Aluminum

BY MICHAEL ANFT

Industry's Shiny Star

PHOTOS COURTESY OF ALCOA INC.

Created out of soil and flecks of minerals a little more than two centuries ago, aluminum has become the modern metal of choice for manufacturers

Beneath a crisp blue sky in remote North Queensland, Australia, the red dirt landscape offers a startling contrast in color. This is the site of the Welpa bauxite mine, a busy operation where front-loaders constantly dig away at vast shallow pits of crumbly ore. Scoop by scoop, the front-loaders deposit their loads into waiting dump trucks. It's hard to imagine how these heaping piles of red dirt could ever amount to anything useful.

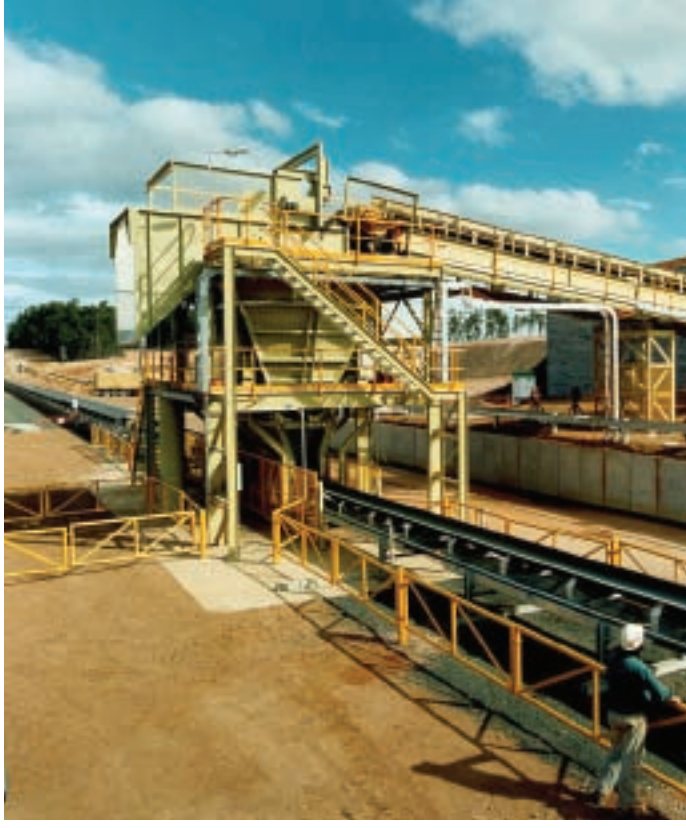
But they will.

During the ensuing days, the pea-sized ore mined here in Australia will be screened, washed, crushed, refined, smelted and fabricated—and ultimately emerge as gleaming ingots of shiny aluminum.

From a single 4-ton truckload of bauxite ore comes enough aluminum to make more than 60,000 soda cans or the space-frames for seven full-sized cars or 40,000 computer memory disks (enough to store all the books ever published).

In the 130 years since scientists discovered the chemical magic behind manufacturing this popular metal, aluminum has become a star of modern industry. Today it trails only iron and steel as the favorite metal of

Aluminum starts as a collection of clay and minerals that comprise bauxite, above left. Top: Molten metal being poured at an aluminum foundry. Temperatures reach more than 1,000 degrees Fahrenheit (538 Celsius) during the manufacturing process.



A worker outside the carbon bake scrubbers at Alcoa's Point Henry smelter in Victoria, Australia, top left. After being mined, bauxite gets offloaded into a crusher, where it is pulverized while traveling via a conveyor, above. At an Alcoa plant in San Ciprian, Spain, a worker examines a conveyor belt full of bauxite, above right. The Pinjarra refinery in Western Australia, right, is one of the world's largest.

builders and manufacturers—for everything from aircraft and appliances to paint and electrical transmission lines.

It's easy to see why aluminum has become a mainstay of consumer goods, increasingly prized by manufacturing companies around the world. Aluminum bonds well with other metals. It is lightweight, reflects heat and is resistant to rust. And it is strong but easily workable, retaining its shape and holding up to extreme cold without becoming brittle.

Perhaps most importantly, aluminum comes from readily available ores and has an unmatched level of recyclability, which helps ensure a ready, renewable supply. (About 34 percent of U.S.-manufactured aluminum comes from reclaimed materials.)

Aluminum might be considered the world's "green metal" but for one reason: It requires a huge amount of electricity and other fuels to convert it from raw bauxite ore to a powder of oxide and then, finally, to a genuine metal.

