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Programme

SCRREEN2

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FACTSHEETS UPDATES **BASED ON THE EU FACTSHEETS 2020**

ALUMINIUM AND BAUXITE

AUTHOR(S):

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ALUMINIUM AND BAUXITE

OVERVIEW

Bauxite is the primary raw material used to produce aluminium metal. It is a heterogeneous ore composed primarily of aluminium-containing minerals (gibbsite, boehmite and diaspore) with varying quantities of silica, iron oxides and other associated minerals. Bauxite generally contains more than 40% of aluminium oxide. Bauxite is refined into an intermediate product, aluminium oxide (alumina), which is then reduced into aluminium.

Aluminium (chemical symbol Al) is a lightweight, silver-grey metal, and a good conductor of heat and electricity. Aluminium's superior malleability and low melting point of 660°C makes it highly workable and versatile. The ability to form numerous alloys enhances its versatility. Furthermore, aluminium is highly corrosion-resistant as it develops a natural oxide layer, protecting it against corrosion. Aluminium has a remarkable strength to weight ratio; some heat-treatable alloys offer similar performance to advanced steels and titanium. Aluminium is fully recyclable and reusable an infinite number of times. The combination of its excellent properties has made aluminium the second most widely used metal in modern society

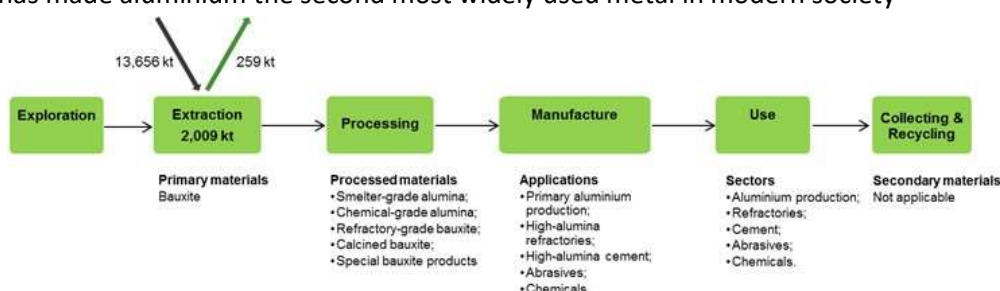


Figure 1. Simplified value chain for bauxite in the EU¹

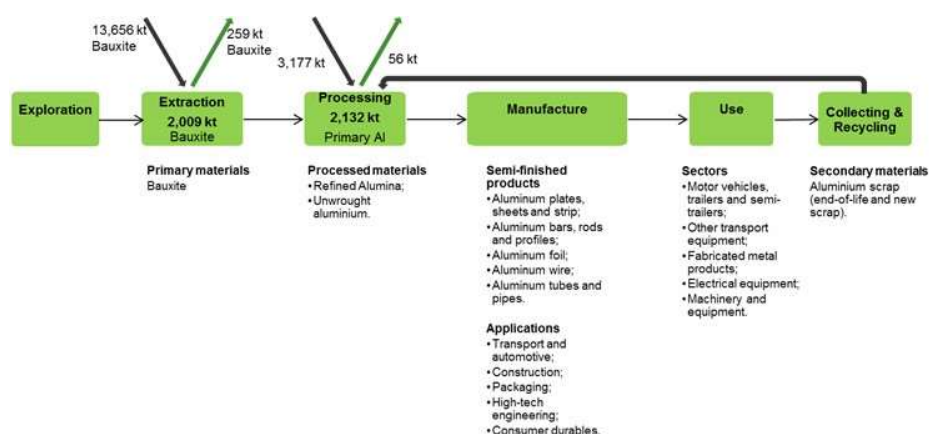


Figure 2. Simplified value chain for aluminium in the EU²

¹ JRC elaboration on multiple sources (see next sections)

² JRC elaboration on multiple sources (see next sections)

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Table 1. Bauxite supply and demand at extraction stage, in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
336,197,330	Australia 28% China 21% Guinea 18% Brazil 10% India 7%	16,146,077	5%	Guinea 63% Brazil 13% Greece 10% Sierra Leone 9% Turkey 2%	89%

Table 2. Aluminium supply and demand at processing stage, in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
62,734,647	China 56% Russia 6% India 5% Canada 5% United Arab Emirates 4%	4,980,933	8%	Russia 19% Germany 11% Mozambique 10% Iceland 14% France 8% Spain, Romania 6% Greece 4% Slovakia 3% Sweden 2%	58%

Prices: Aluminium is an exchange-traded commodity, listed in the London Metal Exchange (LME) and the Shanghai Futures Exchange (SHFE). After its peak in spring 2008, aluminium’s price collapsed by almost 50%, and recovery started in early 2009. Alumina prices have been relatively stable from 2011 to early 2017, as a percentage of LME aluminium price. In 2017 and 2018, alumina price surged driven by market tightness caused by production disruptions at Hydro’s Alunorte alumina refinery, and sanctions against UC Rusal (Thomas, 2018), traded on some occasions at 30% of the outright aluminium price. Throughout 2018’s escalation in alumina prices, the LME aluminium price became disconnected from the market, and instead of increasing in line with the raw materials, the aluminium price remained flat (Fastmarkets, 2019).

Primary supply: Bauxite was mined in 30 countries in 2020 with the total production averaged over the 2016–2020 period to 336.2 million tonnes per year. Australia is the leading producer for the period 2016-2020 with 28% of the world’s total production followed by China (21%), Guinea (18 %) Brazil (10%) and India (7%). The EU annual production of bauxite (average 2016-2020) is about 1.8 million tonnes per year, corresponding approximately only 0.5% of the world’s bauxite production. 93% of the EU production was mined in Greece. The global aluminium production averaged at 64 million tonnes.

Secondary supply: Bauxite is consumed during all of its uses and therefore is not available for recycling. Although some refractory products are subsequently recycled, this is generally to further refractory applications and is very small in quantity compared to the global production of bauxite. The majority of bauxite uses results in a substance that is subsequently transformed into a different product, e.g. cement into concrete or alumina into aluminium metal (SCRREEN workshops 2019). Aluminium is infinitely recyclable without downgrading its quality. Secondary aluminium is produced by melting aluminium scrap. The scrap utilised in secondary aluminium production consists of 'new scrap' which is generated during the production and

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fabrication of wrought and cast products, and 'old scrap' which is recovered from articles at the end of their useful life such as used beverage cans or packaging. Recycling of aluminium needs as little as 5% of the energy originally used for its primary production, with obvious financial and environmental benefits. More than one-third of all the aluminium produced globally originates from scrap.

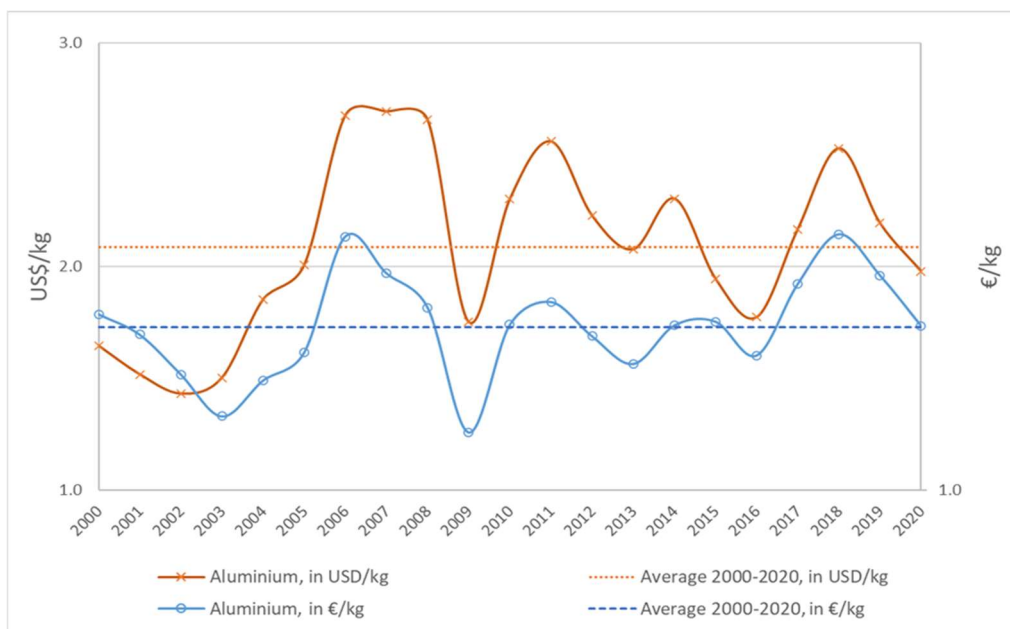


Figure 3. Annual average price of aluminium between 2000 and 2020 (USGS, 2022).

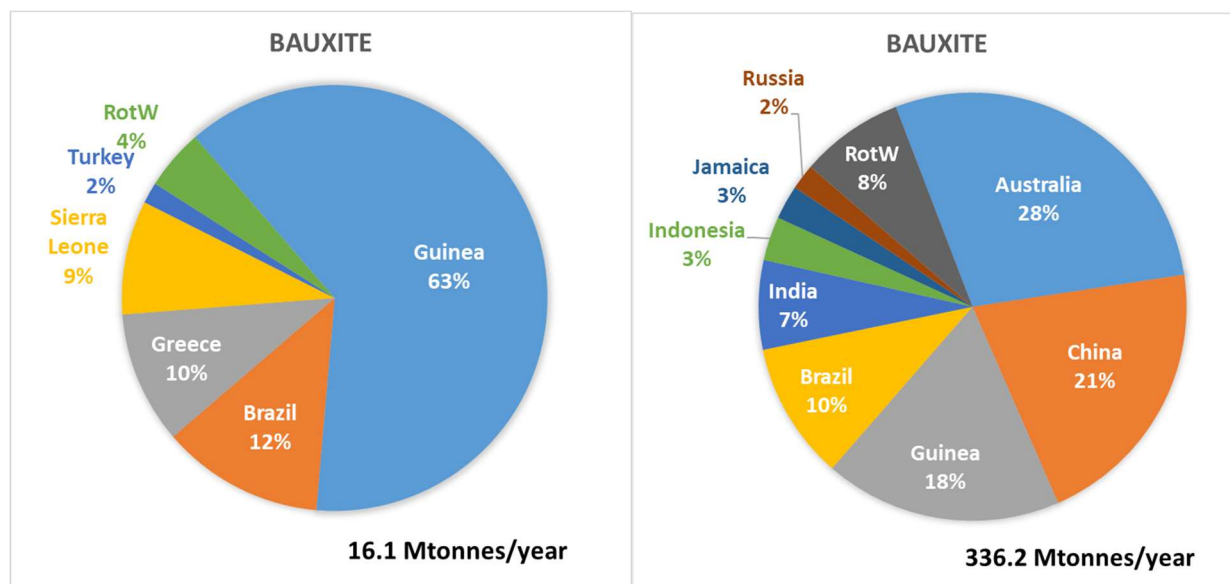


Figure 4. EU sourcing of bauxite (Eurostat 2022) and global mine production (WMD 2022) at extraction stage, average 2016-2020

Uses: Most of the bauxite mined worldwide is refined into alumina, with the remainder consumed directly for non-metallurgical applications. Non-metallurgical applications of bauxite, including those of chemical-grade

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alumina, are found in refractories, cement, abrasives and chemicals. Furthermore, it is highly used in mobility, construction, packaging and even high-tech engineering. Aluminium’s excellent combination of properties (lightweight, adaptable, corrosion-resistant, etc) together with its relative cost-effectiveness have led to its widespread use in a variety of applications (OECD 2015).

