The U.S. Carbon Advantage in Chemicals Manufacturing

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EXECUTIVE SUMMARY

The United States chemicals manufacturing industry has a distinct carbon efficiency advantage compared to other major producing countries. This conclusion is supported by a new data analysis of five major bulk chemical products that are manufactured around the globe using a variety of production methods and feedstock inputs.

Despite the U.S. carbon advantage and increasing global recognition of the need to value lower carbon manufacturing, there are no trade policies in place to reward more carbon efficient manufacturing, hold less efficient producers accountable, or establish incentives throughout the global marketplace to decarbonize this energy intensive sector.

Chemical products from building insulation to lightweight materials used in cars to hydrogen fuels will be important in our quest to decarbonize the global economy. At the same time, global decarbonization will require the global chemicals industry—the third largest industrial source of greenhouse gas emissions—to rapidly improve its carbon efficiency.

If international trade rules valued lower carbon manufacturing processes, U.S. chemicals manufacturers would realize a competitive advantage over producers in most major producing regions. Over time, higher carbon production would lose out to lower carbon production, as incentives would drive all global producers to compete to find ever-more carbon efficient methods. Improvements in the carbon intensity of chemicals manufacturing will lower global emissions while supplying products for decarbonization in other sectors.

While the chemicals industry, its supply chains, and trade flows are complex and warrant deeper analysis, the U.S. carbon advantage is unambiguous. With changes to trade policy, U.S. chemicals producers can leverage their carbon advantage to lower global emissions and improve their competitive position in the global marketplace. Key findings from this report include:

- Global decarbonization will require substantial investments to reduce greehouse gas emissions from the chemicals industry—worldwide the third largest industrial source of direct carbon emissions.
- Of the bulk chemicals studied, U.S. producers are 10–40% more carbon efficient than the global average (see Table A).
- Among the largest producing regions for these products, the U.S. and EU consistently rank among the most carbon efficient producers.
- The U.S. carbon advantage over major producers in China, the largest chemical manufacturing region, is particularly stark. It is twice as carbon efficient as China in producing ammonia, a critical component of fertilizer, and nearly three times as efficient at producing polypropylene, a critical component of many plastics.
- An international trade system that accounts for the carbon intensity of chemicals production would give a competitive advantage to more carbon efficient firms today, while creating incentives for all global producers to lower their emissions moving forward.

TABLE A.
AMERICA’S CARBON EFFICIENCY ADVANTAGE IN BULK CHEMICALS MANUFACTURING VS. GLOBAL TOP PRODUCERS

	USA	China	EU	Saudi Arabia	World
Benzene	1.0	1.4	1.5	1.3	1.3
Toluene	1.0	1.2	1.2	1.1	1.1
Ammonia	1.0	2.1	1.0	0.9*	1.3
Polyethylene	1.0	1.8	0.8	1.1	1.1
Polypropylene	1.0	2.9	1.0	1.4	1.6

*Not a major producer of ammonia

🟥	U.S. Carbon Advantage (foreign competitors less carbon efficient)
🟦	U.S. Carbon Disadvantage (foreign competitors more carbon efficient)
⬜	U.S. Carbon Efficiency or Equivalent

Source: Carbon Minds (2022), cm.chemicals database V1.01 2022; index calculations by Climate Leadership Council

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This is an illustrative look at the relative carbon intensity of production across the major actors in global chemicals manufacturing. Across individual chemicals, the largest manufacturers may differ. For example, the largest producers of ammonia are China, the EU, Russia, the U.S., and India; Saudi Arabia is a negligible producer. We anticipate that the actual U.S. carbon advantage is greater than indicated given known limitations to data quality from some major international producers.

The Council used data from Carbon Minds to assemble Table A; for ease of comparison, we’ve indexed U.S. carbon intensity to 1.0. As this chart shows, major global manufacturers release, on average, 10-60% more emissions to create these same bulk chemicals. That means that U.S. producers are 10-40% more carbon efficient than their global competitors. In some cases, major producers emit more than twice the emissions as U.S. manufacturers. Chinese ammonia production is 2.1 times higher than U.S. production; Chinese polypropylene production is nearly three times higher than U.S. production.

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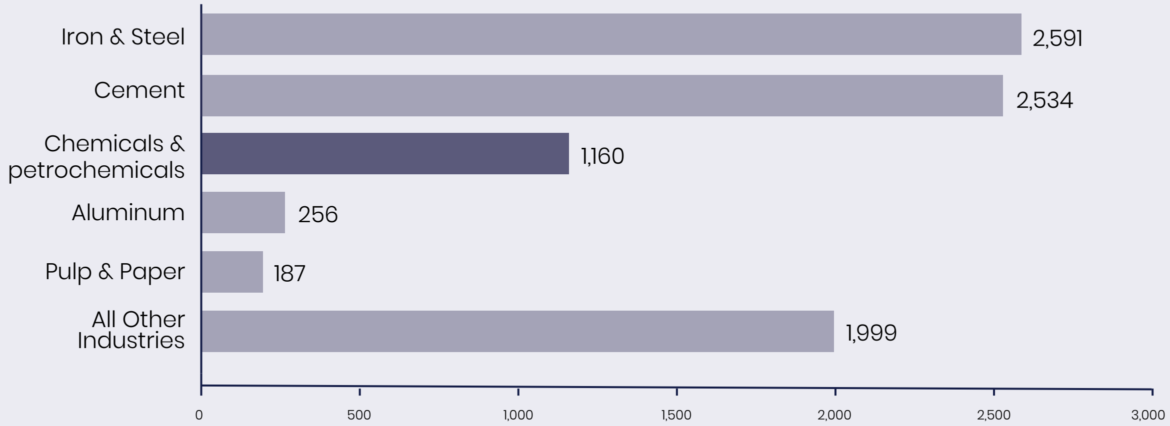
INTRODUCTION

Chemicals are ubiquitous in our lives. They are found in our smartphones, the clothes we wear, the medicines we take, and the fertilizers that produce the food we eat. More than 96% of manufactured goods are directly touched by the chemicals industry.[1] Such products are the end point of complex production chains based on tens of thousands of individual chemical products.

