ENVIRONMENTAL METRICS REPORT

YEAR 2010 DATA

FINAL

SEPTEMBER 2014
1 Introduction

This report serves as an adjunct to the “Global Life Cycle Inventory Data for the Primary Aluminium Industry” (2013) report, delivering Life Cycle Impact Assessment (LCIA) results for the worldwide aluminium industry using 2010 data.

The LCIA phase of a Life Cycle Assessment (LCA) is the evaluation of potential environmental and human impacts of environmental resource uses and releases by an industrial process or processes, identified during the Life Cycle Inventory (LCI).

Key Steps of an LCIA:

1. Selection and definition of relevant environmental (or health) impact categories - e.g. global warming, acidification, terrestrial toxicity.
2. Classification of LCI results according to selected impact categories (e.g. classifying tetrafluoromethane, methane and carbon dioxide emissions as having global warming potential).
3. Characterization of LCI results within impact categories by multiplying them with science-based factors and adding them up to category indicator results.
4. Normalization: the calculation of the magnitude of the category indicator results relative to some reference information, e.g. category indicator results of other materials.
5. Grouping: sorting and ranking of the impact categories.
6. Weighting: converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices; data prior to weighting should remain available.
7. Data quality analysis: better understanding the reliability of the collection of indicator results, the LCIA profile.

The ISO 14040 series states that the first three steps – impact category selection, classification, and characterization – are mandatory steps for an LCIA. The remaining steps are optional, depending on the goal and scope of the study.

In line with the ISO standard and the goal and scope, this report will address both the mandatory steps listed above.

1.1 Goal & Scope Definition

In brief, the goal and scope of this study is “to characterize accurately and at the global level resource inputs and significant environmental releases associated with the production of primary aluminium”. For the full goal and scope definition, please see the “Global Life Cycle Inventory Data for the Primary Aluminium Industry” (2013) report available at (http://www.world-aluminium.org/publications/tagged/life%20cycle/).
2 Methodology

This section describes the various methodologies used to produce LCIA results for the global aluminium industry.

2.1 Selection & Definition of Impact Categories

In accordance with the 2014 *PE International* publication “Harmonization of LCA methodologies for Metals (v1.01)” the LCIA methodology followed in this assessment is CML, with the following impact categories selected:

- Acidification potential
- Depletion of fossil energy resources
- Eutrophication potential
- Global warming potential
- Ozone depletion potential
- Smog potential (photochemical oxidant creation potential)
- Water Scarcity

In addition, a breakdown of the relative contribution to global warming potential of industrial processes in the primary aluminium value chain is included. For a complete description of the selected impact categories see Appendix A.

Table 1 - Pre-defined set of CML mid-point impact categories and indicator per kg of aluminium ingot

<table>
<thead>
<tr>
<th>Category Indicator Results</th>
<th>Unit (per kg Al)</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification Potential (AP)</td>
<td>kg SO₂ e</td>
<td>CML2001-Nov 2010</td>
</tr>
<tr>
<td>Depletion of fossil energy resources</td>
<td>MJ</td>
<td>net cal. value</td>
</tr>
<tr>
<td>Eutrophication Potential (EP)</td>
<td>kg PO₄ e</td>
<td>CML2001-Nov 2010</td>
</tr>
<tr>
<td>Global Warming Potential (GWP 100 years)</td>
<td>kg CO₂ e</td>
<td>CML2001-Nov 2010</td>
</tr>
<tr>
<td>Ozone Depletion Potential (ODP, steady state)</td>
<td>kg CCl₃F e</td>
<td>CML2001-Nov 2010</td>
</tr>
<tr>
<td>Photo-Oxidant Creation Potential (POCP)</td>
<td>kg C₂H₄ e</td>
<td>CML2001-Nov 2010</td>
</tr>
<tr>
<td>Water scarcity footprint (WSFP)</td>
<td>m³ H₂O e</td>
<td>ISO 14046:2014</td>
</tr>
</tbody>
</table>
2.2 Classification & Characterisation

As described in ISO 14044, the assessment of potential environmental impacts is divided into two steps which must be performed as a minimum:

- Assigning life cycle inventory results to life cycle impact categories (classification).
- Characterization of LCI results within impact categories by multiplying them with science-based factors and adding them up to category indicator results.

The two steps can be completed simultaneously using software tools to produce LCIA results.

