The U.S. Aluminum Industry's Energy Problem and Energy Solution

February 2023

SAFE | CENTER FOR Strategic Industrial Materials

Table of Contents

KEY TAKEAWAYS

- In the face of rising demand, a critical segment of aluminum is declining. Energy and environmental issues are at the core of this dichotomy.
- Defense, aerospace, electric power, and transportation have long been and will continue to demand aluminum.
- Electrification of transport and deployment of renewable energy technologies will increase demand for primary aluminum.
- Together, existing and new drivers for aluminum are growing rapidly, which will widen the gap between demand and secure supply.
- As vital as recycling is, the volume of secondary output is not sufficient to meet rising demand; more U.S. production of primary aluminum is needed.
- Narrowed focus on the smelting process of the supply chain will help overcome the U.S. demand-secure production gap.
- Production of primary aluminum from allied countries is also decreasing or stagnant.
- Without action on domestic primary, the U.S. is at risk of a much larger reliance on the UAE, Russia, and China for critical infrastructures, military needs, and clean technologies.
- Energy challenges underpin this threat and undermine the economic viability of the primary aluminum industry in the U.S. and abroad.
- China is meeting this energy challenge through subsidies, thus prompting overproduction and hollowing out the aluminum industry across almost all segments with low prices.
- Lowering and stabilizing energy costs—commensurate with an energy transition and climate goals—will bolster industry.
- Decarbonizing innovations in primary aluminum technologies can be a lifeline to industry as green aluminum becomes increasingly globally competitive.
- Current and new policy tools—discussed in a follow-on report—must be leveraged to overcome these challenges.

SECTION ONE

Aluminum's Criticality
Existing and Growing Demand Drivers

Aluminum is an essential element of the U.S. economy. From building and electrical infrastructure to the aerospace and defense sectors, aluminum has long been critical to U.S. economic and national security. Aluminum will remain a key input for those sectors and will play a crucial role in decarbonizing the power, transportation, and building sectors. Meeting demand will allow the United States to meet its environmental commitments on an accelerated timeline. Existing and growing uses of aluminum are driving the United States' need for this industrial material.

Aluminum Uses

Aluminum has several unique characteristics that make it an ideal metal for a range of critical applications. Compared to most metals, for example, it has a higher strength to weight ratio, making it highly desirable for light weighting.[1] Aluminum is also resistant to rusting, wrapping, and rotting, which provides aluminum end products, such as electrical wires or automotive parts, greater durability and longevity relative to alternative metals. Aluminum is highly conductive, especially when accounting for its weight and cost. Almost infinitely recyclable, 75 percent of all aluminum produced is in circulation still today.[2] With all these benefits, aluminum has become integral to the defense, aerospace, electricity, and passenger vehicles sectors.

Defense

The U.S. military relies on aluminum to preserve national security. Aluminum has many notable defense applications, including armor plates for vehicles, aircraft structural parts and components, naval vessels, space and missile components, and propellants.

Aluminum's ability to reduce the weight of military transportation vehicles is crucial for those vessels' agility and creating a competitive advantage relative to any potential adversaries.[3] This metal has several military aircraft applications; its damage tolerance ensures aircrafts withstand harsh environments without cracking or failure. Further, high-purity aluminum has specific and critical applications in aircraft, space, naval, and ground vehicles.[4]

1 Howard Precision Metals, Inc. (2022) Why are Aluminum Alloys Used in the Auto Industry?

2 Aluminum Association (2021), Recycling.

3 U.S. Department of Commerce (2018), The Effect of Imports of Aluminum on the National Security.

4 Ibid.

High-Purity Aluminum

- High-purity grades of aluminum ensure aluminum end products have "greater flexible strength, fracture toughness, improved high-temperature operating ability, and corrosion resistance."
- Industry determines purity classifications, not governments.
- High-purity grades are over 99.9 percent pure aluminum. The average purity level of primary aluminum produced is 99.9 percent. Standard-purity aluminum, predominately secondary, is approximately 99.7 percent.

Source: U.S. Department of Commerce, 2018.

Aluminum makes up 75 to 80 percent of the modern aircraft.

It is therefore imperative the United States have a secure source of primary aluminum, especially high-purity aluminum. The defense industry consumes 10 percent of U.S.-produced high-purity aluminum every year.[5] It is assumed the U.S. Department of Defense will continue to consume around 150 thousand metric tons of aluminum annually, over 15 percent of which is high-purity.[6]

Aerospace

Beyond the defense industry, U.S. aerospace consumes the remaining 90 percent of U.S. produced high-purity aluminum, to access the same benefits of formability, toughness, and durability. Not limited to high-purity, aluminum makes up 75 to 80 percent of the modern aircraft.[7] It is used in the frame, wings, fuselage, and supporting structures of cargo aircrafts and commercial airlines.[8] The most prominent metal used in spacecrafts, aluminum alloys completely made up the sphere of the first spacecraft launched in the 1950s. ***Aluminum's mechanical stability, weight-to-strength ratio, and thermal management are unparalleled among metals***.[9] In 2020, aluminum alloys represented more than 40 percent of the total aerospace materials market.[10]

Demand for aluminum correlates to the aerospace industry's growth and net zero commitments. North America, the largest market for the aluminum alloys used in aerospace, is expected to grow 3.5 percent every year through to 2028 due to rising U.S. demand.[11] At the same time, 290 airlines, including 10 major U.S. airlines, have made 2050 net zero commitments.[12] These decarbonization promises increase demand for aluminum because of its light weighting capabilities, which enable greater fuel efficiency and resulting cost-savings for aircrafts. However, given aluminum's energy-intensity, (see Section 2), airlines may consider alternative metals with lower carbon profiles if they are conducting full lifecycle emissions analyses.

Electricity

Aluminum has been playing an ever-growing role in the U.S. electrical grid since World War II. It is the fourth most conductive metal.[13] Metals, such as gold, silver, and copper that are higher in conductivity, cost more. Silver also has a tendency to rust.[14] ***Aluminum is consequently the preferred option for high-voltage long distance transmission lines.*** It is three times lighter and three and a half times cheaper than copper.[15] Aluminum's lower conductivity rate results in fewer electricity losses than copper. This is advantageous given electricity losses are compounded as electricity travels longer distances.

5 Ibid.

6 Ibid.

7 Metals Supermarkets (0216) History of Aluminum in the Aerospace Industry.

8 Howard Precision (2022), What is Aerospace Aluminum? Aluminum Alloys Used in the Aerospace Industry.

9 Ibid.

10 Reports and Data (2019), Aluminum alloys Aerospace Materials Market.

11 Ibid.

12 Eurativ (2021), World Airlines commit to 'net zero' CO2 emissions by 2050.

13 Gabrian (2022), Does Aluminum Conduct Electricity? What You Need to Know.

14 QuestTech (2018), Best Conductor of Electricity: Choosing the Right Metals.

15 IEA (2021), The Role of Critical Minerals in Clean Energy Transitions.

The electrical sector represented 16 percent of U.S. aluminum consumption in 2021.[16] Demand is expected to increase here, as the United States works to upgrade its aging transmission lines and power transformers, 75 percent of which are more than 25 years old.[17] Stated U.S. policy goals related to clean energy deployment, if acted on, are likely to meaningfully increase demand for aluminum. The "Aluminum in the Clean Energy Transition" section of this report expands on this dynamic.

Passenger Vehicles

The transportation sector has leveraged aluminum's advantages since day one of mass production; the 1923 Ford Model T was clad with aluminum panels.[18] Including aviation, transportation represented 35 percent of U.S. aluminum consumption. consumption in 2021.[19] Passenger vehicles dominate demand in this sector. Just since 2016, the aluminum content in the average North American vehicle has increased by 62 pounds, with the total aluminum content per vehicle estimated at 459 pounds in 2020.[20] ***Vehicles may be complex, but at the same time need to be affordable, lightweight, safe, and rust resistant. Aluminum fits those needs, from the shock resistant bumper to the lightweight vehicle hood.***

16 USGS (2022), Minerals Commodities Summary Aluminum.

17 Reuters (2022), Creaky U.S. power grid threatens progress on renewables, EVs.

18 Model T Ford Fix (2019), 1923 Model T Ford.

19 USGS (2022), Minerals Commodities Summary Aluminum.

20 DuckerFrontier (2020), cited in Recycling Today (2021), Geared for Growth.

Demand for aluminum for the automotive industry is on the rise, owing to increasingly stringent fuel economy standards, rising gas prices, and size increases in vehicles. Aluminum content in vehicles is expected to increase 12 percent total between 2020-2026.[21] However, aluminum used in vehicles is not typically all newly produced primary aluminum. To save on energy, 86 percent of car's are recycled, reused, or used.[22] Electric vehicles are another major driver of aluminum in the automotive industry (see next section).

Aluminum in the Clean Energy Transition

Technologies needed for the clean energy transition accelerate aluminum demand even further. While governments are focused on securing supply of battery materials, such as cobalt, nickel, and lithium, ***International Energy Agency (IEA) analysis found aluminum is second to only copper in its across-the-board importance for clean energy technologies.***[23] Aluminum is of high importance to solar photovoltaic (PV) technologies, EVs, and electricity networks (Table 1).

21 Light Metal Age (2020), Aluminum Continues Unprecedented Growth in Automotive Applications.

22 Alliance for Automotive Innovation (202) Automotive Recycling.

23 IEA (2021), The Role of Critical Minerals in Clean Energy Transitions.

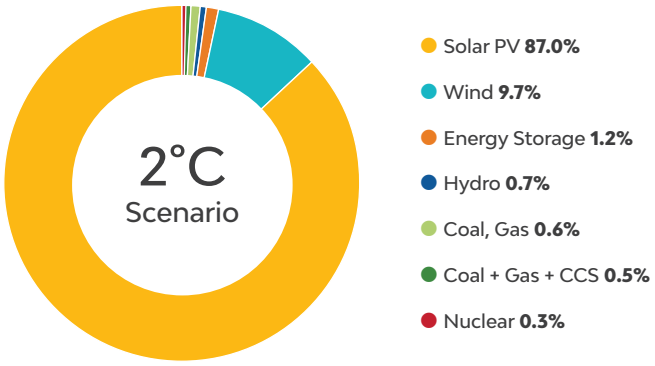
Table 1 Critical Mineral Needs for Clean Energy Technologies

	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminum
Solar PV	●	○	○	○	○	○	○	○	●
Wind	●	○	●	○	●	●	●	○	●
Hydro	●	○	○	○	○	●	●	○	●
CSP	●	○	●	○	○	●	●	○	●
Bioenergy	●	○	○	○	○	○	●	○	●
Geothermal	○	○	●	○	○	●	○	○	○
Nuclear	●	○	●	○	○	●	○	○	○
Electricity networks	●	○	○	○	○	○	○	○	●
EVs and battery storage	●	●	●	●	●	○	○	○	●
Hydrogen	○	○	●	○	●	○	○	●	●

Relative Importance of Minerals for a clean energy technology ● **High** ● **Moderate** ○ **Low**

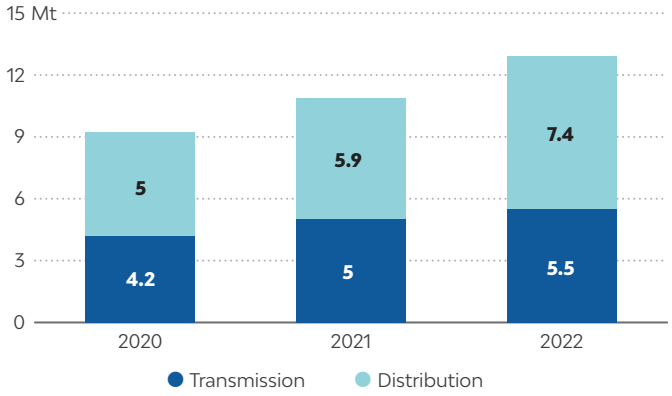
Note: CSP = concentrating solar power; REEs = rare earth elements; PGM = platinum group metals.
Source: IEA (2021), The Role of Critical Minerals in Clean Energy Transitions.

