Global Insights: Energy and Environmental Aluminum Solutions

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SAFE | CENTER FOR Strategic Industrial Materials

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KEY TAKEAWAYS

- The United States is not alone in its primary aluminum production challenges, whether they be the high emissions profile, energy costs, or price volatility in the global market.
- Other countries' approaches to assure aluminum production in the face of shared challenges can yield insights on how the United States can support a waning domestic primary industry.
- The environmental movement has ushered in a new age of policies. Carbon pricing, demand-response, and decarbonization carrots and sticks are changing the game for energy-intensive industries, like aluminum.
- Primary aluminum producers abroad are responding with new innovations and potentially more resilient profit streams.
- Some aluminum producers that are employing innovative technologies or leaning into regulatory requirements on energy have operations in the United States. Yet, they don't employ these strategies here, showing how companies adjust to different market requirements.
- Not all policies are new. Use of longer standing policies, like price pegging or subsidies to assure smelter resiliency, underscores what U.S. primary producers are up against globally.
- Aluminum producers have varying success in different markets. Their success has long been linked to their access to reliable and affordable energy. Going forward, their success is entangled with the clean energy and environmental movements.
- The United States must learn from these global insights in order to usher in the next generation of competitive and clean aluminum smelters to meet growing demand at home and abroad.

CONTEXT

The U.S. aluminum industry is at a tipping point. Aluminum has a crucial role to play in the clean energy transition, yet carbon emissions from primary aluminum production detract from this potential. At the same time, long-term challenges to the domestic aluminum industry persist. China's primary aluminum overcapacity suppresses aluminum prices, hindering transparent price discovery needed for markets to function properly, and making it harder for all forms of U.S. aluminum to compete. Simultaneously, a lack of abundant, stable, and affordable energy for U.S. smelters is pushing them into decline. SAFE's Center for Strategic Industrial Materials (C-SIM) released a report, "Aluminum's Energy Problem and Energy Solution" (February 2023), which elucidates how the U.S. clean energy transition is a make-or-break moment for this once thriving domestic industry.

As a global commodity used across multiple industries, aluminum production problems evolve with changes to domestic policies and international trade. U.S. policies, such as the *Inflation Reduction Act*, *Infrastructure Investment and Jobs Act*, and *CHIPS Act*, are shifting the backdrop of the aluminum production challenges, and not always for the better. All the while, other aluminum producing countries are dealing with the same China and energy problems, testing different policy responses. C-SIM is publishing a series of reports on how aluminum's energy problem and energy solution are playing out overseas and within a new policy landscape at home.

These reports aim to answer the following questions:

- **"Legislative Analysis for the U.S. Aluminum Industry" (May 2023):** Now with an infrastructure law, a climate law, and other laws clearly linking commodity supply chain weak points to national security threats, where does U.S. aluminum stand? Do these new laws help or hurt the aluminum energy problem?
- **"Political Tailwinds: Examining Trade Policy for the U.S. Aluminum Industry" (June 2023)** Domestic politics have seeped into aluminum trade policy for the last three administrations. How will the Global Arrangement on Sustainable Steel and Aluminum effort learn from previous attempts to use trade to remedy these complex issues? Will this trade mechanism provide relief from the energy cost problem and China price problem?
- **"Global Insights: Energy and Environmental Aluminum Solutions" (August 2023):** How are other countries able to produce aluminum in the face of these shared challenges? What unique energy and climate policies can the United States learn from to help sustain its much-needed primary sector?

The answers to these questions will help industry and government determine an effective pathway forward. This pathway will ensure the domestic aluminum industry can sustain during the clean energy transition. As huge transformational investments shift supply chains and decrease manufacturing and power emissions, it is paramount that component parts, like aluminum, are not overlooked. Aluminum is the foundation of the current U.S. economy and the fuel for new energy sources and technologies of the future.

The United States needs aluminum, whether it is made domestically or not. These reports aim to inform how government and industry can come together to ensure the former.

