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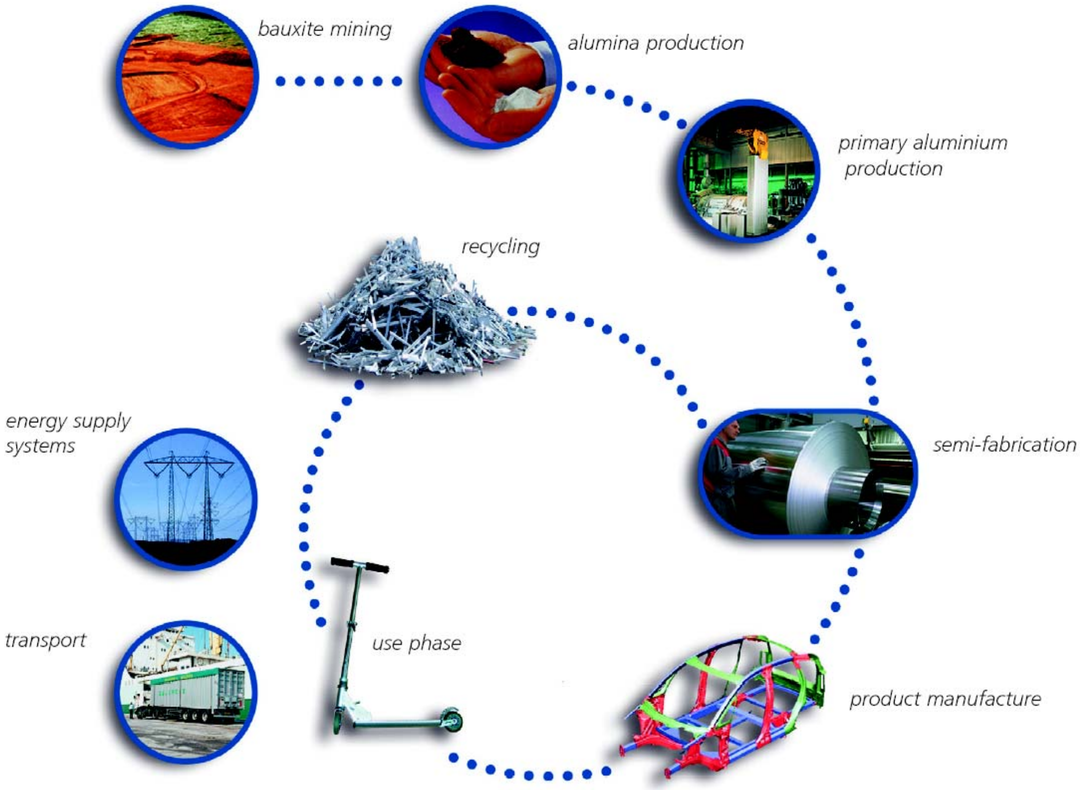
Environmental Profile Report for the European Aluminium Industry

April 2008

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 56% in 2007, 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 [17], the European aluminium industry recommends to credit the environmental benefits resulting from recycling through the end-of-life recycling approach and not through the inappropriate recycled metal content approach which has no real environmental significance. 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.aluminium.org).

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 [8-9]. This document is based on environmental data related to the year 2005. It updates the previous datasets which have been published in the following documents [1-3]:

- Ecological Profile Report for the European Aluminium Industry published in 1996 (reference years 1994 and 1992)
- Environmental Profile Report for the European Aluminium Industry published in 2000 (reference year 1998)
- The 2 updates of the Environmental Profile Report for the European Aluminium Industry published in 2005 (reference year 2002)
    - Primary aluminium
    - Semi-finished aluminium products and process scrap recycling

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.

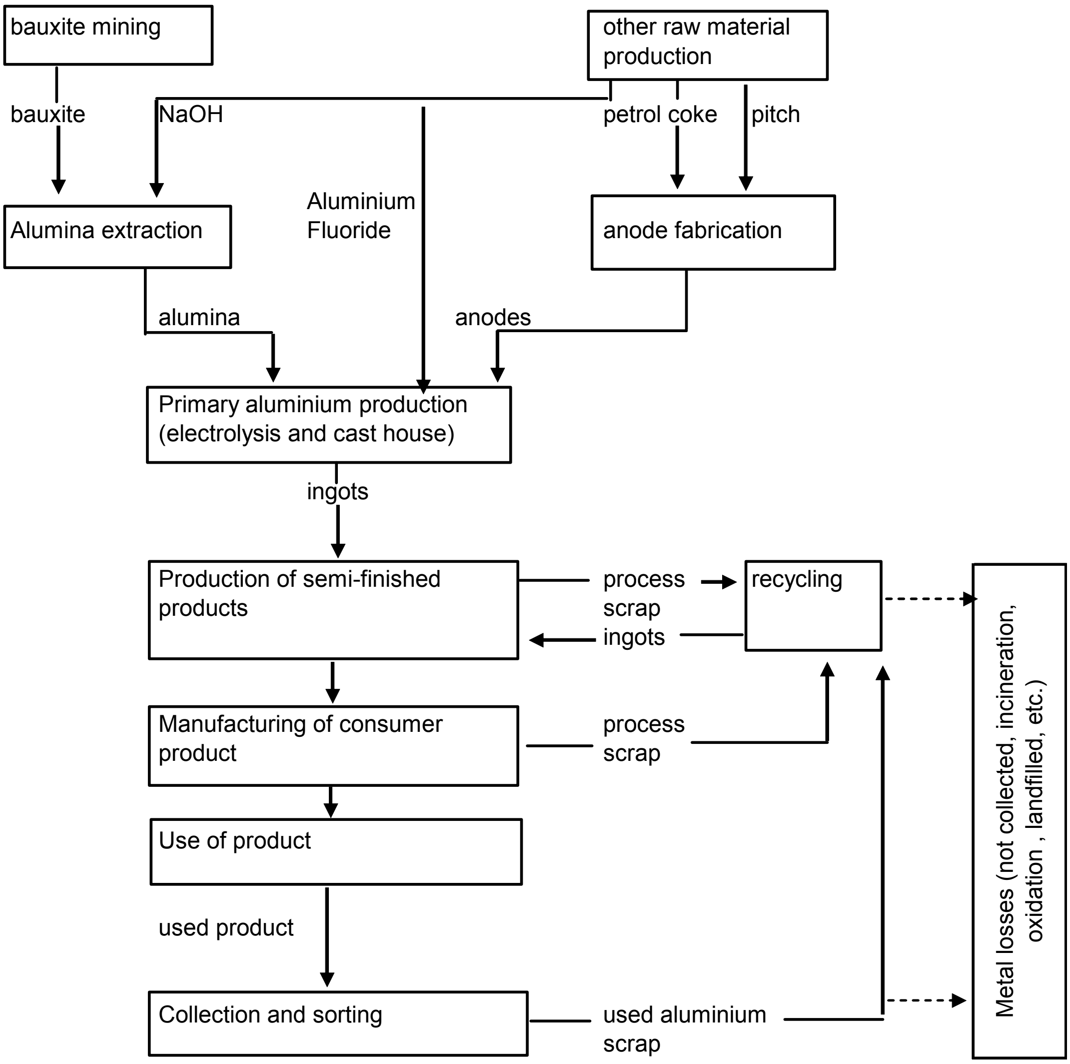

Fig. 1.1 Simplified life cycle material flow chart of an aluminium product

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. Aluminium from the smelters is alloyed and 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 metal, 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 2006 a new extensive environmental survey covering the year 2005, 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:

- for LCA studies related to aluminium products fabricated in Europe , i.e. product made of aluminium or containing aluminium.
- for 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 substituted 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 include the recycling of all the aluminium from process scrap, chips, dross or salt slag which are produced along the production or transformation route. 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 2005:

- 1 dataset on primary aluminium production,
- 3 datasets on semi-finished aluminium products fabrication, respectively sheet, profile & foil,
- 1 dataset on clean process scrap remelting,
- 1 dataset on the recycling of special scrap and end of life aluminium products.

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

The '**primary**' LCI dataset 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 to the European market. Since the electricity production is the major contributor to the environmental aspects, a specific electricity model has been developed based on the European production and the structure of the imports which represents 36% of the primary aluminium used in Europe in 2005 (see section 3).

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, 5 and 6)

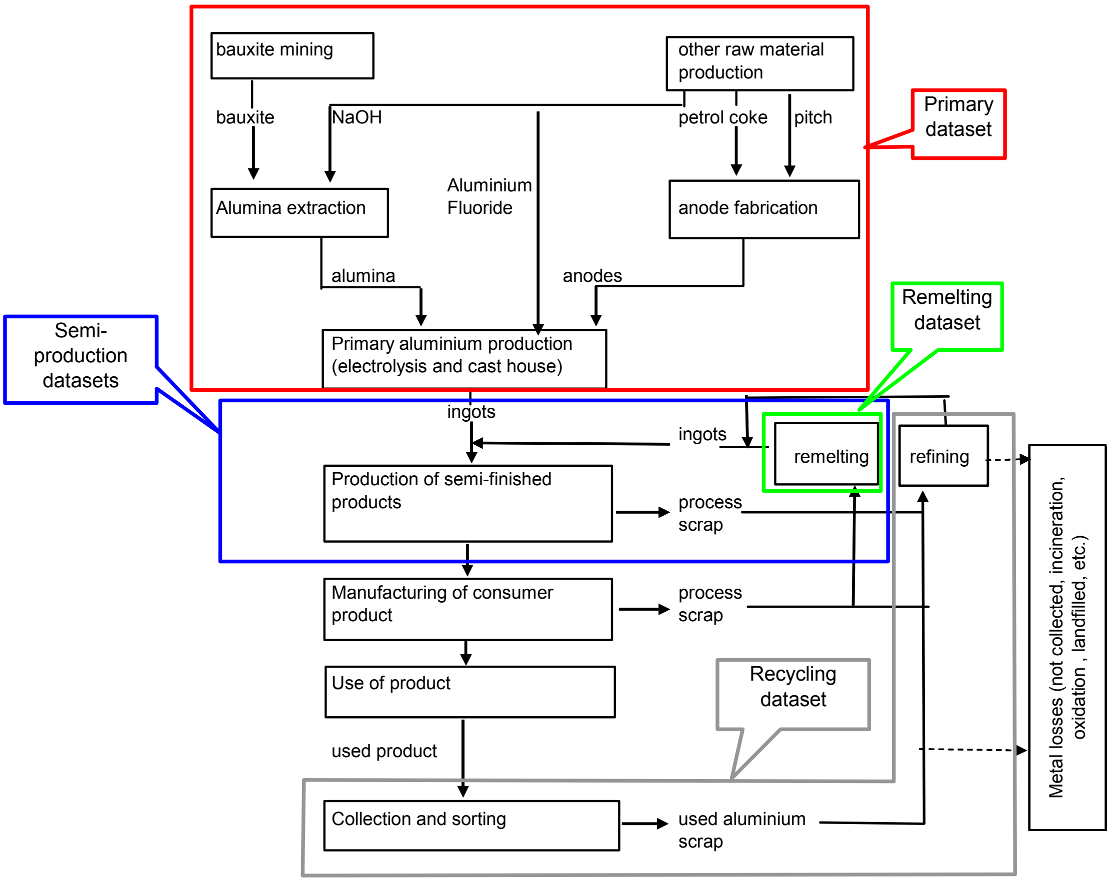

Fig. 2.1 System boundaries of the various LCI datasets

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 scraps preparation phase like shredding, cutting, balling, sorting or/and de-coating as well as 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 [6]. 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) or OEA (www.oea-alurecycling.org) 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 a product or a service,
- 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 2.8 on system boundaries).

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 (www.aluminium.org).

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 2005. The various European plants participating in the survey delivered absolute figures of process inputs/outputs for the whole year 2005 (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 associated LCI datasets.

To generate the European average, an 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 in collaboration with an independent expert. The data collection procedures, the various questionnaires and the consolidated data are part of internal environmental reports which have been submitted to the reviewer for scrutiny. These reports have been validated by the EAA Product Stewardship Working Group. The LCI models (see section 2.7) have been developed in collaboration with PE-International. Six meetings have been organised with Walter Klöpffer, the reviewer, to assess the data collection and consolidation procedures and to examine their integration into the LCI models.

2.6 Allocation principles

As much as possible, allocation has been avoided by expanding the system boundaries (see section 2.8). 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 only significant allocation cases concern 2 ancillary processes:

1) the **production of caustic soda** (NaOH used in the alumina production). In such a case, NaOH and Chlorine are simultaneously produced from the Solvay process. LCI data related to the caustic soda production have been allocated to NaOH on a mass basis.
2) The **production of electricity with co-generation of steam (CHP: combined heat and power).** In this case, allocation is based on the exergetic content, i.e. available or utilizable energy. This allocation principle distributes the environmental aspects of electricity production based on the exergy ratio between electricity and steam. The exergy corresponds to the utilisable energy of a system, i.e. the maximum work possible with the electricity and the steam that brings the system into equilibrium with the environment. The exergy from electricity corresponds directly to the delivered electrical energy. The exergy from steam depends on the initial temperature and pressure of the steam (before use) and its final temperature and pressure after work delivery. Co-generation is used

currently for about 15% of the European electricity production (source COGEN EUROPE, The European Association for the Promotion of Cogeneration www.cogen.org). The exergy of steam is usually comprised between 20 and 40% of the total exergy output. As a result, for the EU25 electricity grid mix, such allocation principle distributes about 5% of the environmental aspects to thermal energy (steam) while 95% are attributed to the electricity production. Regarding the electricity model developed for the primary aluminium production, allocation to thermal energy (steam) is much lower than 5% due to the high hydropower share and the low coal-based electricity production resulting in a lower CHP ratio.

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 LCI data modelling requires not only the combination of the various aluminium processes involved in the production chain but also their connection to ancillary processes like electricity production, fuel extraction and preparation or ancillary raw material production. In a full LCA, the Life Cycle Inventory analysis is ideally based on elementary flows, i.e. material or energy which is drawn from the environment or which is discarded to the environment without subsequent human transformation. Since LCI datasets constitute the building blocks of the Life Cycle Inventory analysis, they should be ideally based on elementary flows, except for some valuable input(s) or/and output(s), i.e. aluminium semi-products in these specific cases.

The GaBi software version 4 [13] has been used to model and develop the various LCI datasets related to the year 2005. Previously, the EAA LCI datasets were produced with the so-called “LCA-2” software which was specifically developed for this purpose. The use of the GaBi software allows including additional processes and materials within the system boundaries and also offers more modelling possibilities. As a result, the new LCI modelling approach has been refined and improved in order to better approach reality. In addition, updated LCI data included in the GaBi software have been used for ancillary processes while the “LCA-2” software mainly used data from BUWAL 250 [11]. Main differences between the current modelling approach (i.e. year 2005) and past modelling approach (years 2002 &1998) are reported in section 2.11.

2.8 System boundaries & background data

The aluminium processes need to be supplemented by relevant supply subsystems or processing subsystems for input and output flows. This system extension is shown in Fig. 2.2 for energy and ancillary raw materials. Instead of reporting the different forms of energy used or listing non-elementary flows, this system extension allows to list elementary flow data of the energy supply subsystem or ancillary raw material subsystem, i.e. element which are directly drawn from the environment. Outputs are then ideally emissions to water, soil and air. 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 not been modelled and integrated within the system boundaries, excepted for the incineration operation. In a next survey, specific data will be collected on solid waste processing and treatment in order to be able to model such operations and to integrate them within the system boundaries.

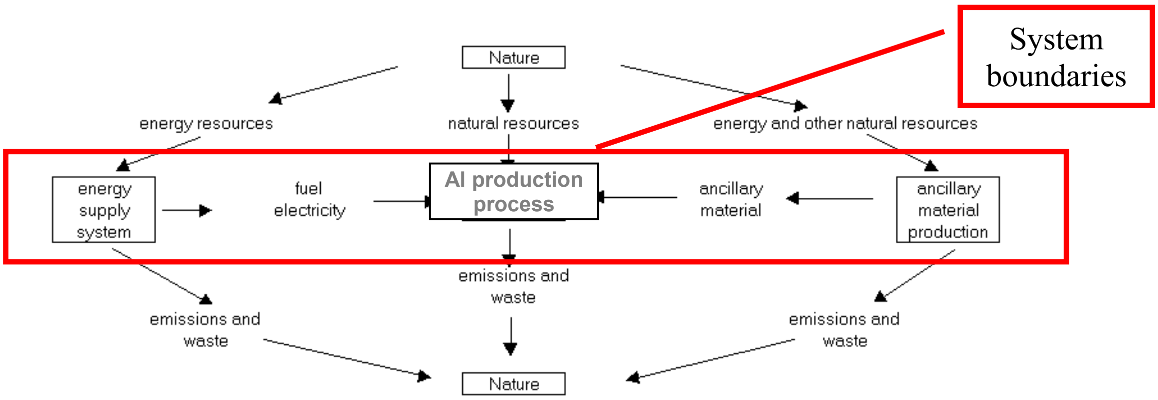

Fig. 2.2 Inclusion of supplementary processes

In addition to the environmental data related to the aluminium processes collected through the EAA surveys, additional inventory datasets (background data) related to supplementary processes have been used. The most important are (list not exhaustive):

- Limestone production
- Caustic soda production
- Aluminium fluoride production
- Petroleum coke production
- Pitch production
- Electricity supply systems
- Fuel supply systems and fuel combustion
- Transportation (boat only)

For Bauxite mining, dataset from the International Aluminium Institute (reference year 2005) has been used [5]. For the supplementary processes as well as for transport, the background data available within the GaBi software version 4 have been used [13].

