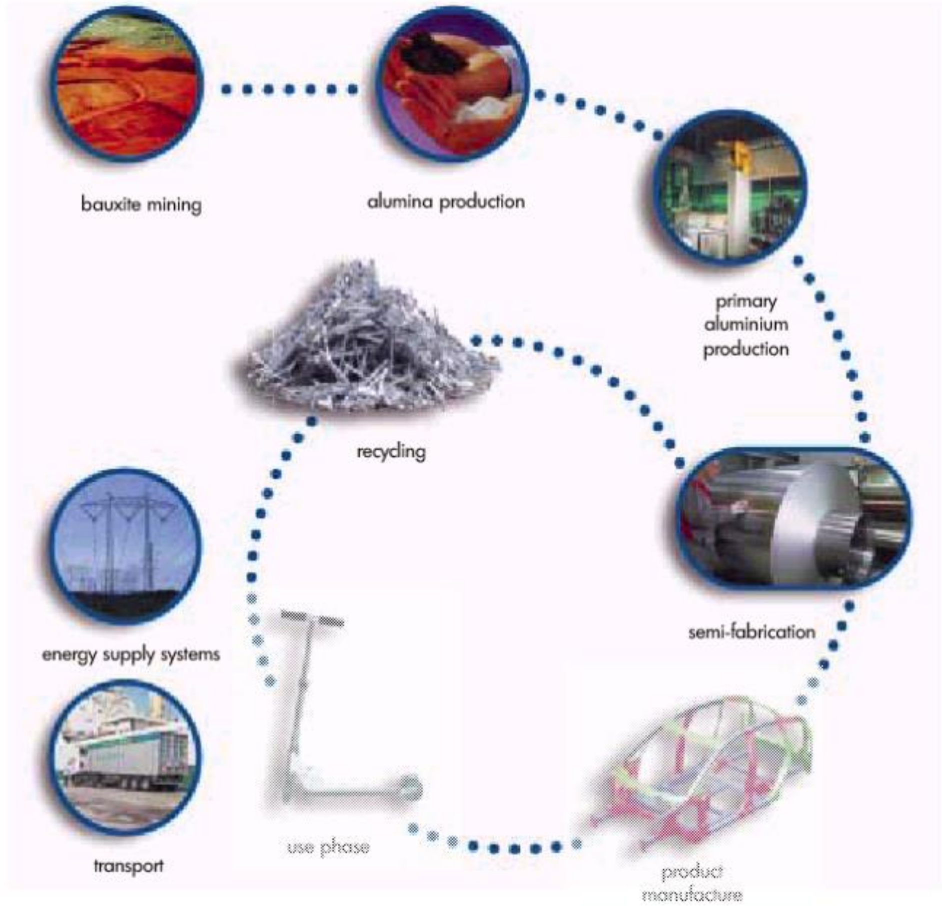
european aluminium association

Environmental Profile Report for the European Aluminium Industry

April 2013-
Data for the year 2010

Life Cycle Inventory data for aluminium production and transformation processes in Europe



Aluminium for Future Generations

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0. Preface

The European aluminium industry promotes life-cycle thinking and supports the use of LCA which contributes to further environmental improvements in aluminium product development in a life cycle concept. Whenever organisations are doing LCA for aluminium products in which it is appropriate to use European data, the European Aluminium Association contributes in supplying information and data, making its best to provide information in line with the study goal and scope.

The European aluminium industry is striving to reduce the environmental footprint of its processes and products by promoting:

- efficient use of resources and energy,
- reduction of emissions to air and water,
- reduction of waste.
- high recycling rates at the end of the product life-cycle.

After use, aluminium products are a valuable re-usable resource which is efficiently recycled through well-established collection schemes, scrap preparation technologies and refining processes. The European recycling rates for end products are currently around 90% for the automotive sector and for the building sector. The recovery rates of used aluminium packaging vary depending on the specific products and the collection practices operated in the different countries. Concerning aluminium cans, the official European collection rate reached 67% in 2010, without considering informal recycling routes. Since the current aluminium product range is extremely wide, the end-of-life recycling rates can vary significantly.

As supported by the whole metal industry [14], the European aluminium industry recommends considering the environmental benefits resulting from recycling through the end-of-life recycling approach and not through the recycled metal content approach which is incomplete and has limited environmental significance for metal products. The end-of-life recycling approach is based on a product life cycle and material stewardship perspective. It considers the fate of products after their use stage and the resultant material output flows. The European aluminium industry recommends using the so-called substitution methodology to consider the benefits of aluminium recycling in LCA. This methodology is explained within the technical paper "aluminium recycling in LCA" which can be downloaded from the EAA website (www.alueurope.eu).

This environmental report provides up-to-date life cycle inventory data (LCI) for aluminium production and transformation processes in Europe. This report and the associated LCI data have been developed in full reference to the 2 relevant ISO standards ISO 14040 and 14044 [6-7]. This document is based on environmental data related to the year 2010. It updates the previous datasets which have been published in May 2008 with reference year 2005 [1] and in September 2005 with reference year 2002 [2].

1. The aluminium product life cycle

The typical life cycle of an aluminium product system can be modelled using a system of different process steps in accordance with the flow chart reported in Fig. 1.1

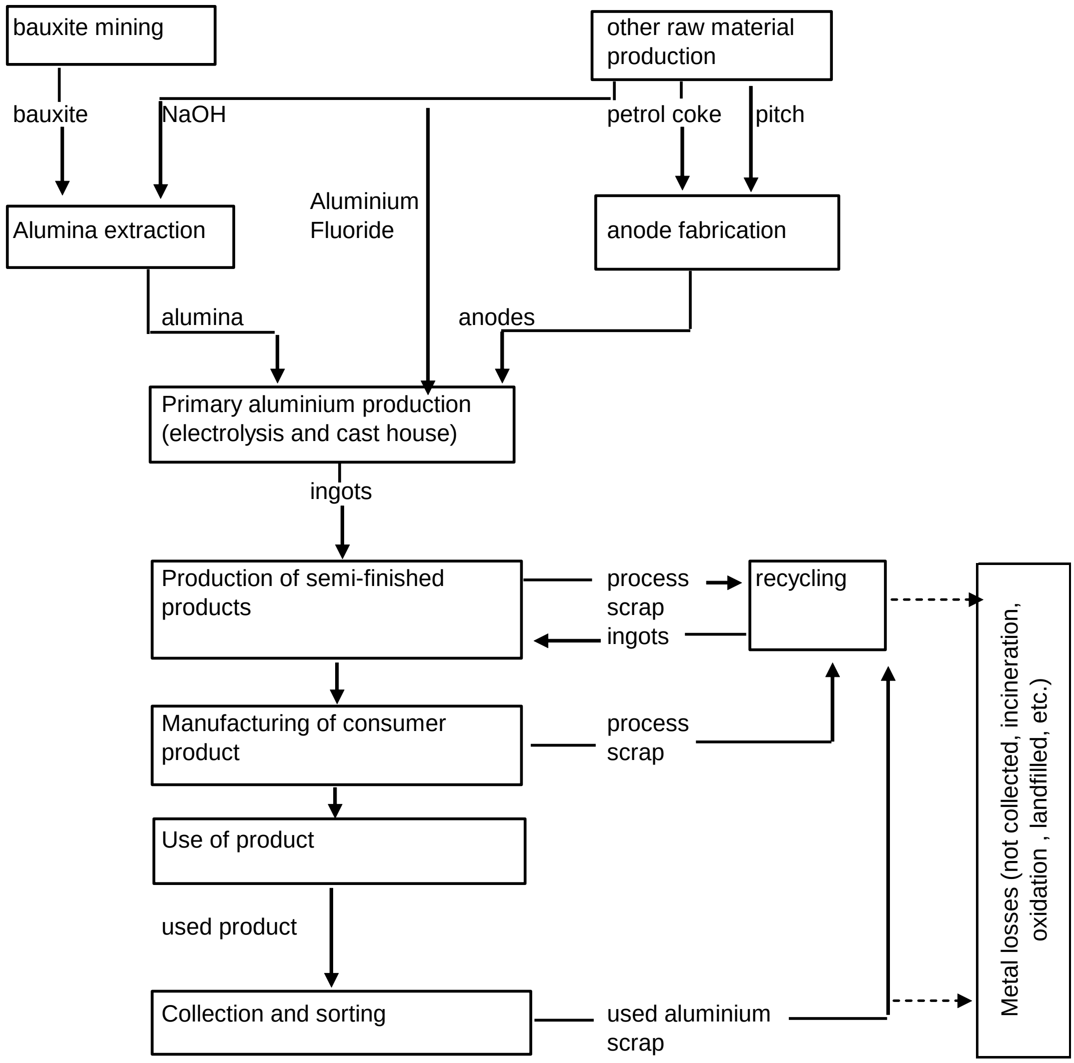

Fig. 1.1 Simplified life cycle material flow chart of an aluminium product

The main raw material for aluminium is bauxite, which is extracted from bauxite mines and processed into aluminium oxide at alumina plants.

Aluminium metal is produced from aluminium oxide by an electrolytic process. In addition to alumina, the main raw materials are carbon anodes and aluminium fluoride. In a cast house, aluminium from the smelters, aluminium scrap and alloying elements are mixed together to reach the appropriate composition and then cast into ingots for rolling, extrusion or product casting.

Wrought aluminium products are fabricated from ingots by hot working (mainly a rolling or an extrusion process) which is normally followed by cold working and /or finishing operations.

Aluminium castings are manufactured by the solidification of molten alloys, followed by finishing operations.

Aluminium production scrap is formed during the various aluminium fabrication steps. This scrap is either recycled in a closed loop at the plant where it is generated, or recycled outside the plant by specialised remelters.

Aluminium scrap from products after their service life is to a large extent recovered for recycling into new aluminium products.

2. Description of the LCI project

2.1 Goal & scope of the LCI project

In order to update its various European LCI datasets related to aluminium processes, the EAA has decided to organise in 2011 a new extensive environmental survey covering the year 2010, in which the European aluminium producers provided input and output data of environmental relevance for their respective production facilities. These data have been aggregated at European level and averages representative for Europe have been calculated for the various processes and sub-processes involved in the aluminium value chain. These European averages were then used within various LCI models in order to develop generic European LCI datasets, i.e. lists of quantified elementary flows, associated with the main aluminium production or transformation processes.
These data provided by the EAA members for their own process steps are the most up-to-date average data available for these processes, and it is recommended that they be used for LCA purposes, whenever generic aluminium data for Europe are needed. Older literature data should be disregarded, as they may no longer be representative due to technological improvements, progress in operating performance, changes with regard to raw materials or waste treatment, etc.

These updated environmental data and associated LCI datasets, which are annexed to this report, should be used for:

- LCA studies related to aluminium products fabricated in Europe, i.e. product made of aluminium or containing aluminium.
- updating the various environmental and LCI databases related to aluminium processes in Europe

As such, these datasets are intended for use as a reference material for life cycle assessment (LCA) studies of products made of, or containing, aluminium. To complete the product system under study, the user should collect the following additional data and information:

- Inventory data on the production of components not made of aluminium,
- Inventory data on the fabrication and the assembly of the final product system from semi-fabricated aluminium components and possibly other material pieces,
- Inventory data associated with the use phase of the product system.
- Inventory data related to the end of life treatment, with a special focus on the collection and recycling processes for aluminium.

The **geographical area** covered by these datasets is Europe which is composed of **the EU27 and the EFTA countries (Norway, Switzerland and Iceland)**.

The LCI modelling is based on a **pure aluminium mass flow.** Alloying elements have been neglected and replaced by pure aluminium. This simplification is reasonable for most of the wrought aluminium alloys which usually contain less than 5% of alloying elements. For cast alloys, it is recommended to the user to analyse more closely the contribution of alloying elements, mainly silicon and magnesium, since such alloying elements usually constitute 5 to 15% of the mass of the casting alloys.

The LCI models use the substitution principle for scrap produced along the processing route, i.e. the recycling of all the aluminium from process scrap, chips, dross or salt slag which are produced along the production or transformation route are directly recycled into the lifecycle model. According to this modelling approach, the only valuable aluminium product exiting the LCI model is either the aluminium ingot or the aluminium semi-finished product. As a consequence, this approach supports the **dataset modularity,** i.e. the possibility to combine them directly**.** For the datasets addressing semi-production, remelting and refining, this approach allows **evaluating the true environmental aspects of these aluminium processes, since it also considers the possible metal losses.**

The LCI modelling also considers **ancillary processes** like fuel preparation, electricity production or ancillary material production in order to develop **LCI datasets mainly composed of elementary flows**, i.e. material or energy directly drawn from the environment without previous human transformation or material or energy released into the environment without subsequent human transformation.

The following LCI datasets have been developed from the environmental surveys covering the year 2010:

- 2 datasets on primary aluminium production, one "produced[1] in Europe" primary datasets (A) and one "Used in Europe[2]" primary datasets (B)
- 3 datasets on semi-finished aluminium products fabrication, respectively sheet, profile & foil and extrusion
- 1 dataset on clean process scrap remelting,
- 1 dataset on the recycling of end of life aluminium products.

The system boundaries of these various datasets are reported in Fig. 2.1.

The "produced in Europe" **primary** LCI dataset (A) corresponds to the production of 1 tonne of ingot from primary aluminium, i.e. from bauxite mining up to the sawn aluminium ingot ready for delivery. This dataset includes all the environmental aspects of the various process steps and raw materials used to deliver 1 tonne of sawn primary ingot produced by the European smelters. Since the electricity production is the major contributor to the environmental aspects, a specific electricity model has been developed based on the electricity consumed by the European smelters (see section 3.4).

The "used in Europe" primary' LCI dataset (B) is similar to the previous dataset but considers the primary aluminium which is imported into Europe and which represent

[1] Produced by smelters located in Europe (i.e without imports of primary aluminium ingots)
[2] Including imports of primary ingots from outside Europe : 44% of primary aluminium used in Europe is imported (Source : Eurostat for EU27 and national customs data for EFTA countries)

44% of the primary aluminium used in Europe in 2010 (see section 3). Global data from the International Aluminium institute [3] have been used for modelling the primary aluminium produced outside Europe and a specific electricity model for the electrolysis process has been developed (see section 3.4) based on the origins of the imports.

The '**semi-production**' LCI datasets (**sheet, foil or profile**) correspond to the transformation of a sawn aluminium ingot into a semi-product, i.e. profile, sheet or foil ready for delivery to the user. These 'semi-production' datasets include the recycling of the scrap and chips generated during this semi-fabrication stage as well as the recycling of the dross. The 3 datasets correspond respectively to the production of 1 tonne of profile, sheet or foil. EAFA (European Aluminium Foil Association, www.alufoil.org) and EAA worked together for developing the foil dataset (see sections: 4-Aluminium sheet production ; 5-Aluminium foil production and 6-Aluminium extrusion).

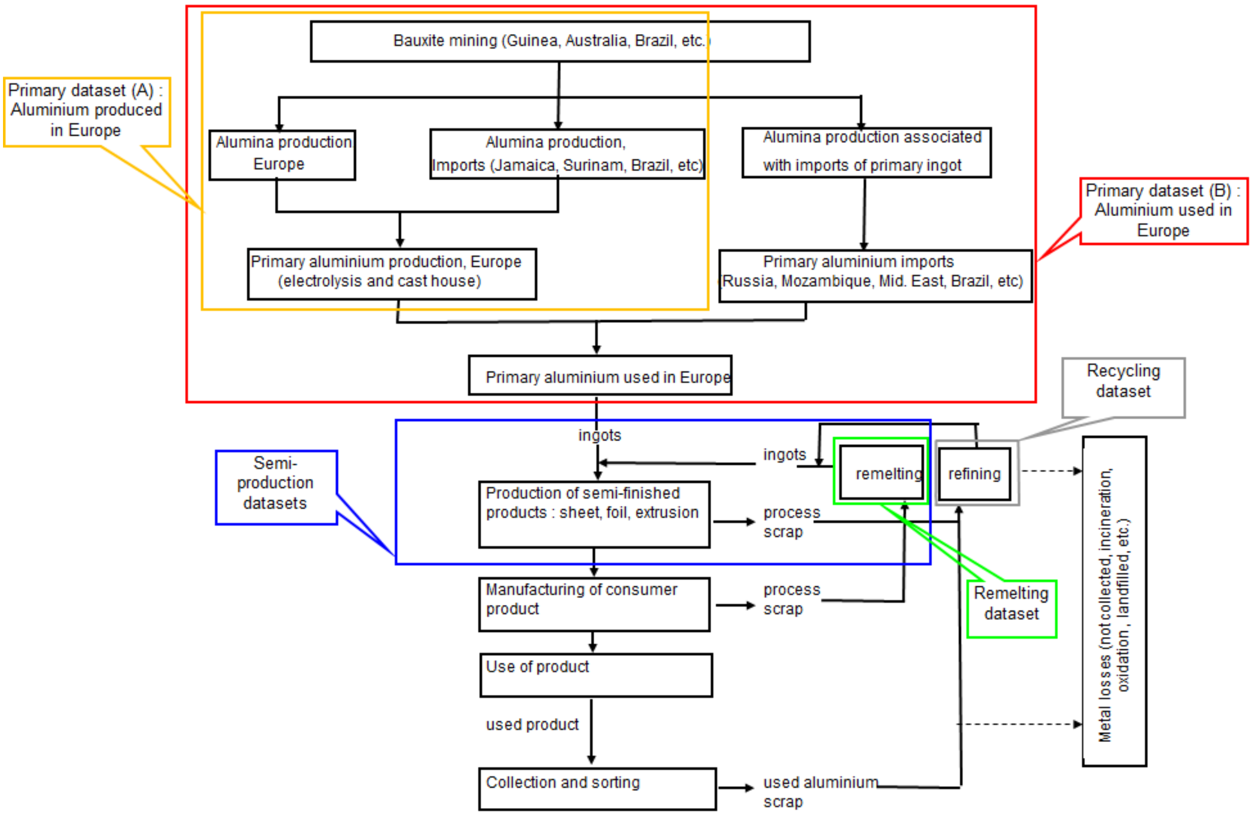

Fig. 2.1 System boundaries of the various LCI datasets

The '**remelting'** LCI dataset corresponds to the production of 1 tonne of aluminium ingot from clean process scrap (also called new scrap). This dataset also includes the recycling of dross & skimmings. This dataset should be used for the recycling of process scrap as well as for the recycling of some specific end-of-life products using well controlled collection schemes like big aluminium pieces in building or aluminium beverage cans collected through specific collection networks.

The '**recycling'** LCI dataset corresponds to the production of 1 tonne of aluminium ingot from the modelled mix of the European scrap market (excluding clean process scrap). This datasets includes the melting, purifying and casting operations. It also

includes the salt slag processing. EAA and OEA (Organisation of European Aluminium refiners and remelters) worked together for developing this 'recycling' dataset.

The 'recycling' dataset is based on the recycling of the European scrap mix according to the ESSUM model [8]. Recycling efficiency and recycling routes highly depend on scrap origin and quality. As a result, for specific aluminium applications or products, it is highly recommended to analyse more closely the recycling scenario(s) and the recycling routes in order to develop more adapted models and associated LCI datasets. Please contact EAA (LCI@eaa.be) for more specific information.

2.2 How to use these LCI datasets in LCA studies

EAA recommends using these LCI datasets in accordance with methodologies within the framework of the following international standards:

- ISO 14040:2006 Environmental Management - Life Cycle Assessment – Principles and framework
- ISO 14044:2006 Environmental Management – Life Cycle Assessment – Requirements and guidelines

The following key features of these standards are of special importance for aluminium

- LCA is a technique for assessing the environmental aspects and potential impacts associated with goods and services,
- LCA should include the following phases:
  - Goal and Scope Definition
  - Life Cycle Inventory Analysis
  - Life Cycle Impact Assessment
  - Interpretation.

LCA covers product systems which comprise the full life cycle of a product, including raw material acquisition, fabrication, transportation, use, recycling/disposal and energy and ancillary material supply operations. Ideally, elementary flows should constitute the sole input and output of such a product system, i.e. material or energy which is drawn from the environment or which is discarded to the environment without subsequent human transformation.

As previously stated, the LCI modelling includes **system extension to ancillary processes** so that **LCI datasets are mainly composed of elementary flows**. These LCI datasets are then ready for integration into LCA studies or LCI databases. (see section 2.9 on background data).

Regarding recycling, the European aluminium industry recommends crediting the environmental benefits resulting from recycling through the so-called '**substitution' methodology**. This methodology is explained within the technical paper "aluminium recycling in LCA" downloadable from the EAA website.

2.3 Data collection, consolidation and averaging

Inventory data for European aluminium production have been collected with full reference to ISO standards 14040 and 14044 on Life Cycle Assessment.

The present life cycle inventory data for aluminium is derived from various industry surveys covering the year 2010. The various European plants participating in the survey delivered absolute figures of process inputs/outputs for the whole year 2010 (tonnes, GJ, m^3, etc.). After aggregation, these input and output data were used to calculate **European averages**. These European averages were then integrated within specific LCI models in order to generate the corresponding LCI datasets.

To generate the European average, a horizontal aggregation was used, i.e. averaging for each fabrication step. This horizontal aggregation supports the modular approach which allows an easy combination between the process and which gives details on the contribution of the various process steps to the complete LCI dataset.

2.4 Cut-off rules

Input and output data have been collected through detailed questionnaires which have been developed and refined from the first surveys organised in 1994 - 1996. In practice, this means that, at least, all material flows going into the aluminium processes (inputs) higher than 1% of the total mass flow (t) or higher than 1% of the total primary energy input (MJ) are part of the system and modelled in order to calculate elementary flows. All material flows leaving the product system (outputs) accounting for more than 1% of the total mass flow is part of the system. All available inputs and outputs, even below the 1% threshold, have been considered for the LCI calculation. For hazardous and toxic materials and substances the cut-off rules do not apply.

