Life Cycle Assessment

LCA Full Length Report

ISO 14040/44*

*International Organization
for Standardization

Building Beautiful Forever™

Contents

Introduction

Life Cycle of Aluminium Production

Life Cycle Assessment Results

Introduction

IMS Metrics has prepared this LCA study.
It has been prepared following EN 15804:2012 + A2:2019 requirements and PCR 2019:14 v 1.3.1

A Life Cycle Assessment (LCA) is an established, empirically grounded methodology that delves into the systemic examination of various flows, such as material and energy, that intersect with the lifespan of a particular product, innovation, service, or production framework. This strategic approach aspires to encapsulate a thorough and integrative scrutiny of these elements, from the inception of raw material procurement to the manufacturing phase, active utilisation, and culminating at the End-of-Life (EoL) stewardship.

As delineated by the International Organization for Standardization's ISO 14040/44 benchmarks, the LCA process unfolds over four distinct stages.

1. **Goal and scope**
(Framework and objective of the study)

2. **Life cycle inventory**
(Input/output analysis of mass and energy flows from operations along the aluminium products value chain)

3. **Life cycle impact assessment**
(Evaluation of environmental relevance, e.g., Global warming potential)

4. **Interpretation**
(e.g., Optimisation potential)

This study's purpose and envisioned application of its outcomes are articulated in the initial goal-setting and scope delineation phase. This stage also establishes the constraints, information prerequisites, and foundational assumptions needed to comprehensively evaluate the product system in focus and other pertinent study parameters.

The study is designed to address queries presented by the primary audience and the engaged stakeholders. Simultaneously, it considers the prospective applications of its findings. Considering its technological, geographical, and temporal reach, this study's scope restricts the system's limits. This encompasses the product system's characteristics and the depth and intricacy the study seeks to explore.

In the Life Cycle Inventory (LCI) phase, there's both a qualitative and quantitative evaluation of the resources and energy consumed (inputs) and the resultant products, by-products, and environmental discharges in the form of unabsorbed emissions and waste processing requirements (outputs) specific to the product system in review. Knotwood's LCI data will home exclusively on process-driven inputs and outputs. Factors like transportation and ancillary equipment inputs—encompassing equipment upkeep and operation—are excluded from this analysis.

The LCI data serves multiple purposes: it offers a comprehensive view of emissions, waste, and resource utilisation linked with the material or product under investigation; it can guide enhancements in production or product efficacy; or it can undergo a more profound examination to shed light on potential environmental repercussions stemming from the system, as seen in Life Cycle Impact Assessment and Interpretation (LCIA).

Goal

This LCA analysis provides stakeholders with contemporary LCI information about powder-coated aluminium. The focus will be strictly on processes, scrutinising elements such as electricity, water, gas, and residual products.

Activities related to the environmental impact of caustic pretreatment fall outside the scope of this study. The LCI's coverage extends from inception to the point of distribution, with packaging details excluded due to their variability based on shipping specifications.

Scope

The scope of the study comprises a "cradle to gate" LCI, starting with the extraction of the bauxite ore at the mine, including the production of aluminium ingot and the manufacturing of the aluminium extrusion before undergoing electrostatic powder coating as a sustainable finishing technique predominantly used on metals.

In the process, items are pre-treated before the coating is applied using a specialised gun that charges powder particles, attracting them to the grounded workpiece. After application, items are oven heated, causing the powder to melt, fuse, and cure into a durable surface.

Powder coating stands out for its environmental benefits: it's virtually solvent-free, emitting minimal volatile organic compounds (VOCs). Additionally, its electrostatic nature maximises adherence, minimising waste as any over-spray is captured.

Knotwood's manufacturing process produces a resilient imitation wood finish that is resistant to chipping, fading, and wear and is available in diverse colours and textures. Knotwood's method aligns with eco-friendly practices, emphasising durability and resource efficiency. The included and excluded system boundaries can be found in Tables 1 & 2.

Product System Boundaries

The product being examined is an electrostatically charged powder-coated aluminium extrusion. Its content, manufacture, and impact represent the average current technological and technical processes of aluminium extrusion and Knotwood's powder coating manufacturing processes.

Knotwood's process will be investigated, and the LCI assessment will be used as the basis for Knotwood's standard product line. Knotwood shall not have any liability, duty or obligation for or relating to the data contained herein, any errors, inaccuracies, omissions in the data, or any actions taken in reliance thereon.

For the LCA, the system boundaries are defined to encompass distinct stages of the product's life cycle, namely A1-A3 and C1-C4, with an additional Module D to be reported independently:

(below)

It's also vital to note that packaging, being highly variable and specific to individual customers and occurring post-production, is not included within these boundaries.

This exclusion allows our LCA to concentrate on the environmental impacts until the process completion, enabling a more standardised and product-centric evaluation that applies to various uses and consumers.

A1-A3 (Cradle-to-Gate):

This segment covers the initial phases, starting from raw material extraction (A1), transport to the manufacturing and processing facility (A2), and the actual aluminium extrusion manufacturing and powder coating (A3). Water use in the extrusion and painting is not considered here, as it does not direct product manufacturing. The closed-circuit operation of this water system also helps to mitigate environmental impact.

C1-C4 (End-of-Life):

These stages address the product's life cycle completion, from deconstruction (C1) and waste transport (C2) to waste processing (C3) and final disposal (C4). This comprehensive view is essential to fully understand the product's environmental footprint over its entire lifespan.

Module D (Extended Impacts):

Reported separately, this module delves into factors like recycling potential and material reuse. These aspects provide a broader perspective on the product's environmental performance beyond its immediate life cycle.

