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To cite this version:

HAL Id: hal-04035933
https://hal.science/hal-04035933
Submitted on 18 Mar 2023

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Aluminum

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Aluminum is the most abundant metal in the earth’s crust. It occurs naturally in its oxidized state in a variety of sedimentary rocks such as bauxite. Alumina (Al₂O₃) is itself a material with good mechanical, chemical and thermal qualities, used traditionally in the production of ceramics. Its isomorphic form, beta-alumina, became a promising material for manufacturing solid electrolytes in the 1970s. Alums, hydrated double sulfate salts of aluminum (Al₂(SO₄)₃nH₂O), have been used since Roman antiquity in dyeing and tanning processes. However, the story of aluminum as a metallic material capable of replacing conventional metals in a wide range of industrial applications only began in the nineteenth century, since its production is intimately bound up with the history of electric power. Extracting aluminum from its ores requires large amounts of electricity, exemplifying the relational identity of certain materials, that is to say as natural entities that offer performances only in relation to specific conditions and circumstances. Cheap electricity produces the cheap metal that helped shape the modern world during the twentieth century. However, the identity and the image of the metal has changed significantly over the past two centuries. It was initially prepared as a semi-precious metal used in jewelry and silversmithing. Then, when its price dropped, it became a common material widely used in everyday life. The properties of the metal—lightweight, conductive, non-toxic and easily machined—make it an ideal material for transportation and packaging. But if aluminum lived up to its promises throughout the twentieth century, this successful career also has a darker side.

From scientific curiosity to semi-precious metal

The discovery of aluminum was the result of a long journey which began in the eighteenth century with research dedicated to plant growth and soils. (1) The research movement started in 1792 with Lavoisier and was pursued by Humphry Davy in 1804. The scientific agenda can be seen in the ‘alumina’ entry in L’Encyclopédie méthodique, in its 1792 edition: “The desires of chemists are still very far from being satisfied as to what they would like to know about alumina. The intimate nature of this earth is still entirely unknown, like that of other earthy materials.” (2 p193). Theodore de Saussure, in 1801, devoted a detailed notice to alumina in the Journal de physique, d’histoire naturelle et des arts, (3) and explained his observations and his methods of production. Three years later, in his 1804 reference book, Recherches chimiques sur la végétation, (4) he mentioned his observations of the presence of alumina in the ashes of various plants on which he had conducted experiments.

In the same year, while using a voltaic pile to split common compounds such as alum, a white mineral used since Greek and Roman antiquity for dyeing and tanning processes –, Humphry Davy identified the presence of two metals in it: potassium and another one that he failed to isolate as a simple substance. He first named it ‘aluminium’ then changed this name to ‘aluminum’ in 1807 before adopting ‘aluminium’ in his Elements of Chemical Philosophy in 1812. His hesitation was the source of a persistent spelling confusion despite the chemists’ concerns to standardize their nomenclature. The term ‘aluminium’ is recommended today by the International Union of Pure and Applied Chemistry because it retains the suffix ‘-ium’
used for other metals such as sodium or potassium. But this official term is still in competition with ‘aluminum’ adopted by Webster’s dictionary, in American language. Whatever its name, this simple metallic substance is difficult to extract from its ores. It was first isolated in an impure form by Hans Christian Ørsted in 1825. In 1827 Friedrich Wöhler obtained a few grains of pure aluminum by reducing its oxide with potassium. The French chemist Henri Sainte-Claire Deville reproduced Wöhler’s experiment using liquid sodium instead of potassium aluminum and succeeded, for the first time, in obtaining significant quantities of the metal. (5) Sainte-Claire Deville’s research culminated in the winter of 1853-1854 and he made his first communication to the Paris Academy of Sciences in its session of 6 February 1854. In March 1854, for the first time in the world, an aluminum blade was presented to the public. In his cover letter to the Academy, the scientist specified that tests had been carried out on the metal for three months. (6) Sainte-Claire Deville’s success was carefully orchestrated and the greatest scientists of the time were recruited to applaud it. (1) In August 1854, he performed his experiment before a number of fellow chemists including Jean-Baptiste Dumas, Louis-Jacques Thénard, Jean-Baptiste Boussingault and Théophile-Jules Pelouze. (7) Others, such as the German researcher Justus von Liebig, received a sample of the metal. This was a particularly strategic gift: in addition to his qualities as a chemist which were recognized worldwide, especially in the realm of foodstuffs, von Liebig was also a collaborator of Wöhler. So aluminum emerged first of all then as a scientific curiosity. Sainte-Claire Deville’s discovery was also publicized in North America. In 1854, The Mining Journal reported on a presentation by Henry Wurtz at a meeting of the New Jersey National History Society:

