) of each final product |
| Equations | 4 |
| Source of data | Private industry public disclosures, industry groups and associations |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Due to the limited publication of private industry data, project proponents may be required to rely on industry data of average typical fuel consumption for metal production operations |
| Purpose of Data | Calculations of baseline emissions |
| Comments | N/A |

| Data / Parameter | $E_{base}$ |
|---|---|
| Data unit | (kWh, MWh, GWh or other/year) |
| Description | Amount of electricity consumed by equipment within the project boundary for metal ore mining including all activities required to extract and process raw ore for further conversion |
| Equations | 2 |
| Source of data | Private industry public disclosures, industry groups and associations |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Due to the limited publication of private industry data, project proponents may be required to rely on industry data of average typical fuel consumption for mining operations |
| Purpose of Data | Calculations of baseline emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $E_{prod}$ |
| Data unit | (kWh, MWh, GWh or other/year) |
| Description | Amount of electricity consumed by equipment within the project boundary for the production (e.g. pyrometallurgy, hydrometallurgy) of each final product |
| Equations | 4 |
| Source of data | Private industry public disclosures, industry groups and associations |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Due to the limited publication of private industry data, project proponents may be required to rely on industry data of average typical fuel consumption for mining operations |
| Purpose of Data | Calculations of baseline emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $C\%_{\mathrm{in,out}}$ |
| Data unit | % |
| Description | Percent Carbon (approximate) of each raw material or product out of process |
| Equations | 3, 7 |
| Source of data | Material specification datasheet, laboratory analysis data |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | Percent carbon is necessary to calculate the approximate contribution of $CO_2$ emissions from raw materials to the total emissions of the baseline and project |
| Purpose of Data | Calculations of baseline emissions<br>Calculations of project emissions |

| | |
|---|---|
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | 0.00366 |
| Data unit | N/A |
| Description | Conversion factor for calculation of metric tons of $CO_2$ based on percent carbon |
| Equations | 3, 7 |
| Source of data | Periodic table of elements |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | $CO_2$ = 44.0087 g/mol<br>C = 12.0107 g/mol<br>$=(\frac{44.0087 g/mol}{12.0107\ g/mol})$ / 1,000<br>=0.00366 |
| Purpose of Data | Calculations of baseline emissions<br>Calculations of project emissions |
| Comments | N/A |

| | |
|---|---|
| Data / Parameter | $FCi$ |
| Data unit | % |
| Description | Approximate % of Total Production emissions allocated to produce each final product within the project boundary |
| Equations | 5 |
| Source of data | Utility bills, equipment design, operating parameters |
| Value applied | N/A |
| Justification of choice of data or description of measurement methods and procedures applied | Project proponents that manufacture more than one final product must be capable of allocating (approximately) the amount of GHG emissions attributable to each specific final product to allow for comparison to baseline emissions of each final product |
| Purpose of Data | Calculations of project emissions |

| | |
|---|---|
| Comments | If only one final product is being manufactured, project proponent should enter 1 for 100% of emissions allocation |

| | |
|---|---|
| Data / Parameter | $\mathrm{Material}_{\mathrm{base}_{\mathrm{in}}}$ |
| Data unit | kg |
| Description | Annual pounds of each raw material added in process |
| Equations | 3 |
| Source of data | Private industry public disclosures, industry groups and associations |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Due to the limited publication of private industry data, value may not be available to project proponents. |
| Purpose of Data | Calculations of baseline emissions |
| Comments | In the absence available data for completing the calculation, the project proponent should conservatively enter zero for $\mathrm{RawM}_{\mathrm{E}}$ |

| | |
|---|---|
| Data / Parameter | $\mathrm{Material}_{\mathrm{base}_{\mathrm{out}}}$ |
| Data unit | kg |
| Description | Annual pounds of each raw material added in process |
| Equations | 3 |
| Source of data | Private industry public disclosures, industry groups and associations |
| Value applied | |
| Justification of choice of data or description of measurement methods and procedures applied | Due to the limited publication of private industry data, value may not be available to project proponents. |
| Purpose of Data | Calculations of baseline emissions |

| | |
|---|---|
| Comments | In the absence available data for completing the calculation, the project proponent should conservatively enter zero for $\mathrm{RawM_E}$ |

## 9.2 Data and Parameters Monitored

| | |
|---|---|
| Data / Parameter: | $\mathrm{E_{proj}}$ |
| Data unit: | kWh, MWh, GWh or other/year |
| Description: | Quantity of electricity used by project operations supplied by the grid in year |
| Equations | 8 |
| Source of data: | Measurements at the project facility or electric utility bills |
| Description of measurement methods and procedures to be applied: | Use calibrated electricity meters. Calibration must be conducted according to the equipment manufacturer's specifications. Alternatively, utility billing data can be used |
| Frequency of monitoring/recording: | Data must be monitored continuously and recorded on at least a daily basis. If utility data is used, monthly bills are acceptable |
| QA/QC procedures to be applied: | The consistency of metered electricity generation should be cross-checked with receipts from electricity purchases where applicable |
| Purpose of data: | Calculation of project emissions. |
| Calculation method: | N/A |
| Comments: | Project proponents that produce multiple finished products for comparison to the baseline should have the ability to approximate the amount of fuel consumption attributable to each finished product. |

| | |
|---|---|
| Data / Parameter: | $\mathrm{F_{proj}}$ |
| Data unit: | L, $m^3$ or other/year |
| Description: | Quantity of fossil fuel used by the project facility in year |
| Equations | 9 |
| Source of data: | Measurements at the project facility or utility bills |

| | |
|---|---|
| Description of measurement methods and procedures to be applied: | Use calibrated flow or gas meters. Calibration must be conducted according to the equipment manufacturer's specifications. Alternatively, utility billing data can be used |
| Frequency of monitoring/recording: | Data must be monitored continuously and recorded monthly. If utility data is used, monthly bills are acceptable |
| QA/QC procedures to be applied: | The consistency of metered fuel use should be cross-checked with receipts from fuel suppliers where applicable |
| Purpose of data: | Calculation of project emissions |
| Calculation method: | N/A |
| Comments: | Project proponents that produce multiple finished products for comparison to the baseline should have the ability to approximate the amount of fuel consumption attributable to each finished product. |