Chemical manufacturing is also a cornerstone of American manufacturing. The U.S. is the second-largest global manufacturer, producing 13% of the global chemicals supply. Chemicals represent the largest U.S. manufacturing sector and the largest source of U.S. exports.[2,3] The industry directly employs more than half a million people in the U.S. and supports 4.1 million jobs across agriculture, construction, health care, waste management, and other major American industries.[4] Though basic chemicals manufacturing is concentrated along the U.S. Gulf Coast, 47 states produce chemical products like plastics, fertilizers, fibers, and pharmaceuticals.[5]

CHART 1.
ANNUAL DIRECT GLOBAL EMISSIONS BY INDUSTRIAL SECTOR, 2020 MTC02



Source: IEA, Tracking Industry 2021

Climate ambitious economies have begun to explore policies to address the interplay between global trade flows and carbon emissions. The chemicals industry is a natural candidate for such policies for the following reasons:

- Chemical products are important for decarbonizing the global economy. These include insulation materials to boost building efficiency, lightweight plastics to lower shipping energy demand, clean hydrogen to fuel the future, coatings to improve the efficiency of solar panels, and innovative new products from ongoing investments in research and development.

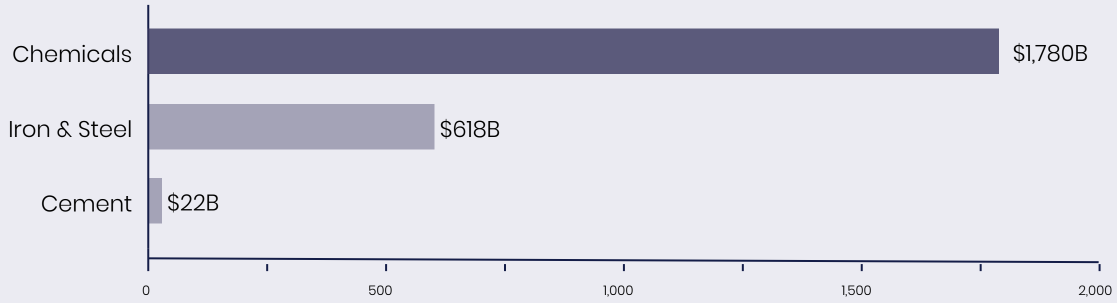
- The chemicals industry is a significant source of carbon emissions. It is the third largest industrial source of direct carbon emissions, after iron and steel and cement.[6] Global climate action will require substantial investments to reduce the greenhouse gas emissions from the chemicals industry—in the U.S. and all major producing countries—while simultaneously ensuring that innovative chemical products can continue to drive decarbonization efforts across the economy.

- Chemicals are heavily traded. The value of global chemicals shipments is nearly three times the value of the combined international shipments of iron and steel and cement.[7] Robust global competition keeps margins in the chemicals industry tight, with strong incentives to cut costs and weak incentives to support investments that reduce emissions.

- In their current form, international trade rules do not value chemical products made with fewer carbon emissions. They do not reward carbon efficient producers nor penalize carbon intensive producers.

CHART 2.

VALUE OF GLOBAL SHIPMENTS OF CHEMICALS, IRON & STEEL, AND CEMENT, USD 2020



Source: Observatory of Economic Complexity (OEC) Harmonized System Products database

The industrial sector drives nearly a third of global carbon emissions. To meet decarbonization goals, climate ambitious countries need to adopt policies that can address these emissions. To date, concerns about international competitiveness have inhibited such action. Instead, many countries have focused on containing costs to industry, rather than limiting emissions.

Emerging policies that link climate and trade envision a new paradigm: reward carbon efficient producers with preferential treatment in the trade system and hold less efficient producers accountable. The European Union is introducing a carbon border adjustment mechanism to price emissions associated with imported industrial goods. Meanwhile, the U.S. is negotiating with the EU on a policy to preference lower-carbon imports of steel and aluminum. These policies are coming, and carbon efficient industry leaders stand to benefit.

Introducing trade rules that value lower carbon intensity would give carbon efficient chemicals manufacturers a competitive edge over less carbon efficient producers. This would support investments in existing and new facilities to boost efficiency and lower emissions, especially at facilities that engage in robust international trade. Over the long term, trade terms that value carbon efficiency would provide incentives for producers across the globe to outcompete one another on the basis of environmental performance and drive down global emissions.

Such rules will benefit from additional study on how carbon emissions are embedded in globally traded chemical products and how carbon intensity varies by producers and countries. But even the most basic data already paint a clear picture: policies to reward companies that are making chemicals with fewer emissions can help cut global industrial emissions and hold high emitters accountable.