Figure 1 Total Aluminum Demand by Energy Technology through 2050



Source: World Bank, 2020.

Figure 2 Global Aluminum Demand (Mt) for Electricity Grids



Source: IEA, 2020.

Solar

Aluminum is the most prevalent material in solar PV. Predominately used in frames and inverters, aluminum accounts for 85 percent of solar components. Its reflective property increases solar panel efficiency. If the Biden-Harris administration is planning to reach its 2035 net-zero grid goal, more solar PV deployment is likely. To reach deep grid decarbonization in this timeline, the U.S. Department of Energy estimates a 40 percent increase in solar PV by 2035 is needed.[24] The World Bank estimates under a 2-degree scenario, solar PV will account for 87 percent of aluminum demand from clean energy technologies (See Figure 1). ***More solar PV translates into substantial demand for more aluminum***.[25]

Electric Vehicles

The electric vehicle transition only increases aluminum's importance to the automotive sector. Alumina, which is an aluminum oxide, is used in some lithium-ion batteries in battery electric vehicles (BEVs)—namely the cathode in a nickel-cobalt-aluminum-oxide battery. ***Alumina's use over manganese, which is used in the more common nickel-cobalt-manganese battery, increases the battery lifespan***. The benefit of aluminum's weight cannot be overstated for the electrification of transport. At more than 9,000 pounds, the battery of the GMC Hummer EV is three times the weight of an entire Honda Civic.[26]

With new policies incentivizing BEVs and automotive manufacturer commitments to electrify their fleets, EVs are projected to represent 40-45 percent of new car sales in the United States by 2035.[27] Further, governments and manufacturers are angling to build these vehicles in North America. As such, half of aluminum demand growth from now to 2030 is predicted to occur in the transportation sector.[28] With BEVs using 42 percent more aluminum per vehicle than non-BEVs, aluminum demand will grow alongside BEV adoption.[29]

Electricity Networks Fueled by Distributed Energy

Aluminum's role in electricity networks compounds its importance to renewable energies, as it enables their grid connectivity. The U.S. Department of Energy claims there is enough energy from solar, wind, hydropower, geothermal, storage, and nuclear to power 1 billion homes today. However, a 60 percent increase in electricity transmission is needed to connect U.S. consumers to renewable energy sources (with an emphasis on more long-distance high-voltage lines). [30]

Considering these policies, the ***IEA estimates global demand for aluminum for transmission and distribution infrastructure is expected to increase by more than 40 percent*** (Figure 2). This increase (3.7 Mt) is more aluminum than Canada produced in 2021.

24 U.S. Department of Energy (2022), Solar Futures Study.

25 The Aluminum Association (2022), Aluminum a Key Material for Renewable Energy.

26 CNN (2021), Why electric cars are so much heavier than regular cars.

27 HIS Markit (2021), Pivoting to an Electrified Future: The Automotive Industry Amps Up.

28 CRU International, Opportunities for aluminum in a post-Covid economy, January 28, 2022, p. 20.

29 DuckerFrontier (2020), cited in Recycling Today (2021), Geared for Growth.

30 U.S. Department of Energy (2022), Queued Up... But in Need of Transmission.

SECTION TWO

Supply Chain Analysis
The Primary Challenge

With demand clearly on the rise, the United States should evaluate whether it is likely to maintain a secure and reliable supply of aluminum or whether vulnerabilities exist in the supply chain. Looking carefully at each part of the aluminum production process, it is apparent the supply-side challenge lies in the smelting part of primary production. The most foundationally critical and energy intensive step, the smelting process has a larger impact on secure supply than the downstream and secondary processes and the mining and refining subsets of primary production.

Global trends reinforce primary is at the root of the problem. U.S. primary production, including of high-purity aluminum, has fallen, and allied trading partners' share of primary production is either stagnant or also dropping.[31] Meanwhile, China dwarfs all other primary aluminum producers and, with the 2022 curtailment of the Century Aluminum Hawesville, KY smelter, the Middle East and China remain the major producers of high-purity aluminum today.[32]

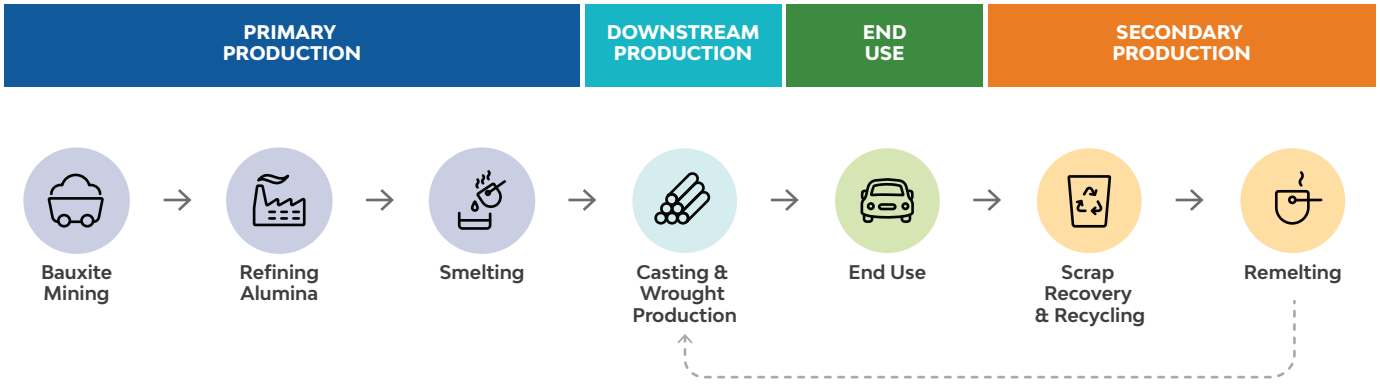
31 USGS (2022), Bauxite and Alumina

32 U.S. Department of Commerce (2018), The Effect of Imports of Aluminum on the National Security.

Aluminum Production Process

Before aluminum is utilized as an armored plate, electrical wire, or car door, it must be transformed through complicated production processes. There are three types of aluminum production: primary, secondary, and downstream. Within primary production, there are three discrete steps: mining bauxite, refining alumina, and smelting (Figure 3).

Figure 3 Aluminum Production Process



Source: OECD, 2020.

Refined from bauxite, alumina (pictured) is the key feedstock for producing aluminum.

Primary Aluminum Production: Mining Bauxite

The first step of the primary aluminum process is mining bauxite, which is almost always found near the surface of the earth. Of all the stages of primary production, bauxite mining is comparatively efficient in terms of the carbon emissions, accounting for just 0.25 percent of total sector emissions.[33] Other environmental impacts include water pollution and soil erosion, which must be managed.[34]

Deposits are in Africa (32 percent), Oceania (23 percent) South America and the Caribbean (21 percent), Asia (18 percent), and elsewhere (6 percent).[35] There are small bauxite reserves in the southeastern United States, though these are not currently being developed and are inadequate to meet U.S. demand over the long term.[36]

The U.S. Geological Survey does not consider the lack of domestic mining of bauxite, which is also true of many other major primary producing countries, a concern.[37] Global bauxite resources are estimated at 55-75 billion tons, which is seen as sufficient to meet world demand for at least another 100 years.[38] In 2021, 70 percent of bauxite was refined for alumina. The remaining 30 percent went to various industrial uses, like cement, chemicals, proppants, and refractories.[39]

33 International Aluminum Institute (2021), Aluminum Sector Greenhouse Gas Pathways to 2050, p. 4.

34 Malays J Med Sci (2016), Potential Health Impacts of Bauxite Mining in Kuantan.

35 See Note 32.

36 Aluminum Association (2021), Production: Bauxite.

37 USGS (2022), Minerals Commodities Summary Alumina and Bauxite.

38 Ibid.

39 Ibid.

Primary Aluminum Production: Refining Alumina

Next, bauxite ore is refined into alumina. Alumina is an aluminum oxide, and approximately two tons of bauxite are required to make one ton of alumina.[40] Alumina is created by grinding bauxite, heating it with steam, and reheating it in a calciner. On average, this process accounts for about 27 percent of energy in the primary production process and 22 percent of carbon emissions.[41]

Alumina refining tends to happen closer to the mine for ease of transport. The United States has some alumina refining. In 2021, one U.S. alumina refinery was responsible for all of U.S. domestic production (1 Mt). Only about 55 percent of that alumina was refined into primary. Even with a smaller domestic supply, alumina refining is not considered a roadblock in primary production, given Western Hemisphere and allied capacity. [42]

Primary Aluminum Production: Smelting

Finally, aluminum is created through the Hall-Heroult (electrolysis) process involving alumina and anodes. During electrolysis, approximately one ton of aluminum is produced from two tons of alumina. The smelting process is very energy-intensive, requiring a near-constant flow of electricity. It thereby accounts for 68 percent of energy in primary production and 75 percent of carbon emissions.[43]

Three companies (Alcoa, Century Aluminum, and Magnitude 7 Metals) currently operate six primary

40 Natural Resources Canada (2022), Aluminum Facts.

41 Bloomberg New Energy Foundation (2021), Decarbonizing Aluminum: Technologies and Costs.

42 See Note 38.

43 Ibid.

Figure 4 U.S. Primary Smelting Plants, Annual Capacity & Production (Thousand Metric Tons)

CURTAILED COMPLETELY

279

Alcoa Intalco

Ferndale, WA

The Intalco plant idled in July 2020 due to high power prices and low aluminum prices. In 2022, there were private equity efforts to revive this smelter that have officially halted. As of January 2023, it remains curtailed.

CLOSED

146

Alcoa Wenatche

Wenatche, WA

Alcoa curtailed this plant in 2015 and closed it in 2021. Alcoa had a contract with Chelan County PUD from 2011 to 2028, providing power equivalent to 26 percent of the output of Rocky Reach and Rock Island dams. They amended the contract during curtailment and ultimate plant shut down.

CURTAILED

110 269

Alcoa Warrick

Newburgh, IN

Operational, sold to Kaiser Aluminum in April 2021, though Alcoa retains ownership. Alcoa also owns and operates its own 657 MW power plant that is co-located with the smelter. It purchases coal from third parties to power this plant. Alcoa sited operational challenges as the reason for curtailment in 2022.

