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Final Report

Life Cycle Impact Assessment of Aluminum Beverage Cans

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ACRONYMS

AA	Aluminum Association
AP	Acidification Potential
CMI	Can Manufacturers Institute
CML	Centre of Environmental Science at Leiden
EoL	End-of-Life
EP	Eutrophication Potential
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
IAI	International Aluminum Institute
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-methane volatile organic compound
ODP	Ozone Depletion Potential
PEA	PE Americas
POCP	Photochemical Ozone Creation Potential
RSI	Recycled scrap ingot
UBC	Used Beverage Can
USGS	United States Geological Survey
VOC	Volatile organic compound

EXECUTIVE SUMMARY

This report outlines the life cycle inventory of an aluminum beverage can produced in the United States. The study was commissioned by the Aluminum Association (AA) to respond appropriately to the increasing market demand for life cycle data on the environmental performance of products. A life cycle inventory of a product quantifies all material and energy use and environmental releases over its entire life cycle - from raw material acquisition through to ultimate disposal.

The goal of this study is to provide the Aluminum Association, concerned aluminum industry stakeholders, and life cycle assessment practitioners with up-to-date life cycle inventory data for beverage cans of the following sizes as produced in North America: 8 oz., 12 oz., 16 oz., 24 oz. and 32 oz. The scope of the study is “cradle-to-grave”, i.e. starting with the extraction of the bauxite ore and including all processes required to produce an aluminum ingot, manufacture the aluminum beverage can, and recover and recycle secondary raw material from the used beverage can (UBC).

Two approaches to model the recycling system (closed loop recycling approach and recycled content approach) were considered to ensure that the study’s results can be directly compared with the results of other studies, which might use either of these approaches.

Both approaches used a common set of baseline assumptions, as defined below:

- Average can weight of 13.34 kg per 1000 cans
- The used beverage can recycling rate in the year 2006 is 51.6%
- The recycled content of the beverage can in the U.S. in 2007 is 67.8%
- Post production and run-a-round scrap from rolling mills is completely recycled in a closed loop. The production of secondary aluminum ingot from post production and run-a-round scrap does not require any input of primary aluminum.
- Can manufacturing scrap is dealt with in the same manner as UBC scrap and included in the recycled content of the can.

Aluminum beverage cans are manufactured through the following major processes (Figure A): primary aluminum production (including bauxite mining and alumina refining), secondary aluminum production; aluminum can sheet production, and can manufacturing. These are shown in Figure A.

At the end of life of its useful functions, UBCs are collected, shipped and recycled back to new aluminum metal. A proportion of the UBCs, however, are lost to landfills or other types of sinks due to consumer behaviors.

In modeling both the primary aluminum and secondary aluminum production processes, a functional unit of 1000 kg aluminum ingot is used. Separate models for North America (US and Canada) and global production were used to reflect the mixture of primary aluminum consumption in the US in the target year. The production of secondary aluminum starts with scrap collection and ends with secondary metal processing. The casting of aluminum for subsequent can sheet production is considered as one process.

In producing 1000 kg of primary aluminum, 5246 kg of mined and processed bauxite was used to produce 1915 kg of alumina. 1018 kg of liquid metal was generated out of the electrolysis reduction process, 1000 kg of ingot was casted in the end, and the rest of the metal was recycled back in a closed loop.

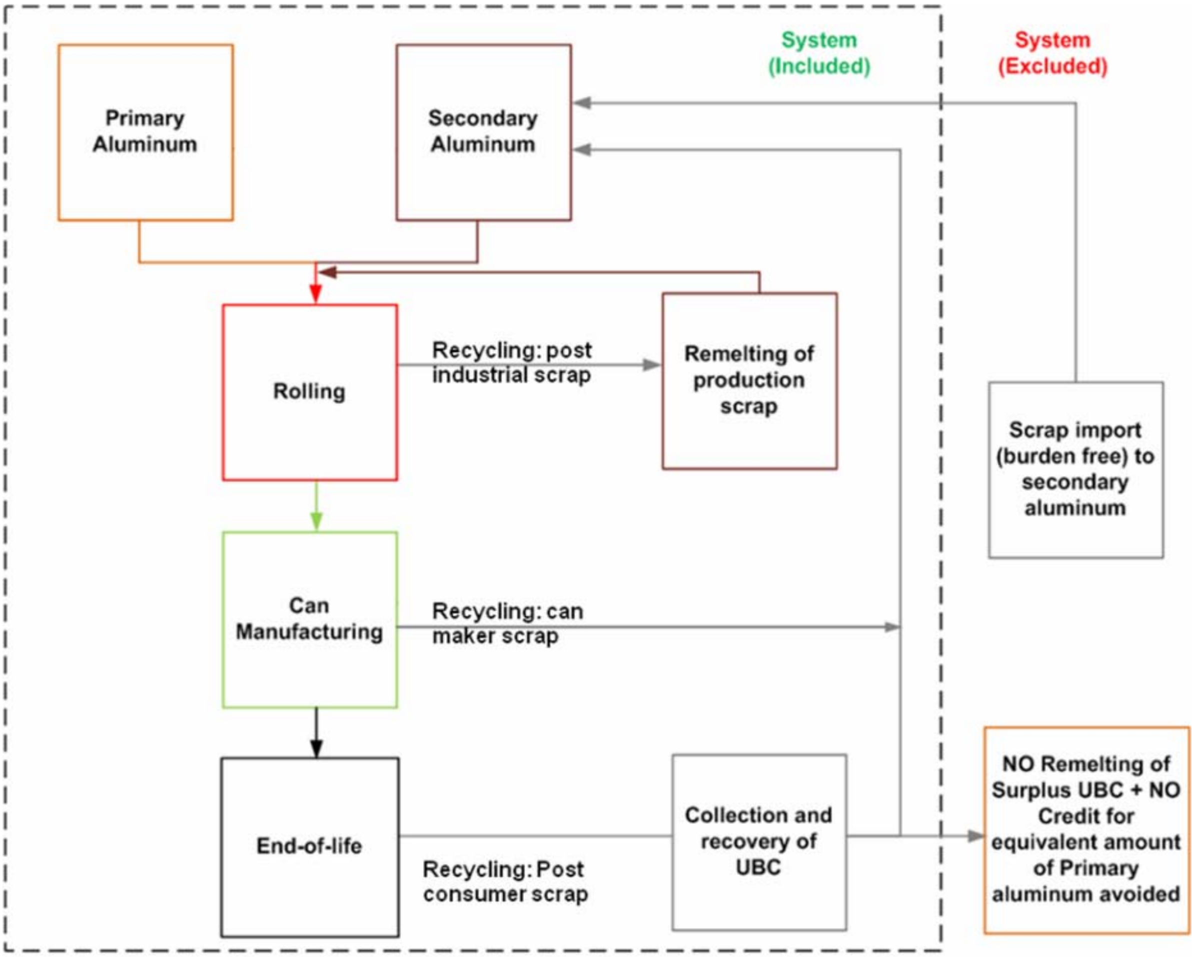

Figure A: Processes in the life-cycle of aluminum cans (recycled content perspective)

Process based primary energy demand, which includes primary energy used for fuel production, transportation, and electricity generation and transmission, for 1000 kg primary aluminum (bauxite mining, alumina refining, electrolysis, and ingot casting) is shown in the table below.

Process-Based Primary Energy Demand for 1000kg Primary Aluminum Production

	Bauxite Mining	Alumina Refining	Electrolysis	Ingot Casting
Primary Energy Demand for fuel production, transportation, & electricity generation and transmission	1.02 GJ	27.36 GJ	124.27 GJ	2.36 GJ
Energy from non-fossil fuel sources, from above numbers	0.02 GJ	0.28 GJ	49.75 GJ	0.23 GJ

Primary energy demand for 1000 kg secondary aluminum production was 6909 MJ (including scrap preparation) which required 1059 kg of unprocessed scrap as input.

In making can sheets, primary aluminum, secondary aluminum, and can making scrap (the skeleton, or web scrap, usually sold by can makers) were mixed and melted in the secondary melting furnaces, and/or in the primary cast house to produce ingots for rolling. The rolled can sheets, including can body sheets and can lid sheets, were shipped to can makers to manufacture the final products.

Under the closed-loop/end-of-life approach, the production of 1000 cans at a can manufacturing plant requires 16.78 kg of aluminum sheet (inclusive of can body and lid). The can manufacturing process yields 3.447 kg of post-industrial scrap (the skeleton) and is shipped back to the remelting plants. The rolling mills generates 6.501 kg of scrap metal and it is immediately recycled back to the rolling process. This is treated as an internal run-around scrap.

In order to produce 16.78 kg of aluminum sheet (for 1000 cans), the total amount of aluminum ingot input required for the rolling process is 23.31 kg. This is produced from:

- 8.736 kg of secondary aluminum produced from UBC scrap, non-can post-consumer scrap, and non-can post-industrial scrap
- 3.447 kg of aluminum produced from can post-industrial scrap (skeleton from can manufacturing plants)
- 5.8 kg of primary aluminum, and
- 6.501 kg of aluminum from rolling process which is treated as a internal run-around scrap

At the End of Life (EoL), 6.984 kg of UBC scrap (51.6% of the average can weight of 13.34 kg per 1000 cans) are recovered. The can product system in the U.S. for the year 2006 requires 12.23 kg of scrap for the production of secondary ingot. An additional 1.797 kg of scrap is therefore required to make up this deficit. In the recycled content approach, this additional scrap is sourced from a "scrap sink" and there is no "net burden" given to the product system. The "scrap sink" can be considered as a stockpile of secondary raw material which is not utilized for further processing and recovery of the material.

In the recycled content system, the total primary energy demand per 1000 cans with a 51.6% UBC recycling rate is 1692 MJ. The share of total primary energy demand over all life cycle stages of the can is shown in Figure B.

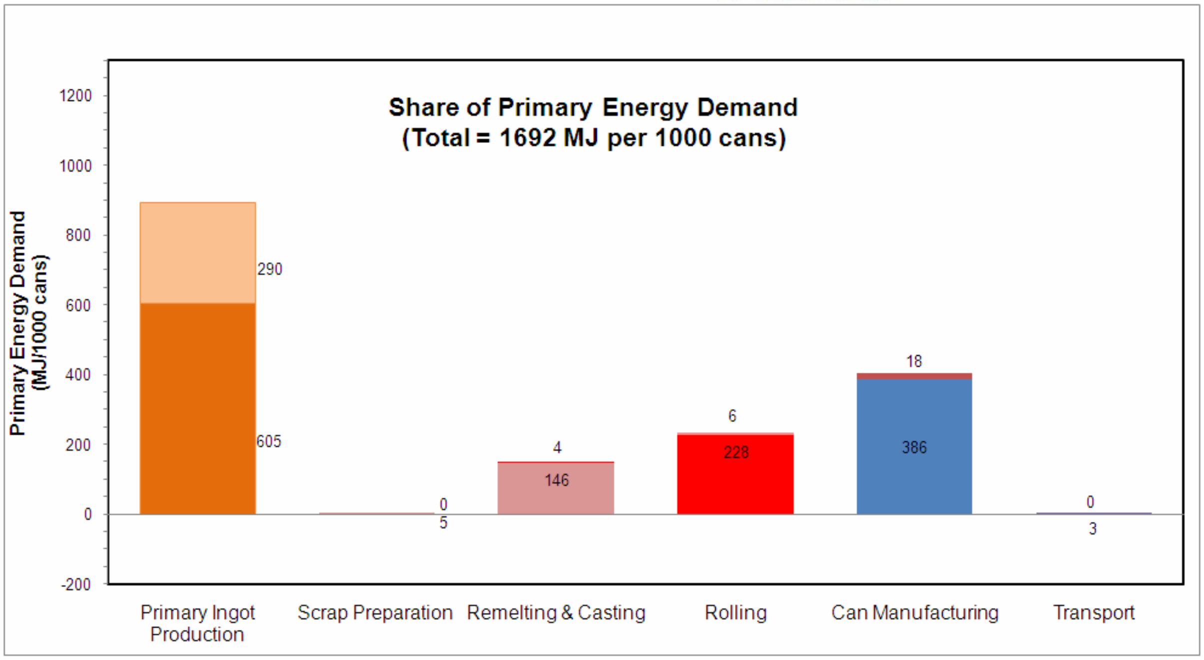

Figure B: PE breakup for can life-cycle (recycled content)

The solid color portion of each bar represents the non-renewable fraction of primary energy and the light-shaded portion represents the renewable fraction of primary energy.

The environmental footprint of 1000 cans under each approach (closed loop and recycled content) is listed in the table below:

Table A. Environmental Footprint of 1000 Cans

Selected LCI Parameters	Closed Loop	Recycled Content	Unit
Primary energy demand	**1943**	**1692**	**MJ**
Non renewable energy resources	1540	1374	MJ
Renewable energy resources	403.3	318.3	MJ
INPUTS			
Can sheet	16.78	16.78	Kg
OUTPUTS			
Carbon dioxide	121.6	105.9	Kg
Carbon monoxide	0.047	0.041	Kg

Nitrogen oxides	0.24	0.211	Kg
Sulphur dioxide	0.436	0.376	Kg
VOCs	0.209	0.188	Kg
Selected LCIA Parameters (CML 2001)			
Global warming potential (GWP 100 years)	131.5	113.8	kg CO_2 Eq.
Acidification potential (AP)	0.613	0.532	kg SO_2 Eq.
Eutrophication potential (EP)	1.565	1.561	kg Phosphate Eq.
Photochemical Ozone creation potential (POCP)	0.051	0.046	kg Ethene Eq.
Ozone Layer depletion potential (OPD)	3.76E-06	3.61E-06	kg R11 Eq.

Under the closed loop approach, the mass flows per 1000 cans are similar to the recycled content approach flows except for the fact that the deficit scrap metal which is imported into the system is assigned a “net burden” which is the sum of the environmental burdens associated with the amount of primary aluminum ingot required to replace this deficit minus those associated with the re-melting of surplus scrap to produce secondary aluminum ingot. Therefore, the environmental footprint of the cans in the recycled content approach appears to be lower than in the closed loop consideration.

To examine the influence of the UBC recycling rates on the environmental performance of the beverage can product system, additional scenarios are evaluated based on the following UBC recycling rates:

- 30% - Hypothetical low UBC recycling rate
- 45.1% - UBC recycling rate estimated by Container Recycling Institute (ca. 2004) (CRI, 2008)
- 62% - Peak UBC recycling rate achieved during the mid 1990s
- 75% - Aluminum Association future goal for UBC recycling rate

The variation in total primary energy demand per 1000 cans under different scenarios is shown in Figure C and the results are presented for both closed loop/end-of-life and recycled content approaches.

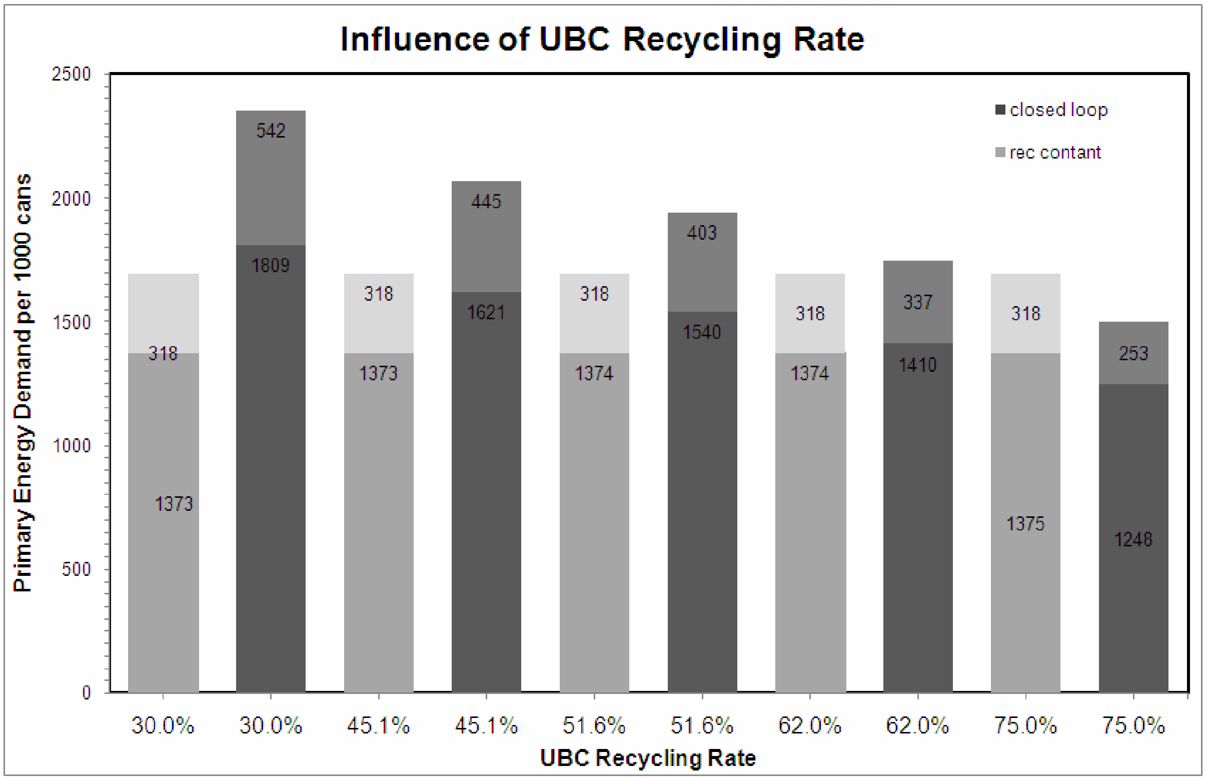

Figure C: Variation of primary energy with recycling rates for closed loop and recycled content approaches

At a higher UBC recycling rate (i.e. 75%), the closed loop approach seems more favorable, whereas at a lower recycling rate (i.e. 30%), the recycled content approach seems more favorable, as the product system would still try to maintain the recycled content of the can and sources of scrap might be from product systems other than the can system. The reason is that the recycled content approach cuts off both, surplus UBC scrap as well as an unsaturated scrap demand in case the recycling rate is lower than the recycled content of the can.. As a result, the primary energy demand under the recycled constant approach does not change as the recycling rate is varied. It is likely that recycled content of the can will increase as the UBC recycling rate increases, under the assumption that more UBC scrap will be available in the market for can making. However, there are other market forces (e.g. export of UBC scrap to other countries, use of UBC scrap for automotive sheet production) which can influence the availability of UBC scrap to secondary aluminum producers. The influence of various factors which determine the recycled content of the can in United States is beyond the scope of this study. Therefore, in the study the recycled content of UBCs in cans was kept constant at 67.8% and only the UBC recycling rate was varied in scenario analysis.

Detailed discussions of the study's results are extensively documented in this report, but the following main conclusions can be drawn from the results of the study:

- The environmental profile of primary aluminum production has a significant influence on the overall environmental burden results for the manufacture of a beverage can. The contribution is around 53% in the case of the recycled content approach and 46% for closed loop approach.

- The electrolysis unit process of primary aluminum production accounts for between 72 and 79% of the can's environmental impacts. However, it is the upstream environmental burdens associated with the electricity used for electrolysis that is the main contributor to these impacts[1]. Can manufacturing and rolling operations also contribute considerably to the environmental burdens associated with production of beverage cans.
- At present, with the used beverage can (UBC) recycling rate of 51.6%, the difference of 250MJ per 1000 cans between environmental burdens under closed loop and recycled content approaches is significant and in favor of the recycled content approach. This is due to the fact that the amount of metal needed to satisfy the recycled content of the can sheet is greater than the amount of metal collected. In the closed loop approach, this deficit is sourced from primary metal while in the recycled content approach, the additional scrap is imported into the system burden-free. However, as the Aluminum Association achieves higher UBC recycling rates, the closed loop approach will produce more favorable results.

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[1] Power production and consumption associated with those upstream processes however are out of control of the aluminum industry and thus cannot be directly influenced by the aluminum industry.

1 INTRODUCTION

Life cycle assessment (LCA) is a standardized scientific method for systematic analysis of flows (e.g. mass and energy) associated with the life cycle of a specified product, a technology, a service or manufacturing process systems (ISO, 2006a). The approach in principle aims at a holistic and comprehensive analysis of the above items including raw materials acquisition, manufacturing as well as use and End-of-life (EoL) management. According to the International Organization for Standardization (ISO) 14040/44 standards, an LCA study consists of four phases : (1) goal and scope (framework and objective of the study); (2) life cycle inventory (input/output analysis of mass and energy flows from operations along the aluminum products value chain); (3) life cycle impact assessment (evaluation of environmental relevance, e.g. global warming potential); and (4) interpretation (e.g. optimization potential) (ISO, 2006a; ISO, 2006b).

The goal and scope stage outlines the rationale of the study, the anticipated use of the results of the study, the boundary conditions, the data requirements and the assumptions to analyze the product system under consideration, and other similar technical specifications for the study. The goal of the study is to answer the specific questions which have been raised by the target audience and the stakeholders involved, while considering potential uses of the study's results. The scope of the study defines the systems' boundary in terms of technological, geographical, and temporal coverage of the study, attributes of the product system, and the level of detail and the complexity addressed by the study.

The life cycle inventory (LCI) stage documents qualitatively and quantitatively analyze the materials and energy used (inputs) as well as the products and by-products generated and the environmental releases in terms of non-retained emissions to the environmental compartments and the wastes to be treated (outputs) for the product system being studied. The LCI data can be used on its own to: understand total emissions, wastes and resource-use associated with the material or the product being studied; improve production or product performance; or be further analyzed and interpreted to provide insights into the potential environmental impacts from the system (life cycle impact assessment and interpretation, LCIA).

In 1991, Alcoa, Alcan, and Reynolds commissioned a LCI analysis of the 12 oz. North American aluminum beverage can. The results of this previous study represented:

- The industry average information on environmental performance of the three participating companies with respect to their operations on primary aluminum ingot production, secondary aluminum ingot production, and aluminum can sheet production (Alcoa, Alcan and Reynolds (acquired by Alcoa in 2000)),
- The cumulative resources and environmental burdens associated with the manufacturing of 1,000 cans including bauxite mining, alumina refining, smelting, ingot casting, can sheet fabrication, can making, can-filling (including the burdens of the beverage as well), consumer use and recovery of used beverage cans (UBC), and recycling,
- The actual industry average operations and a 62.4% post consumer recycling rate representative of the North American aluminum beverage can industry in 1991.

The study quantified all significant inputs and outputs of the beverage can system. The input categories included 99.0% of the mass of raw materials identified in the system and 99.6% of the energy consumed. The environmental releases were quantified for air, water and solid waste and sub-divided into process-related, fuel-related and transportation-related data categories. More detailed information and results are available in the study report of Pomper, Hauser and Richards

(1994). The companies were competitors in the beverage can market and thus prohibited the sharing of market relevant data under anti-trust regulations. Therefore, the information generated by the study was consolidated by the LCI practitioner. The information derived from the study was presented in an aggregated form as a weighted averaged of the three individual company's data and thus was in line with the anti-trust regulations.

In order to conform with the increasing pressure from product manufacturers and the consumer retail markets to select environmentally preferable packaging options, Aluminum Association (AA) engaged PE Americas (PEA) to help update the aluminum beverage can LCI to the most up-to-date industry data available.

The aim of the study is to generate high-quality, up-to-date data on the environmental performance of aluminum beverage can production including the flow of secondary materials from End of Life back into beverage cans. With such an LCI database, the Aluminum Association and its member companies can assist other organizations to understand and communicate the environmental benefits of manufacturing with aluminum rather than other materials with similar physical properties. At the same time, this database helps site-level personnel understand the environmental performance of their manufacturing processes, and the potential environmental benefits of process improvements. Beyond the operations of a single manufacturing site, the LCI database evaluates the environmental performance of beverage cans throughout their entire life cycle. It provides useful insights for different stakeholder groups, such as primary or secondary aluminum producers, aluminum users, waste recyclers, government agencies, non-governmental organizations, LCA practitioners, and media.

For this study, a core project team was established to direct, review, and coordinate the activities associated with methodological agreement, collection of data, modeling, presentation and dissemination of the LCI results. The members of the core group for this project are: Craig Covert [Alcoa], Geoff Cullen [Can Manufacturers Institute], Jim Fava [PE Americas & Five Winds International], Ken Martchek [Alcoa], Robert Strieter [Aluminum Association] and Gerri Walsh [Ball].

Different companies participated in the study to provide data for the various production stages of the beverage can include: Mill Rolling (Alcoa, Logan Aluminum, and Wise Alloys), Can Manufacturing (Can Manufacturing Institute) and other Secondary Aluminum Producers (Aleris, Novelis).

2 GOAL AND SCOPE OF THE STUDY

2.1 GOAL

The goal of this LCA study is to provide the Aluminum Association, the aluminum industry stakeholders, and the LCA practitioners with up-to-date LCI data for beverage cans of the following sizes[2]: 8 oz., 12 oz., 16 oz., 24 oz. and 32 oz.

The update of the beverage can LCI became necessary as the original LCI became increasingly out of date - partly due to technological and technical changes and partly due to the fact that

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[2] The LCI data for the different sizes represent weighted averages.

the original LCI could no longer meet the information needs of today. The updated LCI shall reflect the current technological situation as well as the North American Market situation.

The intended audience for this study is the Aluminum Association itself, the potential customers and decision makers in industry, as well as the general public. The Aluminum Association experts will use the information from this study in an aggregated manner for public communications, to develop marketing materials for potential customers and to provide data to customers for the purpose of developing LCIs within their own applications.

The present update of the beverage can LCI is intended to be used for comparative assertions to be disclosed to the public, and is therefore subject to external critical review according to ISO 14044 guidelines.

2.2 SCOPE

The scope of the study comprises a “cradle-to-grave” LCI, starting with the extraction of the bauxite ore at the mine, including the production of aluminum ingot and the manufacturing of the aluminum beverage can, and ending after the recovery and recycling of the UBC. Table 1 summarizes the system boundaries with regard to the general processes/quantities that are considered in the study. The LCI profile results are provided for each of two different recycling approaches:

- Closed loop recycling
- Recycled content

2.2.1 Product System(s) Boundaries

The product being examined is an average beverage can made of aluminum. Its content, manufacture, and impact represent the current technological and technical situation in the North American market. The function of the beverage can is to serve as container for beverages such as beer or soft drinks. There are no other functions of the analyzed average beverage can considered in this study.

Table 1: Summary of system boundaries

Included	Excluded
• Raw materials extraction • Energy and fuel inputs • Further processing materials (e.g. chemicals, solvents, etc.) • Processing of raw materials and semi-finished products • Transportation of raw and processed materials • Product recycling	• Capital equipment and maintenance • Overhead (heating, lighting) of manufacturing facilities when easily differentiated • Maintenance and operation of equipment • Manufacture of any beverage and its filling in cans • Internal transportation of materials • Use of product • Packaging of cans for distribution to consumers • Human labor • Product disposal (i.e. land filling)

2.2.1.1 Closed loop recycling approach

The system flow chart for closed loop conditions is presented below in Figure 1. The flow chart highlights the recycling of post-industrial clean can scrap (from rolling and can manufacturing) as well as the recycling of post-consumer scrap (UBC from the EoL phase).

The closed loop approach is based on a product life cycle and material stewardship perspective. It considers the fate of products after their use phase and the resultant material output flows. In evaluating the environmental impacts of a product system using this approach, the EoL management of the product is also taken into account and therefore, possible changes to improve the system can be considered. The specific origin of input material (whether primary or recycled) is irrelevant as typically the net conservation of material is what minimizes the total environmental impacts.

Under this framework, the product being examined is considered to be completely recycled once it reaches the EoL phase. Material losses during the collection and processing of UBC as well as those associated with the production of secondary material feedstock out of UBC are taken into account. Consistent with ISO 14044, these losses are considered to be replaced by primary material feedstock. For a given product system, a certain amount of secondary raw material feedstock is required (determined by existing market conditions). It is sourced from both post-industrial and post-consumer scrap. In most product systems, post-industrial scrap is recycled in a closed loop and partially satisfies the demand for secondary raw material feedstock (Figure 1). The remaining demand for secondary material feedstock is met with post-consumer scrap, i.e. UBC.

If the amount of UBC scrap generated is less than what the product system requires, then the environmental burdens associated with meeting the secondary raw material feedstock demand are included in this closed-loop model, i.e. the environmental implications associated with supplementary raw material production is considered (Table 2). If, however, the amount of UBC scrap is larger than what the product system requires, then the product system receives a net credit, equivalent to the sum of environmental impacts from primary material extraction and re-melting of surplus post-consumer scrap.

A designer using this approach focuses on optimizing product recovery and material recyclability. By facilitating greater end-of-life recycling, the decision-maker mitigates the loss of material after product use. This approach assesses the consequences at the end-of-life of the product based on established technical practices, and supports decisions for an efficient market. This concept allows design for recycling.

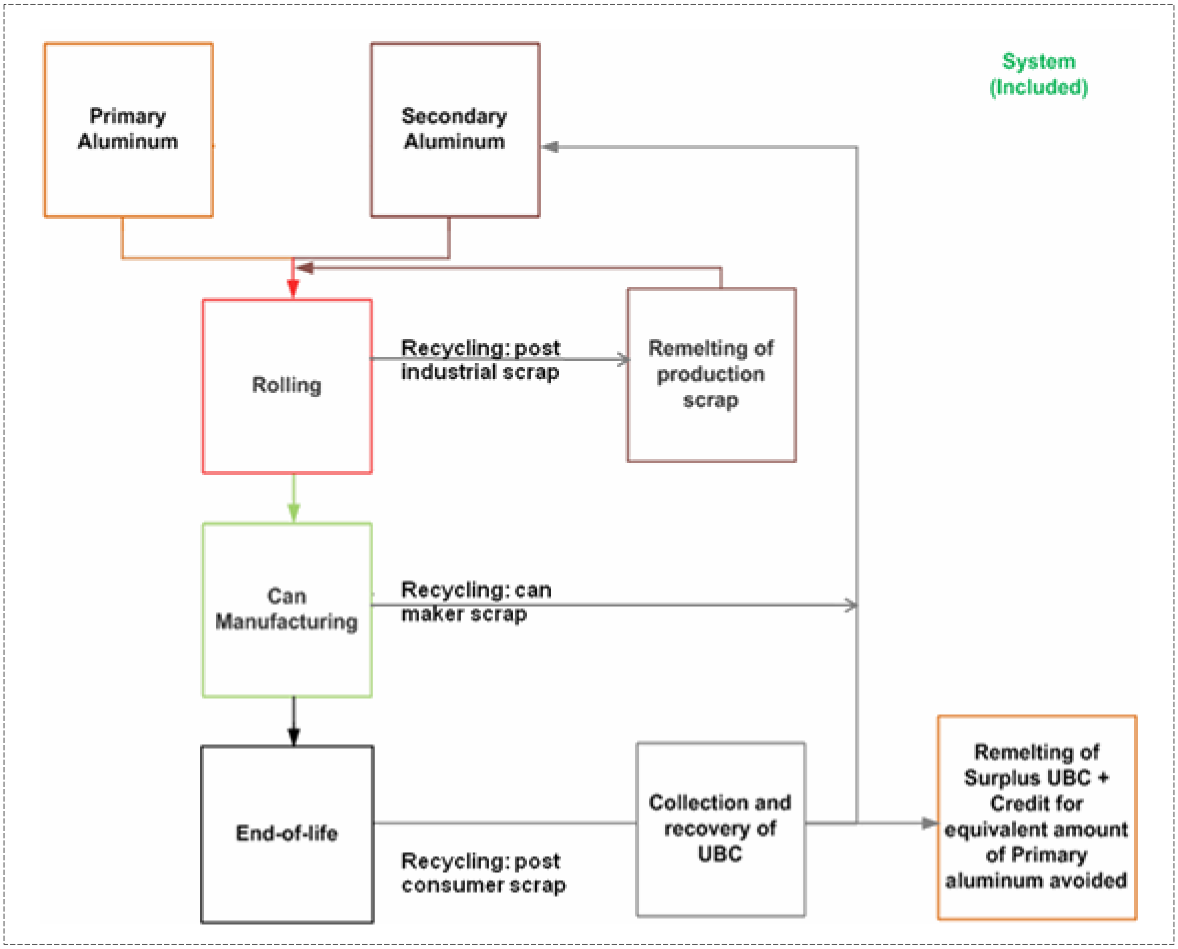

Figure 1: Process flow chart indicating the system boundary for aluminum beverage can under closed loop recycling conditions. The product being examined is considered to be completely recycled once it reaches the EoL phase. Material losses during both the collection and the processing of UBC as well as losses associated with the production of secondary material feedstock out of UBC are taken into account. In the case of excess UBC scrap, the product system receives a net credit equivalent to the sum of primary material avoided. The flow chart highlights the recycling of post-industrial can scrap (from rolling and can manufacturing) as well as the recycling of post-consumer (UBC) scrap (from the EoL phase).

