The first 200 years of aluminum - what comes next?

Ken Evans

28th June 2024

Aluminum – a growth industry in crisis!

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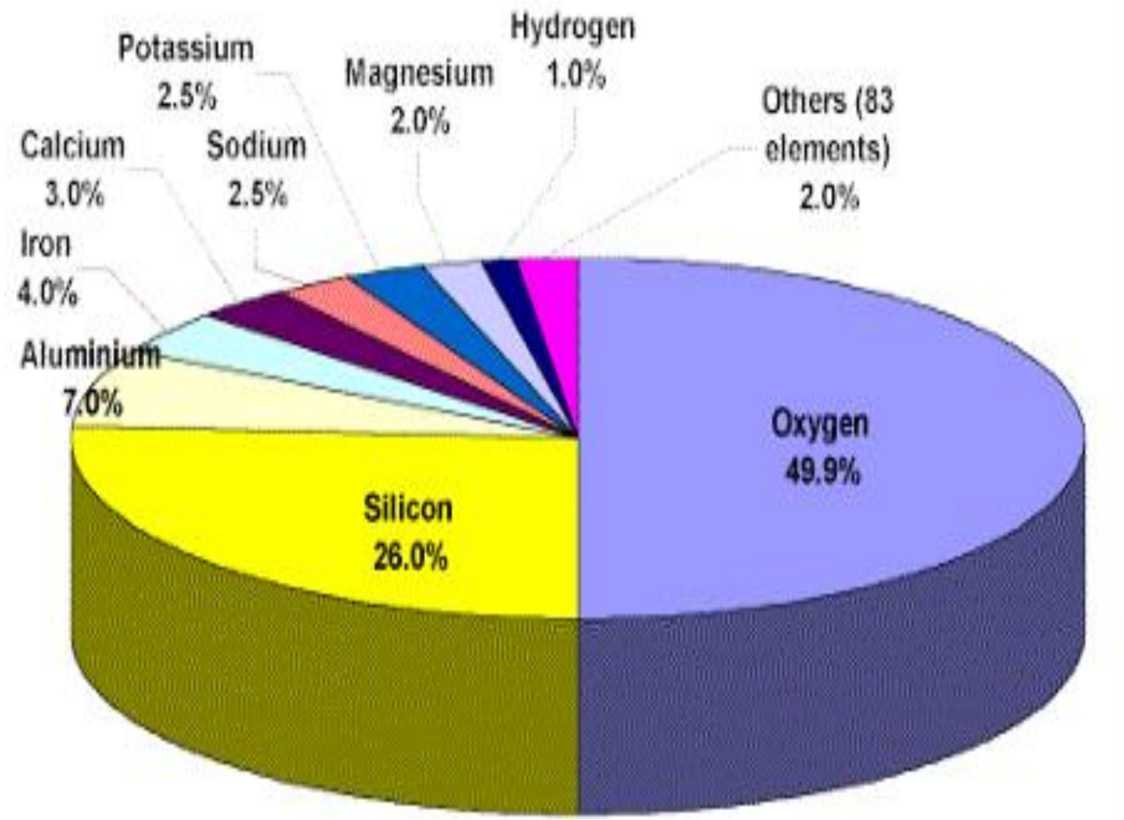
Topics

- Early history.
- Overview of technology to make aluminum from bauxite:
    - Bayer process → Calcination → Hall-Héroult;
    - Alternative routes;
    - Major technical changes in the manufacturing routes since 1890s.
- Driving forces behind locations of production.
- Current production of bauxite, alumina and aluminum.
- How this has changed dramatically since 2020.
- Areas of growth and predictions for aluminum demand to 2050.
- SGA and NMGA
- Major issues the industry is facing: decarbonization, red mud/bauxite residue, availability of bauxite.
- A few comments on how the industry and regions are approaching these problems.
- Where next for the industry?

Aluminum in the earth's crust

- 3rd most abundant element
- Most abundant metal in the earth's crust – 8.23%
- Never present as the metal in nature
- Main component of aluminosilicate rocks and clays
- Group 3 in the periodic table with gallium, indium, and thallium



1808 - Davy tries to isolate aluminum

- Aluminum compounds were known by the Egyptians (1000 BC) and Romans – alum. Mordant and tanning.
- English chemist Sir Humphry Davy (1778-1829) exposed red hot alumina to potassium vapour without effect.
- Davy made extensive experiments aiming to break down the aluminum oxide (alumina) by electrolysis in molten salts. He did not succeed in producing pure aluminum but was able to prepare an aluminum-iron alloy.
- "Had I been so fortunate as to have [...] procured the metallic substances I was in search of, I should have proposed [...] the name of alumium".

1821 - Discovery of bauxite

French professor Pierre Berthier (1782-1861) discovers aluminum ore, bauxite, while prospecting for iron ores in southern France.

- Named “Terre d’alumina des Beaux” after the village of Les Beaux (Provence) where discovery was made.
- It was considered as a possible iron ore source due to its red color, but was found to contain too much aluminum oxide.
- Name was later changed to “beauxite” and then to “bauxite”.
- First thought to be $Al_2O_3.2H_2O$, but later found to be a mixture of the hydroxides $Al(OH)_3$ and AlOOH.

1825 - Ørsted prepares first (impure) sample of aluminum metal

- Danish physicist Hans Christian Ørsted (1777-1851) was in 1824 the first to prepare $AlCl_3$ by passing a stream of chlorine gas over a mixture of alumina and carbon.
- Tried to isolate aluminum metal by reacting $AlCl_3$ with potassium amalgam in 1825.
- When mercury was distilled away, a residue resembling tin was obtained.
- Never repeated his experiments, did not further work on aluminum.
- Sample was impure (aluminum amalgam, containing potassium).

1827- Wöhler prepares first samples of aluminum

- German chemist Friedrich Wöhler (1800-1882) started to work on aluminum after a visit to Ørsted.
- Heated mixture of $AlCl_3$ and potassium metal in a crucible (violent reaction).
- Reaction mass was treated with water to remove KCl.
- Aluminum was produced in the form of a grey powder, but the small amount was insufficient to establish the properties of the metal.
- Stopped for 18 years to work further on aluminum.

1845 - Wöhler produces first pure Al samples

- Wöhler continues his previous studies on aluminum.
- Produces 10–15 mg of metal globules by passing $AlCl_3$ vapour over molten potassium.
- Determines properties of aluminum, including density, malleability, and ductility.
- Discovered that aluminum has a relatively low melting point (660°C).
- Amount of aluminum prepared was so small that the metal remained a rarity.

1854 - Reduction process with sodium

- French chemist Henri Sainte-Claire Deville (1818-1881) develops a process to prepare aluminum metal by reduction of $AlCl_3$ with sodium.

- Sodium is less reactive and easier to handle than potassium and can be produced more cheaply.

1855 - first aluminum objects

- Sainte-Claire Deville makes an aluminum medal that he offered to Wöhler in recognition of Wöhler's work of 1827.
- Bars of aluminum produced by Sainte-Claire Deville were presented to the public at the World Exhibition in as 'silver from clay'.
- In those days, the metal was significantly more expensive than gold and Napoléon III proudly displayed aluminum cutlery at his state banquets.
- With the support of Napoléon III, Sainte-Claire Deville sets up the first plant for aluminum production in Javel, close to Paris. (Napoléon III was hoping to develop lightweight body armour for his cavalry).

1884 – Washington memorial

- A 6 pound pyramid of aluminum was placed on top of the Washington memorial

1986 - Electrolysis process to make aluminum

- On 23 April, Héroult files a patent for the production of aluminium by fused-salt electrolysis of alumina dissolved in a molten cryolite bath.
- On 9 July, Hall files a patent for the production of aluminium by fused-salt electrolysis of alumina dissolved in a molten cryolite bath.
- Hall was able to prove that he had made aluminium by the new method before the date of the French patent to obtain patent protection in the United States. Evidence from his family and former teacher Jewett, including two postmarked letters to his brother, George, helped to establish the priority of Hall's discovery in the United States (successful experiment on February 23, 1886)
- Hall got the patent rights for the USA and Héroult for Europe

Electrolyis patents

Charles Martin Hall

- US patent 400664, "Process of Reducing Aluminium from its Fluoride Salts by Electrolysis", issued 2nd April 1889

Paul Héroult

- French patent no. 175,711 Filed: 23 April 1886; issued: 1st September 1886

Coincidence Hall and Héroult (1863-1914)

- Finding an economical process for refining aluminium was widely recognized as a prime target for inventors
- Electrochemistry had begun to mature as an applied science.
- Large electricity-generating dynamos were being developed commercially.
- Interest had been aroused in the chemistry of fluorine-containing substances.
- Hall and Héroult were skilled experimentalist, who not only devised a method of making aluminium metal, but made most of their apparatus and prepared many of their chemicals.
- Héroult and Hall had good access to scientific journals and where following the latest developments in the field
- Héroult and Hall had a burning desire to be a successful inventor and industrialist.

Bayer process 1888 - 1892

- Karl Josef Bayer (1847-1904) modified the Le Châtelier process in two stages
- Bayer developed his process while working for the Tentelev Chemical Plant (St. Petersburg, Russia), $Al(OH)_3$ was used as a mordant for dyeing textiles
- 1888: replaced CO_2 by seed of $Al(OH)_3$ on which precipitation took place by vigorous agitation. Product was pure and easily filterable
- 1892: introduced the pressure leaching step (in an autoclave) which transformed the process into a fully hydrometallurgical process.
  (= first high-high pressure hydrometallurgical process)
  He also found that the alkaline mother liquor obtained after the precipitation of $Al(OH)_3$ could be recycled
- Process based on his two patents became known as the *Bayer process*
- Process received immediate recognition and is used today in practically the same way as described in the original patents.

Alumina plants

- 1893 - Gardanne in France using bauxite from Les Baux.
- 1894 - British Aluminium in Larne, UK using local bauxite.
- 1903 – Pittsburgh Reduction Company in East St Louis, Illinois using bauxite from Arkansas.

1888 - Aluminum production in USA

- Charles Hall, with the support of his friends, established the Pittsburgh Reduction Company which launched its first smelter in Kensington outside Pittsburgh on 18^{th} September 1888. It produced only 20-25 kg of aluminium per day in the first few months, but quickly accelerated to 240 kg daily by 1890.

- The Pittsburgh Reduction Company built new smelters in New York State near the new Niagara hydroelectric power station. The Pittsburgh Reduction Company was reorganised into the Aluminium Company of America, Alcoa in 1907.

1888 - Aluminum production in Europe

- Switzerland
  - 1888 Héroult backed by the Swiss Metallurgical Society and Rathenau built a plant in Neuhausen to make aluminum next to a hydro- electric power station. Several expansions from 40 tonnes of aluminum in 1890 to 450 tonnes in 1895.
  - Later to become Alusuisse.
- France
  - 1889 April in Froges near Grenoble.
- UK
  - 1894 Foyers (Scotland) – Lord Kelvin, British Aluminium.

