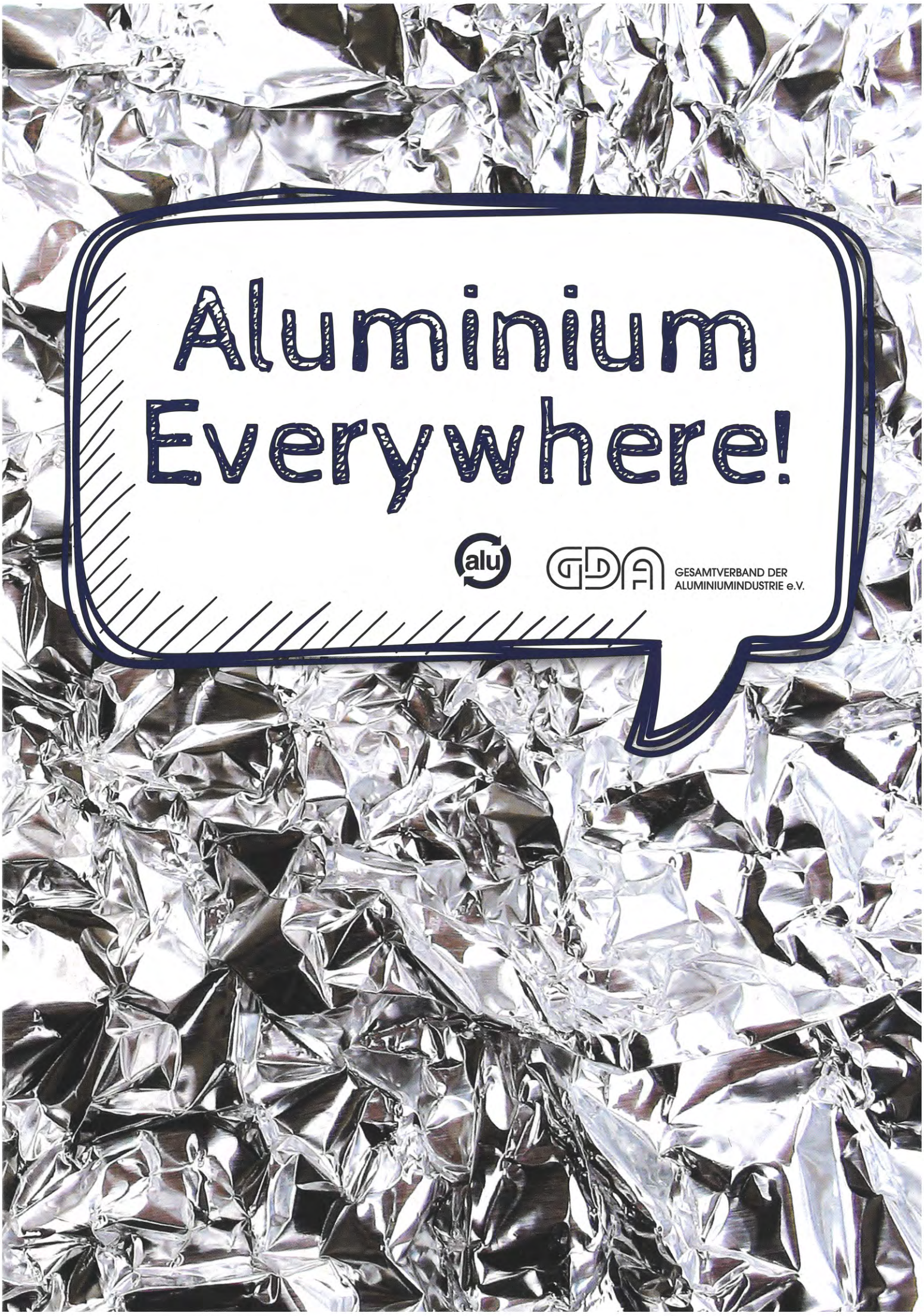
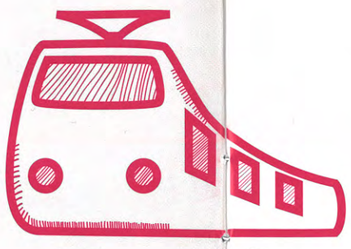

Aluminium
Everywhere!
alu
GDA
GESAMTVERBAND DER
ALUMINIUMINDUSTRIE e.V.

Aluminium Everywhere!

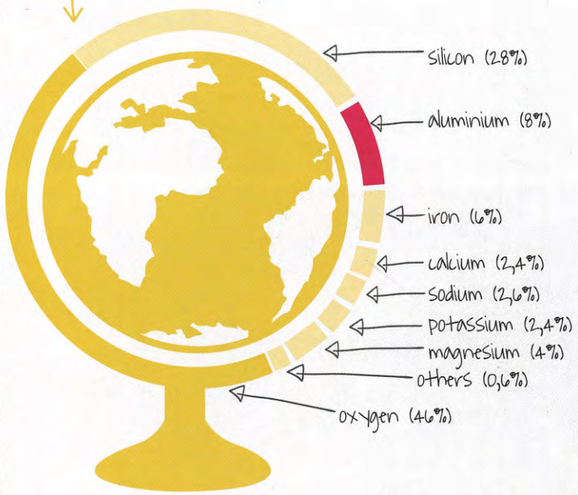
Is Aluminium in it?

