Decarbonizing Aluminum

Rolling Out a More Sustainable Sector

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Introduction

As the effects of climate change intensify, countries and industries alike are seeking new ways to decarbonize to meet emissions targets, avoid carbon border tariffs, and reduce energy costs. Today, energy use in industry is the number one contributor to global greenhouse gas (GHG) emissions. Therefore, decarbonization of heavy industry would have a direct and immediate impact on reducing GHG emissions and slowing climate change. Aluminum is the second most used metal in the world. Its applications are numerous and fundamental, from electrical transmission to defense and construction. Aluminum is also a key input in other goods that help reduce emissions, such as electric vehicles and energy-efficient buildings, meaning that decarbonizing aluminum can help industries that are playing a critical role in global climate efforts. This paper evaluates global progress on sectoral emissions reductions and assesses policies governments can pursue to accelerate decarbonization of the aluminum sector.

The aluminum industry consists of three component segments: upstream aluminum, downstream aluminum, and recycled aluminum. The upstream aluminum sector is responsible for the sourcing of raw material components from mined bauxite that is then refined into alumina and smelted into aluminum. Aluminum production is usually accomplished in two phases. In the first stage, bauxite ore is refined to obtain aluminum oxide through the Bayer process. The Hall-Heroult process of smelting the aluminum oxide to release pure aluminum comprises the second stage. Upstream production of aluminum involves the mining of bauxite and refining it into alumina. The downstream segment refers to the production of semi-fabricated aluminum products and their use in a wide range of sectors, from manufacturing and automobiles to construction and consumer products. Aluminum not only offers durability, but also is infinitely recyclable, meaning it has clear environmental benefits compared to other similar inputs, such as steel or plastic.

While aluminum does offer some environmental benefits, producing it is carbon intensive. Aluminum production processes have changed very little since the 1800s, and many countries continue to rely
on coal to produce the electricity required for aluminum production. Globally, the aluminum sector contributes roughly 2 percent of GHG emissions—equivalent to about 1.1 billion tons of carbon dioxide (CO₂). Yet demand for aluminum is expected to increase by 50 to 80 percent by 2050. In 2019, the aluminum industry consumed 6 percent of all global coal-fired electricity, exceeding the total amount of coal-fired electricity generated in Europe. That same year, coal-fired electricity used in aluminum electrolysis produced 636 million tons of CO₂ emissions, or 58 percent of the sector’s carbon footprint. On average, 72 percent of GHG emissions from primary production of aluminum are from electricity, meaning greater use of renewable energy in aluminum production could significantly decrease the sector’s carbon output. According to the Intergovernmental Panel on Climate Change (IPCC), global CO₂ emissions need to decrease by 45 percent by 2030 in order to keep global warming below the 1.5 degree threshold. By accelerating the deployment of renewables and designing policies that encourage and support the decarbonization of heavy industry, the private and public sectors can play key roles in helping to reduce carbon emissions, while also continuing to grow the global economy.

The industry faces a daunting challenge of cutting GHG emissions by 77 percent by 2050, representing a reduction of CO₂ emissions from 1.1 billion tons to 250 million tons, while simultaneously expanding capacity to meet demand. Within the industry, production processes and emissions footprints differ by country. China is home to the world’s most heavily polluting aluminum industry because it relies on coal-powered electricity. China is also the world’s largest aluminum producer, accounting for over 55 percent of global aluminum production and demand. Decarbonizing China’s aluminum sector could have far-ranging consequences for global emissions targets. The world’s most sustainable aluminum industry, on the other hand, is in Canada. 90 percent of Canadian aluminum is produced in Quebec, where it is considered the most sustainable in the world since it is produced almost entirely with hydroelectric power. Several of the sector’s leading companies, such as Alcoa and Rio Tinto, have proposed joint ventures in Quebec, where they seek to develop the world’s first carbon-free aluminum smelting facility. The U.S. aluminum industry, meanwhile, has made significant strides in reducing its carbon footprint. Thanks to increased aluminum recycling and decarbonization technology, the carbon intensity of aluminum production has decreased 43 percent since 1991, but producers in the United States and elsewhere must further advance sustainability efforts to meet current climate obligations.

While government intervention has primarily focused on trade remedies and environmental standards, the aluminum sector itself has led efforts to decarbonize, particularly via new technology in upstream and downstream production to create sustainable aluminum. Broadly, sustainable aluminum is aluminum that (1) is produced with a high percentage of renewable power, (2) leverages new technologies to streamline processing, (3) minimizes and eliminates waste and, (4) maximizes product end-of-life cycles through recycling. These elements together comprise what can be described as “sustainable” aluminum. In addition to sustainable aluminum itself, aluminum offers a lightweight and durable alternative to other inputs, such as steel and plastic, which can be heavier and more carbon-intensive to produce, meaning that aluminum has far-ranging sustainability benefits throughout the value chain. In addition to building resilient and renewable power grids, governments have several other policy tools at their disposal, from supporting the free trade of renewable electricity to ensuring resilient recycling supply chains. This paper assesses progress on emissions reductions within the aluminum sector and evaluates policies governments can pursue to accelerate decarbonization of the sector.

**Obstacles**

Many aluminum firms around the world have made significant progress in decarbonizing their manufacturing processes, but there remain significant obstacles on the path to a net-zero future. The
most pressing problems relate to electrical grids. The U.S. grid relies on dated technology that is often unable to handle a heavy load of electricity, which is often derived from non-renewable sources. In 2020, **19.8 percent** of electricity generation in the United States was renewable, meaning the grid needs to add more renewable sources to help companies meet their decarbonization targets. However, the location of renewable energy production, such as offshore wind farms or major solar fields, is often distant from production facilities, meaning that electricity must travel far to reach the end user. In the United States, 5 percent of electricity is lost in transmission. Also, unlike coal or oil, renewable electricity cannot be trucked to a location where it is then converted into energy.

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Transmission capacity is thus central to making the grid more renewable since power lines can only carry so much electricity at one time. Congestion throughout the electrical grid can also lead to “curtailment,” in which wind and solar do not operate because the grid cannot absorb more electricity. This lack of capacity has led to other issues. In Vermont, grid bottlenecks resulted in the reduction of power from wind generators because the grid could not absorb additional electricity. This bottleneck led to a two-year moratorium on new wind and solar projects, ultimately devaluing locally produced renewable energy.