2.5 Data quality, validation and modelling

Expert judgement was used to identify outliers and to select data to be included in the consolidation. As far as possible, before any decision of excluding data, reporting companies have been contacted and outliers have been possibly corrected according to the company feedback. Data consolidation, averaging and modelling have been done by the EAA. The data collection procedures, the various questionnaires and the consolidated data are part of internal environmental reports which have been validated by the EAA Technical Working Group of the Sustainability Committee. The LCI models (see section 2.7) have been developed in collaboration with PE-International. The final draft of the environmental profile report was reviewed by Prof. Dr. Walter Klöpffer as an independent external expert. Details about the review process are given in section 2.11 and at the end of this report within the annexed reviewer report.

2.6 Allocation principles

As much as possible, allocation has been avoided by expanding the system boundaries (see section 2.9). Each LCI dataset includes the aluminium scrap and dross recycling so that the only valuable material exiting the system is the aluminium ingot or semi-product (sheet, foil, extrusion).

The incineration of solid waste considers energy recovery (thermal and electricity). To avoid any allocation, such energy is directly re-introduced in the LCI model and the energy input is reduced accordingly. This procedure corresponds to energetic closed-loop recycling. In any case, such energy input from incineration is very limited (less than 1%).

2.7 Software tool for LCI data modelling

The GaBi software version 5 [11] has been used to model and develop the various LCI datasets related to the year 2010. The previous EAA LCI datasets were produced with the GaBi software version 4.

2.8 Global Aluminium (IAI) data[3] vs. EAA data

In order to model aluminium processes taking place outside Europe (see Fig. 2.1), global average process data have been used. These processes are listed below as well as their respective contribution into the 2 LCI datasets.

Table 2-1 Respective contribution[4] of the different process used for the 2 LCI datasets

Process step	Produced in Europe LCI dataset	Used in Europe LCI dataset
Bauxite mining	100% on IAI data (no EAA data)	100% on IAI data (no EAA data)
Alumina production	42% on IAI data and 58% on EAA data	68% on IAI data and 32% on EAA data
Electrolysis including anode production and casting	0% on IAI data and 100% on EAA data	44% on IAI data and 56% on EAA data

Since, Europe is a big importer of alumina and primary aluminium, the modelling of the "used in Europe" LCI dataset assumes that the whole alumina and primary aluminium produced in Europe is used in Europe. This assumption is confirmed by statistics (from Eurostat and national customs) since less than 10% of the alumina and 2% of aluminium produced in EU27 and EFTA countries are exported outside Europe.

2.9 Background data

In addition to the environmental data related to the aluminium processes collected by EAA and by IAI, additional inventory datasets (background data) related to supplementary processes have been used. These datasets are included in the GaBi database version 5 [11]. The most important are (list not exhaustive):

- Limestone production (DE, 2010):
- Caustic soda production (DE, 2010)
- Aluminium fluoride production (RER, 2010)
- Petroleum coke production (EU27, 2008)
- Pitch production (EU 27, 2008)
- Electricity supply systems (EU27, GLO, 2008)
- Fuel supply systems and fuel combustion (EU27, 2008)
- Transportation (GLO, 2010)

[3] IAI data don't include China
[4] Based on Eurostat (EU27) and national customs data (EFTA countries)

In current LCA methodology, solid wastes are not listed as elementary flows provided they are recycled, incinerated, composted or legally landfilled. This LCA methodology integrates such incineration, recycling or landfilling operations within the system boundaries and models the emissions associated with such operations. In the various LCI datasets developed within this report, the treatment of the solid wastes have been modelled and integrated within the system boundaries. For most solid wastes which are landfilled, emissions have been calculated based on average LCI models since it was not possible to collect or model specific emission data in relation to their behaviour in landfilling sites.

2.9.1 Thermal energy used in aluminium processes

Many aluminium processes use fossil fuels (natural gas, propane, diesel, coal, etc.) as thermal energy sources. While input figures have been collected regarding the consumption of these fuels, only restricted data have been collected regarding the air emissions which are mainly associated with the combustion of these fuels. The collected data usually covers only particulates, SO_2 and NO_X.

In order to consider properly the various air emissions associated with the combustion of the fuels, the modelling also includes the use of LCI data for fuel supply systems and fuel combustion which are available in the GaBi software (reference year 2008 – EU27).

As schematised in Fig. 2.2 for the air emissions associated with the alumina production process, the survey reported figures, i.e. particulates, SO_2 and NOx, are then complemented with all the other air emissions which are associated with the preparation and the combustion of these fossil fuels. Precautions were taken to avoid double counting of the reported emissions.

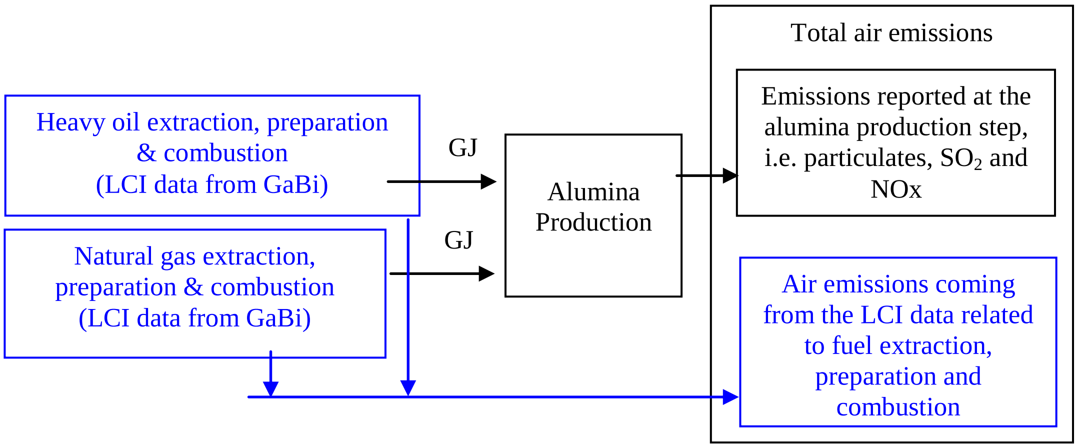

Fig. 2.2 Use of background LCI data related to fuel supply systems and combustion (Background GaBi LCI data in blue)

The total air emission from the alumina production is then a combination of reported figures for the main emissions completed with LCI data representative for fuel extraction, preparation and combustion. This approach has been systematically applied for any aluminium processes in which fuel combustion takes place.

2.9.2 Direct CO_2 emissions in aluminium processes

Direct CO_2 emissions have been calculated for the various aluminium processes based on their respective fuel consumption. The CO_2 conversion factors representative for EU-27 have been taken from GaBi 5 and are reported in the next Table 2-2.

Table 2-2 CO_2 conversion factor for the various fuels

Fuel type	CO_2 intensity (kg CO_2/MJ)
Heavy oil	$9,01.10^{-2}$
Natural gas	$6,77.10^{-2}$
Hard coal	$1,04.10^{-1}$
Diesel / light oil	$8.96.10^{-2}$
Propane	$8,64.10^{-2}$
Steam	$7,52.10^{-2}$

2.9.3 Electricity production

Electricity production has been included in the system boundaries. Electricity production is particularly critical for the electrolysis step, i.e. the smelter, since about 15 MWh/tonne of primary aluminium is used. Three specific models have been developed: two models for the electricity used by the European smelters, i.e. one for "pre-baked" smelters and one for "Soderberg" smelters, and one model for the electricity used by smelters exporting to the European market. These models are described in the section 3.4.

For the other processes, any electricity consumption is supposed to be reflected by the LCI data related to the EU27 electricity model (reference[5] year 2008) are used.

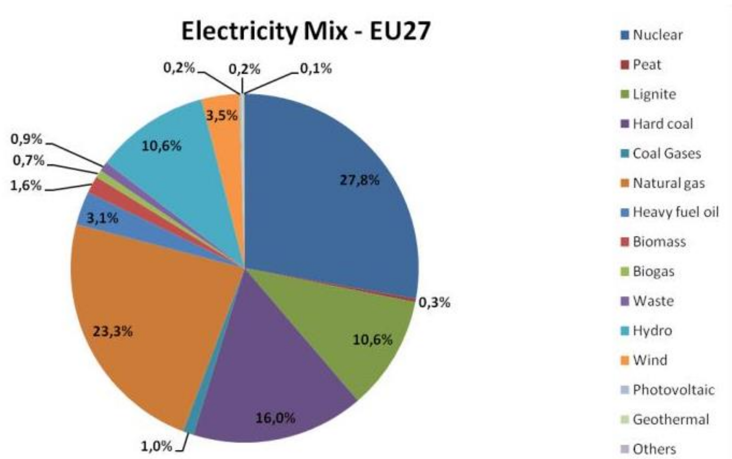

Fig. 2.3 Electricity Mix EU27

[5] 2008 data were used by default : 2010 data were not available in Gabi 5 software

Table 2-3 Main environmental indicators for the production of 1 kWh based on the EU-27 electricity grid mix

Environmental indicators[6] per kWh electricity,	Value
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	4,01E-08
Acidification Potential (AP) [kg SO_2-Equiv.]	2,08E-03
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,12E-04
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	4,89E-01
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	3,19E-08
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1,27E-04
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	9,78E+00
Primary energy from renewable raw materials (net cal. value) [MJ]	1,25E+00
Primary energy from non-renewable resources (net cal. value) [MJ]	8,53E+00

2.9.4 Transport

Bauxite, alumina and primary ingots imported into Europe are transported mainly by sea boat and to a lesser extent by river (barge), road and rail transport. While only sea transport was considered in 2005, the new transport model considers all these transport modes into the EAA LCI dataset of primary aluminium.
Bauxite used in Europe is imported, mainly from Guinea, Australia and Brazil. Average transport distance for imported bauxite is about 6.100 km by sea. Alumina used in Europe is mainly sourced from Jamaica, Suriname and Brazil. Average transport distance for the imported alumina to Europe is around 4.700 km by sea. In addition, the present model assumes an average sea transport distance of 2.500 km for the primary ingots imported into Europe (main sources of imports Russia, Mozambique, Brazil and the Middle East).
Road and rail transport have also been modelled for the bauxite and alumina imports in Europe. Fig. 2.4 summarises the average transport distances used in the model.

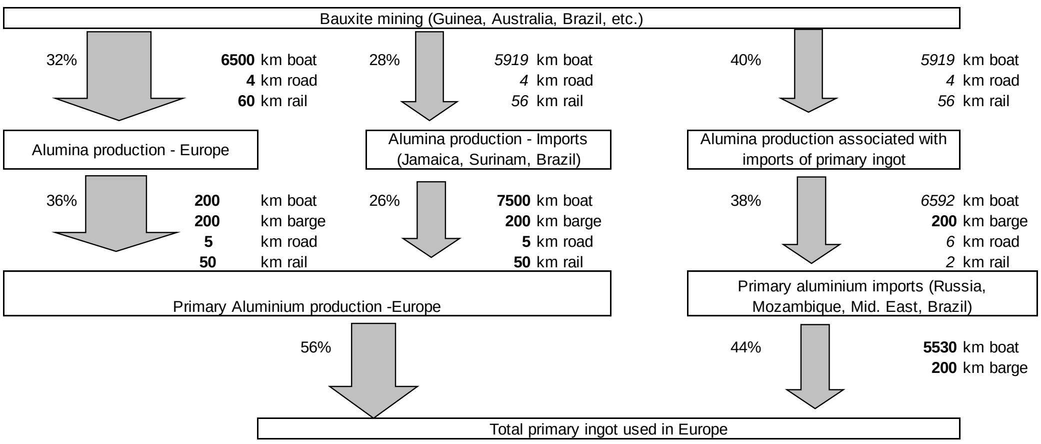

Fig. 2.4 Average transport distances of bauxite, alumina and imported aluminium

[6] A brief presentation of the environmental impact categories is given in Table 2-6

Table 2-4 Average transport distances

Year	Type of transport	Unit	Bauxite	Alumina	Primary
1998 & 2002	Ocean/Cargo	km	7.106	3.737	N.A.
	Coastal/barge	km	2	204	
	Road	km	334	15	
	Rail	km	11	42	
2005	Ocean/Cargo	km	6.250	2.400	
2010	Ocean/Cargo	km	6.104	4.516	2.433
	Barge	km	-	200	88
	Road	km	4	5	-
	Rail	km	57	32	-

A specific fuel consumption of 0,54 g of heavy oil per tonne transported and per km has been used (bulk carrier between 10.000 and 200.000 tonnes). As a result, the transport of 1 tonne of alumina or bauxite on 5.000 km gives then a consumption of 2,7 kg of heavy oil.

No transport data has been integrated into the other LCI datasets.

2.10 LCI data and environmental indicators

The above described modelling allows developing LCI datasets which are mainly composed of elementary flows. The detailed datasets are available on request as excel document (please email lci@eaa.be).

For each LCI dataset, indicators have been calculated and reported for a pre-defined set of impact categories. **It is important to highlight that these environmental indicators are purely informative and should not be used for evaluating the environmental aspects of aluminium processes in Europe or for comparative purposes between various materials. As highlighted in ISO 14040 and 14044, only the environmental aspects of a product system or a service in a life cycle perspective, i.e. from cradle to grave or from cradle to recycling, is scientifically sound.** The predefined set of impact categories is reported in Table 2-5.

Table 2-6 gives a short explanation and definition of these impact categories.

Table 2-5 Pre-defined set of environmental impact categories.

Impact categories	Unit	Methodology
Depletion of Abiotic Resources (ADP)	[kg Sb-Equiv.]	CML2001- Nov 2010
Acidification Potential (AP)	[kg SO_2-Equiv.]	CML2001- Nov 2010
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	CML2001- Nov 2010
Greenhouse Gas emission (GWP 100 years)	[kg CO_2-Equiv.]	CML2001- Nov 2010
Ozone Layer Depletion Potential (ODP, steady state)	[kg R11-Equiv.]	CML2001- Nov 2010
Photo-oxidant Creation Potential (POCP)	[kg Ethene-Equiv.]	CML2001- Nov 2010
Total Primary energy	[MJ]	net cal. value
Primary energy from renewable raw materials	[MJ]	net cal. value
Primary energy from non-renewable resources	[MJ]	net cal. value

Table 2-6 Brief description of the pre-selected environmental impact categories

Indicators	Short description
Depletion of Abiotic Resources (ADP)	Resources are classified on the basis of their origin as biotic and abiotic. Biotic resources are derived from living organisms. Abiotic resources are derived from the non-living world (e.g., land, water, and air). Mineral and power resources are also abiotic resources, some of which (like fossil fuels) are derived from formerly living nature. ADP estimates the consumption of these abiotic resources.
Acidification Potential (AP)	This relates to the increase in quantity of acid substances in the low atmosphere, at the cause of "acid rain" and the decline of surface waters and forests. Acidification potential is caused by direct outlets of acids or by outlets of gases that form acid in contact with air humidity and are deposited to soil and water. Examples are: SO_2, NOx, Ammonia. The main sources for emissions of acidifying substances are agriculture and fossil fuel combustion used for electricity production, heating and transport.
Eutrophication Potential (EP)	Aqueous eutrophication is characterized by the introduction of nutrients in the form of phosphatised and nitrogenous compounds for example, which leads to the proliferation of algae and the associated adverse biological effects. This phenomenon can lead to a reduction in the content of dissolved oxygen in the water which may result to the death of flora and fauna.
Greenhouse Gas emission (GWP 100 years)	The "greenhouse effect" is the increase in the average temperature of the atmosphere caused by the increase in the average atmospheric concentration of various substances of anthropogenic origin (CO_2, methane, CFC...). Greenhouse gases are components of the atmosphere that contribute to the greenhouse effect by reducing outgoing long wave heat radiation resulting from their absorption by these gases like CO_2, CH_4 and PFC.
Ozone Layer Depletion Potential (ODP, steady state)	Stratospheric ozone depletion (especially above poles) results mainly from a catalytic destruction of ozone by atomic chlorine and bromine. The main source of these halogen atoms in the stratosphere is photodissociation of chlorofluorocarbon (CFC) compounds, commonly called freons, and of bromofluorocarbon compounds known as halons. These compounds are transported into the stratosphere after being emitted at the surface.
Photo-oxidant Creation Potential (POCP)	The majority of tropospheric ozone formation occurs when nitrogen oxides (NOx), carbon monoxide (CO) and volatile organic compounds (VOCs), such as xylene, react in the atmosphere in the presence of sunlight. NOx and VOCs are called ozone precursors. There is a great deal of evidence to show that high concentrations (ppm) of ozone, created by high concentrations of pollution and daylight UV rays at the earth's surface, can harm lung function and irritate the respiratory system
Total primary energy	Primary energy is energy that has not been subjected to any conversion or transformation process, e.g. Energy contained in crude oil.
Primary energy from renewable raw materials	Primary energy is energy that has not been subjected to any conversion or transformation process. Renewable energy refers to solar power, wind power, hydroelectricity, biomass and biofuels. For aluminium primary production, hydropower is the most significant renewable energy for electricity production.
Primary energy from non-renewable resources	Primary energy is energy that has not been subjected to any conversion or transformation process. Non-renewable energy is energy taken from finite resources like coal, crude oil, natural gas or uranium.

For each LCI dataset, the various processes and materials involved in the system boundaries have been **classified in 5 categories, i.e. direct processes, auxiliary, transport, electricity and thermal energy** so that the LCI data and the indicators can be distributed among such 5 categories.

These 5 categories are defined as follows:

- **Direct process**: Direct material consumption/use or direct emissions associated with the aluminium processes. The following processes are considered as aluminium processes:
  - **Primary production**: bauxite mining, alumina production, anode/paste production, electrolysis, casting.
  - **Semi-production**: ingot homogenisation, ingot scalping, hot rolling, cold rolling, annealing, finishing & packaging, extrusion, foil rolling, scrap remelting, dross recycling.
  - **Recycling**: scrap remelting, scrap refining, dross recycling, salt slag treatment.
- **Electricity**: all the processes and materials needed to produce the electricity directly used by the aluminium processes. It includes fuel extraction and preparation.
- **Thermal energy**: all the processes and materials needed to produce the thermal energy directly used in the aluminium processes, excluding pitch and coke used for the anode production
- **Auxiliary**: all ancillary processes and materials used in the aluminium processes. It concerns mainly caustic soda, lime and aluminium fluoride.
- **Transport**: Sea, river, road and rail transport for bauxite and alumina and sea and river transport for imported ingots.

2.11 Critical review by independent expert

A critical review has been performed by Professor Dr. Walter Klöpffer, Editor-in-chief, International Journal of Life Cycle Assessment, Am Dachsberg 56E, D-60435 Frankfurt. Taking into account the previous in-depth reviewing exercise [15-16], this new review process has been limited to this external report including a plausibility check of the LCI datasets. Hence, the reviewing process has been done “a posteriori”, i.e. based on the draft environmental report and the various LCI datasets. The review has been organised in agreement with the ISO 14040 and 14044 recommendations. It included one phone discussion and two face-to-face meetings. The reviewing report of Professor Klöpffer is annexed at the end of this document.

2.12 Main differences between current and approach used in 2005 dataset

Compared to the previous LCI datasets related to the year 2005, the following improvements have been performed in order to increase the robustness and the completeness of the LCI datasets related to primary aluminium:

- Use of global aluminium data [3] : primary aluminium imported into Europe as well as aluminium processes taking place outside Europe, e.g. alumina production and bauxite mining, have been modelled on basis of the global average data developed by the International Aluminium Institute [3]. For the user convenience, these process data have been reported in the corresponding tables of this report. In the previous LCI datasets, only a specific electricity model was used for the imported primary aluminium but the process data were the EAA data, excepted PFC and fluoride emission data which were extracted from the IAI report. Hence, the new modelling approach better reflects the reality and allows developing the 2 datasets for primary aluminium while only one LCI dataset including imports was developed previously.

- Transport modelling: a complete transport model (see 2.9.4) has been developed to consider not only sea transport as done in the previous LCI datasets but also river, train and road transport.

The main changes compared to the previous modelling approach are reported in Table 2-7. For the primary model, a new and refined electricity model has been developed. This electricity model is explained under the section 3.4. while the transport model is explained in section 2.9.4. For semi-finished products production and scrap remelting, the same modelling approach has been used as in the previous Environmental Profile Report. Due to the impossibility to collect robust figures related to the scrap preparation phase, the refining model does not cover any longer this process step (see section 7.7).

Table 2-7 Differences between current and past modelling

Generic differences		2005	2010
LCIA Methodology		CML 2001 – Nov 2007	CML 2001 – Nov 2010
Modeling tool		GaBi 4 software	GaBi 5 software
Main data sources for ancillary processes		GaBi & ELCD data (ref years between 2002 & 2006)	GaBi & ELCD data (ref years between 2008 and 2010)
Electricity production (excluding electrolysis step)		EU25 grid mix in GaBi (ref year 2002)	EU27 grid mix in GaBi (ref year 2008)
Specific differences		**2005**	**2010**
Primary aluminium modeling	Al processes outside Europe	Use of EAA data except for some key emission data where IAI data were used	Use of IAI data
	Transport modeling	Only sea transport for bauxite and alumina	Full transport modeling including river, rail and road transport
	European Electricity model (smelters)	Based on a consolidation of energy sources at country level and a modeling of electricity production at country level which is then consolidated at European level	Based on a consolidation of energy sources at European level and a modeling of electricity production at European level
	Electricity model for imports (smelters)	Based on national grid mix of significant importing countries and specific mix for Russian aluminium producers	Based on national grid mix of significant importing countries and specific mix for Russia, Ukraine and the Middle East (based on specific data from aluminium producers)
Recycling	Refining model	Scrap preparation included	Scrap preparation excluded

Due to all these differences (generic and specific one) between 2005 and 2010, a simple comparison of the environmental indicators results for 2010 values with the former environmental indicators is not relevant (especially regarding LCIA methodology for ADP indicator). Therefore, only the environmental indicators results for 2010 are presented in this document.