This report is an important step in examining differences in the carbon intensity of chemicals manufacturing across major producing countries and describes the consequences of the current trade regime for decarbonization efforts in the chemicals sector. The Climate Leadership Council partnered with Carbon Minds, a data services firm that has assembled a model of the global chemicals industry that combines market data, technical data about production processes and preferences, and trade data. Their analysis allows for an examination of production locations and volumes by supplier, technologies used and process parameters, and international trade flows for more than 70 chemicals across thousands of companies, countries, and regions.[8]

TRADE TERMS THAT VALUE CARBON EFFICIENCY WOULD PROVIDE INCENTIVES FOR PRODUCERS ACROSS THE GLOBE TO OUTCOMPETE ONE ANOTHER ON THE BASIS OF ENVIRONMENTAL PERFORMANCE AND DRIVE DOWN GLOBAL EMISSIONS.

The available data are valuable but have unavoidable limits. The quality of inputs to Carbon Minds's modelled data depends upon what manufacturers and governments publicly disclose in different jurisdictions around the world and is asymmetric: data quality and disclosures are relatively high in some jurisdictions, like the U.S. and EU, but less robust in others, like China and Russia. The comparisons in this report are likely to be conservative and thus the carbon advantage enjoyed by U.S. and EU industry over less transparent markets may be even greater than presented. The data also assess contributions to global carbon emissions but do not capture impacts to localized pollutants and environmental quality, which should be thoughtfully considered by lawmakers in policy development. Nevertheless, this is a substantive step forward in our understanding about the differences in carbon intensity across major producers.

This analysis builds on the literature demonstrating a general U.S. carbon efficiency advantage in manufacturing. The U.S. carbon advantage has been well documented, first by the Climate Leadership Council and subsequently by the Organization of Economic Cooperation and Development (OECD).[9] As data availability improves, the Council continues to examine the relative carbon intensity of individual sectors. For example, a May 2021 analysis documented a significant U.S. carbon advantage over key trading partners in the steel sector and illuminated the competitive benefits achievable under policies that effectively reward low-carbon producers.[10] Given the wide disparities in carbon intensity identified in the following analysis, greater exploration of policies that can leverage the U.S. carbon advantage in the chemical sector for the benefit of the global climate and domestic economy is warranted.

2

QUANTIFYING CARBON EFFICIENCY ACROSS BORDERS

The global chemicals industry is complex. The U.S. chemicals industry alone produces more than 70,000 unique types of products from a relatively narrow range of raw material inputs including fossil fuels, plant matter, minerals, air, and water. These inputs are converted through a multitude of processes for end uses across pharmaceuticals, agriculture, energy, construction, aerospace, transportation, and consumer products. There may be a single pathway or dozens of distinct pathways to produce each individual chemical product. Similarly, single inputs may be converted into thousands of final products as diverse as herbicides, cups, and electronics.[11] Documenting the carbon intensity of production across the entire chemicals industry in all its diversity and complexity is beyond the scope of existing capabilities.

This analysis focuses on five widely-produced bulk chemicals, each of which is manufactured primarily from fossil fuel feedstocks, namely oil, gas, and coal. We detail the relative carbon efficiency of benzene, toluene, ammonia, polyethylene, and polypropylene. These chemicals are subsequently converted into a wide variety of products, including fertilizers; textiles; car parts; laundry detergent and its containers; paint thinners; and protective equipment.

The international chemicals trade is dominated by just a few markets with robust domestic industries, a dominant position in international trade, and secure access to feedstocks: the EU, China, the U.S., and Saudi Arabia. Across individual chemicals, the largest manufacturers may differ. For example, the largest producers of ammonia are China, the EU, Russia, the U.S., and India; Saudi Arabia is a negligible producer. The relative carbon intensity of manufacturing these chemicals is summarized in Table A. Because supply chains and production processes for the same chemical can vary widely, these figures reflect a weighted average carbon intensity of manufacturing from the unique mix of production processes and inputs used in that country. In many cases, America's carbon advantage is likely even greater than this data suggest when factors such as data quality and disclosure, investments in maintenance and modernization, capacity utilization, and other attributes are considered.

For ease of use, carbon intensities throughout the report are presented relative to the average carbon efficiency of U.S. production. Carbon intensity figures above 1.0 indicate that manufacturing that chemical in that market is more carbon intensive than manufacturing the same chemical in the U.S.; carbon intensity figures below 1.0 indicate that manufacturing that chemical in that market is less carbon intensive than manufacturing the same chemical in the U.S.

The U.S. chemicals industry produces all five bulk chemicals with fewer carbon emissions than the world average, and with considerable chemical-specific advantages over other key manufacturing markets. In the following section, we examine these figures from these key price-setting markets and other large competitors. The U.S. carbon advantage reflects cleaner material inputs (e.g., natural gas over coal) and preferences for cleaner production pathways (e.g., more efficient manufacturing processes). As a result, the U.S. has a carbon advantage over average global production across the five bulk chemicals studied. The U.S. is 10-40% more carbon efficient than the global average and as much as 65% more carbon efficient than Chinese competitors (see Table A for emissions intensity data indexed to the U.S. chemicals sector).

The Carbon Minds data represent a major leap forward in understanding the two most important factors in determining the carbon intensity of chemicals manufacturing: manufacturing process and raw material preferences. One manufacturer, BASF, estimates that manufacturing emissions and energy sources make up nearly 20% of total lifecycle emissions in the chemicals industry; about half is related to the choice of raw materials.[12]

This analysis is the first of its kind to attempt a comparison of relative carbon intensity of manufacturing in the chemicals sector and represents a considerable and timely leap forward in our collective understanding. Nevertheless, emissions measurement remains challenging. The data in this report do not capture some important elements like recent changes in manufacturing processes and preferences or under-reported emissions associated with raw material sources, particularly natural gas. As the industry improves its capacity to measure carbon intensity, future versions of this analysis may have access to more precise and complete data.

