3 ALUMINIUM AND BAUXITE

3.1 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, alumina, which is then smelted into aluminium.

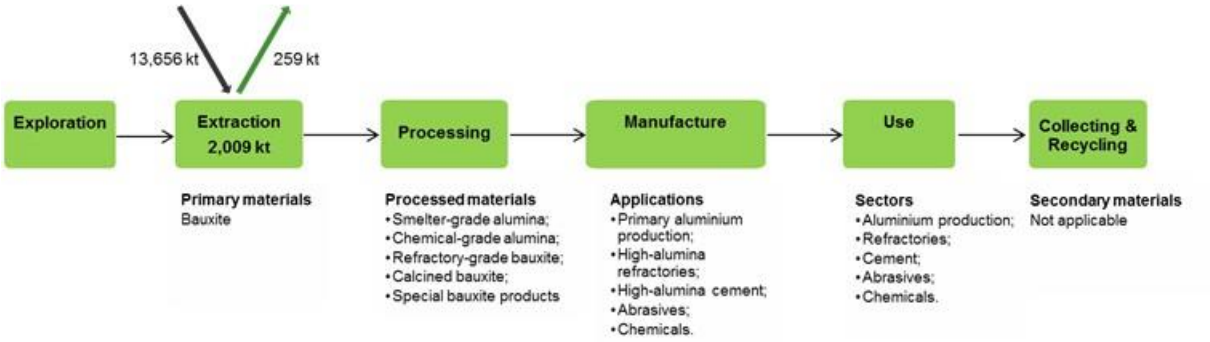


Figure 22: Simplified value chain for bauxite for the EU, averaged over 2012-2016[11]

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. Also, 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. Another key property is that aluminium has a remarkable strength to weight ratio; some heat-treatable alloys offer similar performance to advanced steels and titanium. As a final point, 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 (European Aluminium 2019d) (IAI 2019e)(Hydro 2019)(Aluminium Association 2019).

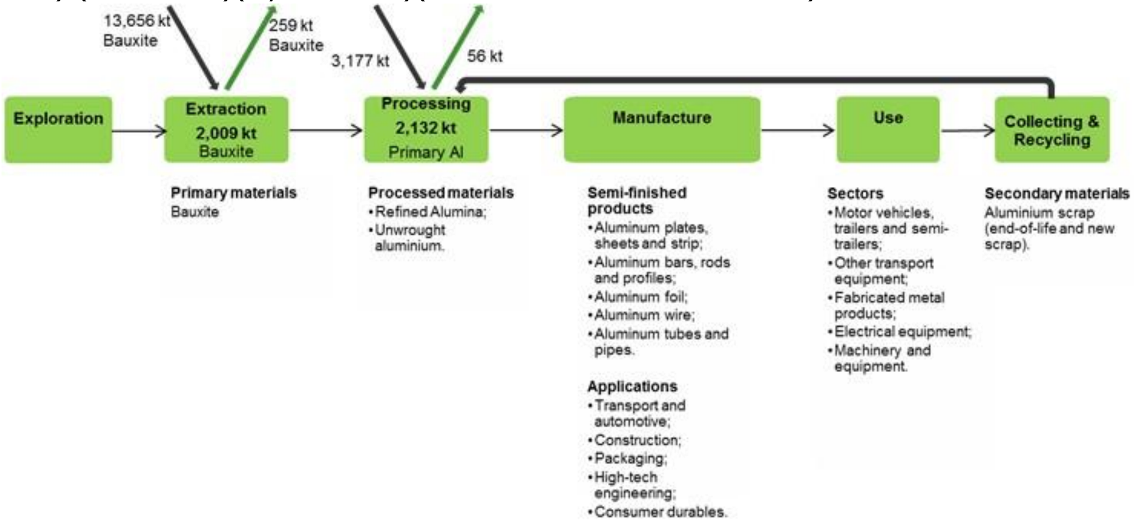


Figure 23: Simplified value chain for aluminium for the EU, averaged over 2012-2016

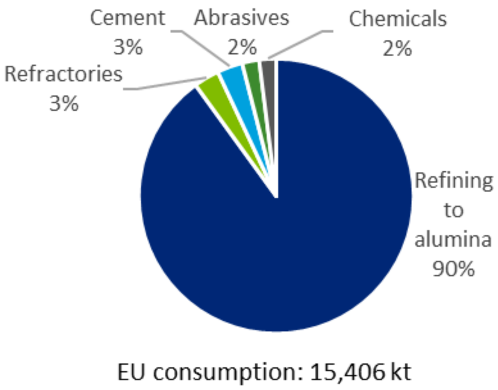
[11] JRC elaboration on multiple sources (see next sections)

Bauxite and aluminium are assessed separately in order to address bauxite's importance in the aluminium supply chain. But also the non-metallurgical applications of bauxite and bauxite-sourced materials to the downstream manufacturing industry. Bauxite is analysed at the extraction stage, i.e. bauxite ore, and aluminium at the processing stage, in the form of primary aluminium. No assessment has been made for the criticality of the intermediate stage between bauxite and primary aluminium, namely the production of alumina. However, information for alumina refining is provided in the factsheet.

The trade codes used in this assessment are: CN 26060000 "Aluminium ores and concentrates", for bauxite; CN 76011000 "Aluminium, not alloyed, unwrought" and CN 76012010 "Unwrought primary aluminium alloys", for primary aluminium (Eurostat Comext 2019).

In 2016, the value of the world production of bauxite is estimated at EUR 12.7 billion, and of primary aluminium at EUR 86 billion. The leading importers are China for bauxite and the US for unwrought aluminium. The most significant exporting countries for bauxite are Australia, Malaysia and Guinea, while for unwrought aluminium are Canada, Russia and the United Arab Emirates. Demand for primary aluminium is forecasted to remain strong in Europe and worldwide by 2050, increasing by 50% up to 2050 globally compared to 2017 demand. The growth of the European demand for semi-finished aluminium is expected to rise strongly by a rate of 39% from 2017 to 2050, driven by transport (55% of growth), construction (28% of growth), and packaging (25% of growth).

World market prices for primary aluminium dropped significantly by 39% over the 2007-2016 period. In 2018, the average annual price of aluminium rose to USD 2,108/t, i.e. a price increase of 31% since 2016. Nevertheless, in real terms the price a declined by about 24% since 2007.



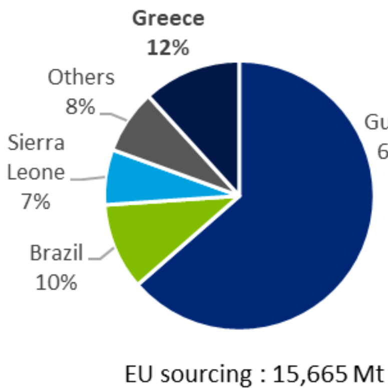


Figure 24: End uses (International Aluminium Association and literature; SCRREEN workshops 2019) and EU sourcing of bauxite (average 2012-2016) (WMD 2019; Eurostat Comext 2019).

The EU consumption of bauxite was 15,406 kt per year averaged over 2012-2016, which are mostly sourced through imports, mainly from Guinea (63%) and Brazil (10%). Greece is the leading domestic producer, contributing to EU sourcing by 12%. The import reliance of the EU was 87% between 2012 and 2016.

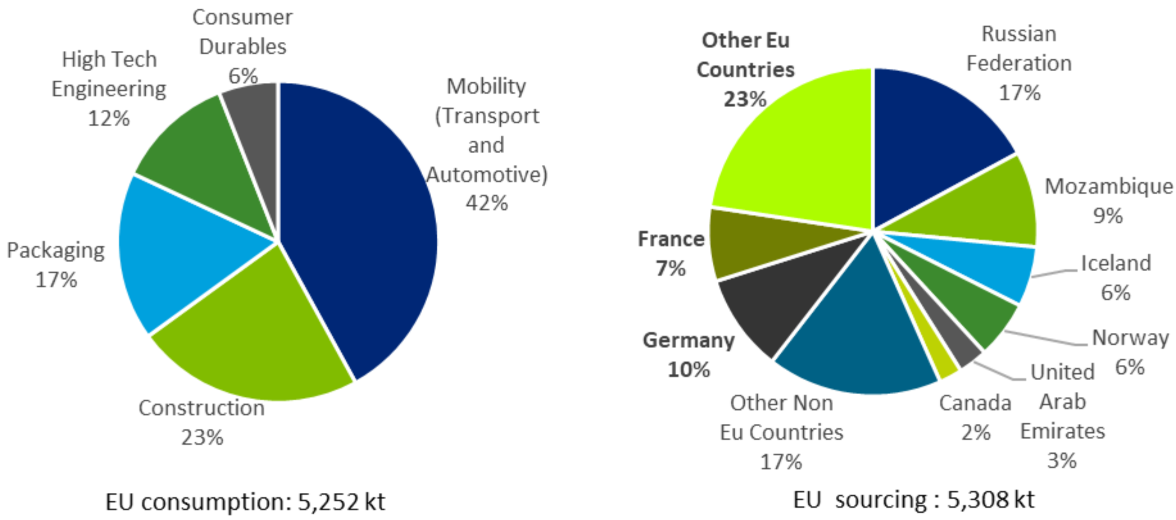


Figure 25: End uses (European Aluminium 2018a) and EU sourcing of aluminium (average 2012-2016) (WMD 2019; Eurostat Comext 2019).

Averaged over 2012 to 2016, the consumption of primary aluminium in the EU was 5,252 kt, which are sourced through domestic production, mainly in Germany (10%) and France (7%), and through imports, mostly from Russia (17%) and Mozambique (9%). The Import reliance of the EU was 59% (average 2012-2016) (Euro Comext 2019).Approximately 90% of bauxite mined in the world is converted to alumina (aluminium oxide) using the Bayer process. Around 80–90% of the world's alumina is smelted to aluminium using the Hall-Heroult process. The typical bauxite grade useable in the Bayer process consists of 50-55% Al_2O_3, up to 30% of Fe_2O_3, and up to 1.5% of SiO_2. Bauxite is also used in refractories, cement, abrasives, chemicals and other minor uses. Practically, aluminium extraction of other ores or minerals than bauxite is not commercially available.

Aluminium products are used in many domains, including transportation (aircrafts, vehicles, trains, boats, etc.), buildings and construction (windows, doors, cladding, curtain walls, etc.), packaging (beverage cans, foil, food trays, boxes, etc.), high-tech engineering (electrical transmission lines, ladders, cylinder blocks, pistons, pulleys, etc.) and consumer products (domestic appliances, cooking utensils, cutlery, coins, etc.). A wide range of substitutes exists for aluminium, e.g. composite materials, magnesium, titanium and steel in mobility applications, steel and wood in construction, glass and plastic for packaging applications, copper for electrical applications.

The aluminium industry and aluminium are at the core of the implementation of the European Commission's long-term strategy for a modern, competitive, prosperous and climate-neutral economy by 2050 [12]. As an energy-intensive industry, aluminium production covers the largest part of the greenhouse gas emissions of the EU non-ferrous metals sector, despite the considerable decrease of emissions achieved during the last years. The European aluminium sector accounted in 2016 for around 1% of the verified emissions of all stationary installations of the European Union and about 2% of its industrial emissions (European Commission 2018).

Further emissions reduction in the aluminium industry is achievable through new low-carbon technologies for primary production, the shift to secondary production through additional recycling, and by a decarbonised power sector. Finally, aluminium's unique properties make it a key enabler for the low-carbon and circular economy in areas such as the light-weighting in mobility, energy efficiency in construction, wind power, etc.

[12] https://ec.europa.eu/clima/policies/strategies/2050_en

(European Political Strategy Centre 2018) (European Aluminium 2019c)(European Aluminium 2019e).

Estimates of world bauxite reserves are 30,000 million t, which are mainly located in tropical and subtropical regions. Guinea (25%) and Australia (20%) have the world's largest bauxite reserves. In the EU, Greece holds the largest exploitable bauxite deposits (250 million t) (USGS 2018b). Bauxite resources are also located in France, Hungary and Romania (Minerals4EU 2019).

The world production of bauxite is about 280 million t annually (average 2012-2016), with 29% mined in Australia and 20% in China. The EU mine production of bauxite is around 2 million t per year, with 92% produced in Greece. Global alumina annual average production amounts to nearly 109 million t in Al_2O_3 content, and China represented 47% of the worldwide output. Australia (19%) and Brazil (9%) are other prominent market players in the world supply of alumina. The EU alumina production is 5.8 million t per year, with Ireland (30%) and Spain (25%) producing more than half (BGS 2019).