| | |
|---|---|
| Data / Parameter: | $Material_{in}$ |
| Data unit: | kg |
| Description: | Annual quantity of each carbon-containing raw material added in process |
| Equations | 7 |
| Source of data: | Measurements at project facility |
| Description of measurement methods and procedures to be applied: | Carbon-containing raw materials must be weighed on scales that have available calibration procedures from the manufacturer. |
| Frequency of monitoring/recording: | Annual |
| QA/QC procedures to be applied: | Calibration of scales must be conducted according to the equipment manufacturer's specifications. |
| Purpose of data: | Calculations of baseline emissions<br>Calculations of project emissions |
| Calculation method: | Scale readouts |
| Comments: | N/A |

| | |
|---|---|
| Data / Parameter: | $Material_{out}$ |
| Data unit: | kg |
| Description: | Annual quantity of each carbon-containing raw material added in process |
| Equations | 7 |
| Source of data: | Measurements at project facility |
| Description of measurement methods and procedures to be applied: | Carbon-containing raw materials must be weighed on scales that have available calibration records. |
| Frequency of monitoring/recording: | Annual |
| QA/QC procedures to be applied: | Calibration of scales must be conducted according to the equipment manufacturer's specifications. |
| Purpose of data: | Calculations of baseline emissions<br>Calculations of project emissions |
| Calculation method: | Scale readouts |
| Comments: | N/A |

| | |
|---|---|
| Data / Parameter: | $Project_{Prod}$ |
| Data unit: | t |
| Description: | Annual production of each specific final product (e.g. metal, metal oxide or alloy) |
| Equations | 5 |
| Source of data: | Production reports maintained by project facility |
| Description of measurement methods and procedures to be applied: | Final products should be weighed on scales that have available calibration records. If weighing by scales is not feasible, project proponent must be able to demonstrate a verifiable method for calculating final product weight. |

| | |
|---|---|
| Frequency of monitoring/recording: | Daily |
| QA/QC procedures to be applied: | Review of production reports, inventory reports and or shipping reports |
| Purpose of data: | Calculations of project emissions |
| Calculation method: | N/A |
| Comments: | N/A |

## 9.3 Description of the Monitoring Plan

The project proponent must establish, maintain and apply a monitoring plan that includes criteria and procedures for obtaining, recording, compiling and analyzing data, parameters and other information important for quantifying and reporting GHG emissions relevant for the project and baseline scenarios. Monitoring procedures must address the following:

- Types of data and information to be reported
- Units of measurement
- Origin of the data
- Monitoring methodologies (e.g., estimation, modeling, measurement and calculation)
- Type of equipment used
- Monitoring times and frequencies
- QA/QC procedures
- Monitoring roles and responsibilities, including experience and training requirements
- Retention of project data.

Where measurement and monitoring equipment is used, the project proponent must ensure the equipment is calibrated according to manufacturer recommendations or relevant industry standards.

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# APPENDIX I: PERFORMANCE METHOD

## Applicability Conditions

Various metal bearing ores and minerals are abundantly available throughout the world and are the primary source for the manufacturing of metals, metal oxides or alloys. A review of various literature sources indicates the following for primary source metals addressed in this methodology:

- The world's nickel resources are currently estimated at almost 300 million tons. Nickel-containing ores are currently mined in more than 25 countries worldwide. Australia, Indonesia, South Africa, Russia and Canada account for more than 50% of the global nickel resources. In 2017, Brazil produced 25,000 metric tons - 24% of which was produced using recycled material. (18)

- Eleven companies producing between 2.5kt and 35ktpy of molybdenum accounted for about two thirds of world molybdenum mine production in 2008, a further nine or ten companies produced more than 1kt, with the remainder coming from numerous small producers, mainly in China. About 2% of supply is in the form of recycled molybdenum (20)

- In 2019, 125,960 thousand metric tonnes of Alumina was manufactured using primary methods from the following regions of the world: China (56%), Australia (16%), South Africa (9%), Africa-Asia (8%), West Europe (5%), East/Central Europe (4%), North America (2%).(26)

- Vanadium co-production from steel slags, derived from vanadiferous iron ores remains the most common source of vanadium supply, accounting for 70.6% of production in 2019. Primary production accounted for 17.7% of supply in 2019. Secondary production from spent catalysts remains a higher-cost form of production than primary- and co-production and accounted for an estimated 11.7% of total supply in 2019.(24)

Mining activities associated with primary manufacturing of metal ores and minerals can impact social and environmental systems in direct and indirect ways. Mine exploration, construction, operation, and maintenance may result in land-use change, and may have associated negative impacts on environments, including deforestation, erosion, contamination and alteration of soil profiles, contamination of local streams and wetlands, and an increase in noise level, dust and emission. Mine abandonment, decommissioning and repurposing may also result in similar significant environmental impacts, such as soil and water contamination. Beyond the mines themselves, infrastructure built to support mining activities, such as roads, ports, railway tracks, and power lines, can affect migratory routes of animals and increase habitat fragmentation.(6)

The secondary manufacturing process is the conversion of metal constituents contained in waste streams such as: refinery residue upgrading catalyst, gasification ashes, power plant slags and fly ash, residues, sludges, slurries, or other metal bearing waste streams. The waste streams, often classified as hazardous waste, are typically destined for disposal by landfilling, thermal destruction, or other disposal methods. The secondary manufacturing process offers an alternative to disposal through implementation of proprietary recycling and re-use technologies.

Recycling of refinery residue upgrading catalysts or other metal bearing waste by pyrometallurgical, hydrometallurgical or other methodologies typically require the implementation of a multitude of environmental pollution control systems to mitigate potential impacts related to the storage and processing of the waste feedstocks. The need for such rigorous environmental controls can add a significant cost to a Project.

As an example, the United States (U.S.) law demands a strict management regime for refinery residue upgrading catalyst, as a listed hazardous waste under U.S. Environmental Protection Agency (USEPA) Resource Conservation Recovery Act (RCRA). The USEPA and along with state-specific regulations require implementation of controls with the highest level of environmental stewardship and risk mitigation to meet the imposed regulatory requirements. Examples of controls include:

- Specially designed raw material storage buildings designed to contain free liquids (including oil) that migrate from the catalyst and are collected in the subfloor dual-liner containment system.
- Roasting systems which expose the catalysts to temperatures and air in excess of that required for sulfur and carbon combustion, to eliminate the materials pyrophoric tendencies, while destroying benzene and any hazardous PAHs
- Utilizing a Circulating Dry Scrubber (CDS) and baghouse which are the Best Available Control Technology (BACT) to control sulfur dioxide ($SO_2$) and Best Available Technology (BAT) for particulate matter (PM) from the roaster exhaust.