“[Sainte-Claire Deville] has succeeded in obtaining pure aluminum in considerable masses, and ascertaining thoroughly its properties. […] It may safely be predicted, allowing Deville’s assertions to be correct, and they have been confirmed by a Commission appointed by the French Academy of Science to investigate the matter, that some of us now present may yet live to eat with forks and spoons composed of aluminum, on aluminum dishes, food cooked in aluminum utensils upon an aluminum stove, and possibly while seated upon aluminum chairs in houses or ships composed of the same metal.” (8)

It was still a long way, however, from this scientific discovery to the industrial production of aluminum utensils. (9) In 1854, and with some financial support from Emperor Napoleon III, the Javel factory in Paris produced the first blades of aluminum, that were as expensive as silver ones. At the Paris International Exhibition of 1855, a number of objects, such as metal tumblers designed by the goldsmith and tableware company Christofle, and gradually crafted out of the small quantities of metal produced, were presented to the public. This firm also made a splendid epergne ordered by the Emperor for the imperial palace of Compiègne.
In a fiction *From the Earth to the Moon, A Direct Route in 97 Hours, 20 Minutes*, French novelist Jules Verne accurately described the tentative design of an enormous space gun to launch three people onto the moon. To the enthusiast engineers in charge of the project, aluminum appeared as the best material for the projectile. 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, and seems to have been created for the express purpose of furnishing us with the material for our projectile. (10, p.38)

**Everywhere in daily life**

Aluminum first came into existence then as a substitute for precious metals used for luxury items. By the end of the nineteenth century, however, the industrial production of the metal had witnessed its timid beginnings. The Salindres factory, in the Gard department in the South of France, located near bauxite mines, had already manufactured 45 tons of aluminum by 1889. Because of its gold color, the aluminum-bronze alloy was particularly successful. However, aluminum artifacts were still the hallmarks of the salons of the French bourgeoisie. It was to become a common, mass-produced material only in the early years of the twentieth century, when the obstacles along the route towards a commercially viable material were finally removed.

In 1886 two young men working independently, Paul Héroult in France and Charles-Martin Hall in the United States, found a way to overcome a major obstacle in the electrolytic process used to reduce aluminum oxide. To avoid the formation of aluminum hydroxide when the oxide was dissolved in water, they used molten cryolite as a solvent and electrolyzed the molten salt. The scaling-up of the electrolysis of molten cryolite still required high temperatures however and considerable power. The commercial success of aluminum production was dependent then on the availability of a cheap source of energy, hydroelectricity. It was hydroelectricity that made the mass production of aluminum possible. Aluminum plants consequently flourished in specific geographical areas such as the Alps or near the Niagara Falls where water falls or dammed mountain lakes could provide cheap hydroelectricity.

In 1907, aluminum selling prices fell sharply from 3.1 francs per kilogram to 1.5 francs. Several factors explain this price fall. The Hall / Héroult patents had fallen into the public domain and outsiders had appeared, leading to overproduction. The market, still weak, did not have many outlets for aluminum. But the development of the aluminum-copper-manganese-magnesium alloy by the German Alfred Wilm, between 1906 and 1909, was a decisive step in the development of the use of the metal in aeronautics.