2.2.1.2 Recycled content approach

The system flow chart for the recycled content approach is presented below in Figure 2. The recycled content approach adopts a waste management perspective, where the sourcing of raw material feedstock (both primary and secondary raw materials) is considered to be of importance. It assumes that the use of recycled material is a good indicator of environmental benefit. In the case of Aluminum for example, the benefits of recycling (primary material production and waste disposal avoidance) outweigh the burdens of post-consumer collection and processing. The recycled content approach aims at promoting a market for recycled materials that is otherwise limited, uneconomic or immature. It may also serve as a good metric for materials that would otherwise be incinerated or landfilled as waste (assuming that these waste management treatment processes would result in higher environmental impacts than the material's recycling).

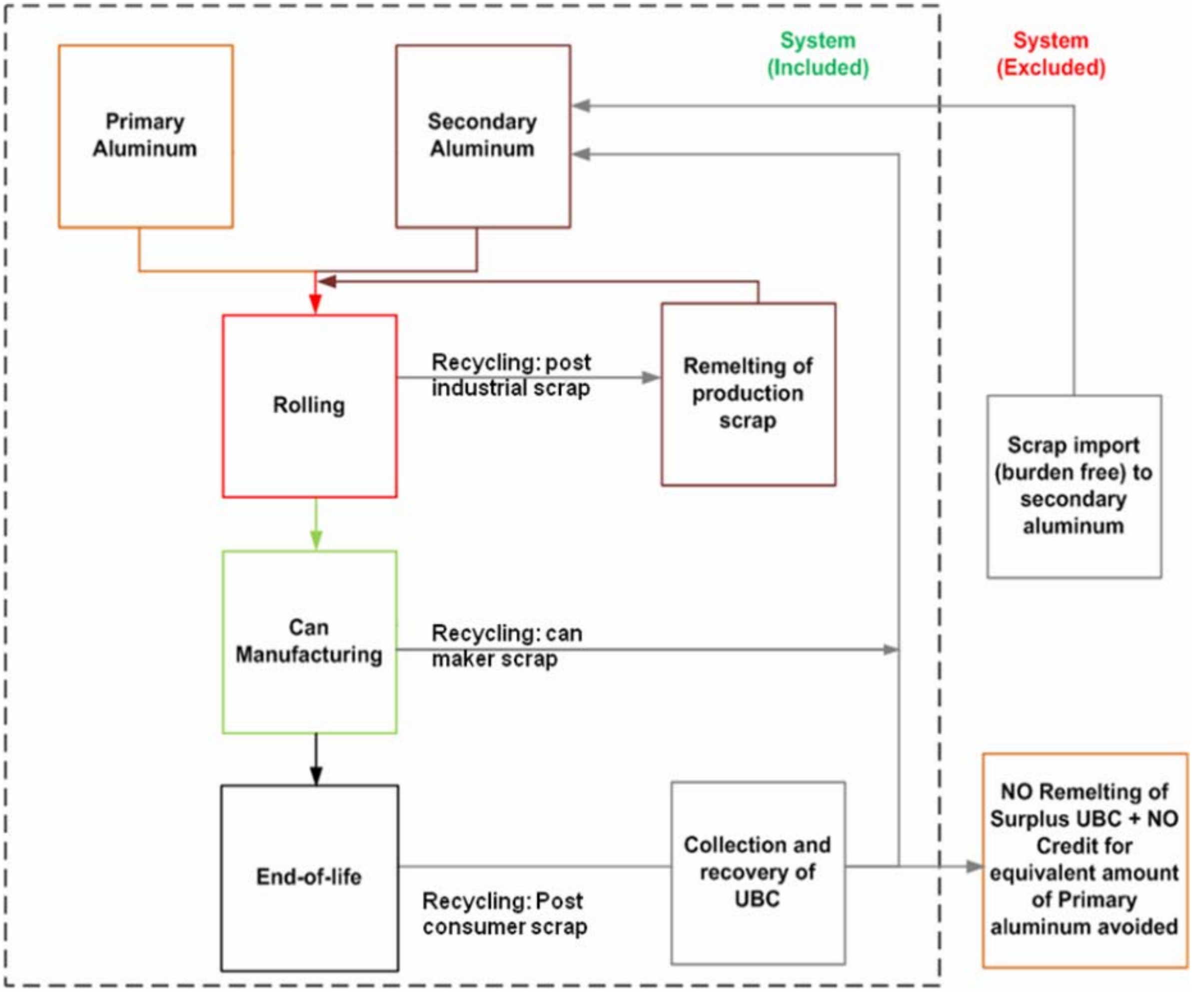

Figure 2: Process flow chart indicating the system boundary for aluminum beverage can under recycled content conditions. This approach excludes consideration of actual collection and recycling efficiencies, rather considers "snap shots" of current material feed situation in terms of primary and secondary materials. If the amount of UBC scrap is greater than what the product system requires, then the surplus UBC scrap leaves the system without any consideration of environmental burdens associated.

In the recycled content approach, the amount of secondary raw material feedstock in the final product is usually specified. The product system then meets the specified recycled content by sourcing secondary raw materials from post-industrial scrap and from UBC. This approach differs from the closed loop approach in its accounting for environmental impacts when the amount of aluminum available from post-industrial scrap and UBC recovery does not meet the specified amount of recycled content. If the amount of post-industrial scrap and UBC recycling is less than the product system requires, then additional secondary aluminum is imported burden-free, i.e. the environmental burdens associated with meeting the secondary raw material feedstock demand are excluded (Figure 2). If, however, the amount of UBC scrap is greater than what the product system requires, then the surplus UBC scrap leaves the system without receiving credit for avoided environmental burdens. In this manner the system boundary is still constructed to fairly allocate environmental burdens in a system with recycled content. It should be noted that the recycling of post-industrial rolling scrap is still considered part of a closed loop, which is generally true of current manufacturing practices.

Unfortunately, the application of the recycled content approach may create market distortions and environmental inefficiencies. If a designer specifies a high recycled content in a well-meaning effort to increase the overall environmental performance of a product, it may stimulate the market to direct recycled feedstock towards designated products and away from production where recycling is most economical. For metals, where there is a limited supply of recycled feedstocks, market stimulation is ineffective and may result in inefficient processing and unnecessary transportation.

The key characteristics of the two approaches are described in Table 2.

Table 2: Key characteristics of the closed loop and recycled content approaches

Closed loop approach	Recycled content approach
• Adopts a product life cycle and material stewardship perspective • EoL material is recycled and fed back in a closed loop (can to can) production • Metal losses have to be replaced by virgin material (losses during remelting of production and EoL scrap, collection and processing of UBCs) • In case the amount of UBC scrap collected in the EoL phase exceeds the amount of UBC scrap consumed (as secondary raw material) for can production in a given system, the product system under consideration receives a net credit equivalent to the sum of primary aluminum avoided and the remelting of surplus UBC scrap • If the can product system for a given system requires more secondary raw materials from UBC than it generates, then additional burdens associated with the production of primary raw material replacing the missing amount of secondary raw material from UBC scrap are included	• Adopts a waste management perspective • Excludes the consideration of actual collection and recycling efficiencies, rather considers “snap shots” of current material feed situation in terms of primary and secondary raw materials • Surplus secondary material in form of UBC scrap leaves the can production system burden free (i.e. no burdens associated with remelting of surplus UBC scrap and no credit for the equivalent amount of primary aluminum avoided is assigned) • If the can product system for a given system requires more UBC scrap than it generates, then additional burdens of importing UBC scrap are excluded (UBC scrap is imported without consideration of remelting efforts).

2.2.2 Data Collection, Software and Databases

The study included data collection in the following categories for rolling, can manufacturing and secondary aluminum production:

- Fuel and energy use,
- Use of raw materials, ancillary materials,
- Products, co-products,
- Emissions to air, water and soil,

- Wastes.

Primary data collection of information, which is representative for specific production operations, was accomplished by distributing documented questionnaires in the form of EXCEL spreadsheets to all participating companies. Wherever possible, this study is based on primary data collected from the participating companies and their respective production sites. In cases where primary data was not available, secondary data readily available from literature, previous LCI studies, and life cycle databases was used for the analysis. The sources for secondary data are documented in this study report. In the absence of secondary data, expert approximations were used to close the data gaps.

The LCA model was created using the GaBi 4 software system (current release GaBi 4.3, http://www.gabi-software.com) for life cycle assessment, developed by PE INTERNATIONAL. The databases contained in the GaBi software provide the LCI data of the raw and process materials used in the background system.

2.2.3 Data Calculation

This study utilized a combination of vertical and horizontal averaging methods to derive the mean value of the primary data. The vertical method (see Figure 3) was applied consistently to all the companies as this method is more representative of actual industrial processes. However, in the case of identical processes, e.g. rolling, the horizontal averaging method (see Figure 4) was used.

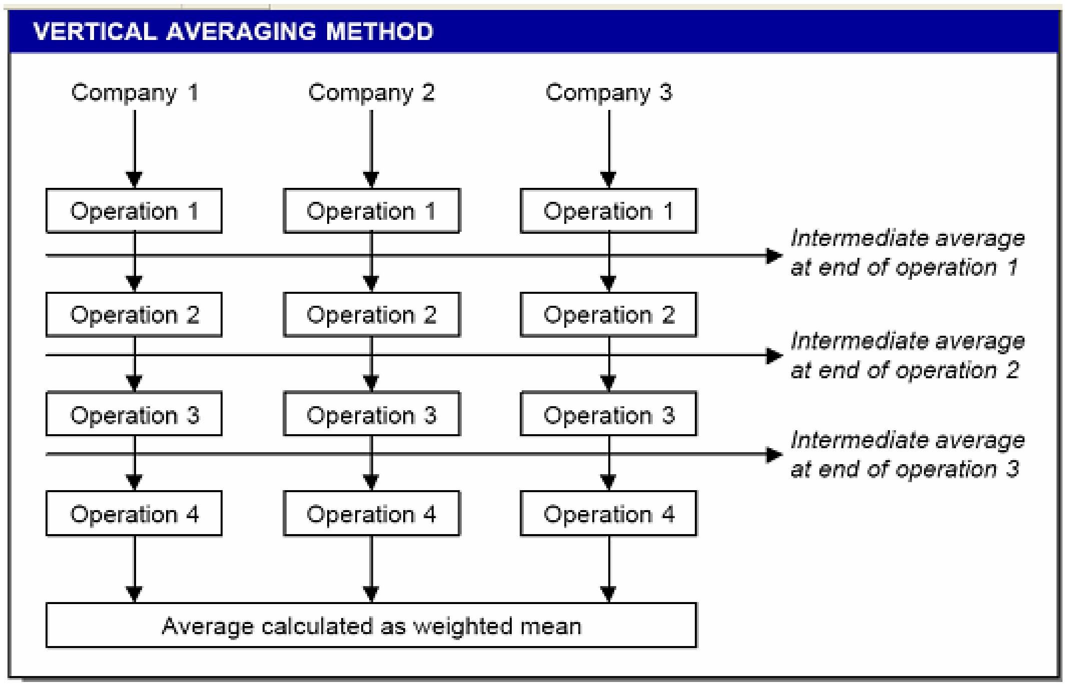

Figure 3: Illustration of the Vertical averaging method. The final average is calculated from a weighted mean of the sum of all the operations of each company. Intermediate averages may also be calculated after each operation. (ECOBILAN, 2001).

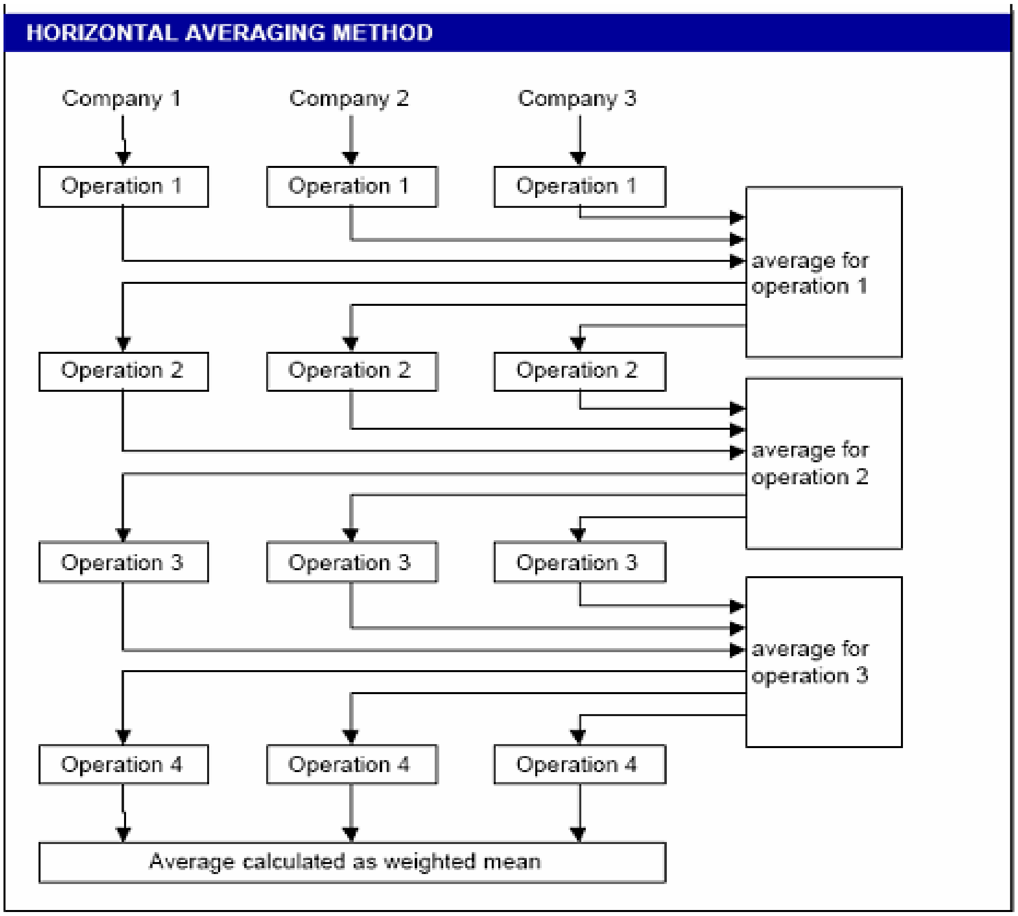

Figure 4: Illustration of the Horizontal averaging method. Averages are calculated after each operation and are used as the inputs for the next operation. In our context, this method is used when a particular company does not produce an intermediate product or when there is insufficient data for an intermediate operation (ECOBILAN, 2001).

2.2.4 Functional Unit

The functional unit of the study is to produce one thousand aluminum beverage cans representing weighted averages of the can sizes defined above.

2.2.5 Cut- off Criteria

The following cut-off criteria were used to ensure that all relevant environmental impacts were represented in the study:

- **Mass** – If a flow is less than 1% of the cumulative mass of all the inputs and outputs depending on the type of flow) of the LCI model, it may be excluded, provided its environmental relevance is not a concern.
- **Energy** – If a flow is less than 1% of the cumulative energy of all the inputs and outputs depending on the type of flow) of the LCI model, it may be excluded, provided its environmental relevance is not a concern.

- **Environmental relevance** – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it will be included. All material flows which leave the system (emissions) and whose environmental impact is higher than 1 % of the whole impact of an impact category that has been considered in the assessment, shall be covered.
- The **sum** of the neglected material flows shall not exceed 5% of mass, energy or environmental relevance.

2.2.6 Allocation

In this study, no allocation was applied as all co-products are considered in each of the recycling models described above (ISO, 2006b). Any recovered materials recycled into other products are treated as waste, thereby providing a maximum allocation of burdens to aluminum can production.

2.2.7 Life Cycle Impact Assessment Methodology & Impact Categories Considered

It was determined during the scope development process that a comprehensive set of environmental impact categories were to be investigated. For the purposes of succinct communication of the study results, the following impact categories were determined to best represent the Aluminum Association's priorities in issues related to sustainability:

- Global Warming Potential (GWP) (100 years; includes carbon dioxide (CO_2) and other greenhouse gas (GHG) relevant emissions),
- Acidification Potential (AP),
- Photochemical Ozone Creation Potential (POCP) – also called Summer Smog,
- Eutrophication Potential (EP), and
- Ozone Depletion Potential (ODP).

The meaning and significance of these impact categories is discussed in detail in Appendix C: Impact Indicators of this report. The impact assessment results were calculated using characterization factors published by the Centre of Environmental Science at Leiden University (CML), the Netherlands (CML, 2001). The CML 2001 methodology is the most widely applied impact assessment method in LCA studies around the world.

2.2.8 Data Quality Requirements

The following paragraphs document the comprehensive data quality requirements adopted according to ISO14044 (ISO, 2006b).

2.2.8.1 Temporal Coverage

Primary data collected from the participating companies and associations for their operational activities are representative for the year 2006 (reference year). Additional data necessary to model base material production and energy generation, etc. were adopted from the GaBi 4 software system database. The most recent North American LCI sub-dataset from the International Aluminum Institute (IAI) LCI Dataset for primary aluminum dates back to 2005. This deviation from the defined reference year has been taken into account as it is being assumed that there are no radical changes in the technology for rolling operations and can manufacturing from the year 2005 to 2006.

2.2.8.2 Geographical Coverage

The geographical coverage for this study is as follows:

- Primary Aluminum Production - North America,

  Data source: IAI, representative for North American situation

- Aluminum Sheet Rolling – United States

  3 major sheet producers (4 sites) in the US accounting for about 1.7 million tons of sheet produced in the US

- Can Manufacturing – United States

  Data source: CMI,representative for operations in the U.S

- Secondary Aluminum Production – United States

  Data source: 4 of the largest producers (5 sites) of secondary aluminum in the US covering about 2 million metric tons of secondary aluminium production.

2.2.8.3 Technological Coverage

In this study, site-specific data representing the current technology mix for aluminum can sheet production, can manufacture, and secondary aluminum production was collected. Primary aluminum production data (including bauxite mining, alumina refining, aluminum smelting, and primary ingot production) in North America were provided by the IAI. The scope of the IAI data on primary aluminum production in North America is as follows:

- Bauxite mining – global average,
- Alumina refining – global average,
- Electrolysis – North America,
- Primary ingot casting – North America.

Ancillary and process material data, such as the production of chemicals, fuels, energy and power, was adopted as average industry mixes from the GaBi 4 software system database (current release GaBi 4.3, http://www.gabi-software.com).

2.2.8.4 Completeness

During the data collection, each production facility was required to assign a data quality indicator to the data reported. The data quality indicators are classified as follows:

- Measured - If the data value reported is based upon continuous physical measurement (e.g. electricity or water consumption is based upon measurement of respective meters at the facility),
- Calculated - If the data reported has been calculated using a certain empirical formula or factors (e.g. emission factor for CO_2 or SO_2 depending upon the type of fuel used and process technology),
- Averaged - If the data reported is based upon an average of a number of values or measurements (e.g. the amount of smelting slag generated),

- Estimated - If the data reported is based upon informed estimates or expert judgment (e.g. the distance the raw materials are transported before they arrive at the facility).

Although it is difficult to conduct a comprehensive data quality and reliability check on the data reported from several production sites, consistency and quality checks for mass and energy balance results were conducted and results compared with published data - particularly process and flow data in previous LCI studies. The checks showed that the reported data was in the range reported by similar studies within comparable boundary conditions. In addition the data quality was evaluated using the Weidema methodology on LCA data quality (Weidema et al., International Journal of LCA 3 (5) page 259-265; 1998). Appendix D shows the results of the evaluation as well as the applied evaluation criteria for data quality, ranging for one to five, where one is the best quality and five the most uncertain. The evaluation showed the data conformed to criteria values of one or two (see Appendix D).

This quality assurance (QA) process was performed at different stages of the project. The objective of the QA process was to ensure that the data collection, the development of the LCI model, and the final results are consistent with the scope of the study and that the study delivers the required information.

2.2.9 Critical Review

The results of the LCA study are intended to support external communication; therefore in order to be compliant with ISO 14044, a critical review of the study was conducted.

The goal and scope of the critical review is defined in accordance with ISO 14044, paragraph 6.1. Following ISO 14044, the critical review process shall ensure that (ISO, 2006b):

- the methods used to carry out the LCA are consistent with this International Standard
- the methods used to carry out the LCA are scientifically and technically valid
- the data used are appropriate and reasonable in relation to the goal of the study
- the interpretations reflect the limitations identified and the goal of the study
- the study report is transparent and consistent

The review of this study was done by the LCI core group members and an independent review panel comprised of the following members:

- Todd Boggess [Secat], Chair
- Mary Ann Curran [United States Environmental Protection Agency]
- Bruce Vigon [SETAC]

A dialogue between the critical reviewers and the project team allowed continual integration of critical review feedback into the structure of the study, and the drafting of this final report.

3 PRIMARY ALUMINUM PRODUCTION

This chapter describes the unit processes associated with primary aluminum ingot production. The following sections cover a description of the process being modeled (Chapter 3.1), presentation of the LCI results (Chapter 3.2) and presentation of the LCIA Results (Chapter 3.3). The relevant supporting information used to model the LCI profile of a primary aluminum ingot produced in North America is noted where relevant to the portions of this section (e.g. IAI, 2005; USGS, 2006, 2007).

3.1 PROCESS DESCRIPTION

The life cycle stages of primary aluminum material processing includes the component processes of bauxite mining, alumina refining, electrolysis (including smelting and anode production), and primary ingot casting. A process flow diagram is shown in Figure 5. The initial raw material is the bauxite ore and final product is the primary aluminum ingot with intermediate products of alumina (aluminum oxide) and aluminum (liquid) metal.

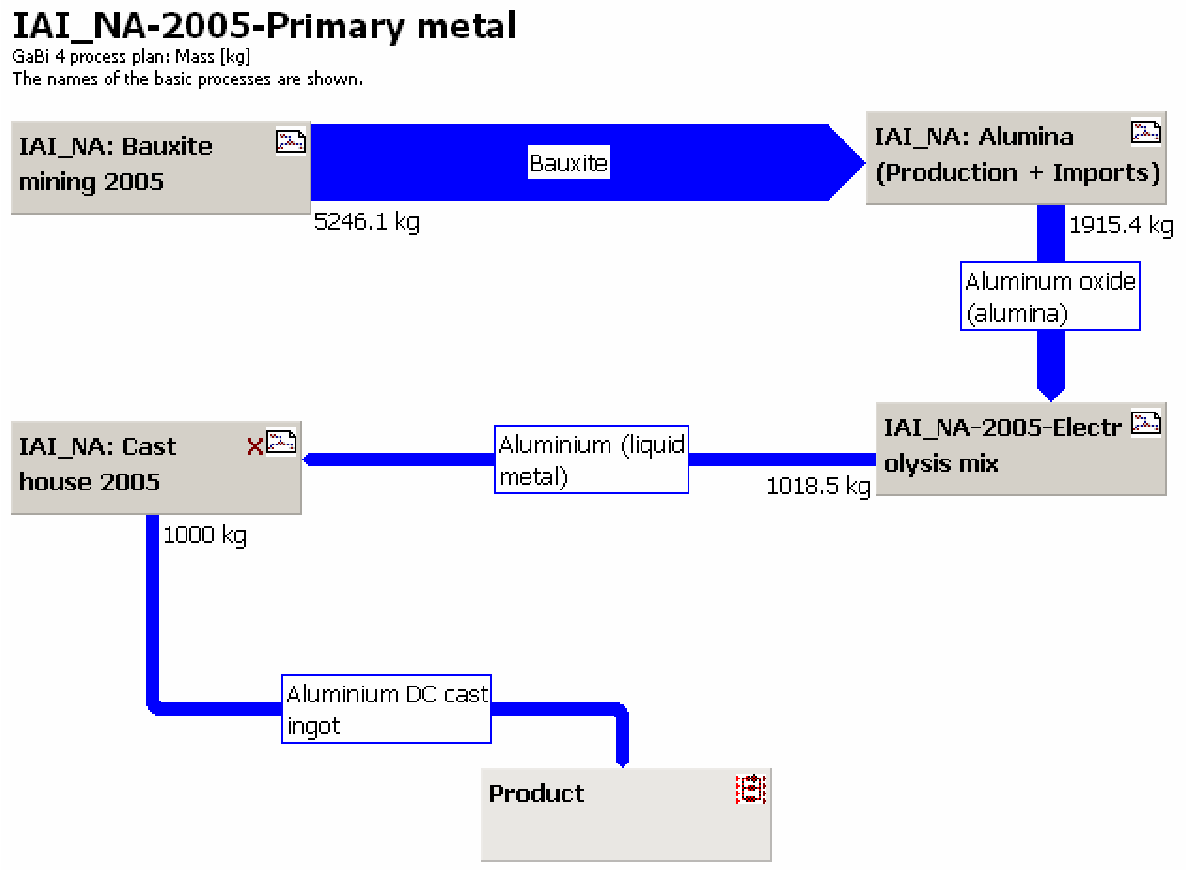

Figure 5: Process chain for the production of 1000 kg of primary aluminum.

In this study, the primary aluminum production in the U.S. is modeled based upon the LCI data obtained from IAI and statistics on bauxite, alumina and aluminum published annually by the

U.S. Geological Survey (USGS). Overall, the data quality and consistency of the IAI data has been identified to be of high quality.

North America imports bauxite and alumina, both of which are intermediates of the same ingredient in the can making process. To be able to represent the simple production process shown in Figure 5, a more complex model had to be implemented, wherein the alumina imports were converted into equivalent amounts of bauxite to be mined using the IAI global average of 2.739 tons of bauxite per metric ton of alumina produced. The additional amount of bauxite to be mined was added to the bauxite imports model as shown in Figure 6.

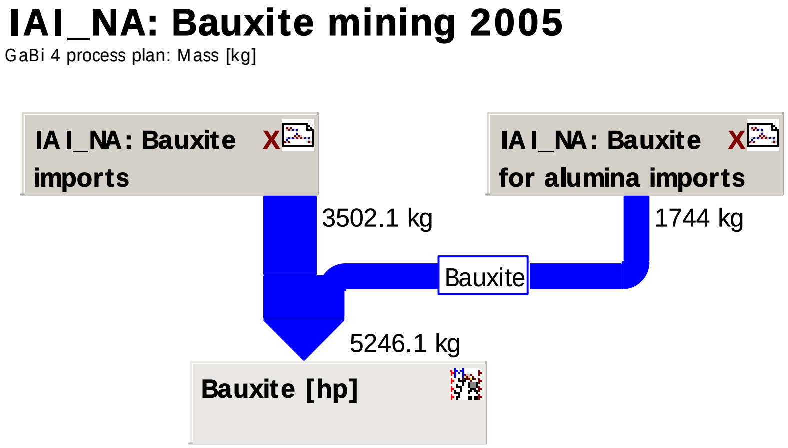

Figure 6: Bauxite imports into North America. "IAI_NA: Bauxite for alumina imports" represents the bauxite-equivalents of the amount of alumina imported into NA. Figures are representative for the production of 1000 kg of primary aluminum.

The following sub-sections characterize the generic process description for each of the unit processes associated with primary aluminum production and are based on the profile of the aluminum industry outlined in previous studies (AA, 1998; IAI, 2005).

3.1.1 Bauxite Mining

Bauxite ore is the primary raw material source for the aluminum production. Aluminum is almost exclusively produced from Bauxite. This ore consists primarily of the minerals gibbsite $Al(OH)_3$, boehmite, and diaspore AlOOH, together with minor fractions of the iron oxides goethite and hematite, the clay mineral kaolin and small amounts of TiO_2. Bauxite is typically found at a depth of 0 to 600 feet beneath the earth crust, with an average depth of 80 feet. It is mined in open-pit mines by removing the overburden. The removed material is stockpiled for use in restoring the site after the bauxite has been excavated. The bauxite deposit is loosened by means of explosives, depending on its hardness and other local conditions. In some cases the bauxite is crushed in a grinding process using dust control equipment to prevent from excessive dust emission, and/or treated with water to remove impurities before it is shipped. This washing process is called beneficiation. Beneficiated bauxite will typically be dried prior to shipment to the refinery. The wastewater from washing is normally retained in a settling pond and recycled for continual use.

This bauxite mining unit process begins with the extraction and processing of the bauxite ore and it ends with the output of beneficiated bauxite to be refined in the subsequent process to produce alumina. The operations associated with this unit process include (AA, 1999; IAI, 2005):

- The extraction of bauxite rich minerals on-site,
- Beneficiation activities such as grinding, washing, screening, and drying,
- Treatment of mining site residues and waste, and
- Restoration activities such as grading, dressing, and planting.

Unit process inputs and outputs are show in Table 3.

Table 3 Inputs and outputs for the bauxite mining process. Flows are representative for 1000 kg primary aluminum production

Flow	Unit	Amount
Inputs		
Diesel [Crude oil products]	kg	6.0436
Power [Electric power]	MJ	36.21
Thermal energy (heavy fuel oil) [Thermal energy]	MJ	52.89
Thermal energy (natural gas) [Thermal energy]	MJ	0.07
Bauxite [Non renewable resources]	kg	5775.8
Water (sea water) [Water]	kg	302
Water (surface water) [Water]	kg	2633.7
Outputs		
Bauxite [Inorganic intermediate products]	kg	5246.2
Dust (unspecified) [Particles to air]	kg	5.1
Overburden (deposited) [Stockpile goods]	kg	529.6
Steam [Inorganic emissions to air]	kg	143.6
Water (sea water) [Water]	kg	261.6
Water (surface water) [Water]	kg	2514.9

The domestic bauxite production in the US is less than 1% of the total demand of bauxite (USGS, 2007). Most of the domestically produced bauxite is utilized for non-metallurgical applications such as abrasives, chemical, refractory materials (USGS, 2007). Therefore, the bauxite demand for metallurgical purposes (i.e. to produce metallic aluminum) in the U.S. is primarily met through imports. The bauxite imports based on their country of origin to the U.S. in 2005 is given in Table 4. Brazil is the largest exporter of bauxite (accounting for approximately 33% of the total bauxite imports to the U.S.) followed by Guinea and Jamaica. The group of countries included in the "Others" category are China, India, the Dominican Republic and Venezuela.

The bauxite mining model is based on global average IAI data except for energy sources and fuels where country-specific data was used. The U.S. scenario (basically a mix of bauxite importing sources and quantities) was used to represent that of Canada also. It was therefore chosen as representative for the entire North American region. This assumption was based on the fact that the overall contribution of the bauxite mining process to the environmental impacts is small compared with other processes considered. Therefore the impact of such an assumption would be negligible in the final results. As an illustration of the processes considered in the mining process, the bauxite mining model for Brazil is shown in Figure 7 on the following page.

Table 4: Breakdown of bauxite imports to the U.S. in 2005 [USGS, 2007] by Country. Brazil is the largest exporter of Bauxite to the U.S. accounting for nearly one-third of the total imports to the U.S.

Country	Bauxite import (thousand metric tons)
Australia	232
Brazil	3210
Guinea	2460
Guyana	1280
Jamaica	1760
Others	916
Total	**9858**

The transportation of bauxite from each individual country to the U.S. is considered in the model to create the bauxite import mix model as shown in Figure 8. It is assumed that bauxite is transported through a bulk commodity ocean carrier utilizing heavy fuel oil as its energy source. The transportation distance was approximated based upon the average nautical distance between a major port in each of the bauxite exporting countries and New Orleans in the U.S. The transportation distance for bauxite imports from "Other" countries was based upon the weighted average distance from the countries comprising the "Others" category. The transportation distance was estimated using a web-based calculator (World Ports Distances, 2007).

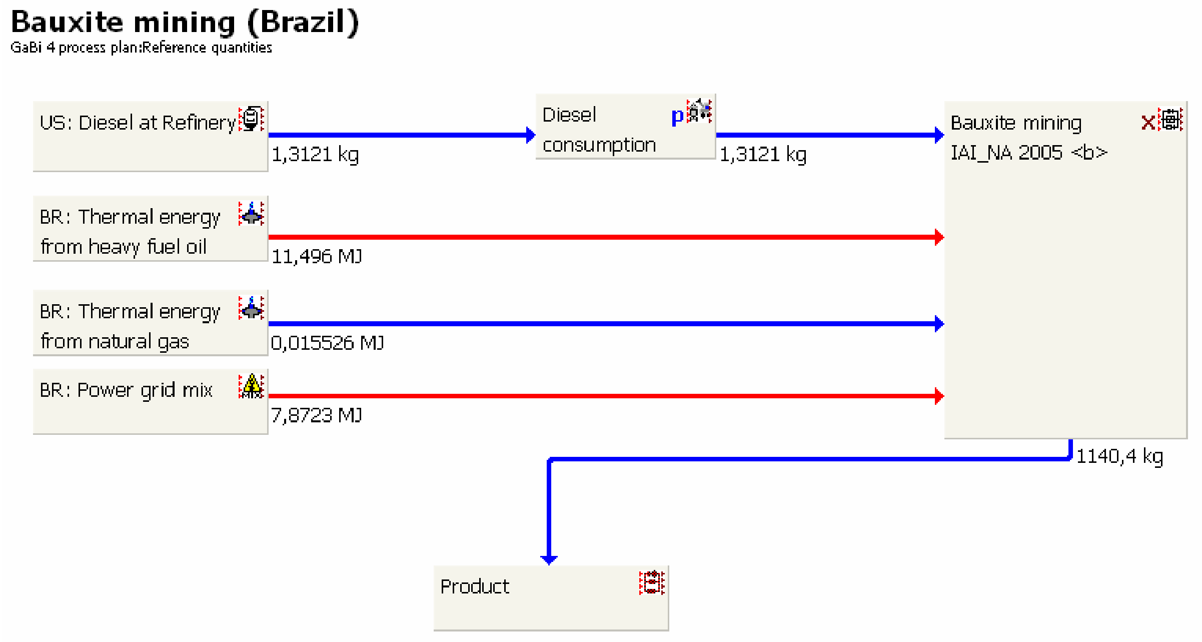

Figure 7: Bauxite mining in Brazil. Figure used as an example to illustrate the mining process modeled for the LCI. Flows are representative for the production of 1000 kg of primary aluminum (scaled to the share of bauxite imports from Brazil).