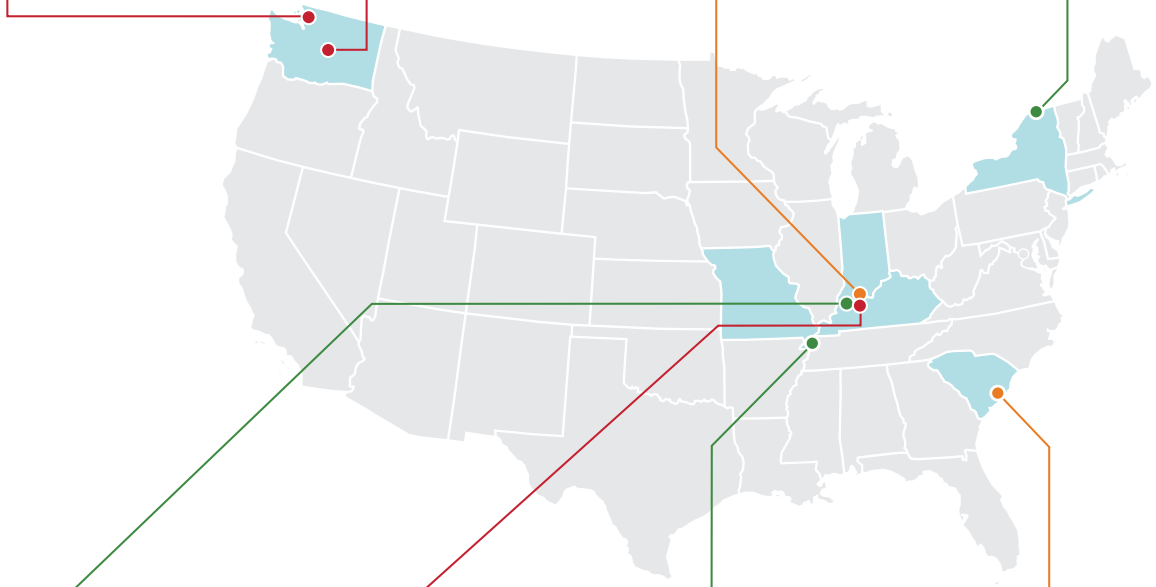
OPERATING

130

Alcoa Massena

Massena, NY

In 2019, Alcoa reached a 7-year deal with the New York Power Authority to remain in Massena through at least 2026. This contract provides hydroelectricity to power the Massena smelter.



OPERATING

218

Century Aluminum Seebree

Seebree, KY

Expanded capacity in late 2018. In 2014, Century Aluminum received approval to buy energy on the wholesale market rather than power generated by Big Rivers Electric Corp.

CURTAILED COMPLETELY

252

Century Aluminum Hawkesville

Hawkesville, KY

Restored a 50,000 mt/year potline in 2020 but curtailed in 2022. They cited skyrocketing energy prices due to the Ukraine-Russia situation as the reason for needing to curtail this plant in 2022. NOTE: This is the only U.S. smelter producing high-purity military grade aluminum.

OPERATING

263

Magnitude 7 Metals

Marston, MO

Bankrupted smelter reopened following imposition of aluminum tariffs and a new power contract with Associated Electric Cooperative Inc in 2018.

CURTAILED

173 231

Century Aluminum Mount Holly

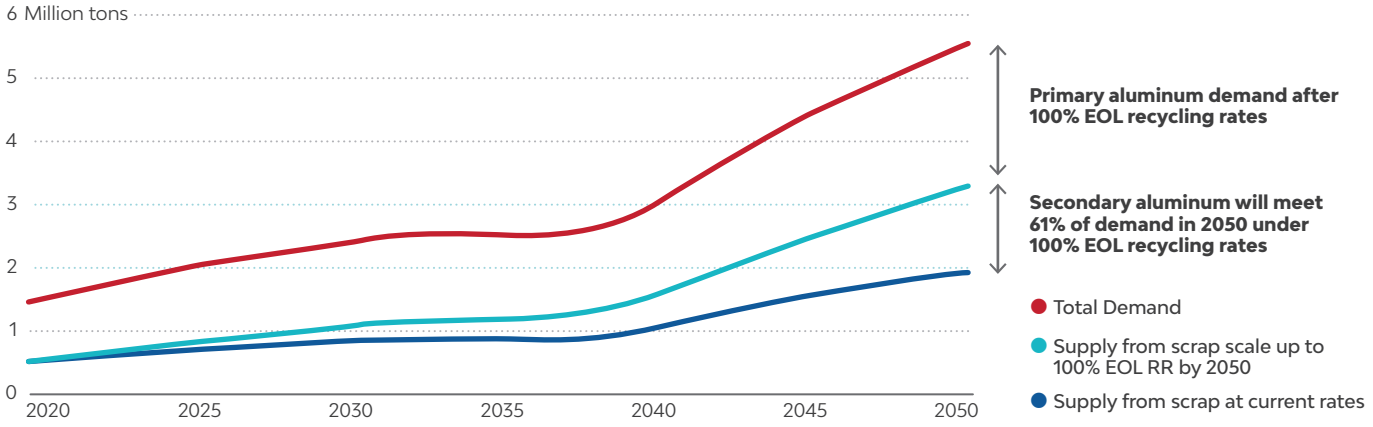
Mount Holly, SC

In April 2021, initiated restart of 57,000 mt/year (50 percent production increase) after finalizing a power supply contract with Santee Cooper that would run through year-end 2023.

* All capacity and production estimates in thousand metric tons per year.

Source: OECD, 2020. i. U.S. Geological Survey (2021), Aluminum Statistics and Information; King5 News (2021), Ferndale rethinks its future after hundreds lose jobs at aluminum plant; ii. S&P (2021), Alcoa completes sale of Warrick smelter to Kaiser Aluminum; iii. U.S. Geological Survey (2021), Aluminum Statistics and Information; iv. Energy Information Administration (2021), New York State Profile and Energy Estimates; NCPR (2019), Alcoa, NYPA reach 7-year deal to stay in Massena; v. U.S. Geological Survey (2021), Aluminum Statistics and Information; S&P (2021), North American output climbs more than 4 percent in 2020: IAI; vi. USGS (2021), Aluminum in February 2021; vii. S&P Global (2018), Century rolls out 2 expansion programs for Sebree aluminum smelter; viii. Magnitude 7 Metals. Tim McLaughlin (2020), Trade war tradeoff: How a Missouri town got America's dirtiest air, Reuters. Energy Information Administration (2021), Reuters (2020), Exclusive: Aluminum smelter resurrected on Trump tariffs may close as losses mount'.

Figure 5 Aluminum Recycling Projections Relative to Annual Aluminum Demand: 2° Scenario



Note: EOL recycling rates are assumed to increase annually to meet 100 percent EOL by 2050. This means that secondary aluminum meets an increasing amount of aluminum demand over time. EOL = end of life, RR = recycling rates.Source: IEA (2021), The Role of Critical Minerals in Clean Energy Transitions
Source: World Bank (2020), Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition.

smelters in the United States. (Figure 4). In 2021, these smelters operated at 55 percent capacity, meaning they had the ability to produce 1.64 Mt of aluminum, but only produced 880 thousand tons of aluminum. [44]

This lack of smelting puts the United States in an import reliant position. In 2021, United States apparent consumption was 4.3 Mt of aluminum. The U.S. thus leverages its long-term trade and defense relationship with its neighbor, Canada, to fill this gap. Canada's nine smelters operated at 95 percent capacity in 2021, producing 3.1 Mt of aluminum. 90 percent of this went to the U.S.[45] To meet its remaining demand, the U.S. relies on trade with other countries. ***The top import sources, besides Canada, for the past five years have been the United Arab Emirates (UAE), Russia, and China***.[46]

Only one North American smelter, located in Kentucky, can produce high-purity military-grade aluminum needed for defense, aerospace, and certain electronics. According to the U.S. Department of Defense, "should this one U.S. smelter close, the U.S. would be left without an adequate domestic supplier for key national security needs. ***The only other high-volume producers of high-purity aluminum are located in the UAE and China."*** *This Kentucky plant was curtailed in June of 2022.*

Secondary Aluminum Production

Aluminum can be reproduced using recycled scrap instead of alumina from bauxite.[47] This process involves collecting and recovering scrap aluminum, sorting, and remelting it, and then casting it to be used again. Secondary aluminum smelters use just 6-10 percent of the energy of primary smelters and generate just 5 percent of the carbon emissions associated with primary production.[48]

As capital costs, like that of energy, are much lower for secondary production, this U.S. industry has been growing. Domestic secondary production has doubled since the 1980s, positioning the U.S. as a major global producer and exporter. [49]

Despite the benefits of recycling and growth of U.S. secondary production, the aluminum industry is unable to transition entirely because recycled aluminum cannot be used for all applications. As discussed above, primary and high-purity aluminum is favored in certain sectors, such as for aerospace and defense.[50]

Moreover, there is not currently enough scrap aluminum available to meet the rising demand for aluminum. This is especially true when considering the sustainability goals previously discussed. The World Bank found even when recycling is at 100 percent and secondary aluminum is maximized to meet an increasing demand across its lifecycle, more primary is needed (Figure 5).

44 USGS (2022), Minerals Commodities Summary Aluminum.

45 Government of Canada (2022), Steel and aluminum.

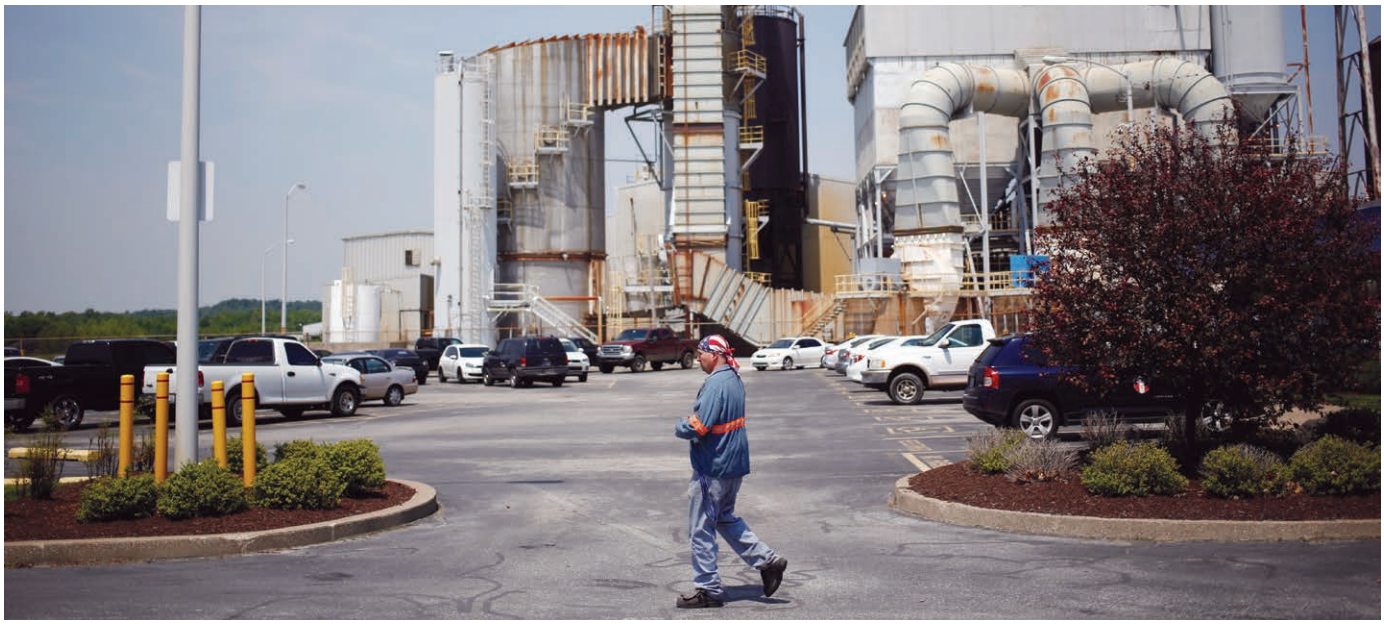
46 USGS (2022), Minerals Commodities Summary Aluminum.

