MATTER DIS//ASSEMBLED: Revealing the Economies and Ecologies of Aluminum

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“When the bombers got back to their base, the steel cylinders were taken
from the racks and shipped back to the United States of America, where factories
were operating night and day, dismantling the cylinders, separating the dangerous
contents into minerals... ....The minerals were then shipped to specialists in
remote areas. It was their business to put them into the ground, to hide them
cleverly, so they would never hurt anybody ever again.”
- Kurt Vonnegut, Slaughterhouse V
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This project seeks to understand matter through the environments it creates. These environments, created through production, end-use, and disposal, extend to the scale of the world, the territory and the product. In a globalized world, the separate environments of a single material are highly external, and while we may know where a material comes from, the consequences of its extraction and manufacture are out-of-site, out-of-mind.

This externalization is evident for Aluminum, which has a diverse and often contradictory range of environments. Historically, Aluminum’s cultural understandings lead to the following conclusions:

**Velocity**
Its extremely low weight, less than half that of steel, allowed humans to build structures for movement at unprecedented speeds on land, sea, and air travel.

**Tectonics**
From airplanes to automobiles to curtain walls, aluminum can be machined, shaped, and extruded into a wide variety of assemblies.

**Future**
Since the early 20th Century, aluminum has been a symbol for Modernity and the future, due to its strength, lightness, and luminosity.

While this characterizes its manufacture and end use, the extraction, refining, reduction, and disposal of aluminum have much different realities. These realities present a counter-thesis:

**Intensive**
At 279 MJ/kg, Aluminum’s embodied energy is one of the highest in any building material. That is over 6 times more energy than Copper, and 10 times more energy than low-carbon steel.

**Landscape**
Bauxite Mining, Red Mud, Hydroelectric: The primary production of aluminum requires the permanent alteration of landscapes at massive scales, often displacing populations in the thousands.

**Garbage**
In 2012, 55 million aluminum cans were not recycled, filling landfills and requiring the massive amounts of primary energy to produce more.
Proposal

In architecture, aluminum is utilized through The Assembly. In Matter Disassembled, I propose formal disassembly as a basis for revealing the hidden realities of aluminum. I contend that a didactic architecture of aluminum can be achieved through the identification of parts, connections, and ensembles, followed by meaningful reassembly.

Archigram - Plug-in City - 1964


Yona Friedman - Villa Spatial - 1959

Rania Ghosn and El Hadi Jazairy - Geographies of Trash: Collect - 2015

2000-2001: Due to spiked energy costs, most Alcoa smelting facilities in the Pacific Northwest shut down.

2000: China bans the import of foreign scrap and recycling waste. This causes the global price of scrap to plummet, since the largest buyer left the market.

2018: Due to a trade war with China, taking tariffs on steel and aluminum, this is causing the price of aluminum in the US to skyrocket.

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Raw Aluminum Production (USA)

Raw Aluminum Price (USA)

Scrap Aluminum Price (USA)
# Properties & Uses

<table>
<thead>
<tr>
<th>Metal</th>
<th>Matter Density (g/cm³)</th>
<th>Melting Point (ºC)</th>
<th>Thermal Conductivity (W/mK)</th>
<th>Electrical Resistivity (Ohm•cm)</th>
<th>Modulus of Elasticity (GPa)</th>
<th>Shear Modulus (GPa)</th>
<th>Hardness (Vickers Scale)</th>
<th>Primary Embodied Energy (MJ/kg)</th>
<th>Secondary Embodied Energy (MJ/kg)</th>
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<tr>
<td>Al</td>
<td>2.7</td>
<td>660.4</td>
<td>210</td>
<td>2.70 x 10⁻⁶</td>
<td>68</td>
<td>14</td>
<td>68</td>
<td>279</td>
<td>93% Energy Reduction</td>
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<tr>
<td>Cu</td>
<td>8.9</td>
<td>1083</td>
<td>400</td>
<td>1.70 x 10⁴</td>
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<td>200</td>
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<td>60</td>
<td>High Energy Smelting</td>
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<td>1370</td>
<td>47.0</td>
<td>1.70 x 10⁻⁶</td>
<td>15</td>
<td>200</td>
<td>15</td>
<td>26</td>
<td>Soft Metal</td>
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<tr>
<td>C</td>
<td>7.1</td>
<td>419.6</td>
<td>112</td>
<td>5.92 x 10⁻⁶</td>
<td>25</td>
<td>80</td>
<td>25</td>
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<td>13.1</td>
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<td></td>
<td>7.3</td>
<td>Low R Value</td>
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## Metal by the Numbers