3.1.2 Alumina Production

Alumina refining comprises the conversion of bauxite to aluminum oxide Al_2O_3 (alumina) using the Bayer process (e.g. Chin 1988; Droy and Michaux 2003; Mylona et al. 2003; Frank et al. 2008). Most refineries use a mixture of blended bauxite to provide feedstock with consistent properties. The mixture is ground and blended with recycled plant liquor. This liquor contains dissolved sodium carbonate and sodium hydroxide recovered from previous extraction cycles plus supernatant liquor recycled from red mud holding ponds. The slurry is heated and pumped to digesters, which are heated in pressure tanks. In digestion, iron and silicon impurities form insoluble oxides called red mud. The red mud settles out and a rich concentration of sodium aluminates is filtered and seeded to form hydrate alumina crystals in precipitators. These crystals are then heated in a calcination process. The heat in the calciners drives off combined water leaving alumina.

This step of manufacturing begins with the processing of beneficiated bauxite and ends with the output of alumina to be subsequently processed in the smelter. The operations associated with this unit process include (AA, 1999; IAI, 2005):

- bauxite grinding, digestion, and processing of liquors,
- alumina precipitation and calcination,
- maintenance and repair of plants and equipment, and
- treatment of process air, liquids, and solids.

The unit process inputs and outputs are listed in Table 5.

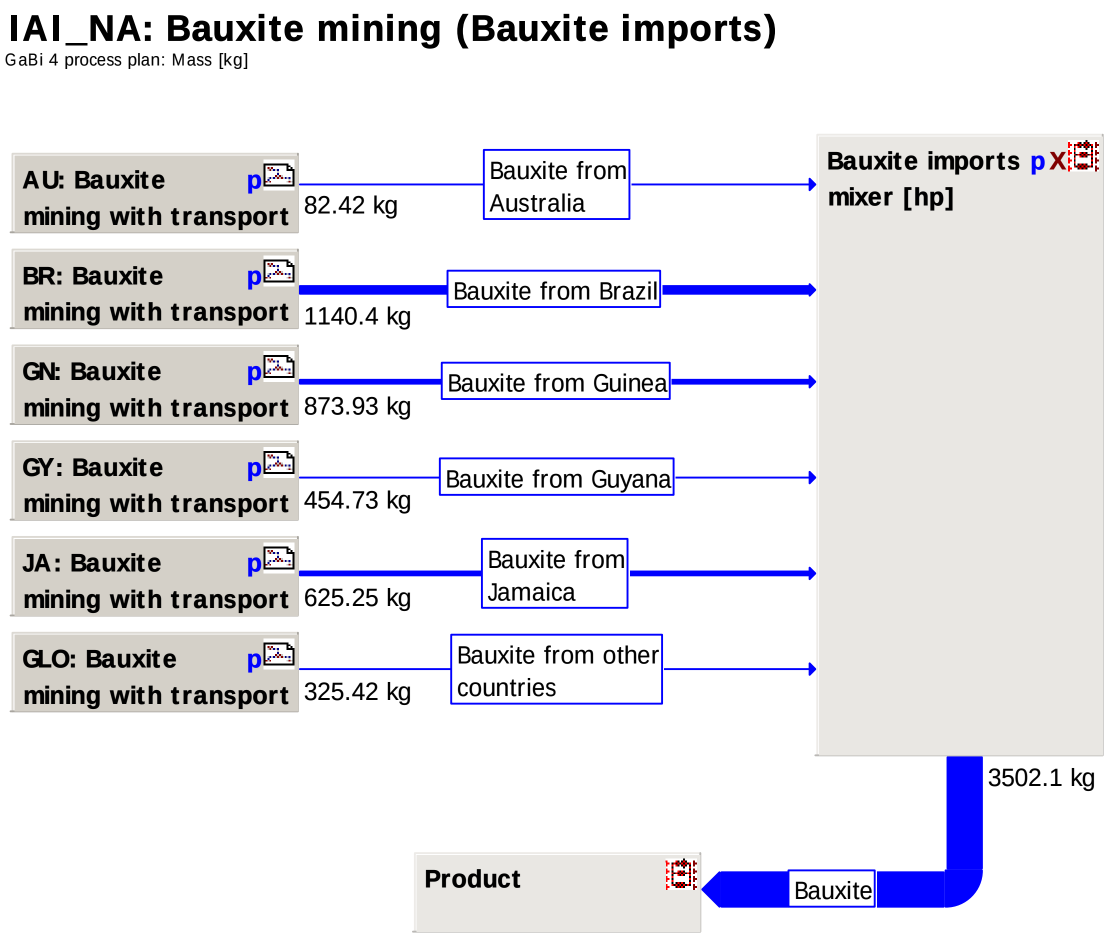

Figure 8: The transportation of Bauxite imported to the US is included in each country-specific model. Prefixes for labels are standard country codes and represent country-specific mining models already discussed. GLO represents the global average mining model applied to mining from other minor exporting countries. Flow quantities are representative of 1000 kg of primary aluminum production (scaled to the share of bauxite imports).

Table 5: Inputs and outputs for the Alumina production unit process. Flows are representative for 1000 kg primary aluminum production.

Flows	Unit	Amount
Inputs		
Inorganic intermediate products		
Bauxite	kg	5246.2
Sodium hydroxide (50%; caustic soda)	kg	172
Lime quicklime (lumpy) [Minerals]	kg	75.5

Energy and fuel inputs		
Diesel	kg	1.31
Power [Electric power]	MJ	865.6
Thermal energy from hard coal	MJ	3060.2
Thermal energy from heavy fuel oil	MJ	7851.7
Thermal energy from natural gas	MJ	7909.6
Water		
Sea water	kg	201.2
Surface water	kg	15190
Outputs		
Products		
Aluminum oxide (alumina)	kg	1915.4
Waste for recovery		
Lubricant (grease) [Hazardous waste for recovery]	kg	0.91
Waste for disposal		
Red mud (dry) [Hazardous waste for disposal]	kg	2187
Industrial waste for municipal disposal	kg	29.3
Waste (solid)	kg	47.1
Sand (Alumina production)	kg	58.3
Emissions to air		
Steam	kg	4989.7
Mercury (+II)	kg	4.02E-04
Emissions to water		
Solids (suspended)	kg	0.091
Water (sea water)	kg	241.4
Water (surface water)	kg	10160.5

According to the IAI, the production of 1 metric ton of alumina requires approximately 2.739 metric tons of bauxite (taking into account the purity of bauxite and losses during processing and transportation) (IAI, 2005). This is a global representative average that has been adopted to model the alumina production process in North America. The alumina production process is shown in Figure 9.

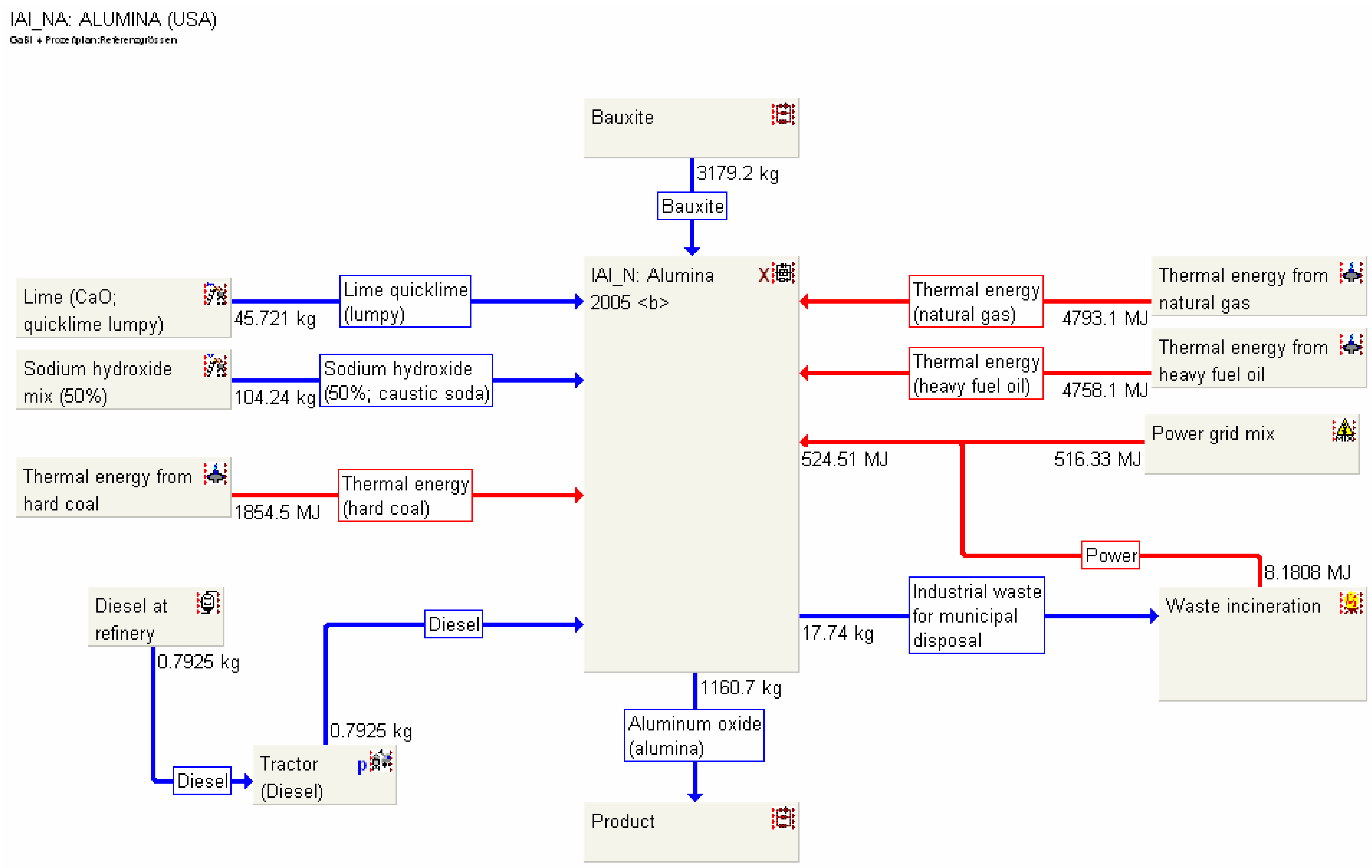

Figure 9: Alumina (Al2O3) production process in the U.S. in 2005. Flow quantities are representative of 1000 kg of primary aluminum production (scaled to the share of direct alumina production).

According to the USGS, the U.S. imported 1,866,000 metric tons of alumina and domestically produced 4,724,000 metric tons of alumina in 2005 (USGS, 2007). The fraction of alumina imports to total alumina consumed for primary aluminum production is approximately 40% (Figure 10).

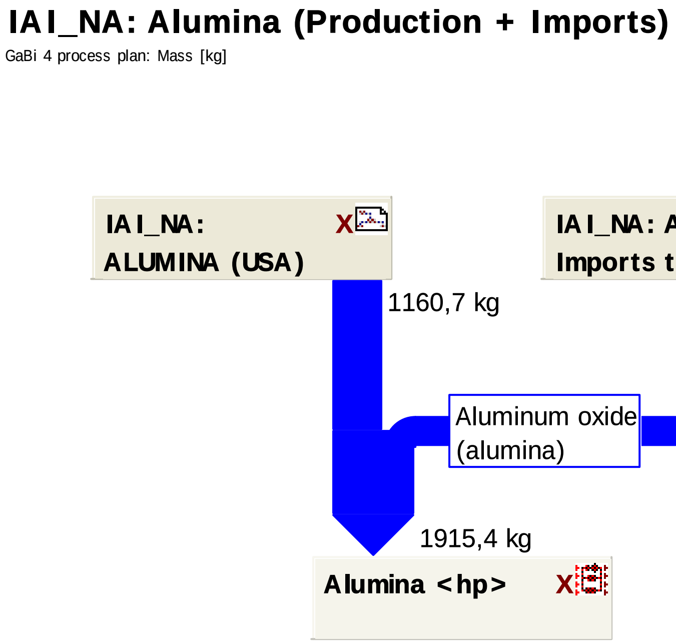

Figure 10: Breakdown of alumina imports and domestically produced alumina in the U.S. in 2005. Flows are representative for producing 1000 kg of primary aluminum.

The imports of alumina from Australia and Suriname accounted for approximately 80% of the total alumina imports to the U.S. The country-specific breakdown of alumina imports to the U.S. in 2005 is given in Table 6. The transportation of alumina imported to the US is included in each country-specific model.

Table 6: Country-wise breakdown of alumina imports to the U.S. in 2005 [USGS, 2007]

Country	Alumina imports (thousand metric tons)
Australia	932
Brazil	17
Canada	103
China	10
France	16
Germany	49
Jamaica	116
Japan	5
Suriname	560
Venezuela	27
Others	31
Total	**1866**

As with the bauxite mining process, it was assumed that the alumina production in the U.S is representative of the entire North American region. As the contribution of the processes involved in producing alumina from bauxite plays a significant role in the environmental impacts of the entire can-making process, this assumption was based upon two key factors: (1) The fact that the most significant environmental factor in alumina production is energy derived directly from fossil fuels (see Figure 9) and therefore, any differences in the results would be minor and only contributed by the difference in efficiencies of the energy converters. (2) The difference in environmental impacts (e.g. GWP-100) between imported and domestically produced alumina is less than 1% and therefore differences in this ratio for Canada do not affect results significantly. A simple sensitivity analysis was used to confirm these assertions.

3.1.3 Anode Production

There are two generic types of reduction cells: prebake and Söderberg (Anseen, Okstad, Innvar, & Olsen, 1979;Bergsdal, Strömann, & Hertwich, 2004; IAI, 2005). The Söderberg design has a single anode which covers most of the top surface of the reduction cell. Anode paste (briquettes) is fed to the top of the anode and as the anode is consumed in the process, the paste feeds downward by gravity. Heat from the pot bakes the paste into a monolithic mass before it gets to the electrolytic bath interface.

The prebake design has pre-fired blocks of solid carbon suspended from axial busbars. The busbars both hold the anodes in place and carry the current required for electrolysis.

The process for making the aggregate for briquettes or prebake blocks is identical. Coke is calcined, ground and blended with pitch to form a paste that is subsequently extruded into blocks or briquettes and allowed to cool. While the briquettes are sent directly to the pots for consumption, the blocks are then sent to a separate baking furnace.

Baking furnace technology has evolved from simple pits that discharged volatiles to the atmosphere during the baking cycle to closed loop type designs that convert the caloric heat of the volatile into a process fuel that reduces net energy consumption. The IAI data for electrolysis represents 85% of production from prebake facilities and the remaining 15% from Söderberg facilities (IAI, 2005).

The operations associated with anode production include (AA, 1999; IAI, 2005):

- recovery of spent anode materials,
- anode mix preparation, block or briquette forming and baking,
- rodding of baked anodes,
- maintenance and repair of plant and equipment, and
- treatment of process air, liquids, and solids.

An illustration of the anode production process implemented in the model is shown in Figure 11. The unit process inputs and outputs are listed in Table 7. Note that for all unit processes, only reported values of carbon dioxide are listed here. These (when shown) are direct emissions from fuel consumption. Note: for the calculation of the LCI and LCIA results, these reported values were excluded and standard GaBi processes were used to calculate emissions. This approach guarantees that all emissions are accounted for correctly and accurately.

Table 7: Inputs and outputs for the anode production unit process. Flows are representative for the production of 1000 kg of primary aluminum.

Flow	Unit	Amount
Inputs		
Materials		
Coke (C carrier)	kg	345.2
Hard coal pitch-Mix (C Träger)	kg	92.32
Refractory [Minerals]	kg	5.819
Steel sheet part (St) [Metal parts]	kg	1.706
Cooling water	kg	200.7
Energy and Fuels		

Diesel	kg	0.401
Power [Electric power]	MJ	213.13
Thermal energy from hard coal	MJ	45.16
Thermal energy from heavy fuel oil	MJ	93.32
Thermal energy from natural gas	MJ	1035.6
Outputs		
Products		
Anode (C carrier)	kg	437.5
Emissions to air		
Carbon dioxide	kg	177.6
Fluorides	kg	0.004
Benzo{a}pyrene [Group PAH to air]	kg	3.48E-05
Polycyclic aromatic hydrocarbons [Group PAH to air]	kg	0.0281
Emissions to water		
Fluoride	kg	0.0002
Oil (unspecified)	kg	5.02E-05
Polycyclic aromatic hydrocarbons (PAH)	kg	5.52E-05
Solids (suspended)	kg	0.0005

3.1.4 Aluminum Smelting

Molten aluminum is produced from alumina by the Hall-Heroult electrolytic process (e.g. Frank, et al., 2008; Grjotheim & Kvande, 1993). This involves two steps: dissolving the alumina (Al_2O_3) produced in the preceding aluminum refining step in a molten cryolitic bath, and passing electric current through this solution, thereby decomposing the alumina into aluminum and oxygen. Aluminum is tapped out of the reduction cell (pot) at daily intervals and the oxygen bonds with the carbon to form carbon dioxide and carbon monoxide.

Aluminum smelters typically use air pollution control systems to monitor and reduce emissions. The primary system is typically a scrubber. Some plants use dry scrubbers with alumina as the absorbent that is subsequently fed to the pots and allows for the recovery of scrubbed materials. Other plants use wet scrubbers, which re-circulate an alkaline solution to absorb emissions. Unlike dry scrubbers, wet scrubbers absorb carbon dioxide, nitrogen oxide and sulfur dioxide that are entrained in the waste water liquor.

This unit process begins with the processing of alumina and ends with the output of molten primary aluminum to be subsequently cast into primary ingot in the casting process. The operations associated with electrolysis include (AA, 1999; IAI, 2005):

- recovery, preparation, and handling of process materials,
- manufacture of major process equipment (e.g., cathode shells),
- process of control activities (metal, bath, heat),
- maintenance and repair of plant and equipment, and
- treatment of process air, liquids, and solids.

The total crude aluminum consumption in the U.S. in the year 2005 is shown in the Table 8. The domestic production of primary aluminum in the U.S. and imports from Canada account for approximately 42% and 32%, respectively, of the total crude aluminum consumption.

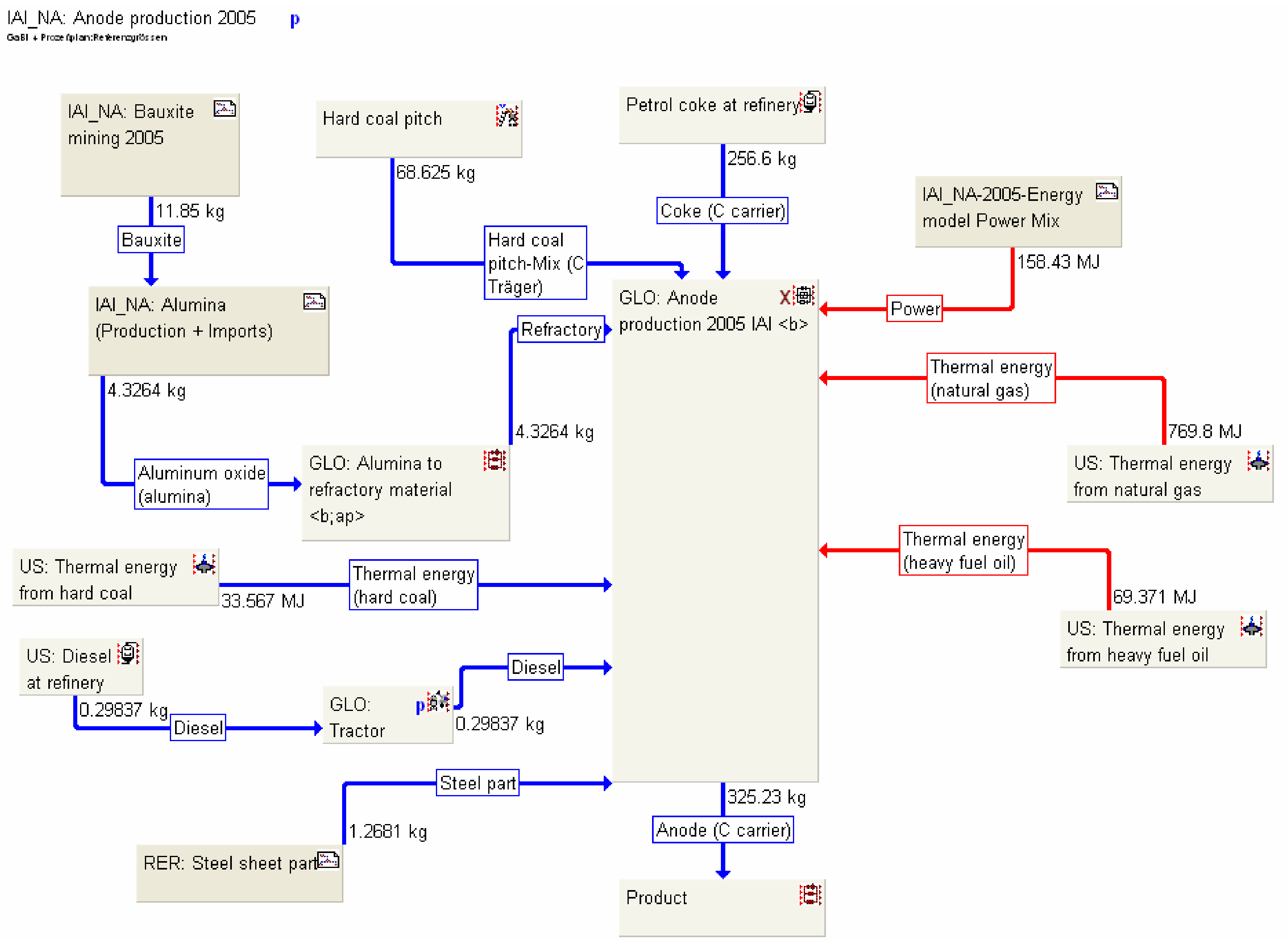

Figure 11: Illustration of the Anode production process. All flows are representative for 1000 kg primary Al. production (domestic component).

Table 8: Crude aluminum consumption in the U.S. (domestic production plus imports) in 2005 (USGS, 2006)

Region	Country	Aluminum crude	Percentage share (%)
		Quantity (metric tons)	
Africa		**77700**	**1.31%**
	South Africa	77700	
North America		**4401000**	**74.34%**
	USA	2481000	41.91%
	Canada	1920000	32.43%
Latin America		**230136**	**3.89%**
	Argentina	65600	
	Brazil	19400	
	Mexico	97	
	Panama	39	
	Venezuela	145000	
Asia		**297623**	**5.03%**
	Bahrain	22700	
	China	68200	
	Japan	536	
	Korea	87	
	Tajikistan	127000	
	United Arab Emirates	79100	
Europe		**850157**	**14.36%**
	Belgium	36	
	France	789	
	Germany	2400	
	Italy	757	

	Netherlands	436	
	Norway	4060	
	Spain	79	
	UK	22600	
	Russia	819000	
Oceania		**63200**	**1.07%**
	Australia	63200	
Total		**5919816**	**100%**

The imports of crude aluminum to the U.S. (excluding Canada) account for 26% of the total consumption and therefore, the North American share (U.S. and Canada) is 74%. The breakdown of the electrolysis mix into imported and domestic components is highlighted in Figure 12.

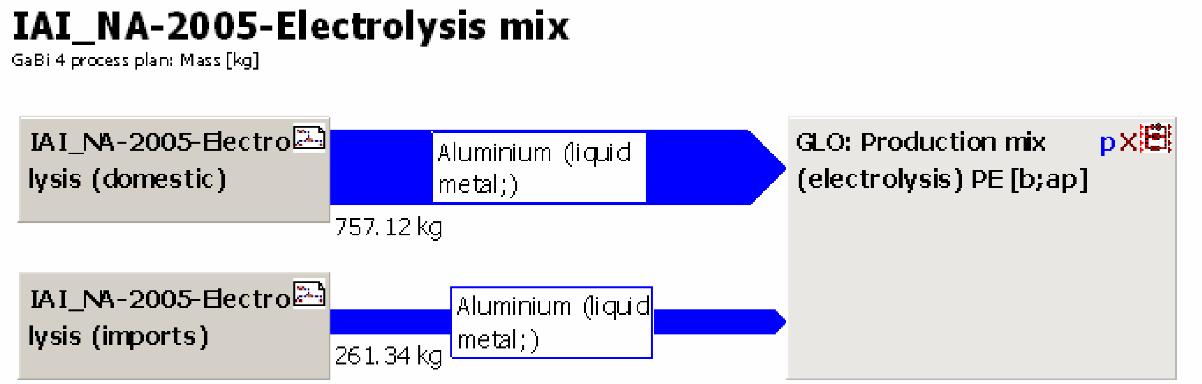

Figure 12: Electrolysis mix representative for the U.S. in 2005. All flows are representative for producing 1000 kg of primary aluminum.

The electrolysis process models for domestic production and import mix are shown in Figure 13 and Figure 14, respectively. Table 9 and Table 10 list the inputs and outputs of these two processes.

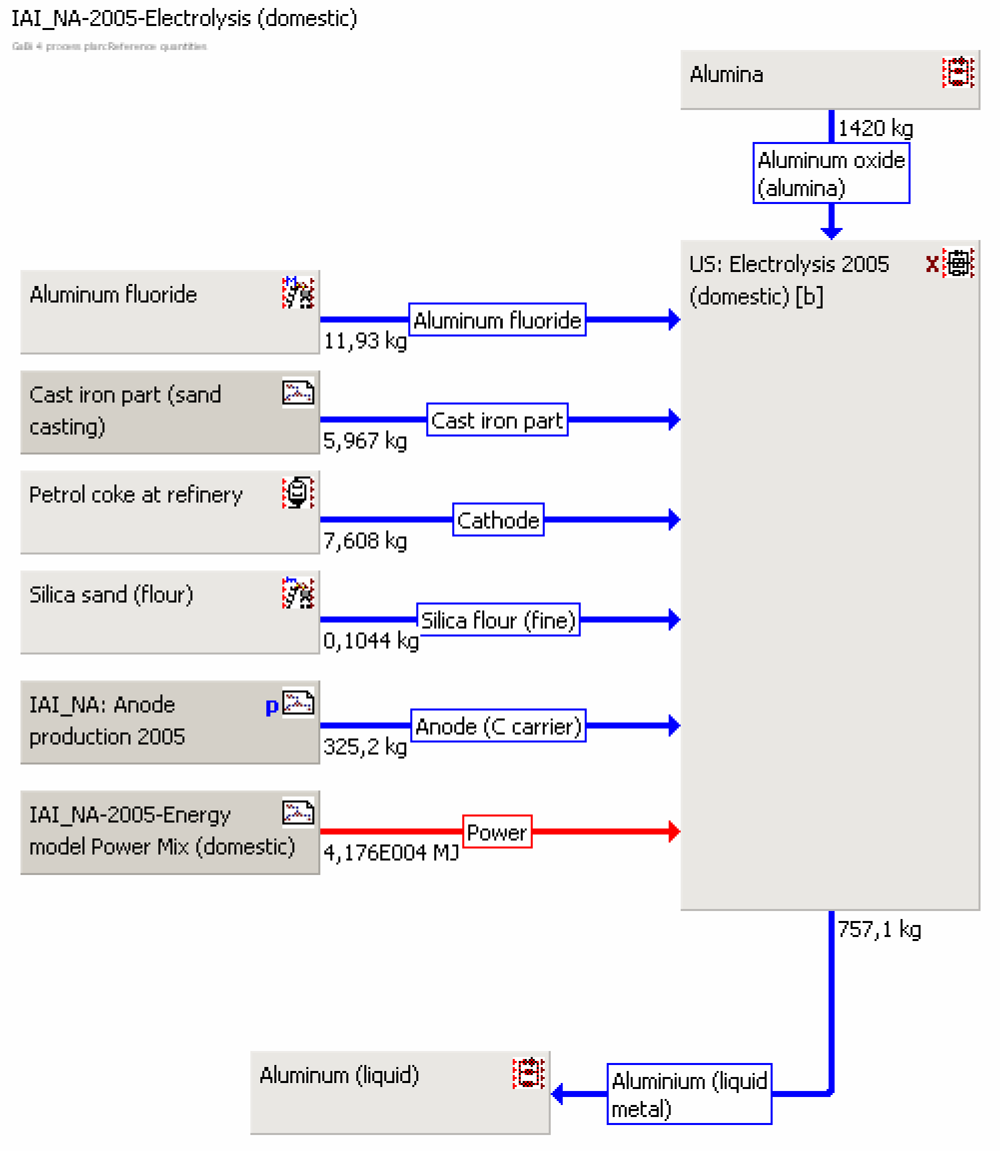

Figure 13: Electrolysis process model for crude aluminum production representative for the U.S. in 2005. All flows are representative for producing 1000 kg of primary aluminum.

Table 9: Inputs and outputs for the domestic component of Electrolysis unit process.

Flow	Unit	Amount
Inputs		
Materials		
Aluminum fluoride	kg	11.94
Aluminum oxide (alumina)	kg	1420.3

Anode (C carrier)	kg	325.2
Blasting abrasive	kg	0.104
Cathode	kg	7.61
Steel sheet part (St)	kg	5.97
Water	kg	9026
Water (sea water)	kg	74.59
Energy and fuels		
Power [Electric power]	MJ	41762
Outputs		
Products		
Aluminum (liquid metal)	kg	757.12
Waste for recovery		
Aluminum oxide (alumina)	kg	2.91
Refractory	kg	5.82
Smelter recycling by-product	kg	6.12
Emissions to air		
Carbon dioxide	kg	1181.6
Fluorides	kg	0.589
Benzo{a}pyrene [Group PAH to air]	kg	0.002
Polycyclic aromatic hydrocarbons [Group PAH to air]	kg	0.216
Tetrafluoromethane (CF4)	kg	0.112
Hexafluoroethane (C2F6; R116)	kg	0.0112
Emissions to water		
Fluoride	kg	0.037
Oil (unspecified)	kg	0.005
Solids (suspended)	kg	0.067

Polycyclic aromatic hydrocarbons (PAH, unspec.)	kg	1.79E-04
Hazardous waste		
Carbon (unspecified)	kg	5.45
Refractory	kg	10.67
Sludge	kg	12.83
Water [Water]	kg	11860
Water (sea water) [Water]	kg	74.6

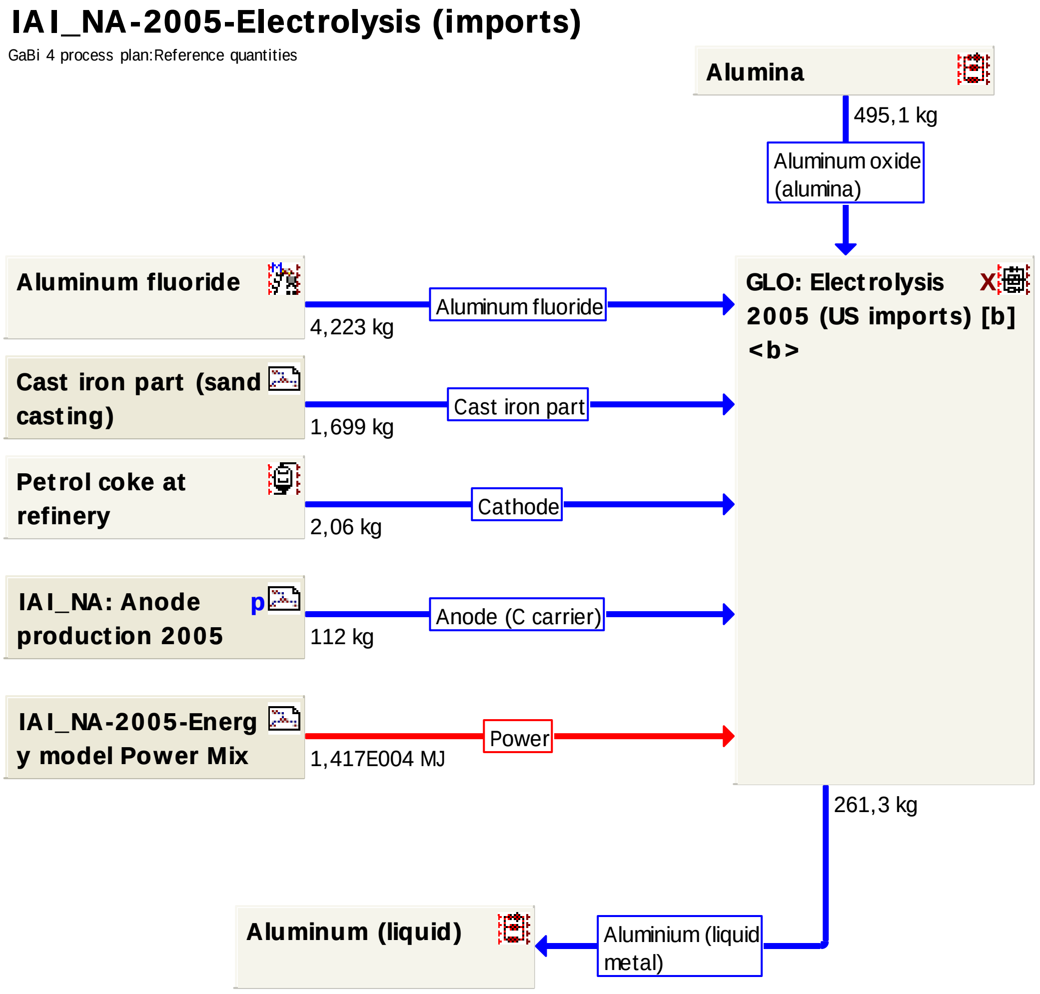

Figure 14: Electrolysis process model for crude aluminum imported to the U.S. as representative for 2005. All flows are representative for producing 1000 kg of primary aluminum.