Humble Beginnings

Among major metals, aluminum comes from arguably the humblest beginnings.

The material that ends up becoming aluminum starts as a collection of clay and minerals that comprise bauxite in the topmost layers of the Earth's crust. Aluminum makes up 8 percent of the Earth's crust—more than any other metal—and is third among elements, behind only oxygen and silicon.

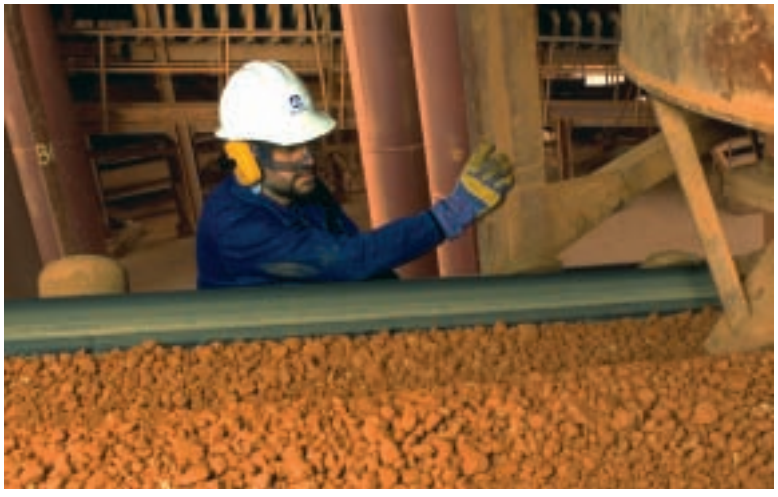
Aluminum compounds have been used for thousands of years. In 5000 B.C., ancient Persian potters used clay containing aluminum oxide to make stronger tableware. A few millennia later, Babylonians, Egyptians, Greeks and Romans turned various crude forms of aluminum into cosmetics, dyes and medicines.

But unlike other metals, including copper and bronze, that were mined and forged for thousands of years, aluminum doesn't occur naturally as a metal. No one could see it.

Finally, in 1808, British chemist Humphry Davy proved the metal's existence and gave aluminum its name. It would take more than 70 more years to develop a high-volume, low-cost process for making the metal. During those intervening decades, aluminum was so rare that its price rivaled that of gold or silver (See "More Precious Than Gold," p. 11).

By 1884, total annual production of aluminum in the U.S. was just 125 pounds. Enter Charles Martin Hall. He was a young student at Oberlin College when he became intrigued by a challenge issued by his chemistry professor. Professor Frank Jewett handed around small pellets of aluminum—produced at that point by a labor-intensive process that involved heating sodium with aluminum chloride. Whoever could discover a cheap way to make this metal would become rich, Jewett predicted to the class.

Hall was hooked. He converted his backyard woodshed into a laboratory and began experimenting. He first learned how to make aluminum oxide—a white powdery substance known today as alumina. Then, in 1886, the 22-year-old Hall succeeded with the second crucial step. He filled a carbon crucible with a cryolite bath, added the alumina and then passed an electric current through it. The result? A congealed mass that, when cooled, could be shattered…into small pellets of pure aluminum.



More Precious Than Gold

ALUMINUM HAS ROLLED OFF OF FACTORY LINES FOR ONLY A CENTURY or so. For decades after its metallic properties were discovered in the early 19th century, the shimmery stuff was nearly impossible to extract from bauxite ore. What's more, those who could separate it lacked a cheap process that would churn out large amounts of it, so only small bits were made. Aluminum was considered a precious metal, more valuable than gold.

The metal's rareness and showiness made it a favorite among royals. Bars of it were displayed alongside the French crown jewels during the Universal Exposition of 1855. Smelted bits of it formed a crown for the king of Denmark. And, tale has it that Napoleon III treated his favored guests to rare aluminum table utensils.

Despite some modest improvements in extraction and manufacturing in the ensuing years, aluminum was worth about as much as silver in 1884, when the United States made only 125 pounds of it (56 kilograms). More than 6 pounds of that—about 100 ounces (2.7 kg.)—were set aside for a lasting memorial. The largest piece of aluminum ever cast at the time was maneuvered into place atop the capstone of a new, 555-foot-tall obelisk made of Maryland granite, marble and sandstone: the Washington Monument. Aluminum, cast by William Frishmuth, an architect and metallurgist, topped what was then the world's loftiest structure. It was the first time the metal had been used in architecture.

