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Iron and Steel Decarbonization by 2050: An Opportunity for Workers and Communities

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About the Roosevelt Project

The Roosevelt Project takes an interdisciplinary approach to the transitional challenges associated with progress toward a deeply decarbonized economy. The project aims to chart a path forward through the transition that minimizes worker and community dislocations and enables at-risk communities to sustain employment levels by taking advantage of the economic opportunities present for regional economic development. The first phase looked at the history of such transitions in the United States in order to provide a foundation of lessons learned. The second phase examined four places in the United States that are facing uncertainty as the energy system changes. The third phase analyzes large-scale changes that are needed in critical areas of the economy. The project was initiated by former Secretary of Energy, Ernest J. Moniz, and engages a breadth of MIT and Harvard faculty and researchers across academic domains including Economics, Engineering, Sociology, Urban Studies and Planning, and Political Science.

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List of Abbreviations

AD	Antidumping Duties
AISI	American Iron and Steel Institute
BCA	Benefit-Cost Analysis
BF	Blast Furnace
BIL	Bipartisan Infrastructure Law (same as IIJA)
BOF	Basic Oxygen Furnace
CAT	Cap and Trade
CBA	Community Benefits Agreement
CBAM	Carbon Border Adjustment Mechanism
CBP	U.S. Customs and Border Protection
CBP	Community Benefits Plan
CCA	Clean Competition Act of 2022
CCS	Carbon Capture and Sequestration
CCSC	Coordinated Committee of Steel Companies
CCU	Carbon Capture and Utilization
CF&I	Colorado Fuel and Iron Company
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CMC	Commercial Metals Company
COLA	Cost-of-Living Allowance
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
CVD	Countervailing Duties
DAC	Direct Air Capture
DOC	U.S. Department of Commerce
DOE	U.S. Department of Energy
DOL	U.S. Department of Labor
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EITE	Energy-Intensive Trade-Exposed (Industries)
EJSCREEN	U.S. EPA's Environmental Justice Screening and Mapping Tool
ENA	Experimental Negotiating Agreement
EPA	U.S. Environmental Protection Agency
ESF	Electric Smelting Furnace
EU CBAM	European Union Carbon Border Adjustment Mechanism
EU ETS	European Union Emissions Trading System
FAIR	Fair, Affordable, Innovative, and Resilient Transition and Competition Act of 2021
FPFA	Foreign Pollution Fee Act of 2023
FY	Fiscal Year
GATT	General Agreement on Tariffs and Trade
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHGRP	EPA Greenhouse Gas Reporting Program
GRI	Global Reporting Initiative
GSA	Global Arrangement on Sustainable Steel and Aluminum
GSSC	Global Steel Climate Council
HBI	Hot Briquetted Iron
H2Hubs	Regional Clean Hydrogen Hubs Program
HTS	Harmonized Tariff Schedule
IEA	International Energy Agency
IIJA	Infrastructure Investment and Jobs Act (same as BIL)
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
ISG	International Steel Group

ISO	International Organization for Standardization
ITA	U.S. International Trade Administration
LBAM	Leakage Border Adjustment Mechanism
MBQ	Merchant Bar Quality
MEA	Multilateral Environmental Agreement
MFN	Most Favored Nation
MRV	Monitoring, Reporting, and Verification
mt	Metric Tons
MMT	Million Metric Tons
MW	Megawatts
NAFTA	North American Free Trade Agreement
NG	Natural Gas
NREL	National Renewable Energy Laboratory
OCED	U.S. Office of Clean Energy Demonstrations
OSM	Oregon Steel Mills
PLA	Project Labor Agreement
PM	Particulate Matter
PNTR	Permanent Normalization of Trade Relations
PPA	Power Purchase Agreement
PROVE IT	Providing Reliable, Objective, Verifiable Emissions Intensity and Transparency Act of 2023
PUC	Public Utilities Commission
PV	Photovoltaic
QCEW	Quarterly Census of Employment and Wages
R&D	Research and Development
RE	Renewable Energy
RGGI	Regional Greenhouse Gas Initiative
RMP	Risk Management Plan
SASB	Sustainability Accounting Standards Board
SDG	Sustainable Development Goals
SEC	U.S. Securities and Exchange Commission
SSBP	Sustainable Steel Buyers Platform
st	Short Ton
STAC	Steel Tripartite Advisory Committee
TAA	Trade Adjustment Assistance
tcs	Ton of Crude Steel
TCFD	Task Force on Climate-Related Financial Disclosures
TCP	Trade and Climate Policy
tpa	Tons per Annum (metric)
TRQ	Tariff Rate Quota
USDA	U.S. Department of Agriculture
USDT	U.S. Department of the Treasury
USITC	U.S. International Trade Commission
USMCA	United States-Mexico-Canada Agreement
USTR	U.S. Trade Representative
USW	United Steelworkers
WIB	Workforce Investment Board
WTO	World Trade Organization

Preface

The Roosevelt Project launched in 2017 to address the challenges facing workers and communities as our economy decarbonizes and our energy and industrial systems undergo substantial related change, ideally at a rapid pace compared with past major societal transformations. How do regional economies adjust to the decline of a key industry? What happens to the workers in those industries and those in the surrounding economies? How can regional, state, and federal governments anticipate and adapt to industrial decline and to the invention of new industries? What is the role of civil society, foundations, unions, colleges and universities, national labs, and other institutions in helping “energy communities” gain from the clean energy transition? The American experience offers rich and instructive cases of success and of failure in societal transformation that can help the United States—and others—navigate the changes in our economy that will come with evolving energy systems.

The Roosevelt Project stands on three pillars—economy, environment, and equity. These are exemplified by the namesakes of the Project: Franklin Delano Roosevelt’s presidency saved the American economy from collapse during the Great Depression; Theodore Roosevelt’s presidency recognized and protected the natural wonders of the American continent; Eleanor Roosevelt was an unwavering champion of social equity and justice. These are the lenses through which the Roosevelt Project has examined the societal implications of the clean energy transition.

The Roosevelt Project has conducted three waves of inquiry into equitable energy and industrial transition. The first phase looked at the history of such transitions in the United States in order to provide a foundation of lessons learned. The second phase examined four places in the United States that are facing uncertainty as the energy system changes. The third phase, of which this report is a part, analyzes large-scale changes that are needed in critical areas of the economy. All Roosevelt Project reports are available at https://ceepr.mit.edu/roosevelt-studies.

This study is one of three investigations into the challenges and opportunities in critical parts of the American energy sector: long-distance electric transmission, strategic metals and minerals, and low-carbon steel. Each presents key infrastructure and industrial challenges that must occur for the United States to take full advantage of the nation’s low-carbon energy resources.

- Grid: A significant expansion of long-distance transmission capacity is needed to connect remote wind and solar resources to major urban and industrial users and represents an important part of the solution to meeting major electrification demands of the new economy.
- Minerals: Electrification of transportation, steel, buildings, and other end uses (such as AI-driven data centers) will require expanded access to critical minerals, such as lithium, cobalt, nickel, copper, rare earths and many others. Extraction and processing of these minerals present environmental challenges, including for frontline communities and tribal lands.
- Steel: Decarbonizing steel has proved difficult and slow. Solutions will need integration of community, workforce, competitiveness and trade priorities.

We hope that the Roosevelt Project will continue to inform the debate about simultaneously advancing social equity and the clean energy transition.

Ernest J. Moniz
Cecil and Ida Green Professor of Physics and Engineering Systems Emeritus, MIT
13th U.S. Secretary of Energy
Faculty Director, The Roosevelt Project

Executive Summary and Recommendations

Steel and the steel industry are critical to societies today due to their central role in manufacturing and infrastructure as well as their long-standing importance for defense. Ensuring a sufficient supply of steel for the U.S. economy while deeply reducing greenhouse gas (GHG) emissions to address climate change will require solutions that integrate community, workforce, competitiveness, trade, and national security priorities. This case study lays out a path for accelerating decarbonization of the iron and steel industry that benefits workers and communities. The recommendations of this study outline a framework for comprehensively supporting the technology and infrastructure required for decarbonization, using revenues from an established policy instrument, Section 232 tariffs.

Steel production in the United States has undergone a unique evolution over the past 75 years as the share of electric arc furnace (EAF) production, frequently by new players, has increased dramatically relative to that of the integrated or BF-BOF route—converting iron ore to iron in a blast furnace (BF) and refining it along with scrap into steel in a basic oxygen furnace (BOF). In the United States today, 70% of steel is produced in EAFs and 30% in BOFs, compared to shares of 30% and 70%, respectively, 40 years ago. This transformation has shifted steel production to new regions of the country and involved new workforces and communities. This transition is the principal reason why the emissions intensity of steel in the United States is relatively low, at approximately 1 metric ton (mt) of CO_2 per mt of crude steel (tCO_2/tcs). It is also reflected in the fact that worldwide steel production accounts for 7% of total energy-related CO_2 emissions, while in the United States, its production accounts for only 2%.

Future steel production in the United States, including its decarbonization, will be shaped by a range of conditions and constraints. These include: (1) the availability and cost of inputs, including high-quality scrap, (2) technology readiness and implementation to further reduce GHG emissions from domestic ironmaking and integrated mills, (3) the economics of meeting surface product quality requirements with EAF technologies, (4) the cost of producing ore-based metallics for EAF production with very low CO_2 emissions, (5) the availability of decarbonized electricity to support large industrial loads for all steelmaking facilities, (6) future global and domestic demand for steel, and (7) national security and trade considerations.

Overcoming the Economic Challenge

The challenges in decarbonizing iron and steel production in the United States are mainly economic rather than technical. The ironmaking process is the major source of GHG emissions, although mining, transport, steelmaking, electricity generation, and downstream processing also contribute substantially. Several decarbonization options for current iron and steel production routes are available today.

For illustrative purposes, this analysis provides cost estimates for two options to reduce GHG emissions from both EAF and BF-BOF steelmaking that support a reduction of 70–75% of Scope 1 and 2 GHG emissions relative to 2023 levels. Scope 1 is defined as direct emissions, while Scope 2 is indirect emissions from purchased electricity or heat. Scope 3 is other indirect emissions across the supply chain, both upstream and downstream of iron and steel production. For

BF-BOF plants, this analysis models carbon capture and sequestration (CCS) on BFs as well as direct reduced iron (DRI) produced using natural gas with CCS, plus a melt furnace using existing BOFs. For EAF steelmaking, the model focuses on DRI produced using natural gas with CCS or DRI produced using hydrogen, which is generated via electrolysis with decarbonized electricity.

Relative to the cost of producing steel today, each of these pathways is expensive. The required capital outlays will be approximately $27–41 billion through mid-century; that is, between $1 and $1.6 billion per year, a massive increase in the capital budget of most steel-producing companies. Since there is currently no measurable economic return associated with steel decarbonization investments, companies are unlikely to invest at the rate required to meet national and global climate change mitigation goals, reducing or eliminating GHG emissions. Hence federal policy plays an essential role in providing incentives for decarbonizing investments.

The incremental operating costs of these investments are also substantial. These costs can be partially or fully offset by existing 45Q and 45V Inflation Reduction Act tax credits. However, both tax credits are currently set to expire at the end of 2032, and their implementation should be extended and expanded to provide operating cost relief.

Utilizing Section 232 steel tariff revenues, currently $1.5–2.5 billion annually, to fund decarbonization capital investments (implemented through an effective review process and possibly some cost-sharing requirements) would enable steel companies to pursue decarbonization aggressively and emerge as global technology leaders. These investments would support existing iron and steel industry jobs and benefit communities by improving local air quality.

Benefits to Steelmaking Communities and Workers

For this study, we conducted surveys of communities near iron and steel production sites. In general, survey respondents note several contributions of the steel industry's presence, including high-paying jobs with benefits, public revenue, and other forms of direct economic support. In 2023, employees in EAF and BF-BOF production earned approximately $2,040 per week, 54% above average U.S. wages.

The surveys find that 82% of respondents associate steel plants with positive community impacts related to job creation and to work-related skills development. Respondents generally feel positively toward decarbonization. Economic issues, particularly job and retirement security, are the top concerns for all surveyed communities. Respondents also indicated they would like to see higher wages and greater job creation, retirement benefits, and job training. Respondents are most concerned with the rising cost of living and job loss, including layoffs and outsourcing.

Trade Policy for Steel Decarbonization

Trade policy is essential to maintaining a healthy steel industry, both in the United States and worldwide, by discouraging unfair trade practices and supporting high-quality jobs and strong environmental performance. Current Section 232 tariffs have not only strengthened national security, their primary purpose, but have also impacted mainly products from countries that have relatively high GHG emissions from steel production. Trade policy will continue to have consequences for steel decarbonization, since companies and nations that incur the related costs risk losing competitiveness to overseas producers that continue to emit GHGs at current rates. Efforts to address this risk through a carbon-based border adjustment mechanism (CBAM) have been pursued by the European Union and others but to date this approach, despite its theoretical appeal, has not been adopted in the United States. Thus, this case study recommends that existing Section 232 tariffs on direct steel imports should be continued for at least five to eight years and the revenues allocated for the capital expenditures required for steel decarbonization. In the long term, a carbon border adjustment mechanism (CBAM) negotiated between the United States and key trading partners could provide a sustained source of funding based on the GHG emissions intensity of direct and indirect imports, once accounting protocols and verification systems have been agreed upon and established.

Recommendations

This case study generated four key recommendations, laid out below, for a self-funded framework to accelerate deep decarbonization of the iron and steel industry in the United States.

Recommendation 1: Create a national public-private commission to provide leadership and oversight for accelerated iron and steel decarbonization. This commission should be composed of industry, appropriate government agencies, labor, technical experts, and community members. Industry, government, labor, and community representatives should have the opportunity to nominate their own representatives, who would be confirmed by the executive branch. The commission would have broad responsibility to design and review a federal plan for iron and steel decarbonization by 2050. Consistent with federal advisory committee rules and SEC requirements, the commission's key responsibilities would include: (1) developing consensus criteria for net-zero compatible technologies eligible for federal support and overseeing implementation, (2) identifying critical iron and steel decarbonization infrastructure projects, and (3) producing, by December 1, 2025, a roadmap report on iron and steel decarbonization by 2050, which would be used as guidance by implementing federal agencies. The commission should also issue an annual report to the executive and Congress describing the industry's decarbonization program, tracking its progress toward decarbonization goals (based on internationally common or at least interoperable CO_2 emissions accounting boundaries), and identifying gaps in various complementary dimensions of the steel transition.

Recommendation 2: Appropriate Section 232 revenues to fund iron and steel decarbonization by 2050. Section 232 tariffs should be maintained and extended for at least five to eight years or until an agreement on a CBAM is reached with major trade partners. The related Section 232 revenues should be used to fund capital costs for iron and steel decarbonization. A new Office of Steel Decarbonization, administered by the U.S. Department of Energy, should be established to review grant applications and award iron and steel industry decarbonization grants following the guidance supplied by the commission's roadmap report on iron and steel decarbonization and annual reports to the executive and Congress. Once a CBAM is in place to provide funding for decarbonization of iron and steelmaking, Section 232 revenues should revert to the U.S. Department of the Treasury.

Recommendation 3: Extend and augment existing IIJA and IRA programs and tax credits to support iron and steel decarbonization. The funds appropriated for the Industrial Demonstrations Program (IDP), CCS, and the Regional Clean Hydrogen Hubs Program (H2Hubs) will contribute to enabling both early plant-specific investments and deep decarbonization through the provision of infrastructure to access clean electricity and hydrogen. Existing IRA tax credits such as 45Q and 45V will be necessary for iron and steel decarbonization by 2050 and should be adjusted for inflation and extended for the industry beyond their current expiration at the end of 2032. Since multiple federal agencies have a range of authorities and programs that could impact the speed and success of iron and steel industry decarbonization efforts, an interagency working group, including representatives of the DOC, DOE, DOL, USDT, and EPA, should be established to coordinate federal support across federal agencies for iron and steel plants to decarbonize using new and existing programs. This working group should coordinate its activities with the commission and the DOE's Office of Steel Decarbonization and be mandated to address roadblocks to iron and steel industry access to enabling infrastructure, such as decarbonized electricity; carbon capture, transport, and sequestration; and clean hydrogen.

Recommendation 4: Involve community members and workforce representatives early and often in decarbonization planning. Iron and steel companies should proactively engage community members and workforce representatives, including labor unions, to design decarbonization plans with accountability for outcomes. These engagement strategies will need to be site-specific, addressing unique legacies and stakeholder dynamics. Training and upskilling opportunities for affected employees will be an essential component of all decarbonization plans. Companies should ensure that any public health and environmental co-benefits of decarbonization investments are key components of community engagement and part of the design of any Community Benefits Plans (CBPs). Ultimately, Community Benefits Agreements that codify job quality, public health, and environmental targets with accountability provisions are an essential outcome of both community engagement and CBPs and should be required of all federal grant recipients.

1. Introduction

Steel is essential to societies worldwide. At the same time, global iron and steel production accounts for 7% of CO_2 emissions from the energy sector, including process emissions. In the United States, iron- and steelmaking contributes only 2% to national CO_2 emissions, due largely to a much greater share of scrap use and EAF steelmaking. Both the global and U.S. industries face increasing pressure to lower CO_2 emissions drastically to address climate change.

Enabling early investments in steel produced with very low CO_2 emissions and supporting markets for these decarbonized products also carries implications for domestic economic competitiveness, trade, national security, and community stability. The ongoing armed conflicts in Ukraine and in the Middle East and increasing tension in United States-China relations have forced a reevaluation of supply chains and trade relations for both efficiency and security. Done well, decarbonization can address all these issues while also creating jobs and improving environmental quality for communities near iron and steel production across the United States.

This case study, part of the third phase of the Roosevelt Project, describes how U.S. policy can support a path to decarbonization of the iron and steel industry that simultaneously addresses the concerns of steelworkers, companies, and communities across the United States. Its framework supports an immediate transition based on known technologies, while maintaining incentives to innovate in the future. This case study also summarizes a broad range of stakeholder viewpoints, primarily taken from a survey of communities located near U.S. BF-BOF and EAF steel production sites along with a series of in-depth interviews. The analysis is rooted in the realities of the global and U.S. domestic steel industry today while drawing lessons from the past, especially from the period of bankruptcies in the industry in the 1980s and 1990s and the adversity it created for workers and communities.

A cornerstone of this analysis is identifying a robust mechanism for funding the substantial capital costs of deep decarbonization in the near term, positioning the domestic industry to take the lead, both nationally and globally. Shielding producers and consumers—as well as workers and communities—from the near-term costs of decarbonization will limit adverse impacts on both the industry's national competitiveness and the nation's social fabric. This analysis proposes that such support initially be funded with existing Section 232 steel tariff revenues for the next five to eight years or until a permanent CO_2-targeted framework can be established.

An early start is necessary because the window for the United States to take the lead in decarbonized iron and steel production is rapidly closing. Carbon pricing for iron and steel products is already in place in Europe—where border carbon tariffs have been announced—and is being developed in China, the world's largest steel-producing nation. More countries will likely adopt these mechanisms within the next decade. In addition, government support for iron and steel decarbonization investments and enabling infrastructure is in place in Europe and Japan. A federal financial commitment to deep decarbonization by mid-century will affect near-term industry investment decisions, such as blast furnace relines, and provide greater certainty to the value of long-term capital investments. While U.S. iron and steel production is on average less GHG emissions intensive than most, this position may turn into a liability if it leads to complacency and inaction.

On the other hand, an approach that enables both EAF and integrated producers, workers, and communities to proactively shape first-of-a-kind decarbonization investments could ensure broad-based benefits.

This case study is structured as follows: **Chapter 2** provides a background on the U.S. iron and steel industry's production, technology, and climate change impact in a global context. **Chapter 3** describes decarbonization options for the industry and estimates the cost of substantially reducing GHG emissions from U.S. iron and steel production—up to 75% reduction in CO_2 emissions—by mid-century. **Chapter 4** describes the results of a survey of residents living near iron and steel production sites, placing them in the context of a growing diversity of steelmaking communities in the United States. **Chapter 5** examines what lessons we can learn from past transitions in the U.S. industry, most notably its collapse in the 1980s and 1990s and resulting dislocation. **Chapter 6** examines U.S. trade policy for steel and builds the case for using existing tariffs to fund the early years of the industry's decarbonization transition. **Chapter 7** summarizes our recommendations.

2. The Steel Industry in the United States and Its Global Context

Key messages:

- Steel and the steel industry are critical due to their central role in supporting manufacturing and infrastructure as well as their long-standing importance for defense. The global steel industry is a major source of GHG emissions. Thus, addressing the global challenge of climate change requires decarbonization of iron- and steelmaking processes. Along many dimensions, the United States is already a global leader in decarbonizing steel.
- Decarbonization of iron and steel production is intertwined with climate, trade, and national security policy in the United States and around the world.
- Global economic developments and relatively low per capita demand for steel in the United States, given its development stage, have led to a reduction in the United States' global share of steel production, from 53% in the 1950s to 4% today. Nevertheless, the United States is still the world's fourth-largest producer and third-largest consumer of steel, reflecting its status as the world's largest direct and indirect steel importer. Steel production technology in the United States has evolved over the past 75 years, as the share of EAF production, frequently by new players, has increased dramatically relative to the integrated route. This transformation has shifted steel production to new regions of the country and involved new workforces. In the United States in 2022, approximately 70% of crude steel was produced via the EAF route and 30% via the BF-BOF route. Globally, these shares are roughly reversed. As a result, average CO_2 intensity per ton of crude steel (tcs) in the United States is about half of the world average. U.S. BF-BOF plant CO_2 intensity is also lower than the global average.
- Future steel production in the United States, including the decarbonization of the steel industry, will be shaped by several factors. These include: (1) the availability and cost of inputs, including high-quality scrap, (2) technology readiness and implementation to further reduce GHG emissions from domestic ironmaking and integrated mills, (3) the economics of meeting surface product quality requirements with EAF technologies, (4) the cost of producing ore-based metallics for EAF production with very low CO_2 emissions, (5) the availability of decarbonized electricity to support large industrial loads for all steelmaking facilities, (6) future global and domestic demand for steel, (7) national security and trade considerations.

Steel has maintained a prominent position on the national agenda due to its importance to the economy, jobs, and national defense; its exposure to trade; and more recently, its GHG intensity of production. The United States, the largest producer of steel at the end of World War II, is now the fourth-largest steel-producing nation, behind China, India, and Japan. China has made massive investments in its steel industry over the past 30 years and its production now accounts for over half of the world's output, while the United States produces only 4% of the global total. Although steel produced in the U.S. is, on average, less GHG emissions intensive per metric ton (mt) than worldwide production, iron and steel in the United States accounts for 2% of U.S. GHG emissions, including process emissions. The United States imports almost as much steel as it produces, either as raw steel and semifinished steel products or as indirect imports in the form of automobiles, car parts, and appliances, making it the largest importer of steel in the world. Most direct and indirect imports are sourced from producers with a much higher GHG intensity of production and related logistics.

Four complexities of the global steel industry will shape its decarbonization in the United States:

1. Variation across countries and regions in access to inputs, including raw materials, energy sources, and supporting infrastructures;
2. Variation across countries and regions in demand for products by stage of economic development;
3. Variation across countries and regions in the role of trade versus domestic production of steel and its downstream products, introducing the possibility of relocation to less regulated countries (often labeled “carbon leakage”) in response to domestic pressure to mitigate GHG emissions; and
4. A common role of iron and steel in national security, due to their importance in essential infrastructure, as well as their critical status in the production of armament and munitions.

Consequently, initiatives to decarbonize the industry in one country will inevitably become intertwined with climate, trade, and national security policy in multiple countries.