Funding new projects for secondary manufacturing processing for metal bearing waste streams can be challenging due to the cost of environmental risk mitigation and emission control and price volatility in the metal's markets. Organizations often must identify alternative financing opportunities, such as Green Bonds, to secure the funding required to build a fully compliant facility.

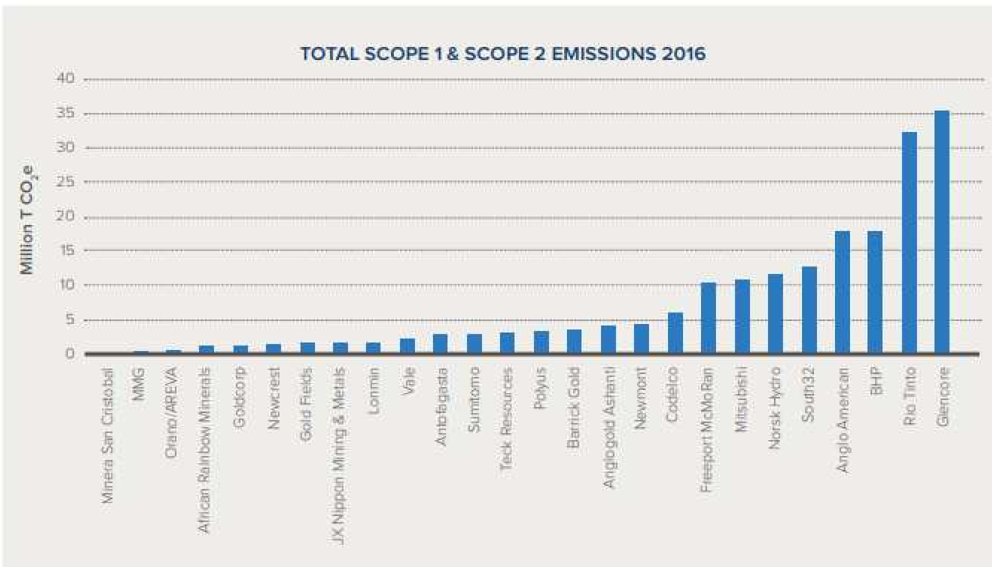
Metal bearing ores and minerals are abundantly available throughout the world and are mined on most continents as the primary source for the manufacturing of metals. Primary metals manufacturing of refined ore requires additional processing (i.e. electric arc, thermite, etc.) to manufacture ferroalloys and alumina. Processing may occur at the same location where the ores are mined, for integrated operations or require shipment to remote processing plants. Based on the diverse geographic reach of primary manufacturing it is conservative to apply data from one geographic area to another when aggregated industry data and geographical applicable emission factors are considered.

## Baseline Scenario

The following information on the trends in mining is excerpted from *Decarbonization Pathways for Mines: A Headlamp in the Darkness*, published by The Rocky Mountain Institute.[(1)] The review included an assessment of how the mining industry is performing with respect to reducing its carbon emissions, and the associated problems with current measures and data tracking was discussed.

The initial analysis focused on the 27 members of the International Council on Mining and Metals (ICMM). The mining companies were evaluated only on their scope 1 (direct) and scope 2 (purchased or acquired electricity, steam, heat, and cooling) emissions. The absolute emissions for the ICMM members in 2016  are presented in Figure 1a below.

**Figure 1a**




The authors further looked at the change in emissions from 2014 to 2016 as shown in Figure1b. Fourteen (14) members decreased their total emissions, 10 increased, and three did not have enough data to be plotted.

**Figure 1b**

Most of the changes appear small; only six were greater than 1 million tons in either direction. However, normalizing for the size of the company and looking at the percentage change (Figure 1c) shows that some of these shifts are very significant, especially for smaller mining companies.

Figure 1c


Of the 10 companies that decreased their total emissions by more than 10%, five had total emissions of less than 3 million tons in 2016. Similarly, of the four companies that increased total emissions by more than 20%, all had total 2016 emissions of less than 3 million tons.

The United States Environmental Protection Agency Greenhouse Gas Reporting Program (GHGRP) publishes data aggregated for various industries including the metals sector. The metals sector consists of metal production facilities that smelt, refine, and/or cast ferrous and nonferrous metals, including primary aluminum, ferroalloy, iron and steel, lead, magnesium, and zinc, from ore, pig, or scrap using electrometallurgical and other methods. The sector also includes foundries and any other metal production facility operating under NAICS codes beginning with 331 (Primary Metal Manufacturing). Primary aluminum, ferroalloy, iron and steel, lead, magnesium, and zinc production facilities report GHG emissions from metal smelting, refining, and/or casting activities, as well as from stationary fuel combustion sources. All other metal production facilities report only the GHG emissions from stationary fuel combustion sources.

An evaluation of the data demonstrates a continued decline in total $CO_2$ and other emissions from the metals sectors operations. Figure 1d presents the trend of emissions of $CO_2$ from the United States Metals Sector, by Subsector.