Can you believe it! Aluminium is the third most abundant element in the Earth's crust; it accounts for as much as eight per cent, with oxygen accounting for 46 per cent and silicon 28 per cent. It means aluminium is the most abundant metal (iron: 6%). But what is the real story behind this silvery white light metal?



train

Distribution of elements in the Earth's crust



Every child is familiar with the aluminium foil in mum's kitchen cupboard. Aluminium was extremely rare even as recently as the nineteenth century; it was considerably more expensive than gold and was used as a particularly precious metal in jewellery. Rare? Although aluminium is readily abundant in the Earth's crust, it is never found in the pure form in nature. Metallic aluminium has always had to be extracted using a very elaborate extraction process. Things are no different today. But today we have the right equipment to do this. Some 48 million tonnes of primary aluminium are produced every year. In addition, about eight million tonnes of recycled aluminium are also produced from melted down aluminium scrap. And the trend is upwards, because the global demand for aluminium is increasing. Today, this once rare metal has become an everyday commodity that one can no longer imagine being without. Aluminium is everywhere! Why?

Because you can do make practically anything from aluminium:

- When architects and design engineers build a house, they are glad that aluminium is corrosion resistant.
- The packaging industry is happy because it can use aluminium to produce lightweight and attractive packaging that offers protection against light, oxygen, germs and humidity.
- The manufacturers of the different means of transport and transportation are pleased to have a material that is so easy to process and can be used to make parts for kickboards, cycles, cars, trucks, trains, aircraft or rockets.

Basically, one differentiates between aluminium as a metal and aluminium in the form of chemical compounds. Metallic aluminium is used in the building and construction sector, in the car industry, for aircraft construction, for the manufacture of electrical appliances and household equipment, or for packaging. Aluminium compounds are produced in chemical processes and used for pharmaceutical and cosmetic applications, in medicinal products, cosmetics or foodstuffs. Neither of them is a risk to health provided prescribed limits are observed.

building construction
photo: Hydro Aluminium

cake moulds
photo: GDA

tubes
photo: Linhardt

aerosol cans/spray cans
photo: Linhardt

markers
photo: Linhardt

Al

bicycle

tablet tube
photo: Linhardt

foil
photo: Hydro Aluminium

car

beverage can

Aluminium - A Lustrous History

Copper, tin, iron, lead, silver and gold have all been around since time immemorial; in contrast, aluminium was only discovered in the 19th century. The light metal is now the second most important industrially used metal after steel with applications in virtually all fields of technology and everyday life. But let us start at the beginning.

About 1000 BC: Alum, a chemical compound of aluminium and sulphur that occurs naturally, is being used to dye clothing in Egypt and Babylonia.

1807: Humphry Davy discovers the element as a constituent in an iron alloy and proposes calling it 'aluminium'.


bauxite
photo: Hydro Aluminium

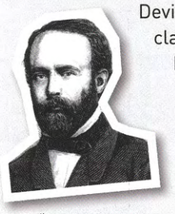
1821: The raw material for aluminium - bauxite - is discovered in the south of France and is named after the place where it was found: Les Baux near Arles.

1825: Hans Christian Oersted obtains pure aluminium for the first time by reducing aluminium chloride with potassium amalgam.

1827: Using pure potassium, Friedrich Wöhler manages to reduce 30 grams of anhydrous aluminium chloride to a grey powder 'which when examined more carefully, especially in sunlight, appears to consist of a myriad of metal particles'.

1852: Robert Bunsen improves Davy's method for the electrolytic separation of metallic aluminium.

1854: Henri Étienne Sainte-Claire Deville discovers the first technically feasible chemical process for the extraction of aluminium. Sainte-Claire Deville's aluminium ingots - 'silver from clay' - arouse great interest at the Paris Exposition Universelle of 1855. Some 200 tonnes of aluminium will be produced in this way by 1890, mostly for items of jewellery. However, the metal is still too expensive for widespread use. Incidentally, when Napoleon III hosts a lavish celebration, some of the distinguished guests are allowed to enjoy the exquisite food using cutlery made from aluminium. Less important guests have to make do with the usual silver cutlery.


Deville

In 1854 the famous French chemist Henri Sainte-Claire Deville succeeds in producing aluminium as a solid mass. 'This valuable metal possesses the whiteness of silver, the indestructibility of gold, the tenacity of iron, the fusibility of copper, the lightness of glass. It is easily wrought, is very widely distributed, forming the base of most of the rocks, is three times lighter than iron ... '

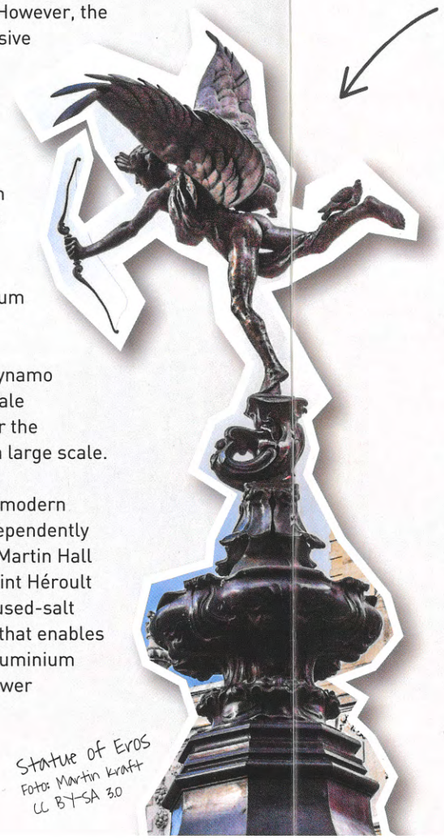
[extract from Jules Verne's book 'From the Earth to the Moon' published in 1865]

