Territories of Matter: 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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I contend that architecture is a waypoint for the circulation of matter and energy in a larger territory. A single material implies a vast global network, fraught with toxic ecologies and economic disparities.

Aluminum, for example, presents a global network that is particularly unsettling, but rarely thought of. Known for its lightness, strength, and versatility, it is used for everything from disposable cans to curtain walls to Christmas trees. But the final products only account for small percentage the territory of aluminum. For example, the surface mining of bauxite, or aluminum ore, stretches over dozens of miles in a single site, destroying the tropical rainforests where significant numbers of mines operate. The refining of bauxite creates massive pools of caustic red mud, ruining soil and threatening groundwater supplies. Millions of tons of recycled scrap aluminum are currently being dumped into landfills as a result of China’s ban on the import of recyclables, leading to higher demand for primary aluminum, which takes 10 times more energy to produce than recycled aluminum.
But why does this matter to us? Kiel Moe writes that, “Designers can make large-scale territories more, or less, powerful based on their practices, designs, and specifications. When these territories and pathways of intake are externalized beyond the discipline and profession of architecture, this latent power is forfeited to others, if it is considered at all.” More and more, the enormity and complexity of these territories leads architects to do just that: to pretend these pathways of intake are not their problem.

In response, this project seeks to rectify the damages, close the gaps, and reveal the hidden realities of this material. To do this, the scales of intervention must match the enormous scales of the environmental destruction that are taking place. My interventions are represented under construction, since they will grow overtime as an indexical measure of the build-up of waste in the global system. I have chosen three sites throughout the territory of aluminum in which to intervene, and two waste materials to repurpose as didactic devices.
# Properties & Uses

<table>
<thead>
<tr>
<th>Metal</th>
<th>Matter Density (g/cm³)</th>
<th>Melting Pt (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>25</td>
<td>15</td>
<td>279</td>
<td>93% Energy Reduction</td>
</tr>
<tr>
<td>Cu</td>
<td>9.0</td>
<td>1083</td>
<td>400</td>
<td>1.70 x 10⁻⁶</td>
<td>110</td>
<td>46</td>
<td>50</td>
<td>60</td>
<td>High Energy Smelting</td>
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<tr>
<td>Fe</td>
<td>7.9</td>
<td>1370</td>
<td>47.0</td>
<td>1.70 x 10⁻⁶</td>
<td>200</td>
<td>80</td>
<td>126</td>
<td>26.5</td>
<td>99% Energy Reduction</td>
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<td>7.1</td>
<td>419.6</td>
<td>112</td>
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<td>327.5</td>
<td>33.0</td>
<td>2.06 x 10⁻⁵</td>
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<td>4.9</td>
<td>5</td>
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</tr>
</tbody>
</table>

**Comments:**
- Extremely Low-weight
- Low R Value
- Electrically Conductive
- Soft Metal
Transportation 36%
Packaging & Containers: 23%

Building & Construction: 16%
Consumer Durables
Electrical

7%
1808: Alumina is discovered as an oxide of Aluminum by Sir Humphrey Davy.

1845: Frederick Wohler discovers aluminum's density and weight.

1821: Pierre Berthier discovers Bauxite, the ore containing alumina, in Les Baux-en-Provence, France.

1884: 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, co-founder of the Bauhaus, praises aluminum’s “homogeneity, weather resistance, water repellency, rust-proofness, its susceptibility to precision fitting of parts, and the beauty of surface that Aluminum affords.”

1919: Alcoa advertises the properties of aluminum through the Fortune Magazine ad, “Peer into the Future.”

1935: The Empire State Building in New York City is completed, and it is the first large-scale use of aluminum in building, with the spandrels and the mast at the top made of Aluminum. It also realized the ambition of “Velocity and Luminosity” in Architecture at the largest scale yet.

1939: At the New York World’s Fair, General Motors’ Futurama exhibit models the city of the future: skyscrapers, 7 lane raised highways, and driverless cars, all dreams brought into being with the new light metal technologies.