As long as decarbonization entails large and uncertain investments for the industry, companies will face difficulty justifying decarbonization costs. Iron and steel production is strongly exposed to volatility in the macroeconomy. Over the past decade, profit margins in the industry averaged between 8% and 10%, constraining the budget for R&D—although a few top performers achieved margins of 20% to 30% over the same period.[1] Nevertheless, decarbonization of the industry is projected to cost billions of dollars—exceeding the market capitalization of the largest industry players.

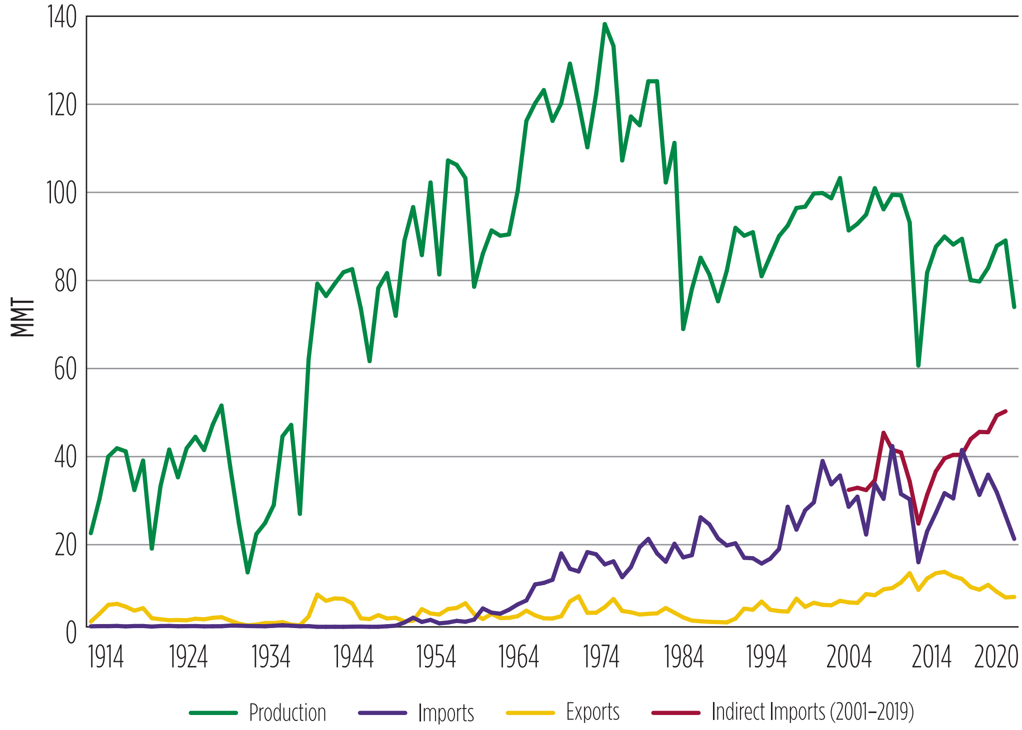
By describing steel production and use in the U.S. economy in a global context, this chapter sets the stage for an analysis of decarbonization pathways for the industry (in chapter 3) and consideration of the characteristics and views of communities near iron and steel production (in chapter 4), the lessons from past industrial policy (in chapter 5), and the role of trade policy (in chapter 6).

2.1 U.S. Production: A Brief History

The U.S. iron and steel industry emerged in the early 20th century as the core of U.S. manufacturing capacity. The industry played a pivotal role in the competitiveness of the U.S. manufacturing sector and in employment nationwide, producing the world’s first $1 billion company, U. S. Steel. These attributes, and others, help to explain the prominent position of the iron and steel industry on the federal policy agenda and industrial policy efforts to support it since the 19th century.

For much of the industrial age, iron and steel were produced and consumed domestically—in part due to their low weight to value ratio but also due to steel’s importance as an input to critical infrastructure and national defense. After the end of World War II, steel production in the United States grew and then peaked around 1970 before sharply declining in the 1980s amid global industry overcapacity (see figure 2.1). In 1950, the United States produced 100 million metric tons (MMT) of steel, almost 53% of the 189 MMT produced globally.[2] In 2022, the United States produced only 81 MMT, or 4.3% of a global total of 1,885 MMT (see figure 2.2).[3]

Figure 2.1 U.S. raw steel production, imports, and exports since 1914. Data on indirect imports is only available from 2001 to 2019.[4]



2.2 Global Integration of Steel Markets

Openness to trade has created new pressures for the domestic industry. While the role of the U.S. domestic steel industry in the global market has declined, the role of direct imports in the U.S. market has grown considerably, fluctuating for the last 30 years between 20 and 40 MMT.[5] By 2022, direct and, importantly, indirect steel imports added together grew to reach around the same level as U.S. domestic production, while the U.S. share of the global production declined again between 2000 and 2020. Following China's entry into the World Trade Organization in 2001, steel production in that country expanded to meet both domestic and, increasingly, global demand (see figure 2.3). China is also a major exporter of intermediate and finished products with a high embodied steel content, such as construction materials, motor vehicles, and appliances and their components.

The U.S. government has long considered domestic production of steel to be critical for national security, even as shares of direct and indirect imports of steel have increased. A 2018 report found that these imports had reached levels that "threaten to impair the national security of the United States," leading to the imposition of tariffs under Section 232 of the Trade Expansion Act of 1962, which are still in effect today.[6] Excessive imports were attributed to distortions resulting from "non-market excess capacity." Exempt from tariffs are imports from Argentina, Australia, Brazil, Canada, Japan, Mexico, South Korea, and the member countries of the European Union.[7] In addition to arguments that domestic steel production is consistent with a free and fair market-based global trading system, maintaining domestic production is further considered important for national defense and for limiting shortages and/or price increases that could result from supply chain disruptions.

Figure 2.2: Steel production in the United States and worldwide since 1950 (in million metric tons (MMT)).[8]

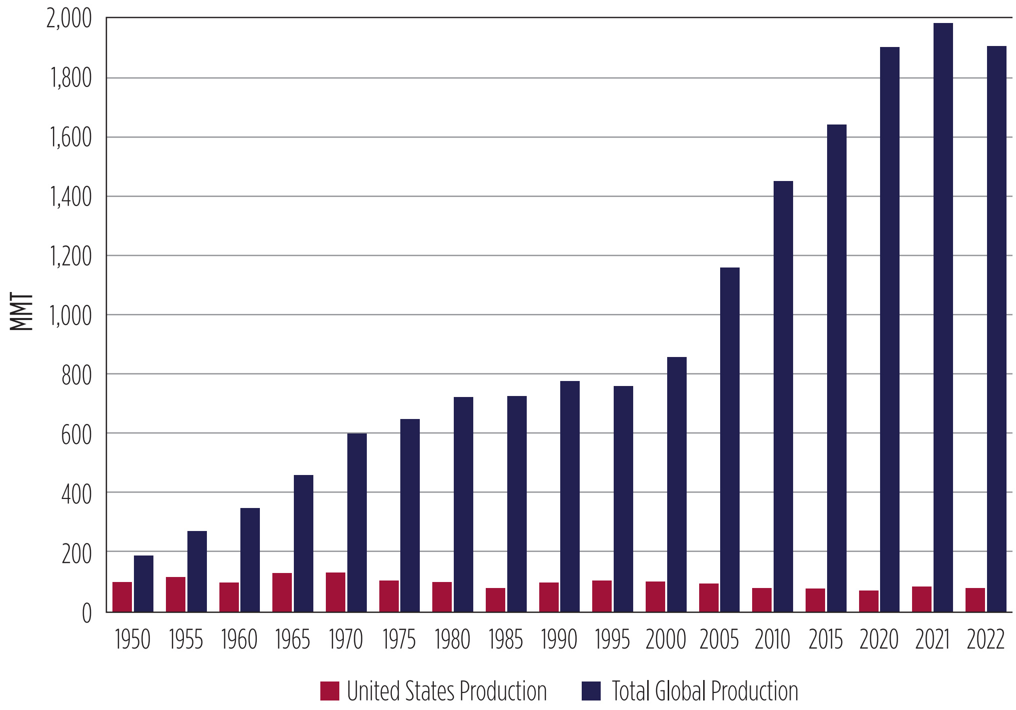
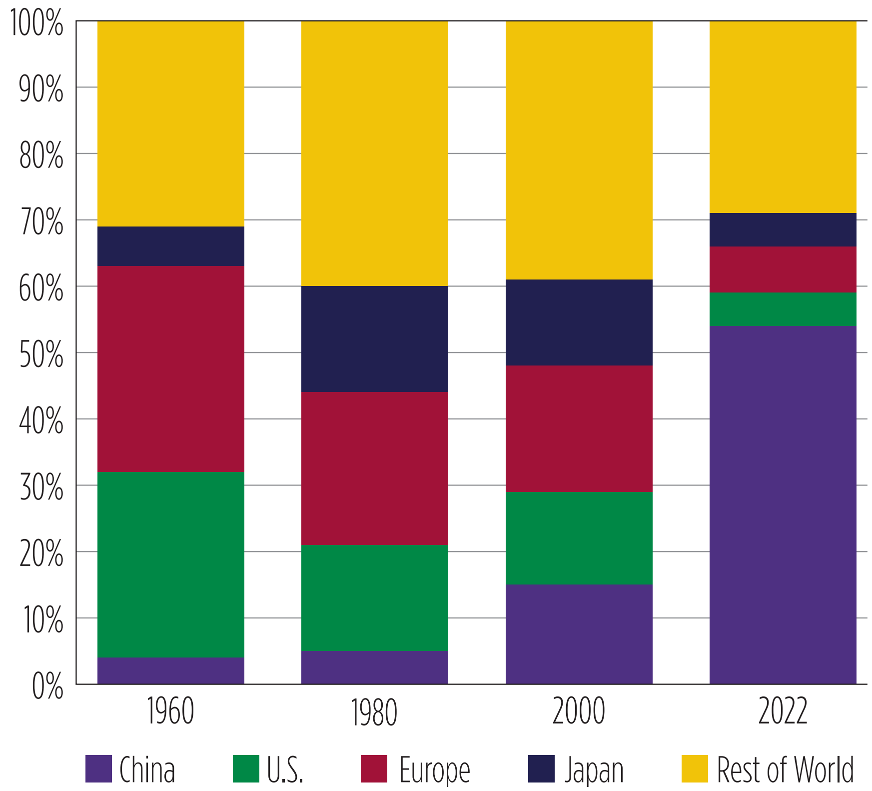


Figure 2.3: Share of crude steel production in major world regions and trends from 1960 to 2022.[9]



The growth of China's share of the global steel industry is shown in figure 2.3. While a relatively small amount of steel is directly imported from China into the United States, China's influence on steel pricing and export market participation is considerable. In 2022, China was the largest direct steel exporter in the world at 68.1 MMT (roughly 17% of global direct steel exports). That same year, exports represented only 7% of China's roughly 1,000 MMT of production, and only 4.4 MMT entered North America.[10]

Globally, China is also the largest source of indirect steel exports, which include products such as automobiles, appliances, and electronic equipment. In 2019, the United States was the largest indirect importer of steel products at 49 MMT; it was also the largest net indirect importer at 28.1 MMT (after offsetting indirect imports with U.S. indirect exports).[11] Total direct and indirect imports of steel into the United States in 2019 totaled 78.7 MMT, while U.S. domestic steel production was 88 MMT in the same year.

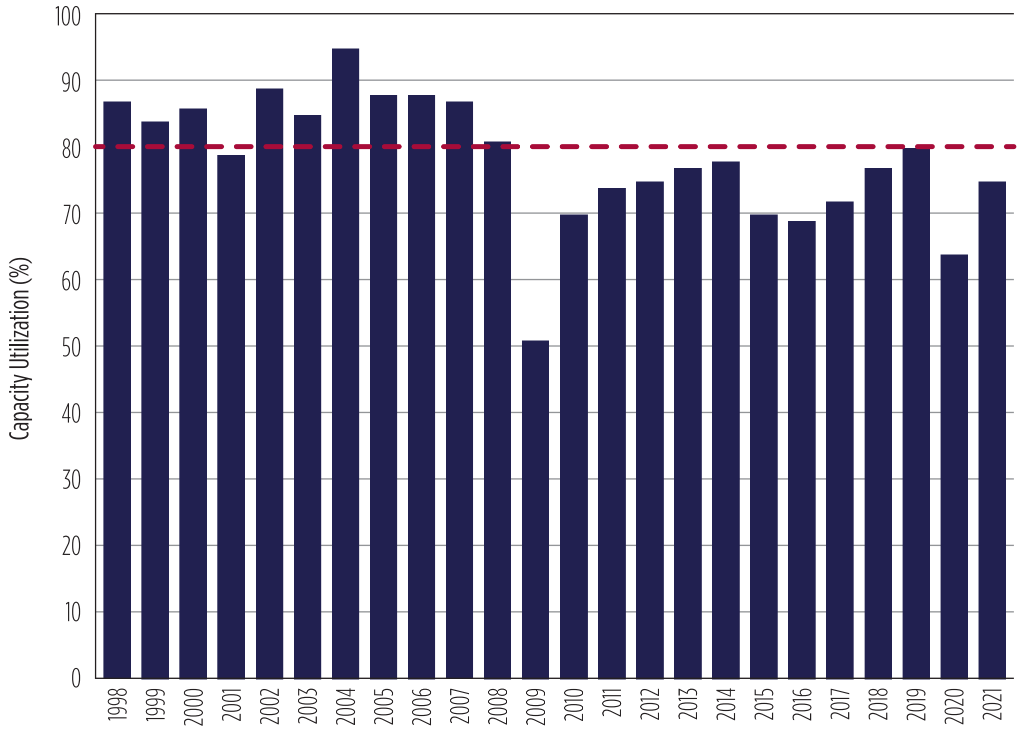
In the 25 years between 1975 and 2000, the percentage of global steel produced for direct export rose dramatically, from 22.6% to 39.2%.[12] Global steel production increased from 506.9 MMT to 783.6 MMT, with 70% of that increase dedicated to exports.[13] This dramatic rise in exports around the world, coinciding with the financial crisis in Asia in the late 1990s, resulted in a sharp decline in steel prices in the United States.

In 2000, in the wake of 48 steel company bankruptcies in the U.S., the U.S. Department of Commerce (DOC) issued its *Report to the President, Global Steel Trade: Structural Problems and Future Solutions*. This report noted: "The world steel industry is characterized by a variety of anti-competitive practices. The effect of such practices is that investment decisions as well as pricing and sales almost certainly are different from what would occur in a purely competitive market."[14]

In that year, the United States produced 102 MMT of steel in a global market of 850 MMT. The United States and China shares of the global market were roughly equivalent at 14% and 15%. The 2000 DOC report had identified roughly 300 MMT of global excess capacity and noted that the steel industry in any country would have trouble operating profitably at less than 80% capacity (see figure 2.4 for actual capacity utilization, 1998–2021). U.S. policymakers struggled to find a path forward, debating the role of tariffs to offset dumping and foreign government subsidies, while also addressing the excess capacity in global steel production.

At that time, however, there were few, if any, predictions that global demand and production would expand by more than 100% over the next two decades—from 2000 to 2022. Policymakers focused instead on curtailing the excess capacity in 2000, particularly in Russia, Ukraine, India, and Turkey, that was found to be driving down U.S. domestic steel prices.

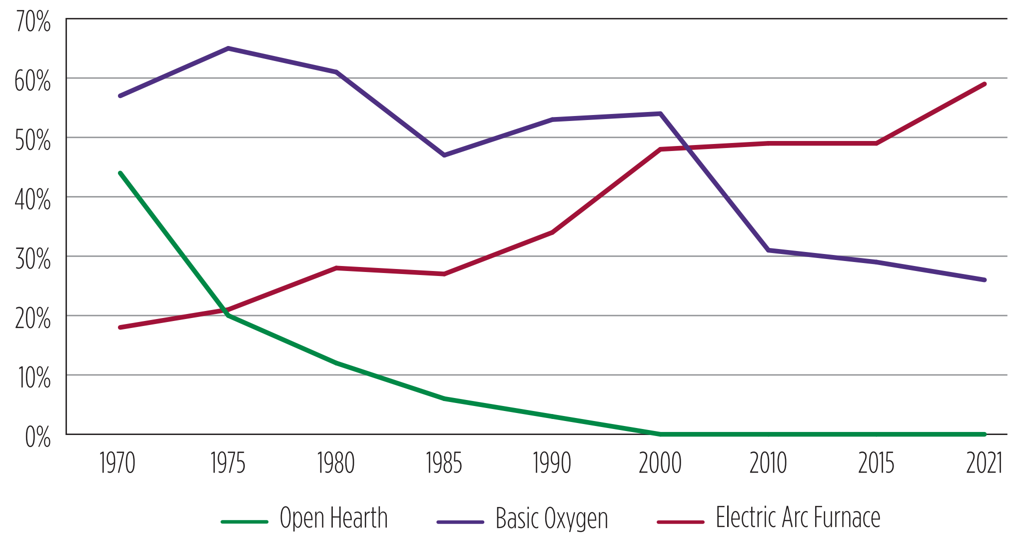
Figure 2.4: Capacity utilization in the steel industry in the United States, 1998–2021.



2.3 U.S. Iron and Steel Production Technology

The technology composition of the U.S. industry changed markedly, from roughly 85% of production in the integrated blast furnace-basic oxygen furnace (BF-BOF) route in 1970 to 69% in the EAF route in 2021 (see figure 2.5).[15] This transition in the U.S. domestic steel industry drastically changed the demographic and geographic structure of the industry, as shown in charts and maps in chapter 4.

Figure 2.5: Share of open hearth furnace, basic oxygen furnace, and electric arc furnace steelmaking in the United States, 1970–2021.[16]



Although iron and steelmaking technology in the United States has shifted, globally the industry is still largely reliant on BF-BOF technology. In 2022, 72% of global steelmaking used BF-BOFs, while just over 28% used EAFs.[17] Other than the United States, India is the only country that makes over half of its steel in EAFs, accounting for 54% of total production.[18] However, since India's EAF production uses substantial shares of DRI made with coal as a reductant, its CO_2 emissions are much higher than those of countries using primarily scrap-based EAF production. EAFs account for only 9.5% of the steel produced in China today, with the vast majority from BF-BOF production.[19]

A major factor in determining the timeline for decarbonizing the global steel industry will be continued growth in the demand for steel, particularly in emerging markets. Consumption of steel in different countries depends on their stages of industrialization and participation in global trade. At a certain point, developing economies become more steel intensive when they are focused on expanded infrastructure and manufacturing for export. For instance, in 2022, apparent steel consumption in the United States was 279.4 kg per capita, while in China, it was 645.8 kg per capita, reflecting the different stages of development and trade. While the EU countries had a fair amount of variability, overall, the EU averaged 310.3 kg per capita in 2022. Canada was at 351.6 kg per capita and Mexico at 194.8 kg per capita. Less developed regions were far lower: South America at 94.4 kg per capita and Africa at 28.1 kg per capita. In comparison, in 2002, at the start of its rapid steel industry expansion, China was at 148.5 kg per capita.[20]

Industrialization patterns in less developed countries will influence future demand for steel and its principal inputs, including scrap and iron ore. Over the next two decades, China's domestic steel production is expected to peak and decline slightly as demand, especially for new construction, abates, while other regions, such as Africa, Central and South America, India, and Southeast Asia, are likely to see demand grow.[21] Some degree of adaptability will be required in decarbonization strategies, both globally and in the United States, depending on how the demand shifts for steel play out.

2.4 A Global Perspective on GHG Emissions Intensity

Taken as a whole, steel production in the United States ranks among the least GHG emissions intensive in the world. According to the IEA, in 2022, steel emissions comprised roughly 7% of energy-related CO_2 emissions globally—and only 2% in the United States.[22] This difference is largely driven by the much greater reliance on EAFs compared to BF-BOFs in the United States; the substantial reliance on imported steel (because CO_2 emissions occur elsewhere); and a lower per capita steel demand. However, the CO_2 emissions intensity of both EAF and BF-BOF production in the United States (as per 2022 company sustainability reports) is also below the global average for each route, as outlined in table 2.1. (For an extended comparison of sustainability metrics across companies, see the appendix.) The higher global BF-BOF average reflects, in part, India's higher average CO_2 intensity of nearly 3 mt of CO_2 per mt of crude steel.

Table 2.1: Comparison of production and CO_2 emissions intensity per ton of crude steel (tcs) across companies.

Category	Production (MMT)	Scope 1 and 2 CO_2 emissions per ton crude steel (tCO_2/tcs)
Global 2022 steel industry average	1,885	1.77
U.S. 2022 steel industry average	81	0.76
Global 2022 BF-BOF average	1,372	2.21
U. S. Steel U.S. BF-BOF, North America	14.1	1.93
CLF U.S. BF-BOF	11.5	1.6
Nucor EAF	29.5	0.44
Steel Dynamics EAF	11.2	0.41
Gerdau, North America EAF	6.8	0.93 (global average)
CMC EAF	5.8	0.41
U. S. Steel Corporation Osceola & Fairfield EAFs	3.3	0.41 & 0.73 (location & product)
CLF EAF	3.3	1.04
Northstar BlueScope Ohio	3	0.18
SSAB North America EAF	2.4	0.57
Timken EAF	0.7	0.9
Radius Recycling/Cascade EAF	0.4	0

Company Scope 1 averages largely reflect the CO_2 intensity of inputs (including coke, required ore-based metallics, and the availability and cost of prime scrap), as well as process efficiency. Scope 2 emissions are driven mainly by electricity sources, with EAF producers Northstar BlueScope and Cascade relying on nuclear power plant and hydroelectric power, respectively. Making steel that meets surface quality and formability for some applications requires high input shares of virgin material, high-quality prime scrap, or both.

2.5 Industry Considerations for Decarbonization

Considerations that will be important for the iron and steel industry to achieve decarbonization through mid-century include: (1) availability of inputs, including high-quality prime scrap, (2) technology readiness and implementation to further reduce GHG emissions from domestic ironmaking and integrated mills, (3) economics of production across the spectrum of product end-use requirements, (4) the high cost of producing alternative ore-based metallics for steel production, (5) access to zero-carbon electricity, (6) uncertainty in future global steel demand, and (7) responding to national security and trade considerations. Each of these considerations is described in detail below.

(1) Availability of inputs such as prime scrap. In 2019, the United States consumed more than 60 MMT of steel scrap and 47 MMT of iron ore to produce 88 MMT of steel.[23] EAF steel producers combined scrap with varying amounts of ore-based metallics, such as pig iron and DRI, to improve quality, while integrated producers used up to 25% scrap, most of it produced internally, in BOF steelmaking. In 2022, the United States exported 17.5 MMT of scrap steel to 70 countries, the largest shares to Turkey, India, and South Korea.[24] Estimates for the average lifetime of a steel product are in the range of 25 to 35 years, with an average of 30 years.[25] Construction-grade steel, roughly 45% of all steel consumed globally, is estimated to have a lifetime of 100 years.[26] Given relatively stable steel consumption in the United States and a highly efficient recycling market, scrap availability is also relatively stable. The Organisation for Economic Cooperation and Development projects excess global scrap supply but large regional imbalances.[27] As discussed in this report, projections of future steel demand and scrap supply are subject to uncertainty. Producers can invest in further disassembly or processing to remove residual copper and increase prime scrap supply.[28] Local availability of other key inputs, such as natural gas, hydrogen, and electricity, will also drive technology and location choices for future iron and steel production.