Figure 1d

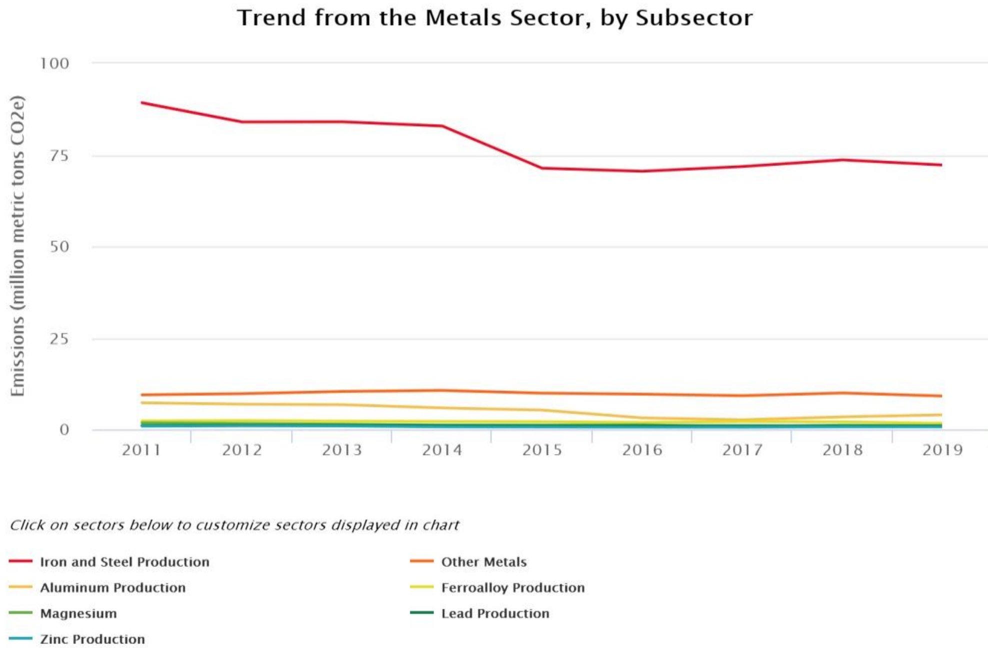



Table 3 presents a summary of the number of U.S. reporters and emissions in the metals sector.

Table 3

## Number of reporters and emissions in the metals sector (as of 9/26/20)

| Metals Sector - Greenhouse Gas Emissions Reported to the GHGRP (all emissions values presented in million metric tons $CO_2e$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| **Number of facilities:** | 299 | 301 | 303 | 306 | 303 | 303 | 296 | 305 | 295 |
| **Total emissions ($CO_2e$):** | 112.0 | 106.8 | 106.9 | 104.5 | 91.4 | 88.0 | 88.1 | 92.0 | 89.7 |
| **Emissions by greenhouse gas ($CO_2e$)** | | | | | | | | | |
| • Carbon dioxide ($CO_2$): | 107.0 | 102.5 | 102.8 | 101.1 | 88.6 | 85.8 | 86.4 | 89.5 | 87.3 |
| • Methane ($CH_4$): | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| • Nitrous oxide ($N_2O$): | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| • Hydrofluorocarbons (HFCs): | ** | ** | 0.1 | 0.1 | 0.1 | 0.1 | ** | 0.1 | 0.1 |
| • Perfluorocarbons (PFCs): | 3.5 | 2.9 | 3.0 | 2.5 | 2.0 | 1.4 | 1.0 | 1.6 | 1.7 |
| • Sulfur hexafluoride ($SF_6$): | 1.5 | 1.3 | 1.0 | 0.7 | 0.7 | 0.8 | 0.7 | 0.7 | 0.6 |

Totals may not equal sum of individual GHGs due to independent rounding.

** Total reported emissions are less than 0.05 million metric tons.

$CO_2$ emissions from the combustion of biomass are NOT included in emissions totals provided above.

## Performance Benchmark

This methodology was developed following an extensive literature search, interviews with experts from mining and manufacturing, consultations with leading experts in GHG quantification, and uses mine-specific data wherever available. However, due to the limited amount of publicly available data (i.e. emissions rates, fuel and electricity consumption, production volumes etc.) for privately owned companies, project proponents must often rely on industry associations data and research, public disclosures, representative generic or default data and conservatively utilized engineering estimates and surrogate data from similar operations.

In developing the benchmark values, no indications of the potential for false positives or false negatives were identified. The primary source of GHG emissions for both primary and secondary manufacturing are related to the use of fuels and electric power, which typically carry a significant cost to the operations and are carefully monitored to identify wastage and potential cost savings. By using publicly available industry associations data and research, public disclosures, representative generic or default data and internationally accepted methodologies to calculate emission rates the potential for over- or underestimating emissions is minimized.

This methodology utilized the following sources for establishing benchmark emission values.

| | |
|---|---|
| Ferronickel: | *Life Cycle Assessment of Nickel Products Reference year 2017 Final Report*. Commissioned by the Nickel Institute and Performed by SPHERA. May 2020 |
| Ferromolybdenum: | *Life Cycle Inventory of Molybdenum Products for Metallurgical Applications: Update Study.** <br><br> *Life Cycle Inventory of Molybdenum Products for Metallurgical Applications: Update Study, Executive Summary 2018.** <br><br> *Prepared for the International Molybdenum Association by Four Elements Consulting, LLC. (2018) |
| Alumina: | Life Cycle Inventory Data and Environmental Metrics for the Primary Aluminum Industry - 2015 Data. Final June 2017. International Aluminium Institute. <br><br> Cradle to gate: life cycle impact of primary aluminium production. The International Journal of Life Cycle Assessment |
| Ferrovanadium: | Mining Vanadium Responsibly - 2018 Environmental, Social and Governance Report. Largo Resources Ltd. <br><br> Vanadium The Green Metal. 2019 Sustainability Report. Largo Resources Ltd. |

The following sections provide additional detail from the referenced sources describing the approaches used to establish the benchmark $CO_2e$ emission values for the crediting baseline of each end product.