1940: Albert Frey designs Frey House I in Palm Springs, CA in the Desert Modernism style, using corrugated aluminum for the exterior walls, aluminum frame windows, and aluminum furniture. (Sheller)

1941: Marcel Breuer and Walter Gropius, recent emigres to the US, are commissioned to design the Aluminum City Terrace in New Kensington, PA. While it showcased mass industrialized housing, it was not constructed with any aluminum, as the war had started and all aluminum had been diverted to war production.

1949: Jean Prouve designs the first in a line of prefabricated aluminum houses for war refugees, known as the Maison Coloniale.

1953: Alcoa’s new corporate headquarters opens in PIttsburg, complete with aluminum curtain walls, electrical systems, and plumbing.

1954: Buckminster Fuller designs the Dymaxion House, a prototype for an automated, mass produced, affordable, transportable, and environmentally efficient home. Fuller designed it to be produced using the same materials and industrial processes as aircraft.

1955: The hippie commune known as Drop City is established near Trinidad, Colorado. The houses are a collection of aluminum skinned geodesic domes, which won Fuller’s Dymaxion award for innovative and economic housing construction in 1967.

1962: NASA’s Vehicle Assembly Building is built in Cape Canaveral. At the time, it was in Chicago, using 2.5 million pounds of aluminum, 3 million pounds of aluminum.

1969: The John Hancock Center is built in Chicago, using 2.5 million pounds of aluminum sheathing.


Art & Architecture
1909: Alfred Wilm develops the first Aluminum Alloy, which becomes the structural basis for German WWI zeppelins.

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.

1901: Thermite is invented through the mixture of aluminum powder and iron oxide. This development allowed the destructive power of bombs to rise exponentially in the coming decades.

1932: 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.”

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

1926: A sheet metal alloy of aluminum is developed, called Alclad, and is used extensively in both military and civil aircraft.

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.

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.

1943: In a single year, the US uses 18 million kWh to produce 920,000 tons of aluminum. That was the equivalent amount of energy to power half the entire country.

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.

1949: Buzz Aldrin and Neil Armstrong land on the moon, the US’s crowning achievement in the Space race.

1957: The USSR launches Sputnik, a mostly aluminum satellite, and the initial move of the Space race in the Cold War.

1968: The Lockheed C-5 Galaxy is introduced as “essentially an all-aluminum aircraft” and is one of the largest aircraft in the Space race, in the world, capable of carrying up to six Apache helicopters.

1969: General Lansana Conte takes power in Guinea, one of the world’s largest bauxite producers.

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

1936: William B. Stout designs the Stout Scarab, the world’s first minivan, with an aluminum body.

1955: 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.

1956: The Reynolds Corporation produces the promotional film, “Aluminum on the March,” to display the properties, production process and uses of aluminum in everyday life.

1965: The Aluminum Christmas Tree was 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 development of the ring pull tabs in 1962.

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

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

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

The first large-scale commercial airplane, the Boeing 707, begins trans-Atlantic flights.

Alcoa uses over 20 billion kWh in the US alone, or the equivalent of 4 million single family homes.

By this year, 25% of single-family homes in the US are mobile homes, due to the affordability of aluminum and popularity of the Ten-Wide mobile home.

In the town of Camelford, Carole Cross died from a rare and aggressive form of Alzheimer's. This was linked to the dumping of 20 tons of aluminum sulfate into the town's water supply.

Alcoa pays an $11.4 million fine for the mercury contamination of Lavaca Bay in Texas.

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

The US enters a trade war with China, raising tariffs on steel and aluminum. This is causing the price of aluminum in the US to skyrocket.
2013: The Indian Supreme Court upheld the Dongria Kondh’s right to stop Vedanta Resources from mining their sacred mountain.

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.

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 Artybasheff designs exoticist portraits of Caribbean people for Alcoa cruise tours.

1941: Alumina production begins in Suriname.

1947: The Akosomba Dam in Ghana creates the world’s largest man-made lake and displaced 84,000 people. The dam was constructed to power nearby aluminum smelting facilities.

1945: Bauxite is discovered in Guinea.

1965: 3 years after Jamaica achieves its independence, Jamaica leads the world in bauxite exports, taking up 28% of the global market.