(2) Technology readiness and implementation to further reduce GHG emissions from domestic ironmaking and integrated mills. Options for reducing GHG emissions from ironmaking in existing blast furnaces include use of biomass, hydrogen injection, and carbon capture combined with either utilization to make saleable products or deep geologic sequestration. Of these, only those options that include CCS are currently projected to meet deep decarbonization goals. While 22 CCS technology projects have been applied in industry sectors around the world—including power plants, ethanol, and fertilizer plants—CCS has yet to be successfully implemented in BFs, and trials have, so far, not demonstrated the necessary 90% or higher capture rates for deep decarbonization.[29] A major obstacle is that the capital investments cannot be justified by current markets. Similar economic barriers prevent decarbonized DRI production with hydrogen for use in melt furnaces with BOFs, an alternative transformation pathway that replaces the blast furnace process entirely. These economic barriers to decarbonization investments are addressed in Chapter 3.

(3) Economics of meeting product quality requirements. Historically, the economics of production have meant that BF-BOF plants have produced a wider range of high-quality steel products, while EAFs have dominated production of alloy or stainless grades that can better tolerate contaminants. However, new EAF capacity—including Nucor's plants in Gallatin, Kentucky, and Apple Grove, West Virginia; U. S. Steel's Big River Works in Osceola, Arkansas; and Steel Dynamics International's plant in Sinton, Texas—uses new casting and rolling technology that may expand the product portfolio to include electrical and exposed automotive steels.[30] The extent to which this trend continues will affect the pace, scale, and technology options for deep decarbonization of iron and steel production.

(4) High cost of alternative ore-based metallics for steel production. Steelmaking requires sufficient quantities of ore-based metallics. DRI has gained traction as an alternative to pig iron for both production routes. While DRI can be economically produced with natural gas in markets with an abundant, low-cost natural gas supply (incurring approximately one-third of the CO_2 emissions of BF iron production), producing low or near-zero CO_2 DRI incurs substantial incremental costs. Currently, 4.5 MMT of DRI are produced in the United States per year (around 4% of global production annually), although domestic steel producers import some DRI from outside of the United States.[31] Meeting projected increases in DRI demand in the United States with decarbonized production requires either CCS when using natural gas as a reductant or substituting hydrogen produced without GHG emissions for natural gas. Both routes incur additional capital and/or variable costs.

(5) Access to zero-carbon electricity. Although, over the past decade, there has been a remarkable increase in the production of renewable electricity in the United States, the direct use of zero-carbon electricity to power EAFs has been limited. One reason is that the electric grids located near many EAFs have relatively high CO_2 emissions factors, due to coal or natural gas generation. A second challenge for relying on wind or solar power is their intermittent availability, which limits the number of hours when they can provide decarbonized power and increases the need for other dispatchable power sources, such as hydro, storage, natural gas, and to some extent, coal and nuclear. Cascade Steel, a subsidiary of Radius Recycling in Oregon, which gets its electricity from the Bonneville Power Administration's hydroelectric generation system, is one of the few U.S. producers that can legitimately claim its products are made with zero-carbon electricity, thus largely eliminating its steelmaking Scope 2 emissions.[32] Other EAF producers are largely dependent on the mix of electricity supplied by the local grid, although many companies are exploring alternatives. In Pueblo, Colorado, EVRAZ North America, the largest single consumer of electricity in the state, collaborated with Lightsource bp, Xcel Energy, and the Colorado Public Utilities Commission to permit and build a 240 MW solar project on 1,800 acres of its mill property (see chapter 4). U. S. Steel will benefit from a large solar facility owned by Entergy Corporation that is adjacent to its Big River Works in Arkansas, while Nucor has used a power purchase agreement (PPA) to bring wind electricity to a new EAF in Sedalia, Missouri (also described in chapter 4).[33] Other steel companies are exploring the use of small modular reactors as a source of reliable, on-site electricity.[34] Several EAF and integrated producers, including Cleveland-Cliffs and CMC, are using virtual PPAs, also highlighted elsewhere in this case study, to offset their Scope 2 emissions.[35]

(6) Projecting global steel demand. The 40-to-60-year lifespan of steel mill assets—or longer, with BF relines, the capital-intensive nature of the steel industry, its centrality to economic growth and national security, and its cyclicality have created obstacles to predicting global steel supply and demand accurately. As a result, global overcapacity has been an ongoing problem for the industry, particularly in countries with relatively well-developed trading systems and partners, such as the United States. Future steel demand is difficult to predict: past assumptions about the growth of the industry have been inaccurate, and future projections vary widely. The World Steel Association reports that between 1950 and 2022, growth in steel production fluctuated from 7.2% to –0.5% per annum. Between 2000 and 2022, when global steel production more than doubled, annual growth rates fluctuated from 6.2% to 0.2%.[36] In its decarbonization projections, the IEA assumes that global steel demand will increase by 10% over the next decade to 1,970 MMT before peaking in 2035, thereafter relying on "avoided demand" (e.g., a reduction in single-occupancy vehicle travel) to help reduce GHG emissions to net zero by 2050.[37] However, the Mission Possible Partnership modeled demand rising globally to 2,547 MMT in 2050, an increase of 36% from 2022, while acknowledging that material recirculation, material efficiency, and use productivity could reduce that demand to 1,509 MMT.[38] Most recently, the U.S. International Trade Commission's 2023 study on the impacts of Section 232 steel tariffs identified 20 million new tons of EAF steel capacity in the United States alone between 2018 and 2024 and projected additional demand driven by the infrastructure and energy transition spending of the IIJA and the IRA.[39] Thus, close monitoring of steel production and demand and continuous updating of long-term forecasts will be essential to decarbonization strategies for the industry. Any increase in steel production or further growth in the EAF share in the United States is projected to require more ore-based iron inputs. As discussed in chapter 5, to foster a stable transition environment for the industry, it will be essential to provide accurate information on steel demand in the United States, implement close monitoring of the impact of both direct and indirect steel imports, and integrate GHG emissions reduction into product demand with "green steel premiums" and/or tax incentives.

(7) National security and trade considerations. Finally, as the rules for global trade and national security are now being debated at a more comprehensive level than at any time since the end of World War II, the role of the iron and steel industry in domestic economic stability has become increasingly evident. Maintaining a modern, competitive, low-CO_2 steel industry with a secure and diverse supply chain and the capacity to produce the entire range of products to meet domestic demand will be critical for the United States in its 21st-century role—as a leader in democracy, social equity, and climate crisis management. As mentioned in the introduction, the armed conflicts in Ukraine and the Middle East along with increasing economic tensions between the United States and China have underscored the importance of economic independence as a key component of national security. In an industry that is critical to national security, such as steel, climate policy must support the economic competitiveness of the domestic industry, an issue that is examined more deeply in chapter 6, on trade policy.

3. Decarbonization Technologies and Costs

Key messages:

- The challenges in decarbonizing the iron and steel industry are primarily economic rather than technical, although multiple technical complexities must be addressed to improve the performance and reduce the cost of decarbonization options.
- Our purpose in this chapter is to generate an estimate of the incremental capital and operating costs of decarbonizing iron and steel production to understand how much public investment will be required. To that end, we have focused on modeling four potential near-term options for decarbonizing today's production. Ultimately, the technical and economic feasibility of these decarbonization pathways will be highly site-specific and depend on ongoing technological innovation and market conditions.
- Our modeling focuses on the cost of transitioning to net-zero-compatible iron and steel production in the United States, reducing industry GHG emissions approximately 70–75% relative to today, focusing primarily on Scope 1 and 2 emissions and including coproduct gases. We consider two representative pathways for each production route:
    - (1) for BOF steelmaking, (a) carbon capture and sequestration (CCS) on the blast furnace or (b) direct reduced iron (DRI) produced using natural gas with CCS, plus a melt furnace using existing basic oxygen furnaces (BOFs), and
    - (2) for existing EAF steelmaking, (a) DRI produced using natural gas with CCS or (b) DRI produced with hydrogen, which can also be produced with very low CO_2 emissions.
- For the nine operating BF-BOF plants in the United States, the existing IRA 45Q tax credit is estimated to cover the incremental annual operating cost (opex) of CCS, estimated at $2.2 billion per year. These retrofits would lower CO_2 emissions from current levels of around 1.8 metric tons (mt) CO_2/tcs to 0.7 mt CO_2/tcs. The capital cost for CCS retrofits is estimated at $14 billion and is largely not addressed by existing policy.
- To support EAF decarbonization, an ample supply—on average, 25% of each EAF charge—of ore-based metallics, produced with very low to zero CO_2 emissions, will be required—recognizing that some applications (e.g., exposed automotive) will require higher percentages, while other applications can be produced with 100% scrap. Investing in scrap upcycling and substituting DRI or green pig iron produced with near-zero CO_2 emissions (e.g., with hydrogen, CCS, and/or biochar) for current imports of CO_2-intensive pig iron will support deep decarbonization of current EAF steel production. Some developing countries may be economically attractive locations for producing iron with near-zero CO_2 emissions, depending on U.S. domestic content requirements and the applicability of U.S.-based incentives.
- IRA credits improve the economics of decarbonized ore-based metallics for EAF use, reducing the annual opex using hydrogen from $5.7 billion to $1.9 billion (inclusive of the 45V credit, which reduces the cost of H_2 produced with near-zero CO_2 emissions from $4.68/kg to $1.68/kg in this study) and the annual opex using CCS with natural gas-based DRI from $1.4 billion to $0.8 billion (45Q credit of $85/ton CO_2 avoided). Estimated capital costs for 16.3 MMT of new DRI production for EAF steelmaking total $13 billion (hydrogen) and $16 billion (CCS), although if the existing 5.2 MMT of DRI can be retrofitted with hydrogen or CCS, costs may be lower.

- Making decarbonized electricity supply available for CCS and electrolyzer operation will be critical to achieve the 70–75% decarbonization modeled in this chapter—and beyond. Hydrogen-based approaches discussed in this chapter assume availability of delivered hydrogen at a cost of $4.68/kg from third-party suppliers. Electrolytic hydrogen, and longer-term electrolytic ironmaking, will require large volumes of inexpensive, decarbonized electricity.
- Investments examined in this chapter are compatible with further deep decarbonization, which would require: (1) decarbonized electricity generation for mining, ore concentration, pelletization, DRI production, EAF operation, CCS operation, and hydrogen production, (2) deep reductions in process emissions from the EAF, (3) increasing the efficiency or rate of CO_2 capture from the facility or process slipstream, (4) electrifying process heating in reheat and finishing furnaces, and (5) purchasing high-quality CO_2 removal credits (e.g., from direct air capture, or DAC), to cover unabated CO_2 emissions.

3.1 Approaches to Decarbonizing Iron and Steel Production

3.1.1 Background

Our analysis of U.S. iron and steel industry decarbonization starts with existing production. Decarbonization options and costs vary across facilities, technologies, and geographies. Several important considerations will broadly affect the viability of decarbonization pathways for the industry.

First, making iron is different from making steel. Making steel via the integrated route, which involves first extracting iron from iron ore using carbon-based reductants and high heat (essentially removing oxygen from iron oxide, in a process known as reduction), is much more GHG emissions intensive than making steel primarily from recycled scrap steel (as iron is already reduced). Nearly two-thirds of U.S. iron and steel GHG emissions originate from blast furnace production of iron, which, after it is refined in the basic oxygen process, accounts for approximately 30% of steel production in the U.S. The EAF route uses primarily scrap steel but also ore-based metallics such as pig iron (produced in blast furnaces) and DRI. These form the most emissions-intensive part of the production process. A major challenge in decarbonizing steel production is to reduce GHG emissions from the ironmaking step.

Second, the capital costs of decarbonization to iron and steel companies are projected to be large (in the range of several billion dollars per year through 2050), far exceeding annual profit and even market capitalization for some companies. This cost burden is estimated to be similarly large for other industrial sectors. Currently, neither tax credits in the IRA and the IIJA nor buyer commitments are sufficient to incentivize the decarbonization investments in technology and infrastructure that are outlined in our main scenario. An additional complication is that steelmakers have limited ability to influence planning, siting, and operation of infrastructure, such as clean electricity and CCS, that are needed for decarbonization.

Third, decarbonization approaches differ in their impacts across the supply chain. For example, production of direct reduced iron using DR-grade pellets—that is, pellets with higher concentrations of iron—increases GHG emissions upstream from mining and processing but reduces GHG emissions downstream (for instance, by eliminating an additional melt step and reducing slag volumes in the steelmaking step).

Fourth, some drivers of the geography of iron- and steelmaking will change, while others may stay the same. The steel industry initially developed in areas with access to inexpensive fossil fuels and raw materials, largely through water-based transport of coal, coke, and iron ore or pellets. Iron- and steelmaking were almost always colocated because the iron could be transferred from the blast furnace to the steel furnace in molten form. By producing iron in a solid state, DRI and other alternative ironmaking processes permit decoupling of the locations of ironmaking and steelmaking. For DRI, costs of natural gas and hydrogen will grow in importance. At the same time, plants may lose process synergies (such as the use of coke oven gas in the blast furnace, or the ability to sell coproduct gases) that are not obviously available in the decarbonized routes. As is discussed further in chapter 4, ample overlap in workforce skills requirements may favor locating decarbonized facilities on or near legacy sites.

These considerations inform the assumptions in our main scenario, which is intended to be illustrative of the capital and infrastructure required to decarbonize production using multiple technological approaches.

3.1.2 Approaches and Applications by Process Route

Five general approaches for decarbonizing iron- and steelmaking could potentially contribute to the decarbonization process:

1. Increased energy efficiency,
2. Low-carbon input substitution (including biomass, hydrogen, and electrification),
3. Implementation of low-carbon iron ore reduction technologies,
4. End-of-pipe CO_2 capture (with conversion and/or piping to sequestration sites), and
5. Purchase of certified CO_2 offsets or reduction credits (for instance, from DAC projects).

These general routes are likely to be applied differently by integrated and EAF producers. Of these options, the third and fourth have the greatest potential to reduce actual GHG emissions from steel operations. These will therefore receive the most attention in our main scenario. We note the importance of continuing to support cost-effective iron and steel decarbonization solutions and incentivize ongoing innovation. For instance, advanced precommercial iron- and steelmaking technologies (such as low-temperature electrolysis for ironmaking and molten oxide electrolysis for iron- and steelmaking) are under development. If these technologies become cost competitive, their deployment could displace the pathways considered in our main scenario.

Decarbonization options for the integrated blast furnace-basic oxygen furnace (BF-BOF). BF-BOF modifications are attractive due to their ability to use existing infrastructure, lowering capital needs and preserving or even increasing jobs. In the near term, several technologies in use or under development may reduce GHG emissions associated with the BF-BOF route. Introducing biomass to the mix of reductants provides modest incremental reductions in CO_2 emissions if cultivated in a carbon-neutral manner (CO_2 released from the blast furnace is offset by CO_2 taken up when the biomass was grown). Using DRI in the blast furnace can reduce the coke required. Introducing an additional heat injection point can improve the operational efficiency of some blast furnaces. Injecting hydrogen into the blast furnace can also help to lower CO_2 emissions by reducing the need for coke by up to 30%.[40] Such enhancements are currently being explored by integrated producers to meet interim goals, but ultimately, these approaches do not support deep reductions in CO_2 emissions. Substantial reductions (60% or more) from the BF-BOF route will likely require CCS. CCS technologies, which also have applications in the production of DRI for EAFs, are described below under a separate heading. Another option for integrated producers involves using DRI, produced with low to zero CO_2 emissions, to make steel in a BOF. Producers such as ThyssenKrupp have selected this option, which is compatible with using standard BF-grade pellets as well as higher-quality DR-grade pellets. Cleveland-Cliffs was recently awarded up to $500 million by the DOE to pursue a similar strategy at its Middletown plant.[41] This option also involves melting the DRI in an electric smelting furnace (ESF) before feeding into the BOF, especially if using BF-grade pellets, to remove additional gangue. Other integrated producers, such as ArcelorMittal Dofasco in Canada, have opted to transition existing sites to DRI-EAF steelmaking.[42]

Decarbonization options for the electric arc furnace (EAF). Steel is made in an EAF by melting recycled scrap steel (plus, for some applications, pre-reduced ore-based metallics) using high-temperature electric arcs and tuning metallurgical composition in several subsequent steps. Direct CO_2 emissions from the EAF are low compared to the integrated route, but the existing number and expected growth of EAFs in the United States make addressing these CO_2 emissions important for achieving climate goals. Using alternative green sources of ore-based metallics (such as green pig iron or DRI produced with natural gas plus CCS or with hydrogen) can further reduce Scope 3 CO_2 emissions.[43] Achieving net-zero emissions through the EAF route depends on the availability of carbon-neutral electricity. Since EAF operations are very electricity intensive, it is critical to address related Scope 2 emissions from electricity generation.

Direct reduced iron (DRI). DRI production, having emerged using coal and natural gas as reductants in parts of the world where they are abundant and alternatives are limited, is now a mature technology that has gained renewed interest. DRI involves the separation of elemental iron from iron oxide without melting. It can be stored and transported in compact form: hot briquetted iron, or HBI. Today, most DRI reactors use natural gas as a reductant and a heat source. Three such reactors exist in the United States: Cleveland-Cliffs Direct Reduction Plant in Toledo, Ohio (DRI/HBI, 1.9 million tpa), ArcelorMittal Texas HBI in Corpus Christi, Texas (DRI, 2 million tpa), and Nucor Direct Reduction Plant in Convent, Louisiana (DRI, 2.5 million tpa). Inexpensive natural gas in the United States, compared to many other regions, makes these facilities economically attractive. It should be noted that direct-reduction processes benefit from high-grade ores (>67% Fe), which in turn may require additional energy and material for beneficiation, implying additional costs. Iron ore for the Toledo DRI facility is sourced from Minnesota, while the DRI plants in the Gulf region source ore from Brazil, Canada, and Norway. Currently, DR-grade ores account for only a small percentage of seaborne iron ore trade. In 2023, the DR-grade pellet premium was $46.3/ton (according to the International Iron Metallics Association) or 20–25% above the cost of 65% ores.

Using natural gas to make DRI reduces CO_2 emissions from Scopes 1 and 2 by roughly two-thirds, compared to ironmaking in the BF. Two major routes offer further reductions: substituting natural gas with hydrogen produced with near-zero CO_2 emissions and/or retrofitting the DRI reactor using natural gas with CCS. DRI reactors that use natural gas can be designed or retrofitted to use high blends of hydrogen (>90%). In practice, hydrogen blending is likely to be limited to 95% to ensure sufficient carburization (addition of carbon to achieve desired material properties).

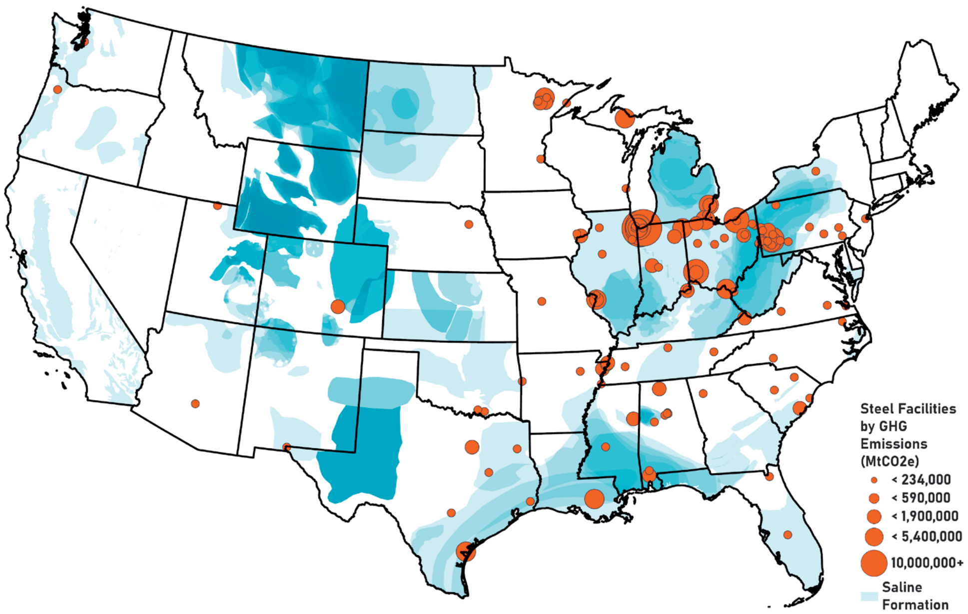
3.2 Supporting Infrastructure

Decarbonizing iron and steel production will require substantial additional investment in supporting infrastructure. Carbon capture, decarbonized electricity, and hydrogen will play a decisive role in the extent of GHG emissions reductions. Regions and jurisdictions will need to overcome context-specific constraints and challenges, such as proximity to viable storage resources, the carbon intensity and capacity of the local grid, opportunities for colocation with other industrial emitters, and the emergence of planned hydrogen hubs. Broadly, siting and permitting challenges related to CO_2 pipelines, transmission infrastructure, and other supporting assets are key barriers to achieving scale. These infrastructure requirements are briefly described below.

3.2.1 Carbon Capture and Sequestration (CCS)

The top gas streams from the blast furnace or DRI reactor, as well as potentially other gas streams (e.g., from cokemaking or on-site electricity generation), are candidates for carbon capture and sequestration (CCS) or carbon capture and utilization (CCU).[44] CCS involves isolating CO_2 from waste gas streams and pressurizing and injecting it underground, while utilization pathways convert CO_2 to products. Capture of 90% of a plant's Scope 1 CO_2 emissions is expected to be possible using carbon capture systems. The United States has geology suitable for long-term CO_2 sequestration located near most BF-BOF plants. As shown in figure 3.1, deep saline formations may be an option for sequestration of CO_2 from existing BF-BOF sites, represented by the largest circles and mainly clustered in the Northeast and the Great Lakes region. When unmineable coal seams (e.g., in southern Illinois) are included, sequestration opportunities increase.

Figure 3.1: Colocation of iron- and steelmaking facilities with deep underground storage in saline formations.

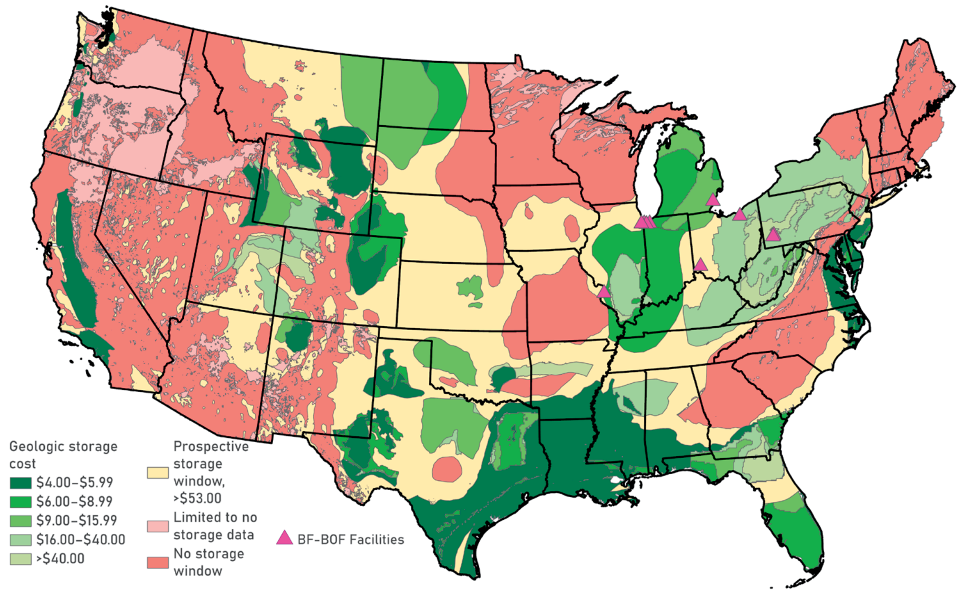


Several steelmakers have plans to develop carbon capture, followed by either sequestration or utilization of the CO_2. However, at present, industrial applications of both CCS and CCU remain on the drawing board or are operating only at a pilot scale in the United States, with very limited CO_2 sequestration demonstrated thus far. In 2022, Cleveland-Cliffs applied for funding from the U.S. Office of Clean Energy Demonstrations (OCED) under the IIJA to conduct a front-end engineering design study of a capture unit for its integrated steel plant at Burns Harbor, Indiana. The project would capture 2.8 MMT of CO_2 per year. U. S. Steel has announced a partnership with CarbonFree to capture and mineralize 50,000 tons of CO_2 per year using CarbonFree's proprietary SkyCycle Process.[45] U. S. Steel is also collaborating with the National Energy Technology Laboratory on carbon capture for the blast furnace at the Mon Valley Works.[46] Utilization of CO_2 produced by steel operations is also under development in Europe. ThyssenKrupp has developed a Carbon-2-Chem facility next to its site in Duisburg, Germany, which is developing pathways for a variety of products. U.S.-based LanzaTech is operating a facility for the conversion of blast furnace CO_2 into ethanol at ArcelorMittal's plant in Ghent, Belgium, and in northeastern China through its joint venture, Shougang LanzaTech.[47] These are all potential applications of CCU to reduce steel-related CO_2 emissions. With current subsidies available in Ghent and low-cost conditions in China, LanzaTech's technology is calculated to pay back within five to seven years. The scale of current CO_2 utilization technologies, however, is small compared to the volume of CO_2 generated at a large integrated steel plant.