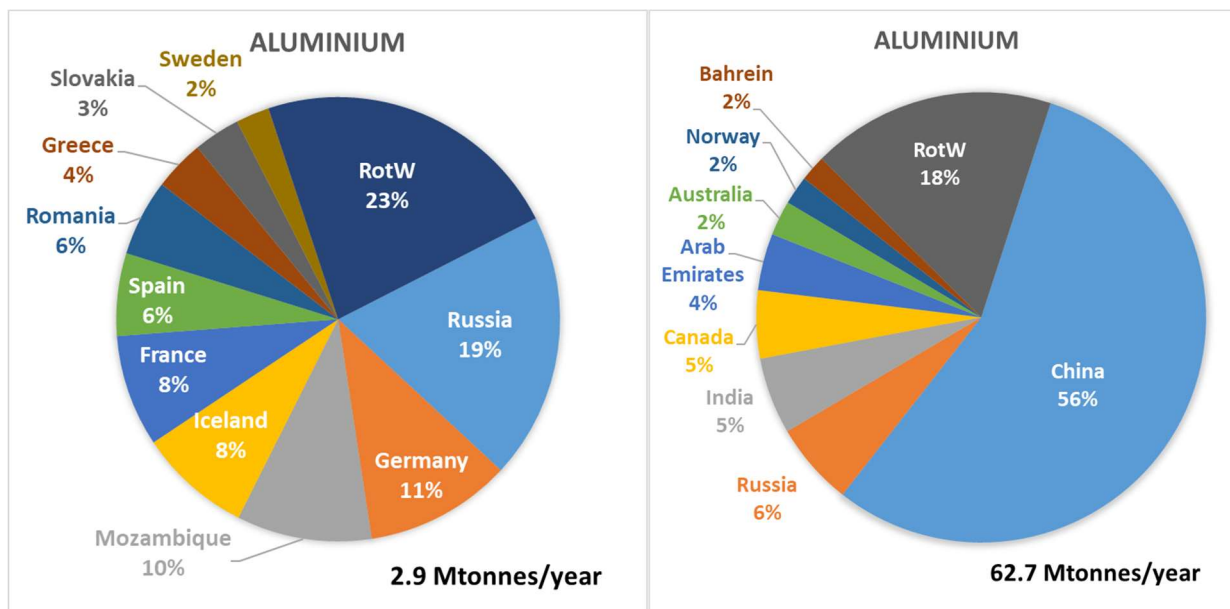


Figure 5. EU sourcing of aluminium (Eurostat 2022) and global production (WMD 2022), at processing stage, average 2016-2020

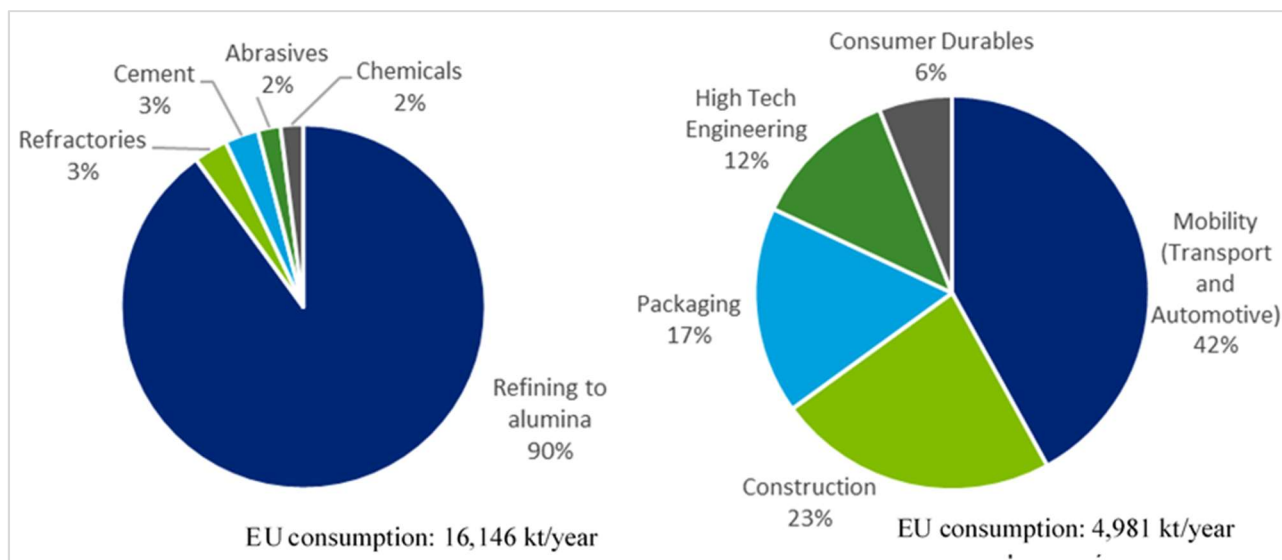


Figure 6: Global end uses of bauxite (International Aluminium Association and literature; SCRREEN expert workshops 2019 & 2022) and refined aluminium (CRM Factsheets 2020) between 2016 and 2020.

Substitution: Alumina production from non-bauxite sources is theoretically possible from nepheline concentrates, and commercial production has been reported in Russia (Vadim Smirnov 1996) (Jorjani and

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Amirhosseini 2007). Information is limited on the costs, performance and production levels. Other potential bauxite substitutes for the supply of alumina are anorthosite, alunite, low-grade kaolin and clay, and coal fly ash (Kuzvart 2006; USGS, 2022). Aluminium can be substituted by carbon-fibre-reinforced plastic in mobility, by steel, plastics (such as PVC or vinyl) and wood in construction, by glass, paper, plastics and steel in packaging. In the high-tech engineering application, copper can replace aluminium in electrical lines for power transmission and distribution, as well as in heat-exchange applications, but the current costs of copper are higher than aluminium. Cast iron and cast steel may also substitute aluminium in specific applications at similar cost and performance.

Table 3. Uses and possible substitutes

Use	Percentage*	Substitutes	Sub share	Cost	Performance
Automotive industry	19%	Composites	15%	Very high (more than 2 times)	Similar
Automotive industry	19%	Steel	70%	Similar or lower	Reduced
Automotive industry	19%	Magnesium	3%	Slightly higher (up to 2 times)	Similar
Automotive industry	19%	Titanium	2%	Very high (more than 2 times)	Similar
Transport equipment	19%	Composites	15%	Very high (more than 2 times)	Similar
Transport equipment	19%	Steel	70%	Similar or lower	Reduced
Transport equipment	19%	Magnesium	3%	Slightly higher (up to 2 times)	Similar
Transport equipment	19%	Titanium	2%	Very high (more than 2 times)	Similar
Construction	21%	Steel	35%	Similar or lower	Similar
Construction	21%	Plastic (PVC, vinyl, etc)	15%	Similar or lower	Similar
Construction	21%	Wood	49%	Similar or lower	Similar
Packaging	15%	Glass	47%	Similar or lower	Similar
Packaging	15%	Plastics	38%	Similar or lower	Similar
Packaging	15%	Steel	12%	Similar or lower	Similar
High tech engineering	11%	Copper	17%	Very high (more than 2 times)	Similar
High tech engineering	11%	Cast iron	17%	Similar or lower	Similar
High tech engineering	11%	Cast steel	16%	Similar or lower	Similar

*Estimated global end use shares of aluminium 2016-2020 (CRM Factsheet, 2022; outputs of SCRREEN Experts Validation Workshop, 2022)

Other issues: The main European legislation on chemicals, Regulation (EC) 1907/2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), only identifies minor environmental and health issues for the aluminium value chain. The smelting of aluminium can produce fluoride emissions but these are not classified as a high risk for humans (BRG 2020). Due to the nature of the bauxite deposits (stratified, horizontal, and shallow), large areas of land are required for mining. Another

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critical environmental issue, arising during the alkaline digestion of bauxite ore in alumina production, is the management of bauxite residues (red mud), along with energy consumption and water management. Globally aluminium/bauxite market represents about 1% of the total world exports. Aluminium production or transformation are an important part of the economy of some countries, even if they are globally small actors. In particular, aluminium ores and concentrates trade represent 7.3% of the total exports of Jamaica, 5.4% for Montenegro and 2.8% for Guyana. Guinea was the EU's most important supplier for bauxite and one of the top world exporters. Guinea has very weak governance (World Bank 2018), and the Human Development Index value for 2017 is very low (0.459), which positions the country at 175 out of 189 countries and territories in the low human development category (UNDP 2018). A report released by Human Rights Watch (2018), focusing on Guinea's two largest mining projects, highlights the profound human rights consequences to local communities that live closest to the fast-growing bauxite mining industry such as damages to water sources, and loss of farmlands, undermined air quality.

MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 4. Bauxite supply and demand at extraction stage, in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
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Table 5. Aluminium supply and demand at processing stage, in metric tonnes, 2016-2020 average

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The geographic distribution of the aluminium industry has shifted significantly during the last 20 years to regions endowed with abundant bauxite or energy resources. New countries have emerged as significant bauxite producers (e.g. China, and Guinea, and production in the global alumina industry has been relocated from industrialized countries towards countries with access to plentiful and inexpensive bauxite sources.

The world production of bauxite from 2016 to 2020 averaged at about 336.2 million tonnes and global aluminium production averaged at 64 million tonnes.

A recent report by the Organisation for Economic Cooperation and Development (OECD, 2019), has highlighted government interventions to the aluminium industry and the related market distortions in the global aluminium value chain. The report concludes that non-market forces appear to explain some of the increases in capacity in the aluminium sector and that the associated market distortions are a genuine concern for the aluminium industry. According to the findings of the study, government support is common throughout the aluminium value chain as all companies examined in the study received support in financial or non-financial form. Government intervention is relatively large in aluminium smelting and exceptionally large in China and countries of the Gulf Cooperation Council. The report asserts that of the documented subsidies provided to the 17 international companies examined, 85% has gone to five Chinese companies. Massive government support to the rapidly growing aluminium smelting industry in China is mostly in the form of energy subsidies and concessional finance.

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Another key finding of the study is that apart from direct state support upstream in the value chain, trade measures such as China’s export taxes on primary aluminium and incomplete value-added tax (VAT) rebates on exports of certain aluminium products has benefited downstream producers of semi-finished and fabricated articles of aluminium. Export restrictions discourage exports of primary aluminium, therefore making aluminium cheaper to producers of semis in China than it would otherwise have been and facilitating their exports due to a cost advantage over global competition.

OUTLOOK FOR SUPPLY AND DEMAND

In addition to market distortions related to Chinese aluminium supply, the global market for aluminium has also faced some disruptions in 2022 due to Russian military operations in Ukraine. The Russian aluminium company Rusal, which is the world’s largest non-Chinese supplier, has not faced EU or US sanctions as of June 2022. However, in response to the Ukraine crisis, Australia has prohibited bauxite exports to Rusal, which accounted for 20% of their supply. Moreover, the company is currently having to delay investments in production capacity due to the high interest rate environment in Russia (Stonestreet, 2022).

While aluminium supply faces some geopolitical risks, the demand is expected to grow significantly over the next decade. Indeed, the International Aluminium Initiative expected demand to increase by 33.3 Mt between 2020 and 2030, eventually reaching 119.5 Mt. They expect that 63% of this growth to be driven by Asian economies, primarily China. The transportation and electricity sectors are forecast to be the largest drivers of increased aluminium demand. This is notably due to the shift towards light weight electric vehicles and solar energy, both of which are much more aluminium intensive than conventional alternatives (Initiative, 2022).

EU TRADE

For the purpose of this assessment, aluminium is evaluated at both extraction and processing stage. Figure 7 to Figure 8 illustrate the import and export trend of various aluminium products both at extraction and refining stage. At extraction stage, for aluminium ores and concentrates it seems that the import and export both have remained at stable level since 2010. Currently the import quantity is around 14.5 million tonnes which is slightly lower than last year’s quantity of 15.7 million tonne. Export of aluminium ores and concentrate from EU to other countries is minor compared to the export share.

Table 6. Relevant Eurostat CN trade codes for Aluminium

Mining		Processing/refining	
CN trade code	title	CN trade code	title
26060000	Aluminium ores and concentrates	76011000	Aluminium, not alloyed, unwrought

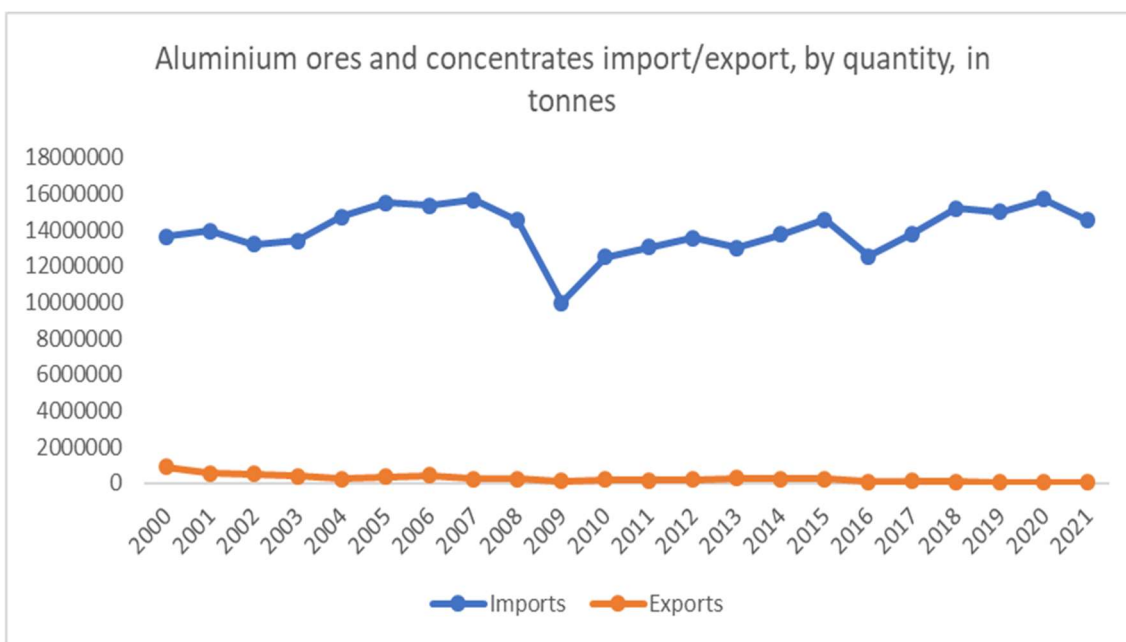


Figure 7. EU trade flows of Aluminium (Bauxite) ores and concentrates (CN 26060000) from 2000 to 2021 (based on Eurostat, 2022)

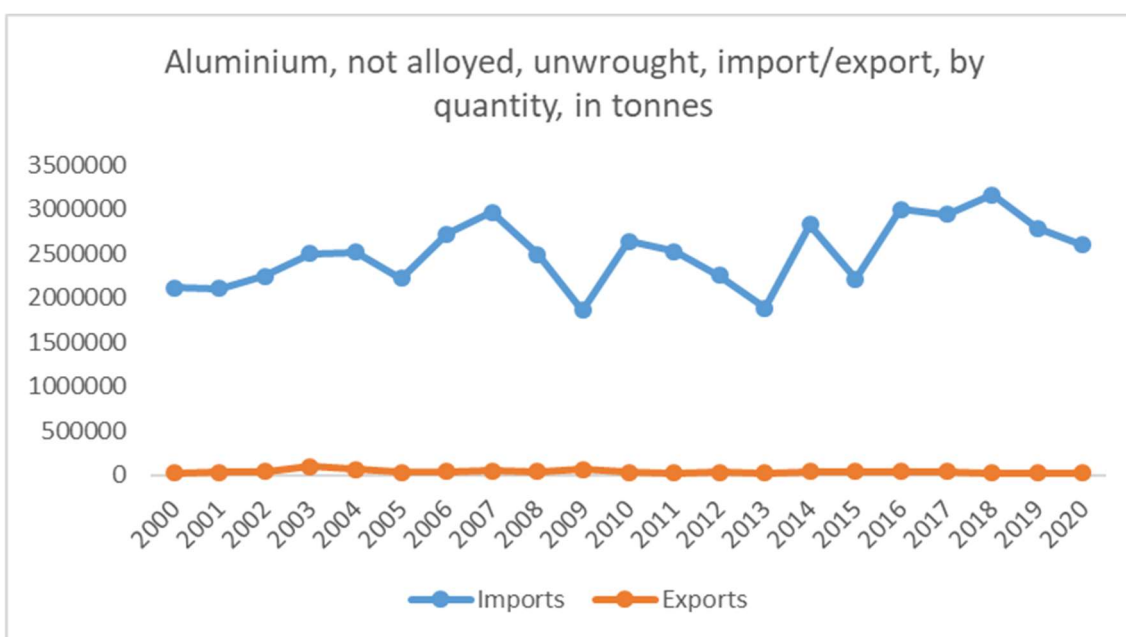


Figure 8. EU trade flows of Aluminium, not alloyed, unwrought, (CN 7601100) from 2000 to 2020 (based on Eurostat, 2022)

Figure 9 to Figure 10 illustrate the share of import in EU for aluminium products from various countries. The main supplier for aluminium ores and concentrates to EU is Guinea followed by Brazil and Sierra Leone. Australia used to be a major supplier in early decade of 2000s until 2009 and post that, EU has switched to Sierra Leone.