THE U.S. CHEMICALS INDUSTRY PRODUCES ALL FIVE BULK CHEMICALS WITH FEWER CARBON EMISSIONS THAN THE WORLD AVERAGE.

3

WHO HAS THE CARBON ADVANTAGE?

Each of these five bulk chemicals is primarily manufactured from fossil fuels. They are the chemical foundation, or feedstock, for plastics, pharmaceuticals, electronic materials, and fertilizers, among thousands of other products that support diverse industries and household applications.

These five chemicals are often described as "petrochemicals." Oil, gas, natural gas liquids, and sometimes coal, are separated or processed into inputs like naphtha, ethane, propane, or coal gas.[13] These inputs can be purified, processed through "crackers" under high temperature and pressure into smaller hydrocarbons, or further modified with catalysts or through reactions into bulk chemicals. Bulk chemicals are further converted into thousands of chemical products.

The bulk chemicals industry is mature and expanding rapidly to meet consumer demand. These products are global commodities such that their prices can swiftly rise and fall in response to global supply and demand factors and the peculiarities of conditions in major manufacturing regions. Profit margins tend to be low or sometimes negative. Economic returns might be realized by the subsequent manufacture of higher-value products by integrated producers, rather than in the manufacture of bulk chemicals themselves.[14]

This section examines in further detail the diverse pathways that support the production of our five target chemicals and how they differ by country. As we dive into the individual chemicals, we'll consider relative carbon intensity in world-leading manufacturers for those commodities, in addition to the price-setting markets described in Section II.

BENZENE

Benzene is the simplest aromatic hydrocarbon, a building block for a variety of applications. It is made mostly from oil and coal. It is used as an input to products as diverse as Styrofoam packing peanuts, herbicides, baseball helmets, medical equipment, and tires.[15] Benzene is primarily manufactured by reforming or cracking other hydrocarbons or by simplifying more complex aromatics (like toluene, discussed next). Carbon Minds documents nine possible production pathways.[16]

U.S. benzene manufacturers hold a significant carbon efficiency advantage over all major global producers. Depending on the mode of production, the nature and purity of inputs, and the sources of electricity and process heat, production pathways for benzene can vary in carbon intensity by more than 400%. In other words, the most carbon efficient producers are five times as efficient as the most carbon intensive, despite producing a substitutable product. The largest contributors to emissions intensity are emissions associated with the production of inputs, direct emissions during the manufacturing process, and emissions associated with process heat, or the heat required to achieve reaction temperature.[17] The primary sources of such emissions vary widely depending on the method used to manufacture benzene.

Among the largest global manufacturers of benzene are China, South Korea, the U.S., Japan, and the EU, each of which uses a wide variety of production pathways. The carbon intensity of benzene manufacture in each country as estimated by Carbon Minds is described in Table B.

U.S.-made benzene is roughly 25% more carbon efficient than the world average. A key determinant of the U.S. carbon advantage in benzene production is that benzene is a common impurity in gasoline. The U.S. is the single largest refiner of gasoline in the world, allowing it to produce benzene as a byproduct of purifying other refinery products. Effectively, this allows the U.S. to produce large volumes of benzene without employing more carbon intensive processes, like dealkylation or disproportionation of toluene.

TABLE B.

RELATIVE CARBON INTENSITY OF BENZENE MANUFACTURING,
U.S. VS. GLOBAL TOP PRODUCERS

USA	China	EU	Japan	South Korea	Saudi Arabia	World
1.0	1.4	1.5	1.3	1.4	1.3	1.3

🟥 U.S. Carbon Advantage (foreign competitors less carbon efficient)

Source: Carbon Minds (2022), cm.chemicals database V1.01 2022; index calculations by Climate Leadership Council

TOLUENE

Toluene is methylated benzene and is used in the manufacture of diverse final products such as gasoline, foam cushions, industrial solvents, inks, and food preservatives. It's also an important feedstock for benzene and other simple aromatic hydrocarbons.[18] It is most commonly extracted from other supply streams, including directly from crude oil or as a byproduct of producing gasoline, ethylene, propylene, or coking coal. Carbon Minds identifies four manufacturing pathways for toluene.[19]

The carbon intensity of toluene manufacture can differ up to 300%. In other words, the most carbon efficient producers are four times as efficient as the most carbon intensive, despite producing a substitutable product. Generally, the carbon intensity of production is determined by the choice of raw material inputs, followed by emissions from process heat, and by direct emissions during the manufacturing process. As with benzene, the relative contributions of each factor vary considerably across processes.

The largest producers of toluene are China, Korea, Japan, the U.S., India, and Taiwan. Each uses a variety of production pathways, though the carbon intensity of production is, in general, relatively homogenous. The estimated carbon intensities of toluene manufacture in these markets are described in Table C.

The U.S. has a carbon advantage in toluene production over all major global producers. This is likely due to the large scale of U.S. refining. Like benzene, toluene can be extracted from other refinery products, making the U.S. a relatively low-carbon manufacturer as compared with producers that manufacture toluene directly through other processes.

THE U.S. HAS A CARBON ADVANTAGE IN TOLUENE PRODUCTION OVER ALL MAJOR GLOBAL PRODUCERS.