In the electrolysis process, electrical energy is the primary energy resource. The electrical power mix model for electrolysis is discussed below in Section 3.1.6. In this study, the power consumption of electrolysis is found to be 15552 kWh per metric ton of primary aluminum. Overall, according to IAI, the world average power consumption of the electrolysis process is 15289 kWh per metric ton of primary aluminum.

Table 10: Inputs and outputs for the imported component of Electrolysis unit process

Flow	Unit	Amount
Inputs		
Materials		
Aluminum fluoride	kg	4.22
Aluminum oxide (alumina)	kg	495.1
Anode (C carrier)	kg	112
Cathode	kg	2.059
Steel sheet part (St)	kg	1.699
Water	kg	2755
Water (sea water)	kg	4531.5
Energy and fuels		
Power [Electric power]	MJ	14169
Outputs		
Products		
Aluminum (liquid metal)	kg	261.3
Emissions to air		
Carbon dioxide	kg	401
Fluorides	kg	0.268
Tetrafluoromethane (CF4)	kg	0.039
Hexafluoroethane (C2F6; R116)	kg	0.004
Polycyclic aromatic hydrocarbons (PAH) [Group PAH to air]	kg	0.075
Benzo{a}pyrene [Group PAH to air]	kg	6.69E-04

Emissions to water		
Solids (suspended)	kg	0.052
Fluoride	kg	0.082
Polycyclic aromatic hydrocarbons (PAH, unspec.)	kg	4.22E-04
Oil (unspecified)	kg	0.002
Hazardous waste		
Refractory	kg	3.527
Carbon (unspecified)	kg	3.012
Sludge	kg	1.210
Waste for recovery		
Refractory	kg	1.622
Smelter recycling by-product	kg	2.292
Aluminum oxide (alumina)	kg	0.669
Water [Water]	kg	2626.3
Water (sea water) [Water]	kg	4.532

PFC (Perfluorocarbon) generation in Aluminum Smelting

PFC emissions in the aluminum smelting process are listed in Table 9 and Table 10 (as Hexaflouroethane and Tetrafluoroethane) for domestic and imported components respectively. It is estimated that 165.5g of PFCs are emitted per ton of primary aluminum production (IAI, 2005). CO_2 equivalents are calculated based on CML 2001[3] values of 5700 (kg) for CF_4 and 11900 (kg) for C_2F_6 and are listed in Table 15.

3.1.5 Primary Ingot Casting (Cast House)

Molten metal siphoned from the pots is sent to a resident cast house found in each smelter. In some cases, due to proximity, molten metal is transported directly to a shape casting foundry. Molten metal is then transferred to a holding furnace where the composition is adjusted to the specific alloy requested by a customer. In some instances, depending on the application and the bath composition in the pots, some initial hot metal treatment to remove impurities may be done.

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[3] The USEPA and other governments are still using the IPCC 2nd Assessment values of 6,500 for CF4 and 9,200 for C2F6.

When the alloying is complete, the melt is fluxed to remove impurities and reduce gas content. The fluxing consists of slowly bubbling a combination of nitrogen and chlorine or of carbon monoxide, argon, and chlorine through the metal. Fluxing may also be accomplished with an inline degassing technology which performs the same function in a specialized degassing unit.

Fluxing removes entrained gases and inorganic particulates by flotation to the surface of the metal. These impurities (typically called dross) are skimmed off. The skimming process also takes some aluminum and drosses are normally further processed to recover the aluminum content and to make products used in the abrasives and insulation industries.

Depending on the application, metal is then processed through an inline filter to remove any oxides that may have formed. Subsequently, metal is cast into ingots in a variety of methods: open molds (typically for remelt ingot), through direct chill molds for various fabrication shapes, electromagnetic molds for some sheet ingots, and through continuous casters for aluminum coils.

This unit process begins with the processing of molten primary aluminum and ends with the output of sheet ingot suitable for rolling, extruding, or shape casting. The various operations carried out in the cast house include (AA, 1999; IAI, 2005):

- Pretreatment of hot metal (cleaning and auxiliary heating);
- Recovery and handling of internal process scrap;
- Batching, metal treatment, and casting operations;
- Homogenizing, sawing, and packaging and casting operations;
- Maintenance and repair of plant and equipment; and
- Treatment of process air, liquids, and solids.

The model for the primary ingot casting process is shown in Figure 15 . Following the IAI inventory data (IAI, 2005), alloying materials are not considered in the model. The ingot is considered to be composed of 100% aluminum as can be seen in the figure where the alloying process box is used only to re-introduce recycled dross back into the casting process. For the purpose of simplifying the model, the deficit from the otherwise expected 15kg input of alloying material is obtained from the aluminum DC cast ingot.

Table 11: Inputs and outputs for primary ingot casting unit process. Flows are representative for the production of 1000 kg of primary aluminum.

Flow	Unit	Amount
Inputs		
Materials		
Alloy components (Aluminum)	kg	15.05
Aluminum (liquid metal)	kg	1018.5
Chlorine	kg	0.055
Cooling water	kg	100.34
Energy and fuels		
Diesel	kg	3.31
Power [Electric power]	MJ	252.86
Thermal energy from hard coal	MJ	81.3
Thermal energy from natural gas	MJ	1213.7
Outputs		
Products		
Aluminum DC cast ingot	kg	1003.4
Waste for recovery		
Dross	kg	18.36
Filter dust	kg	0.030
Steel scrap (St)	kg	17.26
Waste for disposal		
Dross (Fines)	kg	0.803
Waste (solid)	kg	0.2
Refractory	kg	2.91
Emissions to air		

Hydrogen chloride	kg	0.016
Emissions to water		
Oil (unspecified)	kg	0.010
Solids (suspended)	kg	0.020

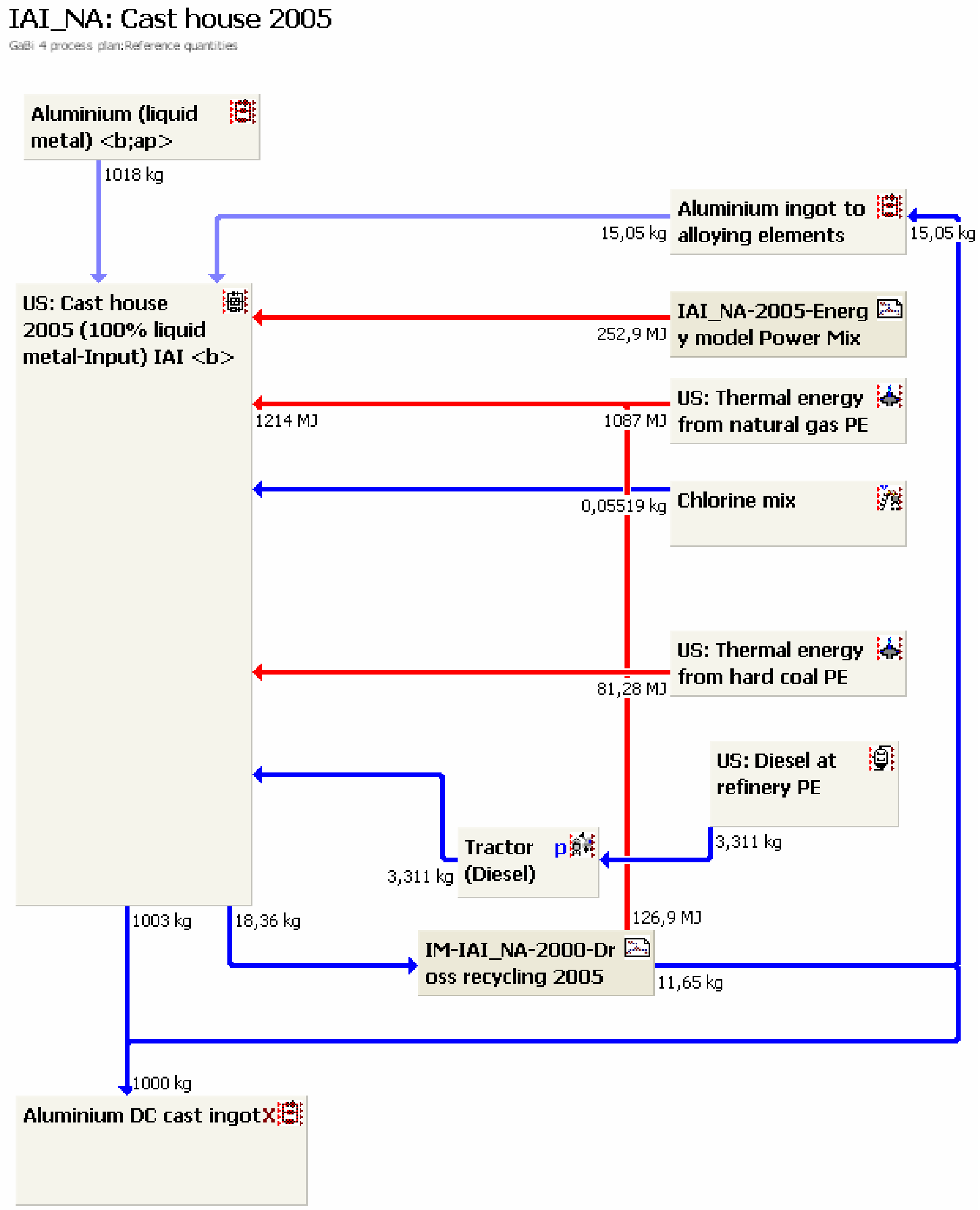

Figure 15: Primary ingot casting process model for primary aluminum production. Flows are representative for 1000 kg of primary aluminum production.

3.1.6 Electrical Power Mix Model for Electrolysis

In order to model the electricity consumption for electrolysis (domestic production and imports), a model for electricity supply has been developed which is based upon the electricity mix of the aluminum industry. The unit process model for electrolysis itself was based on North American practices, and is assumed to be globally the same. The direct electricity input during electrolysis is a critical LCI parameter that can significantly influence the environmental burden of the overall beverage can manufacturing process. Therefore, separate electrical power mix models were created for North America (includes the U.S. and Canada and representing domestic production) and "Other" regions (representing imports) based on the consumption of the aluminum industry. The respective flow charts are shown in Figure 16 and Figure 17, respectively. The electricity consumption for primary aluminum production is based on IAI statistics (IAI, 2007).

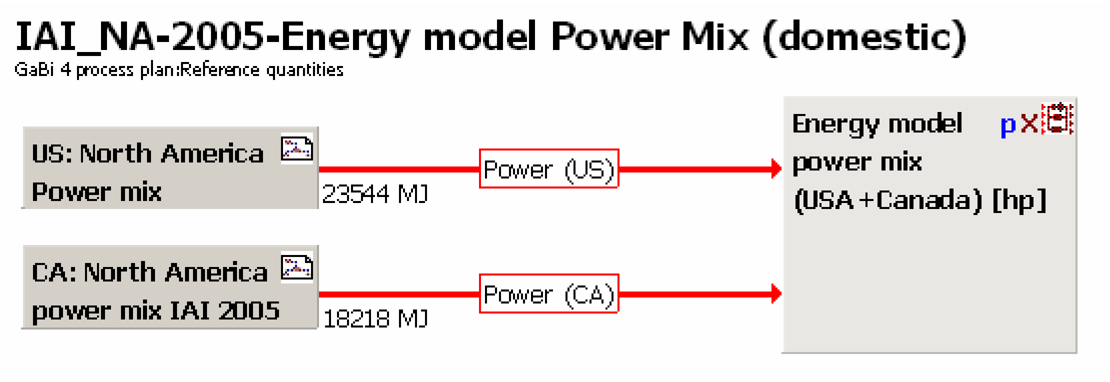

Figure 16: Electrical power mix for electrolysis (domestic mix). Flows are representative for production of the domestic component of 1000 kg of total primary aluminum (scaled to the share of domestic production).

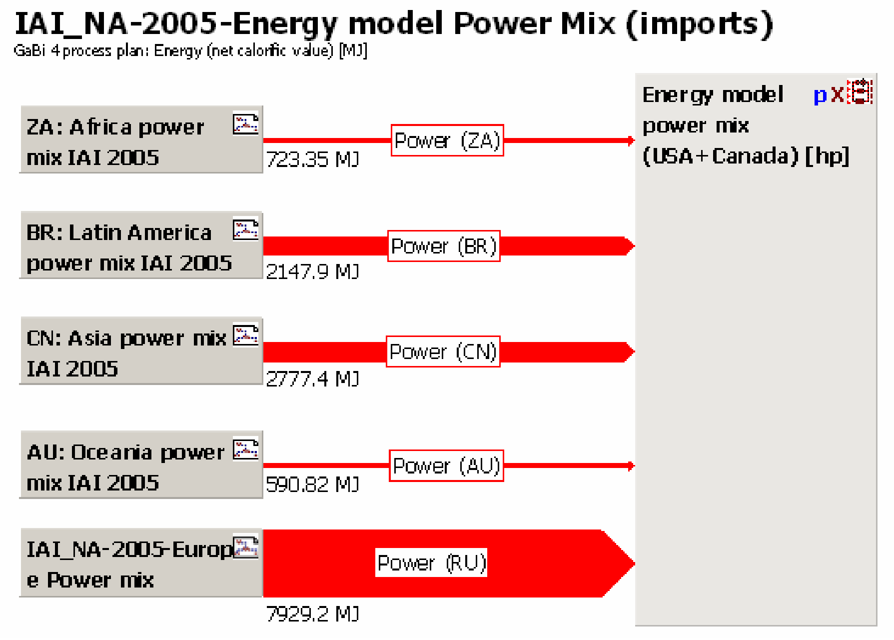

Figure 17: Electrical power mix for electrolysis (imports). Flows are representative for production of the imported component of 1000 kg total primary aluminum (scaled to the share of imports).

The composition of each of the continental or regional power mixes was compiled according to the respective shares of different power production technologies. A representative country from each region having a significant share of the regional power consumption for electrolysis was selected to model the power mix for each region, e.g. Russia for Europe (see Figure 18), Australia for Oceania, etc. (IAI, 2007).

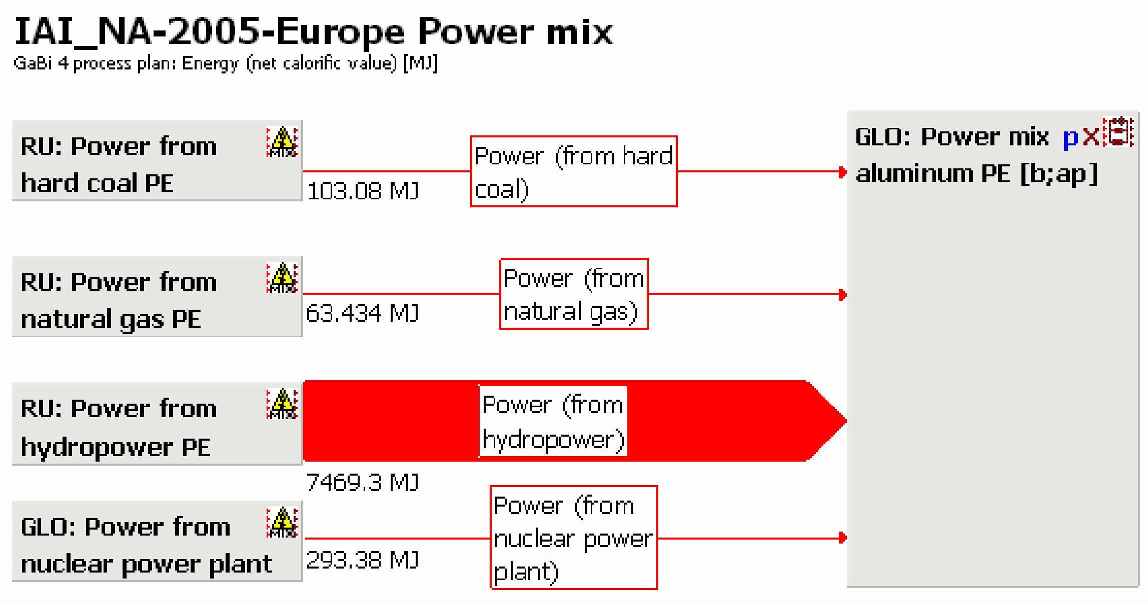

Figure 18: European power mix using Russia as the representative country. Flows are representative for production of the European imports component of 1000 kg of total primary aluminum (scaled to the share of imports).

According to the IAI statistics (IAI, 2007), the power mixes representative for the U.S. and Canada are of the same composition, as they both belong to the category North America (refer to “Area 2” in Table 12 and Table 13). The breakdown of electrical power by energy source consumed in the electrolysis process for the different regions is shown in Table 12 while Table 13 provides the relative contributions of electrical power by energy source consumed in the electrolysis for each region is illustrated. It can be observed that hydropower has the largest share (approximately 69%) in terms of total electricity input for electrolysis for the U.S. and Canada.

Table 12: Breakdown of electrical power (MJ) consumed in electrolysis by energy source for each region [IAI, 2007]

Energy Source	Reported Electrical Power Consumed (Gigawatt hours)						
	Area 1	Area 2	Area 3	Area 4/5	Area 6A/6B	Area 7	Total
	Africa	North America	Latin America	Asia	Europe	Oceania	
Hydro	5808	55249	33195	3868	88228	7659	194187
Coal	17992	23702	0	14182	13480	25618	95334
Oil	0	4	0	599	1722	2	2327
Natural gas	76	233	1412	21572	6704	0	29997
Nuclear	951	473	0	0	15697	0	17121
Total	24827	79841	34607	40221	126191	33279	338966

Table 13: Relative contribution of electrical power consumed in electrolysis by energy source for each region [IAI, 2007]

Energy Source	Reported Electrical Power Consumed (%)						
	Area 1	Area 2	Area 3	Area 4/5	Area 6A/6B	Area 7	Total
	Africa	North America	Latin America	Asia	Europe	Oceania	
Hydro	23.4%	69.2%	95.9%	9.6%	69.9%	23.0%	57.3%
Coal	72.5%	29.7%	0.0%	35.3%	10.7%	77.0%	28.1%
Oil	0.0%	0.0%	0.0%	1.5%	1.4%	0.0%	0.7%
Natural gas	0.3%	0.3%	4.1%	53.6%	5.3%	0.0%	8.8%
Nuclear	3.8%	0.6%	0.0%	0.0%	12.4%	0.0%	5.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

3.2 LCI RESULTS

In this chapter, the most important LCI results are represented for the production of 1 metric ton of primary aluminum ingot in the North America region.

3.2.1 Primary Energy Demand

The primary energy demand is a measure of the total amount of primary energy extracted from the earth, including both non-renewable (i.e. fossil fuels) and renewable (hydropower, wind, solar, etc.) resources, taking into account the efficiency of electric power generation and heating methods.

It is necessary to distinguish the primary energy demand and the energy that is received as so-called “end energy” at the operation site. An example may help to make this point clear:

1. Primary energy would be the amount of hydropower energy generated at the generation site (at the resources sites, for instance in hydropower plants)
2. Hydropower in the “power grid mix” indicates the energy in the distribution network that is ready to be used at the operation site.

The energy efficiency coefficient indicates the efficiency of the energy conversion (and its transmission, if applicable) system, and relates the primary energy demand and the end energy through the following equation:

$$\text{Primary Energy Demand}\,(1) \times \text{Conversion efficiency} = \text{End energy}\,(2)$$

The energy required for electrolysis is primarily provided as electrical power. In the U.S. and Canada, hydroelectric generation provides the majority of electrical power. However, this is not the case for other countries, e.g. Australia, where electrical power generated from coal is the dominant source of energy consumed in the electrolysis process.

More detailed information on the methodology to estimate the primary energy demand from direct energy use data is documented in Appendix A.

The primary energy demand results are illustrated in Figure 19, including a breakdown between non-renewable and renewable resources. The production of 1 metric ton of primary aluminum ingot representative for North American conditions requires 105 GJ of energy from non-renewable sources and 50 GJ from renewable sources. The electrolysis process accounts for 80% of the total primary energy demand. The electrolysis process and the anode production (anode production contributes approximately 14% of the primary energy demand for electrolysis) are highly energy intensive processes compared to other unit processes. As a result of the different power production efficiencies, the overall non-renewable fraction of primary energy for electrolysis is greater than the renewable fraction. The primary energy demand results are summarized in Table 14 below.

Table 14: LCI parameters for the production of 1000 kg of primary aluminum ingot in North America

Inventory parameter	Unit	Bauxite mining	Alumina Refining	Electrolysis	Cast house	Total
Primary Energy Demand	GJ/ton	1.02	27.36	124.27	2.36	155.00
Non renewable	GJ/ton	1.00	27.08	74.52	2.12	104.73
Renewable	GJ/ton	0.02	0.28	49.75	0.23	50.27
CO_2 emissions	ton CO_2/ ton	0.07	2.03	7.47	0.14	9.70

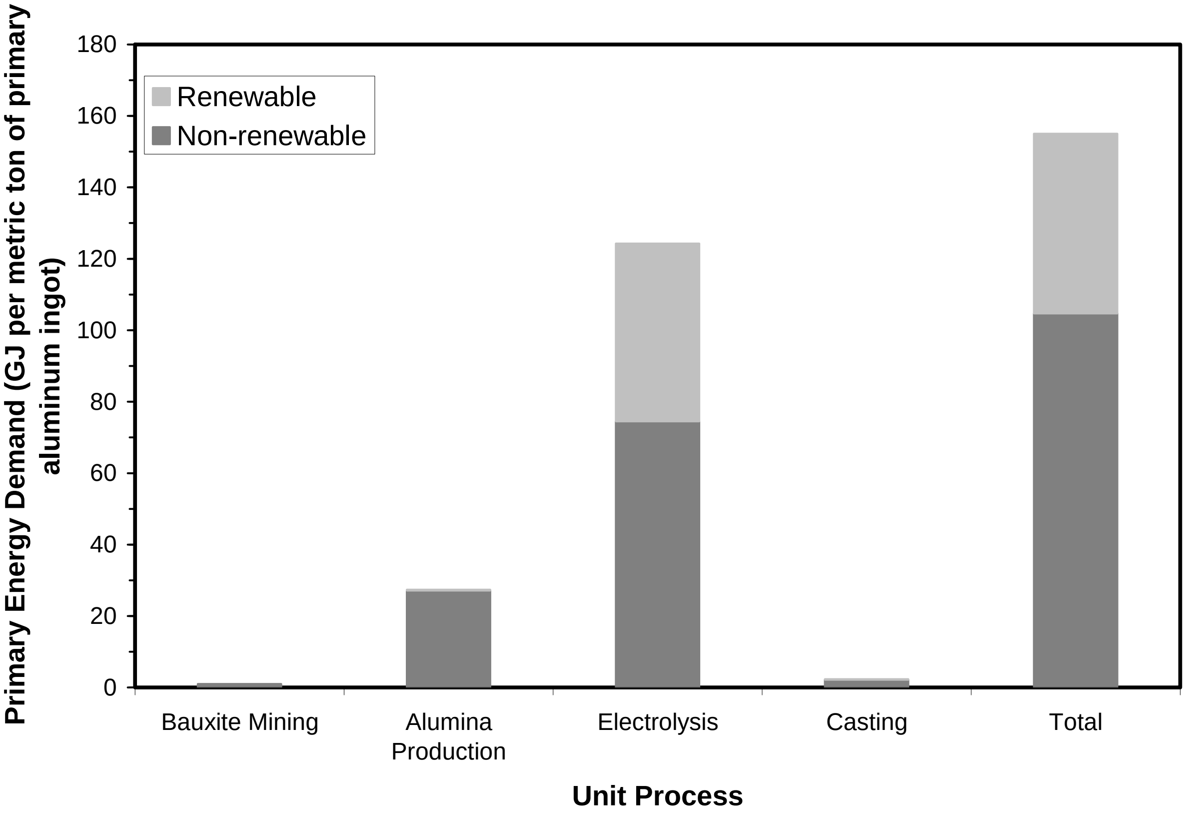

Figure 19: Primary energy demand from renewable and non-renewable sources for primary aluminum ingot production per unit process and in total. Electrolysis accounts for the largest primary energy demand (80%) of which 40% comes from renewable sources, while alumina production, which accounts for only 17.6% of total primary energy demand utilizes 26% of the total non-renewable energy.

3.2.2 Carbon dioxide Emissions

Carbon dioxide is one of the greenhouse gases that contributes to the global warming phenomenon. Carbon dioxide emissions are mainly associated with the conversion of fossil energy carriers (e.g. lignite, crude oil, natural gas) into thermal and/or mechanical energy by means of burning and are expressed in kilograms of CO_2. The carbon dioxide emission results of the LCI are illustrated in Figure 20. It is calculated that about 9.7 metric tons of carbon dioxide is emitted per metric ton of primary aluminum ingot produced. The carbon dioxide results are closely linked to the primary energy demand results and their graphs have much the same shape. The electrolysis process is the largest contributor, producing almost 7.5 metric tons of carbon dioxide for each ton of primary aluminum ingot produced. The upstream emissions associated with the electricity supply chain for electrolysis account for 70% of the total 7.5 metric tons CO_2 for electrolysis. The carbon dioxide results are summarized in Table 14.

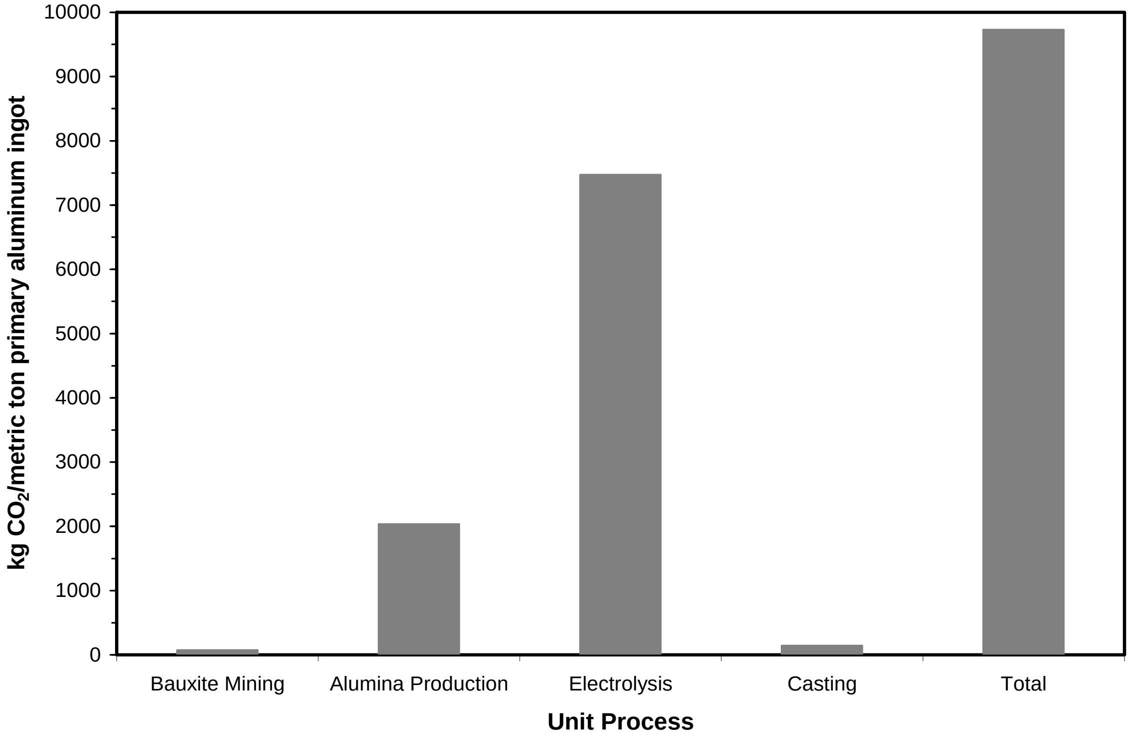

Figure 20: Carbon dioxide emissions during primary aluminum ingot production per unit process in total. Electrolysis is the major contributor to the total CO_2 emissions of which 70% are from the electricity supply chain.

3.3 LCIA RESULTS

In this chapter, the Life Cycle Impact Assessment (LCIA) results are presented for the production of 1 metric ton of primary aluminum ingot in North America. Unlike the Life Cycle Inventory, which only reports sums for individual emissions, the LCIA includes methodologies for weighting and combining different emissions into a metric for significant the Life Cycle Inventory, a Life Cycle Impact Assessment (LCIA).

As described in Section 2.2.7 of this report, the impact assessment results were calculated using characterization factors published by the Centre of Environmental Science at Leiden University (CML), Netherlands (CML, 2001). The CML 2001 methodology is the most widely applied impact assessment method in LCA studies around the world. Additional information on the significance of these impact categories is included in Appendix C: Impact Indicators of this report.

3.3.1 Acidification Potential

The acidification potential is a measure of emissions that cause acidifying effects to the environment and is expressed as kilogram SO_2 Equivalent.

The major acidifying emissions are nitrogen oxides (NO_x) and sulfur dioxide (SO_2), as well as ammonia emissions that lead to ammonium deposition. The acidification potential related to 1000 kg of primary aluminum ingot production in North America amounts to 50.43 kg SO_2 equivalent (Figure 21; Table 16). The relative share of this acidification potential indicator from SO_2 emissions to air is 74%, and from NO_x emissions to air is 25%.

Breaking the emissions down by production stages shows that the electrolysis process is responsible for 77% of the total acidification potential result; followed by alumina refining which has an 18% contribution.

We also note that 74% of the acidification impacts are associated with upstream emissions during electricity production.