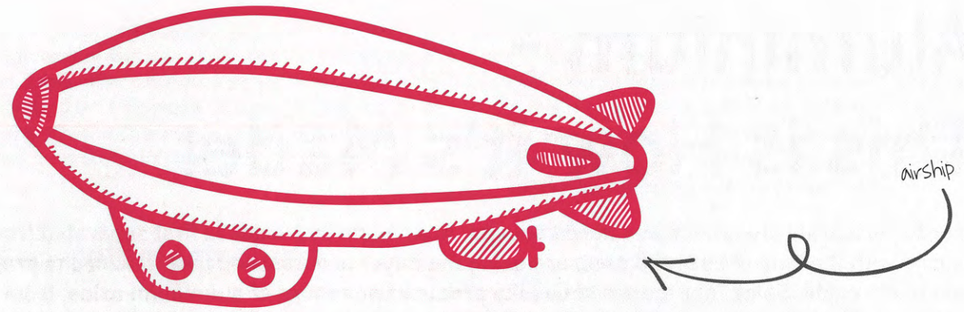
1864: The first wrist watch with an aluminium casing is produced.

1866: Werner von Siemens discovers the dynamo and thereby creates the basis for large-scale production of electricity, and eventually for the extraction of aluminium economically on a large scale.

1886: This is the year of birth of the modern aluminium industry. Independently of each other, Charles Martin Hall and Paul Louis-Toussaint Héroult apply for a patent for fused-salt electrolysis, a process that enables a marked increase in aluminium production and with it lower aluminium prices.


cookware
photo: GDA


Statue of Eros
Foto: Martin Kraft
CC BY-SA 3.0


airship

1887 and 1892: Karl Joseph Bayer patents his Bayer process for the extraction of aluminium oxide (alumina) from bauxite.

1888: Aluminium industries are established in Switzerland and the USA and at the same time the first alumina plants begin operation using the Bayer process.

1889: Household tableware is cast in aluminium.

1893: The Statue of Eros for Piccadilly Circus in London is cast - in aluminium, of course. It will still be in good condition in well over a 100 years' time.

1894: The first aluminium bicycle frame is produced in the USA.

1899: Aluminium propellers are produced for the Zeppelin airship. Aluminium is also used in the frame of the Zeppelin.

1900: Aluminium is used for the first time in printing plates, art, high-rise buildings and steel production. Castings begin to be produced and used in vehicle manufacturing.

1905: Anson Gardner Betts produces pure aluminium using triple layer electrolysis.

1906: Alfred Wilm discovers that heat treatment can increase strength and he uses this finding to develop the age-hardenable alloy Duralumin. It is only now that aluminium becomes a versatile engineering material and is also used in aircraft construction, shipbuilding and in rail and road vehicles.

1912: Production of aluminium foil for the automated packaging of consumer products. From now on, items like chocolate will be wrapped in aluminium foil.


cake moulds
photo: GDA

1913 and 1920: Production of aluminium tubes and aluminium food cans.

1930s: Introduction of extrusion.

1954: Manufacture of the first aluminium aerosol cans ('spray cans').

1980s: Recycling gains in importance. In Europe, the production of recycled aluminium will soon be half that of primary aluminium. Furthermore, aluminium has become an important material for use in air conditioning, solar technology and wind turbines.

1994: The first aluminium spaceframe is used in carmaking. The aluminium framework, into which each portion of the surface is integrated in a load-bearing manner, is characterised by enhanced protection in a crash, while being significantly lighter at the same time.

Today: Aluminium is the most widely used metal after ferrous materials. Research has succeeded in continually improving aluminium's properties. The metal is now used in vehicle manufacturing, structural engineering, mechanical engineering, electronics, air conditioning, solar technology and packaging. There is hardly a field of technology or everyday life where aluminium products are not used. And the aluminium industry has developed into a key sector of the economy.

Aluminium – This is How it's Made!

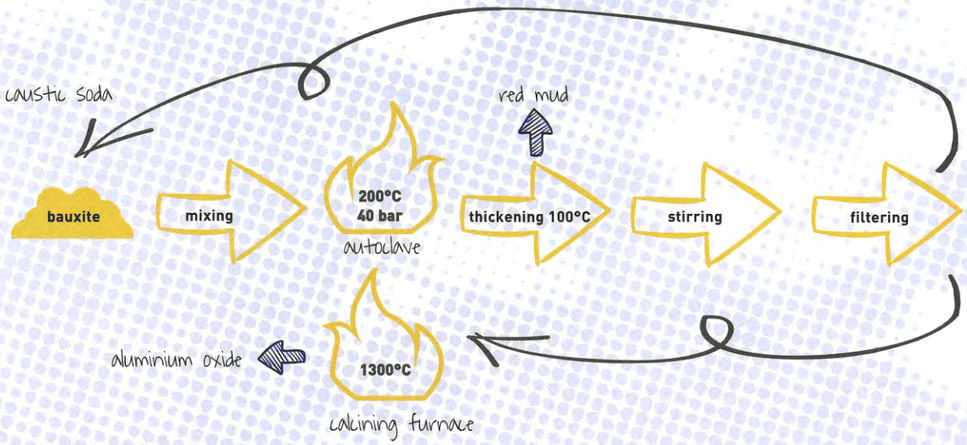
In order to extract aluminium one needs bauxite. Aluminium hydroxide is first separated from the bauxite with the help of heat and pressure using the Bayer process, and then calcined to produce aluminium oxide. Some four tonnes of bauxite produce two tonnes of aluminium oxide, from which about a tonne of aluminium is obtained by fused-salt electrolysis in a second extraction step at an aluminium smelter. Sounds complicated? Then let's go through it again, but this time make notes:

Raw material bauxite Aluminium does not occur in pure form in nature but as aluminium compounds. The highest aluminium concentrations are found in so-called bauxites. These are the result of the weathering of rock containing lime and silicate, and they have a high Al_2O_3 (aluminium oxide) content, which is often over 50 per cent. They are used as the raw material in every aluminium smelter. To obtain large quantities of aluminium one must use large quantities of bauxite. The largest deposits of bauxite are to be found in Guinea, Australia, Brazil, Vietnam, Jamaica and Indonesia.

Bauxite is mainly obtained by opencast mining. Rehabilitation of the bauxite mine is part and parcel of bauxite mining. About 85 per cent of the area used for bauxite mining is rehabilitated, a further ten per cent is developed for agricultural uses and five per cent is given over to residential and industrial areas. In rainforest areas, some three square kilometres a year are used for bauxite mining.

Bayer process

Bauxite contains up to 50 per cent aluminium oxide. Pure aluminium oxide, so-called 'alumina', is first extracted from the bauxite using the Bayer process. The aluminium oxide produced is so fine that it behaves almost like a liquid and can be transported via pipelines. At this stage, the alumina resembles high-grade white sand. It is odourless and non-toxic.



What happens exactly:

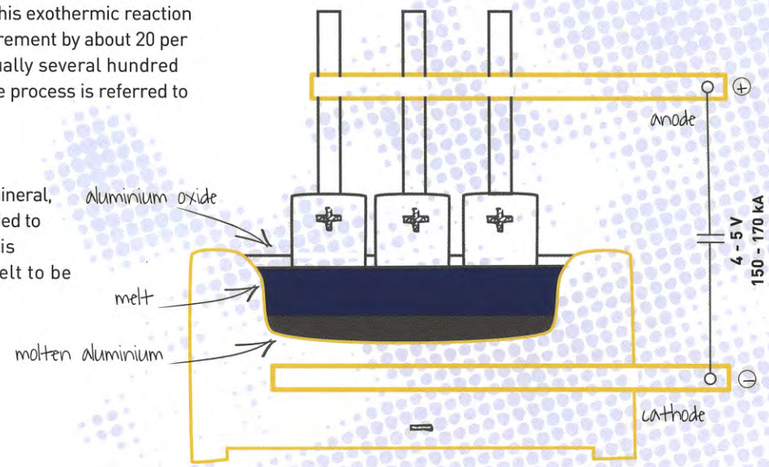
- The bauxite is finely ground and mixed with caustic soda. Depending on the composition of the bauxite, the mixture is subjected to a pressure of up to 40 bar and temperatures between 100 and 320 °C and is stirred for up to several hours in autoclaves (heatable vessels used for chemical reactions carried out under pressure). The caustic soda dissolves aluminium oxide out of the bauxite by forming sodium aluminate. The insoluble constituents of the bauxite form so-called red mud.
- In Germany, the red mud is sent via a piping system to the plants own disposal site, where it is stored. The caustic soda is returned to the production process. In Germany, the production of a tonne of alumina results in the production of about 0.5 tonnes of red mud.
- The liquor is cooled to about 60-70 °C, whereby it becomes oversaturated in aluminium hydroxide; this then crystallises out as a solid under continuous stirring (for example using compressed air). Precipitation is accelerated by addition of aluminium hydroxide in powder form ('seeding') but nevertheless the process still takes some 20 to 60 hours or more.
- Calcination: this is a process in which the water contained in the hydrated alumina is driven off by heating. Water molecules are separated from the aluminium hydroxide at approximately 1100 °C in fluidised-bed furnaces (where the aluminium oxide hydrate is held in suspension by compressed air), leaving behind pure aluminium oxide (containing less than 0.1 per cent impurities).

Fused-salt electrolysis

The pure alumina is then sent to special plants for further processing. A melt consisting of alumina and cryolite is broken down into molten aluminium and oxygen with the help of electric current.

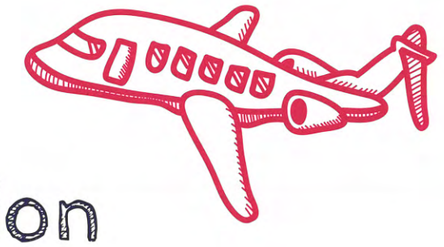
What happens exactly:

- In the aluminium smelter, electric current is first transmitted to the electrolysis cells (so-called 'pots'). Alumina is dissolved in the molten cryolite in the cell. The base of the cell forms the negative pole, the so-called 'cathode'; the positive pole is formed by carbon blocks, the 'anodes'. The anodes are connected to a network of electricity conductors ('busbars'). Current flows though the cell when the blocks are lowered into the molten cryolite. This causes the aluminium oxide dissolved in the cryolite to break down into its constituent parts: aluminium and oxygen.
- The aluminium ions then migrate to the cathode and the oxygen ions migrate to the anodes. Oxygen oxidises the anodes electrochemically, whereby carbon dioxide is produced. The energy released by this exothermic reaction reduces the electrical energy requirement by about 20 per cent. In the smelter, there are usually several hundred cells connected in series. The whole process is referred to as 'aluminium electrolysis'.
- Aluminium oxide only melts at temperatures above 2000 °C, so a mineral, cryolite, is used as a solvent and added to the alumina in small quantities. This allows the temperature of the melt to be reduced to about 960 °C.
- Thanks to the electrolysis process, the aluminium oxide has now become aluminium. The molten metal can be removed directly from the pot by suction. From there the aluminium is transferred to a ceramic-lined transport crucible, which holds about 4000 kilograms of molten aluminium. When the crucible is full it is transported to the foundry using a special vehicle. An oxide skin forms on the surface of the aluminium and this is removed before the aluminium is used in the casthouse. The underlying metal has a purity of about 99.9 per cent. Et voilà – we have commercially pure aluminium!