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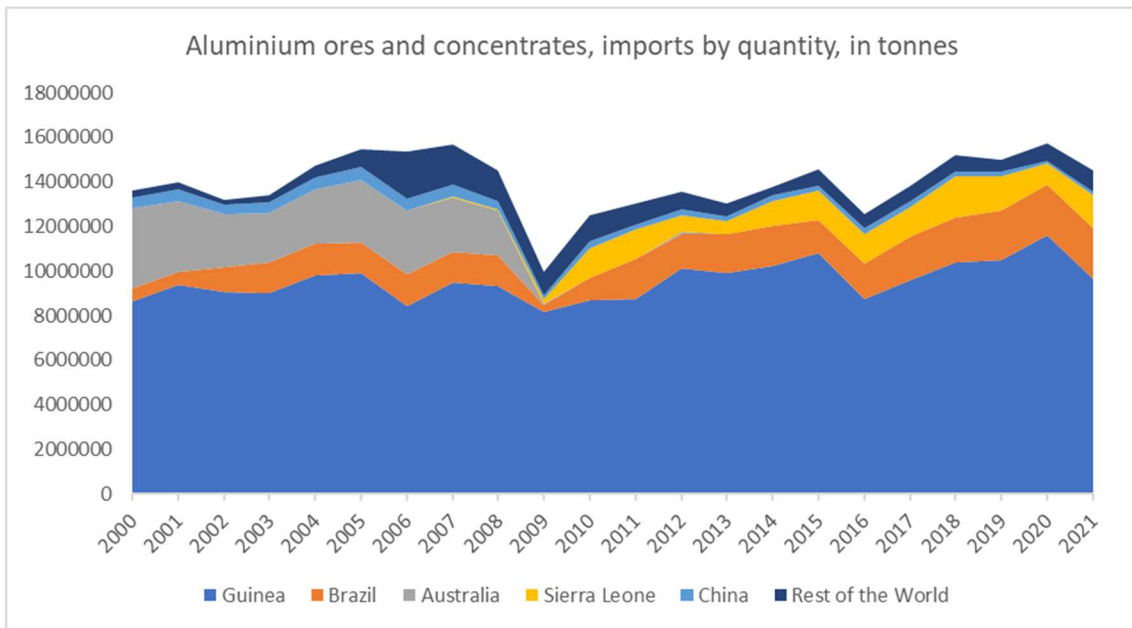


Figure 9. EU imports of Aluminium (Bauxite) ores and concentrates (CN 26060000) by country between 2000 and 2021 (based on Eurostat, 2022)

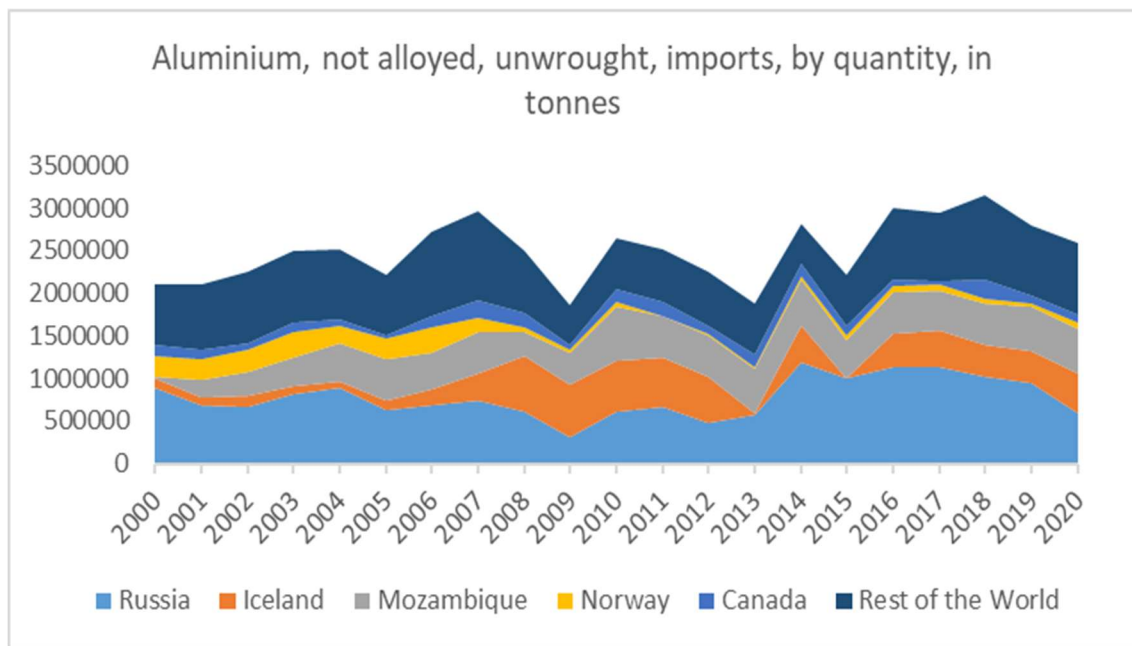


Figure 10. EU imports of Aluminium, not alloyed, unwrought (CN 76011000) by country between 2000 and 2020 (based on Eurostat, 2022)

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PRICE AND PRICE VOLATILITY

Aluminium is an exchange-traded commodity, listed in two exchanges: London Metal Exchange (LME) and the Shanghai Futures Exchange (SHFE).

After its peak in spring 2008, aluminium's price ranged between € 1.6/kg in 2016, and € 2.1/kg in 2008. However, world market prices for primary aluminium have remained significantly lower than the levels reached in 2008.

Alumina prices have been relatively stable from 2011 to early 2017, as a percentage of LME aluminium price. In 2017 and 2018, alumina price surged driven by market tightness caused by production disruptions at Hydro's Alunorte alumina refinery, and sanctions against UC Rusal (Thomas, 2018), traded on some occasions at 30% of the outright aluminium price. Throughout 2018's escalation in alumina prices, the LME aluminium price became disconnected from the market, and instead of increasing in line with the raw materials, the aluminium price remained flat (Fastmarkets, 2019).

In 2018 a short-term peak emerged. The short-term peak observed in April 2018 was the result of US sanctions imposed to the world's second-largest aluminium producer (Rusal), and the widespread uncertainty caused in the international aluminium market. In spring 2018, aluminium became a bone of contention in global trade policy. The US sanctions against Russia were affecting the price of aluminium (Nasswetter, 2018). On April 6, 2018, the US Department of Treasury's Office of Foreign Assets Control (OFAC) imposed sanctions against seven Russian oligarchs, their 12 companies and 17 senior Russian government officials.

The prices sharply increased in 2020 and 2021. Prices were supported by tight supply because of pandemic-driven lockdowns. Base prices for extrusions increased due to increased production costs, including labor, energy, and transportation.

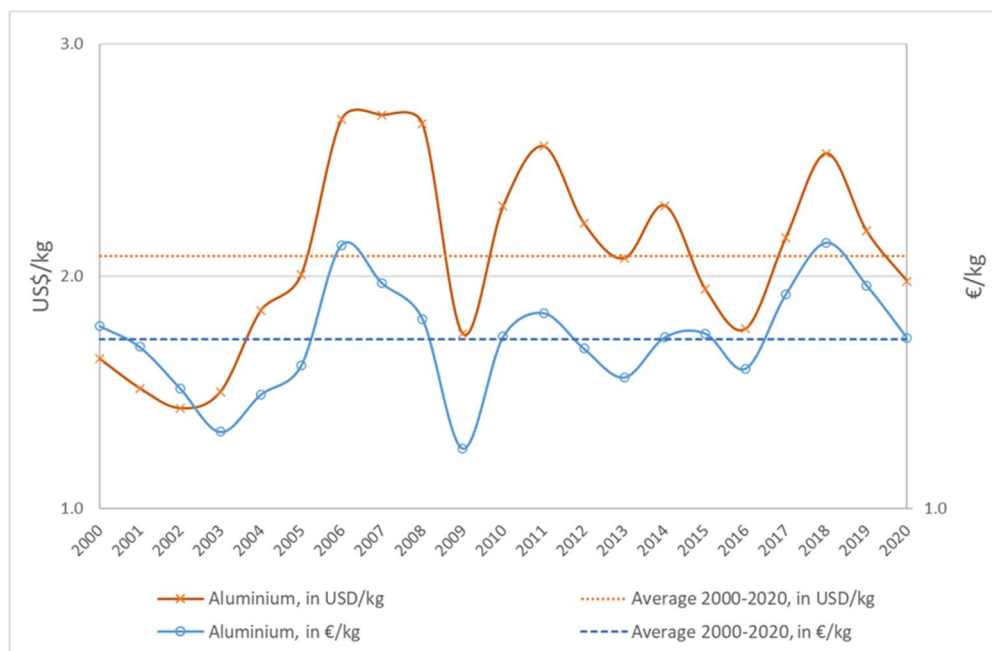


Figure 11. Annual average price of Aluminium between 2000 and 2020 (USGS, 2022)^[1]

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DEMAND

DEMAND AND CONSUMPTION

BAUXITE GLOBAL AND EU DEMAND AND CONSUMPTION

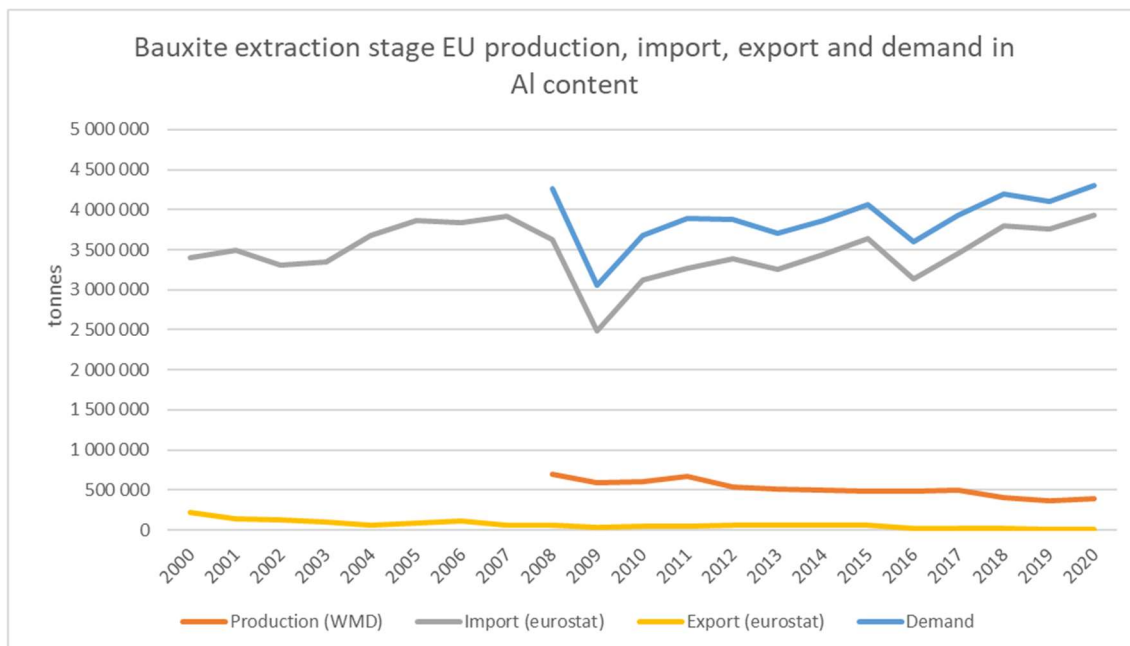


Figure 12. Bauxite (CN 26060000 Aluminium ores and concentrates) extraction stage apparent EU consumption. Production data is available from WMD (2022) for 2008-2020. Bauxite demand is presented in Al content (1kg crude bauxite = 0,25 kg Al, (USGS, 2022)). Consumption is calculated EU production+import-export.