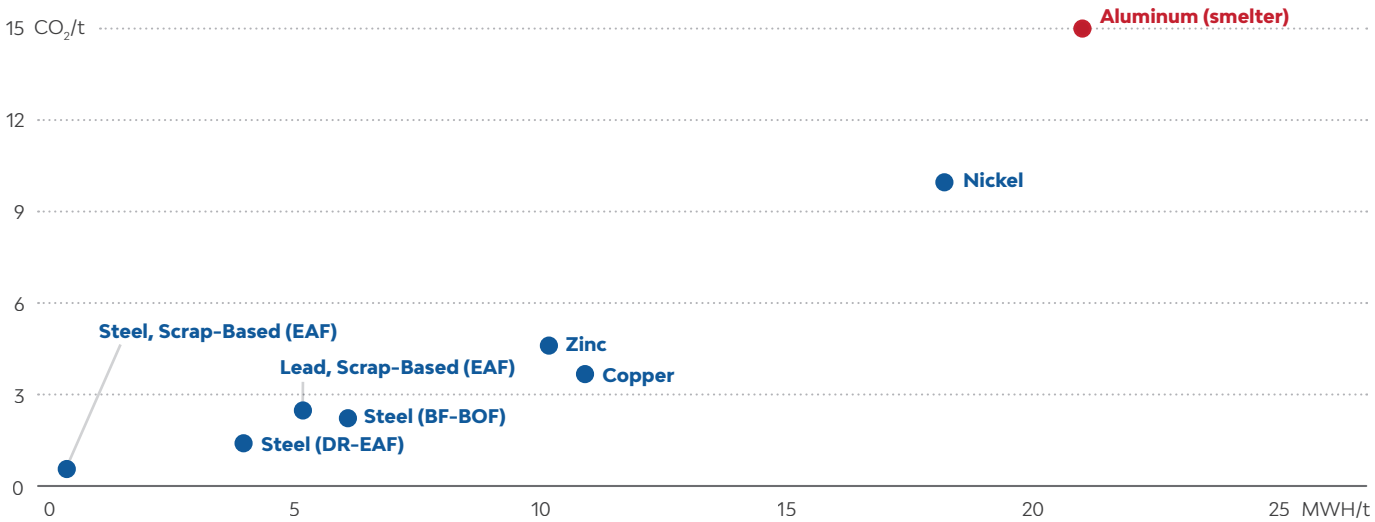
Introduction

The United States is not alone in its primary aluminum challenges. Aluminum-producing countries and aluminum-consuming markets have dealt with market flooding, energy price volatility, and climate change in different fashions. These unique approaches to preserving the primary aluminum sector are sometimes led by industry and sometimes led by governments. Given the varying impacts of recent U.S. policies on its domestic aluminum sector, evaluating other countries' approaches may provide valuable insight into how the United States can sustain its long-standing industry and ensure aluminum plays a crucial role in the transition to a clean and secure future.

Some global policies and practices, like industry-specific energy subsidies and utility-smelter price linking, may not be aligned with the U.S. deregulated power system. However, those policies illuminate how other countries' primary industries are surviving and the important economic relationship between utilities and smelters. Collaboration amongst utilities or grid operators and primary producers takes the smelter-energy link a step further, looking at aluminum as a demand-side response mechanism for electricity. Primary aluminum's energy intensity can be an energy sink to help manage a growing share of variable renewable energy sources on the grid. Overall, these policies present interesting considerations for the United States as both the power and industrial sectors transition away from thermal power.

The introduction of carbon pricing and border adjustments has an immediate downward effect on primary aluminum, due to its incredible energy intensity compared to other metals (See Figure 1). However, in certain regions, these carbon pricing schemes are pushing industry to innovate. Pilots of inert anode technologies, for example, are burgeoning in areas where industry must comply with a new carbon cost to production. The rise of these policies has the power to move the aluminum market in a cleaner direction and may even result in a premium for green aluminum.

Figure 1 Carbon and energy intensity per ton of metal produced



Source: TPI, BloombergNEF, ING

Global Policies & Practices

Electricity Subsidies for Aluminum

It is impossible to talk about aluminum policies without addressing electricity subsidies. As the largest cost in primary aluminum production (40 percent), electricity is critical in determining the profitability of an aluminum smelter.[1] As such, aluminum production was long predicated on governments (including the United States at one point) providing energy support. The high cost of building and maintaining aluminum smelters has concentrated industry into a few dominant players. These companies have capitalized on their negotiation power to obtain low electricity rates in exchange for their investments in many markets.[2]

An Organization for Economic Co-operation and Development (OECD) investigation measuring distortions in the aluminum international value chain found energy subsidies for primary aluminum take many different forms. These include:

- Governments reimbursing smelter energy costs.
- Foregoing taxes on smelter energy use.
- State-owned utilities providing below-cost electricity to smelters.
- Instituting mandates to keep energy prices below-market for smelters.[3]

The Middle East and China are the most dominant primary-producing regions currently engaging in high amounts of energy subsidies. Gulf Cooperation Council (GCC) countries have the largest government ownership and intervention in energy markets; they account for 30 percent of price-driven subsidies in fossil fuels, according to the International Energy Agency (IEA), thus keeping the cost of energy use for smelting low.[4] The Chinese government "is heavily involved in the country's coal market" and can thereby provide companies prices lower than market-value for coal.[5] Recall, 80 percent of Chinese aluminum is currently coal-fire powered.[6]

Additionally, specific smelters in the United States, Canada, Australia, and China engage in direct energy subsidies. The best example here is Québec's published government decree for industrial power access. Smelters leverage special conditions to access electricity from the provincial-owned utility, Hydro-Québec. The OECD found, "the lower prices are generally awarded to aluminum producers are *quid pro quo* for additional investments in

1 OECD, *Measuring distortions in international markets: The aluminium value chain*, 2018.

2 The Australian Institute, *The Aluminum Smelting Industry: Structure, market power, subsidies, and greenhouse gas emissions*, 2002.

3 OECD, *Measuring distortions in international markets: The aluminium value chain*, 2018.

4 Ibid.

5 Ibid.

6 Wood MacKenzie, *Carbon neutrality goal forces Chinese aluminium smelters away from captive coal power*, 2021.

Subsidies & Illegal Subsidies

U.S. law defines subsidies as "financial contributions" by a government which provides a benefit. Subsidies can be direct transfer of funds (grant, loan, infusion of equity), potential transfer (loan guarantee), or a purchase of goods or services.

Subsidies are present in most countries, but they are only "actionable" under the World Trade Organization (WTO) Subsidies Agreement if they injure the domestic industry of another country or if it causes serious prejudice to the interests of another country.

In the case of Chinese aluminum, many countries have levied claims and official complaints that these subsidies are "illegal" and therefore "actionable." These countries, including the United States, assert Chinese aluminum subsidies significantly undercut the price of a similar product (in this case an identical product) in domestic markets and they increase the world market share of the subsidizing country for this specific commodity.

Source: International Trade Agency, 2023

Some Icelandic smelters peg their electricity cost to the price of aluminum through a negotiated deal with the utility stabilizing the volatility of aluminum's largest cost driver.