The economics of CCS and CCU are site- and market-specific. For instance, investments in the EU, with its carbon pricing system and commitment to implementing a CBAM, will be evaluated differently than those in the United States, where investments are incented through a variety of tax credits. Viability may also depend on markets for coproducts, as well as multiparty agreements on how any carbon credits generated will be shared by producer and offtaker.

Another factor is the cultural willingness of iron and steel companies to expand further into the chemicals business, which is already common at some coke production sites.

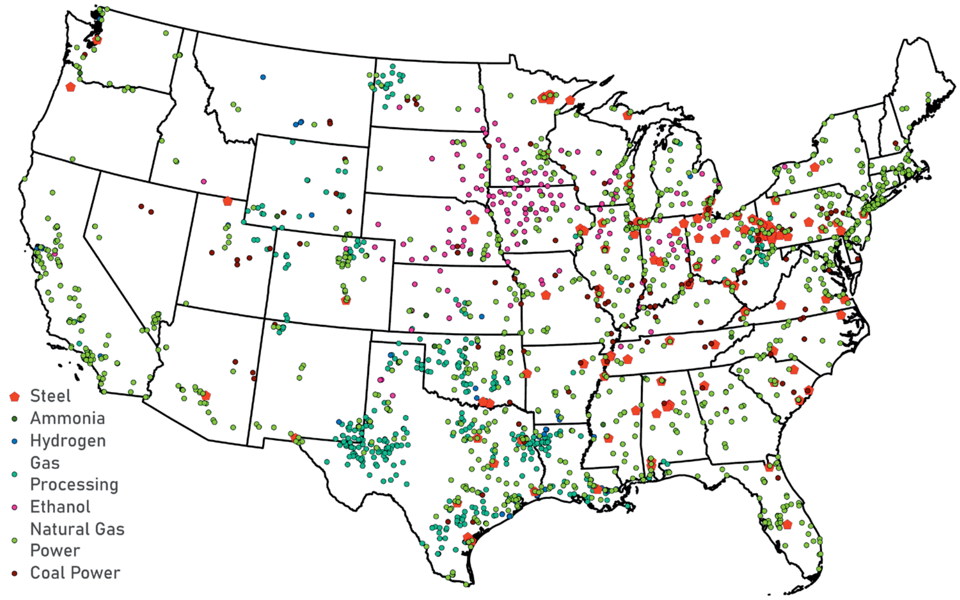
Figure 3.2: BF-BOF facilities and distribution of geologic CO_2-storage options in the United States.[48]



Finally, local permitting regimes, local community support, the regional availability and timing of pipeline infrastructure, other CO_2 sources, and sequestration geology—as well as public acceptance, liability, and pore space ownership compensation—will strongly determine the feasibility of CCS, CCU, and DAC in the U.S. As mentioned, many BF-BOF facilities are in proximity to cost-competitive CO_2 storage resources (see figure 3.2). The extent to which these facilities can meaningfully rely on CCS development will depend on both federal action (such as regulations under the Pipeline and Hazardous Materials Safety Administration and broader federal permitting reform related to interstate infrastructure) and state and local action, including securing Class VI primacy and clarity over siting decisions.

CCS also has potential applications for EAF production. Abating CO_2 emissions from DRI production using CCS is one alternative to hydrogen-based production that is estimated to be lower in cost and, depending on how hydrogen is produced, lower in CO_2 emissions—as is discussed in our scenario exploration. In addition, captured CO_2 (from any source) could be used directly at EAF sites to provide a source of carbon for carburization (addition of carbon to steel to achieve desired properties), which will become particularly important if carbon-poor DRI produced using hydrogen as a reductant is fed directly into the EAF. One advantage is the potential to configure CCS for the EAF in ways that simultaneously reduce dust and other hazardous local pollutant emissions.[49] However, CO_2 concentrations in EAF flue gas are currently relatively dilute (approximately 1% CO_2 by volume) and variable, increasing the cost of capture closer to that of DAC (abatement cost of over $200/ton CO_2).

Figure 3.3: Steel facilities and selected industrial and power facilities that qualify for 45Q.[50]



Steel facilities may benefit from sharing CO_2 infrastructure with nearby emitters, creating industrial clusters that would lower total infrastructure spending and transport costs. Figure 3.3 shows steel facilities and their proximity to selected industrial and power sector facilities that could adopt CCS in the near term. Industrial clusters that are close to ideal storage geology are found on the Gulf Coast and in portions of the Midwest and the Southeast. Programs and efforts to evaluate and plan for shared infrastructure networks could help scale CCS opportunities for steel and other hard-to-abate sectors.

While in this analysis we present averages, the advantages of CCS and CCU relative to other decarbonization technologies are likely to vary by producer and facility, for several reasons. First, costs of capital, labor, raw materials, and energy inputs—in particular, decarbonized electricity—vary across existing and potential future production locations. Iron and steel companies also vary in the extent of their access to ore bodies that can be beneficiated cost effectively to produce DRI-grade pellets, which are expected to be required for certain configurations, such as DRI EAF production. Second, primary steel mills vary in the number of downstream processing plants that would be lost if such facilities were to shut down completely. (The prospect of losing its downstream precision rolling mills is one of the reasons why ThyssenKrupp Duisburg in Germany has opted to pursue the staged introduction of DRI, to be made first with natural gas and then with hydrogen, and an electric smelting furnace, while retaining the downstream BOF and rolling capacity.) Third, plants vary in proximity to other sources of CO_2 for CCS or utilization. Several integrated plants are colocated with other potential power and industrial sources of CO_2 and sequestration geology. Finally, plants vary in the degree to which they rely on recycled coproduct gases (for instance, for power production) or sell these coproduct gases off-site. The loss of these opportunities may alter the economics of decarbonized production for some facilities more than others.

3.2.2 Decarbonized Electricity Supply

Decarbonized electricity on demand will be essential for the decarbonization of the iron and steel industry in the United States, especially given its high share of EAF steelmaking. Decarbonizing the electricity supply to EAFs would reduce CO_2 intensity from 0.4 to 0.2 tCO_2/tcs, which would represent a major reduction in the industry's emissions if implemented at EAFs nationwide. Moreover, without decarbonized electricity, it will be impossible to obtain a decarbonized supply of hydrogen for DRI production or to support CCS, which requires substantial electricity to operate. Availability of decarbonized electricity for these applications is a core assumption of our scenario analysis. Using electricity sourced from the grid and assuming the average current U.S. grid emissions intensity, each of these "decarbonization" technologies would displace far fewer CO_2 emissions. While we assume that today's EAF fleet continues to use electricity at the current grid average CO_2 intensity, we consider the implications of serving this load with decarbonized electricity. From an infrastructure perspective, the financing, planning, and building out of necessary transmission lines and new generation resources remain below levels needed to meet national targets, posing a critical technical and policy challenge for this decarbonization option. In the Southeast, which is home to a large share of the country's EAFs, the additional regional transmission need by 2035 is expected to be 77% of 2020 system levels in a scenario with moderate load growth and high clean energy deployment.[51]

3.2.3 Hydrogen Production and Distribution

Using hydrogen as a reductant and heat source in iron and steel production will require buildout of capacity to produce, store, and transport hydrogen. The production method with the greatest potential to reduce CO_2 emissions involves electrolysis of water powered by clean or renewable energy. This method is currently expensive compared to producing hydrogen from natural gas, which is done without additional CO_2 emissions abatement at refineries across the United States. Adding precombustion CO_2 capture and sequestration to natural gas–based hydrogen production can also substantially reduce CO_2 emissions. While today, hydrogen from natural gas with CCS is expected to be less costly to produce, many studies suggest that over time, costs of hydrogen produced using water and renewable electricity will be competitive with the natural gas pathway.

Regardless of hydrogen source, transportation and storage needs for hydrogen delivery will need to be addressed. Blending hydrogen in existing natural gas pipelines will be limited by the potential for embrittlement and failure of pipeline material. Storage may also be costly, especially for plants that would use comparatively little hydrogen. Sites that are colocated with, and have access to, underground geology suitable for hydrogen storage may realize a substantial cost advantage.

3.3 Net-Zero Compatible Iron and Steel Investment Scenario

Our estimates of the costs of decarbonizing the iron and steel industry in the United States use today's iron and steel production as a starting point and CO_2 emissions benchmark. We then model several different decarbonization routes, acknowledging the importance of continuing to innovate in decarbonization technologies. If other options, such as electrolytic routes, low-cost hydrogen, and utilization of CO_2, become cost competitive, their adoption would ultimately result in lower costs of decarbonization. Hence, this analysis can be viewed as a representative upper bound (before any financing costs) for the cost of decarbonizing the current U.S. industry.

3.3.1 Methodology and Assumptions

Many studies have examined the cost and CO_2 emissions of candidate pathways for decarbonizing iron- and steelmaking processes.[52] We apply capital and variable cost estimates from the original underlying studies (when available, peer reviewed) used for these analyses as well as from actual costs of construction (e.g., for natural gas-DRI) reported in the media. Costs are summarized in table 3.1.

Table 3.1: Capital and variable costs associated with candidate technology pathways in 2022.

Technology	Capital cost ($/t capacity)	Variable cost ($/tcs)	Variable cost after Inflation Reduction Act tax credits ($/tcs)	CO_2 emissions (tCO_2/tcs)
Current technologies				
BF-BOF	529	395	395	1.8
100% Scrap EAF	309	318	318	0.4
Lower CO_2 technologies				
BF-BOF-90% CCS	929	484	372	0.7
100% NG-DRI-90% CCS-ESF-BOF	200	427	396	0.6
100% NG-DRI-EAF	808	361	361	1.1
100% H_2-DRI-EAF	808	707	531	0.6
100% NG-DRI-90% CCS-EAF	973	414	371	0.6

Notes: The cost of retrofitting an existing BF-BOF plant with carbon capture is assumed to be $400/t capacity—although it may be higher for some applications—and is not inclusive of capex for pipelines and storage, which will depend on number of users and throughput. The economics of CO_2 utilization vary depending on the application. Installing CCS on a new DRI plant is estimated to be $165/t capacity.[53] Capital costs: for CCS on the BF-BOF, IEA (2010) inflated to 2022.[54] DRI estimated based on three U.S. installations. We assume a DRI furnace can use up to 100% hydrogen. Pathways involving an EAF include EAF capital costs of $309/t capacity, based on van Ruijin et al.[55] Variable costs: mass and energy balances and assumptions are described in Jaramillo et al.[56] Routes using DRI assume 100% DRI in EAF charge (0% scrap) and adjust in subsequent calculations. Hydrogen is assumed to be procured at $4.68/kg or $1.68/kg with the $3/kg IRA 45V credit, with no CO_2 emissions.[57]

The estimates provided in table 3.1 (shown in 2022 dollars) are used to generate estimates of total undiscounted capital and variable costs for EAF and integrated producers and for the steel industry in the United States as a whole. We use production for 2021 as a benchmark: 26 MMT BF-BOF production (36 MMT capacity) and 56 MMT EAF production (79 MMT capacity). We assume that capital costs are for retrofits or replacement of existing capacity and that variable costs scale with production, around 80% of capacity on average in a given year.

Table 3.1 shows how the Inflation Reduction Act (IRA) changes the variable cost economics of both the hydrogen-DRI and CCS-enabled routes. Our calculations find that the IRA credit is worth roughly $263/tcs for hydrogen-DRI producers, while for CCS, the credit is worth $112/tcs for the BF-BOF route and $43/tcs for the DRI-CCS route, largely due to differences in baseline CO_2 emissions for each process route. Although extension of these credits beyond 2032 is uncertain, we assume in our analysis that the IRA tax credits 45Q and 45V continue beyond their expiration date.

We use these technology costs together with the following assumptions to estimate the costs of decarbonizing U.S. iron and steel production:

- First, we benchmark our estimates of costs assuming that solutions will be needed to decarbonize both BF-BOF and EAF production and associated supply chains and construct two decarbonization options for each route.
- Second, we do not consider changes in imports, either direct or indirect (i.e., steel contained in imported finished products, such as automobiles). Together, direct and indirect steel imports totaled 87% of domestic production in 2019. Import substitution would expand U.S. domestic production, but this possibility is not in the scope of our analysis.
- Third, we assume the industry adopts decarbonizing technologies with the lowest variable cost net of subsidies. As we discuss at the end of this chapter, we further assume that capital costs are substantially reduced by some form of government action.
- Fourth, we take the most robust available estimates of investment and operating costs as proxies for the broader categories of decarbonizing options. For example, we have taken estimated costs for amine-based CCS for the broader category of CCS and CCU. If chemical or biological utilization technologies prove superior to sequestration technologies in the marketplace today, that will encourage their adoption over the sequestration process assumed in our modeling. Our focus on CCS, for example, is not an endorsement of that technology but rather a means to estimate overall investment and cost implications for steel decarbonization.
- Fifth, we assume that decarbonized electricity is available at 7 cents per kWh with zero CO_2 emissions for CCS and hydrogen production. EAFs are assumed to source electricity at the U.S. grid average of 0.39 kg CO_2/kWh, with an electricity cost of 4 cents per kWh.
- Sixth, we assume that limitations on the availability of high-quality scrap steel translate into an average of 25% ore-based metallics—in our scenarios, DRI—in an average EAF charge. This demand would require 16.3 MMT of DRI production.

3.3.2 Scenario Results

The results of this modeling effort are summarized in table 3.2, which assumes two pathways for each route (CCS on the BF or DRI-ESF-BOF for the integrated route) and considers two low-carbon DRI pathways (H_2 and CCS) for the EAF route.

We find that when comparing hydrogen to CCS for DRI, hydrogen capital costs are lower, but annual opex is considerably higher, especially if IRA credits are not included. Relying on CCS for both integrated and EAF route decarbonization requires a viable CCS solution; although the technology is considered mature, it has yet to be widely deployed, and for ironmaking implementation, it is still in the very early stages.

Importantly, the cost of decarbonizing EAF steelmaking strongly depends on the assumed share of DRI in an EAF charge. The total variable cost of decarbonizing EAF production with NG-DRI-CCS for EAF steelmaking increases by an order of magnitude as DRI share in the EAF charge rises from 10% to 100%. Estimated costs using hydrogen today would be even higher and also scale linearly with the amount of DRI in the EAF charge.

Table 3.2: Comparison of estimated costs to reduce CO_2 emissions from iron and steelmaking by 70–75% in the United States.

Cost by pathway (billions, total or per annum)	**Case 1: CCS for integrated / H_2-DRI for EAF**	**Case 2: CCS for integrated / NG-DRI-CCS for EAF**	**Case 3: DRI-ESF-BOF for integrated / H_2-DRI for EAF**	**Case 4: DRI-ESF-BOF for integrated / NG-DRI-CCS for EAF**
One-time capex				
BF-BOF	$14.0	$14.0	$25.0	$25.0
EAF production	$13.0	$16.0	$13.0	$16.0
Total capex ($ B)	**$27.0**	**$30.0**	**$38.0**	**$41.0**
Annual incremental opex				
Inc. BF-BOF	$2.2	$2.2	$0.8	$0.8
Inc. DRI for EAF	$5.7	$1.4	$5.7	$1.4
Inc. BF-BOF-CCS after IRA	$0	$0	$0	$0
Inc. DRI for EAF after IRA	$1.9	$0.8	$1.9	$0.8
Incremental BF–BOF and EAF total after IRA ($ B/year)	**$1.9**	**$0.8**	**$1.9**	**$0.8**
Additional cost of decarbonized electricity for ESF or EAF* ($ B/year)	**$0.8**	**$0.8**	**$0.8**	**$0.8**

** Assumes 3 cents per kWh increase in the levelized cost of electricity to provide decarbonized supply.*

Two additional considerations are worth noting in table 3.2. First, these scenarios do not achieve net-zero CO_2 emissions—while 70–75% of GHG emissions are reduced, a substantial residual remains. This is particularly true for integrated operations, where coke ovens and BOF steel shops remain as major GHG emitters. CCS itself is assumed to capture no more than 90% of BF (or DRI) emissions. Additional GHG emissions are associated with reheat furnaces, coating lines, annealing operations, intraplant transport, and other activities and are assumed to remain unchanged. CO_2 emissions from such operations could be reduced or even eliminated (e.g., using zero-carbon electricity), but this is beyond the scope of this analysis. Further policy initiatives may be required to address this residual. Finally, we have not considered ways to reduce emissions from iron ore mining and beneficiation.

Second, as stated earlier, we have treated modeled technologies as proxies for a wider range of technologies that are being pursued by research institutions or commercial firms. The range of options being developed and explored is both wide and encouraging.[58] Insofar as other decarbonizing technologies ultimately prove superior in reducing CO_2 and/or offering lower costs, these alternatives could displace the technologies we have modeled. It is important that policy remain agnostic regarding technology choices and thus does not inhibit the development and commercialization of alternatives.

Today, the costs of decarbonization for the steel industry are substantial, and there is currently a lack of sufficiently powerful incentives for the industry to incur such expenses. Implementation of a carbon price (e.g., in a cap-and-trade system) could in principle provide such an incentive. However, as the experience of the European Union indicates, this is not a panacea: many European countries provide additional assistance for transformational investments. Moreover, carbon pricing does not appear politically feasible in the United States today, despite the potential impetus and revenue it could provide for decarbonization investments.

Net zero steel purchasing requirements could provide incentives for decarbonization, but such initiatives so far have not generated much impact.

Realistically, therefore, to accelerate the decarbonization of steel production in the U.S. in the current policy environment, some form of government support is required. Current policies (such as the IRA) address, in part, the related increase in operating costs. However, tax credits should be extended and expanded to include the highly cyclical, capital-intensive steel industry, so that they fully offset the incremental operating costs associated with decarbonization during this transition. In addition, EAF producers should be given operating-cost relief comparable to what is currently available to integrated producers.

Capital costs, however, are more concerning: as shown in table 3.2, capital costs for decarbonizing the steel industry between now and 2050 are between $1 billion and $1.6 billion per year. The companies themselves cannot support these capital costs; the estimate for integrated operations, for example, is equivalent to roughly half current capital spending for maintaining and improving existing facilities. Since there is no measurable economic return associated with decarbonizing investments, companies are unlikely to invest at the rate required to reduce or eliminate GHG emissions in a timely manner. The existing government programs that support capital investment for pilot projects, although worthwhile, are inadequate to contribute to meaningful GHG reductions.

Instead, we recommend that the government directly fund decarbonizing investments by utilizing Section 232 steel tariff revenues (currently $1.5–2.5 billion annually). This recommendation is discussed further in chapter 6. Making such funds available, implemented through an effective oversight and review process and possibly some cost-sharing requirements, would create a very strong incentive for steel companies to pursue decarbonization aggressively. Indeed, it is not difficult to envision a scenario where such a funding mechanism would trigger strong competition among steel companies to achieve the lowest possible carbon footprint.

3.4 Recommendations: Decarbonization Technology and Policy

Policies to support the technology transformation needed to decarbonize the steel industry should include several criteria:

1. Provide adequate incentives for decarbonization. While the establishment of a carbon price and a related carbon market might achieve this most efficiently, this is an unlikely policy initiative in the medium term. We therefore focus on competitive grants and tax credits in our analysis. Regardless of approach, however, the key is to ensure the necessary impact.
2. Maintain a level playing field for both integrated and EAF producers. Policies that favor one segment of the industry over the other are unlikely to gain the support required for implementation. As a priority of the Roosevelt Project, it is also important to preserve current employment levels and encourage investment in existing steelmaking communities.
3. Strive to be impartial across different potential technological solutions. Market incentives are a powerful tool for developing and prioritizing technological options, and governmental policies should not disrupt that process.
4. Ensure that steel decarbonization in the U.S. is not derailed by surges of direct and indirect imports. Failure to account for trade flows implies severe negative consequences both economically and environmentally.

Our analysis leads to the following recommendations:

Decarbonization technology and policy recommendation 1: Continue existing BIL and IRA policy support beyond 2032. The IRA 45Q tax credit for CCS and CCU will be critical for decarbonizing steel, as well as other industries, and should be extended beyond 2032. The 45Q credit has prompted one company, Exxon Mobil, to collaborate with Nucor to install CCS on a DRI reactor in Louisiana. However, the credit's applicability to both BF and DRI ironmaking should also be emphasized. Remaining barriers at the state and federal levels should further be addressed to accelerate CCS deployment safely.[59]

Decarbonization technology and policy recommendation 2: Extend Section 232 steel tariffs for five to eight years, allocating revenues generated for major iron and steel decarbonization investments. Provide immediate funding to early movers to invest in decarbonized iron and steel production by directing Section 232 steel tariff revenues to grants focused specifically on:

1. Capex for CCS/CCU and hydrogen applications for the blast furnace and DRI,
2. Expansion of decarbonized electricity supply for both EAF and integrated steel producers, and
3. CCS and hydrogen tie-in infrastructure.

Decarbonization technology and policy recommendation 3: Provide ongoing R&D support for technologies at all stages. Support for the development of new, potential breakthrough technologies—such as electrolytic iron- and steelmaking—should be increased, with results and prospects publicized so that companies can incorporate such potential into their long-term capital planning.

Decarbonization technology and policy recommendation 4: Support deployment of decarbonized infrastructure. To ensure infrastructure investments are made in locations needed to support decarbonization of industrial sites, as part of the application process for 48C, national and state governments should appoint regional expert groups to inform coordinated planning among representatives of electric power, CCS/CCU, hydrogen, and industry producers/operators, in particular for expanded transmission networks and CO_2 pipelines and sequestration sites.

Decarbonization technology and policy recommendation 5: Set accounting standards and regulations that incentivize investments aligned with national net-zero and global 2° C goals. CO_2 accounting frameworks required for company reporting should be updated to include a broader system boundary and clearly define the process steps. At minimum, CO_2 emissions associated with cokemaking and use and coproduct gases should be included to inform a more comprehensive standard that is compatible with international standards, such as that advanced by the World Steel Association.