TABLE C.
RELATIVE CARBON INTENSITY OF TOLUENE MANUFACTURING,
U.S. VS. GLOBAL TOP PRODUCERS

USA	China	EU	India	Japan	South Korea	Saudi Arabia	Taiwan	World
1.0	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1

🟥 U.S. Carbon Advantage (foreign competitors less carbon efficient)

Source: Carbon Minds (2022), cm.chemicals database V1.01 2022; index calculations by Climate Leadership Council

AMMONIA

Ammonia supports global agriculture and industrial processes and represents a promising avenue for the global hydrogen energy trade. The majority of ammonia manufactured today is used either directly as a fertilizer or as an input to fertilizers; other applications include emissions abatement, explosives, foams, fibers, and refrigeration.[20] Ammonia is made by combining two inputs: nitrogen from air and hydrogen, typically extracted from fossil fuels via the Haber-Bosch process.[21]

Ammonia production is energy intensive. The largest source of emissions from ammonia production, about 70% of the total, comes from the production of hydrogen. Today, hydrogen largely comes from two primary sources: natural gas and coal. Because natural gas is more hydrogen-dense than coal, ammonia manufactured with hydrogen from natural gas has less than half the emissions of ammonia manufactured with hydrogen sourced from coal.[22] Hydrogen sourced from the electrolysis of water has been produced since 1921. So-called "green" or renewable hydrogen, which requires renewable electricity, has not yet been fully commercially developed, with less than 0.02 million metric tons produced annually.[23]

Smaller contributions to emissions include electricity generation to run ammonia manufacturing facilities, indirect emissions associated with extracting and producing fossil fuel feedstocks, and characteristics including the design, age, modernization, and capacity utilization of individual facilities.

TABLE D.

RELATIVE CARBON INTENSITY OF AMMONIA MANUFACTURING, U.S. VS. GLOBAL TOP PRODUCERS

USA	China	EU	India	Russia	World
1.0	2.1	1.0	1.0	1.0*	1.3

*This does not account for high and under-counted fugitive methane emissions within the Russian natural gas supply chain.

🟥	U.S. Carbon Advantage (foreign competitors less carbon efficient)
⬜	U.S. Carbon Efficiency or Equivalent

Source: Carbon Minds (2022), cm.chemicals database V1.01 2022; index calculations by Climate Leadership Council

The five largest global manufacturers of ammonia are China, the EU, Russia, the U.S., and India. Of these countries, only China and India use coal as a source of hydrogen. In China, coal represents nearly 80% of the national ammonia market, compared with just 5% in India.[24] As reflected in the Carbon Minds data, the choice of feedstock has the biggest impact on the carbon intensity of ammonia production, with China having a carbon intensity that is at least two times that of the United States. U.S. ammonia producers are at least 24% less carbon intensive than the global average.

Aside from China's coal-heavy ammonia sector, all other major manufacturers have similar carbon intensities. Important differences in carbon intensity are obscured by the data and the U.S. and EU advantage are likely to be considerably larger than reported. Notably, upstream emissions associated with the extraction and production of fossil fuel feedstocks vary, though data is presently weak in this area, particularly in less regulated producing regions outside of North America and Europe. For example, the Russian oil and gas sector is 70% more methane intensive than the U.S. oil and gas sector.[25] The International Energy Agency has estimated that the emissions intensity of ammonia production could be 15% higher if methane emissions were considered.[26] Given wide differences in upstream methane emissions, the variation in the carbon intensity of ammonia production could vary anywhere from 5% to 50%.

Already, the U.S. benefits from its preferential use of natural gas as an ammonia feedstock, which supplies 92% of domestic production.[27] The U.S. and EU carbon advantage is only likely to expand as major producers realize investments in carbon capture and sequestration and green ammonia production. U.S. methane emissions are also likely to fall under a new methane emissions fee.[28]

U.S. AMMONIA PRODUCERS ARE AT LEAST 24% LESS CARBON INTENSIVE THAN THE GLOBAL AVERAGE.

POLYETHYLENE

Polyethylene is the most widely produced input for plastics products as diverse as plastic bags, beverage bottles, diapers, piping systems, and bulletproof vests.[29] Chemically, polyethylene is less homogenous than other bulk chemicals explored in this paper, with low- and high-density versions and various forms to suit different applications. Each variety carries a different commercial value on the international marketplace.

Polyethylene is a heavily traded commodity. It is made from ethylene, a lightweight and flammable gas that is generally not traded. Ethylene is manufactured through a variety of cracking, conversion, or purification pathways from crude oil fractions or natural gas.[30] More than half of the global ethylene supply is converted to polyethylene.[31]

There are more than 30 distinct manufacturing processes to produce polyethylene, many of them specific to individual proprietary processes to achieve specific polymer characteristics. Depending on the pathway, carbon intensities in the polyethylene industry vary as much as 1,000%. In other words, the most carbon efficient producers are 11 times as efficient as the most carbon intensive ones. The single largest contributor to emissions from polyethylene production is related to the emissions associated with raw material inputs (roughly 75%), followed by emissions associated with electricity and process heat (totaling about 20%).

The largest global polyethylene manufacturers include China, the EU, the U.S., Saudi Arabia, India, and Korea. China is also far and away the largest global purchaser of polyethylene, absorbing a significant share of the global supply to feed its dominant plastics manufacturing sector. The relative carbon intensity of manufacturing from these major producers is detailed in Table E.

TABLE E.