Québec."[7] That said, the other countries mentioned have provided similar deals to secure economic development guarantees. The extent of these policies is somewhat opaque, with veiled reporting in certain countries and the utilization of "captive power" in some cases.[8]

Subsidies are not necessarily a best practice policy for aluminum smelters, but the OECD report findings prove energy subsidies—whether legal or illegal—are ever-present in competitive aluminum production. The United States has a largely deregulated electricity market, making federal subsidy options less likely for the federal government. However, pressure is mounting for the federal government to recognize U.S. industry's disadvantage. For example, when a private equity firm's attempt to resurrect the Washington State Intalco smelter came to a halt in late 2022, electricity costs were explicitly blamed. Joshua Gotbaum, an adviser to the private equity firm, Blue Wolf, 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."[9] The conclusive takeaway from these subsidies is the prolific relationship between primary aluminum competitiveness and energy cost.

Smelter-Utility Collaboration

Policies enabling cooperation between smelters and utilities further emphasize the important energy-primary aluminum economic link. Some Icelandic smelters peg their electricity cost to the price of aluminum, through a negotiated deal with the utility. In the midst of production challenges, Australia has been exploring ways to make smelters more flexible users of their energy consumption to save the industry while transitioning their economy away from fossil fuels.

Pegging Prices

Norðurál, which is owned by U.S.-based Century Aluminum and operates four Icelandic smelters, recently lifted the confidentiality of its energy contracts. The contracts revealed the long terms negotiated (18 years minimum, 25 years maximum), ensuring stability of electricity pricing. Three of these contracts also pegged their electricity rates to the global market prices of aluminum.[10] Pegging stabilizes the volatility of aluminum's largest cost driver, which can range drastically. To give an example of energy price instability, from 2007 to 2015, electricity's proportion of the net aluminum value in the Pacific Northwest ranged from 8 percent to as high as 80 percent (Figure 2).[11]

While price pegging kept Norðurál's smelters safe from energy market uncertainty, there are some

7 OECD, *Measuring distortions in international markets: The aluminium value chain*, 2018.

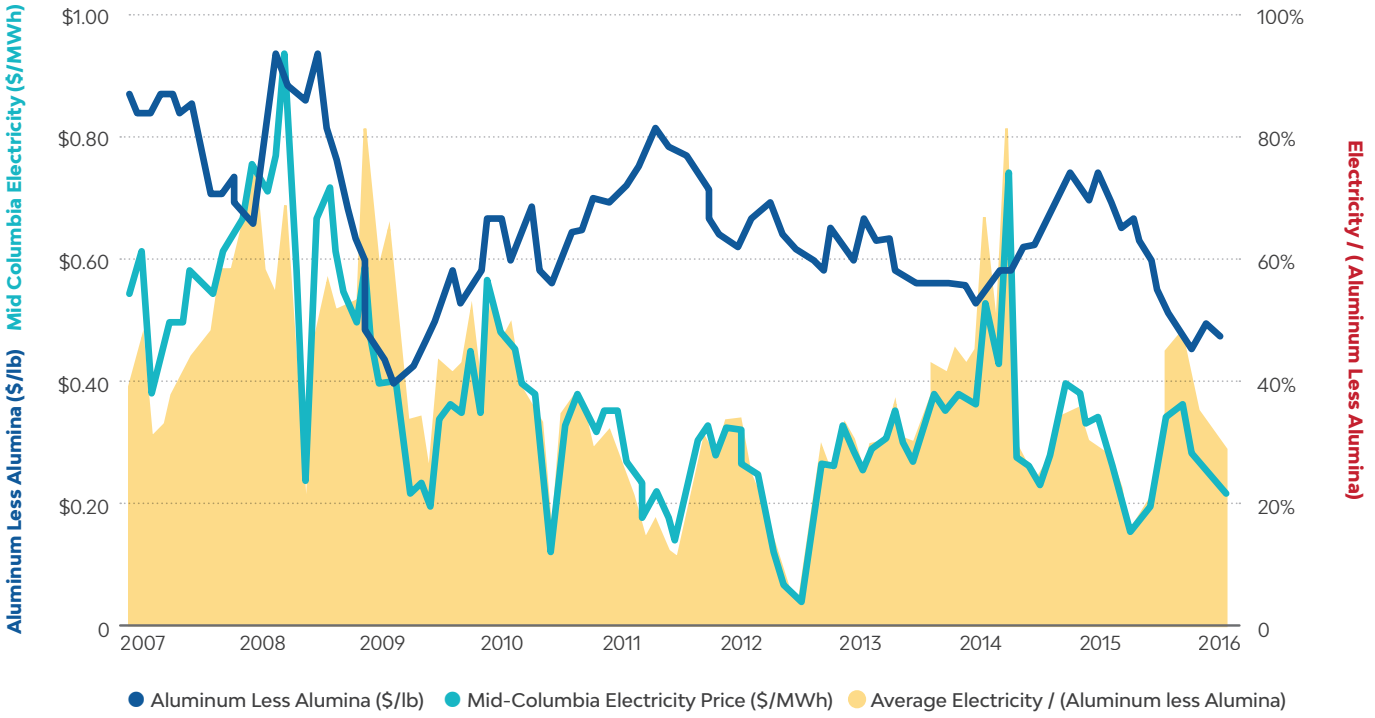
8 Ibid.