Ferronickel: **Benchmark value: 40 $tCO_2e$/t ferronickel**

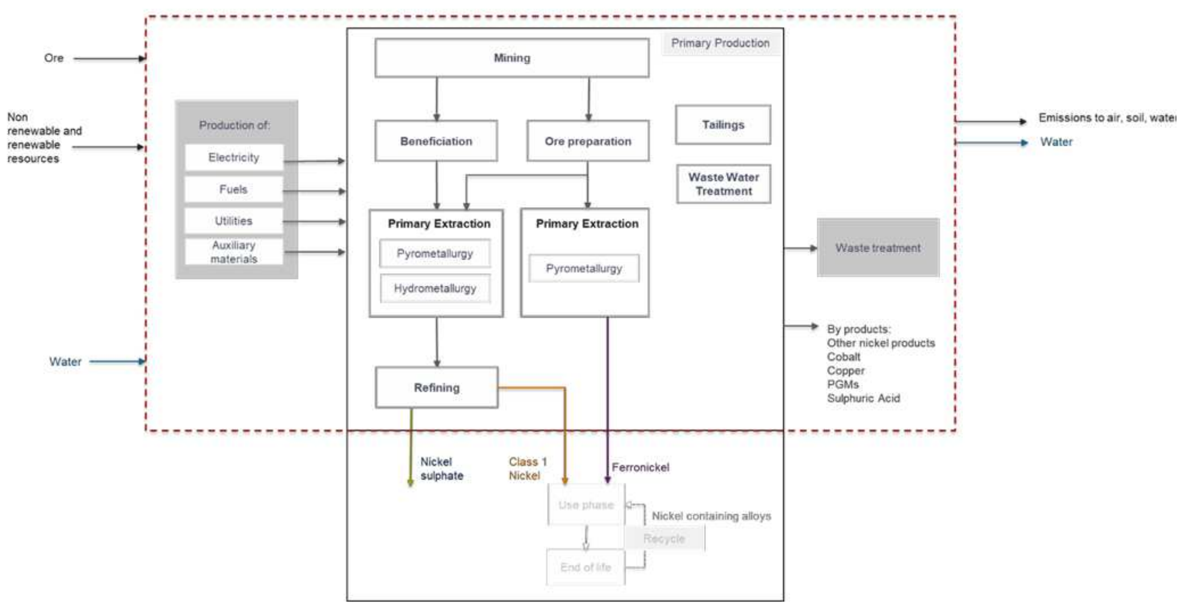
Between 2018 and 2019, the Nickel Institute conducted a Life Cycle Assessment (LCA) on nickel products (Class 1 nickel, ferronickel and nickel sulphate). Based on the input from Nickel Institute members for the year 2017, representing 52% of the global production of Class 1 nickel; 47% of the global production of ferronickel and 15% of the global production of nickel sulphate, the study focused on quantifying the environmental impacts of the cradle to gate production of nickel products.

Primary nickel is produced from either oxidic (lateritic) or sulphidic ore. Class 1 nickel can be produced from both ore types and can be produced from either pyrometallurgical or hydrometallurgical processes. It is also a by-product from precious group metals (PGM) production. Ferronickel (FeNi) is produced exclusively from oxidic (laterite) ore and undergoes pyrometallurgical processing.

The study considers the cradle-to-gate production of nickel products, meaning that it considers impacts associated with the extraction of resources from nature (through mining) through to the point at which the refined product leaves the factory gate. Figure 1e provides a graphic of the LCA system boundaries. The geographical coverage of this study considers the global production of nickel products. 52% (556 000 tons) of globally produced Class 1 nickel (2011: 52%), 47% (734 000 tons) of globally produced ferronickel (2011: 40%) and 15% (105 000 tons) of globally produced nickel sulphate are represented in this study.



**Figure 1e - Life Cycle Assessment of Nickel Products - System Boundaries**

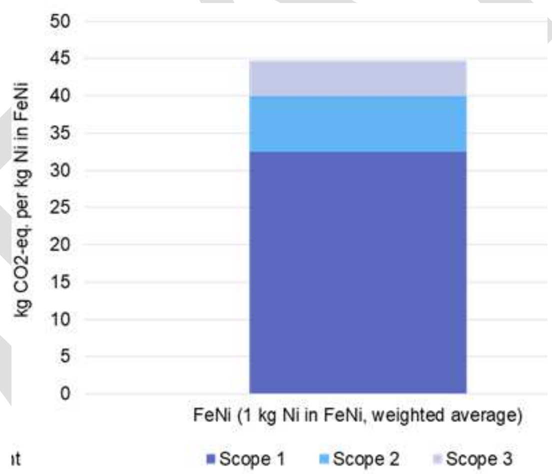


The assessment results are presented for the global warming potential (GWP) showing the contribution of the various processes in the production of ferronickel as well as the $CO_2$-equivalent ($CO_2e$) split into Scopes as defined in the World Resources Institute, "Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard:

- Scope 1: "Direct GHG emissions occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment".
- Scope 2: "Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated".

For the purposes of this VMS methodology only Scope 1 and Scope 2 emissions were included in the benchmark value. Figure 1f below presents a breakdown of the Scope 1, 2 and 3 emissions.

**Figure 1f. Life Cycle Assessment of Nickel Products - Ferronickel Production Scope 1, 2 and 3 emissions**




The assessment further indicates that Scope 1 emissions due to the combustion of fuels, electricity generated on site and reductant use contributes 72%. 43% of Scope 1 emissions are due to electricity generated on site while the balance is a result of fuel combustion and process emissions. Scope 3 emissions contributes 11% to the GWP with 49% a result of the upstream production of fuels and reductants. CO2 emissions make up 97% of the global warming potential emissions.

Ferromolybdenum: **Benchmark value: 7.68 $tCO_2e$/t ferromolybdenum**

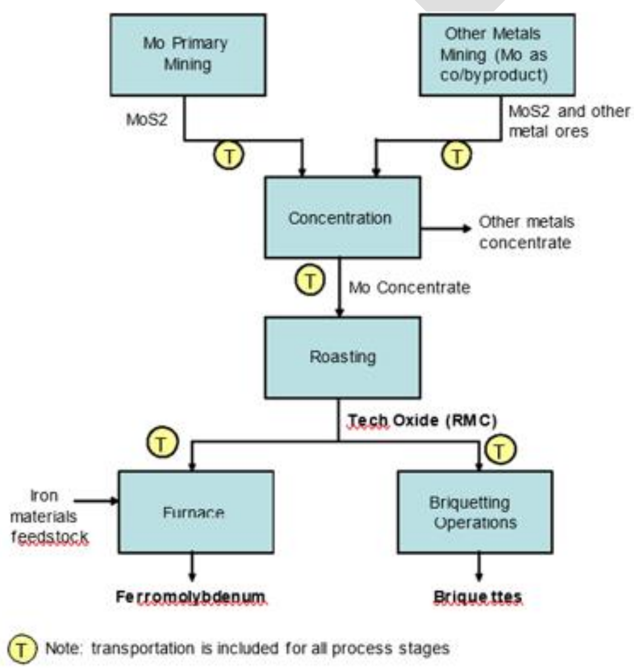
In 2000 the International Molybdenum Association (IMOA) completed a Life Cycle Inventory (LCI) for three molybdenum products for metallurgical applications. In 2008 and again in 2018, IMOA updated the LCI to increase Mo production representativeness and further improve the data quality with current facility and background data.

