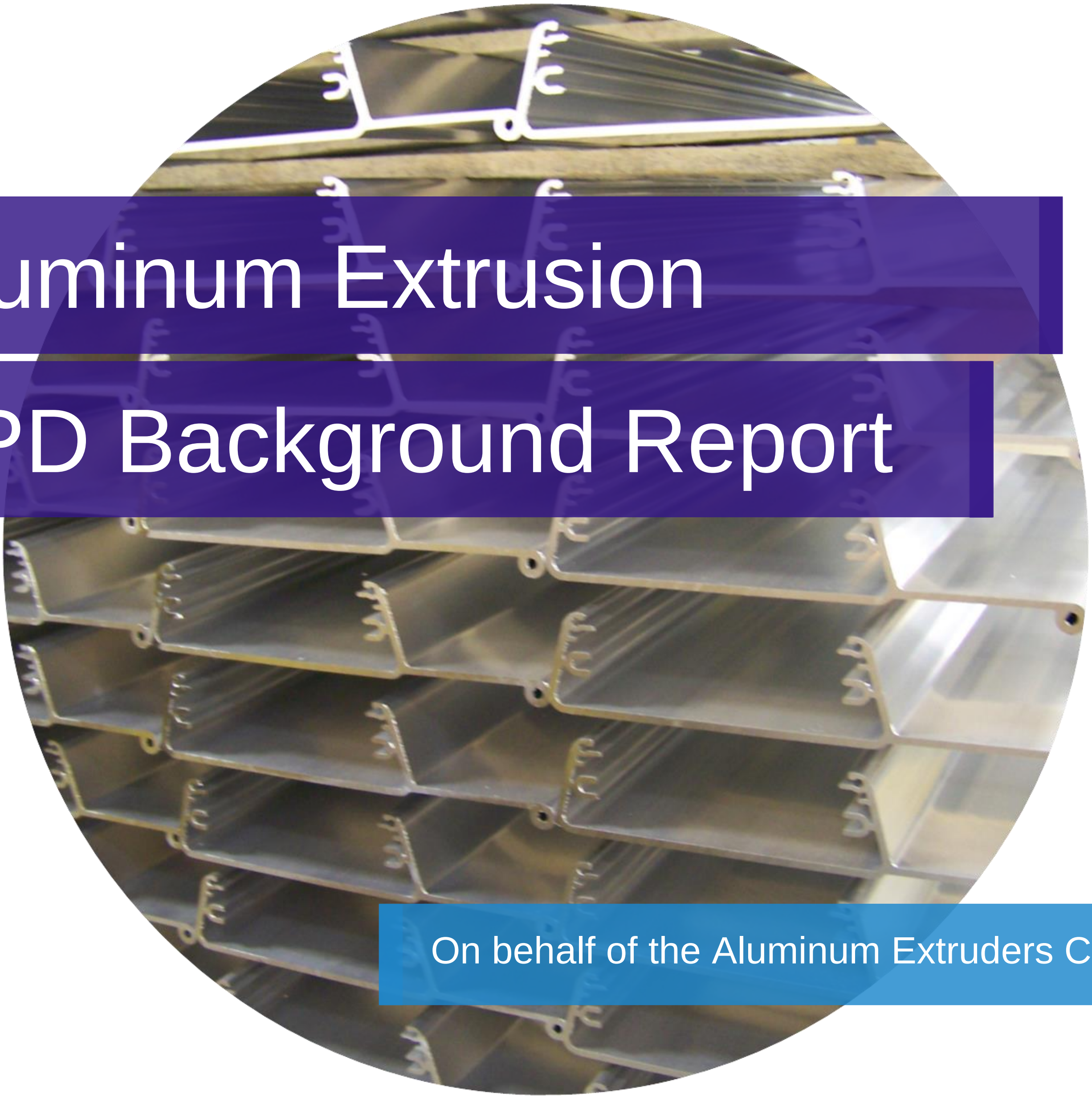

Aluminum Extrusion

EPD Background Report

On behalf of the Aluminum Extruders Council

Report version: 1.4

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On behalf of thinkstep AG and its subsidiaries

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Table of Contents

List of Figures

List of Tables

List of Acronyms

AA	Aluminum Association
ADP	Abiotic Depletion Potential
AEC	Aluminum Extruders Council
AP	Acidification Potential
CML	Centre of Environmental Science at Leiden
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GWP	Global Warming Potential
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
SFP	Smog Formation Potential
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts
VOC	Volatile Organic Compound

Glossary

Life cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life cycle interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Functional unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20)

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

Closed-loop and open-loop allocation of recycled material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

(ISO 14044:2006, section 4.3.4.3.3)

Foreground system

“Those processes of the system that are specific to it … and/or directly affected by decisions analyzed in the study.” (JRC 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

“Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good….” (JRC 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

“Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment” (ISO 14044:2006, section 3.45).

1. Goal of the Study

The Aluminum Extruders Council (AEC), formed over 60 years ago, is the trade association for the North American aluminum extrusion industry. With approximately 60 U.S. and Canadian extruder members, and a similar number of aluminum producers and other industry suppliers, AEC members represent an estimated 75% of North American aluminum extrusion production.

Today, AEC focuses on three distinct missions:

- Promoting the effective application of aluminum extrusions to solve product challenges in a wide range of industries. Whether helping create more energy efficient buildings, improving automotive performance, facilitating the transition to LED lighting, or advancing products in a wide range of other industries, extrusions are playing a major role.
- Advancing extrusion technology, via member training, networking, benchmarking, best-practice sharing and research & development projects and conferences.
- Ensuring fair trade.

The goal of the study is to create two industry average Environmental Product Declarations (EPDs), one for mill finished, anodized, or painted aluminum extrusions, and one for thermally improved aluminum extrusions (again, mill finished, anodized, or painted) according to IBU's Product Category Rule (PCR) for *Products of aluminum and aluminum alloys* (IBU, 2014) and UL Environment's North American addendum (UL Environment, 2015).

The intended audience for this report includes the program operator, UL Environment (ULE), as well as the reviewer who will be assessing the conformance of the life cycle assessment (LCA) to the chosen product category rule. The audience further includes AEC and its participating member companies. To foster further transparency, thinkstep recommends that this report be made available upon request to all third parties to whom the EPD is provided. Company-specific information has been aggregated to create a production volume-weighted, industry average based on product mass; therefore, confidential information specific to each company is not disclosed in this report.

Results presented in this document do not constitute comparative assertions. However, these results will be disclosed to the public via EPDs, which architects and builders will be able to use to compare AEC's products with similar products presented in other EPDs that follow the same PCR. In order to be published by a program operator, the EPD will undergo a verification for conformance to the PCR.

This study was commissioned by AEC and performed by thinkstep, Inc. The study has been conducted in accordance with the ISO 14040/44 guidelines. Conformance of the background LCA study as well as the final EPDs with the guiding PCR and with ISO 14025, ISO 14040, and ISO 14044 was verified by ULE.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product System

This declaration covers a range of aluminum extrusion products manufactured by AEC members in North America. The products considered in this declaration are as follows:

- Mill finished aluminum extrusion
- Painted aluminum extrusion
- Anodized aluminum extrusion
- Thermally improved, mill finished aluminum extrusion
- Thermally improved, painted aluminum extrusion
- Thermally improved, anodized aluminum extrusion

This first, comprehensive, industry-wide EPD for the six aluminum extrusion products is based on information supplied by 11 AEC member companies in the U.S. and Canada. The data comes from 28 separate extrusion facilities, with a total of over 85 extrusion presses, 9 anodizing lines, 12 paint lines (liquid and powder), 4 thermal improvement operations and 12 cast houses that produce scrap-based extrusion billet. In aggregate, the facilities in the analysis produced 1.7 billion pounds of extrusion in 2015, about 1/3 of total North American production for the year. The participating AEC members and facilities under their operational control were:

Company	Extrusion	Anodizing	Painting	Thermal Improvement	Cast House
Aerolite Extrusion Company	X		X	X	
Alexandria Industries	X				
Almag Aluminum, Inc.	X				
Apel Extrusions Limited	X	X	X		
Bonnell Aluminum	X	X	X		X
Jordan Aluminum Extrusions	X	X	X		
Pennex Aluminum Company, LLC	X				X
Sapa Extrusions North America	X	X	X	X	X
Sierra Aluminum	X	X	X	X	X
Tri-City Extrusion	X				
Western Extrusions Corp.	X	X	X	X	
Total	28	9	12	4	12

Aluminum extrusions in 6000 series alloy (the predominant production of the participants) are approximately 96.2% to 98.6% aluminum by mass, with alloying elements composing the remaining mass percent. The percent aluminum by mass of the painted, anodized, and thermally improved extrusions does not vary significantly from this, and can be found in section 3.2.3. Additional technical data can be found in Table 2-1.

Table 2-1: Technical data for aluminum extrusions (6xxx alloy, tempers T1-T6)

Name	Value	Unit
Density	2.66 – 2.84	$(kg/m^3) \times 10^3$
Melting point (typical)	475 – 655	°C
Electrical conductivity (typical) at 20°C /	Equal volume: 16 – 36	Ms/m (0.58 x %IACS)
Thermal conductivity (typical) at 25°C /	170 – 210	W/m·K
Average coefficient of thermal expansion (typical) 20°C to 100°C / 68°F to 212°F	22.3 – 23.9	per °C
Modulus of elasticity (typical)	69 – 73	$MPa \times 10^3$
Hardness (typical)	40 – 95 (47 – 96)	HB (Rockwell E)
Yield strength (min)	60 – 330	MPa
Ultimate tensile strength (min)	120 – 370	MPa
Breaking elongation (min) (50mm & 4D)	>4	%
Chemical composition	Varying by alloy, Al 96.2 – 98.6	% by mass

At the plants for each of the participating AEC members, the aluminum is extruded and then either anodized, painted or left unfinished (mill finish). The finished aluminum is then either sold as is or a thermal break is applied. Downstream fabrication operations, such as tight-tolerance cutting, machining, and assembly, are excluded due to the wide diversity of such operations. Because of their many attributes and the variety of available finishing options, aluminum extrusions are useful in a myriad of products in various market sectors, including building and construction, transportation, electrical and energy, medical and consumer, machinery, military, and air. Some uses in these market sectors are as follows:

- **Building and construction:** windows, doors, curtain walls, façade systems, skylights, canopies, louvers, light shelves, interior partitions, bridges, etc.
- **Transportation:** automotive structural and chassis components, crash management systems, auto body and trim components, truck and trailer components, rail passenger and freight car components, etc.
- **Electrical and energy:** electronics housings and heat sinks, LED lighting components, solar energy mounting and racking systems, cable raceways, conduit, etc.
- **Medical and consumer durables:** components of recreation products, home & garden tools, appliances, ambulatory care products, medical diagnostic equipment, etc.

2.2. Declared Unit

The declared unit is ***one metric ton (1,000 kg) of extruded aluminum***, including the optional surface treatments described in section 2.1.

2.3. System Boundary

The scope of the study includes raw material sourcing and extraction, manufacturing, and end-of-life (EoL) disposal of aluminum extrusions, along with a credit for recycling in future product systems. The included life cycle stages are summarized in Table 2-2, according to the EN15804 standard referenced in the PCR.

Table 2-2: Life cycle modules included in EPD

Production			Installation		Use stage							End-of-Life				Next product system
Raw material supply (extraction, processing, recycled material)	Transport to manufacturer	Manufacturing	Transport to building site	Installation into building	Use / application	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction / demolition	Transport to EoL	Waste processing for reuse, recovery or recycling	Disposal	Reuse, recovery or recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	X

X = declared module; MND = module not declared

Table 2-3: System Boundaries

Included	Excluded
✓ Raw materials production (bauxite, chemicals, minerals, etc.) (A1) ✓ Upstream electricity generation for production (A1) ✓ Inbound transportation of raw materials (A2) ✓ Product manufacturing and packaging (A3) ✓ Use of auxiliary materials, water, and energy during manufacturing (A3) ✓ Emissions to air, water, and soil during manufacturing ✓ Disposal (C4) and recycling credits (D) ✓ Internal transportation (within a manufacturing facility)	× Construction of capital equipment × Maintenance and operation of support equipment (e.g., employee facilities, etc.) × Packaging of raw materials × Human labor and employee commute × Fabrication (e.g., cutting, bending, welding) × Transport of finished products to installation site (A4), and application of product (A5) × Use stage (B1-B7) × Deconstruction (C1), transport to EoL (C2), and waste processing (C3)

2.3.1. Time Coverage

The data are intended to represent aluminum extrusion production during the 2015 calendar year. As such, each participating AEC member company provided primary data for 12 consecutive months during the 2014 and 2015 calendar years. These data were then used to calculate average production values for each company.

2.3.2. Technology Coverage

This study is intended to be representative of the aluminum extrusion and associated finishing processes. All foreground data was collected from AEC members for their facilities and is intended to represent average extrusion and finishing technologies.

2.3.3. Geographical Coverage

This background LCA represents AEC members' products produced in the United States and Canada. Background data are representative of these countries, with exceptions noted in Section 3.3.

Regionally specific datasets were used to represent each manufacturing location's energy consumption, but proxy datasets were used as needed for raw material inputs to address lack of data for a specific material or for a specific geographical region. These proxy datasets were chosen for their technological representativeness of the actual materials.

2.4. Allocation

2.4.1. Co-Product and Multi-Input Allocation

Where manufacturing inputs, such as electricity use, were not sub-metered for the individual extrusion and finishing processes, they were allocated based on the production weighted industry average energy and water use per metric ton for the respective processes. Some companies did not have meters for individual processes, and allocated electricity based on estimates by industry experts and water resources based on production volumes. No other co-product allocation occurs in the product foreground system. No multi-input allocation occurs in the product system. Allocation was used in the GaBi background data, as described below.

Allocation of upstream data (energy and materials):

- For all refinery products, allocation by mass and net calorific value is applied. The manufacturing route of every refinery product is modeled and so the effort of the production of these products is calculated specifically. Two allocation rules are applied: 1. the raw material (crude oil) consumption of the respective stages, which is necessary for the production of a product or an intermediate product, is allocated by energy (mass of the product * calorific value of the product); and 2. the energy consumption (thermal energy, steam, electricity) of a process, e.g. atmospheric distillation, being required by a product or an intermediate product, are charged on the product according to the share of the throughput of the stage (mass allocation).

- Materials and chemicals needed during manufacturing are modeled using the allocation rule most suitable for the respective product. For further information on a specific product see http://www.gabi-software.com/international/databases/gabi-databases/.