The global primary aluminium production between 2012 and 2016 amounted to 54,628 kt per year. China is the world's largest producer of primary aluminium, making up over half of the worldwide output (52%). Russia (7%) and Canada (5%) are the second and third world producer respectively. The EU production of primary aluminium is nearly 2,131 kt per year, averaged over 2012 to 2016. Germany (24%) and France (19%) are the leading EU producers. Recycling represents a significant aspect of global aluminium supply, as more than one-third of aluminium metal that is produced globally originates from old or new scrap. In the EU, the ratio of recycling from old scrap to European demand for aluminium (end-of-life recycling input rate) results in 12% in 2013 (Passarini et al. 2018).

The massive expansion during the last decade of Chinese capacity in all stages of the aluminium value chain driven by government intervention has distorted the global aluminium market substantially. Guinea, which is the main source for the EU supply of bauxite, has very weak governance which makes up a considerable risk to the responsible sourcing of bauxite and aluminium.

3.2 Market analysis, trade and prices

3.2.1 Global market

The geographic distribution of the aluminium industry producing centres 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, Brazil and Indonesia), while production in the global alumina industry has been relocated from the industrialised countries towards countries with access to plentiful and inexpensive bauxite sources.

The world production of bauxite in 2016 was about 287,951 kt (WMD 2019), worth approximately EUR 12.7 billion[13]. In 2015, the main exporting countries were Malaysia (30%), Australia (23%), and Guinea (20%). Guinea is the fastest-growing exporter of bauxite. China accounted for 62% of world imports by weight (see Figure 26).

[13] Estimation based on average price of bauxite in 2016 (EUR 44 per tonne) and the world bauxite production in 2016 of 287,951 kt

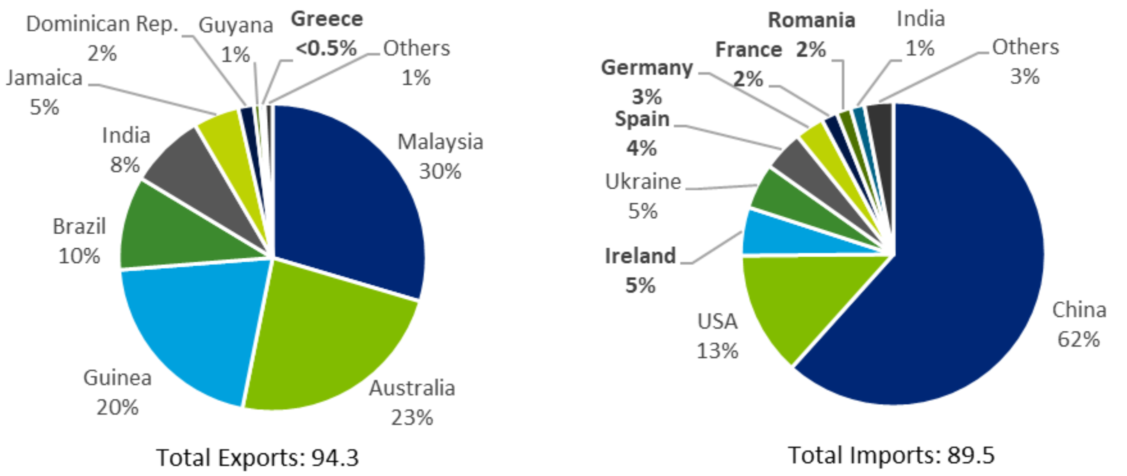


Figure 26: Top-10 bauxite exporting (left) and importing (right) countries in 2015 by weight. Data from (UN Comtrade 2019)

The world production of alumina in 2016 was approximately 118,000 kt (BGS 2019). China has become the largest alumina producer, but continues to import a large share of its bauxite needs (see Figure 26). As shown in Figure 27, in 2016 the main exporting countries were Australia (36%) and Brazil (20%), whereas the major importers were the United Arab Emirates (11%), Russia (11%) and Canada (10%).

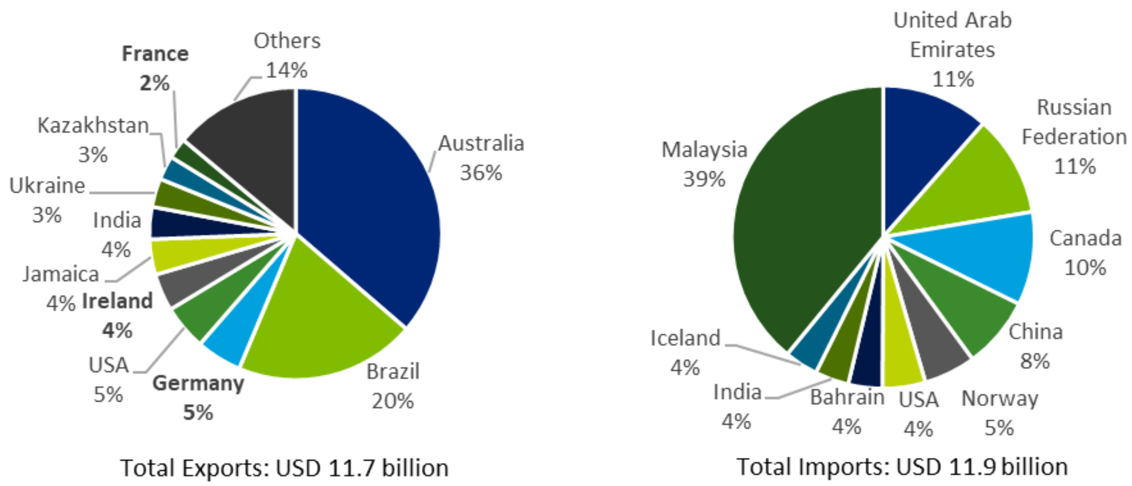


Figure 27: Top-10 alumina exporting (left) and importing (right) countries in 2016 by value (UN Comtrade 2019)

In the case of primary aluminium production, the shift in the geographic distribution is determined to a large extent by variations in energy prices. Primary output moved from long-established producers in the US, Japan and Europe (except Norway and Iceland) to emerging ones, mostly in China, but also the Middle East and Russia. These emerging producers benefited from combinations of access to abundant and cheap electric power, favourable government policies and programs, and expanding domestic and foreign markets (USITC 2017). Most of the rapidly growing global smelting capacity was installed in China (90% of all new capacity during the last decade), as it is reflected in Figure 28. The continuous increase of aluminium-smelting capacity has led to a decline in world prices of both primary aluminium and downstream exported aluminium products (EC 2018a). In 2018, China accounted for 57% of the world's supply of primary aluminium, up from 11% in 1999 (IAI 2019d). The overwhelming expansion of China’s primary production has also driven the massive build-up of China's refining capacity for alumina (Aluminum Association et al. 2018).

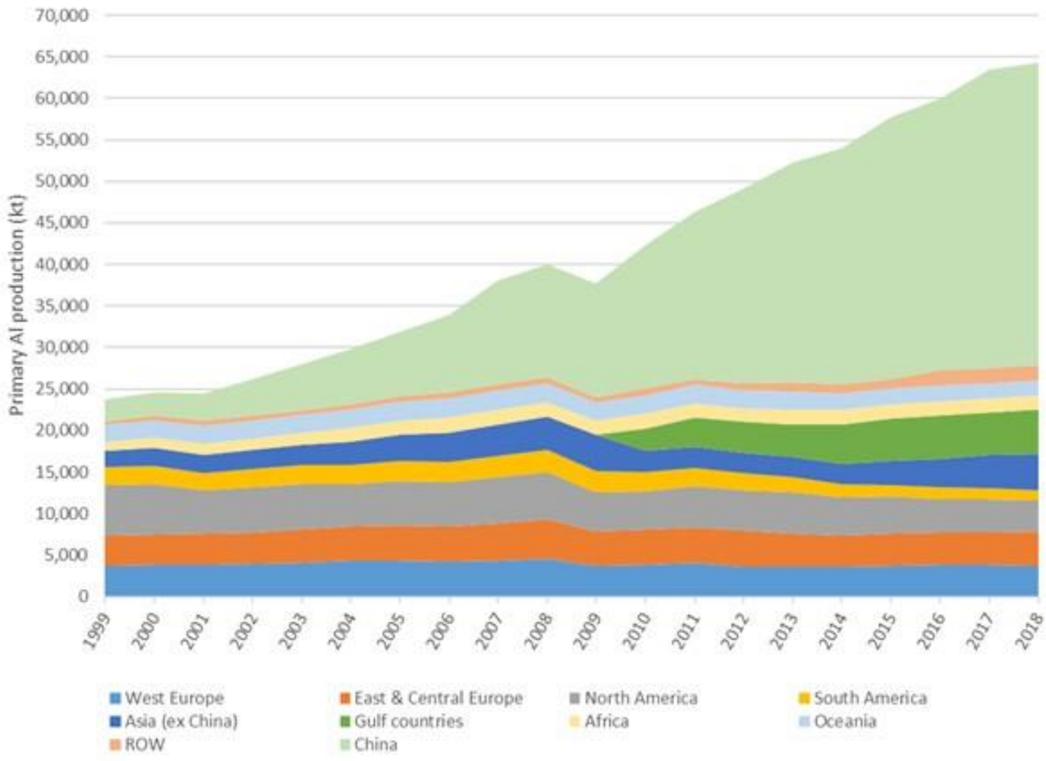


Figure 28. Growth of primary aluminium production by global region, 1999-2018 (in thousand t) (IAI 2019d)

A recent report by the Organisation for Economic Cooperation and Development (USGS, 2019b), 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.

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.

The world production of primary aluminium in 2016 was about 58,649 kt (WMD 2019) worth approximately EUR 86 billion[14]. The US (18%) was the largest recipient of unwrought aluminium, followed by Germany (11%) and Japan (9%). As regards exports, Canada (12%), Russia (12%), and the United Arab Emirates (11%) were the leading world suppliers of unwrought aluminium in 2016 (

Figure 29).

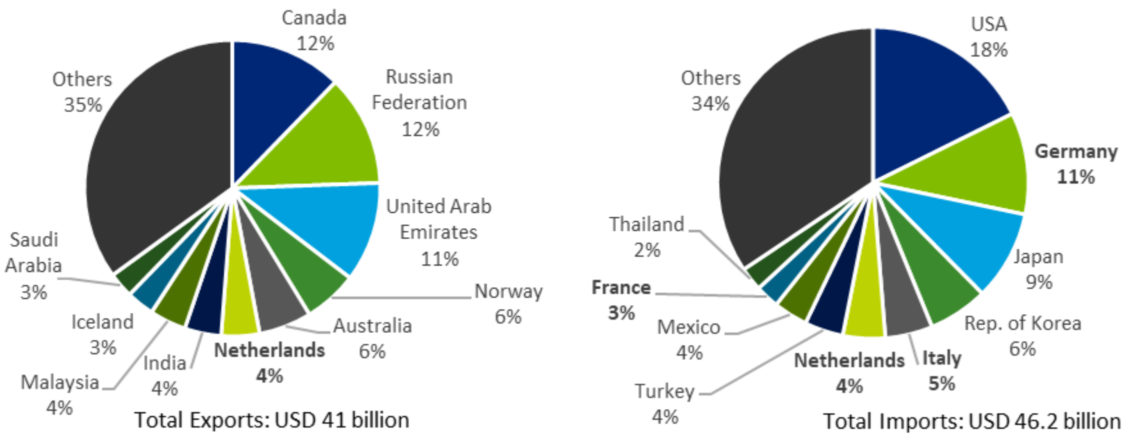


Figure 29: Top-10 unwrought aluminium exporting (left) and importing (right) countries in 2016 by value (UN Comtrade 2019)

Another distinctive feature of the global aluminium industry that has changed during the last decades is the degree of concentration and integration at the company level. Currently many producers are not fully integrated with upstream and downstream stages in the value chain as they used to be with vertically integrated companies having assets from bauxite mining to aluminium smelting and further downstream (Nappi 2013).