- **Aluminium**: 2.7 g/cm³, 660.4 ºC, 210 W/mK, 2.70 x 10⁻⁶ Ohm•cm, 68 GPa, 14 Vickers, 279 MJ/kg, 93% Energy Reduction
- **Copper**: 8.9 g/cm³, 1083 ºC, 400 W/mK, 1.70 x 10⁴ Ohm•cm, 25 GPa, 200 Vickers, 60 MJ/kg, High Energy Smelting
- **Iron**: 7.9 g/cm³, 1370 ºC, 47.0 W/mK, 1.70 x 10⁻⁶ Ohm•cm, 15 GPa, 26 Vickers, 26 MJ/kg, Soft Metal
- **Zinc**: 7.1 g/cm³, 419.6 ºC, 112 W/mK, 5.92 x 10⁻⁶ Ohm•cm, 25 GPa, 80 Vickers, 13.1 MJ/kg, Electrically Conductive
- **Lead**: 8.2 g/cm³, 207.2 ºC, 33.0 W/mK, 2.06 x 10⁻⁵ Ohm•cm, 5 GPa, 11.5 Vickers, 7.3 MJ/kg, Extremely Low-weight

## Raw Material

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## General Manufacture

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Consumer Durables
Electrical
Machinery & Equipment
7%
7%
7%
1808: Alumina is discovered as an oxide of Aluminum by Sir Humphry Davy.

1814: Pierre Berthier discovers Bauxite, the ore containing alumina, in Les Baux-en-Provence, France.

1821: Friedrich Wohler discovers aluminum’s density and weight.

1831: The electrochemical smelting process, now known as the Hall-Heroult Process, is developed simultaneously by Charles Hall (USA) and Paul Heroult (France). This process, still used today, allows for the large scale production of aluminum.

1845: The recently formed Aluminum Company of America (Alcoa) opens a smelter near Niagara Falls to make use of the hydroelectric power plant.


1856: The electrochemical smelting process, now known as the Hall-Heroult Process, is developed simultaneously by Charles Hall (USA) and Paul Heroult (France). This process, still used today, allows for the large scale production of aluminum.

1858: Henry Bessemer discovers a process for converting iron into steel.

1861: The first aluminum can is invented by Charles Courvoisier and Samuel Knight.

1865: The City of New York holds its first aluminum can competition.

1873: The recently formed Aluminum Company of America (Alcoa) opens its first smelter near Nanticoke, Pennsylvania.

1883: The first American aluminum can is produced.

1884: Being a luxury material at the time, a 100 oz aluminum cap was placed at the top of the Washington Monument, for both ornament and to serve as a lightning cap.

1886: The electrochemical smelting process, now known as the Hall-Heroult Process, is developed simultaneously by Charles Hall (USA) and Paul Heroult (France). This process, still used today, allows for the large scale production of aluminum.

1893: The recently formed Aluminum Company of America (Alcoa) opens a smelter near Niagara Falls to make use of the hydroelectric power plant.

1909: The Futurist Manifesto is published by F.T. Marinetti, declaring, “We declare that the splendor of the world has been enriched by a new beauty, a beauty of speed.”

1910: Walter Gropius, cofounder of the Bauhaus, praises aluminum’s “homogeneity, durability, and beauty of materials and industrial precision.”
1901: Thermite is invented through the reaction of aluminum powder and iron oxide. This development allows for the destructive power of bombs to rise exponentially in the coming decades.