Upgrading transmission lines and building new ones are both costly and time-intensive, which can slow the development of new renewable energy projects. For example, an investor funding the development of a solar field would need assurances that the solar field would connect to the grid, meaning the existence of transmission lines is often a first step that precedes the development of additional renewable energy projects. This creates a renewable energy chicken-and-egg dynamic.

One way of mitigating these problems is to build ultra-high voltage (UHV) lines. Only two countries currently have functional UHVs: China and Brazil. China has 30 functional UHV lines versus 2 in Brazil, where the Chinese built both. Domestically, China is currently pursuing a **$300 billion** project over 30 years to modernize and update its grid, arguably putting it at the forefront of government initiatives to modernize grids.

In the United States, the Biden administration’s agenda seeks to upgrade the U.S. electrical grid through both the Bipartisan Infrastructure Framework (BIF) and the Build Back Better Act (BBBA). The BIF, which was signed into law in November 2021, allocates **$65 billion** for grid resiliency and upgrades, although only $2.5 billion is budgeted for new transmission lines, arguably far too little to deliver a major grid overhaul. Also in November, the House of Representatives passed the BBBA, which allocates $555 billion to fight climate change. Nestled in the BBBA is $2.9 billion to upgrade the electrical grid to make it more renewable. However, progress on passing BBBA has stalled, and its fate is uncertain.

Another problem compounding the sustainability limitations of the existing electrical grid is that the United States does not have a national grid. Instead, grids are divided by jurisdiction. In most cases, these
result in regional groupings. However, Florida has its own grid, as does Texas, where the grid infamously faltered amid a deep freeze in 2021. One of the few issues nearly all climate professionals agree on is that larger grids are ideal. The distribution of energy across a wider geographic area allows for improved efficiency, reduced power pricing, and the accelerated integration of renewable energy. To meet climate goals and decarbonize heavy industry, the United States should pursue a more integrated grid that both improves efficiency and incentivizes new renewable energy projects.

The most urgent hurdles for the aluminum industry to overcome in its path to decarbonization relate to the electric grid. However, other targeted policies can also accelerate the decarbonization of the aluminum sector. For example, policies such as new recycling incentives, anti-plastic regulations, and reliable trade policies from the government can help encourage deeper decarbonization without sacrificing the health of the domestic industry.

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Government Policy to Encourage Aluminum Sustainability

RENEWABLE ELECTRICITY
Governments have several policy options to encourage and support sustainability in heavy industry sectors. They can invest in renewable grids, ensure the free flow of cross-border electricity, encourage recycling, and provide tax incentives to firms that decarbonize. The cost of aluminum decarbonization is related primarily to the cost of transitioning the electricity used to produce it. The estimated cost of decarbonizing the aluminum sector ranges from $500 billion to $1.5 trillion. The most cost-effective way to produce sustainable aluminum, which is now price competitive with traditional, fossil-fuel-based aluminum, is by sourcing electricity from renewable energy sources, such as hydro, solar, and wind power. Hydropower is considered the best option for decarbonizing aluminum because of its storage capacity. Hydropower is derived from two reservoirs at different elevations that transfer water back and forth through a turbine, thereby generating electricity. Although hydropower facilities in certain regions are susceptible to variable rainfall, hydropower in general is more reliable than wind and solar. Wind and solar power are more prone to weather and daylight changes and require battery storage on an industrial scale that has proven costly and difficult to build. Robust government investment in a reliable, renewable power grid—where companies could transition to more sustainable production processes—could significantly accelerate emissions reductions.

In 2020, U.S. production of primary aluminum totaled 1.0 million metric tons,¹ accounting for 1.5 percent of the world’s primary aluminum production. That same year, the value of primary aluminum amounted to $1.98 billion. Secondary aluminum production in the United States in 2020 equaled 3.2 million metric tons. Transportation applications, such as aluminum used in goods from bicycles and automobiles to aircraft, account for the majority of domestic consumption (40 percent), followed by packaging (21

¹. Primary aluminum is made from raw materials or ingots in an energy-intensive process. Secondary aluminum involves recycling scrap metal to form new products in what is typically a less energy-intensive process. For more information, see the U.S. Energy Information Administration.
percent), building (14 percent), electrical (8 percent), consumer durables (7 percent), machinery (7 percent) and other (3 percent). The United States is the world's ninth-largest producer of primary aluminum—aluminum produced directly from bauxite—accounting for roughly 1.7 percent of global supply. In the United States, the aluminum industry accounts for about $171.90 billion in total economic output, equivalent to roughly 0.79 percent of the GDP. Aluminum manufacturers and wholesalers directly employed 166,228 workers in 2020, while employment in aluminum manufacturing is roughly 56,900.

In the United States, proposed legislation could bolster efforts to reduce emissions within the aluminum sector. The House-passed version of the reconciliation bill allocates $555 billion to clean energy and climate investments and $320 billion to clean energy tax credits for utility scale and residential clean energy storage, transmission, vehicles, and manufacturing.

Additionally, the package allocates $110 billion in investments for clean energy technology, including funding for technological advancements for batteries, solar power, and other advanced materials. It also includes $4 billion in funding for “advanced industrial technology” that helps reduce industrial GHG emissions to achieve net-zero emissions at industrial facilities that produce materials such as steel, aluminum, cement, concrete, and glass.

Another way that governments can facilitate decarbonization of heavy industry is to ensure that renewable energy can be traded freely across borders. Canada is the United States’ largest partner for energy and electricity trade, with bilateral energy flows reaching $119 billion in 2019. The U.S. and Canadian electricity grids are connected at about three dozen locations across the border. In 2020, Canada exported 67.5 million megawatt hours (MWh) to the United States, equivalent to 1.7 percent of total U.S. electricity production and roughly 11 percent of total Canadian generation. In an interconnected electricity system, hydropower functions both as an energy storage mechanism and as a flexible power supply that can be ramped up or down quickly, which helps stabilize both supply and cost of electricity. In the United States, states like New York and Minnesota are increasingly using Canadian hydropower to help achieve clean energy goals.