47 Aluminum Association (2021), Recycling.

48 Congressional Research Service (2021), U.S. Aluminum Manufacturing: National Security and Tariffs; United States International Trade Commission (2017), Aluminum: Competitive Conditions Affecting the U.S. Industry, footnote 42.

49 Congressional Research Service (2022), U.S. Aluminum Manufacturing: Industry Trends and Sustainability.

50 Congressional Research Service (2021), U.S. Aluminum Manufacturing: National Security and Tariffs.



Operations at Century Aluminum's Smelter In Western Kentucky. U.S. smelters require significant operational upgrades to compete globally.

Downstream Production

Downstream production includes casting and wrought production of aluminum. Casting forms non-mechanical (non-wrought) products and involves pouring molten aluminum into a mold or injecting it into steel, then cooling to solidify it. Wrought production refers to the rolling, drawing, extruding, forging, or otherwise mechanical working of aluminum products. Downstream cast and wrought aluminum products include wire, extruded products (bars, rods), and rolled products (sheet, foil).

Compared to primary production, downstream production uses much less energy and produces fewer carbon emissions, only requiring enough energy to heat and shape the already formed metal.[51] Because of the cost of transport, downstream production is often located close to end-markets or ports.

Within the U.S. context, the downstream segment is the largest of the three. Dozens of downstream production facilities across the country were responsible for 75 percent of the aluminum industry's $31.5 billion 2020 earnings. With plenty of aluminum in circulation in the United States, along with imports of scrap for transformation, the downstream segment has substantial supply.[52]

Downstream production, as well as secondary production, face competition from unfairly priced Chinese aluminum. However, this stems from Chinese practices in primary production, discussed in Section 3.

51 International Aluminum Institute (2021), Aluminum Sector Greenhouse Gas Pathways to 2050, Figure 8.

52 Congressional Research Service (2022), U.S. Aluminum Manufacturing: Industry Trends and Sustainability.

Global Production

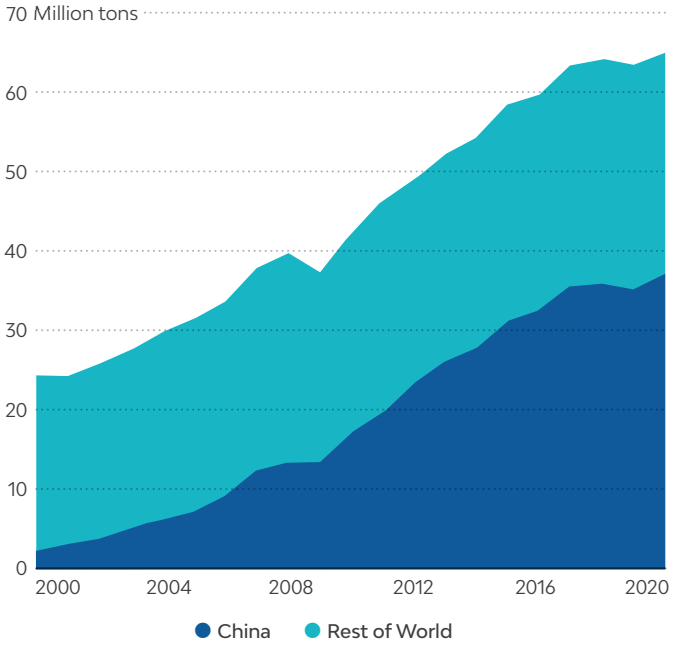
The supply chain analysis in the previous section illuminated U.S. smelting capacity as the segment within domestic industry contributing to supply deficiencies. The global context of primary production shows the United States is not alone in this smelting challenge; other allied trading partners are facing similar hurdles, impacting the United States' ability to access secure supply.

Table 2 World Smelter Production, 2021

Country	Primary production (thousands of metric tons)	Percent of Global Production
China	39,000	57.4%
India	3,900	5.7%
Russia	3,700	5.4%
Canada	3,100	4.6%
UAE	2,600	3.8%
Australia	1,600	2.4%
Bahrain	1,500	2.2%
Norway	1,400	2.1%
U.S.	880	1.3%
Iceland	880	1.3%
Other	9,400	13.8%

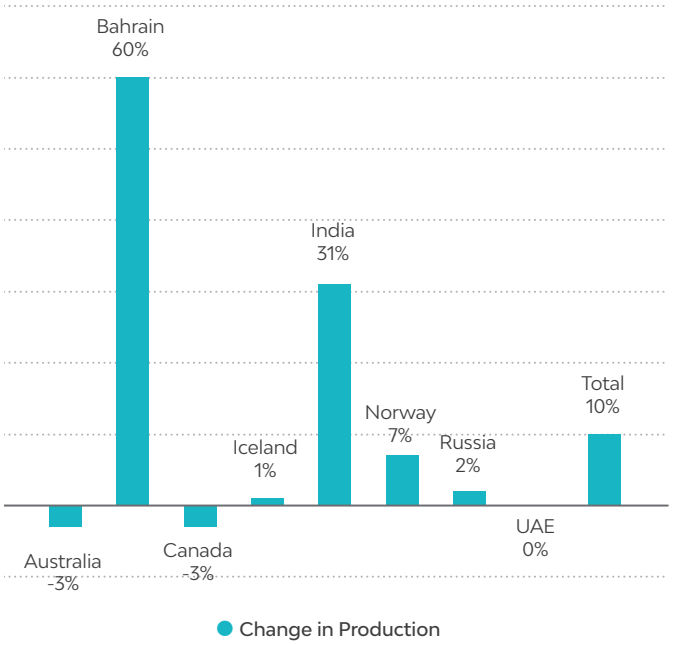
Source: U.S. Geological Survey, 2022.

Figure 6 Primary Aluminum Production, China vs. Rest of World, 2000-2020



Source: Global Efficiency Intelligence, 2022.

Figure 7 Change in Primary Production of Major Producer Countries Ex China, 2016-2020



Source: U.S. Geological Survey, 2022.

As it currently stands, diversified primary exports meet the United States' gap between secure supply and demand. However, with global demand for aluminum anticipated to increase by 33.3 Mt by 2030, the United States' gap becomes of increasing concern.

Top Primary Producers

10 countries represent over 85 percent of total primary production. China is by far the largest producer. The next largest producer, India, produces 90 percent less than China annually. ***China's global dominance carries with it national and economic security concerns for producer countries that struggle to compete.*** Chinese dominance impacts downstream competition and global pricing, through overproduction of primary aluminum (see Section 3). [53]

With over 180 smelters in 2018, China's primary capacity is growing.[54] The United States, with only 6 smelters today, has fallen from the largest global producer in 2000 to 9th in 2021. Meanwhile, China's primary production has grown over 787 percent during the same time period (Figure 6).[55]

Some countries have still been able to increase primary production in recent years (Figure 7). From 2016 to 2020, Bahrain saw a 60 percent increase in production. India and Norway also had noteworthy increases of 31 percent and 7 percent respectively. However, the largest U.S. exporters, Canada, the UAE, and Russia saw stagnant or declining growth. ***In addition to Canada, other major U.S. defense allies faced a decrease in production***. Australia saw a 3 percent decrease and Europe, despite Norway and Iceland's production increases, experienced a net 8 percent decrease.[56] It is also important to note that, while Norway and Iceland are burgeoning areas for primary production, they exclusively sell to customers in Europe.[57]

Global Demand Versus Production

Even though China's primary output is growing, demand is outpacing production. This dynamic holds true across almost all regions, except the Middle East, Oceania, and Africa. Within North America, Canada's production uniquely outpaces demand. But this is to serve the highly integrated North American market. As discussed, almost 90 percent of Canadian primary feeds U.S. demand.

53 Global Efficiency Intelligence (2022), Aluminum Climate Impact.

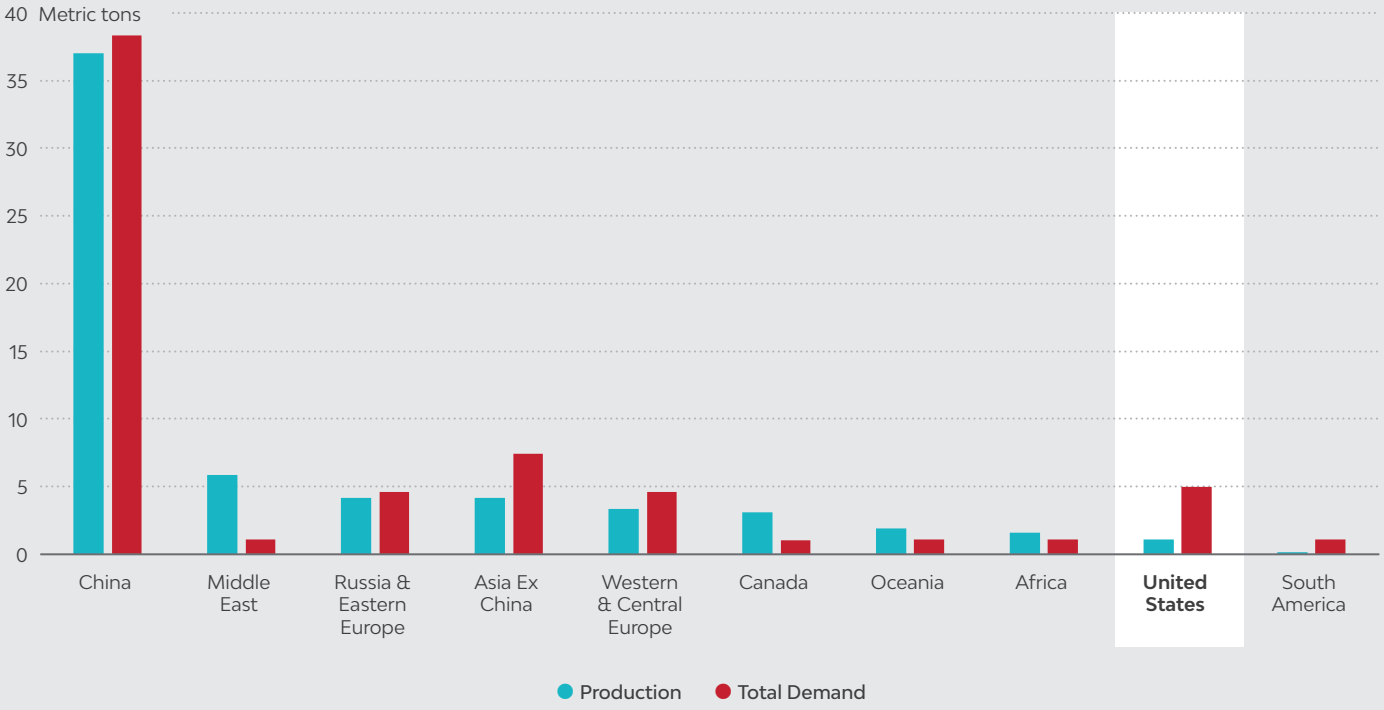
54 U.S. Department of Commerce (2018), The Effect of Imports of Aluminum on the National Security.