4. Communities and Workers in the Low-Carbon Iron and Steel Transition

Key messages:

- A survey of eight communities found that the steel industry's presence provides high-paying jobs with benefits, public revenue, and other forms of direct economic support. Survey respondents generally felt positively toward the industry and toward its decarbonization.
- While the number of iron and steel industry employees has fallen over time, the steel industry remains a crucial pillar of employment in many communities. It can also provide a source of above-average-wage jobs with benefits in new areas as the industry expands.
- Communities around BF-BOF and EAF plants differ substantially in geography, demographics, and the local environmental impacts of steelmaking. The implications of different decarbonization options for communities located near EAF and BF-BOF plants will also be distinct and should be recognized and reflected in the choice of technologies and Community Benefits Plans (CBPs) and Community Benefits Agreements (CBAs), as well as any transition assistance programs.
- Decarbonization of iron and steel production offers a broad set of opportunities and public health co-benefits. Communities located near steel production sites face relatively high exposure to environmental harms—some of them ranking among those with the highest levels in the country. Incentives and funding to support decarbonization should fully account for their ability to provide these co-benefits, such as improving air quality and lowering health-related spending. Since many communities may not be aware of these co-benefits, developers and policymakers should communicate them and support their realization through project planning, CBPs and CBAs, and accountability mechanisms.

The impact of the iron and steel industry extends far beyond the production floor. This chapter examines the characteristics and perceptions of communities living near iron and steel production sites. It examines the evolution of the steel industry's geographic footprint, the social and economic impacts of deindustrialization, and how community members have experienced industry shifts as well as their views on decarbonization. Generally, our surveys found that industry presence can benefit communities—for instance, via high-paying jobs with benefits, public revenue, and other forms of direct economic support. In 2023, community members employed by iron and steel producers (either EAF and BF-BOF producers) earned an average of $2,040 per week, 54% above average U.S. wages.[60] Communities often receive municipal, county, and state tax revenues collected from industry. Locally, plants or companies often directly support pillars of community and civic life, including but not limited to libraries, sports teams, and faith communities.[61]

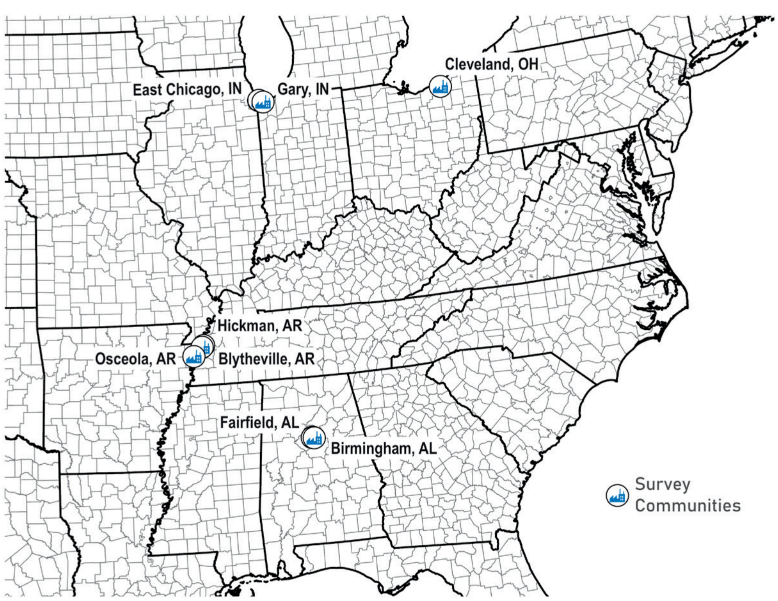
Historically, proximity to an industrial site has also come with negative impacts. A plant may emit air pollutants or introduce other forms of environmental harm that directly affect human health and ecosystems, agriculture, and recreation. Even stringent regulations, flawlessly implemented, do not eliminate all environmental impacts. Social inequities have been perpetuated by some employers, who provide unequal access to jobs, energy, and other resources based on race, class, or other sociodemographic characteristics. These inequities have, in turn, shaped broader community biases and may continue to limit opportunities for those in underrepresented or vulnerable groups. In the steel industry, negative impacts vary across sites and differ by production technology, regional institutional history, and community and business culture. As decarbonization is likely to result in local changes for many communities near iron and steel plants, it is important to understand and address the historical context in which this technological change is expected to take place.

In this chapter, we report the results of our survey of community members living within 25 miles of steel mills in eight distinct communities, five with EAFs and three with BF-BOFs. Two of those communities have experienced the transition from BF-BOF steelmaking to EAFs. This chapter also reports the histories of four communities where iron and steel production has already experienced technological change, helping to inform the low-carbon transition. The physical environment, human health, and residential well-being of these communities have historically received far less attention than the industries they host. Our recommendations in this chapter focus on how community engagement can result in long-term benefits from steel decarbonization.

4.1 Survey Analysis and Results

In late 2023 and early 2024, a survey study was conducted in eight communities in Arkansas, Alabama, Indiana, and Ohio with active iron and steel production sites. The goal of the survey was to gain a deeper understanding of how residents and workers understand the presence of steel production in their communities and their attitude toward the economic, environmental justice, and public health implications of industrial decarbonization. These locations were identified as representative of three major domestic steel companies as well as both EAF and BF-BOF steelmaking processes. They are geographically diverse, including highly urbanized communities and rural areas, as well as predominantly white and racially diverse regions.

Figure 4.1: Locations of communities surveyed.



All surveyed counties register higher unemployment rates than the national average and national median household incomes lower than average (based on five-year estimates from the American Community Survey). Across socioeconomic indicators, Mississippi County, Arkansas—which includes Blytheville, Hickman, and Osceola—ranks lowest. The county is also the least populated of those surveyed, with a 2021 population of just over 41,000. By contrast, Cuyahoga, Ohio, home to metropolitan Cleveland, is the most populous of the surveyed counties, followed by Jefferson County, Alabama, whose county seat is Birmingham. Jefferson has the largest non-white population of the four counties; approximately 43% of the county's population is Black. Jefferson County also recorded the lowest unemployment rate and the highest education attainment of the surveyed set. Lake County, Indiana, the state's second most populous county, registers the highest median household income ($62,052 in 2021) and the lowest proportion of the population with an income-to-poverty ratio of less than 50%.

The surveyed communities span the history of steel production in the United States. They include established legacy production sites such as the United States Steel Corporation's Gary Works, one of the largest integrated mills in North America, in Gary, Indiana. Cleveland-Cliffs' Cleveland Works, another BF-BOF facility, is situated on 870 acres along the Cuyahoga River and employs over 2,100 people in greater Cleveland.[62] This area has played a major role in steelmaking in the United States since the mid-19th century. East Chicago is adjacent to Cleveland-Cliffs' Indiana Harbor BF-BOF plant. In Alabama, the proximity of Birmingham to the resources-rich Jones Valley and competitive labor and transport costs activated a core steel production region in the South. Both Birmingham and Fairfield, Alabama, were once home to BF-BOF technologies but now host only EAFs. The presence of steel production in other communities is much newer. Northeast Arkansas has become a locus of the steel industry just over the past decade, after major investments by Nucor and U. S. Steel. U. S. Steel's decision to build a new three-million-ton EAF facility in Osceola, Arkansas, in 2022 is reported to be the largest single capital investment in the state's history.[63]

4.1.1 Survey Methodology

Over 1,300 residents were surveyed online based on zip codes that fell within a 25-mile radius of major steelmaking facilities in Birmingham and Fairfield, Alabama; Gary and East Chicago, Indiana; and Cleveland, Ohio. In Blytheville, Hickman, and Osceola, Arkansas, the surveys were conducted online as well as by SMS and mail. Where necessary, responses were weighted within each state by gender, age, race/ethnicity, and income to align them with their proportions in the general population. The sampling margin of error of this survey was ±2.7 percentage points. For comparison, after the original survey was completed, a second general population survey was conducted nationally among 1,100 residents who were not part of the steel industry. The national survey provides a baseline with which to compare results from the communities selected for this analysis. Where necessary, results were weighted by gender, age, race/ethnicity, and income to align them with their actual proportions in the national population. The sampling margin of error of the national survey was ±3.0 percentage points.

Table 4.1: Sample sizes (number of residents surveyed) in different states and margin of error.

Location	Sample size	Sampling margin of error
Arkansas	247	6.2%
Alabama	340	5.3%
Ohio	330	5.4%
Indiana	390	5.0%
Total	1,307	2.7%
U.S. general population	1,100	3.0%

Respondents were asked a series of questions related to their awareness and attitudes toward steel production in their communities and to evaluate key economic, environmental, and social issues that affect their lives. The survey also considered how residents thought about decarbonization and their views on steel company accountability and corporate citizenship. Finally, respondents were asked about their proximity to steel plants and their views about proposed new steel production facilities in their communities.

4.1.2 Demographic Profile of Surveyed Geographies

The demographic profiles of the surveyed geographies provide a more granular view of the neighborhoods and communities of respondents. Communities in Fairfield, Birmingham, East Chicago, and Gary reported a larger share of people of color than the national average. By contrast, the Arkansas zip codes in Blytheville, Hickman, and Osceola have lower percentages of people of color than broader Mississippi County, Arkansas. All geographies register unemployment rates higher than the national average, with the highest rates in East Chicago (9.3%) and Gary (9.1%). All geographies also have higher percentages of people with an income-to-poverty ratio under 0.5, compared to the national average of 5.8%, indicating relatively higher levels of poverty in surveyed communities. However, in certain places, median household incomes are slightly higher than their county equivalents: $62,365 in Fairfield and $61,883 in Birmingham, compared to $58,330 for all of Jefferson County, Alabama. This is also true for the zip codes surveyed in Cleveland, which registers a median household income of $71,318, compared to $55,109 for Cuyahoga County, and in East Chicago, where the median income of surveyed zip codes average $71,393, higher than Lake County's median household income of $62,052.

Table 4.2: Surveyed communities demographic profile: zip codes within a 25-mile radius of a steel facility.[64]

Location	People of color	Less than high school education	Unemployed	Median household income	Households with ratio of income to poverty level under 0.5	Share over age 64 years
Blytheville, AR	24.6%	19.7%	7.2%	$ 45,397	7.5%	16.8%
Hickman, AR	23.0%	20.2%	7.1%	$ 44,317	8.0%	16.8%
Osceola, AR	24.6%	20.0%	7.6%	$ 49,475	8.1%	17.4%
Fairfield, AL	41.0%	11.0%	6.7%	$ 62,365	7.2%	16.0%
Birmingham, AL	41.4%	11.1%	6.7%	$ 61,883	7.3%	16.0%
Cleveland, OH	29.9%	8.2%	6.4%	$ 71,318	6.3%	18.7%
East Chicago, IN	49.0%	10.7%	9.3%	$ 71,393	7.5%	15.5%
Gary, IN	51.1%	10.7%	9.1%	$ 67,785	8.2%	16.2%
U.S. average	31.9%	11.1%	5.5%	$ 69,021	5.8%	16.1%

4.1.3 Survey Insights and Results

Surveyed residents within a 25-mile radius are relatively unaware of steel plants located in their communities, but a plurality indicate favorable views of steel plants. The survey found that less than half (46%) of respondents were aware that they lived near a steelmaking facility. Awareness was highest in the EAF communities of Blytheville and Hickman in Arkansas (61% and 65%, respectively) and lowest in the integrated steelmaking communities of Cleveland, Ohio, and East Chicago, Indiana (40% and 45%, respectively). Respondents indicated largely neutral to favorable views of steel plants in their communities: overall, about 78% of those surveyed indicated they felt neutral, somewhat favorable, or very favorable toward local steel plants.

Steel plants are associated with job creation and economic development, and economic issues are top of mind for community members. A significant majority (82%) of those surveyed associated steel plants with positive community impacts, particularly related to job creation and work-related skills development. Positive association with local steel plants was highest in Blytheville (96%), Fairfield (91%), and Birmingham (87%). A clear finding from the survey is that economic issues, particularly job and retirement security, are the top issues across all surveyed communities. Moreover, respondents indicated they would like to see higher wages and greater job creation, retirement benefits, and job training and are most concerned with higher prices and job losses, including layoffs and outsourcing.

Familiarity with decarbonization is low among respondents, but a clear majority of residents think it will have a positive impact on their communities. Survey results indicate relatively low familiarity with decarbonization, with fewer than one in four (23%) saying they are familiar with the term. This is lower than the general population, in which approximately 31% indicate familiarity with decarbonization. Unaided, more than two in three (69%) residents thought decarbonization would have a positive effect on their community. After an explanation of decarbonization, about 76% of respondents answered it would have a positive impact on their communities. Residents in the counties in Ohio and Indiana, the locations of the BF-BOF plants, reported the largest change after the explanation of decarbonization. The survey also found that members of steelmaking communities are slightly more likely to think that decarbonization will have a positive effect than the general population. Among decarbonization technologies, respondents were most familiar with clean electricity and hydrogen fuels replacing fossil fuel resources. With regard to community concerns around decarbonization, respondents identified higher costs and job losses as the top issues.

Environmental well-being is a low priority. When asked which community issues they prioritize, respondents ranked environmental well-being lowest. Of the geographies surveyed, concern for environmental well-being was lowest in the Arkansas communities and highest in Cleveland, Ohio. However, respondents also reported that their local steel plants contribute to the problem of air pollution and pollution broadly (including land and water). These are strong negative associations with steel plants, in spite of the stated lower priority of environmental concerns.

These findings reveal several insights into these communities and the social dimensions of steel decarbonization. First, iron and steel production is clearly associated with economic activity and job creation in respondents' regions, and economic issues rank high among community concerns. This is consistent with the demographic analysis shown earlier that finds that, while the median household income is relatively high in many of the surveyed zip codes, unemployment rates and poverty levels are higher than the national average, particularly for communities near integrated facilities. Second, while awareness of decarbonization is low, there is strong community support for enabling production processes that lower dependence on fossil fuels, a sentiment shared across geographies and production types. Third, environmental concerns rank low, although respondents associate plants with environmental pollution. What these findings underscore is the opportunity to build consensus around iron and steel decarbonization strategies that provide environmental co-benefits while also delivering economic stability to neighboring communities and workforces.

4.2 Steelmaking Communities Today

The survey results provide insight into community perceptions of the iron and steel industry and its decarbonization. The remainder of this chapter describes the geographic footprint and environmental impacts of iron and steel supply chains in the United States and develops four case studies focused on what decarbonization investments may look like from the perspective of communities.

Figure 4.2: Iron and steel production–related sites.

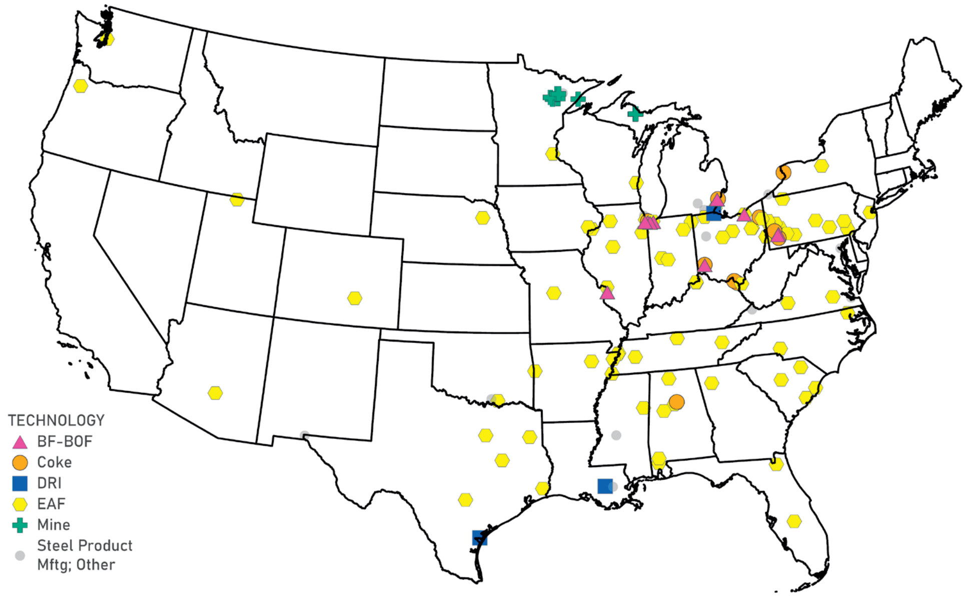
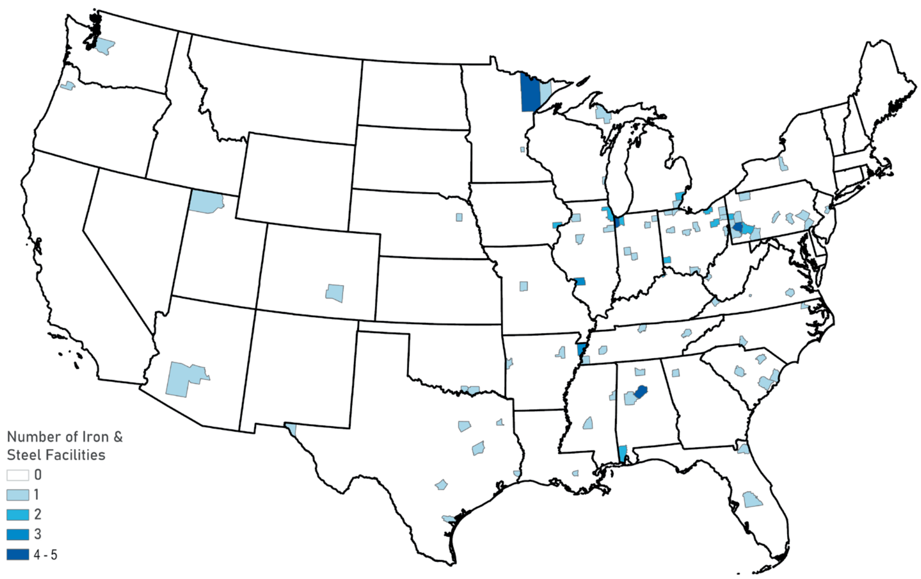


Figure 4.3: Number of sites with iron and steel facilities, by county.



Compared to a half century ago, today's iron and steel industry is much more dispersed, due in part to the rise of EAFs. In 2022, the domestic steel industry included over 100 steelmaking facilities, 7 iron ore mines, 3 DRI plants, and 8 coke ovens across 31 states, including Ohio, Pennsylvania, and Indiana, which together are home to over one third of all domestic steel facilities and account for approximately 43% of the country's total raw steel production.[65] In terms of greenhouse gas emissions, facilities in these three states generate a large share of the industry's Scope 1 emissions (nearly 69% of the industry's total).[66] The productive center of integrated steelmaking remains in Appalachian Pennsylvania and the Industrial Midwest, while the rise of EAFs has expanded the industry's geographic footprint into communities in the West and the Southeast over the past several decades.

In total, 91 counties are home to at least one operating iron and steel production site, defining the geography of communities associated with iron and steel production across the United States (see figure 4.3). Notably, several counties register four or more steel facilities or iron ore mines: St. Louis County, Minnesota; Allegheny County, Pennsylvania; Lake County, Indiana; and Jefferson County, Alabama. Over the past several decades, the South has emerged as a growing regional powerhouse in steel production, rivaling the Midwest. Data from the American Iron and Steel Institute (AISI) show that raw steel production in the South averaged nearly 601,000 short tons (st)/week in 2020, outpacing the Great Lakes' output of nearly 535,000 st/week. Alabama, home to a steel industry that developed in the post–Civil War era, has in recent years secured several steel-related investments, including the United States Steel Corporation's $412 million EAF in Fairfield and the planned expansion of CMC Steel Alabama's Birmingham facility.

Table 4.3: Steel industry GHG emissions (Scope 1) by technology or process.[67]

Technology or process	Facilities count	Scope 1 GHG emissions (MT CO_2e)	Share Scope 1 GHG emissions
BF-BOF	11	36,173,515	59.2%
Coke	8	4,249,783	7.0%
EAF	82	13,470,152	22.0%
DRI	3	2,613,283	4.4%
Mine	7	3,322,947	5.4%
Other	9	1,236,282	2.0%
Total	120	61,130,175	100%

4.3 Environmental Impacts in Steelmaking Communities

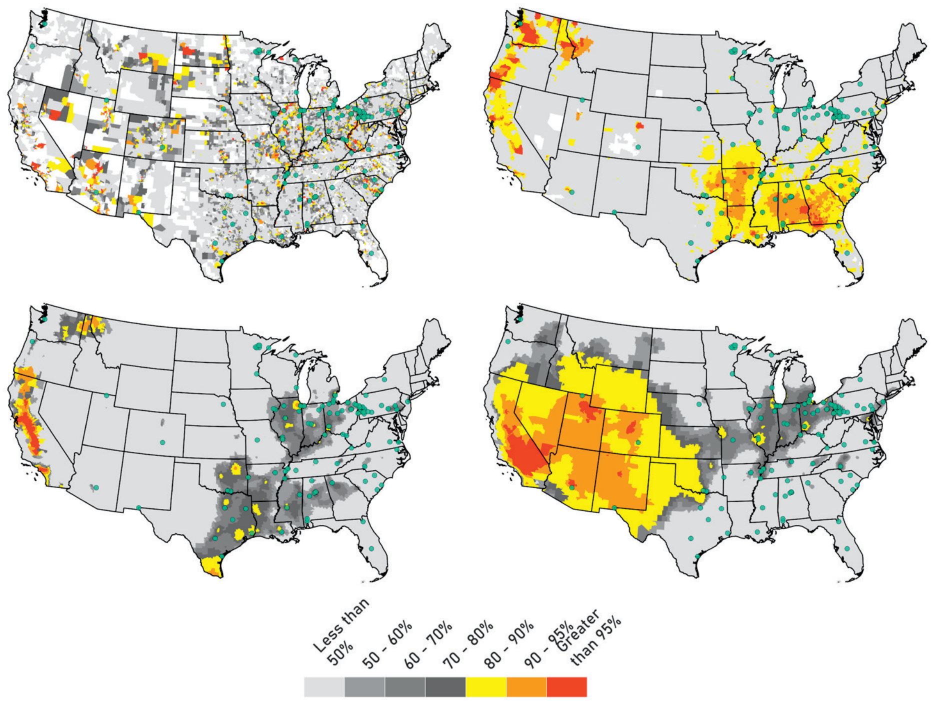
The integrated facilities account for the majority of the industry's Scope 1 emissions from large facilities, at nearly 60% according to the latest estimates from the EPA's Facility Level Information on GreenHouse gases Tool. Large EAFs generate 22% of the steel industry's Scope 1 GHG emissions. In general, areas with BF-BOF facilities tend to register greater exposure to environmental harms than areas with EAFs. Table 4.4 shows the mean percentile of steel census tracts by type of steel facility, using data from the U.S. EPA's Environmental Justice Screening and Mapping Tool (EJSCREEN) and the Greenhouse Gas Reporting Program (GHGRP). On average, census tracts where BF-BOF facilities are located rank above the 50th percentile in exposure to ozone, diesel particulate matter, air toxics cancer risk, and wastewater discharge, as well as proximity to Superfund sites and hazardous waste facilities—and higher than census tracts where EAF steel facilities are located.[68] Air toxics cancer risk, which considers lifetime cancer risk from inhalation of air toxics, is particularly high in census tracts with BF-BOF facilities and coke plants, which register respectively in the 88th percentile and 90th percentile nationally. While EAF census tracts on average rank lower than BF-BOF tracts, they rank above the 50th percentile nationally in environmental burdens such as air toxics cancer risk, proximity to risk management plan (RMP) facilities, and wastewater discharge.