The aim of the 2018 study was to develop updated Life Cycle Inventory Data (LCI) profiles for the intermediate molybdenum products for metallurgical applications, as covered by the previous LCIs:

- Roasted molybdenite concentrates (RMC), also known as “technical grade molybdenum oxide” or “tech oxide”, in powder form
- RMC in briquette form
- Ferromolybdenum (FeMo)

The LCIs are cradle-to-gate, encompassing the processes that include resource extraction from the earth through to the point at which the molybdenum products are ready for shipment to customers, including packaging. The LCIs are based on current data on process technologies, energy and materials consumed, and environmental outputs. Figure 1g provides a graphic of the LCI system boundary.

Figure 1g Life Cycle Inventory of Molybdenum Products for Metallurgical Applications
Overall Metallurgical Mo LCI System Boundary




The primary molybdenum data collected and modeled for this study is sourced from facilities in eight countries spanning Asia, Europe, North America, and South America, and represents approximately 30% of total global molybdenum produced and 46% of global production minus China. Data were collected for the years 2015 or 2016, based on the most representative production year, and came from primary and byproduct mines and conversion facilities.

The results of the assessment identified emissions of 7.68 $tCO_2e/t$ ferromolybdenum. Table 4 presents an extract of the calculated emissions for product cradle-to-gate inventory (per 1k Ferromolybdenum).

**Table 4.** Life Cycle Inventory of Molybdenum Products for Metallurgical Applications: Update Study Product Cradle-to-Gate Inventory (per 1k Ferromolybdenum)

| | Flow | Unit | FeMo Total (67% Mo) |
|---|---|---|---|
| Raw materials | Crude oil (resource) | kg | 3.79 E-01 |
| | Hard coal (resource) | kg | 1.17 E+00 |
| | Lignite (resource) | kg | 2.39 E-01 |
| | Natural gas (resource) | kg | 5.80 E-01 |
| | Uranium (resource) | kg | 1.78 E-05 |
| | Molybdenum | kg | 1.04 E+00 |
| | Iron | kg | 2.08 E-01 |
| | Limestone (calcium carbonate) | kg | 1.33 E+00 |
| | Water | kg | 5.97 E+02 |
| Air emissions | Carbon dioxide | kg | 7.68 E+00 |
| | Carbon monoxide | kg | 1.61 E-02 |
| | Hydrogen chloride | kg | 2.78 E-04 |
| | Hydrogen cyanide (prussic acid) | kg | 8.23 E-09 |
| | Hydrogen fluoride | kg | 2.49 E-05 |
| | Hydrogen sulphide | kg | 6.10 E-04 |
| | Nitrogen oxides | kg | 3.29 E-02 |
| | Sulphur oxides | kg | 2.48 E-02 |
| | Ammonia | kg | 9.70 E-05 |
| | Particles to air | kg | 2.08 E-02 |
| | Methane | kg | 2.26 E-02 |
| | Group NMVOC to air | kg | 1.13 E-03 |
| | Nitrous oxide (laughing gas) | kg | 1.70 E-04 |
| | Molybdenum | kg | 3.10 E-05 |
| | Copper | kg | -1.27 E-06 |
| | Lead | kg | 1.59 E-05 |
| | Mercury | kg | 1.53 E-07 |
| | Zinc | kg | 1.95 E-06 |

Alumina: **Benchmark value: 3.8 $tCO_2e$/t alumina**

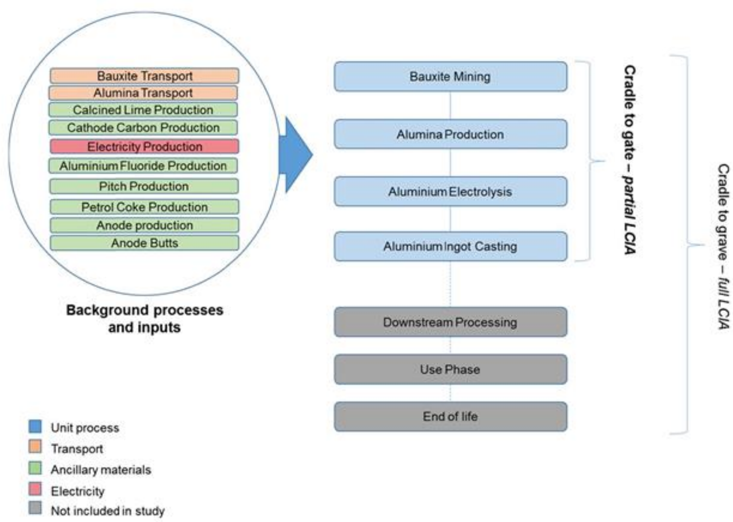
The International Aluminium Institute (IAI) is a global institute with a current membership that represents over 60 % of worldwide bauxite, alumina and primary aluminum production. The collection of global aluminum industry data for use in LCAs was initiated by the IAI in 1998, although the Institute has been collecting energy and other relevant data since the 1970s. Life cycle inventory (LCI) data has since been published for the reference years 2000, 2005 and 2010. The 2014 publication of an Environmental Metrics Report, based on the 2010 LCI, was the first time that the Institute published the results of a cradle-to-gate impact assessment. This analysis brought together the input and output flows identified in the inventory phase, with background datasets, published in third party LCA databases, to evaluate the potential environmental impacts of primary aluminum ingot production, from cradle- to-gate.

The 2015 report builds on the Institute's Life Cycle work to date and aims to publish all significant life cycle inventory (LCI) data from primary aluminum production processes, from mining of bauxite ore to ingot manufacture, including: raw material inputs, energy use, emissions to air and water and solid waste generation. The primary aluminum production process can be summarized as follows:

1. Aluminium-containing ores (bauxites) are mined, predominantly at shallow depths using open cast methods.
2. Aluminium oxide (alumina) is extracted from bauxite through a thermo-chemical digestion process, leaving a waste product comprising the remaining mineralogical contents of the ore.
3. An electrolytic process reduces the alumina into its constituent elements oxygen, emitted as CO2 by reaction with a carbon anode, and aluminum, collected as liquid metal.
4. This molten aluminum is cast into ingots, the usual form suitable for further fabrication of semi-finished aluminum products

Figure 1h. provides a graphic of the system boundary of the cradle to gate study.