Bauxite to aluminum route

Very dependent on the quality of bauxite and the process route but approximately:

- 4 tonnes of bauxite
- 2 tonnes of aluminum oxide (via aluminum hydroxide)
- 1 tonne of aluminum metal

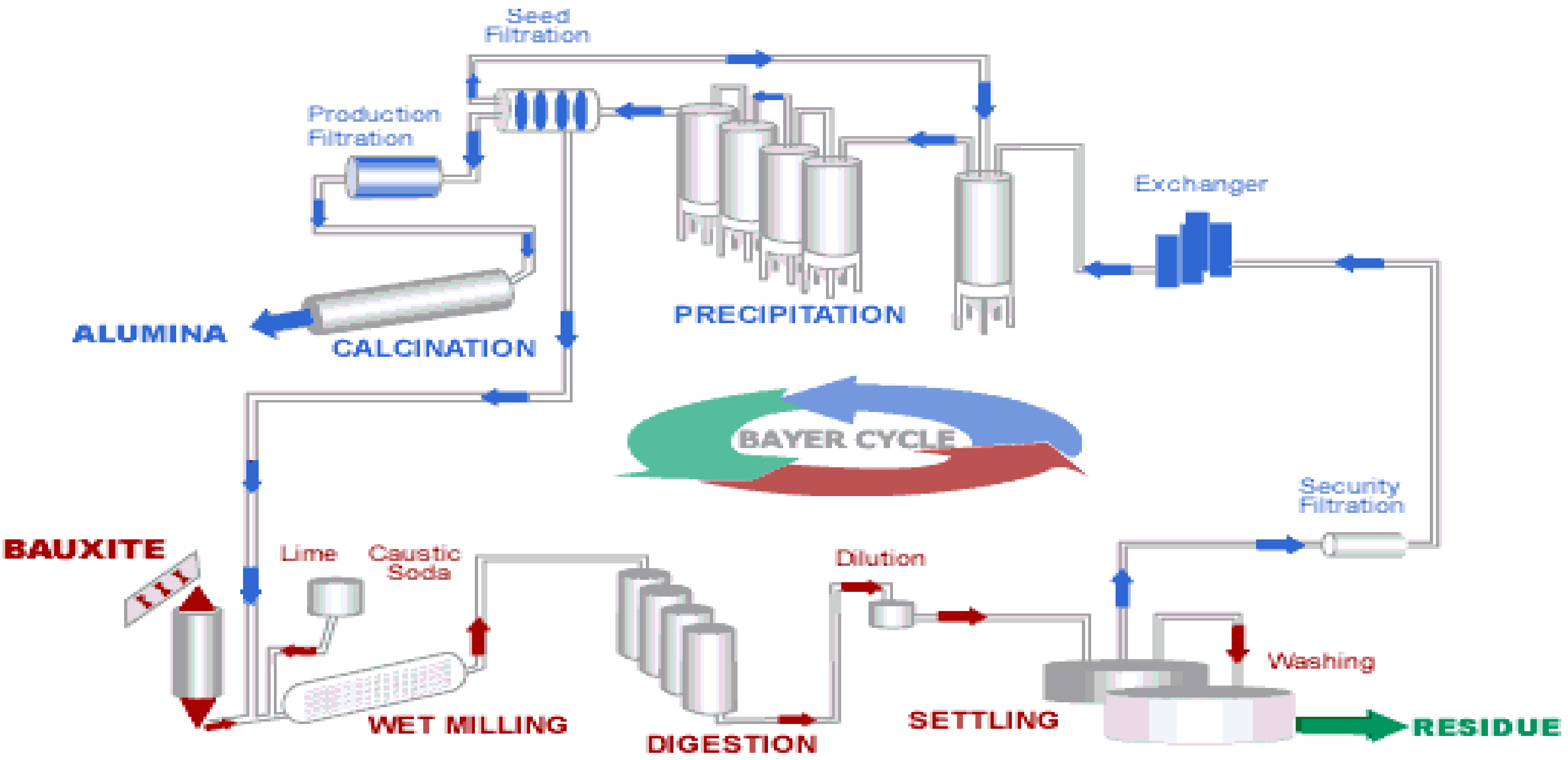
Also produces:

- 2.5 tonnes of bauxite residue
- 16 tonnes of CO_2 equivalent (4 t for HEP, 20 t for coal)

Bauxite: types and distribution

- Types:
  - Lateritic – high in gibbsite – generally found in equatorial regions: Brazil, Ghana etc.
  - Karstic – high in boehmite – generally found in temperate zones: Greece, Hungary etc.
- Aluminous compounds present
  - Gibbsite - $Al(OH)_3$
  - Boehmite - AlOOH
  - Diaspore - AlOOH
- Main impurities
  - Oxides of iron, titanium, calcium, silicon (reactive (kaolin) and crystalline (quartz)), organics
- Minor impurities
  - Magnesium, manganese, chromium, vanadium, zinc, zirconium, rare earths, thorium, uranium etc

Bayer process



Digestion processes for bauxite

Varies by type of bauxite composition:

- Gibbsitic
  - 140 to 155°C , pressure 3 atmospheres, sodium hydroxide concentration 2.4 to 2.75 M
- Boehmitic
  - 240 to 250°C, pressure 6 atmospheres, sodium hydroxide concentration 3.5 to 3.75 M
- Diasporic
  - 250 to 280°C

Industrial process routes for alumina

Bauxite to aluminum oxide (alumina) to aluminum

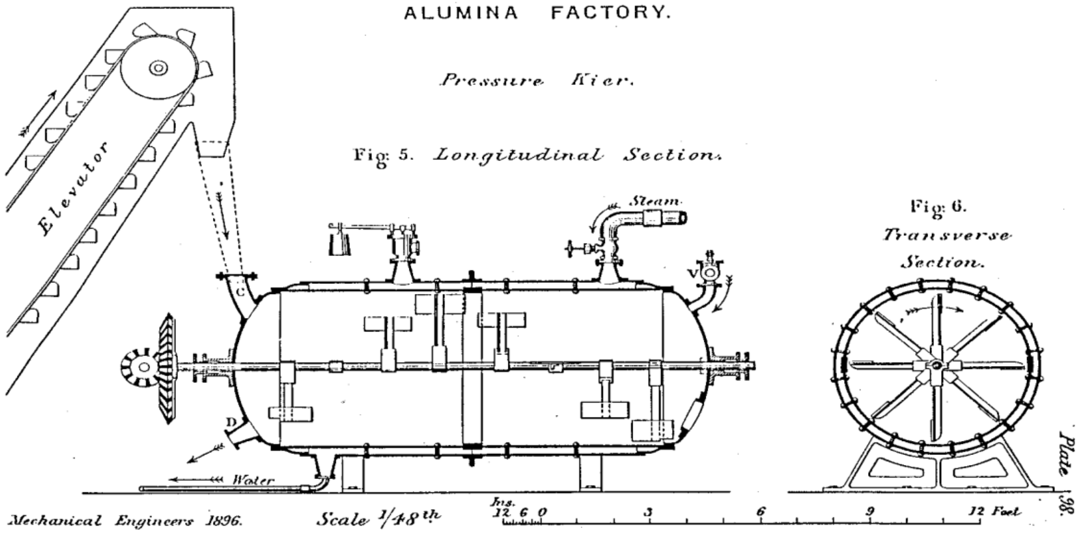
- Aluminum oxide (alumina)
  - 96% produced via Bayer process from bauxite
  - 2% from nepheline syenite
  - 2% via Bayer sinter route

- Initial plants 10,000's t/a

- Now many plants at 3 to 4 Mt/y, largest at 6.3 Mt/a

Alumina production scale

1893 - Bayer design 10,000 t/y



100 years later 6.3 Mt/y

Locations of plants

Rationale for plant locations - alumina

- Historically
  - Power - coal, lignite etc.
  - Bauxite availability
  - Port
  - Proximity to industrialized areas
- 1950-1970s
  - Next to bauxite deposits
  - Port
  - Move to Jamaica, Suriname, Australia
  - Larger plants > 2 Mt/y
- 2000s
  - Political
  - China India
- Future
  - Political
  - Bauxite availability
  - Bauxite residue issues/tax
  - China
  - India
  - Indonesia

Rationale for plant locations - smelters

- Initially
  - Power
  - HEP
  - Industrialized areas
- 1950 - 1970s
  - Power
  - Integrated plants to alumina refineries
- 2000s
  - Cheap gas move to Middle East
  - China
  - India
- Future
  - Green electricity
  - Political
  - Political stability
  - Carbon taxes

Changes in Bayer alumina production

- Basic process remains the same as Bayer's patents
- Huge scale up in size give efficiency improvements
- Extraction conditions changed to match the bauxite characteristics
- Sweetening with better quality bauxites
- Much better control of soda recovery
- Better heat recovery
- Minimization of water utilization
- Better control of crystallization process - particle size, morphology
- Improved management of red mud/bauxite residue/processed bauxite

Alternatives to the Bayer process

A) Anorthosite - anorthite $CaAl_2SiO_3$ and albite $NaAlSi_3O_3$

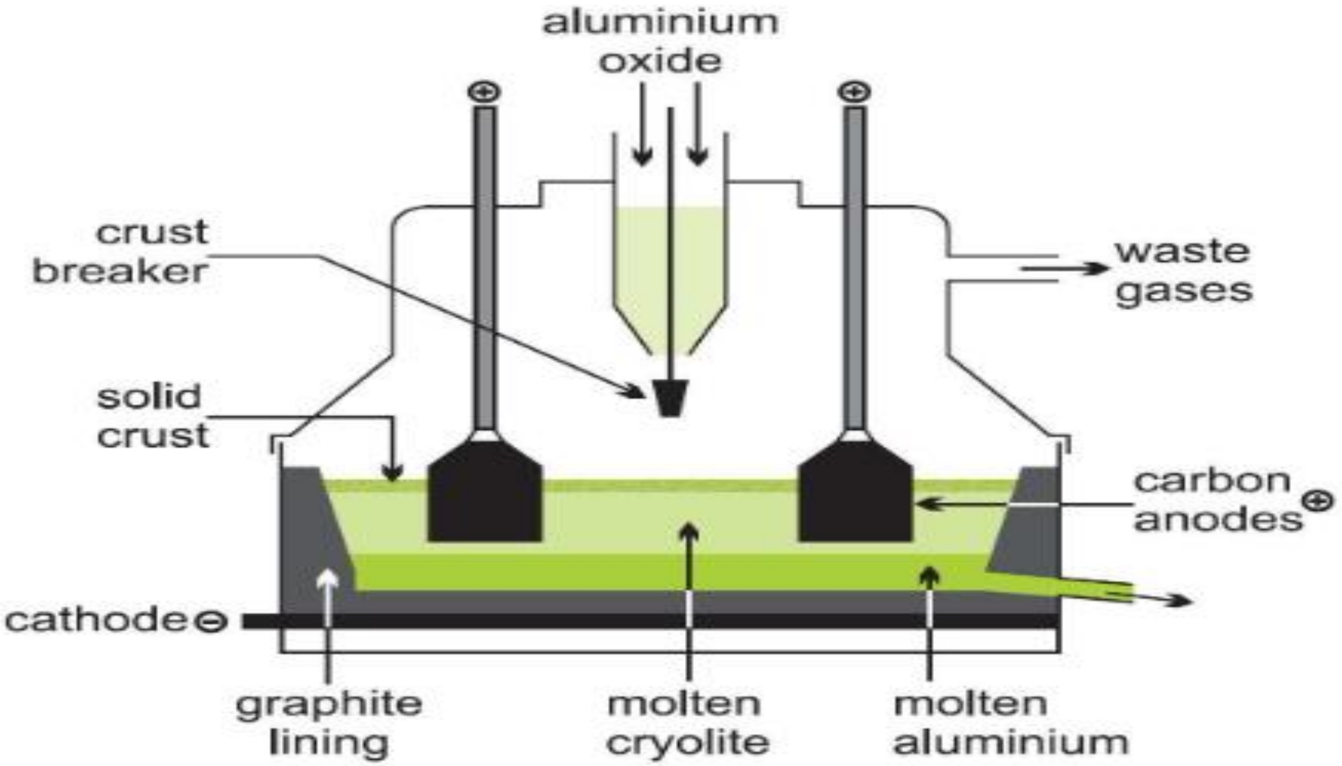
- Mixed with limestone and sodium carbonate calcined at 1250-1300°C.
- Leached with water.