2.8.1 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 2002 – EU25).

As schematised in Fig.2.3 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.

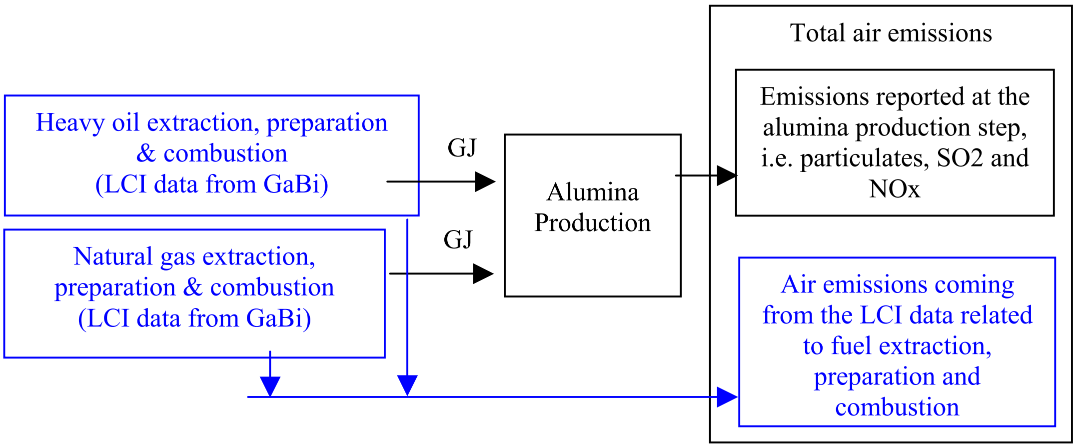

Fig. 2.3 Use of background LCI data related to fuel supply systems and combustion (Background GaBi LCI data in blue)

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.

2.8.2 Electricity production

Electricity production has been included in the system boundaries. Electricity production is particularly critical for the electrolysis step since about 15 MWh/tonne of primary aluminium is used. A specific model has been developed to take into account the structure of the European primary aluminium production as well as the primary aluminium imports to the European market. This model is described in the section 3.4.

For all the other aluminium processes, LCI data related to the EU25 electricity model (reference year 2002) are used. The corresponding power grid mix is reported in Fig 2.4. This EU25 electricity LCI dataset considers 6% of transmission losses. In the previous LCI modelling project referring to the years 1998 and 2002, the UCPTE electricity model was used. The distribution of the energy sources within this UCPTE model and the EU-25 model is quite significant as reported in table 2.1. Shares of hydropower and nuclear energy are significantly reduced in EU25 model vs. UCPTE while fossil fuel energy is significantly up, about 53% in EU25 model vs. 43% for the UCPTE model. As a result, CO_2 & GHG emissions are increased of about 25% in the new EU25 model in comparison to the UCPTE model. This change will significantly affect the LCI data using the EU25 electricity model. It is particularly the case for the sheet, foil and extrusion processes.

Table 2.1 Main energy sources for the UCPTE and EU-25 electricity models

Electricity Model	EU25 (2002)	UCPTE
Used in EAA model	2005	1998 & 2002
Share of Energy sources		
Hydro	10,3%	16,4%
Hard Coal	18,9%	17,4%
Brown coal	10,7%	7,8%
Oil	6,0%	10,7%
Gas	17,3%	7,4%
Nuclear	32,1%	40,3%
Others	4,7%	
Total	100,0%	100,0%
Main emissions (kg/MWh)		
CO2	535	429
Dust	0,116	0,512
NOx (as NO2)	0,99	0,92
SO2	2,74	2,26
GHG emission		
Kg CO2-equiv./MWh	564	454

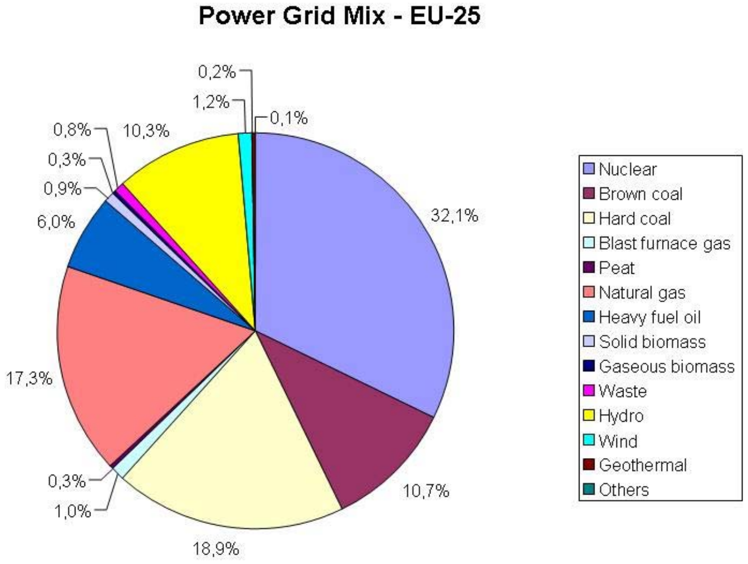
Power Grid Mix - EU-25

Fig. 2.4 EU25 Power grid mix for electricity production used in the LCI modelling (except for primary aluminium production) © PE International – GaBi database, reference year 2002

2.8.3 Transport

Only the sea transport of bauxite and alumina has been modelled and integrated into the LCI dataset for primary aluminium. No transport data have been integrated into the other LCI datasets.

Bauxite used in Europe is imported, mainly from Guinea, Australia and Brazil. Average transport distance for imported bauxite is about 8500 km by sea. Average transport distance for the imported alumina to Europe is around 8000 km by sea. The model also considers 1000 km as the transport distance for bauxite used in the alumina plants exporting to Europe. No transport distance has been considered for the alumina produced in Europe. This transport model has been used also for bauxite and alumina which are used for the production of primary aluminium which is imported into Europe. Fig. 2.5 summarises the average transport distances used in the model.

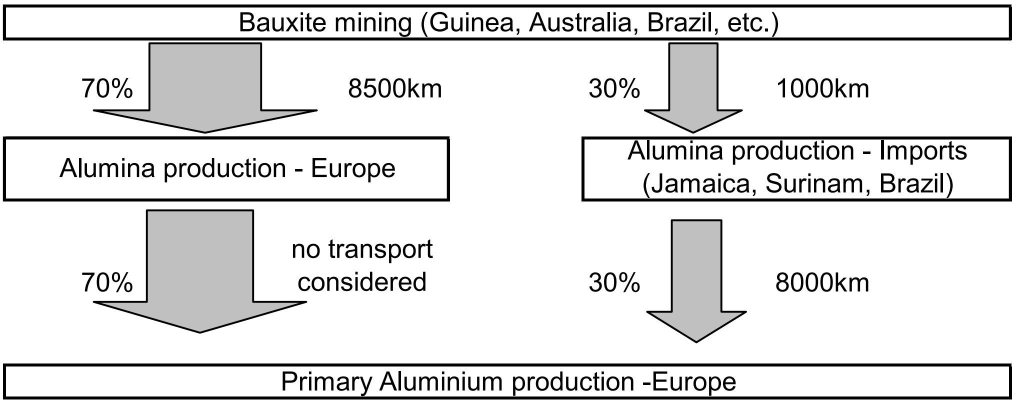

Fig. 2.5 Average sea transport distances of bauxite and alumina

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 8.000 km gives then a consumption of 4.29 kg of heavy oil.

In 1998 survey, data related to road and rail transport distances were also collected and transport distances of alumina and bauxite by these 2 transport means were also modelled. In a next survey, new data should be collected to include these road and rail transports into the LCI model. The table 2.2 highlights the main differences between 2005 & 1998 transport model.

Table 2.2 Average transport distances for bauxite and alumina

Year	Type of transport		Bauxite	Alumina
1998 & 2002	Ocean/Cargo	km	7106	3737
	Coastal/barge	km	2	204
	Road	km	334	15
	Rail	km	11	42
2005	Ocean/Cargo	km	6250*	2400*

*Average distances considering also imported bauxite and alumina.

2.9 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 dataset, most significant and relevant elementary flows are also reported in this master document as summary tables.

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 environmentally sound. The predefined set of impact categories is reported in Table 2.3. Table 2.4 gives a short explanation and definition of these impact categories.

Table 2.3 Pre-defined set of environmental impact categories.

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

Table 2.4 Brief description of the pre-selected environmental impact categories

Indicator	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, CH4 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
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 preparation (shredding, baling, etc.), 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**: Only sea transport for bauxite and alumina.

2.10 Critical review by independent expert

The data collection and consolidation exercise as well as the LCI datasets development have been reviewed by Professor Dr. Walter Klöpffer, Editor-in-chief, International Journal of Life Cycle Assessment, Am Dachsberg 56E, D-60435 Frankfurt. The reviewing report of Professor Klöpffer is annexed at the end of this document. The reviewing process has been organised through an interactive approach and in agreement with the ISO 14040 and 14044 recommendations. Six meetings were organised with the reviewer in order to present and assess the data collection and consolidation procedures and to examine their integration into the LCI models.

2.11 Main differences between current and past modelling approaches

Table 2.5 summarises the main differences between the current and past modelling approaches. A major difference concerns the modelling tool. The updated LCI data have been modelled with the GaBi software (version 4) which includes LCI data for the various ancillary processes. This new tool gives definitely more modelling possibilities than the previous software, i.e. the so-called “LCA-2”, which was developed specifically for the European Aluminium Association and which contained a limited number of LCI data for ancillary processes. The geographical boundaries has also been expanded from “EU15 + EFTA countries” to “EU27+EFTA countries”. The substitution of alloying elements by pure aluminium in the model is also a novelty compared to previous modelling approach. This substitution of alloying elements allows an easy tracking of the metal loss from the new LCI datasets while it was not directly possible with the “old” datasets.

For the primary model, a new and refined electricity model has been developed. This model is explained under the section 3.4. The modelling of the cast house has been also slightly changed to include the sawing of ingot ends and their direct remelting.
For semi-finished products production and scrap remelting, the most significant change concerns the inclusion in the model of the dross recycling and the salt slag treatment. For foil production, the new model assumes that 20% of the production uses strip casting technology while the old model was based only on the classical

production route; no distinction between thin and thick gauges have been possible from the new collected data. For the refining model, a new European scrap mass flow analysis based on the ESSUM model [6] has been used to better control the material input into the recycling model.

Table 2.5 Main differences between LCI modelling approaches of 1998 and 2005

Generic differences		2005	2002 & 1998
Modelling tool		GaBi software	LCA 2 software
Main data sources for ancillary processes		GaBi & ELCD (ref years between 2002 & 2006)	BUWAL 250 (ref year 1998)
Geographical boundaries		EU 27 + EFTA	EU 15 + EFTA
Electricity production model (excluding electrolysis step)		EU25 model developed in GaBi (2002 figures)	UCPTE model
LCI data modularity (i.e. easy combination between the LCI datasets)		Yes (Substitution of alloying elements by pure aluminium and dross/salt slag recycling are included)	No (No substitution of alloying elements by pure aluminium and dross & salt slag recycling not included)
Specific differences		2005	2002 & 1998
Primary aluminium modelling	Transport modelling	Only sea transport for bauxite and alumina	Sea, rail and road transport for bauxite and alumina
	European Electricity model	Based on a consolidation of energy sources at country level and a modelling of electricity production at country level which is then consolidated at European level	Based on a consolidation of energy sources at European level and the modelling of electricity production based on the consolidated European electricity mix
	Electricity model for imports	Based on national grid mix of significant importing countries and specific mix for Russian aluminium producers	Based on IAI 1995 statistical report on energy sources and specific grid mix for Russian producers based on GDA study (German Aluminium Association)
	Cast house	Based on real conditions considering the recycling of sawn ends, sawn ingot as output	Based on virtual aluminium input of 100% liquid aluminium, unsawn ingot as output
Semi-production (extrusion, rolling, foil)	Production chain	All process steps from ingot up to semi-product, excluding ingot sawing	All process steps from ingot up to semi-product, including ingot sawing.
	Process scrap recycling	The recycling of all the scrap produced along production chain are considered, including the dross and salt slag recycling, sawn ingot as output	The remelting of all the scrap produced along production chain are considered, but the recycling of the dross and salt slag is not included, unsawn ingot as output
Sheet production	Ingot homogenisation	Included	Not directly included (see page 22 of the previous report)
Foil production	Modelling	Based 20% on strip casting and 80% on classical production route	Based 100% on classical production route (hot rolling, cold rolling and foil production)
	Foil gauge	No distinction between thick and thin gauge	Distinction between thin gauge (5-20µm) and thick gauge (20-200µm)
Recycling	Remelting model	Dross recycling and salt slag treatment included	Dross recycling and salt slag treatment NOT included
	Refining model	Aluminium scrap input based on ESSUM model [6].	No specific model for scrap flow analysis

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 150 million tonnes of bauxite are mined each year. The major locations of deposits are found in a wide belt around the equator. Bauxite is currently being extracted in Australia (in excess of 40 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 2005 [5] (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 so-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.

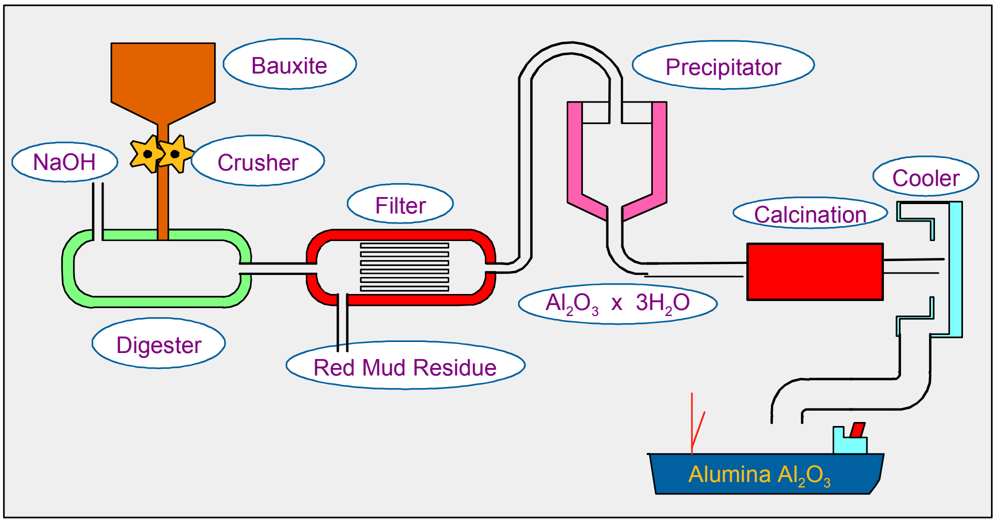

Fig.3.1 Alumina production process

About 2.2 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 230 kWh/t of electricity (see table 3.3 for details).

Solid waste 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 which is frequently called “red mud”. Even if constituents are non-toxic and largely insoluble, red mud requests special handling due to the residual alkaline content resulting from the extraction process. Current practice is to deposit red mud 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. Red mud disposal sites can be re-cultivated once they have dried out. The use of red mud as filler material for road construction or as additive in cement industry is still marginal, but increasing.

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 1920 and 1925 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 2005, the European production mix was 90% of prebake technology for 10% of Söderberg technology.

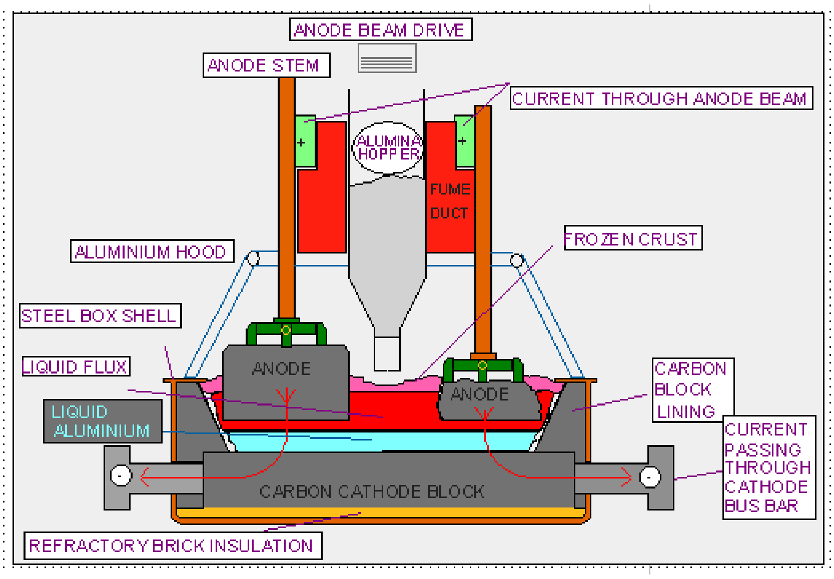

Fig. 3.2 Aluminium electrolytic cell – prebake technology

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 2005, the average electricity consumption of the European smelters was 14914 kWh/tonne of aluminium (min. 13000 kWh – Max 18000 kWh). For imported primary aluminium which represents 36% of the use, this average electricity consumption is 15227 kWh/tonne. 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 and 6)

3.2 Data collection and averaging

The yearly input and output data were collected through 3 environmental surveys covering the year 2005 and focussing 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	6	6,57 Mt (89% used for aluminium production)	90%
Paste and anode production	22 (16 anodes and 6 paste)	2,3 Mt	90%
Electrolysis and cast house	35 (27 pre-bake and 8 Söderberg)	4,5 Mt	92%

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 IAI survey based on the year 2005. 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
Area		World (IAI)
Year		2005
Inputs		
Raw materials		
Fresh Water	m^3	0,5
Sea Water	m^3	0,1
Fuels and electricity		
Diesel Oil	kg	1,1
Heavy Oil	kg	0,2
Electricity	kWh	1,9
Outputs		
Air emissions		
Particulates	kg	0,95
Water emissions		
Fresh Water	m^3	0,47
Sea Water	m^3	0,05

No data about land occupation and about rehabilitation conditions and time have been collected. Considering the growing importance of the land use impact category within LCA studies, it would make sense to collect such types of data within a next survey.