As regards the exports restrictions imposed by the top-producing countries in 2017 for bauxite, Guinea had in place an export tax of 2%, and India an export tax of 15% along with a captive mining measure. China eliminated an export quota in 2013. For alumina, no restrictive measures to exports were imposed by the major producing countries in 2017. For unwrought aluminium, China applied an export tax of 15% in 2017, for both HS6 codes 760110 and 760120. An export tax of 1.25% imposed to exports of unwrought aluminium alloys (HS 760120) by the Russian Federation was effective until August 2016 (OECD 2019a).

3.2.1 Outlook for supply and demand

Consumption of bauxite and alumina follows the trend of aluminium production closely. World consumption of alumina for non-metallurgical uses is expected to increase slightly, attributable to continued growth in consumption of aluminium-hydroxide-based fire retardant materials and other alumina-based chemicals. Demand for high-purity alumina for devices such as smartphones, laptops, and tablets is also expected to continue to increase, although the effect on the total demand for bauxite and alumina would be marginal because of the limited volume of this market relative to aluminium smelting. Also, new entrants to the high-purity alumina market are expected to use high-alumina

[14] Estimation based on average LME price of high-grade aluminium in 2016 (EUR 1,471 per tonne) and the global primary Al production in 2016 of 58,649 kt. Value of recycled aluminium production is not included.

clay instead of bauxite as the raw material for their processes, as higher purity levels can be obtained using high-alumina clay (USGS 2019a).

World demand for aluminium is expected to increase as the global economy continues to expand and aluminium products become more accessible to consumers in developing economies (USGS 2019a). Demand for aluminium is driven by the light-weighting trend in mobility, the need for energy-efficient buildings and light packaging and other applications (e.g. engineered products) (Dessart and Bontoux 2017).

According to published data in a recent European Aluminium Association's report (CRU data in (European Aluminium 2019e)), world demand for primary aluminium is expected to increase by 50% by 2050, approaching 108 million t per year in 2050. European (EU28 + EFTA) demand for primary aluminium is forecasted to reach 9 million t. Chinese demand is expected to peak at almost 50 million t per year around 2035; by 2050, China will have a 40% share of primary aluminium demand. The most rapid growth is projected to be in India, which is going to replace China in terms of expansion of demand for primary aluminium by the mid-2030s, growing from 4% to 16% of global demand.

Europe is the second-largest consumer of primary aluminium and is likely to remain so until at least 2050. The total European aluminium ingot demand in 2050 will reach nearly 18 million t, and it will be met by almost equal shares of primary (production + imports) and recycled aluminium production (see Figure 30 and Figure 31). In a baseline scenario of the future primary aluminium production in Europe, domestic production of primary aluminium is expected to meet around 25% of the aluminium ingot demand by 2050. The average growth rate of semi-finished aluminium consumption is forecasted to 39% from 2017 to 2050. The main growth drivers of aluminium consumption in Europe will be increasing demand in applications where aluminium's unique properties make it the material of choice, i.e. transport (up 55% compared to 2017), construction (up 28% compared to 2017) and packaging (up 25% compared to 2017) (CRU data in (European Aluminium 2019e)).

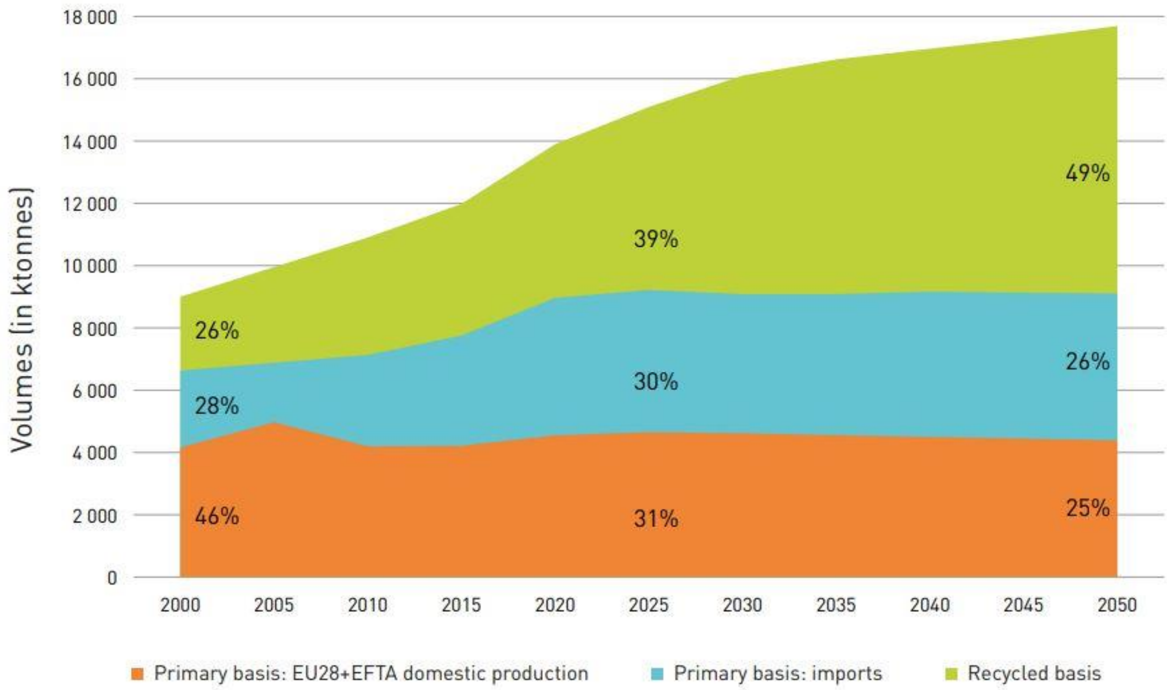


Figure 30: Forecast of primary production in Europe (EU28+EFTA) (2000-2050) (CRU datasets in (European Aluminium 2019e)).

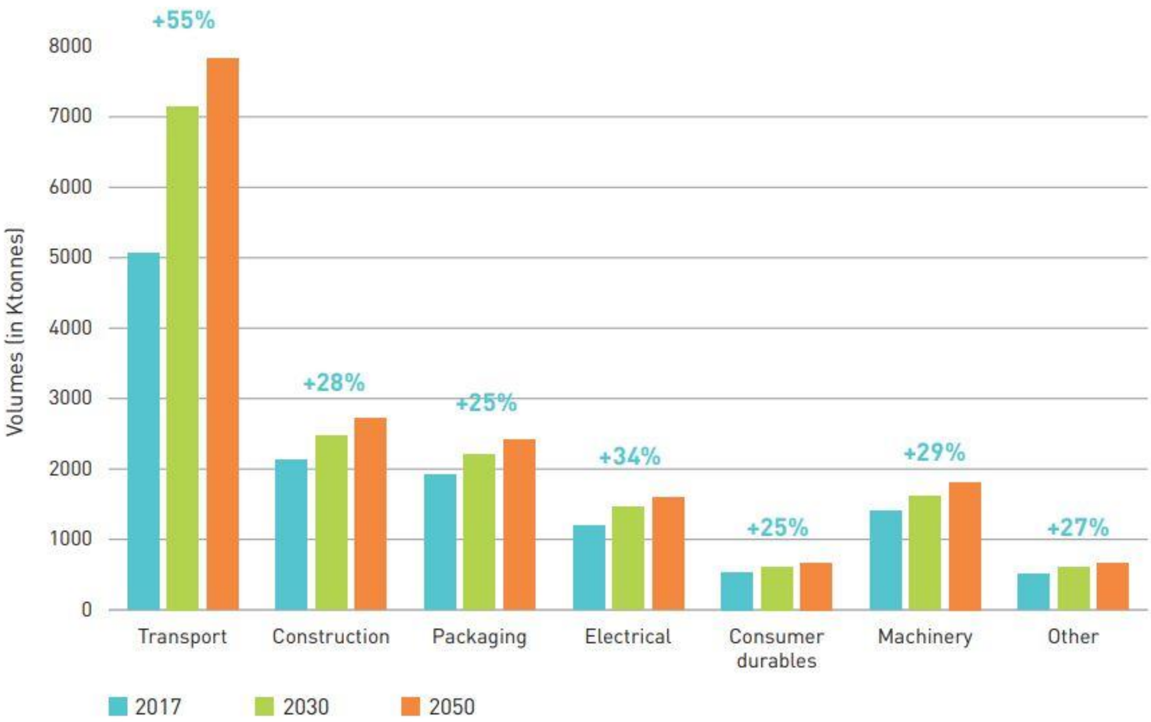


Figure 31: Demand by end use sector in Europe (EU28 + EFTA) from 2017-2050 (CRU datasets in (European Aluminium 2019e)).

Table 13 summarises that the supply and demand of both aluminium and bauxite are expected to grow in the future.

Table 13: Qualitative forecast of supply and demand of aluminium and bauxite

Materials	Criticality of the material in 2020		Demand forecast			Supply forecast		
	Yes	No	5 years	10 years	20 years	5 years	10 years	20 years
Bauxite	x		+	+	+	+	+	+
Aluminium		x	+	+	+	+	+	+

3.2.2 EU trade

Although the EU does produce over 2,009 kt of bauxite per year and 2,131 kt of primary aluminium per year (averaged over 2012–2016). These figures are small compared to the scale of imports: 13,656 kt for bauxite and 3,176 kt for primary aluminium, as an average for the 2012-2016 period. Exports of bauxite (259 kt), and export of primary aluminium (56 kt) are considerably smaller compared to imports. Figure 32 presents the trade flows for bauxite and Figure 34 for primary aluminium. In contrast, the EU is a net exporter for alumina: 2,120 kt of Al_2O_3 exports and 910 kt of Al_2O_3 imports, as an average for the 2012-2016 period) (Figure 33).

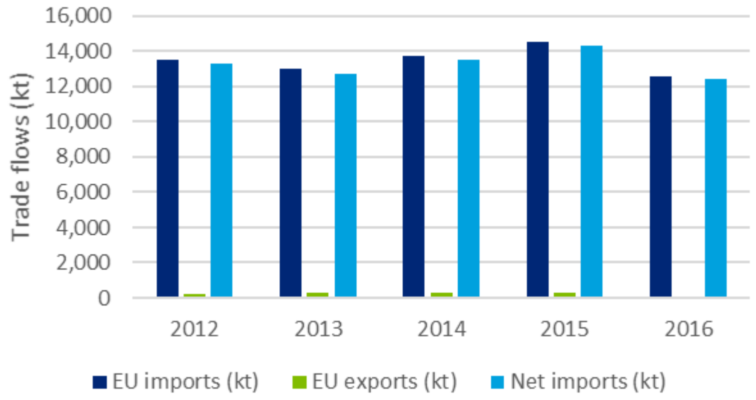


Figure 32: EU trade flows for bauxite (Eurostat Comext 2019)

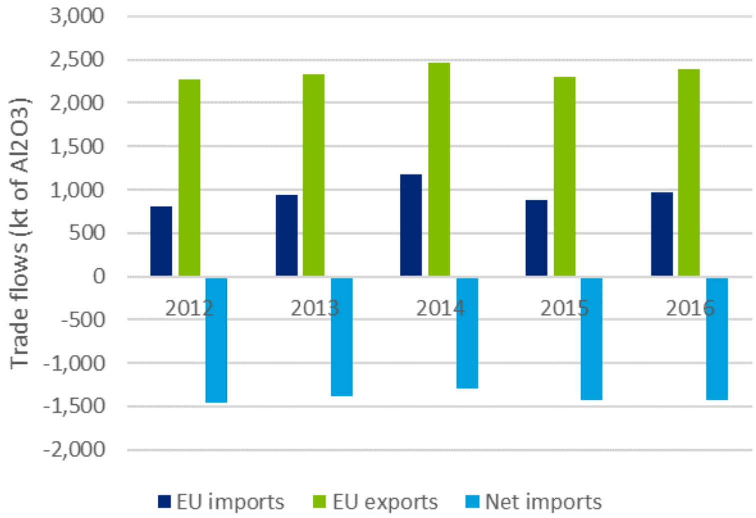


Figure 33: EU trade flows for alumina[15] (Eurostat Comext 2019)

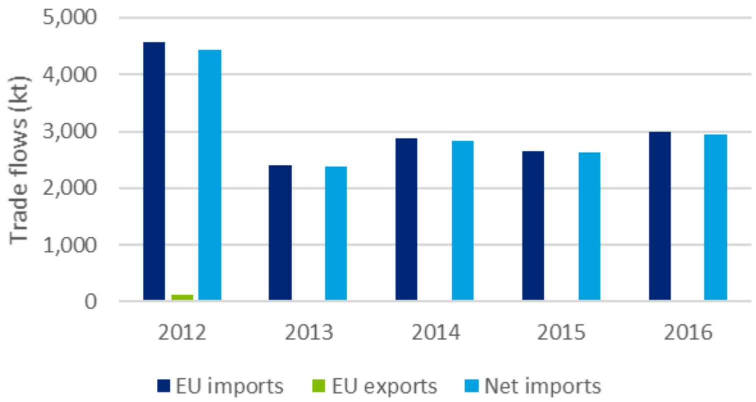


Figure 34: EU trade flows for primary aluminium (Eurostat Comext 2019)

[15] Trade codes: HS 281820 'Aluminium oxide (excl. Artificial corundum)', HS 281830 'Aluminium hydroxide'. Trade flows of aluminium hydroxide are converted to Al_2O_3 content

The countries of origin of imports of bauxite and primary aluminium are shown in Figure 35. For bauxite, the EU is dependent mainly on Guinea for its supplies with an average of 9,959 kt imported from that country per year. Imports from Brazil [16] amounted to approximately 1,623 kt per year, and from Sierra Leone to 1,036 kt per year. Imports of primary aluminium were more evenly distributed. The leading suppliers were Russia (an average of 897 kt per year), Mozambique (495 kt), Iceland (311 kt), and Norway (300 kt). As before these figures are all averaged over 2012–2016.