These findings are consistent with other recent analyses that have focused on the environmental justice dimensions of industrial production more broadly. Proximity to steel production has been associated with air pollutants that impact autonomic nervous system control of the heart and broader cardiovascular physiology.[69] EAF steelmaking carries its own environmental burdens. The coproduction of slag and dust that contains hazardous heavy metals in EAF production remains a key public health issue.[70] These disparate environmental burdens and public health challenges are an important consideration when planning iron and steel decarbonization, given that some technologies may offer local environmental benefits, including improved air quality and a reduction in other environmental harms. Moreover, the disproportionate burdens placed on lower-income individuals, people of color, and other fenceline communities must be prioritized, since residents of these communities have historically shouldered the negative impacts of industrial production. For example, 27% of people living within three miles of BF-BOF facilities are Black, more than twice the percentage of Black people in the U.S. population.[71]

Table 4.4: Mean percentile of steel facility census tracts by steel facility and impact type across selected environmental exposures.[72]

Steel facility type	Ozone	Diesel PM	Air toxics risk	Toxic releases air	Superfund site	RMP facility proximity	Hazardous waste proximity	Underground storage tanks	Wastewater discharge
BF	72	77	88	76	58	76	75	68	83
Coke works	62	59	90	69	60	75	67	52	80
DRI	32	51	55	53	33	84	60	28	67
EAF	51	44	70	61	42	60	57	44	66
Mine	11	3	24	16	6	16	14	20	59
Other	63	41	82	57	40	62	63	52	63

Figure 4.4: Selected environmental burdens by census tract (clockwise from top left): wastewater discharge, respiratory hazards, PM, ozone.[73]



4.4 Sociodemographic and Labor Market Conditions of Steelmaking Communities

Table 4.5: Mean percentage of steel facility census tracts across selected sociodemographic factors.[74] *Low income* is defined as household income less than or equal to twice the federal poverty level.[75]

Steel facility type	% Low income	% Unemployed	% Less than high school education	% Over age 64	% Minority population
Blast	47	10	13	14	51
Coke	53	8	13	14	47
DRI	34	9	17	15	46
EAF	36	6	13	16	30
Mine	24	4	6	26	7
Other	40	6	15	16	36
U.S.	29	6	11	16	32

Although total industry employment has declined, the steel workforce remains a crucial pillar of U.S. industry and regional economic activity. In 2022, domestically produced raw steel was valued at about $132 billion, a 13% increase from 2021.[76] The broader steel industry employed over 136,000 people in 2022, which can be further broken down to workers directly employed in iron and steel production (82,100 workers or 60.3%) and those employed in steel product manufacturing (54,100 or 39.7%).[77] In the 10 years between 2012 and 2022, total steel industry employment declined by 10.6%. According to the Quarterly Census of Employment and Wages (QCEW) collected by the Bureau of Labor Statistics, in the third quarter of 2023, annual wages averaged $106,080 for steel mills and

$77,324 for steel product manufacturing.[78] These averages included both EAF and BF-BOF steelmakers and both unionized and nonunionized companies. By comparison, the annual average wage was $77,896 for the entire manufacturing sector and $69,056 for all employment.[79] The five states with the highest average pay in iron and steel production were North Carolina, Louisiana, Pennsylvania, Indiana, and Arkansas.[80] While 100% of production and maintenance employees of BF-BOF facilities and iron ore mines are represented by unions, only about 20% of employees of EAF facilities are similarly represented.

Although the scenarios we consider in chapter 3 held steel production constant, recent legislation such as the IIJA may lead to an increase in domestic steel demand. According to the American Iron and Steel Institute, $100 billion of infrastructure investment could create demand for five MMT of steel, and an additional federal outlay of that amount would be expected to lead to 5,048 worker-years of employment in steel production.[81] The ability to meet any increase in demand with domestic production may further depend on availability and cost of key inputs, such as prime scrap, which may imply a need for more green DRI or pig iron production.

It is important to understand the differences across communities near iron and steel facilities when planning for decarbonization. Across sociodemographic factors, census tracts that are home to BF-BOF facilities have higher proportions of low-income individuals, higher unemployment rates, and higher proportions of people of color compared to EAFs and the national average. In these locations, exposure to harmful air pollutants coincides with higher proportions of low-income and minority residents. The proportion of the population without a high school education is similar between BF-BOF and EAF census tracts, and both have slightly higher proportions than the national average. Of the facilities compared, DRI census tracts have the highest proportion of individuals without a high school education, while communities near iron ore mining sites have the lowest (at 5.6%), the lowest unemployment rates, and a higher proportion of people older than 64 (over 25%).

4.5 Place-Based Case Studies of Decarbonization and Communities

The following four case studies provide examples of technological investments and initiatives that support decarbonization and how they have involved and impacted communities.

4.5.1 Gary, Indiana: Can Decarbonization Technologies Improve Community Outcomes?

One of the best examples of the challenges to legacy communities can be seen in Gary, Indiana, a “model” city created and designed in the early 20th century for integrated steel production. The town was a segregated city with a “First Subdivision” for the white, upper-class steel management employees, described as an “ideal suburb, with sidewalks, utilities, trees, lawns, and [a] bustling downtown sector for ‘only the very well-paid employees,’” and “The Patch” for the lower class, Black, and European immigrants.[83] By the 1960s, Gary was a town of 178,000 people, 39% of whom were Black. Over the next 60 years, a decline in manufacturing jobs resulted in a loss of population and the flight of white residents to the suburbs, leaving the town 78% Black and with a higher unemployment rate (12.8%) and worse educational attainment (52% high school education or less) than the United States on average.[84]

Gary is adjacent to the United States Steel Corporation's Gary Works on the shore of Lake Michigan and sandwiched between the Cleveland-Cliffs steel mills in Indiana Harbor and Burns Harbor. Mills close to Gary, Indiana, release substantial amounts of airborne particulate matter ($PM_{2.5}$), ozone, and other toxins in proximity to fenceline communities. Asthma among adults and life expectancy in Gary are among the worst in the United States, with most of the city above the 90th percentile nationally in both categories.[85] Member of the community Kimmie Gordon, founder of Brown Faces Green Spaces asserts that things need to change, saying, "We have such beauty available to us and access to it, but it's being tainted by the very thing that made Gary Gary in the first place: the largest steel manufacturer in the nation."[86]

Decarbonization may offer a positive future for the residents of Gary, both economically and environmentally, if it allows operations to continue with a substantial reduction of environmental impact. Reflecting on the opportunities of decarbonization, Eddie Melton, mayor of the City of Gary, shared with our case study team, "The steel manufacturing process is highly carbon intensive and woven into the fabric of Gary's history. As this industry grows, it's important that manufacturers act urgently to adopt methods and technologies to minimize their carbon footprint. We must protect our workforce, stabilize our cities, and embrace a cleaner, greener future. The actions of industry players today have the power to shape a brighter tomorrow for cities like Gary and ensure a better quality of life for generations to come."[87]

CCS may prove to be one example. The Great Plains Institute, in its 2023 analysis of the air quality improvements associated with broad adoption of CCS technology for industrial decarbonization, estimated that the public health benefits for Indiana, Michigan, Illinois, Wisconsin, and Minnesota would range from $63.8 million to $144 million annually. These co-benefits result from the importance of first removing the air pollutants NO_x and SO_2 from the captured gas prior to transport and sequestration or utilization.[88] Currently, several efforts are underway by U. S. Steel and Cleveland-Cliffs to test the applicability of new technologies in the area's blast furnaces, including U. S. Steel's CO_2 conversion project with CarbonFree to convert CO_2 to calcium carbonate and Cleveland-Cliffs' engineering study on CO_2 capture at its Burns Harbor facility and its hydrogen injection pilot at Indiana Harbor.

4.5.2 Minnesota Iron Range Communities

Northern Minnesota has provided the bulk of America's iron ore for steelmaking for almost a century and a half. At its high point during World War II, between 1941 and 1945, the Iron Range produced over 333 MMT of high-grade ore, over 70% of U.S. production.[89] In the first half of the 20th century, Minnesota's iron mining communities were largely populated by immigrants from Scandinavia, Finland, and Eastern Europe.[90] Northern Minnesota's iron and steel industry history has gone through two distinct phases and may now be entering a third as the steel industry starts to decarbonize.

Until the early 1950s, iron ore mining in Minnesota was focused on "natural" ore with an iron content of 65–70% or more, which could be used in blast furnaces and open hearth furnaces to make steel. By the end of World War II, the natural ore deposits were exhausted, and there was some question about whether the domestic iron ore industry could survive. But long-standing research at the University of Minnesota by Dr. Edward Davis (in the 1930s and 40s) had shown how to successfully process lower-grade ores, specifically taconite, for use in blast furnaces. Taconite, which has an iron content of 25–30%, was first crushed and then ground into a powder in giant rotating mills, then separated from the tailings with rotating drum magnets. The residue was then reformulated into pellets with a 65% iron content. In later years, limestone was also added to make so-called flux pellets, which reduced the need for limestone in the blast furnaces.[91]

As a result of that research, the first taconite plant was built in the early 1950s in Silver Bay, Minnesota. In 1957, the largest industrial investment in U.S. history at the time was made to build the second taconite plant, the Erie Mining Company in Aurora-Hoyt Lakes, along with a power plant, railroad line, and port loading facility on Lake Superior in Taconite Harbor. On opening, these operations employed over 6,000 members of the United Steelworkers.[92] Taconite production reached its peak in the mid-1970s, when nearly a dozen taconite plants spread across the Iron Range in Minnesota and the Marquette Range in the Upper Peninsula of Michigan, producing over 70 MMT of ore per year.[93]

The mines were all open pit operations, relying on heavy earth-moving equipment, massive amounts of energy, and both production employees and large maintenance crews. This modernization of the industry revitalized Iron Range communities, driving down unemployment from over 10% in 1973 in St. Louis County to virtually zero in Hibbing, Minnesota, the heart of the Mesabi Iron Range, two years later.[94]

Over the last 50 years, the increase in the use of scrap in EAFs has resulted in a decline in taconite pellet production in Minnesota, ranging from a low of 17 MMT in 2009 to a high of 39 MMT in 2018, supplying blast furnaces in both the United States and Canada.[95] In 2023, Minnesota taconite plants produced 35 MMT.[96] A 2020 economic impacts study by the University of Minnesota in Duluth found that the iron ore industry in the state directly employed just under 4,000 people and supported an additional 4,960 indirect and induced jobs.[97] Today, the six operating taconite mines and processing plants in Minnesota, owned by Cleveland-Cliffs and U. S. Steel, are 100% unionized. These sites pay some of the highest wages in the state. QCEW data from the Bureau of Labor Statistics showed average weekly wages of $1,998 in the second quarter of 2023, or $104,000 per year.[98] Average weekly wages in Minnesota were $1,314, or roughly $68,000 per year.[99]

Decarbonization of iron and steel production in the United States may generate both opportunities and threats to Minnesota's Iron Range communities, which are spread across three counties along the Mesabi ore body. If raw materials are domestically sourced, investments in CCS for the BF-BOF and DRI will provide a stable, long-term customer base for the iron ore pellets produced by the six existing taconite plants. For instance, hot-briquetted iron (HBI) is currently produced by Cleveland-Cliffs with Minnesota pellets in its facility in Toledo, Ohio. U. S. Steel has also recently invested $150 million in a next-generation facility in Keewatin, Minnesota, for producing direct reduction–grade taconite pellets (up to 68% iron ore) to be used to produce DRI for EAF steelmaking.[100]

Minnesota is also a candidate location for the production of DRI and green steel. Currently, most DRI used by EAFs in the United States is produced in Louisiana and Mississippi, using iron ore imported from Brazil, Canada, and Norway, with the remainder produced overseas (see chapter 3). For example, DRI is shipped directly from Trinidad by Nucor.[101] One key issue is the flammability of DRI when it is shipped in enclosed containers, such as on ships or railcars.[102] Treatment of DRI to avoid this problem or conversion to HBI is an added expense.

In a recent project launched by the DOE's Communities Local Energy Action Plan in Duluth and assisted by the National Renewable Energy Laboratory (NREL), researchers led by Dr. Jennifer King concluded that northern Minnesota was one of the most competitive sites in the United States for the development of a green steel industry.[103] This research identified the key economic factors important for producing decarbonized steel as (1) abundant, low-cost zero-carbon electricity, (2) existing pipeline infrastructure, (3) proximity to existing transportation infrastructure, and (4) underground hydrogen storage potential. These factors, all combined with the abundant iron ore resources of Minnesota, led researchers to identify northeastern Minnesota as a top candidate for the next generation of iron ore and steel production in a decarbonized industry.

4.5.3 Making Steel with Renewable Energy in Sedalia and Pueblo

For EAF producers, electricity can account for 10% or more of the cost of producing steel. Our research revealed that making clean electricity available to steel producers can be a key factor in deciding where to locate a new mill or whether to continue to operate an existing mill. These decisions have implications for the preservation or creation of jobs and for the well-being of proximate communities. The two mini-cases below describe how two EAF steel companies collaborated with stakeholders to secure access to renewable electricity for their operations at an affordable and reliable price. While these are two pioneering examples, with sufficient support and coordination, many elements could be replicated to expand the availability of low-cost decarbonized electricity to EAF steel production, CO_2 capture at blast furnaces and direct reduced iron reactors, and electrolysis for clean hydrogen—all major end uses that are expected to grow in the low-carbon transition.

Wind energy for a new EAF site. In 2017, Nucor announced plans for construction of a $250 million EAF mill in Sedalia, Missouri.[104] Sedalia offered several advantages for the steelmaker, including access to scrap and proximity to consumers for the mill's steel rebar products. Additionally, a $10 million federal grant connected Sedalia's industrial park to the broader rail system.[105] Another major allure of Sedalia for Nucor was perhaps more unconventional: abundant wind.

The Nucor Sedalia mill became the first wind-powered steel mill in the United States through a 75 MW power purchase agreement (PPA) with utility Evergy,[106] commencing operation in January 2020.[107] In a similar configuration to EVRAZ Pueblo, the Nucor Sedalia mill is still supplied from the grid—through the Southern Power Pool transmission network.[108] But with the PPA, wind energy provided by Evergy is expected to offset 100% of the mill's electricity demand. Underpinning the PPA deal was the Missouri "steel mill bill," enacted in 2017, which permitted utilities to offer a regulated "competitive electric rate" for consumers with demands of greater than 50 MW.[109] The Missouri Public Service Commission granted this negotiated electric rate for the Nucor project in December 2019.[110]

The arrangement is a win-win for Nucor, marking a tangible effort to reduce CO_2 emissions while securing long-term certainty for mill operation through the PPA electricity rate.[111] The project also provided jobs for the region: over 500 workers were involved in construction, and the mill is anticipated to employ 250 full-time workers with starting salaries of nearly double the regional average entry-level wage.[112] Spurred on by the Nucor plant, other businesses are showing interest in Sedalia—promising further economic benefits to the area.

In Missouri, as well as neighboring Iowa and Kansas, there is a growing recognition among companies, advocacy groups, and regulators alike of the region's abundant clean wind energy potential.[113] The Nucor Sedalia mill and PPA may serve as a key model for decarbonization of the industry—wedding technology, policy, local economic development, and clean energy resources to produce green steel.

Connecting an existing mill to solar energy. Steel has long been important for Pueblo, Colorado, beginning in the 1880s when the Colorado Fuel and Iron Company (CF&I) began iron- and steelmaking operations.[114] CF&I grew rapidly during the first half of the 20th century but faced substantial challenges during the latter half. In the 1960s, foreign competition and domestic legislation (notably, a mandate on minimum scrap content that forced substantial investment in recycling technology) put pressure on the company. CF&I constructed its first EAF on-site in 1973 to replace open hearth furnace operations.[115] CF&I filed for bankruptcy in 1990 following the 1980s steel crisis, which is discussed in chapter 5. Oregon Steel Mills (OSM) purchased the operations three years later, renaming the Pueblo site Rocky Mountain Steel Mills. In 1997, disagreements between OSM and the United Steelworkers (USW) union over labor contract renewal terms led to a three-month walkout.[116] OSM then refused to rehire union workers who had participated in the strike. The resulting conflict lasted for seven years. The USW filed unfair labor practice and environmental lawsuits against OSM with the National Labor Relations Board. In response, OSM negotiated a settlement with the USW that included accepting a union-nominated director to its board and awarding back pay for all employees.[117] In 2007, EVRAZ, a UK-based steelmaker, purchased OSM, followed by its 2008 acquisition of Canadian steelmaker IPSCO—leading to the present ownership in Pueblo.[118]

In December 2021, a 240 MW solar photovoltaic (PV) array came online in Pueblo, rendering the EVRAZ plant the largest "solar-powered" steelmaking facility in the world.[119] The project, dubbed Bighorn Solar, annually produces electricity equivalent to roughly 90% of EVRAZ's electricity demand in Pueblo. In exchange for renewable electricity from Bighorn Solar, EVRAZ made a commitment to Pueblo and the State of Colorado to invest $500 million in a new long rail mill, creating an additional 300 jobs for the community and securing 1,000 existing jobs at the facility.[120]

By 2021, Pueblo, in many ways a poster child for the decline of steelmaking in the United States, had reinvented itself as a pioneer in decarbonized steel. However, in the late 2010s, the future of EVRAZ in Pueblo was far from certain.[121] Electricity from the coal-fired Comanche power plants, operated by utility provider Xcel Energy, was neither cheap nor consistently available. EVRAZ, the largest producer of rail in North America, sought to build a new facility for the production of 320-foot-long rails, which faced high demand from freight rail companies, and began considering sites nationwide. Mark Valentine, counsel for EVRAZ in the Bighorn Solar deal, explained that the company was already paying a premium to transport rail products across the country. States in the Midwest offered cheaper transport and an abundant, qualified labor pool. Nonunionized labor and abundant raw materials could be found in the South. Additionally, the Southeast offered cheap coal- or natural gas–based electricity, in the range of $0.035/kWh, guaranteed in the medium term of 5 to 10 years—a compelling draw for the company, noted former CEO Conrad Winkler.

In 2017, while EVRAZ considered its options, Xcel began to explore the closure of the coal-fired Comanche power plants in response to the State of Colorado's mandate for 80% of power to be provided from renewable sources by 2030.[122] Discussions with the Pueblo community revealed fears that the loss of jobs at the Comanche plants, coupled with the potential departure of EVRAZ, would be devastating to the local workforce. It became clear that a workable path forward could only be achieved by bringing all stakeholders to the table.

Solar PV emerged as an alternate solution. According to former Colorado Public Utilities Commission (PUC) staffer Keith Hay, EVRAZ had the land to house a sizable array and knew that the project would both enable long-term planning and certainty for a new rail mill and complement efforts to fully electrify their existing EAF operations. Initially, EVRAZ hoped to connect "behind the meter" but was faced with challenges over reliability, systems safety, and interconnection. The backup plan—sending solar through the grid, to be purchased back by EVRAZ—involved a more complicated negotiation process. The linchpin was a Colorado statute allowing the utility to petition for a special "economic development rate," designed to incentivize businesses to stay in Colorado when the state would otherwise lose a significant employer. EVRAZ and Xcel agreed to hammer out a contract to lock in long-term electricity rates, thus granting the steelmaker the necessary cost certainty to remain in Pueblo.[123] As Hay described, local politicians quickly agreed with the idea of solar. The Pueblo community's response was overwhelmingly positive.[124] According to Valentine, communication with Xcel was also key for convincing the utility of the business case for Bighorn Solar—a case strong enough for Xcel to commit to the complex regulatory negotiations that would eventually bring solar-powered steelmaking to Pueblo.

After over a year of negotiation, EVRAZ and Xcel agreed to a contract, which was then green-lighted by the PUC in September 2018.[125] In public testimony, PUC staff witness Erin O'Neill stated that the deal satisfied all four criteria of the Colorado "economic development rate" statute: (1) the off-tariff electric rate paid by EVRAZ would still exceed the variable cost of generation, (2) EVRAZ had demonstrated a credible threat of leaving the state, (3) Xcel customers would not pay higher rates (O'Neill: "Across a wide range of alternative assumptions…the contract is unlikely to adversely affect remaining ratepayers."), and (4) the contract served the public interest. Indeed, an EVRAZ departure from the state would spell "increased electricity costs for remaining ratepayers, fewer well-paying jobs in Pueblo, a lower tax base, and less solar energy," an estimated $400 million per year in forfeited economic development. O'Neill's report further cited "clean energy and environmental benefits to the Pueblo area" from the proposed solar project.

In September 2019, Colorado governor Jared Polis officially announced plans for Bighorn Solar, in conjunction with EVRAZ, Xcel, and solar developer Lightsource bp.[126] Key to the arrangement were long-term PPAs that locked in the electricity rates.[127] Lightsource bp could produce electricity under $0.03/kWh, which would be sold to Xcel and then on to EVRAZ. In particular, the 20-year PPA between Xcel and EVRAZ enabled the steelmaker to proceed with plans for the new rail mill, an estimated $500 million project that would bring 300 more jobs to Pueblo. Additionally, noted Valentine, EVRAZ would remain an "interruptible" customer under the newly designed tariff, allowing the utility to occasionally interrupt service to the steelmaker during times of peak electricity demand, thereby reducing stress on the grid as a whole. Lightsource bp secured $285 million in financing in October 2020, kicking off a yearlong construction process that would employ 300 workers.[128] Bighorn Solar would come to occupy nearly 1,600 acres of EVRAZ land (plus an additional 200 acres of Pueblo and private land), an arrangement that Annie Stefanec (EVRAZ director of communications and government affairs) identified as another crucial component of the project's realization.

In the end, extensive coordination throughout the process with the County and City of Pueblo, the Pueblo Economic Development Corporation (PEDCO), and members of the community paved the way for Bighorn Solar.[129] Valentine credits the Colorado governor's office—under Polis and his predecessor, John Hickenlooper—for their outsized contribution to the project, from start to finish. Crucial to the project's success was the recognition that all stakeholders could benefit. For EVRAZ, the 20-year PPA at the negotiated rate and nearly $95 million in state and local incentives established economic certainty and reaffirmed Pueblo's commitment to the steelmaker. Xcel took a major step toward grid decarbonization, displacing an estimated 433,770 tons of CO_2 per year, while retaining the business of their largest electricity consumer.[130] Lightsource bp, a 50:50 joint venture with UK-based bp, added a stable asset to its growing portfolio of renewables.[131] Last but not least, Pueblo preserved its identity as a steel town and the community guaranteed future employment for hundreds of local workers.

Looking ahead, Pueblo faces ongoing challenges in its trailblazing quest to decarbonize. Although returns on investments continue to flow to companies such as EVRAZ and CS Wind and to the region in the form of local and state taxes, local communities continue to face hurdles to achieving economic benefits.[132] For instance, closure of the Comanche coal plant has accelerated, with Xcel moving the expected retirement date forward from 2070 (the initial expected lifetime of Comanche 3)—first to 2040, then to 2034, and finally to 2031.[133] Xcel is slated to pay out property taxes on the plant through 2040 (roughly $25 million per year to Pueblo County), assuaging fears over the impact of lost tax revenue on public services. Yet ratepayers are largely bearing the costs of statewide coal plant closures. In August 2023, Xcel reached a settlement with state agencies for a $96 million rate hike (25% of which will cover coal plant decommissioning) after the PUC rejected a proposal from the Office of the Utility Consumer Advocate to bundle costs into a securitized bond upon the closure of Comanche 3.[134] The Comanche plant may soon be the site of a long-duration iron air battery storage system, as Xcel (in partnership with Form Energy) seeks to accelerate Colorado's grid decarbonization and maintain employment in Pueblo.[135]

Though the EVRAZ Pueblo case is unique in some ways, stakeholders interviewed pointed to a few key success factors that likely exist elsewhere. The combination of Colorado's ambitious goals for decarbonization, regulation of utilities through the economic development rate statute, recognition of the cultural and economic value of the steel industry to Pueblo, and transparency and open communication among parties were cited as important. Above all was the willingness of all parties to recognize and act to avoid the potential negative social impacts of closure on the Pueblo community as they worked to collectively build a solution.