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 2005 can be compared with figures of the years 2002 and 1998 as well with worldwide figures (survey organised by IAI) for the years 2000 and 2005.

About 2200 kg of bauxite is used in Europe for producing 1000 kg of alumina. Bauxite consumption slightly increased since 1998 due to the progressive use of lower grade concentrate. Average bauxite consumption at worldwide level is significantly higher, i.e. around 2700 kg due to the use of lower grade concentrate. Red mud production follows this trend. While 706 kg are produced in Europe in 2005 per tonne of alumina, 1142 kg are produced at worldwide level.

European producers uses 67 kg of caustic soda and 43 kg of calcined lime as reactive chemicals. 3,25 m^3 of fresh water enters the process and 1,9 m^3 exits, giving a consumption of about 1,35 m^3. About 1,4 m^3 of water is used.

European alumina production uses mainly heavy oil (204 kg/tonne) as a source of thermal energy while worldwide production is more balanced between coal, heavy oil and natural gas. Compared to worldwide averages, thermal energy is lower in Europe while electricity consumption is higher.

Table 3.3 Direct input and output data for the production of 1 tonne of alumina

	Unit	**Alumina production (1 tonne of alumina)**				
Area		Europe (EAA)			World (IAI)	
Year		2005	2002	1998	2005	2000
Inputs						
Raw materials						
Bauxite	kg	2199	2147	2138	2739	2685
Caustic Soda (NaOH 100%)	kg	67	59	60	89	82
Calcined Lime	kg	43	47	46	40	45
Fresh Water	m^3	3,25	3,6	3,7	7,9	3,3
Sea Water	m^3		0		0,1	3,4
Fuels and electricity						
Coal	kg	0	0	8,5	88,4	96
Diesel Oil	kg	0,3	19,6	0	0,7	0,6
Heavy Oil	kg	204,1	222,4	212	101,4	115
Natural Gas	kg	24,0	17,6	26,4	92,8	96,8
Propane	kg	3,0				
Total Thermal energy	*MJ*	*9.514*	*10.649*	*10.043*	*10.970*	*11.925*
Electricity	kWh	241	237	230	126	106
Outputs						
Air emissions						
Particulates	kg	0,23	0,21	0,67	0,17	0,63
NOx (as NO2)	kg	1,22	1,06	1,57	0,88	1,17
SO2	kg	3,94	7,59	10,5	3,4	5,3
Water emissions						
Fresh Water	m^3	1,9	2,8	2,3	5,3	3,3
Sea Water	m^3				0,1	3,4
Oil/Grease	kg	0,078	0,084		0,47	0,07
Suspended Solids	kg	0,07	0,13	0,26	0,05	0,74
Mercury	**g**	0,0001	0,012			0,001
By-products for external recycling						
Bauxite residue	kg	8,4	5,8		11,1	1,2
Other by-Products	kg	4,5	0,4		5,6	1,8
Solid waste						
Bauxite residue (red mud)	kg	706	713	669	1142	990
Other waste (sand, tailings, etc.)	kg	60	26	21	25	25

No specific data have been collected about land occupation and rehabilitation time for the red mud deposits. Considering the growing importance of the land use impact category within LCA studies, it would make sense to collect such types of data within a next survey.

3.2.3 Anode & paste production

Direct input and output data related to the production of 1 tonne of mixed paste (10%) and anode (90%) are reported in table 3.4. Average European figures of the year 2005 can be compared with figures of the years 2002 and 1998 as well with worldwide figures (survey organised by IAI) for the years 2000 and 2005.

Table 3.4 Direct input and output data for the production of 1 tonne of anode (90% prebake anode, 10% carbon paste)

	Unit	**Anode / paste production**				
Area		Europe (EAA)			World (IAI)	
Year		2005	2002	1998	2005	2000
Inputs						
Raw materials						
Petrol Coke	kg	737	712	691	681	689
Pitch	kg	173	178	171	171	182
Recycled butts	kg	165	164	188	N.A.	N.A.
Total carbon input		1075	1054	1050		
Other raw material inputs						
Fresh Water	m^3	3	1,9	4,3	2,3	2,2
Sea Water	m^3	1,4	2,6			0,002
Refractory materials	kg	11	8,8	10,1	6,2	12,5
Steel (for anodes)	kg	1,2	1,6		5,1	3,1
Fuels and electricity						
Coal	kg	0	4,3	0,0	2,2	2,1
Diesel Oil	kg	0,02	2,7	0,2	2,3	3,2
Heavy Oil	kg	14,2	16,7	23,1	11,3	14,1
Natural Gas	kg	45,9	44,7	41,0	42,3	42,4
Total Thermal energy	*MJ*	*2677*	*2987*	*2820*	*2568*	*2721*
Electricity	kWh	145	153	131	129	141
Outputs						
Air emissions						
Fluoride Gaseous (as F)	kg	0,052	0,087	0,09	0,014	0,046
Fluoride Particulate (as F)	kg	0,035	0,063	0,05	0,002	0,01
Particulates	kg	0,21	0,25	0,31	0,207	0,3
NOx (as NO2)	kg	0,32	0,29	0,24	0,253	0,29
SO2	kg	1,54	1,23	0,91	1,95	1,7
Total PAH	kg	0,051	0,062	0,098	0,06	0,055
BaP (Benzo-a-Pyrene)	**g**	0,14	0,67	3,2	0,08	0,24
Water emissions						
Fresh Water	m^3	2,3			0,92	
Sea Water	m^3	1,4				
Fluoride (as F)	kg				0,0005	
Oil/Grease	kg				0,0001	
PAH (6 Borneff components)	g	0,1			0,13	
Suspended Solids	kg	0,3			0,002	
By-products for external recycling						
Other by-Products	kg	10,5	6,1	26,5	6,2	6,4
Refractory material	kg	6	9,3		6,7	6,9
Steel	kg	4,1	0,7		3,7	3,9
Solid waste						
Carbon waste	kg	1,7	5,1	4,6	18,1	5,4
Other landfill waste	kg	2,6	3,2		4,1	5,7
Refractory waste - landfill	kg	0,4	2,6	10,5	1,8	6,2
Scrubber sludges	kg	0,6	0		0,5	1,9

In 2002 and 2005 as compared to 1998, return butts have contributed less as raw material for the production of anodes (165 kg/t instead of 188). Use of Petrol coke has increased accordingly (737 kg/tonne) in 2005. Fuel and electricity consumption in

Europe is stable and similar to global figures. Fresh water and seawater are used mainly for gas scrubbing.

Regarding air emissions, particulate fluoride (-55% over 2002) and gaseous fluoride (minus 60% over 2002) decrease in Europe but are still higher than the world (IAI) average. The more intensive use of recycled anode butts (contaminated with fluorides) may explain these higher figures as well as possible difference in exhaust fume treatment technology. Since 1998, PAH emissions decrease to the range of the world (IAI) average. BaP is significantly reduced from 1998 (3,2g/t) till 2005 (0,14g/t) but European figure is higher than global average (0,08 g/t).

By-products and waste are quite stable in Europe. Carbon waste is higher at global level than in Europe.

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 2005 can be compared with figures of the years 2002 and 1998 as well with worldwide figures (survey organised by IAI) for the years 2000 and 2005.

Comments on input trends
Alumina consumption is stable around 1923-1925 kg/tonne. Gross (536 kg/t) and net (428kg/t) carbon anode & paste consumption are slightly down from 1998 till 2005.
Aluminium fluoride consumption (18,9kg/t) is stable.
European electricity consumption in 2005 reaches 14914 kWh/t, i.e. 4% down compared to 1998. This positive trend results from optimised operating conditions, combined with the progressive phasing out of Söderberg plants which reduce their share in total European production. Average electricity consumption at global level is about 2,5% higher in 2005, i.e. 15289 kWh/t.

Fresh water is mainly use 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).

	Unit	**Electrolysis**				
Area		Europe (EAA)			World (IAI)	
Year		2005	2002	1998	2005	2000
Inputs						
Raw materials						
Alumina	kg	1925	1924	1923	1923	1925
Anode/paste (gross)	kg	536	553	557		
Anode/paste (net)	kg	428	447	448	435	441
Aluminium Fluoride	kg	18,9	19,0	18,7	16,4	17,4
Cathode Carbon	kg	6,3	10,3	7,5	8	6,1
Other raw material inputs						
Fresh Water	m3	9,6	5,2		5,3	2,9
Sea Water	m3	58	69,2		17,6	20,7
Refractory materials	kg	8,6	9,88	8,6	5,4	6,1
Steel (for cathodes)	kg	5,4	7,5	9,4	6,6	5,5
Collar/ramming paste	kg			6,5		
Fuels and electricity						
Diesel Oil	kg			1,5		
Heavy Oil	kg			0,7		
Natural Gas	kg			2,4		
Electricity	kWh	14.914	15.389	15.574	15.289	15365
Outputs						
Air emissions						
Fluoride Gaseous (as F)	kg	0,56	0,53	0,54	0,55	0,55
Fluoride Particulate (as F)	kg	0,44	0,41	0,61	0,49	0,5
Particulates	kg	2,3	2,33	2,62	3,7	3,3
NOx (as NO2)	kg	0,65	0,41	0,16	0,32	0,35
SO2	kg	8,2	8,3	8,85	14,9	13,6
Total PAH	kg	0,041	0,031	0,047	0,29	0,13
BaP (Benzo-a-Pyrene)	**g**	1,3	1,47	2,75	2,6	5
CF4	kg	0,087	0,164	0,252	0,13	0,22
C2F6	kg	0,01	0,014	0,028	0,013	0,021
Water emissions						
Fresh Water	m^3	9,1	4,8		4,9	3,1
Sea Water	m^3	57	69,3		17,6	20,9
Fluoride (as F)	kg	0,62	0,56		0,32	0,2
Oil/Grease	kg	0,001	0,005		0,008	0,008
PAH (6 Borneff components)	g	3,32	1,81		1,64	3,77
Suspended Solids	kg	0,81	0,57		0,2	0,21
By-products for external recycling						
Anode butts	*kg*	*107*	*106*	*109*		
Refractory material	kg	0,9			2,3	0,5
SPL carbon fuel/reuse	kg	4,7	7,7	9,6	4,8	9,9
SPL refr.bricks-reuse	kg	4,8	7,9		4	5,5
Steel	kg	5,8	11,5	7	8,9	6,9
Other by-products	kg	5	5,45	4,5		5,1
Solid waste (landfilled)						
Carbon waste	kg	6,8	3,3	3,1	6,9	4,6
Refractory waste - landfill	kg	0,3	0,07		0,5	1,2
Scrubber sludges & filter dust	kg	1,3	1,9	2	4,7	13,7
SPL - landfill	kg	13,4	19,9	22,9	13,2	17,3
Waste alumina	kg	1,4	2,3		2,6	4,7
Other landfill waste	kg	5,3	6,3	5,1		7,3

Comments on output trends

European fluoride air emissions are stable and similar to the global figures. Regarding other air emissions, Europe appears more efficient than rest of the world regarding SO_2, PAH (Polycyclic Aromatic Hydrocarbons) and BaP (Benzo[a]Pyrene) but less efficient regarding NOx. PFC emissions in 2005 (0,087 kg CF_4/t & 0,010 kg C_2F_6/t) are significantly reduced compared to 1998, i.e. about 65% reduction. European PFC figures are about 30% lower than global average. Reduction in PFC emissions results from a better control of the alumina feeding process which significantly reduces the frequency of the anode effects as well as from the lower contribution of the Söderberg technology to the European mix.

As stressed for the water input, European average emission data for water output is not very significant.

In 2005, about 20 kg of solid by-products are recycled and about 27 kg of solid waste are landfilled in Europe per tonne of liquid aluminium. Global figures are similar to European ones.

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 2005 can be compared with figures of the years 2002 and 1998 as well with worldwide figures (survey organised by IAI) for the years 2000 and 2005.

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 2005, solid metal input represents about 25% of the metal input.

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 quite similar to the global consumption. Europe uses more electricity but the consumption stays small compared to the use at the electrolysis step. Comparison with the year 1998 is not directly possible since figures related to 1998 have been extrapolated in order to reflect an input of 100% liquid aluminium.

Table 3.6 Direct inputs and outputs for the production of 1 tonne of sawn aluminium ingot at the cast house.

	Unit	Ingot Casting				
Area		Europe (EAA)			World (IAI)	
Year		2005	2002	1998	2005	2000
Inputs						
Raw materials						
Liquid aluminium from electrolysis	*kg*	784	843	832		
Aluminium ingot	*kg*	99	133	169		
Aluminium scrap	*kg*	108	35			
Total Aluminium	*kg*	*991*	*1011*	*1001*		
Alloy additives	kg	31	17	11	20	20
Chlorine	kg	0,030	0,06	0,1	0,036	0,07
Other raw material inputs						
Fresh Water	m3	3,1	7,5	4,7	4,5	3,15
Sea Water	m3	0,8	1			0,23
Refractory materials	kg			0,7		
Fuels and electricity						
Coal	kg				1,2	
Diesel Oil	kg	0,8		*0,1**	1,4	0,1
Heavy Oil	kg	7,7		*10,9**	5,7	10
Natural Gas	kg	20,3		*13,9**	24	41,6
Total Thermal energy	*MJ*	*1276*		*1082**	*1424*	*2312*
Electricity	kWh	126		*16**	83	81
Outputs						
Air emissions						
Particulates	kg	0,042	0,06	0,0003	0,02	0,1
NOx (as NO2)	kg	0,17	0,18	0,064	0,11	0,16
SO_2	kg	0,32	0,62	0,031	0,04	0,29
HCl (Hydrogen Chloride)	kg	0,042	0,02		0,01	0,07
Water emissions						
Fresh Water **	m^3	2,5	6,0			
Oil/Grease	kg	0,007	0,01		0,01	0,01
Suspended Solids	kg	0,02	0,02		0,03	0,03
By-products for external recycling						
Dross	kg	15,7	20,5	18,6	13,3	16,0
Filter dust	kg	0,65	0,14		0,63	0,72
Refractory material	kg	0,44	0,47		0,24	0,61
Scrap sold	kg	2,2	1,63			2,8
Solid waste (landfill)						
Dross - landfill	kg	2,1	1,36		2,5	9,7
Filter dust - landfill	kg	0,2	0,19		0,15	0,5
Refractory waste - landfill	kg	0,4	0,8	0,9	1,2	0,8
Other landfill wastes	kg	1,3	1,02		0,2	1,6

(*) Figures extrapolated for 100% liquid aluminium as an input

** Due to inconsistencies, water output is calculated on basis of 80% of water input.

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) which represents 17.8 kg/t in Europe from which 15.7 kg is recycled. 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 2005, reported in tables 3.3 to 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**: 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. The modelling will consider such addition of solid aluminium but as pure aluminium which is internally recycled within the cast house. As a result, alloying elements (31 kg/tonne of ingot) are then substituted by a pure solid aluminium input.

- **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 dross which are landfilled, the oxidation of the aluminium melt and the aluminium metal which is not recovered from the dross. The model calculates the metal losses to 6 kg/tonne (i.e. 0.6% of metal losses).

Based on above assumption, 1006 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
Considering above modelling assumptions, the average consumptions of main raw materials for producing 1 tonne of ingot have been calculated and are reported in Fig.3.4 and table 3.7.

Within this new model, 1006 kg of liquid aluminium from the electrolysis are needed to produce 1 tonne of sawn ingot. The amount of 6 kg represents the metal losses mainly due to oxidation during casting, sawing and scrap remelting. In the previous model, 1001 kg of liquid aluminium were needed to produce 1 tonne of ingot. As reminder, the previous model did not substitute alloying elements by pure aluminium and did not include dross recycling within the system boundaries so that metal losses could not be directly evaluated.

Table 3.7 Main raw materials for the production of 1 tonne of primary ingot.

Main raw materials	Process step	Year		
		2005	2002	1998
Bauxite (input alumina)	Alumina	**4259**	4131	4111
Caustic Soda (50%)	Alumina	**260**	226	231
Lime	Alumina	**83**	90	88
Alumina	Electrolysis	**1936**	1924	1923
Anode/paste (net)	Electrolysis	**428**	447	448
Liquid aluminium	Casting	**1006**	1000	1001

The substitution of alloying elements in the new model apparently increases the alumina consumption since 1936 kg are needed per tonne of sawn ingot while 1923 kg were consumed in 1998. 4259 kg of bauxite are used according to the new model vs. 4111 kg according to the 1998 model.