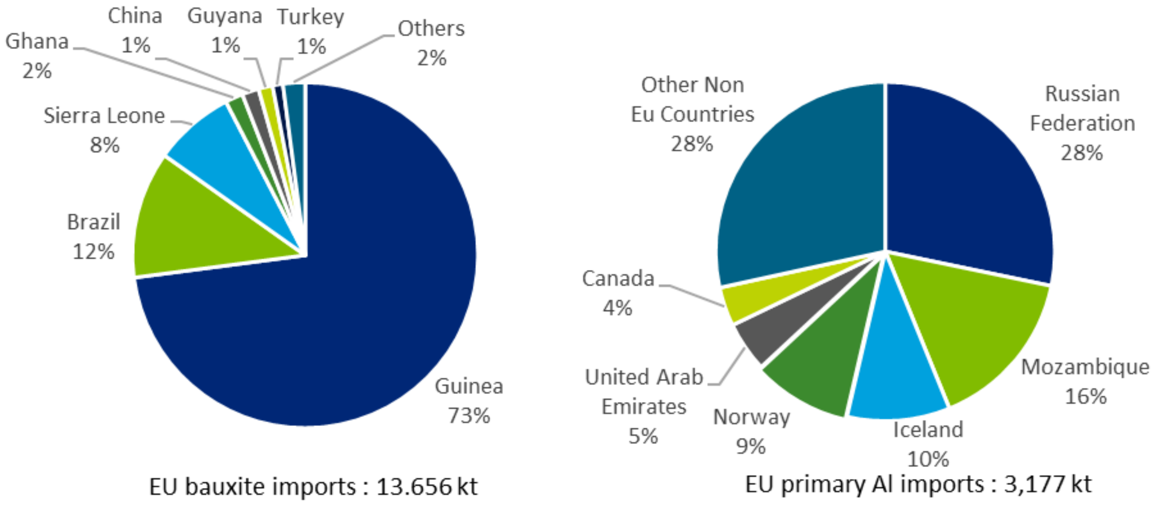


Figure 35: EU imports of bauxite (left) and primary aluminium (right). Average 2012-2016 (Eurostat Comext 2019)

Guinea, the main exporter and principal supplier of bauxite to the EU, has an export tax of 2%, in force since 2011. The leading exporters of unwrought aluminium to the EU applied no export restrictions in 2017. A tax of 1.25% applied by the Russian Federation to exports of unwrought aluminium alloys is no longer in effect since September 2016 (OECD, 2019a). Norway and Iceland, two of the important exporters of primary aluminium to the EU, are part of the European Economic Area agreement (EEA) which is in place since 1994 (European Commission 2019). Canada is part of the Comprehensive Economic and Trade Agreement (CETA) which is entered into force provisionally in 2017. Finally, the EU signed an Economic Partnership Agreement (EPA) on 10 June 2016 with the Southern African Development Community (SADC). Among other countries, the agreement comprises Mozambique, a significant exporter of primary aluminium to the EU, which started applying the EPA in February 2018 (European Commission 2019).

3.2.3 Prices and price volatility

Metallurgical-grade bauxite is mainly traded under long-term contracts, and the prices for these are generally not published (USGS 2018a). Spot prices for speciality forms of bauxite and alumina for non-metallurgical applications are published by trade journals (USGS 2018a). From June 2013 to June 2018, bauxite prices in China ranged from EUR 36 to EUR 68 per t, with an average of EUR 47 per t (see Figure 36).

[16] The EU has concluded a trade agreement with the four founding members of Mercosur (Argentina, Brazil, Paraguay, and Uruguay) as part of a bi-regional Association Agreement. https://ec.europa.eu/trade/policy/countries-and-regions/regions/mercosur/

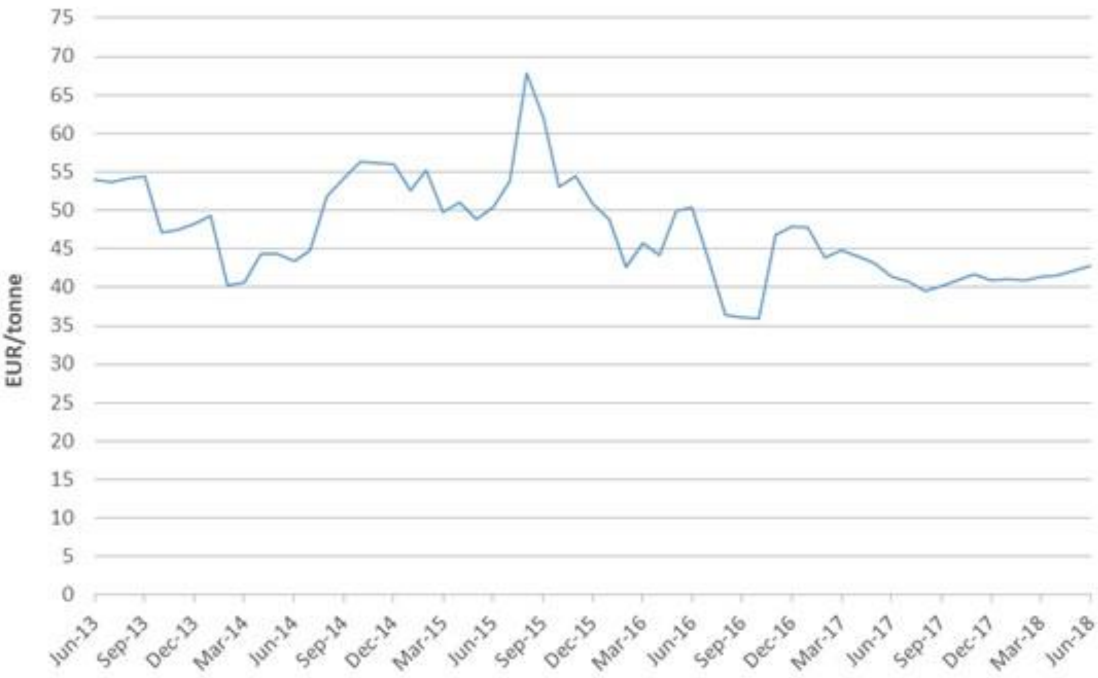


Figure 36: Bauxite price trend, CIF Qingdao port, monthly average (€/t). Data from (S&P Global Market Intelligence 2018)

The alumina market was priced as a percentage of the London Metal Exchange (LME) aluminium price in the past, and some companies still use long-term LME-based contracts. Since 2010, the market has moved to use indices of spot prices calculated by price-reporting agencies based on transactions in the physical market, because of the changing dynamics of the LME and the alumina market and the increased cost of caustic soda (Fastmarkets MB 2019). LME launched a new cash-settled futures contract of alumina on March 2019 settled against CRU Alumina Price Index and the Fastmarkets MB Alumina FOB Australia Index by equal weighting to each index (Fastmarkets MB 2019)(LME 2019). The Chicago Mercantile Exchange (CME) also has an exchange-traded futures contract based on the Fastmarkets MB Alumina Fob Australia index (CME Group 2019).

Alumina prices have been relatively stable from 2011 to early 2017, as a percentage of LME aluminium price. According to CRU data, the CRU Alumina Price index (API) has been the 17% of the LME aluminium price on average. 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 MB 2019b).

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

- LME: All primary aluminium contracts globally (excluding China) are traded on the LME with a base price that is listed daily. LME prices are determined on the basis of global supply and demand. On top of the LME base price, an additional market premium is negotiated between buyer and seller for physical material contracts across the value chain. The market premiums account for the manufacturing of value-added products depending on the shape, alloy and other aspects, the delivery location to reflect costs associated with transaction and transportation from storage warehouses to downstream plants, the existing tariff status, and other contractual services. The LME base price is not negotiated between the buyer and seller as it is the global reference point. For example, the all-in price of the metal a wrought producer may charge includes the prevailing LME exchange cost for the relevant volume of aluminium along with the premium fee (European Aluminium 2018c) (USITC 2017) (London Metal Exchange 2017);

- SHFE: Aluminium base prices in China are set on the SHFE, where only Chinese companies can trade aluminium (European Aluminium 2018c).

Both in LME and SHFE paper transactions represent much higher movements than physical ones. Therefore, speculators' anticipations of potential global movements are reflected in prices (Aluminum Association et al. 2018).

After its peak in spring 2008, aluminium's price collapsed by almost 50%, and recovery started in early 2009. However, world market prices for primary aluminium have remained significantly lower than the levels reached in 2008 (Figure 37). China is increasing its aluminium-smelting capacity continuously, accounting for more than half of the world's supply since 2013, which has caused the decline of prices worldwide not only of primary aluminium but also of downstream semi-finished and finished aluminium products exported by China (EC 2018b).

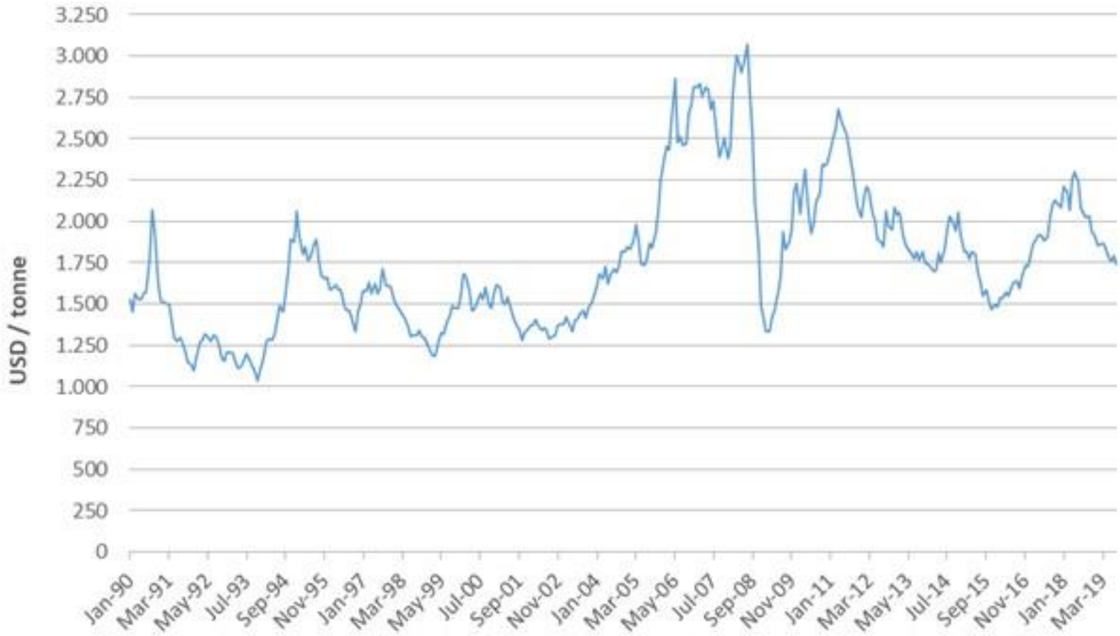


Figure 37: Monthly London Metal Exchange (LME) aluminium settlement[17] price[18], unalloyed primary ingots of a minimum 99.7% purity, in USD/t. (World Bank 2019)

In real terms, the average annual aluminium price (LME settlement price) declined by 38% from 2007 to 2016 (World Bank 2019). In 2017, the average annual LME settlement price of aluminium increased to USD 1,968 per t; a price increase of 19% since 2016, driven by winter closures and supply reform in China (Thomas 2018). Nevertheless, the average annual aluminium price in 2019 remained approximately 27% lower in real terms in comparison to 2007. 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. The monthly aluminium price at the LME rose to almost USD 2,600 per t (EUR 1907 per t), which

[17] Settlement price beginning 2005; previously cash price

[18] Nominal prices, not adjusted for inflation

marked a 6-year high (DERA 2018). Since then, world aluminium prices are generally declining, and the monthly LME-cash price dropped to USD 1,724 per t (EUR 1,558 per t) in August 2019 (see Figure 38).