55 USGS (2022), Minerals Commodities Summary Aluminum.df and Zhao, et. Al (2022), Improving aluminium resource efficiency in China: Based upon material flow analysis and entropy analysis.

56 International Aluminum (2022), Primary Aluminum Production.

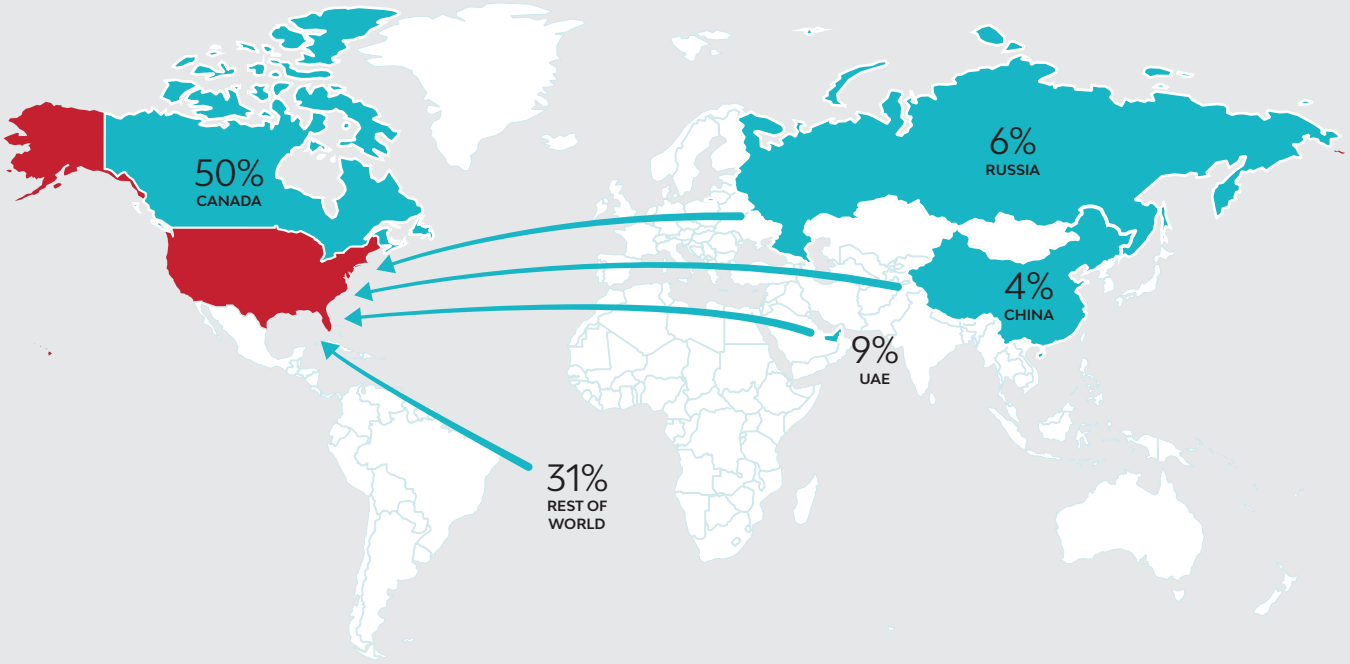
57 Congressional Research Service (2022), U.S. Aluminum Manufacturing: Industry Trends and Sustainability.

Figure 8 Primary Production Versus Demand, 2020



Source: Statista, 2022 and IAI, 2022.

Figure 9 U.S. Major Import Countries, 2017-2020



Source: U.S. Geological Survey, 2022.

After trade with Canada, the U.S. is still left with a nearly 2 Mt disparity (Figure 8).

This gap is met today with imports from a diverse set of countries. Recall, after Canada, the top U.S. import countries for primary from 2017-2020 were the UAE (9 percent), Russia (6 percent), and China (4 percent) (Figure 9).[58]

With U.S. demand increasing, domestic smelting production facing challenges, and Canada's primary production not expected to increase, the U.S. reliance on these non-allied countries will grow. This dynamic is even more pronounced when overlaying production of these regions with their own domestic demand; for the most part, these are the countries with the capacity to export.

Without action on domestic primary, the U.S. is at risk of a much larger reliance on the UAE, Russia, and China for critical infrastructures, military needs, and clean technologies. When the U.S. was missing just one part of the automotive supply chain, semiconductors, it shaved 1% of U.S. gross domestic product (GDP) for 2021.[59] With semiconductors, it was an unintended shortage with major impacts. With the United States' increasing challenge in accessing secure supply of aluminum, nefarious intents could cause major disruptions in vital sectors.

58 USGS (2022), Minerals Commodities Summary Aluminum.

59 Bloomberg (2022), Biden Aide Deese Says Semiconductor Shortage Cost 1% of U.S. GDP.

SECTION THREE

The Root Problem & Solution
Energy & Environment

The primary sector challenge is not new. The Trump-Pence administration lasered in on the national security impacts of rising import dependence for primary aluminum, evoking Section 232 of the Trade Expansion Act.[60] While this intervention and the proceeding tariffs were able to help some domestic players (Figure 4), they did not hit at the core problem: energy.

The economic viability of a primary aluminum smelter is based on the oscillating margin between aluminum price and cost of production. Given energy is the number one input in primary aluminum, electricity prices have sweeping impacts over primary aluminum costs. Meanwhile, the London Metals Exchange (LME) largely dictates the price of aluminum on global markets. This price is influenced by an array of factors, given the diversity of aluminum's end uses. A looming factor likely to shock the market is whether the United States bans Russian aluminum, which would weaken global demand and thus increase prices.[61] Still, the largest of these factors is China's rise to the top of global primary output and the subsequent rise of heavily subsidized Chinese aluminum product exports. Per the U.S. Department of Defense, China's overproduction has "suppressed global aluminum prices."[62]

In the face of China's market flooding on prices, certain countries have been able to maintain their stronghold on primary production. What ensured their resilience? Lower energy costs. **With climate change motivating an overhaul in energy systems, the United States should hone in on the interrelationship of energy and smelter economic viability to revitalize the primary sector, while also considering the full lifecycle impacts of aluminum on emissions**.

The United States is in the process of rolling out policies to revolutionize and decarbonize its grid, which can stabilize and lower electricity prices. However, as Section 1 proved, success of renewable energy and transmission deployment is contingent on access to and the cost of inputs, namely aluminum.

At the same time, the U.S. power sector is facing a swath of new challenges. The rise of EVs puts additional pressure on the grid and corporate sustainability commitments are upping the competition for clean energy. The energy crisis in Europe, with its rippling effects across the globe, is also increasing the cost of U.S. electricity. This dynamic makes it much harder for energy-intensive industries, especially those operating without affordable energy, to compete globally.

Overall, the future of the domestic primary industry is entangled with energy security and decarbonization. Primary aluminum emits carbon directly in its smelting process and through its use of fossil fuels, but it is needed for the U.S. clean energy transition. Meanwhile, a lack of reliable and affordable energy sources, exacerbated by the Russia-Ukraine situation, threatens the viability of the domestic primary aluminum industry. These two tracks must be aligned. **Lowering and stabilizing energy costs—commensurate with an energy transition and climate goals—will bolster the primary industry and thus enable decarbonization**.

Economic Viability: The Energy Problem

Given energy is the number one input of primary aluminum, the cost of energy greatly impacts its economic viability. Smelting requires consistent high-wattage power—giving aluminum its nickname, "congealed electricity." On average, it takes 17,000 kwh

60 U.S. Department of Commerce (2018), The Effect of Imports of Aluminum on the National Security.

61 CNBC (2022), Sanctions on Russia aluminum could send ripple effects through global supply chains.

62 See Note 70.

Alcoa Aluminum Smelter, Massena, NY. Smelting aluminum requires consistent high-wattage power, giving aluminum its nickname, "congealed electricity."

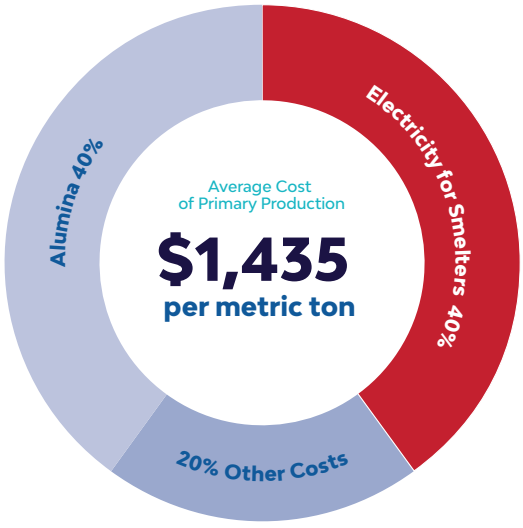
of energy to produce 1 ton of aluminum.[63] For context, the average annual electricity use of a U.S. household is just over 10,000 kwh.[64] As a result, electricity is estimated to represent 40 percent of primary aluminum costs (Figure 10).[65]

63 Civil Engineering Materials (2016), Alloys and nonferrous metals.

64 Organisation for Economic Cooperation and Development (2019), Measuring distortions in international markets: the aluminum value chain, footnote 19, p. 39; United States International Trade Commission (2017), Aluminum: Competitive Conditions Affecting the U.S. Industry, Figure 2.6. Note that, in Canada, energy accounts for about 30% of smelters' operating costs. Aluminum Association of Canada (2021), Energy efficiency reflecting a global trend.

65 Congressional Research Service (2022), U.S. Aluminum Manufacturing: Industry Trends and Sustainability.

Figure 10 Primary Production Costs



Source: OECD and USITC, 2015.

While this average is high, energy costs vary substantially by region, country, and even state. In fact, energy costs account for up to 70 percent of variation in total aluminum production cost.[66] As such, primary electricity costs, and their resulting impact on aluminum smelter profitability, fluctuate as well.

Contrasting the United States to countries with an abundance of affordable energy emphasizes this interrelationship. **Whereas looking at the damaging impact of Europe's energy crisis on its primary industry, a fate the United States is already beginning to experience, stresses the need for imminent action**.

Primary from Countries with Abundant and Affordable Energy

In 2019, the average cost of one kilowatt-hour of electricity was $0.163 in the U.S. compared with $0.123 in Canada, $0.081 in Russia, and $0.109 in the UAE.[67] While the differences in these numbers may seem small, when multiplied to produce Mt of aluminum, the total cost variance is stark.