For instance, between Gabi 4 and Gabi 5 software, a more accurate modelling of the "*thermal energy from natural gas*", has led to an increase of +15% of the emission of carbon dioxide (CO_2eq) and an increase of + 13% of the total primary energy demand (MJ).

3. Primary production

3.1 Process steps description

3.1.1 Bauxite Mining

The common raw material for aluminium production, bauxite is composed primarily of one or more aluminium hydroxide compounds, plus silica, iron and titanium oxides as the main impurities.

More than 200 million tonnes of bauxite have been mined in 2010 worldwide. The major locations of deposits are found in a wide belt around the equator. Bauxite is currently being extracted in Australia (in excess of 60 million tonnes per year), Central and South America (Jamaica, Brazil, Surinam, Venezuela, Guyana), Africa (Guinea), Asia (India, China), Russia, Kazakhstan and Europe (Greece). Bauxite is mainly extracted by open-cast mining.

The environmental data related to bauxite mining have been collected and developed by the International Aluminium Institute (IAI) for the year 2010 (see Table 3-2).

3.1.2 Alumina production

Bauxite has to be processed into pure aluminium oxide (alumina) before it can be converted to aluminium by electrolysis. This is achieved through the use of the Bayer chemical process in alumina refineries. The aluminium oxide contained in bauxite is selectively leached from the other substances in an alkaline solution within a digester. Caustic soda and lime are the main reactants in this leaching process which takes place in autoclaves at temperature between 100 and 350°C (depending on alumina reactivity). The solution is then filtered to remove all insoluble particles which constitute the bauxite residue (also called "red mud"). On cooling, the aluminium hydroxide is then precipitated from the soda solution, washed and dried while the soda solution is recycled. The aluminium hydroxide is then calcined, usually in fluidised-bed furnaces, at about 1100°C. The end-product, aluminium oxide (Al_2O_3), is a fine grained white powder.

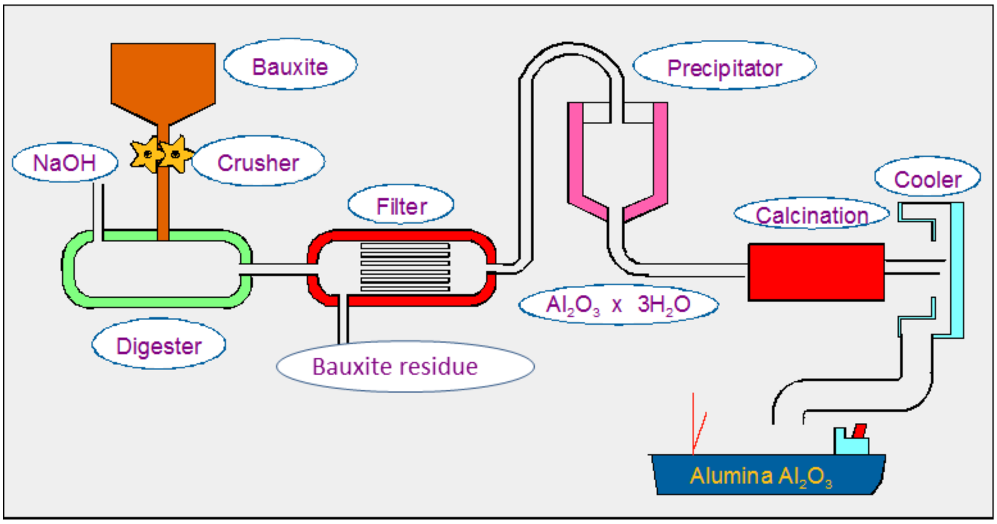

Fig. 3.1 Alumina production process

About 2,3 tonnes of bauxite is used in Europe per tonne of alumina. The calcination process and, to a lesser extent, the leaching process consumes most of the thermal energy. About 10 GJ of thermal energy is used per tonne of alumina as well as 180 kWh/t of electricity (see Table 3-3 for details).

Solid wastes arising in alumina production are composed of 2 main streams:

- Tailings, inerts and sand which are separated from the bauxite ore prior the leaching process
- The residue of the leaching process: bauxite residue. Even if constituents are mostly non-toxic and largely insoluble, bauxite residue requests special handling due to the residual alkaline content resulting from the extraction process. Depending on the bauxite residue filtration and rinsing process, the alkalinity of the residual solution may vary significantly. Current practice is usually to deposit bauxite residue on or near the site in specially designed sealed ponds from which excess water is returned to the process. With time, the alkali residues react with carbon dioxide from the air to form sodium carbonate. Bauxite residue disposal sites can be re-cultivated once they have dried out. The use of bauxite residue as filler material for road construction or as additive in cement industry is still marginal, but increasing. For more reference about the bauxite residue management please consult the Bauxite Residue Management document available on the EAA website[4].

3.1.3 Electrolysis

Primary aluminium is produced in electrolysis plants (frequently called "smelters"), where the pure alumina is reduced into aluminium metal by the Hall-Héroult process. Between 1.920 and 1.925 kg of alumina is needed to produce 1 tonne of aluminium. The reduction of alumina into liquid aluminium is operated at around 950 degrees Celsius in a fluorinated bath (i.e. cryolite) under high intensity electrical current. This process takes place in electrolytic cells (or "pots", see Fig. 3.2), where carbon cathodes form the bottom of the pot and act as the negative electrode. Carbon anodes (positive electrodes) are held at the top of the pot and are consumed during the process when they react with the oxygen coming from the alumina. There are two major types of cell technology in use. All potlines built in Europe since the early 1970s use the prebake anode technology, where the anodes, manufactured from a mixture of petroleum coke and coal tar pitch (acting as a binder), are ‘pre-baked’ in separate anode plants. In the Söderberg technology, the carbonaceous mixture is fed directly into the top part of the pot, where ‘self-baking’ anodes are produced using the heat released by the electrolytic process. In 2010, 95% of the primary aluminium in Europe was produced using prebake technology.

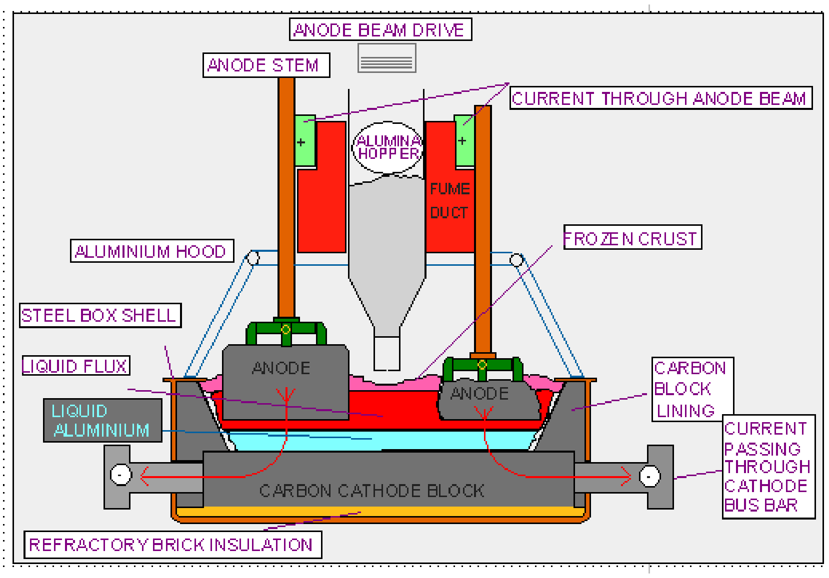

Fig. 3.2 Aluminium electrolytic cell – prebake technology

The electrical energy required for the primary smelting process constitutes the major part of energy consumption in aluminium primary production and has therefore been very carefully handled. Specific consumption data have been obtained from all smelters in order to calculate a true weighted average. The total consumption consists of the following elements:

- Rectifying loss
- DC power usage
- Pollution control equipment
- Auxiliary power (general plant use)
- Electric transmission losses of 2% have been taken into account from power stations to primary smelters, as all primary smelters have their energy delivered by high voltage lines from power stations located nearby, and operate their own transformer facilities.

In 2010, the average electricity consumption of European smelters is 14.887 kWh/tonne. In 2005, this average electricity consumption was 14.914 kWh/tonne of aluminium produced in Europe. For imported primary aluminium which represents 44% of the use, this average electricity consumption is 15.500 kWh/tonne in 2010. In 2005, this average electricity consumption was 15.227 kWh/tonne of imported aluminium.
Both values of electricity consumption have been increased by 2% in the model for considering the transmission losses between the power plant and the smelters. A specific electricity model is developed under the section 3.4 for the production of the electricity which is used at the electrolysis step.

3.1.4 Cast house

At regular intervals, molten aluminium tapped from the pots is transported to the cast house where it is alloyed (according to the user's needs) in holding furnaces by the addition of other metals and aluminium scrap cleaned of oxides and gases, and then cast into ingots. Cast houses produce a wide variety of products and alloys. Since it is not possible to produce one dataset for every type of product and alloy, average data have been developed for a generic aluminium ingot covering ingot for rolling (slabs), for extrusion (billets) or for remelting. Rolling slabs and extrusion billets (see Fig.

3.3) are produced through Direct Chill (DC) casting technology (liquid metal is poured into short moulds on a platform and then cooled when the platform is lowered into a water-filled pit).

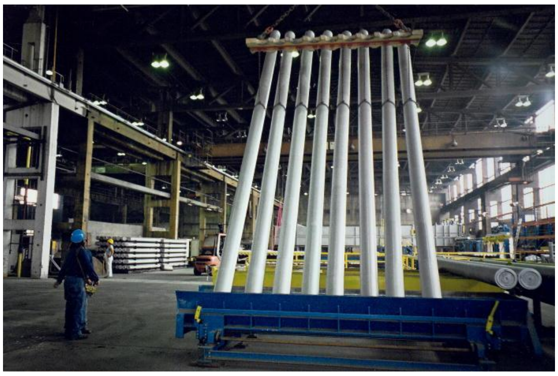


Fig. 3.3 DC-cast extrusion billets (cylindrical) or rolling slabs (rectangular)

Before exiting the cast house, the ends of the rolling slabs and extrusion billets are usually sawed and directly recycled into the holding furnace. In the current model, the product exiting the cast house is a sawn rolling ingot, a sawn extrusion ingot or an ingot for remelting.

Further treatment of rolling and extrusion ingots, such as homogenisation and scalping are covered in the semi-finished product sections (see sections 4,5,6)

3.2 Data collection and averaging

The yearly input and output data were collected through questionnaires covering the year 2010 and focusing respectively on alumina production, on anode and paste production and on electrolysis and casting. Survey coverage in terms of number of replies, tonnages and European coverage is reported in Table 3-1.

Table 3-1 European representativity of the primary data

Process	No. of responses	Total production	Coverage (EU27 + EFTA)
Alumina production	5	5,4 Mt	84%
Paste and anode production	19 (16 anodes and 3 paste)	2,1 Mt	90%
Electrolysis and cast house	28 (25 Pre-bake and 3 Söderberg)	3,9 Mt (liquid aluminium)	93%

After aggregation, European averages have been calculated according to the following reference flows:

- Alumina: total tonnage of alumina production
- Paste and anode: total tonnage of paste production plus total tonnage of baked anode production
- Electrolysis: total tonnage of liquid aluminium produced at the electrolysis
- Cast house: total tonnage of sawn ingot production

Details about direct inputs and outputs of each process are given in the next sub-sections.

3.2.1 Bauxite mining

Input and output data have been taken from the worldwide IAI survey based on the year 2010. These data, reported in Table 3-2, refers to the extraction and the preparation of 1 tonne of bauxite ready for delivery to the alumina plant.

Table 3-2 Direct input and output data for the extraction and preparation of 1 tonne of bauxite

	Unit	Bauxite mining World (IAI) 2010
Inputs		
Raw materials		
Fresh Water	m^3/t	0,5
Sea Water	m^3/t	0,7
Fuels and electricity		
Heavy oil	kg/t	0,2
Diesel oil	kg/t	0,3
Electricity	kWh/t	0,9
Outputs		
Air emissions		
Carbon dioxide[7] (CO_2)	kg/t	2
Particulates	kg/t	0,17
Water discharge		
Fresh Water	m^3/t	0,05
Sea Water	m^3/t	0,7

No specific data about land occupation and about rehabilitation conditions[8] have been collected in the 2010 LCI exercise. However the global aluminium industry is collecting specific land occupation and rehabilitation data in its periodical surveys. Full and comprehensive data on rehabilitation of bauxite mines can be accessed on the “bauxite mine rehabilitation survey” report [5] available on IAI website.

3.2.2 Alumina production

Direct input and output data related to the production of 1 tonne of alumina are reported in Table 3-3. Average European figures of the year 2010 can be compared with figures of 2005 as well with worldwide figures (survey organised by IAI) for the year 2010.
About 2.250 kg of bauxite is used in Europe for producing 1.000 kg of alumina. Bauxite consumption slightly increased since 2005 due to the progressive use of lower grade concentrate. Average bauxite consumption at worldwide level is significantly higher, i.e. 2.880 kg due to the use of lower grade concentrate. European producers uses 53 kg of caustic soda (as 100%) and 42 kg of calcined lime as reactive chemicals. 3,6 m^3 of fresh water enters the process and 3,1 m^3 exits, giving a consumption of about 0,5 m^3.
European alumina production still uses mainly heavy oil (127 kg/tonne) as a source of thermal energy in spite of a strong trend since 2005 to substitute this fuel by natural gas. Worldwide production is more natural gas intensive. Compared to worldwide

[7] Estimated from “fuel combustion“ (see. Table 2-2)
[8] The top soil removed during mining operations in order to access bauxite ore is stored and re-used later during mining rehabilitation operations. As a proxy, between 0,2 and 0,5 m² of land is used for mining operation / tonne of bauxite extracted..

averages, thermal energy consumption is lower in Europe (10.371 MJ/t alumina in Europe *vs*. 10.954 MJ/t alumina worldwide), while electricity consumption is higher.

Table 3-3 Direct input and output data for the production of 1 tonne of alumina (Al_2O_3)

Alumina production	**Relative figures per 1t of Alumina (Al_2O_3)**			
Inputs	**Unit**	**EAA**		**IAI**
Materials		2010	2005	2010
Bauxite	kg/t	2.251	2.199	2.881
NaOH (as 100%)	kg/t	53	67	79
CaO	kg/t	42	43	40
Fresh Water	m^3/t	3,6	3,3	2,6
Sea Water	m^3/t	0,0	0,0	0,6
Energy				
Coal	MJ/t	0	0	1.850
Heavy oil	MJ/t	5.822	8.544	3.818
Diesel oil	MJ/t	1	10	4
Natural Gas	MJ/t	4.299	1.284	5.282
Propane	MJ/t		139	
Steam	MJ/t	249	386	
Total thermal energy	**MJ/t**	**10.371**	**10.363**	**10.954**
Electricity	kWh/t	181	241	79
Output				
Air emissions				
Particulates	kg/t	0,14	0,23	0,56
SO_2	kg/t	2,68	3,94	2,40
NO_X	kg/t	1,11	1,22	0,68
Hg	g/t	0,06	0,32	0,24
Carbon dioxide[9] (CO_2)	kg/t	834	899	893
Water discharge				
Fresh water	m^3/t	3,1	1,9	1,4
Sea water	m^3/t	0,0	0,0	0,6
Suspended solids	kg/t	0,23	0,07	0,02
Oil	kg/t	0,10	0,08	0,77
Hg	g/t	*1,26E-04*	1,26E-04	6,80E-05
By-products				
Bauxite residue	kg/t	4	8	2
Solid Waste				
Bauxite residue	kg/t	671	706	1.354
Any other solid industrial waste	kg/t	48	60	18
Of which any other landfill wastes	kg/t	6,9		8,5
Of which any hazardous waste according to local legislation	kg/t	0,2		9,3

The aluminium industry has specific guidelines on bauxite residue deposit and rehabilitation. These guidelines are reported in a bauxite residue management document which can be downloaded from the EAA website [4].

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[9] Estimated from "fuel combustion" (see. Table 2-2)

3.2.3 Anode & paste production

Direct input and output data related to the production of 1 tonne of mixed paste (5%) and anode (95%) are reported in Table 3-4. Average European figures of the year 2010 can be compared with 2005 data as well with worldwide figures (survey organised by IAI) for 2010.

Table 3-4 Direct input and output data for the production of 1 tonne of anode / paste

Anode/paste production	Unit	Relative figures per 1t of anode / paste		
		EAA		IAI
		2010	2005	2010
Total production	kg	For 1000 kg of mixed anode (95%) and paste (5%)	For 1000 kg of mixed anode (88%) and paste (12%)	For 1000 kg of mixed anode (89%) and paste (11%)
Inputs				
Materials				
Calcined Coke	kg/t	717	737	672
Pitch	kg/t	152	173	168
Butts Used	kg/t	204	165	
Green anodes imported	kg/t	3		
Total raw carbon	kg/t	1.076	1.075	NA
Energy				
Heavy oil	kg/t	9,3	14,2	28,4
	MJ/t	430	599	1197
Diesel oil	kg/t	0,3	0,0	5,0
	MJ/t	15,5	1,0	230
Natural Gas	m^3/t	58,5	57,4	43,8
	MJ/t	2.225	2.150	1664
Other source	MJ/t	90	245	
Total thermal energy	***MJ/t***	***2.760***	***2.996***	***3091***
Electricity	kWh/t	108	145	114
Total energy	***MJ/t***	***3.147***	***3.516***	***3.501***
Other inputs				
Fresh Water	m^3/t	5,6	3,0	1,5
Refractory material	kg/t	5,9	11,0	6,4
Steel	kg/t	4,1	1,2	5,4
Output				
Air emissions				
Particulates	kg/t	0,25	0,21	0,2
SO_2	kg/t	0,77	1,54	3,90
NO_X	kg/t	0,45	0,32	0,68
Carbon dioxide (CO_2)[10]	kg/t	199	221	241
Part. Fluor	kg/t	2,31E-03	3,49E-02	1,93E-03
Gaseous Fluor	kg/t	0,01	0,19	0,01
PAH	kg/t	0,06	0,15	0,05
B(a)P	g/t	0,06	0,14	0,19
Water discharge				
Fresh water	m^3/t	2,2	2,3	1,4
Suspended solids	kg/t	0,14	0,30	0,03
PAH (6 Borneff components)	g/t	0,96	0,10	0,03

[10] Estimated from “fuel combustion” (see Table 2-2)

Anode/paste production	Unit	Relative figures per 1t of anode / paste		
		EAA		IAI
		2010	2005	2010
By-products or solid waste				
Carbon waste output	kg/t	9,6	1,7	15,8
Steel to be externally recycled	kg/t	1,8	4,1	6,8
Refractory material for external recycling	kg/t	8,7	6,0	4,2
Refractory material that is not recycled	kg/t	3,0	0,4	4,0
Scrubber sludges output	kg/t	0,6	0,6	0,3
Other externally recycled by product	kg/t	3,2	10,5	8,8
Other landfill waste	kg/t	4,1	2,6	3,8
Of which hazardous waste according to local legislation	kg/t	1,4		2,6

In 2010 compared to 2005, return butts have contributed more as raw material for the production of anodes (204 kg/t instead of 165 kg/t). Use of petrol coke has decreased accordingly (717 kg/t vs 737 kg/t in 2005). Fuel and electricity consumption in Europe is decreasing compared to 2005 and below global averages.

There is a significant reduction in most of the air emissions, in particular the particulate and gaseous fluoride emissions, which are each reduced by 93% compared to 2005 (trend experienced at global level also). Gaseous Fluoride emissions are nevertheless still remaining above the world (IAI) average, probably due to anode exhaust fume treatment technology. PAH emissions decrease by 58% compared to 2005, and stay in the range of the world (IAI) average with comparable respondents.

3.2.4 Electrolysis (Smelter)

Direct input and output data related to the production of 1 tonne of liquid aluminium at the electrolysis step are reported in Table 3-5. Average European figures of the year 2010 can be compared with figures of 2005 as well with worldwide figures (survey organised by IAI) for the year 2010.

<u>Comments on input trends</u>

Alumina consumption is stable around 1.920 – 1.925 kg/tonne. Gross (542 kg/t) and net (440 kg/t) carbon anode & paste consumption are slightly up from 2005. Aluminium fluoride consumption (15,8 kg/t) is comparable to world average.

European electricity consumption in 2010 reaches 14.877 kWh/t. Average electricity consumption at global level is about 2,7% higher in 2010, i.e. 15.274 kWh/t.

Fresh water is mainly used for cooling but also, in some cases, for wet scrubbing. Fresh water use highly depends on the location of the smelters since big discrepancies appear between water stressed areas, unstressed areas and coastal regions. Accordingly, the average European fresh water input figure from Table 3-5 couldn’t be considered as a reliable European average.

Seawater use is involved for wet scrubbing, i.e. for smelter air cleaning systems. This process is relevant to a limited number of companies, but significant quantities are reported, since the principle is based on absorbing smelter air emissions into seawater

in harmless concentrations. Accordingly, the average European seawater input figure from Table 3-5 cannot be considered as a reliable European average.

Table 3-5 Direct inputs and outputs for the production of 1 tonne of liquid aluminium at the electrolysis step (smelter).