B) Nepheline - $Na_3KAl_4Si_4O_{16}$ and nepheline syenite

- Calcined with limestone

- C) Clay – low pH route (HCl) – used for high purity alumina
- D) Fly ash – small plants China
- E) Pedersen process - bauxite + limestone + coke – pig iron recovered - alumina recovered from calcium aluminate slag – 17,000 t/y in Norway 1928-1969

Electrolytic cell to make aluminum



Aluminum by the electrolytic process

- $2\ O^{2-} + C \rightarrow CO_2 + 4\ e^-$
- $2\ Al_2O_3 + 3\ C \rightarrow 4\ Al + 3\ CO_2$
- Pure cryolite has a melting point of 1009°C. With a small percentage of alumina dissolved in it, its melting point drops to about 1000°C. Besides having a relatively low melting point, cryolite is used as an electrolyte because, among other things, it also dissolves alumina well, conducts electricity, dissociates electrolytically at higher voltage than alumina, and also has a lower density than aluminum at the temperatures required by the electrolysis.
- Aluminium fluoride (AlF_3) is usually added to the electrolyte. The ratio NaF/AlF_3 is called the cryolite ratio and it is 3 in pure cryolite. In industrial production, AlF_3 is added so that the cryolite ratio is 2–3 to further reduce the melting point, so that the electrolysis can happen at temperatures between 940 and 980°C. The density of liquid aluminum is 2.3 g/mL at temperatures between 950 and 1000°C. The density of the electrolyte should be less than 2.1 g/mL, so that the molten aluminum separates from the electrolyte and settles properly to the bottom of the electrolysis cell. In addition to AlF_3, other additives like lithium fluoride may be added to alter different properties (melting point, density, conductivity etc.) of the electrolyte.
- The mixture is electrolysed by passing a low voltage (under 5 V) direct current at 100–300 kA through it. This causes liquid aluminium to be deposited at the cathode, while the oxygen from the alumina combines with carbon from the anode to produce mostly carbon dioxide.

Changes in smelting process

- Move from Soderberg anodes – self baking anodes – released poly aromatic hydrocarbons
- Pre-bake anodes introduced in the 1970s
- Higher currents
- Average power intensity is 15 kWh/kg best < 13 kWh/kg of Al
- Better control of power
- Non-consumable anodes
- Several processes tried starting from aluminum chloride e.g. Toth

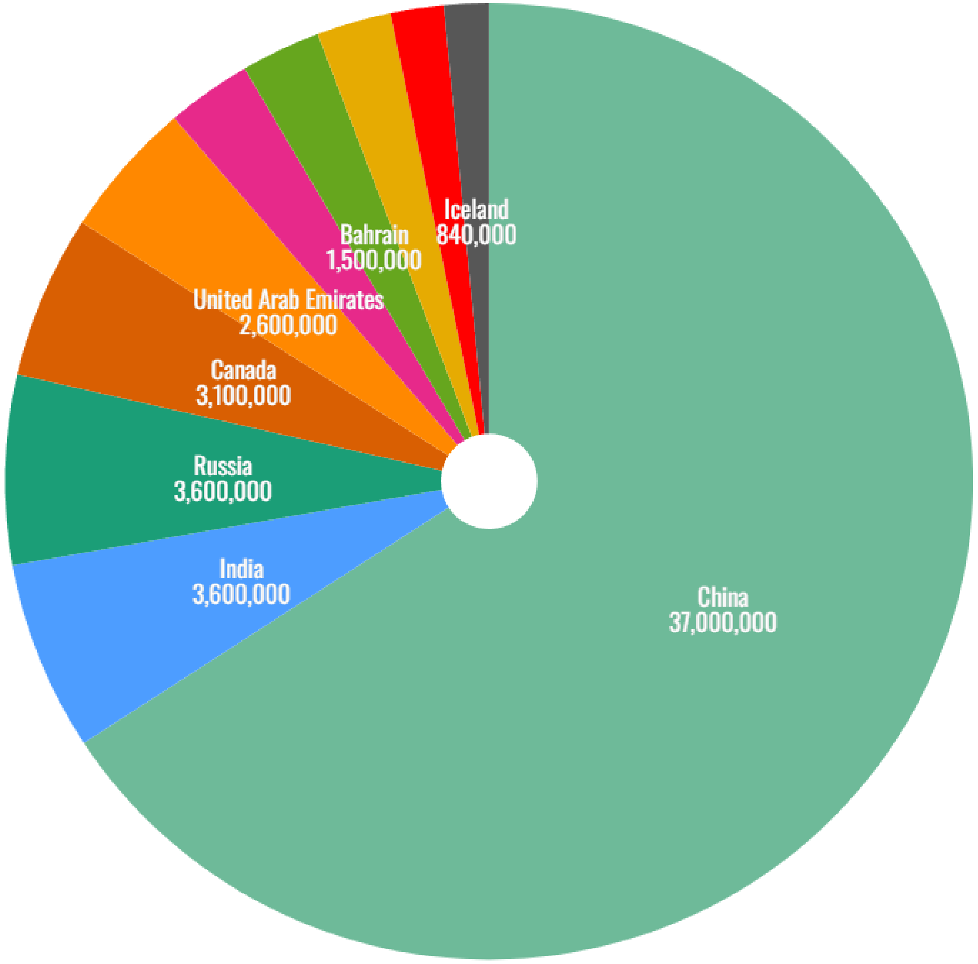
Carbon free aluminum technology

28th June 2024

- Rio Tinto to install carbon free aluminium smelting cells using first ELYSIS technology licence
- The plant will have the capacity to produce up to 2,500 tonnes of commercial quality aluminium per year without direct greenhouse gas emissions, with first production targeted by 2027. It will be located adjacent to the existing Arvida smelter, allowing the use of the current alumina supply and casting facilities.

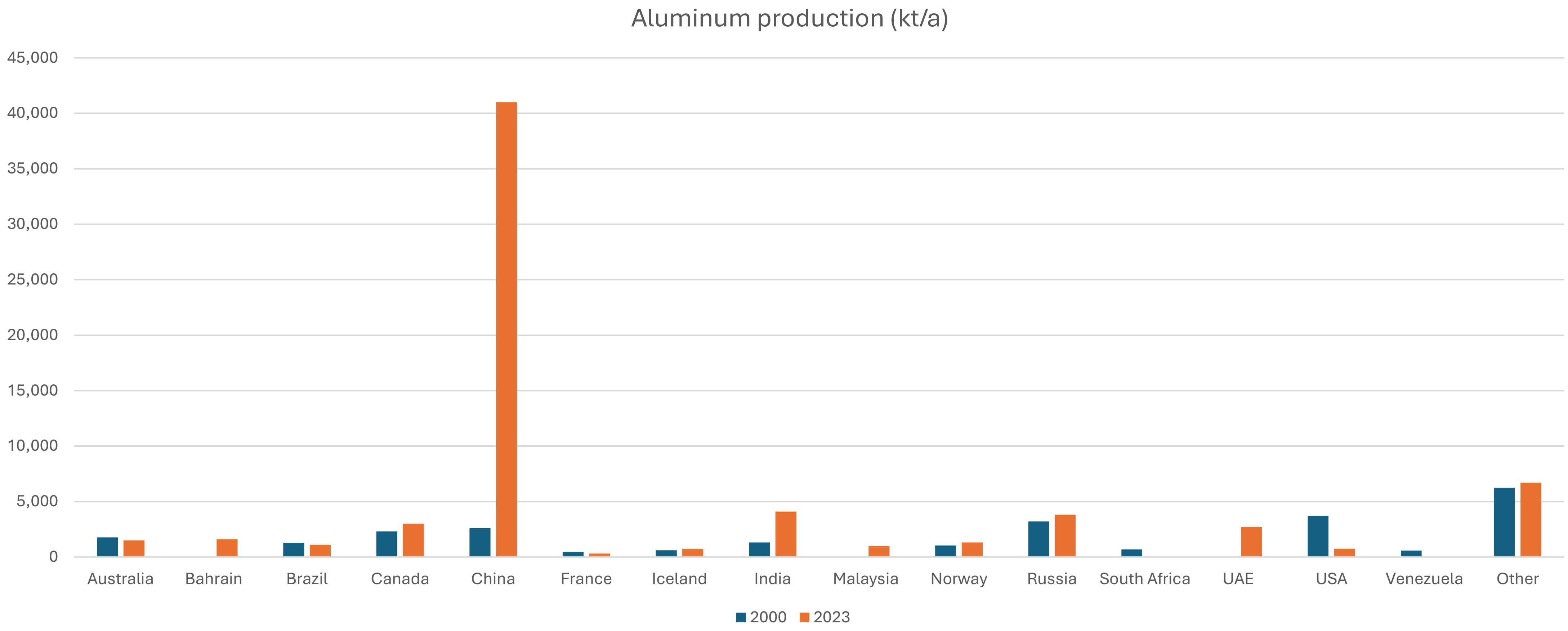
Production volumes
Aluminum, alumina, bauxite

Aluminum production by country 2020 (tonnes)



IAI data

Annual aluminum production 2000 - 2023



IAI data

Changes in aluminum production (kt/a)

	1995	2000	2023
Australia	1,300	1,770	1,500
Bahrain			1,600
Brazil	1,210	1,260	1,100
Canada	2,240	2,300	3,000
China		2,600	41,000
France	400	450	300
Iceland		1,030	730
India			4,100
Malaysia			980
Norway	845		1,300
Russia	2,710	3,200	3,800
South Africa		690	
UAE			2,700
USA	3,350	3,700	750
Venezuela	600	580	
Other	6,650	6,240	6,700
World	19,300	23,900	70,000

- Production between 2000 to 2023 increased by 103%
- Production in USA fell from 3.7 Mt to 0.75 Mt
- Huge growth in China, now produce 41 Mt (59%)
- Huge growth in India
- Huge growth in the Middle East
- Steady decline in Europe (except Norway)
- Venezuela stopped

IAI data

USA production and consumption

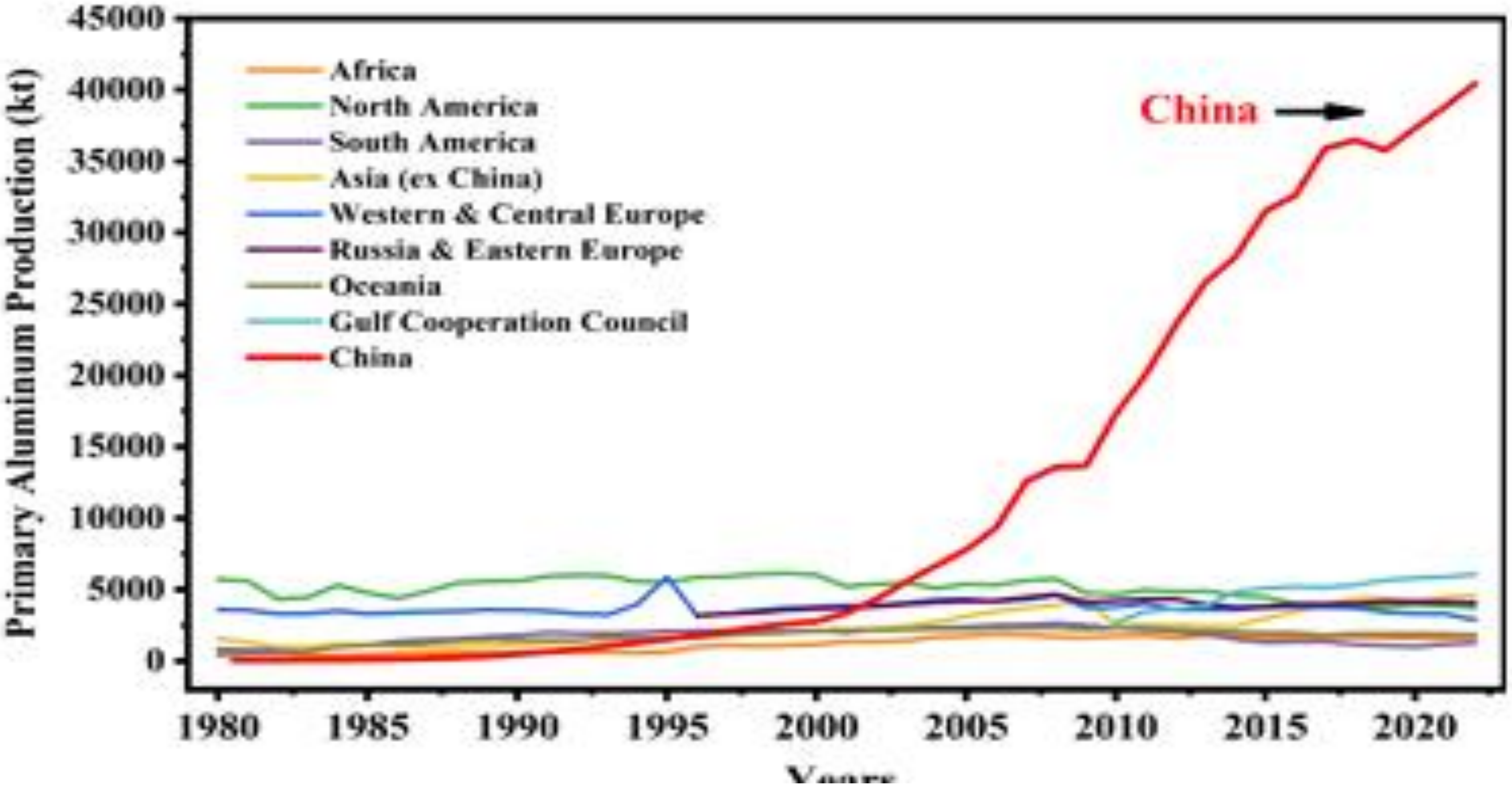
Salient Statistics—United States:	2019	2020	2021	2022	2023[e]
Production:					
Primary	1,090	1,010	889	861	750
Secondary (from old scrap)	1,540	1,420	1,520	1,450	1,500
Secondary (from new scrap)	1,920	1,630	1,780	1,890	1,800
Imports for consumption:					
Crude and semimanufactures	5,280	4,260	4,820	5,610	4,800
Scrap	596	542	680	690	740
Exports:					
Crude and semimanufactures	1,110	906	900	1,040	1,200
Scrap	1,860	1,840	2,100	2,000	2,100
Consumption, apparent[2]	4,980	3,930	4,020	4,760	4,000
Supply, apparent[3]	6,910	5,560	5,800	6,650	5,800
Price, ingot, average U.S. market (spot), cents per pound[4]	99.5	89.7	138.5	152.6	130
Stocks, yearend:					
Aluminum industry	1,600	1,490	1,870	2,050	1,800
London Metal Exchange (LME), U.S. warehouses[5]	120	235	69	9	4
Employment, number[6]	32,900	30,100	28,900	30,200	30,000
Net import reliance[7] as a percentage of apparent consumption	47	38	40	52	44