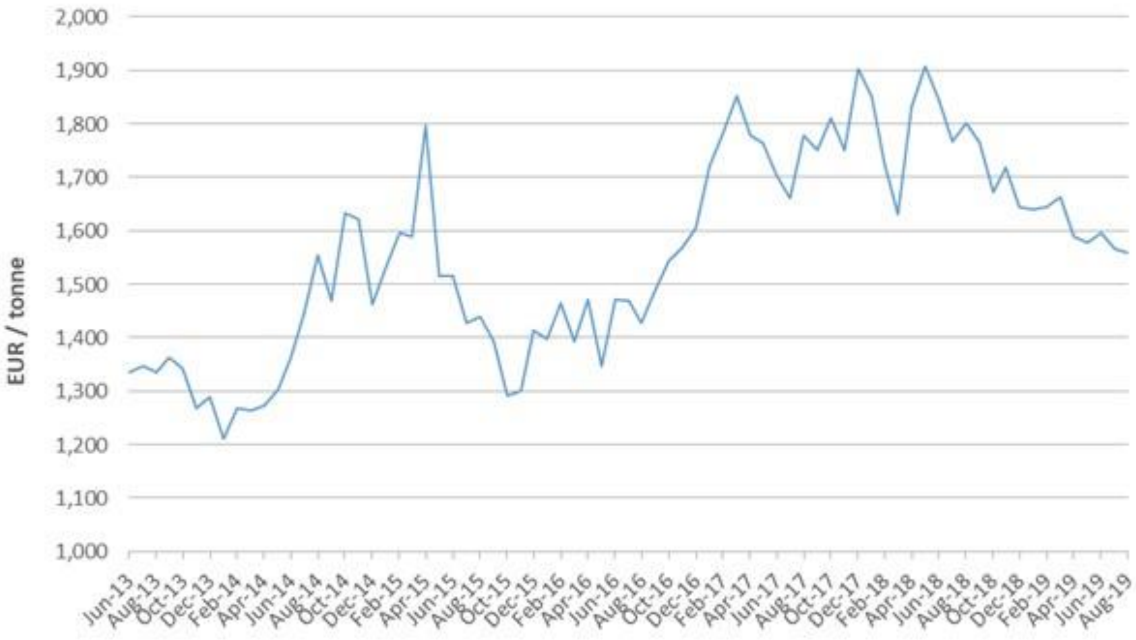


Figure 38. Monthly London Metal Exchange (LME) aluminium price[19] (99.7% cash), in EUR/t (S&P Global Market Intelligence 2019)

Figure 39 shows aluminium long term prices from 1910 to 2018. It shows real prices, lower and upper real price benchmarks (solid line for real price, solid horizontal line for lower real price benchmark, dashed line for upper real price benchmark, real prices deflated by using US PPI, basis 2017, vertical dashed line indicates break in price specification) (Buchholz, 2019).

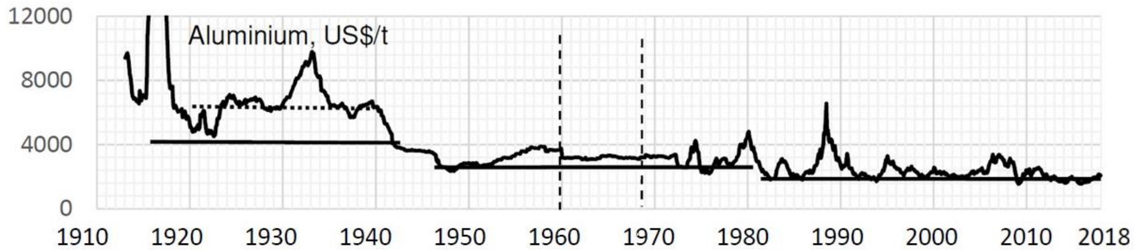


Figure 39: Long term prices for Aluminium. USD per t. (Buchholz et al., 2019)

3.3 EU demand

3.3.1 EU consumption of bauxite

The EU apparent consumption of bauxite between 2012 and 2016 is calculated at about 15,406 kt per year. Of this 1,750 kt per year came from within the EU (calculated as EU production minus exports to non-EU countries) with the remaining 13,656 kt imported from outside the EU. Based on these figures, it is not surprising that the net import reliance for the EU is high at 87% (averaged over 2012-2016).

[19] Not adjusted for inflation

3.3.2 Uses and end-uses of bauxite in the EU

The majority (95%) of bauxite mined worldwide is refined into alumina, and the remainder (5%) is consumed directly for non-metallurgical applications. The share of bauxite output which is converted to alumina for the production of aluminium metal (smelter-grade) ranges from 85% to 89%, while the proportion used for the production of alumina for other applications (chemical-grade) is reported to vary from 6% to 10% (V. Hill and Sehnke, 2006) (Flook, 2015). Non-metallurgical applications of bauxite, including those of chemical-grade alumina, are found in refractories, cement, abrasives and chemicals.

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).

Aluminous cement is used where rapid strength and/or resistance to certain types of corrosion are required. Calcined chemical grade alumina is required for the production of high-purity alumina cement for castable monolithic refractories.

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

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 applixations in ceramic proppants for oil and gas drilling fluids, in welding fluxes, as slag adjuster and in road surfacing are included under this category.

The main categories of end uses for bauxite between 2012 and 2016 are shown in Figure 40.

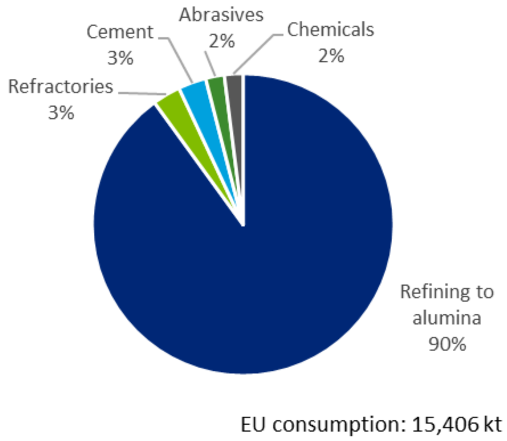


Figure 40: Global end uses of bauxite (International Aluminium Association and literature; SCRREEN workshops 2019), and EU consumption of bauxite (average 2012-2016) (WMD 2019; Eurostat Comext 2019)

The relevant industry sectors are described using the NACE sector codes in Table 14.

Table 14: Bauxite applications, 2-digit and associated 4-digit NACE sectors, and value-added per sector (Eurostat 2019)

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	55,426	C2442 – Aluminium production
Refractories	C23 – Manufacture of other non-metallic mineral products	57,255	C2320 – Manufacture of refractory products

Cement	C23 – Manufacture of other non-metallic mineral products	57,255	C2351 – Manufacture of cement
Abrasives	C23 – Manufacture of other non-metallic mineral products	57,255	C2391 – Production of abrasive products
Chemicals	C20 – Manufacture of chemicals and chemical products	105,514	C2013 – Manufacture of other inorganic basic chemicals

3.3.3 EU consumption of aluminium

For primary aluminium, the EU apparent consumption is calculated at 5,252 kt per year (average 2012-2016) and of this 2,075 kt came from within the EU (again calculated as EU production minus exports to non-EU countries). The remaining 3,177 kt were imported from outside the EU, resulting in net import reliance of 59% averaged over 2012-2016.

Figure 41 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).

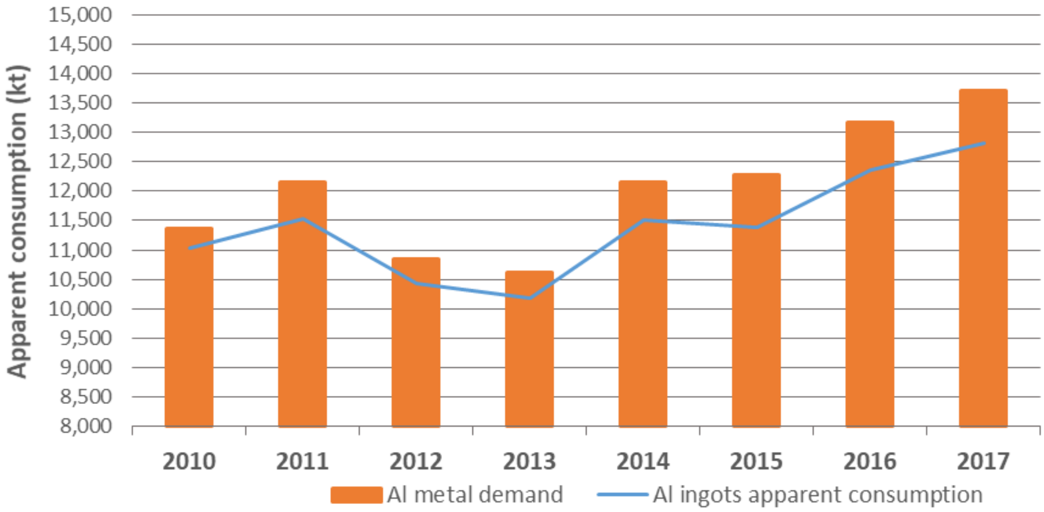


Figure 41: Aluminium ingots apparent consumption[20] and aluminium metal demand[21]

3.3.4 Uses and end-uses of aluminium in the EU

Figure 42 shows the EU end uses of aluminium in 2017, and Figure 43 presents the end uses of aluminium worldwide in 2015.

[20] 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

[21] 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)

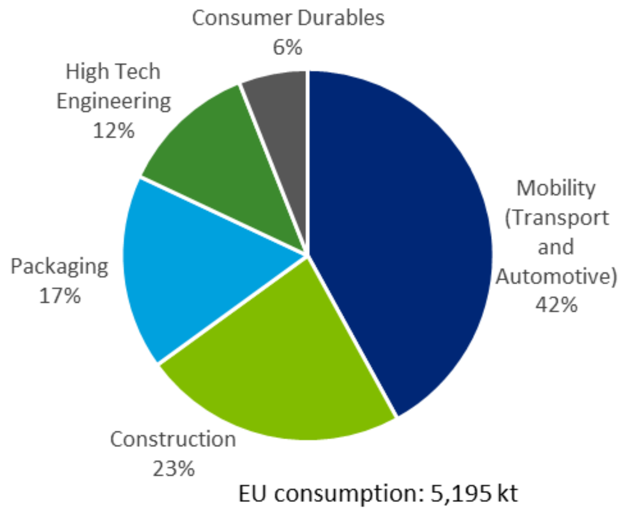


Figure 42: Main end uses of aluminium in Europe in 2017 (European Aluminium 2018), and EU consumption of primary aluminium (average 2012-2016)

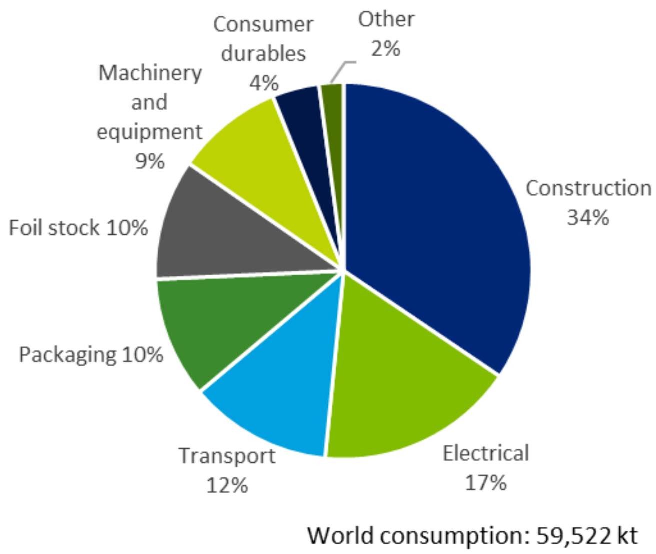


Figure 43: World consumption of aluminium by major end-use sectors, 2015. (CRU data in (USITC 2017))

Aluminium's excellent combination of properties together with its relative cost-effectiveness have led to its widespread use in a variety of applications (OECD 2015). The following paragraphs provide some examples because there is insufficient space in this factsheet to list them all.