Bauxite extraction stage EU consumption is presented by HS code CN 26060000 Aluminium ores and concentrates. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from WMD (2022).

Based on Eurostat Comext (2022) and WMD (2022) average import reliance of bauxite at extraction stage is 86.5% for 2008-2020. The average import reliance for 2016-2020 is 89.2%.

ALUMINIUM GLOBAL AND EU DEMAND AND CONSUMPTION

The world annual average refined aluminium consumption was about 65,000,000 tonnes in 2019-2021 (World Bureau of Metal Statistics, 2022).

Figure 13 demonstrates the aluminium ingots apparent consumption by the EU industry in comparison with the total aluminium metal demand from 2010 to 2017, as they are derived from official statistics (Eurostat).

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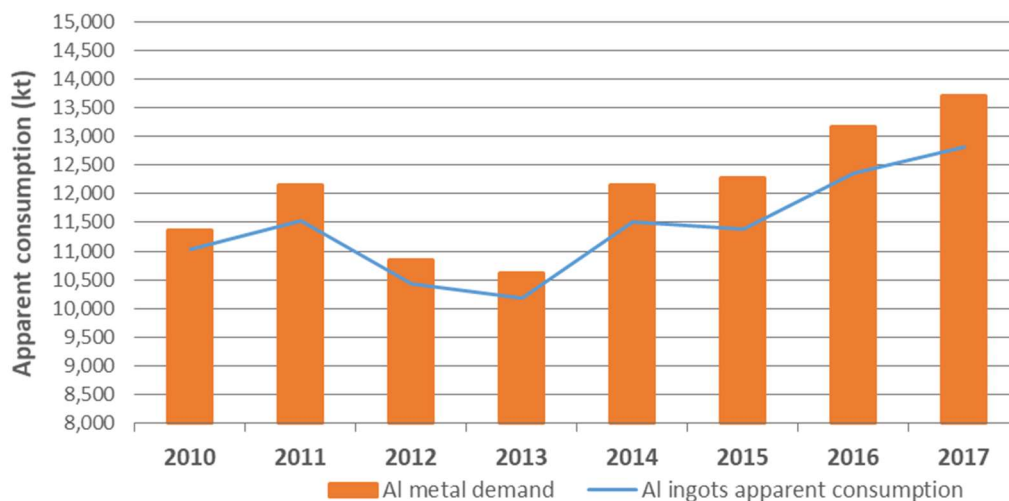


Figure 13: Aluminium ingots apparent consumption³ and aluminium metal demand⁴.

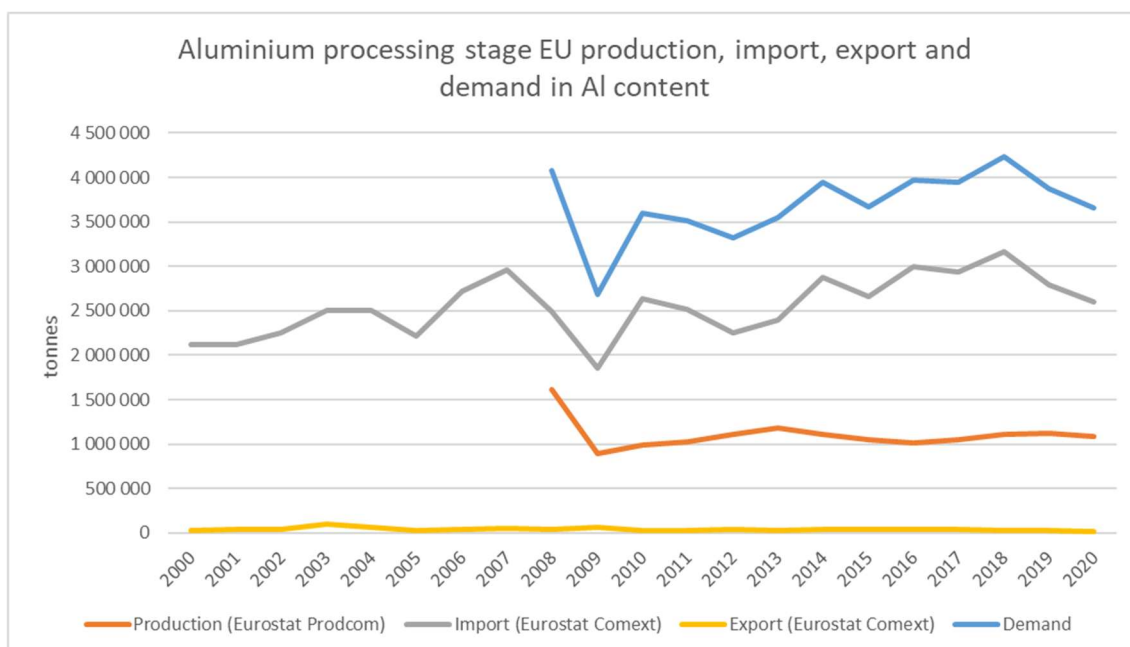


Figure 14. Aluminium (CN 76011000 Aluminium, not alloyed, unwrought) processing stage apparent EU consumption. Production data from Eurostat Prodcom (2022) are available for 2008-2020. Consumption is calculated in aluminium content (EU production+import-export).

³ Calculated as domestic production of unwrought aluminium (PRODCOM codes PRC 24421130, PRC 24421154) plus net imports of unwrought aluminium (HS 760110, HS 760120). It is necessary to note that in the criticality assessment, primary aluminium is analysed, and not unwrought aluminium

⁴ Calculated as domestic production of unwrought aluminium plus net imports of unwrought aluminium (HS 760110, HS 760120), semi-finished aluminium products (HS 7604-HS 7609), powders and flakes (HS 7603) and castings and forgings (HS 761699)

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Aluminium processing stage (primary aluminium) EU consumption is presented by HS codes CN 76011000 Aluminium, not alloyed, unwrought and CN 760120 Unwrought primary aluminium alloys. Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from Eurostat Prodcom (2022) using PRCCODE 24421130 Unwrought non-alloy aluminium (excluding powders and flakes).

Based on Eurostat Comext (2022) and Eurostat Prodcom (2022) average import reliance of aluminium is 46.7% for 2008-2020. The average import reliance for 2016-2020 is 41.0%.

USES AND END-USES

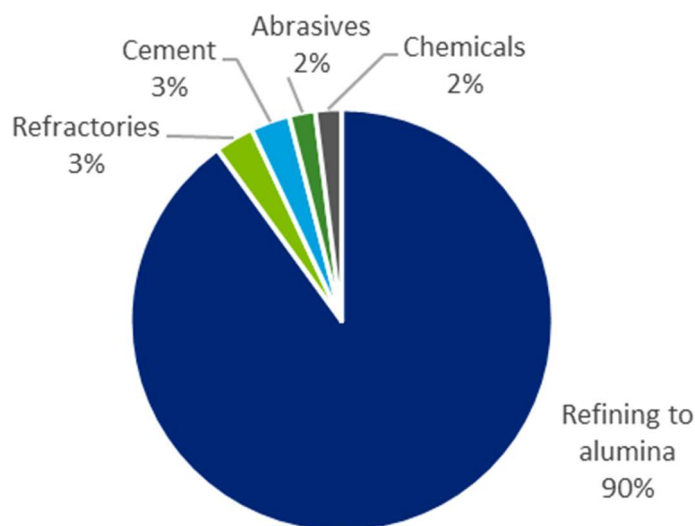
Most of the bauxite mined worldwide is refined into alumina, with the remainder consumed directly for non-metallurgical applications.

Non-metallurgical applications of bauxite, including those of chemical-grade alumina, are found in refractories, cement, abrasives and chemicals.

In abrasives, calcined bauxite and calcined speciality-grade alumina are used for the manufacture of abrasive materials for grinding.

The main global end-use categories for bauxite are shown in Figure 15. The figures remain unchanged since the 2020 factsheet update (RMIS 2022; SCRREEN Validation Workshop. 2022; SCRREEN draft EC data 2023-25).

The relevant industry sectors are described using the NACE sector codes in Table 7.



EU consumption: 16,146 kt/year

Figure 15: Global end uses of bauxite (International Aluminium Association and literature; SCRREEN expert workshops 2019 & 2022) between 2016 and 2020.

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Table 7. Bauxite applications, 2-digit and associated 4-digit NACE sectors and value added per sector in 2019 (Data from the Eurostat database; Eurostat, 2022c)

Applications for bauxite	2-digit NACE sector	Value-added of NACE 2 sector (millions €)	4-digit NACE sector(s)
Refining to alumina	C24 – Manufacture of basic metals	63,700.40	C2442 – Aluminium production
Refractories	C23 – Manufacture of other non-metallic mineral products	72,396.30	C2320 – Manufacture of refractory products
Cement	C23 – Manufacture of other non-metallic mineral products		C2351 – Manufacture of cement
Abrasives	C23 – Manufacture of other non-metallic mineral products		C2391 – Production of abrasive products
Chemicals	C20 – Manufacture of chemicals and chemical products	117,150.40* *Data to 2014 only	C2013 – Manufacture of other inorganic basic chemicals

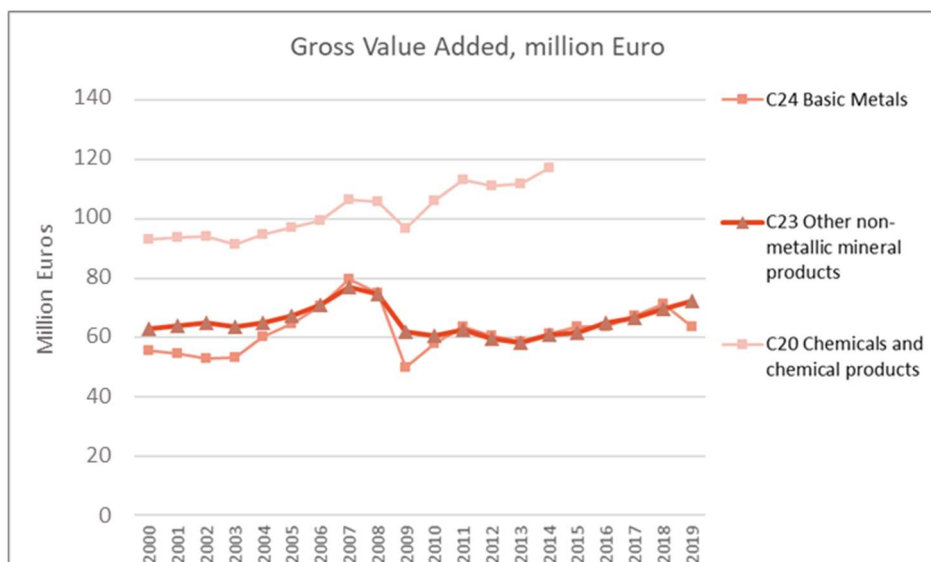


Figure 16. Value added per 2-digit NACE sector over time (Eurostat, 2022)

APPLICATIONS OF BAUXITE

REFINING TO ALUMINA

The share of bauxite output which is converted to alumina to produce aluminium metal (smelter-grade) ranges from 85% to 89%, while the proportion used to produce alumina for other applications (chemical-grade) is reported to vary from 6% to 10% (V. Hill and Sehnke, 2006) (Flook, 2015).

REFRACTORIES

Refractory-grade bauxite or sintered chemical-grade alumina are used for the manufacture of high-alumina refractories, mainly for the iron and steel industry (Flook, 2015).

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CEMENT

Aluminous cement is used where rapid strength and/or resistance to certain types of corrosion are required. Calcined chemical grade alumina is required to produce high-purity alumina cement for castable monolithic refractories. It is also used as a desiccating agent, adsorbent, catalyst and in the manufacture of dental cement.

ABRASIVES

Calcined alumina is a synthetic corundum, which is a very hard material (9 on the Mohs Hardness Scale). Calcined alumina is crushed, separated by size, and used as an abrasive. Aluminium oxide sandpaper, polishing powders, and polishing suspensions are made from calcined alumina.

CHEMICALS

The chemical uses of bauxite include the production of aluminium sulphate (used as a flocculating agent in water or effluent treatment), aluminium chloride, and aluminium fluoride or sodium aluminate. Bauxite applications in ceramic proppants for oil and gas drilling fluids, in welding fluxes, as slag adjuster and in road surfacing are included under this category.

APPLICATIONS OF ALUMINIUM

Aluminium’s excellent combination of properties (lightweight, adaptable, corrosion-resistant, etc) together with its relative cost-effectiveness have led to its widespread use in a variety of applications (OECD 2015).

Figure 17 shows the EU end uses of aluminium in 2017 and the end uses of aluminium worldwide in 2015. Data remains unchanged from 2020 factsheet (RMIS 2022; SCRREEN Validation Workshop, 2022; SCRREEN Draft data 2023-25).