TABLE 1 **Product Category Rules** EN 15804:2012+A2:2019

A1	X	Extraction and Upstream Production	**Production Stage**
A2	X	Transport to Factory	
A3	X	Manufacturing	
A4	MND	Transport to Site	**Construction Stage**
A5	MND	Installation	
B1	MND	Use Stage	**Use Stage**
B2	MND	Maintenance	
B3	MND	Repair	
B4	MND	Replacement	
B5	MND	Refurbishment	
B6	MND	Operational Energy Use	
B7	MND	Operational Water Use	
C1	X	Deconstruction and Demolition	**End-of-Life Stage**
C2	X	Transport	
C3	X	Water Processing	
C4	X	Disposal of Waste	
D	X (Reported Separately)	Potential Net Benefits from Reuse, Recycling, and/or Energy Recovery Beyond the System Boundary	**Optional**

TABLE 2 **LCA System Boundaries** Summary

Included

- Raw materials extraction – generalised data used
- Energy and fuel inputs at press, stretching and ovens
- Overhead (heating, lighting) of manufacturing facilities
- Powder Coating Production, Pre-Treatment Coating Application and Curing
- Transport

Excluded

- Capital equipment and maintenance
- Maintenance and operation of equipment
- Transportation in any form of the material
- Product disposal or other generated waste product of processes
- Packaging
- Use of product
- Human labour
- Effluent process and impact

In shaping the LCA, we have applied selective criteria to maintain a sharp focus on the most pertinent environmental aspects. This approach, while streamlining our assessment, is aligned with standard practices and hinges on transparency and relevance.

The following elements are not included:

Water Use in the Manufacturing Process:

Although essential for manufacture, maintenance and operation, the closed-circuit design of our water system significantly reduces environmental impact, supporting our decision to exclude this factor from our assessment.

Packaging Considerations:

Given the variability and customer-specific nature of packaging, which occurs post-production, this element falls outside our current LCA scope. Our focus remains steadfast on the product up to the process gate.

Employee Transportation:

Employees' commute is not accounted for in this LCA. This factor is outside our operational control and doesn't directly influence the product's environmental footprint within the scope of this declaration.

Capital Goods Impact:

The environmental impact stemming from the production and disposal of capital goods, such as manufacturing machinery and equipment, is excluded. This is due to the inherent complexity and variability of these impacts, making them challenging to quantify accurately in the context of this specific product.

These exclusions, while integral to our approach, are not taken lightly. They are informed decisions aimed at honing our focus on the most significant environmental aspects directly tied to the production of the product, thereby ensuring the clarity and relevance of our assessment.

Data Collection, Software and Databases

The study included data collection for aluminium extrusion:

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

Information for specific production operations was primarily gathered by analysing supply invoices.

This research leans on initial data obtained from the International Aluminium Institute, collaborating companies, and, when feasible, their specific production locations.

When direct data was lacking, we used secondary sources like academic literature, prior LCI research, and life cycle databases. This study diligently cites these secondary data origins. If primary and secondary data were missing, we made educated estimates to fill in the gaps.

The aluminium life cycle data was chiefly sourced from IAI, AA, and other relevant aluminium studies, with a significant portion rooted in global production processes. While this data is a valuable reference, it’s not an absolute representation of the aluminium acquired or generated by Knotwood.

Data was collected via the International Aluminium Institute (IAI), Aluminium Association (AA), and European Aluminium (EA). They are the rightful owners of the data sourced via their publications.

Functional Unit

The functional unit of the study is one tonne of extruded/ coated product.

Geographical Coverage

The geographic coverage is Australia and Global Averages.
The specific geographic range of individual production processes is summed in Figure 1.

TABLE 3 **Geographic Coverage** of this study by life cycle stages

Major Unit Process	Geographic Coverage	Life Cycle Stage
Bauxite Mining	Global	**Primary Metal Production**
Alumina	Global	
Anode Production	For the smelting and ingot casting processes, it is the aluminium industry-specific power mix based on power contracts and captive power capacities, representing all smelters as well as countries that net export of non-alloyed primary aluminium Australia for other processes; it is the average grid mix of the relevant production country or region.	
Aluminium Smelting	Global	
Electricity Generation	Global	
Ingot or Billet Casting	Global	**Semi-Fabrication**
Mill Finished Extruded Product	Australia & Global	**Aluminium Extrusion**
Powder Coating Production, Pre-Treatment Coating Application and Curing	Qld Australia - Knotwood Australia Manufacturing Facility	**Powder Coating**

Completeness

Knotwood was required to assign a quality indicator to the reported data during the data collection. The data quality indicators are classified as follows:

Measured

Data derived from continuous, direct physical assessments, like readings from electricity or water meters at a facility.

Calculated

Data determined through specific empirical equations or factors, such as emission rates for CO2 or SO2 based on fuel type and processing methods.

Averaged

Data resulting from the mean of multiple values or observations.

Estimated

Data based on well-informed guesses or expert evaluations.

While a thorough verification of data quality and reliability from the site presents challenges, we've ensured consistency and quality by cross-referencing mass and energy balance outcomes with published data, especially from prior LCI studies focusing on process and flow data.

Our evaluations confirmed that the provided data aligns with findings from other studies under similar boundary conditions.

Life Cycle of Aluminium, Production and Powder Coating

Relevant Knowledge

IMS Metrics has prepared this LCA study.
It has been prepared following EN 15804:2012 + A2:2019 requirements and PCR 2019:14 v 1.3.1

Aluminium

Aluminium, a silver-white metal derived from bauxite — a rock with over 50% aluminium hydroxides from tropical weathering — is Earth's third most prevalent element, following oxygen and silicon, and dominates as the crust's most abundant metal.

Historically, humans utilised aluminium-rich compounds; for instance, pottery was crafted from aluminium silicate-rich clays. There was a time when aluminium's value was so esteemed that it was favoured over gold for making cutlery for the elite.

Aluminium production follows two pathways: deriving primary aluminium from ore and recycling from scrap and previously used products. Given its widespread industrial use, a cost-effective, eco-friendly recycling process is crucial for sustainable progress.

Aluminium ranks second-most recycled metal after steel, with roughly a third sourced from scrap. Everyday items, like beverage cans and household goods, are the primary contributors to aluminium scrap.

Life Cycle of Aluminium

Aluminium boasts a life cycle unparalleled by most metals. Its resistance to corrosion and its recyclability, using only a tiny portion of the energy needed for primary production, render it a remarkable material, adaptable and reusable time after time.

The life cycle phases for processing primary aluminium encompass bauxite mining, alumina refining, and electrolysis, which includes smelting and anode production, culminating in direct ingot casting.

Figures 1 and 2 depict the process flow. The journey begins with bauxite ore and culminates in the primary aluminium ingot/billet, with alumina (aluminium oxide) and molten aluminium as the intermediate products.