Both the LCI datasets and LCIA results were modelled in GaBi version 6. The data used in the GaBi database for classification are published by:

- International Organization for Standardization (ISO);
- Society of Environmental Toxicology and Chemistry (SETAC);
- World Meteorological Organisation (WMO); and
- Intergovernmental Panel on Climate Change (IPCC).
2.3 LCI Data Modelling in GaBi Version 6

LCI datasets related to year 2010 were supplemented with data collected in IAI annual surveys (energy; http://www.world-aluminium.org/statistics/primary-aluminium-smelting-energy-intensity/, http://www.world-aluminium.org/statistics/primary-aluminium-smelting-power-consumption/, and perfluorocarbons (PFC); http://www.world-aluminium.org/statistics/perfluorocarbon-pfc-emissions/) to create the GaBi cradle to gate model.

Growth in primary aluminium production continues to be driven by China and the GCC countries and, since the late 1990s, is based on latest point fed prebake technology. Global primary aluminium production in 2010 was 42 million tonnes.

Figure 1 - Location of primary aluminium production, 1990 & 2006-2013 (SOURCE: IAI & CRU)

At present, and for the past 5 years or more China’s primary aluminium demand been in balance with its production, meaning that (for primary aluminium at least), Chinese metal has not been available for consumption outside China. We therefore present here two datasets, one global (GLO), quantifying the impact of the entire sector, and one global minus China (RoW), which reflects the impact of primary metal that is available to the market outside of China.

The differences between the GLO and RoW datasets are in the energy and PFC data – which are available on the IAI website split by region. Both datasets contain the global average LCI data, as this is not published by region and does not contain Chinese data.

Figure 2 and Figure 3 (page 8) show how the primary aluminium data have been modelled in GaBi.
In addition to the inventory data related to the aluminium processes collected as part of the IAI LCI and annual surveys, additional inventory datasets (background data) related to supplementary processes have been used. These datasets are included in the GaBi database version 6. The most important are listed below, though it should be noted that the list is not exhaustive:

- Limestone production (DE*, 2010)
- Caustic soda production (DE, 2010)
- Aluminium fluoride production (RER**, 2010)
- Petroleum coke production (EU27, 2008)
- Pitch production (DE, 2008)
- Electricity supply systems (GLO 2010)
- Fuel supply systems and fuel combustion (EU27 2009, GLO 2010)
- Transportation (GLO, 2010)

NB: Processing of residues (e.g. bauxite residue, dross and spent pot lining) is not included.

*DE = Germany
**RER = Europe
Figure 2 - Global data model in GaBi version 6

Figure 3 - Rest of World data model in GaBi version 6
2.3.1 Electricity Modelling

Primary aluminium production is an energy intensive process; the largest percentage of electricity used is in the electrolysis process (>95%); it is therefore important to represent accurately the electricity consumption using detailed data collected by the IAI.

An industry specific model was built within the GaBi database for the electrolysis process (for both prebake and Søderberg technologies) based on the IAI 2010 Power Consumption data (http://www.world-aluminium.org/statistics/primary-aluminium-smelting-power-consumption/).

Table 2 - Electricity sources for Global and Rest of World electrolysis datasets

<table>
<thead>
<tr>
<th></th>
<th>Global</th>
<th>RoW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro</td>
<td>41%</td>
<td>65%</td>
</tr>
<tr>
<td>Coal</td>
<td>51%</td>
<td>23%</td>
</tr>
<tr>
<td>Oil</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>5%</td>
<td>9%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2%</td>
<td>4%</td>
</tr>
</tbody>
</table>

NB. Any errors in total percentages are due to rounding

Regional electricity mixes (for the IAI reporting regions) were developed from individual LCI datasets for each energy carrier present within GaBi (using proxy data for regions with limited data – e.g. South Africa for Africa), based on the energy share reported in the 2010 IAI Energy Survey (see figure 4) of aluminium smelters worldwide (http://www.world-aluminium.org/media/filer_public/2013/01/15/iai_form_es001.pdf).

Figure 4 - Global Prebake Electrolysis: Africa Electricity Grid Mix
Based on production figures, each regional grid mix then feeds into the total global mix as seen in Figure 5.

Figure 5 - Global Prebake Electrolysis: Global Electricity Mix
2.3.2 Thermal Energy Modelling

A similar modelling process was used for thermal energy input for the following unit processes:

- Bauxite Mining;
- Anode Production;
- Paste Production; and
- Ingot Casting.