A recent report from the U.S. International Trade Commission (ITC) compares the Minnesota-Manitoba example with Denmark’s ability to deploy large quantities of wind power via transmission connections to hydropower resources in Norway and Sweden. In North America, several new cross-border transmission lines have been proposed, most along existing rights-of-way. These are dependent upon ongoing demand from states. For example, the Champlain Hudson Power Express is a high-voltage direct current transmission line from the Canadian border to New York City and is expected to go into service in 2025. This transmission line will help New York meet its goal of 70 percent renewable energy by 2030 and will be equivalent to removing 44 percent of cars from New York City streets. The ability to trade renewable energy across borders is key to decarbonization, including in the aluminum sector.

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Cross-border transfers of electricity are enough to power 7 million households. Nearly 81 percent of Canadian electricity, compared with 39 percent of U.S. power, is derived from renewable sources, such as hydropower, wind, and other renewables. In 2020, 67 percent of Canadian electricity came from hydropower, while 60 percent of U.S. power came from fossil fuels, largely natural gas. The United States
and Canada have similar carbon neutrality goals for their electricity sectors. The United States aims for a carbon neutral power sector by 2035, while Canada aims for 90 percent renewable power by 2030. While President Biden has not directly mentioned importing renewable power, he stated in a direct reference to Canada that no source of clean power is “off the table.” That said, the most recent text of the U.S. House of Representative’s budget reconciliation bill would give a 10 percent credit under the Section 136101 Credit for Electricity Produced from Certain Renewable Resources for renewable energy products domestically produced in the United States.

**REDUCING DEMAND AND ENCOURAGING RECYCLING**

In addition to leveraging renewable electricity, another sustainability benefit of aluminum is that it can be infinitely recycled, meaning it can play a key sustainability role in downstream aluminum products, from cars to cans. Recycled aluminum saves 90 percent of energy during production when compared with virgin aluminum material. Over 75 percent of plastic ever produced has been discarded as waste, while almost 75 percent of aluminum ever produced is still in use today. The beverage can is one of the most ubiquitous uses of aluminum, and recycling has been built into its modern supply chain at a massive scale. Every minute in the United States, 105,784 aluminum cans are recycled, contributing to an industry average of 73 percent recycled content in a given aluminum beverage can. However, of the 3,890,000 tons of aluminum produced in 2018 in the United States, only 670,000 tons of it were recycled, meaning the vast majority of aluminum produced ended up in landfills. In the United States, the recycling rate for aluminum is 49.8 percent, versus 76.3 percent in Europe, meaning that additional incentives to recycle could help fill an important gap that would encourage reuse while reducing pressure to produce virgin aluminum.

Aluminum Metals Waste Management: 1960–2018

To decarbonize aluminum, it is also necessary to recycle available scrap metal. Though the viability of aluminum recycling varies based on how well it is sorted, roughly 30 percent of total aluminum demand could be met through recycled scrap, with the potential to increase to 39 percent by 2050, even as demand is projected to grow. A major constraint to increasing aluminum recycling is the finite amount of aluminum scrap that emerges from waste streams each year. In the United States, the largest source of recyclable aluminum continues to be municipal solid waste streams. Nevertheless, there are efforts to increase recycling processes to make better use of existing aluminum. For example, a project at the University of Michigan aims

![Aluminum Metals Waste Management: 1960–2018](image-url)
to provide insights on how to better design automobiles so that the ease of scrapping and recycling is taken into account during the initial design phase. These small but significant changes are increasing in importance as demand for lightweight aluminum increases alongside the deployment of electric vehicles.

Local, state, and national policies that foster increased participation in curbside and local recycling programs are an important strategy to achieve sustainability goals, especially since only 32 percent of Americans recycled in 2019. Europe has led the way in boosting curbside aluminum recycling, with plastic, metal, and drink carton (PMD) sorting schemes growing in adoption and efficiency. In the United States, Maine is the top state for recycling aluminum cans, with recycling rates of 72 percent. Maine’s success can be attributed to their strong container deposit laws, or “bottle bills,” which have the highest deposit rates among the 10 states and Guam that provide refunds for aluminum can recycling. Meanwhile, West Virginia had the lowest aluminum can recycling rate at 2 percent. Despite a 1989 law aimed at reducing landfill waste by 50 percent by 2010, West Virginia has not made any progress toward that goal.

Two bills currently under consideration in the U.S. Congress could help incentivize recycling in the aluminum industry. Creating a national deposit system, as proposed in the “Break Free From Plastic Pollution Act (BFFPFA)” (S. 984) and the CLEAN Future Act (H.R. 1512), would help expand on subnational success. While the BFFPFA builds off existing state efforts to limit plastic pollution, it proposes a new National Beverage Container Program that would mandate retailers charge a deposit for a beverage container at point of sale that could be refunded upon recycling. The CLEAN Future Act, a comprehensive decarbonization legislative package, includes a national deposit system in addition to new standards and programs to incentivize and regulate beverage containers and recycling. Public infrastructure investments in enhancing recycling facility efficiency can also help address the almost 25 percent of aluminum cans that are missorted and not recycled.

Another step in encouraging greater sustainability in the aluminum industry is to deploy better recycling technology. In the recycling supply chain, one of the most difficult breakthroughs to achieve relates to sorting technologies that can distinguish between various types and qualities of metals. To enhance recycling efficiency, facilities must have access to sorting technology such as manual eddy current separators, which sort recycling inputs by material type, as well as the more advanced X-ray transmission technology for metals. X-ray technology can determine differences in quality and material density and sort product accordingly for all metals, including aluminum. After sorting, aluminum scrap is typically sent to smelters, where it undergoes an energy-intensive process. However, recycling facilities are beginning to take the additional step of sorting aluminum into specific alloys, a process key for closing the circular economy loop. Most aluminum sorted at recycling facilities is derived from products manufactured over 10 years ago. Aluminum sorting technology was designed to fulfill the needs of those types of aluminum and is not suited to sort aluminum produced more recently, since more aluminum alloys are being used in production today. Technology that can detect key differences in recycled material, including assessing product density, exists but is comparatively more expensive than traditional sorting technology. Since aluminum and alloy content will continue to evolve, it is important that the government continually promotes new recycling technologies so that it meets not only the sustainability needs of today but also those of tomorrow.