2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3. More information on the end-of-life approach used in this report can be found in section 3.2.5

Material recycling (avoided burden approach): Open scrap inputs from the production stage are subtracted from scrap to be recycled at end of life to give the net scrap output from the product life cycle. This remaining net scrap is then sent to material recycling. The original burden of the primary material input is then allocated between the current and subsequent life cycle using the mass of recovered secondary material to scale the substituted primary material, i.e., applying a credit for the substitution of primary material by secondary so as to distribute burdens appropriately among the different product life cycles. These subsequent process steps are modeled using industry average inventories.

Energy recovery (avoided burden approach): In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. Credits are assigned for power and heat outputs using the regional grid mix and thermal energy from natural gas. The latter represents the cleanest fossil fuel and therefore results in a conservative estimate of the avoided burden.

Landfilling (avoided burden approach): In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring vs. power production). A credit is assigned for power output using the regional grid mix.

Module D: Module D declares potential loads and benefits of secondary material, secondary fuel, or recovered energy leaving the product system. Module D recognizes the “design for reuse, recycling and recovery” concept for buildings by indicating the potential benefits of avoided future use of primary materials and fuels while taking into account the loads associated with the recycling and recovery processes beyond the system boundary. Where a secondary material or fuel crosses the system boundary e.g. at the end-of-waste state and if it substitutes another material or fuel in the following product system, the potential benefits or avoided loads were calculated based on a specified scenario which is consistent with any other scenario for waste processing and is based on current average technology or practice.

2.5. Cut-off Criteria

The cut-off criteria for including or excluding materials, energy and emissions data of the study are as follows:

- ✓ Mass – If a flow is less than 1% of the cumulative mass of the model it may be excluded, providing its environmental relevance is not a concern.
- ✓ Energy – If a flow is less than 1% of the cumulative energy of the model it may be excluded, providing its environmental relevance is not a concern.
- ✓ Environmental relevance – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it was included. Material flows which leave the system (emissions) and whose environmental impact is greater than 1% of the whole impact of an impact category that has been considered in the assessment must be covered. This judgment was made based on experience and documented as necessary.

No cut-off criteria were applied in this study. In cases where no matching life cycle inventories were available to represent a flow, proxy data were applied based on conservative assumptions regarding environmental impacts.

The choice of proxy data is documented in section 3. The influence of these proxy data on the results of the assessment has been carefully analyzed and is discussed in section 5.

2.6. Selection of LCIA Methodology and Impact Categories

According to the PCR, the following environmental indicators shall be calculated and declared:

Table 2-4: Environmental impact categories

Parameter	Parameter	CML Unit	TRACI 2.1 unit
GWP	Global warming potential	[kg CO_2-Eq.]	[kg CO_2 eq.]
ODP	Depletion potential of the stratospheric ozone layer	[kg CFC11-Eq.]	[kg R 11 eq.]
AP	Acidification potential of land and water	[kg SO_2-Eq.]	[kg SO_2 eq.]
EP	Eutrophication potential	[kg $(PO_4)^{3-}$ -Eq.]	[kg N eq.]
POCP	Formation potential of tropospheric ozone photochemical oxidants	[kg ethene-Eq.]	[kg O_3 eq.]
ADPE	Abiotic depletion potential for non-fossil resources	[kg Sb-Eq.]	—
ADPF	Abiotic depletion potential for fossil resources	[MJ]	—

Table 2-5: Resource use categories

Parameter	Parameter	Unit
PERE	Renewable primary energy as energy carrier	[MJ]
PERM	Renewable primary energy resources as material utilization	[MJ]
PERT	Total use of renewable primary energy resources	[MJ]
PENRE	Non-renewable primary energy as energy carrier	[MJ]
PENRM	Non-renewable primary energy as material-utilization	[MJ]
PENRT	Total use of non-renewable primary energy resources	[MJ]
SM	Use of secondary material	[MJ]
RSF	Use of renewable secondary fuels	[MJ]
NRSF	Use of non-renewable secondary fuels	[MJ]
FW	Use of fresh water	[m^3]

Table 2-6: Output flows and waste categories

Parameter	Parameter	Unit
HWD	Hazardous waste disposed	[kg]
NHWD	Non-hazardous waste disposed	[kg]
RWD	Radioactive waste disposed	[kg]
CRU	Components for re-use	[kg]

Parameter	Parameter	Unit
MFR	Materials for recycling	[kg]
MER	Materials for energy recovery	[kg]
EEE	Exported electrical energy	[MJ]
EET	Exported thermal energy	[MJ]

Hazardous waste reported by participants is characterized by the Resource Conservation and Recovery Act (RCRA), Subtitle 3. Background data may adhere to different regional legislation when defining hazardous waste.

The impact assessment results are calculated using characterization factors published by the University of Leiden's Centre of Environmental Sciences (CML 2001, v4.1) (Guinée, et al., 2002), as well as those published by the United States Environmental Protection Agency through its Tool for Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI 2.1) (Bare, 2012; EPA, 2012).

It shall be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the reported emissions represent only that fraction of the total environmental load that corresponds to the declared unit.

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.7. Interpretation to Be Used

The interpretation discusses the relevant findings and the data quality. No grouping or further quantitative cross-category weighting of impact categories have been applied. Instead, each impact is discussed in isolation, without reference to other impact categories, before final conclusions and recommendations are made.

2.8. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves.
- Consistency refers to modeling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modeling choices, data sources, emission factors, or other artefacts.
- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope.

An evaluation of the data quality with regard to these requirements is provided in section 5 of this report.

2.9. Software and Database

The LCA model was created using the GaBi ts Software system for life cycle engineering, developed by thinkstep AG. The GaBi 2016 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.10. Verification

The background LCA report and EPD must be verified before publication. Report verification was conducted by Thomas P. Gloria, Ph.D., of Industrial Ecology Consultants on behalf of Wade Stout, EPD Project Manager for UL Environment. This verification was performed against ISO 14040/44, EN15804, and the selected PCR for products of aluminum and aluminum alloys.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

All primary data were collected using customized data collection templates, which were sent out by email to the respective data providers in the participating companies. Participating facilities produce mill finished aluminum, products with one finishing step, and/or products with two finishing steps, all of which are available to the consumer. Finishing is either co-located with mill finished aluminum or occurs at a third-party facility. Primary data was not collected for finishing steps at third-party facilities. Horizontal averaging was used to create representative, production-weighted average inventories. When deciding the best way to create inventories for multiple finished goods produced at different facilities within an organization, both vertical and horizontal averaging options were considered. Vertical averaging best captures the actual flow of goods within a facility, to third-party finishers, and to consumers for a given reference year. However, it may not be a good proxy for subsequent years as relationships between facilities and third-party finishers may change year over year. Horizontal averaging is therefore more appropriate in cases where the LCA results are intended to possess a certain ‘shelf life’, as in this case where the EPD is supposed to remain valid over a period of five years. This topic is discussed further in section 4.3.2, along with a scenario analysis comparing the two methods.

Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. Benchmarking was performed using descriptive statistics. The industry data was ranked into quartiles and outliers were determined using boundaries determined by the interquartile range (IQR). Bounds were calculated using the formulas in Figure 3-1.

$$Lower\ bound = Q_1 - 1.5(IQR)$$

$$Upper\ bound = Q_3 + 1.5(IQR)$$

Figure 3-1: Equations for upper and lower bounds of data for determining outliers

Companies were also given the quartile benchmarks to compare their individual company data to the industry data. If gaps, outliers, or other inconsistencies occurred, thinkstep engaged with the data provider to resolve any open issues.

3.2. Product System

3.2.1. Overview of Product System

AEC member companies produce surface-treated (anodized, painted), thermally improved, and/or mill finished aluminum extrusions. Figure 3-2 provides an overview of the manufacturing process for the aluminum extrusion products. Billets, either cast on site or purchased from an external supplier, are extruded into profiles using steel dies. The extruded profiles may then be anodized or painted. Mill finished and surface-treated profiles may then undergo a thermal breaking process (thermal improvement). At EoL, the product is disassembled (e.g., during deconstruction of a building’s façade) and materials are recovered for recycling. Raw material extraction and processing, processing of secondary material input, transport of materials to manufacturer, and manufacturing are included in the production, or cradle-to-gate, stage of the product. The use stage is excluded from system boundaries but the disposal is considered because of the significant recycling potential of aluminum products.

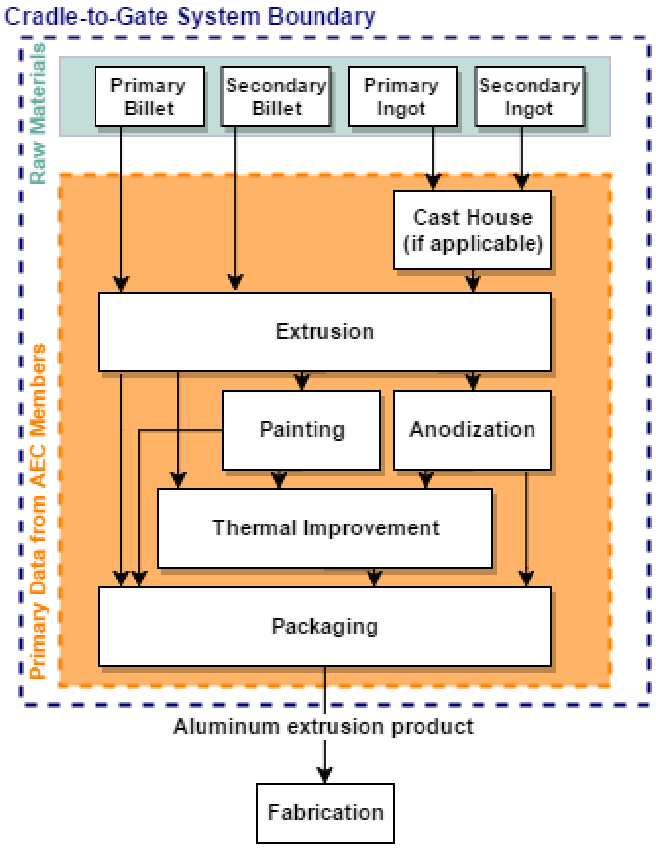


Figure 3-2: Extrusion manufacturing diagram

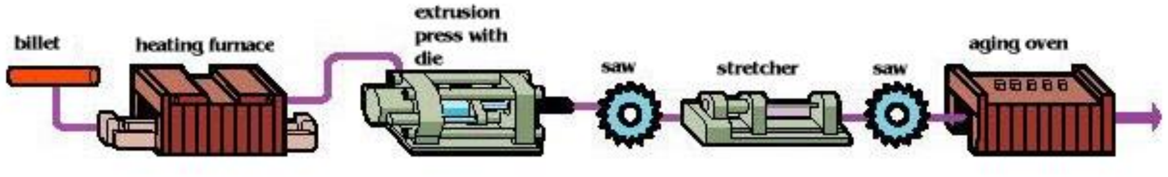
3.2.2. Production Stage

Extrusion

The production stage starts with extraction and processing of aluminum ingot, billet, and ancillary materials, followed by the transportation of these materials to the plant.

The extrusion manufacturing process, as shown in Figure 3-3, takes cast extrusion billet (round bar stock, produced from direct chill molds and typically ranging in diameter from 6 to 14 inches, depending on the extrusion press on which it will be processed) and produces extruded profiles. The process begins with an inline preheat furnace that elevates the temperature of the billet to a predetermined level, depending on the alloy. If not already cut to length, the billet is then sheared and placed into a hydraulic press, which then forces the semi-plastic billet through a heated steel die to form the desired shape. The length of the resulting extrusion is dictated by the take-off tables. The extrusions are air cooled or water quenched, with specific quench parameters dependent on alloy and desired properties. The extrusion is then clamped and stretched to straighten the profile.

Figure 3-3: Extrusion manufacturing process schematic



The straightened lengths are cut to intermediate or final length multiples and then typically aged in an aging oven to achieve the desired temper. Subsequently, the profile lengths are packed for shipment, finished with anodized, painted, or mechanical finishes, and/or further fabricated (e.g. cut to smaller, precise lengths, thermally enhanced, machined, bent, punched, etc.) The extent and sequence of these subsequent operations will be dependent on specific customer specifications. Any further fabrication as noted above is outside the scope of this EPD, as is any finishing (painting or anodizing) performed by a remote, third-party service provider.

Any production scrap generated during the extrusion and surface-treatment processes is collected and sent either to the company’s own cast house or to recycling facilities; in the LCA model, a credit is applied for recycled scrap which is equivalent to primary aluminum less recycling operations (e.g., cleaning, re-melting, and casting).

Painting

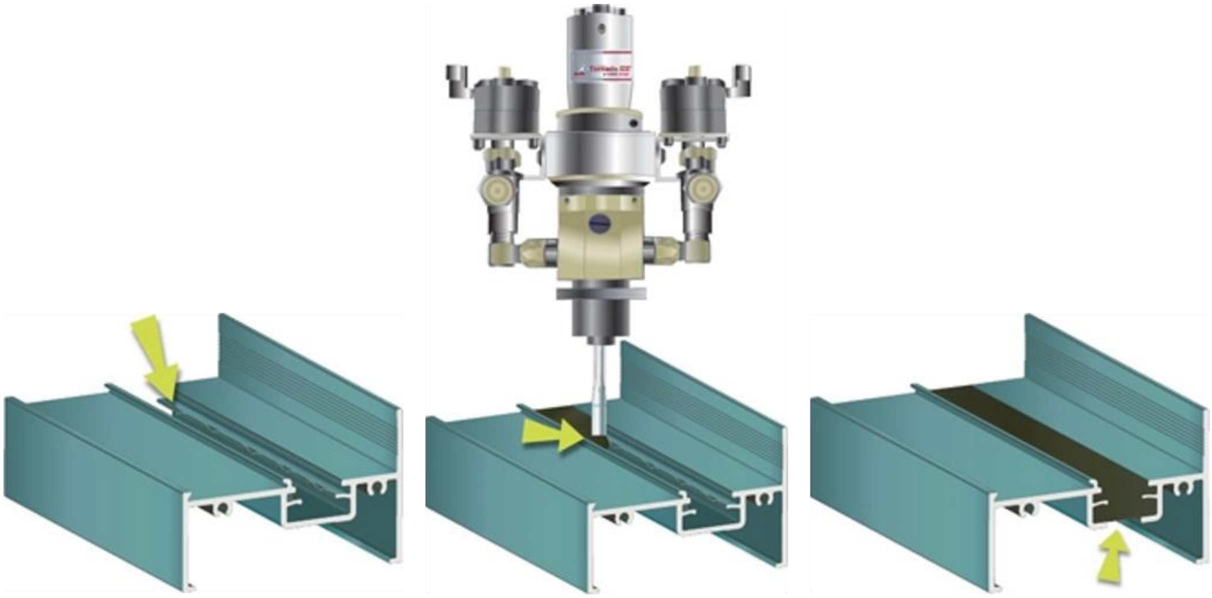
Extrusions to be painted are typically cleaned and then treated with a pre-coat in either a vertical or horizontal paint booth. Depending on the ultimate paint performance desired, a variety of pre-coats and primers may be employed. After pre-treatment, the extrusions will be coated with a liquid or powder paint and baked. Various paint formulations may be used depending on the desired performance.