Life Cycle of Powder-Coated Aluminium

Electrostatic powder-coated aluminium undergoes a comprehensive life cycle. Before coating, aluminium undergoes pre-treatment, including degreasing and blasting, ensuring optimal adhesion.

The coating is applied electrostatically, with a specialised gun charging the powder, ensuring uniform adherence. This is followed by curing in an oven, solidifying the coating into a durable finish.

This finish enhances aluminium's resilience against chipping, corrosion, and UV degradation, making it ideal for diverse applications from construction.

Concluding its life cycle, aluminium offers significant sustainability: it can be efficiently recycled, preserving its properties with reduced energy. Alternatively, if the coating deteriorates, the aluminium can be refinished, prolonging its utility. This life cycle emphasises the material's durability and eco-efficiency.

The initial step of the process is bauxite mining, followed by refining, production, fabrication, extruding, rolling, casting and finally, recycling.

Bauxite mining

Aluminium production starts with removing raw material bauxite, which contains 15-25% aluminium and is mainly found in a belt around the equator.

Alumina refining

Using the Bayer process, alumina (aluminium oxide) is extracted from bauxite in a refinery. The alumina is then used to produce the primary metal at a ratio of 2:1.

(2 tonnes of alumina = 1 tonne of aluminium)

Primary aluminium production

The aluminium atom in alumina is bonded to oxygen and needs to be broken by electrolysis to produce aluminium metal. This is done in large production lines and is an energy-intensive process.

Aluminium fabrication

It is essential to produce aluminium and provide it to the suppliers for extrusion ingot, sheet ingot, foundry alloys and high-purity aluminium with a global presence. The most common uses of primary aluminium are extruding, rolling, and casting.

Bauxite Mining

Aluminium production primarily relies on bauxite ore as its raw material. Almost all aluminium is derived from bauxite, which mainly comprises minerals like gibbsite Al (OH)3, boehmite, diaspore AlOOH, minor iron oxides like goethite and hematite, the clay mineral kaolin, and traces of TiO2.

Found between 0 to 600 feet below the earth's surface, bauxite is typically mined from open pits at an average depth of 80 feet. Overburden removal paves the way for extraction, with the removed material set aside for site restoration post-mining. Depending on the deposit's characteristics, explosives may loosen it.

Post-extraction, bauxite might be crushed and undergo a washing process called beneficiation to eliminate impurities. This often includes using dust control measures to curtail dust emissions. Post-beneficiation, the bauxite is typically dried before heading to the refinery, with the washing wastewater retained for recycling.

The bauxite mining process starts with ore extraction and processing, culminating in delivering beneficiated bauxite for alumina production.

Key operations include:

- On-site extraction of bauxite-rich minerals,
- Beneficiation processes like grinding and washing,
- Handling of mining residues and waste,
- Post-mining restoration activities.

Alumina Production

Refineries typically blend different bauxite sources to achieve consistent feed-stock qualities. This blend is mixed with recycled plant liquor, which carries dissolved sodium carbonate and sodium hydroxide from earlier cycles and supernatant liquor from red mud reservoirs.

This mixture is heated and channeled to digesters housed in pressure tanks. Iron and silicon impurities form an insoluble substance known as red mud during digestion.

As this settles, a concentrated sodium aluminate solution is filtered and seeded to produce hydrate alumina crystals in precipitators. These crystals undergo calcination, where heat eliminates water, leaving behind alumina.

This phase spans from processing beneficiated bauxite to producing alumina for smelting.

Key operations include:

- Bauxite grinding and liquor processing,
- Precipitation and calcination of alumina,
- Plant and equipment upkeep,
- Treatment of process air fluids and solids.

As per the IAI, on average, globally, producing a metric tonne of alumina demands around 2.739 metric tonnes of bauxite, factoring in bauxite purity and losses during various stages.

Anode Production

Reduction cells in aluminium production can be categorised into two main types: Prebake and Söderberg. In the Söderberg design, a single anode spans most of the cell's top surface. As this anode is used up, anode paste descends by gravity, solidifying it into a unified structure before reaching the electrolytic bath.

Conversely, the Prebake design features pre-fired carbon blocks held by busbars, stabilising the anodes and conducting the necessary electrolysis current. To produce the aggregate for either briquettes or Prebake blocks, coke undergoes calcination, grinding, and mixing with pitch to form a paste. This paste is then shaped into blocks or briquettes and cooled. While briquettes go straight to the pots, blocks are forwarded to a separate baking oven.

Oven technology has advanced from basic designs releasing volatiles into the atmosphere to sophisticated systems that harness the volatiles' energy, optimising energy use. According to IAI statistics, 85% of electrolysis production stems from Prebake units, with the remaining 15% from Söderberg units.

Anode production operations encompass:

- Spent anode material recovery
- Anode mix preparation, shaping, and baking
- Anode rodding
- Equipment and plant maintenance
- Processing of air, fluids, and solids

Aluminium Smelting

The Hall-Heroult electrolytic process transforms alumina into molten aluminium. It first involves dissolving the alumina in a molten cryolitic bath and then applying an electric current, breaking it down into aluminium and oxygen.

Aluminium is periodically drawn from the reduction cell, while oxygen combines with carbon to produce carbon dioxide and carbon monoxide. To manage emissions, aluminium smelters employ air pollution control mechanisms, primarily scrubbers.

Some utilise dry scrubbers with alumina as an absorbent, allowing recovered materials to be reused. Others use wet scrubbers that capture wastewater's carbon dioxide, nitrogen oxide, and sulphur dioxide.

This phase spans from processing alumina to producing molten primary aluminium, set for casting into ingots.

Key activities related to electrolysis include:

- Handling and preparation of materials,
- Creation of primary equipment (like cathode shells)
- Control tasks for metal, bath, and heat,
- Upkeep of equipment and facilities,
- Treatment of process air, fluids, and solids.

Electrolysis primarily relies on electrical energy. As per IAI, this process's global average energy consumption is 15,289 kWh for every metric tonne of primary aluminium.