**Figure 1h. System Boundary of the Cradle to Gate Study**




The *Cradle to gate: life cycle impact of primary aluminum production* presents the methodology used for the 2010 global LCI as well as the methodology, models and results for the Life Cycle Impact Analysis (LCIA) for primary aluminum globally (GLO) and for the world excluding China (rest of world (RoW)). For the purposes of this methodology the GLO combined global warming potential (GWP) of bauxite and alumina refining were used.

The results of the assessment identified emissions of 3.8 $tCO_2e$/t aluminum. Figure 1i. presents a graphical image of the breakdown of the GWP by unit process and process types while Table 5. presents the numerical GWP values.

Figure 1i. Global GWP by unit process and process types

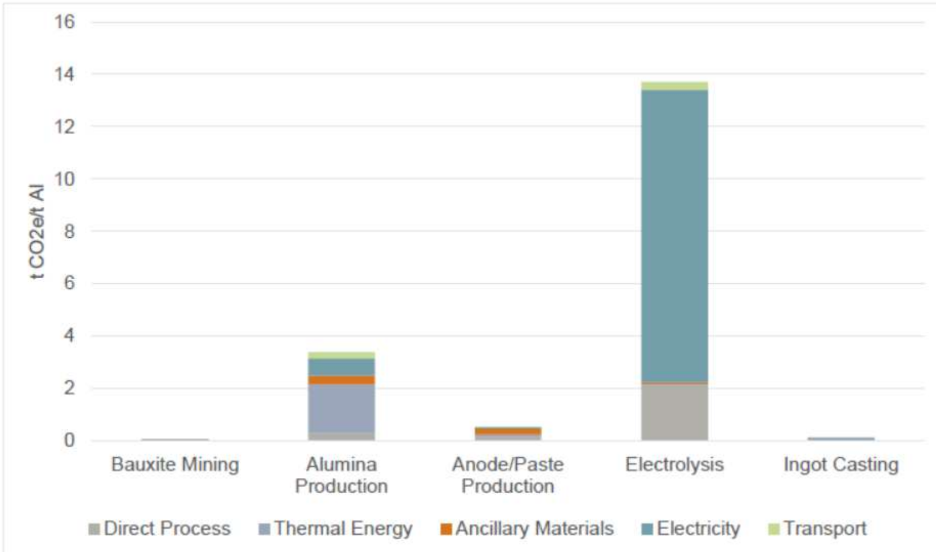



Table 5. Global GWP numerical values by unit process and process types

| GLO | Bauxite mining | Alumina refining | Anode/paste production | Electrolysis | Ingot casting | Total | Primary energy (MJ) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | R | NR |
| Electricity | <0.1 | 0.4 | <0.1 | 9.2 | <0.1 | 9.7 | 27 | 104 |
| Process and auxiliary | <0.1 | 0.7 | 0.4 | 2.3 | <0.1 | 3.5 | 0 | 18 |
| Thermal energy | <0.1 | 2.2 | 0.1 | <0.1 | 0.1 | 2.4 | 0 | 31 |
| Transport | 0 | 0.5 | <0.1 | 0.4 | 0 | 0.8 | 0 | 10 |
| Total | <0.1 | 3.8 | 0.6 | 11.9 | 0.2 | 16.5 | 27 | 163 |

<u>Vanadium Pentoxide:</u> **Benchmark value: 6.14 tCO2e/t of vanadium pentoxide**

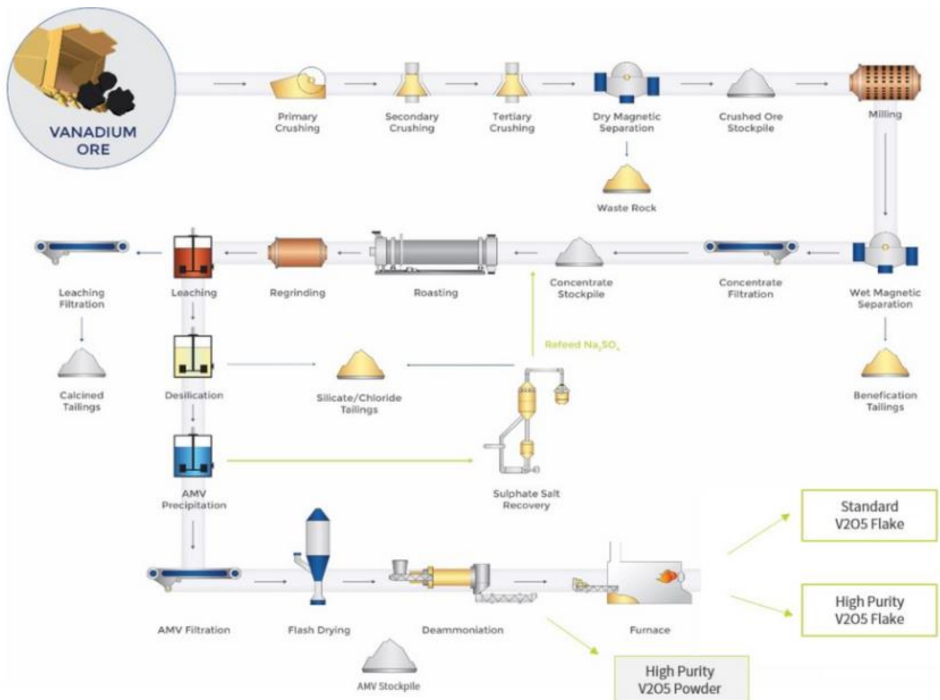
<u>Ferrovanadium:</u> **Benchmark value: 11.04 $tCO_2e$/t ferrovanadium**

Titaniferous magnetite is the most important source for vanadium presently, accounting for about 85% of the current world vanadium pentoxide (V2O5) production. $V_2O_5$ is used for various products such as electrolyte for vanadium redox flow batteries and as a source of vanadium in production of ferrovanadium. Ferrovanadium (FeV), an alloy is typically formed by combining iron and $V_2O_5$ through an aluminothermic reaction. The content of vanadium in FeV can range between 35% to 85%.

The Maracás Menchen Mine boasts one of the highest-grade vanadium resources in the world, and is 99.4% owned by Largo Resources Ltd. The Maracás Menchen Mine property is in the eastern Bahia

State of Brazil. In 2019, the mine manufactured 10,577 tons of V2O5 (vanadium pentoxide) flake and powder. Figure 1h. presents an overview of the Maracás Menchen mine operations.