Recycling: In 2023, aluminum recovered from purchased scrap in the United States was about 3.3 million tons, of which about 55% came from new (manufacturing) scrap and 45% from old scrap (discarded aluminum products). Aluminum recovered from old scrap was equivalent to about 38% of apparent consumption.

Import Sources (2019–22): Canada, 52%; United Arab Emirates, 8%; Bahrain, 4%; Russia, 4%; and other, 32%.

USGS data

Primary aluminum production by region



IAI data

Alumina production by country (kt/a)

	Production	
country	2022	2023
Australia	19 500	19 000
Brazil	10 000	10 000
canada	1 360	1 600
china	81 900	82 000
Germany	1 000	720
Greece	860	860
Guinea	340	330
India	7 500	7 300
Indonesia	1 200	1 200
Ireland	1 630	1 200
Jamaica	634	1 500
Kazakhstan	1 340	1 300
Russia	3 080	2 400
Saudi Arabia	1 900	1 800
Spain	1 340	640
Turkey	300	290
Ukraine	300	closed
United Arab Emirates	2 430	2 300
United States	920	780
Vietnam	1 430	1 400
Other countries	1 200	880
World total (rounded)	140 000	140 000

USGS data

Alumina production changes - closures

Steady growth globally from 49.3 Mt in 2000 to 140 Mt in 2023

USA 4.8 Mt in 2000 to 0.8 Mt in 2023

- Decline with closure of Sherwin, Point Comfort, Burnside, St Croix
- One alumina refinery remaining – Gramercy

- Europe
  - Slow but steady decline - 5 remaining alumina refineries 7 Mt in 2023
  - Closure of Gardanne, Ajka, Burntisland, Bergheim, Schwandorf, Tulcea (shutdown)
- Australia 15 Mt in 2000 to 19Mt in 2023
  - Closure of Gove, Kwinana
- Jamaica 3.6 Mt in 2000 to 1.5 Mt in 2023
  - Closure of Kirkvine, Alpart (shutdown)
- Suriname – closure Suralco (1.6 Mt)

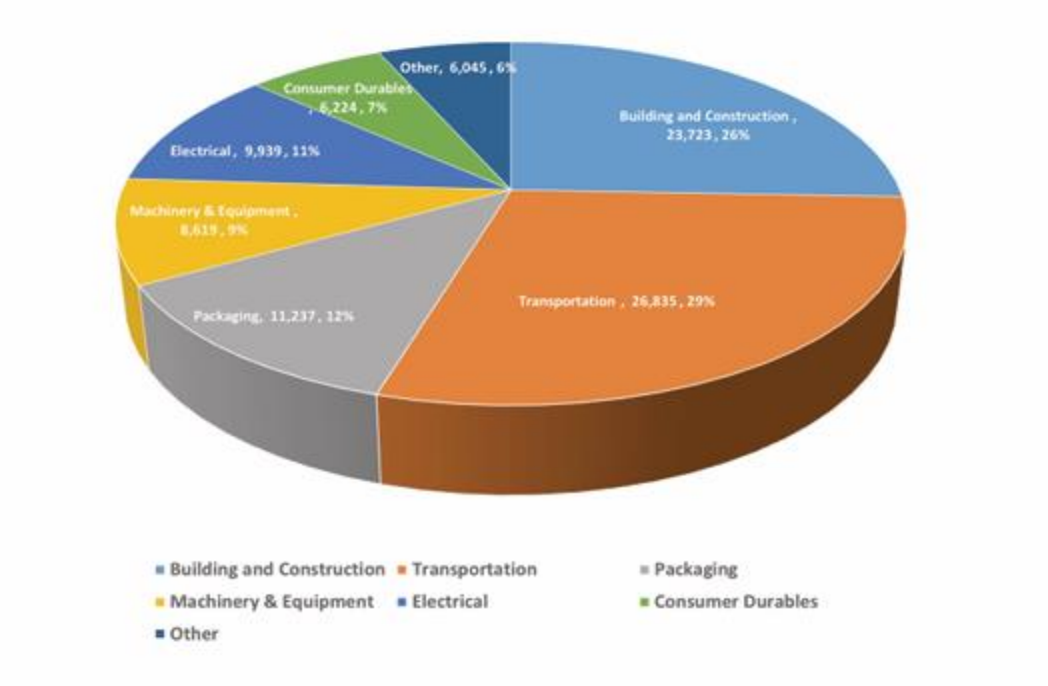
Alumina production – growth areas

- China – now has 44 alumina refineries with 20 having a capacity of > 2 Mt/y – 82 Mt in 2023
- India – 10 alumina refineries, rapid growth has occurred and is predicted 7.3 Mt in 2023
- Middle East - Saudi Arabia, UAE – 4.1 Mt
- Indonesia – 4 alumina refineries
- Vietnam – 1 but large expansions planned
- Guinea – 1 but several options being considered

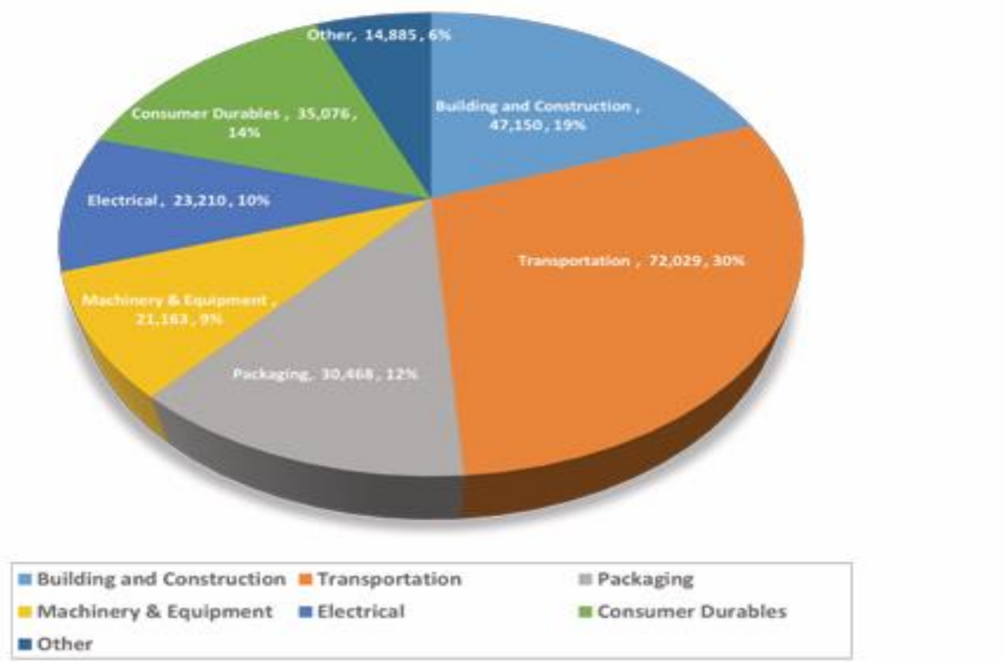
Aluminum growth

Demand for aluminum by application

2018 actual (93 ktpa)



2050 forecast (244 ktpa)

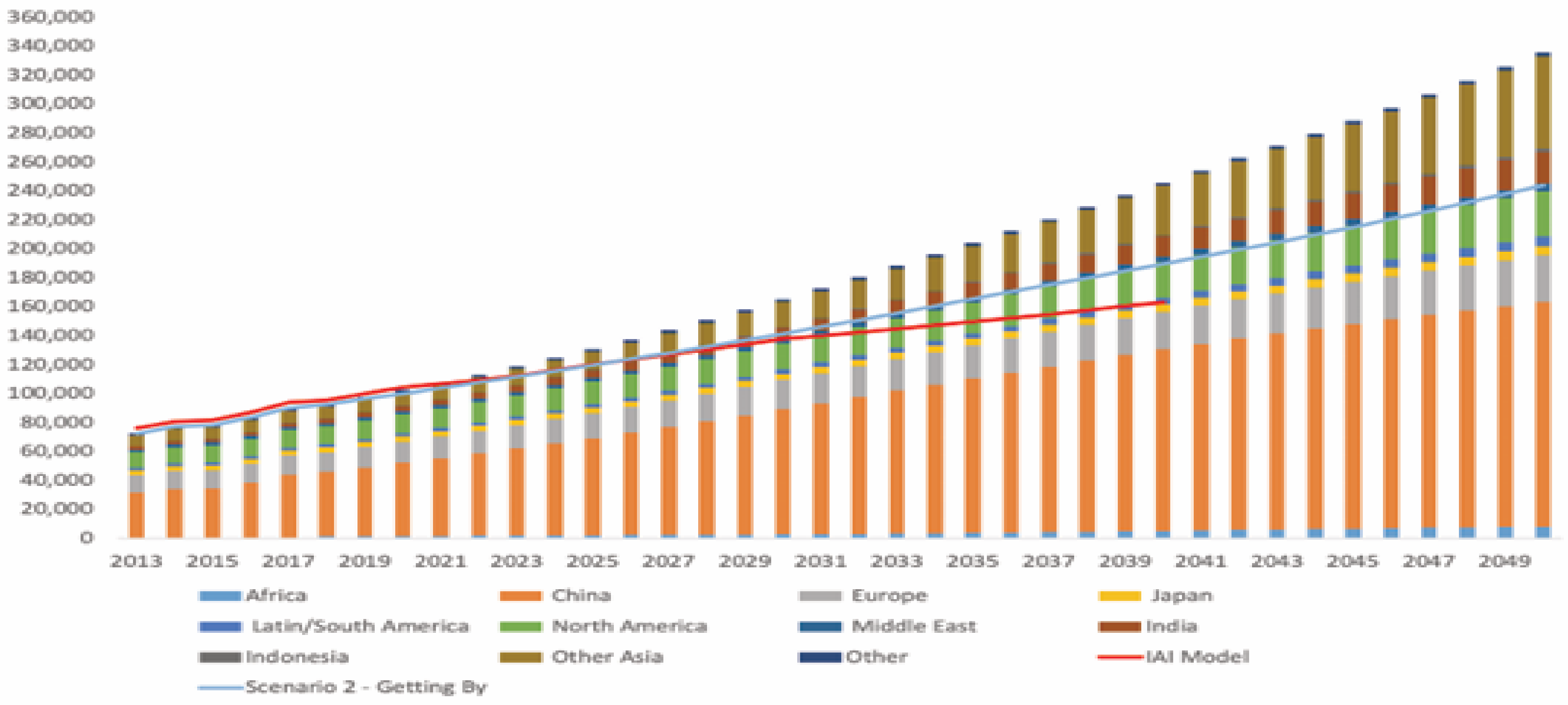


IAI data

Drivers for growth - aluminum in EVs

- Electric vehicles
- Up 250 kg for EV cf. 70 kg for ICE
  - Chassis, wheels, battery pack, electric housing protection
- Forecasts in Al usage
  - 2.1 Mt in 2020
  - 5.5 Mt in 2023
  - 8.6 Mt in 2026
  - 12.1 Mt in 2030