PFC (Perfluorocarbon) generation in Aluminium Smelting

TABLE 4 **Perfluorocarbon** (PFC) emmissions of aluminium smelting 2022, representing 1,000kg or qluminium ingot

Category	Unit	Amount
Tetrafluoromethane (CF4) (CO2 eq./tonne aluminium ingot)	Kg	234.7
Hexafluoroethane (C2F6) (CO2 eq./tonne aluminium ingot)	Kg	36.6

Primary Ingot Casting (Cast House)

Molten aluminium extracted from pots is typically channeled to an on-site cast house within each smelter. In certain instances, due to proximity, it's directly transported to a shape-casting foundry.

Here, it's moved to a holding furnace, where its composition is tailored to customer-specified alloy requirements. Preliminary hot metal treatments might be necessary to eliminate impurities based on the application and pot bath composition. Once alloying is finalised, the melt fluxes to purge impurities and diminish gas content.

Fluxing involves introducing a mixture of gases like nitrogen, chlorine, carbon monoxide, and argon into the metal. This can also be achieved using specialised inline degassing units. Fluxing facilitates the rise of impurities, termed 'dross', to the metal's surface for removal. Dross contains aluminium, often reclaimed and utilised in industries like abrasives and insulation.

The metal might then pass through inline filters to eliminate any formed oxides. The purified metal is cast into ingots using various techniques, including open moulds, direct chill moulds, electromagnetic moulds, and continuous casters.

This phase commences with molten primary aluminium processing and concludes with the production of sheet ingots ready for rolling extrusion or shape casting.

Key cast house activities encompass:

- Hot metal pre-treatment,
- Internal process scrap management,
- Alloy batching, treatment, and casting,
- Ingot homogenisation, cutting, packaging, and casting,
- Equipment and facility maintenance,
- Processing of air, fluids, and solids.

Though the ingot is essentially 100% aluminium, life cycle data for the billet process remains elusive. Thus, ingot data offers the most pertinent insights regarding inputs and outputs.

TABLE 5 **Selected LCI for 1,000kg** of primary aluminium ingot as per International Aluminium

Inventory Category	Primary Ingot (North American Production)	Primary Ingot (Consumption Mix in Market)
Energy (MJ)		
Non-Renewable Energy	8.15E+04	8.28E+04
Hydroelectric Energy	5.27E+04	5.18E+04
Other Renewable Energy (non-hydro)	1.15E+04	1.08E+03
Resources (kg)		
Bauxite	5.42E+03	5.44E+03
Net fresh Water (excluding energy)	1.12E+04	7.60E+03
Air Emissions (kg)		
Carbon Dioxide	7.87E+03	7.84E+03
Carbon Monoxide	2.05E+00	2.51E+00
Chlorine	1.53E-04	2.20E-04
Fluorine/Fluorides	3.69E-01	3.62E-01
Hydrogen Chloride	1.15E-01	1.20E-01
Hydrogen Fluoride	3.43E-01	3.67E-01
Nitrogen Oxides	1.09E+01	1.29E+01
Nitrous Oxide	9.53E-02	9.06E-02
Sulfur Oxides	1.62E-15	1.31E-15
Non-methane VOCs	7.83E-01	9.86E-01
Methane	9.72E+00	1.03E+01
Dust (PM10)	7.11E-03	6.67E-01
Dust (PM2.5)	1.95E+00	2.00E+00
Fresh Water Emissions (kg)		
Biological Oxygen Demand (BOD)	1.35E-02	1.43E-02
Chemical Oxygen Demand (COD)	3.56E+00	3.18E-02
Heavy Metals	5.15E+01	4.19E+01
Ammonia	1.06E-03	9.95E-04
Fluorine/Fluorides	1.87E+00	1.65E+00
Phosphate	4.54E-03	4.24E-03
Solid waste (kg)		
Total waste (excluding mining overburden)	3.85E+03	3.95E+03

IAI, EA

TABLE 6 **Primary Aluminium Ingot** as per International Aluminium

Primary Energy and C02 Emissions Breakdown by Unit Process for the Production of 1,000kg of Primary Aluminium as per International Aluminium

Inventory Parameter	Unit	Bauxite Mining	Alumina Refining	Electrolysis	Cast House	Total
Primary Energy Demand	GJ	0.61	32.87	99.93	1.91	**135.32**
Non-Renewable	GJ	0.59	31.48	17.57	1.83	**81.48**
Renewable	GJ	0.02	1.39	52.35	0.08	**53.84**
C02 Emissions	MTC02	0.05	2.65	5.07	0.11	**7.87**

Note: CO2 emissions represent one of the greenhouse gases

Aluminium Extrusion

Extrusion involves pushing a metal ingot or billet through a steel mould to produce a lengthened shape with a consistent cross-section. This process enables aluminium to be moulded into various shapes using existing profiles.

Aluminium's amenability to extrusion sets it apart, as this technique is intricate for other metals. Products from extrusion are increasingly utilised in structural components. Aluminium extrusion is a contemporary, efficient technique for swiftly crafting profiles for novel products.

The popularity of aluminium extrusions stems from their adaptability, merging the material's properties with the product's form.

An extruded profile is characterised by its elongated nature relative to its cross-section. Aluminium extrusion permits intricate custom designs, categorising profiles into solid, hollow, and semi-hollow types.

Aluminium Extrusion (Process)

The process of extrusion is stepwise explained in the below flowchart.

Step 1:
A round die is either crafted or retrieved from storage if already available.

Step 2:
A cylindrical aluminium alloy block, termed a billet, is sliced from a lengthier alloy log and preheated between 400-500°C, ensuring it's pliable but not liquefied.

Step 3:
The warmed billet is mechanically moved to the extrusion press. Before placement, a lubricant is applied, ensuring the billet doesn't adhere to the extrusion RAM.

Step 4:
Within the extrusion press, the hydraulic RAM exerts up to 15,000 tonnes of force, directing the billet into the press container, which conforms to the container's walls.

Step 5:
The alloy is then pressured against the extrusion die. With sustained force, it emerges shaped as a complete profile.

Step 6:
A puller seizes the emerging extrusion, guiding it along a runout table at a matching speed and cooling it via a water bath or fans.

Step 7:
Upon reaching the table's end, the extrusion is severed from the ongoing process using a hot saw. Temperature is crucial throughout these steps.