Production of liquid aluminium at the electrolysis step (smelter)	**Unit**	**European average per tonne of Al output**		
		EAA		**IAI**
		2010	**2005**	**2010**
Total production	kg	1000 kg of production mix : 95% Prebake and 5% Soderberg	1000 kg of production mix : 88% Prebake and 12% Soderberg	1000 kg of production mix: 89% Prebake /11% Soderberg)
Input				
Raw materials				
Alumina	kg/t	1.920	1.925	1.934
Anode PB gross	kg/t	517	477	477
Anode PB net	kg/t	415	369	429
Paste VS	kg/t	25,1	59	58
Anode/paste (gross)	**kg/t**	**542**	**536**	**535**
Anode/paste (net)	**kg/t**	**440**	**428**	**439**
Aluminium Fluoride	kg/t	15,8	18,9	16,2
Cathode Carbon	kg/t	6,9	6,3	6,0
Other raw material				
Fresh Water	m^3/t	16,9	12,3	8,1
Sea Water	m^3/t	48,5	80,9	6,3
Refractory materials	kg/t	8,0	8,6	7,6
Steel (for cathodes)	kg/t	3,8	5,4	4,0
Energy				
Electricity	MWh/t	14,88	14,91	15,27
Output				
Air emissions				
Particulates	kg/t	0,84	1,95	2,6
SO_2	kg/t	7,40	8,19	14,91
NO_X (as NO_2)	kg/t	0,44	0,65	0,25
Carbon dioxide[11] (CO_2)	kg/t	1.574	1.521	1.733
Fluoride Particulate (as F)	kg/t	0,18	0,44	0,55
Fluoride Gaseous (as F)	kg/t	0,34	0,56	0,57
Total PAH	kg/t	0,013	0,041	0,054
BaP (Benzo-a-Pyrene)	g/t	0,26	1,29	0,74
CF_4	kg/t	0,04	0,09	0,08
C_2F_6	kg/t	0,004	0,014	0,010
Total PFC	kg/t	0,04	0,10	0,09
Water emissions				
Fresh Water	m^3/t	15,5	11,3	7,5
Sea Water	m^3/t	48,5	57,0	5,8
Fluoride (as F)	kg/t	0,35	0,71	0,06
Spent Pot Lining, SPL				
Total SPL output from normal operations	kg/t	19,9	*25,2*	*24,5*
Total SPL for external recycling	kg/t	8,8	10,8	16,8

[11] Estimated from anode / paste consumption (anode: 98% carbon; paste : 90% carbon)

Production of liquid aluminium at the electrolysis step (smelter)	Unit	European average per tonne of Al output		
		EAA		IAI
		2010	2005	2010
SPL deposited	kg/t	10,3	14,4	7,7
SPL stored from normal operation	kg/t	0,7		

Comments on input/output trends:
Specific anode consumption has to be considered taking into account the changes in the mix of PB and VS technology between 2005 and 2010. Fluoride use is down compared to 2005.
Refractory material input is relatively stable compared to 2005, as input of steel for cathodes fell by 29%.
Water input figures depends on local water availability, i.e. is much lower if using water recycling systems, and specific conclusions on water use in smelting are not fully straightforward.

Air emissions: A significant reduction is recorded for PFC emissions (CF4 down 60% and C_2F_6 71% compared to 2005). This brings the total PFC emissions down 94% compared to 1990 (60% lower than in 2005, and 55% lower than the 2010 world average PFC emissions).
SO_2 emissions are 7,4 kg/t and NO_X emissions are 0,44 kg/t, both emissions decrease respectively by 10 and 33% compared to 2005.

Water emissions: Fluoride emissions are 51% down compared to 2005. Figures for fluoride emissions in water are influenced by the smelters with wet scrubbing technologies. If smelters with wet scrubbers are not considered in this aggregation, the average F to water would be 0,14 kg/t. Wet scrubbing is mainly used by Scandinavian smelters located along the sea and using sea water.

3.2.5 Cast house

Direct input and output data related to the production of 1 tonne of sawn ingot at the cast house are reported in Table 3-6. Average European figures of the year 2010 can be compared with figures of 2005 as well with worldwide figures (survey organised by IAI) for the year 2010.

Comments on input trends :
Aluminium input of the cast house is not only composed of liquid aluminium coming from the electrolysis but consists also in solid metals like alloying elements, aluminium scrap and ingot for remelting, mainly for preparing the right alloy composition and for remelting the ends of the extrusion ingot and rolling ingots which are usually sawn at the cast house location. In 2010, the metal input mix is composed of liquid metal (74%), remelt ingot (14%), scrap (10%) and alloy additives (2%).

As already stated for the electrolysis step, water input is highly dependent on the smelter location so that a European average has little significance.

The use of fuels at European level is higher than the global consumption, due to a higher input of solid aluminium, i.e. scrap and remelt ingot. Europe uses more electricity but the consumption stays small compared to the use at the electrolysis

step. The natural gas use increase compared to 2005 is due to the increased fraction of remelt ingot used by the primary cast house.

Table 3-6 Direct inputs and outputs for the production of 1 tonne of sawn aluminium ingot at the cast house.

Cast house	Relative figures per T of cast Aluminium			
	Unit	EAA		IAI
Input		2010	2005	2010
Metal				
Liquid Al (electro)	kg/t	751	784	971
Remelt ingot	kg/t	142	99	50
Al Scraps	kg/t	102	108	23
Alloy additives	kg/t	24	31	20
Total metal input (cast house)	kg/t	1.019	1.022	1.064
Other raw material inputs				
Fresh Water	m^3/t	8,3	3,1	3,5
Sea Water	m^3/t	0,0	1,0	
Chlorine	kg/t	0,05	0,03	0,04
Argon	kg/t	2,11		
Nitrogen	kg/t	0,22		
Energy				
Coal	MJ/t			24
Heavy oil	MJ/t	186	326	113
Diesel oil	MJ/t	46	35	32
Natural gas	MJ/t	1.349	928	761
Other source	MJ/t	4	10	
Total thermal energy	MJ/t	1.585	1.299	930
Electricity	kWh/t	98	126	68
Total energy consumption	MJ/t	1.936	1.753	1.175
Output				
Air emissions				
Particulates	kg/t	0,04	0,04	0,04
SO_2	kg/t	0,15	0,32	0,11
NO_X (as NO_2)	kg/t	0,21	0,17	0,07
HCl (Hydrogen Chloride)	kg/t	0,02	0,04	0,02
Carbon dioxide[12] (CO_2)	kg/t	113	96	67
Water emissions				
Fresh Water	m^3/t	8,7	2,5	3,3
Oil/Grease	kg/t	0,00	0,01	0,04
Suspended Solids	kg/t	0,34	0,02	0,14
By-products for external recycling				
Dross	kg/t	17,8	15,7	16
Filter dust	kg/t	0,9	0,6	1,5
Refractory material	kg/t	0,7	0,4	0,7
Scrap sold	kg/t	2,9	2,2	4,4
Solid waste				
Dross - landfill	kg/t		2,1	5,3
Filter dust - landfill	kg/t	0,5	0,2	0,5
Other landfill wastes	kg/t	1,1	1,3	0,6
Refractory waste - landfill	kg/t	0,6	0,4	0,5
Total solid waste	*kg/t*	*2,3*	*3,9*	*6,9*

[12] Estimated from "fuel combustion" (see. Table 2-2)

Comments on outputs
European averages of air emissions at cast house are not very significant since, in many cases, such figures are included in the electrolysis step and no specific figures are given for the cast house.

Most significant by-product is the dross (mix of aluminium oxide and entrapped aluminium metal). After mechanical hot pressing for extracting most of the liquid metal, the dross is recycled internally or externally in rotary furnaces (see section 7.5).

3.3 Material flow modelling

Average European data of the year 2010, reported in Table 3-3 to Table 3-6, are used to model the primary production route by combining such processes along the production chain, i.e. from bauxite mining up to sawn primary ingot. Such process combination requires some simplifications and some hypotheses regarding the material flow modelling, which are reported below:

- Cast house modelling:

- **Aluminium input**: In practice, aluminium input of the cast house is usually composed not only liquid aluminium from the smelter but also solid materials like alloying elements, aluminium scrap and/or ingot for remelting. Solid material represents about 25% of the input. In the material flow model, only liquid aluminium from the smelter will be considered so that the solid metal input is substituted by liquid primary aluminium. A conservative reduction of 25% of the fuel consumption for European production is considered accordingly in the model in comparison to energy data reported in Table 3-6.

- **Dross recycling**: the model includes the dross recycling within the system while it is not the case for the Table 3-6. It is assumed that aluminium recovered from dross recycling is returned as input to the cast house.

- **Metal losses at the cast house**: the model considers the metal losses due to the oxidation of the aluminium melt and the aluminium metal which is not recovered from the dross. The model calculates the metal losses to 1 kg/tonne (i.e. 0.1% of metal losses).

Based on above assumption, 1.001 kg of liquid aluminium from the electrolysis are then needed to produce 1 tonne of sawn extrusion or rolling ingot.

- Anode and paste production modelling

While carbon paste is entirely consumed during the electrolysis process using the Söderberg technology, carbon anode used in smelters using pre-bake technology is not entirely consumed. When about 80% of the anode is consumed, the so-called anode butt is then removed from the cell (and replaced by a new one). This anode butt is then returned to the anode production facility where it is crushed and recycled into the anode production process. In the modelling process, slight adaptations of the raw material input were needed in order to make it consistent with the recycled input from anode butt which are coming back from the electrolysis process.

- Materials flow modelling, European production

Considering above modelling assumptions, the average consumptions of main raw materials for **producing 1 tonne of ingot in Europe** have been calculated and are reported in Fig. 3.4 and Table 3-7.

Table 3-7 Main raw materials for the production of 1 tonne of primary ingot, Europe

Main raw materials (kg)	Process step	Year		
		2010	2005	2002
Bauxite (input alumina)	Alumina	**4.326**	**4.259**	4.131
Caustic Soda (100%)	Alumina	**102**	**130**	113
Lime	Alumina	**81**	**83**	90
Alumina	Electrolysis	**1.922**	**1.936**	1.924
Anode/paste (net)	Electrolysis	**440**	**431**	447
Liquid aluminium	Casting	**1.001**	**1.006**	1.000

For the primary aluminium production in Europe, 1.922 tonnes of alumina and 440 kg anodes are needed to produce 1 tonne of cast primary aluminium. 4.326 kg of bauxite are used according to the new model vs. 4.259 kg according to the 2005 model.

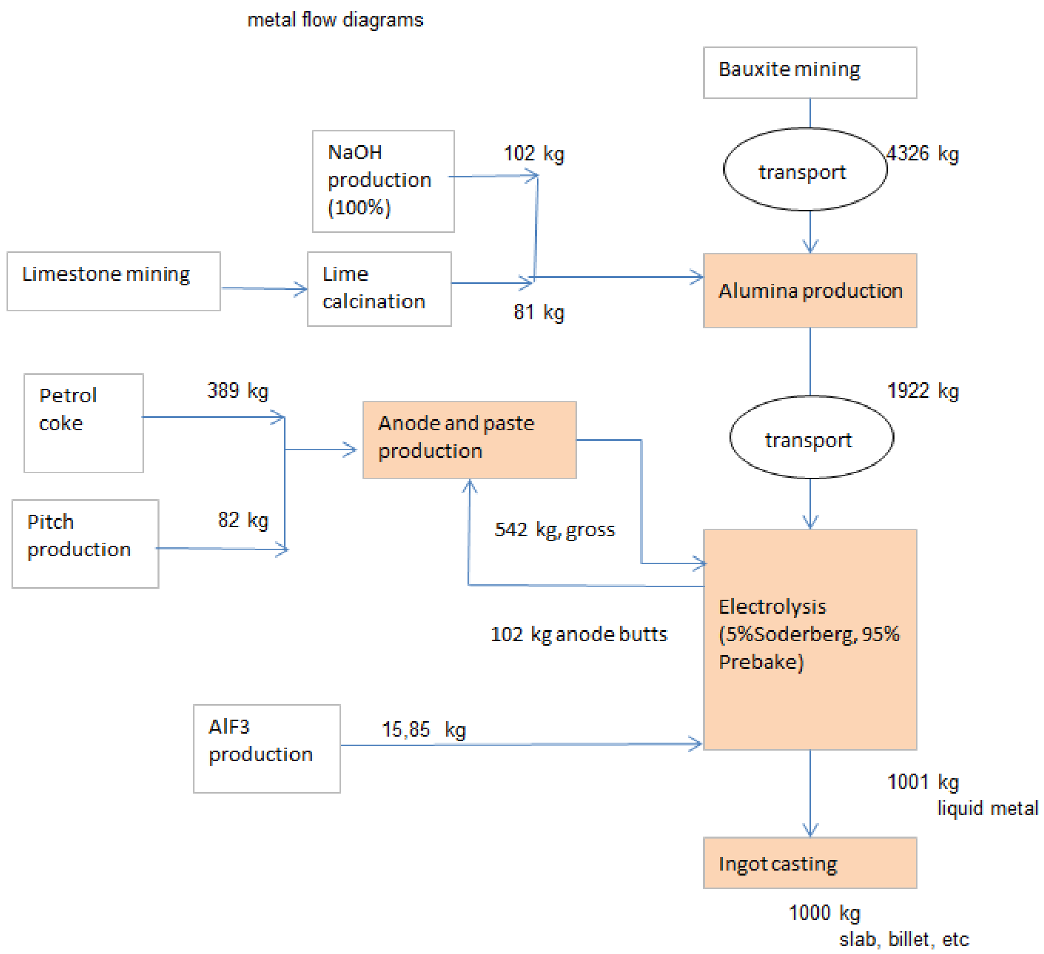

Fig. 3.4 Main raw material inputs for primary aluminium production in Europe

3.4 EAA electricity models for aluminium electrolysis (smelters)

Since most of the energy used for producing primary aluminium is electricity at the electrolysis step, it is crucial to model precisely this electricity production. As currently about 45% of the primary aluminium used in Europe is imported, it is also necessary to take into account specific data relative to the electricity which is used for the production of primary aluminium imported into Europe. The 3 next sub-sections explain how European production and imported primary aluminium are considered.

The following models have been developed:

- Electricity used by European smelters using the pre-bake technology
- Electricity used by European smelters using Soderberg technology
- Electricity used by smelters exporting to Europe

As it has been done in the previous model, the electricity consumption data reported under Table 3-6 have been increased by 2% into the model in order to consider the losses related to the electricity transport.

3.4.1 Overview of European smelters localisation

The map below gives an overview of the localisation of the European smelters (2010 data[13]) and their relative capacity of production.

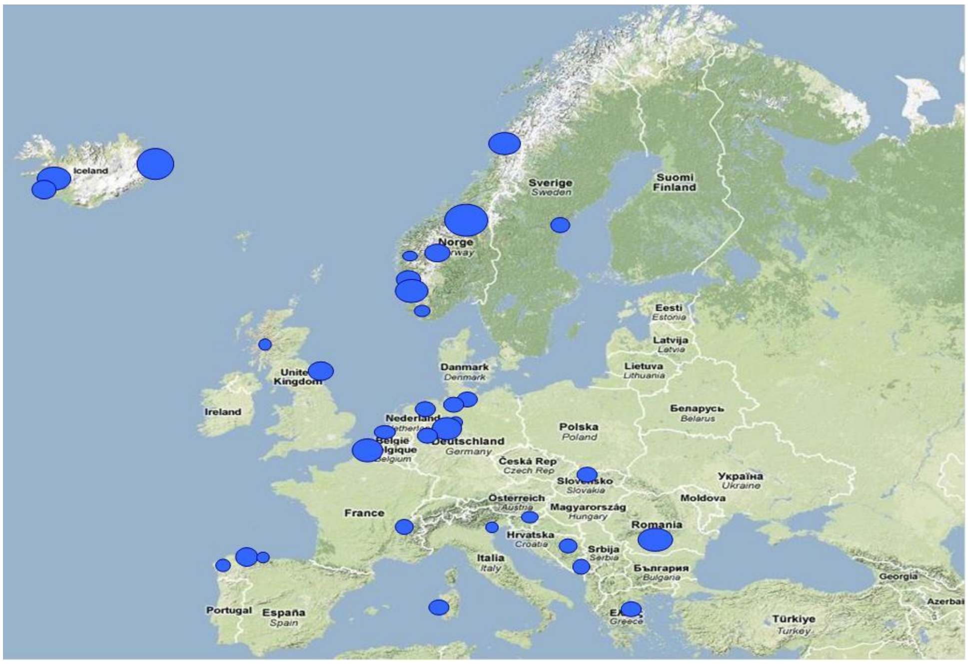

Fig. 3.5 European map of smelters by capacity of production – 2010 data

In 2010, Iceland and Norway represented almost 40 % of the installed capacity (nameplate capacity) and about 43% of the European production of primary aluminium.

[13] This map is only valid for 2010 and doesn't represent the current situation

3.4.2 Electricity used by European primary aluminium smelters – pre-bake technology

The electricity model uses the electricity consumption reported by the various European smelters using the pre-bake technology. This consumption is distributed among various energy sources as stipulated in their electricity contract. The model is developed in several steps which are described below:

1) Consolidation at European level for each energy source.
The electricity consumption reported by the smelters is aggregated by energy sources at European level. This consolidation gives, for the year 2010, a table listing the electricity consumption in TWh or GWh for each energy source.

2) Calculating contribution of the various countries for each energy source
The relative share of each country is then calculated, for each energy source. This normalisation allows identifying the main contributors for each electricity source.

3) Modelling the electricity production for each energy source
For each energy source, e.g. hydropower or coal, a simplified model for the production of electricity is calculated based on the main contributing countries. This model uses the various LCI datasets for electricity production, available in the GaBi software, which are country-specific and specific to the energy source. As reported in Table 3-8, the production of 1 kWh of hard coal is based on LCI data from Germany and UK.

4) Building the European model
Each of these LCI datasets has been weighted according to their respective contribution in the European electricity model. As example, the LCI dataset for electricity from coal contributes to 17% to the total. The combination of these LCI datasets result in LCI datasets related to the production of 1kWh of electricity used in Europe for the production of primary aluminium by pre-bake smelters.

Table 3-8 reports the European consolidation of the energy sources for the electricity production which is used by the European smelters using pre-baked technology as well as the countries used to build the European model.

Table 3-8 European electricity Model – Year 2010

	European electricity model (Year 2010)		
Share of Energy sources	**%**	**Mains contributing countries**	**LCI data used in the electricity model**
Hydro	**54%**	Norway and Iceland	Norway
Coal	**17%**	Germany, UK and Greece	Germany and UK
Oil	**1%**	Germany	Germany
Gas	**10%**	NL, Italy and Spain	NL, Italy and Spain
Nuclear	**18%**	France, Slovakia and Germany	France and Germany
Other (biomass)	**0%**	-	-
Total	**100%**	**-**	**-**

The corresponding indicators based on the model presented above are reported in Table 3-9.

Table 3-9 Environmental indicators for the production of 1 kWh electricity, European model

Environmental indicators per kWh electricity, European model	Values
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	1,07E-07
Acidification Potential (AP) [kg SO_2-Equiv.]	5,37E-04
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	5,11E-05
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	2,39E-01
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	2,91E-08
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	3,95E-05
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,72E+00
Primary energy from renewable raw materials (net cal. value) [MJ]	2,31E+00
Primary energy from non-renewable resources (net cal. value) [MJ]	4,41E+00

3.4.3 Electricity used by European primary aluminium smelters – Soderberg technology

A similar model has been developed for the European smelters using the Soderberg technology. Considering the limited number and contribution of these smelters, this electricity model is not reproduced in this report.

3.4.4 Electricity used for the production of imported aluminium

In 2010, 44% of the primary aluminium used in Europe (i.e. EU27 & EFTA countries) came from imports (Source: customs statistics - Eurostat).
As reported in Table 3-10, most of these imports come from Russia (32%), Mozambique (22%) and Canada (11%).

Table 3-10 Geographical distribution of the primary aluminium main imports into Europe – 2010 (source Eurostat for EU27 and national customs data for EFTA countries)

Share of imports into EAA region (=EU27+EFTA) 2010		
Region	**%**	**Countries (%)**
Rest of Europe	39%	Russia (83%), Bosnia Herzegovina (5%), Turkey (5%)
North America	11%	Canada
South America	9%	Brazil (86%)
Middle East & Central and West Asia	11%	UAE (59%), Bahrain 31%, Tajikistan 7%
Africa	28%	Mozambique 79%, S Africa (8%), Egypt (7%), Cameroon (5%)
Oceania	1%	-
South Asia	1%	-
Total	**100%**	**-**

Table 3-11 is used to model the electricity production for the primary aluminium imported into Europe. The various steps and hypotheses of this modelling methodology are the following:

- Only countries listed in Table 3-10 have been considered for the model. These countries represent more than 90% of the aluminium imported into Europe.
- Use of the national electricity grid mix for the countries listed in Table 3-10, except for Russia, Ukraine, Canada and the Middle East for

which specific data provided by the aluminium producers have been used. Data from the International Energy Agency have been used to determine the national grids for electricity production [12].

- Weighting and consolidation of the country grid mixes have been done at regional and global levels. Consolidated figures are reported in Table 3-11.
- For each of these regions, modelling of the electricity production is based on a simplified electricity grid mix using power plant data which are representative for major sources of imports, e.g. electricity from nuclear sources and biomass for Brazil, hydropower, hard coal and natural gas for Russia.
- Consolidation of the electricity production data at global level. The consolidation of the energy sources for the electricity production which is used by imported aluminium is reported in Table 3-11.

Table 3-11 Energy sources for the electricity used for the production of imported primary aluminium

Area	Import share[14]	Energy source[15]					
		Hydropower	Coal	Oil	Natural gas	Biomass	Nuclear
Rest of Europe	40,1%	34,7%	5,4%	0,0%	0,0%	0,0%	0,1%
Africa	28,1%	24,1%	2,0%	0,3%	1,6%	0,0%	0,1%
North America	11,1%	11,1%	0,0%	0,0%	0,0%	0,0%	0,0%
Latin America	9,3%	7,8%	0,2%	0,3%	0,5%	0,4%	0,2%
Middle East & Central and West Asia	11,3%	0,8%	0,0%	0,1%	10,4%	0,0%	0,0%
Total	**100,0%**	**78,5%**	**7,6%**	**0,8%**	**12,4%**	**0,4%**	**0,4%**
LCI datasets used as proxy	**-**	**Russia**	**Russia**	**South Africa**	**Russia[16]**	**Brazil**	**Brazil**

The main environmental indicators corresponding to the production of 1 kWh of electricity used by the smelters importing aluminium to Europe is reported in Table 3-12.