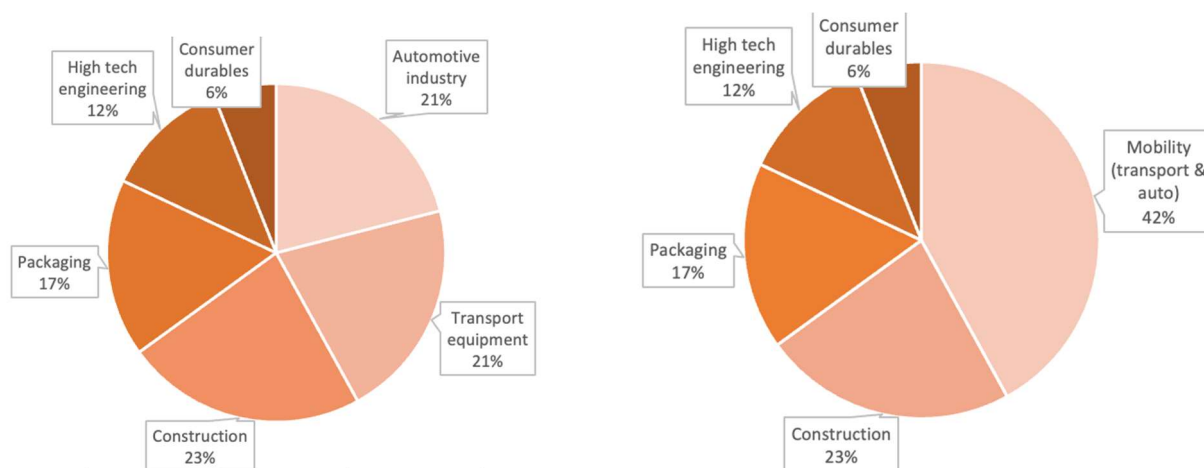


Figure 17. Main end uses of aluminium in Europe in 2017 (left, European Aluminium 2018), and worldwide in 2017 (right, updated by SCRREEN experts, 2022)

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Table 8. Aluminium applications, 2-digit and associated 4-digit NACE sectors and value added per sector
(Data from the Eurostat database; Eurostat, 2022c)

Applications for primary aluminium	2-digit NACE sector	Value-added of NACE 2 sector (M€) at 2019	Examples of 4-digit NACE sector(s)
Mobility (Transport and Automotive)	C29 – Manufacture of motor vehicles, trailers and semi-trailers	234,398.60	C2910 – Manufacture of motor vehicles; C2920 Manufacture of bodies for motor vehicles; C2932 – Other parts for motor vehicles;
	C30 – Manufacture of other transport equipment	49,129.00*	C3030 – Manufacture of air and spacecraft; C3011 – Building of ships and floating structures; C3020 – Manufacture of railway locomotives and rolling stock; C3092 – Manufacture of bicycles
Construction	C25 – Manufacture of fabricated metal products, except machinery and equipment	186,073.40	C2511 – Manufacture of metal structures and parts of structures; C2512 – Manufacture of doors and windows of metal; C2599 – Manufacture of other fabricated metal products n.e.c.
Packaging	C25 – Manufacture of fabricated metal products, except machinery and equipment		C2592 – Manufacture of light metal packaging
High-Tech Engineering	C28 – Manufacture of machinery and equipment not elsewhere specified	200,138.50*	C2811 – Manufacture of engines; C2812 – Manufacture of fluid power equipment; C2893 – Manufacture of machinery for food processing; C2529 – Manufacture of tanks, reservoirs and containers of metal; C2732 – Manufacture of other electronic and electrical wires and cables.
Consumer Durables	C25 - Manufacture of fabricated metal products, except machinery and equipment	186,073.40	C2571 – Manufacture of cutlery

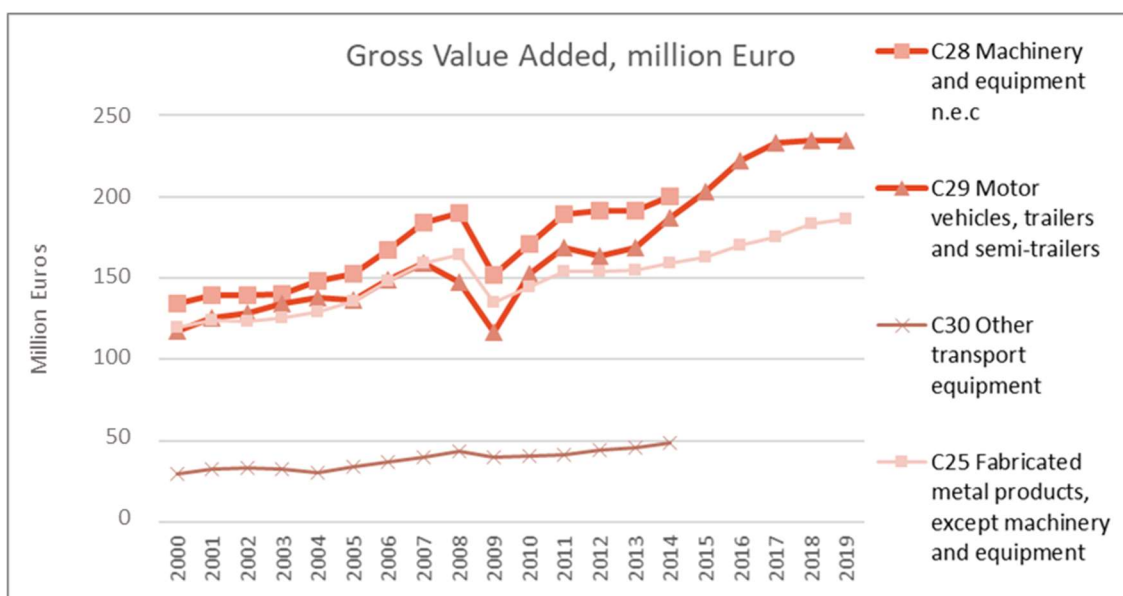


Figure 18. Value added per 2-digit NACE sector over time (Eurostat, 2022)

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Below is a non-exhaustive summary of examples of use:

MOBILITY (TRANSPORT AND AUTOMOTIVE)

Aluminium is used in the manufacture of road vehicles (cars, buses, trucks), trains, aircraft, ships, spacecraft, bicycles, etc.

Within road vehicles, aluminium is used for body panels, engine blocks, transmission housings, wheels, radiators, cylinder heads, heat exchangers, pistons, etc. Although aluminium often represents less than 10% of the total quantity of materials utilised in a car, due to its favourable strength to weight ratio its use can significantly reduce weight n.

Aluminium is used in aircraft where its lightness, workability and strength make it an ideal material. Some of the most common aircraft models are 70–80% aluminium.

Aluminium's lightweight property can reduce the weight of a vehicles (from passenger aircraft to cars), helping to increase fuel and payload efficiencies and reduce CO₂ emissions.

CONSTRUCTION

Within the construction sector can be found in a multitude of applications. Essential uses are in manufacturing doors, windows, cladding, roofing, staircases, air conditioning units, solar protection, parts of internal walls and other components. Aluminium retains its useful properties for long periods, providing architectural design advantages. (European Aluminium).

PACKAGING

Aluminium is one of the most versatile forms of packaging. It can be formed into almost any shape and it is non-toxic. Its main use is to protect food, drinks and pharmaceutical products against damage from light, liquid, temperature or biological contamination.

By type of aluminium packaging, flexible packaging (wraps, plain foil, lidding, household foil etc.) represents 28% of the market, semi-rigid packaging 18% (trays and other food containers), and rigid packaging 54% (beverage and food cans, aerosol cans, closures, tubes, etc.) (European Aluminium 2014).

HIGH-TECH ENGINEERING

High-tech engineering includes mechanical engineering applications such as pistons, cylinder blocks, pulleys, guide rails, optical equipment, pneumatic cylinders, and measuring instruments.

It is also used in electrical and heat transfer engineering applications such as power cables, ladders, cable sheathing, heat exchangers, busbars (electrical conductors), and cooling fins.

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CONSUMER DURABLES

Wide usage in the manufacture of cooking utensils, watches, outer casings of some types of equipment (e.g., photographic equipment, smartphones, tablet computers, etc.), electrical appliances, LED lighting, paints, alloys for coins, cookers, boilers, sports equipment, mirrors and reflectors.

Aluminium utensils are easy to wash, corrosion-resistant, not easily damaged, and the material is an excellent heat conductor allowing heat to spread evenly through a cooking pan (for example).

SUBSTITUTION

Table 9. Uses and possible substitutes for bauxite and aluminium

Use	Percentage*	Substitutes	Sub share	Cost	Performance
Automotive industry	19%	Composites	15%	Very high (more than 2 times)	Similar
Automotive industry	19%	Steel	70%	Similar or lower	Reduced
Automotive industry	19%	Magnesium	3%	Slightly higher (up to 2 times)	Similar
Automotive industry	19%	Titanium	2%	Very high (more than 2 times)	Similar
Transport equipment	19%	Composites	15%	Very high (more than 2 times)	Similar
Transport equipment	19%	Steel	70%	Similar or lower	Reduced
Transport equipment	19%	Magnesium	3%	Slightly higher (up to 2 times)	Similar
Transport equipment	19%	Titanium	2%	Very high (more than 2 times)	Similar
Construction	21%	Steel	35%	Similar or lower	Similar
Construction	21%	Plastic (PVC, vinyl, etc)	15%	Similar or lower	Similar
Construction	21%	Wood	49%	Similar or lower	Similar
Packaging	15%	Glass	47%	Similar or lower	Similar
Packaging	15%	Plastics	38%	Similar or lower	Similar
Packaging	15%	Steel	12%	Similar or lower	Similar
High tech engineering	11%	Copper	17%	Very high (more than 2 times)	Similar
High tech engineering	11%	Cast iron	17%	Similar or lower	Similar
High tech engineering	11%	Cast steel	16%	Similar or lower	Similar

*Estimated global end use shares of aluminium 2016-2020 (CRM Factsheet, 2022; outputs of SCRREEN Experts Validation Workshop, 2022)

BAUXITE: REFINING TO ALUMINA

Alumina production from non-bauxite sources is theoretically possible from nepheline concentrates, and commercial production has been reported in Russia (Vadim Smirnov 1996) (Jorjani and Amirhosseini 2007). Information is limited on the costs, performance and production levels.

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Other potential bauxite substitutes for the supply of alumina are anorthosite, alunite, low-grade kaolin and clay, and coal fly ash (Kuzvart, 2006; USGS, 2022). Anorthosite, which is abundantly available worldwide, has been evaluated with success as a source of aluminium ore in Norway, but the process developed was not commercially compatible with existing bauxite-based alumina production (Wanvik 2000). The project AISiCal funded by Horizon 2020 (September 2019–August 2023) is researching further the technology for producing alumina from anorthosite which generates no bauxite residues (CORDIS 2019). In general, no evidence was found to suggest that bauxite substitution with the above potential substitutes is currently carried out on a commercial scale.

SUBSTITUTES FOR OTHER APPLICATIONS WERE NOT CONSIDERED IN THE ASSESSMENT AS THEIR APPLICATION SHARES WERE LESS THAN 10% EACH. ALUMINIUM: MOBILITY (TRANSPORT & AUTOMOTIVE)

Composites such as carbon-fibre-reinforced plastic have been successfully used for many applications, e.g., in cars, fuselages and wings of aeroplanes, but the cost is currently significantly higher than aluminium (USGS 2019) (Rao et al. 2018). Composites, titanium, steel and magnesium are also possible substitutes in this sector (e.g., ground transportation uses). (USGS, 2022)

Steel is the only one of these materials with lower cost to aluminium, although it is heavier than aluminium, and consequently, for specific applications, the performance could be lower (USGS 2019) (Djukanovic 2016) (Musfirah and Jaharah 2012).

ALUMINIUM: CONSTRUCTION

In the construction sector, steel, plastics (such as PVC or vinyl) and wood were considered as possible substitutes. In all cases, the cost and performance were assessed to be similar to aluminium. (USGS, 2022).

ALUMINIUM: PACKAGING

For packaging, glass, paper, plastics and steel are potential substitutes for aluminium for packaging applications, and again for all of these, the performance was similar, and costs same or lower. (USGS, 2022)

ALUMINIUM: HIGH-TECH ENGINEERING

In the high-tech engineering application, copper can replace aluminium in electrical lines for power transmission and distribution, as well as in heat-exchange applications, but the current costs of copper are higher than aluminium. Cast iron and cast steel may also substitute aluminium in specific applications at similar cost and performance.

ALUMINIUM: CONSUMER DURABLES

Potential substitutes for consumer durables were not assessed as this application sector represents less than 10% of aluminium demand. However, copper can substitute aluminium in cooking utensils and home appliances (e.g., refrigerators) (Graedel et al. 2015b).

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SUPPLY

EU SUPPLY CHAIN

EU demand for aluminium is 13,513 ktonnes per year calculated as average for years 2016-2020 (Eurostat, 2021).

Within the EU between 2016 and 2020, bauxite was mined in four countries (Greece, France, Croatia, Hungary) and the combined (crude) bauxite output from these countries is about 1,760 ktonnes per year (average for years 2016-2020). This corresponds approximately only 0.5% of the world's total production of bauxite. The overall average (2016-2020) global production of bauxite is 336,197 ktonnes per year, and Australia is the largest producing country accounting 28% of the world's bauxite production. Greece is the leading EU bauxite producer, corresponding 93% (1,628 ktonnes) of the EU bauxite production, and small quantities of bauxite are also mined in France (6%; 115 ktonnes), Croatia (1%; 12kt) and Hungary (<1%; average 2016-2018 4 ktonnes, no reported bauxite production in Hungary after 2018). (WMD, 2022) In addition to EU domestic production, 14,458 ktonnes per year of bauxite is imported to the EU (average import 2016-2020). Based on Eurostat Comext (2022) and WMD (2022) the average import reliance for bauxite 2016-2020 is 89.2%.

From 2016 to 2020, EU primary aluminium production figures are rather small (average 2,116 ktonnes per year), corresponding approximately 3.6% of world aluminium production (62,414 ktonnes). China is the largest aluminium producing country with more than 34,868 ktonnes production per year (average for 2016-2020) (WMD, 2022). In addition to the total EU production of primary aluminium, a further 5,926 ktonnes per year of aluminium was imported into the EU (average 2016-2020).