4.5.4 From BF-BOF to EAF in Fairfield, Alabama

In 2015, the community of Fairfield, Alabama, was faced with monumental upheaval. Beset by unfavorable global steel market conditions, the United States

Steel Corporation announced in August the permanent closure of the BF and a majority of flat-rolling operations at the Fairfield Works.[136] The shutdown put 1,100 jobs on the chopping block. Just months later, in December, the company halted construction on the EAF on-site, citing similar economic concerns.[137] Although production at the nearby U. S. Steel tubular mill continued, the community in Fairfield was in distress.[138] By the end of 2015, only 220 workers remained—a far cry from the 2,000 that worked on-site at the start of the 21st century.[139]

Kevin Key, Veterans of Steel coordinator for USW District 9, described the turmoil in the workforce at the time. Although the United States Steel Corporation had already committed to eventually replacing the BF with the EAF, global overproduction and dumping were blamed for the change in the company's plans. According to Key, a handful of union workers were able to retain employment at the tubular mill, but many were not so fortunate. Fairfield, already facing $8 million in debt in 2015, experienced a mass exodus of businesses in the wake of the Fairfield Works closure.[140] Key noted that the departure of businesses was soon followed by an uptick in crime. Without steel production, the community was dying.

In 2018, with the initiation of Section 232 steel tariffs, the United States Steel Corporation was suddenly faced with more favorable market conditions, allowing it to resume construction of the EAF in 2019.[141] The $412 million project, clocking in at a capacity of 1.6 MMT per year, came online in October 2020.[142] A year after the EAF opened, in 2021, the revived Fairfield Works would come to employ a total of 850 union workers.[143]

As Key described, the United States Steel Corporation and the USW reached an agreement whereby the union workers that had been laid off from the BF and flat mill operations in 2015 received first priority for jobs at the newly opened EAF. Though the transition to secondary steelmaking required adjustments to staffing rotations and roles, Key noted that many workers found themselves with responsibilities similar to their previous assignments in the blast furnace. The EAF was located on the same site as the former BF, further contributing to the feeling of familiarity for returning workers. Perhaps most significantly, workers were, once more, able to return to hot metal work.

Across the Atlantic, another blast furnace community faces a parallel challenge. In January 2024, Tata Steel announced the closure of two BFs at the largest mill in the UK, located in Port Talbot, Wales.[144] The BFs will be replaced with an EAF in a £1.25 billion project (£500 million coming from the British government) that will cut on-site emissions by an estimated 85% but may cost up to 2,800 of the 4,000 jobs at the plant. Unions have criticized the move, which would shutter both BFs by the end of 2024, arguing that Tata ignored a more gradual shutdown plan proposed by the unions that would have lessened the impact on the workforce. Port Talbot is a snapshot of the larger quandary of decarbonizing the steel industry without sacrificing social and economic welfare.

Fairfield was forced to file for bankruptcy in 2020.[145] But although the road to recovery is a long one, the return of steel production with the EAF is a positive sign for the region. Fairfield's story shows how industrial and trade policy can potentially uplift communities near production facilities faced with transition across the country.

4.6 Recommendations: Community Engagement

As our survey results and the four case studies in this chapter suggest, decarbonization of iron and steel production presents unique challenges and opportunities for neighboring communities.

The type of decarbonization pathway will influence the impacts on the community. Communities near EAFs may see little change, especially if producers use 100% scrap or DRI is produced elsewhere. In fact, these communities may be positively surprised to learn that EAFs are already relatively climate and environmentally friendly compared to other ways of making steel. By contrast, communities near BF-BOF facilities may see a greater improvement in air quality, which is required for CCS to be effective—or would accompany a transition to DRI. Public communication, especially as it relates to CCS, is likely to be critical to long-term public support.[146]

For EAF steelmaking operations, the availability of low- and zero-carbon power is critical to decarbonization. There may also be opportunities for CCS or hydrogen deployment in DRI production and downstream reheat and treatment furnaces. For BF-BOF facilities, options for partially addressing CO_2 emissions include hydrogen injection with top gas recycling, while CCS retrofitting or use of DRI in the BOF together with a melt furnace are projected to offer deeper reductions, as described in chapter 3. These pathways are expected to heterogeneously affect workers and the broader community in which steel plants operate; thus, federal strategies must account for communities near existing and new iron and steel facilities.

First, to maximize the community benefits of steel decarbonization, policy should evaluate local economic impacts and prioritize localized benefits. Community members near iron and steel facilities care deeply about job security and retention, wages, and retirement. Demographic analyses in this chapter indicate that many steelmaking communities today occupy areas with higher unemployment rates and levels of poverty, due in part to the lingering effects of deindustrialization. Policy options that generate local economic benefits, including both job creation and preservation, should be prioritized. However, policymakers and regulators should also evaluate and plan for potential job and wage losses and provide economic development alternatives and support for affected workers.

Community engagement recommendation 1: Support economic development plans and strategies that tie decarbonization to steel workforce and community revitalization near facilities recently closed or experiencing downsizing of iron and steel production. This includes readying the talent pipeline for a workforce whose age composition is shifting, as older workers retire and a new generation takes on the mantle, and investments and programs for re-skilling, upskilling, training, and broadening the skill transferability of the steel workforce.[147] Beyond workforce development, federal and local authorities should plan for and incentivize the reuse of former production sites, including their associated infrastructure and proximity to adjacent industries, as a mechanism of preserving the economic anchor of these sites. This is especially true for legacy steelmaking communities and areas with local economies that are highly dependent on steel production. A current example of this reuse is the U.S. Wind monopile plant on the former Bethlehem steel mill site in Sparrows Point, Maryland. Recent bipartisan legislation, such as the Resilient Communities Act, that aims to direct funds from penalties of unfair trade practices to impacted communities is a step in the right direction.[148] Another example mentioned in chapter 3 is the decision to develop hydrogen-ready natural gas DRI-EAF steel production at ArcelorMittal Dofasco as part of the company's decarbonization strategy.

Community engagement recommendation 2: **Build and expand mechanisms that engender and empower collaboration between workers, community organizations, management, and local/regional authorities to codevelop social protection plans that accompany industrial transitions.** Emphasize the importance of proactive leadership by industry in initiating engagement. Community Benefits Plans (CBPs) and Community Benefits Agreements (CBAs)—legally binding contracts between developers and host municipalities and local community or workforce groups, including labor unions—offer blueprints for such mechanisms and should be adapted to the challenges and opportunities of industrial decarbonization. Accountability is the key to success when evaluating the outcomes of CBPs and CBAs. Clear, enforceable agreements should be required in any federal government–supported decarbonization project.

Community engagement recommendation 3: **Fund education, research, development, and deployment efforts that target place-based programming and investments to economically distressed regions or high-impact areas.** As technology development will be a critical enabler of decarbonization across the steel supply chain, government incentives should evaluate where public spending can offer the highest social impact, including taking advantage of existing knowledge and research institutions and industrial clusters.

Decarbonization policy should also recognize and account for public health and environmental justice co-benefits. Communities located near steel production sites face relatively high exposure to a number of environmental harms—some of them ranking among those with the highest levels of environmental harms in the country. Incentives and funding to support decarbonization should fully account for their ability to provide co-benefits such as improving air quality and lowering health-related spending.

Community engagement recommendation 4: Provide incentives to pilot, test, and scale decarbonization technologies that offer co-benefits such as reductions in conventional air pollutants, fuel switching, and utilizing waste streams. These programs should include public awareness campaigns and knowledge-sharing to inform communities, and they should incorporate environmental justice objectives to help target benefits to historically affected groups. Benefits-cost analyses (BCAs) and other impact evaluations should prioritize comprehensive accounting for public health impacts. Government grants, tax incentives, and loan guarantees for steel industry decarbonization should require co-benefit studies. Consider offering bonus tax credits for CCS and hydrogen projects that provide measurable public health benefits in steelmaking communities.

Finally, policy for decarbonizing iron and steel production should provide opportunities for community input and knowledge-sharing to strengthen community buy-in. Enabling technologies and infrastructure such as low-carbon electricity and CCS depends, in large part, on local buy-in. The recent pauses of CO_2 pipeline development in Illinois and South Dakota and growing opposition to renewable energy siting more broadly point to the power that communities have in determining options for decarbonizing solutions. Moreover, as our survey found, awareness of decarbonization is low in steelmaking communities, but support is high. Community members need opportunities and platforms to ask questions, provide feedback, learn, and engage with decarbonization efforts to reduce local opposition.

Community engagement recommendation 5: Encourage and fund opportunities for proactive engagement of industry, labor union representatives, and local authorities to develop partnerships that could help in planning and implementing decarbonization projects. Encouragement and funding should come from national and state governments and foundations. Survey results suggest that communities are receptive to the benefits of decarbonization and steel plants are viewed relatively positively in their host communities. Companies can strengthen their roles as civic leaders by being proactive in their engagement with their neighbors and the communities in which their workers reside. These forums can institutionalize dialogue and collaboration between companies, workers and their representatives, community members, and local authorities and offer alternative avenues for public input and dispute resolution.

Community engagement recommendation 6: Include explicit funding for community benefits, involvement, and participation compensation when developing state and federal permitting reforms. Regulatory reform that accelerates climate-beneficial infrastructure deployment, lowers permitting timelines, and consolidates review processes will be needed to activate and accelerate steel decarbonization. At the federal level, this should include proactive federal planning to designate high-potential energy corridors and enhanced interagency coordination. At the state level, recent efforts in California and New York provide precedents for the creation of a renewable energy siting office and consolidated permitting.

5. Lessons from Past Industrial Policy for Iron and Steel

Key messages:

- In the 2020s, industrial policy has gained prominence as a key determinant of global economic competitiveness and, in some countries, as an enabler of decarbonization investments to meet climate change goals. Once characterized as undue interference by government in economic activity, industrial policy is now regarded as the fabric that weaves together federal tax, trade, regulatory, workforce, and national security priorities and reflects them in economic policy.
- During World War II and the postwar resurgence of the American economy in the 1950s and 1960s, trilateral stakeholder commissions proved to be an effective mechanism for integrating the interests of government, industry, and labor. However, they were discarded in the 1970s and 1980s in favor of a laissez-faire approach to economic policy that encouraged trade liberalization and globalization.
- The history of the steel industry, its workforce, and its communities from 1975 to 2000 provides insights on how to support future technological change while reducing the risk of large-scale job losses, community erosion, and business collapse. While there is never certainty in managing technological change, there are guardrails and process improvements that can reflect employee and community interests.
- The emergence of climate change as an existential threat has compelled a reevaluation of how to use industrial policy to manage the challenge of global collective action. This chapter analyzes the shortcomings of modern industrial policy and makes recommendations on how to avoid negative impacts in the design of decarbonization policies.
- We recommend an industrial policy that addresses community and employee impacts with direct engagement, improved research, and collaboration among all stakeholders.

Much has been written about the collapse of the steel industry from its high point and the role played by business strategy and labor relations. But, in retrospect, little has been written about the failure of industrial policy to mitigate the outcomes on workers and their communities, as that term, *industrial policy*, fell out of favor in the successive administrations of Reagan, Bush, and Clinton, all of whom presided over efforts to expand global economic integration.[149]

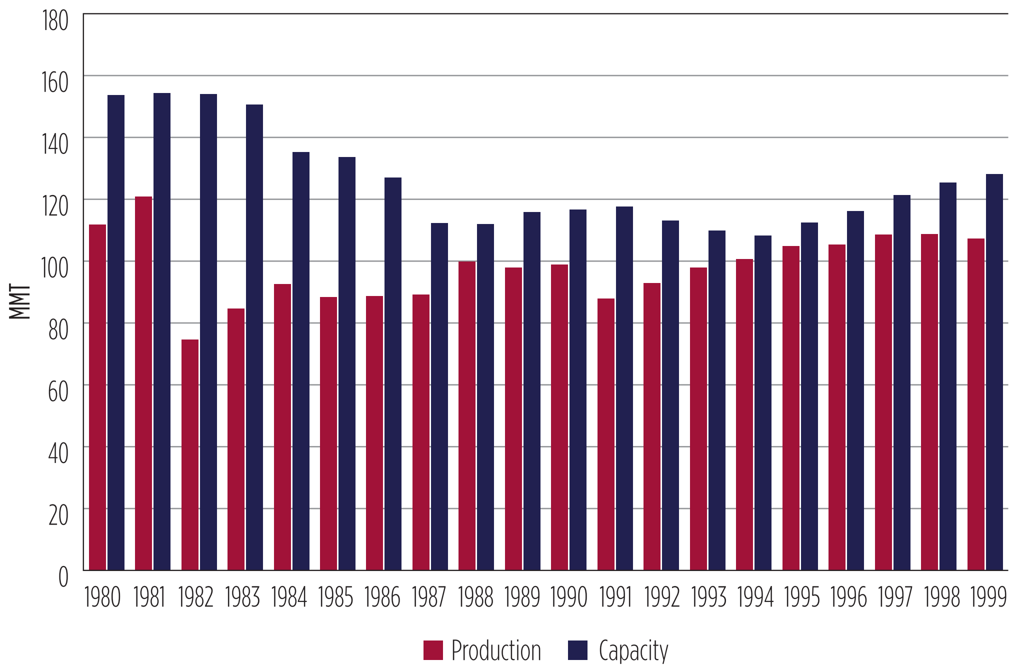
Joseph Stiglitz, during his tenure as chief economist at the World Bank, broadly defined industrial policy as "government policies directed at affecting the economic structure of the economy."[150] In the American steel industry from the late 1940s through the 1970s, this meant a focus on control of prices and influence over labor relations. Presidents cared about steel prices since any increase would ripple through the economy at large, stoking inflation. And labor relations played a critical role in both labor costs and steel shortages, driven by industry-wide strikes that occurred in 1946, 1949, 1952, 1956, and 1959 in an industry that was overwhelmingly unionized.[151]

But in the 1980s and '90s, U.S. views on industrial policy changed significantly, shifting from a focus on New Deal labor policies and support for the international alliances that defeated the Axis powers to the integration of American manufacturing into the burgeoning global economy. The primary focus of this chapter is to examine what lessons can be learned from the turbulent transition of the steel industry after World War II into the late 1990s, assess the current state of the steel industry in the United States, and determine whether the negative impacts of that era on workers and their communities can be avoided in the transition to a decarbonized industry today. In particular, this chapter focuses on how the missing pieces of industrial policy from that era might be redesigned today.

Starting in the 1980s, over 300,000 steel jobs were lost, giving credence to the term "Rust Belt" to describe much of northeastern Illinois, northwestern Indiana, southern Michigan, much of Ohio, western Pennsylvania, northern West Virginia, and many other communities linked to iron and steel production, such as the Iron Range of northern Minnesota; Provo, Utah; east Los Angeles; parts of Houston; and Birmingham, Alabama.[152]

Today's steel industry occupies a very different geography than the industry of 1980. Its current workforce is 20% of its former size, and yet its output is approximately the same (see figure 5.1). Also, as noted earlier, its technologies are markedly different, with roughly 70% of its steel produced primarily from scrap steel in EAFs and only 30% with primarily iron ore taconite pellets in BF-BOF facilities. The hourly workforce today is only 24% unionized, compared to 90% in 1970.[153]

Figure 5.1: U.S. crude steel production and capacity.[154]



These factors make the challenges of decarbonization markedly different from those of the transition to a globally integrated industry in earlier decades. Nonetheless, both transitions are influenced by technological change and global steel market dynamics. Those nine communities that are home to the country's remaining BFs may experience challenges strikingly similar to those of the past, while a more fragmented set of decarbonization options and impacts will confront the communities that are home to the country's 95 EAFs.[155]

5.1 Steel Industrial Policy, 1945–80

In the United States immediately after World War II, the steel industry was seen as the driver of the economy. "At the end of the war, the industry was preeminent in the world. It had set stunning production records during the conflict and accounted for 54.1 percent of the world's raw steel production in 1946."[156] The largest steel industry in the world was at the center of the largest global manufacturing economy. As such, the steel industry bore the scrutiny of a succession of U.S. presidents, including Truman, Eisenhower, Kennedy, Johnson, Nixon, and Carter. From Truman's attempted seizure of the industry in 1952 to Kennedy's jawboning over prices with Roger Blough, CEO of U. S. Steel, to Carter's resurrection of a tripartite board of government, industry, and labor to mediate the industry's role in the U.S. economy, influencing the steel industry was key to the presidency.[157] Not until the Reagan administration in 1980, when Carter's tripartite commission was dissolved, did the presidency and the economy embrace a more laissez-faire approach to both the industry's challenges and its future.[158]

But the industry had been facing challenges for decades. As Grant McConnell notes in his book *Steel and the Presidency, 1962:*

> "As the decade of the sixties arrived, there were increasing signs that the steel industry in the United States was in less than vibrant health. Productive capacity had increased by almost one-half in the decade. In the same period, however, utilization of that increasing capacity had almost steadily declined. In 1960 utilization was only two-thirds. It declined further in the two years that followed. There were various factors that contributed to this condition—the operation of the economy as a whole below capacity, the decline of steel exports and competition. Steel was entering the United States from Europe and Japan. This competition was concentrated in a relatively few products and by itself was not of a scale to be troubling to the industry as a whole. However, there were other sources of competition. Plastics, other metals, and even paper were aggressively entering markets which had belonged to steel. The development of prestressed concrete robbed steel of much of its market in the building industry. Technological development in steel itself reduced the amount of steel necessary in many uses. Steel was stronger, and new designs of such structures as bridges now called for far less tonnage of the basic material of steel. The industry, responding to the challenge of aluminum, developed a technique for making sheets for cans that required much less steel. This 'thin tin' was a fine response to the competition of a substitute material, but it implied a reduction in steel tonnage for this use. Moreover, there were steel products of former importance which were themselves suffering from the impact of obsolescence. Thus, the industry, particularly [the] United States Steel [Corporation], was splendidly equipped to produce rails, but unfortunately the railroads were not in an expansionist mood."[159]

In that era in the United States, many critical areas were unaddressed by industrial policy, including:

- accurate market forecasts,
- the impact of steel product substitutions by plastic and aluminum,
- technology development and deployment, particularly continuous casting, the basic oxygen process, electric arc furnace expansion, and new iron ore products such as taconite pellets, direct reduced iron, and hot briquetted iron,

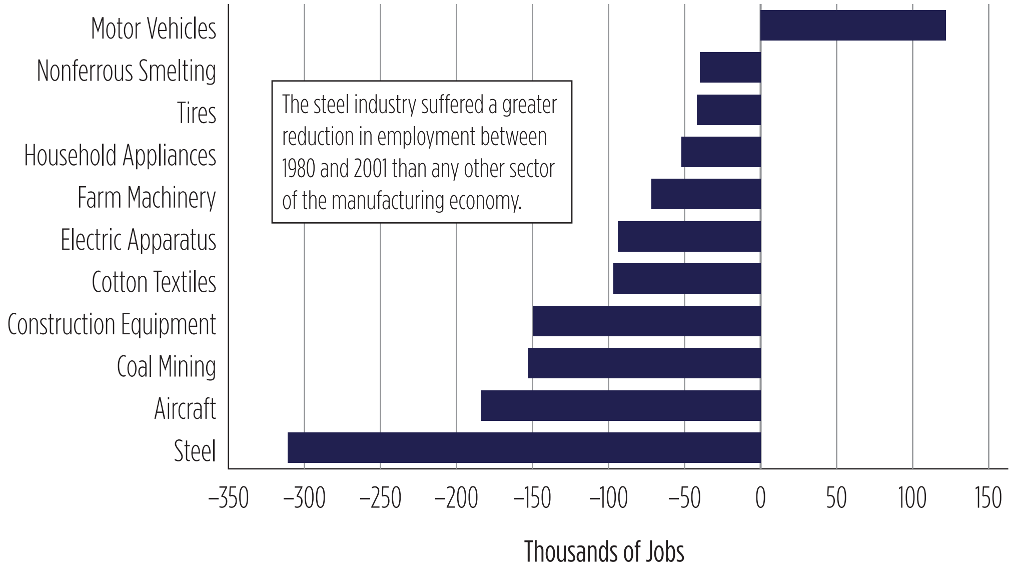
- trade policy,
- corporate governance and shareholder rights,
- the framework of U.S. labor relations,
- workforce development, and
- community impacts.

Nonetheless, in 1975, the American Iron and Steel Institute, the industry's trade association, predicted that by 1983, raw steel production in the United States would need to rise to 170 MMT.[160] Other experts estimated needs as high as 190 MMT by 1980.[161] There was little awareness of the likelihood that plastics and aluminum might displace steel in a myriad of product uses, from automotive parts to beverage containers. New and more efficient technologies, adopted in Europe and Japan as their industries rebuilt from World War II, were seen as expensive and a misallocation of capital with the anticipated market growth. Trade was incorrectly understood as a limitless opportunity for the steel industry in the United States.

The narrow framework of American labor law, limiting collective bargaining to the mandatory subjects of wages, benefits, and working conditions, was seen as a strategic advantage over the broader governance structure of European labor law, which envisioned industry-wide bargaining and works councils to promote worker involvement. Other than monopoly and, increasingly, environmental regulation in the United States, there was little concern over corporate governance by regulatory agencies. After World War II, workforce regulation was primarily a task for the union and the company. Five consecutive national strikes culminated in the 1959 steel strike, the largest in U.S. history, involving over 500,000 workers. That strike ended when the Eisenhower administration secured a court injunction under the Taft-Hartley Act, signaling the start of the erosion of labor rights in the United States.[162]

In each of these critical areas, the focus of industry stakeholders on prices and labor relations, coupled with a lack of broader industrial policy, contributed to the factors that led to the rapid and catastrophic decline of the iron and steel industry. Instead of growing by 50% as predicted by AISI, the market in the United States contracted to barely 75 MMT in 1982 (see figure 5.1). Imported steel grew from 4 MMT in 1960 to 20 MMT two decades later (see figure 5.3). By 2001, the industry's employment had declined by 311,000 (see figure 5.2). One community, Youngstown, Ohio, lost 5,000 employees on September 9, 1977, when the first of five steel mills in the area closed.[163] Youngstown's population of almost 141,000 in 1970 had fallen to just over 65,000 in 2019.[164]

Figure 5.2: Change in manufacturing employment, thousands of jobs in major industries, 1980–2001.



In the late 1970s, as the crisis worsened, President Carter attempted to bring the various parties to the table to discuss solutions, initiating the Steel Tripartite Advisory Committee (STAC).[165] On September 30, 1980, the committee released its statement, highlighting the importance of collaboration between government, industry, and labor for investment in modernization, support for R&D, heightened trade enforcement, environmental compliance, worker retraining, community development, and a return to the tripartite system of industrial policy.[166] But before a comprehensive strategy could be enacted, Carter was defeated by Reagan, who disbanded the STAC. The Reagan administration's response to the market share growth of steel companies based in Japan and Europe was to urge adoption of voluntary restraint agreements, limiting imports from Europe to 20.2% of domestic steel consumption. Nonetheless, steel imports rose to 26.4% by 1984.[167] By the end of the Reagan presidency, steel imports had risen by over 40%.[168]

While the domestic steel market shrank due to product substitution and a rise in direct and indirect imports, steelmaking technology in the United States shifted. In 1960, there were 18 EAF companies in the United States, operating 18 plants and shipping just 3 MMT of steel, a mere 4.2% of domestic shipments.[169] By 1980, there were 42 EAF companies, operating 51 plants that shipped 11.9 MMT of steel, an increase of almost 400%.[170] By 1990, shipments had risen to 20.2 MMT, 23.8% of total domestic shipments.[171] Only a handful of these EAFs were operated by the 10 large integrated steel producers.