Canadian smelters are almost entirely (96 percent) powered by hydroelectricity, contributing to lower production costs.[68] As of 2015, average smelter energy costs were half of U.S. levels ($252 vs. $532 per ton).[69]

66 Organisation for Economic Cooperation and Development (2019), Measuring distortions in international markets: the aluminum value chain, footnote 19, p. 39; United States International Trade Commission (2017), Aluminum: Competitive Conditions Affecting the U.S. Industry,. Aluminum Association of Canada (2021), Energy efficiency reflecting a global trend.

67 https://sgp.fas.org/crs/misc/R47294.pdf World Bank, "GovData360, Getting electricity: Price of electricity,"

68 Aluminum Association of Canada (2019), GHG Emissions.

69 United States International Trade Commission (2017), Aluminum: Competitive Conditions Affecting the U.S. Industry.

Similarly, Russia's largest aluminum producer, Rusal, sources 95 percent of its electricity from hydropower in Siberia[70] Rusal is also the world's largest non-Chinese aluminum producer, emphasizing how reliable and affordable energy sources increase competitiveness, even in the face of market manipulations. Finally, the UAE's only primary producer, Emirates Global Aluminum (EGA), has 33 captive GE natural gas turbines providing 5,200 MW of power to its aluminum smelter.[71] The UAE holds the world's 5th largest natural gas reserves, assuring stable access to this affordable energy for decades to come.[72] That said, EGA is exploring options to leverage its other natural resources, such as solar irradiation potential, to fuel smelting.

U.S. Primary Production & Energy

Stable and abundant sources of energy largely dictated U.S. smelters' ability to endure economic challenges—whether they be Chinese overproduction, energy price volatility, or both. Energy is linked to the statuses of several U.S. Alcoa smelters in the last several years.

- Alcoa curtailed its Wenatche, WA smelter in 2015 and then closed it in 2021. They had an 11-year contract lasting until 2028 with Chelan County PUD to provide the equivalent of 26 percent of the output of Rocky Reach and Rock Island dams to this smelter. The two parties canceled the contract when the plant shut down. During the same time, Alcoa opened a new smelter in Iceland, where electricity is 30 percent less, on average, than the U.S.[73]
- Similarly, the Alcoa Intalco smelter fully idled in 2020. Private equity efforts—led by Blue Wolf Capital and backed by labor unions—to re-open this plant broke down at the end of 2022 due to electricity costs; an advisor to Blue Wolf Capital asserted, **"unless Congress and the Biden Administration do what virtually every other nation does—provide affordable electricity with government help—the U.S. aluminum industry will vanish and America's energy transition will be forced to rely on the goodwill of other nations."**[74]
- Finally, Alcoa's Messina, NY smelter remains fully operational. Alcoa has a 7-year agreement with the New York Power Authority through to 2026. This plant is fueled by hydropower.

Alcoa's Warrick smelter was also curtailed in 2022. The company asserted this was due to operational challenges, namely worker and expertise shortages. This decision reveals a secondary impact of this industry's decline in the U.S.

The remaining U.S. smelters, owned by Century Aluminum and Magnitude 7 Metals, have also connected energy with their respective smelter's economic viability in recent years.

- In 2018, Magnitude 7 Metals secured a contract with Associated Electric Cooperative Inc., supplying their Marston, MO smelter with an electricity mix of natural gas, coal, hydropower, and wind. Magnitude 7 Metals claimed this contract is why they were able reopen the plant.
- In 2021, Century Aluminum's Mt. Holly, SC smelter restarted 57,000 tons/year in production (a 50 percent increase) after finalizing a power supply contract with Santee Cooper. Unfortunately, this contract ends in 2023.
- Century Aluminum fully curtailed the only U.S. high-purity smelter (Hawesville, KY) in July 2022, citing skyrocketing energy prices. Prior to curtailment, they were buying energy on the wholesale market for this smelter, exposing them substantially to higher price volatility risk.

Europe: The Canary in the Coal Mine

The Russia-Ukraine situation, which continues to shake global energy markets, has hindered Europe's primary sector. In 2022, Europe's primary production fell to its lowest levels since 1970. Major producers claim this could be the extinction of the primary industry in many European areas, as projected power prices for 2024 and 2025 continue to soar. [75]

Other variables at play in Europe exacerbate this situation. Manufacturers are trying to avoid Russian-produced aluminum as a show of solidarity to Ukraine. This, in turn, is tightening European supply and driving up prices. U.S. aluminum tariffs and the EU's push for industrial decarbonization put the European primary industry at a disadvantage, prior to the energy shortage.

70 Fitch solutions (2021), Russia Aluminum Production to Rise as Growth Steadies.

71 Engineering News-Record (2022), UAE Aluminum Maker Investigates Hydrogen to Cut GHG Emissions.

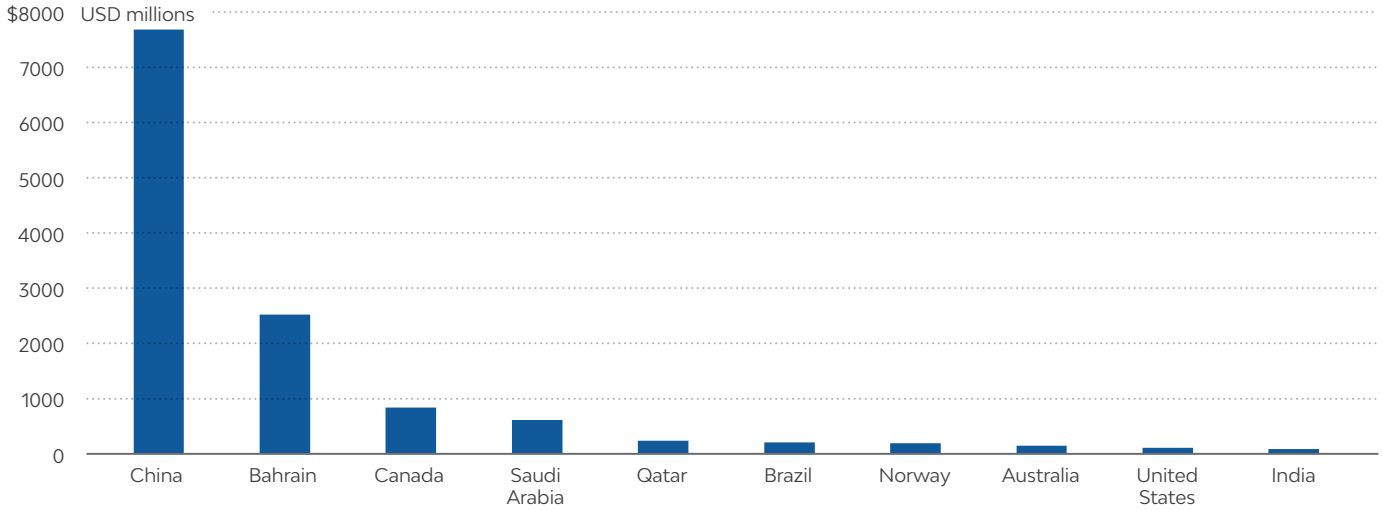
72 Embassy of the United Arab Emirates Washington, DC (2022), UAE Economy.

73 The New York Times (2017), American Companies still make aluminum in Iceland.

74 Washington Post (2022), Biden wants 'green' economy, but talks fail to revive key aluminum plant." Hyperlink: https://www.washingtonpost.com/climate-environment/2022/12/16/biden-wants-green-economy-talks-fail-revive-key-aluminum-plant/

75 Bloomberg (2022). Metal Plants Feeding Europe's Factories Face an Existential Crisis.

Figure 11 Total Non-Financial Government Support By Country, 2013-17



Note: Data are based on a sample of firms.
Source: OECD, 2019.

Despite those important considerations, energy prices remain the main threat. The escalating European energy crisis and its impacts on energy-intensive industries have already crept into the U.S. market. The curtailment of the Hawesville smelter occurred after six months of high energy prices, post invasion. Century Aluminum pointed to the Russia-Ukraine conflict as the reason they idled their smelter.[76]

Europe's experience puts the U.S. primary challenge in a dire context. The Congressional Research Service's 2022 U.S. Aluminum Manufacturing report recognized this contagion and cautioned, **"U.S. primary smelters seem likely to face greater headwinds due to...rising energy costs, which have led to recent production curtailments and idling of capacity."** [77]

China's Energy Subsidies

China's rapid primary aluminum growth and overproduction is linked to energy. As proven, abundant and affordable sources of energy ensure primary aluminum's lasting resiliency. With the fourth largest coal reserves (14 percent) and the largest amount of installed capacity (1,064 gigawatts), China meets those criteria.[78] 80 percent of China's smelters are coal-fire powered.[79]

This energy connection is more evident when considering China's intimate involvement in the aluminum supply chain; China has the most state-owned capacity out of any country and the highest amount of non-financial government support, which is mainly energy subsidies (Figure 11). The opaque relationship between producers and government veils the extent of energy subsidies. However, China's apparent resilience to periods of high coal pricing—namely 2011-2015 and following Russia's attack on Ukraine—proves the government's hand in industry's overproduction. In 2011, coal prices were relatively high, but paradoxically, so were Chinese smelter profit margins. **These energy subsidies in the primary sector have led to the formation of excess capacities, causing "a supply glut in China which has depressed prices and pushed surplus materials into export markets."** [80]

Leveraging The Clean Energy Transition

The clean energy transition is breathing new life into the primary aluminum sector. Not only is it driving demand for aluminum, but it also has the potential to solve primary's core energy problem.

Renewable energies are becoming cost competitive with fossil fuels. The new U.S. tax credits under the Inflation Reduction Act (IRA) will only increase their affordability. As distributed renewable energies

76 Century Aluminum (2022), Century Aluminum to Temporarily Idle its Hawesville Smelter Due to Soaring Energy Prices; Issues WARN Notice to Employees

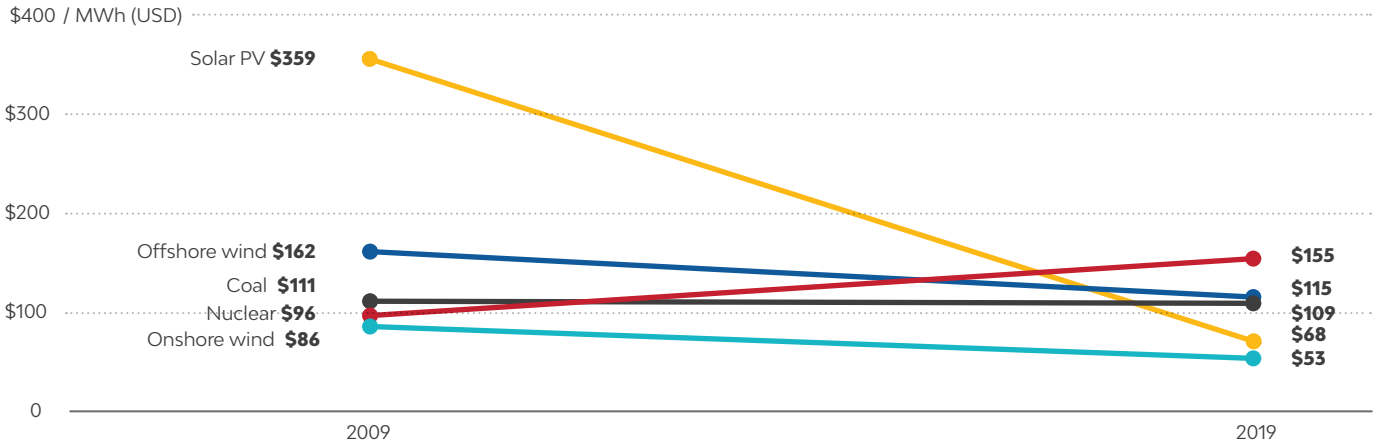
77 Congressional Research Service (2022), U.S. Aluminum Manufacturing: Industry Trends and Sustainability.