RELATIVE CARBON INTENSITY OF POLYETHYLENE MANUFACTURING, U.S. VS. GLOBAL TOP PRODUCERS

USA	China	EU	India	South Korea	Saudi Arabia	World
1.0	1.8	0.8	1.1	0.9	1.1	1.1

🟥	U.S. Carbon Advantage (foreign competitors less carbon efficient)
🟦	U.S. Carbon Disadvantage (foreign competitors more carbon efficient)

Source: Carbon Minds (2022), cm.chemicals database V1.01 2022; index calculations by Climate Leadership Council

At 10% more carbon efficient than the world average, the U.S. carbon advantage in polyethylene manufacturing is narrower than other bulk chemicals but important given its position as the world's second largest manufacturer of the chemical. Yet it is hard to attribute the U.S. carbon advantage with precision given the variability in production methods across the industry. The U.S. uses nearly 20 distinct polyethylene manufacturing pathways; every major global producer uses at least ten.

Given the outsized importance of the carbon intensity of material inputs, much of the U.S. advantage is likely attributable to high-quality, efficiently produced raw materials sourced from readily available natural gas and natural gas liquids as well as the relatively carbon efficient U.S. refining sector. As discussed below, the U.S. electricity sector is also significantly more carbon efficient than the world average and leading competitors. Even when using identical production pathways, Chinese polyethylene production is as much as five times more carbon intensive than U.S. production.

THE U.S. CARBON ADVANTAGE IN POLYETHYLENE MANUFACTURING IS NARROWER THAN OTHER BULK CHEMICALS BUT IMPORTANT GIVEN ITS POSITION AS THE WORLD'S SECOND LARGEST MANUFACTURER OF THE CHEMICAL.

POLYPROPYLENE

Polypropylene is the second-largest feedstock for plastics and is generally harder, more heat resistant, and flexible than polyethylene. Applications include textiles, filtration systems, packaging, furniture, and toys.[32] Polypropylene is not homogenous and can be manufactured to different specifications for its variety of uses.

Polypropylene is produced by converting propylene, which is manufactured through similar processes as ethylene (and often as a co-product of ethylene). Such processes include cracking or converting crude oil derivatives like natural gas liquids or naphtha.[33] More than two-thirds of propylene is converted to polypropylene.[34]

There are seven primary manufacturing processes for polypropylene with carbon intensities that vary as much as 600%. In other words, the most carbon efficient producers are seven times as efficient as the most carbon intensive producers. Like polyethylene, the emissions associated with the manufacture of raw material inputs, in this case propylene, are the largest contributor to the carbon intensity of polypropylene production (about 80%), followed by electricity and process heat (about 15% together).

China, the U.S., the EU, India, Saudi Arabia, and Korea are the largest global producers of polypropylene. China is also the largest global purchaser of polypropylene, integrating a large share of global production from more carbon efficient manufacturers into its supply stream to produce globally traded plastic products. The relative carbon intensity of manufacturing from these major producers is detailed in Table F.

The U.S. has a significant carbon advantage in polypropylene manufacture against major global competitors. This advantage is primarily attributable to the quality and relatively low-carbon intensity of inputs, which are natural gas and other products of the relatively carbon efficient U.S. refining sector. Access to lower-carbon U.S. electricity supplies improves carbon efficiency as well. Even when using identical production pathways, U.S. production is two to four times more carbon efficient than Chinese production.

TABLE F.

RELATIVE CARBON INTENSITY OF POLYPROPYLENE MANUFACTURING,
U.S. VS. GLOBAL TOP PRODUCERS

USA	China	EU	India	South Korea	Saudi Arabia	World
1.0	2.9	1.0	1.2	1.2	1.4	1.6

🟥	U.S. Carbon Advantage (foreign competitors less carbon efficient)
⬜	U.S. Carbon Efficiency or Equivalent

Source: Carbon Minds (2022), cm.chemicals database V1.01 2022; index calculations by Climate Leadership Council

4

THE NEED FOR POLICIES TO INCENTIVIZE DECARBONIZATION IN THE CHEMICALS SECTOR

As we've shown, the carbon intensity of chemicals manufacturing can vary widely–even by a factor as high as ten–to produce chemically identical or comparable outputs. In some cases, this divergence in carbon intensity may be an underestimate, especially when data on the emissions associated with raw materials, electricity, or process heat production are unreliable.

Given the global nature of the chemicals trade, it is significant that existing trade rules have no mechanism to reward carbon efficient competitors. Indeed, given tight margins and low profits for bulk chemicals, many operators may find it difficult to access capital or make major investments in operational efficiency, manufacturing processes, or the quality or purity of material inputs. Without valuing lower carbon intensity, trade rules favor lowest-cost producers in regions with laxer environmental standards and reduced operational costs.

Moreover, some foreign governments offer subsidies, trade protection, and other supports to their domestic chemicals manufacturing industry. This has allowed some countries to rapidly expand domestic production and put increasing competitive pressures on cleaner producers like the U.S. and EU. These markets also tend to value increased production over improvements to operational efficiency, driving further differences in the relative carbon intensity of production.

Policy that rewards carbon efficiency in the global chemicals industry can have a meaningful impact on climate change. Worldwide, the industry is the third largest industrial source of greenhouse gas emissions. And more than 96% of manufactured goods are directly touched by the industry.[35] Given the importance of bulk chemicals to economic activity, the carbon intensity of chemicals manufacturing affects the relative carbon efficiency of the entire economy. Trade rules that establish clear market rewards for manufacturers can shift production toward more carbon efficient markets and methods and displace production from the most emissive manufacturers. In turn, the global economy can become less carbon intensive.