1954: Bauxite is discovered in Guinea.

1970: Guyana nationalizes their bauxite resources.

2000s: China’s aluminum production skyrockets. Between 2006 and 2010, production jumps from 3.86 million tons to 17 million tons. Between 2004 and 2012, their share of the global market jumped from 11% to 37%.

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.

2005: China’s aluminum production skyrocketed. Between 2006 and 2010, production jumps from 3.86 million tons to 17 million tons. Between 2004 and 2012, their share of the global market jumped from 11% to 37%.

1917: Alcoa’s first bauxite mine opens in Suriname.

1921: Alcoa’s begins its presence in Equitorial Guinea, a French colony at the time.

1941: Alumina production begins in Suriname.

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

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.

1970: Guyana nationalizes their bauxite resources.

1984: General Lansana Conte takes power in Guinea, one of the world’s largest bauxite producers.

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Global Industrialization
Bauxite Mine: Weipa, Australia

Embodied Energy: 2.3 MJ/kg
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 ground into smaller, more workable pieces and shipped to an alumina refinery.
Red Mud Runoff
Caustic Soda
Digestion
Flash Tanks
Precipitation
Calcination

Fe₂O₃
SiO₂
H₂O

Alumina (Al₂O₃)

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

Alumina Refinery: Queensland, Australia
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.
99.9% Pure Aluminum

Embodied Energy: 193.6 MJ/kg (240.4 MJ/kg total)

Aluminum Reduction Facility: Pingguo, China
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.
Aluminum Use & Disposal: Pittsburgh, PA, USA
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.
Informal Settlement: Agbobloshie E-Waste Dump, Ghana
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.
Trommel Separator
Conveyor Belt
Eddy Current Separator
Metal Baler

Single Stream Recycling: Newby Island Resource Recovery, CA, USA
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.
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. (Sheller)

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 at a massive scale. (Shelley)

2000-2001: Due to spikes in energy costs, Northwest shuts down. (Sheller)

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. (Sheller)

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1970: Guyana nationalizes their bauxite resources. (Sheller)

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

2018: China, raising tariffs on steel and aluminum. This is causing the price of aluminum in the US to skyrocket. (Sheller)

1955: Wally Byam starts the Caravan Club, drawing from the popularity of the airstream trailer. (Sheller)

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

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

1968: Aluminum cans make up over 80% of the canned beer market, due in part to the development of the ring pull tabs in 1962. (Sheller)

1962: A 50 ft aluminum antennae transmits American Telstar Satellite. (Sheller)

1930: An Alcoa ad in the Saturday evening post predicts "Soon - nearly all trucks and buses will have aluminum bodies". (Sheller)

1931: Alcoa advertises the properties of aluminum through the Fortune Magazine ad, "Peer into the Future." (Sheller)

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

1940: Albert Frey designs Frey House I in Palm Springs, CA in the Desert Modernism style, using corrugated aluminum for the exterior walls, aluminum frame windows, and aluminum furniture. (Sheller)

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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." (Sheller)
Red Mud Reefs
Bauxite Tailings
Great Barrier Reef, AUS
The first site places us at sea off the western Australian coast; the only visible masses across the horizon are a series of red hills. As your ship approaches, the red hills are revealed to be piles of complex geometric forms, all with a red hue. People from the ship climb onto the piles; some playing by the water, some continuing to the peak. You look down at the water and realize these modules cover the sea floor for miles around, with coral sprouting up here and there on the concrete substrate. In the distance, Drones place the individual modules precisely, so the total mass of pieces can create a designed boundary, or a distinctly unnatural organization of a new natural space. In this intervention, Concrete modules are deployed with the purpose of recovering the Great Barrier Reef and encapsulating bauxite tailings. Due to recent bleaching events in 2016 and 2017, over half of the reef has died out. While the only surefire way to save the reef is to reduce global emissions, one of the ways to help it recover faster is with concrete artificial reefs, seeded with genetically modified bleach-resistant coral. The modules use a friction based aggregate structure, allowing the random piling of modules without connective joints and the creation of small crevasses for marine life to shelter. I have chosen this specific area of the reef since it is well within the bleaching dead zone, and it is in the middle of this pinch point between restricted areas, where ships are forced into view of the massive accumulation of reef modules.
Site Modules
Bauxite Residue Quantification