Electricity, electricity, electricity

Electrolysis requires lots of energy. After all, there are 170,000 amps of direct current flowing at 4.4 volts. Between 13 and 15 kilowatt hours (kWh) of electricity are needed to produce a kilogram of aluminium. Each pot produces about 1300 kilograms a day. The energy used would be sufficient to meet the needs of a family of four for three to four years. Hydroelectric power is a suitable means of producing such large quantities of electric power. Worldwide, the major part of the energy used to produce primary aluminium is provided by hydroelectric power. One huge advantage: hydroelectric power can be converted into electricity without any significant energy losses. And what is more: unlike the electricity produced by the combustion of fossil fuels, the production of electricity from hydroelectric power is free from eco-unfriendly emissions.



Aluminium - Tuned to Perfection

Aluminium is often chosen specially because it is easy to shape and machine. The metal can be plastically deformed with little force being required and can be joined using almost every technique available. Processing is mainly carried out in rolling mills and extrusion plants. Thanks to the latest technology, aluminium can even be welded or permanently bonded. An overview of the numerous possibilities to process aluminium is given below.

Extrusion Cast extrusion billets are used as the starting material. They are heated to 400-520 °C and then placed in the heated container of the press, where they are forced under pressure through the cavities in a steel die. This can produce the widest possible range of shapes from unsymmetrical, open, half-open through to hollow. Profiles up to 25 metres long can be produced for manufacturing railway rolling stock or ships' masts.

Rolling Continuously cast aluminium slabs of rectangular cross-section are the starting material for rolling; they can be two metres wide and weigh 20 tonnes. The slabs are heated to 550 °C and then rolled to plate or strip in several passes on a hot-rolling stand.

Foil rolling The term 'aluminium foil' describes rolled products less than 0.2 millimetres thick. Foil is produced today by cold rolling in foil mills in several rolling steps (passes) – mostly from commercially pure aluminium. The starting material is foil stock, usually 0.6-0.8 millimetres thick. Foil can be treated mechanically or chemically, printed, lacquered or laminated. Aluminium foil for packaging can be as thin as 5-6 microns.

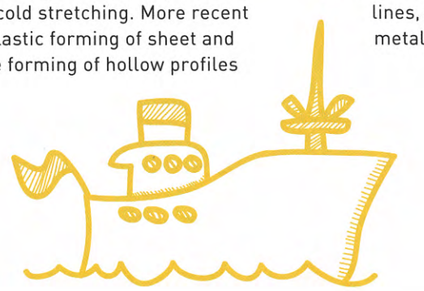
Casting Cast products made from aluminium are obtained using different processes depending on the specific requirements. Compared with heavy-metal castings, the benefits are a high degree of dimensional accuracy, a large weight saving and clean, smooth surfaces.

Forming Aluminium can very easily be deformed plastically when cold. Processing is carried out on the same machines as are used for other materials like steel or copper. The best-known forming processes are bending, folding, spinning, beating, deep drawing, impact extrusion and cold stretching. More recent processes are superplastic forming of sheet and internal high pressure forming of hollow profiles and tubes.