On February 15, 2022, the Biden administration announced a plan to advance a cleaner U.S. industrial to reduce emissions and reinvigorate domestic manufacturing. The plan aims to invest $8 billion in green hydrogen, establish a Buy Clean task force, and leverage carbon-based trade, such as the Global Arrangement on Sustainable Steel and Aluminum, to decarbonize heavy industry.
In addition to helping reduce emissions, aluminum recycling can also play a role in minimizing trade frictions. Increased recycling of existing aluminum scrap could result in a greater amount of aluminum in circulation within the U.S. economy, reducing the need for tariffs and other trade remedies that ultimately raise costs on consumers. By incentivizing increased recycling, whether through tax breaks and investments for recyclers or by investing in new recycling research and development (R&D), the government can simultaneously encourage freer trade and reduced emissions.

**Lessons from the Foreign Steel and Aluminum Industries**

While transatlantic cooperation on industrial decarbonization is important, climate change is a global commons problem. Therefore, it is imperative that China join this or a similar effort since it is the world's largest producer of both steel and aluminum. Although further behind on decarbonizing heavy industry, China's experience offers some guidance on pursuing decarbonization of heavy industry. In 2020, President Xi Jinping announced that China's emissions would peak by 2030 and that the country would achieve carbon neutrality by 2060. Steel accounts for 15 percent of China's carbon emissions, the most of any manufacturing sector in China, while aluminum accounts for nearly 4 percent. As a result, steel and aluminum decarbonization have been made key government priorities. China's 14th Five-Year Plan for 2021–2025 charts targets for steel and aluminum carbon optimization that ministries, provinces, and firms have begun to enact.

Despite grand ambitions, China's success in reducing emissions related to heavy industry has been mixed. The Ministry of Industry and Information Technology's draft five-year roadmap for the steel industry calls for crude steel output to fall in 2021. However, Chinese steel output totaled 93.9 million tons in June 2021, 2.5 percent above production in June 2020 and 28 percent above production in June 2017, hurting the chances of China meeting this target. While steel output declined in the historic production hubs of Hebei and Tianjin in the north, these reductions were offset by production increases in all other provinces. As a result, Chinese steel production grew 12 percent during the first two quarters of 2021. While more aggressive production curbs in August have led to a slight decline in Chinese steel production, it is projected that Chinese crude steel net capacity will increase by 40 million tons by the year's end. This highlights the difficulty of decarbonizing a major Chinese growth industry in the face of sustained global demand for steel.

China's use of regulatory authority to crack down on existing and potential high-emission plants has been more successful. China's National Development and Reform Commission (NDRC) has issued code-red warnings in nine provinces or regions to suspend energy-intensive steel projects. It has also identified over 350 projects that don't meet Chinese energy standards and has vowed to block them. Concerns of steel supply shortages from closing energy-intensive plants have led China's Customs Tariff Commission of the State Council to shift its trade policy, raising export tariffs and lowering import tariffs on steel.

Major Chinese firms have also implemented their own decarbonization plans. Baowu Steel, the world's largest steel producer, has committed to reach peak emissions by 2023, reduce emissions 30 percent by 2025, and fully decarbonize by 2050. Rival HBIS Group, the second-largest Chinese producer, plans for emissions to peak in 2022, a 30 percent reduction of emissions by 2030, and full decarbonization by 2050. Both companies are heavily investing in hydrogen-based steel production R&D to lower energy usage in their steelmaking. However, the economic and climate benefits for hydrogen-based steel production are still unclear with this innovative production process still in its infancy. While China's attempts to reduce emissions in the steel sector are laudable, they provide valuable lessons for decarbonizing other energy-intensive sectors, including aluminum.
China similarly aims to peak carbon emissions in the aluminum industry before 2025, while decarbonizing by midcentury, presenting unique challenges to this electricity-intensive industry. To meet Beijing’s new decarbonization demands, provinces have begun to power down production. Inner Mongolian aluminum plants, drawn to the region due to its cheap coal power, have faced production cutbacks. In the southern province of Guanxi, smelters were ordered to reduce run rates during a peak power demand period. Xinjiang, a hub of almost 20 percent of Chinese aluminum production capacity, also directed 10 percent production cuts in several of its main smelters.

In provinces rich with hydropower capacity, aluminum production has become less carbon intensive. In the southern province of Yunnan, the region’s 70 percent mix of hydroelectric power and cheap energy rates drew millions of tons of new aluminum production over the past few years. However, an unforeseen drought this summer has led to an unprecedented hydropower shortage, forcing provincial authorities to order a 30 percent reduction in aluminum production until the end of 2021. The fragility of the situation in Yunnan has led the central government’s NDRC to issue a directive to aluminum companies to diversify future plants away from hydroelectric power and toward wind and solar. Hydroelectric power represents low-hanging fruit for aluminum decarbonization, meaning this new policy complicates China’s attempts to reach peak aluminum emissions by 2025. Ongoing decarbonization directives and new energy crises have increased uncertainty in domestic and international aluminum markets, with Chinese aluminum prices reaching a 13-year high. Though earlier projections had China maintaining its record-breaking 60 percent of global aluminum production this year, these recent events have increased uncertainty.

In the cases of both steel and aluminum decarbonization in China, high ambitions have yet to translate to tangible results. Both examples highlight the difficulties in decarbonizing entire industries in the face of persistent fluctuations of supply and demand regarding goods and energy alike. The difficulties China faces in decarbonizing its leading industrial sectors point to the opportunities firms in North America and Europe have to lead in future decarbonization efforts. Canada’s efforts to decarbonize the aluminum sector through the Elysis project, as well as Iceland’s zero-emissions Arctus Metals—which could reduce Iceland’s emissions by 30 percent—both illustrate the important role advanced aluminum manufacturing and R&D can play in future decarbonization. Above all, the different experiences of aluminum firms around the world, from China to Iceland, underscore the importance of a diversified and reliant renewable energy supply.