Figure 1h. Overview of the Maracás Menchen mine operations(12)




In 2018 and 2019, Largo Resources Ltd. issued publicly available Sustainability Reports. Although quantities of greenhouse gases are not specifically presented in the reports, the organization does provide the values for Energy Consumed by Weight or Volume, as seen in Table 6.

Table 6. Energy Consumed by Weight or Volume (2018, 2019)

| | 2018 | 2019 |
|---|---|---|
| Total energy consumption | 53,993,135.25 KWh | 53,750,000.00 KWh |
| Heavy fuel oil (HFO)* | 32.6 tonnes/day | 35.8 tonnes/day |
| Diesel (mine and industrial operations) | 17.7 tonnes/day | 18.6 tonnes/day |
| Liquified petroleum gas (LPG) | 27 kg/day | 30 kg/day |
| Electrical power | 4,000 MWh | 6,136 MWh |

* 25% of the HFO consumed is recycled from the Maracás Menchen Mine's thermoelectric power plant.

For the purposes of this methodology the average of the 2018 and 2019 energy consumed by weight or volume was used to calculate the benchmark value.

The 2019 Sustainability report from Largo provides annual production of Vanadium for 2019 and 2018. Largo expresses production numbers in $V_2O_5$ and we will convert this to Vanadium to be consistent with the project method.

1. Calculation of $CO_2$ emissions by energy source

$CO_2$ emissions were calculated utilizing the following formula:

$$\sum Emissions_{CO2\text{-}e,\ energy} = Energy\ \ Consumption_{fuel} \bullet Emission\ Factor_{GHG,\ fuel}$$

Where:

| | |
|---|---|
| Emissions $_{CO2\text{-}e,\ energy}$ | = emissions for given GHG by type of fuel or power |
| Fuel Consumption $_{fuel}$ | = amount of fuel combusted, or electricity consumed |
| Emission Factor$_{GHG,fuel}$ | = default emission factor of a given GHG by type of fuel or power |

| Energy Source | Estimated Annual Fuel Consumption | Specific $CO_2$ Emission Factor | Emissions $CO_2e$ (t $CO_2e$/year) |
|---|---|---|---|
| Heavy Fuel Oil | 12,483 t | 3.11 t $CO_2/t_{fuel}$ (a) | 38,822.13 |
| Diesel | 6,625 t | 3.15 t $CO_2/t_{fuel}$ (a) | 20,867.96 |
| LPG | 11 t | 3.01 t $CO_2/t_{fuel}$ (a) | 34.51 |
| Electric Power | 5,068 MWh | 0.54 t $CO_2$/MWh (b) | 2,731.59 |
| | | $\sum$ Emissions $_{CO2\text{-}e,\ energy}$ | **62,456.47** |

(a) Engineering ToolBox, (2009)

(b) Institute for Global Environmental Strategies (IGES) (2020). List of Grid Emission Factors

2. Calculation of $CO_2$ emissions for vanadium pentoxide production

The production of Vanadium at Largo's Menchen Mine was found in Largo's 2019 Sustainability report. The $V_2O_5$ production that was provided was in pounds. The average of the two years was found.

| Production | 2018 | 2019 |
|---|---|---|
| $V_2O_5$ (lbs) | 21,574,076 | 23,300,000 |
| $V_2O_5$ (t) | 9,786 | 10,569 |
| | $\boldsymbol{Baseline}$ $\mathrm{V205}_{\boldsymbol{Prod}}$ | **10,178** |

(a) Largo 2019 Sustainability Report

The $tCO_2e/t\ V_2O_5$ was calculated using the following equation

$$BE_x = \left(\sum Emissions_{CO2-e,energy}\right) / \ Baseline\ \mathrm{V205}_{Prod}$$

Where:

| | |
|---|---|
| $BE_x$ | = Annual baseline emissions per unit of metal production (tCO2e/t of final product) |
| $\sum$Emissions $_{CO2\text{-}e,\ energy}$ | = emissions for given GHG by type of fuel or power |
| $\text{Baseline V2O5}_{\text{Prod}}$ | = Average Annual final product production (t) |

$BE_x = (\ 62{,}456.47\ \text{tCO2e})\ /\ 10{,}178$ t V2O5= 6.14 tCO2e/t of $V_2O_5$

3. <u>Calculation of $CO_2$ emissions for ferrovandium production – thermite reaction</u>

$V_2O_5$ is used as a source of vanadium in production of ferrovanadium. Ferrovanadium (FeV), an alloy is typically formed by combining iron and vanadium through an aluminothermic reaction. Aluminothermic reactions yield a negligible amount $CO_2$ and the subsequent mechanical equipment used for further refinement (crushing and sizing) of the ferrovanadium is typically powered by small horsepower electric motors which yield a small amount of scope 2 emissions. For the purposes of this methodology a conservative estimate of 500 t $CO_2$e/year is used for establishing the benchmark value.

The production of $V_2O_5$ at Largo's Menchen Mine was converted to metric tons and then converted to Vanadium (V) (56.02% of Vanadium in $V_2O_5$). The average of the two years was found.

| Production | 2018 | 2019 |
|---|---|---|
| $V_2O_5$ (lbs) | 21,574,076 | 23,300,000 |
| $V_2O_5$ (t) | 9,786 | 10,569 |
| Vanadium (t) | 5,482 | 5,921 |
| | $\boldsymbol{Baseline\ V_{Prod}}$ | **5,701 t** |

(b) Largo 2019 Sustainability Report

The $tCO_2e$/t FeV was calculated using the following equation

$$BE_x = \left(\sum Emissions_{CO2-e,energy}\right) /\ Baseline\ V_{Prod}$$

Where:

| | |
|---|---|
| $BE_x$ | = Annual baseline emissions per unit of metal production (tCO2e/t of final product) |
| $\sum$Emissions $_{CO2\text{-}e,\ energy}$ | = emissions for given GHG by type of fuel or power |
| $\text{Baseline V}_{\text{Prod}}$ | = Average Annual final product production (t) |

$BE_x = (\ 62{,}456.47\ \text{tCO2e} + 500\ \text{tCO2e})\ /\ 5{,}701$ t V = 11.04 tCO2e/t of ferrovanadium