During the First World War, in its context of scarcity, aluminum was used as an ersatz for silver and copper and began to look like the metal of the poor. As a cheap metal its uses expanded while its image deteriorated. Fortunately, however, the new metal also catalyzed the creativity of designers. In the interwar period they were generously funded by aluminum companies to improve the image of the metal. Unlike other metals, by means of anodization, aluminum can be colored while keeping the material visible. This characteristic has been widely exploited by designers for decorative purposes and in everyday commodities. The
streamline movement in the United States, with Raymond Loewy or Russel Wright, and the
modernist and avant-garde movements in Europe with Gio Ponti, Robert Mallet-Stevens or
Jacques Le Chevallier, managed to change the image of light alloys.(13, 14) The products
they designed have entered the most famous decorative arts museums in the world.
Transportation has been the most important sector for the development of aluminum alloys
since the First World War and continues to be so in 2020.(14) Aviation, in particular,
benefited from the development of Duralumin, a light and resistant aluminum-copper alloy,
the sheets of which are quenched to increase their rigidity. For rocketry and aerospace
applications, new high-performance alloys have been designed. In the automobile industry,
aluminum was introduced as early as 1899 for the Jamais Contente, the ‘never-satisfied’, an
electric vehicle which could be driven faster than 100 kilometers an hour. Aluminum alloys
are still used today for casting engine parts and truck bodies. A few aluminum boats have also
been successfully developed, such as ore carriers or sailing boats. Some are famous like Le
Migron designed by Alfred Nobel in 1892 or Eric Tabarly’s Pen Duik III in 1967. Yet steel is
still largely dominant in the boat building industry.
Packaging and kitchen utensils represent the second important sector for aluminum
applications. During the interwar years, it was developed for pots and camping gear and in the
1950s it became an essential material in the kitchen. Its ability to go from very cold to very
hot without alteration opened up the freezing and baking markets. Flexible packaging took
advantage of its waterproofness and its ability to be rolled into extremely thin sheets. During
the Second World War, multi-layer packaging was developed for the US military and
subsequently transferred to the civilian market. Rolled with paper and plastic or coated with a
varnish, aluminum is present in fruit juice cartons, toothpaste tubes and drink cans.
Aluminum also found some niche applications in buildings. Decorations of the Bordeaux
Cathedral in France, the pyramidal cap of the Washington Monument, the so-called Eros
statue of 1893 at Piccadilly circus in London or the roofing of the dome of the church of San
Gioacchino in Prati, in Rome, were among the first architectural projects to use aluminum.
Later, the excellent mechanical properties of aluminum manufactured by the Kaiser company
after the Second World War enabled Buckminster Fuller to design new architectural forms for
houses and domes. Its capacity to be cast in curved shapes meant that aluminum could also be
used for door frames, windows and façades with innovative shapes. This was the case, for
example, of the decorative façade of the Die Zeit newspaper office in Vienna, designed by
Otto Wagner in Vienna in 1902. In skyscrapers, aluminum has become a key material for
façades on account of its lightness and strength. Jean Prouvé, a French metal worker and self-
taught architect and designer, pioneered the construction of all-aluminum houses and tropical
pavilions using techniques inspired by aircraft construction.(14)

A monopolistic industry
The successful expansion of aluminum in our everyday urban landscape was made possible
by the regular increase in its industrial production. In 1918, world production stood at
131,000 tons, in 1968 at about 10 million tons. It reached 20 million tons in 1996, then
doubling again and in less than 15 years: 40 million tons in 2010 and 63.7 million tons in
2019. China has become the leading producer with more than half the world’s production. In
2018, India and Russia were in second place, each producing 3.7 million tons. The United
States is now in tenth position with 890,000 tons. This spectacular expansion from the second
half of the 20th century is related to the price of electricity and to the fact that multinational
companies producing aluminum can jurisdiction-hop to wherever they find the best
conditions.
Figures for the consumption of aluminum show similar increase, with marked accelerations during the periods of war. For primary aluminum, it was estimated at 196,000 tons in 1918, its highest historical level. It exceeded one million tons consumed in 1943 (1.7 million) of which more than half was consumed by the United States. Consumption then reached 10 million tons in 1971 and 20 million in 2000. If we add primary and secondary aluminum—aluminum that is made from recycling—consumption reached 38 million tons in 2000. Primary aluminum is produced from the electrolysis of alumina; secondary aluminum is obtained by recycling recovered waste such as cans, pots, planes, etc. Recycling developed after the Second World War in a context of scarcity.

The mass-production and consumption of aluminum is based on a specific economic model. In addition to cheap electricity, the industrial production of aluminum requires heavy banking investments. The aluminum industry worldwide is a typically capitalistic industry in the hands of few monopolistic companies. From 1886 until the First World war, there were only five: The Aluminum Company of America (Alcoa Inc.) in the United States, Société Electrométallurgique de Froges and Compagnie des produits chimiques d’Alais et de la Camargue (Pechiney, after merger in 1921) in France, Aluminium Industrie Aktien Gesellschaft (AIAG) in Switzerland and the British Aluminium Company Ltd. in the United Kingdom.