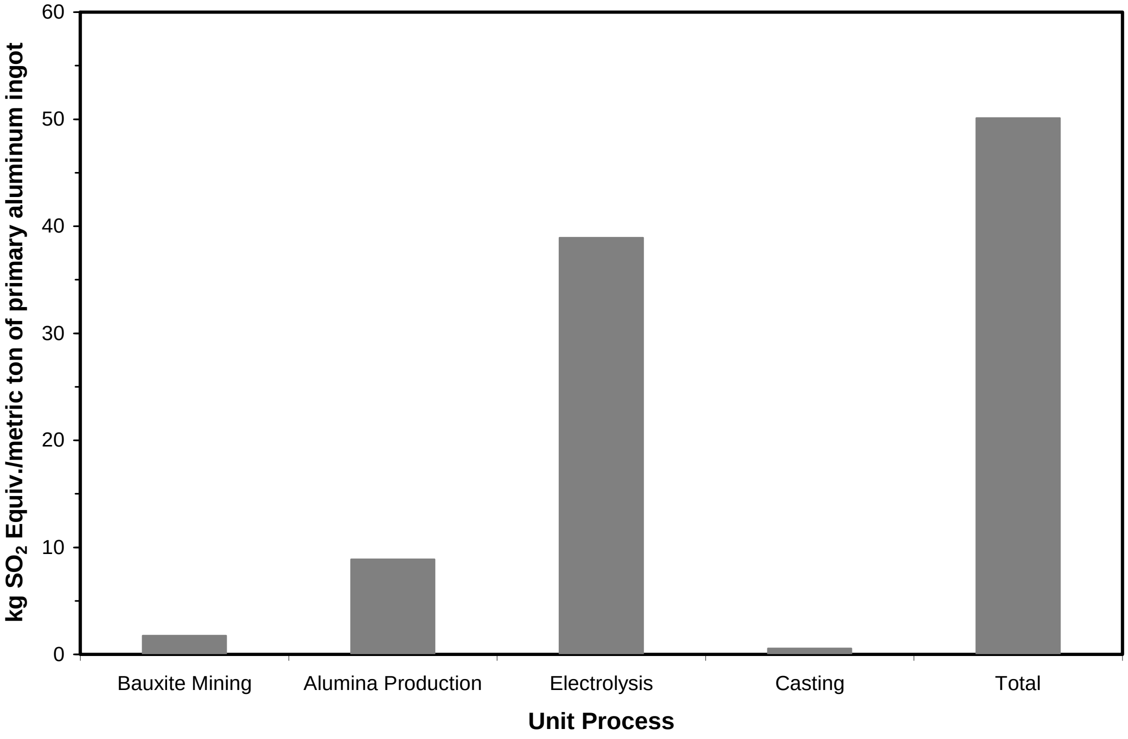

Figure 21: Acidification potential results for primary aluminum ingot production. 77% of the total acidification potential result is attributed to the process of electrolysis and upstream emissions from electricity generation account for 74% of the total AP.

3.3.2 Eutrophication Potential

The eutrophication potential is a measure of emissions that cause eutrophying effects to the environment and is expressed as kilogram of Phosphate Equivalent. The eutrophication of aquatic systems is primarily caused by excessive inputs of nitrogen and phosphorus (mostly as a result of over-fertilization).

The eutrophication potential related to the manufacture of 1 metric ton of primary aluminum ingot in North America amounts to almost 2.35 kg Phosphate equivalent (Figure 22; Table 16). The eutrophication potential from emissions to air (mainly NO_x emissions) contributes to 95% of the total impacts. The remaining 4% of the eutrophication potential is due to emissions to water (mainly from nitrate emissions, chemical oxygen demand COD and NO_x releases to water). The remainder of the eutrophication impact indicator comes from emissions to soil, which represents 0.7% (mainly from ammonia and phosphorus releases).

Breaking the impact down by contributions from different production stages, Figure 22 shows that the alumina refining and electrolysis processes together are responsible for 91% of the eutrophication impacts result, with individual contributions of 72% and 19%, respectively. Emissions to air from upstream processes (such as electricity production) account for approximately two-thirds (67%) of the total eutrophication potential result.

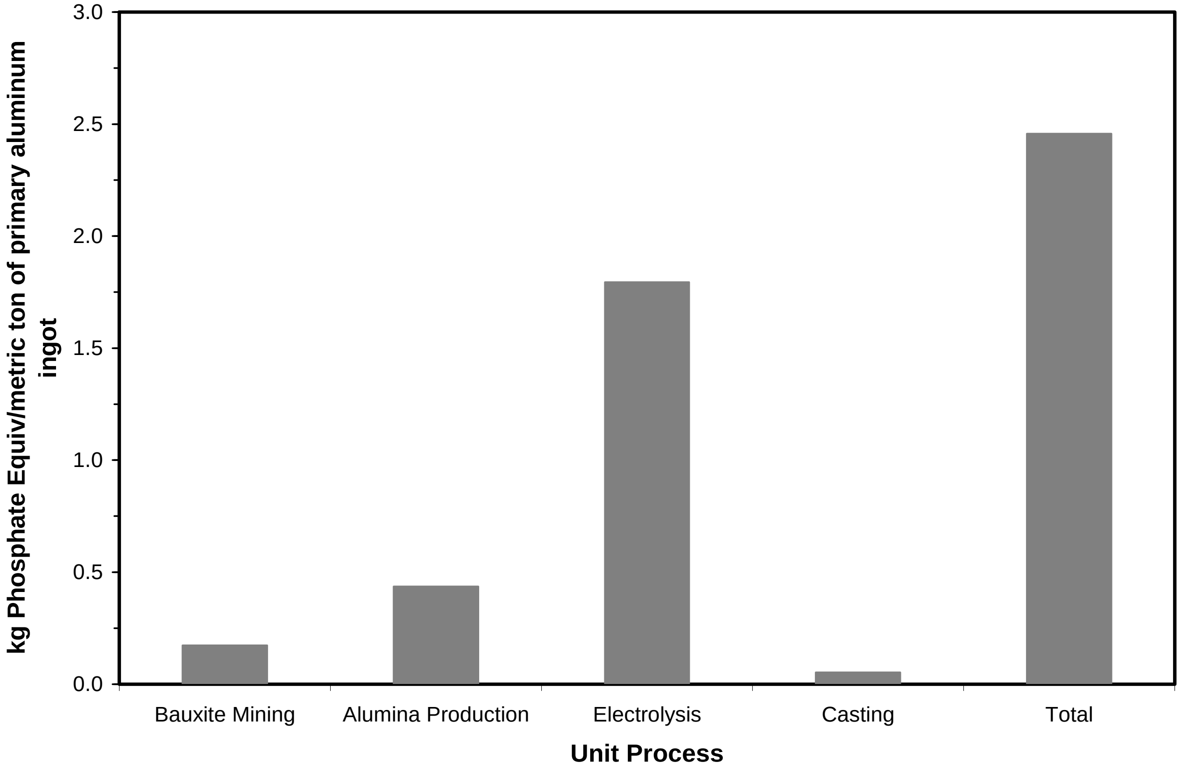

Figure 22: Eutrophication potential results for primary aluminum production. Alumina production and electrolysis together account for about 91% of the total EP of which indirect emissions to air account for 67%.

3.3.3 Global Warming Potential (100 years)

The Global Warming Potential (GWP) is a measure of the emission of greenhouse gases (GHG) such as CO_2 and methane (CH_4) and is expressed as kilogram of CO_2-equivalents. Greenhouse gas emissions are found to cause an increase in the absorption of radiation emitted by the sun and reflected by the earth, magnifying the natural greenhouse effect.

The total global warming potential (GWP) related to the production of 1 metric ton of primary aluminum ingot in North America is 11068 kg CO_2 equivalent. A breakdown of the GWP impact by component greenhouse gases shows that almost 85.8% of the net GWP comes from CO_2, 9.79% from Tetrafluoromethane, 2.56% from CH_4, 1.6% from Hexafluoroethane, and 0.3% from nitrous oxide (N_2O).

A breakdown of the results by individual production stages is shown in Figure 23 and shows that 79% of the global warming impacts come from the electrolysis process. Alumina refining is next largest contributor with a 19% share of net global warming potential.

The share of global warming potential from direct greenhouse gas emissions is approximately 25% of net GWP impact, while indirect CO_2 emissions (mainly from electricity production) account for another 50% of net GWP impact.

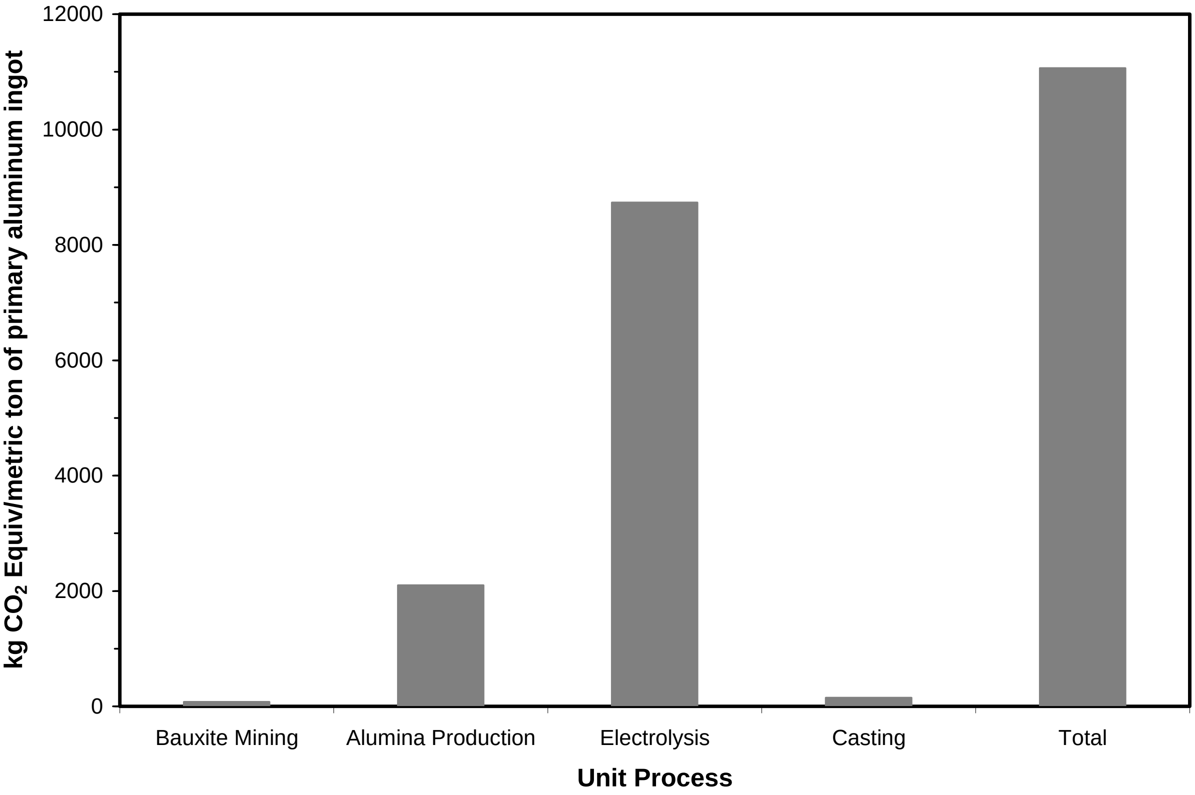

Figure 23: Global warming potential results for primary aluminum ingot production. The electrolysis process is responsible for 79% of the global warming impacts, of which 85.8% are due to CO_2 emissions.

GHG analysis and breakdown into scope 1, 2 and 3

Based upon the request of the Aluminum Association and the core group members, the GHG emission results for the primary aluminum ingot production were further categorized applying the concept of scopes as outlined in the Greenhouse Gas (GHG) Protocol (WRI and WBCSD, 2004). As the GHG Protocol was not designed to be applied to products[4], the results categorization was performed as closely as possible to the requirements of the GHG Protocol. Following the concept of scopes, the breakdown of the GHG emissions as determined in compliance with the ISO 14044 standard (ISO, 2006b) is provided for Scope 1 (direct GHG emissions), Scope 2 (indirect GHG emissions attributable to energy conversion processes) and Scope 3 (further GHG emissions from the supply chain)[5]. The results are illustrated in Table 15.

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: Indirect GHG emissions from electricity are comprised of GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electric-

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[4] The GHG protocol is applicable to the companies only.

[5] Detailed information about the standard and is application are available from www.ghgprotocol.org.

ity 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.

Scope 3: Other indirect GHG emissions are an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Some examples of Scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services.

We recommend that sustainability issues be assessed and addressed by taking the whole supply chain (or rather the supply web) into account. This allows consideration of both direct GHG emissions as well as emissions indirectly associated with the respective production processes.

Table 15: Scope 1, 2, and 3 CO2 Equivalent emissions for primary aluminum ingot production.

kg CO2equiv. / ton Aluminum												
	Bauxite mining		**Alumina refining**		**Anode production**		**smelting**		**casting**		**Total**	
	AA	IAI	AA	IAI	AA	IAI	AA	IAI	AA	IAI	AA	IAI
Process					178	177	1584	1584			1762	1761
Electricity	11	5	170	122	19	30	5152	4922	40	36	5392	5115
Fossil fuels	58	23	1409	1346	95	69			95	84	1657	1522
PFC							1037	1159			1037	1159
Fuel supply chain	8		238		10		406		15		677	0
Auxiliary material			279		227		37				543	0
total scope 1+2	69	28	1579	1468	292	276	7773	7665	135	120	**9848**	9558
total scope 1+2 +3	77		2096		529		8216		150		**11068**	

Scope 1 refers to GHG emissions from the process itself (1762 kg CO_2 equivalent), from burning the fossil fuels for thermal energy demand at the factory (1657 kg CO_2 equivalent) and specific emissions from the smelting stage(1037 kg CO_2 equivalent).

Scope 2 refers to GHG emissions from upstream processes such as electricity production, which contribute 5392 kg CO_2 equivalent.

Scope 3 refers to GHG emissions coming from the supply chains (677 kg CO_2 equivalent) and auxiliary materials (543 kg CO_2 equivalent), for a total of 1221 kg CO_2 equivalent.

The sum of Scope 1 and 2 emissions indicates the GHG emissions which are the responsibility of the factory, which for production of one metric ton of primary aluminum ingot is 9848 kg CO_2

equivalent[6]. This value is in the same range as the 9558 kg CO_2 equivalent figure mentioned in the IAI report. However, this figure for Scope 1 and 2 emissions does not reflect the full life cycle impacts, and the 1221 kg CO_2 equivalent Scope 3 emissions must be included to find that the full life cycle global warming potential from producing one metric ton of primary aluminum ingot is 11068 kg of CO_2 equivalent.

3.3.4 Photochemical Ozone Creation Potential

The Photochemical Ozone Creation Potential (POCP) measures the emissions of precursors that contribute to low level smog (also called Summer Smog), produced by the reaction of NO_x and volatile organic compounds (VOC) under the influence of ultra violet light. POCP is expressed as kg Ethene equivalent.

The POCP results are illustrated in Figure 24 as well as in Table 16. The POCP related to the production of one metric ton of primary aluminum in North America is 3.06 kg Ethene equivalent. The breakdown of emissions to air which contribute to smog creation potential for primary aluminum production is 59% from SO_2, 19% from non-methane volatile organic compounds (NMVOC), 17 % from NO_x, and 2% from methane.

Like the other life cycle impact categories, the electrolysis process is the largest contributor to smog creation impacts, accounting for 77% of the total POCP. This is followed by alumina refining which is responsible for 19% of the net smog creation impact.

Approximately 70% of these contributing emissions are associated with production of electricity required for primary aluminum ingot production.

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[6] Note: these figures indicates a CO2-equivalent for all GHG-emissions (total score) and is not to be mistaken for effective CO2 emissions.

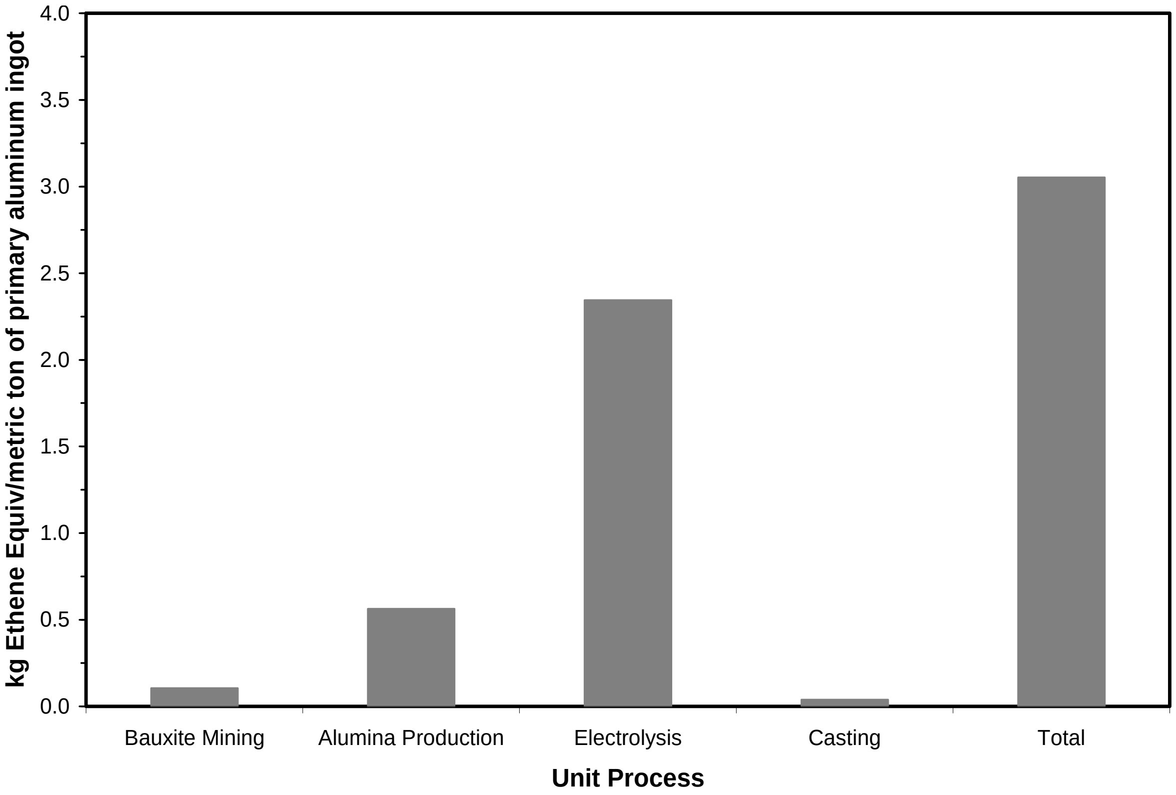

Figure 24: Photochemical ozone creation potential results for primary aluminum ingot production. Electrolysis is the largest contributor to smog creation impacts, accounting for 77% of the total POCP, of which 70% are attributed to electricity production.

Table 16: LCIA results for production of 1000 kg of primary aluminum ingot in North America.

Impact Assessment Category	Unit	Bauxite mining	Alumina Refining	Electrolysis	Cast house	Total
Global Warming Potential	ton CO_2 Equiv./ton	0.05	2.12	8.74	0.15	11.06
Acidification Potential	kg SO_2 Equiv./ton	1.80	9.16	38.92	0.55	50.43
Eutrophication Potential	kg Phosphate Equiv./ton	0.16	0.47	1.79	0.05	2.48
Photochemical Ozone Creation Potential	kg Ethene Equiv./ton	0.10	0.58	2.35	0.04	3.06

4 BEVERAGE CAN PRODUCTION

This chapter describes in a comprehensive way the manufacturing of beverage cans as representative for the U.S. market conditions. It includes sub-sections on the process description (Chapter 4.1), data collection and modeling (Chapter 4.2), the LCI results (Chapter 4.3) and the LCIA results (Chapter 4.4).

4.1 PROCESS DESCRIPTION

4.1.1 Can Sheet

The manufacturing of the aluminum beverage can begins with the conversion of ingots into can stock and lid stock coil, which are subsequently converted into can bodies and lids at the can manufacturing plant. The process chain at a rolling mill is illustrated in Figure 25. In Hot mill rolling, aluminum ingots (approximately 18 to 26 inches thick and weighing approximately 15 to 30 metric tons) are preheated to about 1000°F and fed through a hot reversing mill. In the reversing mill, the coil passes back and forth between rollers and the thickness is reduced from the initial thickness to between 1 to 2 inches with a corresponding increase in length. Following the reverse mills, the slabs are fed to a continuous hot mill where the thickness is further reduced to less that ¼ inch in thickness. The metal, called re-roll or hot coil, is rolled into coil and ready to be transferred to the cold mill.

Prior to the cold mill, the coils may be annealed to give the metal the workability for downstream processing. Some plants have moved towards self annealing which requires no additional energy investment as the industry has improved their energy management. The coils are then passed through multiple sets of continuous rollers to reduce the gauge to approximately 0.012 inches required by the can makers. The coils are slit to the width and cut to the length required by can manufacturers. The coils are packaged to prevent damage to the metal in shipping.

Sheet rolling differs slightly based on the final use of the can sheet – for the body of the can or the lid. The main difference is a coating step for sheets that are used in lid making. Inputs and outputs for the sheet rolling process are shown in Table 17 and Table 18 for the body sheet and lid sheet processes respectively.

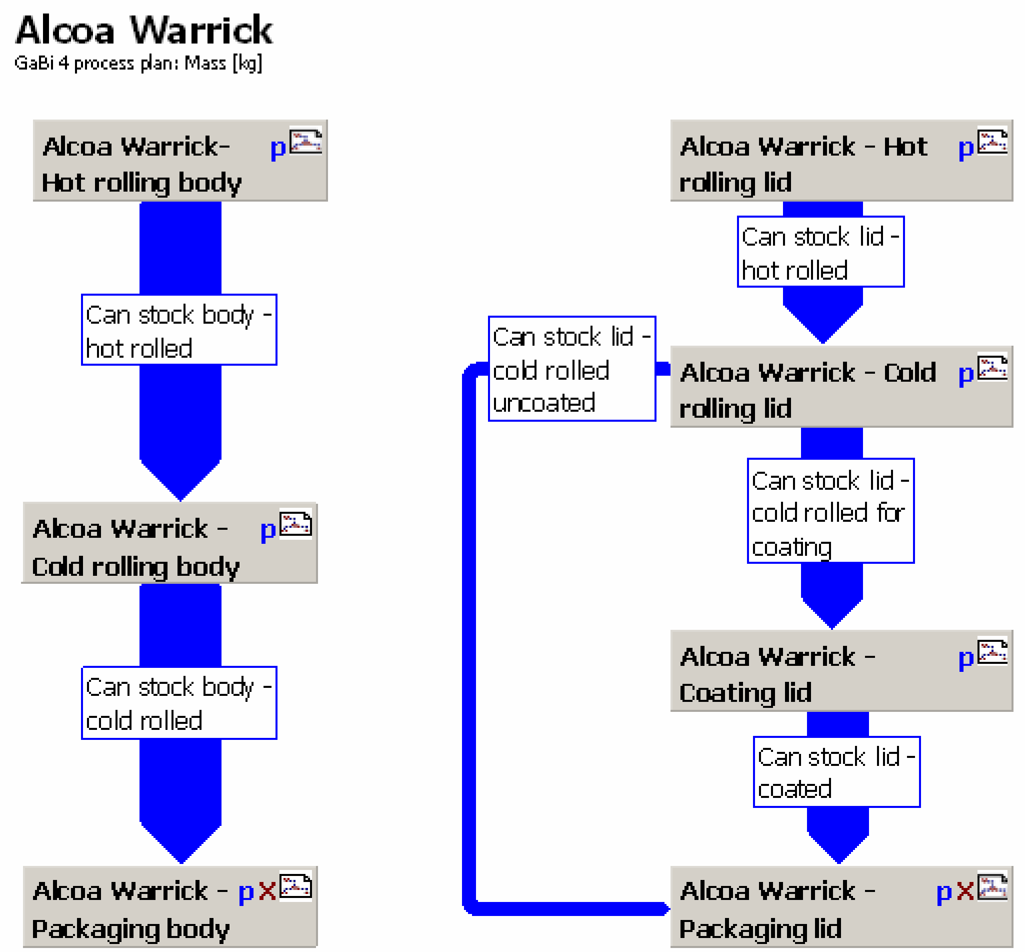

Figure 25: Unit process chain representative for one particular rolling mill site. The flow chart demonstrates the assembly of the single process steps in the GaBi4-Software in order to quantify the average LCI data for a can sheet. Can sheet making is separated into two parts, related to the production of the a) lid and b) the body components. The can sheet making process differs in the coating which the lids receive. The ratio of lid to body production (by weight) is approximately 22/78. This single model was customized for each of the surveyed sites and resulting inventories were weighted and averaged.

Table 17: Input and Output flows for the can sheet making unit process (scaled to the body component). Flows are representative for 1000 kg of can sheet production (780 kg of body component).

Flows	Units	Amount
INPUTS		
Energy and Fuels		
Thermal energy (natural gas)	MJ	3077
Power	MJ	1025

Thermal energy (heavy fuel oil)	MJ	36.45
Steam (MJ)	MJ	6.95
Thermal energy (light fuel oil)	MJ	3.079
Thermal energy (LPG)	MJ	1.262
Kerosene	kg	0.1
Diesel	kg	0.079
Gasoline (regular)	kg	0.011
Heavy fuel oil	kg	0.003
Metals		
Aluminum Ingot	kg	1072
Steel	kg	0.13
Operating Materials		
Process water	kg	835.6
Cooling water	kg	473.0
Rolling oil	kg	3.603
Lubricant (unspecified)	kg	1.185
Hydraulic oil	kg	0.811
Filter media	kg	0.616
Lubricating oil	kg	0.391
Solvent	kg	0.006
Other Materials		
Wooden pallets (EURO, 40% moisture)	kg	2.535
Coatings (unspecified)	kg	2.306
Sulphuric acid (100%)	kg	0.651
Cardboard (packaging)	kg	0.303
Polyethylene-film (PE)	kg	0.141
Paper Plastic Composite	kg	0.073

Foam	kg	0.036
Phosphoric acid	kg	0.024
Chromic acid	kg	0.009
OUTPUTS		
Products		
Can stock body	kg	780.0
Emissions to air		
VOC (unspecified)	kg	1.333
Dust (unspecified)	kg	0.136
Nitrogen oxides	kg	0.117
Carbon monoxide	kg	0.088
Hydrogen fluoride	kg	0.002
Ethyl benzene	kg	0.001
Sulphur dioxide	kg	0.001
Emissions to water		
Waste water	kg	2032
Solids (dissolved)	g	144.2
Solids (suspended)	g	24.36
Biological oxygen demand (BOD)	g	12.39
Chloride	g	9.185
Chemical oxygen demand (COD)	g	2.479
Aluminum ion (+III)	g	0.144
Aluminum (+III)	g	4.73E-02
Zinc (+II)	g	2.2E-02
Ammonium / ammonia	g	1.23E-03
Other wastes		

Aluminum scrap	kg	291.6
Non-hazardous waste for land-filling	kg	4.113
Non-hazardous waste for further processing	kg	0.949
Scrap metal for recycling, excluding aluminum	kg	0.405
Hazardous waste for further processing	kg	0.068
Hazardous waste for land-filling	kg	0.022

Table 18: Input and Output flows for the can sheet making unit process (scaled to the lid component). Flows are representative for 1000 kg of can sheet production (220 kg lid component).

Flows	Units	Amount
INPUTS		
Energy and Fuels		
Thermal energy (natural gas)	MJ	917.7
Power	MJ	636.5
Thermal energy (MJ)	MJ	47.87
Steam (MJ)	MJ	41.59
Thermal energy (heavy fuel oil)	MJ	10.06
Thermal energy (light fuel oil)	MJ	0.695
Kerosene	kg	0.186
Diesel	kg	0.107
Gasoline (regular)	kg	0.009
Metals		
Aluminum Ingot	kg	316.9
Steel	kg	0.034
Operating Materials		
Process water	kg	312.0
Cooling water	kg	108.3

Solvent	kg	6.712
Lubricant (unspecified)	kg	3.706
Rolling oil	kg	3.354
Hydraulic oil	kg	0.229
Filter media	kg	0.214
Lubricating oil	kg	0.15
Other Materials		
Epoxy resin	kg	9.265
Wooden pallets (EURO, 40% moisture)	kg	3.851
Vinyl chloride (VCM; chloroethene)	kg	0.761
Coatings (unspecified)	kg	0.598
Cardboard (packaging)	kg	0.365
Naphtha	kg	0.350
Sodium carbonate (soda)	kg	0.304
Sulphuric acid (100%)	kg	0.28
Polyester resin (unsaturated; UP)	kg	0.223
Succinic acid dibutylene ester	kg	0.180
Xylene (o-xylene; 1,2-dimethyl benzene)	kg	0.179
Phosphoric acid	kg	0.133
OUTPUTS		
Products		
Can stock lid - packaged	Kg	220
Emissions to air		
VOC (unspecified)	Kg	0.395
Nitrogen oxides	Kg	0.063
Dust (unspecified)	Kg	0.027

Xylene (dimethyl benzene)	Kg	0.020
Carbon monoxide	Kg	0.019
Trimethylbenzene	g	3.01
Toluene (methyl benzene)	g	2.31
Ammonia	g	1.389
Ethyl benzene	g	1.233
Methyl isobutyl ketone	g	7.76
Sulphur dioxide	g	4.11
Cumene (isopropylbenzene)	g	2.89
Emissions to water		
Waste water	kg	1063
Solids (dissolved)	kg	0.032
Solids (suspended)	g	20.05
Biological oxygen demand (BOD)	g	7.798
Chemical oxygen demand (COD)	g	7.172
Chloride	g	2.356
Aluminum ion (+III)	g	0.242
Aluminum (+III)	g	1.23E-02
Chromium (unspecified)	g	2.37E-03
Other Wastes		
Aluminum scrap	kg	95.72
Non-hazardous waste for further processing	kg	3.030
Non-hazardous waste for land-filling	kg	1.684
Hazardous waste for land-filling	kg	1.093
Hazardous waste for incineration	kg	1.026
Hazardous waste for further processing	kg	0.323

4.1.2 Can Manufacturing

Aluminum coils are shipped from the rolling mills to can manufacturing plants. Within the can manufacturing plants, coils are set upright and moved into position to feed the cupping press. The coil is unwound and lubricated at a rate needed to feed the press. In the cupping press, blanks or discs are stamped and then pressed into cups. This process results in generation of manufacturing (skeleton) scrap which is then shipped back to secondary casting facilities. The cups then undergo a series of forming, ironing, and punching operations to form the final profile of the can as per the desired specifications. In order to ensure a flat top, the cans are trimmed at the top. The trim scrap is also shipped back to secondary casting facilities. After trimming, the cans undergo a series of washing steps before being dried in an oven. Paints are then applied externally to the cans, the paint acting as a label for the can product. The cans are then further internally coated to establish a barrier between the metal and beverage.

The next step, necking of the can, reduces the diameter of the open end of the can to match the diameter of the lid. The diameter of the lid is smaller than the can diameter, allowing for an overall reduction in the amount of aluminum used in a finished aluminum can. After the diameter has been reduced, the flange that forms part of the seal to the lid is formed. The cans then undergo a quality control process to check the integrity of the final product before they are shipped to fillers. The cans are stacked onto plastic pallets in shipping.

Layers of cans are separated using corrugated paper or plastic sheets. The entire pallet is then banded together with plastic bands and in rare cases is covered with shrink wrap to protect the cans from damage and dirt during both shipping and storage.

Can lids are manufactured from a different alloy than can body. Alloys for can lids have higher magnesium content in place of the manganese used in the bodies, as lids are designed to be stiffer than the can body. Following the cold rolling, the can stocks for lids is cleaned and coated and shipped to the manufacturer. Lids can be manufactured from either coils or from scrolled sheets. The manufacturing steps are very similar independent of the type of feed so only the coil fed process will be described here. The major steps in the process are stamping out ends, curling the edges of the shells, applying the sealing compound, stamping tabs, stamping the end features onto the ends, and finally attaching the tabs to the ends to make a completed lid. An illustration of the can making process is shown in Figure 26 and Table 19 lists the inputs and outputs of the can-making process.