Aluminum growth 2013 to 2050



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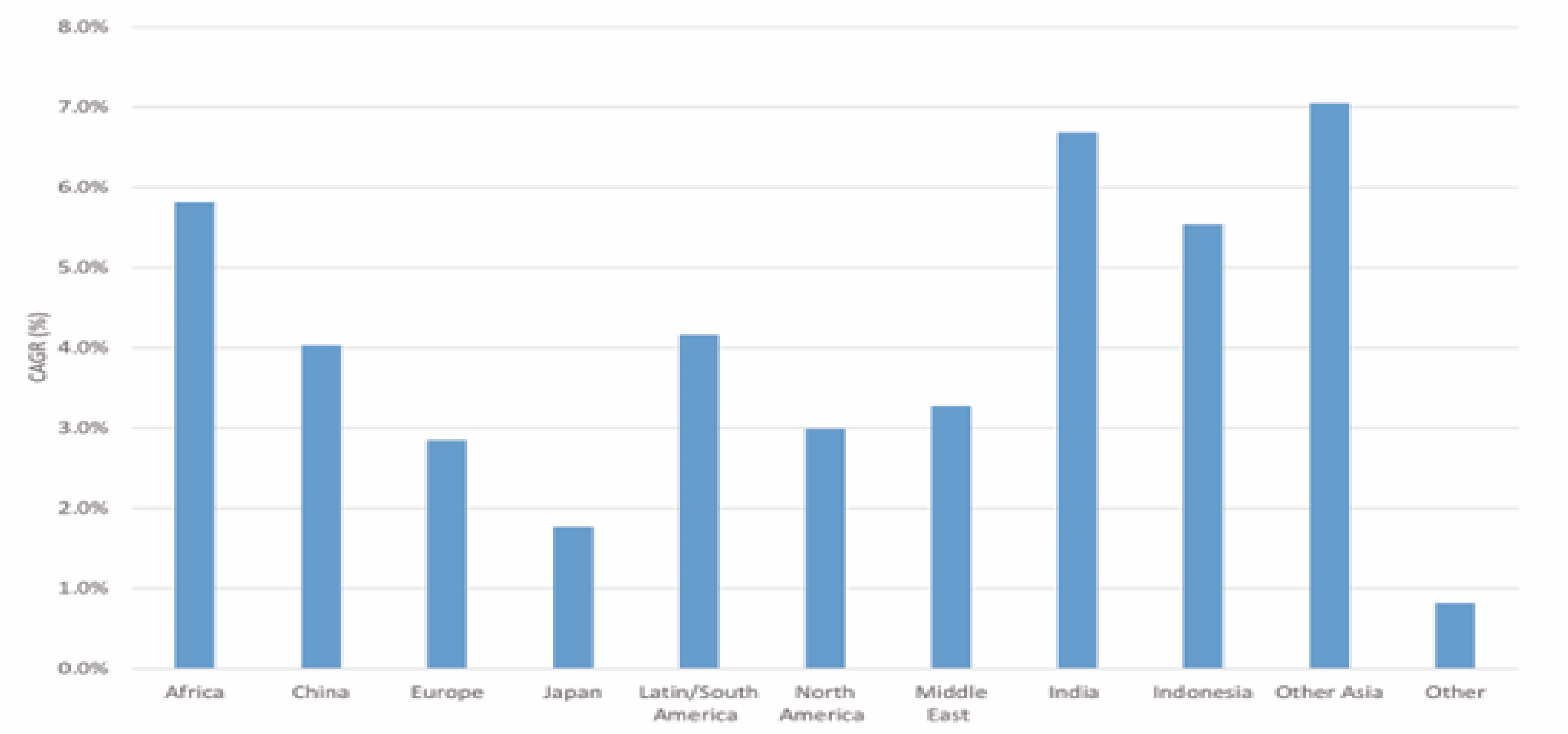
Forecast regional growth CAGR by region 2020 to 2050



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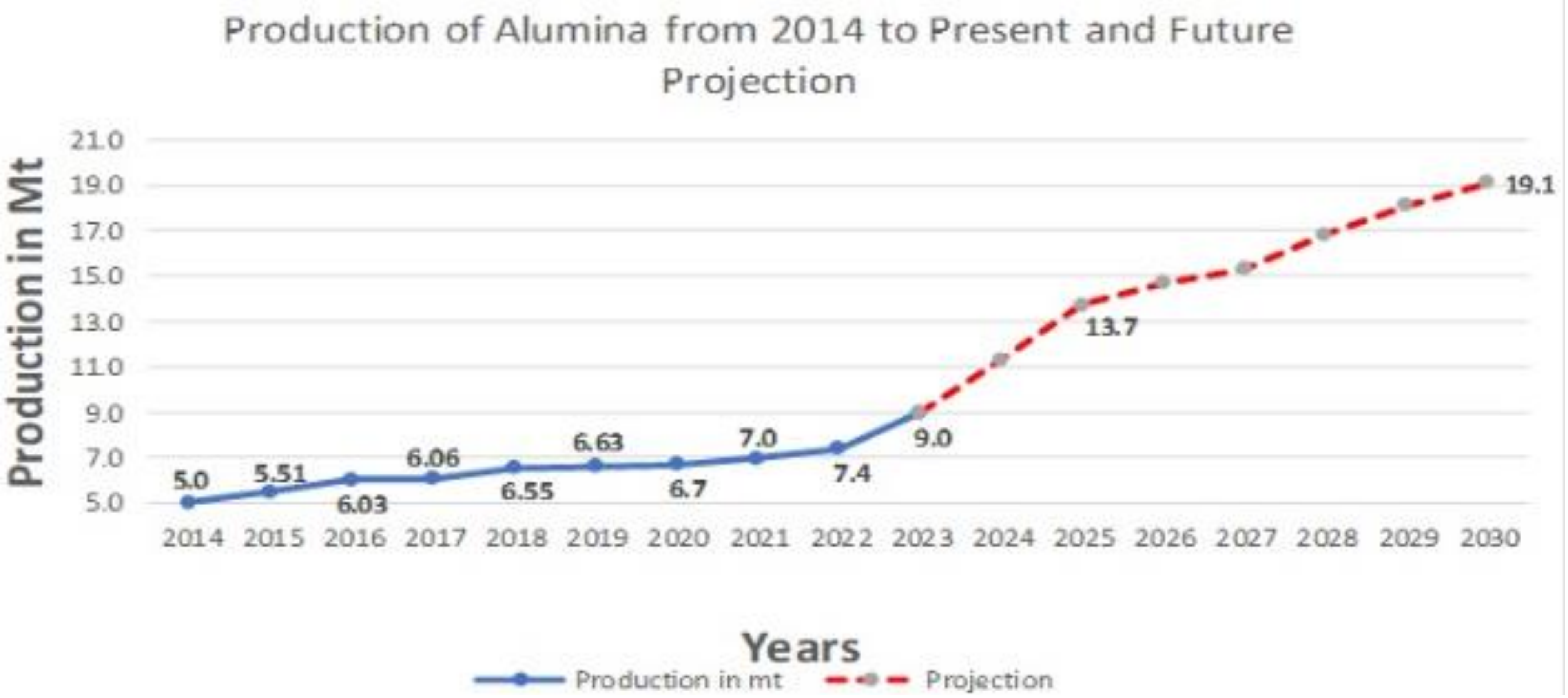
Alumina production India (Mt)



Alumina market

- Smelter grade alumina (SGA) or Metallurgical alumina for making aluminum metal

- Non-metallurgical alumina or Chemical grade
  - Commodity aluminum hydroxide
  - Speciality aluminum hydroxides
  - Speciality aluminum oxides

Aluminum hydroxide uses

- Aluminum sulfate manufacture
- PAC (poly aluminum chloride) manufacture
- Sodium aluminate manufacture
- Fine precipitated hydrate feedstock
- White hydrate feedstock
- Milled grades for fire retardants
- Toothpaste
- Pseudoboehmite production (FCC or other oil refinery catalysts)
- Aluminium fluoride production
- Glass manufacture, especially high quality glasses that require carefully controlled alumina levels, lenses etc.

Aluminum hydroxide uses - 2

- Glazes/frits
- Titania coating
- Zeolite production
- Ammonium aluminum sulfate production
- Aluminum nitrate
- Aluminum chloride production
- High purity aluminum hydroxide for stomach antacids
- Activated alumina feedstock
- Feedstock for speciality alumina production including ceramic, refractory aluminas
- Titania replacement in paper
- Titania replacement in paint

Speciality aluminum oxides

- Ceramic aluminas
  - Electronics
  - Armor plating for vehicles
  - Flak jackets
  - Tool tips aluminas
  - Chemical and erosion resistant pump parts
  - Spark plugs
  - Crucibles
  - Bone replacement parts

- Refractory aluminas
- Polishing aluminas
- Tabular aluminas
- Fused alumina

Issues

The issues facing the industry

- Waste management
  - Bauxite residue/red mud/processed bauxite (170 Mt/y)
  - Spent pot linings
- Electricity requirement in smelting
  - 3% of global CO_2 emissions
  - CO_2 taxes
  - Need to decarbonize
- Bauxite availability
  - Good quality, easily extractable bauxite deposits are being depleted
  - China has high silica bauxites
  - Dependency on Guinea

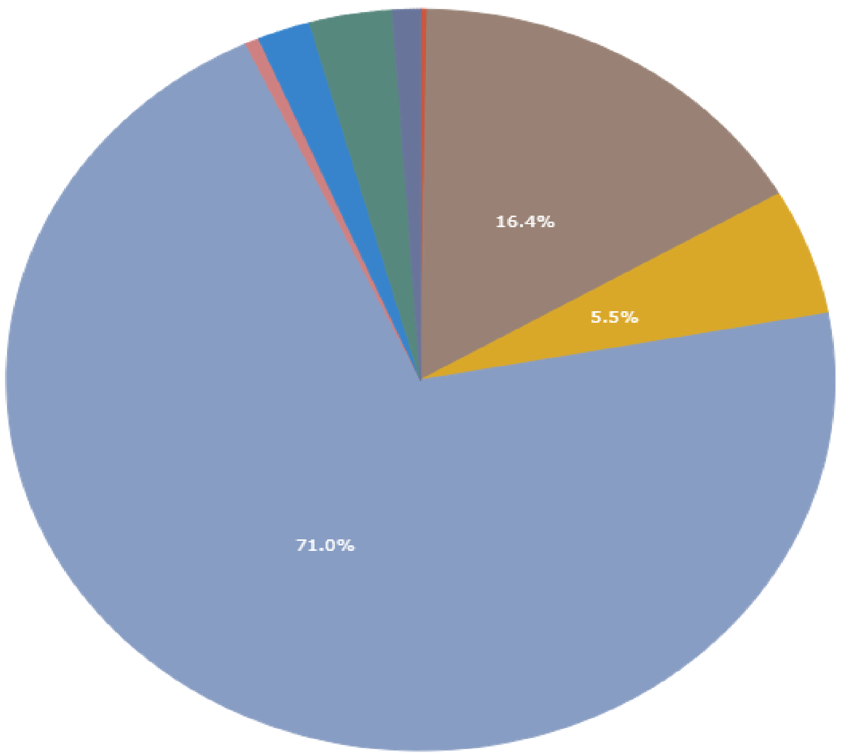
Bauxite residue - magnitude of the problem

- Annual alumina production 170 Mt in 2023 - 96% via Bayer process
- Range of bauxite residue produced per tonne of alumina – 0.5 to 4 t/t alumina
- Number of active alumina refineries – 75
- Number of closed residue disposal sites – over 50
- All residue disposed of on land – all disposal in estuaries, and at sea stopped at the end of 2016
- Only about 2 to 3% is used
- Amount stockpiled – 4,000 Mt – an enormous deposit to mine!