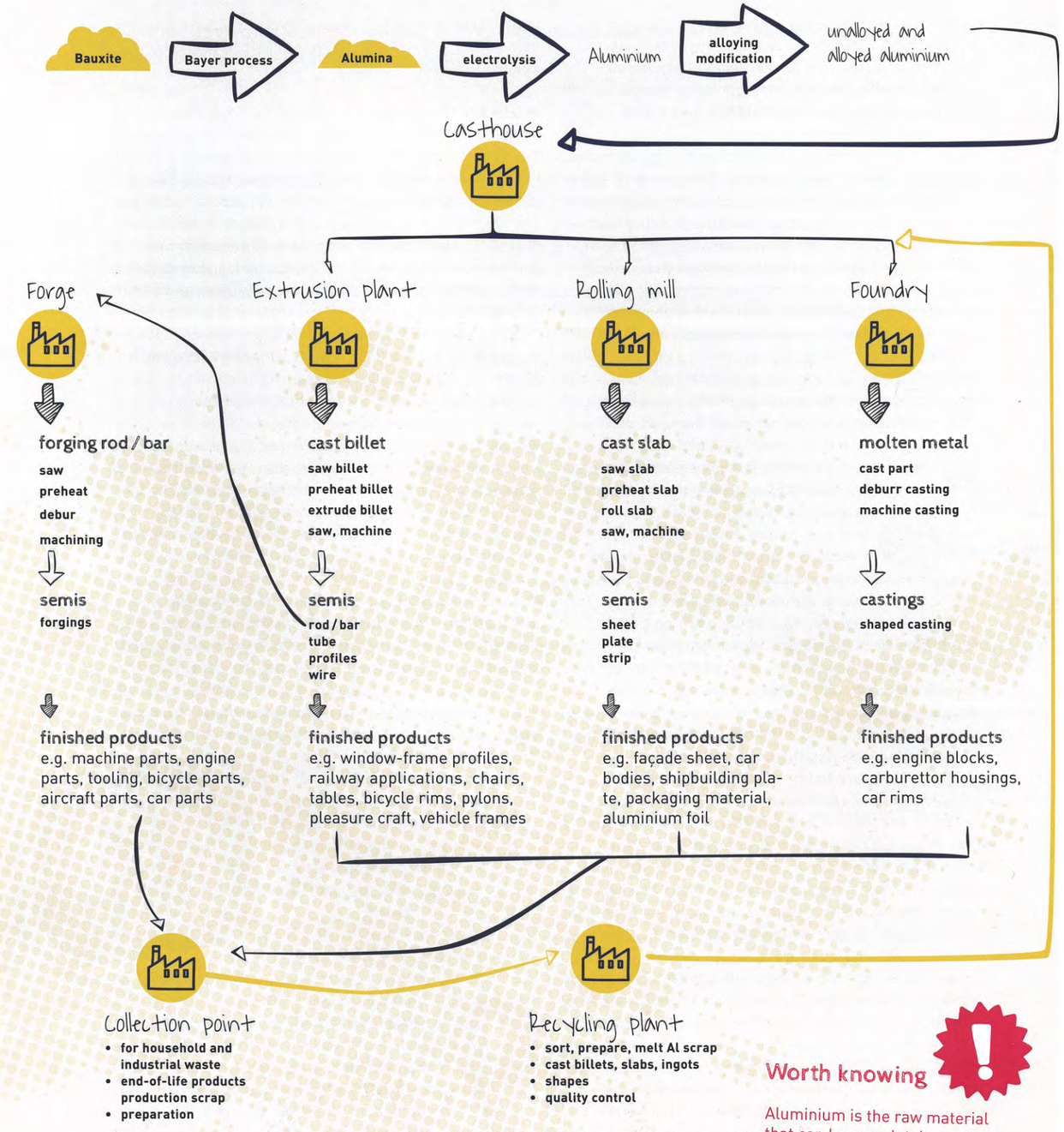
Machining Basically, aluminium can be machined using all machining processes. Machining of aluminium is carried out at considerably higher cutting speeds and much lower cutting forces than are used for steel. Cold worked or age hardened materials are easier to machine than soft materials. It is important to use tooling that is suitable for the intended purpose and machines that enable the permitted high cutting speeds to be used.

Joining That which belongs together can come together. To join aluminium parts one can use riveting, welding or bonding. Riveting produces tight joints that are corrosion resistant. During welding, one must consider the reaction of the metal with oxygen because this can quickly lead to an oxide skin forming. This is prevented if a gas like argon or helium is used to shield the joint. Bonding has the clear advantage that it can transfer forces uniformly without weakening the bulk material (very much appreciated in carmaking and aircraft construction as well as in aerospace applications).

Surface treatment An endlessly varied range of decorative designs is possible with aluminium. The light metal can be ground, brushed or polished to remove surface roughness. It can be subsequently anodised if one wishes. Anodising is an electrolytic process in which the natural oxide layer of the metal is strengthened and made porous in a bath of dilute sulphuric acid and which is thus capable - if desired - of incorporating pigment particles. A uniform matte surface structure can be obtained by pickling. The highest possible sheen is achieved with extreme-purity aluminium and alloys based on extreme-purity aluminium (bright-finish alloys) using chemical or electrolytic brightening. Deep etching can be used to produce raised or sunken lettering, lines, areas and symbols by localised removal of metal. Aluminium fulfils every wish!



Steps in the Production of Aluminium



Worth knowing

Aluminium is the raw material that can be completely recycled and fully used again!

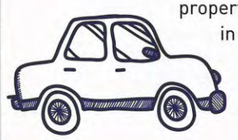
Aluminium #versatile

Aluminium is durable, useful and one cannot imagine a world without it. What's the reason? Aluminium's diverse properties! Aluminium is:

non-combustible. This proves to be a major benefit in most applications, especially in the building and construction industry. Certain types of aluminium powder are inflammable; amongst other things, aluminium is also used as a fuel in space travel.

#energy saving. Moving parts made of aluminium have a lower mass than comparable parts made of steel, which means less energy is required during acceleration or slowing down. Full use is made of this in the manufacture of energy-saving aircraft and other means of transport. The lightness of packaging also saves energy during transport. An eco-friendly approach is also adopted during recycling: aluminium's low melting point, 660 °C, leads to energy savings during melting as well.

#strong. Aluminium is in the process of replacing iron and steel in mechanical engineering applications. Thanks to alloying, the light metal can be made as strong and stable as steel, but is still light. This property is gladly utilised among other things in the lightweight construction of houses and machines.



#ductile. Aluminium can be shaped with or without the formation of chips using any common process. This means there is nothing to stop it being used in the widest possible range of shapes and forms.

#lightweight. Aluminium has a density of 2.7 grams per cubic centimetre and is thus only a third as heavy as iron. The light metal is therefore ideally suitable as a packaging material. On top of this is the fact that aluminium can be rolled very thinly and can be processed relatively easily to thin foil.

magnetisable. Aluminium is non-magnetic. This is important in electrical engineering, electronics and mechanical engineering. However, the metal can be magnetised using eddy current, something that is used for example during waste separation.

reflective. Aluminium is a good reflector of heat, light and electromagnetic waves. The metallic shine resulting from reflection is used in paints.