Anodization

If extrusions are to be anodized, they are cleaned and etched (with either caustic or acid etch) in a series of baths. Subsequently, they are immersed in an acid electrolyte bath and an electrical current is passed through the solution. A cathode is mounted to the inside of the anodizing tank, while the aluminum extrusions act as an anode. Oxygen ions are released from the electrolyte and combine with aluminum atoms at the surface of the extrusion being anodized, thereby creating a durable aluminum oxide layer fully integrated with the underlying aluminum. Organic or inorganic colorants can subsequently be added. The final step is a sealing stage to enhance durability.

Thermal improvement

Two alternative thermal barrier processes are typically employed. The first is a "pour & debridge" system in which a polyurethane liquid is allowed to harden in a "pocket" designed into the extrusion, as shown in Figure 3-4. The aluminum forming the pocket is then removed to allow the hardened polyurethane to act as an insulator. The second process is a polyamide strip system where a rigid polyamide strip is mechanically crimped between two extrusions designed to accept the strip—thus creating the insulator. This is shown in Figure 3-5.

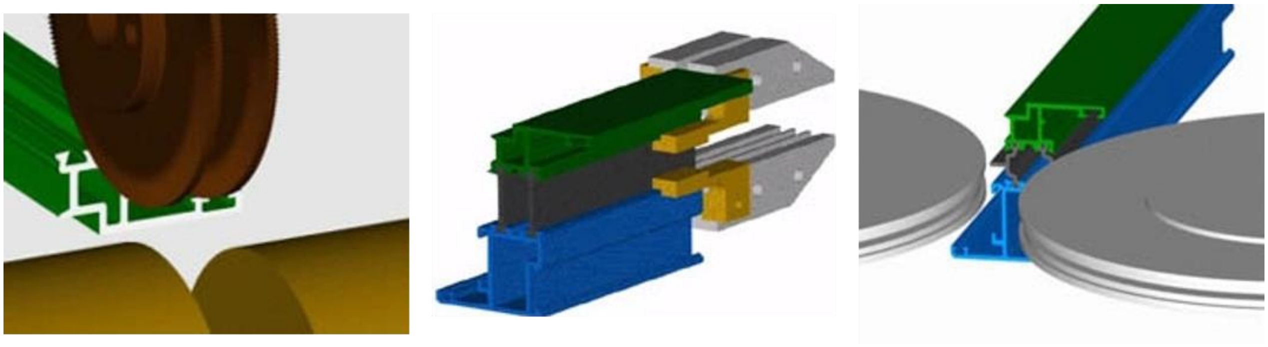


1. Prepare
The aluminum profile is extruded with a strategically placed channel to encapsulate an insulating polymer. The channel surface is conditioned with special equipment to create a "mechanical lock"

2. Pour
A two-part polymer is dispensed into the channel as a liquid, then hardens into a strong, structural insulating element

3. Debridge
The metal "bridge" is mechanically removed from the bottom of the channel, eliminating the conductive aluminum element and producing a non-metal-to-metal thermal barrier

Figure 3-4: Pour & debridge process



1. Profile knurling
A knurling wheel is used to produce "teeth" between 0.15 mm and 0.30 mm long in a pocket of the inner and outer extruded profiles that will be joined by the Strip to comprise the frame. These "teeth" will bite into the Strip during the crimping process and insure adequate shear strength for the composite profile.

2. Strip insertion
Typically, the Polyamide Strip is pulled or pushed into the extrusion profile, using specialized equipment. However, manual insertion can also be used, and there are assembly methods that pull or push the profile onto the Strip. The preferred method is up to the installer.

3. Crimping
Three sets of wheels rotate the extrusion onto the Strip and mechanically lock the components together. Over 1300 pounds of pressure is applied in stages, and the resulting aluminum/Strip assembly will then act as a load-bearing composite. Shear testing is typically conducted periodically to verify that the process has produced an assembly that will perform structurally as required.

Figure 3-5: Polyamide strip process

3.2.3. Product Composition

Extruded aluminum products produced in North America typically contain a considerable proportion of metal recycled from aluminum scrap. The average metal composition of North American products, based on metal feedstock information collected from the companies participating in this EPD is as follows:

Table 3-1: Metal composition of AEC extruded aluminum products

Category of Metal Source	Percentage (by mass)
Primary Metal (including alloying agents)	45.8%
Recovered Aluminum from Post-Industrial (Pre-Consumer) Scrap	40.6%
Recovered Aluminum from Post-Consumer Scrap	13.6%

Extrusions are made from both primary billet and secondary billet, with a varying degree of recycled metal content. Billets are either sourced externally or produced at a company-owned cast house. When produced at a company-owned cast house, internal process (run-around) scrap, post-industrial scrap, and post-consumer scrap are melted together with primary and secondary aluminum ingot feedstock sourced from an external supplier. Extruded aluminum products produced for different customers, applications, and market sectors may vary substantially in recycled content, ranging from 100% primary aluminum to nearly 100% aluminum scrap.

Definitions of the feedstocks used in the extrusion process are found in Table 3-2. The definitions of internal process (run-around) scrap, post-industrial scrap, and post-consumer scrap are consistent with the ISO 14021/25 (2006) standards and related interpretations by ULE.

Table 3-2: Aluminum extrusion primary and secondary feedstocks

Aluminum Source	Definition
Primary Ingot	Prime aluminum that has not been processed in any way since its origination at a smelter
Secondary Ingot	A solid of cast scrap aluminum to be cast into billet
Primary Billet	Log or billet produced from hot molten aluminum directly from a smelter with negligible recycled content and that has not been solidified and re-melted prior to casting
Secondary Billet	A solid of cast scrap aluminum that originates from aluminum that is not in a molten state from a smelter
Post-Consumer Scrap	Scrap generated by the retirement of a consumer or industrial product e.g. wheels, wire, and reclaimed material from building demolition or renovation
Post-Industrial Scrap (Pre-Consumer)	Scrap generated by industrial or manufacturing waste that can be introduced into a melting process without substantial treatment e.g. extrusion drop-offs from cutting, off-spec material, and scrap generated during subsequent processing by extruders or fabricators
Internal Process (Run-Around) scrap	Scrap generated as part of a repeated closed-loop manufacturing process. Excluded from metal composition declaration.

Data was only available for primary and secondary aluminum ingot. To ensure that the correct recycled content of purchased aluminum billet was modeled, an approach as shown in Figure 3-6 was taken. All scrap was modeled as burden free when it enters the system. When a company provided data for their own cast house, this primary ingot and aluminum ingot were input into the cast house in the amounts provided. When companies did not provided data for their own billet, primary ingot was modeled with the Aluminum Association dataset (or the International Aluminum Institute “Rest of World” dataset for non-domestic sources), and secondary billet was modeled with a ratio of primary ingot and aluminum scrap corresponding to the recycled content of the billet. Both primary ingot and aluminum scrap went through a remelting process. When companies were not able to provide the recycled content of their purchased secondary billet, an assumption was made based on the industry average.

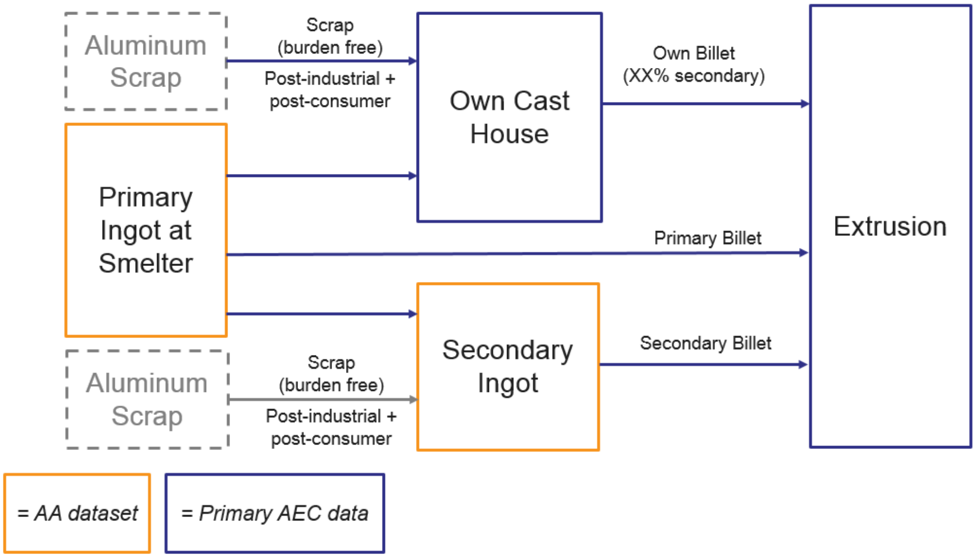


Figure 3-6: Secondary billet modeling approach

As the extrusion process is a shaping of the aluminum billet, only surface-treatment processes, i.e., anodizing and painting, alter the material content of the finished extrusion process. The percent by mass added by anodizing or painting is not large enough to significantly alter the percent by mass of the aluminum extrusion. The product composition of the extruded, anodized, painted, and thermally improved extrusions are shown in Table 3-3.

Table 3-3: Material composition of the extrusion products under study

	Extrusion, mill finish	Extrusion, painted	Extrusion, anodized**	Thermally improved extrusion, mill finish	Thermally improved extrusion, painted	Thermally improved extrusion, anodized**
Aluminum*	100%	>95%	100%	>97%	>93%	>97%
Paint		<5%			<5%	
Acrylic	-	*12%*	-	-	*12%*	-
Polyester	-	*51%*	-	-	*51%*	-
PVDF	-	*37%*	-	-	*37%*	-
Thermal break				<3%	<3%	<3%
Polyurethane	-	-	-	*93%*	*93%*	*93%*
Polyamide	-	-	-	*7%*	*7%*	*7%*

*As in Table 2-1, the aluminum itself could have a chemical composition of Al of 96.2% - 98.6%, depending on alloy.
**Anodization chemicals do not adhere to the extrusion.

AEC members' aluminum extrusion products are manufactured in Canada and the United States but billet and ingot are purchased from both domestic and international suppliers. International billet and ingot were sourced from Russia, the Middle East, and South America, or from the London Metal Exchange (LME) warehouses. Since the exact country of origin was unknown for billet sourced from the LME warehouses, specific countries were not modeled for the international billet, and all international billet was considered generic international. When the source of the aluminum billet or ingot was unknown, an estimate was made based on the U.S. and Canada Aluminum Extrusion Billet Demand internal survey conducted by The Aluminum Association. Based on the results of this survey, when billet or ingot origin was unknown, it was assumed that 59.4% of billet was from domestic producers and 40.6% was imported from international producers. This is similar to the primary ingot and billet origin of companies that were able to determine provenance – 57.4% domestic and 42.6% international. It was also assumed that all secondary billet originated in North America, which is supported by the Aluminum Association survey. Secondary includes secondary billet, ingot, and post-consumer, post-industrial, and run-around scrap. On average, secondary billet contains 22% primary aluminum.

Table 3-4: Country of origin of AEC extruded aluminum products

Origin	Source	Total (Billet + Ingot) [% by mass]
Domestic	**Primary**	22.0%
Domestic	**Secondary**	61.6%
International	**Primary**	16.3%

3.2.4. Production Process

This section provides information on the inputs and outputs of the main unit processes. Unit process information for billet casting, extrusion, painting, anodizing and thermal improvement are found in Table 3-5, Table 3-6, Table 3-7, Table 3-8, and Table 3-9,respectively.