9 Steve Mufson, "Biden wants 'green' economy, but talks fail to revive key aluminum plant," The Washington Post, 2022.

10 Norðurál, *Norðurál's Energy Purchases*, 2020.

11 Energy GPS LLC, *Response to Request for Comment: Section 232 National Security Investigation of Imports of Aluminum, 82 Fed. Reg. 21509 (May 9, 2017) & 82 Fed. Reg. 25597 (June 2, 2017) paper summarizing the historic rise and dramatic decline of the Pacific Northwest aluminum industry*, 2017.

Figure 2 Electricity Prices Versus Net Aluminum Prices (Aluminum Less Alumina)



Source: Energy GPS LLC, 2017

Price Pegging

Pegging is defined as "making transactions in a security, currency, or commodity in order to stabilize or target its value." It is most commonly used with currency exchange rates. To avoid volatility, one country will peg their currency to another country's more stable currency. The U.S. dollar is commonly pegged in this sense.

In regards to aluminum, the electricity price is being pegged to the aluminum price. Both of these prices vary in stability. However, if they move together, the net gains for the smelter will be more consistent. Utilities also stand to win when aluminum prices are higher under this scenario. Price pegging also prevents the worst case scenario of aluminum price dipping far below electricity prices, making it impossible for smelters to churn a profit.

Sources: Investopedia, NASDAQ, 2023

limitations to this policy's application in the United States. These smelters forgo potential profitability gains when global aluminum prices are high and energy prices remain low. It is likely for this reason Norðurál opted to abandon price pegging when renewing their 1997 contract for their fourth aluminum smelter in 2016.[12]

Further, U.S. electricity contracts for smelters are shorter term, at least in recent years. For example, Century Aluminum's Mt. Holly smelter's power supply contract with Santee Cooper only runs from April 2021 to the end of 2023.[13] Century's shorter contract in South Carolina versus their Nordic projects use of price pegging in Iceland highlights how companies cannot always seamlessly employ the same strategies in different markets.

One U.S. smelter stands out though. Alcoa's Massena smelter, which celebrated its 120th anniversary last year, negotiated a low-cost energy contract tying the price of power to future changes in the price of aluminum (see Table 1).[14] The original power purchase agreement was finalized in 2015, but was renewed again until 2026. Throughout the last

12 Norðurál, *Norðurál's Energy Purchases*, 2020.

13 Century Aluminum, *Century Aluminum Finalizes Mt. Holly Power Contract; Restart Project on Schedule*, 2021

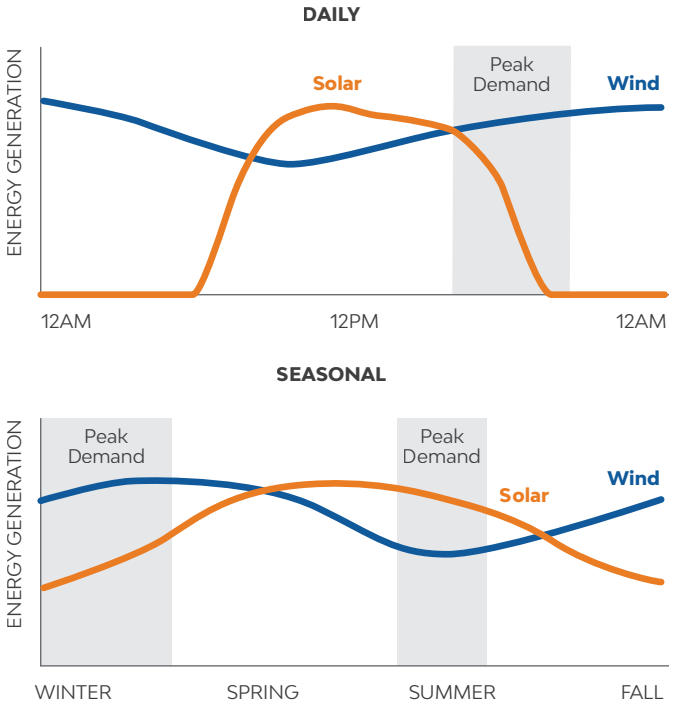
14 Power Authority of the State of New York, *Agreement For The Sale of Firm Hydroelectric Power And Energy From The St. Lawrence-Fdr Power Project To Alcoa Usa Corp*, 2016.

Table 1 Base Rates Schedule

Aluminum Price ($/metric ton)	Base Rate ($/MWh)
Below 1,500	12.25
1,500 - 1,799	12.25
1,800 - 1,899	14.00
1 ,900 - 1,999	15.75
2,000 - 2,099	17.50
2,100 - 2,199	19.25
2,200 - 2,299	21.00
2,300 - 2,399	22.75
2,400 - 2,499	24.50
2,500 - 2,599	26.25
2,600 - 2,699	28.00
2,700 - 2,799	29.75
2,800 - 2,899	31.50
2,900 - 2,999	33.25
3,000 - 3,099	35.00
3,100 - 3,199	36.75
3,200 - 3,299	38.50
3,300 - 3,399	40.25
3,400 and above	42.00

Source: Alcoa Power Contract, 2019

Figure 3 U.S. Renewable Generation Patterns



Source: Congressional Research Service, 2019

several years of aluminum curtailments and closures, Massena has been resilient due to this pricing scheme. However, when the original deal was announced, the company and the state received backlash. The deal, which was unanimously backed by authority members, gives Alcoa the cheapest energy out of any commercial customer in the state.