Major issues

- Decarbonization
  - The world's aluminum smelters consume about 3.5% of the total global electric power. Globally, the aluminum industry emits around 450 Mt of CO_2-equivalents annually (around 2% of world's total emission).
- Bauxite residue/red mud generation
  - The industry produces 170 Mt/a of waste
- Bauxite availability
  - Quality of readily available sources from 'stable' countries
  - Guinea – politically 'unstable'
  - Indonesia – drive to use the bauxite within Indonesia and not export

$CO_{2\ e}$ emissions aluminum sector



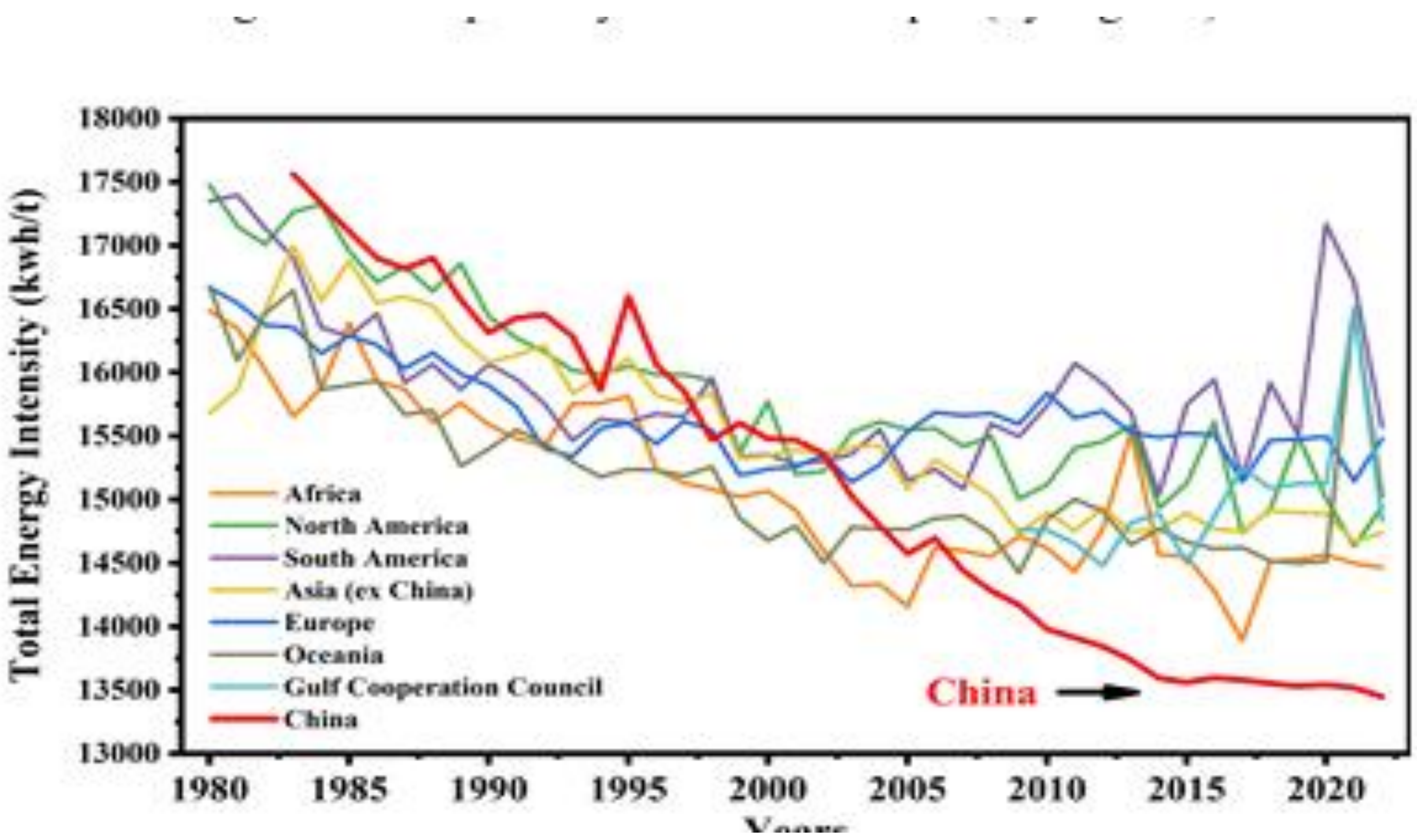
IAI annual statistics

Primary aluminum smelting power consumption (Gwh)

Period		Africa	North America	South America	Asia (ex China)	Europe	Oceania	Gulf Cooperation Council	China	World Reported	Estimated Unreported
2022	Aluminium Production (tonnes)	1,620,000	3,743,000	1,288,000	4,591,000	6,994,000	1,843,000	6,074,000	40,430,000	69,038,000	2,455,000
	Reporting Production (tonnes)	1,292,414	3,279,389	1,230,386	1,398,407	6,567,363	1,843,000	6,007,367	40,213,587	61,831,913	
	Power Mix										
	Hydro	8,147	46,819	22,841	1,159	111,198	16,274	0	103,832	310,270*	
	Other Renewable	0	257	625	167	3,932	1,424	810	30,825	38,039*	
	Other non-renewable	0	0	0	0	142	0	0	0	142*	
	Coal	10,344	1,828	95	21,277	777	18,126	0	402,890	455,337*	
	Oil	0	2	2	2	199	0	2	0	207*	
	Natural Gas	0	3	3,734	0	1,060	133	89,980	0	94,910*	
	Nuclear	0	30	28	0	1,772	0	0	3,245	5,075*	
	Total	18,491	48,939	27,324	22,606	119,081	35,956	90,791	540,792	903,980*	70,000*

IAI data

Aluminum intensity by region



IAI data

Routes to lower energy utilisation in smelting

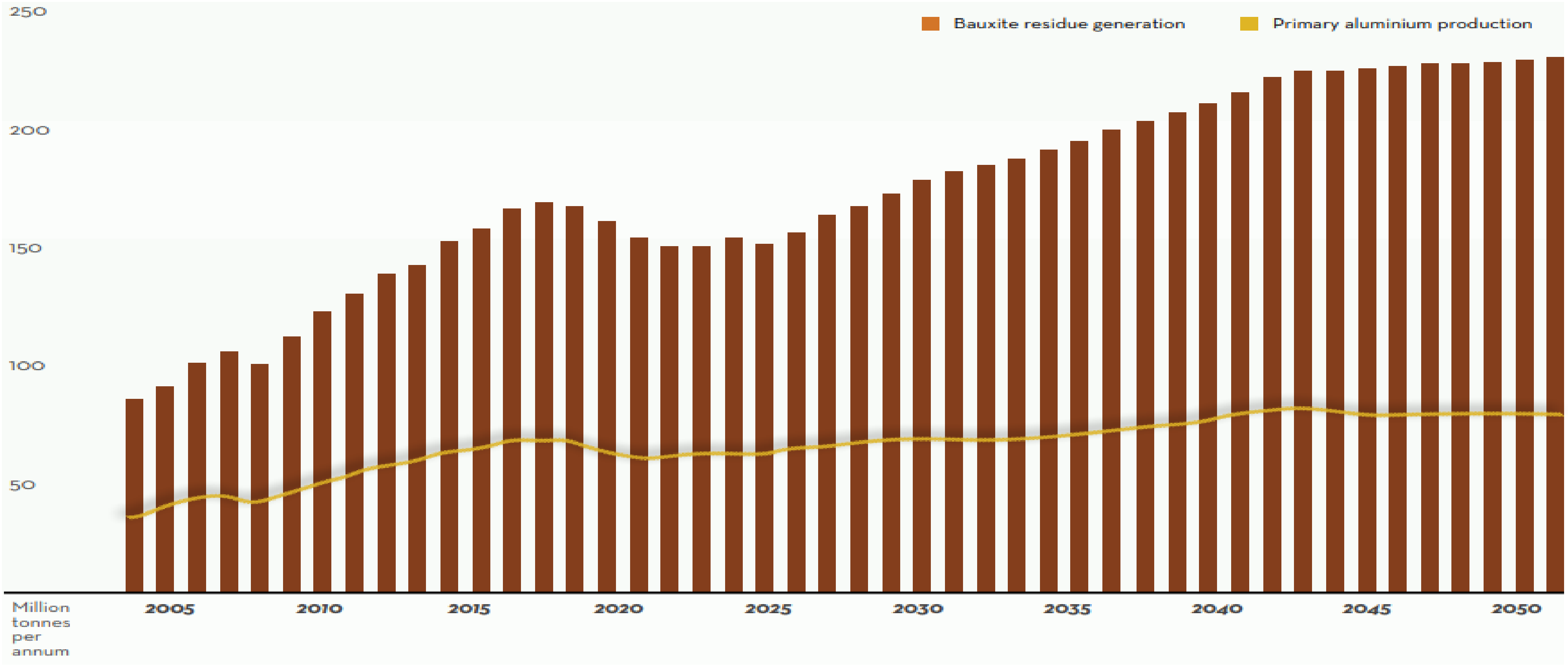
- Larger anodes and/or larger and modified anode stubs and yoke
- Slotted anodes for better gas bubble drainage, reducing the anode effect
- Better anode rodding procedures to minimize external voltage drops
- Changes in current collector bar design and larger dimension (use of copper in the bars)
- Casting of cathode bus bars instead of ramming to obtain better contact resistance
- Modification of side lining from carbon to SiC
- Better side lining and steel shell ventilation
- Improved magnetic field compensation
- Conductor redesign and making a trade-off between voltage reduction and heat dissipation decrease

Emission data

Type (elect, direct, combustion etc.)	Process step (refining, smelting, recycling etc.) — Million tonnes of CO_2e								
2022 (108 Mt primary + secondary)	Mining	Refining	Anode Production	Electrolysis	Casting	Recycling	Semis Production	Internal Scrap Remelting	All
Electricity	0.3	22	2	616	2	4	14	3	663
Perfluorocarbon (PFC)				52					52
Process (CO2)			8	103					111
Ancillary Materials		30	45	5					80
Thermal Energy	2.6	114	6		4	19	22	9	177
Transport		16		13					29
Total-Cradle to Gate	2.9	183	60	789	7	23	36	11	1112