Table 3-5: Unit process, billet casting

Type		Flow	Value	Unit	DQI*
Inputs	**Aluminum**	Primary aluminum ingot	0.297	t	Measured
		Secondary aluminum ingot	0.0283	t	Measured
		Aluminum scrap (external, post-consumer scrap)	0.179	t	Measured
		Aluminum scrap (external, post-industrial scrap)	0.522	t	Measured
		Aluminum scrap (internal)	0.0509	t	Measured
	Energy	Electricity	148	kWh	Measured
		Natural gas	4.97	MMBtu	Measured
		Propane (internal transport)	0.492	L	Measured
		Diesel	1.50	L	Measured
		Fuel oil	0.253	L	Measured
	Cryogenic gases	Nitrogen	1.45	m^3	Measured
		Argon	0.476	m^3	Measured
		Other	0.00241	m^3	Measured
	Alloying elements	Magnesium	2.53	kg	Measured
		Silicon	1.59	kg	Measured
		Other	1.83	kg	Measured

Type		Flow	Value	Unit	DQI*
	Water	Water (municipal + ground)	704	L	Measured
Outputs	**Aluminum**	Aluminum billet	1.00	t	Measured
		Aluminum to recycling (internal)	0.0509	t	Measured
		Aluminum to recycling (external)	0.0276	t	Measured
	Wastes	Non-hazardous waste to landfill	2.79	kg	Measured
		Non-hazardous waste to recovery	6.65	kg	Measured
		Hazardous waste to disposal	0.235	kg	Measured
		Waste water to treatment	388	L	Measured
		Water vapor	316	L	Calculated

Table 3-6: Unit process, extrusion

Type		Flow	Value	Unit	DQI*
Inputs	**Aluminum**	Primary aluminum billet	0.339	t	Measured
		Secondary aluminum billet	0.328	t	Measured
		Aluminum billet (from company-owned cast house)	0.649	t	Measured
	Energy	Electricity	537	kWh	Measured
		Natural gas	3.07	MMBtu	Measured
		Propane (internal transport)	1.95	L	Measured
	Materials	Dies	5.07	kg	Measured
		Sodium hydroxide (100%)	7.84	kg	Measured
		Hydraulic oil	2.16	kg	Measured
		Nitrogen	0.000870	L	Measured
	Water	Water (municipal + ground)	1,020	L	Measured
Outputs	**Aluminum**	Mill finished aluminum extrusion	1.00	t	Measured
		Aluminum scrap	0.359	t	Measured
	Wastes	Steel dies to recycling (external)	5.15	kg	Measured
		Non-hazardous waste to landfill	4.89	kg	Measured
		Non-hazardous waste to recovery	1.65	kg	Measured
		Non-hazardous waste to incineration	0.434	kg	Measured
		Hazardous waste to disposal	2.96	kg	Measured
		Hydraulic oil to disposal	1.34	kg	Measured
		Recovered sodium hydroxide	1.72	kg	Measured
		Waste water to treatment	601	L	Measured

Type		Flow	Value	Unit	DQI*
		Water vapor	420	L	Calculated

Table 3-7: Unit process, painting

Type		Flow	Value	Unit	DQI*
Inputs	**Aluminum**	Aluminum extrusion	1.07	t	Measured
	Energy	Electricity	226	kWh	Measured
		Natural gas	3.65	MMBtu	Measured
		Propane (internal transport)	2.24	L	Measured
	Liquid paint	PVDF	16.2	kg	Measured
		Polyester	22.5	kg	Measured
		Acrylic	5.39	kg	Measured
	Solvents	Ethyl Acetate	0.107	kg	Measured
		Xylene	10.5	kg	Measured
		Isopropanol	0.711	kg	Measured
		Naphtha	1.44	kg	Measured
	Pre-treatment chemicals	Chrome pre-treatment chemicals*	3.25	kg	Measured
		Non-chrome pre-treatment chemicals	4.09	kg	Measured
	Water	Water	1405	L	Measured
Outputs	**Aluminum**	Painted aluminum extrusion	1.00	t	Measured
		Aluminum to recycling	0.0729	t	Measured
	Wastes	Non-hazardous waste to landfill	2.28	kg	Measured
		Hazardous waste to disposal	27.2	kg	Measured
		Hazardous waste to recovery	1.77	kg	Measured
		Waste water to municipal treatment	508	L	Measured
		Water vapor	897	L	Calculated
	Emissions	VOC	6.33	kg	Calculated

*Chrome pre-treatment only used with high-performance PVDF paints

Table 3-8: Unit process, anodization

Type		Flow	Value	Unit	DQI*
Inputs	**Aluminum**	Aluminum extrusion	1.03	t	Measured
	Energy	Electricity	923	kWh	Measured
		Natural gas	5.08	MMBtu	Measured

Type		Flow	Value	Unit	DQI*
		Propane (internal transport)	2.36	L	Measured
	Anodization Chemicals	Acid Etch	32.3	kg	Measured
		Anodize	102	kg	Measured
		Bright Dip	9.33	kg	Measured
		Caustic Etch	40.5	kg	Measured
		Cleaner Tank	25.0	kg	Measured
		De-Oxidizing	1.43	kg	Measured
		Electrolytic Color	1.77	kg	Measured
		Gold Color	2.26	kg	Measured
		Seal	3.69	kg	Measured
		Unknown	7.72	kg	Measured
	Water	Water	11,000	L	Measured
Outputs	**Aluminum**	Anodized aluminum extrusion	1.00	t	Measured
		Aluminum to recycling	0.0229	t	Measured
	Wastes	Non-hazardous waste to landfill	166	kg	Measured
		Non-hazardous waste to recovery	62.3	kg	Measured
		Non-hazardous waste to incineration	0.171	kg	Measured
		Hazardous waste to disposal	8.71	kg	Measured
		Waste water to treatment	8,000	L	Measured
		Water Vapor	3,000	L	Calculated

Table 3-9: Unit process, thermal improvement

Type		Flow	Value	Unit	DQI*
Inputs	**Aluminum**	Painted aluminum extrusion	0.588	t	Measured
		Anodized aluminum extrusion	0.214	t	Measured
		Mill aluminum extrusion	0.229	t	Measured
	Energy	Electricity	38.9	kWh	Measured
		Propane (internal transport)	3.21	L	Measured
	Materials	Polyurethane	24.8	kg	Measured
		Polyamide	1.74	kg	Measured
		AZO-Purge MP2	0.0241	kg	Measured
		Alodine	57.3	kg	Measured
Outputs	**Aluminum**	Thermally improved aluminum extrusion	1.00	t	Measured
		Aluminum to recycling	0.0392	t	Measured

3.2.5. End-of-Life

At the life cycle level, aluminum was modeled as part of an open-loop recycling system using the avoided burden allocation approach, as shown in Figure 3-7.

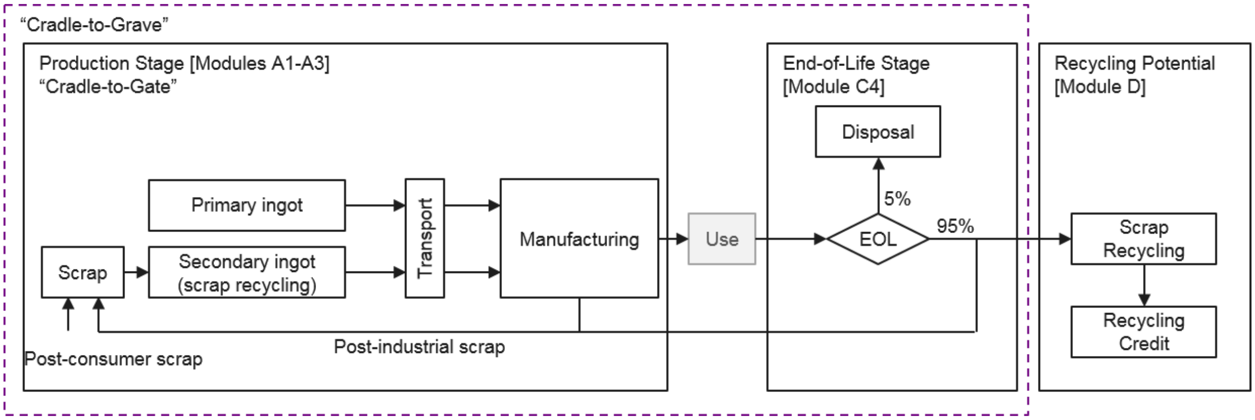


Figure 3-7: End-of-Life Approach, Cradle to Grave + Module D

A 95% recycling rate was used for the aluminum extrusion and a credit was assigned to the life cycle equal to the avoided burden of primary production, accounting for the burden from scrap collection, processing, re-melting and casting. The credit was reported in module D. The 95% recycling rate is a global estimate for aluminum in the building and transportation sectors (International Aluminum Association, 2013) which has been supported by minimum values published in a United Nations report (UNEP, 2011). The remaining 5% not captured in the recycling loop are modeled as being landfilled and were reported in module C4. Scrap is generated in the finishing steps as well which leads to a higher scrap credit in module D.

3.3. Background Data

3.3.1. Fuels and Energy

National/regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi ts database 2016. Table 3-10 shows the most relevant LCI datasets used in modeling the product systems. Electricity consumption in the United States was modeled using regional, consumption-based power mix based on the EPA's eGRID data found in GaBi that account for imports from neighboring countries/regions. For a better overview of the 22 available regions, refer to the map shown in Figure 3-8.

Electricity produced in Canada, was modeled using regional grid mixes developed from available information on production mixes and connected to upstream GaBi data.

Figure 3-8: Regional electricity GaBi datasets based on eGrid and FERC data

Documentation for all GaBi datasets can be found at http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/.

Table 3-10: Key energy datasets used in inventory analysis

Energy	Dataset	Data Provider	Ref. Year	Geography
Diesel	Diesel mix at refinery	thinkstep	2012	US
	Diesel at refinery	thinkstep	2012	US
Electricity	Electricity from biogas	thinkstep	2012	CA
	Electricity from biomass (solid)	thinkstep	2012	CA
	Electricity from hard coal	thinkstep	2012	CA
	Electricity from heavy fuel oil (HFO)	thinkstep	2012	CA
	Electricity from hydro power	thinkstep	2012	CA
	Electricity from lignite	thinkstep	2012	CA
	Electricity from natural gas	thinkstep	2012	CA
	Electricity from nuclear	thinkstep	2012	CA
	Electricity from photovoltaic	thinkstep	2012	CA
	Electricity from waste	thinkstep	2012	CA
	Electricity from wind power	thinkstep	2012	CA
	Electricity from photovoltaic	thinkstep	2012	US
	Electricity grid mix – AZNM	thinkstep	2010	US
	Electricity grid mix – CAMX	thinkstep	2010	US

Energy	Dataset	Data Provider	Ref. Year	Geography
	Electricity grid mix – ERCT	thinkstep	2010	US
	Electricity grid mix – FRCC	thinkstep	2010	US
	Electricity grid mix – MISO	thinkstep	2010	US
	Electricity grid mix – NWPP	thinkstep	2010	US
	Electricity grid mix – PJM	thinkstep	2010	US
	Electricity grid mix – RFCW (w/o MISO + PJM)	thinkstep	2010	US
	Electricity grid mix – SPNO	thinkstep	2010	US
	Electricity grid mix – SRMV	thinkstep	2010	US
	Electricity grid mix – SRSO	thinkstep	2010	US
	Electricity grid mix – SRTV (without MISO)	thinkstep	2010	US
	Electricity grid mix – SRVC (without PJM)	thinkstep	2010	US
Heavy fuel oil	Heavy fuel oil at refinery (0.3wt.% S)	thinkstep	2012	US
	Heavy fuel oil at refinery (2.5wt.% S)	thinkstep	2012	US
Natural gas	Natural gas mix ts	thinkstep	2012	US
	Thermal energy from natural gas	thinkstep	2012	US
Propane	Propane at refinery	thinkstep	2012	US
	Thermal energy from propane	thinkstep	2012	US

3.3.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the GaBi ts database 2016. Table 3-11 shows the most relevant LCI datasets used in modeling the product systems. Documentation for all GaBi datasets can be found at http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/.

Table 3-11: Key material and process datasets used in inventory analysis

Material / Process	Dataset	Data Provider	Proxy*	Ref. Year	Geo.
Aluminum -domestic, primary	Primary Aluminum Ingot	AA/thinkstep	None	2010	RNA
Aluminum- domestic, secondary	Secondary Aluminum Ingot	AA/thinkstep	None	2010	RNA
Aluminum- international, primary	Aluminium ingot mix IAI	IAI	None	2010	RoW
Alloying elements	Boron trioxide (estimation)	thinkstep	Geo.	2015	DE
	Magnesium chloride	thinkstep	Geo.	2015	DE
	Magnesium	thinkstep	Geo.	2015	CN
	Copper mix (99,999% from electrolysis)	thinkstep	None	2015	GLO

Material / Process	Dataset	Data Provider	Proxy*	Ref. Year	Geo.
	Silicon mix (99%)	thinkstep	None	2015	GLO
	Ferro chrome mix	thinkstep	Geo.	2015	DE
	Ferro manganese	thinkstep	Geo.	2015	ZA
	Titanium	thinkstep	None	2015	GLO
	Antimony (Hydrometallurgy route)	thinkstep	Geo.	2015	CN
	Iron ore-mix	thinkstep	Geo.	2015	DE
	Lead (99,995%)	thinkstep	None	2015	RNA
Anodization chemicals					
1,2-dibromo-2,4-dicyanobutane	Cyanuric chloride (via trimerization of cyanogen chloride)	thinkstep	Geo. Tech.	2015	DE
Acetic acid	Acetic acid from methanol (low pressure carbonylation) (Monsanto process)	thinkstep	None	2015	US
Acid Etch	Hydrogen fluoride	thinkstep	Geo.	2015	DE
Alcohol polyglycolether	Carrier (fatty ester of polyglycolether and modified polyalcohol)	thinkstep	Tech.	2015	GLO
Alkaline cleaner	Trisodium phosphate	thinkstep	Tech.	2015	GLO
Ammonia	Ammonia (NH3)	thinkstep	None	2015	US
Ammonia hydroxide	Ammonia water (weight share 25% NH3)	thinkstep	None	2015	US
Ammonium bifluoride	Hydrogen fluoride	thinkstep	Geo. Tech.	2015	DE
Copper sulfate	Copper sulphate (from Copper)	thinkstep	None	2015	US
Desmut additive	Iron (III) chloride	thinkstep	Tech.	2015	US
Desmut additive	Sulphuric acid aq. mix (96%)	thinkstep	Tech.	2015	US
Diammonium phosphate	Diammonium phosphate granular fertilizer (DAP)	thinkstep	Geo.	2015	DE
Disodium hexadecyldiphenyloxide disulfonate	Sodium alkylbenzenesulfonate (from benzene and paraffins over alkyl chloride)	thinkstep	Geo. Tech.	2015	DE
Etch additive	Azoic dye (chromium complex azoic dyestuff)	thinkstep	Tech.	2015	GLO
Gold color	Iron (III) chloride	thinkstep	Tech.	2015	US
Hydrochloric acid	Hydrochloric acid mix (100%)	thinkstep	Geo.	2015	DE
Hydrogen peroxide	Hydrogen peroxide (100%; H2O2) (Hydrogen from steam reforming)	thinkstep	None	2015	US
Seal	Magnesium Hydroxide (from sea water)	thinkstep	Geo. Tech.	2015	EU-27
Seal	Nickel mix	thinkstep	Tech.	2015	GLO
Seal	Acetic acid from methanol (low pressure carbonylation) (Monsanto process)	thinkstep	Tech.	2015	US
Silicone emulsion defoamer	Silicone fluids (low viscous) (from organosilanes) (estimation)	thinkstep	None	2015	US