It still rests atop the oversized pillar today, demonstrating the metal's resistance to oxidation—though only the birds can see it.—**M.A.**

Weeks after Hall's discovery, the electrolytic extraction process he developed was replicated independently by Paul Heroult in France. It became known as the Hall-Heroult smelting process. Within two years, Hall found financial backing, built a plant in Pittsburgh and began producing the first commercial aluminum.

In the years that followed, Hall continued to improve on the process, reducing the price of aluminum from $4.86 a pound [$113 today] to 78 cents in 1893 [$19.20 today]. The operation that would eventually become the Aluminum Company of America (Alcoa Inc.), today the world leader in the production and management of aluminum, was off and running.

Akin to Alchemy

Today, aluminum is manufactured in plants all over the world. While operations differ in size and scope, all follow the same basic process—a process that could almost pass for alchemy. In the words of Alcoa's written history of the metal, "It all begins with dirt…"

On the floor of a smelter in Wenatchee, Washington, above. Alcoa's Corporate Center on Pittsburgh's North Shore riverfront, above right, is a gleaming aluminum-and-glass structure. By recycling aluminum cans, below right, manufacturers use only 5 percent of the energy needed to make the metal from ore.

Mining: While bauxite, an ore rich in aluminum oxide, was first mined in France, today most bauxite mining occurs in Australia (the world's larger producer of the ore), Africa and the Caribbean.

At the Welpa mine near Queensland, Australia, which stretches across some 2,500 square kilometers [1,550 square miles], about 16.5 million tons of bauxite is mined each year, according to the Australian Aluminum Council. Once extracted from the shallow pits, the red bauxite ore is hauled by trucks to a dump station, then moved by conveyors or rail to a plant where the ore is screened, washed and stockpiled before being shipped to nearby refineries.

Refining: At the refinery, workers grind the bauxite ore, then mix it with lime and caustic soda. This mix is pumped into high-pressure containers and then heated—a process developed and named for scientist Karl Bayer. The caustic soda dissolves the aluminum oxide, which is then precipitated out of the solution, washed and heated to drive off any water. The result? A pure white powder resembling sugar that's known as alumina.

Alumina serves as the raw material for the Hall-Heroult smelting process. But it can also be used for a wide range of products—from toothpaste and fluorescent light bulbs to rocket fuel and ceramic windshields for military aircraft. Roughly 10 percent of alumina produced each year winds up in products other than aluminum.

Smelting: At the smelter, the alumina powder is placed in large, carbon-lined cells (known as reduction pots) and dissolved in a molten cryolite bath (comprised of sodium aluminum fluoride) that reaches temperatures of about 1,780 degrees F [970 Celsius]. Reduction pots are arranged in rows of 50 to 200 pots that connect to form an electric circuit.

The transformation occurs when a powerful electric current is passed through the bath, breaking the bonds between the aluminum and oxygen atoms in the alumina molecules. Once freed, the aluminum atoms settle to the bottom of the pot as molten metal, which is siphoned off.

What is a Metal?

WHETHER AN ELEMENT, COMPOUND or alloy, a metal is characterized by high electrical conductivity. Metals—which comprise about two-thirds of the known elements in the periodic table—readily lose electrons to form positive ions. Those ions are surrounded by delocalized electrons, which are responsible for the conductivity.

Metals can differ widely in terms of their hardness, ductility, malleability, density and melting point—making it difficult to distinguish between them and non-metals.

Aluminum, atomic No. 13 in the periodic table, does not exist naturally, but is an important constituent of many minerals.

More than 30 percent of the 25 billion pounds of annual aluminum supply in the U.S. comes from recycled sources. No other metal approaches that level of renewability.

Smelters typically house two or three potlines, and most potlines produce about 66,000 to 110,000 tons of aluminum annually. Smelters operate the pots seven days a week, 24 hours a day.

Fabricating: Once aluminum leaves the smelting pots it is moved into furnaces for mixing with other metals (such as copper, zinc, manganese or magnesium)—a choice determined by how the product will eventually be used. For structural components in aircraft and truck wheels, for instance, a common copper and magnesium aluminum alloy offers a high strength-to-weight ratio and good fatigue resistance. After being purified through a process called fluxing, the metal is poured into molds or cast directly into ingots. Further fabrication may include casting, rolling, forging, drawing or extruding.