TRADE RULES THAT ESTABLISH CLEAR MARKET REWARDS FOR MANUFACTURERS CAN SHIFT PRODUCTION TOWARD MORE CARBON EFFICIENT MARKETS AND METHODS AND DISPLACE PRODUCTION FROM THE MOST EMISSIVE MANUFACTURERS.

CHINA'S ADVANTAGE IN PRODUCING CHEAP, HIGH CARBON-INTENSITY CHEMICALS

China's role as a major, low-cost player in the global chemical industry illustrates the challenges for decarbonization.

The most significant determinant of the carbon intensity of bulk manufacturing production tends to be the carbon emissions associated with accessing raw materials. China is the only major manufacturer with a continuing and disproportionate dependence on coal-derived inputs for bulk chemicals manufacturing. To use coal, rather than oil and gas, it must be mined, processed, and then gasified, an energy intensive process of accessing the light hydrocarbons necessary for bulk chemicals manufacture. As a consequence, China tends to have disproportionately high emissions to create chemically identical products.

In addition, China has an enormously competitive position on capital deployment in the chemicals sector, with costs about 40% lower than similar deployment in the U.S.[36] Low-cost capital ensures that the Chinese chemicals industry can outpace growth in other major markets. Given that Chinese carbon intensities for manufacturing bulk chemicals are 20-200% higher on average than comparable U.S. carbon intensities, its ongoing rapid growth in chemicals manufacturing capacity is not only a threat to U.S. and EU chemical plants but also to worldwide industrial decarbonization efforts.

THE UNITED STATES' CARBON ADVANTAGE

The U.S. has an efficient, innovative economy and a power sector that has been steadily decarbonizing for more than a decade. As a result, even though the U.S. is the second largest emitter of greenhouse gases, its industries are among the most carbon efficient in the world. In fact, U.S. industries, across sectors, are far more carbon efficient than most of their key trading partners, as described in the Climate Leadership Council's September 2020 report, *America's Carbon Advantage*. Table G describes the relative carbon intensity of production across industries and the electricity sector for the major chemical producers studied in this report.

The U.S. chemicals industry benefits from low-cost, reliable, domestically produced raw materials, especially access to natural gas, natural gas liquids, and the byproducts of a sophisticated and robust U.S. refining sector. These are crucial petrochemical inputs, and the U.S. chemicals industry has uniquely good access to lower-carbon supplies. Natural gas provides more than half of the energy requirements for the U.S. chemicals sector and more than half of the primary material input.[37] Indeed, the shale gas boom starting in the 2010s has driven down chemical manufacturing costs and allowed the U.S. to expand production capacity while remaining especially competitive on carbon intensity.

The EU and Saudi Arabia tend to use oil and natural gas as their primary petrochemical inputs. Note that Saudi Arabia has a slightly higher carbon intensity across the chemicals explored in this analysis; artificially low domestic fuel prices may be dampening the incentive to make the investments in process changes and energy efficiency that have helped U.S. and EU manufacturers cut emissions.

The second most important determinant of carbon intensity, generally, is the carbon intensity of electricity and process heat production. Here, again, the U.S. has an advantage. Thanks to the significant share of U.S. electricity production from natural gas, nuclear, and renewables, the U.S. generates electricity with lower emissions than the world average and much lower emissions than major chemicals competitors China and Saudi Arabia.

TABLE G.

AMERICA'S CARBON EFFICIENCY ADVANTAGE ACROSS SECTORS VS. MAJOR CHEMICAL MANUFACTURERS

	USA	China	EU	Saudi Arabia	World
Agriculture, forestry and fishing	1.0	1.2	1.2	0.4	1.0
Mining and extraction of energy producing products	1.0	2.2	0.9	0.3	1.3
Mining and quarrying of non-energy producing products	1.0	2.2	0.8	2.4	1.4
Mining support service activities	1.0	5.2	1.9	0.7	1.9
Food products, beverages and tobacco	1.0	1.4	0.8	3.4	1.1
Textiles, wearing apparel, leather and related products	1.0	1.8	0.8	4.7	1.5
Wood and products of wood and cork	1.0	1.8	0.9	3.4	1.4
Paper products and printing	1.0	1.7	0.8	3.1	1.2
Coke and refined petroleum products	1.0	1.6	1.3	0.8	1.3
Chemicals and pharmaceutical products	1.0	2.6	0.8	3.1	1.6
Rubber and plastic products	1.0	2.7	0.7	5.0	2.0
Other non-metallic mineral products	1.0	1.6	1.0	1.9	1.3
Basic metals	1.0	1.8	0.9	1.9	1.5
Fabricated metal products	1.0	3.1	0.9	1.7	1.8
Computer, electronic and optical products	1.0	5.7	2.1	16.0	4.0
Electrical equipment	1.0	3.1	1.0	3.2	2.2
Machinery and equipment	1.0	2.8	0.8	4.3	1.8
Motor vehicles, trailers and semi-trailers	1.0	2.4	0.7	2.2	1.3
Other transport equipment	1.0	2.8	0.8	4.0	1.5
Other manufacturing; repair and installation of machinery and equipment	1.0	2.8	0.7	14.1	1.9
Economy-wide carbon intensity	**1.0**	**3.2**	**0.9**	**2.7**	**1.8**