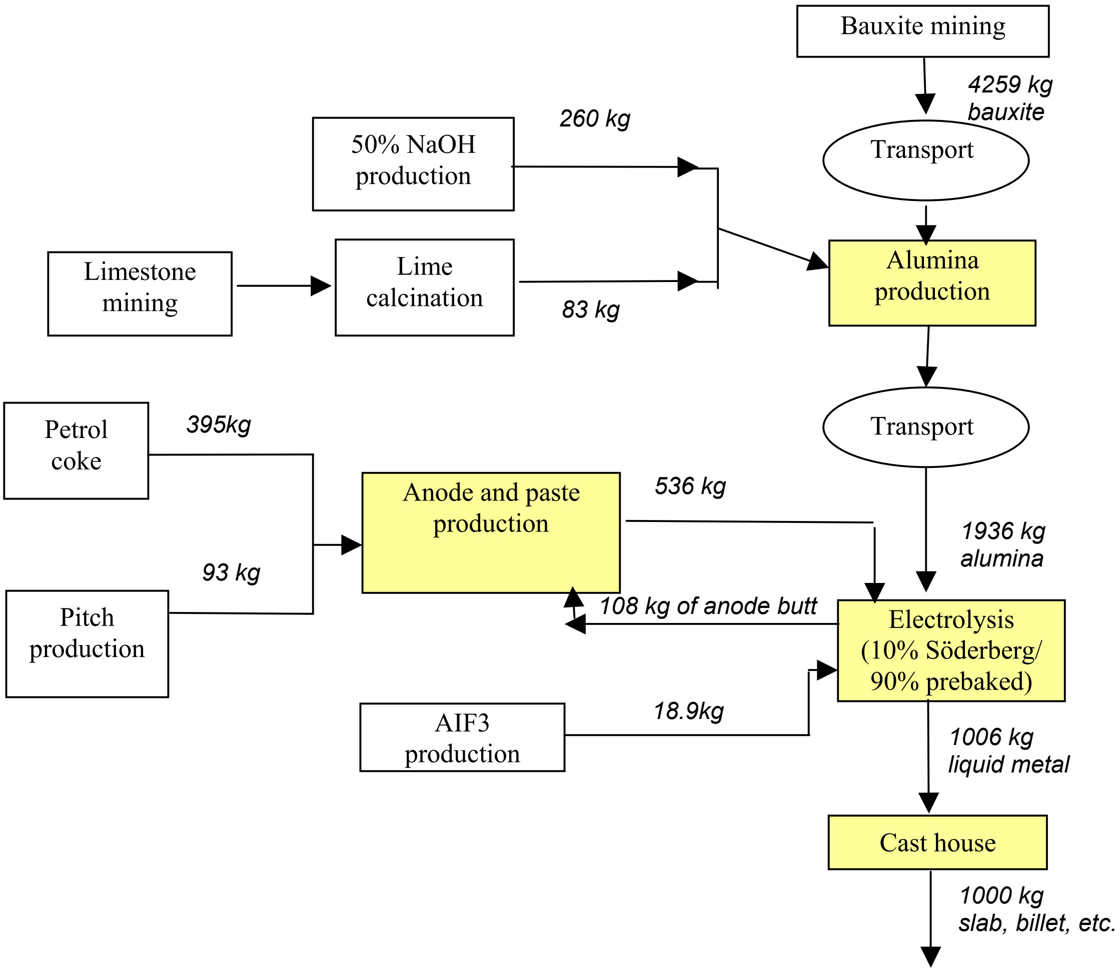

Fig. 3.4 Main raw material inputs for primary aluminium production in Europe.

3.4 EAA electricity model 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 about one third 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 which is imported to Europe. The two next sub-sections explain how European production and imported primary aluminium are considered to build the EAA electricity model.

3.4.1 Electricity used by European primary aluminium smelters

The electricity model uses the electricity consumption reported by the various European smelters participating in the survey. 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 National level for each energy source.**
The electricity consumption reported by the smelters is firstly aggregated by energy sources at national level. This consolidation gives, for the year 2005, a table listing, for each European country producing primary aluminium (included in the reporting survey), the electricity consumption in TWh or GWh for each energy sources. For confidentiality issue, this matrix cannot be reproduced.

2) Consolidation at European level for calculating the total electricity consumption
National consumptions are then consolidated at European level in order to calculate the total electricity consumption in Europe for the primary aluminium production of the reporting smelters.

3) Calculating contribution of each country per energy source
The contribution of each energy source within each country is then calculated by dividing the "country vs. energy sources" matrix by the total European electricity consumption. This normalisation allows distributing the production of 1 kWh at European level among the various European countries and energy sources.

4) Modelling the electricity production in each European country according to the specific distribution of the energy sources
For each country, the production of electricity is modelled according to the specific distribution of the energy sources. 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. Each of these LCI datasets related to electricity production has been weighted according to their respective contribution in the European model.

5) Building the European model
The various national LCI blocks are then combined at European level in order to model the LCI datasets associated with the production of 1kWh of electricity used in Europe for the production of primary aluminium.

Table 3.10, under section 3.4.3, reports the European consolidation of the energy sources for the electricity production which is used by the European smelters. Such figures are reported for the years 2005, 2002 and 1998.

3.4.2 Electricity used for the production of imported aluminium

In 2005, 36% of the primary aluminium used in Europe (i.e. EU27 & EFTA countries) came from imports. This figure has been calculated from average customs statistics (source Eurostat) on 4 years from 2003 until 2006 in order to remove any influence of year-specific data inconsistent with the overall trend.

As reported in table 3.8, most of these imports come from Russia (40%), Mozambique (18%) and Brazil (12%).

Table 3.8 Geographical distribution of the primary aluminium imports into Europe – average on years 2003 – 2006 (source Eurostat)

Area	Import share	Origins
Rest of Europe:	48%	80% Russia, 8% Montenegro, 5% Bosnia Herzegovina, 3% Ukraine
Africa	23%	71% Mozambique, 9% Cameroon, 7% South Africa, 7 % Egypt
Latin America	14%	90% Brazil
Asia	10%	47% United Arab Emirates, 40% Tajikistan
North America	4%	91% Canada
Oceania	1%	
Total	100%	

Table 3.8 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 3.8 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 3.8, except for Russia and Ukraine for which specific data provided by the aluminium producer have been used. Data from the International Energy Agency (reference year 2005) have been used to determine the national grids for electricity production [18].
- Weighting and consolidation of the country grid mixes have been done at regional level. Consolidated figures are reported in table 3.9.
- For each of these regions, modelling of the electricity production based on the calculated electricity grid mix, using power plant data which are representative for the region, e.g. electricity from natural gas in Latin America uses Brazilian data or electricity from coal in Africa uses South African data.
- 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 3.9.

Table 3.9 Energy sources for the electricity used for the production of imported primary aluminium

Area	Import share	Electricity production					
		Hydropower	Coal	Oil	Natural gas	Biomass	Nuclear
Rest of Europe	48%	88,4%	2,9%	0,1%	4,3%	0,0%	4,3%
Africa	23%	85,6%	6,9%	1,6%	5,8%	0,0%	0,4%
North America	4%	58,0%	17,0%	3,0%	6,0%	1,0%	15,0%
Latin America	13%	84,0%	2,0%	3,0%	5,0%	4,0%	2,0%
Asia	10%	45,1%	0,0%	1,1%	53,9%	0,0%	0,0%
Oceania	1%	Not considered					
Consolidation		**81,5%**	**4,0%**	**1,0%**	**9,8%**	**0,6%**	**3,1%**

Based on the energy survey of the year 2005 organised by the International aluminium Institute and based on the structure of the primary imports, the calculation of the specific electricity consumption at the smelter gives **15227 kWh/tonne** for the imported aluminium, excluding the assumed 2% of transmission losses.

3.4.3 EAA electricity model

Fig. 3.5 schematises the EAA electricity model combining the 64% of European production and the 36% of primary aluminium imports.

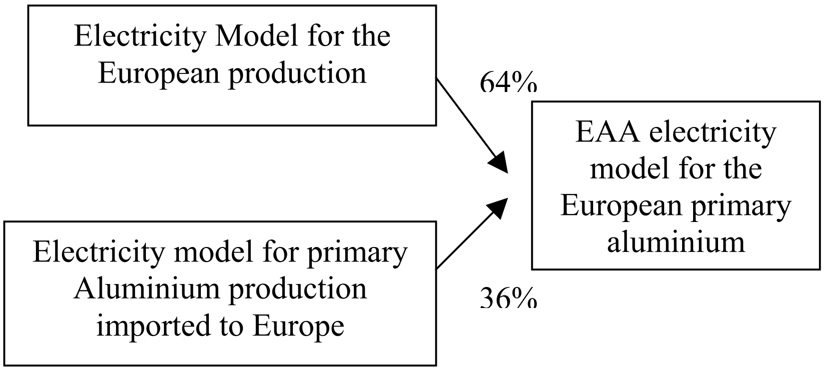

Fig. 3.5 EAA model of electricity production for the European primary aluminium considering the aluminium imports

Table 3.10 reports the share of the various energy sources for the electricity production of the EAA model, including the imports. Figures related to the previous model developed for the years 1998 and 2002 are also reported.

Table 3.10 Distribution of the energy sources for the EAA electricity model

	European model			Imports			EAA model		
Year	**2005**	2002	1998	**2005**	2002	1998	**2005**	**2002**	1998
Production share	**64%**	68%	61%	**36%**	32%	39%			
Share of Energy sources									
Hydro	**44,9%**	45,7%	40,5%	**81,5%**	67,9%	71,0%	**58,0%**	52,8%	52,4%
Hard Coal	**14,8%**	15,8%	17,5%	**4,0%**	26,4%	23,7%	**10,9%**	19,2%	19,9%
Brown coal	**5,8%**	6,7%	7,7%		0,0%		**3,7%**	4,6%	4,7%
Oil	**2,7%**	4,8%	5,1%	**1,0%**	0,0%	0,4%	**2,1%**	3,3%	3,3%
Gas	**9,8%**	7,6%	5,5%	**9,8%**	4,2%	3,6%	**9,8%**	6,5%	4,8%
Nuclear	**21,8%**	19,4%	23,7%	**3,1%**	1,4%	1,3%	**15,0%**	13,6%	15,0%
Other (biomass)	**0,2%**			**0,6%**			**0,3%**	0,0%	
Total	**100,0%**	100,0%	100,0%	**100,0%**		100,0%	**100,0%**	**100,0%**	100,0%

According to the consolidated model (EAA model), hydropower appears clearly the most significant source of energy to produce the electricity consumed by the primary aluminium which is used in Europe. This hydropower share increased from about 53% in 2002 and 1998 to 58% in 2005.

For the European model, the increase of the share of the hydropower since 1998 results mainly from expansion and new plants located in Nordic countries (Norway and Iceland).

Regarding imports, the high share of hydropower can be explained as follows:

- In Russia, most of the smelters are located directly in the neighbourhood of hydropower plants which supply directly their electricity
- The other countries exporting primary aluminium to Europe use mostly hydropower to produce their electricity, e.g. Mozambique, Cameroon, Canada or Tajikistan.

The second point also explains the big difference with the previous modelling approach which only differentiated 2 exporting regions: Imports from Russia and imports from Western world. In this previous model, the share of hydropower for the imports from Western world reached 61% while it reaches about 75% with the new model considering the precise origins of the imported aluminium.

While coal represented about 25% of the energy source in the 1998 EAA model, it represents 15% only in the 2005 model, 10,9% from hard coal and 3,7% from brown coal. In the meantime, natural gas is becoming a significant energy source since its share has doubled from 4,8% in 1998 to 9,8% in 2005. The nuclear energy is stable around 15%.

Primary energy resources, main air emissions figures and GHG emission associated with the electricity production for 1 tonne of primary aluminium is reported in table 3.11.

Table 3.11 Energy resources, air and GHG emissions for the electricity consumed by the electrolysis step for 1 tonne of primary aluminium according to the EAA model

	Unit	European smelters			EAA model		
Year		**2005**	2002	1998	**2005**	2002	1998
Smelter consumption	kWh	**14914**	15389	15574	**15027**	15389	15574
Total consumption (including 2% transmissin losses)	kWh	**15212**	15697	15885	**15328**	15697	15885
Primary energy resources							
brown coal	kg	**983**	1523	1993	**634**	1034	1207
hard coal	kg	**883**	925	1049	**703**	1112	1187
natural gas	kg	**367**	312	194	**383**	267	166,4
crude oil	kg	**126**	225	248	**93**	161	164
nuclear electricity	kWh	**3316**	2979	3627	**2299**	2071	2241
hydroelectricity	kWh	**6830**	7002	6225	**8890**	8114	8072
Air emissions							
CO2	kg	**4562**	5259	5617	**4230**	5405	5499
CO	kg	**1,47**	0,92	0.89	**1,4**	0,9	0.84
SO2	kg	**15,5**	23,7	36.4	**13,4**	23,1	30.0
NOx (as NO2)	kg	**7,8**	11,2	12.0	**7,5**	12,3	12.5
CH4	kg	**9,8**	13,3	13.6	**8,6**	16,7	17.0
Dust	kg	**1**	6,6	6.9	**0,9**	7,5	7.6
GHG	kg CO2 equiv	**4836**			**4462**	**5783**	**5884**

For the electricity production, significant reductions are observed in term of air emissions and primary energy consumption, compared to the year 1998 and 2002. Only natural gas increases while all other primary energy resources are reduced. This is particularly the case for the combined EAA model due to the high hydropower share of the electricity consumed by the aluminium production which is imported to Europe. The CO_2 emission for the production of electricity which is used at the electrolysis step is then significantly reduced since 4230 kg of

CO_2 per tonne of electrolysed aluminium is calculated in 2005 against 5405 kg in 2002 or 5499 kg in 1998. This reduction of about 23% is mainly due to the higher share of hydropower and the improved efficiency of power plants. SO_2, NO_x, CH_4 and dust are also significantly reduced.

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. European averages of the year 2005, as reported in tables 3.3 to 3.6, have been used for the model. The only exception concerns air emissions of the electrolysis step for the imported aluminium. In such case, worldwide IAI data of the year 2005 have been used. The full LCI dataset is available on request at lci@eaa.be. Table 3.12 reports the main LCI data while table 3.13 reports the associated informative environmental indicators.

Comments on input trends

In 2005, it is calculated that 4259 kg of bauxite is directly needed to produce 1 tonne of primary aluminium against 4111 kg and 4131 kg respectively in 1998 and 2002. This increase results from the progressive use of lower grade concentrate and from the higher alumina consumption resulting from the new modelling approach substituting alloying elements by pure aluminium. Limestone and sodium chloride are the two other major raw materials which are consumed (alumina process).

Except for natural gas, the consumption of fossil fuels is considerably reduced. This reduction results mainly from the refined electricity model which relies more on hydropower-based electricity and from the better efficiency of fuel-based power plant compared to BUWAL data [11] used in the previous modelling approach. The reduction of electricity consumption (4% vs. 1998) at the electrolysis step and the reduction of anode consumption (4% vs. 1998) also contribute to this decrease in fossil-based primary energy.

Comments on output trends

Regarding air emissions, significant reductions are observed for dust, organic compounds, CO_2, SO_2, CH_4 and NO_x, mainly due to the lower contribution of the electricity production and the optimised process and combustion conditions. Fluoride emissions (HF & fluorides) are stable. PAH and BaP emissions are increased vs. 1998 due to the contribution of emissions from imported aluminium. PFC emissions, i.e. C_2F_6 (R116 - hexafluoroethane) and CF_4 (Tetrafluoromethane), are significantly reduced thanks to a better control of the anode effects.

Red mud (1375 kg/tonne) is slightly increasing vs. 1998 but stable vs. 2002. Solid waste for landfilling, mainly composed of refractories, accounts for about 25 kg/tonne. About 40 kg of solid output for recovery or recycling are produced from which 25 kg is bauxite residue (red mud) which is further processed.

Table 3.12 Main LCI data for the production of 1 tonne of primary aluminium used in Europe – data of the year 2005, 2002 and 1998.