78 U.S. Energy Information Adminsitration (2022), How much coal is in the U.S.? and Statista (2022), Countries with the largest installed capacity of coal power plants worldwide.

79 Wood Mackenzie (2021), Carbon neutrality goal forces Chinese aluminium smelters away from captive coal power.

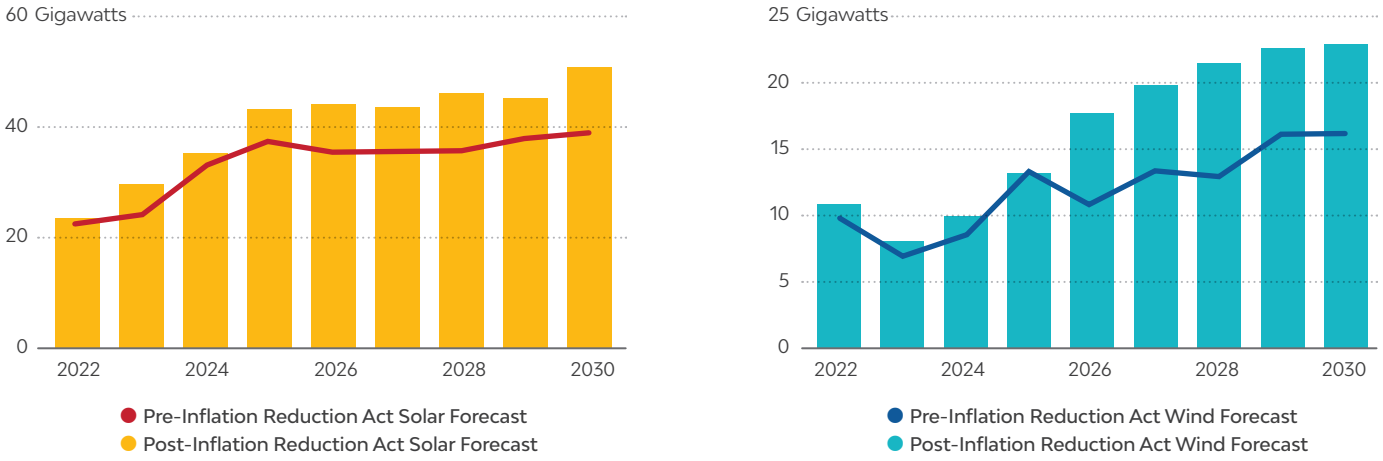
80 OECD (2018), Measuring distortions in international markets: The aluminium value chain.

Figure 12 Price (USD) per megawatt hour of electricity, by source



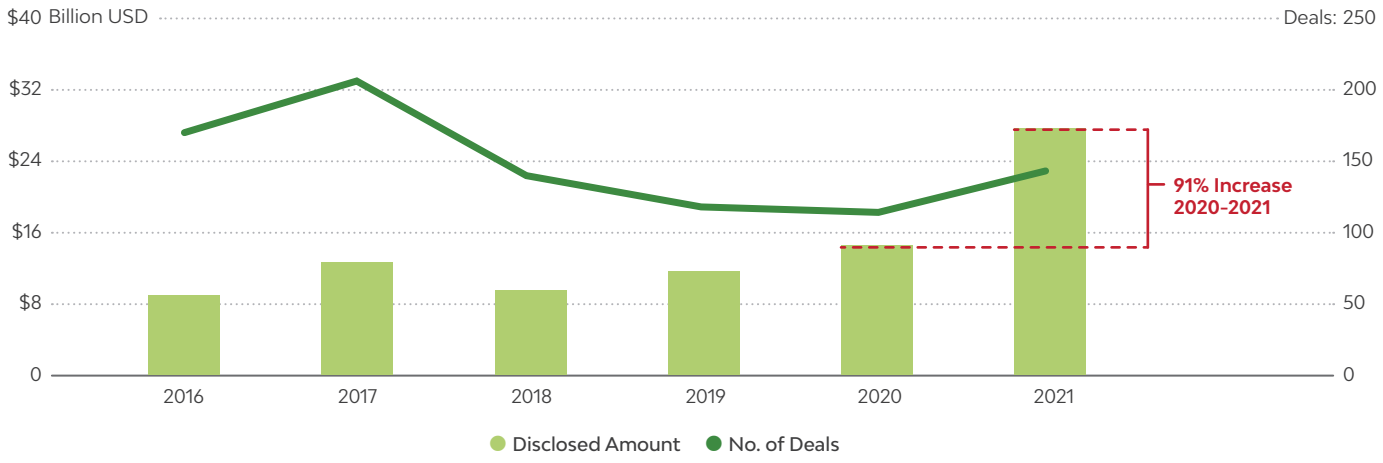
Note: Global weighted average of levelized costs.
Source: Statista, 2021.

Figure 13 IRA increase in annual solar & wind installations



Note: Data are based on a sample of firms.
Source: Bloomberg NEF, 2022.

Figure 14 Solar Corporate Funding 2010-2021



Note: Data are based on a sample of firms.
Source: Mercom Capital Group, 2021.

these sources are shielded from global market price volatility. Governments, the private sector, and civil society are exploring different mechanisms to push decarbonization—from promoting high environmental standards to carbon sectoral trade agreements.

The clean energy transition is also churning out disruptive technologies with the potential to further revitalize the primary sector. If applied to smelters, innovations in inert anodes used in the electrolysis process can not only decrease carbon emissions, but also result in operational savings.

To fully leverage this green transition, aluminum must be looked at holistically, from how it enables decarbonization to how it contributes to climate change.

Can Clean Energy Cut Primary Cost?

The costs of renewable energy sources, such as wind and solar, fell substantially in the past decade. Figure 12 shows decreases in their levelized costs, which captures the full cost of each energy source throughout its lifetime, without subsidies. Solar PV's price decrease is the most significant; its levelized cost fell over 80 percent in the last decade. Both onshore and offshore wind energy also saw price decreases over this time, while coal and nuclear saw price increases.[81]

Every U.S. smelter, except Massena, currently sources at least part of its energy from coal and natural gas. The upward price pressure on fossil fuels, as wind and solar become more abundant, makes renewable energy not only the most cost-effective option, but also the best option to maintain economic competitiveness.

The age of smelters compounds this cost impact. The youngest U.S. smelter is Mt. Holly, and it was built in 1980. As a result, U.S. smelters are less energy efficient. This equates to an even greater reliance on fossil fuels, as their prices continue to rise.

Since the turn of the decade, the energy market has shifted substantially, with the passage of the IRA in 2022, the rise of sustainability standards, and the Ukraine-Russia conflict.

The IRA introduces many new incentives to increase the production and distribution of wind and solar energies (Figure 13). Bloomberg New Energy Finance (BloombergNEF) projects a 20 percent increase in these energies by 2030, directly because of this climate bill. Though, the IRA does not negate uncertainties for these technologies, such as tariff disputes and import barriers for solar, as well as potential supply chain constraints for both. Nonetheless, the impact on the proliferation of clean energies is substantial. [82]

Also contributing to this growth are private sector sustainability commitments and new government policies enshrining sustainability standards in trade. Major companies in the United States and all over the world are releasing sustainability strategies, which are subsequently driving demand for and investment in renewable energy technologies. Corporate spending for solar projects, including venture capital funding and private equity, was $27.8 billion in 2021—a 91 percent increase compared to 2020 (Figure 14).[83] At the same time, the corporate drive to decarbonize supply chains increases competition for aluminum producers to access these new energy sources for their production.

Governments are putting their own twist on sustainability. In 2022, the U.S. Department of State launched Minerals Security Partnership with almost a dozen other countries. It aims to increase the financing of responsibly mined, processed, and recycled critical minerals, which bauxite and aluminum fall under.[84] In 2021, the United States and European Union announced they would negotiate a carbon-based sectoral arrangement on steel and aluminum.[85] The United States is essentially providing market access contingent upon low emission production. While much remains to be seen on this agreement, it sends the market signal that green aluminum will be more competitive.

Even though the sustainability movement is already facing challenges and trade mechanisms can be removed in a change of administration, one lasting factor in the ability of renewable energies to ensure smelter viability is their resistance to global energy market volatility. As discussed in the previous section, Russia's invasion of Ukraine is driving up prices of fossil fuels. However, new onshore wind and large-scale solar plants remain comparatively competitive; **BloombergNEF found "new onshore wind now costs about $46 per megawatt-hour, while large-scale solar plants cost $45 per megawatt-hour. In comparison, new coal-fired plants cost $74 per MWh, while gas plants are $81 per MWh."**[86]

This 40 percent cost advantage for wind and solar occurred despite rising prices of materials, shipping, and labor for these renewable energies. The ability to shield primary smelters from major energy price volatility, which equates to 70 percent of the variation

81 Stastita (2021), The Falling Cost of Renewable Energy.

82 BloombergNEF (2022), The U.S. Trifecta of Oil, Gas and Clean Energy Growth in Five Charts.

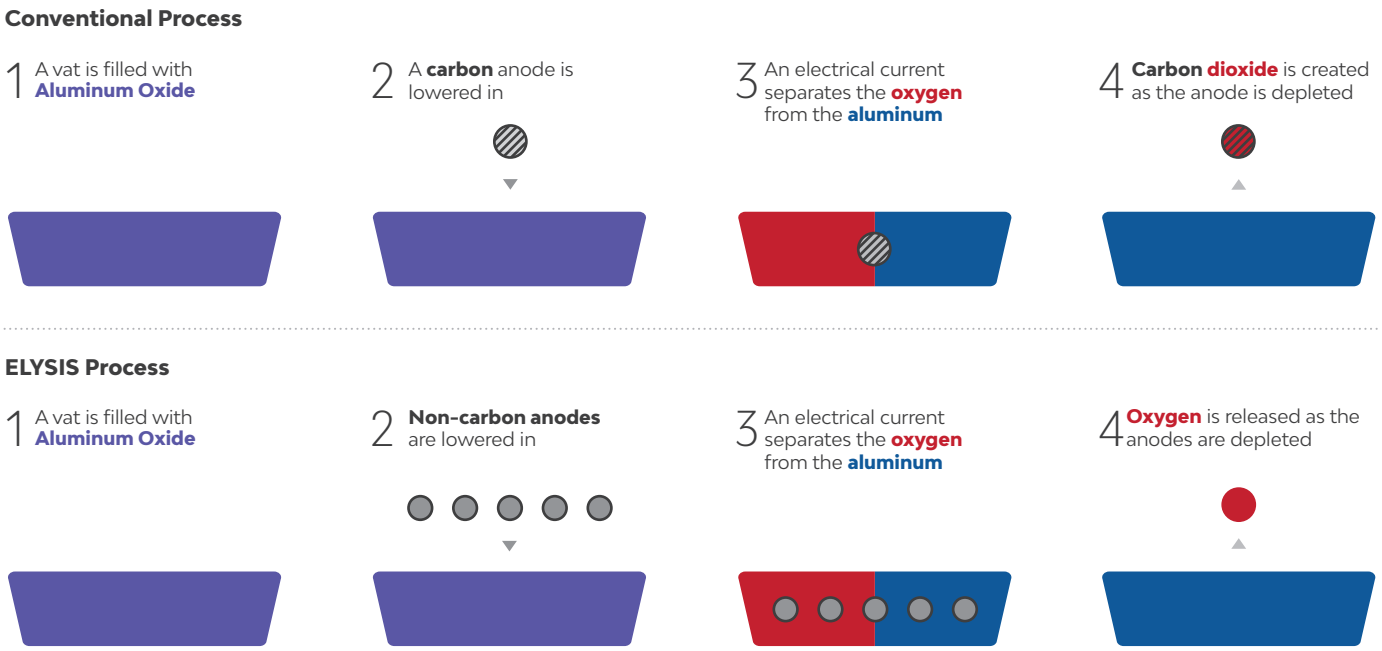
83 Solar Industry (222), Corproate funding for Solar Mercom Capital Group