Material / Process	Dataset	Data Provider	Proxy*	Ref. Year	Geo.
Soaping Agent	C12-15 Alcohol (petro) Ethoxylate, 3 moles EO(No. 11 - Matrix)	thinkstep/ ERASM	Geo. Tech.	2011	EU-27
Soaping Agent	Soaping agent (alkyl-amino-polyglycolic compound)	thinkstep	None	2015	GLO
Sodium hydroxide	Sodium hydroxide (caustic soda) mix (100%)	thinkstep	None	2015	US
Sodium persulfate	Potassium persulfate	thinkstep	Geo. Tech.	2015	DE
Sodium sulfide	Sodium sulphate	thinkstep	Tech.	2015	GLO
Stannous sulfate	Tin	thinkstep	Tech.	2015	GLO
Sugar derivative	Sugar (from sugar cane)	thinkstep	Tech.	2015	US
Sulfuric acid	Sulphuric acid aq. mix (96%)	thinkstep	None	2015	US
Surfactant	Non-ionic surfactant (ethylene oxid derivatives)	thinkstep	None	2015	GLO
Triazine derivative sodium salt	Melamine	thinkstep	Geo. Tech.	2015	DE
Water	Water deionized	thinkstep	None	2015	US
Argon (gaseous)	Argon (gaseous)	thinkstep	None	2015	US
Chlorine (gaseous)	Chlorine mix	thinkstep	None	2015	US
Chrome pre-treatment chemicals	Chromic acid	thinkstep	Tech.	2015	US
Dies	Steel cold rolled coil worldsteel	worldsteel	None	2007	RNA
Dies recycling	Value of scrap worldsteel	worldsteel	None	2007	GLO
Hydraulic oil	Lubricants at refinery	thinkstep	None	2012	US
Nitric acid	Nitric acid (60%)	thinkstep	None	2015	US
Nitrogen (gaseous)	Nitrogen (gaseous)	thinkstep	None	2015	US
Nitrogen (liquid)	Nitrogen (liquid)	thinkstep	None	2015	US
Non chrome pre-treatment chemicals	Potassium hydroxide (KOH)	thinkstep	Tech.	2015	US
	Hydrogen fluoride by-product gypsum highly pure	thinkstep	Tech.	2015	US
	Sulphuric acid aq. mix (96%)	thinkstep	Tech.	2015	US
	Phosphoric acid (100%) (wet process)	thinkstep	Tech.	2015	US
	Iron (III) chloride	thinkstep	Tech.	2015	US
	Ethylenediaminetetraacetic acid (EDTA) (estimated)	thinkstep	Geo. Tech.	2015	EU-27
	Triethanolamine (TEA)	thinkstep	Tech.	2015	US
	Water deionized	thinkstep	Tech.	2015	US
	Chromic acid	thinkstep	Tech.	2015	US
	Sodium hydroxide (caustic soda) mix (100%)	thinkstep	Tech.	2015	US
Oxygen (gaseous)	Oxygen (gaseous)	thinkstep	None	2015	US

Material / Process	Dataset	Data Provider	Proxy*	Ref. Year	Geo.
Packaging	Average corrugated board box (paper/cardboard)	thinkstep	Geo.	2015	EU-27
	PET fabric (1 sqm)	thinkstep	Geo.	2015	DE
	Fiberglass Duct Wrap	NAIMA	Tech.	2007	US
	Polyurethane rigid foam (PU)	Plastics Europe	Geo.	2005	RER
	Jute hessain net	thinkstep	Geo.	2015	IN
	Softwood plywood CORRIM	CORRIM	None	2011	RNA
	Kraft paper (EN15804 A1-A3)	thinkstep	Geo.	2015	EU-27
	Polyethylene film (LDPE/PE-LD)	thinkstep	None	2015	US
	Biaxial oriented polypropylene film (BOPP)	thinkstep	None	2015	US
	Steel cold rolled coil	worldsteel	Tech.	2007	RNA
	Softwood plywood CORRIM	CORRIM	None	2011	RNA
Paints	Cyclohexanone	thinkstep	None	2015	US
	Acrylate resin (epoxy functional)	thinkstep	Geo. Tech.	2015	EU-27
	Polyvinylidene fluoride (PVDF)	thinkstep	Geo. Tech.	2015	DE
	Polymethyl Methacrylate Granulate (PMMA) (estimation)	thinkstep	None	2015	US
	Aliphatic/aromatic copolyester	thinkstep	None	2015	US
Thermal Break-Polyamide	Polyamide 6.6 granulate (PA 6.6) (HMDA over Adiponitrile)	thinkstep	None	2013	US
Thermal Break-Polyurethane	Thermoplastic polyurethane (TPU, TPE-U) adhesive	thinkstep	None	2015	US
Sodium hydroxide	Sodium hydroxide (caustic soda) mix (100%)	thinkstep	None	2015	US
Sulfuric acid	Sulphuric acid aq. mix (96%)	thinkstep	None	2015	US
Titanium dioxide	Titanium dioxide pigment (sulphate process)	thinkstep	None	2015	US
Waste treatment	Hazardous waste (non-specific) (no C, worst case scenario incl. landfill)	thinkstep	None	2015	GLO
	Hazardous waste (non-specific) (C rich, worst case scenario incl. landfill)	thinkstep	None	2015	GLO
	Ferro metals on landfill	thinkstep	None	2015	US
	Glass/inert waste in waste incineration plant	thinkstep	None	2015	US
	Glass/inert on landfill	thinkstep	None	2015	US
	Municipal waste water treatment (mix)	thinkstep	None	2015	US
	Wood product (OSB, particle board) waste in waste incineration plant	thinkstep	None	2015	US
End-of-Life Recycling	Primary Aluminum Ingot	AA/thinkstep	None	2010	RNA

Material / Process	Dataset	Data Provider	Proxy*	Ref. Year	Geo.
	Secondary Aluminum Ingot	AA/thinkstep	None	2010	RNA
	Glass/inert on landfill	thinkstep	None	2015	US
Water	Water deionized	thinkstep	None	2015	US
	Tap water from groundwater	thinkstep	None	2015	US
Xylene	o-Xylene	thinkstep	None	2015	US

* Geo.: Geographical proxy; Tech.: Technological proxy

3.3.3. Transportation

The GaBi datasets for road and ocean transports and fuels were used to model transportation. Truck transportation within the United States was modeled using the GaBi ts US truck transportation datasets. Vehicle types, fuel usage, and emissions for these transportation processes were developed using a GaBi model based on the last US Census Bureau Vehicle Inventory and Use Survey (2002) and US EPA emissions standards for heavy trucks in 2007. The 2002 VIUS survey is the latest available survey describing truck fleet fuel consumption and utilization ratios in the US, and the 2007 EPA emissions standards are considered to be the best-available data for describing current US truck emissions for different truck classes. Transportation datasets are summarized in Table 3-12.

Table 3-12: Transportation and road fuel datasets

Transport	Dataset name	Data Provider	Ref. Year	Geo.
Ship	Container ship	thinkstep	2015	GLO
Rail	Rail transport cargo – Diesel	thinkstep	2015	GLO
Truck	Truck - Trailer, basic enclosed / 45,000 lb payload - 8b	thinkstep	2015	US

4. LCIA Results

This section contains the results for the impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Overall Results

4.1.1. Impact assessment results

The life cycle impact results for the various extrusion products are presented in Table 4-1 through Table 4-6. The majority of impacts lie with the production stage of the life cycle. Module D burdens are negative due to the credit given for recycling at EoL. While all extrusion products have the same recycling rate and recycled content, the generation of scrap during the finishing processes leads to an increased credit in module D compared to the mill finished extrusion.

Table 4-1: Impact assessment, mill finished extrusion, per metric ton

Impact Category	Unit	A1-A3	C4	D
CML 2001 (v4.1)				
Global warming potential	kg CO_2 eq	7,510	2.24	-4,910
Ozone depletion potential	kg CFC-11 eq	8.27E-07	4.29E-11	-2.08E-07
Acidification potential	kg SO_2 eq	49.2	0.00970	-35.1
Eutrophication potential	kg PO_4^{3-} eq	2.74	0.00124	-1.45
Photochemical ozone creation potential	kg C_2H_4 eq	2.71	9.84E-04	-1.76
Abiotic depletion potential for non-fossil resources	kg Sb eq	0.00494	8.59E-07	-0.00263
Abiotic depletion potential for fossil resources	MJ	78,400	33.9	-45,200
TRACI 2.1				
Global warming potential	kg CO_2 eq	7,510	2.26	-4,900
Ozone depletion potential	kg CFC-11 eq	8.90E-07	4.56E-11	-2.21E-07
Acidification potential	kg SO_2 eq	46.5	0.0104	-32.3
Eutrophication potential	kg N eq	1.03	5.81E-04	-0.519
Smog formation potential	kg O_3 eq	457	0.203	-250
Fossil fuel consumption	MJ	6,970	4.35	-2,990

Table 4-2: Impact assessment, painted extrusion, per metric ton

Impact Category	Unit	A1-A3	C4	D
CML 2001 (v4.1)				
Global warming potential	kg CO_2 eq	8,900	2.24	-5,310
Ozone depletion potential	kg CFC-11 eq	9.43E-05	4.29E-11	-2.25E-07
Acidification potential	kg SO_2 eq	54.6	0.00970	-37.9
Eutrophication potential	kg PO_4^{3-} eq	3.18	0.00124	-1.57
Photochemical ozone creation potential	kg C_2H_4 eq	4.05	9.84E-04	-1.90
Abiotic depletion potential for non-fossil resources	kg Sb eq	0.00685	8.59E-07	-0.00285
Abiotic depletion potential for fossil resources	MJ	97,500	33.9	-48,900
TRACI 2.1				
Global warming potential	kg CO_2 eq	8,910	2.26	-5,300
Ozone depletion potential	kg CFC-11 eq	4.46E-05	4.56E-11	-2.39E-07
Acidification potential	kg SO_2 eq	51.9	0.0104	-34.9
Eutrophication potential	kg N eq	1.24	5.81E-04	-0.561
Smog formation potential	kg O_3 eq	529	0.203	-270
Fossil fuel consumption	MJ	9,160	4.35	-3,230

Table 4-3: Impact assessment, anodized extrusion, per metric ton

Impact Category	Unit	A1-A3	C4	D
CML 2001 (v4.1)				
Global warming potential	kg CO_2 eq	9,060	2.24	-5,070
Ozone depletion potential	kg CFC-11 eq	1.10E-06	4.29E-11	-2.15E-07
Acidification potential	kg SO_2 eq	56.1	0.00970	-36.2
Eutrophication potential	kg PO_4^{3-} eq	3.47	0.00124	-1.50
Photochemical ozone creation potential	kg C_2H_4 eq	3.18	9.84E-04	-1.81
Abiotic depletion potential for non-fossil resources	kg Sb eq	0.01180	8.59E-07	-0.00272
Abiotic depletion potential for fossil resources	MJ	99,600	33.9	-46,600
TRACI 2.1				
Global warming potential	kg CO_2 eq	9,070	2.26	-5,060
Ozone depletion potential	kg CFC-11 eq	1.18E-06	4.56E-11	-2.28E-07
Acidification potential	kg SO_2 eq	53.3	0.0104	-33.4
Eutrophication potential	kg N eq	1.56	5.81E-04	-0.536
Smog formation potential	kg O_3 eq	515	0.203	-258
Fossil fuel consumption	MJ	9,200	4.35	-3,080

Table 4-4: Impact assessment, thermally improved mill finished extrusion, per metric ton

Impact Category	Unit	A1-A3	C4	D
CML 2001 (v4.1)				
Global warming potential	kg CO_2 eq	8,340	2.24	-5,140
Ozone depletion potential	kg CFC-11 eq	8.82E-07	4.29E-11	-2.18E-07
Acidification potential	kg SO_2 eq	52.3	0.00970	-36.7
Eutrophication potential	kg PO_4^{3-} eq	3.10	0.00124	-1.52
Photochemical ozone creation potential	kg C_2H_4 eq	2.96	9.84E-04	-1.84
Abiotic depletion potential for non-fossil resources	kg Sb eq	0.01720	8.59E-07	-0.00275
Abiotic depletion potential for fossil resources	MJ	88,800	33.9	-47,300
TRACI 2.1				
Global warming potential	kg CO_2 eq	8,340	2.26	-5,130
Ozone depletion potential	kg CFC-11 eq	9.48E-07	4.56E-11	-2.32E-07
Acidification potential	kg SO_2 eq	49.8	0.0104	-33.8
Eutrophication potential	kg N eq	1.24	5.81E-04	-0.543
Smog formation potential	kg O_3 eq	503	0.203	-262
Fossil fuel consumption	MJ	8,150	4.35	-3,130

Table 4-5: Impact assessment, thermally improved painted extrusion, per metric ton

Impact Category	Unit	A1-A3	C4	D
CML 2001 (v4.1)				
Global warming potential	kg CO_2 eq	9,770	2.24	-5,550
Ozone depletion potential	kg CFC-11 eq	9.73E-05	4.29E-11	-2.35E-07
Acidification potential	kg SO_2 eq	58.0	0.00970	-39.7
Eutrophication potential	kg PO_4^{3-} eq	3.55	0.00124	-1.64
Photochemical ozone creation potential	kg C_2H_4 eq	4.34	9.84E-04	-1.99
Abiotic depletion potential for non-fossil resources	kg Sb eq	0.01920	8.59E-07	-0.00298
Abiotic depletion potential for fossil resources	MJ	109,000	33.9	-51,100
TRACI 2.1				
Global warming potential	kg CO_2 eq	9,780	2.26	-5,540
Ozone depletion potential	kg CFC-11 eq	4.60E-05	4.56E-11	-2.50E-07
Acidification potential	kg SO_2 eq	55.3	0.0104	-36.5
Eutrophication potential	kg N eq	1.45	5.81E-04	-0.587
Smog formation potential	kg O_3 eq	577	0.203	-283
Fossil fuel consumption	MJ	10,400	4.35	-3,380

Table 4-6: Impact assessment, thermally improved anodized extrusion, per metric ton

Impact Category	Unit	A1-A3	C4	D
CML 2001 (v4.1)				
Global warming potential	kg CO_2 eq	9,930	2.24	-5,300
Ozone depletion potential	kg CFC-11 eq	1.16E-06	4.29E-11	-2.24E-07
Acidification potential	kg SO_2 eq	59.5	0.00970	-37.9
Eutrophication potential	kg PO_4^{3-} eq	3.85	0.00124	-1.57
Photochemical ozone creation potential	kg C_2H_4 eq	3.44	9.84E-04	-1.90
Abiotic depletion potential for non-fossil resources	kg Sb eq	0.02430	8.59E-07	-0.00284
Abiotic depletion potential for fossil resources	MJ	111,000	33.9	-48,800
TRACI 2.1				
Global warming potential	kg CO_2 eq	9,950	2.26	-5,290
Ozone depletion potential	kg CFC-11 eq	1.25E-06	4.56E-11	-2.39E-07
Acidification potential	kg SO_2 eq	56.8	0.0104	-34.9
Eutrophication potential	kg N eq	1.78	5.81E-04	-0.560
Smog formation potential	kg O_3 eq	562	0.203	-270
Fossil fuel consumption	MJ	10,400	4.35	-3,230

4.1.2. Resource use results

The life cycle resource use results for the various extrusion products are presented in Table 4-7 through Table 4-12Table 4-1, as required by the PCR.