Alcoa's Massena smelter embodies the tradeoffs of the price pegging policy approach. Meanwhile, Century's market-based application of price-pegging emphasizes the importance of local politics and energy sources in negotiating power purchase agreements. [15]

Aluminum Smelters as a Demand-Side Response Mechanism

Another creative policy being considered in Australia and Europe is re-envisioning how aluminum smelters can partake in a distributed renewable energy system. As more renewable sources are integrated into the grid, variability of energy generation will increase; the grid will see higher amounts of supply when the sun is shining, and the wind is blowing (see Figure 3). To provide balance to a grid with higher renewable penetration, demand-side response is needed.

The Institute for Energy Economics and Financial Analysis (IEEFA) in Australia proposes downtrodden aluminum smelters "seize this technology opportunity and re-orientate their businesses towards more flexible energy consumption."[16] IEEFA enumerates the advantages smelters, utilities, and consumers can reap:

- Smelters profit from reduced electricity and operation costs, the latter from payment for providing demand-side response services to the Australian Energy Market Commission (AEMC);
- Aluminum producers prevent forced curtailment of their smelters, which AEMO has the authority to do, when energy generation is insufficient to meet demand;
- Smelters, utilities, and consumers benefit from grid decarbonization and lower-emission primary aluminum, which is becoming increasingly competitive; and
- Consumers gain security of electricity supply with smelter's releasing energy back into the grid in moments of net energy shortfall, which is invaluable "during seasonal electricity supply shortages and increasingly extreme weather events." [17]

15 Brian Nearing, "State power authority gives Alcoa cheapest electrical rate, fears other businesses will seek same deal," The Times Union, 2015.

16 Institute for Energy Economics and Financial Analysis, *IIEFA update: Australia's aluminium smelters need a technology retrofit to offer demand response capacity*, 2020.

17 Ibid.

With an elevated motivation following the Russia-Ukraine spurred energy crisis, EU company TRIMET is promoting the flexibility its aluminum company can provide the grid. In Europe there used to be region-wide regulations that enabled demand-response. From 2014 to mid-2022, European "transmission system operators used this load flexibility 452 times."[18] While regulation expired in 2022, Italy and France both maintain similar national laws. TRIMET has adapted their electrolysis process to be better stabilize the power grid.[19] The company's overt advocacy for regulation of industrial loads suggests smelter profitability gains from playing an active role in balancing variable solar PV and wind energies.

Still, there are hurdles to implementing the demand response practice abroad and at home. The "reorientation" of the aluminum smelter model is not so easy, as evidenced by TRIMET's special electrolysis process. In the current smelting sequence, power interruptions can affect the operation of aluminum cells in smelting.[20] Some smelters have to adapt to consistent challenges with grid capacity, but special routines and response plans must be in place to deal with those shortages.[21] This policy concept does show great promise to concurrently resolve two major challenges to the clean energy transition (aluminum's energy intensity and the inconsistency of renewable sources). Engagement in the clean energy transition gives older, and thereby less energy efficient, aluminum smelters the social license to operate.

Carbon Taxes, Fees, and Programs Motivating Innovation

To incorporate the externality of carbon emissions into economic systems, several countries have introduced carbon pricing and border adjustment mechanisms. Canada has a mosaic of carbon pricing schemes led out of the provinces. The European Union (EU) has a domestic carbon price and recently introduced a carbon border adjustment program. China has hyper targeted aluminum decarbonization in a 2021 action plan, though commitments to that plan have been more mixed. These countries not only include major aluminum producers, but also their regulations, which collectively may shift markets. Most importantly, these regulations are spurring private sector innovation as primary producers work to avoid carbon fees.

EU Carbon Border Adjustment

Introduced in 2021, the EU's carbon border adjustment mechanism (CBAM) would impose a tax on imported goods depending on the carbon intensity of their production relative to production in the EU. Due in part to the prospect of a pending European carbon tax, Russian aluminum giant Rusal (the largest non-Chinese aluminum producer) announced plans to split off its higher carbon assets into a separate company and focus on lower-carbon aluminum for European export.[22] Still, if the tax simply causes exporters to "resource shuffle" and sell higher-carbon aluminum in less regulated markets, its net carbon impacts may be minimal.[23]

While not a major exporter of primary aluminum, the EU has a demonstrated ability to "export" its regulations abroad—a phenomenon known as the Brussels Effect.[24] Within weeks of the EU CBAM proposal, Senate Democrats proposed a similar plan to impose a border tax on imports from countries with insufficiently ambitious climate plans.[25] However, the likelihood of any carbon pricing legislation passing both chambers of Congress is very low.

Canadian Carbon Pricing

In 2016, the Pan-Canadian Framework on Clean Growth and Climate Change (PCF) debuted Canada's federal-provincial-territorial climate change mitigation plan.[26] Under the PCF, Canada's 10 provinces and three territories have the autonomy to implement their own carbon pricing systems, provided they meet the federal benchmark—presently CAD 40 and ramping up to CAD 170 by 2030.[27]

Almost a decade before the federal legislation, Canada's largest aluminum producer, Québec, was at the provincial vanguard of enacting its own unique carbon mitigation policies. The National Assembly enacted a carbon levy that later evolved into its current cap and trade (C&T) system.[28] Not to be

18 TRIMET, *Industrial load flexibility | General statement on the energy market situation*, 2023.

19 TRIMET, *Conserving Resources, Easing the Pressure On Climate, Protecting the Landscape And Environment*, 2023.

20 Aluminum International Today Buyers' Directory, *Power failure, re-start, and repair*, 2011.

21 Ibid.

22 Dylan Griffiths and Yuliya Fedorinova, "Russian Metals Giant Plans Split to Focus on Green Aluminum," Bloomberg, 2021.