84 U.S" Department of State (2022), Minerals Security Partnership.

85 White House (2021), FACT SHEET: The United States and European Union To Negotiate World's First Carbon-Based Sectoral Arrangement on Steel and Aluminum Trade.

86 Bloomberg (2022), Renewable Power Costs Rise, Just Not as Much as Fossil Fuels.

Figure 15 Carbon-free aluminum process with ELYSIS



Source: Bloomberg, 2021.

in aluminum production costs, is extremely beneficial. Increased certainty over energy costs will ensure the economic viability of U.S. primary.

Disruptive Technologies

The clean energy transition is also prompting new innovations to decarbonize energy-intensive industry, such as primary aluminum, with the added benefit of cost-savings.

As discussed in Section 2, when alumina goes through the smelting process, electricity runs through the mixture of alumina and an anode. These anodes have historically been carbon-based. The electricity induces a chemical reaction, splitting the raw aluminum from the oxygen, which then combines with the carbon anode and is released off as carbon dioxide. The carbon emitted from this process is responsible for 13 percent of primary production emissions with an estimated carbon intensity of 1.5 t CO2 per ton of aluminum.[87]

A new technology, ELYSIS, focuses on eliminating emissions from smelting. ELYSIS is a joint venture between Alcoa and Rio Tinto with funding from Apple, the Canadian government, and the provincial government of Québec. Their collaboration has resulted in an innovative non-carbon-based anode, which eliminates the carbon emissions in electrolysis (Figure 15).[88] After a successful pilot project in 2019, ELYSIS announced in April 2021 that it had selected Rio Tinto's Alma smelter in Québec as the first installation site to deploy its inert anode technology at commercial scale.[89]

Inert anodes increase the economic viability of primary aluminum. While traditional carbon anodes need to be replaced every 25 days, ELYSIS' inert anodes last for two years, reducing operating costs by 15 percent.[90] With economies of scale, production of the anodes themselves could also become cheaper than carbon anodes.[91] As such, BloombergNEF projects inert anodes are likely to become the industry standard for new smelters built from 2030 onward, with the potential to cost-dependently retrofit existing smelters as well.[92]

87 Bloomberg New Energy Foundation (2021), Decarbonizing Aluminum: Technologies and Costs.

88 Ibid.

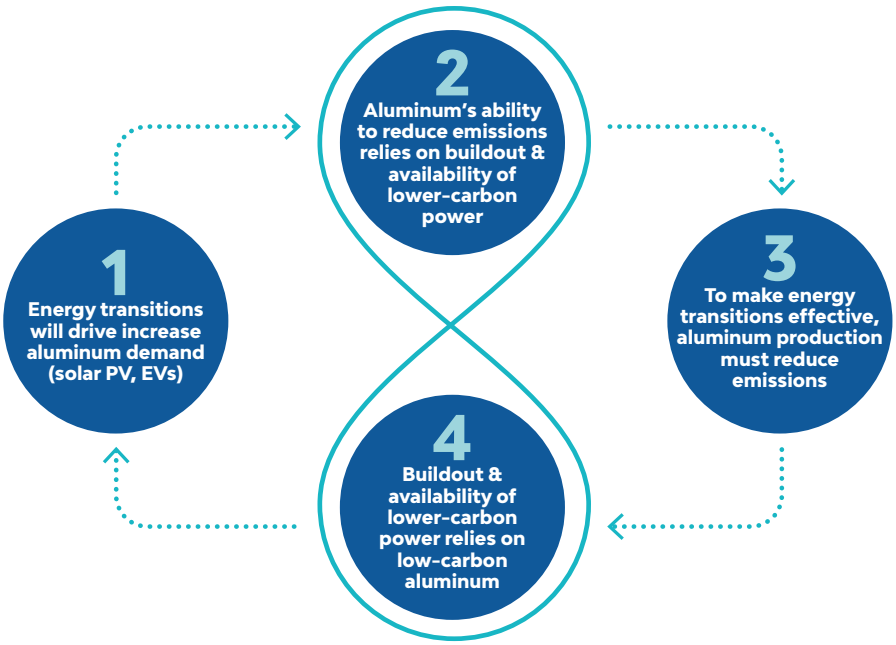
89 CRU Group (2021), Emission control accelerates pace of inert anode development.

90 Bloomberg (2021), With a Push From Apple, Rival Aluminum Makers Team Up Against CO2.

91 Bloomberg New Energy Foundation (2021), Decarbonizing Aluminum: Technologies and Costs.

92 Ibid.

Figure 16 Aluminum's Energy Transition Circularity



Source: Wood Mackenzie, 2021.

Tackling Aluminum's Energy Transition Circularity

The clean energy transition's influence on energy prices and innovations, as well as the additional demand it generates for primary aluminum (Section 1) create a paradox. Wood Mackenzie analysts have termed this "aluminum's energy transition circularity." The rate at which the aluminum industry can reduce emissions at scale is a function of the buildout and availability of lower-carbon energy sources, which itself, is a function of the use of low-carbon aluminum (Figure 16). Consequently, the growth trajectory of aluminum demand is likely to be a function of the success of global decarbonization efforts.[93]

Solving this circularity problem is of utmost importance. Decarbonization of U.S. aluminum production, specifically primary, is key to economic vitality. This includes incorporating innovations, such as ELYSIS, in the smelting process, and sourcing electricity from renewable energy sources. But it must be done quickly enough to keep pace with the clean energy transition.

The success of these efforts will be a key determinant of future production trends: who can supply the additional 40 million metric tons of additional primary demand through 2050, and who can do it in a way to ensure aluminum is sufficiently carbon-competitive to justify its use in the buildout of the low-carbon world.

93 Wood Mackenzie (2021), Decarbonisation: is aluminium a solution or a problem?

Conclusion

Aluminum is needed for the economy of today and the economy of the future. It assures U.S. security through its military, electrical, and transportation uses. Aluminum's role in the clean energy transition increases its criticality and demand. However, energy challenges in primary aluminum production, whether they be a lack of affordable sources in the United States or Chinese energy subsidies creating untenably low pricing, prevent the United States and its allies from meeting rising demand with secure supply sources.

The United States has learned how supply chain vulnerabilities can send shock waves through the economy. But it took the semiconductor shortage increasing inflation by 25 percent and shaving 1 percent of U.S. GDP in 2021, for the United States to act.[94]

Semiconductors mirror aluminum. Like aluminum, "semiconductors enable nearly every modern industrial, commercial, and military system, including smartphones, aircraft, weapons systems, and the electric grid."[95] As a result, they both are critical to U.S. economic and national security.[96] Aluminum is also integral to U.S. decarbonization, which the Biden-Harris administration has prioritized.

The United States should not learn the same lesson twice. Whether it be from:

- Global demand for aluminum outpacing supply,
- Chinese primary overproduction thwarting U.S. competitiveness, or
- Europe's energy crisis undermining U.S. smelters' survivability.

It is clear: aluminum is headed down a similar path. Without action, the United States will either increase dependence on adversarial countries for defense, economic security, and clean technology, fail to meet climate change commitments, with a resulting loss to global competitiveness, or both.

The United States has the benefit of seeing a potential supply shock coming. By leveraging new and existing policies, the United States has the power to avoid these damaging results. The *Infrastructure Investment and Jobs Act* and the *Inflation Reduction Act* create opportunities for industry to overcome current and future energy challenges. These laws also increase clean energy deployment, thus advancing the U.S. primary aluminum sector's potential economic viability.

More is needed. The Center for Strategic Industrial Materials will release reports examining domestic and global policy options for aluminum to preserve economic and national security while enabling a clean technology transition.

94 Bloomberg (2022), Biden Aide Deese Says Semiconductor Shortage Cost 1% of U.S. GDP.

95 Senate Republican Policy Committee (2021), Semiconductors: Key to Economic and National Security.

96 Ibid.

SAFE

SAFE is a non-partisan, non-profit policy thought leadership organization dedicated to accelerating the real-world deployment of secure, resilient, and sustainable transportation and energy solutions of the United States and its partners and allies by shaping policies, perceptions, and practices that create opportunity for all. SAFE unites prominent military and business leaders to develop and advocate for policies that improve America's energy security by significantly curtailing our dependence on oil and promoting responsible use of our domestic energy resources. SAFE relies on the knowledge and experience of four-star retired military officers, Fortune 500 CEOs, and its expert staff to produce high-quality, fact-based analysis and policy recommendations for lawmakers, regulatory agencies, and the public.

ENERGY SECURITY LEADERSHIP COUNCIL

The Energy Security Leadership Council (ESLC), a group of business and former military leaders committed to reducing U.S. oil dependence. The ESLC is chaired by Adam Goldstein, Former Vice Chairman, Royal Caribbean Cruise Lines, and General James T. Conway, the 34th Commandant of the U.S. Marine Corps, and retains its strategic mix of business and four-star former military leaders.

CENTER FOR
Strategic Industrial Materials

C-SIM is a policy initiative dedicated to advancing more secure, reliable, and sustainable supply chains for aluminum and other industrial materials critical to America's national and economic security. The Center is exploring new federal government purchasing regulations that prioritize domestic aluminum and developing policy recommendations designed to reduce carbon emissions to net zero by 2035.

Acknowledgement
This publication was produced by Abigail Hunter, a non-resident fellow of the SAFE Center for Strategic Industrial Materials and Master of Arts in Sustainable Energy student at Johns Hopkins School of Advanced International Studies (SAIS).

Media Contact
For media inquiries please contact Thayer C. Scott, tscott@secureenergy.org and (703) 509-6503.

SAFE · 1111 19th Street, NW #406 Washington, DC 20036 · 202.461.2360 · secureenergy.org