Trade, Tariffs, and Border Adjustments

Aluminum has been subject to government intervention through both trade and environmental policy tools. In March 2018, President Trump applied 10 percent tariffs on certain aluminum imports using his authority under Section 232 of the Trade Expansion Act of 1962. Section 232 gives the president power to impose restrictions on certain imports based on determinations by the Department of Commerce that the product under investigation is “being imported into the United States in such quantities or under such circumstances as to threaten to impair the national security.” Some countries, including Australia, Mexico, and Canada, negotiated exemptions from these tariffs. Several World Trade Organization (WTO) members have challenged these tariffs under the WTO and have enacted retaliatory measures. To date, these tariffs have not motivated aluminum manufacturers to participate in reshoring efforts, although supply chain disruptions could potentially encourage firms to engage in that. The United States International Trade Commission also recently approved trade remedy duties pursuant to a determination that the U.S. aluminum industry is materially injured as a result of imports of aluminum foil from Armenia, Brazil, Oman, Russia, and Turkey. As a result, the Department of Commerce has issued countervailing duty and antidumping duty orders on the imports of aluminum foil.
As the effects of climate change intensify, countries have taken it upon themselves to use trade as a tool to spur greater international action on climate change. The European Union’s recently proposed Carbon Border Adjustment Mechanism (CBAM) seeks to limit carbon leakage and encourage a race to the top when it comes to environmental standards and emissions reductions. A form of off-shoring, carbon leakage occurs when businesses facing strict emissions regulations move their carbon-intensive production processes to countries with less strict rules, causing emissions to “leak” across borders. While the actual prevalence of carbon leakage is still the subject of debate, it is possible that certain regulatory conditions would encourage firms to move production facilities elsewhere, which could result in the loss of U.S. manufacturing jobs. Additionally, this would mean that fewer carbon-intensive U.S. products would be relatively more expensive than imports from countries with less strict regulatory regimes. As currently written, aluminum is one of the five sectors covered by the EU CBAM, along with iron and steel, cement, fertilizers, and electricity.

Under the proposed CBAM, beginning in 2023, importers of non-EU aluminum will need to report both their direct and indirect emissions, making the decarbonization of aluminum an increasingly urgent matter for the industry. Given the relatively low carbon intensity of aluminum production in the United States, the CBAM would not affect aluminum produced in the United States, meaning U.S. exports of aluminum to Europe would not likely be subject to carbon tariffs. Under the EU CBAM, non-EU aluminum producers must track emissions and provide this data in accordance with EU Commission methodologies. Embedded emissions in imported aluminum must also be verified and approved, meaning that aluminum importers carry a compliance burden when importing aluminum into the European Union. Starting in 2026, aluminum may only be imported by registered importers, meaning that non-EU aluminum producers must verify customer registration or file to be a registered EU importer themselves. Financial obligations under the CBAM will also go into effect for the aluminum sector in 2026. CBAM certificate prices will be calculated as the average weekly auction price of the EU Emissions Trading System (ETS) allowances, and credit will be given to non-EU producers for any carbon price paid in their country of domestic production.

The U.S. border carbon adjustment (BCA) that was proposed but not ultimately included in the House reconciliation package would have calculated costs as “domestic environmental costs incurred” times “greenhouse gas emissions of the product.” The Treasury Department would have been tasked with calculating “domestic environmental costs incurred” by U.S. aluminum firms on an annual basis, based on an average cost incurred by aluminum companies to comply with federal, state, regional, and local emissions reduction regulations. The Treasury Department would also have calculated “production greenhouse gas emissions” by measuring the CO$_2$ emissions associated with the product’s production, manufacture, or assembly. It remains unclear whether this will be a default emissions calculation for the aluminum industry as a whole or based on actual emissions per production facility like with the EU CBAM calculation. While Canada accounts for 50 percent of aluminum imported into the United States, due to its relatively low carbon footprint, it would not be subject to a future BCA. On the other hand, a BCA would be particularly worrisome for a country like China, which supplies 13.3 percent of U.S. aluminum. Due to the carbon intensity of aluminum production in China, Chinese aluminum would be subject to tariffs under the BCA. In addition to a BCA, there is renewed optimism among congressional Democrats that they may be able to include a carbon price of $20 per ton in the final reconciliation bill, although they currently lack sufficient support for the inclusion of a carbon tax.

Carbon border adjustments such as these (and others proposed by countries such as Canada, Japan, and Russia) risk increasing global fragmentation as countries erect trade barriers in a bid to simultaneously reduce free-riding and protect local industries. Global fragmentation risks becoming further intensified since different carbon accounting methodologies can lead to the ensnarement of entire sectors into carbon
adjustment measures. Harmonizing these methodologies and creating international agreements regarding carbon life cycle assessments (LCAs) can help forestall the effects of these “carbon protectionist” measures.

**Preventing a Competitive Disadvantage for Domestic Producers**

To ensure that producers are not disadvantaged during the decarbonization transition, governments should adopt targeted policies that help reduce the financial impact on firms. First, governments should work to ensure an energy supply that is both reliable and low cost. Europe and China serve as cautionary examples for how to avoid some of the pitfalls of the volatility of energy markets. In Europe, the transition toward renewable energy has been hampered by rising demand, lagging deployments of wind and solar, and an inadequate supply of existing energy sources, such as natural gas. This confluence of factors has led to an inadequate supply and higher prices. Termed “energy poverty” by the European Union, high energy prices have led governments to reconsider their renewable energy pricing schemes. In Germany, a tax on renewable power was reduced by a third to alleviate pressure on consumers.

China, too, has experienced bumps in its road to decarbonization. Despite the government-mandated maximum price on energy, recent surges in market-driven coal prices have led to blackouts in half of Chinese provinces. The increase in coal prices in China has been fueled by several factors. Coal supply shortages have been exacerbated by an unofficial import ban on Australian coal shipments due to tense political relations between the two countries. Other sources of supply, including imports from Indonesia, have been affected by heavy rainfall in coal-producing regions, leading to more limited exports from the country. On the domestic front, China’s heavily controlled electricity pricing system has made it unprofitable for power plants to operate with high coal prices. The government has since adjusted its policy to adopt market-based pricing to reduce market distortions and encourage greater production. Moreover, the export surge created by the coronavirus pandemic in electricity-intensive industries has affected energy supplies, which indirectly has affected the price of coal. Previously implemented curbs on coal mining for environmental and safety reasons have also contributed to the rise in coal prices. In addition to adjusting pricing schemes, China has ordered more coal to be mined and has increased imports of coal, primarily from Russia and Indonesia. However, ongoing electricity shortages and an unusually cold winter could exacerbate and prolong this energy shortage.