Table 4-7: Resource use, mill finished extrusion, per metric ton

Resource	Unit	A1-A3	C4	D
Renewable primary energy as energy carrier	MJ	32,200	2.20	-29,100
Renewable primary energy resource as material utilization	MJ	-	-	-
Total use of renewable primary energy resources	MJ	32,200	2.20	-29,100
Non-renewable primary energy as energy carrier	MJ	82,300	35	-46,400
Non-renewable primary energy as material utilization	MJ	-	-	-
Total use of non-renewable primary energy resources	MJ	82,300	35	-46,400
Use of secondary materials	kg	709	-	-
Use of renewable secondary fuels	MJ	-	-	-
Use of non-renewable secondary fuels	MJ	-	-	-
Use of net fresh water	m^3	128	0.00535	-127

Table 4-8: Resource use, painted extrusion, per metric ton

Resource	Unit	A1-A3	C4	D
Renewable primary energy as energy carrier	MJ	35,200	2.20	-31,400
Renewable primary energy resource as material utilization	MJ	-	-	-
Total use of renewable primary energy resources	MJ	35,200	2.20	-31,400
Non-renewable primary energy as energy carrier	MJ	102,000	34.8	-50,200
Non-renewable primary energy as material utilization	MJ	-	-	-
Total use of non-renewable primary energy resources	MJ	102,000	34.8	-50,200
Use of secondary materials	kg	764	-	-
Use of renewable secondary fuels	MJ	-	-	-
Use of non-renewable secondary fuels	MJ	-	-	-
Use of net fresh water	m^3	140	0.00535	-137

Table 4-9: Resource use, anodized extrusion, per metric ton

Resource	Unit	A1-A3	C4	D
Renewable primary energy as energy carrier	MJ	34,400	2.20	-30,000
Renewable primary energy resource as material utilization	MJ	-	-	-
Total use of renewable primary energy resources	MJ	34,400	2.20	-30,000
Non-renewable primary energy as energy carrier	MJ	106,000	35	-47,900
Non-renewable primary energy as material utilization	MJ	-	-	-
Total use of non-renewable primary energy resources	MJ	106,000	35	-47,900
Use of secondary materials	kg	729	-	-
Use of renewable secondary fuels	MJ	-	-	-
Use of non-renewable secondary fuels	MJ	-	-	-
Use of net fresh water	m^3	140	0.00535	-131

Table 4-10: Resource use, thermally improved mill finished extrusion, per metric ton

Resource	Unit	A1-A3	C4	D
Renewable primary energy as energy carrier	MJ	33,400	2.20	-30,400
Renewable primary energy resource as material utilization	MJ	-	-	-
Total use of renewable primary energy resources	MJ	33,400	2.20	-30,400
Non-renewable primary energy as energy carrier	MJ	93,200	35.0	-48,600
Non-renewable primary energy as material utilization	MJ	-	-	-
Total use of non-renewable primary energy resources	MJ	93,200	35.0	-48,600
Use of secondary materials	kg	730	-	-
Use of renewable secondary fuels	MJ	-	-	-
Use of non-renewable secondary fuels	MJ	-	-	-
Use of net fresh water	m^3	133	0.00535	-133

Table 4-11: Resource use, thermally improved painted extrusion, per metric ton

Resource	Unit	A1-A3	C4	D
Renewable primary energy as energy carrier	MJ	36,500	2.20	-32,900
Renewable primary energy resource as material utilization	MJ	-	-	-
Total use of renewable primary energy resources	MJ	36,500	2.20	-32,900
Non-renewable primary energy as energy carrier	MJ	114,000	34.8	-52,400
Non-renewable primary energy as material utilization	MJ	-	-	-
Total use of non-renewable primary energy resources	MJ	114,000	34.8	-52,400
Use of secondary materials	kg	787	-	-
Use of renewable secondary fuels	MJ	-	-	-
Use of non-renewable secondary fuels	MJ	-	-	-
Use of net fresh water	m^3	146	0.00535	-143

Table 4-12: Resource use, thermally improved anodized extrusion, per metric ton

Resource	Unit	A1-A3	C4	D
Renewable primary energy as energy carrier	MJ	35,700	2.20	-31,400
Renewable primary energy resource as material utilization	MJ	-	-	-
Total use of renewable primary energy resources	MJ	35,700	2.20	-31,400
Non-renewable primary energy as energy carrier	MJ	117,000	34.8	-50,100
Non-renewable primary energy as material utilization	MJ	-	-	-
Total use of non-renewable primary energy resources	MJ	117,000	34.8	-50,100
Use of secondary materials	kg	752	-	-
Use of renewable secondary fuels	MJ	-	-	-
Use of non-renewable secondary fuels	MJ	-	-	-
Use of net fresh water	m^3	151	0.00535	-135

4.1.3. Output flow and waste categories results

The life cycle output flow and waste deposition results for the various extrusion products are presented in Table 4-13 through Table 4-18, as required by the PCR.

Table 4-13: Output flows and waste, mill finished extrusion, per metric ton

Waste	Unit	A1-A3	C4	D
Hazardous waste disposed	kg	0.727	6.66E-08	-0.464
Non-hazardous waste disposed	kg	1,810	50.1	-1,570
Radioactive waste disposed	kg	1.59	0.000354	-0.489
Components for re-use	kg	-	-	-
Materials for recycling	kg	380	-	950
Materials for energy recovery	MJ	-	-	-
Exported energy per energy carrier	MJ	-	-	-

Table 4-14: Output flows and waste, painted extrusion, per metric ton

Waste	Unit	A1-A3	C4	D
Hazardous waste disposed	kg	0.783	6.66E-08	-0.502
Non-hazardous waste disposed	kg	2,000	50.1	-1,690
Radioactive waste disposed	kg	1.96	0.000354	-0.528
Components for re-use	kg	-	-	-
Materials for recycling	kg	485	-	950
Materials for energy recovery	MJ	-	-	-
Exported energy per energy carrier	MJ	-	-	-

Table 4-15: Output flows and waste, anodized extrusion, per metric ton

Waste	Unit	A1-A3	C4	D
Hazardous waste disposed	kg	0.820	6.66E-08	-0.479
Non-hazardous waste disposed	kg	2,110	50.1	-1,620
Radioactive waste disposed	kg	2.44	0.000354	-0.504
Components for re-use	kg	-	-	-
Materials for recycling	kg	419	-	950
Materials for energy recovery	MJ	-	-	-
Exported energy per energy carrier	MJ	-	-	-

Table 4-16: Output flows and waste, thermally improved mill finished extrusion, per metric ton

Waste	Unit	A1-A3	C4	D
Hazardous waste disposed	kg	0.749	6.66E-08	-0.526
Non-hazardous waste disposed	kg	1,870	50.1	-1,780
Radioactive waste disposed	kg	1.75	0.000354	-0.554
Components for re-use	kg	-	-	-
Materials for recycling	kg	430	-	950
Materials for energy recovery	MJ	-	-	-
Exported energy per energy carrier	MJ	-	-	-

Table 4-17: Output flows and waste, thermally improved painted extrusion, per metric ton

Waste	Unit	A1-A3	C4	D
Hazardous waste disposed	kg	0.807	6.66E-08	-0.525
Non-hazardous waste disposed	kg	2,070	50.1	-1,770
Radioactive waste disposed	kg	2.14	0.000354	-0.552
Components for re-use	kg	-	-	-
Materials for recycling	kg	539	-	950
Materials for energy recovery	MJ	-	-	-
Exported energy per energy carrier	MJ	-	-	-

Table 4-18: Output flows and waste, thermally improved anodized extrusion, per metric ton

Waste	Unit	A1-A3	C4	D
Hazardous waste disposed	kg	0.845	6.66E-08	-0.501
Non-hazardous waste disposed	kg	2,180	50.1	-1,690
Radioactive waste disposed	kg	2.63	0.000354	-0.527
Components for re-use	kg	-	-	-
Materials for recycling	kg	472	-	950
Materials for energy recovery	MJ	-	-	-
Exported energy per energy carrier	MJ	-	-	-

4.2. Detailed Results

Figure 4-1 presents the detailed results of the extrusion process. It can be seen that the primary drivers of burden are the inputs of aluminum: primary and secondary billet purchases as well as billet coming from companies' own cast houses, which is made from a mix of primary and secondary ingot. The extrusion process category is significant for ODP due to the use of worldsteel datasets for the dies' material and for its recycling credit after use. Electricity, thermal energy, and inbound transport of the aluminum are significant drivers in the extrusion process itself, when the burden of aluminum is ignored.

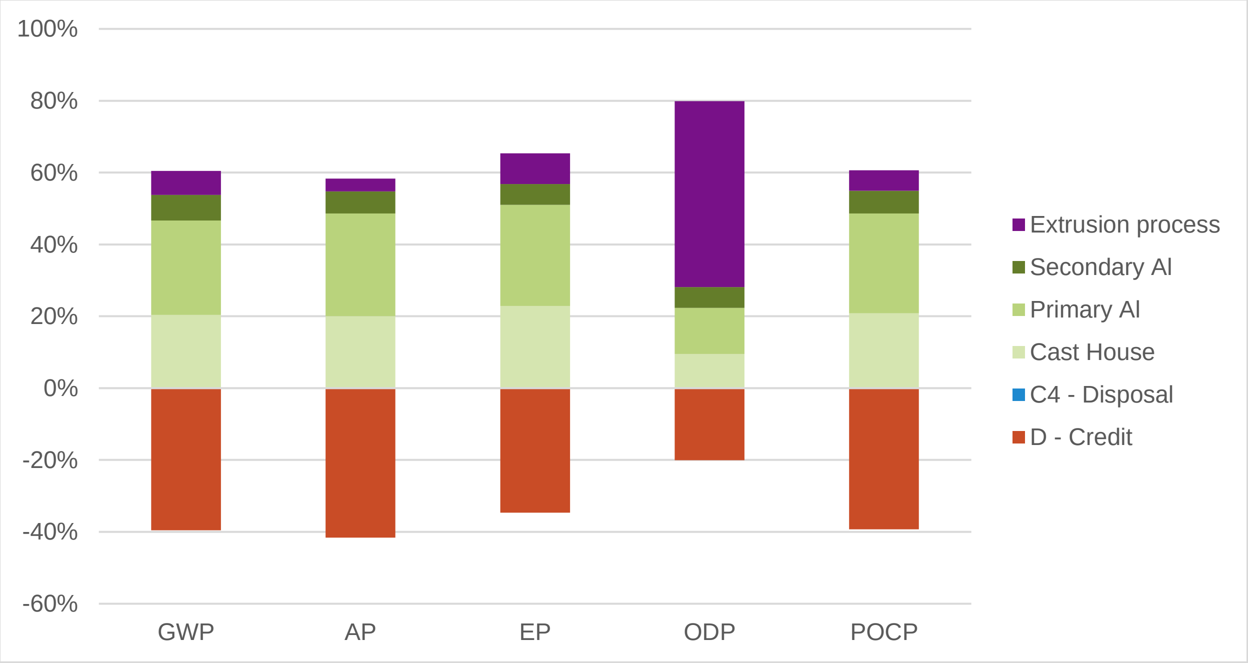


Figure 4-1: Relative extrusion impacts, by category

Figure 4-2 presents the relative results of the painted extrusion. Painting represents up to 20% of the total burden, with the exception of ODP which is the majority of the impact due to the use of PVDF paint. ODP is driven by the production of HCFC 141b and HCFC 142b, which is used to make vinylidene fluoride, the precursor to PVDF. HCFC 141b, HCFC 142b, and TCE are emitted in the production, thus driving ODP. The rest of the paint impacts are also driven by the paint materials used by the companies.

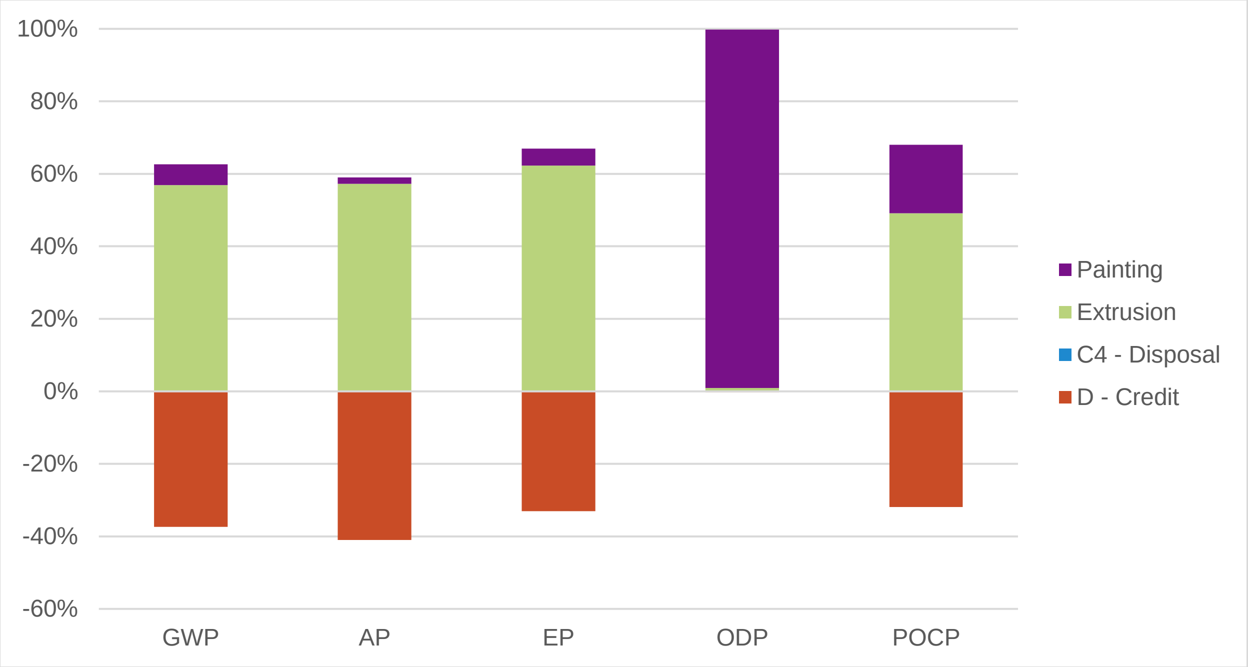


Figure 4-2: Relative painted extrusion impacts, by category

Figure 4-3 presents the anodized extrusion results. Anodization contributes between 6% and 19% of total burdens, driven by the electricity and thermal energy inputs.