Step 8:
Despite the initial cooling, the extrusion requires further cooling.

Step 9:
The extrusions are transferred post-shearing to a cooling table, resting until they attain room temperature. Subsequently, they undergo stretching.

Step 10:
To rectify natural profile twists, each is fastened at both ends and stretched to achieve straightness and meet specifications.

Step 11:
Profiles are then moved to a saw table and cut to predetermined lengths, typically 8-21 feet. Their properties are now consistent. Post-sawing, they can be sent to an aging oven.

Step 12:
But not before undergoing protective treatments like coating or painting to fend off corrosion.

Powder Coated Aluminium

Electrostatic powder coating is a cutting-edge finishing technique extensively used on aluminium due to its durability, aesthetic appeal, and environmental benefits.

In this process, aluminium pieces are pre-treated, typically through cleaning and degreasing, to ensure a contaminant-free surface. This guarantees optimal adhesion of the powder and enhances the longevity and resistance of the coating.

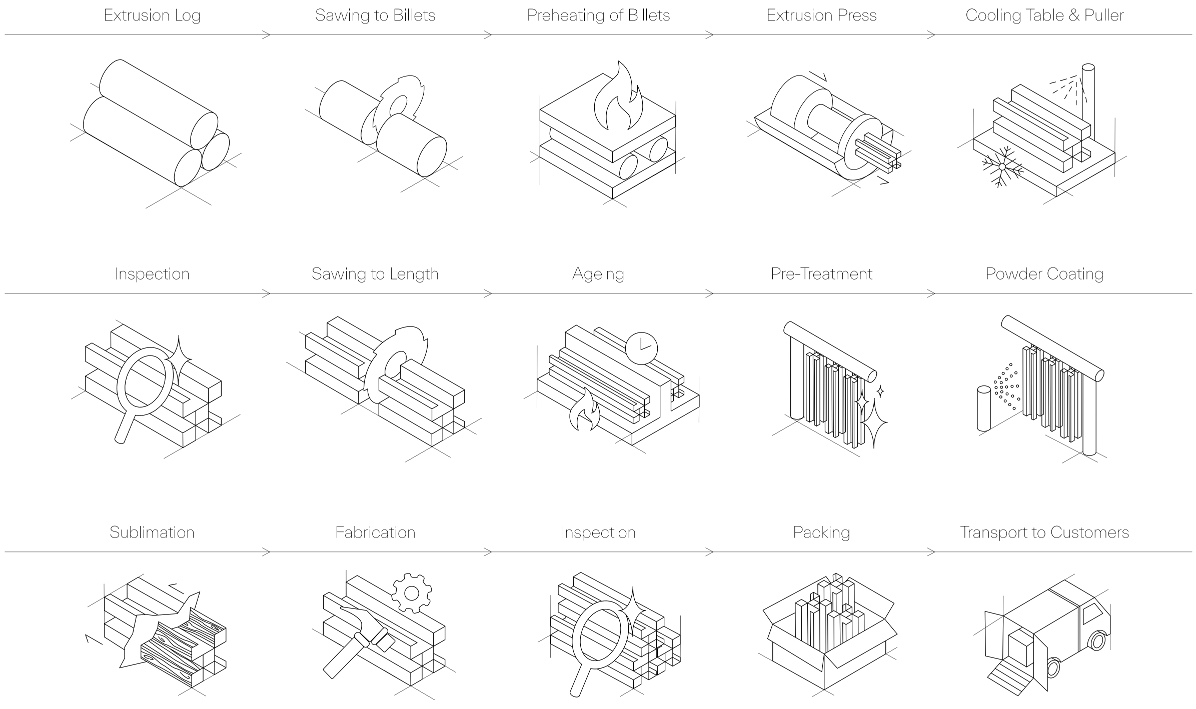
The actual coating application involves an electrostatic gun, which imparts a positive electric charge to the powder particles. When sprayed, these charged particles are attracted to the grounded aluminium, ensuring a uniform and comprehensive coating. Post application, the aluminium is placed in a curing oven.

The powder melts, flows over the surface, and hardens into a resilient, continuous film. This film not only enhances the aesthetic appeal of the aluminium but also provides a corrosion-resistant barrier, safeguarding the metal from environmental factors.

Electrostatic powder coating on aluminium is favoured for its ecological advantages, as it emits negligible volatile organic compounds (VOCs) and ensures almost 100% material utilisation, minimising waste.

The result is a sleek, durable, and sustainable finish, making Knotwood's product the preferred choice for many applications.

FIGURE 1 **Powder Coated Aluminium** Extrusion and Manufacturing



Product Range and Use

Knotwood offers various materials used for building and construction purposes, including facades, garage doors, cladding, fencing, gates and doors, interiors, outdoor cover decking, etc.

FIGURE 2 **Products** of Knotwood

Facades

Fences Gates & Doors

Decking

Balustrades

Awnings & Pergolas

Garage Doors

Advantages

Durability

Knotwood's aluminium products last longer than products made from plastic, steel, or other metals. Due to its weight and corrosion resistance properties, aluminium is a solid metal. Knotwood's Aluminium products can quickly adapt to hot and cold temperatures, making them usable in any environment.

Economically Viable

Knotwood is affordable compared to other metals. One reason for its attractive price is that it is the most abundant metal on earth.

Environmentally Friendly

Knotwood products can be easily recyclable, making them more environmentally friendly than many other metals.

Useful in a Range of Industries

We can ensure our customers obtain the products they need due to the diversity of designs available for Knotwood products.

Excellent Conductor of Heat and Cold

Extruded Knotwood products provide many benefits compared to other metals. Not only are Knotwood products solid and lightweight, but they are also superb conductors of cold and heat. As a result, aluminium extruded components in the shape of heat sinks are a great alternative to using copper to disperse heat.

Life Cycle Assessment Results for Knotwood

Primary Energy Demand

Primary energy demand gauges the cumulative amount of primary energy sourced from the earth.

This encompasses non-renewable resources like fossil fuels and renewable ones like solar. The measure considers the efficacy of electricity generation and heating techniques. Knotwood utilises a blend of grid solar power and natural gas.