These companies held the monopoly until the patents fell into the public domain in 1907. After the First World War, the five pioneer companies helped other countries to develop their technology. But in most countries, as in Argentina or in Japan for example, a monopolistic position was the rule rather than the exception.(15,16)

In 1901 an international cartel was set up, the Aluminum Association. One of the oldest and strongest economic cartels in the world, it remained more or less effective until the 1950s. The Aluminum Association and the industrial companies fixed the price of the metal and shared out the world market, whilst keeping their national markets sheltered from competition. In the United States, the Sherman Act, an antitrust law of 1890, forced Alcoa to split from its Canadian subsidiary in 1928. Thanks to a dumping action, the Canadian Alcan company managed to conquer foreign markets in the 1930s.

After the Second World War, and under American influence, the Treaty of Rome in Europe adopted an anti-cartel position that would force the national companies to put an end to this trust economy (17,18,19). However, their practices changed only on a superficial level; industrial associations were created to lobby actively with the common market authorities at Brussels. But the introduction of aluminum on the London Metal Exchange in 1978 marked a sharp break in the balance established in the late 1880s by the major Western producers.(20) Henceforth, the sales price of the aluminum ingot was subject to speculation like copper or nickel. This came as a shock, the effects of which were accentuated by the fall of the Berlin Wall and the arrival of low-priced ex-Soviet metal on the Western market. Aluminum prices plunged and the value of aluminum companies fell. For the historical actors, these events opened a period of profound reconfiguration. Most disappeared, acquired by their competitors in more or less friendly takeover operations. In 2020, only the American Alcoa remains from among the five historical companies and world ranking is completely different. After being held for a long time by North Americans and Europeans, leadership is now dominated by Chinese and Russians.(21) Four Chinese companies are among the nine largest producers in the world. The Russian company Russal is in third place, Rio Tinto (Anglo-Australian) in fifth, Emirates global Aluminum (United Arab Emirates) is sixth, and Alcoa (USA) eighth followed by the Norwegian Norsk Hydro. Production capacities have exploded, with ever-larger smelters.(22) Only about forty countries in the world produce primary aluminum.
The dark side of the metal

The successful, innovative and surprising applications of aluminum—from jewelry to saucepans and from airplanes to telescope mirrors—all illustrate the metal’s success story.(12) Since its early applications, however, the metal has raised concerns about risks and potentially harmful effects. The creation of aluminum production plants sparked protests against their local impact in terms of pollution. Such controversies increased with the intensification of production in the second half of the twentieth century, particularly on account of the environmental footprint of the massive exploitation sites of bauxite mines and alumina production.(23)

Unlike other metals that are trace elements (copper, iron, zinc), aluminum is not necessary for the human metabolism. Beginning in the middle of the nineteenth century, its consumption in metallic form (from kitchen utensils) and as a food additive (baking powder) raised the question of the safety of its use in foodstuffs.(1) At the end of the nineteenth century, this use of aluminum in food production raised two scientific controversies. One concerned the analysis of the material used for the equipment of French and German soldiers, their flasks in particular. Three scientists, two German and one French, challenged the safety of aluminum on the grounds that the metal was corroded by the liquids in the flasks. These arguments were refuted by the rest of the scientific community, not unreasonably considering the nature of the material studied and the conditions of the analysis: samples came from objects made of metal obtained from the early days of industrial production when poorly controlled technical parameters would leave impurities.

A second controversy in the United States opposed the champions of baking powder containing aluminum salts to a group claiming that this baking powder was toxic. The latter included producers of aluminum-free baking powder as well as independent researchers convinced of its toxicity. It was the longest food controversy in American history. Theodore Roosevelt set up a special committee, the Remsen board, responsible for assessing the potential risks of aluminum. For the first time brief clinical trials were carried out on humans. Other trials, on dogs and rats, led to the deterioration of the animals’ health and, in some cases, to their death. These observations made it possible to record the neurotoxic effects of aluminum when ingested in large doses, as well as the presence of the metal in various organs such as the liver, the spleen and the brain. Nevertheless, these results did not prevent the use of aluminum in baking powder.