The entire aluminum manufacturing process is run by a law of halves: It takes 4 tons of bauxite to make 2 tons of alumina, from which manufacturers can reap 1 ton of metal.

Though manufacturers have made attempts over the past century to replace the Hall-Heroult smelting process, their efforts turned out to be too costly or environmentally troublesome. So it remains the industry standard today.

Thus, high-energy consumption remains a trademark of aluminum. Up to 40 percent of the cost of manufacturing aluminum comes from the electric power used to smelt it. Even though domestic operations have become more efficient in recent years—using about half the electricity to make a pound of aluminum than it took 50 years ago—the number of primary aluminum smelters in the United States has dropped from 33 in 1970 to 15, the result of the higher cost of domestic energy. (Industry representatives are quick to point out that, despite the shuttering of smelting facilities, the nation's factories churn out only 1 percent less aluminum than they did 40 years ago.)

Predictably, many aluminum conglomerates have transplanted operations to countries with cheap sources of traditional energy, such as China, Russia and South Africa. In Iceland, Alcoa made headlines when it spent $1.1 billion to flood a 22-square-mile area there to tap that country's vast hydroelectric and geothermal sources of power.

Countries with plentiful sources of natural gas, such as the United Arab Emirates, are becoming aluminum powerhouses, too. Wherever there are developing or inexpensive sources of energy,

Craning a coil of aluminum sheet, above. Dawn unfolds at an ingot storage location in Kitts Green, United Kingdom, above right. Workers prepare an enormous aluminum ingot to be rolled into can sheet, right.

you'll find aluminum makers (See "Top Makers By Country," p. 15). Of the 39 million metric tons of the metal produced in 2008, China—home to heaps of cheap coal and few environmental regulations to limit its use—was the top producer. It accounted for one-third of the total global production, with 13.2 million tons.

A Sustainable Product

Fortunately, melting down recycled aluminum cans and other products made from the metal requires only 5 percent of the energy needed to make the metal from ore. After melting, the serviceable metal retains the same physical properties as smelter-made aluminum.

More than 30 percent of the 25 billion pounds of annual aluminum supply in the U.S. comes from recycled sources. No other metal approaches that level of renewability. Of the 100 billion aluminum cans produced each year in the U.S., roughly two-thirds are returned for recycling. The reclamation rate for aluminum from automobiles is even higher—about 90 percent.

According to Alcoa, more than 70 percent of the aluminum ever produced

is still in use—equaling 586 million metric tons of a total 806 metric tons manufactured since 1886, the time of Hall's discovery.

After aluminum is either recycled or smelted, and then milled at more than 200 facilities in the U.S., it is made into $40 billion worth of products and exports, notes the Aluminum Association, which represents primary producers of the metal. The metal's lightweight durability continues to advance its popularity, with carmakers clamoring for more of it for auto bodies, engines and housings. In 2006, aluminum became the second-most used metal in new cars and trucks worldwide, surpassing iron.

Nearly 4 billion pounds of aluminum are used each year in construction (1.8 billion kilograms), while more than 5 billion pounds per year are shipped as beverage cans, food containers and various types of foil (2.3 billion kg.).

Toward a Sustainable Future

Back at the Welpa bauxite mine in Australia, workers continue digging, loading and unloading enormous piles of crumbly red soil.