Table 3-12 Environmental indicators per kWh of electricity produced, Import Model

Environmental indicators per kWh electricity, Imports model	Values
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	1,71E-07
Acidification Potential (AP) [kg SO_2-Equiv.]	1,66E-03
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	9,55E-05
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	2,03E-01
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	3,29E-10
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	9,15E-05
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,05E+00
Primary energy from renewable raw materials (net cal. value) [MJ]	3,43E+00
Primary energy from non-renewable resources (net cal. value) [MJ]	2,61E+00

[14] South Asia and Oceania were neglected (≤ 2% of the imports of primary aluminium : see Table 3-10)

[15] For each energy source the main area used as proxy is highlighted (ex : Rest of Europe i.e Russia for hydropower and coal)

[16] Russia have been used by default for modeling some Middle East Countries (UAE, Bahrain, etc.) : no LCI datasets are available for Middle East countries

3.5 European LCI dataset and environmental indicators for primary aluminium

The GaBi software was used to calculate the European LCI dataset for primary aluminium in accordance with the modelling hypotheses reported in sections 3.3 and 3.4 and summarised in Fig. 3.6.

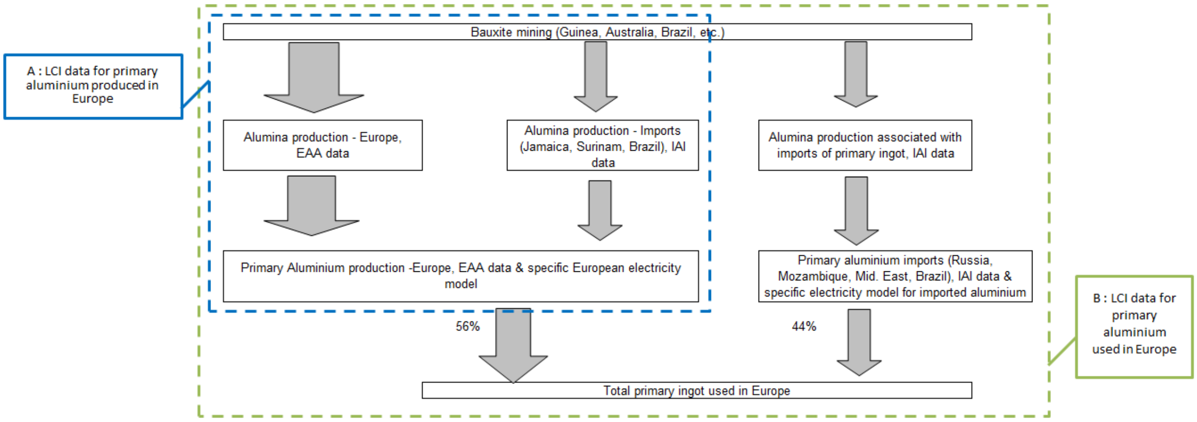

Fig. 3.6 Modelling principle for generating the European LCI datasets for primary aluminium

2 types of LCI datasets have been generated:

A- The "Produced in Europe" primary aluminium LCI dataset

B- The "Used in Europe" primary aluminium LCI dataset

For the aluminium ingots used in Europe, a combined model for the primary production in Europe (PFPB and VSS) and imports has been used. For each of these models, specific input and output data, together with specific modelling electricity sources have been developed as previously described. Fig. 3.7 shows how the primary aluminium data have been modelled in the GaBi software.

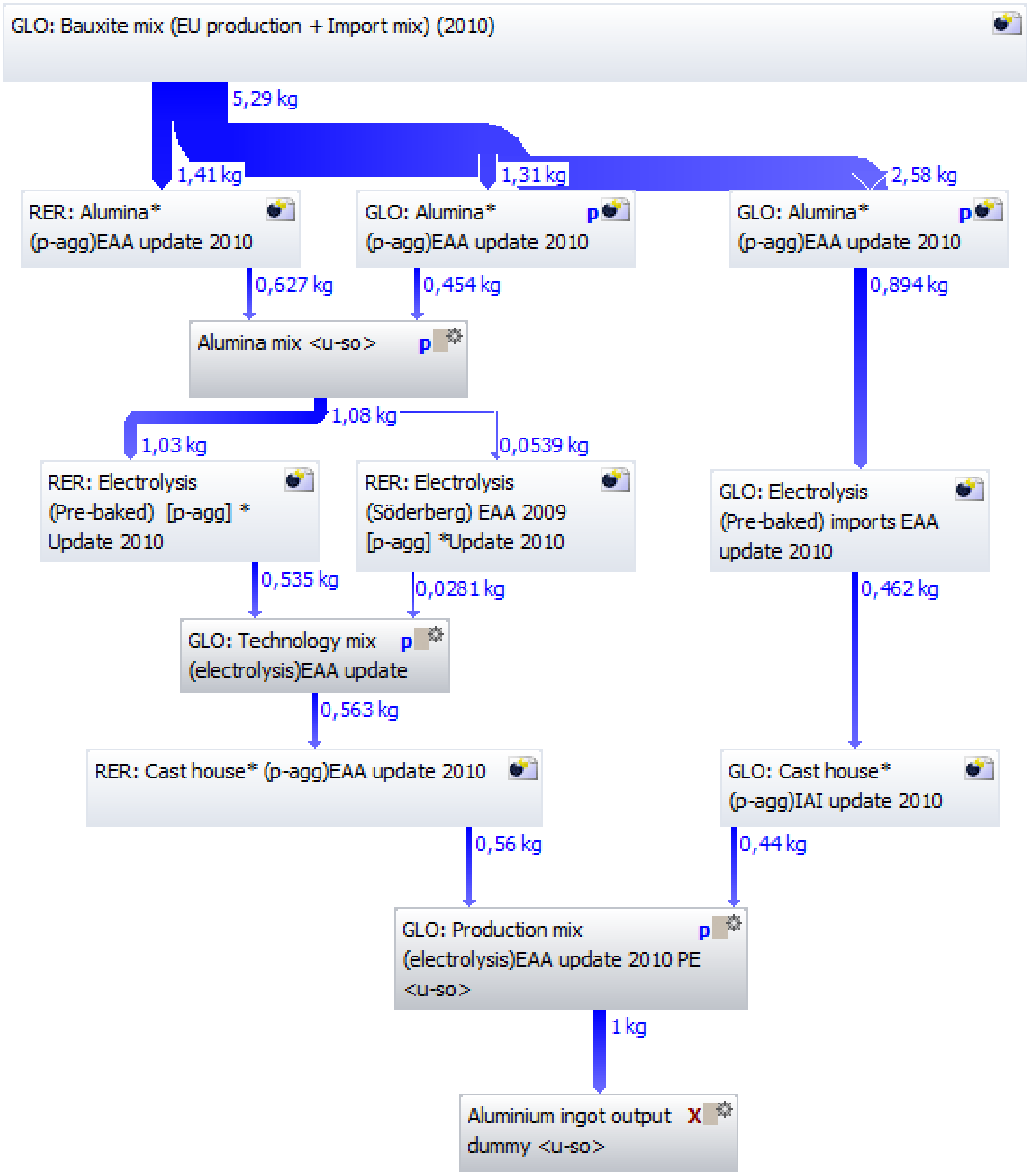

Fig. 3.7 Modelling using Gabi software (RER = Europe; GLO = Global)

The full LCI datasets are available on request at lci@eaa.be while the corresponding set of Environmental indicators are reported in Table 3-13 for the "used in Europe" LCI dataset and in Table 3-14 for the 'produced in Europe" LCI dataset.

Environmental indicators

Associated environmental indicators for the predefined impact categories are reported in Table 3-13 and Table 3-14. **These sets of environmental indicators are purely informative and should not be used for evaluating the environmental impact of the primary aluminium in Europe or for comparative purposes between various materials. As highlighted in ISO 14040 and 14044, only the environmental aspects of a product system or a service in a life cycle perspective, i.e. from cradle to grave or from cradle to recycling, is scientifically sound.**

Table 3-13 Main environmental indicators (per tonne of ingot) for the "used in Europe" LCI primary aluminium dataset.

EAA indicators (per tonne of primary ingot)	Total 2010	Process and auxiliary	Thermal energy	Electricity	Transport
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**4,87E-03**	54%	1%	45%	0%
Acidification Potential (AP) [kg SO2-Equiv.]	**4,73E+01**	35%	16%	36%	12%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**2,48E+00**	14%	16%	47%	24%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**8,75E+03**	33%	23%	42%	2%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**2,57E-04**	1%	1%	98%	0%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**2,75E+00**	31%	18%	38%	13%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**1,57E+05**	14%	18%	66%	2%
Primary energy from renewable raw materials (net cal. value) [MJ]	**4,57E+04**	1%	0%	99%	0%
Primary energy from non-renewable resources (net cal. value) [MJ]	**1,11E+05**	19%	25%	53%	2%

Table 3-14 Main environmental indicators (per tonne of ingot) for the "produced in Europe" LCI primary aluminium dataset

EAA indicators (per tonne of primary ingot)	Total 2010	Process and auxiliary	Thermal energy	Electricity	Transport
CML2001 - Nov. 2010, Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**4,11E-03**	57%	1%	41%	0%
CML2001 - Nov. 2010, Acidification Potential (AP) [kg SO_2-Equiv.]	**3,28E+01**	37%	23%	27%	13%
CML2001 - Nov. 2010, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**1,91E+00**	17%	19%	42%	22%
CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**8,48E+03**	31%	23%	45%	2%
CML2001 - Nov. 2010, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**4,43E-04**	0%	0%	99%	0%
CML2001 - Nov. 2010, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**2,06E+00**	32%	24%	31%	12%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**1,56E+05**	13%	17%	68%	1%
Primary energy from renewable raw materials (net cal. value) [MJ]	**3,66E+04**	1%	0%	99%	0%
Primary energy from non-renewable resources (net cal. value) [MJ]	**1,20E+05**	17%	23%	59%	2%

From Table 3-13 and Table 3-14, it's appearing that the environmental impacts of primary aluminium produced in Europe are lower that the environmental impacts of aluminium used in Europe.

For instance, 1 tonne of primary aluminium ingot produced in Europe emits -3% less kg.CO_2eq (i.e. 0,27 kg.CO_2.eq) than 1 tonne of primary aluminium ingot used (European production and import) in Europe.

4. Aluminium sheet production

4.1 Process steps description

With a thickness comprised between 0,2 and 6 mm, sheet is the most common aluminium rolled product. The starting stock for most rolled products is the DC (Direct Chill semi-continuous cast) ingot. The size of the ingot depends on the size of the DC unit available, the hot rolling mill capacity, volume required for a particular end use and to some extent the alloys being cast. Ingots up to over 32 tons in weight, 500 - 600 mm thick, 2.000 mm wide and 9.000 mm long are produced. Before rolling operations, the rolling ingot is machined to cut the ends (sawing) and to even the surfaces (scalping).

According to alloy grade, a thermal treatment of homogenisation may be applied (see Fig. 4.1). The DC ingot is then pre-heated to around 500°C prior to successive passes through a hot rolling mill where it is reduced in thickness to about 4 - 6 mm. The strip from the hot rolling mill is coiled and stored before cold rolling which is usually done in the same site. Cold mills, in a wide range of types and sizes are available; some are single stand, others 3 stands and some 5 stands. Final thickness of the cold rolled strip or sheet is usually comprised between 0,2 and 2 mm.

Finishing operations include:
- Sizing, e.g. trimming, slitting and blanking
- Annealing according to alloy grades
- Final surface preparation (excluding coating and/or painting)

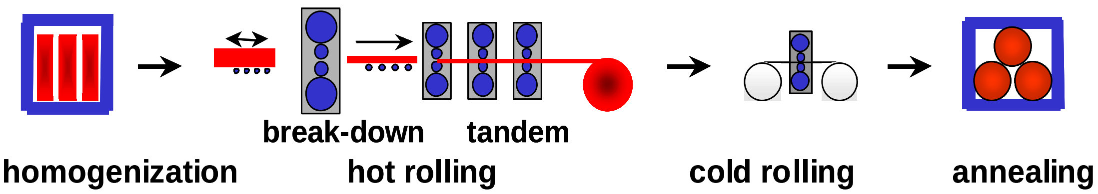

Fig. 4.1 Main process steps in aluminium sheet production

The sheet production from sawn ingot up to finished sheet generates about 380 kg of scrap by tonne of sheet. These scraps are recycled into new ingots through remelting which is usually performed on-site in integrated cast houses. This internal recycling of process scrap is part of the LCI dataset for the sheet production as illustrated in Fig. 4.2.

4.2 Data collection, averaging and modelling

The LCI dataset related to sheet production were developed through an EAA survey covering European aluminium rolling mills as well as their integrated cast house in which process scrap are remelted into rolling ingots (slabs). Data from 20 European rolling mills have been collected and included in the European consolidation.

The EAA survey coverage for the year 2010 reaches 76% for the cold rolled sheet production in Europe. Detailed figures are reported in Table 4-1.

Table 4-1 EAA survey coverage for European rolling mills

	Total production in Europe (Mt)	Total production reported (Mt)	Survey coverage (%)
Cast-houses (slabs)	3,1	2,1	**68**
Rolling mills	4,2	3,2 (1)	**76**

(1) Total strip and sheet output, with no further surface treatment, plate excluded;

Regarding alloys, the generic dataset corresponds to 24% hard alloys, 48% intermediate alloys and 27 % soft alloys.

About 2% of the reported output is plate (which has not been considered in the survey), 51% is sheet between 0,5 and 6 mm, sheet thinner than 0,5 mm represents 46%.
Regarding the end-use applications, 14% of the reported output is destined to transport, 8% to building and 40% to packaging applications. The reported data shows slight differences with the actual split of the total European end-use markets for rolled products. This is due to more reporting in our LCI survey coming from plants active in rigid packaging (can stock).

The LCI datasets for sheet production includes the sheet production chain and the recycling of process scrap produced at the various process steps of the sheet production as well as the dross recycling process. The flow diagram of this LCI dataset for sheet production is reported in Fig. 4.2.

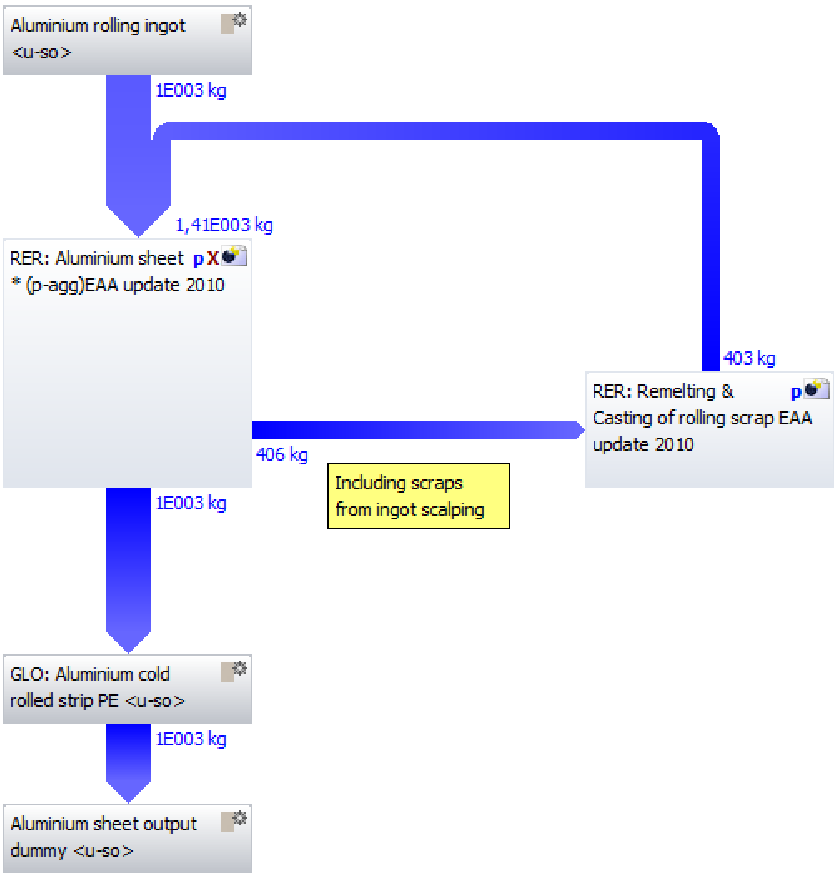

Fig. 4.2 Flow diagram for aluminium sheet production (RER: EU27 + EFTA countries)

Direct input and output data related to the sheet production chain and the remelting of process scrap are reported in Table 4-2. These inputs and outputs are normalised to 1.000 kg of finished aluminium sheet.

Table 4-2 Direct inputs and outputs for the sheet production and the corresponding scrap remelting – Figures normalised to 1.000 kg of finished sheet.

Aluminium rolling processes - Figures for 1 tonne of sheet output		**Sheet production**	**Scrap Remelting**	**Total**	**Total**
		Year			
Inputs	**Unit**	**2010**			**2005**
Aluminium					
Unscalped rolling ingots	kg/t	1.004		**1.004**	**1.004**
Clean scrap	*kg/t*		*406*		
Energy					
Heavy Oil	MJ/t	0	31	**31**	**51**
Diesel and light fuel Oil	MJ/t	1	27	**28**	**204**
Natural Gas	MJ/t	1.868	1.434	**3.302**	**3.148**
Propane	MJ/t	20	61	**81**	**48**
Total thermal energy	*MJ/t*	*1.889*	*1.554*	**3.443**	***3.450***
Electricity	kWh/t	518	50	**569**	**726**
Total energy (ther. + elec)	*MJ/t*	*3.755*	*1.736*	***5.490***	***6.056***
Ancillary products					
Fluxing salts	kg/t		9,0	**9,0**	**1,7**
Argon	kg/t		0,7	**0,7**	**0,9**
Chlorine	kg/t		0,1	**0,1**	**0,1**
Nitrogen	kg/t	8,7	0,2	**8,9**	
Absorbant for exhaust gas treatment	kg/t		0,3	**0,3**	
Filter tones	kg/t				**0,7**
Emulsion, hot rolling (oil content)	kg/t	1,4		**1,4**	**1,5**
Oil, cold rolling	kg/t	2,0		**2,0**	**3,8**
Filter earths for cold rolling	kg/t	0,8		**0,8**	
Lubricants and hydraulic oils	kg/t				**1,0**
Paper & cardboard for packaging	kg/t	0,6		**0,6**	**1,8**
Wood for packaging	kg/t	11,2		**11,2**	**8,2**
Steel for packaging	kg/t	0,3		**0,3**	**0,5**
Plastic for packaging	kg/t	0,4		**0,4**	**0,5**
Water					
Process water	m^3/t	0,6	0,4	**1,0**	
Cooling water	m^3/t	7,6	2,0	**9,6**	
Total water supply	m^3/t	8,2	2,4	**10,6**	**10,2**
Outputs					
Aluminium					
Finished cold rolled sheet	kg/t	1.000		**1.000**	**1.000**
Emissions to air					
Chlorine (as Cl_2)	kg/t		5,36E-04	**5,36E-04**	
Other inorganic chlorinated compounds (expressed as HCl)	kg/t		6,35E-03	**6,35E-03**	
Carbon dioxide[17] (CO_2)	kg/t	128	108	**236**	**240**
Dust/particulates, total	kg/t	0,02	0,02	**0,04**	**0,03**

[17] Estimated from "fuel combustion" (see. Table 2-2)

Aluminium rolling processes - Figures for 1 tonne of sheet output		Sheet production	Scrap Remelting	Total	Total
		Year			
		2010			2005
NO_X, as nitrogen dioxide	kg/t	0,28	0,14	**0,42**	**0,35**
SO_2	kg/t	0,01	0,03	**0,03**	**0,04**
Total gaseous organic carbon (TOC)	kg/t	0,32	0,02	**0,34**	
from which is NMHC (Non-Methane HydroCarbons)	kg/t	0,00	0,00	**0,00**	
Emissions to water					
Water output	m^3/t	7,6	2,2	**9,8**	**5,8**
COD (direct discharge)	kg/t		1,43E-02	**1,43E-02**	**2,87E-01**
Waste (excluding dross, aluminium scrap & demolition waste)					
Hazardous waste for land-filling	kg/t	1,6	0,3	**2,0**	**2,2**
Hazardous waste for incineration	kg/t	0,7	0,0	**0,8**	**2,2**
Hazardous waste for further processing	kg/t	6,8	2,4	**9,2**	**7,7**
Total hazardous waste	kg/t	*9,2*	*2,7*	**11,9**	***12,2***
Non-haz. waste for land-filling	kg/t	0,9	0,0	**1,0**	**1,9**
Non-haz. waste for incineration	kg/t	0,2	0,0	**0,3**	**0,7**
Non-haz. waste for further processing	kg/t	3,5	2,3	**5,8**	**5,3**
Total non-hazardous waste	kg/t	*4,7*	*2,4*	**7,0**	***7,9***
By-products					
Metal scrap for recycling, excluding aluminium	kg/t	1,6	0,3	**1,9**	**1,5**

4.3 Environmental indicators for sheet production

The GaBi software was used to calculate the European LCI dataset for sheet production in accordance with the flow diagram described in Fig. 4.2. This LCI dataset is available on request at lci@eaa.be and associated environmental indicators are presented in Table 4-3.

Table 4-3 Environmental indicators for the sheet production

EAA indicators (per tonne of aluminium sheet)	Total 2010	Direct, auxiliary & thermal	Electricity
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**1,23E-04**	81%	19%
Acidification Potential (AP) [kg SO_2-Equiv.]	**1,78E+00**	31%	69%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**1,56E-01**	58%	42%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**5,68E+02**	49%	51%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**1,95E-05**	3%	97%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**1,86E-01**	60%	40%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**1,07E+04**	46%	54%
Primary energy from renewable raw materials (net cal. value) [MJ]	**8,80E+02**	16%	84%
Primary energy from non-renewable resources (net cal. value) [MJ]	**9,80E+03**	48%	52%

5. Aluminium foil production

5.1 Process steps description

Aluminium foil is used in varying gauges and in a number of alloys for a variety of applications. It is available in thickness from 5 microns to 200 microns (i.e. 0,005 to 0,2 mm) and can be supplied in a range of finishes.