To incentivize firms to decarbonize aluminum, renewable energy must be both affordable and reliable. At current rates, the cost of hydropower is already 40 percent cheaper than fossil fuel energy. Furthermore, other renewables, such as wind and solar, are expected to drop below the cost of hydropower, making them even more price competitive in the coming years. However, the upper limit for aluminum companies to transition to renewable power is roughly $40 per megawatt hour of power. Demonstrating how difficult it is to achieve that price point, hydropower in the United States averages a levelized cost of $55.26, and that is after tax credits. While onshore and solar energy generation has become even cheaper, with averaged levelized costs after tax credits of each at $36.93 and $30.43, respectively, limited deployment hinders their availability for powering aluminum plants. Solar power makes up a mere 3 percent of U.S. electricity generation, while wind makes up 8.4 percent of utility-scale electricity generation. While the cost of building new solar and wind plants is cheaper than building a new fossil fuel plant, fossil fuel electricity remains cheaper and, importantly, more accessible in many U.S. markets.

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*To incentivize firms to decarbonize aluminum, renewable energy must be both affordable and reliable.*
Nevertheless, aluminum producers can purchase clean power through power purchase agreements (PPAs), which ensure that enough renewable power is generated to cover the electricity demand of smelters. In certain parts of the United States, aluminum smelters can obtain power at as low as $15/MWh. When balanced with other energy inputs, the cost rises to between $40 and $50/MWh, which is still cost competitive with coal. Overall, government investment in electricity grids that are both renewable and reliable would incentivize a faster and broader decarbonization of the aluminum sector.

To ensure that domestic aluminum producers who decarbonize are not disadvantaged compared with firms in other countries that maintain carbon-intensive production practices amid weaker regulation, governments should consider the introduction of a carbon border adjustment measure, similar to what the European Union has proposed with its CBAM. The CBAM shields domestic heavy industry—in this case, steel, aluminum, cement, and fertilizers—from unfair competition in countries with weaker environmental regulations. Furthermore, the EU CBAM is intended to be WTO compliant. First, the CBAM meets the non-discrimination test under the General Agreement on Tariffs and Trade (GATT) Article III, which prohibits domestic protection at the expense of imports. A legally compliant border adjustment also must not violate GATT Article I, which prohibits discrimination among trading partners. As currently proposed, the EU CBAM appears to comply with both criteria, particularly since varying carbon content of goods affects the likeness of products traded. Overall, the European Union has designed a policy that both incentivizes decarbonization abroad while protecting domestic industry that has already demonstrated progress on decarbonization. The European Union’s decarbonization efforts present an opportunity for closer climate collaboration with both the United States and China, although closer collaboration would likely be contingent upon the creation of a U.S. emissions trading scheme and a higher domestic price of carbon in China.

**Industry and Government Collaboration on Climate Targets**

Companies are already racing to take advantage of affordable opportunities to leverage cheaper power, particularly in Canada. In the technology sector, Apple is leading the way in sustainably sourcing upstream aluminum through a $60 million joint venture with Alcoa, Rio Tinto, and the governments of Canada and Quebec. Known as Elysis, the Montreal-based venture plans to remove all direct GHG emissions from aluminum smelting. By removing carbon anodes from aluminum’s electrolysis smelting reaction and replacing them with new nonreactive materials, the process would only emit oxygen as a byproduct. Though still in R&D, the technology—when coupled with hydropower energy sourcing—aims to become commercially viable by 2024. For Apple, this new process brings with it the potential to decarbonize over 24 percent of its manufacturing carbon footprint, the largest share of its carbon emissions. If adopted in Canada alone, it is estimated that ELYSIS technology could eliminate 6.5 million metric tons of annual GHG emissions. Although ELYSIS is launching in Canada, if successful, countries around the world could adopt it to decarbonize their own aluminum production facilities. Separately, Alcoa is exploring new technology to further reduce carbon emissions following the receipt of a grant from the Australian Renewable Energy Agency (ARENA). With that funding, Alcoa is exploring using mechanical vapor recompression that could help convert waste vapor into steam, ultimately reducing one refinery’s carbon footprint by 70 percent.

In the downstream aluminum sector, companies take primary aluminum product and adapt it to specific value-added products and solutions. Examples of downstream aluminum products include bars, rods, sheet, plate, tubes, pipes, extrusions, castings, and forgings that can become automobile components, electric goods, construction and packaging materials, and consumer products ranging from smart tablets to coffee makers and chairs. The United States has over one thousand downstream aluminum production companies, representing the largest aluminum segment in the domestic industry and the second-largest downstream segment in the world, behind China. The largest downstream U.S. aluminum producers...
include Indian-owned and Atlanta-based Novelis, California-based Kaiser Aluminum, Dutch-owned and Baltimore-based Constellium, Pittsburgh-based Arconic, and Norwegian-owned Sapa Extrusions.

Major growth is projected in the use of downstream aluminum in the transportation sector, and aluminum provides the automotive and aircraft industries with important sustainability opportunities. At present, aluminum recycling in the automotive industry is highly efficient with a 91 percent recycling rate, mostly from end-of-life automotive aluminum. However, aluminum components make up only an average of 12 percent of vehicle weight, a figure expected to rise to 16 percent by 2028. Part of this is driven by the growth in electric vehicle deployment, which requires low vehicle chassis weight to accommodate increased battery weight. For example, aluminum use in the Tesla Model 3 allows the car to maintain a relatively low curb weight even with a heavy battery pack. Tesla continues to bet on aluminum to drive future growth, with a recent patent on a new aluminum alloy and investments in new aluminum casting machines in its Berlin and Shanghai plants. The Department of Energy’s Vehicle Technologies Office has also launched an R&D initiative at the Pacific Northwest National Laboratory with Ford and General Motors to develop new alloys and production processes to make aluminum lighter and more durable in new vehicles. Public and private sector actions like these suggest a future of expanded automotive demand for aluminum and opportunities to build a more robust circular economy based on recycled domestic aluminum rather than imported foreign aluminum.