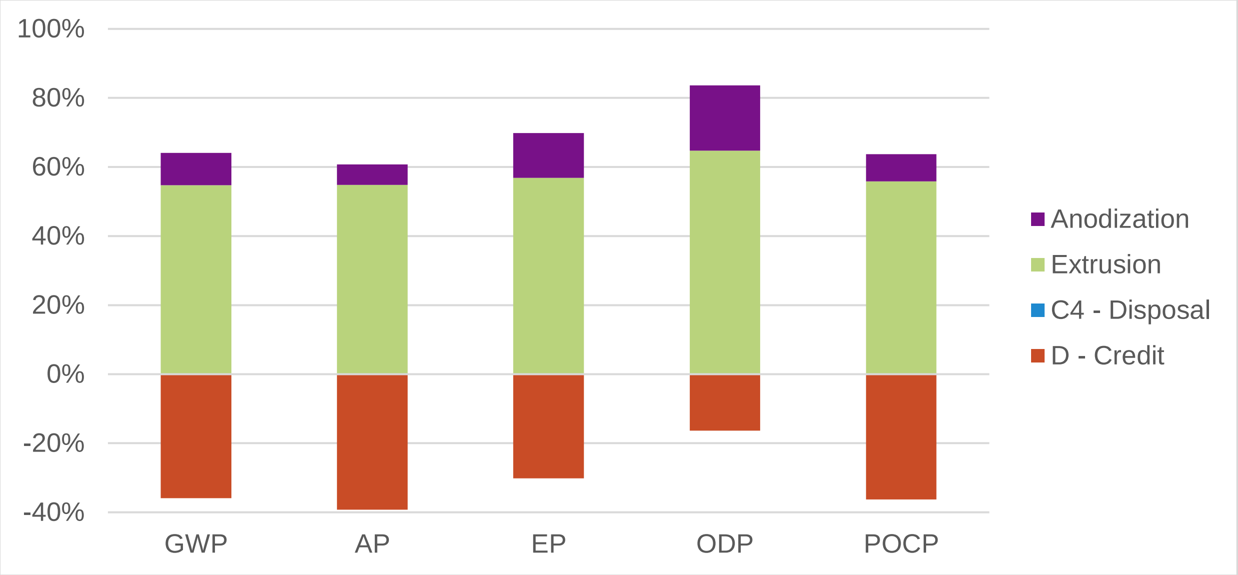


Figure 4-3: Relative anodized extrusion impacts, by category

Figure 4-4, Figure 4-5, and Figure 4-6 present the thermally improved mill finished, painted, and anodized relative results. It can be seen that thermal improvement adds no more than 10% to the overall burden. The primary driver of the thermal improvement burdens is material inputs, both thermal break material and pretreatment material.

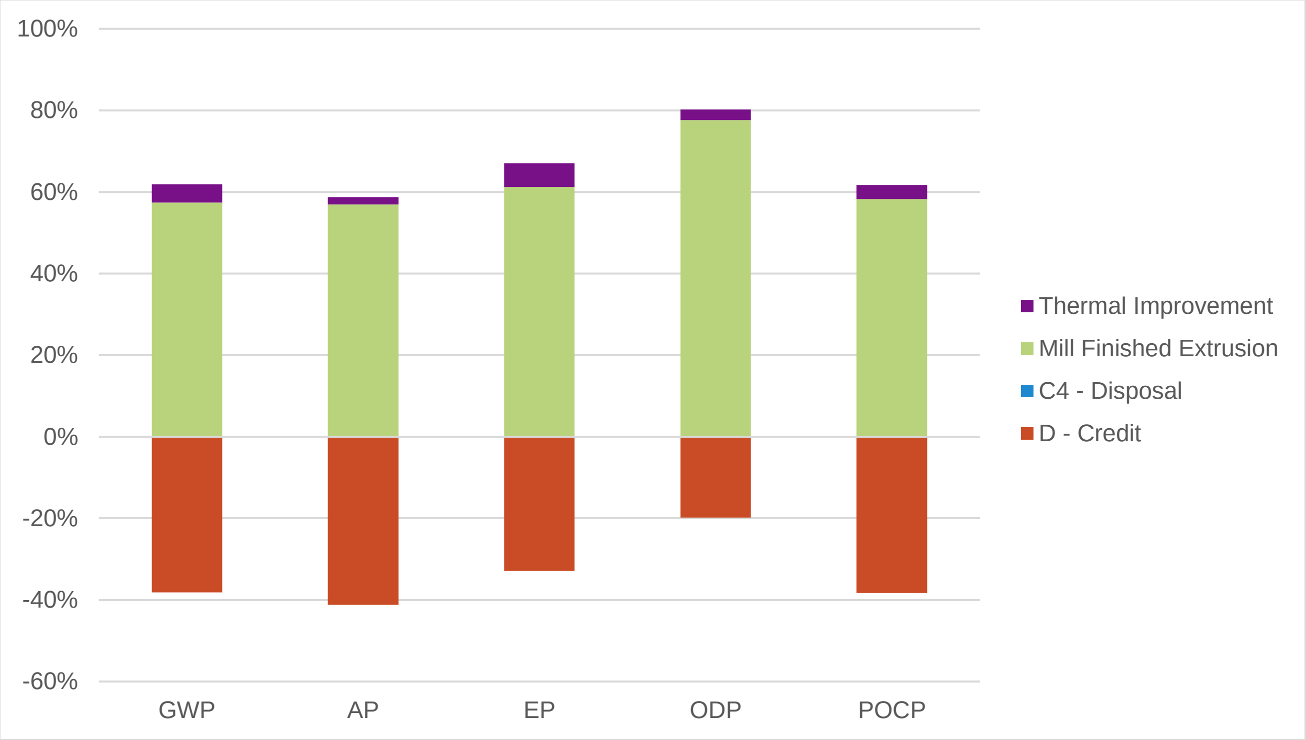


Figure 4-4: Relative thermally improved mill finished extrusion impacts, by category

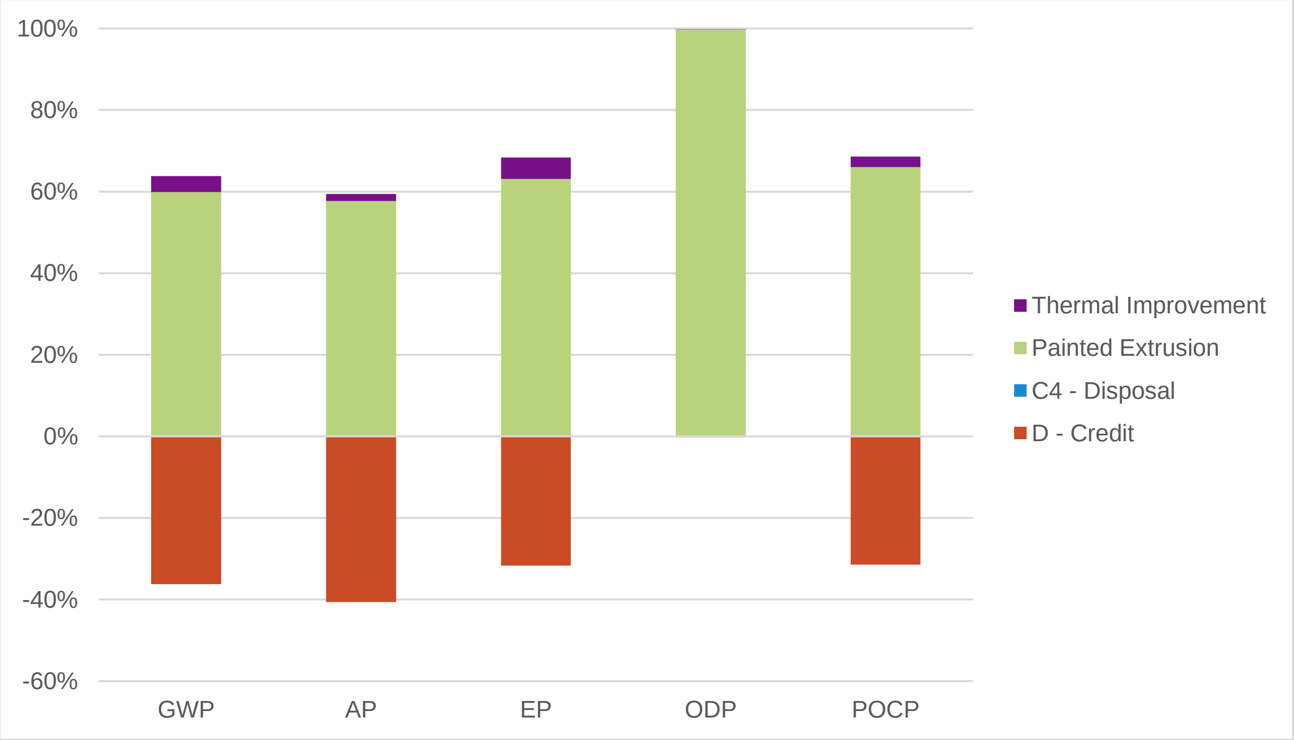


Figure 4-5: Relative thermally improved painted extrusion impacts, by category

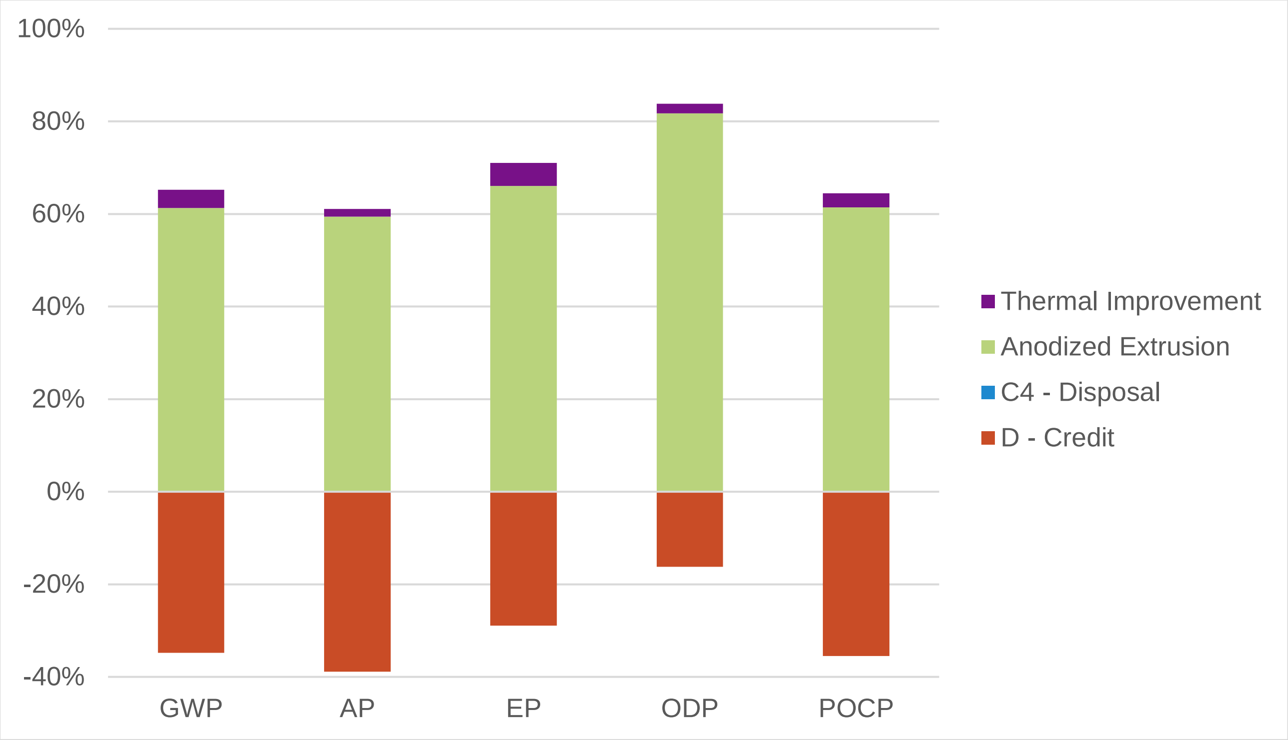


Figure 4-6: Relative thermally improved anodized extrusion impacts, by category

4.3. Scenario Analysis

4.3.1. Primary aluminum geographic source

It would be easy to assume that all the extrusions were produced from ingot and billet sources from North America, however, this was not the case. Aluminum association (AA) data was used to model production in North America and an International Aluminum Institute (IAI) dataset was used to model production internationally, in regions other than Europe, North America, and China. To determine the impact of sourcing all primary ingot and billet from North America, all incoming primary ingot was modeled using the AA primary ingot dataset. Secondary ingot and billet were already assumed to be sourced domestically.

Table 4-19 presents the results of this scenario analysis as a total and as a percent difference from the baseline for mill finished extrusion.

Table 4-19: Scenario analysis results of sourcing aluminum from 100% domestic sources

Per metric ton	GWP [kg CO_2-eq]	AP [kg SO_2-eq]	EP [kg $(PO_4)^{3-}$-eq]	ODP [kg CFC11-eq]	POCP [kg C_2H_4-eq]
Baseline	7,510	49.2	2.74	8.27E-07	2.71
100% domestic	7,140	43.2	2.19	8.59E-07	2.38
Percent difference	-5%	-12%	-20%	4%	-12%

It can be seen that the results would decrease significantly if all the aluminum were modeled as being sourced domestically. The most significant changes can be seen in AP, EP, and POCP. This is most likely due to the difference in electricity mix used by the two datasets, as shown in Table 4-20. The lower fraction of coal and natural gas in the North American electricity mix as used for aluminum production would lead to fewer nitrogen oxide and sulfur dioxide emissions, which affect AP, EP, and POCP most significantly.

Table 4-20: Electricity mix used in background primary aluminum datasets

	Rest of world (RoW)[1]	North America[2]
Hydro	38%	75%
Coal	53%	24%
Oil	0%	0%
Gas	8%	1%
Nuclear	2%	1%

4.3.2. Vertical vs. horizontal averaging

Figure 4-7 and Figure 4-8 present the two options for combining data to generate industry average results. The baseline scenario (horizontal) ignores the fact that some extrusions go to the consumer while others go on to further processing. Instead it weights the mill finished average based on the total weight of all extrusions produced. Alternatively, the vertical average approach weights the mill finish extrusion results only based on the amount going to the consumer, and excludes the weight of extrusions going on to further processing.