23 Ibid; Neil Hume, "EU aluminium groups seek exclusion from carbon border tax," Financial Times, 2021.

24 Aoife White, "How the 'Brussels Effect' helps the EU rule the world," Bloomberg, 2020.

25 Life Friedman, "Democrats Propose a Border Tax Based on Countries' Greenhouse Gas Emissions," New York Times, 2021.

26 Government of Canada, "Carbon Pollution Pricing Systems across Canada," 2021.

27 Maxime Joselow, "National Carbon Tax Upheld by Canada's Supreme Court," E&E News, Scientific America, 2021.

28 See Note 107.

Figure 4 Percent CO_2 aluminum emissions

67% China

33% Rest of World

Source: Global Efficiency Intelligence, 2021

outdone, Canada's other aluminum producer, British Columbia, implemented an economy-wide carbon tax in 2008.

As the fourth largest, but also the third lowest emitting primary producer, Canada's carbon pricing policies have a more targeted impact on its smelters.[29] With the lion's share of electricity sourced from hydropower, the approximately 2 tons of CO_2 emitted per ton of aluminum smelter emissions are linked to Scope 1 emissions from electrolysis. With hydropower fueling the rest of the economy, aluminum emissions are in the carbon spotlight for these two provinces. Industry thus faces pressure to incorporate decarbonization technology in the smelting process to avoid carbon fees.

Canada is also exploring the option to implement a carbon border adjustment.[30] Given how integrated the United States and Canadian aluminum supply chains are, a potential Canadian CBAM aluminum would most likely have a substantial impact on U.S. exporters of aluminum and aluminum products. While uncertainties regarding the legality[31] and administrative feasibility[32] of a carbon import tax remain, the European effort is likely to be instructive towards future policy measures around the globe.

China Aluminum Decarbonization Plan

While China has been toying with a carbon tax, the government's 2021 carbon reduction action plan lays a specific plan to eliminate emissions from its aluminum sector. After taking five years to formulate benchmarks and efficiency references for the aluminum sector, the government will institute support measures to enable decarbonization. China's aluminum plan aligns with their commitment to achieve carbon neutrality by 2060.[33] Expected measures include:

- Support to upgrade production techniques to increase energy efficiency and decrease emissions.
- Phase out of inefficient and backward production capacity.
- Government assistance to develop emissions-reductions technologies.
- Migration of smelters to regions with more abundant sources of hydroelectricity.
- Implementation of a "multi-step electricity price mechanism for aluminum."[34]

With aluminum demand expected to grow significantly in the coming decades, constrained Chinese primary production supply would have major implications for the global aluminum industry. Nonetheless, it is unclear whether China will prioritize emission reductions in its "policy trilemma"—the balancing of decarbonization with strong

29 Natural Resources Canada, "Aluminum Facts," 2022. and Global Efficiency Intelligence, "Aluminum Climate Impact - An International Benchmarking of Energy and CO_2 Intensities" 2021.

30 Government of Canada, "Exploring Carbon Border Adjustments for Canada," 2021.

31 Muyu Xi and David Stanway, "China says EU's planned carbon border tax violates trade principles," Reuters, 2021.

32 Keybridge interview with industrial emissions policy expert.

33 Argus Media, "China sets carbon reduction plans for steel, aluminum," 2021.

34 Ibid.

economicgrowth and stable commodity prices.[35] The migration of smelters to hydroelectric-powered regions suggests the Chinese aluminum industry is taking some of its emissions targets seriously, but developments in other industrial sectors raise questions. For example, China recently announced new coal and steel projects that are projected to emit 150 million metric tons of CO_2 per year (equivalent to the state of Indiana's annual emissions).[36]

If successful, the gains would be monumental. China's aluminum sector represents 67 percent of energy-related CO_2 emissions from primary production. A carbon-neutral Chinese aluminum market could decrease total global GHG emissions by over 1 percent.[37]

Zooming in on aluminum emissions makes sense for China, with 57 percent of global aluminum production occurring in its provinces.[38] Moreover, the implementation in CBAM in Europe and elsewhere and increasing carbon pricing trends could create additional export challenges for China if their smelters do not decarbonize. While it may be harder to have such a narrow focus in the U.S., there are merits to this approach in terms of alleviating supply-side shortcomings.

35 ING, "What does the China 'trilemma' mean for metals?," 2021.

36 Lauri Myllyvirta, "China's power & steel firms continue to invest in coal even as emissions surge cools down," Centre for Research on Energy and Clean Air, 2021. and EIA, "Energy-Related CO_2 Emission Data Tables," 2020.

37 Ali Hasanbeigi, et al., Aluminum Climate Impact - An International Benchmarking of Energy and CO_2 Intensities, Global Efficiency Intelligence (2021).

38 Natural Resources Canada, "Aluminum Facts," 2022.

Anodes in Aluminum Smelting

When alumina goes through the smelting process, electricity runs through the mixture of alumina and an anode. Historically, these anodes have 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. 1.5 tons CO_2 per ton of aluminum on average are emitted from electrolysis.

Companies are developing new forms of anodes or deploying specific types of carbon capture technologies to eliminate these emissions.