Electricity generation	**1.0**	**1.4**	**0.7**	**1.5**	**1.2**

🟥	U.S. Carbon Advantage (foreign competitors less carbon efficient)
🟦	U.S. Carbon Disadvantage (foreign competitors more carbon efficient)
⬜	U.S. Carbon Efficiency or Equivalent

Source: sectoral carbon intensity data from MacroDyn Group calculations based on data from the International Energy Agency, the World Input-Output Database environmental accounts, and the Global Trade Analysis Project; electricity data from Our World in Data

Many industrial facilities produce their own electricity and process heat on-site via cogeneration. The U.S. and EU especially have invested widely in cogeneration to produce electricity and process heat at or directly for manufacturing facilities.[38]

It's not just sources of electricity, but how efficiently that electricity is used. The U.S. has made considerable energy efficiency investments across the chemicals industry. Combined with the adoption of cogeneration, this investment has led to fuel and power consumption falling by half over the last 50 years, even as manufacturing expanded dramatically. This allows the U.S. to produce more with less, keeping carbon emissions stable while driving down other greenhouse gases, like NOx, HFCs, and methane. Reflecting general carbon intensity trends, Europe and North America are world leaders in industrial energy productivity, outpacing China and the Middle East by two to three times.[39]

THE U.S. HAS AN EFFICIENT, INNOVATIVE ECONOMY AND A POWER SECTOR THAT HAS BEEN STEADILY DECARBONIZING FOR MORE THAN A DECADE. AS A RESULT, ITS INDUSTRIES ARE AMONG THE MOST CARBON EFFICIENT IN THE WORLD.

5

CONCLUSION

The U.S. chemicals industry enjoys a considerable carbon advantage in manufacturing against major global competitors in the chemicals industry generally, and specifically in the manufacture of five key bulk chemicals. At present, there are no mechanisms to directly reward the carbon efficiency of U.S. chemicals production, especially since the manufactured product is relatively homogenous and easy to substitute. The current rules of global trade reward low-cost manufacture, not innovation or investment consistent with decarbonization. In the absence of these trade policies, we will face greater political and economic barriers to further reducing emissions from the international and domestic chemicals industry, which given its size, is essential for meeting our climate goals.

Emerging climate and trade policies can reverse these trends. Given the tight margins in the bulk chemicals industry, the incremental benefit of trade policies that reward carbon efficiency can drive considerable carbon intensity improvements across capacity utilization decisions, capital investments, input choices, energy production, and process selection. For example, the EU is considering chemicals in its carbon border adjustment mechanism, which would require chemicals importers to bear costs for the carbon emissions released during chemicals manufacture. Depending on its final design, this policy could give U.S. chemicals an edge in the European market compared to more carbon intensive production from China and Saudi Arabia in particular.

As the global conversation about climate and trade policy gains steam, additional policy levers via adoption of a U.S. carbon price and border carbon adjustment (such as that proposed by the Baker-Shultz Carbon Dividends Plan), unilateral carbon border adjustment mechanisms (currently being considered in Canada and the UK), climate clubs (currently under consideration among G7 states), or individual commodity agreements (currently in negotiation between the U.S. and EU) present new avenues to reward more carbon efficient manufacture.

U.S. policymakers have a unique opportunity to leverage the U.S. carbon advantage in chemicals manufacturing and to partner with other clean, climate ambitious markets to realize and reward the low-hanging fruit in emissions reductions already available in the chemicals sector. In turn, this momentum can tilt global industry trends toward better climate outcomes.

Carbon intensity data is constantly improving, and better information related to facilities, products, and inputs will improve our understanding of the U.S. carbon advantage and future decarbonization opportunities. The Council and others will continue to explore ways to grow the pool of carbon intensity data and to identify pathways that will improve prospects both for decarbonization and the competitive position of carbon efficient firms.

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Catrina Rorke serves as executive director of the Center for Climate and Trade and senior vice president, policy and research at the Climate Leadership Council. Prior to joining the Council, Ms. Rorke was director of energy policy and senior fellow at the R Street Institute and also founded the energy program at the American Action Forum. As a legislative assistant to former U.S. Rep. Bob Inglis of South Carolina, Ms. Rorke helped develop the first Republican-sponsored carbon tax bill. She began her career as a presidential management fellow with the National Oceanic and Atmospheric Association.

ABOUT THE CENTER FOR CLIMATE AND TRADE

The Climate Leadership Council's Center for Climate and Trade explores and advances policies that leverage trade relationships and the global market economy towards greater international cooperation and climate ambition.

This report is a work product of the Climate Leadership Council and does not necessarily reflect the views of its organizational partners.

APPENDIX: CARBON MINDS MODEL DESCRIPTION AND LIMITATIONS

The cm.chemicals database is a life-cycle inventory database for more than 1000 chemicals and plastics in 190 regions worldwide. The database was developed over many years by German data provider and consultancy Carbon Minds. Launched in 2020 and updated annually, the database integrates with all major life cycle assessment software. The data within cm.chemicals is secondary data, generated from a proprietary, internally consistent methodology, which allows for a high degree of regionalization.

The carbon minds database allows producers to benchmark their footprints with competitors and to optimize the carbon footprints from a company's perspective. It enables life-cycle assessments whose results translate into reduction potentials of environmental impacts along the entire chemical and plastics value chain.

In September 2021, the methodology behind the cm.chemicals database received certification from TÜV Rheinland for compliance with ISO 14040/14044. The reviews take place annually. The current methodology document can be found here: https://www.carbon-minds.com/cm-chemicals-methodology.pdf.

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