Year	**2005**						**2002**	**1998**	Comments/difference
Main inputs (kg)	**Total**	Direct process	Auxiliary	Electricity	Thermal energy	Transport	**Total**	**Total**	
Bauxite	**4272**	4259	13	0	0	0	4131	4111	
Energy sources									
Crude oil	**762**	285,7	14,2	99,4	343,2	19,5	1381	1369	
Hard coal	**892**	110,2	35,0	738,2	8,1	0,4	1360	1464	
Brown coal	**756**	6,6	69,4	675,8	3,8	0,3	1144	1328	
Natural gas	**650**	28,8	24,2	404,7	190,8	1,5	445	408	
Main outputs (kg)									
Emissions to air									
Carbon dioxide - CO2	**8566**	1804	353	4584	1758	68	10521	10634	
Carbon monoxide - CO	**3,08**	0,52	0,25	1,53	0,57	0,21	3,3	96	
Fluorides (particles)	**0,55**	0,55	0,00	0,00	0,00	0,00	0,44	0,49	Excluding HF
Hydrogen chloride - HCl	**0,24**	0,04	0,00	0,18	0,01	0,00	1,26	1,4	
Hydrogen fluoride - HF	**0,60**	0,56	0,00	0,03	0,00	0,00	0,71	0,75	
Nitrogen oxides - Nox	**14,0**	1,2	0,4	8,2	2,7	1,4	24	27	
Sulphur dioxide -SO2	**34,2**	11,5	0,6	15,0	6,3	0,8	66,3	72	
Methane	**14,32**	2,06	0,56	9,21	2,43	0,06	21	20	
Group NMVOC to air (non-methane volatile organic compounds)									
Group PAH to air	**0,151**	0,150	0,000	0,000	0,000	0,000	0,066	0,1	
Benzo{a}pyrene	**0,0024**	0,0024	0,0000	0,0000	0,0000	0,0000	0,0018	0,0032	
R 116 (hexafluoroethane -C2F6)	**0,010**	0,010	0,000	0,000	0,000	0,000	0,014	0,028	
Tetrafluoromethane -CF4	**0,109**	0,109	0,000	0,000	0,000	0,000	0,16	0,252	
Ethane	**0,314**	0,051	0,009	0,137	0,114	0,003			Not listed in 1998
Propane	**0,406**	0,089	0,009	0,147	0,156	0,005			Not listed in 1998
Total NMVOC to air	***2,008***	*0,646*	*0,057*	*0,713*	*0,526*	*0,067*	*9,9*	*9,9*	
Particles to air									
Aluminum oxide (dust)	**1,34**	1,34	0,00	0,00	0,00	0,00			Not listed in 1998
Dust (PM10)	**0,15**	0,01	0,00	0,08	0,06	0,00			Not listed in 1998
Dust (PM2.5)	**0,73**	0,00	0,01	0,58	0,13	0,00			Not listed in 1998
Dust (unspecified)	**7,27**	6,49	0,36	0,34	0,03	0,04			Not listed in 1998
Total particles to air	***9,49***	*7,84*	*0,38*	*1,00*	*0,22*	*0,04*	*16,5*	*27*	
Solid waste (deposited)									
Red mud (dry)	**1375**	1374	0	0	0	0	1373	1286	Main residues from alumina production
Solid Waste (landfilled)									
Refractory (including SPL landfilled)	**15,1**	15,1	0,0	0,0	0,0	0,0	22,2	22,2	SPL included
Sludge	**4,0**	2,2	1,9	0,0	0,0	0,0		2,0	
Dross (Fines)	**5,8**	5,8	0,0	0,0	0,0	0,0	0,8	0,11	
Solid output for incineration									
Carbon waste (including SPL carbon fraction)	**0,0**	**(12,6)**	**0,0**	**0,0**	**0,0**	**0,0**	7,7	9,6	Incineration included in the 2005 model
Solid output for recovery or recycling									
Dross	**0,0**	(15,7)	0,0	0,0	0,0	0,0	20,5	18,6	Dross recycling included in the 2005 model
Aluminum oxide (alumina)	**1,4**	1,4	0,0	0,0	0,0	0,0			
Bauxite residue	**25,2**	25,2	0,0	0,0	0,0	0,0	11,2		
Refractory (including SPL refractory fraction)	**7,8**	7,8	0,0	0,0	0,0	0,0	**13,5**		
Smelter by-products	**4,5**	4,5	0,0	0,0	0,0	0,0	9,6		
Steel scrap (St)	**0,0**	(7,3)	0,0	0,0	0,0	0,0	11,9	7	Steel recycling and production included in the 2005 model

Environmental indicators

Associated environmental indicators for the predefined impact categories are reported in table 3.13. **This set of environmental indicators is purely informative and should not be used for evaluating the environmental footprint 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 environmentally sound.**

Table 3.13 Main environmental indicators for the production of 1 tonne of sawn primary aluminium ingot used in Europe.

EAA indicators (per tonne of primary ingot)	**Total**	Direct process	Auxiliary	Electricity	Thermal energy	Transport
Depletion of Abiotic Resources (ADP) [kg Sb-Equiv.]	**45,36**	8,03	1,61	23,64	11,65	0,43
Acidification Potential (AP) [kg SO2-Equiv.]	**43,94**	12,03	0,87	20,98	8,20	1,86
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**1,94**	0,19	0,06	1,13	0,38	0,19
GHG emission (GWP 100 years) [kg CO2-Equiv.]	**9677**	2594	368	4826	1820	69
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**9,79E-04**	3,19E-06	2,73E-05	9,44E-04	4,39E-06	8,45E-08
Photo-oxidant Creation Potential (POCP) [kg Ethene-Equiv.]	**2,670**	0,659	0,067	1,293	0,541	0,110
Primary energy from renewable raw materials (net cal. value) [MJ]	**42386**	28	138	42162	56	1
Primary energy from non-renewable resources (net cal. value) [MJ]	**130699**	16872	4358	84169	24395	905

This table highlights that electricity production contributes significantly to the various environmental indicators. GHG emission reaches 9677 kg CO_2-equiv./tonne of aluminium ingot, 50% coming from the electricity production (4826 kg/t) while the aluminium processes (mainly anode/paste consumption and PFC emissions) contribute to slightly more than 25%, thermal energy (mainly at the alumina step), auxiliary processes and transport account for slightly less 25% of this indicator. Primary energy consumption from non-renewable resources reaches 131 MJ/kg in total, 84 MJ resulting from the electricity production, 24 MJ from the thermal energy, 17 MJ from the aluminium processes (mainly anode/paste consumption) and 5 MJ from transport and auxiliary processes.

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, 2000 mm wide and 9000 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)

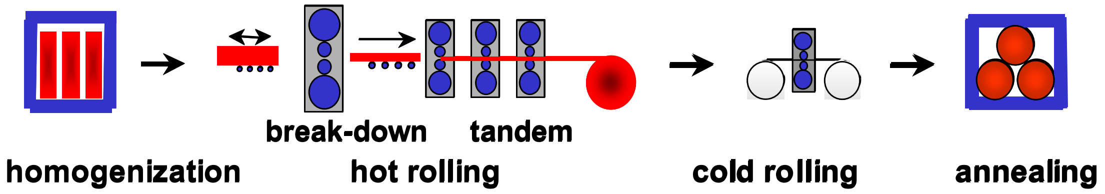

Fig. 4.1 Main process steps in aluminium sheet production

The sheet production from sawn ingot up to finished sheet generates about 380 kg of scrap by tonne of sheet. These scrap 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 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 2005 reaches 76% for the 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 (%)**
Integrated cast-houses (slabs production)	3.77	2.55	**68**
Rolling mills	4.39	3.33 (1)	**76**

(1) Total strip, sheet and plate output excluding hot rolled plate and hot rolled strip

Regarding alloys, the LCI dataset corresponds to 28% hard alloys (e.g. 2xxx, 7xxx, 5xxx with Mg > 1,5%), 46% intermediate alloys (e.g. 3xxx, 5xxx with Mg<1,5%, 6xxx, 8xxx) and 26 % soft alloys (e.g. 1xxx).

Regarding gauges, 47% is sheet between 0.5 and 6 mm, sheet thinner than 0,5 mm represents 46% while about 7% of the production output is plate, i.e. thicker than 6 mm. It can be estimated that the average sheet thickness associated with this survey is about 0.5 mm.

Main end-use applications are transport (20%), can stock (18%), foil stock (11%) and building applications (11%). A big part (30%) is going to stockists, i.e. semi-products reseller.

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.

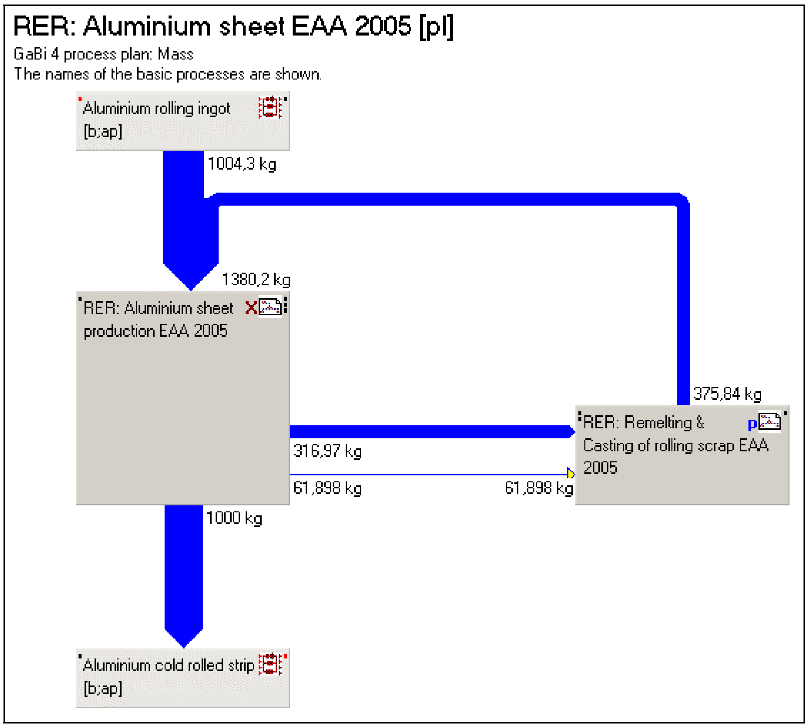

Fig. 4.2 Flow diagram for aluminium sheet production
(RER: EU27 + EFTA countries).

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 1000 kg of finished aluminium sheet.

Table 4.2 Direct inputs and outputs for the sheet production and the corresponding scrap remelting – Figures normalised to 1000 kg of finished sheet.

Aluminium rolling processes - Figures for 1 tonne of sheet output		Sheet production	Scrap Remelting	**Total**		
Year		2005			2002	1998
Aluminium inputs	Unit					
Unscalped rolling ingots	kg	1004		**1004**	1012	1012
Clean scrap	*kg*		*383*			
Aluminium outputs						
Finished cold rolled sheet	kg	1000		**1000**	1000	1000
Energy inputs						
Heavy Oil	kg	0,0	1,0	**1,0**		
Diesel and light fuel Oil	kg	4,6	0,1	**4,8**	3,2	0,75
Natural Gas	kg	41	28	**68,8**	89	94,4
Propane	kg	0,0	1,0	**1,0**		
Total thermal energy	*MJ*	*2.083*	*1359*	***3.441***	*4201*	*4349*
Electricity	kWh	662	64,4	**726**	600	667
Ancillary products, inputs						
Fluxing salts	kg		1,72	**1,72**	1,8	0,38
Argon	kg		0,86	**0,86**	1	0,91
Chlorine	kg		0,05	**0,05**	0,025	0,008
Filter tones	kg	0,59	0,13	**0,73**		
Emulsion, hot rolling (oil content)	kg	1,46	0,00	**1,46**		
Oil, cold rolling	kg	3,83	0,00	**3,83**	2,4	3,8
Lubricants and hydraulic oils	kg	0,95	0,02	**0,97**		
Paper & cardboard for packaging	kg	1,85	0,00	**1,85**	0,02	0,1
Wood for packaging	kg	8,17	0,00	**8,17**	5,9	10
Steel for packaging	kg	0,48	0,00	**0,48**	0,5	0,5
Plastic for packaging	kg	0,52	0,00	**0,52**	0,25	0,4
Water inputs						
Water	m^3	5,9	4,2	**10,2**	10,1	42
Emissions to air						
Carbon monoxide (CO)	kg	0,46	0,04	**0,50**		
Dust/particulates, total	kg	0,02	0,02	**0,03**		
Dust/particulates PM10 (<10µm)	kg/t	0,00	0,01	**0,01**		
Dust/particulates PM2.5 (<2.5µm)	kg/t	0,00	0,01	**0,01**		
NOX, as nitrogen dioxide	kg	0,23	0,13	**0,35**		
SO2	kg	0,02	0,02	**0,04**		
VOC	kg	0,36	0,02	**0,38**	0,45	0,44
Organic hydrocarbons (not included in VOC)	kg	0,37	0,00	**0,37**		
Emissions to water						
Water output	m^3	3,9	1,81	**5,8**		
COD (direct discharge)	kg	0,29	0,00	**0,29**	0,089	0,079
Waste (excluding dross, aluminium scrap & demolition waste)						
Hazardous waste for land-filling	kg	0,91	1,32	**2,23**	7,2	4,8
Hazardous waste for incineration	kg	2,22	0,02	**2,24**	2,4	2,3
Hazardous waste for further processing	kg	2,23	5,48	**7,71**		
Total hazardous waste	*kg*	*5,36*	*6,82*	***12,18***	*9,60*	*7,10*
Non-haz. waste for land-filling	kg	1,77	0,12	**1,89**	11,7	6,5
Non-haz. waste for incineration	kg	0,60	0,11	**0,72**		
Non-haz. waste for further processing	kg	4,86	0,44	**5,29**		
Total non-hazardous waste	*kg*	*7,23*	*0,67*	***7,91***	*11,7*	*13,6*
By-products						
Metal scrap for recycling, excluding aluminium	kg	1,24	0,22	**1,45**		

4.3 European LCI dataset for aluminium 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. Main LCI data are reported in table 4.3 and associated indicators in table 4.4.

Table 4.3 Main LCI data for the production of 1 tonne of aluminium sheet from the rolling ingot

Year	2005			2002	1998
Inputs (kg/t)	**Total**	Direct process, thermal & ancillary	Electricity	Total *	Total *
Aluminium rolling ingot	**1004,3**			1012	**1012**
Energy resources					
Crude oil	**26,5**	14,5	12,1	21,4	21
Hard coal	**61,0**	1,1	59,9	64,2	71,9
Brown coal	**97,6**	1,3	96,4	67,7	75,7
Natural gas	**102,0**	72,8	29,2	92,3	99,3
Outputs (kg/t)					
Cold rolled strip/sheet	**1000**			1000	1000
Main air emissions					
CO2	**589**	217	385	464	499
NOx	**1,03**	0,31	0,71	0,76	0,81
SO2	**2,11**	0,14	1,97	1,52	
Dust	**0,12**	0,04	0,08	0,3	0,33
VOC (unspec.)	**0,38**	0,38	0,00	0,45	0,44
Methane	**1,29**	0,54	0,75	1,2	1,3

* dross recycling and ingot homogeneisation not included in 1998 & 2002 modeling

Table 4.4 Environmental indicators for the sheet production

EAA indicators (per tonne of aluminium sheet)	**Total**	Direct, auxillary & thermal	Electricity
Abiotic Depletion (ADP) [kg Sb-Equiv.]	**4,04**	1,97	2,07
Acidification Potential (AP) [kg SO2-Equiv.]	**2,96**	0,44	2,53
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**0,164**	0,065	0,098
Greenhouse gas emission (GWP 100 years) [kg CO2-Equiv.]	**644**	237	407
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**9,76E-05**	7,27E-07	9,69E-05
Photo-Oxidant Creation Potential (POCP) [kg Ethene-Equiv.]	**0,282**	0,138	0,144
Primary energy from renewable raw materials (net cal. value) [MJ]	**731**	121	610
Primary energy from non-renewable resources (net cal. value) [MJ]	**12019**	4117	7902

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.

Foil fabrication 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.

In addition to the classical production route, 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. In the LCI dataset, a ratio of 80% classical route/20% strip casting was used.

The foil production from as-cast ingot up to finished sheet generates about 600 kg of scrap by tonne of foil. These scrap 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 modeling

EAFA (European Aluminium Foil Association, www.alufoil.org) and EAA worked together for developing the foil dataset. As reported in table 5.1, the EAA-EAFA survey coverage for the year 2005 reaches about 50% for the foil production in Europe (EU27 + EFTA countries).

Table 5.1 Survey coverage for European foil production

	Total production in Europe (kt)	reported (kt)	**vey coverage (%)**
Foil production	800	406	**51**

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 20% of the production done through strip casting technology and 80% through classical production route.

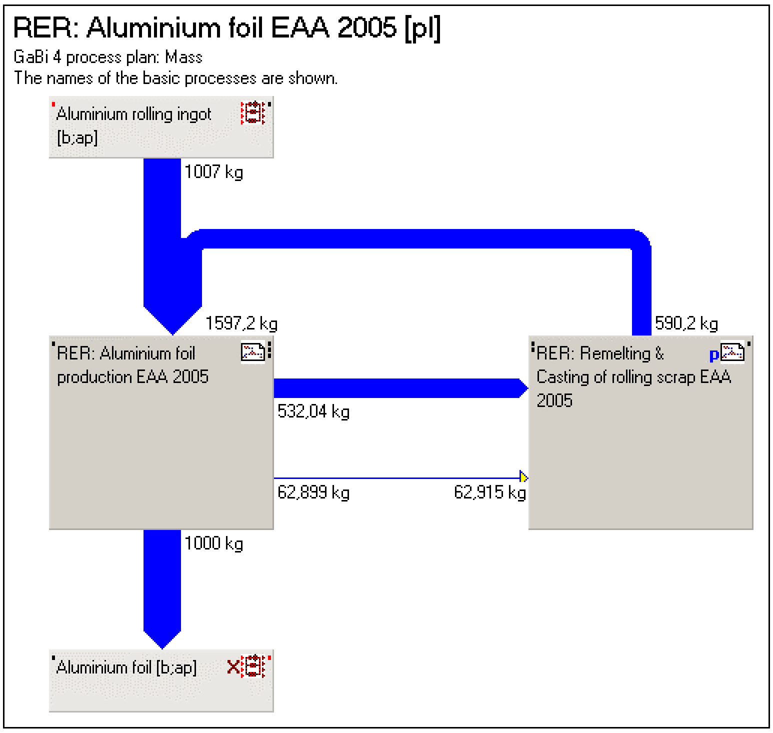

Fig. 5.1 Flow diagram for aluminium foil production.
(RER: EU27 + EFTA countries).

In table 5.2, 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 595 kg of process scrap.

Table 5.2 Direct inputs and outputs for the foil production and the corresponding scrap recycling – Figures normalised to 1000 kg of finished foil.