The aerospace industry illustrates the benefits that aluminum offers as industries increasingly seek to decarbonize. Aluminum components have been a part of aerospace vehicles since the first flight of the Wright brothers, and today aluminum components make up 80 percent of a typical modern commercial transport aircraft by weight. Just like in automobiles, the low weight and high strength of aluminum makes it an attractive material for enhancing aerospace efficiency and sustainability. While traditional aircraft manufacturing typically relied on a handful of aluminum alloys—primarily aluminum alloy 2024—next-generation aircraft are increasingly relying on composite alloys. Made up of a combination of materials with different properties, new particulate composites that suspend other particles within aluminum alloy are becoming more popular than pure aluminum in aerospace. The prevalence of aluminum-lithium (Al-Li) composites is growing, with Alcoa investing $90 million in the world’s largest Al-Li production facility in Indiana. Several aluminum firms have also signed billion-dollar long-term Al-Li supply contracts with Boeing, Airbus, and other major aircraft manufacturers.

Additive manufacturing technologies, often referred to as “3D printing,” also have important aerospace sustainability benefits. For its new 702MP satellite, Boeing used a novel recycled aluminum printing process to reduce its weight by 28 pounds prior to launch. While there is projected demand for lightweight aerospace aluminum going forward, the World Economic Forum estimates efficiency improvements from combining lightweight materials in production with operational optimization on the ground and in-flight would reduce aviation’s total CO₂ emissions by no more than 5 percent. Although small, these steps to reduce emissions, combined across sectors, play a direct role in enhancing the sustainability of heavy industry. Nevertheless, decarbonizing upstream aluminum offers the most immediate and efficient way of achieving deep decarbonization.

The Industry as a Model for Border Adjustments

A recent announcement from the United States and European Union marries both trade and environmental objectives and seeks to encourage a virtuous circle of trade policy rather than a system of mutual recrimination. To limit overcapacity of carbon-intensive steel from China and other countries, the United States and European Union announced they would negotiate a carbon-based sectoral agreement.
on steel and aluminum by 2024. The first of its kind, the arrangement would prioritize decarbonizing the aluminum and steel industries, which account for over 10 percent of total global emissions. The agreement replaces the U.S. Section 232 tariffs with tariff rate quotas, allowing pre-determined amounts of EU-based steel and aluminum to enter the U.S. market without application of Section 232 tariffs. The carbon specifics of the agreement remain murky, and the United States and European Union have agreed only to negotiate plans that consider the carbon intensity and global overcapacity of steel and aluminum. These provisions will be recommended by a newly formed working group of both parties and other participating countries, as the arrangement is intended to be open to any country interested in restricting the trade of high-carbon steel and aluminum products. Even before its implementation, the deal has already been hailed as a mechanism to keep each party’s steel and aluminum industries globally competitive, while incentivizing deeper decarbonization. Overall, the transatlantic agreement to recognize the carbon intensity of steel and aluminum represents a joint effort to reign in potential carbon leakage while encouraging countries and producers to pursue a virtuous circle of trade and decarbonization policy. In addition to addressing carbon emissions and overcapacity of Chinese steel and aluminum, this joint transatlantic announcement represents a step by governments to ensure that climate regulation does not put domestic aluminum producers at a competitive disadvantage relative to economies with weaker regulations. However, absent China, the deal represents relatively limited progress in the immediate term. The United States has also announced negotiations with Japan and the United Kingdom for similar bilateral agreements that would also seek to reduce tariffs and encourage decarbonization of heavy industry.

ENVIRONMENTAL REGULATION
In addition to government intervention regarding the trade of aluminum, the sector also faces environmental regulatory measures. The Environmental Protection Agency (EPA) and aluminum industry have worked in concert to improve efficiency of aluminum production and reduce sectoral emissions of perfluorocarbons (PFCs or PFAS), which are potent GHGs released during primary aluminum production that trap heat in the atmosphere. “Anode effects,” which occur when the electrolytic process bath falls below critical levels, release PFCs. Minimizing anode effects, for example by making changes to alumina feeding techniques or enhancing computer monitoring, has been proven to reduce PFC emissions. Primary aluminum production and semiconductor fabrication are the world’s two largest sources of PFC emissions, meaning streamlining production processes can help reduce negative environmental externalities.

In October 2021, the Biden administration announced plans to regulate PFAS, the toxic “forever chemicals” that have been linked to health problems such as cancer. The overall strategy of the EPA in this regard is to focus on researching PFAS and designing regulations that restrict their release into air, land, and water, and clean up contamination to protect human health and ecological systems. This may impact the downstream industries that use aluminum in their manufacturing processes. Primary and secondary aluminum production is also subject to national emission standards for hazardous air pollutants. Manufacturers are required to report numerous operational environmental data to the EPA’s Toxic Release Inventory and the National Emissions Inventory. The EPA is authorized to require the maximum degree of reduction in emissions of hazardous air pollutants under the Clean Air Act.

Another environmental consideration within the aluminum sector is the age—and therefore the efficiency—of smelters. Of the six primary smelters in operation in the United States, the newest one opened in 1980. Upgrading smelters or using newer ones can help reduce sectoral emissions, but building new smelters costs upwards of $1 billion. Government investment in new smelters could help streamline aluminum processes and reduce the overall amount of harmful byproduct, but sourcing electricity from renewable power is the fastest and most cost-effective method for immediate emissions reductions on a large scale.
Another way to ensure that producers are not hurt is to work internationally to advance decarbonization measures. The recent EU-U.S. proposal to decarbonize steel and aluminum attempts to do that. The European Union and United States have long contended with two interrelated problems: Chinese dumping of steel and aluminum, and Chinese carbon emissions that have continued to grow despite the urgent need to decarbonize. In their recent joint statement regarding steel and aluminum, the European Union and United States jointly attempt to reconcile both these problems in a way that would decrease market access for more carbon-intensive products, while increasing protections for domestic EU and U.S. producers whose aluminum is far more climate competitive than Chinese products.

The EU-U.S. Joint Statement on steel and aluminum provides a roadmap on the rules that may be jointly developed to address non-market excess capacity and carbon intensity. It lists six types of actions that they would undertake, and chief among those are two mechanisms for restricting market access: (1) restrict market access for non-participants that do not meet conditions of market orientation and that contribute to non-market excess capacity, through application of appropriate measures including trade defense instruments; and (2) restrict market access for non-participants that do not meet standards for low-carbon intensity (emphasis added).