Source: C-SIM, 2023

Link to the Inert Anode and Capture Innovations

Whether it is their own industry or their trading partners', countries implementing carbon policies are motivating companies to innovate themselves out of their Scope 1 aluminum emissions quandary. The electrolysis process generates 13 percent of primary production emissions on average.[39] If refiners and smelters can access renewable power to fuel the smelters, electrolysis becomes the predominant carbon contributor in the primary process. Producers and governments are thereby investing in R&D to commercialize inert anodes to eliminate the carbon anode and its resulting aluminum emissions.[40]

Canada's ELYSIS and Russia's Rusal are in advance stages of pilot projects for deployment of inert anode technology. Alcoa and Rio Tinto—through the ELYSIS partnership—are testing a pilot for inert anode application at a Québec smelter. Rusal shared it successfully used its inert anode technology to produce high-grade aluminum with an emissions profile of less than 0.01 tons of CO_2 per ton of aluminum.[41]

TRIMET the aluminum company with smelters in Germany and France is also actively pursuing inert technologies. Through a partnership with an Icelandic aluminum company and University of Saarland (USAAR), TRIMET is developing what they call a "breakthrough aluminum process." Using multiple vertical inert anodes and cathodes, produced in a low-temperature electrolyte, they are able to emit oxygen instead of CO_2 in smelting. While they are still pre-pilot stage, the companies remain committed to rolling out this technology across their European smelters. [42]

Investment in inert anode technologies is in part a response to incorporating the carbon externality into primary aluminum's cost of production in both the markets companies operate smelters (Canada and Europe) and sell their aluminum (Europe). If this final decarbonization frontier is reached in piloting inert anode technologies, inert anodes are expected to become the industry standard for new smelters after

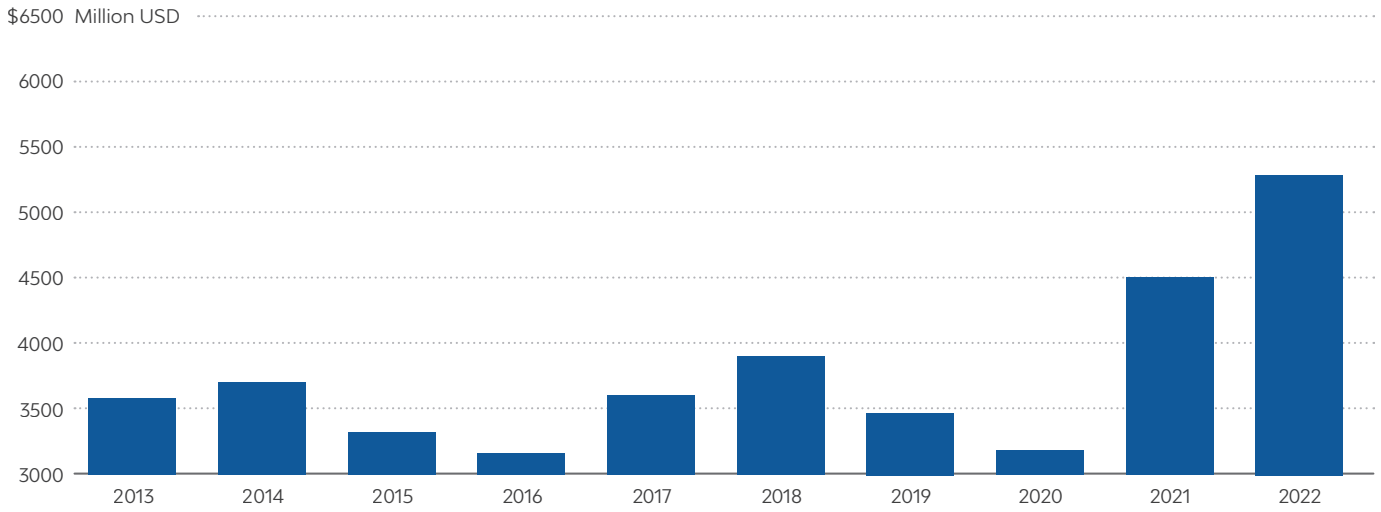
39 Bloomberg New Energy Foundation, *Decarbonizing Aluminum: Technologies and Costs*, 2021.

40 Anthony Everiss, "Emission control accelerates pace of inert anode development," CRU Group, 2021.

41 Anthony Everiss, "Emission control accelerates pace of inert anode development," CRU Group, 2021.

42 TRIMET, "CO_2-Free Aluminum Production," 2023.

Figure 5 EU Imports of Aluminum from Norway (USD)



Source: Trading Economics, 2023

2030, with the potential to retrofit existing smelters as well.[43]

One company, motivated by European carbon fees and border adjustments, is taking a different approach to decrease direct smelter emissions. The Norwegian company, Hydro, actively moved away from its Søderberg process, which uses anodes made from a mixture of coke and pitch to replace the traditional prebaked anodes and is far more damaging to the environment in terms of emissions. Since then, they have been committed to incorporating carbon capture technologies in their smelting process. After testing over 50 different CO_2 capture technologies, Hydro announced in January 2023 that they would invest $20 million in an MIT spin-off company called Verdox. Together, they will work to commercialize an "all-electric carbon removal technology applicable both for capturing emissions from aluminum production and directly from air."[44] Hydro's commitment here should not be surprising, given the increases in EU imports of Norwegian aluminum over the last decade, peaking at $5.09 billion in primary imports in 2022 (see Figure 5).[45]

The United States is taking the carrot approach to Europe, Canada, and China's carbon tax and R&D investment combo. The *Inflation Reduction Act* and *Infrastructure Investment and Jobs Act* provide grant opportunities and incentives for heavy industry and the manufacturing sector to decarbonize. However, aluminum producers face fierce competition here form other energy-intenstive industries, while still enduring energy cost challenges.