Aluminium foil production - Figures for 1 tonne of finished foil		Foil production	Scrap remelting	**Total**	Total thin gauge*	Total thick gauge*
Year		**2005**			**1998****	
Main aluminium inputs	Unit					
ingots	kg	1007		**1007**	1032	1027
Clean scrap	*kg*		*595*			
Main aluminium outputs						
Dross/skimmings	*kg*		*24,5*		33	27,7
Metal content of dross/skimmings	*%*		*60%*			
Clean scrap	*kg*	*595*				
Finished foil	kg	1000		**1000**	1000	1000
End use energy inputs						
Heavy Oil	kg	2,9	1,7	**4,6**		
Diesel and light fuel Oil	kg	0,4	0,2	**0,6**	16	5,9
Natural Gas	kg	92	46	**138**	167	132
Other energy source (LPG)	kg	0,0	1,7	**1,7**		
Total thermal energy	*MJ*	*4.342*	*2257*	***6.599***	*8.323*	*6.291*
Electricity	kWh	1.486	107,0	**1.593**	1.936	1.605
Ancillary products, inputs						
Fluxing salts	kg		2,86	**2,86**	0,8	0,66
Argon	kg		1,43	**1,43**	1,9	1,6
Chlorine	kg		0,03	**0,03**	0,016	0,013
Filter tones	kg	1,24	0,22	**1,46**		
Emulsion, hot rolling (oil content)	kg	2,70		**2,70**		
Oil, cold rolling	kg	24,10		**24,1**	41	31
Lubricants and hydraulic oils	kg	0,67	0,03	**0,70**		
Paper & cardboard for packaging	kg	1,90		**1,90**	0,13	0,12
Wood for packaging	kg	28,50		**28,5**	41	39
Steel for packaging	kg	3,10		**3,10**	2,4	2,4
Plastic for packaging	kg	0,63		**0,63**	0,84	0,49
Water input						
Water input***	m^3	9,1	7,0	**16,1**	124	100
Emissions to air						
Carbon monoxide (CO)	kg	0,41	0,06	**0,47**		
Dust/particulates, total	kg	0,30	0,03	**0,33**		
Dust/particulates PM10 (<10µm)	kg		0,02	**0,02**		
Dust/particulates PM2.5 (<2.5µm)	kg		0,01	**0,01**		
NOX, as nitrogen dioxide	kg	0,86	0,21	**1,07**		
SO2	kg	0,29	0,03	**0,32**		
VOC	kg	2,19	0,03	**2,22**	12	6,4
Organic hydrocarbons (not included in VOC)	kg	0,29		**0,29**		
Emissions to water						
Water output***	m^3	6,4	3,00	**9,4**		
COD (direct discharge)	kg	0,006		**0,006**		
Waste (excluding dross, aluminium scrap & demolition waste)						
Hazardous waste for land-filling	kg	0,73	2,19	**2,92**	14	11
Hazardous waste for incineration	kg	2,75	0,04	**2,79**	10	9,8
Hazardous waste for further processing	kg	15,74	9,10	**24,84**		
Total hazardous waste	*kg*	*19,22*	*11,33*	***30,55***	*24*	*20,8*
Non-haz. waste for land-filling	kg	4,77	0,20	**4,97**	21	16
Non-haz. waste for incineration	kg	0,69	0,19	**0,88**		
Non-haz. waste for further processing	kg	9,72	0,73	**10,45**		
Total non-hazardous waste	*kg*	*15,18*	*1,12*	***16,30***	*21*	*16*
By-products						
Metal scrap for recycling, excluding aluminium	kg	3,68	0,36	**4,04**		

* thin is between 5 and 20 µm, thick is between 20 and 200 µm **dross recycling not included in 1998 model

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

5.3 European LCI dataset 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. Main LCI data are reported in table 5.3 and associated environmental indicators are listed in table 5.4.

Table 5.3 Main LCI data for the production of 1 tonne of aluminium foil from an ingot

Year	2005			1998	
	Total	Direct, auxillary & thermal	Electricity	Total thin gauge*	Total thick gauge*
Main Inputs					
Aluminium ingot	**1007**			1027	1032
Non-renewable energy resources					
Crude oil	**63**	36,0	26,7	79	58
Hard coal	**137**	4,2	132,6	221	183
Brown coal	**216**	2,9	213,3	233	193
Natural gas	**212**	147,5	64,3	220	175
Main outputs					
Aluminium foil	**1000**			1000	1000
Main air emissions					
Carbon dioxide -CO2	**1238**	385	853	1367	1090
Nitrogen oxides - NOx	**2,69**	1,11	1,58	2,4	1,9
Sulphur dioxide - SO2	**4,88**	0,52	4,36	4,8	3,9
Dust	**0,53**	0,35	0,18	0,69	1
VOC (unspec.)	**2,22**	2,22	0,00	12	6,4

*dross recycling not included in 1998

Table 5.4 Environmental indicators for the production of 1 tonne of aluminium foil from an ingot.

Environmental indicators (per tonne of foil)	Total	Direct, auxillary & thermal	Electricity
Abiotic Depletion (ADP) [kg Sb-Equiv.]	8,59	4,02	4,58
Acidification Potential (AP) [kg SO2-Equiv.]	6,90	1,31	5,60
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	0,37	0,16	0,22
Greenhouse gas emission (GWP 100 years) [kg CO2-Equiv.]	1353	454	899
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	2,16E-04	1,75E-06	2,15E-04
Photo-oxidant Creation Potential (POCP) [kg Ethene-Equiv.]	0,72	0,40	0,32
Primary energy from renewable raw materials (net cal. value) [MJ]	1.731	381	1.350
Primary energy from non-renewable resources (net cal. value) [MJ]	25.898	8.416	17.483

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

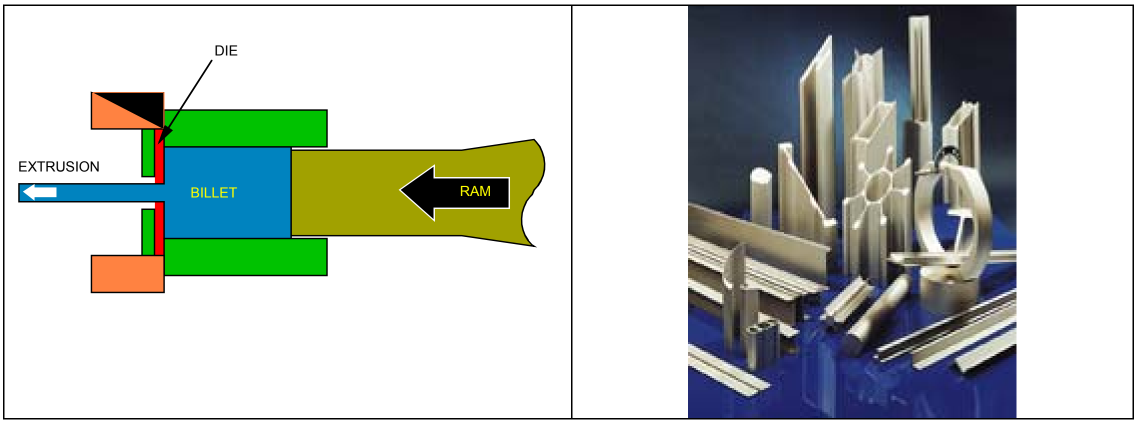

Fig. 6.1 Extrusion process principle and some aluminium extruded products

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 modeling

41 plants/sites have been integrated in the consolidation process representing 978kt of extrusion output, i.e. about 33% of the European production as reported in table 6.1.

Table 6.1 Survey coverage for aluminium extrusion

Total production in EU27 and EFTA countries	Total production reported	Survey coverage
2.980.000 tonnes	978.000 tonnes	33%

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%)	1%
	Soft alloys, e.g. 1xxx, 3xxx, 5xxx (Mg<1,5%), 6xxx	99%
	Total	100%
Thermal treatment after extrusion	percentage of aged products	91%
	percentage of non-aged products	9%
	Total	100%
Type of extruded products	Bars and rods	7%
	Tubes & profiles, Big circumscribing circle (> 300 mm)	14%
	Other tubes & profiles	78%
	Other types of products	1%
	Total	100%
Applications	Aeronautics	0%
	Other transports	22%
	Building	43%
	Engineering	16%
	Others (including stockists)	19%
	Total	100%

Regarding alloys, the consolidation corresponds to soft alloys exclusively, mainly 6xxx series. Aged extrusion products represent 91% of the output while 9% is non-aged products. Bar and rods represents 7% of the production. 14% 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 (78% of the production). In absence of hard alloys, there is almost no application in aeronautics. Nevertheless, 22% of the extrusion output is used in transport. The biggest market is building, i.e. 43%, while engineering applications stands for 16%. 19% 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.

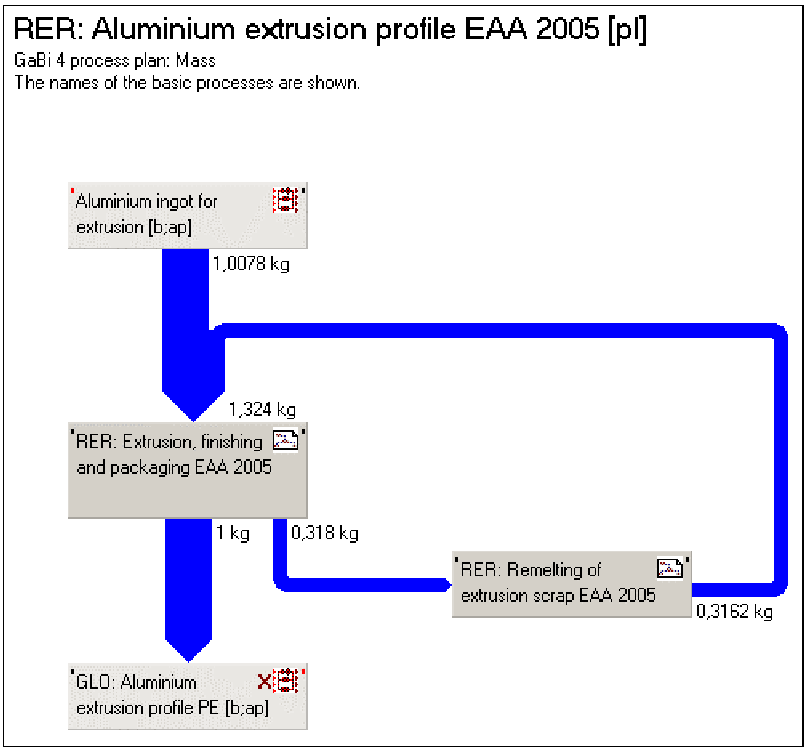

Fig. 6.2 Flow diagram for aluminium extrusion production (RER: EU27 + EFTA countries).

Table 6.3 Direct inputs and outputs for extrusion and the corresponding scrap recycling – Figures normalised to 1000 kg of finished extruded product.

	Unit	Extrusion	Scrap Remelting	Total		
Year		**2005**			2002	1998
Main aluminium inputs						
Extrusion ingot	kg	1008		**1008**	1013	1013
Clean scrap	*kg*		*324*			
Main aluminium outputs						
Dross/skimmings	*kg*		*10*		15,3	18,4
Metal content of dross/skimmings	*%*		*60%*			
Clean scrap	*kg*	*324*				
Finished profile	kg	1000		**1000**	1000	1000
End use Energy						
Heavy Oil	kg		0,4	**0,4**		
Diesel and light fuel Oil	kg	1,1	0,3	**1,4**	1,25	0,65
Natural Gas	kg	47,7	25,6	**73,3**	81	101
Total thermal energy	*MJ*	*2.402*	*1.216*	***3.619***	*3.904*	*4.827*
Electricity	kWh	758	118	**876**	913	1321
Ancillaries inputs						
Argon	kg		0,73	**0,73**		0,53
Chlorine	kg		0,04	**0,04**	0,011	0,081
Water input (mainly cooling)	m3	2,4	3,5	**5,9**	11	30
Acids, calculated as 100% H_2SO_4	kg	6,9		**6,9**		
Alkalis, calculated as 100% NaOH	kg	11,3		**11,3**	15	28
Paper & cardboard for packaging	kg	7,5		**7,5**		
Wood for packaging	kg	26		**26**	17	28
Steel for packaging	kg	0,7		**0,7**	1,8	0,9
Plastic for packaging	kg	2,5		**2,5**	4,5	2,1
Outputs						
Water output	m3	1,9	2,8	4,7	9	26
Emissions to air						
NOX, as nitrogen dioxide	kg	0,15	0,22	**0,37**		
SO2	kg	0,03	0	**0,03**		
Dust/particulates, total	kg		0,04	**0,04**		
Water						
Water output	m3	1,83	3,26	**5,1**		
Hazardous waste						
Spent caustic bath/sludge for land-filling	kg	3,6	0	**3,6**	33	29
Spent caustic bath/sludge for further processing	kg	21,6	0	**21,6**		
Hazardous waste for land-filling	kg	1,26	0,51	**1,8**	2,4	1,6
Other hazardous waste for further processing	kg	9,33	0	**9,3**		
Hazardous waste for incineration	kg	1,72	0,04	**1,8**	2,2	1,7
Total hazardous waste	*kg*	*37,5*	*0,5*	***38,1***	37,6	32,3
Non-hazardous waste (excluding aluminium scrap, dross/skimmings & demolition waste)						
Non-haz. waste for land-filling	kg	2,05	1,74	**3,79**		
Non-haz. waste for incineration	kg	2,11	0,07	**2,18**		
Non-haz. waste for further processing	kg	8,74	0,26	**9**		
Total non-hazardous waste	*kg*	*12,9*	*2,07*	*14,97*	19	23
By-products						
Metal scrap for recycling, excluding aluminium	kg	6,81	0,46	**7,27**		

6.3 European LCI dataset 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 . Main LCI data for 1 tonne of extrusion are reported in table 6.4 and associated indicators in table 6.5.

Table 6.4 Main LCI data for the production of 1 tonne of aluminium extrusion from an ingot

Year	2005			2002	1998
Inputs (kg)	**Total**	Process, thermal & auxillary	Electricity	Total *	Total *
Aluminium ingot	**1008**			**1013**	**1013**
Non renewable energy resources					
Crude oil	**22,7**	7,9	14,8	31	43
Hard coal	**77,1**	3,7	73,5	104	151
Brown coal	**126,2**	8,0	118,2	110	158
Natural gas	**123,7**	88,1	35,6	106	135
Outputs (kg)					
Aluminium extrusion	**1000**			1000	1000
Main air emissions					
CO2	**683**	211	472	632	860
NOx	**1,56**	0,69	0,88	1,1	1,5
SO2	**2,6**	0,21	2,4	3,2	3,2
Dust	**0,11**	0,01	0,10	0,47	0,69
Methane	**1,58**	0,66	0,92	1,6	2,2

Table 6.5 Environmental indicators for the production of 1 tonne of aluminium extrusion from an ingot

EAA indicators (per tonne of aluminium profile)	**Total**	**Direct, auxilary & thermal**	**Electricity**
Abiotic Depletion (ADP) [kg Sb-Equiv.]	4,70	2,16	2,53
Acidification Potential (AP) [kg SO2-Equiv.]	3,80	0,70	3,10
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	0,22	0,10	0,12
Greenhouse gas emission (GWP 100 years) [kg CO2-Equiv.]	726	227	498
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1,22E-04	3,33E-06	1,19E-04
Photo-Oxidant Creation Potential (POCP) [kg Ethene-Equiv.]	0,23	0,06	0,18
Primary energy from renewable raw materials (net cal. value) [MJ]	1146	398	748
Primary energy from non-renewable resources (net cal. value) [MJ]	14311	4625	9686

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 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) [7]. This brochure is available from the EAA website (www.aluminium.org).

The 'recycling' data were obtained through a survey organised by the OEA (Organisation of European Aluminium Refiners and Remelters) in cooperation with the IAI (International Aluminium Institute). 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.

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 trough 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. It will include the scrap preparation phase.**

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		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 Products from the aluminium recycling industry.

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 [6]

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 Aluminium scrap mass flow modelling

The scrap mass flow modelling has been done through a joint effort between the European Aluminium Association and the Organisation of European Aluminium Refiners and Remelters (OEA). The scrap flow modelling uses the calculation methodology as described in [6]. The European consolidation for the year 2005 is reported in table 7.2 according to the various categories listed in EN 13920 [10]. This consolidation considers all new and old scrap which are tolled or purchased in Europe. Internal scrap are not considered. Scrap flows highlighted in yellow are considered in model 2 (aluminium recycling) while other scrap flows refer to the model 1 (process scrap remelting).