The largest market for aluminium in Europe is the transport sector (see Figure 42) where the metal is used in the manufacture of road vehicles (cars, buses, trucks), trains, aircraft, ships, spacecraft, bicycles, etc. Within a vehicle, aluminium is sometimes used for body panels, but it is also used for 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 with consequent improvements in fuel consumption. The second example of this sector is the use of aluminium in aircraft where its lightness, workability and strength make it an ideal material. Some of the most common aircraft models in the world today are 70–80% aluminium.

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, which means it is beneficial for architects in designing buildings.

Aluminium is one of the most versatile forms of *packaging*, as it can be formed into almost any shape. It is mainly used to protect food, drinks and pharmaceutical products against damage from light, liquid, temperature or bacteria, and it is non-toxic. 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 includes mechanical engineering applications such as pistons, cylinder blocks, pulleys, guide rails, optical equipment, pneumatic cylinders, measuring instruments, etc. It also comprises electrical and heat transfer engineering applications such as power cables, ladders, cable sheathing, heat exchangers, busbars (electrical conductors), cooling fins, etc.

Aluminium is also widely used to manufacture *consumer durables* such as cooking utensils, watches, the outer casing of some types of equipment (e.g. photographic equipment, smartphones, tablet computers, etc.), electrical appliances, LED lighting, paints, alloys for some coins, cookers, boilers, sports equipment, mirrors and reflectors, etc. As an example, 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.

The relevant industry sectors are described using the NACE sector codes in Table 15.

Table 15: Aluminium applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector (Eurostat 2019)

Applications for primary aluminium	2-digit NACE sector	Value-added of NACE 2 sector (M€)	Examples of 4-digit NACE sector(s)
Mobility (Transport and Automotive)	Both C29 – Manufacture of motor vehicles, trailers and semi-trailers, AND C30 – Manufacture of other transport equipment	160,603 AND 44,304	C2910 – Manufacture of motor vehicles; C2920 Manufacture of bodies for motor vehicles; C2932 – Other parts for motor vehicles; 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

Applications for primary aluminium	**2-digit NACE sector**	**Value-added of NACE 2 sector (M€)**	**Examples of 4-digit NACE sector(s)**
Construction	C25 – Manufacture of fabricated metal products, except machinery and equipment	148,351	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	148,351	C2592 – Manufacture of light metal packaging
High-Tech Engineering	C28 – Manufacture of machinery and equipment not elsewhere specified	182,859	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	148,351	C2571 – Manufacture of cutlery

3.3.5 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 Amirhosseini 2007). However, 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). In particular, 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 AlSiCal funded by Horizon 2020 (September 2019–August 2023) is going to research 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. However, refineries were under feasibility studies or construction worldwide in 2015 to produce high-purity (99.99%) alumina from high-alumina clays, therefore substituting bauxite (USGS 2016).

For aluminium, a variety of substitutes were assessed. Steel is considered the primary substitute material for aluminium in mobility, construction, packaging and machinery applications (Graedel et al. 2015b).

For the mobility applications (transport and 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). Titanium and magnesium are also possible substitutes in this sector. Steel is the only one of these materials with lower cost to aluminium. However, steel is heavier than aluminium, and consequently, for specific applications, the performance could be lower (USGS 2019) (Djukanovic 2016) (Musfirah and Jaharah 2012).

In the construction sector, additionally to 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.

Glass, plastics and steel are potential substitutes for aluminium for packaging applications, and again for all of these, the performance was considered to be similar, and costs same or lower.

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.

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).

3.4 Supply

3.4.1 EU supply chain

The aluminium flows through the EU economy in 2013 are shown in Figure 44.

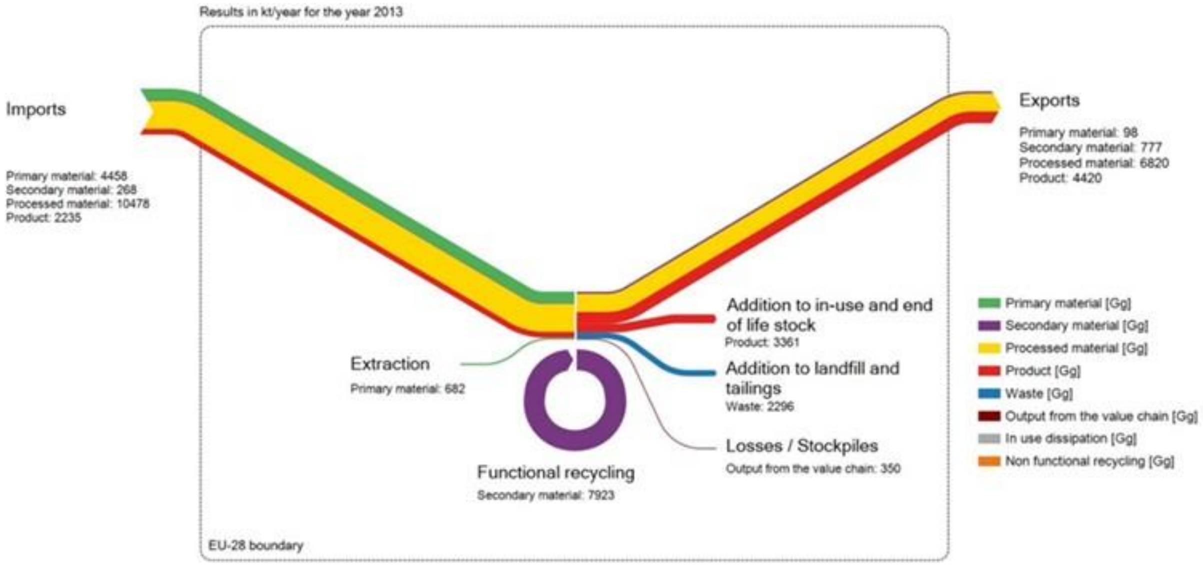


Figure 44: Simplified MSA of aluminium flows in the EU in 2013 (Passarini et al. 2018)

3.4.1.1 EU sourcing of bauxite

Within the EU, bauxite was mined between 2012 and 2016 in four countries, but the combined output from these countries (about 2,000 kt per year) represents less than 1% of the world's total production of bauxite. EU production is small when compared to the overall global production of more than 281,000 kt per year, or compared to the largest producing country: Australia (80,092 kt per year).

Greece is the leading EU bauxite producer, with a yearly output of nearly 1,850 kt, averaged over 2012-2016. 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 Hungary and France (around 80 kt per year each) and Croatia (under 9 kt per year).

In addition to domestic production, more than 13,656 kt per year of bauxite are imported to the EU. Of these imports, 33% go to Ireland, with another 26% imported by Spain, 18% by Germany, 9% by Romania, 8% by France, and 3% by Greece. EU's net import reliance between 2012-2016 was 87% for bauxite. Figure 45 presents the EU sourcing (domestic production + imports) of bauxite.

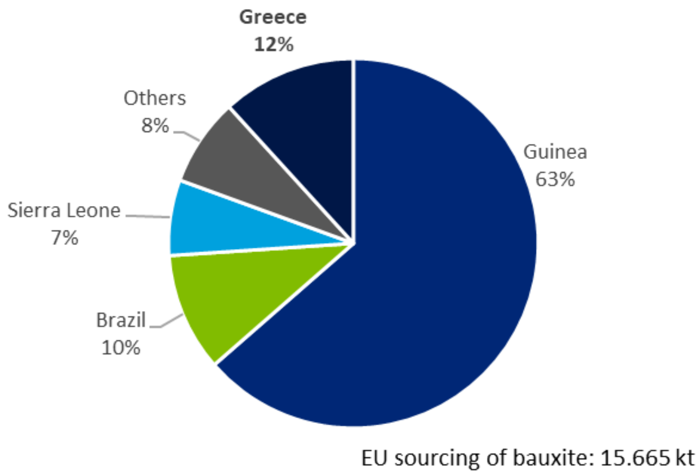


Figure 45: EU sourcing of bauxite. Average 2012-2016 (WMD 2019; Eurostat Comext 2019)

3.4.1.2 EU sourcing of alumina

Table 16 presents the active alumina refineries in 2018 in six EU countries. The EU output averaged 5,793 kt in Al_2O_3 content over 2012–2016 contributing to about 5% of the global production of alumina. Imports to the EU totalled 910 kt in Al_2O_3 content and as an average over the same period. Figure 46 provides the EU sourcing (domestic production + imports) for alumina.

Table 16. 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 (kt)	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	

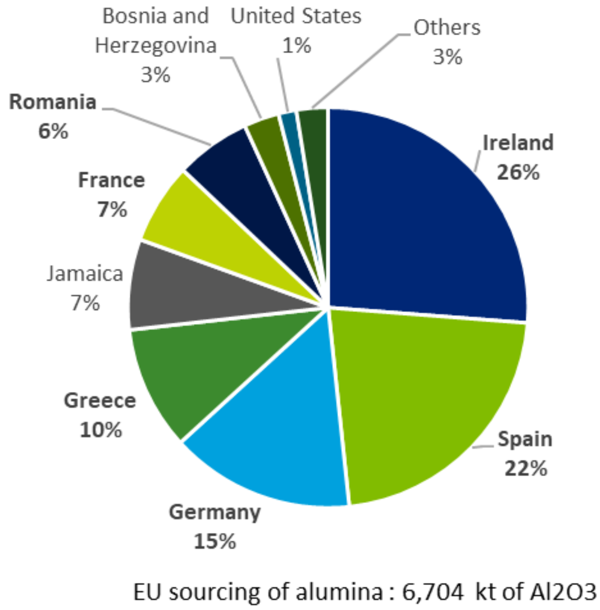


Figure 46: EU sourcing of alumina. Average 2012-2016. Production data from (BGS 2019a) and trade flows[22] from (Eurostat Comext 2019)

3.4.1.3 EU sourcing of primary aluminium

As regards primary aluminium, in 2018 there are fifteen active aluminium smelters in nine countries in the EU, contributing about 4% to world production. Production levels averaged over 2012–2016 data, vary between 504 kt in Germany to 47 kt in the Netherlands. These figures are rather small when compared to the global total of 54,628 kt per year, or compared to China, the largest producing country with more than 28,336 kt per year.

Table 17. 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 (kt)	Shutdown Capacity (kt)
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

[22] Trade codes: HS 281820 'Aluminium oxide (excl. Artificial corundum)', HS 281830 'Aluminium hydroxide'. Trade flows of aluminium hydroxide are converted to Al2O3 content

Plant	Country	Operator	Ownership	Annual capacity (kt)	Shutdown Capacity (kt)
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

In addition to the total EU production of primary aluminium of nearly 2,132 kt per year, a further 3,178 kt per year of primary aluminium was imported into the EU (average 2012-2016). The net import reliance is 59% for primary aluminium. Figure 47 presents the EU sourcing (domestic production + imports) of primary aluminium.

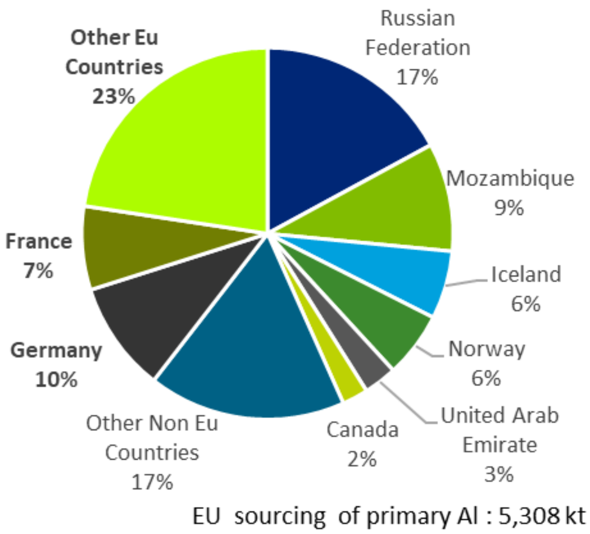


Figure 47: EU sourcing of primary aluminium. Average 2012-2016 (WMD 2019; Eurostat Comext 2019)

3.4.1.4 EU supply of recycled aluminium

The European Aluminium Association reports that the number of recycling plants in Europe was 220 in 2015, many of which are small and medium-sized enterprises (SMEs) (European Aluminium 2016). Over a third of EU consumption in aluminium ingots is satisfied by recycling of old and new scrap (Figure 48).