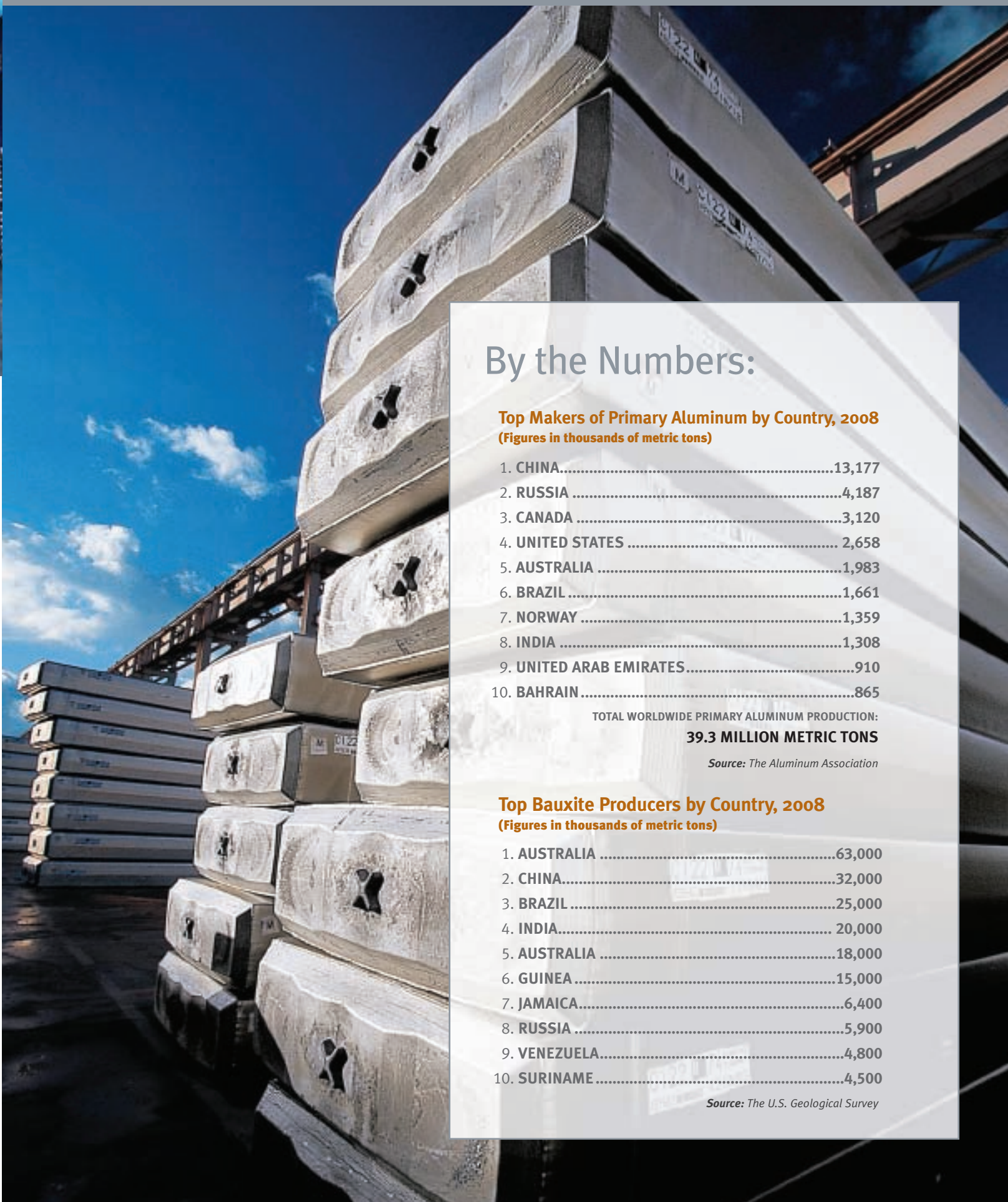
Australia is the world's largest producer and exporter of alumina, and the fifth largest producer of aluminum. For that reason, the Australia Aluminum Council is committed to mitigating the industry's negative impact on the environment.

Before mining begins at the Welpa mine, workers first take up the existing vegetation. Once all the bauxite ore has been removed from that section, the land is re-planted with indigenous bushes and grass.

Thus, the pebbly red ground that once, improbably, gave rise to tons of gleaming silver metal will revert back to its natural state—a blanket of green grass and shrubbery.

Sue De Pasquale contributed to the reporting and writing of this article.

FACTS AND FIGURES



By the Numbers:

Top Makers of Primary Aluminum by Country, 2008
(Figures in thousands of metric tons)

1. CHINA.....13,177
2. RUSSIA.....4,187
3. CANADA.....3,120
4. UNITED STATES..... 2,658
5. AUSTRALIA.....1,983
6. BRAZIL.....1,661
7. NORWAY.....1,359
8. INDIA.....1,308
9. UNITED ARAB EMIRATES.....910
10. BAHRAIN.....865

TOTAL WORLDWIDE PRIMARY ALUMINUM PRODUCTION:
39.3 MILLION METRIC TONS

Source: *The Aluminum Association*

Top Bauxite Producers by Country, 2008
(Figures in thousands of metric tons)

1. AUSTRALIA.....63,000
2. CHINA.....32,000
3. BRAZIL.....25,000
4. INDIA..... 20,000
5. AUSTRALIA.....18,000
6. GUINEA.....15,000
7. JAMAICA.....6,400
8. RUSSIA.....5,900
9. VENEZUELA.....4,800
10. SURINAME.....4,500

Source: *The U.S. Geological Survey*