IAI data

Bauxite residue generation



IAI data

Possible consequence if not properly stored

Ajka Alumina Plant – October 2010

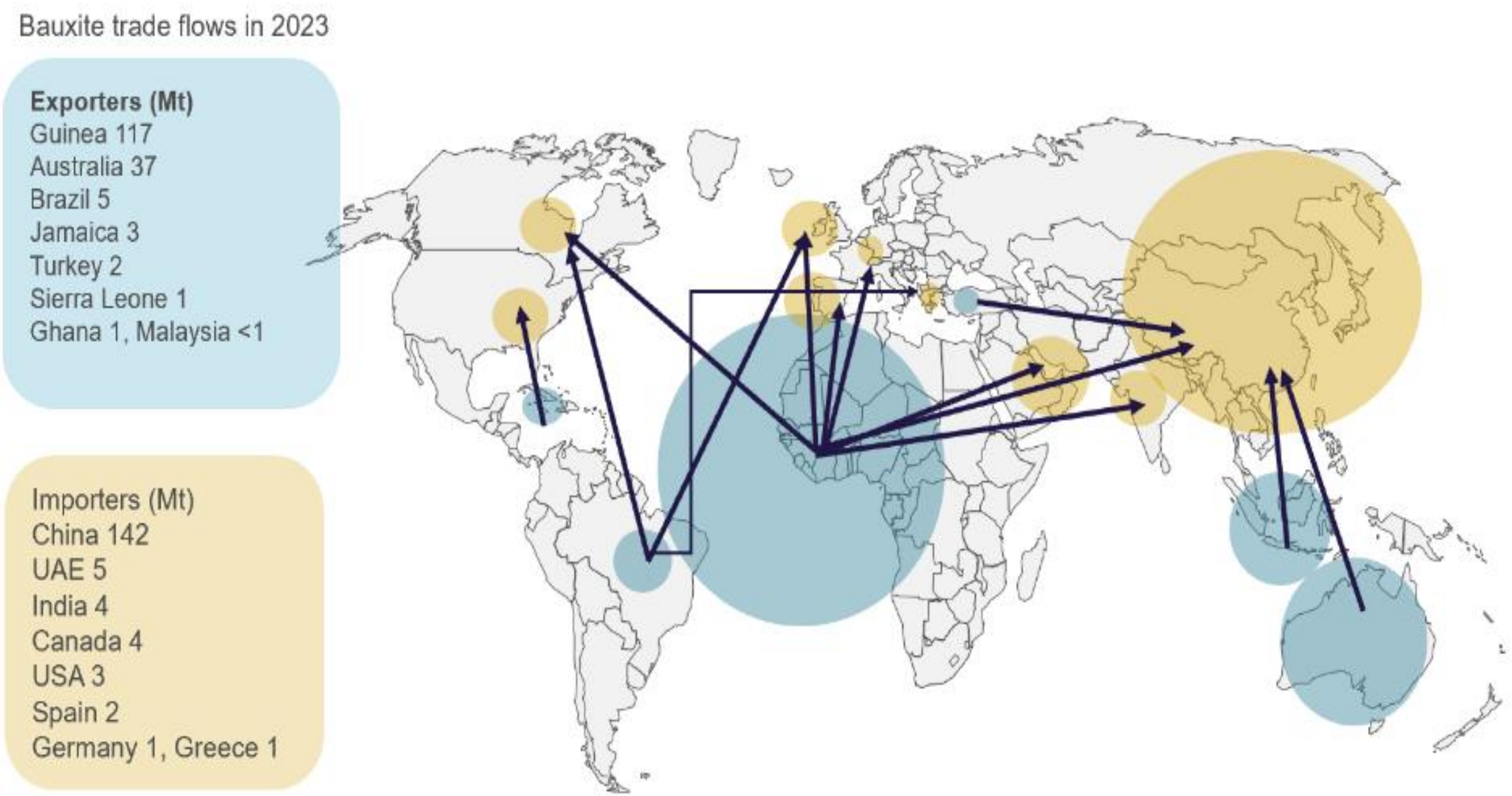
Ajka Alumina Plant – October 2010

Ajka Disaster – October 2010

Impact of Ajka incident

- 700,000 m^2 of caustic bauxite residue slurry released as a result of a dam failure
- 10 people killed
- 150 people hospitalised
- Three settlements overwhelmed
- 300 houses destroyed or severely damaged
- 14 km^2 of agricultural land along Torna and Marcal waterways inundated with caustic liquor/bauxite residue
- Extensive contamination of the River Danube
- Negative publicity – radioactivity, arsenic etc

Bauxite trade flow - 2023

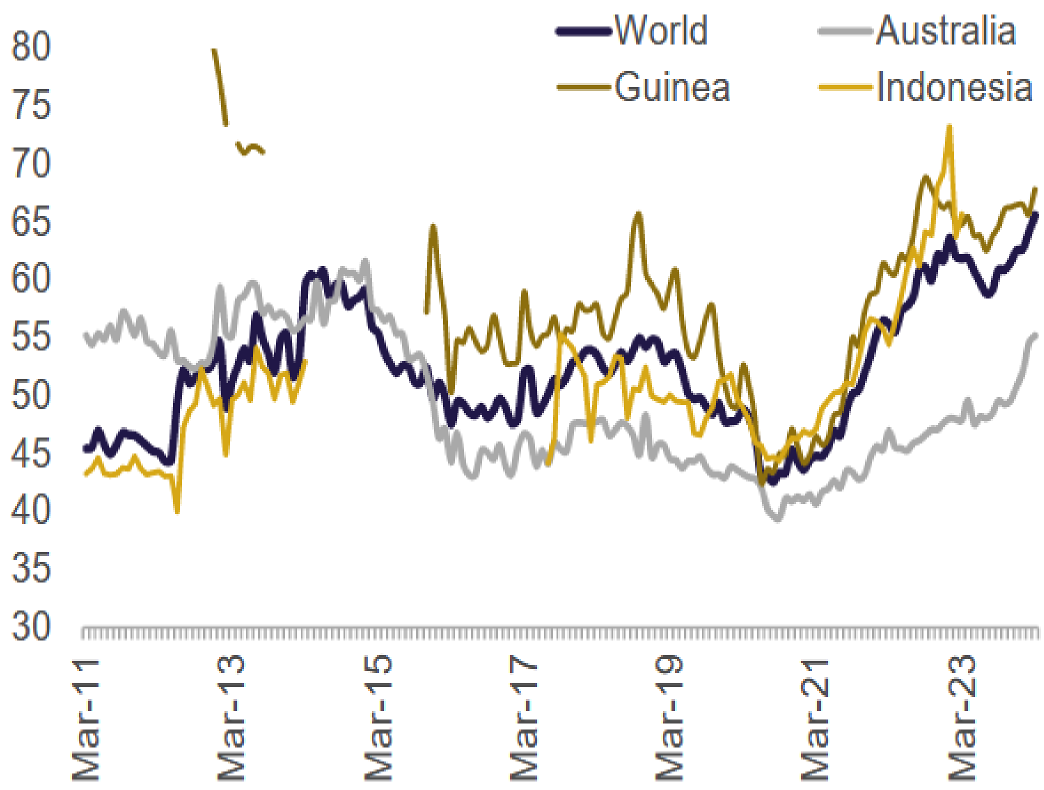


- **Guinea** bauxite shipments largely unaffected by **military coup** in September 2021, and **oil terminal explosion** in December 2023. Dominant bauxite exporter to China.
- **China** contending with domestic mine **closures.** Increased dependency on seaborne bauxite.
- **Indonesia bauxite export ban** remaining in place.
- **Australian** ore is competitive, and freight advantage to the China market

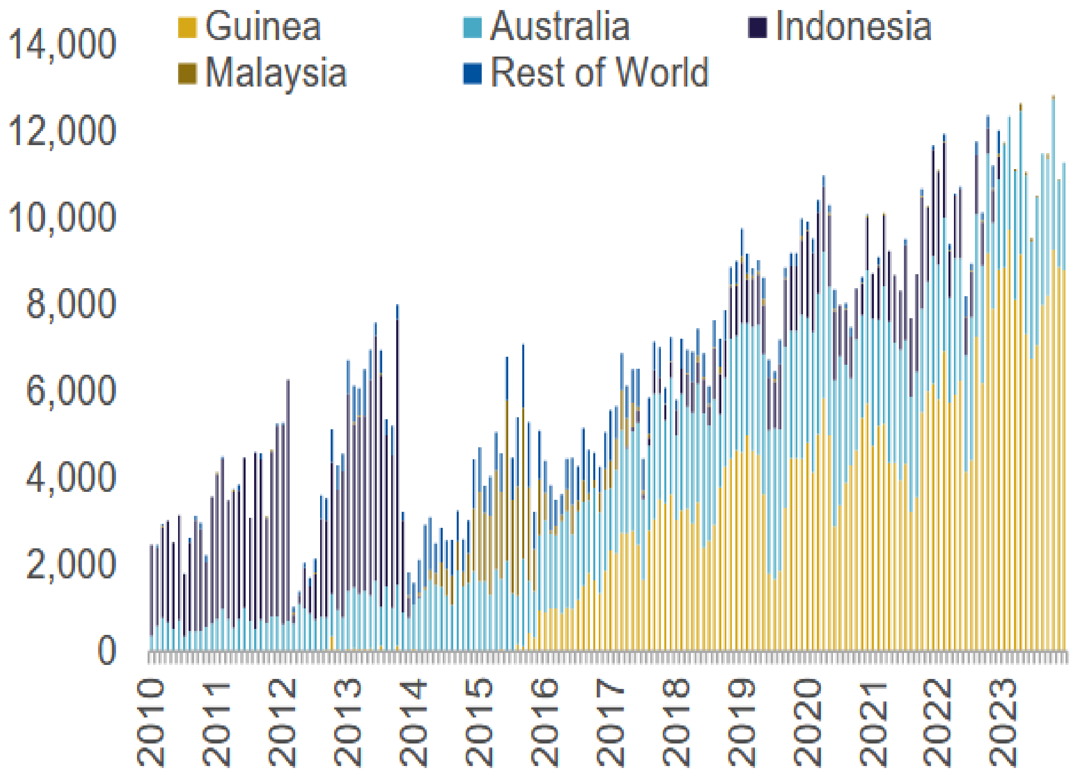
CRU data

Bauxite: prices and supply

Bauxite prices, $ /t China CIF



Chinese bauxite imports, '000 t

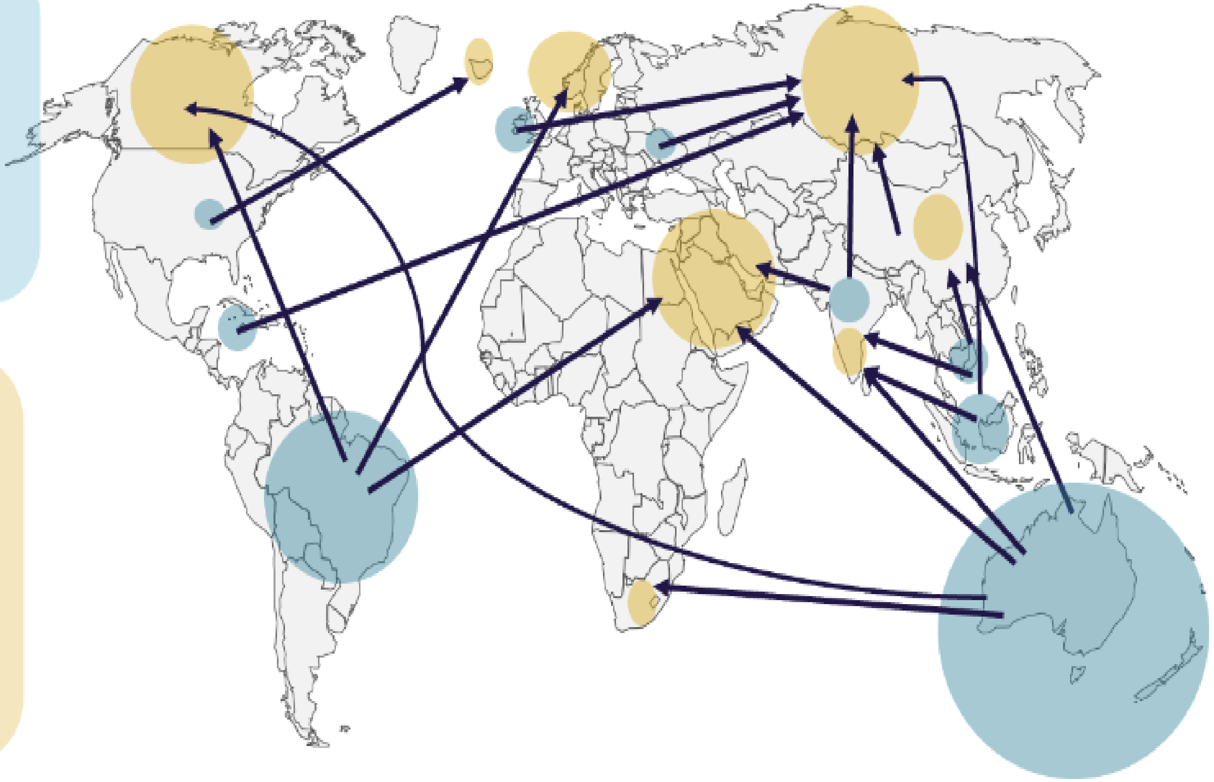


CRU data

Alumina trade flows - 2023

Exporters (Mt)
Australia 17
Brazil 9
Indonesia 2
India 2
Ireland 2
Jamaica 1
Vietnam 1

Importers (Mt)
Russia 5
Canada 4
Bahrain 3
Norway 3
UAE 3
India 2
Malaysia 2
China 2



- Aluminium companies in Middle East and Asia aiming to be increasingly **integrated upstream.** Either by investing in existing refining assets or building greenfield alumina refineries.
- **Australia has banned alumina exports to Russia** since March 2022.
- **China** is traditionally an alumina net-importer, but has capability to export significant tonnes during times of upheaval in the market.
- **Indonesia and Vietnam** emerging as notable alumina producers.
- **Kwinana** refinery in Western Australia **curtailed** in 2024 Q2.