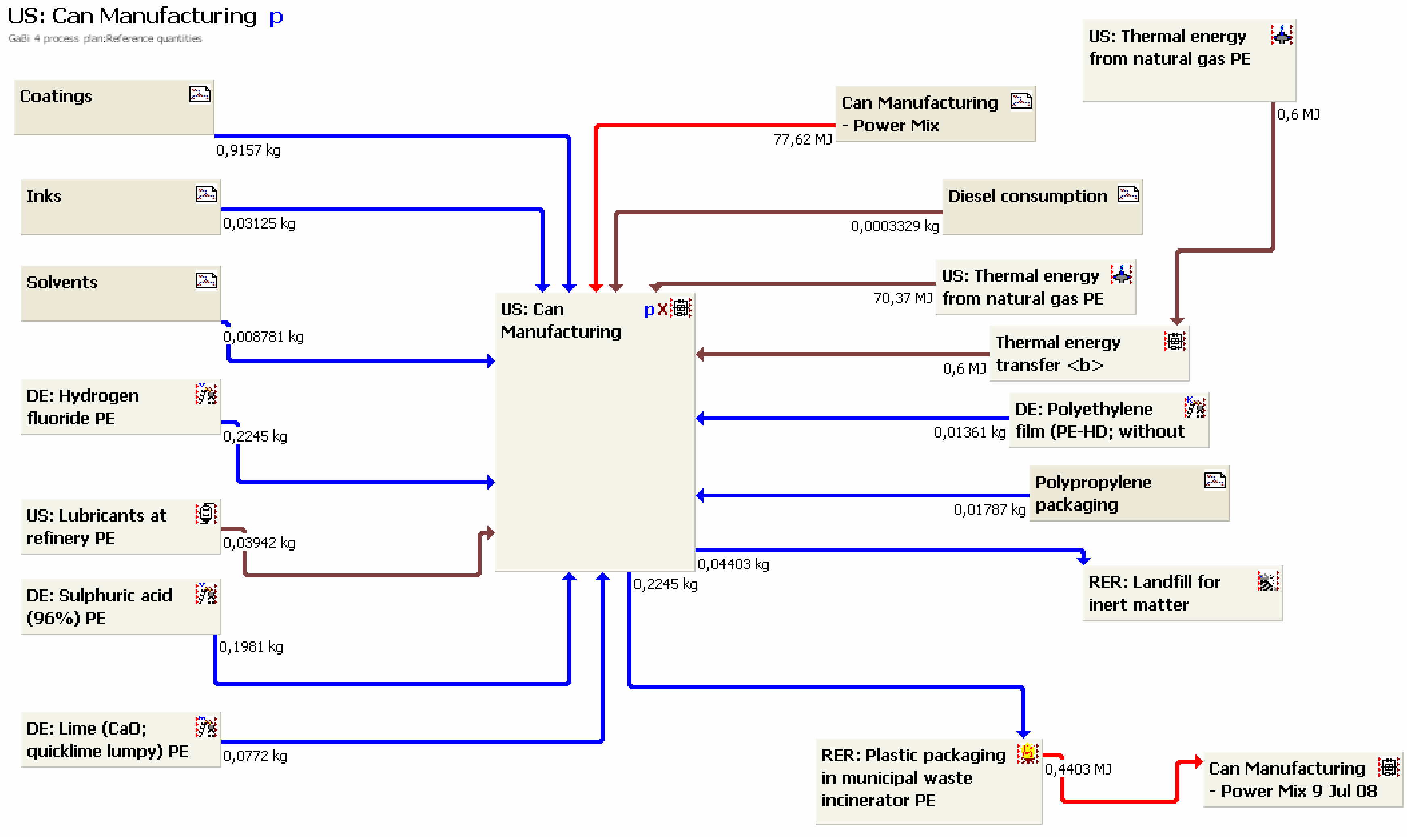

Figure 26: Illustration of the Can making process. Flows are representative for the production of 1000 cans. Data is contributed by the weighted average of inventories in the surveyed sites (see Data Collection and Modeling).

Table 19: Inputs and outputs for the can making unit process. Flows are representative for the manufacturing of 1000 cans from aluminum sheet.

Flows	Units	Amount
INPUTS		
Energy and Fuels		
Power	MJ	77.62
Thermal energy (natural gas)	MJ	70.37
Thermal energy (LPG)	MJ	0.6
Diesel	g	3.329
Metals		
Aluminum sheet	kg	16.78
Other Materials		
Water	kg	85.77
Coatings (can)	kg	0.916
Hydrogen fluoride	kg	0.225
Sulphuric acid aq. (96%)	kg	0.198
Lime quicklime (lumpy)	g	77.20
Lubricating oil	g	39.42
Inks (can)	g	31.25
Polyethylene part (PE)	g	13.61
Polypropylene part (PP)	g	17.87
Solvent	g	8.781
OUTPUTS		
Products		
2 PC Can	pcs.	1000
Emissions to air		

Alcohols (unspec.)	g	43.77
Ethylene glycol	g	23.9
Ether (unspec.)	g	4.03
Formaldehyde (methanol)	g	2.02
Naphtha	g	0.987
Xylene (dimethyl benzene)	g	2.36E-2
Manganese (+II)	g	1.13E-2
Hydrogen fluoride	g	9.21E-3
Ethyl benzene	g	6.23E-4
Methanol	g	2.47E-4
Emissions to water		
Waste water	kg	58.63
Phosphorus	kg	0.5
Solids (dissolved)	kg	0.11
Sulphate	kg	0.045
Chemical oxygen demand (COD)	kg	0.026
Calcium (+II)	kg	0.02
Biological oxygen demand (BOD)	g	3.9
Chloride	g	3.5
Solids (suspended)	g	3.5
Total organic bounded carbon	g	2.4
Sodium (+I)	g	2.1
Oil (unspecified)	g	1.4
Nitrogen (as total N)	g	0.84
Fluoride	g	0.45
Aluminum (+III)	g	0.43

Potassium	g	0.3
Magnesium (+III)	kg	1.4E-4
Silicate particles	kg	7.6E-5
Arsenic (+V)	kg	3E-5
Strontium	kg	1.4E-5
Manganese (+II)	kg	9.2E-6
Phenol (hydroxy benzene)	kg	8.3E-6
Sulphide	kg	5.2E-6
Iron	kg	3.3E-6
Zinc (+II)	kg	3E-6
Selenium	kg	2.9E-6
Copper (+II)	kg	2.6E-6
Barium	kg	1.3E-6
Chlorine	kg	1.2E-6
Lead (+II)	kg	9.1E-7
Chromium (unspecified)	kg	9E-7
Cadmium (+II)	kg	8.6E-7
Cyanide	kg	5.2E-7
Nickel (+II)	kg	3.5E-7
Silver	kg	2.9E-7
Mercury (+II)	kg	1.1E-8
Other Wastes		
Aluminum scrap	kg	3.447
Total waste for incineration	kg	0.225
Sludge	kg	0.174
Waste (recycling)	kg	0.13

Waste (incineration)	g	49.66
Waste (landfill)	g	44.03
Sludge (from processing)	g	26.31
Hazardous waste for incineration	g	0.752

4.1.3 Secondary Aluminum Ingot / Recycling

The secondary aluminum production process includes the unit processes of shredding, decoating, remelting and secondary ingot casting as shown in Figure 27. The secondary aluminum ingot is produced from post-consumer scrap (UBC) recovered from the consumer waste stream. The UBCs may be collected in a municipal curbside program and dropped off by individuals or groups interested in generating revenue.

UBCs must be treated prior to their melting in a furnace. First, the UBCs are shredded to remove trapped water and other contaminants. The uniform size of the shreds helps material flow in downstream processing. The shreds are passed under magnetic separators to remove ferrous contamination. In some facilities, air knives are also used to prevent the inclusion of heavy contamination such as lead, stainless steel, or zinc.

The metal leaves the shredders and passes into a decoating unit. This unit heats the metal and coatings, resulting in the vaporization and oxidation of the coatings. The decoating process results in the transfer of the hot metal to the melting furnace. Primary aluminum metal is consumed to make up for system melt loss and sweeten the composition if necessary. In addition, alloying additives are also added to the final specifications of the ingot to be produced. The casting process is similar to the process described in the section on Primary Ingot Casting (Cast House) (Chapter 3.1.5).

The scrap preparation is separated from remelting and casting and unit process information is shown in Table 20 and Table 21. It is important to note that these numbers are specific for aluminum ingots used in can making and in no way are representative of the aluminum ingot production in general (AA).

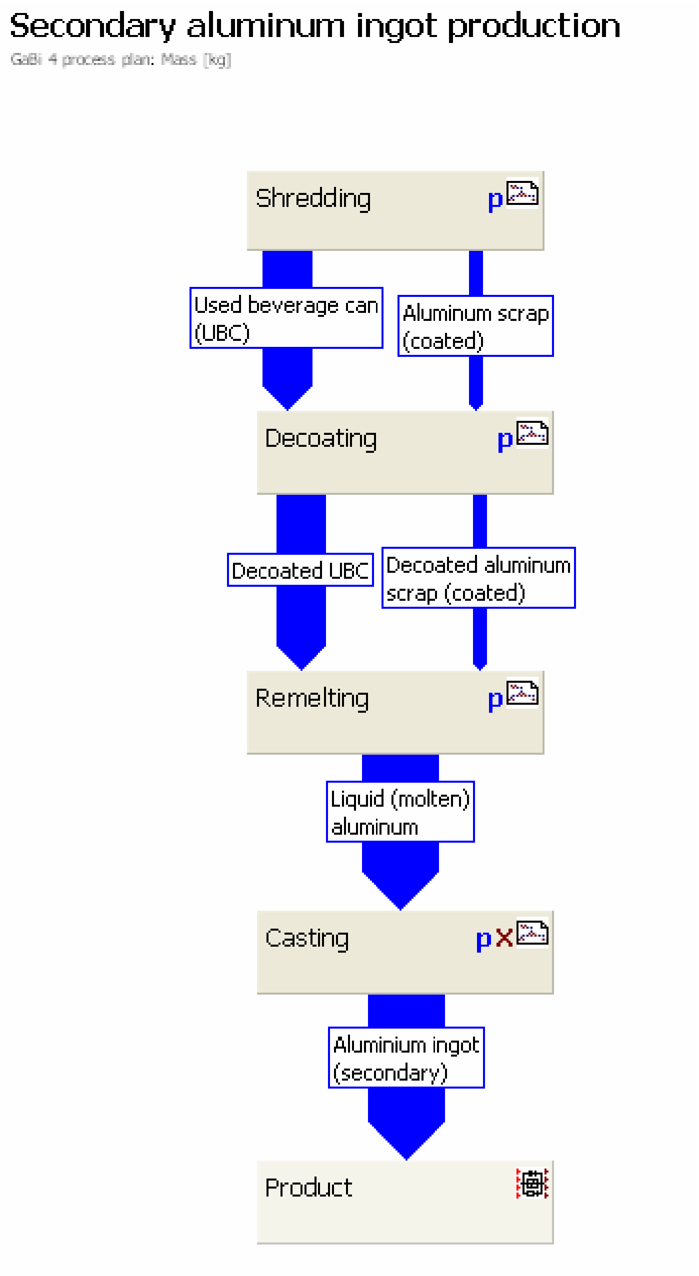

Figure 27: Unit process chain at one selected secondary aluminum production site illustrating the attempt to quantify the LCI data for secondary aluminum ingot production

Table 20: Input and output flows for scrap preparation unit processes (i.e. shredding & decoating). The figures indicate the average overall surveyed sites. Flows are representative for 1000 kg of prepared scrap.

Flows	Units	Amount
INPUTS		
Energy and Fuels		
Thermal energy (MJ)	MJ	281.22
Power	MJ	30.91
Metals		
Aluminum scrap	kg	1013
Operating Materials		
Calcium hydroxide	kg	0.656
OUTPUTS		
Products		
Aluminum scrap (processed)	kg	1000
Emissions to air		
Hydrogen chloride	g	6.21
Nitrogen dioxide	g	2.071
Sulphur dioxide	kg	8.63E-06
VOC (unspecified)	g	3.667
Other emissions to air	kg	3.97E-10
Dust (unspecified)	g	23.49
Other wastes		
Aluminum Fines	kg	5.103
Hazardous waste for land-filling	kg	0.1
Baghouse lime	kg	0.042
Non-hazardous waste for land-filling	kg	2.791

UBC Contamination	kg	6.57

Table 21: Input and output flows for remelting and casting unit processes. The figures indicate the average overall surveyed sites. Flows are representative for 1000 kg of rolling ingot.

Flows	Units	Amount
INPUTS		
Energy and Fuels		
Thermal energy (natural gas)	MJ	1890
Power	MJ	1022
Thermal energy (LPG)	MJ	15.56
Thermal energy (light fuel oil)	MJ	1.481
Diesel	kg	0.704
Power (From waste)	MJ	0.020
Gasoline (regular)	kg	0.012
Kerosene	g	1.074
Thermal energy (propane)	MJ	6.53E-04
Metals		
Aluminum	kg	1046
Alloy components	kg	5.669
Operating Materials		
Cooling water	kg	848
Filter media	kg	0.972
Hydraulic oil	kg	0.823
Lubricant (unspecified)	kg	0.496
Process water	kg	716.5
Salt (flux)	kg	0.176

Other Materials		
Sodium chloride (rock salt)	kg	2.564
Potassium chloride	kg	2.564
Sodium chloride (rock salt)	kg	0.6
Sodium hydroxide (100%; caustic soda)	kg	0.097
Sulphuric acid (100%)	kg	0.867
Cryolite	kg	0.214
Sodium hypochlorite	kg	0.014
Refractory	kg	0.007
OUTPUTS		
Products		
Aluminum rolling ingot	kg	1000
Emissions to air		
Dust (unspecified)	kg	0.121
Nitrogen oxides	kg	0.112
Hydrogen chloride	kg	0.106
Nitrogen dioxide	kg	0.102
Carbon monoxide	kg	0.083
Sulphur dioxide	g	4.336
Hydrogen fluoride	g	3.451
Chlorine	g	1.62
Other emissions to air	g	1.355
Ammonia	g	0.444
Lead (+II)	kg	4.51E-06
Dioxins (unspec.)	kg	1.5E-11
Emissions to water		

Waste water	kg	1637
Solids (dissolved)	kg	0.128
Chemical oxygen demand (COD)	kg	0.021
Biological oxygen demand (BOD)	kg	0.013
Chloride	g	9.47
Suspended solids, unspecified	g	3.014
Oil (unspecified)	g	2.08
Solids (suspended)	g	1.755
Aluminum (+III)	g	0.844
Aluminum ion (+III)	g	0.166
Ammonia	kg	3.61E-05
Zinc ion (+II)	kg	2.15E-05
Zinc (+II)	kg	4.51E-06
Cyanide	kg	4.51E-06
Other wastes		
Dross	kg	39.37
Non-hazardous waste for further processing	kg	28.33
Non-hazardous waste for land-filling	kg	6.922
Coated scrap (All 5XXX series alloy)	kg	3.526
Scrap metal for recycling, excluding aluminum	kg	1.07
Baghouse lime	kg	0.560
Aluminum Fines	kg	0.275

Post-industrial scrap or manufacturing scrap is produced at rolling mills, can manufacturing plants, and can fillers (excluded from data collection in this study). In the rolling mills, scrap is mainly generated by trimming the ends and sides of the sheet during the production of the coils. Within can manufacturing, skeleton scrap is generated in the stamping process to manufacture the cups. The scrap from rolling mills and can manufacturing plants is treated in a similar manner since neither has been coated (i.e. it is clean scrap). In the underlying model, this scrap is considered to be directly re-melted into ingots and fed back into the rolling process.

4.2 DATA COLLECTION AND MODELING

4.2.1 Can Sheet

In total, four sites provided data on can sheet production for this study. Overall, the data quality and the consistency of the collected data have been identified to be of medium to high quality. Participating sites represent the following listing of can sheet producers:

- Alcoa – Two sites
- Logan Aluminum (a joint venture of Novelis Inc. and ARCO Aluminum) – One site
- Wise Alloys – One site

In total, about 1.7 million metric tons per year of can sheet production are represented by the provided data.

The process model for each of the received data sets was created in the GaBi 4 software system database (release GaBi 4.3, http://www.gabi-software.com). The following data requirements for upstream supplies have been applied:

- *Energy supply, including electricity and fuels*: Regional electricity grid mixes (representative of the state/region in which the rolling mill is located) and U.S. specific fuels data available in GaBi 4 database have been used.
- *Aluminum ingots*: For primary aluminum ingots, the inventory represented in section 3.1 which is based on the IAI data, has been used. For secondary ingots, two separate LCI profiles were estimated . The two profiles represent the production of secondary aluminum ingot from UBC scrap. Manufacturing scrap is considered to be directly re-melted and fed back into the rolling process.
- *Process materials*: Data from the GaBi 4 software system database have been used.

In addition, transportation burdens (transport of primary and secondary ingots to rolling mills and transport of aluminum can sheet to can manufacturing plants) were also included. The data on transportation was based upon information provided by companies and/or informed estimates and are given in Appendix B

4.2.2 Can Manufacturing

In this study, the manufacturing of cans was modeled based upon the data provided by the Can Manufacturers Institute (CMI). CMI provided aggregated industry average information on a per-one thousand-can basis, representative for operations in the U.S. It also provided data on direct raw material, ancillary, and energy inputs as well as direct releases to the environment from can manufacture operations. Overall, the data quality and consistency of the provided data has been identified to be of high quality. The distribution of the production volume by different can sizes in 2006 is illustrated in Table 22. It can be observed that the 12 oz (including all variants) beverage can accounts for approximately 89.37% of the total two piece aluminum beverage can production in the U.S.

Table 22: Distribution of the can production volume by can size in 2006 [Source: CMI]

Can Size	Production volume (%)
8 oz	3.48
12 oz	89.37
16 oz	3.96
Others	3.19

The system boundary for modeling the can manufacturing in this study was defined from delivery of aluminum sheets to can manufacturers to packaged can bodies and lids leaving the gate of the can manufacturing facility. The following data requirements for upstream supplies have been applied:

- *Energy supply, including electricity and fuels*: CMI provided the state-wise breakdown of electricity consumption data. The state-wise electricity data was aggregated to estimate regional breakdowns of electricity consumption. A regional power mix process on a 1 MJ basis was created utilizing the regional grid mixes datasets available in GaBi 4 LCI database for the U.S. The power mix process is illustrated in Figure 28. The fuel datasets (e.g. diesel, natural gas) from the GaBi 4 database have been used.
- *Aluminum sheet*: The aluminum sheet inventory generated within this study has been used, representing the most up-to-date information on aluminum sheet production.
- *Coating, Inks, and Solvents*: CMI provided representative information on the composition of coatings, inks and solvents. In view of the confidentiality of the composition mix, further details cannot be provided in this report. Representative datasets from GaBi 4 were used to create the composition mix for coatings, inks, and solvents.
- *Other process materials*: Data from the GaBi 4 databases have been used to characterize other ancillary materials used in can manufacturing.

In total, five sites provided data on secondary aluminum production for this study. Overall, the data quality and consistency of the collected data has been identified to be of medium quality.

Participating sites represent the following listing of secondary aluminum producers:

- Alcoa – Two sites
- Aleris – One site
- Logan Aluminum (a joint venture of Novelis Inc. and ARCO Aluminum) – One site
- Novelis – One site

In total, about 2 million metric tons per year of secondary aluminum ingot production are represented by the provided data.

The process model for each of the received datasets was created in the GaBi 4 software system database (release GaBi 4.3, http://www.gabi-software.com). The following data requirements for upstream supplies have been applied:

- *Energy supply, including electricity and fuels*: Regional electricity grid mixes (representative of the state/region in which a secondary aluminum production facility is located) and U.S. specific fuels data available in the GaBi 4 database have been used.
- *Aluminum ingots*: For recycled scrap ingots (RSI), dataset from the GaBi 4 database has been used.
- *Process materials*: Data from the GaBi 4 software system database (release GaBi 4.3, http://www.gabi-software.com) have been used.

In addition, transportation burdens (transport of primary ingots to the facility, transport of manufacturing and UBC scrap) were included. The data on transportation was based upon information provided by the companies and/or informed estimates and are given in Appendix B.

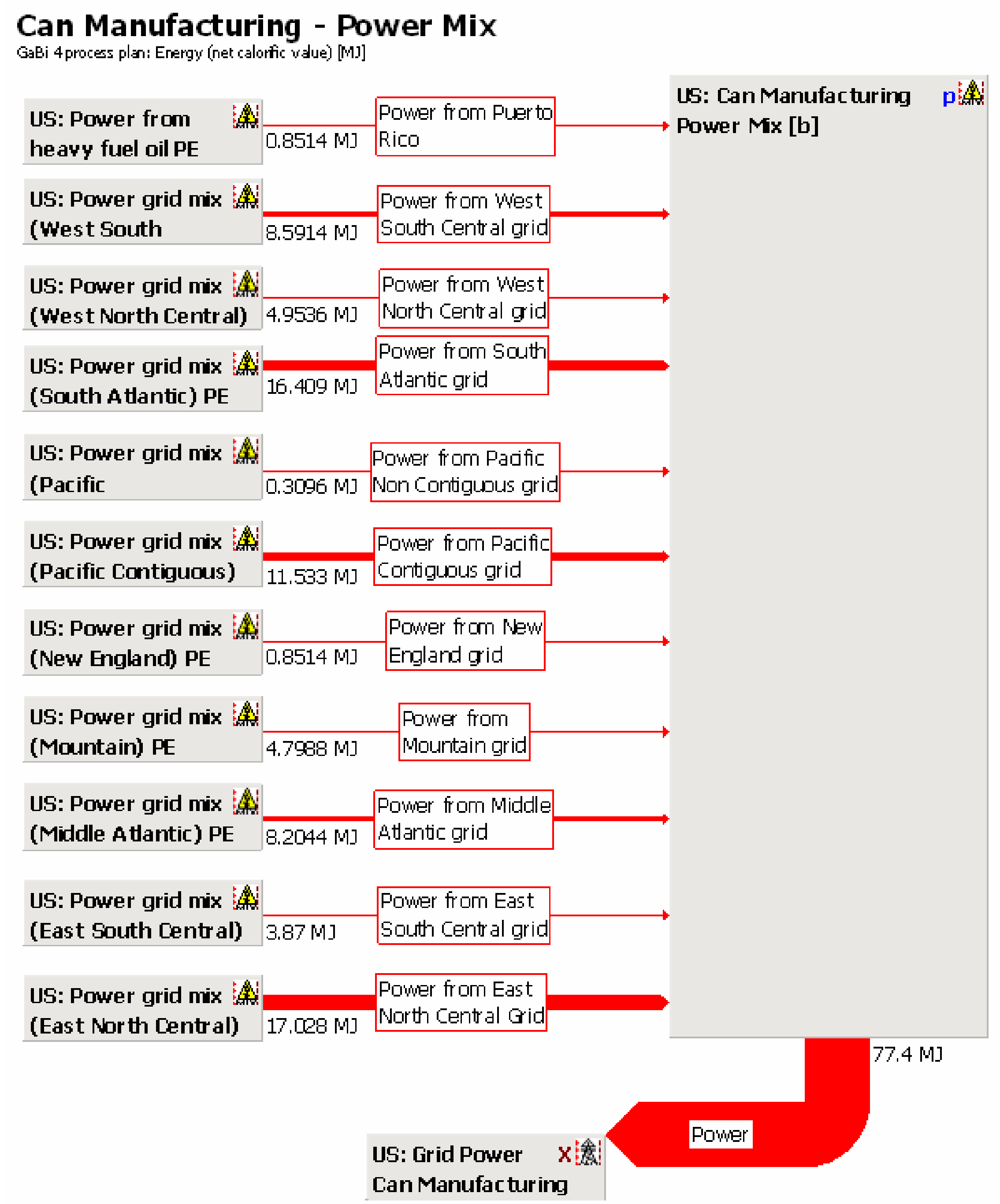

Figure 28: Power Mix Process for the Can Manufacturing Model. Flows are representative for the production of 1000 cans.

4.3 LCI RESULTS (AVERAGED “GATE-TO-GATE” INVENTORIES)

In this chapter, the important LCI results (“gate-to-gate”) are presented for the production of beverage cans in the U.S (i.e. provisioning of primary metal is not included in these results). The LCI results per 1000 cans can be represented on the basis of 1000 oz. of volume of fill by dividing the results by a factor of 12.408.

4.3.1 Beverage Can Sheet

The averaged “gate-to-gate” LCI of aluminum can sheets (representative of can body and lid stock) is given in Table 23. The company specific vertical LCI profiles were averaged using the production volume as the weighting criteria to estimate the industry LCI profile of can sheet production in the U.S. In Table 23, only selected inputs and outputs have been highlighted. The dominant fuel used is natural gas (refer to unit process information) and this represents sound environmental practices since use of other fossil fuels such as coal or fuel oil would result in higher combustion-related emissions to air.

Table 23: Averaged LCI data for can sheet (mix) production process (1000 kg of aluminum sheet) representing “gate-to-gate” information.

Selected LCI Parameters	Inventory results per ton of sheet	Unit
Primary energy demand	**13.95**	**GJ**
Non renewable energy resources	13.58	GJ
Renewable energy resources	0.369	GJ
INPUTS		
Aluminum rolling ingot	1389	Kg
OUTPUTS		
Carbon dioxide	870	Kg
Carbon monoxide	0.328	Kg
Nitrogen oxides	1.931	Kg
Sulphur dioxide	2.741	Kg
VOCs	3.27	Kg
Selected LCIA Parameters (CML 2001)	Inventory results per ton of sheet	Unit
Global warming potential (GWP 100 years)	907.2	kg CO2 Eq.
Acidification potential (AP)	4.118	kg SO2 Eq.

Eutrophication potential (EP)	0.281	kg Phosphate Eq.
Photochemical Ozone creation potential (POCP)	0.488	kg Ethene Eq.
Ozone Layer depletion potential (ODP)	3.44E-05	kg R11 Eq.

4.3.2 Can Manufacturing

The “gate-to-gate” inventory parameters of the can manufacturing model are illustrated in Table 24. This inventory characterizes only selected direct raw material, ancillary, and energy inputs and the direct releases to the environment for the can manufacturing process. The included air emissions result from the combustion of natural gas and liquefied petroleum gas and the use of diesel, coatings, inks, and solvents during can manufacturing.

The average weight of 1000 cans was estimated using two approaches. In the first approach, the weight was estimated as the difference of the total aluminum sheet input and the amount of scrap generated during can manufacturing. Using this approach, the average weight per 1000 cans is 13.3356 kg. Alternatively, the average weight per 1000 cans can be determined by taking the weighted average of the weight of different can sizes. The average weight for different can sizes was provided by CMI. Using the second approach, the average weight of 1000 cans was estimated to be 13.534 kg. Therefore, the difference in weight per 1000 cans for two approaches is approximately 0.1984 kg. The core group of the project recommended using the estimate of 13.3356 kg per 1000 cans in this study.

Table 24: Averaged LCI data on can manufacturing process (per 1000 cans) representing “gate-to-gate” information

Selected LCI Parameters	Inventory results per 1000 cans	Unit
Primary energy demand	**404.5**	**MJ**
Non renewable energy resources	386.3	MJ
Renewable energy resources	18.2	MJ
INPUTS		
Can sheet	16.78	Kg
OUTPUTS		
Carbon dioxide	24.62	Kg
Carbon monoxide	8.439	g
Nitrogen oxides	49.87	g

Sulphur dioxide	78.36	g
VOCs	0.1137	Kg
Selected LCIA Parameters (CML 2001)	Inventory results per 1000 cans	Unit
Global warming potential (GWP 100 years)	25.07	kg CO2 Eq.
Acidification potential (AP)	0.116	kg SO2 Eq.
Eutrophication potential (EP)	1.538	kg Phosphate Eq.
Photochemical Ozone creation potential (POCP)	0.017	kg Ethene Eq.
Ozone Layer depletion potential (ODP)	1.87E-06	kg R11 Eq.

4.3.3 Secondary Aluminum Ingot / Recycling

The averaged “gate-to-gate” LCI of secondary aluminum production is illustrated in Table 25 and Table 26. The company-specific vertical LCI profiles were averaged using production volumes as the weighting criteria to estimate the industry LCI profile of secondary aluminum ingot in the U.S. In the following tables, only selected inputs and outputs have been compiled and the included air emissions arise from the consumption of natural gas and diesel. The primary energy source is natural gas (refer to unit process information).

Table 25: Averaged LCI data for scrap preparation (1000 kg of prepared scrap) representing “gate-to-gate” information

Selected LCI Parameters	Inventory results per ton of prepared scrap	Unit
Primary energy demand	**437.4**	**MJ**
Non renewable energy resources	435.1	MJ
Renewable energy resources	2.282	MJ
INPUTS		
Aluminum scrap	1013	Kg
OUTPUTS		
Carbon dioxide	28.5	Kg
Carbon monoxide	88.46	g
Nitrogen oxides	52.55	g

Sulphur dioxide	53.40	g
VOCs	49.38	g
Selected LCIA Parameters (CML 2001)	Inventory results per ton of prepared scrap	Unit
Global warming potential (GWP 100 years)	29.49	kg CO2 Eq.
Acidification potential (AP)	97.45	g SO2 Eq.
Eutrophication potential (EP)	7.364	g Phosphate Eq.
Photochemical Ozone creation potential (POCP)	8.493	g Ethene Eq.
Ozone Layer depletion potential (ODP)	9.13E-07	kg R11 Eq.

Table 26: Averaged LCI data for remelting and casting (1000 kg of secondary aluminum ingot) representing “gate-to-gate” information

Selected LCI Parameters	Inventory results per ton of secondary ingot	Unit
Primary energy demand	**6451**	**MJ**
Non renewable energy resources	6279	MJ
Renewable energy resources	172.9	MJ
INPUTS		
Aluminum	1046	Kg
OUTPUTS		
Carbon dioxide	425.5	Kg
Carbon monoxide	0.107	kg
Nitrogen oxides	0.984	kg
Sulphur dioxide	1.481	Kg
VOCs	0.655	Kg
Selected LCIA Parameters (CML 2001)	Inventory results per ton of secondary ingot	Unit

Global warming potential (GWP 100 years)	431.7	kg CO2 Eq.
Acidification potential (AP)	2.348	kg SO2 Eq.
Eutrophication potential (EP)	0.148	kg Phosphate Eq.
Photochemical Ozone creation potential (POCP)	0.133	kg Ethene Eq.
Ozone Layer depletion potential (ODP)	2.05E-05	kg R11 Eq.

4.4 LCI AND LCIA RESULTS PER 1000 CANS

This section presents the LCIA results for the beverage cans for the two EoL approaches – closed loop and recycled content. A baseline scenario is defined for the approaches and the parameters and/or assumptions:

- Average can weight of 13.34 kg per 1000 cans
- The UBC recycling rate in the year 2006 is 51.6% (AA, 2007)
- The recycled content of the beverage can in the U.S. in 2007 is 67.8%
- Post production and run-a-round scrap from rolling mills is completely recycled in a closed loop (as seen in Figure 1). The production of secondary aluminum ingot from post production and run-a-round scrap does not require any input of primary aluminum.
- Can manufacturing scrap is dealt with in the same manner as UBC scrap and included in the recycled content of the can.

The LCIA results per 1000 cans can be represented on the basis of 1000 oz. of volume of fill by dividing the results by a factor of 12.41.

The energy for primary ingot production represented here in all considerations includes part of the aluminum output as liquid metal. This means that not all aluminum output from this process is in ingot form and therefore, these numbers cannot be directly compared with those stated earlier (e.g. Table 14) for primary aluminum production.

4.4.1 Closed Loop Approach

Under a closed loop approach, the mass flows (per 1000 cans) over the complete life cycle of the beverage can are shown in Figure 29.

The production of 1000 cans at a can manufacturing plant requires 16.78 kg of aluminum sheet (inclusive of can body and lid). The can manufacturing process yields 3.447 g of post production scrap. The amount of post production scrap generated at rolling mills is 6.501 kg.

In order to produce 16.78 kg of aluminum sheet, the total amount of aluminum ingot input required for the rolling process is 23.31 kg. This consists of:

- 6.218 kg of ingot produced from post production scrap (from rolling mills) and

- 17.09 kg secondary ingot with 67.8% scrap input (excluding rolling scrap) to the remelting process

At the End of Life (EoL), 6.984 kg of UBC scrap (51.6% of the average can weight of 13.34 kg per 1000 cans) is recovered. 12.23 kg of scrap is required, of which only 10.433 kg are recovered from can makers and UBC collection combined. The deficit of 1.797 kg in the latter are assigned a "net burden" which amount to the corresponding amount of primary metal needed as a replacement, minus the burdens for scrap preparation and remelting. The selected LCI/LCIA results of the beverage can under the closed loop approach are shown in Table 27.

With regard to the primary energy demand in the closed loop system, the total primary energy demand per 1000 cans with a 51.6% UBC recycling rate is 1,943 MJ. The breakdown share of total primary energy demand over all life cycle stages of the can is shown in Figure 30. The primary energy demand for the production process (including the "upstream" processes such as raw materials and energy) are presented for both the primary and the secondary aluminum ingot production. Similarly, the impact scores for the rolling and can manufacturing are given. The fraction of renewable energy sources is shown as light shaded bars; the fraction of non-renewable energy sources is shown as full bars.

Overall, a majority of the primary energy demand is met with non-renewable energy resources. As discussed previously in Section 3.2.1 on primary energy demand, the end-energy used at the operation sites is dominated by hydropower (which generates power based upon renewable resources). However, the significantly lower conversion efficiency of other power generation plants that use non-renewable energy sources (such as hard coal) causes the impact score to be higher than that associated with the renewable energy resources. The calculations are developed in detail in Appendix A.

Examining the LCI results for CO_2 emission to air, it can be observed that the production of primary aluminum ingot has a significant influence on the overall environmental impact score because of its high primary energy consumption.