For the LCI, only primary energy will be factored in. The combined energy consumption at Knotwood stood at 1,631.43 MWh for the measured period.

In June 2023, Knotwood invested in a solar system to reduce grid energy requirements; energy generation was measured from July – September 2023, where total electrical from the grid consumption was 70.916 MWh.

Based on current production rates, Knotwood can estimate an expected 38% C02e reduction for the 23/24 period.

TABLE 7 **Mill Finish Input and Output Flow** (for the Extrusion Process)

Flows represent a year of mill finish aluminium based on 2000 tonnes

Substance Name	Air Point Emission (kg)	Air Point EETs	Air Fugitive Emission (kg)	Air Fugitive EETs	Air Total Emission (kg)
Arsenic & Compounds	0.000376689	___4_			0.000376689
Beryllium & Compounds	0.00000226187	___4_			0.00000226187
Cadmium & Compounds	0.00207049	___4_			0.0020704
Carbon Monoxide	158.331	___4_			158.331
Chromium (III) Compounds	0.00263595	___4_			0.00263595
Cobalt & Compounds	0.000153112	___4_			0.000153112
Copper & Compounds	0.00160071	___4_			0.00160071
Lead & Compounds	0.000939548	___4_			0.000939548
Manganese & Compounds	0.00071684	___4_			0.00071684
Mercury & Compounds	0.000488913	___4_			0.000488913
Nickel & Compounds	0.00394958	___4_			0.00394958
Oxides of Nitrogen	187.91	___4_			187.91
Particulate Matter ≤10.0 µm	13.9192	___4_			13.9192
Particulate Matter ≤2.5 µm	13.9192	___4_			13.9192
Polychlorinated Dioxins & Furans (TEQ)	0.00000000930849	___4_			0.00000000930849
Polycyclic Aromatic Hydrocarbons (B[a]Peg)	0.00120053	___4_			0.00120053
Selenium & Compounds	0.0000446285	___4_			0.0000446285
Sulfur Dioxide	2.07536	___4_			2.07536
Total Volatile Organic Compounds	10.3524	___4_			10.3524
Zinc & Compounds	0.054024	___4_			0.054024
Carbon Monoxide			0	___4_	
Oxides of Nitrogen			0	___4_	
Polycyclic Aromatic Hydrocarbons (B[a]Peq)			0	___4_	
Total Volatile Organic Compounds			0	___4_	

TABLE 8 **Electrostatic Input and Output Flow** (for the Extrusion Process)

Flows represent a year of Electrostatic Powder Coated Products based on 2000 tonnes

Substance Name	Air Point Emission (kg)	Air Point EETs	Air Fugitive Emission (kg)	Air Fugitive EETs	Air Total Emission (kg)
Arsenic & Compounds	0.000322641	___4_			0.000322641
Beryllium & Compounds	0.00000193734	___4_			0.00000193734
Cadmium & Compounds	0.00177341	___4_			0.00177341
Carbon Monoxide	135.614	___4_			135.614
Chromium (III) Compounds	0.00225774	___4_			0.00225774
Cobalt & Compounds	0.000131143	___4_			0.000131143
Copper & Compounds	0.00137104	___4_			0.00137104
Lead & Compounds	0.00080474	___4_			0.00080474
Manganese & Compounds	0.000613987	___4_			0.000613987
Mercury & Compounds	0.000418763	___4_			0.000418763
Nickel & Compounds	0.00338289	___4_			0.00338289
Oxides of Nitrogen	160.948	___4_			160.948
Particulate Matter ≤10.0 µm	11.9221	___4_			11.9221
Particulate Matter ≤2.5 µm	11.9221	___4_			11.9221
Polychlorinated Dioxins & Furans (TEQ)	0.00000000797289	___4_			0.00000000797289
Polycyclic Aromatic Hydrocarbons (B[a]Peq)	0.00102828	___4_			0.00102828
Selenium & Compounds	0.0000382252	___4_			0.0000382252
Sulfur Dioxide	1.77758	___4_			1.77758
Total Volatile Organic Compounds	8.86704	___4_			8.86704
Zinc & Compounds	0.0462726	___4_			0.0462726
Carbon Monoxide			93.1392	___4_	93.1392
Oxides of Nitrogen			145.53	___4_	145.53
Polycyclic Aromatic Hydrocarbons (B[a]Peq)			0.000000349272	___4_	0.000000349272
Total Volatile Organic Compounds			12.2243	___4_	12.2243

TABLE 9 **Combined Input and Output Flow** (for the Extrusion Process)

Flows represent a year-long extruded aluminium and electrostatic powder-coated product combined on 2000 tonnes

Substance Name	Air Point Emission (kg)	Air Point EETs	Air Fugitive Emission (kg)	Air Fugitive EETs	Air Total Emission (kg)
Arsenic & Compounds	0.00069933	___4_			0.00069933
Beryllium & Compounds	0.00000419921	___4_			0.00000419921
Cadmium & Compounds	0.00384389	___4_			0.00384389
Carbon Monoxide	293.945	___4_			293.945
Chromium (III) Compounds	0.0048937	___4_			0.0048937
Cobalt & Compounds	0.000284254	___4_			0.000284254
Copper & Compounds	0.00297175	___4_			0.00297175
Lead & Compounds	0.00174429	___4_			0.00174429
Manganese & Compounds	0.00133083	___4_			0.00133083
Mercury & Compounds	0.000907676	___4_			0.000907676
Nickel & Compounds	0.00733247	___4_			0.00733247
Oxides of Nitrogen	348.858	___4_			348.858
Particulate Matter ≤10.0 µm	25.8413	___4_			25.8413
Particulate Matter ≤2.5 µm	25.8413	___4_			25.8413
Polychlorinated Dioxins & Furans (TEQ)	0.0000000172814	___4_			0.0000000172814
Polycyclic Aromatic Hydrocarbons (B[a]Peg)	0.00222881	___4_			0.00222881
Selenium & Compounds	0.0000828537	___4_			0.0000828537
Sulfur Dioxide	3.85294	___4_			3.85294
Total Volatile Organic Compounds	19.2195	___4_			19.2195
Zinc & Compounds	0.100297	___4_			0.100297
Carbon Monoxide			93.1392	___4_	93.1392
Oxides of Nitrogen			145.53	___4_	145.53
Polycyclic Aromatic Hydrocarbons (B[a]Peq)			0.000000349272	___4_	0.000000349272
Total Volatile Organic Compounds			12.2243	___4_	12.2243

Environmental Impact

Greenhouse Gas Emission Intensity – Primary Aluminium (Tonnes of CO2e Per Tonne of Primary Aluminium) – International Aluminium Institute

Carbon Dioxide Emissions

Carbon dioxide is one of the greenhouse gases contributing to global warming. Carbon dioxide emissions are mainly associated with converting fossil energy carriers (e.g., lignite, crude oil, natural gas) into thermal and mechanical energy using burning and are expressed in kilograms of CO2.