Table 10. Relevant Eurostat production codes for aluminium.

Mining		Processing/refining	
HS code	title	HS code	title
CN26060000	Aluminium ores and concentrates	CN28182000	Aluminium oxide
		CN28183000	Aluminium hydroxide
		CN76011000	Aluminium, not alloyed, unwrought
		CN760120	Unwrought primary aluminium alloys
	PRODCOM code	title	
	24421200	Aluminium oxide	
	20132570	Aluminium hydroxide	
	24421130	Unwrought non-alloy aluminium (excluding powders and flakes)	
	24421153	Unwrought aluminium alloys in primary form (excluding aluminium powders and flakes)	

For aluminium the end-of-life recycling rate (EOL-RR) corresponds value of 69%. However, a considerable fraction of secondary aluminium at end-of-life collected for recycling is actually exported from the EU. Taking this into account and if that fraction is excluded from the calculation, EOL-RR becomes 51%. (Passarini et al., 2018)

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SUPPLY FROM PRIMARY MATERIALS

GEOLOGY, RESOURCES AND RESERVES OF BAUXITE

GEOLOGY

Aluminium is the most common metallic element, making up approximately 8% of the Earth's crust, and the third most abundant element after oxygen and silicon. In the upper crust, the abundance of Al_2O_3 is 15.4wt% (Rudnick and Gao, 2014) (V. Hill and Sehnke, 2006). Although aluminium occurs in a wide range of minerals (mainly oxides and silicates), it is too reactive to occur naturally. Therefore, it is challenging to extract aluminium from most of the minerals in which it is present. Bauxite is the only ore used for the commercial extraction of aluminium, which may contain 40-60% aluminium oxide (Aluminium Association 2007).

Bauxite is a heterogeneous rock composed of a wide variety of minerals. The bauxite ores consist primarily of the aluminium hydroxide gibbsite (65% Al_2O_3), boehmite and diaspore (each around 85% Al_2O_3), or their mixtures, with varying proportions of silica, iron oxides, titania, aluminosilicates and other impurities. Each of these three types of bauxite has different characteristics that make them more or less desirable for mining and metallurgical purposes (Vassiliadou 2015).

Deposits of bauxite are residual accumulations caused by intense lateritic weathering. Most bauxite deposits can be classified into two categories: those developed over carbonate rocks (karst bauxite); and those developed over other types of rocks (lateritic bauxite). The karst bauxites occur predominantly in the Caribbean (e.g. Jamaica), Mediterranean (e.g. Greece, France), China, Central Urals and Kazakhstan. The lateritic bauxites which are the major source for world's production are found mostly in Africa (e.g. Guinea), South Asia (e.g. India), Australia, North and South America (e.g. Guyana) (V. G. Hill and Sehnke 2006).

GLOBAL RESOURCES AND RESERVES:

Globally, the United States Geological Survey (USGS, 2018b) estimates that known resources of bauxite are in the range of 55–75 billion tonnes, in Africa (32%), Oceania (23%), South America and the Caribbean (21%), Asia (18%), and elsewhere (6%). USGS notes that because the aluminium element is so abundant across the world, there are “essentially inexhaustible” quantities in materials other than bauxite. However, these are currently not economical to extract and therefore should not yet be included in any estimates of resources.

The world's known bauxite reserves are estimated by USGS (2022) at about 30 billion tonnes. A total of 90% of these are concentrated as large blanket deposits in tropical and subtropical regions where bauxite typically occurs in extensive, relatively thin near-surface layers (layer thickness generally is 4-6 metres) (IAI 2019a). Guinea has the largest known bauxite reserves globally (25%), followed by Australia (17%), Vietnam (12%) and Brazil (9%). Global reserves of bauxite are sufficient to last at least another 100 years at the rate of extraction in 2016 (WMD 2019; USGS 2018b).

EU RESOURCES AND RESERVES

According to USGS (2018b), the largest exploitable deposits of bauxite in the EU are located in Greece with estimated reserves of 250 million tonnes. The most important known exploitable deposits are located in the

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mountainous zone of Helikon-Parnassus-Giona-Iti, where reserves are estimated at approximately 100 million tonnes (Vassiliadou, 2015) (Tsirambides and Filippidis, 2012). The Minerals4EU (2019) project published bauxite resources and reserves data for some EU countries. Of these, only Romania reported statistical data in compliance with the United Nations Framework Classification (UNFC) system of reporting. Data cannot be summed as they are partial, and they do not use the same reporting code.

Table 11. Global reserves of bauxite in 2020 (USGS, 2022)

Country	Bauxite Reserves (million tonnes)	Percentage of the total (%)
Guinea	7,400	25
Australia	5,100	17
Vietnam	3,700	12
Brazil	2,700	9
Jamaica	2,000	6
Indonesia	1,200	4
China	1,000	3
India	660	2
Russia	500	2
Saudi Arabia	190	1
Malaysia	170	<1
Kazakhstan	160	<1
United States	20	<1
Other countries (unspecified)	4,900	<1
World total (rounded)	30,000	100

Table 12. Bauxite resources data for the EU (Minerals4EU 2019)

Country	Reporting code	Quantity (million tonnes of bauxite)	Grade (% Al ₂ O ₃)	Classification
France	None	432	NA	Historic resource estimate
Greece	USGS	130	35-40	Indicated
	USGS	240	NA	Inferred
Hungary	Russian Classification	5.28	NA	A
	Russian Classification	9.73	NA	B
	Russian Classification	72.19	NA	C1
	Russian Classification	36.73	NA	C2
Romania	UNFC	97	NA	333
Italy	None	1.25	NA	Sub-Economic

Table 13. Bauxite reserves data for the EU

Country	Reporting code	Quantity (million tonnes of bauxite)	Grade (% Al ₂ O ₃)	Classification	Source
Greece	None	250	NA	NA	(USGS 2018b)
Romania	UNFC	2.5	NA	121	(Minerals4EU) 2019
Italy	None	1	NA	Estimated	Minerals4EU 2019

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EXPLORATION AND NEW MINE DEVELOPMENT PROJECTS IN THE EU

No active exploration projects are reported in the EU (S&P Global Market Intelligence 2019b). The H2020 “Smart Exploration” (2019) research project targets the Gerolekas bauxite exploration site in Greece.

GLOBAL AND EU MINE PRODUCTION

For bauxite extraction, conventional surface mining techniques are commonly applied. Bauxite does not require complex beneficiation because the ore grade is usually already sufficient; simple mineral processing techniques (crushing, washing and screening) are only needed to remove clay and fine sands before shipment to alumina refineries or other markets (IAI 2019a).

Bauxite is typically classified according to its intended commercial application, e.g. metallurgical, abrasive, cement, chemical etc. Of all bauxite mined, in 2014 about 95% is refined to alumina for aluminium smelting and other uses, and the remainder (5%) is used directly for non-metallurgical bauxite applications (V. Hill and Sehnke 2006; Flook 2015).

Globally bauxite was mined in 30 countries in 2020 with the total production averaged over the 2016–2020 period to 336,197 ktonnes per year. Australia is the leading producer for the period 2016–2020 with the average production 95,611 ktonnes per year and accounts approximately 28% of the world’s total production followed by China (21%; 70,061 ktonnes), Guinea (18%; 60,328 ktonnes,) Brazil (10%; 34,901kt) and India (7%; 22,683 ktonnes). Together these countries hold an 84% share of world bauxite mine production. (WMD, 2022)

Top ten bauxite producers and the rest of the world (ROW) for the period 1984–2020 are shown in Figure 19 according to WMD (2022) data.

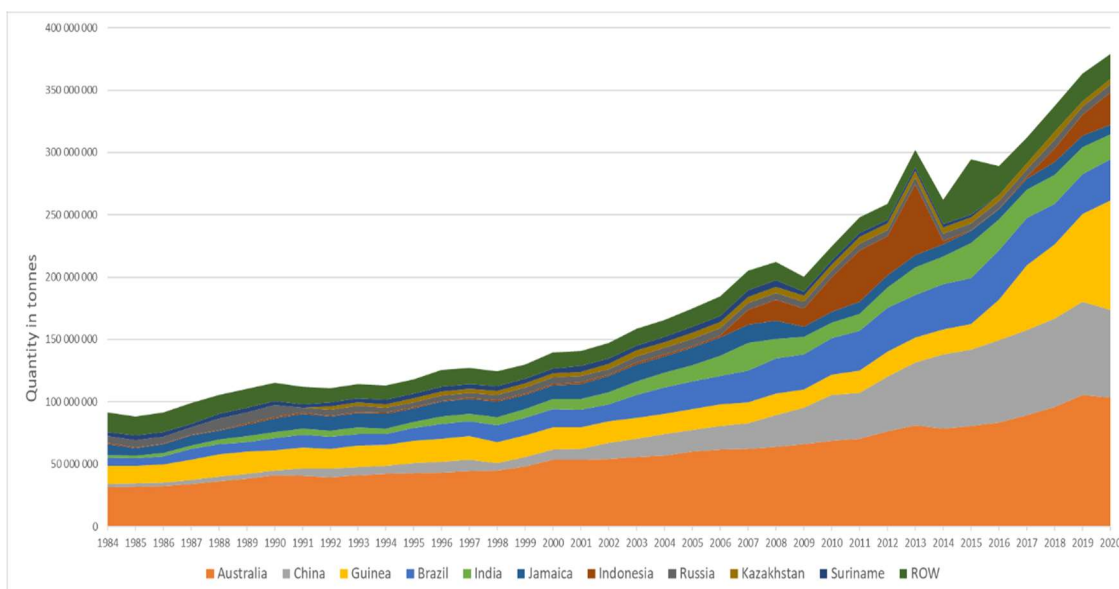


Figure 19. Top ten global bauxite producers and the rest of the world (ROW) for the period 1984–2020 (WMD, 2022)

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The EU annual production of bauxite (average 2016-2020) is about 1,760 ktonnes per year, corresponding approximately to only 0.5% of the world's bauxite production. 93% of the EU production was mined in Greece (average production 2016-2020 1,628 ktonnes). Operating mines are located in the Parnassos-Giona zone in Central Greece and are owned by Mytilineos Holdings SA and Imerys Industrial Minerals Greece (Vassiliadou 2015) (S&P Global Market Intelligence 2019b). 90% of the mining of bauxite in Greece takes place in underground exploitations and 10% in opencast ones (Mining Greece 2019). Small quantities of bauxite are also mined in France (7%; 115 ktonnes), Croatia (1%; 12 ktonnes) and Hungary (average 2016-2018 4 ktonnes). There was no reported bauxite production in Hungary after 2018. (WMD, 2022)

PROCESSING

ALUMINA REFINING

The bulk of world bauxite production is used as feed for the manufacture of alumina (aluminium oxide, Al_2O_3) via a wet chemical caustic leach process known as the Bayer process. Typically, 2-3 tonnes of bauxite are required to produce one tonne of alumina. At the refinery, the bauxite is washed and milled to reduce the particle size, and any excessive silica is removed. Hot caustic soda is added to dissolve the aluminium-bearing minerals (gibbsite, boehmite and diaspore) to form a saturated solution within a digester at temperatures of between 140°C and 280°C depending on the type of ore. The slurry is then rapidly cooled in a series of flash tanks to around 106°C and a chemical flocculant added to assist in the sedimentation of the solid bauxite residue so that it can be removed from the saturated solution in settling tanks and filters. Next, the saturated solution is progressively cooled under controlled conditions, and aluminium trihydrate precipitates as crystals; with a chemical formula of $\text{Al}(\text{OH})_3$ this is also known as 'alumina hydrate'. These crystals are separated from the remaining liquor using vacuum filtration and calcined at 1,100 °C to form alumina (IAI 2019a).

The produced alumina can be classified as smelter-grade for aluminium smelting, or chemical-grade for other applications. Smelter-grade alumina represents a share of 89-94% of the total alumina output (Flook, 2015) (V. Hill and Sehnke, 2006). The chemical-grade alumina can be further distinguished to speciality calcined alumina grades and alumina trihydrate, with a market share of 45% and 55%, respectively (Flook 2015).

WORLD AND EU PRODUCTION OF ALUMINA

The annual world production of alumina average amounted 161,400 ktonnes over the period 2016-2020. The largest alumina producer was China (accounts for 54% of the world alumina production in 2020), followed by Australia (accounts for 15% of the world alumina production in 2020) and Brazil (accounts for 7% of the world alumina production in 2020) (USGS, 2022).

Within the EU there are alumina refineries in six EU countries France, Germany, Greece, Ireland, Romania and Spain with a combined total production of alumina 5,818 ktonnes per year (2016-2020) that accounts approximately to 4% of the global total alumina production. Alumina imports to the EU totalled 824 ktonnes in Al_2O_3 content as an average over the same period. Table 14 presents the active alumina refineries in 2018.

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Table 14. Operating alumina refineries in the EU by capacity in 2018. Data from (Balomenos 2019), (S&P Global Market Intelligence 2019a), companies' websites.