1909: Alfred Wilm develops the first Aluminum Alloy, which becomes the structural basis for German WWI zepplins.

1914-1918: To meet the demands of the First World War, Alcoa increases production 40%, producing 152 million pounds of Aluminum for the Allied forces.

1914: Kaiser Aluminum publishes an advertisement showcasing the various uses of aluminum in the newly consumer-driven society. Such uses include roofing, mailboxes, TV antennae, fences, road signs, cars, and furniture.

1926: A sheet metal alloy of aluminum is developed, called Alclad, and is used extensively in both military and civil aircraft. Mussolini's fascist government embraces the potentials of light metal, describing aluminum as "not only the metal of the Fatherland; it is also the metal of progress, the real material of unreal velocities."

1930: An Alcoa ad in the Saturday evening Post predicts "Soon - nearly all trucks and buses will have aluminum bodies!"

1933: The USSR builds its first aluminum smelting plant based on designs stolen from the United States. Its operations were critical to the Allied victory of WWII.

1933: Buckminster Fuller designs the Dymaxion Car, drawing from the streamlined shape of an airplane fuselage.

1933: Bauxite and oil are discovered in Algeria, opening up a new market for aluminum.

1938-1944: US production of aluminum increases from 143,000 tons per year to 766,000 tons per year.

1939-1943: With more than 600% increase in aluminum production, 304,000 military airplanes are produced using 3.5 billion pounds of aluminum, or more than 85% of Alcoa's output.

1942: Eight Nazi saboteurs arrive in the USA with the specific goal of sabotaging US aluminum production, knowing it was key to the Allied war effort.

1948: The Reynolds Corporation produces the promotional film, "Aluminum on the March," to display the properties, production process and uses of aluminum in everyday life—fences, road signs, cars, and furniture.

1949: Aluminum can ends make up over 80% of the canned beer market, due in part to the development of the ring pull tab in 1962.

1955: Wally Byam starts the Caravan Club International, a new movement created by the popularity of the airstream trailer.

1955: A 50 ft aluminum antennae transmits satellite television for the first time through the American Telstar Satellite.

1956: The Aluminum Christmas Tree is featured as a plotpoint in the Charlie Brown Christmas Special, showing its popularity at the time.

1968: Aluminum can ends make up over 80% of the canned beer market, due in part to the privatization of bauxite resources leading to protests and a series of violent massacres by security forces.

1969: Buzz Aldrin and Neil Armstrong land on the moon, the US's crowning achievement in the Space race.

1974-5: Alcoa begins to advertise and expand their recycling operations, recycling 85 million cans in 1974.

1993-1994: General James Coxe, a former General Motors executive, takes power in Guinea, one of the world's largest bauxite producers.

2001: In the United States, over 51 million aluminum cans were not recycled.

2007-2009: In Guinea, Civil unrest linked to the privatization of bauxite resources leads to protests and a series of violent massacres by security forces.
1920s: Throughout the 1920s, Alcoa began building hydroelectric dams in the US and Canada to power their aluminum smelters. These dams damaged the environment and displaced indigenous communities on a massive scale.

1954: By this year, Alcoa employs over 50,000 workers and uses over 17 hydroelectric power plants in the United States.

1952: The U.S. United States sets the record for the highest average speed, thanks to its aluminum body.

1958: The first large-scale commercial jetplane, the Boeing 707, begins transatlantic US flights.

1967: The Afobaka Dam is built to supply power to an Alcoa smelter in Suriname. It creates an artificial lake on the Suriname River in the illegally appropriated Saamaka Maroon territory, covering about 43 villages.

1965: The Akosomba Dam in Ghana creates the world’s largest man-made lake and displaced 84,000 people. The dam was built to power nearby aluminum smelting facilities.

1967: The Indian Supreme Court upheld the Dongria Kondh’s right to stop Vedanta Resources from mining their sacred mountain.