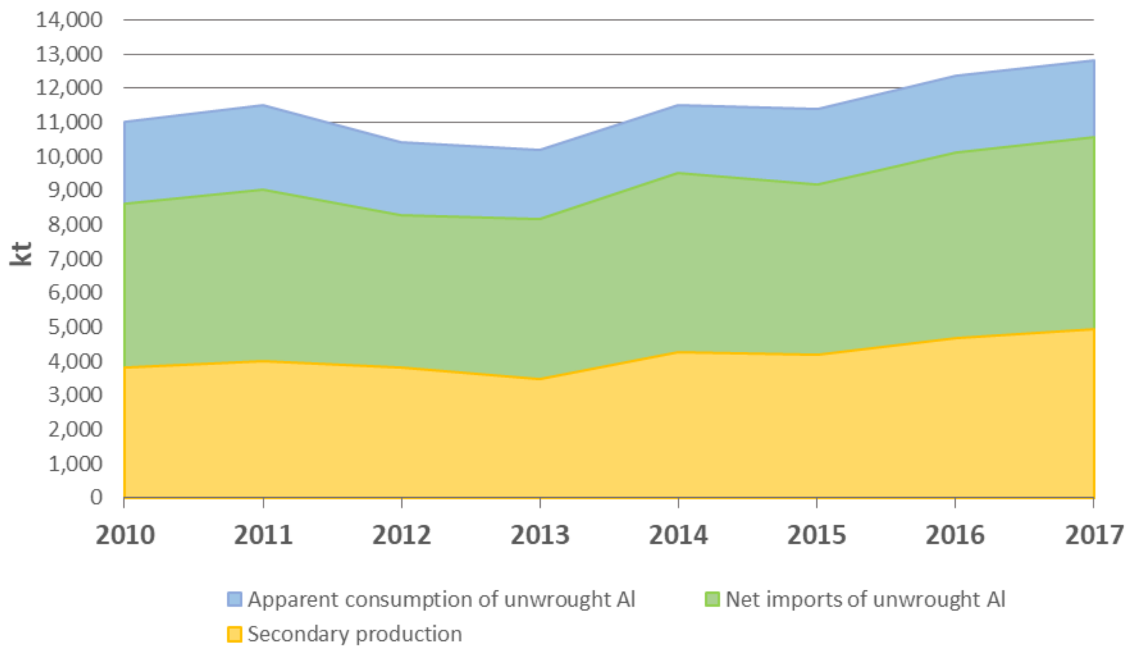


Figure 48: Contribution of secondary production and net imports to the EU consumption of unwrought Al (ingots). Background data[23] from (Eurostat Prodcom, 2019) (Eurostat Comext, 2019)

[23] The apparent consumption of unwrought Al is calculated from official Eurostat data for shipments and net imports. PRC codes used for production (sold) of unwrought Al: 24421153 and 24421155 from 2010 to 2012; 24421130 and 24421154 from 2013 to 2017. CN codes for trade flows of unwrought Al: CN 76011000, CN 76012000 and CN 76011080. The

3.4.2 Supply from primary materials

3.4.2.1 Geology, resources and reserves of bauxite

Geological occurrence: 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 15.4 wt% (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 (Aluminum Association 2007).

Bauxite is a heterogeneous rock composed of a wide variety of minerals. The bauxite ores consist primarily of the aluminium hydroxides 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[24]: Globally, the United States Geological Survey (USGS, 2018b) estimates that known resources of bauxite are in the range of 55–75 billion t, 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 at about 30 billion t. 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 (20%), Vietnam (12%) and Brazil (9%). Global reserves of bauxite are sufficient to last at least another 100 years at the

secondary production is estimated by subtracting primary production from the total unwrought Al production, and may not reflect secondary ingot production by integrated casthouses.

[24] There is no single source of comprehensive evaluations for resources and reserves that apply the same criteria to deposits of bauxite in different geographic areas of the EU or globally. The USGS collects information about the quantity and quality of mineral resources but does not directly measure reserves, and companies or governments do not directly report reserves to the USGS. Individual companies may publish regular mineral resource and reserve reports, but reporting is done using a variety of systems of reporting depending on the location of their operation, their corporate identity and stock market requirements. Translations between national reporting codes are possible by application of the CRIRSCO template, which is also consistent with the United Nations Framework Classification (UNFC) system. However, reserve and resource data are changing continuously as exploration and mining proceed and are thus influenced by market conditions and should be followed continuously.

rate of extraction in 2016 (WMD 2019; USGS 2018b). The breakdown per counties is given in Table 18.

Table 18: Global reserves of bauxite in 2017 (USGS 2018b)

Country	Bauxite Reserves (million t)	Percentage of the total (%)
Guinea	7,400	25.0
Australia	6,000	20.0
Vietnam	3,700	12.0
Brazil	2,600	9.0
Jamaica	2,000	7.0
China	1,000	3.0
Indonesia	1,000	3.0
Guyana	850	3.0
India	830	3.0
Russia	500	2.0
Greece	250	1.0
Saudi Arabia	210	1.0
Kazakhstan	160	1.0
Malaysia	110	1.0
United States	20	1.0
Other countries (unspecified)	3,200	11.0
World total (rounded)	30,000	100

EU resources and reserves[25]*:* According to USGS (2018b), the largest exploitable deposits of bauxite in the EU are located in Greece with estimated reserves of 250 million t. The most important known exploitable deposits are located in the zone of mountains 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.

[25] For Europe, there is no complete and harmonised dataset that presents total EU resource and reserve estimates for bauxite. The Minerals4EU project is the only EU-level repository of some mineral resource and reserve data for fluorspar, but this information does not provide a complete picture for Europe. It includes estimates based on a variety of reporting codes used by different countries, and different types of non-comparable datasets (e.g. historic estimates, inferred reserves figures only, etc.). In addition, translations of Minerals4EU data by application of the CRIRSCO template is not always possible, meaning that not all resource and reserve data for bauxite the national/regional level is consistent with the United Nations Framework Classification (UNFC) system (Minerals4EU 2019). Many documented resources in Europe are based on historic estimates and are of little current economic interest. Data for these may not always be presentable in accordance with the UNFC system. However, a very solid estimation can be done by experts.

Table 19: Bauxite resources data for the EU (Minerals4EU 2019)

Country	Reporting code	Quantity (million t of bauxite)	Grade (% Al_2O_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 20: Bauxite reserves data for the EU

Country	Reporting code	Quantity (million t of bauxite)	Grade (% Al_2O_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

3.4.2.2 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.

3.4.2.3 Bauxite mining

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).

3.4.2.4 World and EU mine production of bauxite

Globally bauxite was mined in 32 countries in 2016 with total production averaged over the 2012–2016 period to more than 281,123 kt per year. Figure 49 demonstrates the most significant producers. Australia is the leading producer and accounts for 28% of the world total. China (20%), Brazil (13%), India (8%) and Guinea (8%) are other important producers and together with Australia hold a 77% share of world mine production.

The EU annual production of bauxite (average 2012-2016) is about 2,009 kt. 92% of the EU production was mined in Greece (0.7% of world total, 92% of EU production); much lower bauxite quantities were extracted in Hungary, France and Croatia (<0.1% each of global total) (WMD 2019).

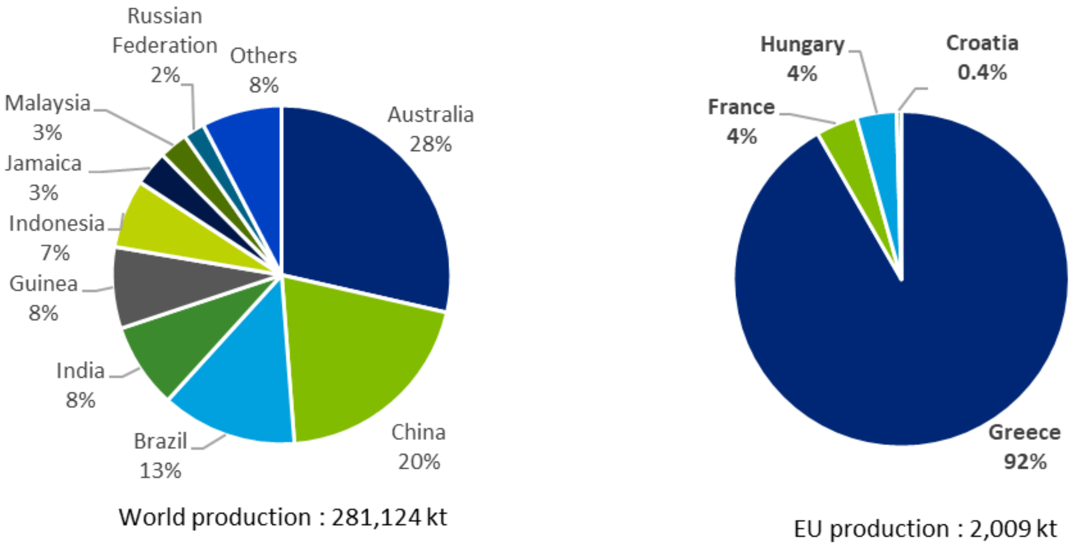


Figure 49: Global and EU mine production of bauxite. Average for the years 2012-2016 (WMD 2019)

3.4.3 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 t of bauxite are required to produce one t 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 $Al(OH)_3$ 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).

3.4.3.1 World and EU production of alumina

The annual average output of alumina amounted 108,752000 kt over the period 2012-2016. The largest producer was China (47% of the worldwide total in 2016), followed by Australia (19%) and Brazil (9%). Within the EU there are alumina refineries in France, Germany, Greece, Ireland, Romania and Spain (Hungary ceased production in 2015), with a combined total of almost 5,794 kt that amounts to 5% of the global total.

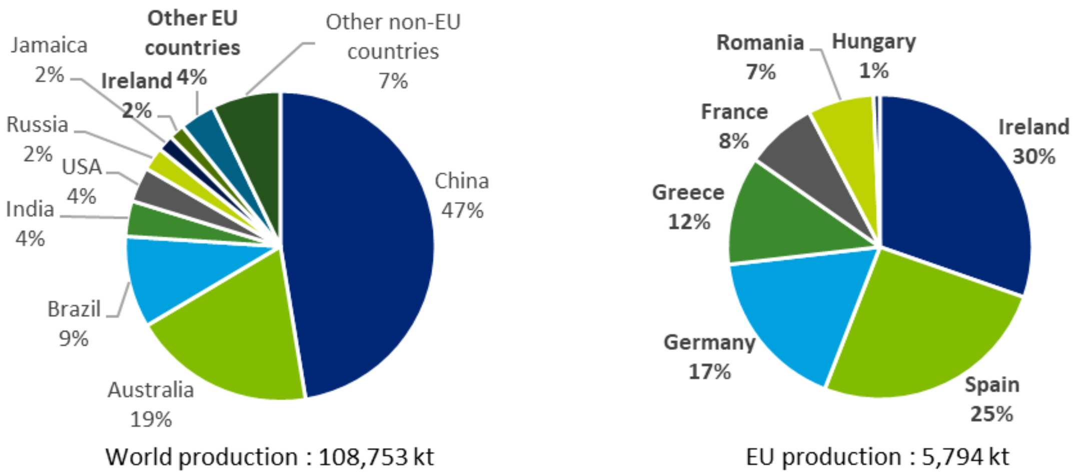


Figure 50: Global and EU production of alumina. Average for the years 2012-2016 (BGS 2019)

3.4.4 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 t of alumina are required to produce one t 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).

3.4.4.1 World and EU production of primary aluminium

The global primary aluminium production over the 2012–2016 period totalled to an average of 54,658 kt per year. The largest world producers are shown in Figure 51. China accounts for 52% of the world's production of primary aluminium. Russia (7%), Canada (5%), United Arab Emirates (4%) and India (4%) are following on the list of major producers (WMD 2019).