Plant	Country	Operator	Ownership	Annual capacity (ktonnes)	Products
Aughinish	Ireland	Aughinish Alumina Ltd	United Co. RUSAL Plc	1,990	Smelter-grade
San Ciprián	Spain	Alcoa World Alumina and Chemicals (AWAC)	Alcoa Corp. (60%), Alumina Ltd (40%)	1,500	Smelter-grade, hydrated alumina
Stade	Germany	Aluminium Oxid Stade (AOS) GmbH	Dadco Alumina & Chemicals Ltd	1,050	Smelter-grade, specialty aluminas
Agios Nikolaos	Greece	Aluminium of Greece	Mytilineos Holdings S.A.	850	Smelter-grade, hydrated alumina
Gardanne	France	ALTEO	H.I.G. Capital Europe	635	Specialty aluminas
Tulcea	Romania	ALUM	Vimetco N.V., Bayraktar Holding (Alro)	500	Smelter-grade, hydrated alumina
Total				6,525	

ALUMINIUM SMELTING

Primary aluminium is obtained from the electrolytic smelting of alumina (aluminium oxide, Al_2O_3) into molten aluminium metal by means of the Hall-Héroult process. This involves passing an electrical current (direct current at 600,000 ampere) into a line of electrolytic cells, or 'pots', connected in a series known as a 'potline'. Each pot is a large carbon-lined container, which forms the cathode of the cell. Inside the pot is an electrolytic bath of molten cryolite at a temperature of 960–980°C into which the alumina powder is dissolved. Aluminium fluoride is added to the solution to optimise the chemistry. Carbon blocks are suspended in the solution to serve as the anode. The electrical current is passed from the anode via the electrolytic bath to the cathode and then on to the anode of the next post in the series. As it passes through the bath, the dissolved alumina is split into molten aluminium and oxygen. The molten aluminium metal sinks to the bottom of the pot from where it is siphoned every day or two in a process known as 'tapping'. Typically, 15,000 kilowatts of electricity and 1.9 tonnes of alumina are required to produce one tonnes of aluminium metal (IAI 2019c) (IAI 2019b) (OECD 2015).

Molten aluminium is either sold directly to customers or transferred to the casthouse, where it is purified, alloyed if necessary and cast into various unwrought products. Forms of unwrought primary aluminium shipped to customers include T-bars, ingots for rolling, extrusion ingots (or billets), continuously cast strips, ingots for forging, ingots for castings (or foundry alloys), pigs, sows, wire rod etc. These shapes are then fabricated into semi-finished products (flat rolled-products, extrusions, wire, etc.) and subsequently into finished goods (Bertram et al. 2017) (USITC 2017).

WORLD AND EU PRODUCTION OF PRIMARY ALUMINIUM

The global primary aluminium production over the 2016–2020 period totalled to an average of 62,414 ktonnes per year. China dominates the markets and accounts for 56% of the world's production of primary aluminium

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(average production of 34,868 ktonnes per year). Russia accounts approximately 6% of the world's production (average production of 3,748 ktonnes per year), India accounts approximately 5.5% of the world's production (average production of 3,449 ktonnes per year), Canada accounts approximately 5% of the world's production (average production of 3,064 ktonnes per year) and United Arab Emirates accounts approximately 4% of the world's production (average production of 2,559 ktonnes per year). Totally these countries account approximately 76% of the world's total primary aluminium production. (WMD, 2022)

EU contributed a total of 2,117 ktonnes of aluminium production per year based on figures averaged over 2016–2020. This corresponds approximately 3.4% of the world's aluminium production. Production levels averaged per year over 2016–2020: 532 ktonnes in Germany (25% of the EU production), 406 ktonnes in France (19% of the EU production), 300kt in Spain (14% of the EU production), 278 ktonnes in Romania (13% of the EU production), 184 ktonnes in Greece (9% of the EU production), 170 ktonnes in Slovakia (8% of the EU production), 122 ktonnes in Sweden (6% of the EU production), 74 ktonnes in Slovenia (3.5% of the EU production), and 52 ktonnes in the Netherlands (2.4% of the EU production) (WMD, 2022).

Top ten global aluminium producers and the rest of the world (ROW) for the period 1984-2020 are shown in Figure 20 according to WMD (2022) data.

There were aluminium smelters active in nine countries: Germany, France, Spain, Romania, Greece, Slovakia, Sweden, Slovenia and Netherlands (Table 15).

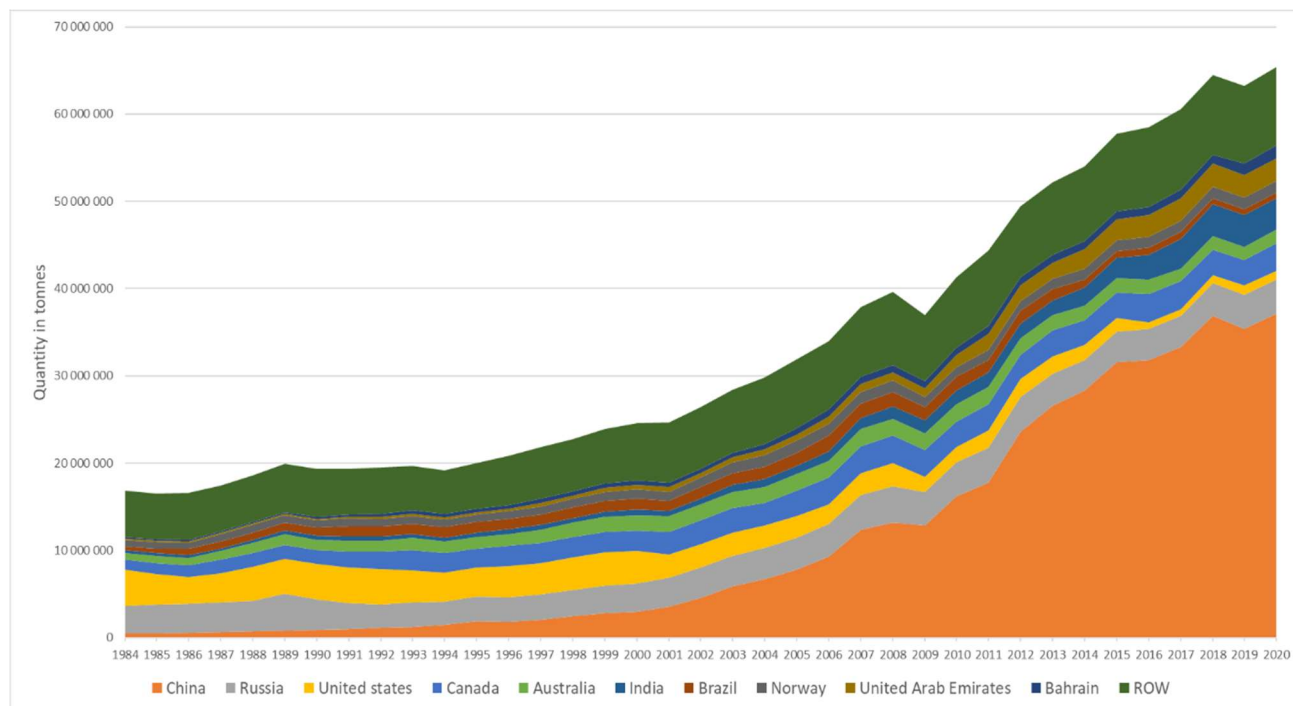


Figure 20. Top ten global aluminium producers and the rest of the world (ROW) for the period 1984-2020 (WMD, 2022)

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Table 15. Operating primary aluminium smelters in the EU by capacity in 2018. Data from (Light Metal Age 2019), (S&P Global Market Intelligence 2019a), companies' websites.

Plant	Country	Operator	Ownership	Annual capacity (ktonnes)	Shutdown Capacity (ktonnes)
Dunkerque	France	Liberty Aluminium Dunkerque	GFG Alliance	285	-
Slatina	Romania	SC Alro SA	Vimetco N.V.	282	-
San Ciprian	Spain	Alcoa Europe	Alcoa Corp.	250	22
Rheinwerk Neuss	Germany	Hydro Aluminium Deutschland GmbH	Norsk Hydro ASA	230	80
Žiar nad Hronom	Slovakia	Slovalco AS	Norsk Hydro ASA (55.3%), Slovalco Invest, a. s. (44.7%)	175	-
Essen	Germany	TRIMET Aluminium SE	TRIMET Aluminium SE	170	-
Delfzijl	Netherlands	Aluminium Delfzijl BV (Aldel)	Damco Aluminium Delfzijl Coöperatie U.A.	111	-
Agios Nikolaos	Greece	Aluminium of Greece	Mytilineos Holdings S.A.	190	-
St Jean de Maurienne	France	TRIMET France	TRIMET Aluminium SE	145	-
Hamburg	Germany	TRIMET Aluminium SE	TRIMET Aluminium SE	135	-
Sundsvall	Sweden	Kubikenborg Aluminium AB (Kubal)	United Co. RUSAL Plc	130	-
Voerde	Germany	TRIMET Aluminium SE	TRIMET Aluminium SE	96	-
Aviles	Spain	Alcoa Inespal SA	Alcoa Corp.	93	27
La Coruña	Spain	Alcoa Inespal SA	Alcoa Corp.	87	26
Kidricevo	Slovenia	Talum d.d.	ELES	85	-
Total				2,464	155

OUTLOOK FOR SUPPLY

In 2021, European primary aluminium production (EU27+EFTA+UK) was forecast to increase by 3.1%. Unfortunately, during the 4th quarter of 2021, the energy price surge affected several European smelters, meaning production growth in 2021 went down by 1.9% (European Aluminium Digital Activity Report 2021-2022).

During the COVID-19 crisis in 2020 and the first half of 2021, smelters manage to navigate demand disruptions even though the costs (of idling a pot or temporary closing a smelter) were very high. However, the ongoing energy crisis and resulting high prices have aggravated the situation. This has forced several EU smelters to cut capacity. From October 2021 to March 2022, Europe lost about 850 ktonnes of primary production capacity, further contributing to a decreasing long-term trend. In 2022, EU primary production is expected to further reduce by 30% versus 2021 (European Aluminium Digital Activity report 2021-2022).

Alcoa has announced the stop of the smelter's 228,000 metric tons of annual capacity for a two-year curtailment, and a commitment by the Company to begin the restart of the smelter in January 2024 (ALCOA 2021). It means that for the two years 2022-2024 the primary aluminium production of Spain will be zero.

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SUPPLY FROM SECONDARY MATERIALS/RECYCLING

Bauxite is consumed during all of its uses and therefore is not available for recycling. Although some refractory products are subsequently recycled, this is generally to further refractory applications and is very small in quantity compared to the global production of bauxite. The majority of bauxite uses results in a substance that is subsequently transformed into a different product, e.g. cement into concrete or alumina into aluminium metal (SCRREEN workshops 2019).

Aluminium is infinitely recyclable without downgrading its quality. Secondary aluminium is produced by melting aluminium scrap. The scrap utilised in secondary aluminium production consists of 'new scrap' which is generated during the production and fabrication of wrought and cast products, and 'old scrap' which is recovered from articles at the end of their useful life such as used beverage cans, packaging etc.

Recycling of aluminium needs as little as 5% of the energy originally used for its primary production, with obvious financial and environmental benefits. More than one-third of all the aluminium produced globally originates from scrap. According to the European Aluminium Association, 37% of the aluminium ingot needs in Europe in 2017 were covered by recycled aluminium (European Aluminium 2019b). The high value of aluminium scrap is a key incentive and significant economic stimulus for recycling (IAI 2009).

According to aluminium MFA study by (Passarini et al. 2018) of the total amount of aluminium old scrap generated at end-of-life (i.e., 4,338 ktonnes Al), about 2,986 ktonnes Al were collected for recycling. This results in an end-of-life recycling rate (EOL-RR) of 69% for aluminium. However, a considerable fraction of secondary aluminium at end-of-life collected for recycling is actually exported from the EU. In case that fraction is excluded from the calculation, EOL-RR becomes 51%. The increasing demand for aluminium, coupled with the long-life of many applications (e.g. buildings, mobility) prevents recycled production from covering the demand, making primary production still necessary (Dessart and Bontoux 2017).

POST-CONSUMER RECYCLING (OLD SCRAP)

End-of-life scrap ('old scrap') is defined as scrap arising from products that have been used but are no longer required because they have been worn out or become obsolete. For aluminium, this includes a wide range of products including aluminium beverage cans or food packaging; components from aircraft, cars or other vehicles; articles arising from the demolition of buildings such as window profiles; or discarded equipment (European Commission 2017). Post-consumer scrap has to be collected and sorted before it can be recycled. According to European Aluminium (2016), EoL-RR in Europe for aluminium used in transport and buildings was over 90%, whereas 60% of the aluminium used in packaging was recycled in 2013. The recycling rate for aluminium beverage cans in the EU, Switzerland, Norway and Iceland reached an all-time record of 74.5% in 2017 (European Aluminium 2019a).

The aluminium industry produces recycled aluminium at 'remelters' and 'refiners', as well as in internal melting and casting facilities ('cast houses'). Remelters supply rolling mills and extruders with rolling ingots or extrusion billets (wrought alloys) for further processing, and refiners supply foundries with casting ingots (casting alloys) and the steel industry with deoxidants (IAI 2009) (European Aluminium 2016). Aluminium scrap is used as an input, including new (pre-consumer) scrap (e.g. cut-off ends, turnings) from manufacturing and

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casting processes and old (post-consumer) scrap from durable and nondurable products (e.g. used beverage cans, window frames).