The average is about 16.6 tonnes of CO2 emitted to produce a metric tonne of aluminium. The coal-based power plants in India and China have around 18 tonnes (18,000 kg) of CO2 per metric tonne of aluminium. The carbon dioxide results are closely linked to the primary energy demand results, and their graphs have the same shape.

TABLE 10 **Greenhouse Gas Emissions Intensity** Primary Aluminium (International Aluminium)

System Boundary

- Full life cycle (cradle-to-gate) greenhouse gas (GHG) emissions (as CO2e);
- All processes, including mining, refining, anode production, electrolysis and casting.
- All sources, including GHG emissions from electricity, direct emissions (CO2 and Non-CO2 GHG emissions), GHG emissions from thermal energy, transport and ancillary materials.
- Global coverage, including informed estimates for non-reporting plants.

	Electricity	Perfluorocarbon (PFC)	Process (C02)	Ancillary Materials	Thermal Energy	Transport	**TOTAL**
	Indirect	***Direct***	***Direct***	***Indirect***	***Direct/Indirect***	***Indirect***	*Cradle to Gate*
Mining	0.01	0.00	0.00	0.00	0.04	0.00	**0.04**
Refining	0.40	0.00	0.00	0.40	1.60	0.20	**2.70**
Anode Production	0.00	0.00	0.10	0.70	0.10	0.00	**0.90**
Electrolysis	10.30	0.80	1.50	0.10	0.00	0.20	**12.90**
Casting	0.00	0.00	0.00	0.00	0.10	0.00	**0.10**
Primary Aluminium	10.70	0.80	1.70	1.20	1.80	0.40	**16.60**

Period: 2022 | Tonnes of CO2e Per Tonne of Primary Aluminium

TABLE 11 **Cradle to Gate** Tonnes of CO2e Per Tonne of Powder Coated Aluminium

Mining	0.04
Refining	2.70
Transport	0.40
Anode Production	0.50
Electrolysis	12.90
Casting	0.10
Transport	0.40
Extrusion	0.50
Interpon EPD	3.197300
Knotwood	0.000375
Total	**20.734**

Acidification Potential

The acidification potential gauges emissions that lead to environmental acidification, denoted in kilogram SO2 Equivalent. Predominantly, this encompasses emissions like nitrogen oxides (NOx), sulfur dioxide (SO2), and ammonia, which results in ammonium deposition.

For every 1000 kg of primary aluminium ingot produced in specific regions, the acidification potential is approximately 37 kg SO2 equivalent. While this figure is rooted in global statistics, it will shape this LCA.

A breakdown of emissions by production phases reveals that the electrolysis process accounts for 69% of the total acidification potential, with alumina refining trailing at 30%.

The bulk of these acidification effects can be traced back to preliminary emissions during power generation. A notable enhancement in these figures is primarily due to a decline in coal-powered electricity generation.

Eutrophication Potential

The eutrophication potential quantifies emissions that lead to environmental eutrophication, presented in terms of kilogram of Phosphate Equivalent. Aquatic system eutrophication primarily stems from excessive nitrogen and phosphorus inputs, often linked to over-fertilisation.

When producing one metric tonne of primary aluminium ingot in certain regions, the eutrophication potential equals roughly 0.82 kg Nitrogen equivalent. While this figure draws from global sources, it will inform this LCA. Airborne emissions, largely NOx, account for 86% of the total eutrophication impacts.

The residual 14% arises from waterborne emissions, predominantly from nitrates, chemical oxygen demand (COD), and NOx discharges into water.

Analysing impacts by production phase, as depicted in Figure 8-2, reveals that the combined alumina refining and electrolysis processes shoulder 98% of eutrophication impacts, splitting their contributions at 57% and 41%, respectively.

Air emissions from preliminary processes, such as power generation, comprise about 67% of the overall eutrophication potential. A comparative analysis with a prior study indicates a commendable 15% decline in the eutrophication potential of primary aluminium production between 2010 and 2022.

Global Warming Potential (100 Years)

The Global Warming Potential (GWP) quantifies greenhouse gas emissions, such as CO2 and methane (CH4), and presents them in kilogram of CO2 equivalents. These emissions intensify the natural greenhouse effect by trapping more of the sun’s radiation. Producing 1,000 kg of primary aluminium ingot in North America results in a GWP of 8,455 kg CO2 equivalent.

Dissecting this GWP, about 93% arises from CO2, 4% from Tetrafluoromethane (CF4), 1% from methane (CH4), 1% from Hexafluoroethane (C2F6), and under 1% from nitrous oxide (N2O). Figures 8-3 illustrate the GWP distribution by production stages, highlighting that electrolysis contributes 65% of the warming impacts, followed by alumina refining at 33%.

Mining and cast house operations account for the remainder. Direct greenhouse gas emissions represent around 47% of the total GWP, while indirect emissions, primarily from electricity production, comprise the other 53%.

When juxtaposed with the 2013 study, there is a noticeable 5% GWP reduction between 2010 and 2016. This decline is primarily due to a higher reliance on renewable electricity and a decreased dependence on coal-fired electricity for smelting.

GHG Analysis & Breakdown into Scopes 1, 2 & 3

Exploring the intricate details of greenhouse gas emissions provides insight into areas of concentration and evaluates the emissions' responsibility' from various entities throughout a product's life cycle. This knowledge is pivotal for shaping policies and strategic planning.