Reef Module Volume: 9.785 ft³
Concrete Density: 145 lb/ft³
Reef Module Weight: 1419 lb
Percentage Bauxite Residue per module: 34%
Weight Red Mud per Module: 482.4 lb
Weight Red Mud per Module Cluster: 92,621 lb

2015 Bauxite Residue Production: 902,849 tons
Percentage Module Cluster to Bauxite Residue tonnage: 4.03x10⁻⁷
Amount Modules to match Bauxite Residue Production: 4.768x10⁸
Scrap Fields
Scrap Aluminum
San Francisco, USA
The second site brings us to the port districts of San Francisco. Towering above on either side of the street are stacks of scrap metal. Many modules are old and rusted, while some have been recently added. There is an opening between modules at the corner to allow entrance to the building, where water still dripping from the bundled metal pieces above. The expanse of scrap extends for several blocks in every direction, growing wider and taller every month. This experience describes one of the many sites for a national reserve for scrap aluminum. The modules, which interlock for vertical stabilization, would cantilever and span over buildings allowing the national reserve site to continue to serve as an urban area. This constant expansion of the site acts as a constant reminder of the overuse and waste of aluminum in the global economy. The end goal of this build up would be a wake-up call to improve the industrial capacity of aluminum recycling in the US, but if the current political climate is any indication, a massive occupation of land may be necessary.
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: The year before China bans the import of garbage, the US sent 819,954 metric tons of aluminum scrap to China. This amount made up 3% of the US's used beverage can exports and 55% of its miscellaneous scrap exports.
Scrap Quantification

Volume Scrap Aluminum per Module: 161.25 ft³
Density Scrap Aluminum: 15 lb/ft³
Weight Scrap Aluminum per Module: 2,419 lb
Weight Scrap Aluminum per Module Cluster: 764,273 lb

2017 Scrap Aluminum Export to China: 902,849 tons
Percentage Scrap Cluster to Export tonnage: 0.039%
Amount Modules to match Scrap Aluminum Export: 746,542
The Third site brings us to the Weipa Bauxite Mine in the tropical wet and dry forests of North Australia. Driving past the natural landscape, one arrives at the open expanse of the mine. Clusters of red ziggurats, towering hundreds of feet high, interrupt the expanse. As one drives on, the ziggurats appear older and older, some grown over with grass and eroding into gentler hills. Eventually, car travel becomes impossible as the hills become overgrown forests, so only backpackers and mountain bikers can continue on. In this intervention, the scarred landscape of the Weipa bauxite mine is remediated with dried, neutralized bauxite tailings and compost. The piling of the bauxite tails acts to store it in vast quantities as well as use it in an important soil horizon. The design does not act as a means of preservation or conservation, but rather a distinctly artificial sculpting of the landscape, a demarcation of the damage done through an act of remediation.
Weipa Mine Extents
2000 ft
Active Mine Site
Initial Sites
27
20
Weipa
Intervention Site 2
160 ft
Mound Placement & Composition

Base Infill Piling

Top Soil & Compost Placement

O Horizon: Compost
A/B Horizon: Top Soil/Red Mud
C Horizon: Sand/Clay
D Horizon: Red Mud Infill

Mound - 2020
Mound - 2030
Mound - 2050
Mound - 2100

Site Modules

Mound Erosion
Bauxite Residue Quantification

Red Mud per Mound Volume: 5.26x10^7 ft^3
Red Mud Density: 168.6 lb/ft^3
Red Mud per Mound Weight: 8.87x10^9 lb
Weight Red Mud per Mound Cluster: 7.99x10^10 lb
Weight Red Mud per Module: 482.4 lb

2015 Bauxite Residue Production: 115,000,000 tons
Percentage Mound Cluster to Bauxite Residue tonnage: 34.7%
Amount Modules to match Bauxite Residue Production: 26