A regional mix was constructed for each energy source (e.g. hard coal), with the percentage share of each region modelled on a relevant proxy LCI dataset (e.g. Brazil for South America) present within the GaBi database (see figure 6 for an example).

Figure 6 - Global Alumina: Thermal Energy Mix from Hard Coal
2.3.3 Categorisation of Processes and Material Inputs and Outputs

The processes (and material inputs/outputs) within the system boundaries of the LCI datasets were classified in four categories; direct and auxiliary processes, transport, electricity and thermal energy. The data was then assigned to the categories using the GaBi software, which allows the contribution of the relevant processes to each impact category to be displayed within the LCIA results.

These four categories are defined as follows:

- Direct & Auxiliary processes: Direct material consumption/use or direct emissions associated with the production of primary aluminium (bauxite mining, alumina production, anode/paste production, electrolysis, and casting) and the ancillary processes and materials used in the production of primary aluminium, which includes caustic soda, lime and aluminium fluoride.
- Electricity: The processes and materials needed to produce the electricity directly used in the production of primary aluminium, including fuel extraction and preparation.
- Thermal energy: The processes and materials needed to produce the thermal energy directly used in the production of primary aluminium, excluding the pitch and coke used for anode production.
- Transport: Ship, road and rail transport of input materials.

2.4 Water Scarcity Footprint methodology

The Water Scarcity Footprint (WSFP) for the production of primary aluminium was calculated using an approach in accordance with ISO 14046.

The WSFP of a plant quantifies to which extent the water consumption of this plant contributes to water scarcity in the region where it operates. For this purpose the WSFP of each plant was determined by multiplying the plant specific water consumption with a local Water Scarcity Index (WSI). WSI values range from 0 to 1, with zero indicating water abundance and 1 indicating dry areas. The plant specific WSFP was then divided by 0.6, which is the average global WSI.

The direct WSFP was determined, based on direct water inputs into the site and water outputs from the site, i.e. without the water impacts of the relevant product or energy flows.

The data for calculating the indirect WSFP were supplied by PE International.

A generic water scarcity footprint per tonne of primary aluminium was then determined by summing up the WSFPs of the plants involved and normalizing it to the reference flow of 1 kg of primary aluminium.
3 Results & Evaluation

The impact category and additional indicator results (including GWP breakdown) were calculated using GaBi version 6 software and are reported per kg aluminium ingot. Water Scarcity Footprint results were calculated as part of a separate project in accordance with ISO 14046.

3.1 LCIA Results

Table 3 - Global and RoW Impact Category indicator results (per kg Al)

<table>
<thead>
<tr>
<th>IAI Impact Category indicator results (per kg primary ingot)</th>
<th>GLO 2010</th>
<th>RoW 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification Potential (AP) [kg SO2-Equiv.]</td>
<td>0.13</td>
<td>0.090</td>
</tr>
<tr>
<td>Depletion of fossil energy resources (Depl. Fossil Energy) [MJ]</td>
<td>163</td>
<td>109</td>
</tr>
<tr>
<td>Eutrophication Potential (EP) [kg Phosphate-Equiv.]</td>
<td>0.011</td>
<td>0.0053</td>
</tr>
<tr>
<td>Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>Ozone Layer Depletion Potential (ODP) [kg R11-Equiv.]</td>
<td>2.9E-10</td>
<td>2.8E-10</td>
</tr>
<tr>
<td>Photochemical Ozone Creation Potential (POCP) [kg Ethene-Equiv.]</td>
<td>0.0085</td>
<td>0.0047</td>
</tr>
<tr>
<td>Water Scarcity Footprint (WSFP) [m3 Water-Equiv.]</td>
<td>0.018</td>
<td>0.010</td>
</tr>
</tbody>
</table>
3.2 Relative Contributions of Processes to Impact Category Indicator Results

Figure 7 - GLO: Relative contributions to indicator results split by process type

Figure 8 - RoW: Relative contributions to indicator results split by process type
3.3 Relative Greenhouse Gas Contribution of Aluminium Production Processes

The following charts and tables show the relative greenhouse gas (GHG) contributions of the aluminium production processes. All figures are reported as kg CO2-Equiv./ kg Al.