Table 7.2 European scrap mass balance for the year 2005 expressed in kt (flows in yellow are part of model 2 "recycling scrap")

				Refiners					
				Rotary Furnace		Reverberatory furnace		Remelters	
Resource	**Origin**		**Model**	**Total**	**Metal**	**Total**	**Metal**	**Total**	**Metal**
Extrusion scrap	Fabrication	kt	1					471	458
Foundry scrap	Fabrication	kt	2	228	190				
Turnings (extrusion & rolling)	Fabrication	kt	2	110	92	110	92		
Turnings (foil)	Fabrication	kt	2	13	13	13	13		
Turnings (foundry)	Fabrication	kt	2	231	194	231	194		
Building	Manufacturing	kt	1			89	83	154	150
Transportation	Manufacturing	kt	1			135	127	222	209
Consumer durables	Manufacturing	kt	1			38	35	49	46
Cans & rigid packaging	Manufacturing	kt	1 & 2			200	173	200	173
Flexible packaging	Manufacturing	kt	2	83	71	21	21		
Cable & wire	Manufacturing	kt	1			46	46		
Engineering	Manufacturing	kt	1			111	104	222	209
Other	Manufacturing	kt	1			19	18	25	23
Turnings	Manufacturing	kt	2	56	47	55	47		
Total new scrap		**kt**		**720**	**607**	**1068**	**952**	**1343**	**1267**
Building	End-of-Life	kt	1&2			100	94	97	91
Shredded transport scrap	End-of-Life	kt	1&2	760	642	0	0	33	31
Dismantled transport scrap	End-of-Life	kt	1&2	16	15	148	139	158	149
Cans and rigid packaging	End-of-Life	kt	1&2	12	11	47	44	233	219
Flexible packaging	End-of-Life	kt	2			182	130		
Engineering	End-of-Life	kt	1&2	307	260	34	29	31	29
Consumer durables	End-of-Life	kt	2	216	183				
Other	End-of-Life	kt	2	33	28				
Total old scrap		**kt**		**1344**	**1139**	**510**	**435**	**552**	**519**

About 5.5 million tonnes of scrap (3.6 million tonnes by refiners and 1.9 by remelters) are used in Europe. For this analysis dross generated by primary cast houses is excluded and new packaging scrap, which is in reality mostly internal scrap, is included. OEA and EAA statistics for the year 2005 give a total tonnage of recycled aluminium of 4.8 million tonnes, which is perfectly in line with the metal content of scrap used in the model. Hence the scrap model used in this exercise is well representative of the reality.

Approximately 50% of the scrap input of the refiners is composed of old scrap. Most of the new scrap going to the refiners are scrap from cast alloys (foundries), contaminated scrap (turnings) or thin-walled scrap possibly coated. The Model 2 "scrap recycling" addresses such category of scrap which are mainly used for producing casting alloys (see flows in yellow in table 7.2). The model 1 "scrap remelting" focuses on clean process scrap of wrought alloys which are mainly used by the remelters and by some refiners to produce new wrought alloys. These 2 models and the associated LCI data are described in the next sections

7.7 Remelting model

7.7.1 Data consolidation, averaging and modeling

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. 15 integrated cast houses have been included in the consolidation, representing a production of about 2.66 Mt of ingot. Such integrated cast houses usually uses a mixed aluminium input composed mainly of clean process scrap (66%), ingot for remelting (21%) and alloying elements (3%) and some liquid aluminium (10%) coming from special scrap (i.e. turnings) remelting in another furnaces. For simplification, only scrap input are considered, i.e. other aluminium inputs are substituted by aluminium scrap. Table 7.3 reports the consolidated direct inputs and outputs calculated for 1 tonne of ingot.

Table 7.3 Direct inputs and outputs for the production of 1 tonne of ingot from clean process scrap (data for model 1) – consolidated data for the years 2005, 2002 & 1998

	Unit	Process scrap remelting & casting		
Year		**2005**	2002	1998
Aluminium inputs				
Clean scrap	kg	**1009**	1014	1014
Alloying elements	kg	**29**	25	21,8
Main aluminium outputs				
Sawn ingots (slab or billet)	kg	**1000**	1000	1000
Dross/skimmings	kg	**42**	42	32,7
Metal content of dross/skimmings		**60%**	60%	60%
Energy inputs				
Heavy Oil	kg	**2,7**	5,6	1,7
Diesel and light fuel Oil	kg	**0,3**	0,3	0,1
Natural Gas	kg	**68,1**	67,2	67,0
Propane	kg	**2,7**		
Total thermal energy	*MJ*	***3.367***	*3.314*	*3.136*
Electricity	kWh	**133**	179	174
Ancillary products, inputs				
Fluxing salts	kg	**0,50**	0,68	0,89
Argon	kg	**2,26**	1,56	2,67
Chlorine	kg	**0,14**	0,14	0,039
Water	m^3	**9,66**	12,55	78
Emissions to air				
Chlorine	kg	**0,006**	N.L.	N.L.
Carbon monoxide (CO)	kg	**0,095**	N.L.	N.L.
Dust/particulates, total	kg	**0,041**	N.L.	N.L.
NOX, as nitrogen dioxide	kg	**0,329**	N.L.	N.L.
SO2	kg	**0,051**	N.L.	N.L.
VOC	kg	**0,050**	N.L.	N.L.
Water				
Water output	m^3	**9,17**	N.L.	N.L.
Waste (excluding dross, aluminium scrap & demolition waste)				
Hazardous waste for land-filling	kg	**2,69**		
Hazardous waste for incineration	kg	**0,06**		
Total hazardous waste	*kg*	***2,75***	2,70	
Non-haz. waste for land-filling	kg	**0,32**		
Non-haz. waste for incineration	kg	**0,27**		
Non-haz. waste for further processing	kg	**1,01**		
Total non-hazardous waste	*kg*	***1,59***	6,00	1,5
By-products				
Metal scrap for recycling, excluding aluminium	kg	**0,51**		

About 3300-3400 MJ 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 1140 MJ/tonne which is needed to heat up and to melt pure aluminium from 20°C up to 720°C [16].

7.7.2 European LCI data 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 7.3. The model includes the dross recycling. The LCI dataset is available on request at lci@eaa.be. Main LCI data for the production of 1 tonne aluminium ingot from new scrap are reported in table 7.4 and associated indicators in table 7.5. The metal losses due to the remelting process, after dross recycling, is calculated to 0.75%, i.e. 7,5 kg/tonne.

Table 7.4 Main LCI data for the production of 1 tonne of aluminium ingot from process scrap

Year	2005			2002	1998
Inputs (kg)	**Total**	Process, thermal & Others	Electricity	**Total ***	**Total ***
Aluminium scrap (100% metal)	**1007**			1014	**1014**
Non renewable energy resources					
Crude oil (resource)	**5,9**	3,4	2,4	11,9	6,2
Hard coal (resource)	**12,5**	0,5	12,0	20,0	18,7
Brown coal (resource)	**20,1**	0,9	19,2	21,5	20,1
Natural gas (resource)	**87,5**	80,9	6,6	74,0	76,7
Outputs (kg)					
Aluminium ingot	**1000**	1000		1000	1000
Main air emissions					
CO2	**298**	219	79	291	316
NOx	**0,39**	0,25	0,14	0,42	0,41
SO2	**0,52**	0,13	0,39	0,81	0,53
Dust	**0,06**	0,05	0,01	0,12	0,1
Organic emissions (total)	**0,84**	0,67	0,17	0,89	0,96
VOC (unspecified)	**0,05**	0,05	0,00		
Methane	**0,72**	0,56	0,16		

* no substitution of alloying elements and no dross recycling included in 1998 & 2002 modeling

Table 7.5 Environmental indicators for the production of 1 tonne of aluminium ingot from process scrap

EAA indicators (per tonne of ingot)	**Total**	Direct process, thermal & auxilary	Electricity
Abiotic Depletion (ADP) [kg Sb-Equiv.]	**2,27**	1,84	0,43
Acidification Potential (AP) [kg SO2-Equiv.]	**0,87**	0,36	0,51
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**0,067**	0,047	0,020
Greenhouse gas emission (GWP 100 years) [kg CO2-Equiv.]	**317**	234	83
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**1,98E-05**	4,39E-07	1,93E-05
Photo-oxidant Creation Potential (POCP) [kg Ethene-Equiv.]	**0,069**	0,040	0,029
Primary energy from renewable raw materials (net cal. value) [MJ]	**125**	3	122
Primary energy from non-renewable resources (net cal. value) [MJ]	**5464**	3849	1615

7.8 Recycling model

7.8.1 Scrap mix

Since this scrap recycling model focuses on old and special scrap (i.e. turnings, casting scrap, etc) recycling, only the relevant flows have been extracted from the table 7.2 in order to define the scrap material flow entering the recycling model. The table 7.6 reports such scrap mass flows.

Table 7.6 European scrap mass flow used for the recycling model (model 2) in kt

		Rotary Furnace		Reverberatory Furnace		Metal
Resource		**Total**	**Metal**	**Total**	**Metal**	
Foundry scrap	kt	228	190	0	0	190
Turnings	kt	410	346	410	346	691
Cans & rigid packaging (old)	kt	12	11	247	217	228
Flexible packaging (old)	kt	83	71	203	150	222
Building (old)	kt	0	0	100	94	94
Shredded transport scrap (old)	kt	760	642	0	0	642
Dismantled transport scrap (old)	kt	16	15	148	139	154
Engineering (old)	kt	307	260	34	29	289
Consumer durables (old)	kt	216	183	0	0	183
Other (old)	kt	33	28	0	0	28
Total	**kt**	**2064**	**1745**	**1141**	**974**	**2719**
Scrap input share			**64%**		**36%**	

According to this table, about 2/3 of the scrap are going to the rotary furnace (64%) and 1/3 to the reverbatory furnace (36%). The table 7.7 reports above flows in metal percentage.

Table 7.7 European scrap mass flow used for the recycling model in %

		Rotary Furnace	Reverberatory furnace
Foundry scrap	kt	11%	0%
Turnings	kt	20%	36%
Cans & rigid packaging (old)	kt	1%	22%
Flexible packaging (old)	kt	4%	18%
Building (old)	kt	0%	9%
Shredded transport scrap (old)	kt	37%	0%
Dismantled transport scrap (old)	kt	1%	13%
Engineering (old)	kt	15%	3%
Consumer durables (old)	kt	10%	0%
Other (old)	kt	2%	0%
Total	**kt**	100%	100%

Scrap from transport applications (mainly automotive) constitutes with turnings, foundry scrap and engineering scrap the main input for rotary furnaces. Turnings, old packaging, building scrap and dismantled scrap from transport application (mainly mass transport) are the main input of the reverbatory furnace.

7.8.2 Scrap preparation

The scrap preparation is highly dependent on the scrap type and origins. A motor block engine, a used beverage can or a facade panel are not prepared in the same way before melting. The table 7.8 reports the typical scrap preparation processes which are applied to the various scrap categories. While some preparation processes are applied systematically to the whole scrap flow, other processes are only applied to a fraction of the scrap flow. It is particularly the case for shredding, sink & float, cutting & balling. The estimated percentage of scrap flow entering these process are mentioned in bracket.

Table 7.8 Main scrap preparation processes according to scrap type

Scrap mass flow	Main preparation processes
Foundry scrap	No processing
Turnings	Drying and de-oiling
Cans & rigid packaging (old)	De-lacquering & Baling
Flexible packaging (old)	Baling
Building (old)	Shredding (50%), Sink & float (20%), balling & cutting (20%)
Transport (old)	Shredding (80%), Dismantling (20%), Sink & float (40%)
Engineering (old)	Shredding (100%), Sink & float (40%)
Consumer durables (old)	Shredding (100%), Sink & float (40%)
Other (old)	Shredding (100%), Sink & float (40%)

Based on tables 7.7 and 7.8, the model for the scrap preparation phase has been developed. The fractions of the European scrap mix entering the various preparation processes are reported in table 7.9. These processes can be applied consequently like "shredding + sink & float" or "cutting and balling + de-lacquering". Table 7.9 is used to evaluate the consolidate model based on the input and output data related to the listed preparation processes.

Table 7.9 Main scrap preparation processes and corresponding scrap mass flow fraction entering the process.

Preparation process	Scrap Mass flow fraction	Input & output data
Shredding - wrought alloys	25,0%	Year 2005
Shreddding -cast alloys	30,0%	Year 1998
Sink & Float	15,0%	Year 1998
Cuting & Baling	20,0%	Year 1998
Drying & deoiling	25,0%	Year 1998
De-lacquering	10,0%	Year 2005
Dismantling	5,0%	No data
No pretraitment	10,0%	

7.8.3 Data consolidation, averaging and modeling

Scrap preparation

Most of the aluminium refiners are not involved in the scrap preparation phase and, except for delacquering & wrought aluminium shredding, it has not been possible to collect updated input and output figures for unit processes of the scrap preparation phase (as detailed in table 7.8 and 7.9). As a result, unit processes data related to the previous survey have been used to produce the new consolidated model for the scrap preparation. This is deemed as an acceptable representation of the unit processes current situation (2005), as no significant changes were recorded in scrap preparation practices since 1998. These scrap preparation unit processes data were eventually combined with the actual scrap mass flow fractions as reported in table 7.9.

Table 7.10 reports the consolidated figures for the scrap preparation phase according to the scrap flows reported in table 7.9. Data for the year 2005 can be compared with the data modelled for the year 1998.

Table 7.10 Consolidated inputs and outputs for the scrap preparation

		Unit	**Consolidated data**	
	YEAR		**2005**	**1998**
Inputs				
Solid input	Foreign elements/contaminants	kg	**200**	***1229***
	Aluminium scrap input	*kg*	***1050***	
Energy Input	Electricity	kWh	**63**	**64**
	Natural gas	kg	**13,5**	**22**
	Fuel oil	kg	**2,1**	**4,16**
	Total thermal energy	MJ	**725**	**1165**
Other inputs	Ferro-Silicon	kg	**1,2**	**0,58**
	Water	kg	**45**	
	Light oil	kg	**0,17**	**0,08**
	Hydraulic oil	kg	**0,01**	
	Detergent	kg	**0,12**	
	Lime	kg	**0,14**	
	Additives	kg	**0,46**	**0,96**
Output				
Aluminium output	Aluminium scrap output	kg	**1000**	**1000**
By-products	(Non-Ferrous) Metals	kg	**115**	**40**
	Iron scrap	kg	**34**	**9,5**
	Oil (for incineration)	kg	**1,25**	**2,6**
Emissions to Air	Dust	kg	**0,10**	**0,03**
	Hydrogen Chloride	kg	**0,01**	**0,01**
Emissions to Land	Dirt	kg	**8**	**1,9**
	Filter dust	kg	**3,52**	**3,3**
	Refractory waste	kg	**0,04**	**0,09**
	Solid waste (unspecified)	kg	**1,61**	**3,2**
	Stones	kg	**8**	**4,2**
	Rubber	kg	**47**	**24**
	Waste sediment	kg	**6,6**	**3,3**

Scrap refining

Unlike scrap preparation, scrap refining went through considerable changes from 1998 to 2005. Even if the aluminium refining industry is still today a quite highly fragmented industry, the number of aluminium refiners in Europe decreased strongly (by 42% in the last 12 years) together with production capacity increases and significant technology improvements. These structural changes resulted in particular with a modified furnace technology mix (see table 7.6), where electric induction furnaces are practically no longer used.

Collecting data among aluminium refiners is very challenging considering the size and the fragmentation of the aluminium recycling industry. As a result, it has not been possible to have a survey coverage level in term of tonnage comparable to the other aluminium processes (primary aluminium, aluminium sheet, aluminium extrusion).

Table 7.11 reports for the scrap refining processes the number of replies, the corresponding tonnage of metal input and the survey coverage.

Table 7.11 Survey coverage for aluminium recycling processes (refiners)

Process	Nb replies	Metal input in kt	European coverage
Scrap refining	10	820	23%

Table 7.12 reports the consolidated figures for the scrap refining phase according to the scrap flows reported in table 7.6. Data for the year 2005 can be compared with the data modelled for the year 1998.

Table 7.12 Direct inputs and outputs for the scrap refining process (combination of 64% rotary furnace and 36% reverbatory) - Figures for 1 tonne of ingot

	Year	**2005**	1998
Inputs			
Raw scrap input (metal + contaminants)	*kg*	***1054***	1033
Alloy input (metal)	*kg*	***64***	78
Salt	kg	**11,3**	13,7
Water (cooling)	m3	**17,8**	N.L.
Sodium aluminum fluoride (Na3AlF6)	kg	**0,72**	
Lime (used for emission treatment)	kg	**3,94**	7,4
Lubricants (maintenance material)	kg	**0,11**	
Nitrogen (N2)	kg	**3,20**	1,8
Chlorine (Cl2)	kg	**0,25**	1,6
Argon	kg	**0,97**	
Refractory	kg	**2,4**	
Fuels & Electricity			
Gas	kg	**83,7**	202,8
Heavy fuel oil	kg	**4,00**	17,1
*Total thermal energy**	MJ	**3990**	9971
Electricity	kWh	**60,8**	353,9
Outputs			
Ingot	kg	**1000**	**1000**
Iron Scrap	kg	**1,7**	2,2
Aluminium oxide	kg	**107**	119
Water	m3	**8,8**	N.L.
Air emissions			
Dust	kg	**0,021**	0,03
Hydrogen Fluoride (HF)	kg	**0,002**	0,004
Hydrogen Chloride (HCl)	kg	**0,038**	0,05
Chlorine (Cl2)	kg	**0,002**	0,0005
Solid waste			
Filter Dust landfilled	kt	**17,39**	24,1
Waste for recycling	kt	**1,20**	2,2
Hazardous Waste landfilled	kt	**0,85**	2

In this recycling model, it is assumed that 15% of additional thermal energy is coming from the combustion of contaminants, i.e. mainly plastics. This additional thermal energy of 600 MJ (15% of the total) has been modelled through the use of LCI data related to the combustion of polyethylene (PE). This corresponds to about 25kg of PE which is burned since the PE calorific value is around 25 MJ/kg.

7.8.4 Material flow and LCI data for the recycling model

Fig. 7.1 reports the flow diagram which is used for the recycling model. 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). Main LCI data are reported in table 7.13.