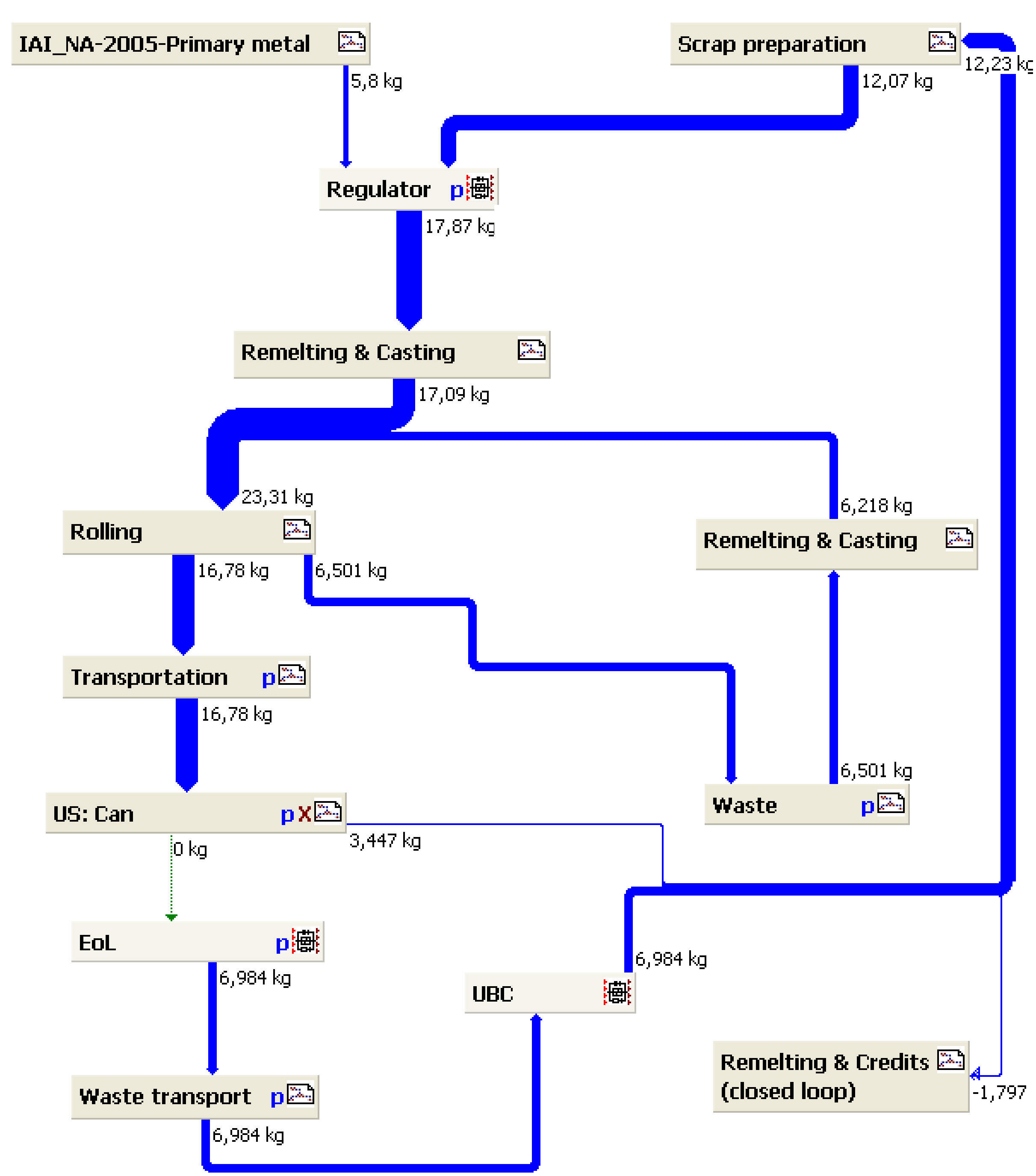

Figure 29: Mass flows (per 1000 cans) over the complete life cycle of the beverage can under closed loop approach (UBC recycling rate 51.6%)

The total amount of carbon dioxide emissions per 1000 cans is around 122 kg. A breakdown of emissions from the different can manufacturing stages woauld show that CO_2 emissions closely match the primary energy demand trends shown in Figure 30, and, therefore, is not shown here.

The process breakdown shows that for both primary energy demand and CO_2 emissions to air, the production of primary aluminum is the key impact source, followed by the can manufacturing with the respective shares of approximately 67% and 20%. With regard to the secondary aluminum production, it is noticed that this process plays a minor role in contributing to the primary energy demand and CO_2 emissions. A detailed examination of energy consumption required for secondary aluminum production shows that most energy required for secondary production goes to production from UBC scrap (around 6% to the overall results), and only a very small share goes to the remelting of the post production scrap (less than 1%).

Table 27: Selected LCI/LCIA results per 1000 cans under closed loop approach

Selected LCI Parameters	Results	Unit
Primary energy demand	**1943**	**MJ**
Non renewable energy resources	1540	MJ
Renewable energy resources	403.3	MJ
INPUTS		
Can sheet	16.78	Kg
OUTPUTS		
Carbon dioxide	121.6	Kg
Carbon monoxide	0.047	Kg
Nitrogen oxides	0.24	Kg
Sulphur dioxide	0.436	Kg
VOCs	0.209	Kg
Selected LCIA Parameters (CML 2001)		
Global warming potential (GWP 100 years)	131.5	kg CO_2 Eq.
Acidification potential (AP)	0.613	kg SO_2 Eq.
Eutrophication potential (EP)	1.565	kg Phosphate Eq.
Photochemical Ozone creation potential (POCP)	0.051	kg Ethene Eq.
Ozone Layer depletion potential (OPD)	3.76E-06	kg R11 Eq.

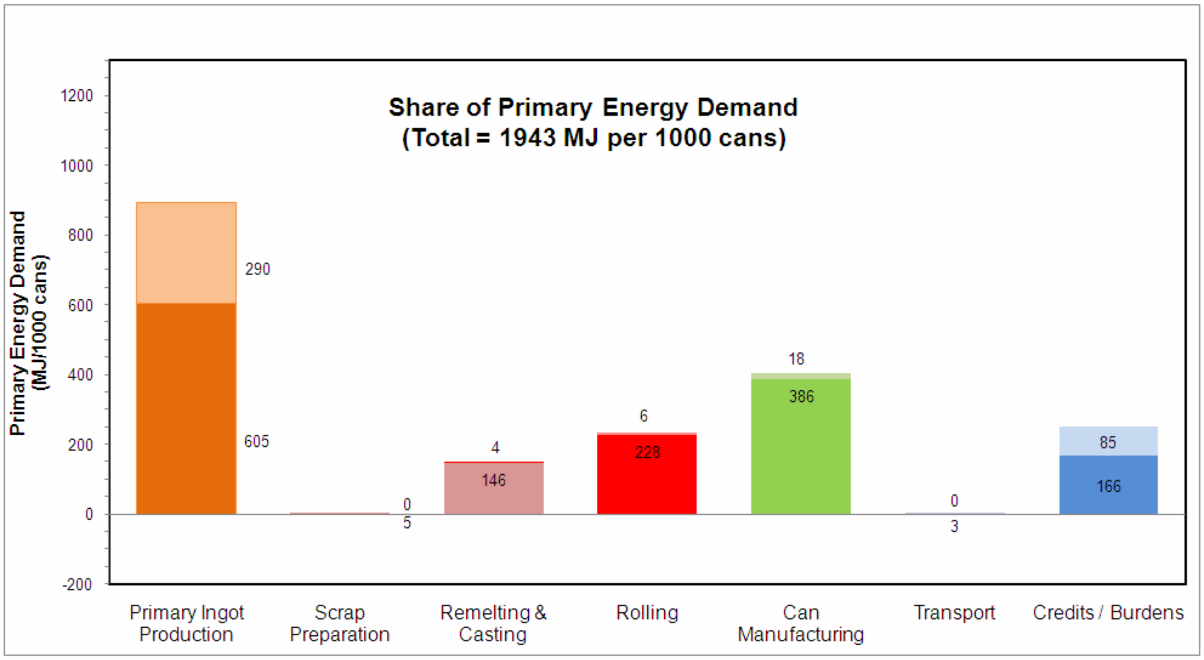

Figure 30: Share of total primary energy demand (MJ per 1000 cans) over the life cycle of the can under closed loop approach. The solid color portion of each bar represents the non-renewable fraction of primary energy and the light-shaded portion represents the renewable fraction of primary energy. Expectedly, primary aluminum production has the highest primary energy demand compared to all other processes.

4.4.2 Recycled content approach

The mass flows (per 1000 cans) over the complete life cycle of the beverage can modeled under a recycled content approach are shown in Figure 31.

The mass flows per 1000 cans are similar to the closed loop approach flows, except for the deficit UBC scrap flows. In the recycled content approach, the surplus UBC scrap flow is assigned to a “scrap sink” and there is no “net burden” given to the product system. The “scrap sink” can be considered as a stockpile of secondary raw material which is not utilized for further processing and recovery of the material. As a result, the environmental burdens of the can product system decreases compared with the closed loop system.

Examining how this change affects our primary LCI metrics, the total primary energy demand is found to decrease by 251 MJ to 1692 MJ per 1000 cans, while the CO_2 emissions decrease by 16 kg to 106 kg CO_2 per 1000 cans. A breakdown of primary energy demand by energy source and life cycle stages for this system model is shown in Figure 32. Except for remelting of surplus UBC and gross credit values, the relative share of total primary demand of other life cycle stages is not different from the closed loop results. The primary energy demand for the production processes (including the “upstream” processes such as raw materials extraction and energy production) are presented for both the primary and the secondary aluminum ingot production. Again, the fraction of renewable energy sources is shown as light-shaded bars, and the fraction of non-renewable energy sources are shown as full bars.

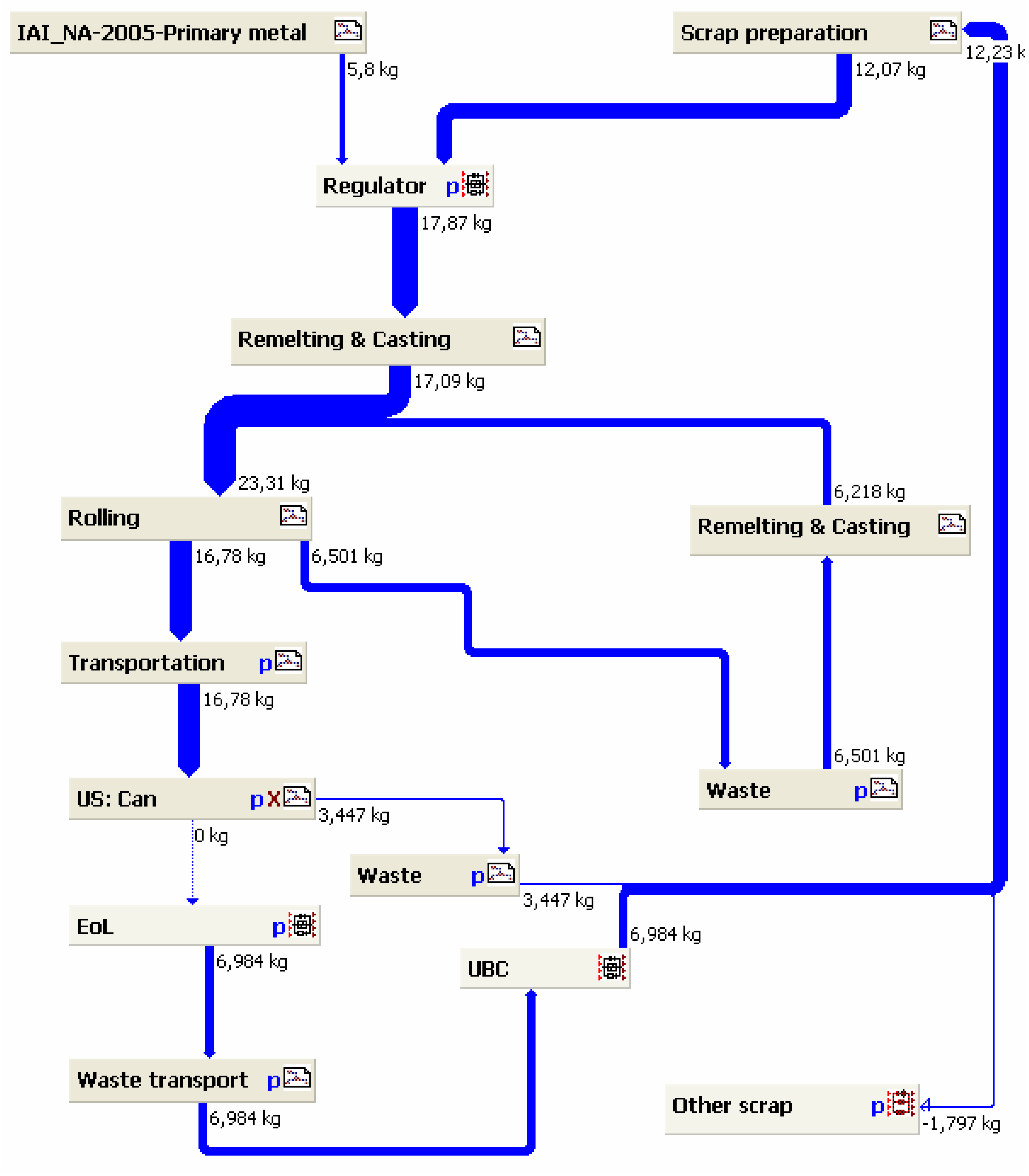

Figure 31: Mass flows (per 1000 cans) over the complete life cycle of the beverage can under recycled content approach (UBC recycling rate 51.6%)

Table 28: Selected LCI and LCIA results per 1000 cans obtained with the recycled content approach

Selected LCI Parameters	Results	Unit
Primary energy demand	**1692**	**MJ**
Non renewable energy resources	1374	MJ
Renewable energy resources	318.3	MJ
INPUTS		
Can sheet	16.78	Kg
OUTPUTS		
Carbon dioxide	105.9	Kg
Carbon monoxide	0.041	Kg
Nitrogen oxides	0.211	Kg
Sulphur dioxide	0.376	Kg
VOCs	0.188	Kg
Selected LCIA Parameters (CML 2001)		
Global warming potential (GWP 100 years)	113.8	kg CO2 Eq.
Acidification potential (AP)	0.532	kg SO2 Eq.
Eutrophication potential (EP)	1.561	kg Phosphate Eq.
Photochemical Ozone creation potential (POCP)	0.046	kg Ethene Eq.
Ozone Layer depletion potential (OPD)	3.61E-06	kg R11 Eq.

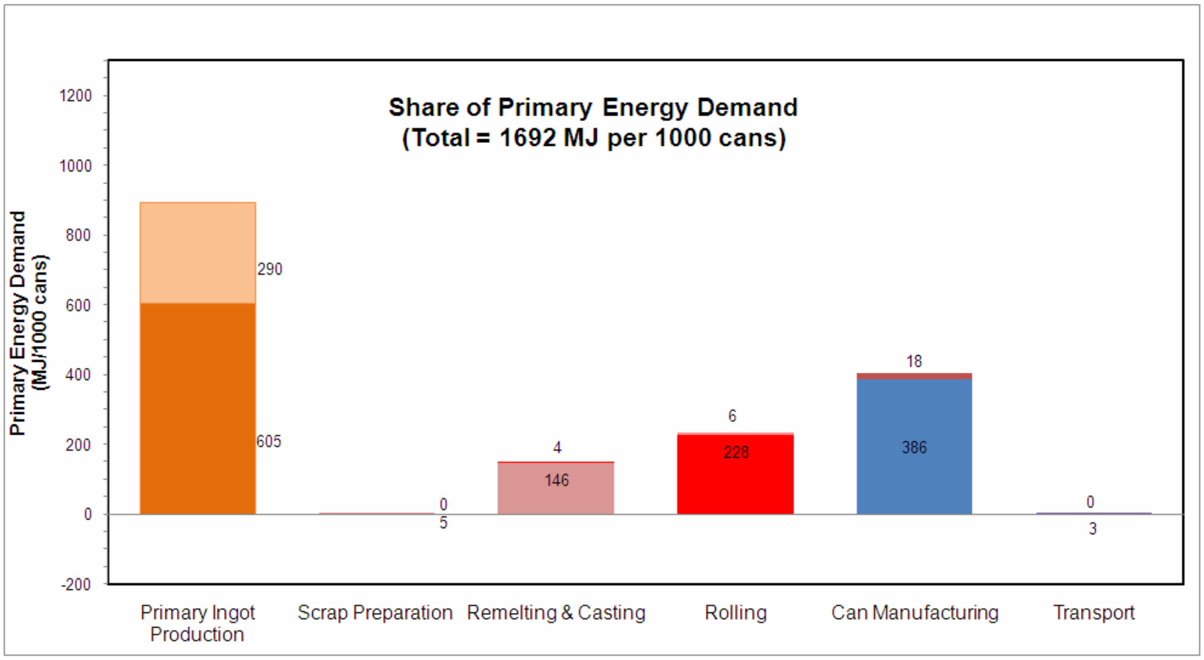

Figure 32: Relative share of total primary energy demand (MJ per 1000 cans) over the life cycle of the can under recycled content approach. The solid color portion for each bar represents the non-renewable fraction of primary energy and the hashed portion represents the renewable fraction of primary energy.

4.5 UBC recycling scenarios

The influence of the UBC recycling rate on the environmental performance of the beverage can product system was evaluated by considering additional scenarios for the following UBC recycling rates:

- 30% - Hypothetical low UBC recycling rate
- 45.1% - UBC recycling rate estimated by Container Recycling Institute (ca. 2004) (CRI, 2008)
- 62% - Peak UBC recycling rate achieved during the mid 1990s
- 75% - Aluminum Association future goal for UBC recycling rate

The lower hypothetical recycling rate scenario was selected to interpret the results, when the recycling rate is lower than the recycled content. The variation in total primary energy demand per 1000 cans under different scenarios is shown in Figure 33 and the results are presented for both closed loop and recycled content approaches. At a higher UBC recycling rate (i.e. 75%), the closed loop approach seems more favorable, whereas at a lower recycling rate (i.e. 30%), the recycled content seems more favorable, as the product system would still try to maintain the recycled content of the can. The reason is that the recycled content approach cuts off both surplus UBC scrap (no additional benefit or credit) as well as an unsaturated scrap demand in case of a recycling rate lower than the recycled content (additional scrap necessary comes without burden). As a result, the primary energy demand under recycled constant approach does not change as the recycling rate is varied. It is likely that recycled content of the can will increase as the UBC recycling rate increases, under the assumption that more UBC scrap will be available in the market for can making. However, there are other market forces (e.g. export of UBC scrap to other countries, use of UBC scrap for automotive sheet production) which can influence the availability of UBC scrap to secondary aluminum producers. The influence of various factors which determine the recycled content of the can in United States is beyond the scope of this study. Therefore, in the study the recycled content of the can was kept constant at 67.8% and only the UBC recycling rate was varied in scenario analysis.

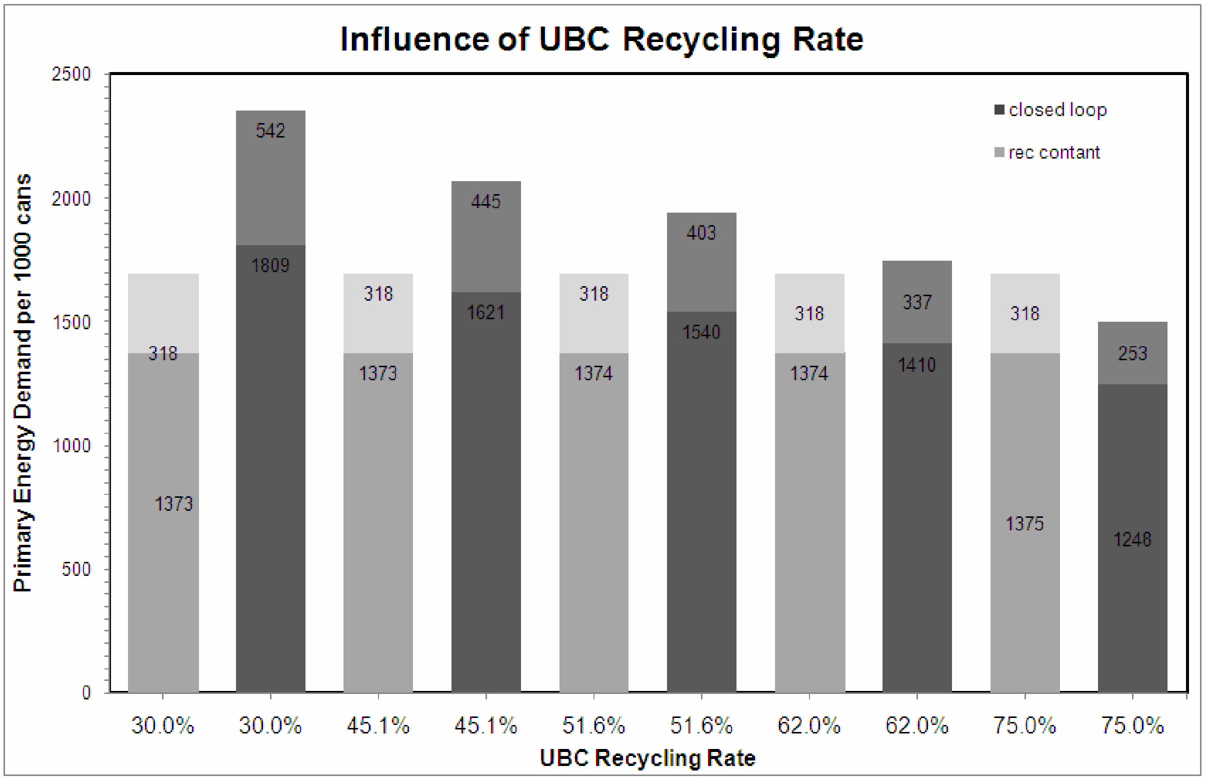

Figure 33. Primary energy demand results per 1000 cans under different UBC recycling rate scenarios for both closed loop and recycled content approaches. The solid color portion for each bar represents the non-renewable fraction of primary energy and the dashed portion represents the renewable fraction of primary energy.

5 CONCLUSIONS

This study provides the Aluminum Association and its member companies with an updated LCI and LCIA of primary aluminum production in North America and aluminum beverage can production in the U.S.

This study quantifies all the significant inputs and outputs to the beverage can system under two approaches to modeling end-of-life impacts: closed loop and recycled content. The system boundary of this life cycle assessment for beverage cans includes primary aluminum production, secondary aluminum production; aluminum can sheet production, can manufacturing, and recycling of UBC.

Information on the primary energy demand for primary aluminum production in North America shows that 67% comes from non-renewable resources. Electrolysis accounts for 80% of the total energy demand for primary production. It is estimated that 11.1 metric tons of CO_2 are emitted per ton of primary aluminum ingot produced of which 8.7 tons (78%)are from the electrolysis process alone. The carbon dioxide emissions profile is similar to the energy profile, since the greatest contribution to greenhouse gases is associated with the combustion of fossil fuels for heat at production sites and upstream environmental burdens associated with generation of electricity. The electrolysis process during primary aluminum production in the U.S. consumes approximately two-thirds of its electricity demand from hydropower. This translates into a relatively lower carbon footprint compared to the use of electricity generated from fossil fuels. However, on account of the lower energy conversion efficiency of fossil fuel-based power generation, the renewable fraction of total primary energy demand is lower than the non-renewable fraction. A further analysis of greenhouse gas (GHG) emissions was done following the guidelines in the GHG Protocol (WRI and WBCSD**).** Scopes 1 and 2 (direct GHG emissions and indirect GHG emissions attributable to energy conversion processes) together contribute to 9,847 kg. CO_2 equivalents emitted per ton of primary aluminum produced while Scope 3 (further GHG emissions from the supply chain) adds another 1,221 kg. CO_2 equivalents to these emissions. Scopes 1 and 2 indicate the emissions that are the direct responsibility of the production factories and the results follow closely with previous studies (IAI).

Concerning the end-of-life considerations, the results of the study indicate that the raw material extraction and processing represent 67% of the total primary energy demand (1943 MJ per 1000 cans) under a closed loop approach, with production of the primary aluminum ingot alone accounting for 46% of net primary energy demand, and production of the secondary aluminum ingot (incl. scrap preparation) accounting for 8% of net primary energy demand. Under the recycled content system model, the contribution of raw material acquisition to total primary energy demand (1692 MJ per 1000 cans) decreases slightly to 62%. This is due to the net “burden” which is given to deficit UBC scrap in the closed loop system model.

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APPENDIX A: ESTIMATION OF TOTAL PRIMARY ENERGY DEMAND FROM DIRECT ENERGY USE

In the U.S., during the production of aluminum (liquid) metal during the electrolysis process, the consumption of direct electricity is mainly from hydropower (approximately 70%). However, due to significantly lower energy conversion efficiency from coal, the environmental impacts associated with the generation of end electricity from coal (efficiency of about 30%) outweigh the relatively low environmental impacts of hydropower (efficiency of about 80%). Because of this, power production from coal dominates the environmental impacts of the total electricity production per kg aluminum (liquid).

The total primary energy demand[7] required to produce 1 kWh of end electricity (3.6 MJ) from each energy source in the U.S. and Canada is given in Table 29 and Table 30, respectively.

Table 29: Total primary energy demand for 1 kWh generation of electricity from different energy sources in the U.S. Data source: GaBi 4 software system database (current release GaBi 4.3, http://www.gabi-software.com)

	Unit	Power from nuclear power plant	Power from hard coal	Power from hydropower plant	Power from natural gas
Primary energy	MJ/kWh	14.323	11.298	4.524	11.136
Non renewable energy resources	MJ/kWh	14.301	11.295	0.022	11.092
Renewable energy resources	MJ/kWh	0.022	0.003	4.502	0.044

In the U.S., to produce 1 kWh from hard coal, it requires approximately 11.3 MJ of primary energy, whereas to produce 1 kWh from hydropower, it requires only 4.5 MJ of primary energy. This difference is on account of variations in the overall efficiency of electricity production as stated above. This is also graphically illustrated in Figure 34.

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[7] Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere, geosphere, or other energy source without any anthropogenic changes

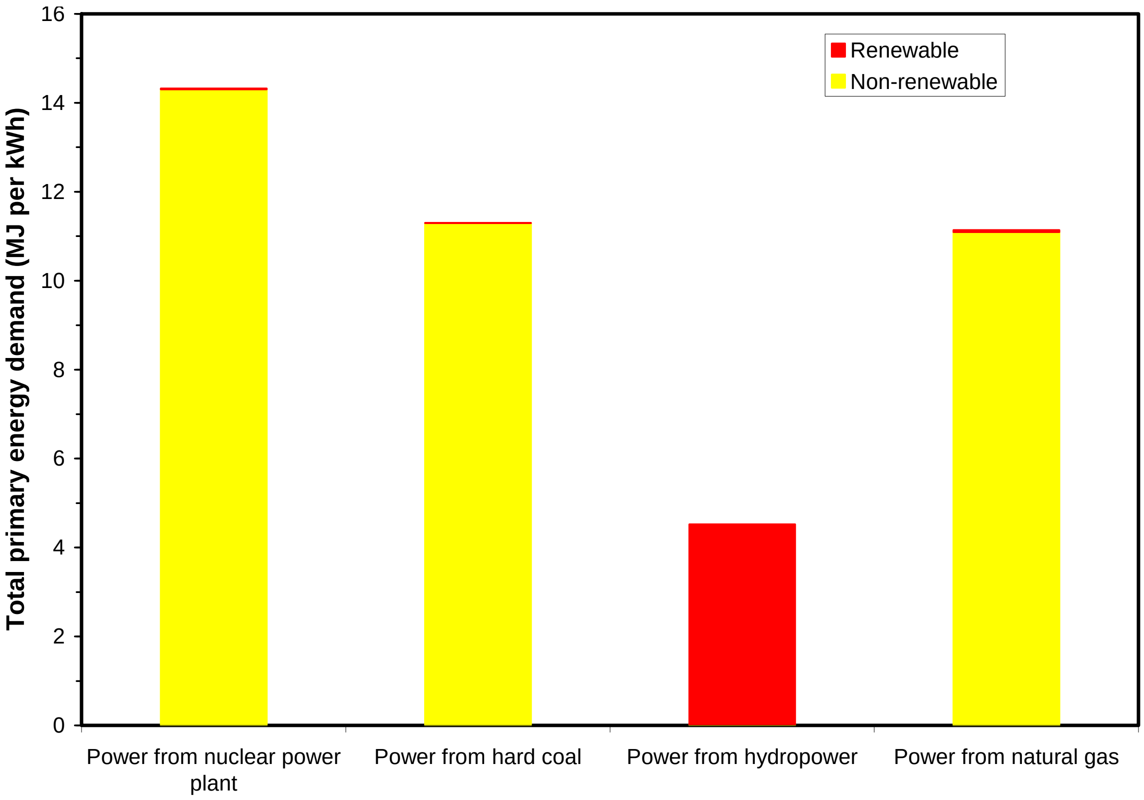

Figure 34: Total primary energy demand for 1 kWh generation of electricity from energy sources in the U.S. (Source: GaBi 4.3 LCI database)

Table 30: Total primary energy demand for 1 kWh generation of electricity from different energy sources in Canada. Data source: GaBi 4 software system database (current release GaBi 4.3, http://www.gabi-software.com)

	Unit	**Power from nuclear power plant**	**Power from hard coal**	**Power from hydroelectric plant**	**Power from natural gas**
Primary energy	MJ/kWh	14.323	12.179	4.500	10.592
Non renewable energy resources	MJ/kWh	14.301	12.162	0.021	10.382
Renewable energy resources	MJ/kWh	0.022	0.017	4.479	0.210

Due to the fact that electricity generation from fossil fuels is less efficient than hydroelectric power generation, sourcing a unit of energy from fossil fuel-based generation sources creates a much higher primary energy demand than sourcing the same amount of energy from renewable resources. As a result, the non-renewable fraction of total primary energy demand is higher than the renewable fraction.

In our study, the direct electricity use of 55.16 MJ per kg aluminum (liquid) metal corresponds to a total primary energy demand of 102.7 MJ (non-renewable fraction – 55.1 MJ and renewable fraction – 47.6 MJ). Although hydropower constitutes approximately 69.4% of direct electricity use for electrolysis in the U.S. and Canada, the renewable fraction is only 46.35% of the total primary energy demand. The estimation of total primary energy demand can be expressed by the following generic formula:

$$\begin{aligned}\text{Total Primary Energy Demand}\\ &= (\text{Total Direct Energy Use})\\ &\times \left(\sum \text{Energy Source Fraction}\right.\\ &\left.\times \text{Equivalent Primary Demand for Specific Energy Source}\right)\end{aligned}$$

In the U.S. and Canada, as provided by the IAI data, it requires approximately 55.16 MJ of direct electricity used to produce 1 kg of aluminum (liquid) metal. The breakdown for electricity generation is 31.1 MJ (56.38%) in the U.S. and 24.06 MJ (43.62%) in Canada. The relative fractions for energy source mix for electricity production for electrolysis in the U.S. and Canada are given below (assumed same for both countries as per IAI data):

- Hydro – 69.4%
- Coal – 29.7%
- Natural gas – 0.6%
- Nuclear – 0.3%

The primary energy demand for electrolysis (from electricity use only) in the U.S. and Canada are calculated as below:

U.S.

$$\text{Total direct energy use (US)} = 55.16\ \text{MJ} * 56.38\% = 31.1\text{MJ} = \frac{31.1}{3.6}\,\text{kWh} = \mathbf{8.64\ kWh}$$

$$\begin{aligned}\text{Non renewable primary energy used for producing 1kWh of electricity mix in US}\\ &= (\text{Hydro})\ 69.4\% \times 0.022 + (\text{Coal})\ 29.7\% \times 11.295 + (\text{Nuclear})0.6\% \times 14.301\\ &+ (\text{Natural gas})0.3\% \times 11.092 = \mathbf{3.484MJ}\end{aligned}$$

$$\begin{aligned}\text{Renewable primary energy used for producing 1kWh of electricity mix in US}\\ &= (\text{Hydro})\ 69.4\% \times 4.502 + (\text{Coal})\ 29.7\% \times 0.003 + (\text{Nuclear})0.6\% \times 0.022\\ &+ (\text{Natural gas})0.3\% \times 0.044 = \mathbf{3.125\ MJ}\end{aligned}$$

$$\begin{aligned}\text{Non renewable primary energy used for producing 8.64 kWh of electricity mix in US}\\ &= 3.484 \times 8.64 = \mathbf{30.1MJ}\end{aligned}$$

$$\begin{aligned}\text{Renewable primary energy used for producing 8.64 kWh of electricity mix in US}\\ &= 3.125 \times 8.64 = \mathbf{27\ MJ}\end{aligned}$$

The above results are also graphically illustrated in Figure 35.