As the text indicates, what the United States and European Union have put forth thus far is not quite a legal agreement. While it represents a step in the right direction for climate change policy, it remains to be seen whether such a bilateral deal would restrain the ability of the international trading system to combat climate change by encouraging countries to undertake their own border adjustment measures. With some of the world’s least carbon-intensive aluminum sectors, the European Union and United States should work to ensure other countries join them in helping build a virtuous circle of trade and climate policy. In the joint statement, the parties also agree to form a technical working group that will “confer on methodologies for calculating steel and aluminum carbon-intensity and share relevant data.”

Since Canadian aluminum is the world’s most decarbonized, and since it will soon be able to produce zero-emissions aluminum, Canadian aluminum sets the bar highest when it comes to designating aluminum products “decarbonized” and to what degree. However, other countries, including both the United States and China, do not possess a renewable energy grid that is similarly diversified with renewables, meaning it is highly unlikely they would be able to meet that standard in the immediate future. Determining a common threshold at which countries can designate aluminum as “decarbonized” is a necessary step and one that should accompany a more detailed effort to reach a global agreement on methodologies for carbon content of goods.

What remains unclear is whether the European Union and United States will develop standards that become the de facto global standard for decarbonized steel and aluminum and whether that will encourage China to accelerate the decarbonization of its own heavy industries. The United States does not have a domestic framework for carbon taxes nor a complementary border tax, making a transatlantic sectoral agreement or “climate club” unfeasible for the foreseeable future. Regardless, the lack of detail in the existing transatlantic proposal makes the contours of trade in these measures unclear at this stage.

Short of concluding a formally recognized international agreement to set a global standard for green steel and aluminum, the United States and European Union could use their recent deal to launch plurilateral talks within the WTO. This plurilateral could serve as a distinct, standalone plurilateral, similar to the Agreement on Climate Change, Trade, and Sustainability (ACCTS). Alternatively, talks could occur under the umbrella of an existing plurilateral, such as the trade and environmental sustainability structured discussions (TESSD), of which China, the European Union, and the United States are all members.
Leading a plurilateral dialogue within the WTO system, based on the existing transatlantic framework for decarbonizing steel and aluminum, would minimize the appearance that the United States and European Union were engaged in purposefully discriminatory behavior and could help accelerate other countries’ bids to decarbonize their own heavy industries.

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Another complicating trade element in the aluminum sector is that countries and companies alike have different ways of calculating the carbon footprint of aluminum. For aluminum sector decarbonization to occur in a fair and equal way, international partners must work together to determine a common and formally adopted methodology for measuring carbon content of aluminum, for example within an international organization like the Organization for Economic Cooperation and Development. Establishing a uniform methodology for measuring emissions and data collection throughout the downstream aluminum supply chain would help ensure that aluminum producers meet their climate targets. A common methodology would also serve as a guardrail for trade policy that encourages countries to use trade to adopt a virtuous circle rather than a race to the bottom in which an increasing number of trade barriers are adopted.

Conclusion

Aluminum is a highly globalized industry. Bauxite is mined in countries like Australia and China, produced in countries like China, Russia, and India, and then distributed around the world. Like climate change, the carbon intensity of aluminum is a global problem. Aluminum accounts for nearly 2 percent of GHG emissions, and, compared with other metals, attributes of aluminum make it particularly attractive as both an industry to decarbonize and to help facilitate emissions reductions in other industries. Aluminum is infinitely recyclable, and it is a key component of other green goods, such as more energy-efficient buildings and electric vehicles. If aluminum production can become carbon neutral, it will play an even greater role in the transition to a less carbon-intensive economy. Together with involvement and input from the private sector, there are established, proven policies governments should pursue to accelerate decarbonization within the sector. In terms of producing aluminum, North America, particularly with expanding pools of renewable energy, is well positioned to take advantage of an emerging comparative advantage when it comes to producing aluminum. Two primary policies the government should pursue are to invest in more resilient, renewable energy grids and to work toward trade liberalization within the aluminum sector.

First and foremost, governments should invest substantially in building more resilient and renewable energy grids. In the aluminum sector, nearly two-thirds of emissions relate to electricity used in aluminum production. Electricity costs can account for 40 percent of primary aluminum production operating costs and have led firms to relocate production facilities to countries with cheaper electricity, namely Canada and Iceland. If encouraging firms to reshore is a government goal, one way to do that without penalizing firms is for the U.S. government to invest in renewable energy that allows companies to take advantage of cheap, renewable electricity. This would help create more certainty in the market, boost revenue for
firms, and encourage deeper and faster decarbonization. If aluminum production facilities have access to reliable and affordable renewable power, this could ease the sector’s historic reliance on coal, particularly in countries such as China and Russia. Furthermore, reliable, renewable, and affordable energy is a much more viable method of encouraging reshoring than trade remedies, which have largely been unsuccessful in encouraging U.S. domestic production increases.

As part of ensuring a resilient renewable energy grid, governments should work together to encourage the free trade of renewable power across borders. Currently, the EU CBAM seeks to impose tariffs on carbon-intensive power. While this could represent a trade barrier in the immediate future, it could also incentivize a race to the top as countries and regions seek to decarbonize their heavy industries. In North America, the U.S. government should avoid temptation to include local content requirements in electricity production, which not only contravenes WTO rules, but would ultimately slow the transition to a decarbonized economy. Taking advantage of Canada’s immense hydropower resources, as Alcoa, Apple, and Rio Tinto have already done, represents significant progress in a North American partnership to decarbonize aluminum. The United States should not pursue policies that would complicate those existing areas of progress.

Overall, the role of government in pursuing the decarbonization of heavy industry is closely interlinked with trade. Governments should reduce or remove tariffs on green aluminum to ensure the fastest and most efficient deployment of more sustainable products, while working to maintain cross-border flows of renewable electricity. If supply chain uncertainty precludes the ability to operate efficient recycling supply chains, domestic governments should invest in new technologies to streamline aluminum recycling, whether through tax incentives or direct subsidies. Through combined action—both at the domestic and international levels and through private and public sector engagement—the world can make meaningful progress on reducing global emissions by accelerating the decarbonization of aluminum.

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