Table 4 - Global greenhouse gas emissions split by unit process and process type

<table>
<thead>
<tr>
<th>Global</th>
<th>Bauxite Mining</th>
<th>Alumina Refining</th>
<th>Anode/Paste Production</th>
<th>Electrolysis</th>
<th>Ingot Casting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>&lt;0.1</td>
<td>0.4</td>
<td>&lt;0.1</td>
<td>9.2</td>
<td>&lt;0.1</td>
<td>9.7</td>
</tr>
<tr>
<td>Process &amp; Auxiliary</td>
<td>&lt;0.1</td>
<td>0.7</td>
<td>0.4</td>
<td>2.3</td>
<td>&lt;0.1</td>
<td>3.5</td>
</tr>
<tr>
<td>Thermal Energy</td>
<td>&lt;0.1</td>
<td>2.2</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Transport</td>
<td>0</td>
<td>0.5</td>
<td>&lt;0.1</td>
<td>0.4</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>Total</td>
<td>&lt;0.1</td>
<td>3.8</td>
<td>0.6</td>
<td>11.9</td>
<td>0.2</td>
<td>16.5</td>
</tr>
</tbody>
</table>

Figure 9 - GLO: Greenhouse gas emissions split by unit process and process type
Table 5 - RoW greenhouse gas emissions split by unit process and process type

<table>
<thead>
<tr>
<th>RoW</th>
<th>Bauxite Mining</th>
<th>Alumina Refining</th>
<th>Anode/Paste Production</th>
<th>Electrolysis</th>
<th>Ingot Casting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>4.6</td>
<td>&lt;0.1</td>
<td>4.8</td>
</tr>
<tr>
<td>Process &amp; Auxiliary</td>
<td>&lt;0.1</td>
<td>0.7</td>
<td>0.4</td>
<td>2.2</td>
<td>&lt;0.1</td>
<td>3.4</td>
</tr>
<tr>
<td>Thermal Energy</td>
<td>&lt;0.1</td>
<td>1.6</td>
<td>0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Transport</td>
<td>0</td>
<td>0.5</td>
<td>&lt;0.1</td>
<td>0.3</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>Total</td>
<td>&lt;0.1</td>
<td>2.8</td>
<td>0.6</td>
<td>7.2</td>
<td>0.2</td>
<td>10.8</td>
</tr>
</tbody>
</table>

Figure 10 - RoW: Greenhouse gas emissions split by unit process and process type

The largest greenhouse gas contributions are attributed to the alumina refining and electrolysis unit processes in both datasets. Both the Global and Rest of World datasets have similar contributions for bauxite mining, anode production and ingot casting.

The most significant differences within the alumina refining and electrolysis processes are the values for electricity and thermal energy. For example GHG values for electricity in electrolysis are 9.2 kg CO2-Equiv./kg Al for the GLO dataset and 4.6 kg CO2-Equiv./kg Al for the RoW dataset. These differences are due to coal based energy production in China, which produces approximately 50% of global aluminium.
4 Interpretation

4.1 Significant issues
Aluminium production is an energy intensive process, and from the results presented above the production of this energy results in a significant contribution to the overall environmental impact.

- Electricity production contributes between 25 and 80% to all impact category results, with higher values in the global dataset due to the coal based electricity production in China.
- From the breakdown of greenhouse gas emissions (Tables 4 and 5), electricity production for electrolysis is the largest contributor for GWP (56% of total for GLO and 43% of total for RoW), with thermal energy production for direct use in alumina refining contributing 13% for GLO and 15% for RoW.

Apart from emissions relating to energy production, other significant influences on the GWP results (14% for GLO and 20% for RoW) are direct emissions from the electrolysis process. Perfluorocarbons (PFCs) are a group of potent greenhouse gases with long atmospheric lifetimes. Tetrafluoromethane (CF₄) and hexafluoroethane (C₂F₆) are PFCs that are produced in the electrolytic process during events referred to as “anode effects” (for further information please see: http://www.world-aluminium.org/media/filer_public/2013/01/15/fl0000441.pdf).

The IAI has collected and published annual data on energy consumption (alumina refining and electrolysis) and anode effects since the 1980s and 1990s respectively. The monitoring of data and sharing of best practices has driven significant reductions in both energy input and PFC emissions by improvements in technology and optimising production conditions.

- In 2010 PFC emissions per tonne were cut by almost 90% compared with 1990. With strong growth in aluminium production over the same period, total annual emissions of PFCs to the atmosphere by the aluminium industry were reduced by 73% despite a 111% increase in primary aluminium production.
- For refining, there was a 9% improvement in energy intensity between 2006 and 2010 and for electrolysis, the total electrical energy consumed per tonne of aluminium was cut by 10%, 1990-2010.