43 Bloomberg New Energy Foundation, *Decarbonizing Aluminum: Technologies and Costs*, 2021.

44 Hydro, "Hydro invests in carbon capture company Verdox to eliminate emissions from aluminium production," 2022.

45 Trading Economics, "European Union Imports of Aluminum from Norway," 2023.

Conclusion

Aluminum-producing countries are facing the same primary producing challenges as the United States, with varying approaches. China is enabling its overproduction with subsidies, and other countries are even following suit—on a smaller scale—to uphold their respective industries and ensure they have sufficient aluminum for downstream applications. Companies and producing countries are taking creative approaches to the energy cost problem—with price pegging and demand-side response. Finally, to deal with the emissions problem, carbon pricing schemes are not only popular but also are driving innovation, with government support. Across these policies and practices a common thread emerges: aluminum is seen as vital and worth preserving.

Of the policies explored, some can be more easily applied in the United States than others. Price pegging and demand response present the easiest application. Price pegging is already being utilized by the most resilient U.S. aluminum smelter, Massena. Though somewhat controversial, price pegging ensures utilities share in the profits with the smelters, while shielding smelters from cost volatilities. Compared to direct and indirect subsidies, price pegging is therefore more palatable in the United States, where a free market is preferred.

Demand response mechanisms, similar to the regulations previously used across Europe and the strategies being considered in Australia, present another win-win for utilities. Adapting aluminum production with power control standards during peak demand can drive the transformation to power supply from renewable sources. Demand response practices and regulations thereby benefit the environment and consumers as well, which is an important priority for the energy-justice-focused Biden administration. Secondarily, playing an active role in enabling the energy transition can give older and more energy inefficient U.S. smelters a greener license to operate.

Other policies, like carbon pricing and energy subsidies are a bit more challenging in application in the United States. Chinese electricity and direct subsidies are the reason why it is been able to grow its aluminum sector over 150% over the last decade. Electricity subsidies and energy access elsewhere show why U.S. primary output has declined over 65 percent since 2005, while other countries have remained relatively stable.[46] While China is an extreme case, countries using subsidies understand the high stakes of preserving domestic production of this critical material. The United States should take note of their interventions. Though, price pegging and demand response may decrease the need for overt government support.

Carbon pricing, which is linked to smelter decarbonization innovations, has faced an uphill battle in the United States for a decade. Aluminum smelters in countries with carbon pricing schemes or affected by them (i.e. Russia with CBAM) are being pushed to innovate. Government R&D support has also played a large role in technological development. Europe, Canada, and Russia will soon benefit from operational efficiencies and lower emissions from inert anode and tailored carbon capture technologies in their smelting process.

As it currently stands, it is unlikely the United States will pass a carbon price due to its political unpopularity. Political paralysis around carbon pricing is not unique to the United States. Carbon pricing has been blamed abroad for harming industry in political fights. For example, former Australian Prime Minister, Tony Abbott, pointed his finger at Australia's carbon price as the reason why Alcoa closed its Point Henry smelter.[47]

46 U.S. Geological Survey, "Minerals Commodities Summary Aluminum," 2010.

47 ABC News, "Tony Abbott not telling the full story on Alcoa and the carbon tax," 2014.

Table 1 Global Aluminum Insights Comparison

Aluminum Policy or Practice	China	Europe	Australia	Canada
Aluminum-specific decarbonization strategy, including R&D support	Yes	–	–	–
Carbon Border Adjustment	–	Yes	–	–
Carbon capture for electrolysis	–	Pilot	–	–
Carbon price	Considering	Yes	Repealed	Yes
Demand response mechanism	–	–	Experimenting	–
Direct subsidies to smelters (loans)	Yes	–	–	–
Indirect energy and electricity subsidies	Yes	–	–	Yes
Inert anode	–	Pilot	–	Pilot
Price pegging	–	Pivoting Away	–	–
Regulating industrial energy loads[1]	–	Yes	–	–
R&D support in decarbonization	–	–	–	Yes

Notes: 1. Europe's ordinance expired, but Italy and France maintain their national regulations
Source: SAFE Analysis

Alcoa not only openly denied any link between the tax and their closure decision, but also claimed they have benefited financially from the carbon price.[48] The effect was damaging enough and the carbon tax was ultimately repealed. Given U.S. aluminum smelters are struggling to stay afloat through the current period of high energy prices, U.S. immobility on carbon pricing may be critical to their continued viability.

Carbon pricing is not the only way to push decarbonization innovation. The United States is rolling out its own policies to abate industrial emissions, as well as developing a Global Arrangement on Sustainable Steel and Aluminum (GASSA) with the EU. C-SIM's report, "Legislative Analysis for the U.S. Aluminum Industry," examines the incentives and programs in the *Inflation Reduction Act* and *Infrastructure Investment and Jobs Act* and *CHIPS Act* aimed at driving decarbonization for industrial materials, like aluminum. Another C-SIM report, "Political Tailwinds: Examining Trade Policy for the U.S. Aluminum Industry," explores how through building common carbon trade barriers for dirtier aluminum the United States and Europe can ensure technology transfer and application of low-emissions innovations.

The United States is entering the phase in its clean energy transition that requires a stable and reliable supply of aluminum. While the United States is not conducive to all foreign policies and practices, their application abroad help explain the market dynamics U.S. smelters are up against. Aluminum is an integral component of clean technologies, alongside other longer-standing defense and economic sectors. These global policies prove other countries understand aluminum's economic importance. Abroad, primary aluminum is not getting left behind in their green transition. Thanks to price-pegging, demand-side response mechanisms, and direct R&D investments, the primary sector in many aluminum producing-countries is solidified in these new economies.

48 Ibid.

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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.

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