During the interwar period, a third controversy took place in Great Britain. A general practitioner, Robert Montague Le Hunte Cooper, observed major signs of chronic fatigue among some of his patients, along with joint pains and dizziness. He also noted that his patients’ condition would improve when they stopped using aluminum kitchen utensils. He delved into the scientific literature on the issue and went on to perform laboratory experiments. But he did not manage to assert his opinion successfully in face of the opposition marshalled by the industrialists defending the metal’s innocuousness. In both the American and British controversies, the aluminum industry reacted strongly, even sponsoring publications by renowned scientists refuting the conclusions unfavorable to aluminum. This practice, typical of industrial lobbies as ‘merchants of doubt’, undermined public trust in science but did not affect the production and consumption of aluminum in the food industries.(24)

The year 1986 marked a turning point in the history of concerns over aluminum after two British researchers identified ‘senile plaques’ comprising an identical distribution of aluminum and silicon in the brains of patients affected by Alzheimer’s disease. Today the role of aluminum in encephalopathies is discussed in scientific publications worldwide. Many mainstream newspapers and daily and weekly publications took up the conclusions of this
work, emphasizing its sensationalism and declaring more or less peremptorily that aluminum was the cause of the epidemic of Alzheimer’s disease. By the end of the twentieth century, it was established that aluminum plays an important role in several diseases: breast cancer, Crohn’s disease, autism and ‘macrophagic myofasciitis’. For the latter, investigations carried out showed the presence, in the macrophages of tissue lesions, of specular inclusions composed of aluminum hydroxide. The phenomenon is related to the use of aluminum as a vaccine adjuvant, in order to improve the immune response of inactivated vaccines. The hypothesis proposed is that chronic fatigue syndrome could be caused by the presence of pathogenic agents or toxic compounds that have immunostimulant effects, provoking an incessant stimulation of the immune system. According to this research, chronic fatigue syndrome is linked to aluminum salts. The widespread use of aluminum in food and agriculture, cosmetics, pharmaceutical industries and water purification, as well as of course in transportation and daily household objects, has multiplied the sources of exposure to the metal, to the point that aluminum particles are now present in the air. Of course, aluminum, as mentioned, is the third constituent element of the Earth’s crust (8.1%) after oxygen and silicon, and before iron (5%), but the rate of exposure of the human body to its possible contamination is today way above the levels seen in the nineteenth century.

Air pollution (fluorine) from aluminum factories aroused protests from the early twentieth century, but conflicts were generally settled by financial compensation for neighboring farmers. The considerable increase in production after the Second World War caused enormous damage to the surrounding flora and fauna and gave rise to occupational diseases. Pressure from environmental movements and from public opinion generally has led manufacturers to find solutions to reduce gas emissions, such as covering the electrolytic cell with recycled gases and the automation of their alumina supply. The situation has improved significantly, but there remains the problem of the huge amounts of electricity consumed to produce aluminum. Although hydroelectricity has been replaced by thermal or nuclear electricity with the subsequent location of factories near deep-water harbors, in the twenty-first century, the establishment of gigantic factories near oilfields raises serious questions about their carbon footprint.

Finally, upstream from metal production itself, the problems of bauxite mines and alumina factories are just as intractable. With prehistoric caves destroyed by Rio Tinto in Australia or threats to sacred sites in India, the demand for bauxite generates strong environmental conflicts and significant impact on the landscape. Likewise, the inability of industrialists to find a solution for recycling the red sludge from alumina production using the Bayer process leads to intolerable situations from an environmental point of view. The ongoing dumping of this toxic sludge in the Mediterranean, off the coast of the Gardanne factory in the South of France, for more than fifty years, and the open-air storage of the sludge with possible industrial accidents as in Ajka (Hungary, 2010) are further illustrations of the environmental risks associated with this industry.

In conclusion, although aluminum oxide has been used since ancient times, the affordances of the metal remained unknown until the mid-nineteenth century. It is now ubiquitous in our daily lives and almost indispensable for a number of applications. The Hall-Héroult process together with cheaper electricity enabled the mass production and consumption of aluminum.

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1 The Bayer process involves three steps: first, crushed bauxite is mixed in a solution of sodium hydroxide (caustic soda) at a temperature of 150 to 200 °C; second, after cooling, this mixture is seeded with crystals to precipitate aluminum hydroxide, leaving an insoluble residue, called red mud or red sludge; third, after washing, the hydroxide is heated in a kiln in order to drive off the water and produce several grades of granular or powdery alumina, including activated alumina, smelter-grade alumina, and calcined alumina.
Until the 1950s, industrial companies, developed and consolidated their niches on the market. In the second half of the twentieth century, the cartel system gradually eroded the quotation of aluminum on the London metal exchange market. From 1978, finance took control of the industrial companies. In addition, the promises of aluminum alloys are seriously compromised by environmental issues. Adverse effects are visible all along the value chain, from the extraction sites to waste management. Presented as the metal of modernity and with a performance capable of being metamorphosed by color and surface treatments, throughout its history it has been an ambivalent material and it remains so today.

References