1941: Alumina production begins in Suriname.

1947: The Minerals (Vesting) Act and The Mining Act are passed in Jamaica, creating extremely low tariffs for Alcoa to mine bauxite.

2004: Bauxite is discovered in Guinea.

1955: The Assarabian Sta in Ghana creates the world’s largest man-made lake and displaced 84,000 people. The dam was built to power nearby aluminum smelting facilities.

1963: 3 years after Jamaica achieves its independence, Jamaica leads the world in bauxite exports, taking up 28% of the global market.

2000s: China’s aluminum production skyrockets. Between 2006 and 2010, production jumps from 3.86 million tons to 13 million tons. Between 2004 and 2012, its share of the global market jumped from 11% to 37%.

1970: Soyinka reorganises their bauxite resources.

1954: General Lansana Conte takes power in Guinea, one of the world’s largest bauxite producers.

2009: The Sayano-Shushenskaya Dam in Siberia had a catastrophic failure, resulting in 17 people dead and 58 people missing. 70% of the dam’s power was dedicated to RUSAL, the Russian aluminum company.

2007: In Suriname, the Saamaka Maroon people win a case in the Inter-American Court of Human Rights, recognizing their rights to self-determination and control of their ancestral land. Since the land is already flooded, there is not much to be done with this ruling.

2000-2001: Due to spikes in energy costs, almost every Alcoa facility in the Pacific Northwest shuts down.

2008: The US housing market collapses, resulting in a global economic recession. Alcoa’s output reduces 13%.

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Aluminum is the 3rd most Abundant element in the Earth’s crust, but is rarely found in its pure state. Usually, it is mined as bauxite ore, a red, rocky substance usually found in tropical and subtropical regions. Some of the largest Bauxite deposits can be found in Australia, Brazil, Ghana, and Jamaica. Bauxite mining occurs through the blasting and collection of the stone, where it is then grinded into smaller, more workable pieces and shipped to an alumina refinery.
From the mine, bauxite is refined into alumina through the Bayer Process. This process removes the silica, iron oxides, and titanium dioxide from the ore mixture, leaving a fine white powder. However, these excess compounds form an alkaline red mud, known as bauxite tailings. This mud must be kept in retention ponds, filling miles and miles of land, where it contaminates the soil permanently.
The alumina is further processed into pure aluminum through the electrochemical smelting process known as the Herroult-Hall Process. From bauxite ore, about 25% of the original mass is reduced to Aluminum. This process uses exorbitant amounts of energy, often requiring the capacity of an entire power plant. Currently, the largest producer of Aluminum through primary smelting is China.
Aluminum’s unique properties as a light metal make it desirable for a wide variety of applications. The three primary means of shaping and machining aluminum are casting, rolling, and extruding. Aluminum is cast into blocks, blooms, and ingots for transportation to manufacturing plants, but is also cast into a variety of geometries that could not otherwise be machined or shaped. Aluminum is rolled into sheets of varying thickness, from plate to foil, which can then be bent or die cast into a variety of shapes. Aluminum is extruded into everything from wire to curtain wall members.
Much like matter’s sites of production, our perception of the sites of end use and disposal are now becoming externalized. Online services grow popular as brick and mortar stores close; more and more cities are starting curbside single-stream recycling programs, creating further dissociation with the processes of matter. This trend applies to aluminum products, especially in packaging and electronics.
Any aluminum waste that is not recycled ends up in a landfill. In a landfill, a large hole is dug, where tons of garbage is piled up, sealed in plastic barriers, and buried. There is no chance of reclamation of this material, and very little in the way of long-term plans to maintain these sites.
Some forms of excess and hazardous waste are illegally exported to the third world. This is the case at the Agbobloshie E-waste Dump in Ghana. At sites like these, informal economies form for the harvesting of precious metals from the dumps. E-waste is burned, melted, and disassembled, leaving aluminum, copper, iron, and other precious metals to be collected. These processes lead to large amounts of air, soil, and water pollution, to the point that many pickers do not live past their twenties.
Typically, when aluminum properly recycled in the US, it is processed through single stream recycling. At a recycling facility such as this, waste is separated by size with a trommel separator, and then by material type with an eddy current and electromagnet. When the aluminum is fully isolated, it is bailed with a hydraulic press to be shipped to a secondary aluminum smelter. Since China banned the import of scrap metal, however, much of the scrap in the US has either piled up with no purpose, or been sent to a landfill.
Alumina (Al₂O₃)