CRU data

Recent trends

- Strong growth in demand has continued despite global problems
- Very significant decline in aluminum smelters in USA – only 6 left
- Very significant decline in alumina in USA – only 1 refinery
- Similar pattern in Europe, both Western and Eastern
- Huge growth in China of both alumina and aluminum production
    - Initially coal powered by growing green power
- Very strong growth in India
- Emerging growth in Indonesia
- Growing reliance on Guinea for bauxite

The future

- Demand for aluminum forecast to remain very strong driven by use in lighter weight transport applications, batteries
- Very difficult to reverse loss of alumina production
  - No new alumina refineries in USA or Europe even if political intervention
  - New alumina refineries in China, India, Indonesia, Guinea

$AlCl_3$

- Difficult to reverse closure of aluminum smelters
  - Political intervention will help to a small degree – need alumina and power
  - Possibly new smelters in areas of HEP, solar power, underground heat sources, nuclear(?) – Canada, Iceland, Siberia, China, Middle East
- Strong increased growth in Indonesia
- Decarbonization in process but relatively slow and mainly driven by mode of electricity production rather than technology

A final thought....

Since I started talking, the alumina industry has produced .....

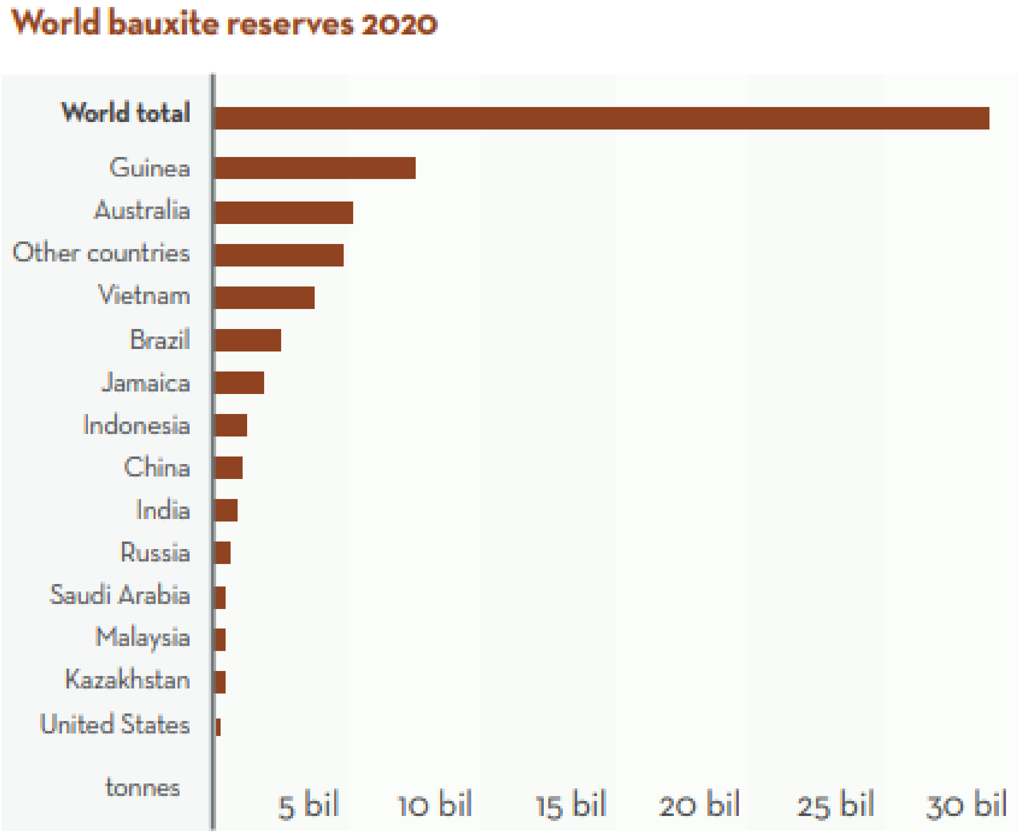
Almost 500 of these filled with bauxite residue

Thank you for your attention

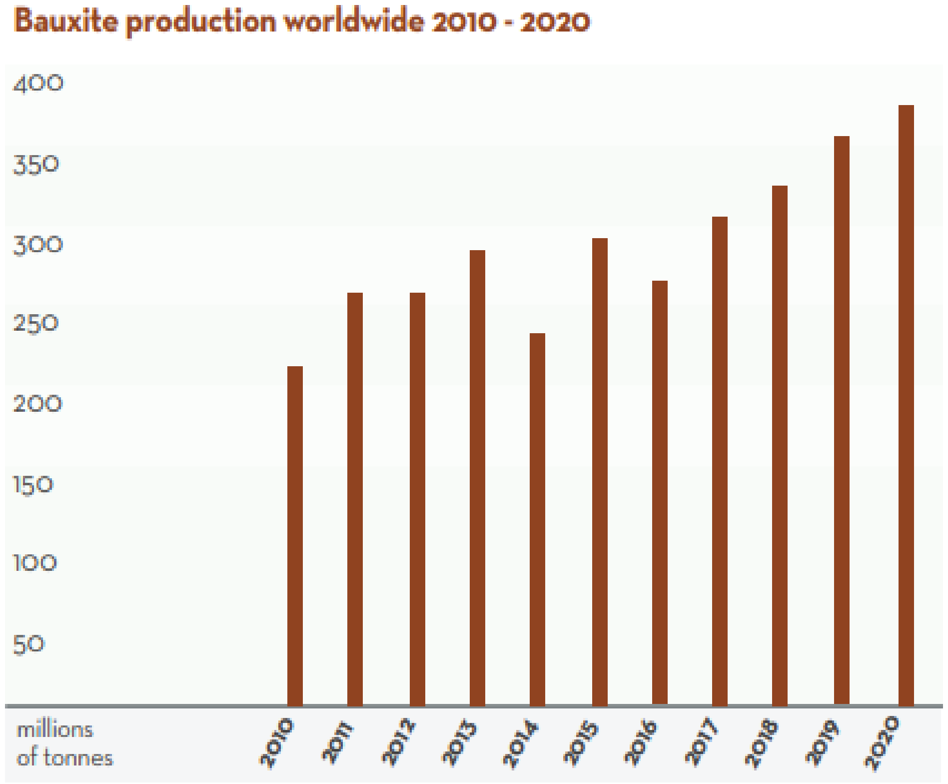
Questions?

Bauxite

World bauxite reserves



Annual production



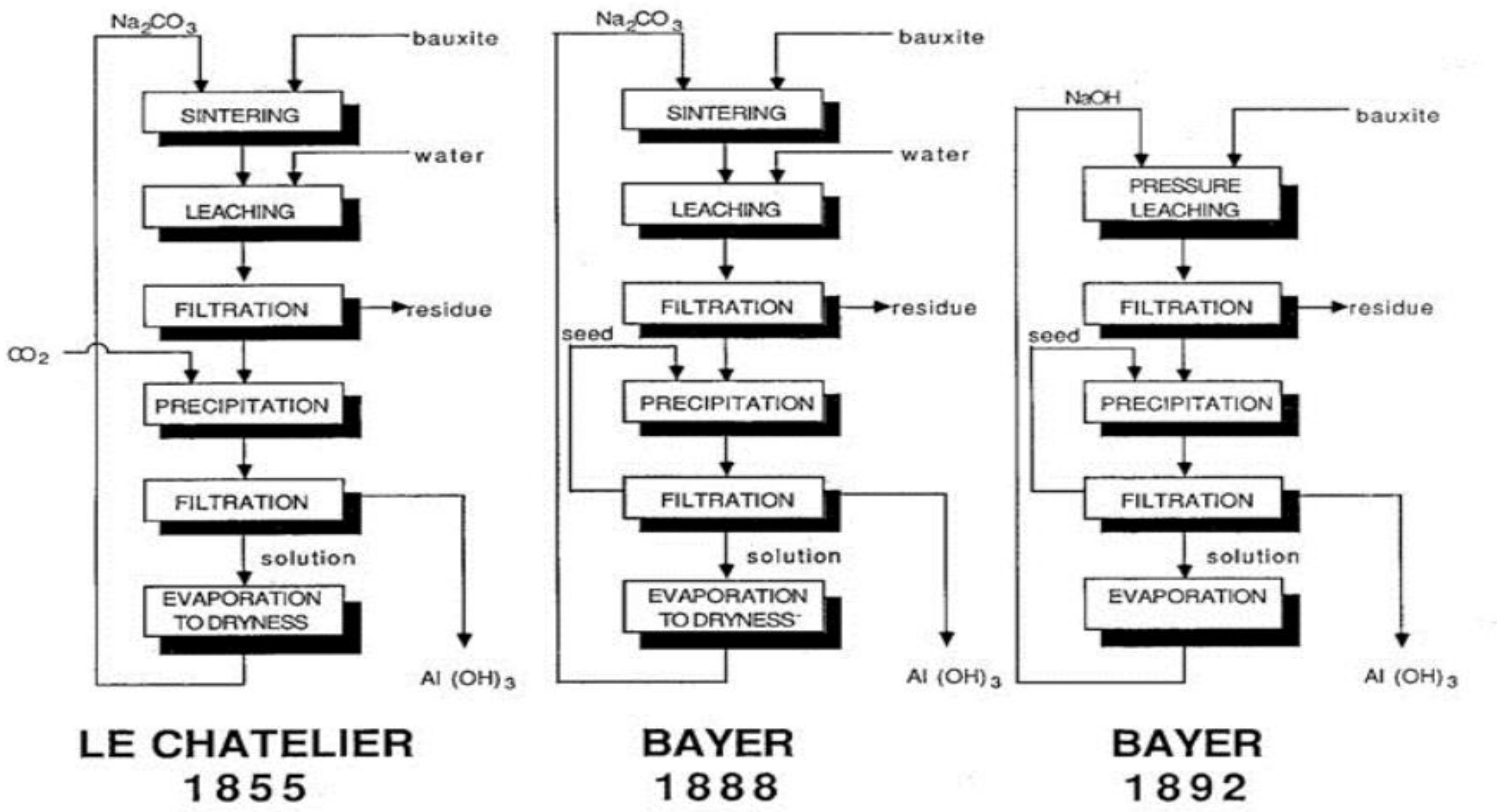
IAI data

EU external funding initiatives

Mainly funded through HORIZON 2020 – € 80,000,000,000. Next phase HORIZON EUROPE (2021-2027) - € 95,510,000,000 (Sustainable economic development).

- **ENEXAL (energy-exergy of Aluminium industry)** Novel Technologies for enhanced energy and exergy efficiencies in the aluminium industry **[2010-2014].**
- **EURARE (European Rare earth resources) [2013-2017].**
- **HORIZON MSCA ETN REDMUD Project – small scale experiments on possible uses [2014-2018].**
- **SCALE - Scandium – Aluminium in Europe [2016 - 2020].**
- **SIDEREWIN - sustainable Electro-wining of Iron [2017- 2022].**
- **ENSUREAL - ensuring sustainable alumina production [2017-2022].**
- **AlSiCal – alternative routes to make the mineral and metal industry more sustainable and environmentally sound [2019-2023].**
- **RemovAL – demonstration units of successful areas from RED MUD project [2018-2023].**
- **ReActiv – cementitious materials [2020-2025].**

Bayer's patents



Management approaches

- Lagooning
- Disposal to quarries, depressions, dammed valleys, captured by sea walls
- River, estuarine, sea disposal (pipeline and ship)
- Seawater neutralisation/pH reduction
- Acid neutralisation
- Mud farming
- Dry mud stacking
- Filtration – drum filters, plate and frame etc
- Carbon dioxide neutralisation
- Sulfur dioxide neutralisation
- Use