Table 16: Material flows relevant to the EOL-RIR⁵ of aluminium in 2013. Data from (Passarini et al. 2018)

MSA Flow	Value (ktonnes)
B.1.1 Production of primary material as main product in EU sent to processing in EU	495.523
B.1.2 Production of primary material as by-product in EU sent to processing in EU	0
C.1.3 Imports to EU of primary material	4,458.156
C.1.4 Imports to EU of secondary material	268.253
D.1.3 Imports to EU of processed material	10,478.176
E.1.6 Products at end of life in EU collected for treatment	4,337.805
F.1.1 Exports from EU of manufactured products at end-of-life	0
F.1.2 Imports to EU of manufactured products at end-of-life	0
G.1.1 Production of secondary material from post-consumer functional recycling in EU sent to processing in EU	2,209.139
G.1.2 Production of secondary material from post-consumer functional recycling in EU sent to manufacture in EU	0

Recycling of old aluminium scrap involves the collection, sorting, pre-treatment, melting and casting. The most significant factors in determining the quantity of aluminium from ‘old scrap’ to be recycled are the collection systems for the wide-ranging end-of-life products and the long lifespan of some of the products. Estimates suggest that 75% of all aluminium ever produced is still in use (European Aluminium 2018b). Secondary aluminium production is characterized by the diversity of old scrap types available (a high variety of alloys, size, type and degree of contamination by paints, ink or plastics) which correspondingly determines the necessary pre-treatment technique (e.g. mechanical separation) and the melting process to be applied (e.g. rotary furnace with salt flux). In the secondary aluminium industry, ‘refiners’ produce casting alloys (e.g. for cast engine blocks) and ‘remelters’ produce wrought alloys (e.g. for sheets and extrusion) (European Aluminium 2016).

According to the MSA study of aluminium (Passarini et al. 2018), the end-of-life recycling input rate (EoL-RIR) results in 12%. The EoL-RIR measures the quantity of end-of-life scrap (i.e. ‘old scrap’) contained within the total amount of metal available to manufacturers (which would also include primary metal and ‘new scrap’). If the EU had processed domestically the flow of aluminium waste and scrap exported in 2015, the EoL-RIR would have increased to 16% (Passarini et al. 2018).

INDUSTRIAL RECYCLING (NEW SCRAP)

Aluminium metal scrap and other aluminium-bearing wastes are also generated during the fabrication and manufacture of aluminium products. This could be in the form of metal that did not meet required specifications, excess metal removed during casting or forging, grinding sludge or turnings generated during machining processes. The recycling of new scrap is more straightforward than for old scrap because it contains less contamination from other materials. New scrap constitutes the most significant source of secondary aluminium, representing about 70% of secondary material input in the EU in 2013 (Passarini et al. 2018).

⁵ $EOL-RIR = (G.1.1 + G.1.2) / (B.1.1 + B.1.2 + C.1.3 + D.1.3 + C.1.4 + G.1.1 + G.1.2)$

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OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

The main European legislation on chemicals, Regulation (EC) 1907/2006 concerning the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH), only identifies minor environmental and health issues for the aluminium value chain. On the other hand, Regulation (EC) 1272/2008, on classification, labelling and packaging (CLP) of substances and mixtures, classifies only some aluminium powder products and some aluminium-containing chemicals (e.g., aluminium chloride, aluminium alkyls) (Georgitzikis 2021).

Aluminium can enter the human body basically through the oral route by food ingestion. Other sources of aluminium are toothpaste, vaccination, antiperspirants, and some drugs. (Alasfar 2021). The EFSA (European Food Safety Authority) established in 2008 a Tolerable Weekly Intake (TWI) of 1 mg aluminium/kg bw/w (EFSA 2008).

The smelting of aluminium can produce fluoride emissions but these are not classified as a high risk for humans (BRG 2020).

ENVIRONMENTAL ISSUES

Due to the nature of the bauxite deposits (stratified, horizontal, and shallow), large areas of land are required for mining. Frequently, mines are within or close to nature-protected areas and tropical forests and/or indigenous lands, which implies significant impacts on biodiversity and local communities. Although not specific to the mining sector, it is significant that the EPI Environmental Performance Index weighted average of the main EU bauxite suppliers (Guinea, Brazil, Sierra Leona, Greece, China and Turkey) shows a lower outcome than that of the world supply mix.

Another critical environmental issue, arising during the alkaline digestion of bauxite ore in alumina production, is the management of bauxite residues (red mud), along with energy consumption, water management and the physical footprint of the plants. Regarding secondary production, the main environmental issues are potential emissions of dust and PCDD/F and solid waste. (Georgitzikis 2021)

NORMATIVE REQUIREMENTS

Regulations, technical instruments and the German water hazardous class, biological exposure indices and regulation of accident insurers⁶ regulating the use of aluminium can be found in the GESTIS Substance database⁷.

⁶ See <https://publikationen.dguv.de/regelwerk/dguv-regeln/1011/benutzung-von-atemschutzgeraeten>

⁷ See <https://gestis-database.dguv.de/data?name=007130>

Furthermore, aluminium is included in the ASI Performance Standard⁸ and the European Aluminium Sustainability Roadmap and the SDG⁹.

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF ALUMINIUM FOR EXPORTING COUNTRIES

Globally Aluminium/bauxite market represents about 1% of the total world exports. Aluminium production or transformation are an important part of the economy of some countries, even if they are globally small actors.

In particular Aluminium ores and concentrates trade represents 7.3% of the total exports of Jamaica, 5.4% for Montenegro and 2.8% for Guyana. When including uses and end uses markets of aluminium, it grows up to 35% for Iceland, 30% for Mozambique, 22% for Montenegro and 20% for Tajikistan.

The 20 first exporting countries of aluminium ore and concentrates or aluminium products represent 75% of the total aluminium trade market.

SOCIAL AND ETHICAL ASPECTS

Bauxite mines are commonly found in the tropical and sub-tropical areas; thus, deposits often overlap or are adjacent to areas of high conservation value. Bauxite mining and related activities usually take place on, or near, indigenous lands and local communities. Mining frequently requires access to large zones of land and water resources that sustain local communities (IAI, Australian Aluminium Council, and Brazilian Aluminium Association 2018).

Guinea was the EU's most important supplying country for bauxite and one of the top world exporters. Guinea has very weak governance (World Bank 2018), and the Human Development Index value for 2017 is very low (0.459), which positions the country at 175 out of 189 countries and territories in the low human development category (UNDP 2018). A report released by Human Rights Watch (2018), focusing on Guinea's two largest mining projects, highlights the profound human rights consequences to local communities that live closest to the fast-growing bauxite mining industry such as damages to water sources, and loss of farmlands, undermined air quality.

In 2015, M.A. Eddin reported child labour in the aluminium cookware industry in Egypt at Mit Ghamr site which accounts for some 60 per cent of the aluminium cookware industry in Egypt, and employs approximately 40-50,000 people, including children. Bad sanitary working conditions were reported according to a study published by the Egyptian Ministry for Environmental Affairs (M.A. Eddin, 2015).

In 2020, the Chinese company Jiangsu Dingsheng New Materials Joint-Stock Co., Ltd published its performance standard audit report (ASI, 2019a). This report states among others that:

⁸ See <https://aluminium-stewardship.org/asi-standards/asi-performance-standard/>

⁹ See <https://www.european-aluminium.eu/about-aluminium/storytime/sdgs/>

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- The Entity implemented a responsible sourcing policy covering environmental, social and governance issues. Implementation of the responsible sourcing policy includes a supplier evaluation checklist. The suppliers audit plan has also been established.
- The Entity has conducted environmental, social, cultural and Human Rights Impact Assessments, including a gender analysis, for new projects or major changes to existing facilities. This process was applied to the ongoing installation of environmental protection facilities for its waste gas treatment.
- The Entity doesn't use child labour below 16 years old. And doesn't arrange young workers (under 18) do dangerous or harmful work, not work overtime. Where instances of child labour are found, responses include: stop working, accompany send child labour to home, pay all remuneration and travel fees. Review age verification process, take actions to avoid recur recurrence. Currently, no young workers in the Entity
- The Entity neither engage in nor support the use of Forced Labour. All workers signed labour contract and filed up in local government. The Entity doesn't require any form of deposit, recruitment fee or equipment advance from Workers either directly or through employment or recruitment agencies.

In the UK, AMG Superalloys UK Limited and AMG Aluminium UK Limited have taken during the 2021 financial year to prevent slavery and human trafficking from taking place in their supply chain, or in any part of their business (AMGAluminium, 2022). This statement is made pursuant to Section 54 of the UK Modern Slavery Act 2015. Organisations with a turnover of £36 million or more must produce and publish a slavery and human trafficking statement each financial year. Modern Slavery takes place in many forms; debt bondage, servitude, child slavery, forced labour and human trafficking. Slavery thrives on every continent and in almost every country and affects the world's most vulnerable people.

Furthermore, the global slavery index (www.globalslaveryindex.org) reported in 2018 that 40.3 million people worldwide are trapped in some form of slavery. Females account for 71% of this figure and 29% are male. The global slavery index figures are updated every four years and will next be available in 2022.

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

a. R&D trends in terms of emerging LCGT

No data available

b. R&D trends in terms emerging application of RM in already existing LCGT

Aluminium can play a key role in low-carbon technologies and energy-efficient applications due to its specific properties such as lightweight, heat and electrical conductivity, corrosion-resistance, recyclability, and formability. Clean energy transitions will impact aluminium demand, with potential for upward pressure from technology shifts that require greater use of aluminium, e.g. for lightweight vehicles and solar energy. Demand growth in the Net Zero Emissions by 2050 Scenario is estimated nearly 10% of total demand from the current level (IEA, report).

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- **Graphene aluminium-ion battery**

Researchers in Australia are working on a graphene aluminium-ion battery that would offer a more sustainable alternative to lithium-ion batteries (GMG, Graphene Manufacturing Group). The new chemistry boasts a longer life, a lower fire risk, and the ability to charge a whopping 70 times faster. The batteries would also inherently be more recyclable than their lithium-ion counterparts¹⁰.

- **Aluminium-air battery technology**

The aluminium-air battery consists of an aluminium anode in an electrolyte solution of potassium hydroxide and uses oxygen from air as the cathode. When the battery is in use, the oxidation reaction of aluminium plus oxygen plus water produces aluminium hydroxide plus electrical energy (AccessScience Editors, 2014).

The BloombergNEF estimate of demand for battery materials is amounting to 14 Mtonnes by 2030, a sevenfold increase from the demand level in 2020. The increase in aluminium consumption by 2050 in energy storage is estimated at 1.2 percent of what is currently used¹¹. To achieve the EU targets of decarbonising the energy sector, the BEV has been considered an important technology to reduce GHG emissions, the acceleration of BEVs adoption still requires effective political planning in the short, medium, and long term (Fuinhas et al., 2021). Thanks to the lightness of aluminium, the aluminium-air battery is considerably lighter than a comparable lithium-ion battery. Tesla Motors also has a number of recent patents and patent applications describing the use of an aluminium-air battery to extend the driving range of an electric vehicle (AccessScience Editors, 2014).

Currently, the aluminium ion battery is considered a very promising technological concept of battery, it emerges the need to achieve progress in the reversible paint stripping of aluminium and in the deposition and identification of suitable electrolytes (solid) and positive electrodes, so that this battery is widely applied (Leisegang et al., 2019). Aluminium as sheet and extruded profiles is the preferred material for BEV body structure, closures and battery enclosures.

- **Hydrogen production (TRL 3-4)**

While using hydrogen doesn't generate carbon emissions, making it typically does. Today, almost all hydrogen is produced using fossil fuel-based processes that together generate more than 2% of all global greenhouse gas emissions. Another option for producing hydrogen comes from reacting aluminium with water. That reaction doesn't typically take place because a layer of aluminium oxide naturally coats the raw metal, preventing it from coming directly into contact with water. The MIT researchers performed a series of tests to explore different aspects of the aluminium-water reaction (MITeI 2021). The projections for 2050 indicate that this technology will demand around 0.7 per cent of the total aluminium used in energy technologies at that time (www.statista.com).

OTHER RESEARCH AND DEVELOPMENT TRENDS

- Highly Reactive Low-valent Aluminium Complexes and their Application in Synthesis and Catalysis¹²

¹⁰ See feeco.com

¹¹ See www.statista.com

¹² See <https://cordis.europa.eu/project/id/101001591>

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outlines a strategy for the development of low-valent aluminium systems through their synthesis, isolation, and reactivity investigation of neutral, ambiphilic, low-valent aluminium compounds, denoted “alumylenes”. These low-valent aluminium species are expected to provide, along with greater understanding of the fundamental behaviour of low-valent aluminium, a varied and deep reactivity profile. These highly reactive compounds will offer a cheap, sustainable and non-toxic alternative to the current transition metal-based industrial chemical processes.

- Removing the waste streams from the primary Aluminium production and other metal sectors in Europe¹³

The RemovAl project will combine, optimize and scale up developed processing technologies for extracting base and critical metals from such industrial residues and valorising the remaining processing residues in the construction sector.

- SisAl Pilot Innovative pilot for Silicon production with low environmental impact using secondary Aluminium and silicon raw materials¹⁴

SisAl Pilot aims to demonstrate a patented novel industrial process to produce silicon (Si, a critical raw material), enabling a shift from today’s carbothermic Submerged Arc Furnace (SAF) process to a far more environmentally and economically alternative: an aluminothermic reduction of quartz in slag that utilizes secondary raw materials such as aluminium (Al) scrap and dross, as replacements for carbon reductants used today.

- SALEMA Substitution of Critical Raw Materials on Aluminium Alloys for electrical vehicles¹⁵

The project addresses in a coordinated and cooperative manner the key challenges in the different levels of the value chain: improving scrap classification and sorting systems to turn scrap into a valuable raw material; demonstrating the feasibility to substitute CRMs in alloying systems; developing recycled aluminium alloys with improved mechanical performance; optimizing High Pressure Die Casting, sheet metal Stamping and Extrusion processes in a timely and cost-efficient manner in order to ensure the adoption of the alloys.

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¹³ See <https://cordis.europa.eu/project/id/776469>

¹⁴ See <https://cordis.europa.eu/project/id/869268>

¹⁵ See <https://cordis.europa.eu/project/id/101003785>

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