#stable. Aluminium reacts so strongly with oxygen that it becomes covered in an extremely thin layer of aluminium oxide as soon as it comes into contact with the oxygen in the air. This layer is so compact that no further oxygen can force its way through to the metal. That is why items made of aluminium have such good protection against external influences.

electrically conductive. Aluminium requires a cross-section that is 1.6 times greater than the equivalent cross-section for copper. However, aluminium is only half the weight. Nowadays, stranded conductors for power supply mostly consist of aluminium with a steel-wire core.

#stylish. Aluminium has a modern, timeless surface that designers love to use. Some interior designs or casings for computers or mobile phones are now using aluminium instead of plastic.

#recyclable. Aluminium is ideally suited for recycling. It can be returned to the material loop using only five per cent of the energy initially required to extract the metal.

#resistant. Aluminium does not rust and is therefore a suitable material for house façades, window frames or simply for any part exposed to wind and weather. The fact that it is also impermeable to gases, light and liquids means that even as the thinnest possible foil it is still very good for use in packaging.

heat-conducting. Aluminium is an outstanding conductor of heat, which is one of the reasons why it is used to produce solar collectors, cookware utensils and brake discs.

#non-toxic. Aluminium does not pose a health risk and so among other things it is an important constituent of packaging for foodstuffs.

Photo: Hydro Aluminium

Worth knowing!

Most properties can be influenced in a targeted manner by alloying or heat treatment. For example, increasing the strength can lead to reduced cold workability (ductility).

Aluminium aka 'The Allrounder'

Whether it be as aluminium foil in the household, as supports in buildings or as pitons in mountaineering – aluminium is used wherever there is a need for weight savings, protective functions, stability or corrosion resistance. After steel, aluminium is the second most important metal for industry. The demand for aluminium worldwide has undergone extremely dynamic development, particularly during the past decade. So let us take a closer look at where this sought-after metal is used!

Building with aluminium

The cupola of a church in Rome was covered with aluminium in the century before last - and the roof is still intact today. Aluminium has now become established in all fields of architecture. Anyone who wants ecological and economic construction, and places importance on durability, uses aluminium throughout the building. The use of alternative sources of energy is creating additional new uses for the metal in heat exchangers, solar units and wind turbines.

Applications: Frames for windows and doors, conservatories, solar shading devices, shower cubicles, balustrades, façade cladding, roof and wall systems, fittings and handles, gratings, antennae and lightning protection devices, load-bearing structures for photovoltaic units.

Transport and transportation

There are compelling arguments for the use of aluminium in chassis, gearboxes and engines: lightness, high payload, low operating costs, long useful life and low maintenance costs. Ever since this became apparent, aluminium casting alloys have been used everywhere in the transport sector. And the best thing is: thanks to the fuel savings made, aircraft, ships, trains and buses built from aluminium already have a positive energy balance after a few years' operation.

Examples: Car industry (body, engine blocks, rear hatches, doors, rims, cylinder heads, effect pigments for lacquer, wheels), cycles, motorcycles, the masts of regatta sailing boats, railed vehicles (ICE trains, trams), commercial vehicles (body structures), aircraft construction, shipping (ferries), flood barriers.

Mechanical and electrical engineering

Nowadays industrial automation is concerned with one thing above all others: controlled movement patterns. That is where aluminium comes into play! Lightweight aluminium parts help robots and handling equipment achieve precision and mobility. When it comes to strength, corrosion resistance and service life, the use of aluminium allows machine parts to be coordinated perfectly with the intended function. In electrical engineering, too, no-one wants to do without highly conductive aluminium any more.

Examples: Cylinders (hydraulic, pneumatic), overhead cables, antennae, shielded telephone or antenna cable, casings of electric motors, control cabinets, high and low voltage cable, busbars, capacitors, carrier strip for chip mounting, basis material for microchips, cooling fin profiles, storage disks for computer systems.

Packaging

Whether in the field of food, cosmetics or medication, one encounters packaging made partly or completely from aluminium whenever one goes shopping. The reason: aluminium is light, forms a tight seal, does not have an extraneous taste, is as resistant to the heat in an oven as it is to the cold in a freezer while still having good thermal conductivity, and thanks to its outstanding barrier properties prevents the ingress of extraneous aromas, dust, germs, oxygen and light. This means that today foodstuffs, for example, can be transported over long distances and stored without difficulty: chocolate stays fresh, sauces keep their spicy taste and fruit juices are full of vitamins.

Examples: All forms of packaging – from the iconic beverage can or tube to containers for shipment overseas, from the bottle closure to medicines that are safely sealed for use in tropical areas, or for attractive cosmetic products.

Sport and leisure

Whenever sporting performance reaches its limits, the question arises as to whether it is not possible to make the equipment used for competition even lighter, faster and easier to handle. That is where aluminium comes in: heavier materials are replaced by lighter ones of the same or even higher strength. All in all: sport and leisure is also a field where aluminium is indispensable.

Examples: Cutlery, tableware, pots, pans, barbecue foil, lamps, ladders, caravans, components for ski lifts, garden chairs, camping items, football goalposts, picture frames, handles for cupboards, fire-protection suits, fire ladders, pitons for mountaineering, design furniture, cycle frames and parts, spikes, studs.