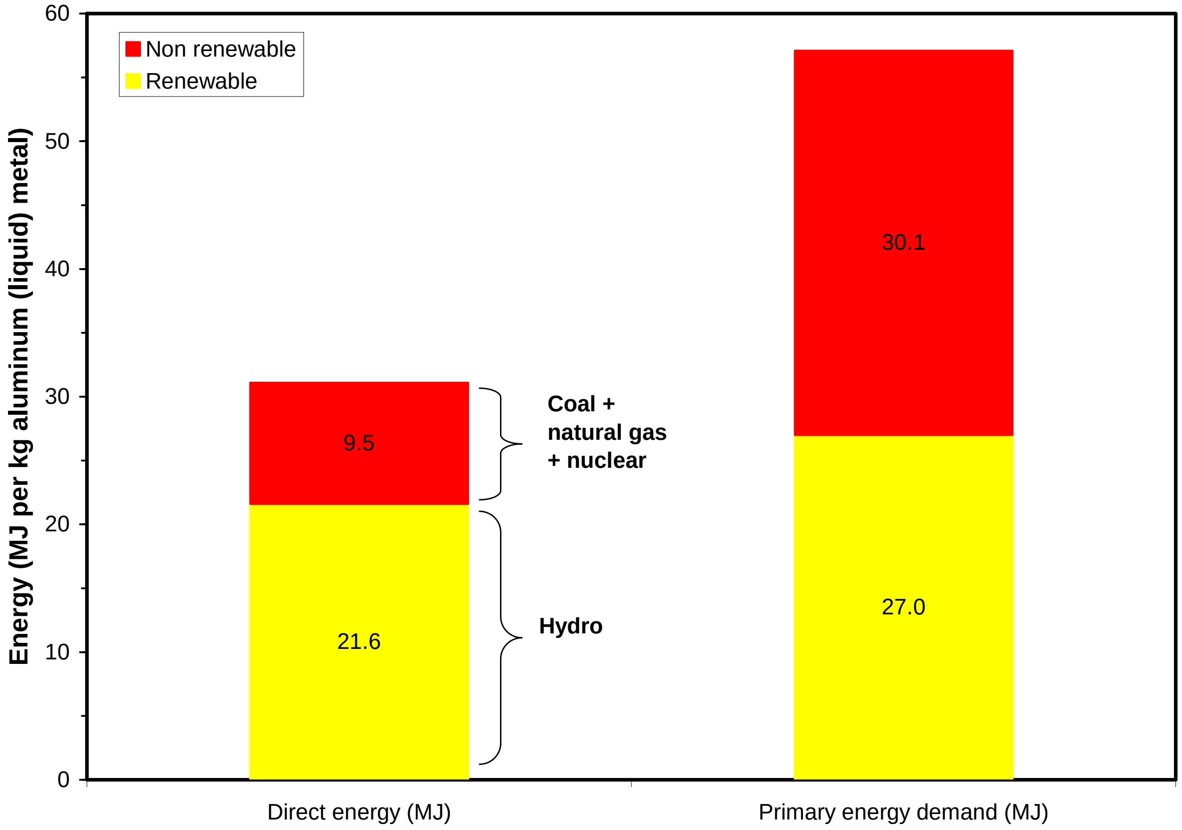

Figure 35: Direct energy (in MJ) and Primary energy demand (in MJ; for electricity use only) for 1 kg of aluminum (liquid) in the U.S.

Canada

$$\text{Total direct energy use (Ca)} = 55.16\ \text{MJ} * 43.62\% = 24.06\text{MJ} = \frac{24.06}{3.6}\text{kWh} = \mathbf{6.68\ kWh}$$

$$\begin{aligned}\text{Non renewable primary energy used for producing 1kWh of electricity mix in Ca}\\ = (\text{Hydro})\ 69.4\% \times 0.021 + (\text{Coal})\ 29.7\% \times 12.162 + (\text{Nuclear})0.6\% \times 14.301\\ + (\text{Natural gas})0.3\% \times 10.382 = \mathbf{3.74MJ}\end{aligned}$$

$$\begin{aligned}\text{Renewable primary energy used for producing 1kWh of electricity mix in Ca}\\ = (\text{Hydro})\ 69.4\% \times 4.429 + (\text{Coal})\ 29.7\% \times 0.017 + (\text{Nuclear})0.6\% \times 0.022\\ + (\text{Natural gas})0.3\% \times 0.21 = \mathbf{3.08\ MJ}\end{aligned}$$

$$\begin{aligned}\text{Non renewable primary energy used for producing 8.64 kWh of electricity mix in Ca.}\\ = 3.74 \times 6.68 = \mathbf{25MJ}\end{aligned}$$

$$\begin{aligned}\text{Renewable primary energy used for producing 8.64 kWh of electricity mix in Ca} = 3.08 \times 6.68\\ = \mathbf{20.6\ MJ}\end{aligned}$$

Total

$$\text{Non renewable primary energy} = \mathbf{30.1 + 25 = 55.1\ MJ}\ (\frac{\mathbf{55.1}}{\mathbf{55.1 + 47.6}} = \mathbf{53.65\%})$$

$$\text{Renewable primary energy} = \mathbf{27 + 20.6 = 47.6\ MJ}\ (\frac{\mathbf{47.6}}{\mathbf{55.1 + 47.6}} = \mathbf{46.35\%})$$

APPENDIX B: TRANSPORTATION DATA FOR RAW MATERIALS AND FINISHED PRODUCTS

Table 31: Transportation data for raw materials and finished products

Raw material/product	Tonnage fraction transported (%)	Mode of transportation	Distance (km)
Primary ingot to secondary furnaces	100%	Rail	2400
Can Body Stock to Can Manufacturer	100%	Rail	100
Transport of UBC scrap from collection point to secondary aluminum producers	100%	Truck	160
Transport of manufacturing scrap to secondary aluminum producer	100%	Truck	160

APPENDIX C: IMPACT INDICATORS

The following describes briefly the various impact categories included in the report[8].

PRIMARY ENERGY CONSUMPTION

Primary energy demand is the quantity of energy directly withdrawn from the hydrosphere, atmosphere, geosphere, or energy source without any anthropogenic changes.

It is a measure of the resource used across the life cycle of a product.

For fossil fuels and uranium, this would be the amount of resource withdrawn expressed in its energy equivalent (i.e. the energy content of the raw material). For renewable resources, the energy-characterized amount of biomass consumed would be described. For hydropower, it would be based on the amount of energy that is gained from the change in the potential energy of the water (i.e. from the height difference). As aggregated values, the following primary energies are designated:

The total **"Primary energy consumption non-renewable"**, given in MJ, essentially characterizes the gain from the energy sources natural gas, crude oil, lignite, coal and uranium. Natural gas and crude oil will be used both for energy production and as material constituents, e.g. in plastics. Coal will primarily be used for energy production. Uranium will only be used for electricity production in nuclear power stations.

The total **"Primary energy consumption renewable"**, given in MJ, is generally accounted separately and comprises hydropower, wind power, solar energy, and biomass. It is important that the end energy (e.g. 1 kWh of electricity) and the primary energy used are not miscalculated with each other; otherwise the efficiency for production or supply of the end energy will not be accounted for.

The energy content of the manufactured products will be considered as feedstock energy content. It will be characterized by the net calorific value of the product. It represents the still usable energy content.

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[8] Please refer to CML (2001) and GaBi documentation at http://documentation.gabi-software.com for more details on the impact categories.

GLOBAL WARMING POTENTIAL

The mechanism of the greenhouse effect can be observed on a small scale in, as the name suggests, greenhouses. These effects are also occurring on a global scale. Incident short-wave radiation from the sun comes into contact with the earth's surface and is partly absorbed (leading to direct warming) and partly reflected as infrared radiation. The reflected part is absorbed by so-called greenhouse gases in the troposphere and is re-radiated in all directions, including back to earth. This results in a warming effect at the earth's surface.

In addition to the natural mechanism, the greenhouse effect is enhanced by human activities. Greenhouse gases that are considered to be caused, or increased, anthropogenically are, for example, carbon dioxide, methane, and CFCs.

Page 25The alongside figure shows the main processes of the anthropogenic greenhouse effect. An analysis of the greenhouse effect should consider possible long term global effects. The global warming potential is calculated in carbon dioxide equivalents (CO_2-Eq.). This means that the greenhouse potential of an emission is given in relation to CO_2. Since the residence time of the gases in the atmosphere is incorporated into the calculation, a time range for the assessment must also be specified. A period of 100 years is customary.

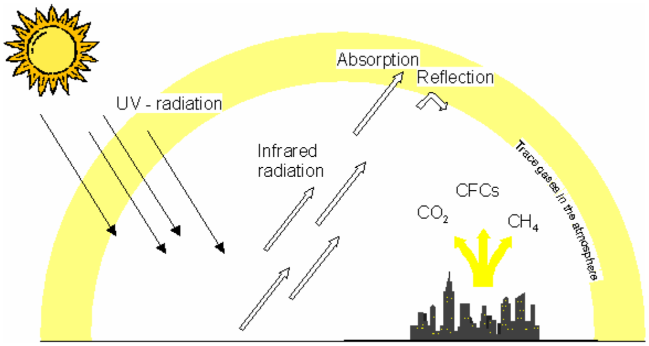


Figure 36: Greenhouse effect

ACIDIFICATION POTENTIAL

The acidification of soils and water occurs predominantly through the transformation of air pollutants into acids. This leads to a decrease in the pH-value of rainwater and fog from 5.6 to 4 or lower. Sulfur dioxide and nitrogen oxide and their respective acids (H_2SO_4 and HNO_3) produce relevant contributions to this acidification. This damages ecosystems, whereby forest dieback is the most well known impact.

Acidification has both direct and indirect damaging effects (such as nutrients being washed out of soils or an increased solubility of metals into soils). But even buildings and building materials can be damaged. Examples include metals and natural stones, which are corroded or disintegrated at an increased rate.

When analyzing acidification, it should be considered that although it is a global problem, the regional effects of acidification can vary. Figure 37 displays the primary impact pathways of acidification. The acidification potential is given in sulfur dioxide equivalents (SO_2-Eq.). The acidification potential is described as the ability of certain substances to build and release H+ ions. Certain emissions can also be considered to have an acidification potential, if the given S-, N- and halogen atoms are set in proportion to the molecular mass of the emission. The reference substance is sulfur dioxide.

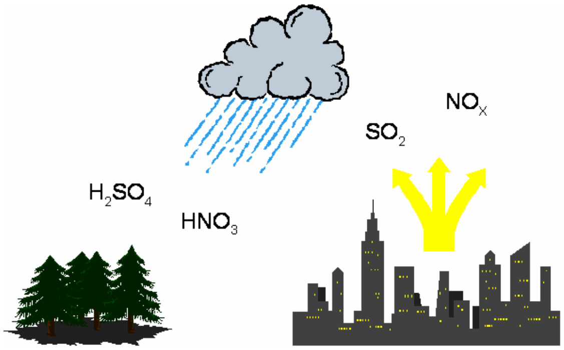


Figure 37: Acidification Potential

EUTROPHICATION POTENTIAL

Eutrophication is the enrichment of nutrients in a certain place. Eutrophication can be aquatic or terrestrial. Air pollutants, wastewater, and fertilization in agriculture all contribute to eutrophication.

The result in water is an accelerated algae growth, which in turn, prevents sunlight from reaching the lower depths. This leads to a decrease in photosynthesis and less oxygen production. In addition, oxygen is needed for the decomposition of dead algae. Both effects cause a decreased oxygen concentration in the water, which can eventually lead to fish dying and to anaerobic decomposition (decomposition without the presence of oxygen). Hydrogen sulfide and methane are thereby produced. This can lead, among others, to the destruction of the eco-system.

In eutrophicated soils, an increased susceptibility of plants to diseases and pests is often observed, as is a degradation of plant stability. If the nutrification level exceeds the amounts of nitrogen necessary for a maximum harvest, it can lead to an enrichment of nitrate. This can cause, by means of leaching, increased nitrate content in groundwater. Nitrate also ends up in drinking water. Nitrate at low levels is harmless from a toxicological point of view. However, nitrite, a reaction product of nitrate, is toxic to humans. The causes of eutrophication are displayed in Figure 38.

The eutrophication potential is calculated in phosphate equivalents (PO_4-Eq). As with acidification potential, it's important to remember that the effects of eutrophication potential differ regionally.

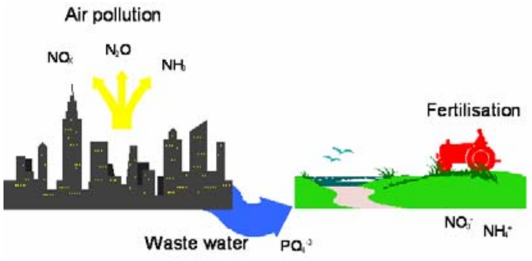


Figure 38: Eutrophication Potential

PHOTOCHEMICAL OZONE CREATION POTENTIAL (SMOG)

Despite playing a protective role in the stratosphere, at ground-level ozone is classified as a damaging trace gas. Photochemical ozone production in the troposphere, also known as summer smog, is suspected to damage vegetation and material. High concentrations of ozone are toxic to humans.

Radiation from the sun and the presence of nitrogen oxides and hydrocarbons create complex chemical reactions, producing aggressive reaction products, one of which is ozone. Nitrogen oxides alone do not cause high ozone concentration levels.

Hydrocarbon emissions occur from incomplete combustion, in conjunction with petroleum processing (storage, turnover, refueling etc.), or from solvents. High concentrations of ozone arise when the temperature is high, humidity is low, when air is relatively static and when there are high concentrations of hydrocarbons. Because CO (mostly emitted from vehicles) reduces the accumulated ozone to CO_2 and O_2, high concentrations of ozone do not often occur near hydrocarbon emission sources. Higher ozone concentrations more commonly arise in areas of clean air, such as forests, where there is less CO.

In Life Cycle Assessments, photochemical ozone creation potential (POCP) is referred to in ethylene-equivalents (C_2H_4-Eq.). When analyzing results, it is important to remember that the actual ozone concentration is strongly influenced by weather and by pollution characteristics of the local conditions.

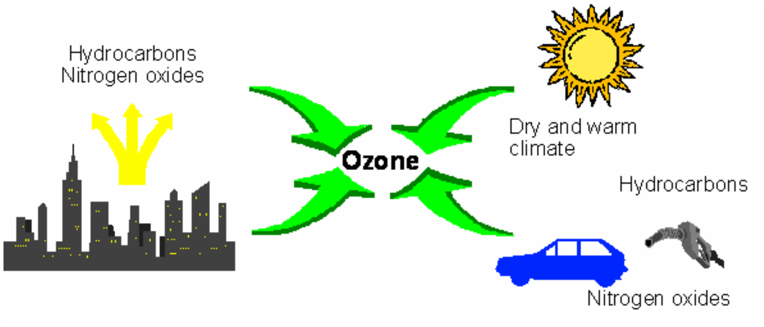


Figure 39: **Photochemical Ozone Creation Potential**

OZONE DEPLETION POTENTIAL

Most ozone resides in the upper part of the atmosphere. This region, called the stratosphere, is more than 10 kilometers (6 miles) above Earth's surface. There, about 90% of atmospheric ozone is contained in the "ozone layer," which shields us from harmful ultraviolet radiation from the Sun. However, it was discovered in the mid-1970s that some human-produced chemicals could destroy ozone and deplete the ozone layer. The resulting increase in ultraviolet radiation at Earth's surface may increase the incidences of skin cancer and eye cataracts.

Human activities cause the emission of halogen source gases that contain chlorine and bromine atoms. These emissions into the atmosphere ultimately lead to stratospheric ozone depletion. The source gases that contain only carbon, chlorine, and fluorine are called "chlorofluorocarbons," usually abbreviated as CFCs. CFCs, along with carbon tetrachloride (CCl_4) and methyl chloroform (CH_3CCl_3), historically have been the most important chlorine-containing gases that are emitted by human activities and destroy stratospheric ozone. These and other chlorine-containing gases have been used in many applications, including refrigeration, air conditioning, foam blowing, aerosol propellants, and cleaning of metals and electronic components.

In Life Cycle Assessments, Ozone Depletion Potential (ODP) is referred to in CFC-11-equivalents. Since most ozone depleting compounds were phased out by the Montreal Protocol in 1987, the stratospheric ozone layer has been recovering and there are very few ozone depleting emissions.

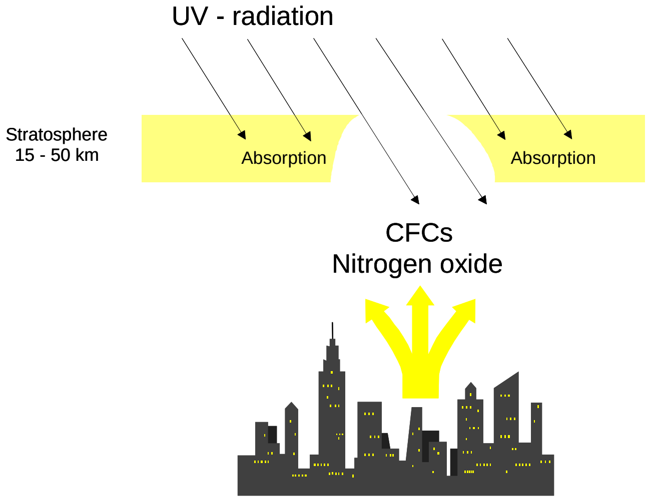


Figure 40: Ozone Depletion Potential

APPENDIX D: DATA QUALITY EVALUATION

Data quality was evaluated using the Weidema methodology as described in the International Journal of LCA 3 (5) page 259-265; 1998, Weidema et al.; LCA data quality. The following tables show the evaluation matrix and the evaluation.

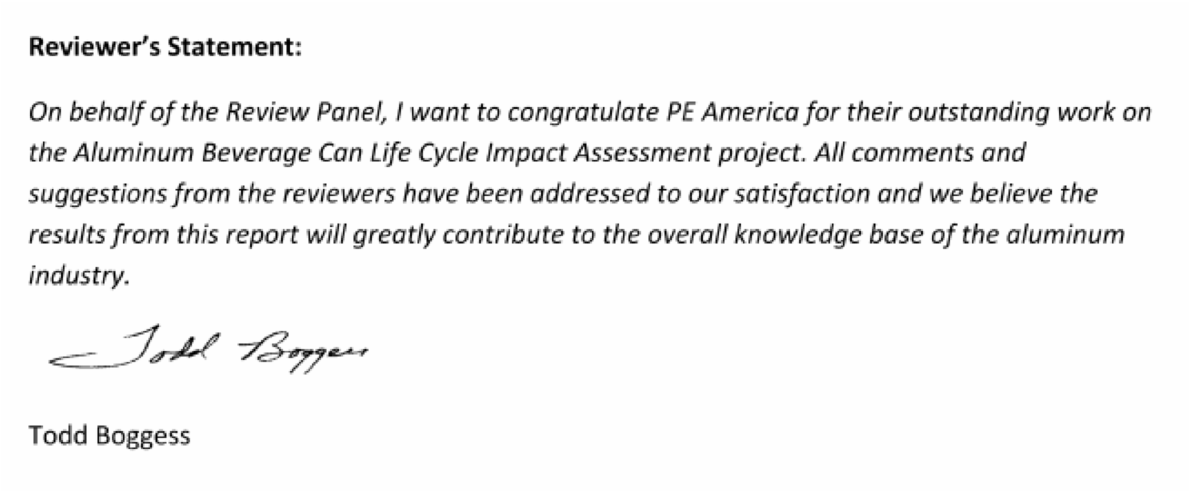
Table 32: Data quality evaluation matrix

Score:	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on assumptions OR non-verified data based on measurements	Non-verified data partly based on assumptions	Qualified estimate (e.g. by industrial expert);	Non-qualified estimate
Representativeness/ Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations	Representative data from a smaller number of sites but adequate periods	Representative data from an adequate number of sites but from shorter periods	Representative data from from a smaller number of sites and shorter periods or incomplete data from an adequate number of sites and periods	Representativeness unknown or incomplete data from a smaller number of sites and/ or from shorter periods
Temporal correlation	Less than 3 years of difference to reference year	Less than 6 years of difference to reference year	Less than 10 years of difference to reference year	Less than 15 years of difference to reference year	Age of data unknown or more than 15 years of difference to reference year
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area (with very different production conditions
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials but similar technology.	Data on related processes or materials but different technology.

Table 33: Results data quality evaluation

Type of data	Reliability of source	Representativeness/ Completeness	Temporal correlation	Geographical correlation	Further technological correlation
Bauxite mining	2 (IAI statistics)	1	1 (2005)	2	1
Alumina refining	2 (IAI statistics)	1	1 (2005)	2	1
Electrolysis	1	1	1 (2005)	1	1
Primary Aluminum production	1	1	1 (2005)	1	1
Secondary Aluminum production	1	1	1 (2006)	1	1
Aluminum sheet rolling	1	1	1 (2006)	1	1
Can manufacturing	2	1	1 (2006)	1	1
End of Life	2	1	1 (2006)	1	1

APPENDIX E: CRITICAL REVIEW REPORT



Reviewer's Statement:

On behalf of the Review Panel, I want to congratulate PE America for their outstanding work on the Aluminum Beverage Can Life Cycle Impact Assessment project. All comments and suggestions from the reviewers have been addressed to our satisfaction and we believe the results from this report will greatly contribute to the overall knowledge base of the aluminum industry.

Todd Boggess

Todd Boggess

5.1 ALUMINUM BEVERAGE CAN LCI REPORT FEBRUARY 2010

REVIEWER COMMENTS FEBRUARY 26, 2010

No	Reviewers comments	Followup
1	Regarding data quality and its discussion in the document, that still could pose some questions when the report is released. The response that data quality is now more uniformly treated, that is, each process or activity now has a statement regarding the quality of the data used, is correct. However, the actual basis for those statements and any implications of the resultant use of the data with that quality rating is not provided. Is it useful to say that the quality is high or medium, yes, because it gives a general impression of the degree of adherence to the four quality category parameters? Do I understand how that rating was arrived at or how/if it affected the use of the information or the drawn conclusions, no.	Appendix D on Data quality evaluation added.
2	One of the original comments in the 4 December document: Even for these operations it isn't possible to discern how the data quality indicators were applied to reach the conclusions regarding aggregated quality." The response merely says "Updated in several places." However, what does it mean to say that data were found to be of high quality? How data quality was determined needs to be explained	Point 1.
3	Page 13 mentions the critical review but where can readers find the review comments? As we discussed the other day, an important part of a critical review for public assertion is full disclosure of what the review found and how issues were resolved. The review process and comments should be included as an appendix.	Appendix E added
4	Specific comments: - Page 3; Should this read "the Aluminum Association experts.." not expects? - Why does Figure 1 have a blue box around the can production but Figure 2 does not? - Figure 9: Are the years (1999 2005 (b)) needed in the Alumina box? The caption says the data reflect 2005. [I realize the figures are probably generated from GaBi and may not be revisable.] Page 74: Only selected data, and impacts, are	Formatting/typographical mistakes fixed.

	shown in this chapter. Where can the entire LCI be found? Page 97: Page 25The alongside figure... ??	

5.2 ALUMINUM BEVERAGE CAN LCI REPORT OCTOBER 2009

REVIEWER COMMENTS DECEMBER 4, 2009

No	Reviewers comments	Followup
1	While our comments have been individually addressed, I feel that some of the responses are cursory (some are even argumentative without a real basis). For example, PEA's response to being asked for the method that will be used for averaging data, the reply is "The final LCI profile will represent industry average of various unit processes." This reply does not provide a description of the method.	There is a section on data calculation where the methods for averaging are explained.
2	I have the impression that the authors have diligently considered our comments, even if the written responses are thin. I see no problem with moving ahead with the next step (conference call?) in the review process	-
3	In the report a number of statements are made in qualitative or non-numerical fashion that does not allow the reader to judge the validity of the preparer's decisions. For example, page x of the Executive Summary contains the statement "Modeling for domestic production was used to reflect the fact that the majority of secondary aluminum consumed in the target year was produced in the US." Without a numerical value, it is not possible to understand if this was a correct determination or not. If the percentage is 85, then it is reasonable; if it is 51, it may not be. Section 2.2.8.2 on page 12 is even less descriptive of why the geographic coverages are valid.	OK. Comment about domestic production was removed as it was misleading. Can ingot is produced in recycling facilities in the US using domestic scrap.
4	There are some numerical discrepancies between the report and the addendum that are not explained. For example, in the third bullet point on page x of the Executive Summary (and elsewhere in the report) it states the recycled content percentage is 67.8%, while on page 5 of the addendum it is 60.1% for the same data year of 2007.	This is mentioned in the addendum. It is a different way of counting recycled content and the results of the addendum reflect this.
5	There are some assumptions or conditions inherent in the system accounting that may not be understandable to audi-	Additional commentary added

	ence members who are not thoroughly familiar with LCI accounting rules. For example, a statement in one of the EoL scenarios that imports scrap burden free is not intuitive. Specifically, the comment “An additional 1.797 kg of scrap is therefore required to make up the deficit which in the recycled content approach is imported “burden-free”…” should have additional commentary as to why this is reasonable. Section 4.4.2, 2nd par. provides a better explanation and should be considered for insertion in the Executive Summary.	in several places.
6	In addition to some grammatical and typographic issues, which, in a minor way, detract from the report’s credibility, there are some place where editing would improve the understanding of the study context and results. For example, on page 2 it states “The aim of the study is to generate high-quality, up-to-date data on the environmental performance of aluminum beverage can production.” It is suggested that slightly amending this to add “including the flow of secondary materials from End of Life back into beverage cans.”, would make it clear that can production is the focus, but sourcing/processing of reusable aluminum is essential to this characterization.	Updated in several places.
7	The rationale for the recycled content approach (page 5) needs to be clear that in addition to the assumptions stated, the benefits of recycling (primary material production and waste disposal avoidance) outweigh the burdens of post-consumer collection and processing. As currently described this net benefit requirement is not clear.	While this is true for Aluminum, it is not always the case with other materials. Comment added.
8	In Section 2.2.9, please correct my affiliation to reflect the transition from Battelle (initial study review) to SETAC (final report and addendum).	OK; no reference in addendum
9	In Section 3.1.5, it indicates that materials from ingot casting (e.g. dross and filter dust)recovered for use in systems other than beverage cans are being treated as wastes (i.e. have no co-product burdens), even though the text implies these are co-products. Although this distinction may be inconsequential in terms of flows or impacts, it seems inconsistent with the statement made earlier regarding allocation. In Section 2.2.6 it stated “In this study, no allocation was applied as all co-products are considered in each of the recycling models described above (ISO, 2006b). Some clarification to the effect that any recovered materials cycled into other products are treated as waste, thereby providing a maximum allocation of burdens to aluminum can production, would resolve this apparent inconsistency.	OK.added in section 2.2.6

10	The data quality discussion throughout the report is inconsistent and in most cases lacking altogether. Actual discussion of data quality, regardless of specificity, is provided for only three sets of processes, primary Al, can sheet, and can production. Even for these operations it is not possible to discern how the data quality indicators were applied to reach the stated conclusions regarding aggregated quality.	Updated in several places.
11	In Section 4.4.1 the first paragraph has a formatting error flagged that has not been fixed	Should be fine now
12	In general, the addendum commentary regarding the two EoL options is understandable and responsive to the earlier input from the review panel. However, there are a number of places where the connection to the full study report needs to be more explicit. For example, nowhere in the addendum does it state that the analysis is for 12 ounce cans. If it is possible for the additional analyses somehow to be separated from the report, the addendum should be more or less stand-alone	The addendum is not for disclosure and therefore, not meant to be a stand-alone document
13	In a similar vein, references to or sources of data need to be complete. In the addendum, either they are missing altogether, for example the 2007 recycled content percentage, or are cited in (source, date) format with the actual citation not included. This is not transparent	Point 12.
14	The significance or lack thereof for the different results between the addendum and the report should be explained. The text simply states they are "minor" and the final paragraph states "there is no significance to the overall LCA results". That much is obvious from the numerical values, but it would be useful to understand why the differences are considered non-significant. If this simply due to the small numerical changes, the data variability, or the difference in impact consequences themselves, the report should so state.	This is stated in the first paragraph – it is another way of counting recycled content. The reason for the differences are explained.
15	The comment made earlier by the review team, and in principle agreed upon by the consultant, to either provide volume-based results or a conversion factor appears not to have been implemented in the addendum. Although the text in Section 4.3 of the report does provide a number:volume conversion factor, it was not clear whether the 1000 can basis conversion to volume was for 12 oz. cans or a weighted average of all sizes	The addendum uses the same parameters as the case of the report. In section 2.1 it is stated that the LCI data represent the weighted average of the different can sizes.
16	If these results, or those of the original report for that matter, are going to be released to third parties, some details on	CML and GaBi References

	the aggregation of inventory flows into LCIA categories and the conversion to impacts needs to be included, even if the actual computations are done entirely within the software. Otherwise, there is a loss of transparency and consequentially credibility. The Appendix C material discusses this in general but does not provide a mapping of flows to impacts, particularly where there is a possibility of inconsistencies in assigning inventory flows to impact categories	added.
17	Schematic on page 4 of Addendum: Shows can manufacturing scrap remelted with rolling process scrap. The reality is that can manufacturing scrap is usually coated, decorated (inks) or contains compound for sealing the can (lids), therefore it is sent through the secondary system, much like UBCs. The arrow should be extended horizontally to connect with that recycle loop. I don't think this affects the analysis, but it represents what actually occurs.	This is the approach adopted in the main report.
18	Assumption on page 5 of Addendum: The comment about no primary aluminum required for production of RSI is correct. However, RSI made from can lids and bodies is generally used to make new can body stock. The RSI made from this mix contains more magnesium than is allowed in 3004 or 3104 alloy specifications, therefore some amount of primary (or other form of purer scrap) is used to dilute the magnesium percentage	This is accounted for in the material flows and has been confirmed by AA.
19	The report seems to exclude the facts that 1. UBCs are used in other aluminum sheet end products, such as building products sheet 2. Other forms of scrap such as building products sheet are used to make RSI that is used in the recycle loop for can body stock. Based on especially (b) above, my belief is the recycled content of cans (from all forms of scrap) is higher than stated in the report	Scrap is treated as scrap in the model irrespective of whether it is can scrap or industrial scrap (as it does not have an influence on the LCA). The percentage of secondary aluminum (from AA and producers) includes all kinds of scrap.

APPENDIX F: CRITICAL REVIEWERS' BIO

Dr. Bruce W. Vigon

Dr. Vigon has designed and executed research and development programs ranging from short term focused studies to multi-million dollar, multi-year efforts for a range of corporate clients and government agencies, both domestically and internationally. Efforts have involved organizations as diverse as the US Environmental Protection Agency, Environment Canada, US Department of Defense, state and provincial governments, various academic institutions, the World Business Council for Sustainable Development, World Wildlife Fund and other environmental advocacy organizations, and a host of private sector companies ranging across the automotive, textiles, consumer products, electronics, defense, and packaging industries. Bruce is a member of SETAC and is active in several focus areas, including life cycle assessment, environmental systems analysis, environmental chemistry, contaminant fate and effects research, and risk assessment, since 1990. He has been Editor of the SETAC Globe LCA Community of Practice newsletter for more than 18 years and has been chair and critical review panelist on more than a half dozen LCA studies, including several highly complex and controversial product and service systems.

Dr. Mary Ann Curran

Dr. Curran directs the US EPA System Analysis Branch's Life Cycle Assessment (LCA) research program which includes the development of LCA methodology, the performance of life-cycle case studies, life-cycle workshops and conferences, and the development of a life cycle data and resources website (www.epa.gov/ORD/NRMRL/lcaccess). As a recognized international expert in LCA, Dr. Curran works closely with the Society of Environmental Toxicology and Chemistry (SETAC), which has been instrumental in advancing LCA awareness worldwide, and actively participates in the UNEP/SETAC Life Cycle Initiative. Dr. Curran also serves on the SETAC -North America LCA Advisory Group. In addition, Dr. Curran is on the editorial boards of the *International Journal of Life Cycle Assessment, Management of Environmental Quality,* and the advisory boards of the on-line journals *Sustainability* and the *International Journal of Environmental Research and Public Health.* Since 2005, Dr. Curran has served as the Subject Editor (Cleaner Production Tools) for the *Journal of Cleaner Production*. She provides technical support to EPA program offices in developing policy and regulations including guidelines for the federal procurement of environmentally-preferable products. Dr. Curran provides technical review and assistance to outside groups on the application of the life cycle concept to areas such as green product and process design and development. She has participated in the technical peer review of industry-sponsored life-cycle studies on various products, such as electricity, diapers, cleaners, plastics, coal ash, building materials, and packaging.

Todd Boggess

Todd is a 1998 graduate of the University of Kentucky with a BS in Economics. Todd is a member of Alpha Kappa Psi, a professional business fraternity. Following graduation, Todd spent two years as a consultant with Systems & Computer Technology, where he provided financial input into the design and update of accounting software for nonprofit organizations. In 2001, Todd accepted a position with the University of Kentucky in the Sponsored Projects Accounting department. There, he managed federal and state funded grants for the University of Kentucky Research Foundation. In December of 2001, Todd joined Secat, Inc. as Business Manager where he oversees all financial and accounting responsibilities. Todd acts as project manager for US Department of Energy contracts granted to Secat, Inc. Todd also serves as Secretary for the Board of Directors for Secat. Secat provides technology and R&D services to materials companies. Todd is currently enrolled in the MBA program at Western Kentucky University and expects to graduate in June 2011.