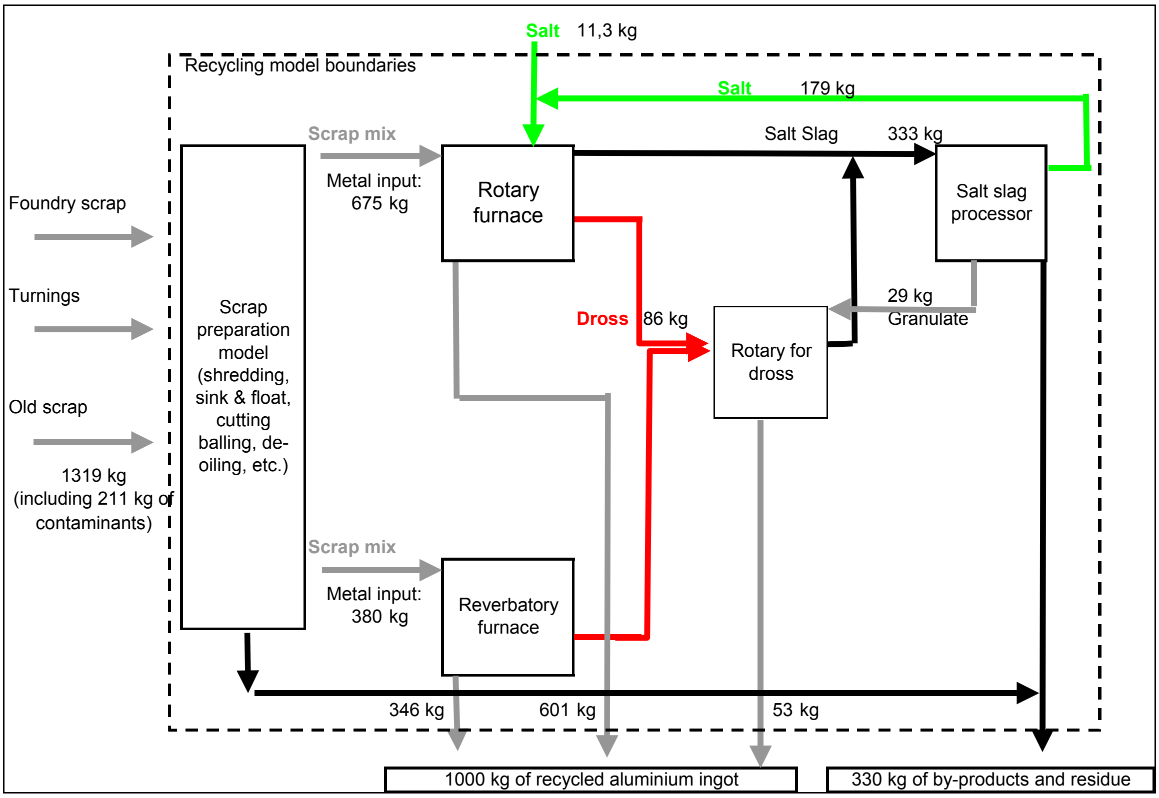

Fig. 7.1 Material flow diagram of the recycling model

Table 7.13 Main LCI data for aluminium recycling per tonne of recycled ingot

Year	**2005**			1998
Inputs (kg)	**Total**	Process, thermal & Others	Electricity	**Total**
Total scrap input (preparation phase	**1319**			1270
Total metal input	**1108**	1108		
Foreign materials	**211**	211		
Metal input (refining)	**1055**	1055		**1033**
Alloying elements*	**0**	(67)		79
Salt	**11,3**	11,3		13,7
Non renewable energy resources				
Crude oil (resource)	**10,9**	8,2	2,7	32,3
Hard coal (resource)	**15,3**	1,9	13,4	45,8
Lignite (resource)	**23,2**	1,7	21,5	49,6
Natural gas (resource)	**120,1**	104,6	15,5	233
Outputs (kg)				
Aluminium ingot	**1000**	**1000**		1000
Aluminium oxide	**107**	**107**		119
Iron scrap	**38**	**38**		12
Residues (rubber, filter dust, etc.)	**180**	**180**		162
Main air emissions				
CO2	**481**	382	99	801
NOx	**0,55**	0,37	0,18	1,1
SO2	**0,7**	0,25	0,45	2
Dust	**0,17**	0,15	0,02	0,29
Organic emissions	**1,08**	0,83	0,25	2,6
Methane	**0,97**	0,74	0,23	

* Alloying elements are substituted by aluminium scrap in the 2005 model - figure provided as information

From the model, it is estimated that 1108 kg of Al scrap enters the scrap preparation phase accompanied with about 211 kg of foreign materials. 1055kg of scrap exits the scrap preparation and enters the melting model for producing 1 tonne of ingot.

Air emissions and primary energy use are significantly reduced compared to 1998. This is mainly due to a significant reduction of thermal energy use for the melting process. About 5.000 MJ of thermal energy from fuels is used in 2005 while more than 8.000 MJ were estimated in 1998. Two main reasons explain this significant evolution:

- In 1998, figures related to energy use were probably overestimated
- In 2005, furnace technologies used by European refiners are significantly improved especially in term of energy transfer and burners technology.

The corresponding environmental indicators are reported in table 7.14.

Table 7.14 Environmental Indicators for aluminium recycling per tonne of recycled ingot – year 2005

Environmental indicators (per tonne of recycled ingot)	Total	Direct, thermal & others	Electricity
Abiotic Depletion (ADP) [kg Sb-Equiv.]	3,13	2,48	0,66
Acidification Potential (AP) [kg SO2-Equiv.]	1,12	0,52	0,59
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	0,080	0,055	0,026
Greenhouse gas emission (GWP 100 years) [kg CO2-Equiv.]	506	391	115
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	2,34E-05	1,80E-06	2,16E-05
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	0,085	0,050	0,035
Primary energy from renewable raw materials (net cal. value) [MJ]	295	159	136
Primary energy from resources (net cal. value) [MJ]	7389	5217	2172

7.8.5 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 sot 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 in table 7.3. Table 7.15 reports specific estimates of metal losses for various old scrap categories [6]. It is recommended to use such specific metal losses within LCA studies. These metal losses refer to the scrap melting and refining phase. Possible losses associated with the collection of the end-of-life aluminium products and the scrap preparation are not included.

Table 7.15 Metal losses during refining for various old scrap categories [6]

Old scrap types	Estimated metal losses for the melting process
Building	1-4%
Shredded Transport Scrap	4-8%
Dismanted Transport Scrap	2-4%
Used Beverage Cans	2-3%
Mixed packaging and foil	2-8%
Engineering	3-7%
Consumer durables	3-7%
Total old scrap	4-6%
Total recycling model	5%

Within the European Reference Life Cycle Data System [14], two generic LCI datasets have been developed from a "cradle to recycling" perspective, respectively for 1 kg of aluminium sheet and for 1 kg of aluminium profile. These two datasets related to aluminium semi-finished products have been developed on basis of the EAA LCI datasets on the production and transformation processes described in this report. These datasets include the aluminium production, the semi-production process (rolling or extrusion) and the end of life aluminium recycling. The 2 LCI datasets and the documentation can be downloaded from the website of the European platform on LCA (http://lca.jrc.ec.europa.eu).

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 tickness 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 aluminum 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 refereed 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.

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12. Report from the independent reviewer

Environmental Profile Report for the European Aluminium Industry

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

Critical Review Report

by

Walter Klöpffer

April 2008

1 Introduction

1.1 Aluminium and the environmental pillar of sustainability

Aluminium belongs to those materials which have been critically discussed for decades, mainly due to the high amount of energy needed to reduce alumina (Al_2O_3) to Al. There are other, minor but not negligible, environmental aspects of the aluminium life cycle, as bauxite mining and the emission of perfluorinated alkanes (CF_4, C_2F_6). The duty of Life Cycle Assessment (LCA) consists in considering quantitatively all important environmental aspects in the life cycle of products (goods and services). Materials, as Al, contribute significantly to the total environmental behaviour of products, but do not necessarily determine it. Making use of the properties of Al, as low density (light weight products), longevity and recyclability can lead to excellent life cycle behaviour, but only if used properly. In order to calculate the Life Cycle Inventories (LCIs) of Al-containing products, reliable data are needed – as presented in the report reviewed here for European conditions.

There is a second aspect of growing importance: the environmental behaviour of a product, process or material is only part of its sustainability which is the ultimate aim of any responsible product development. Certainly, a quantitative assessment of sustainability has to follow the life cycle concept in which the already standardized LCA will play a leading role (Life Cycle Sustainability Assessment of Products – LCSA [1]). Life Cycle Costing (LCC), the quantification of the second, economic, pillar, is available as a draft SETAC guideline [2]. The third one – Societal Life Cycle Assessment (SLCA) is still under development, but progressing rapidly [3,4]. Thus, the contribution of a material to **sustainability** will not only depend on its environmental life cycle performance, as quantified by LCI/LCA, but also on economic and social aspects to be evaluated in a life cycle perspective. As a caveat it should be mentioned that there will be no compensation between the three pillars: even an excellent economic performance cannot outweigh poor environmental and societal performance.

1.2 The role of EAA

The European Aluminium Association has recognised the needs of LCA practitioners and product designers early in the development of standardized LCAs. The first data collection, comprising the reference years 1991/92 (and 1994) appeared in 1996. This first report was followed by a second one in 2000, reference year 1998 [5] and by an update report in 2005, reference year 2002 [6]. The present report is thus the fourth one.

The data collected and updated were offered to and accepted by the LCA community, including the software producers. Generic (or background) data are perfectly suited for commodities to be used in end product LCAs when the exact origin of the material(s) used in a specific product is not known, but only the region, in this case Europe. The present data set will be included into the European (EU) LCA databank and foster the (already strong) European position in generic data collection and provision.

1.3 The critical review, scope and course of action

The review procedure started with a kick-off meeting March 7, 2007 in Brussels, as all the following meetings. It was agreed upon that the review will be performed as a critical review according to the revised ISO standards14040 [7] and 14044 [8]. 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 called LCA. 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 had to be left out for obvious reasons. The other important life cycle stages of Al (mining, alumina production, primary aluminium by electrolysis, melting and remelting, as well as recycling) are treated and together can be considered as a truncated LCI.

The review was conceived as a review by an independent external reviewer according to ISO 14044, section 6.2. A more demanding review according to the panel method (14044, section 6.3) was not deemed necessary, since no comparative assertions can be derived from the data collected.

The meetings 2 to 6 dealt with the data collection results of the life cycle stages mentioned above:

April 17, 2007: EAA LCI Data Management Task Force meeting. Main topic: LCI data reviewing. Draft report on alumina and primary aluminium for 2005. Introduction of the GaBi Software into LCI modelling, including data for ancillary processes.

September 29, 2007: Primary aluminium production, data collection and consolidation; presentation of a suitable energy model.

November 13, 2007: EAA LCI Data Management Task Force meeting. Internal environmental reports on Sheet and associated cast house (10/2007) and Extrusion and associated cast house (11/2007); LCI data sets for external electricity models, sheet production, foil production and extrusion (including GaBi modules)

January 23, 2008: EAA LCI Data Reviewing meeting. Presentation of LCI datasets and associated modelling; presentation of the draft goal & scope chapter.

March 7, 2008: Discussion of aluminium recycling in Europe with Marlen Bertram, International Aluminium Institute (IAI), London [9,10].

The final (7th) meeting took place April 17, 2008. Main topic: Discussion of the draft final report [11] and comments made by the reviewer with Christian Leroy and Bernard de Gélas. A time schedule for the last steps has been adopted.

The updated final report was submitted via email April 25, 2008. The review below refers to this version.

2 About this Environmental Profile Report

2.1 General

The first impression of the report is that it is well structured and written. The report stays in the tradition of the former reports, but offers new aspects. The main change refers to the use of new software for data handling (GaBi 4.0 replacing LCA-2 using BUWAL data), including generic data for ancillary processes and inputs for the energy model. The LCI results can therefore not exactly be compared with the data of the previous reports. There is no break, however, 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. A main methodological improvement with regard to the former projects is the new energy model, especially with regard to imported primary aluminium (36%).

The LCI is presented in the form of building blocs corresponding to the stages of the life cycle in a logical order (see section 2.2). It is worth mentioning that the LCI study is more than a "cradle-to-factory gate" study, as most generic data sets, but comprises the most important end-of-life phase, recycling. This phase is of outmost importance for the Al life cycle, since only a very efficient recycling can reduce the thermodynamically caused high energy demand of aluminium.

The 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). Data consolidation plays a major role in raw data treatment and has been solved in a convincing manner. The geographical coverage includes EU 27 + Norway, Iceland and Switzerland. Due to the inclusion of Al-imports, the actual geographical system boundary is much larger, or even global if the mining and alumina production is considered.

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) can be considered as belonging to LCI, as a - very useful - relict of "proto-LCA" [12] inventory aggregation. It gives additional information compared to other energy-related impact categories as Climate change and depletion of fossil energy resources and encourages energy saving independent of its origin [13,14].

2.2 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, but relevant information about data quality can be found throughout the report in the relevant chapters. No undue conclusions and comparisons are drawn from the results and, thus, the formal deviation from the standard is only mentioned but not criticised here.

The recommendation of the allocation procedure supported by the metal industry (against the "recycled content approach") [15] in the Preface is understandable from EAA´s point of view but in no way binding for the data users: the kind of allocation used depends on the Goal & scope in each individual LCA according to ISO 14040/44.

The horizontal aggregation procedure used for calculating the European averages (2.3) is laudable, since it facilitates the modular approach of LCI/LCA for the users.

There was some discussion about the term „waste", as used in Fig. 2.2 where it is put outside the system boundary together with the emissions. In the reviewer´s opinion there are at least three types of waste:

1. waste to be reused or recycled: stays within the technosphere and, thus within the system boundaries of a typical LCA
2. waste to be collected and removed legally by incineration, controlled landfilling or composting: stays within the technosphere, too; only the **emissions** of the waste removal processes (CO_2, CH_4, organic contaminants to ground water, leached metal ions to ground water etc.) escape into the environment if not collected
3. waste thrown away, e.g. by littering, illegal dumping, burning etc.: ends up in the environment if not collected.

There was a time when solid waste in LCA (if landfilled) was considered as an "emission into soil". This is only true for illegal, uncontrolled land filling. Controlled landfilling is a kind of factory and belongs to the technosphere as long as it is controlled. EAA intends to include appropriate data in future updates (incineration is already included).

LCI data for bauxite mining were taken from IAI and do not contain information about land occupation (area x time), a minimum inventory input requirement for land use impact assessment in LCA. EAA intends to complement the data set in the next round, although it seems difficult to obtain reliable data on land occupation during mining. Since bauxite occurs in relatively thin layers which are peeled of mechanically, large areas of land are deprived of the soil cover and recultivated later. The importance of "land use" as an impact category has increased in recent years, partly as a proxy for biodiversity [16]. In connection with land use, also the "overburden" will be addressed; this not a major problem in bauxite mining, but relevant for recultivation.

The use of heavy oil (high sulphur content) reported to be used for alumina production, although reduced in recent years, is certainly an area for improving the environmental performance of the Al-system. As in the case of sea transport, the use of heavy oil is intolerable.

The change in power grid from UCPTE to the EU-25 grid mix due to the geographical extension and the software change should have been secured by a sensitivity analysis for which there was not enough time. Some changes are discussed in the text, however.

Reporting of PAH and BaP 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.

"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." This message in Chapter 7 is really good news, especially since in a growing market, considering the use of Al in many long-lived product, 100% cannot be reached. As stated correctly, there is still enough opportunity to improve and thus decrease the overall energy demand. The Al-scrap remelting industry is fragmented, despite a consolidation leading to larger units, and data acquisition is not easy. The results obtained in co-operation with OEA (Organisation of European Aluminium Refiners and Remelters) are nevertheless trustworthy and rely on a robust Al-recycling Material Flow Analysis (MFA) published recently [9].

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 [17].

2.3 Additional information

Whereas this report will be available as a freely downloadable PDF document with broad distribution, the full LCI datasets are available on request at lci@eaa.be.

This information has been supplied in the form of six excel data files. These files comprise:

- Primary aluminium 2005
- Aluminium sheet 2005
- Remelting & casting of clean aluminium scrap
- Aluminium recycling 2005
- Aluminium foil 2005
- Aluminium extrusion 2005

These files were supplied in addition to the draft LCI reports. They will be indispensable for software suppliers for updating the data bases.

3 Confirmation by the reviewer

According to ISO 14040 [7]

"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 a few restrictions discussed in the previous sections. With regard to the first item, consistency with ISO 14040/44, there is a formal lack of a section “interpretation” indicated above. It has also been discussed above that the study is not a full LCA, but the standard allows for LCI-studies. As such, the study is conform with ISO.

The methods used in data collection and modelling are described clearly and correspond to the state of the art. They should be published and become standard for generic data collection.

The third item (data) is the heart of the study. The data used in addition to the original data stem from one of the leading software systems. Additional data not shown in this report are made available to interested persons.

The interpretation is in accordance with the restricted scope and refers to the representativity and quality of the original data. Although not statistically analysed, the user can be sure to have the best possible dataset for Al in Europe. In the future there may be a greater demand for statistically analysed data in order to perform error calculations and uncertainty analysis [18]; this may lead to higher expectations with regard to the primary data deliverers.

Finally, the report is transparent and consistent. It is clearly written and well printed.

4 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 more than a decade in an exemplary way.

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

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

Life cycle methods can neither replace nor enforce management decisions. They can, however, inform, educate and lead to new ideas. It is proposed to rethink the whole system including renewable energy (e.g. solar energy) and explore possible new production methods. Although the thermodynamic limits cannot be overcome, there is no reason not to invest in radically new innovation. LCA may act as guide to prevent problem shifting.

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