Similarly to the sheet production, the classical production route uses an aluminium rolling ingot (slab) as starting material for the production of rolled aluminium foil, which is first rolled into foil stock, i.e. the specific input for foil fabrication.

There are two routes of producing aluminium foil. The classical production route is carried out by **cold rolling from foil stock** with a thickness of 0,5 - 1,0 mm as input. For thinner foil thickness, the final rolling steps are carried out by “double-rolling”, i.e. rolling together two foil layers at the same time**.** During cold rolling a mineral oil fraction is used for cooling and lubrication.

Aluminium foil can also be produced directly through the **strip casting** process consisting in casting the molten aluminium directly into a strip which is cold rolled into a foil. This production route is increasingly gaining ground in Europe as it accounts for more than half of the production in 2010.

In the LCI dataset, a ratio of 43% classical route / 57% strip casting was used.

The foil production from as-cast ingot up to finished sheet generates about 390 kg of scrap by tonne of foil. These scraps are recycled into new ingot through remelting which is usually performed on-site in integrated cast houses. This internal recycling of process scrap is part of the LCI dataset for the foil production as illustrated in Fig. 5.1 in the next section.

5.2 Data consolidation, averaging and modelling

EAFA (European Aluminium Foil Association, www.alufoil.org) and EAA worked together for developing the foil dataset.

The flow diagram for foil production is reported in Fig. 5.1. As described in section 5.1, the LCI process modelling is based on 57% of the production done through strip casting technology and 43% through classical production route.

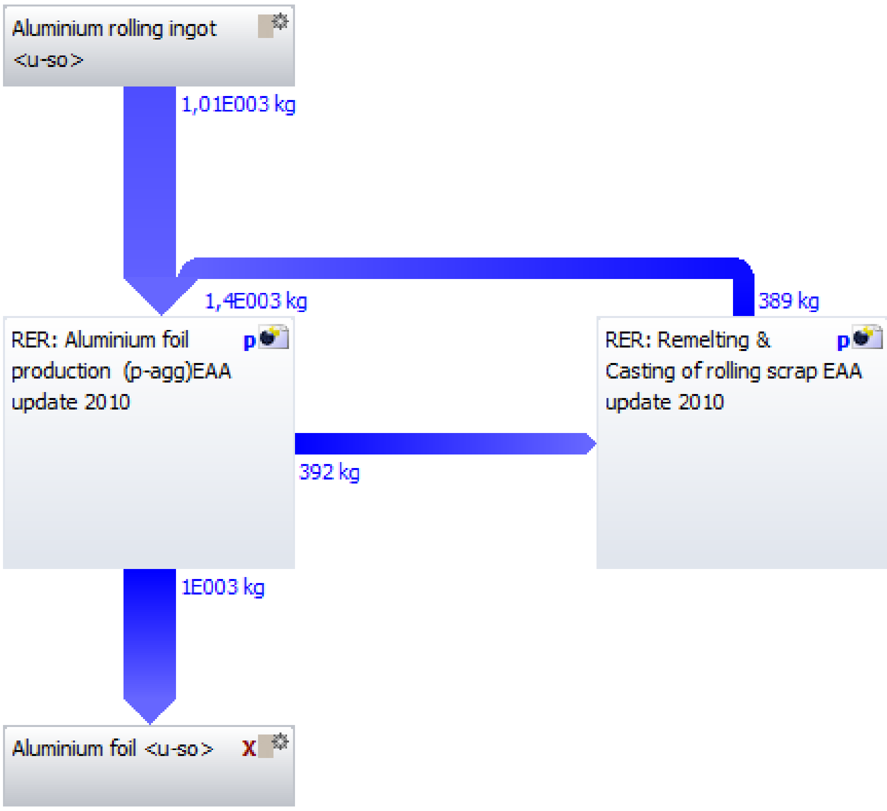

Fig. 5.1 Flow diagram for aluminium foil (including foil rolling, annealing and packaging) production (RER: EU27 + EFTA countries)

In Table 5-1, the specific input and output data related to 1 tonne of foil production are reported. The first column refers to the foil production process, i.e. from ingot up to packaging before delivery to the foil converter while the second column refers to the remelting of 390 kg of process scrap.

Table 5-1 Direct inputs and outputs for the foil production – Figures normalised to 1000 kg of finished foil.

Aluminium foil production - Figures for 1 tonne of finished foil		**Foil production**	**Scrap remelting**	**Total**	**Total**
		Year			
		2010			**2005**
	Unit				
Inputs					
Main aluminium inputs					
Ingots	kg/t	1.010		**1.010**	1.007
Clean scrap	*kg/t*		*390*		
Total	**kg/t**	**1.010**		**1.010**	1.007
Energy					
Heavy oil	MJ/t	1.778		**1.778**	186
Natural Gas	*MJ/t*	1.551	*1.378*	**2.929**	*6.314*
Diesel	MJ/t	0	26	**26**	26

Aluminium foil production - Figures for 1 tonne of finished foil		Foil production	Scrap remelting	Total	Total
		Year			
		2010			2005
Other energy source (LPG)	MJ/t	0		**0**	79
Electricity	*kWh/t*	939	*48*	**987**	*1.593*
Electricity	MJ/t	3.380	174	**3.555**	5.735
Total	**MJ/t**	**6.710**	**1.578**	**8.288**	12.339
Ancillary products					
Fluxing salts	kg/t	0,2	8,7	**8,9**	2,9
Argon	kg/t	0,0	0,7	**0,7**	1,4
Chlorine	kg/t	0,0	0,1	**0,1**	0,0
Nitrogen	kg/t	0,0	0,2	**0,2**	
Filter material	kg/t	4,7		**4,7**	1,5
Rolling and lubricating oil	kg/t	6,4		**6,4**	24,8
Paper & cardboard for packaging	kg/t	1,3		**1,3**	1,9
Wood for packaging and wooden pallets	kg/t	14,7		**14,7**	28,5
Steel for packaging	kg/t	3,2		**3,2**	3,1
Plastic for packaging	kg/t	0,5		**0,5**	0,6
Water					
Water input	m^3/t	12,1	2,3	**14,4**	16,1
Output					
Main products					
Foil stock	kg/t	1.000		**1.000**	1.000
Emission to air					
Chlorine (as Cl_2)	kg/t		5,15E-04	**5,15E-04**	
Other inorganic chlorinated compounds (expressed as HCl)	kg/t		6,10E-03	**6,10E-03**	
Carbon dioxide[18] (CO_2)	kg/t	265	96	**361**	453
Carbon monoxide (CO)	kg/t	0,66		**0,66**	0,47
Dust/particulates, total	kg/t	0,89	0,02	**0,91**	0,33
NO_X, as nitrogen dioxide	kg/t	0,84	0,14	**0,97**	1,07
SO_2	kg/t	0,23	0,03	**0,26**	0,32
VOC	kg/t	1,67		**1,67**	2,22
Waste (excluding dross, aluminium scrap & demolition waste)					
Hazardous waste for land-filling	kg/t	0,7	0,3	**1,0**	2,9
Hazardous waste for incineration	kg/t	7,2	0,0	**7,2**	2,8
Hazardous waste for further processing	kg/t	4,6	2,3	**6,9**	24,8
Total hazardous waste	**kg/t**	**12,5**	**2,6**	**15,1**	30,6
Non-haz. waste for land-filling	kg/t	0,8	0,0	**0,8**	5,0
Non-haz. waste for incineration	kg/t	3,8	0,0	**3,8**	0,9
Non-haz. waste for further processing	kg/t	2,0	2,2	**4,2**	10,5

[18] Estimated from "fuel combustion" (see. Table 2-2)

Aluminium foil production - Figures for 1 tonne of finished foil		Foil production	Scrap remelting	Total	Total
		Year			
		2010			2005
Total non-hazardous waste	**kg/t**	**6,6**	**2,3**	**8,9**	16,3
Water	kg				
Water output*	kg	12,4	2,1	**14,5**	9,4
By-products					
Metal scrap for recycling, excluding aluminium	kg/t	7,9	0,3	**8,2**	4,0

*Water figures are highly variable from site to site and consistency between input and output figures is limited.

5.3 Environmental indicators for aluminium foil production

The GaBi software was used to calculate the European LCI dataset for foil production in accordance with the model described in Fig. 5.1. This LCI dataset is available on request at lci@eaa.be and associated environmental indicators are listed in Table 5-2.

Table 5-2 Environmental indicators for the production of 1 tonne of aluminium foil from an ingot

Environmental indicators (per tonne of aluminium foil)	Total 2010	Process, fuels and auxiliaries	Electricity
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**1,58E-04**	67%	33%
Acidification Potential (AP) [kg SO_2-Equiv.]	**4,08E+00**	40%	60%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**3,62E-01**	63%	37%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**1,10E+03**	44%	56%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**3,70E-05**	3%	97%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**1,05E+00**	85%	15%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**2,11E+04**	43%	57%
Primary energy from renewable raw materials (net cal. value) [MJ]	**1,79E+03**	12%	88%
Primary energy from non-renewable resources (net cal. value) [MJ]	**1,93E+04**	46%	54%

6. Aluminium extrusion

6.1 Process steps description

Aluminium profiles are produced by the extrusion process. The term extrusion is usually applied to both the process, and the product obtained, when a hot cylindrical billet of aluminium is pushed through a shaped die.

The starting material for aluminium extrusion production is an extrusion ingot (usually called log or billet), i.e. a several meters long cylinder with a diameter typically comprised between 20 and 50 cm. These billets are usually produced by DC casting technology. The ends (tops and tails) of the billets are usually sawed at the cast house for direct remelting. Depending on the extrusion presses, the billet can be cut in smaller cylinder pieces before the extrusion process. Just before extrusion, the billet is pre-heated usually around 450 °C - 500 °C. At these temperatures the flow stress of the aluminium alloys is very low and by applying pressure by means of a ram to one end of the billet the metal flows through the steel die, located at the other end of the container to produce a profile, the cross sectional shape of which is defined by the shape of the die. The resulting profile (see Fig. 6.1) can be used in long lengths or cut into short parts for use in structures, vehicles or components.

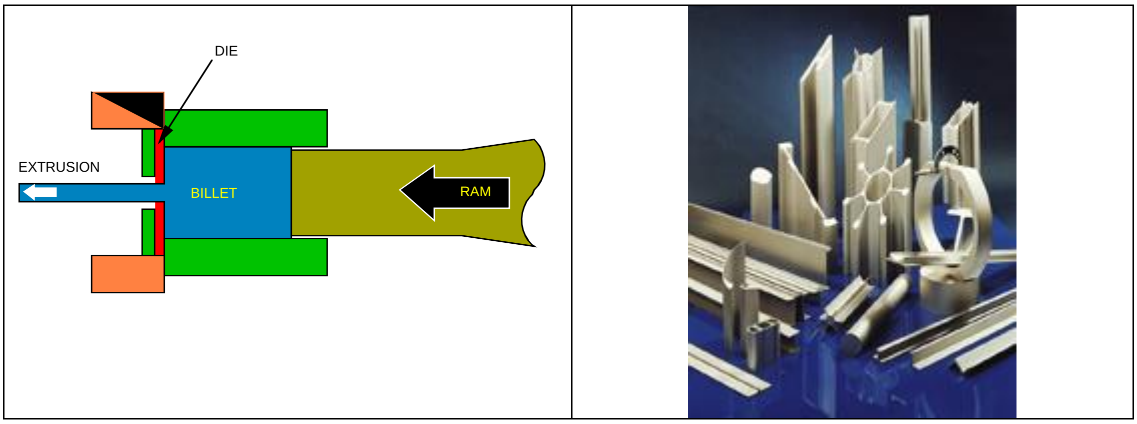

Fig. 6.1 Extrusion process principle and some aluminium extruded products

The extrusion from cast billet up to finished profile generates about 320 kg of scrap by tonne of extrusion. These scrap are recycled into new ingot through remelting which is performed either on-site in integrated cast houses or externally. The recycling of process scrap is part of the LCI dataset for the extrusion production as illustrated in Fig. 6.2.

6.2 Data consolidation, averaging and modelling

69 plants/sites have been integrated in the consolidation process representing 894kt of extrusion output, i.e. about 32% of the European production as reported in Table 6-1.

Table 6-1 Survey coverage for aluminium extrusion

	Total production, Europe (kt)	Total production reported (kt)	Survey coverage (%)
Extrusion	2.827	893,5	**32**

The questionnaire included general questions about the type of alloys, the type of semi-products and their applications. Consolidated percentages representative for the European extrusion mix are reported in Table 6-2.

Table 6-2 General data about extrusion alloys and product types

Type of alloys	Hard alloys, e.g. 2xxx, 7xxx, 5xxx (Mg > 1,5%)	8%
	Soft alloys, e.g. 1xxx, 3xxx, 5xxx (Mg<1,5%), 6xxx	92%
	Total	100%
Thermal treatment after extrusion	percentage of aged products	78%
	percentage of non-aged products	22%
	Total	100%
Type of extruded products	Bars and rods	14%
	Tubes & profiles, Big circumscribing circle (> 300 mm)	12%
	Other tubes & profiles	73%
	Other types of products (please precise)	1%
	Total	100%
Applications	Automotive	15%
	Other transports	10%
	Building	39%
	Engineering	15%
	Others (including stockists)	21%
	Total	100%

Regarding alloys, the generic dataset corresponds to soft alloys (92%,mainly 6xxx series). Aged extrusion products represent 78% of the reported output while 22% is non-aged products. Bar and rods represents 14% of the production. 12% of the production refers to big size profile or tube with a diameter of the circumscribing circle bigger than 300 mm while the big majority of the production is smaller tubes and profiles (73% of the production). The reported data show that 25% of the extrusion output reported is used in transport (automotive and mass transport). This is slightly higher than the actual share of transport in the total shipments of European producers. The biggest market for extruded products is building, i.e. a reported 39%, while engineering applications stands for 15%. 21% of the production goes to other applications, including stockists.

The flow diagram for extrusion is reported in Fig. 6.2. In Table 6-3, the specific inputs and outputs are reported respectively for the extrusion production chain and for the process scrap remelting. These data are normalised to the production of 1 tonne of extrusion.

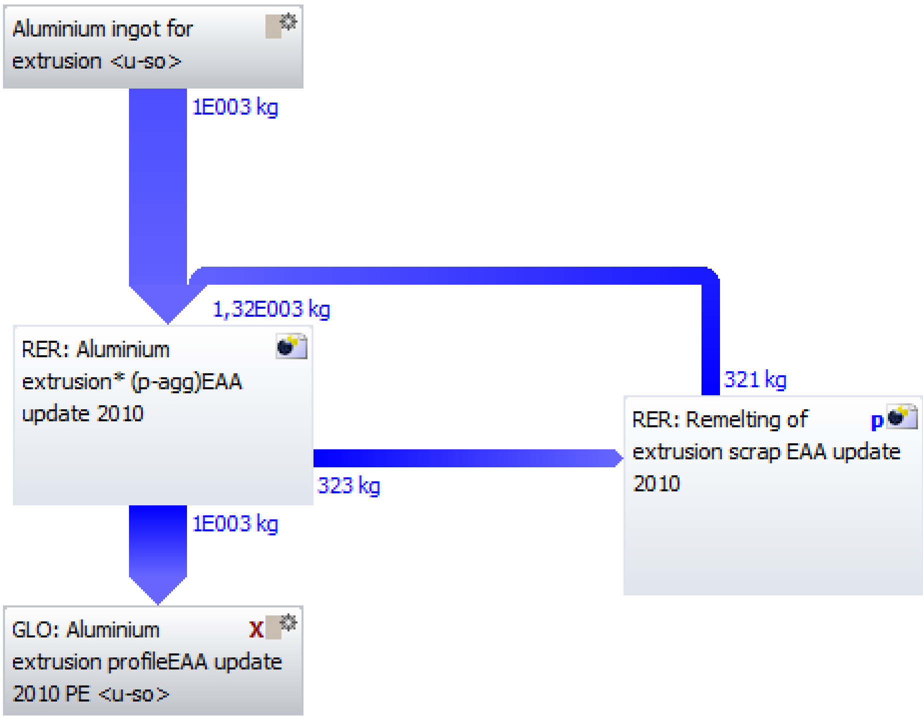

Fig. 6.2 Flow diagram for extrusion production (RER: EU27 + EFTA countries).

Table 6-3 Direct inputs and outputs for extrusion and the corresponding scrap recycling – Figures normalised to 1.000 kg of finished extruded product.

Aluminium extrusion processes - Figures for 1 tonne of extrusion	**Unit**	**Extrusion**	**Scrap Remelting**	**Total**	**Total**
		2010			**2005**
Inputs					
Main aluminium inputs					
Extrusion ingot	kg/t	1.000		**1.000**	**1.008**
Clean scrap	kg/t		323		
Energy					
Heavy Oil	MJ/t	16		**16**	**16**
Diesel and light fuel Oil	MJ/t	66	10	**77**	**60**
Natural gas	MJ/t	2.238	1.094	**3.332**	**3.353**
Total thermal energy	*MJ/t*	*2.320*	*1.104*	**3.425**	***3.429***
Electricity	kWh/t	803	157	**959**	**876**
Total end use energy (fuel + elect.)	*MJ/t*	*5.211*	*1.668*	**6.879**	***6.773***
Ancillaries inputs					
Fluxing salts	kg/t		0,3	**0,3**	
Argon	kg/t		0,3	**0,3**	**0,7**
Nitrogen	kg/t		1,4	**1,4**	
Chlorine	kg/t		0,02	**0,02**	**0,04**
Absorbant for exhaust gas treatment	m^3/t			**0,0**	
Acids, calculated as 100% H_2SO_4	kg/t	5,7		**5,7**	**6,9**
Alkalis, calculated as 100% NaOH	kg/t	12,0		**12,0**	**11,3**
Paper & cardboard for packaging	kg/t	7,1		**7,1**	**7,5**
Wood for packaging	kg/t	11,0		**11,0**	**26,0**

Aluminium extrusion processes - Figures for 1 tonne of extrusion	**Unit**	**Extrusion**	**Scrap Remelting**	**Total**	**Total**
		2010			**2005**
Steel for packaging	kg/t	0,3		**0,3**	**0,7**
Plastic for packaging	kg/t	1,4		**1,4**	**2,5**
Water					
Process water	m^3/t	0,6	0,3	**0,9**	
Cooling water	m^3/t	4,2	3,6	**7,7**	
Total water supply	m^3/t	4,8	3,9	**8,6**	
Outputs					
Main aluminium outputs					
Finished profile	kg/t	1.000		**1.000**	**1.000**
Emissions to air					
Inorganic chlorinated compounds (expressed as HCl)	kg/t		3,38E-03	**3,38E-03**	
Carbon dioxide[19] (CO_2)	kg/t	159	75	**234**	**234**
NO_X, as nitrogen dioxide	kg/t	0,07	0,06	**0,13**	**0,37**
SO_2	kg/t	0,02	0,01	**0,03**	**0,03**
Dust/particulates, total	kg/t	*na*	0,02	**0,02**	**0,04**
TOC	kg/t	0,01		**0,01**	
Water					
Water output	m^3/t	2,6	3,8	**6,4**	**5,1**
COD, chemical oxygen demand (direct discharge)	kg/t	519,1		**519,1**	
Hazardous waste					
Spent caustic bath/sludge for land-filling	kg/t	2,4		**2,4**	**3,6**
Spent caustic bath/sludge for further processing	kg/t	30,3		**30,3**	**21,6**
Hazardous waste for land-filling	kg/t	0,4	0,7	**1,1**	**1,8**
Other hazardous waste for further processing	kg/t	6,6		**6,6**	**9,3**
Hazardous waste for incineration	kg/t	1,1		**1,1**	**1,8**
Total hazardous waste	kg/t	*40,8*	*0,7*	**41,6**	***38,1***
Non-hazardous waste (excluding aluminium scrap, dross/skimmings & demolition waste)					
Non-haz. waste for land-filling	kg/t	0,8	0,5	**1,3**	**3,8**
Non-haz. waste for incineration	kg/t	1,3	0,1	**1,3**	**2,2**
Non-haz. waste for further processing	kg/t	7,3	0,2	**7,5**	**9,0**
Total non-hazardous waste	kg/t	*9,4*	*0,7*	*10,1*	*15,0*
By-products					
Metal scrap for recycling, excluding aluminium	kg/t	3,3	0,9	**4,1**	**7,3**

[19] Estimated from "fuel combustion" (see. Table 2-2)

6.3 Environmental indicators for extrusion production

The GaBi software was used to calculate the European LCI dataset for extrusion production in accordance with the flow diagram described in Fig. 6.2. The LCI dataset is available on request at lci@eaa.be and associated environmental indicators are listed in Table 6-4.

Table 6-4 Environmental indicators for the production of 1 tonne of aluminium extrusion from an ingot

EAA indicators (per tonne of aluminium profile)	Total 2010	Direct, auxiliary & thermal	Electricity
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**3,10E-04**	88%	12%
Acidification Potential (AP) [kg SO_2-Equiv.]	**2,45E+00**	18%	82%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**1,67E-01**	36%	64%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**7,59E+02**	38%	62%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**3,14E-05**	2%	98%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**1,75E-01**	30%	70%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**1,45E+04**	35%	65%
Primary energy from renewable raw materials (net cal. value) [MJ]	**1,41E+03**	15%	85%
Primary energy from non-renewable resources (net cal. value) [MJ]	**1,31E+04**	37%	63%

7. Aluminium recycling

Aluminium has been recycled since the metal first began to be used commercially in the opening decades of the 20th century. Since that time a large number of remelters and refiners have been established, converting new and old aluminium scrap into new ingot, deoxidiser for the steel industry and master alloys. It is estimated that 75% of the aluminium ever produced is still in use today.