Calcination

Precipitation

Bauxite (Al(OH)₃)

Embodied Energy: 2.3 MJ/kg

Caustic Soda Repurposed

Flash Tanks

Digestion

Red Mud Runoff

Fe₂O₃

Caustic Soda Input

SiO₂

H₂O

Embodied Energy: 44.5 MJ/kg (46.8 MJ/kg total)

Aluminum: Full Cycle


1909: The Futurist Manifesto is published by Filippo Tommaso Marinetti, declaring, “We declare that the splendor of the world has been enriched by the beauty of aluminum. Henceforth, chrome, nickel, and aluminum are as recognized by law as the precious stones and metals of old.”

1931: Alcoa advertises the properties of aluminum through the Fortune Magazine ad, “Peer into the Future.”

1936: The Electrochemical Process is developed by Charles Hall (USA) and Paul Heroult (France), process, now known as the Hall-Herroutt Process, is developed simultaneously by Charles Hall and Paul Heroult.

1940: Albert Frey designs Frey House I in Palm Springs, CA in the Desert Modernism style.

1941: Alumina production begins in Suriname.

1947: The Minerals (Vesting) Act and The Mining Act are passed in Jamaica, creating extremely low tariffs for Alcoa to mine bauxite.

1948-9: Boris Artzybasheff designs exoticist portraits of Caribbean people for Alcoa cruise tours.

1955: Kaiser Aluminum publishes an advertisement showcasing the various uses of aluminum in the newly consumer-driven market.

1955: Wally Byam starts the Caravan Club of America to power their aluminum smelters.

1960: “A catastrophe occurred in Hungary in which a massive spill of highly caustic red mud killed several people, wiped out villages and streams, and threatened the Danube River. This toxic spill brought global attention to the pollution caused by bauxite mining, an issue that has usually been ignored outside of activist social movements.”


1965: The Aluminum Christmas Tree was featured as a plotpoint in the Charlie Brown Christmas Special, showing its popularity at the time.

1967: The Afobaka dam is built to supply power to an Alcoa smelter in Suriname. It covers about 43 villages in the Maroon territory, drawing from the Saamaka Maroon community.

1970: Guyana nationalizes their bauxite resources. (Sheller)

1971: Toyo Ito’s Aluminum House is built, designed with the traditional pagoda typology.

1979: The Sayano-Shushenskaya Dam in Siberia had a catastrophic failure, resulting in 71 deaths and the evacuation of thousands of people.

2000-2001: The privatization of bauxite resources in Guinea leads to protests and a series of violent massacres.

2007-2009: In Guinea, civil unrest linked to the privatization of bauxite resources leads to protests and a series of violent massacres.

2010: “A catastrophe occurred in Hungary in which a massive spill of highly caustic red mud killed several people, wiped out villages and streams, and threatened the Danube River. This toxic spill brought global attention to the pollution caused by bauxite mining, an issue that has usually been ignored outside of activist social movements.”

2018: Due to spikes in energy costs, Canada shut down its aluminum smelters.

Products Delivery

Product Disposal
Matter Disassembled

In architecture, aluminum is utilized through The Assembly. In Matter Disassembled, I propose formal disassembly as a basis for revealing the hidden realities of aluminum. I contend that a didactic architecture of aluminum can be achieved through the identification of parts, connections, and ensembles, followed by meaningful reassembly.
Original Assemblies: Exploration of Expression