The industry recognises the significance of these issues and is committed to driving continual improvement through a set of voluntary objectives known as Aluminium for Future Generations.

4.2 Sensitivity and consistency
As reported in the LCI report, all reported data points were checked individually in a systematic approach. Significant variations (+/- 2STD) in reported data, when compared with 2005 data, were queried with reporters and either confirmed or amended as appropriate.
4.3 Limitations

Reporting rates for 2010 surveys are shown in figures 11 and 12. For further information on reporting rates, please see Section 2.1 of the LCI report (http://www.world-aluminium.org/publications/tagged/life%20cycle/).

Figure 11 - GLO response rates and production figures for data year 2010

Figure 12 - RoW response rates and production figures for data year 2010
With regards to modelling in the GaBi v6 database, there are inevitably some limitations to the accuracy of the results given that the quality of background dataset can vary considerably. In addition, proxy datasets have been used when the required datasets were not available. However, the effects of this have been limited by the appropriate selection of the best available datasets, as advised by PE International consultants.

4.4 Conclusion

The publication of this, the first cradle to gate LCIA report published by the IAI, demonstrates the global aluminium industry’s dedication to report openly its environmental impacts and to publish regularly the latest and most representative data.

LCI data is collected on a five year cycle, and as such the next report will be published in 2017 using year 2015 data. During this time, the IAI will continue to monitor advances in LCA methodologies and in accordance with recommendations from future editions of the Harmonization of LCA Methodologies for Metals report, additional impact categories may be added.

In addition, the impact of annually collected IAI statistics on LCI and LCIA results will be evaluated using the GaBi database, and any significant variations will be reported.
### Appendix A: Description of Impact Categories

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Impact Category Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidification Potential (AP)</td>
<td>This relates to the increase in quantity of acidifying substances in the low atmosphere, which cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Acidification potential is caused by direct outlets of acids or by outlets of gases that form acid in contact with air humidity and are deposited to soil and water. Examples are: SO2, NOx and Ammonia.</td>
</tr>
<tr>
<td>Depletion of fossil energy resources</td>
<td>This impact category quantifies the extraction of fossil fuels due to inputs into the system like coal, crude oil, natural gas or uranium.</td>
</tr>
<tr>
<td>Eutrophication Potential (EP)</td>
<td>Aqueous eutrophication (also known as nutrification) is characterized by the introduction of macro-nutrients (e.g. in the form of phosphatised and nitrogenous compounds), which leads to the proliferation of algae and the associated adverse biological effects. This phenomenon can lead to a reduction in the content of dissolved oxygen in the water which may result in the death of flora and fauna.</td>
</tr>
<tr>
<td>Greenhouse Gas emission (GWP 100 years)</td>
<td>Greenhouse gases (e.g. CO₂, CH₄ and C₂F₆) are components of the atmosphere that contribute to the greenhouse effect by absorbing, and subsequently re-emitting, outgoing long wave heat radiation, thus increasing the lower atmosphere temperature. The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission.</td>
</tr>
<tr>
<td>Ozone Layer Depletion Potential (ODP, steady state)</td>
<td>Stratospheric ozone depletion (especially above poles) causes a larger fraction of UV-B radiation to reach the earth surface and results mainly from a catalytic destruction of ozone by atomic chlorine and bromine. The main source of these halogen atoms in the stratosphere is photodissociation of chlorofluorocarbon (CFC) compounds, commonly called freons, and of bromofluorocarbon compounds known as halons. These compounds are transported into the stratosphere after being emitted at the surface.</td>
</tr>
<tr>
<td>Photo-oxidant Creation Potential (POCP)</td>
<td>Photo-oxidant formation is the formation of reactive substances (mainly ozone), created by high concentrations of pollution and daylight UV rays at the earth's surface. There is a great deal of evidence to show that high concentrations (ppm) of these substances (mainly ozone) are injurious to human health and ecosystems and may also damage crops. The majority of tropospheric ozone formation occurs when nitrogen oxides (NOₓ), carbon monoxide (CO) and volatile organic compounds (VOCs), such as xylene, react in the atmosphere in the presence of sunlight. NOₓ and VOCs are called ozone precursors.</td>
</tr>
<tr>
<td>Water Scarcity</td>
<td>Water scarcity is the extent to which demand for water compares with the replenishment of water in an area (e.g. a drainage basin). This impact category quantifies the contribution of the water inputs and water outputs to water scarcity.</td>
</tr>
</tbody>
</table>
Appendix B: Reference Material