There are very good commercial reasons why this recycling has always taken place. The high intrinsic value of aluminium makes remelting economically attractive. Using today's technology aluminium and its alloys can potentially be melted and reused without loss of quality. Remelting the aluminium metal into a new ingot requires much less energy than the primary aluminium production from its ore. Aluminium recycling thus saves raw materials and energy, and also reduces demands on landfill sites.

Recycling is a major consideration in continued aluminium use, representing one of the key attributes of this metal, with far-reaching economic, ecological and social implications. More than half of all the aluminium currently produced in the European Union (EU-27) originates from recycled raw materials and that trend is on the increase. In view of growing end-use demand and a lack of sufficient domestic primary aluminium production in this part of the world, Europe has a huge stake in maximising the collection of all available aluminium, and developing the most resource-efficient scrap treatments and melting processes.

The economic, environmental and technical aspects of aluminium recycling are largely described in the brochure "Aluminium recycling, The Road to High Quality Products" published jointly by the EAA and the Organisation of European Aluminium Refiners and Remelters (OEA) [9].

The 'recycling' data were obtained through data collection organised by the OEA (Organisation of European Aluminium Refiners and Remelters). The high fragmentation of the aluminium recycling industry limits the European coverage. However, a significant effort has been dedicated to model the scrap mass flows and their recycling routes in order to develop 2 models representative of the aluminium recycling of the European scrap mix.

7.1 Scrap terminology

A wide variety of aluminium scrap is processed by the secondary industry. Aluminium scrap terms and definitions are covered in EN 12258-3 [10].

New scrap (also called process scrap) is surplus material that arises during the production and fabrication of aluminium products up to the point where they are sold to the final consumer. Thus extrusion discards, sheet edge trim, turnings, millings and dross could all be described as new scrap.

Old scrap is the aluminium material which is recovered after an aluminium product or component has been produced, used and finally collected for recycling. Old scrap could be a used aluminium beverage can, a car cylinder head, window frames or electrical conductor cable.

7.2 Scrap recycling route and corresponding models

Most new aluminium scrap comes into the recycling industry directly from the fabricators. It is therefore of known quality and alloy and is often uncoated. It can then be melted with little preparation, apart perhaps from baling. Such scrap are usually collected by the so-called remelters and melted in reverbatory furnaces (see description in Table 7-1) in order to produce new wrought aluminium alloys. Some new scrap that arises during semi-finishing processes may be coated with paints, ink or plastics. This scrap can be decoated by passing scrap through an oven or a mesh conveyer whilst hot gases are circulated through the mesh to volatilise or burn off the coating. De-coating is usually the only significant scrap preparation step which can be applied to the scrap input by the remelters. **The first model called "scrap remelting" will address this specific recycling route organised through the remelters**. **No scrap preparation phase is included.**

Old aluminium scrap comes into the recycling industry via a very diversified and efficient network of metal merchants and waste management companies which have the technology to recover aluminium from vehicles, household goods, etc. This is often done using heavy equipment such as shredders, together with magnetic separators, to remove iron, sink-and-float installations, or by the use of eddy current installations to separate aluminium from other materials.

After collection, sorting and preparation, these old scrap are usually purchased by the so-called refiners and are melted into casting alloys, also called foundry alloys. Refiners recycle not only scrap from end-of-life aluminium products but also, scrap from foundries, turnings, skimmings (dross) and aluminium metallics. **The second model called "scrap recycling" will specifically address this recycling route organised through the refiners.**

7.3 Furnace technologies

Several melting processes are used. The choice of process depends upon a number of variables. These include the composition of the scrap, the processes available within a given plant, and economic and scheduling priorities. A breakdown of the most common melting technologies is given in Table 7-1. Molten metal fluxing (to treat the molten metal: chemical adjustment, cleaning, yield maximisation, degassing, etc.) and filtration technology (to remove any unwanted materials prior to casting) has been developed to produce aluminium alloys of the correct quality.
Remelters use mainly reverbatory furnaces so that the "scrap remelting" model is based on this furnace technology only. Refiners use a combination of rotary and reverbatory furnaces which represent about 90% of their furnace technology while induction technology is quite marginal. As a result, the "scrap recycling" model is based on a mix of rotary and reverbatory furnace technologies.

Table 7-1 Furnace types and specificities for aluminium recycling.

Furnace type	Variations	Principal application	Specificities / features	Comments
Reverberatory	Standard	Melting larger volumes of clean scrap and primary feedstock	- Large metal capacity (<=100t). - Few restrictions on feed stock sizes. - Low or no salt flux use - Main co-products: mainly dross	- High yields due to quality of feedstock - Molten metal pumps sometimes used
	Side Well	As above, but enables efficient recovery of some finer feedstocks.	- Large metal capacity. - Wide range of feedstock possible. - Main co-products: dross only	- High yields possible depending upon quality of feedstock - Molten metal pumps sometimes used
	Sloping Hearth	Separation of Al from higher melting point metal contamination (i.e. iron/steel)	- Very efficient at removing high melting point contaminants. - Lower thermal efficiency - Main co-product: mainly dross	- Sometimes incorporated into other furnace types. - Yield dependent on level of contamination.
Rotary	Fixed Axis	Recycling a wide range of feedstocks	- No feedstock restrictions - Large charge volumes possible (<50t) - Feedstock size may be restricted - Relatively high usage of salt flux. - Main co-product: salt slag	- Resultant salt slags can be reprocessed.
	Tilting	As above	- As above, but lower use of salt flux. - Feedstock size may be restricted - Main co-product: salt slag	- Tends to be used for lower scrap grades.
Induction (not used in models)	Coreless	Melting of cleaner scrap or primary feedstock	- High yields obtained. - No salt flux required. - Flexible use (batch and continuous processing possible) - Relatively small load (<10t) - Restricted feedstock type - Feedstock size may be restricted	High cost (electricity)
	Channel	As above.	- High yields obtained. - No combustion gases - No salt flux required -As above, but able to have larger capacities(~20-25t)	High cost (electricity)

The temperature of the molten metal is adjusted and alloying additions may be made with a combination of primary metals, recovered metals and master alloys to ensure the correct chemical composition of the melt.

The main co-product from the reverbatory furnaces is the dross while rotary furnaces which use salt as fluxing agent, produces salt slag (see section 7.5). Both co-products are usually treated in order to recover the aluminium metal and to regenerate the salt. Such treatments are part of the 2 models.

7.4 <u>Products from the aluminium recycling industry.</u>

Whether billets or slabs are produced by primary aluminium smelters or remelters, the alloy type produced is still only a function of the composition of the metal and the input added in their respective cast houses. Filtration, degassing, casting and homogenising technology ensure equivalent product quality.

The aluminium refiners convert most of their materials into foundry ingot, generally based on the aluminium-silicon alloy system with additions of other metals such as copper and magnesium. These ingots, complying with national, international or aerospace specifications, are used to produce aluminium castings. The casting

processes include sand and permanent mould casting, high- and low-pressure casting and investment casting.

The actual mix of recycling techniques applied to a specific product depends on many factors. The treatment of recycling in each specific LCA study should preferably be discussed with aluminium industry representatives (more information at lci@eaa.be)

7.5 Dross recycling and salt slag treatment [8]

In absence of fluxing salt, melting aluminium usually produces residues such as dross or skimmings which is mainly composed of aluminium oxides and entrapped aluminium metal. Depending on the scrap input quality and size, between 20 and 100 kg of dross can be produced per tonne of ingot with a metal content varying from 30 to 60%. Aluminium metal contained in dross or skimmings, is recycled as part of the aluminium refiners' operations. Large pieces of metal are separated from cool skimmings by manual sorting before skimmings are fed to impact or ball mills in which the more friable aluminium oxide is ground up; finer metal fractions may then be recovered with subsequent screening operations. Aluminium metallics, as a product of skimmings recycling operations, are recovered by a variety of methods with varying yield. Skimmings can also be fed directly into rotary furnaces and treated with more or less salt flux. Specific data have been also collected to model dross/skimmings recycling.

Salt flux is used mainly in rotary furnace in order to clean the melt and to collect the contaminants within the so-called salt slag. Salt slag contains between 5 and 20% of aluminium metal. Most of the salt slag is treated to recover the aluminium metal. This treatment includes a crushing and grinding process aiming at recovering the metal granulate which contains about 80% of aluminium metal. About 75% of the metal is recovered in the metal granulate. This metal granulates are melted in rotary furnaces. The non-metallic residue is then leached and the residual metal is oxidised. The oxides and others insoluble compounds are then separated from the leaching solution through filtration. The last step consists in a crystallisation process to regenerate the salt flux. Specific input and output data have been collected in order to model this salt slag treatment and associated aluminium recovery.

7.6 Remelting model

7.6.1 Data consolidation, averaging and modelling

Input and output data used in the "scrap remelting" model have been collected by the EAA. These data are representative for integrated cast houses which are part of rolling plants. 11 integrated cast houses have been included in the consolidation, representing a production of about 2,1 Mt of ingot. Such integrated cast houses usually uses a mixed aluminium input composed mainly of clean process scrap (70%), ingot for remelting (23%) and alloying elements (1%) and some liquid aluminium (7%).
For simplification, only scrap input are considered, i.e. other aluminium inputs are substituted by aluminium scrap. Table 7-2 reports the consolidated direct inputs and outputs calculated for 1 tonne of ingot.

Table 7-2 Direct inputs and outputs for the production of 1 tonne of ingot from clean process scrap (data for model 1 : scrap remelting)

Relative figures calculated for 1 ton of reference flow – Rolling plants - Year 2010		**Remelting**	
		2010	**2005**
Inputs	**Unit**		
Aluminium			
Aluminium scraps	kg/t	**1.041**	1.038
Energy			
Heavy Oil	MJ/t	**77**	109
Diesel and light fuel Oil	MJ/t	**67**	13
Natural Gas	MJ/t	**3.532**	3120
Propane	MJ/t	**151**	125
Total thermal energy	*MJ/t*	***3.828***	*3.367*
Electricity	kWh/t	**124**	133
Total energy (ther. + elec)	*MJ/t*	***4.275***	*3.842*
Ancillary products			
Argon	kg/t	**1,7**	2,3
Nitrogen	kg/t	**0,5**	
Chlorine	kg/t	**0,3**	0,1
Absorbant for exhaust gas treatment	kg/t	**0,8**	
Other ancillary material input	kg/t	**0,5**	
Water			
Process water	m^3/t	**0,9**	
Cooling water	m^3/t	**4,9**	
Total water supply	m^3/t	**5,9**	9,7
Outputs			
Aluminium			
Unscalped rolling ingots	kg/t	**1.000**	1.000
Dross / skimmings	kg/t	**50**	42
Metal content of dross/skimmings	%	**70%**	60%
Emissions to air			
Carbon dioxide[20] (CO_2)	kg/t	**265**	233
Chlorine (as Cl_2)	g/t	**1,3**	6,0
Other inorganic chlorinated compounds (expressed as HCl)	g/t	**15,6**	
Dust/particulates, total	g/t	**52,5**	41,0
NO_X, as nitrogen dioxide	g/t	**353,3**	329,0
SO_2	g/t	**64,7**	51,0
Total gaseous organic carbon (TOC)	g/t	**57,0**	
from which is NMHC (Non-Methane HydroCarbons)	g/t	**4,4**	
Emissions to water			
Water output	m^3/t	**5,4**	9,2
COD, chemical oxygen demand (direct discharge)	g/t	**35,2**	
Waste (excluding dross, aluminium scrap & demolition waste)			
Hazardous waste for land-filling	kg/t	**0,8**	2,7
Hazardous waste for incineration	kg/t	**0,0**	0,1
Hazardous waste for further processing	kg/t	**5,9**	
Total hazardous waste	kg/t	**6,6**	*2,8*
Non-haz. waste for land-filling	kg/t	**0,1**	0,3
Non-haz. waste for incineration	kg/t	**0,1**	0,3

[20] Estimated from “fuel combustion” (see. Table 2-2)

Relative figures calculated for 1 ton of reference flow – Rolling plants - Year 2010		Remelting	
		2010	**2005**
Non-haz. waste for further processing	kg/t	**5,7**	1,0
Metal scrap for recycling, excluding aluminium	kg/t	**0,8**	0,5
Total non-hazardous waste	kg/t	**6,6**	*2,1*

About 3.800MJ of thermal energy are used to melt the scrap and to cast the aluminium. This figure can be compared to the theoretical energy value of 1.140 MJ/tonne which is needed to heat up and to melt pure aluminium from 20°C up to 720°C [13].

The metal losses due to the remelting process, after dross recycling, is calculated to 0.67%, i.e. 6,7 kg/tonne.

7.6.2 Environmental indicators for scrap remelting

The GaBi software was used to calculate the European LCI dataset for producing 1 tonne of sawn ingot from new scrap in accordance with the data reported in Table 7-2. The model includes the dross recycling. The LCI dataset is available on request at lci@eaa.be and environmental indicators are listed in Table 7-3.

Table 7-3 Environmental indicators for the production of 1 tonne of aluminium ingot from process scrap

EAA indicators (per tonne of ingot from process scrap)	Total 2010	Direct, auxiliary & thermal	Electricity
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**7,00E-05**	92%	8%
Acidification Potential (AP) [kg SO_2-Equiv.]	**8,37E-01**	67%	33%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**9,64E-02**	85%	15%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**3,67E+02**	82%	18%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**4,72E-06**	11%	89%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**7,61E-02**	78%	22%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**6,16E+03**	79%	21%
Primary energy from renewable raw materials (net cal. value) [MJ]	**1,90E+02**	14%	86%
Primary energy from non-renewable resources (net cal. value) [MJ]	**5,97E+03**	81%	19%

7.7 <u>Recycling model</u>

7.7.1 Data consolidation, averaging and modelling

Scrap refining

The data for scrap refining has been partially updated compared to 2005, with only the energy and metal flows considered in the update. Together with this, a new mix of the technology rotary vs. reverbatory furnace has been generated, as in Fig. 7.1.

Unlike in 2005, no scrap preparation data has been generated in the 2010 model. As the physical scrap preparation is a process happening outside the system boundaries of the refiners, there is no specific data that has been modelled for scrap preparation phase.

7.7.2 Material flow and environmental indicators for the recycling model

Fig. 7.1 reports the flow diagram which is used for the recycling model [8]. The main inputs are aluminium scrap and salt. As in previous models, alloying elements (mainly silicon and magnesium for recycled aluminium) are substituted by pure aluminium and do not appear on the flow diagram. The main outputs are aluminium ingot and non-metallic residues. Detailed LCI data are available on request (please email lci@eaa.be) and the environmental indicators are listed in Table 7-4.

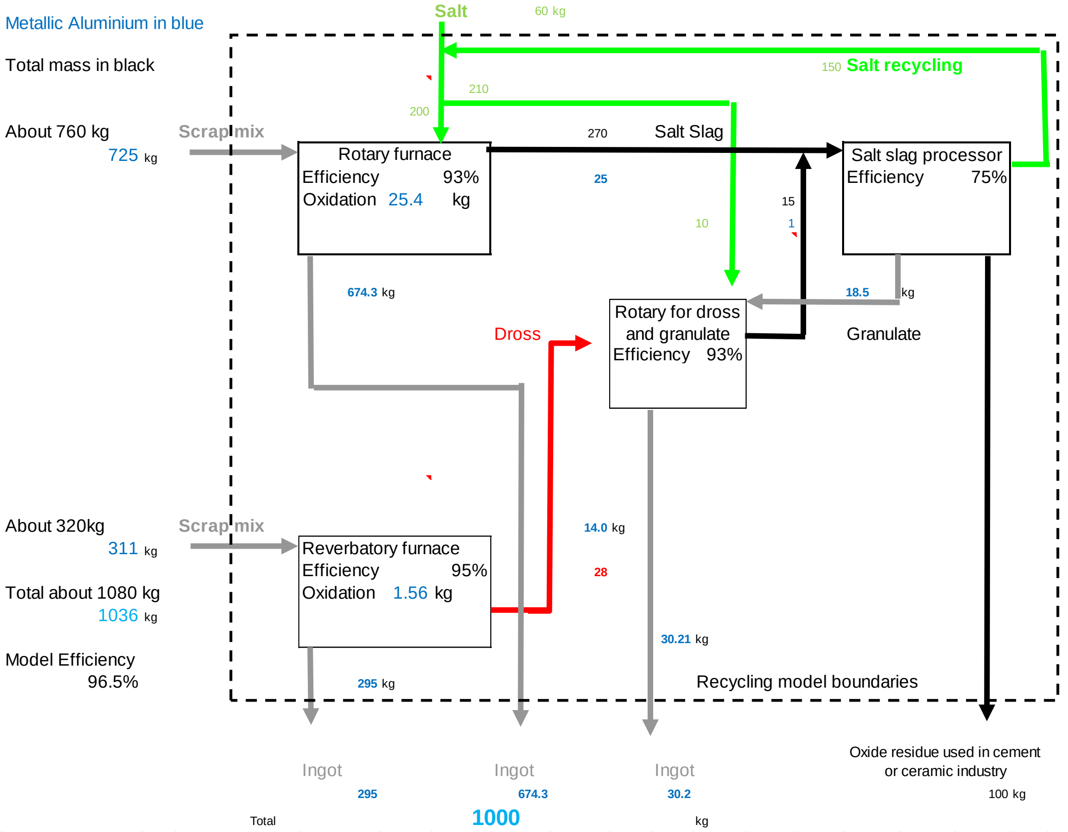

Fig. 7.1 Material flow diagram of the recycling model

From the model, it is estimated that 1.036 kg of aluminium scrap enters the melting model for producing 1 tonne of ingot.

Table 7-4 Environmental Indicators for aluminium recycling per tonne of recycled ingot – year 2010

EAA indicators (per tonne of recycled ingot)	Total 2010	Direct, auxiliary & thermal	Electricity
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**6,93E-04**	99%	1%
Acidification Potential (AP) [kg SO2-Equiv.]	**8,87E-01**	55%	45%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**7,36E-02**	71%	29%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**5,07E+02**	81%	19%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**6,92E-06**	11%	89%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**9,25E-02**	74%	26%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**8,54E+03**	78%	22%
Primary energy from renewable raw materials (net cal. value) [MJ]	**2,74E+02**	12%	88%
Primary energy from non-renewable resources (net cal. value) [MJ]	**8,27E+03**	80%	20%

7.7.3 LCA & aluminium recycling

Preserving the aluminium metal during the whole product life cycle and during recycling should be a main goal for aluminium products since recycled aluminium can be used for producing new wrought or cast aluminium alloys which are used for new products. As a result, any LCA study needs to consider and to credit properly the ability of aluminium to be recycled, usually without any downgrading properties. The European aluminium industry recommends using the so-called substitution methodology which considers that recycled aluminium substitutes primary aluminium so that only metal losses during the whole life cycle needs to be balanced by primary aluminium. Details about such methodology are given in the technical document “LCA & aluminium recycling” which can be downloaded from the EAA website.

As a result, it is crucial to evaluate correctly the metal losses during the recycling phase. The “recycling model” reported in this document is only valid for the scrap mix reported above (see 7.6.1).

8. Glossary & definitions

aluminium:	Metal with a minimum content of 99,0% by mass of aluminium provided that the content by mass of any other element does not exceed the following limits: - iron + silicon content not greater than 1,0% - other element content not greater than 0,10% each, with the exception of copper which is permitted to a content of up to 0,20% provided that neither the chromium nor the manganese content exceeds 0,05% Note: aluminium in the liquid state or in the form of ingots for remelting is often called "unalloyed aluminium".
ancillary material:	Material input that is used by the unit process producing the product, but not directly used in the formation of the product
annealing:	Thermal treatment to soften metal by reduction or removal of stress resulting from cold working and/or by coalescing precipitates from the solid solution.
blank	Piece of metal of regular or irregular shape taken from a flat wrought product intended for subsequent processing such as bending, stamping or deep drawing.
can stock	Sheet or strip used for the fabrication of rigid cans, including lids and tabs, formed by drawing or pressing operations. Can stock covers can body stock, lid stock and tab stock.
casting (process)	Process in which molten metal is poured into a mould and solidified.
casting alloy	Alloy primarily intended for the production of castings.
converter foil	Rolled aluminium in the gauge range 5 µm to 200 µm, produced either by double rolling (5µm to 70 µm), or single rolling (35 µm to 200 µm), typically annealed soft and supplied for further processing such as colouring, printing, embossing or laminating
direct chill (DC) casting	Semi-continuous casting technique in which molten metal is solidified in a water-cooled open-ended mould.
elementary flow	Any flow of raw material entering the system being studied which has been drawn from the environment without previous human transformation; any flow of material leaving the system being studied which is discarded into the environment without subsequent human transformation.
extrusion:	Process in which a billet in a container is forced under pressure though a die aperture
extrusion ingot	Aluminium or aluminium alloy cast in a form suitable for extruding.
foil:	Flat rolled product of rectangular cross-section with uniform thickness equal to or less than 0,20 mm Note: Sometimes the term "foil" covers two different products: - foil : products with lesser thickness; - thin strip : products with greater thickness. The dimensional limitations between these two products may vary from country to country
forming	Process by which a product is transformed into a desired shape without changing its mass.
heat treatment	Heating, holding at elevated temperature and cooling of the solid metal in such a way as to obtain desired tempers or properties. Heating for the sole purpose of hot working is excluded from the meaning of this term.
homogenisation	Process in which metal is heated at high temperature during a specified time, generally in order to facilitate working and to confer certain desirable properties on the semi-fabricated product, in particular to eliminate or decrease micro segregation by diffusion.
hot working	Working of a metal within a temperature range and at a rate such that significant strain does not occur.
ingot for remelting	Metal cast in a form suitable for remelting which has been processed, as appropriate, to adjust the chemical composition and/or to remove certain

	metallic or non-metallic impurities.
PAH	Polycyclic aromatic hydrocarbons
primary aluminium	Aluminium produced by electrolytic reduction from alumina. Remelt metal is excluded from this term.
primary ingot	Ingot produced from primary aluminium. It may incorporate suitably identified uncontaminated scrap from ingot production.
refined aluminium alloy	Aluminium alloy obtained after metallurgical treatment of molten metal obtained from aluminium scrap. **Note :** This term is mainly used for casting alloys.
remelt metal	Wrought aluminium or aluminium alloy obtained by remelting.
rolling ingot	Aluminium or aluminium alloy cast in a form suitable for rolling.
section	Wrought product, usually extruded, of uniform cross-section along its whole length, usually supplied in straight lengths or sometimes in coiled form. Rods, bars, wire, tubes, sheet and strip are excluded from this term.
semi-finished product	Product which is supplied for further fabrication.
sheet/plate	Flat rolled product of rectangular cross-section with uniform thickness between 0,20 mm and 6 mm (sheet) or above 6 mm (plate), supplied in flat straight lengths usually with trimmed or sawn edges. The thickness does not exceed one-tenth of the width.
strip	Flat rolled product of rectangular cross-section with uniform thickness over 0,20 mm, supplied in coils usually with trimmed edges. The thickness does not exceed one-tenth of the width.
solution heat treatment	Process in which an alloy is heated to a suitable temperature and is held at temperature long enough to allow soluble constituents to enter into solid solution and then cooled rapidly enough to hold the constituents in solution.
working	Forming of a metal, generally with elongation but not necessarily in a preferred direction. Working may be carried out hot or cold by such processes as rolling, extruding, forging, etc.
wrought alloy	Alloy primarily intended for the production of wrought products by hot and/or cold working
wrought product	General term for products obtained by hot and/or cold working processes such as extruding, forging, hot rolling, cold rolling or drawing, either exclusively or in combination. Examples of wrought products are rods/bars, wire, tubes, profiles, sheet, strip and forging.