Within the EU for 2012-2016, there were aluminium smelters in Germany, France, Spain, Romania, Greece, Slovakia, Sweden, Slovenia, Netherlands and Italy. These contributed a total of nearly 2,132 kt of aluminium (4% of the global total), based on figures averaged over 2012–2016. Since 2012, the Italian smelter is closed.

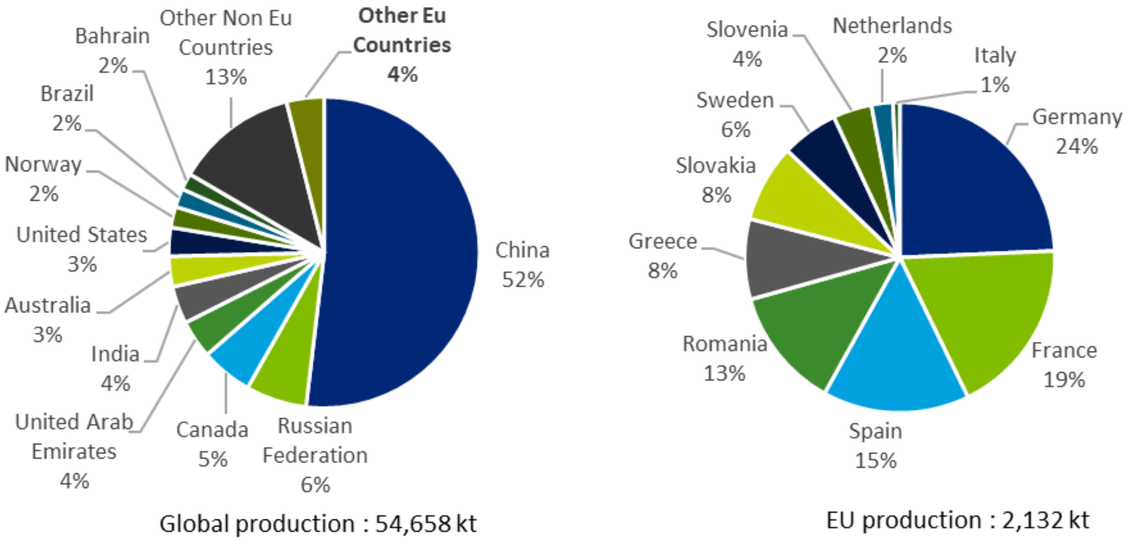


Figure 51: Global and EU production of primary aluminium. Average for the years 2012-2016 (WMD 2019)

3.4.5 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).

While the end-of-life recycling rate (EoL-RR) for aluminium is high, old scrap generally makes up a relatively small share of overall material input to the EU (Passarini et al. 2018). 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).

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

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 (2018), the end-of-life recycling input rate (EoL-RIR) was 12% in 2013 (SCRREEN workshops 2019). 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).

Table 21: Material flows relevant to the EOL-RIR[26] of aluminium in 2013. Data from (Passarini et al. 2018)

MSA Flow	Value (kt)
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

3.4.5.2 Industrial recycling (new scrap)

Aluminium metal scrap and other aluminium-bearing wastes are also generated during the fabrication and manufacture of aluminium products (referred to as 'new scrap' or 'processing scrap'). 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).

3.5 Other considerations

3.5.1 Environmental, and health and safety issues

The most significant environmental concern related to the production of aluminium is greenhouse gas emissions (OECD 2015). Globally, approximately 40% of greenhouse emissions are the result of the aluminium production process itself (direct emissions), and around 60% relates to electricity generation for smelting (indirect emissions) (IAI 2009). As an energy-intensive industry, aluminium production covers the largest part of the EU greenhouse gas emissions of the non-ferrous metals sector, despite the considerable decrease of emissions achieved in the last years. Since 1990, the European primary aluminium production has reduced by 55% the direct CO_2 emissions per t. The European aluminium sector accounted in 2016 for around 1% of the verified emissions of all stationary installations of the EU and about 2% of its industrial emissions (European Commission 2018). Incremental improvements in energy efficiency will not be enough but will require breakthrough innovations in the smelting process to drastically reduce direct carbon emissions by 2050 (European Aluminium 2019e). New low-carbon technologies are under development in aluminium's production route, e.g. low emission electrolysis.

The shift to secondary production through further recycling could bring significant additional benefits, as the recycling of aluminium saves energy consumption by 95% and emissions up to 98% (European Commission 2018). Finally, a decarbonised power sector

[26] 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)

could further reduce the emissions of the aluminium industry (European Aluminium 2018b).

European Aluminium regularly publishes Life Cycle Inventory (LCI) data for the production of aluminium in EU-28 and EFTA countries (Norway, Switzerland and Iceland), verified by external experts. An updated Environmental Profile report was published in 2018 covering the entire aluminium value chain in Europe, from the metal supply (primary and recycling) to semi-fabrication (rolling, foil and extrusion). Based on 2015 production data, the report provides LCI datasets for the key process steps essential for calculating the environmental impacts of aluminium products fabricated in Europe. Among key findings are:

- The Global Warming Potential (GWP) for primary aluminium production in Europe decreased by 21% versus 2010. However, the overall environmental impact of the primary aluminium used in Europe remains relatively stable balanced by an equivalent increase in the environmental impact of imports. The carbon intensity of the primary aluminium production in Europe is approximately 7 kg CO_2-eq per kg of aluminium produced compared to a global average of 18 kg CO_2-eq per kg of aluminium;Since 2010, the Global Warming Potential (GWP) for the aluminium rolling mill process decreased by 25%, for the extrusion process decreased by 11% and for process scrap recycling reduced by 9% (European Aluminium 2018b).

EU OSH requirements exist to protect workers' health and safety, employers need to identify which hazardous substances they use at the workplace, carry out a risk assessment and introduce appropriate, proportionate and effective risk management measures to eliminate or control exposure, to consult with the workers who should receive training and, as appropriate, health surveillance[27].

According to the CLP Regulation European Commission No 1272/2008, aluminium is classified as:

- Water-react. 2
- Pyr. Sol 1 or Flam. Sol. 1

3.5.2 Contribution to low-carbon technologies

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.

Due to its lightweight, improved fuel efficiency and carbon emissions reduction are achievable through increased aluminium use in transport without compromising safety, from passenger aircraft to cars. Aluminium replacing steel in car manufacture reduces the overall weight of the vehicle (Euromines 2019b). Also, aluminium used in buildings improves energy efficiency, notably via windows, curtain walls and ventilated facades (European Aluminium 2019c). The recyclability and durability of aluminium contribute further to the sustainability of buildings. Aluminium recycling rates from construction materials are in the order of 90% while aluminium use in buildings and construction offers long service life without maintenance (Eurometaux 2015)(European Aluminium 2019e). Moreover, aluminium is a material used in wind and solar power installations, as well as in charging infrastructure for electric vehicles (European Aluminium 2019e) (European Political Strategy Centre 2018). In wind turbines in particular, several tonnes of aluminium may be required in parts such as the gearbox, while materials based on aluminium honeycomb technology combining high strength and low weight may be used in blades and cores within wind turbines. In solar thermal systems, aluminium is used primarily in absorbers, casings and frames (Euromines 2019). Finally, aluminium becomes the

[27] https://ec.europa.eu/social/main.jsp?catId=148

preferred material for high and extra-high voltage submarine cables, which will play a significant role in connecting northern and southern Europe, ensuring a more liquid electricity market by transporting renewable energy to where it is needed (European Aluminium 2019e).

3.5.3 Socio-economic issues

Bauxite mines are commonly found in the tropical and sub-tropical area; thus deposits often overlap or are adjacent to, areas of high conservation value. Besides, 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).

The Performance Standard of the Aluminium Stewardship Initiative (ASI, 2019) includes principles for the respect of human rights especially in the context of local community relationships, resettlement, and cooperation with indigenous people, in order to obtain their free and informed consent before the approval of any project affecting their lands or territories.

Guinea, which holds the most extensive world reserves of bauxite, is 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 the Human Rights Watch (2018), focusing on the 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, loss of farmlands, undermined air quality etc.

3.6 Comparison with previous EU assessments

The assessment has been conducted using the revised methodology introduced in the 2017 assessment. For bauxite, the calculation of the supply risk (SR) was carried out at the extraction stage of the value chain, and for primary aluminium at the processing stage, in both cases using both the global HHI and EU HHI calculation as prescribed in the methodology. No assessment has been made of the criticality of the intermediate stage between bauxite and primary aluminium, namely the production of alumina. The same stages for each material were evaluated in the 2017 exercise. It has to be noted that the assessment for aluminium does not address the aluminium ingot supply (i.e. aluminium metal), but only primary aluminium. The results of this and earlier assessments are presented in Table 22.

Table 22: Economic importance and supply risk results for bauxite and aluminium in the assessments of 2011, 2014, 2017, 2020 (European Commission 2011)(European Commission 2014b)(European Commission 2017b)

Assessment	2011			2014			2017			2020	
Indicator	EI	SR		EI	SR		EI	SR		EI	SR
Bauxite	9.5	0.3		8.5	0.6		2.6	2.0		2.9	2.1
Primary Aluminium	8.9	0.2		7.6	0.4		6.5	0.5		5.4	0.6

The revised criticality methodology affects both the economic importance (EI) and supply risk (SR) calculations; therefore the calculated indicators of EI and SR are not directly comparable with results of the 2011 and 2014 assessments. For example, the decrease of economic importance of bauxite between 2014 and 2017 is an interpretation biased by the change in methodology.

For bauxite, the supply risk indicator is marginally higher (SR=2.06, rounded to 2.1) in comparison to the 2017 assessment (SR=2.04, rounded to 2.0). For primary aluminium, the SR result is slightly higher (SR=0.59, rounded to 0.6) compared to the 2017 assessment (SR=0.49, rounded to 0.5), reflecting the rising trend in the concentration of global supply.

The calculation of economic importance is based on the use of the NACE 2-digit sectors and the value-added for the identified sectors (see Table 2 and Table 3). The figures used for the value-added were the averages of the period 2012-2016, corresponding to 27 Member States (i.e. excluding UK).

For bauxite, the same allocation of end uses and corresponding 2-digit NACE sectors was applied in the 2017 and the current assessment for the calculation of the economic importance indicator (EI). The increase in EI in comparison to the 2017 assessment can be attributed to the results scaling step[28], because the value-added of the largest manufacturing sector in the current assessment is lower, as it corresponds to 27 Member States (i.e. excluding UK). In contrast, in the 2017 assessment it was related to EU28.

The calculation of economic importance for aluminium is not straightforward due to its wide-ranging end uses. Hence, for the mobility application sector, two 2-digit NACE sectors have been applied and the calculation formula adjusted to accommodate this. In reality, other 2-digit NACE sectors may include some aluminium which have not been incorporated into the assessment. The difference in the EI of aluminium compared to the previous assessment is attributed to the fact that to each of the applications 'Transport' and 'Automotive' the whole percentage of Al demand (39%) was allocated in 2017. In the current assessment, the updated share of total demand (42%) for these two applications is equally split between them (21% each). Moreover, the applications of "Consumer durables" in the current assessment is associated with the more relevant 2-digit NACE sector C25 "Manufacture of fabricated metal products, except machinery and equipment" and not with the sector C28 "Manufacture of machinery and equipment not elsewhere specified".

3.7 Data sources

The source of bauxite and primary aluminium production data was 'World Mining Data' published by the Austrian Federal Ministry for Sustainability and Tourism and the International Organising Committee for the World Mining Congress. Trade data were extracted from Eurostat's Comext database. The dataset developed by the EU MSA study of aluminium was the source for the EoL-RIR. Data on trade agreements are taken from the DG Trade webpages, which include information on trade agreements between the EU and other countries. Information on export restrictions is derived from the OECD database on export restrictions on Industrial Raw Materials. The European Aluminium Association was the source of end-uses for aluminium products in Europe, and the Aluminium/Bauxite factsheet of the 2017 assesment the source for bauxite end-uses.

[28] The results are scaled by dividing the calculated EI score by the value of the largest manufacturing sector NACE Rev. 2 at the 2-digit level and multiplied by 10, in order to reach the value in the scale between 0-10.

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3.8 Acknowledgments

This factsheet was prepared by the JRC. The authors would like to thank the Ad Hoc Working Group on Critical Raw Materials, as well as experts participating in SCRREEN workshops for their contribution and feedback.