The Continuous Aluminium Loop

On the preceding pages, we have learnt that aluminium is durable and versatile. But it faces an important challenge: lots of energy is required to produce it. Aluminium is therefore too valuable to throw it away after it has only been used once. The good news, though, is that the energy used to produce aluminium is not lost. It remains 'stored' in the metal. Aluminium is therefore also approvingly referred to as an 'energy bank'.

That is not something to which all materials can lay claim. Initially, a lot of energy is needed to produce primary aluminium; however, the aluminium can then be melted down and turned into new products as often as one likes. There is no loss in quality and the energy required is up to 95 per cent less than was needed to produce the aluminium originally. This explains why aluminium scrap in so much in demand, and why there is a nationwide network of metal dealers who collect, sort, compact and classify the aluminium scrap before selling it to the aluminium recycling industry.

In other words: it is worthwhile collecting and reusing even small quantities of scrap. Used aluminium beverage cans once again become molten metal that can be used to produce new beverage cans or other high-grade products. In many fields of application, aluminium stays within a closed material loop and 'real' recycling is carried out. Besides saving energy, recycling also conserves raw materials and makes an important contribution to environmental protection.

Salt slag

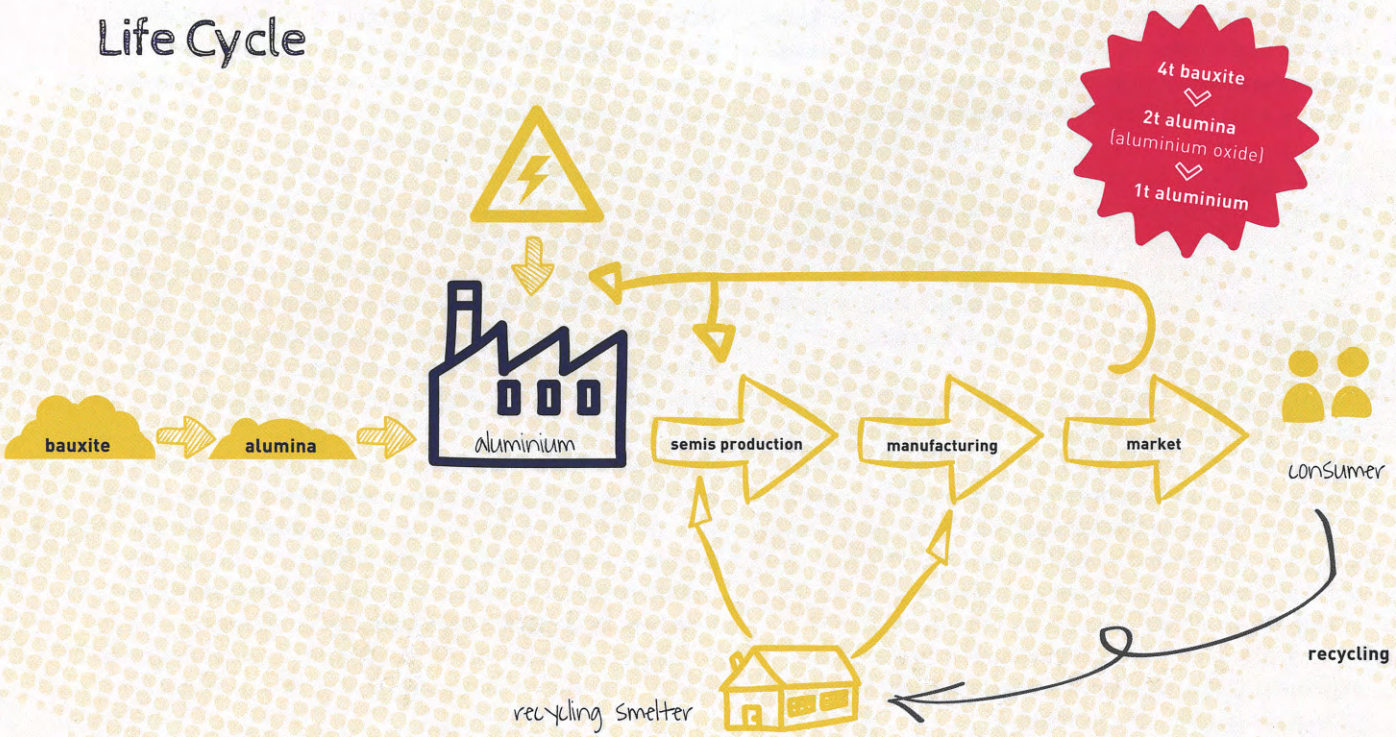
What happens to contaminated scrap? Salts are used. The salts prevent oxidation of the metal during melting and processing and tie up any impurities. The resultant salt slag is then itself recycled. The salt recovered is then added to the melt once again.

The German aluminium industry

In 2016, **546,806 tonnes** of primary aluminium were produced in Germany. During the same period, **722,890 tonnes** of aluminium were recycled.

The German aluminium industry employs about **74,000 people**. It also safeguards additional jobs in the supply industry.

Life Cycle



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It is lighter than steel, can be recycled time and time again and was once more expensive than gold. We are talking about aluminium!

Whether it be as household foil, a camping table or the frame of a mountain bike – we can no longer imagine everyday life without aluminium. The global demand for aluminium has undergone extremely dynamic development, especially in the past ten years. This brochure explains where this young material actually comes from, and why the light metal is indispensable when building machines, high-rise buildings, aircraft or kickboards.

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Additional teaching materials can be found at www.aluinfo.de