Definitions related to aluminium scrap for recycling taken from EN 12258-3

(aluminium) scrap	raw material, destined for trade and industry, mainly consisting of aluminium and/or aluminium alloys, resulting from the collection and/or recovery of - metal that arises at various stages of fabrication or - products after use to be used for the production of wrought and cast alloys and for other production processes
clean scrap	scrap which does not contain foreign material
coated scrap	scrap consisting of pieces with any kind of coating, e.g. paint, varnish, printing ink, plastics, paper, metal
dross	Skimmings with low metal content
new scrap	scrap arising from the production and fabrication of aluminium products
old scrap	scrap arising from products after use
skimmings	material composed of intimately mixed aluminium and aluminium oxides which have been removed from the surface of the molten metal or from the bottom and walls of liquid metal containers, e. g. a furnace, transport ladles, or transfer channels NOTE: The same material with low metal content is often called "dross".
metallics	material produced by the crushing or grinding of skimmings by means of ball mills, hammer mills, impactors, etc. and the selection of the coarser fraction where most of the metallic aluminium is concentrated, by screening
fines	fine-grained portion obtained from the milling of skimmings holding a low metal content but a high content of aluminium oxides and other oxides.
foreign material	any material other than aluminium or aluminium alloys which is physically identifiable as part of a scrap consignment. Foreign material can be attached to pieces of scrap or separate. Examples of foreign material are powder, water, oil or other fluids, grease, wood, plastic, glass, stones, paper, sand, non-aluminium metals, dry paints, inks, lacquers, rubber, dirt.
shredding	reduction of the size of pieces of scrap, end-of-life products or compacted scrap into small pieces, by operations such as crushing or tearing
sorting	separation of different fractions of loose scrap, manually or by other methods
sink and float	processes where materials with different densities are separated through air flotation or heavy media systems
casting alloys	Aluminium alloys used for the production of castings where the final product shape is generated by pouring molten metal into a mould. These aluminium alloys have an alloy concentration of up to 20%, mostly silicon, magnesium and copper. Typical castings are cylinder heads, engine blocks and gearboxes in cars, components used in the mechanical and electrical engineering industries, components for household equipment and many other applications.
deoxidation aluminium	Aluminium consisting of alloys with a high concentration of metallic aluminium (usually exceeding 95%) used to remove free oxygen from liquid steel.
foundry industry	Main customers of refiners. They produce a wide variety of castings which are mostly used in the transport sector.
Refiner	Producer of casting alloys and deoxidation aluminium from scrap of varying composition. Refiners are able to add alloying elements and remove certain unwanted elements after the melting process.
Remelter	Producer of wrought alloys in the form of extrusion billets and rolling slabs from mainly clean and sorted wrought alloy scrap.
Salt slag	By-product that arises when salt (mixture of sodium and potassium chloride) is used to cover the molten metal to prevent oxidation, increase yield and enhance thermal efficiency in the furnace.

Wrought alloys	Aluminium alloys used for wrought products where the final product shape is generated by mechanically forming the solid metal. These aluminium alloys have an alloy concentration comprised between 1 and 10%, mostly manganese, magnesium, silicon, copper and zinc. Typical wrought alloy products are semi-fabricated items in the form of rolled sheets, foil or extruded profiles, which are processed into car body parts, heavy goods vehicle and commercial vehicle components, rail vehicles, building panels, doors, windows, packaging, and so on.
Recycled aluminium	Aluminium ingot obtained from scrap is now referred to as recycling aluminium.
Recycling	Aluminium collection and subsequent treatment and melting of scrap.
Recycling rates	Performance indicators of global recycling performance are as follows: Recycling input rate: Recycled aluminium produced from traded new scrap and old scrap as a percentage of total aluminium (primary and recycled sources) supplied to fabricators. Overall recycling efficiency rate: Recycled aluminium produced from traded new scrap and old scrap as a percentage of aluminium available from new and old scrap sources. End-of-life recycling efficiency rate: Recycled aluminium produced from old scrap as a percentage of aluminium available from old scrap sources. The end-of-life collection rate: Aluminium collected from old scrap as a percentage of aluminium available for collection from old scrap sources. The end-of-life processing rate: Recycled aluminium produced from old scrap as a percentage of aluminium collected from old scrap sources.

9. References

[1] Environmental Profile Report for the European Aluminium Industry, reference year 2005, European Aluminium Association, April 2008.
[2] The 2 updates of the Environmental Profile Report for the European Aluminium Industry - year 2002, European Aluminium Association, September 2005
[3] Life Cycle Assessment of Aluminium: Inventory Data for the primary Aluminium Industry – Year 2010 Update, International Aluminium Institute, STILL IN DRAFT AT THE MOMENT OF THIS PUBLICATION
[4] http://www.alueurope.eu/wp-content/uploads/2011/08/Bauxite-Residue-Management-v.6.pdf
[5] http://www.world-aluminium.org/media/filer_public/2013/01/15/none_9
[6] ISO 14040:2006 Environmental Management - Life Cycle Assessment – Principles and framework
[7] ISO 14044:2006 Environmental Management – Life Cycle Assessment – Requirements and guidelines
[8] U.M.J. Boin, M. Bertram, "Melting Standardized Aluminum Scrap: A mass Balance Model for Europe", Journal of metals, August 2005, pp 26-33.
[9] Aluminium Recycling, The Road to High Quality Products, European Aluminium Association, 2004, www.aluminium.org
[10] EN 12258-3:2003 Aluminium and aluminium alloys. Terms and definitions. Scrap
[11] GABI 2011, GaBi 5: Software and Database for Life Cycle Assessment. LBP, University of Stuttgart and PE International GmbH, Leinfelden-Echterdingen, 2011, http://www.gabi-software.com
[12] International Energy Agency, www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Electricity/Heat
[13] Handbook of Aluminium Recycling, Ch. Schmitz, Vulkan-Verlag, 2006
[14] Declaration by the Metals Industry on Recycling Principles. Int. J. LCA 12 (1) 59-60. Electronic publication November 30, 2006 DOI: http://dx.doi.org/10.1065/lca2006.11.283
[15] W. Klöpffer, "Experiences with the critical review process of aluminium LCI data", Int J Life Cycle Assess (2009) 14 (Suppl 1):S45–S51
[16] Ch.Leroy, "Provision of LCI data in the European aluminium industry Methods and examples", Int J Life Cycle Assess (2009) 14 (Suppl 1):S10–S44

10. List of figures

11. List of tables

12. Report from the independent reviewer

Environmental Profile Report for the European Aluminium Industry

April 2013-
Data for the year 2010

Life Cycle Inventory data for aluminium production and transformation processes in Europe

Critical Review Report

by

Prof. Dr. Walter Klöpffer

LCA CONSULT & REVIEW

Frankfurt/M

April 2013

1 Introduction

This Life Cycle Inventory (LCI) report on Aluminium production, use and transformation stands in the tradition of similar reports (1- 4) prepared by EAA and reviewed by the late Ian Boustead (1-3) and myself (4,5):

1. 1996 (reference years 1991/92 and 1994)
2. 2000 (reference year 1998) [1]
3. 2005 update report (reference year 2002) [2]
4. 2008 (reference year 2005) [3-5]
5. 2013 (reference year 2010)

This service to the LCA community, environmental agencies and the industry is distinguished from other material LCI reports by regular and reliable updates in appropriate intervals. In addition to the information given in the previous reports (1-4) it is now possible to distinguish between Aluminium **produced** in Europe and Aluminium **used** in Europe. This constitutes a major progress which gives more flexibility to the data users. It should also be mentioned that the most recent global and peer reviewed Aluminium data, collected and evaluated by the International Aluminium Institute (IAI), London, have been made available to EAA before the official publication [6]. The IAI data also refer to the year 2010.

2 Organisation and Performance of the Critical Review

The review procedure started with a kick-off meeting February 5, 2013 in Brussels after the contract had been signed January 26. At that date, a draft of the final report, dated January 25 2013 was already available. The critical review is therefore by definition a review “a posteriori” [7,8], but it was early enough to suggest improvements, most of which have been taken into account. It was agreed upon that the review is performed as a “critical review” according to the ISO standards14040 [9] and 14044 [10]. In these standards, LCI-studies, consisting of a Goal & Scope chapter, Life Cycle Inventory and Interpretation are included and can be accepted under the provision that such studies are not designated as LCAs. They are distinguished from a full LCA-study mainly by the absence of the phase Life Cycle Impact Assessment (LCIA). Clearly, in the present study there are further restrictions,

since the manufacture of the final products and the use phases of these products had to be left out for obvious reasons (the same is true for most commodities). The other important life cycle stages of Al (mining, alumina production, primary aluminium production by electrolysis, melting and remelting, as well as recycling) are treated and together can be considered as an LCI study. A few LCIA results are included in the report for information.

The critical review was conceived as a review by one independent external reviewer according to ISO 14044, section 6.2. The more demanding review according to the panel method (14044, section 6.3, at least three reviewers including the chair) was not deemed necessary, since no comparative assertions can be derived from the data collected.

The second (final) meeting took place March 26, 2013 in Brussels. Main topic: Discussion of the revised draft final report and comments made by the reviewer with Christian Leroy and Djibril René (EAA). In addition, Sammy Jones (IAI) came over from London and contributed global aspects of the Aluminium life cycle in addition to the reviewed 2010 data already included in the draft final report by EAA. This inclusion of the brand-new global data was the main difference between the draft from January 25 and the new one received February 19, 2013. Furthermore, several improvements suggested were included in the February version.

The final meeting was also a chance to discuss possible improvements for the next reports by EAA and IAI, which presumably will take 2015 as reference year. A time schedule for the last steps of the final report including the critical review report has also been adopted.

The updated final report was submitted via email April 11, 2013. The review below refers to this version.

3 About this Aluminium Environmental Profile Report

3.1 General

The first impression of the report is that it is well structured, written and illustrated. The report stays in the tradition of the former ones, but offers also some new aspects. The change of older software to GaBi 4, including generic data for ancillary processes, occurred already in the previous version [3-5]. In the present version, GaBi 5 is used, the dual results for the European LCI are introduced (see Introduction) and new global data by IAI are used where appropriate. The LCI results can therefore not exactly be compared with the data of the previous reports. However, as already stated in the previous critical review [3]: "There is no break, so that trends can be observed and discussed with some precaution. The main trend with respect to energy and emissions is one of slow but steady improvement". Some deficiencies with the data around the "cradle" of aluminium [5], e.g. land use, and the bauxite residues ("red mud") problem persisted in the present report with hope of future improvement (see section 5).

The LCI is presented in the form of building blocs corresponding to the stages of the life cycle in a logical order:

Bauxite → alumina → aluminium → melting/sheets, foils [use: excluded] ← recycling

It is worth mentioning that the LCI study is more than a "cradle-to-factory gate" study, or a generic data set, but comprises the most important end-of-life phase, recycling. This phase is of outmost importance for the Aluminium life cycle, since only very efficient recycling can partly compensate, over the life cycle, the thermodynamically caused high energy demand of aluminium production (the reduction of Al_2O_3 to Al metal in the smelters).

The data coverage is excellent for the large industrial installations (e.g. primary aluminium production) and, as to be expected, less so if small companies dominate (as in recycling). Scrap collection has been cancelled in this report due to difficulties in

finding representative data. Data consolidation plays a major role in raw data treatment and has been solved in a convincing manner.

The geographical coverage includes EU 27 + EFTA (Norway, Iceland and Switzerland; “EU 27+3”). Due to the inclusion of Al-imports, the actual geographical system boundary is much larger, or even global if the bauxite mining and alumina production is considered. This is true for the variant “Aluminium used in Europe”, whereas in the variant “Aluminium produced in Europe” only contains imported bauxite and alumina (Al_2O_3) from outside Europe. The smelters are all located within the geographical system boundaries in this variant. Electrical energy is modelled using representative productions in typical countries and regions. The selection process was not easy to understand in the earlier versions of the report and needed some discussion.

Life Cycle Impact Assessment indicator results are included in this report which do not belong to LCI data sets. It is stated, however, that these results are shown for purely informative purposes, not to be used for comparisons. Only the Cumulative Energy Demand (CED), here called “Primary energy demand for renewable and non renewable resources” can be considered as belonging to LCI. It is also given split into renewable and non renewable primary energy, adding up to the total CED. These indicators give additional information compared to other energy-related impact categories such as Climate change and depletion of fossil energy resources. The re-integration of the CED into the mainstream LC(I)A is presently discussed within the UNEP/SETAC Life Cycle Initiative [11].

3.2 Details

The report is structured in a logical way, starting with a description of the aluminium life cycle (1), a project description (Goal & Scope) (2), primary Al production including the bauxite mining, alumina production and electrolysis with electricity model (3), sheet production (4), foil production (5), extrusion (6) and Al recycling (7). Chapters 3 to 7 constitute the truncated Life Cycle Inventory (LCI). It should be mentioned that there is no full LCI (and, hence, no full LCA) of any commodity, since for doing so all uses would have to be modelled: an evidently impossible task. What is

presented in these chapters are the data and sub-system descriptions including flow charts, tables and figures to help the reader through the masses of information. A separate chapter “Interpretation”, as requested by ISO 14040 [5], is missing, a point which was brought to the attention of EAA during the final meeting.

Reporting of PAH and BaP emission data from smelters is laudable. Toxic emissions are sometimes “forgotten” by generic data providers. Polyfluorinated compounds are included as important GHG emissions of the smelters; they have been reduced in recent years, but not yet fully.

The co-operation with the European Reference Life Cycle Data System already resulted in two generic LCI datasets (aluminium sheet and profile) which are publicly available free of charge [12].

4 Confirmation by the independent expert

According to ISO 14040 [9]

"The critical review process shall ensure that:

- *the methods used to carry out the LCA are consistent with the 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."*

These five points can be confirmed with very few restrictions discussed in the previous sections.

With regard to the first item, consistency with ISO 14040/44, it has to be considered that these requirements have been worded for a full LCA study. The study reviewed here is a Life Cycle Inventory (LCI) study of an important commodity. Hence, no Life

Cycle Impact Assessment is necessary (although in this LCI study some LCIA information is given). There remain the phases Goal and scope definition (G&S), Life cycle inventory analysis (not to be confused with LCI study) and Interpretation.

G&S information is given in section 2.1.

The Life cycle inventory analysis is the main topic of the study and is described in due detail. It explains the steps from bauxite mining, alumina production and purification, electrolytic reduction, melting of the metal and formation of sheets, foils and extrusion products, and recycling of used Aluminium.

There is a formal lack of a section "interpretation" indicated above. The information expected from such a section is presented, however scattered throughout the report. Data for land use in mining and bauxite residue ("red mud") management are still scarce or absent; in both cases, detailed management reports by IAI and EAA are cited which can be downloaded free of charge. They contain much relevant information, but not (yet) in a form to be directly useable by LCA practitioners.

The second item, the scientific and technical validity of the methods used, can be confirmed without any restrictions. They correspond to best LCI practise. The methods also developed over the years and four previous studies (see Introduction). The methodology for the actual calculations has been adapted to the progress of software development

The methods used in data collection and modelling are described clearly and correspond to the state of the art. They may contribute to ongoing harmonization/standardization endeavours initiated by UNEP/SETAC ("Shonan guiding Principles" [13]) and the European Union [14].

The third item (data) is the heart of the study. The data used in addition to the original data collected for this study and data collection stem from one of the leading software systems. The data allow the use for studies needing aluminium produced in Europe and aluminium used in Europe. New global data (reference year 2010) are used for

modelling processes outside Europe. Additional data not shown in this report are made available to interested persons on demand.

The interpretation (not as a separate chapter) given is in accordance with the restricted scope and refers to the representativity and quality of the original data. The user can be sure to have the best possible dataset for Al in Europe.

Last, but not least, the report is transparent and consistent. It is clearly written and contains many illustrative, coloured pictures (including a map of the European smelters). A detailed Glossary & Definition table and a list of references round up the report.

5 Summary and recommendations

To sum up, this Project is an excellent example for generic data acquisition, consolidation and presentation. It contributes to the Life Cycle Assessment development by providing reliable data for one important material and continues a tradition of one and a half decade in an exemplary way.

Possible improvements for the next round have been identified, especially by

- including inventory data for land use (bauxite mining)
- improving the solid and liquid waste treatment in LCI (especially bauxite residues)
- improve the consistency with ISO structure (interpretation)
- extend the analysis toward Life Cycle Sustainability Assessment (goal for the future)
- continue to enhancing the recycling
- contribute to further reduction of heavy oil use in alumina production
- continue the co-operation with the EU-LCA databank

The improvement of data-acquisition near the “cradle”, admonished in the critical review of the reference year 2005 [3,5] is not yet visible in this study, but during the final meeting, including IAI, potential improvements were identified. No details can be given at present for reasons of confidentiality.

Life cycle methods have made great progress in recent years, both in the number of studies and in developments toward better data collections and methods extending LCA towards Life Cycle Sustainability Assessment (LCSA) [15]. This should be seen as the ultimate goal in Life cycle studies, so that improvements in environmental or economic behaviour of a product system do not conflict with the social aspects, or vice versa [16].

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References

[1] European Aluminium Association: Environmental Profile Report for the European Aluminium Industry. EAA, Brussels, April 2000

[2] European Aluminium Association: Environmental Profile Report for the European Aluminium Industry. Primary Aluminium update – Year 2002; Semi-finished aluminium products and process scrap recycling Update – Year 2002; Aluminium Recycling in LCA. EAA, Brussels, September 2005

[3] European Aluminium Association: Environmental Profile Report for the European Aluminium Industry. Life Cycle Inventory data for aluminium production and transformation processes in Europe. Year 2005. Brussels, April 2008

[4] Leroy, C. (2009): Provision of LCI data in the European aluminium industry. Methods and examples. Int. J. Life Cycle Asess. 14 (supplement 1) 10-44

[5] Klöpffer, W. (2009): Experiences with the critical review process of aluminium LCI data. Int. J. Life Cycle Assess 14 (supplement 1) 45-51

[6] International Aluminium Institute (IAI): Life Cycle Assessment of Aluminium: Inventory Data for the primary Aluminium Industry - Year 2010 Update. To be published 2013. London.

[7] Klöpffer, W. (2005): The Critical Review Process According to ISO 14040-43: An Analysis of the Standards and Experiences Gained in their Application. Int. J. LCA 10 (2) 98-102

[8] Klöpffer, W. (2012): The critical review of life cycle assessment studies according to ISO 14040 and 14044: origin, purpose and practical performance. Int. J. Life Cycle Assess. 17 (9) 1087-1093

[9] International Standard (ISO): Environmental management - Life cycle assessment: Principles and framework. ISO 14040 (October 2006)

[10] International Standard (ISO): Environmental management - Life cycle assessment: Requirements and Guidelines. ISO 14044 (October 2006)

[11] Klöpffer, W.: Cumulative Energy Demand (CED) – A useful indicator between LCI and LCIA. Workshop on Life Cycle Impact Assessment – Where we are, trends and next Steps. Organized by UNEP/SETAC Life Cycle Initiative. Milano, 20 May 2011

[12] European Commission - Joint Research Centre - Institute for Environment and Sustainability. http://lca.jrc.ec.europa.eu

[13] UNEP/SETAC 2011:
Sonnemann, G.; Vigon, B. (Eds.): Global Guidance Principles for Life Cycle Assessment Databases – "Shonan Guiding Principles". 156 pp. ISBN: 978-92-807-3174-3. UNEP/SETAC Life Cycle Initiative, Paris. Download from http://lcinitiative.unep.fr

[14] European Commission - Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010.

[15] Valdivia, S.; Ugaya, C.M.L.; Sonnemann, G.; Hildenbrand, J. (Eds.): Towards a **L**ife **C**ycle **S**ustainability **A**ssessment. Making informed choices on products. Paris 2011 ISBN: 978-92-807-3175-0. UNEP/SETAC Life Cycle Initiative, Paris. Download from http://lcinitiative.unep.fr

[16] Zamagni, A., Jørgensen, A.; Pesonen, H.-L. (eds.): Life Cycle Sustainability Assessment. Special issue of Int J. Life Cycle Assess.To appear in Vol. 18 (2013)

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