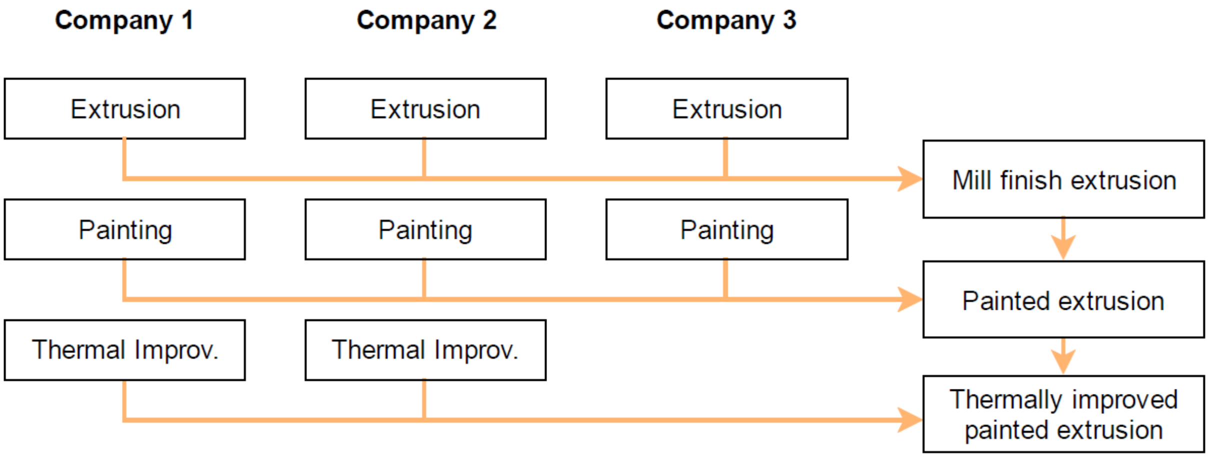


Figure 4-7: Diagram of the horizontal average approach

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[1] p. 5; <http://www.world-aluminium.org/media/filer_public/2013/10/17/2010_life_cycle_inventory_report.pdf>
[2] p. 39 <http://www.aluminum.org/sites/default/files/LCA_Report_Aluminum_Association_12_13.pdf>

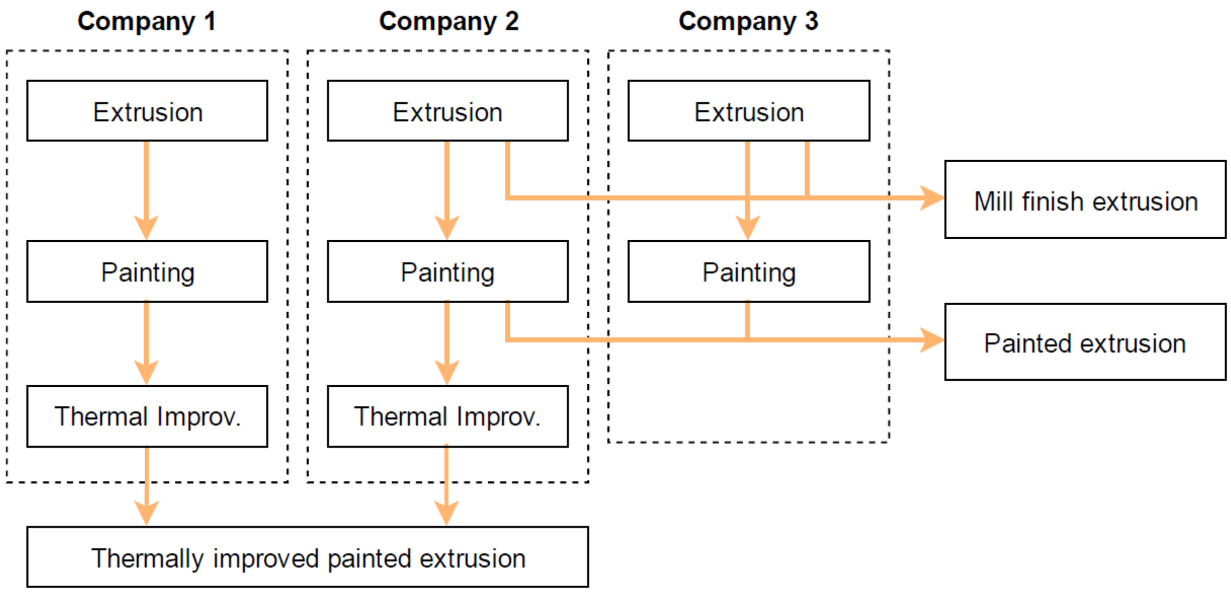

Figure 4-8: Diagram of the vertical average approach

To demonstrate how the two different methods lead to different results, the extrusion unit process for the horizontal average baseline is shown in Table 4-21 alongside the unit process calculated using the vertical average approach.

Table 4-21: Extrusion unit process differences between the horizontal and vertical average approaches

Type		Flow	Horizontal Average	Vertical Average	Unit	DQI*
Inputs	**Aluminum**	Primary aluminum billet	0.339	0.327	t	Measured
		Secondary aluminum billet	0.328	0.324	t	Measured
		Aluminum billet (from company-owned cast house)	0.649	0.666	t	Measured
	Energy	Electricity	537	576	kWh	Measured
		Natural gas	3.07	2.93	MMBtu	Measured
		Propane (internal transport)	1.95	1.84	L	Measured
	Materials	Dies	5.07	4.98	kg	Measured
		Sodium hydroxide (100%)	7.84	7.97	kg	Measured
		Hydraulic oil	2.16	1.98	kg	Measured
		Nitrogen	0.000870	0.000514	L	Measured
	Water	Water (municipal + ground)	1,020	1,073	L	Measured
Outputs	**Aluminum**	Mill finished aluminum extrusion	1.00	1.00	t	Measured
		Aluminum scrap	0.359	0.371	t	Measured
	Wastes	Steel dies to recycling (external)	5.15	4.98	kg	Measured
		Non-hazardous waste to landfill	4.89	4.04	kg	Measured

Type	Flow	Horizontal Average	Vertical Average	Unit	DQI*
	Non-hazardous waste to recovery	1.65	1.87	kg	Measured
	Non-hazardous waste to incineration	0.434	0.46	kg	Measured
	Hazardous waste to disposal	2.96	2.59	kg	Measured
	Hydraulic oil to disposal	1.34	1.33	kg	Measured
	Recovered sodium hydroxide	1.72	2.20	kg	Measured
	Waste water to treatment	601	607	L	Measured
	Water vapor	420	466	L	Calculated

Table 4-22 and Table 4-23 show the percent difference of the vertical average approach compared to the baseline approach of horizontal averaging.

Table 4-22: Percent difference of vertical average v. horizontal average baseline, mill finished, painted, and anodized extrusions

	Mill finished		Painted		Anodized	
Impact Category	A1-A3	D	A1-A3	D	A1-A3	D
CML 2001 (v4.1)						
Global warming potential	-5%	-9%	2%	-10%	19%	14%
Ozone depletion potential	-2%	-9%	0%	-10%	2%	14%
Acidification potential	-6%	-9%	1%	-10%	23%	14%
Eutrophication potential	-8%	-9%	11%	-10%	24%	14%
Photochemical ozone creation potential	-6%	-9%	4%	-10%	22%	14%
Abiotic depletion potential for non-fossil resources	2%	-9%	-11%	-10%	0%	14%
Abiotic depletion potential for fossil resources	-5%	-9%	3%	-10%	17%	14%

Table 4-23: Percent difference of vertical average v. horizontal average baseline, thermally improved mill finished extrusion

Thermally improved	Mill finished		Painted		Anodized	
Impact Category	A1-A3	D	A1-A3	D	A1-A3	D
CML 2001 (v4.1)						
Global warming potential	7%	-8%	21%	9%	10%	40%
Ozone depletion potential	23%	-8%	20%	9%	-28%	40%
Acidification potential	6%	-8%	18%	9%	14%	40%
Eutrophication potential	19%	-8%	42%	9%	2%	40%
Photochemical ozone creation potential	12%	-8%	7%	9%	7%	40%
Abiotic depletion potential for non-fossil resources	67%	-8%	-2%	9%	-48%	40%
Abiotic depletion potential for fossil resources	8%	-8%	23%	9%	4%	40%

The primary contributors to the differences in the two averaging methods were the recycled contents and scrap rates of the products. The recycled contents of the extrusion represented in the vertically averaged products are shown in Table 4-24 and the scrap rates in Table 4-25.

Within the net scrap approach, higher primary metal contents leads to less scrap being looped back at EoL as an input to the product. Within the vertical scenario, this leads to a higher credit in Module D, as seen in anodized, thermally improved painted, and thermally improved anodized. It also results in a higher burden in modules A1-A3. Additionally, a higher scrap rate means more scrap is looped back from manufacturing as an input to the product. This means less scrap has to be looped back at EoL, thus also contributing to an increase in the credit in Module D.

Table 4-24: Metal composition of vertical average products v. horizontal average baseline

Category of Metal Source	*Horizontal Average-Baseline*	Vertical Average					
	Extrusion	Mill Finished	Painted	Anodized	Thermally Improved Mill Finished	Thermally Improved Painted	Thermally Improved Mill Anodized
Primary Metal (including alloying agents)	*45.8%*	43.9%	45.2%	56.8%	46.3%	51.8%	62.8%
Recovered Aluminum from Post-Industrial (Pre-Consumer) Scrap	*40.6%*	41.0%	44.3%	36.1%	39.5%	36.0%	25.8%
Recovered Aluminum from Post-Consumer Scrap	*13.6%*	15.2%	10.5%	7.2%	14.2%	12.2%	11.4%

Table 4-25: Scrap rate of vertical average products v. horizontal average baseline

	Horizontal Average-Baseline	Vertical Average					
	Extrusion	Mill Finished	Painted	Anodized	Thermally Improved Mill Finished	Thermally Improved Painted	Thermally Improved Mill Anodized
Scrap Rate (Extrusion process only)	*35.9%*	37.1%	33.5%	31.3%	34.3%	36.8%	45.0%

5. Interpretation

5.1. Identification of Relevant Findings

The results of this study do not constitute a comparative assertion, though architects and builders will be able to use them to compare AEC's products with similar products presented in other EPDs that follow the same PCR.

The results from the CML 2001 (v4.1) methodology indicate that the largest contributor in most impact categories considered is the aluminum input either from primary or secondary sources or from the company's own cast house. The only exception to this is ODP, which is driven by outdated background datasets, namely worldsteel data used to model the extrusion dies.

5.2. Assumptions and Limitations

As discussed in Section 3.2.3, when companies did not provided data for their own billet, primary ingot was modeled with the Aluminum Association dataset, and secondary billet was modeled with a ratio of primary ingot and aluminum scrap corresponding to the recycled content of the billet. Both primary ingot and aluminum scrap went through a remelting process. When companies were not able to provide the recycled content of their purchased secondary billet, an assumption was made based on the industry average.

Anodization chemicals were modeled using proxies based on the masses available in technical data sheets (TDS) and safety data sheets (SDS). In cases where these masses were incomplete, masses were estimated based on best available data and expert judgement.

Because thousands of different paints are used in the production of painted aluminum extrusions, paints were modeled based on a representative paint product for the three major paint families, PVDF, acrylic, and polyester.

It was not always possible to distinguish intermediate flows between extrusion and the finishing steps. One example of this is packaging. In order to avoid double counting of packaging impacts, total packaging for all six products was aggregated in extrusion.

Where the water inputs and outputs did not balance, it was assumed the difference evaporated as water vapor.

Transport for ancillary materials was not included.

5.3. Results of Scenario Analysis

The first scenario analysis showed that use of primary aluminum from only North America would lower the manufacturing impacts of the extrusions. While the modeling of aluminum as all being sourced domestically is an interesting exercise to understand the differences between international and domestic production, the current study accurately models the origins of primary aluminum ingot.

The second scenario analysis demonstrated that the method for combining data from different facilities (i.e., creating a weighted average) can significantly affect the results. However, as discussed in section 3.1, horizontal averaging is the most appropriate method given that it creates an average that is more stable and can be considered representative of the industry for a longer period of time. Also, logically it follows that, given the process for creating an extrusion doesn't change if it is going to a finishing step or not, the upstream average impacts of the extrusion also should not change.

5.4. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi ts database 2016 were used. The LCI datasets from the GaBi ts database 2016 are widely distributed and used with the GaBi ts Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.4.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Seasonal variations and variations across different manufacturers were balanced out by using yearly averages and production-weighted averages. All background data are sourced from GaBi databases with the documented precision.
- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.4.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

5.4.3. Representativeness

- ✓ **Temporal:** All primary data were collected for a twelve-month period during the 2014 and 2015 calendar years. All secondary data come from the GaBi ts database 2016 and are representative of the years 2007-2015. As the study intended to compare the product systems for the reference year 2014/2015, temporal representativeness is considered to be high.

- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. A map showing locations of companies that provided primary data is shown in Figure 5-1. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high.

Figure 5-1: Map indicating locations of companies that participated in the study

- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high. Data was collected from the 11 participating manufacturers and is representative of AEC production.

5.5. Model Completeness and Consistency

5.5.1. Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regard to the goal and scope of this study.

5.5.2. Consistency

All assumptions, methods, and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimized by predominantly using LCI data from the GaBi ts database 2016. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.6. Conclusions and Recommendations

5.6.1. Conclusions

The goal of this study was to support the development and publication of EPDs for AEC's aluminum extrusions. The results of this study may also be used as an initial benchmark to track future improvements across the industry.

5.6.2. Recommendations

Future participants in the study should consider sub-meters in their facilities to allow for more accurate divisions of operations inputs between the extrusion and finishing process. This would reduce the assumptions required when making these divisions.

Opportunities for improving the overall impact of aluminum extrusions lie with the upstream production of aluminum. Participating companies can work to reduce their scrap rate, requiring less input of aluminum, or focus on increasing their input of secondary ingot or billet. Additionally, it was seen that sourcing primary ingot and billet from domestic sources would decrease environmental burdens when compared to international[3] production.

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[3] International is defined as everywhere but Europe and China. Data comes from the IAI LCA (International Aluminum Association, 2013), for which European data is provided as a separate dataset and Chinese data was not of sufficient quality to be included.

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