In this context, the GHG emission outcomes for primary aluminium ingot production were further subdivided using the scopes concept, as detailed in the Greenhouse Gas (GHG) Protocol (WRI and WBCSD, 2004).

Since the GHG Protocol was not crafted to be product-centric, the results' categorisation adhered as closely as possible to the GHG Protocol's specifications.

Adhering to the scopes concept, the GHG emissions' breakdown, aligned with the ISO 14044 standard (ISO, 2006b), is presented across Scope 1 (direct GHG emissions), Scope 2 (indirect GHG emissions from energy transformation processes), and Scope 3 (additional supply chain GHG emissions)

Scope 1: Direct GHG emissions occur from sources owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment.

Scope 2: Indirect GHG emissions from electricity are comprised of GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electricity purchased or otherwise brought into the company's organisational boundary. Scope 2 emissions physically occur at the facility where electricity is generated.

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

Smog Formation Potential

The Smog Formation Potential (SFP) quantifies the release of agents that lead to ground-level smog formation, a phenomenon resulting from the interplay between NOx and volatile organic compounds (VOC) under ultraviolet light.

The metric is presented in terms of kg ozone (O3) equivalents. The associated SFP data can be viewed in Figure 20. For every metric tonne of primary aluminium produced in North America, the SFP is 273.9 kg O3 equivalent.

The primary contributor to this potential in aluminium production is NOx emissions, which comprise 99% of the SFP.

Of the total smog formation impact, alumina refining is the most significant contributor at 67%, with the electrolysis process following at 30%. Over the span from 2010 to 2016, there was a commendable reduction of 38% in SFP by the industry.

Lifespan of Powder Coated Aluminium

Powder-coated aluminium is used in various products; good technical specifications about aluminium are that it is durable in end-use. In addition to the long life span, the material is low-maintenance compared to other metals.

At the end of the lifespan, aluminium can be recycled. Aluminium is an ideal material for recycling because the metal can be recycled repeatedly without losing quality. Powder-coated aluminium extruded products used in various sectors have variations in their lifespan.

As discussed above, the products are extruded from aluminium; now, we will focus on their lifespans. The lifespan of these products helps to understand and evaluate a product's environmental impact through its life cycle, encompassing extraction, processing of the raw materials, manufacturing, distribution, use, recycling, and finally, disposal.

One of the standard methods is the Life Cycle Analysis (LCA) method, which is used to know the above aspects.

Lifespan in Building & Construction Sectors

In the building and construction sector, powder-coated aluminium is extensively used in windows, roofing, cladding, curtain walling, decking and fences, architectural hardware, shop fitting and partitions, etc. The minimum lifespan of aluminium structures may range from 60-80 years, depending upon the conditions.

Within this timespan, aluminium can be used in any climatic conditions and does not lose its properties in temperatures between –80 °C and +300 °C. Similarly, powder-coated aluminium used for external building purposes has about 25 years—the lifespan of powder-coated aluminium versus C02e per annum over its lifespan.

TABLE 12 **Lifespan** of Powder Coated Aluminium

Products	Lifespan	CO2 Per Annum of Lifespan
External Use	**25+ Years**	0.829
Internal Use	**60+ Years**	0.345

Recycling of Aluminium

Recycling aluminium consumes only 5% of the energy needed to produce the primary metal. Moreover, aluminium retains its quality even after multiple recycling processes, with approximately 75% of all constructed aluminium still in circulation.

Recycling aluminium presents two significant advantages. Firstly, its quality remains consistent regardless of how often it's recycled. Secondly, recycling aluminium is more cost-effective than sourcing it from ore, even considering the expenses of collection, separation, and recycling processes.

An impressive 75% of all manufactured aluminium is still actively used, having gone through numerous recycling cycles.

In terms of end-of-life products, aluminium boasts one of the highest material recycling rates, reaching up to 90% for applications in transport and construction.

This metal's intrinsic value and infinite recyclability make the aluminium beverage can the world's most recycled container, with an average global recycling rate of 60% and exceeding 90% in certain countries.

The recycled aluminium is often reshaped into its original form, such as a window frame or beverage can.

*“When you put the whole picture together,
Aluminium is the right thing to do.”*

References

Knotwood Metrics - Data table, data figures and data contained within the report

Aluminum.org. 2022. *The Aluminum Association.* [online] Available at: <https://www.aluminum.org/> [Accessed 28 July 2022].

Crawford, Robert; Stephan, André; Prideaux, Fabian (2019). EPiC database - Aluminium extruded. University of Melbourne. Dataset. https://doi.org/10.26188/5da551b3248d5

European-aluminium. eu. 2022. *Home - European Aluminium.* [online] Available at: <https://www.european-aluminium.eu/>.

International Aluminium Institute. 2022. *International Aluminium Institute* - International Aluminium Institute. [online] Available at: <https://international-aluminium.org/>.

Constellium.com. 2022. *Life Cycle of Aluminium.* [online] Available at: <https://www.constellium.com/sites/default/files/constellium_-_life_cycle_of_aluminium.pdf>.

PE Americas, 2010. *Life Cycle Impact Assessment of Aluminium Beverage Cans.* [online] Washington DC: Aluminum Association, Inc. Available at: <http://www.avnir.org/documentation/bdd/sg/LCA-2010-AluminumAssoc.pdf>.

Qatalum.com. 2022. *Qatalum - Qatar Aluminium.* [online] Available at: <https://www.qatalum.com/Pages/Home.aspx>.

Zare, R., Nouri, J., Abdoli, M. and Atabi, F., 2016. *LIFE CYCLE ASSESSMENT OF SECONDARY EXTRUDED ALUMINUM PRODUCTION PROCESS IN INDUSTRIAL CITY OF ARAK.* [online] Tehran, Iran: Department of Environmental Management, Graduate School of Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran. Available at: <https://www.aloki.hu/pdf/1402_125135.pdf>.

Life Cycle Assessment

LCA Full Length Report

ISO 14040/44*

This LCA study was completed
following ISO 14040, ISO 14044
and EN 15804:2012 + A2:2019
requirements and PCR 2019:14 v 1.3.1.

IMS Metrics has prepared this LCA study.

2023

*International Organization for
Standardization

KNOTWOOD™
Stunning Aluminium