5.2 Industry and Labor Responses

After the 1959 steel strike, with the encouragement of both the Kennedy and Johnson administrations, both the USW and the industry voluntarily agreed to a system of coordinated bargaining to address the industry's growing trade and technology challenges. Regular strikes in the industry had led to periodic inventory buildups by customers in advance of contract expirations. Imports of steel from the modernized mills in Europe and Japan had also increased in advance of labor negotiations. The Coordinated Committee of Steel Companies (CCSC), chaired by U. S. Steel, joined with the USW in creating the Experimental Negotiating Agreement (ENA) in 1973. The ENA guaranteed a minimum wage increase of 3% per year in addition to a cost-of-living allowance (COLA) in exchange for a no-strike pledge from the union in the event that an overall agreement could not be reached. Disputed items would be submitted to binding arbitration. The ENA was designed to stabilize the industry's boom-bust cycle driven by labor negotiations and prevent a further increase in the market share of imports.

However, the ENA turned out to be highly controversial among members of the USW—one of only two unions in the United States whose members directly elected their national leadership. Steelworkers increasingly were demanding greater participation in the bargaining activities of the union with the industry. As a result, the ENA delivered only three national labor agreements in 1974, 1977, and 1980, resulting in a dramatic increase in steelworker wages—immediately followed, however, by a wave of concession bargaining.[172] More importantly, the ENA did not meaningfully impact the rising levels of imports and product substitution and the growth of EAF production. By 1980, domestic production of steel had declined to 102 MMT from its peak of 137 MMT, with 27% produced by EAFs.[173]

The industry's response to its shrinking market was to cede its lower-priced products—such as rebar, merchant bar quality (MBQ) products, lower-grade structural steel, and wire rod—to EAF companies, rather than invest in EAF steelmaking. At the same time, the industry adopted the larger conglomerate diversification strategy common among American manufacturers during that time, as modeled by General Electric and its CEO Jack Welch.[174] The CEO of U. S. Steel, David Roderick, announced, "I'm in the business of making money, not making steel," when U. S. Steel purchased Marathon Oil in 1982 and changed its name to USX.[175] National Steel, the third largest steel company at that time and known for its high quality and low cost, purchased United Financial Corporation of California, the eleventh largest savings and loan company, in 1981 to diversify its portfolio.[176] Jones and Laughlin merged with aerospace and defense company LTV, becoming LTV Steel.

None of these diversification strategies worked, serving instead to distract management from attacking the root challenges to the technology and market transitions underway in the industry. Eventually, all these mergers were unwound. Similarly, General Electric, the model for conglomerate corporate structure, broke up and is in the process of spinning off its various divisions.

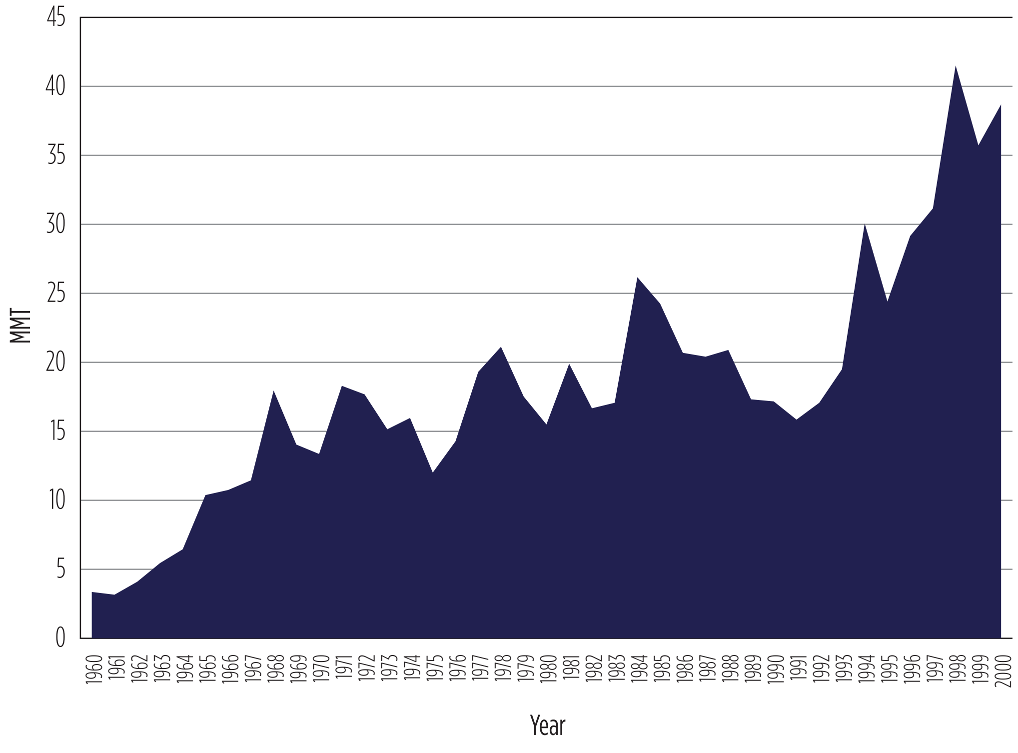
On the labor side, the USW attempted to use the crisis in the integrated industry to redirect the focus of its collective bargaining. Under the leadership of its first Canadian president, Lynn Williams, the union—largely concerned with wages, benefits, and immediate working conditions—adopted its New Directions bargaining platform. Williams's slogan, "The job of management is too important to leave to management alone," rallied the union to get directly involved with permissive subjects of bargaining, including (1) successorship and the terms of business sales, (2) the union's right to nominate members to the steel companies' boards of directors, (3) capital investment plans, (4) employee skills and career development, and (5) other business strategy issues.[177] While this effort was successful in charting a new era of collaboration between the industry and its primary union, it did not stop the downward trajectory of the industry and the growth of its nonunion workforce in the 1990s.

5.3 Trade and Industrial Policy in the 1980s and 1990s

Perhaps the most impactful aspect of U.S. industrial policy in the 1980s and 1990s was its embrace of free trade agreements and institutions, including the World Trade Organization (WTO), the North American Free Trade Agreement (NAFTA), and Permanent Normalization of Trade Relations (PNTR) with China. The net effect was the creation of a global steel market and pricing regime, coupled with substantial state subsidies for most steel industries around the world. In 2011, for instance, half of the 46 largest steel companies in the world were state-owned and accounted for almost 40% of production.[178] Unlike other manufacturing sectors that quickly adopted the free market model through global mergers, the steel industry remained largely nationally constrained until the early 2000s. For instance, 74% of the global tire market was served by just five companies in 2000; similarly, five companies accounted for 57% of the global automotive market and 44% of the aluminum market.[179] That was not the case in the steel industry, in which globally, the top five companies served only 14% of the market.[180]

Between 1960 and 2000, steel imports rose dramatically in the United States, from less than 5 MMT to almost 40 MMT, representing 29% of domestic consumption (see figure 5.3).

Figure 5.3: Imports of steel mill products. (Estimate for 2000 is based on data through November of that year.)[181]

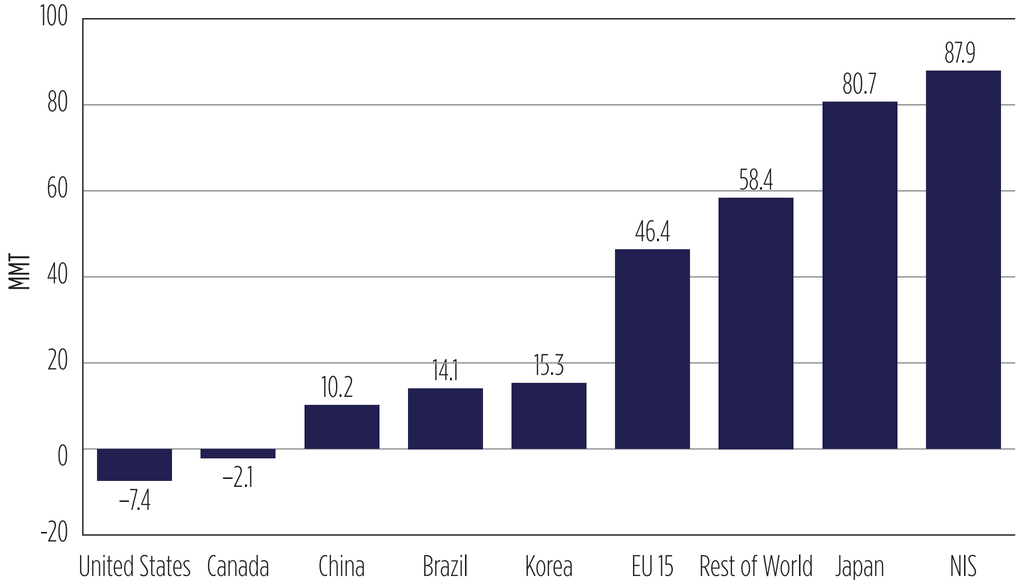


Thus, in spite of a growing global market, the U.S. industry never returned to its highest steel production level of 137 MMT in 1973.[182] At the same time, as noted earlier, EAF production continued to take a larger and larger share of the domestic market, shrinking the presence of the remaining integrated companies. By 2000, EAFs were producing 44.5 MMT—45.1% of the market.[183]

Between 1998 and 2002, 48 U.S.-based steelmakers entered bankruptcy, including LTV Steel, Bethlehem, and National Steel.[184] While some of the physical assets never reopened, others formed the backbone of a new, more globally integrated industry. Many of the bankrupt companies were consolidated under the ownership of the International Steel Group (ISG), led by private equity financier Wilbur Ross, who later sold the entire company to Mittal Steel, an India-based steel company that consolidated many global assets to emerge as the largest steel company in the world at the time, ArcelorMittal, with headquarters in Luxembourg.

By 2000, the world had 300 MMT of excess steel capacity, supported by governments around the world.[185] Only the United States and Canada consumed more steel than they produced. Particularly noteworthy was the excess capacity in Japan, the EU, and the newly independent states (NIS) of the former Soviet Union.

Figure 5.4: Global steelmaking overcapacity, 2000.[186]



In its July 2000 report to the president, *Global Steel Trade: Structural Problems and Future Solutions*, the U.S. Department of Commerce noted, "The thirty-year history of repeated unfair trade actions is symptomatic of underlying market-distorting practices in the global steel market." Subsequently, targeted tariffs were directed toward specific products that were either being dumped (sold below the cost of production) or sold below prices in markets of origin. However, the damage had already been done.

5.4 Impacts on U.S. Employment

As noted in figure 5.2, between 1980 and 2001, the U.S. domestic steel industry lost 311,000 jobs, the most of any manufacturing sector.

The only manufacturing sector that gained employment was the motor vehicle sector, as a result of the domestic content agreements negotiated with Japanese and European motor vehicle companies in the wake of earlier dramatic job losses. These companies then built so-called transplant assembly plants in the United States, avoiding unions by largely locating in southern right-to-work states, despite their unionized status in their home countries.

In the steel industry, the loss of jobs, driven by imports, technology shifts, and automation, had a profound impact on unionization rates of the remaining workforce. According to the USW, almost 90% of eligible production and maintenance steel employees belonged to the union in 1958. By the late 1990s, that number had fallen to 48% in the United States and 52% in Canada. Only a handful of EAF plants were unionized.

5.4.1 Job Retraining and the Trade Adjustment Assistance (TAA) Act

In the years since World War II, the focus of federal unemployment policy in the United States shifted markedly; the U.S. government went from being the "employer of last resort" to providing access to job retraining for employees who lost their jobs through no fault of their own. The history of this change and its impact on the energy transition are documented in the Roosevelt Project's Phase 1 paper *Energy Workforce Development in the 21st Century*.[187] Federal government efforts to provide employment opportunities to the unemployed ended in 1978 with the passage of the Humphrey-Hawkins Full Employment and Balanced Growth Act, an ambitious piece of legislation that was never funded.[188]

To respond to the loss of jobs in the steel industry throughout the period of the mid-1970s to the 1990s and continuing to the present day, the U.S. government has, instead, focused on providing expanded access to unemployment benefits, wage insurance, and retraining for those workers whose unemployment could be directly attributed to the impacts of trade.

As documented in *Energy Workforce Development in the 21st Century,*

> "TAA dates back to the Trade Expansion Act of 1962 and the Trade Act of 1974 and is considered by some to be the model for how economic dislocation should be managed in the U.S. economy and potentially expanded to include those who experience job dislocation from climate solutions or climate-related impacts. TAA provides workers, once they are certified under the program, with extended unemployment benefits of up to 130 weeks, tuition reimbursement for training, occasional relocation support, and a short-term wage subsidy for participants over the age of 50. Over the years, millions of Americans have been certified under the program, although only a minority of those have actually participated in the program. In 1980, alone, for instance, 600,000 workers were certified for retraining (Congressional Research Service 2018).
>
> "Between 2004–2018, the TAA program averaged $821 million per year in program benefits to participants. In the nine years between 2010 and 2018, the program provided services to roughly 247,000 new entrants out of the 994,000 who were certified for eligibility. During that period there was considerable variation with 287,000 certified in 2010 and only 57,000 in 2015. DOL participant data has generally shown re-employment rates of participants in the 72–76% range in recent years. (DOL AnnualReport18). In 2010, during the height of the Great Recession, the re-employment rate for participants was much lower at 59% (DOL AnnualReport10).
>
> "Unfortunately, other recent studies have shown that certified non-participants have had equivalent re-employment rates to participants. A detailed survey of TAA participants and non-participants in 2012, performed for the DOL, found that only 37% of participants were employed in the occupations for which they received training (Mathematica Policy Research/SPR). That study also found that TAA recipients did not enjoy higher wages or better benefits than non-participants after re-employment. For participants over the age of 50,

> this phenomenon was especially pronounced. This spotty track record should be addressed before considering the TAA program as an effective model for how to deal with economic dislocation (McCarthy, 2019)."[189]

During the period of 1975–2002, when the most significant reductions in employment happened in the steel industry, TAA benefits were certified for roughly 220,000 employees in the industry.[190] However, there was substantial variation in the size and scope of benefits provided during this time, with sharp reductions during the Reagan administration that drastically reduced participation in the program.[191]

An additional mechanism that was created to align job opportunities in a given community with the unemployed and their access to training was the local Workforce Investment Board (WIB). The Workforce Investment Act of 1998 gave rise to WIBs, which were required for the distribution of federal job training funding to states and local communities. WIBs were typically administered at the local level by representatives of government, business, labor unions, and other stakeholders. However, a critical missing piece of this mechanism was an industrial strategy focused on economic development and job creation.

5.4.2 Lessons from the American Steel Dislocation of 1975–2000

The current renaissance of industrial policy in the United States can be attributed to several factors.

First, of course, is concern about climate change and how to manage the transitions of multiple sectors of the economy that will have to be decarbonized in a relatively short time.

Second, concern about the rapidly shifting security structure of the global economy and the threats to both energy access and manufacturing supply chains posed by armed conflict in Ukraine and rising tensions between the United States and China—all of which has activated bipartisan policy interest in strengthening and investing in domestic capabilities, similarly to the drivers of industrial policy in the United States just before and during World War II.

And finally, concern about community impacts, which have shown themselves to be stubbornly resistant to laissez-faire solutions over the last three decades. The former communities near iron and steel facilities that lost over 310,000 direct jobs and, perhaps, 10–12 times that number of indirect and induced jobs, by and large, have not recovered. This third concern represents the greatest challenge to a new era of industrial policy designed to support both decarbonization and national security.

In a recent bipartisan InFocus memo, the Congressional Research Service, citing the impacts of the IIJA, the CHIPS Act, and the IRA, attempted to answer the question: what is industrial policy?

> "While there is no formal definition, *industrial policy* commonly refers to a comprehensive, deliberate, and more or less consistent set of government policies designed to change or maintain a particular pattern of production and trade within an economy. It generally involves policies designed to promote emerging industries or prop up declining ones, as well as the channeling of resources into specific sectors and activities considered important for economic growth. A variety of instruments can be used to implement an industrial policy, including subsidies; tariffs and other trade restrictions; rules; regulations;

technical standards; tax incentives; government procurement regimes; and preferential access to credit. In addition to aiming to accelerate economic growth, industrial policies can be designed to safeguard national security, create employment opportunities in specific industries or regions, achieve environmental and social sustainability, or improve the competitiveness and export performance of domestic firms. The impact and effectiveness of such policies in achieving these goals is subject to debate.

"Some analysts maintain that industrial policy need not be executed through an explicit strategy. In the United States, some experts consider various economic policies and programs that have the effect of favoring one industry or type of firm over another to constitute an ad hoc and de facto industrial policy. As such, U.S. industrial policy has consisted primarily of interventions that are not made on the basis of any comprehensive or systematic set of guidelines delineating the kind of production and trade that should be fostered. Instead, they are implemented through generalized or cross-industry policies (e.g., corporate tax rate reductions) and industry or firm-specific policies (e.g., tariffs and support/subsidies for electric-vehicle battery production)."[192]

In spite of the diversity of views on how to define and implement industrial policy in 2024, as expressed by the Congressional Research Service, the three concerns listed earlier are driving the discussion of how to design an industrial policy that will support the decarbonization of the steel industry and do so in a manner that supports its workforce and communities.

5.5 Recommendations: Industrial Policy

Based on the past challenges for the Carter, Reagan, Bush, and Clinton administrations; the industry; its principal union, United Steelworkers; and the grinding, long-term impacts on communities linked to iron and steel production, we recommend addressing the following issues when designing an industrial policy for 2024 through mid-century that supports the decarbonization of the steel industry. These lessons could also apply to other hard-to-decarbonize sectors of the economy.

Industrial policy recommendation 1: Establish an oversight commission for decarbonization of the iron and steel industry with government, labor, industry, and steelmaking community participants to advise on strategic implementation. Establishing tripartite commissions in critical industry sectors was a fundamental and widely accepted practice to mobilize the country, its businesses, and labor unions during World War II. In retrospect, it is easy to see how the Carter administration's effort to revive the Steel Tripartite Advisory Committee (STAC) could have been highly successful in shaping the restructuring and modernization of U.S. iron and steel production while also saving communities. Instead, the Reagan administration's dismantling of the STAC contributed to the chaotic collapse of the industry. Such committees should be reestablished for critical industries in hard-to-decarbonize sectors, including steel, aluminum, cement, chemicals, and a handful of others. These commissions will play a critical role in stabilizing the transition for both communities and companies and moderate the free-for-all between states vying to benefit from technology transitions.

Industrial policy recommendation 2: Integrate trade policy with decarbonization strategies, including labor and environmental performance standards. The failure to develop a strategic approach to trade in the 1970s–1990s undercut any opportunity that the domestic steel industry had for an orderly introduction of new technologies into domestic production. The emergence of a global steel market upended the industry's access to capital. Nationally, regionally, and internationally, the United States should redesign its trade policy for steel and other critical, energy-intensive industries to include labor, human rights, and CO_2 emission standards. While pursuing the inclusion of these standards at the international level, the U.S. government should ready itself to implement carbon border adjustments on a national and potentially, regional basis, for instance through amendments to the United States Mexico Canada (USMCA) Trade Agreement. Border adjustments will be a necessary component of preventing carbon leakage while encouraging decarbonization investments.

Industrial policy recommendation 3: Provide government-funded, up-to-date market and technology data. In the 1970s, steel experts predicted, incorrectly, that U.S. demand would increase 25–40% by the mid-1980s. Similarly, there was little apparent understanding of how technology evolution in both the EU and Japan—as reflected in the development of the basic oxygen process, continuous casting, and the utilization of deep-water ports for cheaper access to low-cost raw materials—would redefine steel costs and prices and upend global markets. Consequently, a fundamental role for industrial policy is to provide regular, fact-checked assessments of the impact of the newest commercial technologies on the industry and global markets. Government, of course, cannot be the sole or final authority on market assessment, but neither can the private sector.

Industrial policy recommendation 4: Fund new technology research, development, and deployment in critical industries. The U.S. government has a strong record of supporting new technology research and, to some extent, development, but its support for deployment has been spotty at best. The U.S. national laboratories' role in solar and wind technology development in the 1960s and 1970s has been well documented, as has those technologies' commercial development in Europe and Asia. Currently, the leaders in developing and deploying green steel technologies, inert anodes for aluminum smelting, and hydrogen electrolysis are all outside the United States. Only in recently passed legislation—the IIJA, the IRA, and the CHIPS Act—has this issue of deployment finally been addressed. These measures must be preserved and extended.

Industrial policy recommendation 5: Prioritize social outcomes for existing industry communities and workforces. The technology transitions in the steel industry, including the adoption of BOFs and continuous casting, as well as the use of EAFs, resulted in shifting the location of steel production both globally and inside the United States. While these transitions in the steel industry were largely guided by the market in the United States, in other parts of the world governments frequently played an important role. For the hard-to-decarbonize sectors, the United States should consider decarbonization investments in communities where current iron and steel facilities are located—including through engagement of local communities and stakeholders. The use of bonus tax credits for communities reliant on fossil fuel jobs, the targeting of Justice40 census tracts for investment, the use of Community Benefits Plans and Agreements, and the encouragement of PLAs and neutrality labor recognition agreements are all important steps in the IRA, the CHIPS Act, and the IIJA.

Industrial policy recommendation 6: Link economic development strategies with workforce retraining in impacted communities. As described in this chapter, one of the critical failures of the TAA was the disconnection between its workforce retraining programs and actual jobs. Retraining took place without direct involvement in a complementary economic development plan for the affected community. One of the benefits of a long-term decarbonization strategy is that job loss, retraining, and reemployment can take place in a deliberate and sequential process without the sudden, cataclysmic events that were typical of steel mill bankruptcies and closures in the 1980s and ’90s. Specific plans to address decarbonization strategies should be required and funded for each affected community, including an assessment of job loss or growth, skills requirements, and training needs that are aligned with economic development plans. A special role will be played by those energy companies, such as utilities, infrastructure contractors, and transmission and distribution companies, that are transitioning to new forms and sources of energy rather than going out of business.

Industrial policy recommendation 7: Expand the role of universities. Many commercial and academic partnerships already exist between the steel industry and neighboring institutions. Expanding and providing federal funding for these partnerships will accelerate and support decarbonization in the industry. As barriers to decarbonization in the industry become better understood, awards like the Earthshot Prize should help drive forward solutions. In the late 1930s and 1940s, as Minnesota’s high-grade iron ore became depleted, the future of the Iron Range was in doubt. However, as a result of the pioneering work of the University of Minnesota and its Professor Edward Davis, a process was developed for crushing and purifying low-grade taconite ore to create iron ore pellets suitable for blast furnaces, resulting in billions of dollars of investment over the last 75 years. Similar partnerships need to be supported by the federal government to build the next generation of critical industries and address remaining technology barriers.

6. Industrial, Trade, and Climate Policy

Key Messages

- Trade policy is essential to maintaining a healthy steel industry, both in the United States and worldwide. It can discourage unfair trade practices and support high-quality jobs and strong environmental performance. Countries that encourage companies to adopt systems for reporting GHGs and to advance decarbonization investments will ensure that their industries remain competitive.
- Section 232 tariffs on direct steel imports provide a short-term incentive and a revenue source to invest in steel decarbonization in the United States. Precedent and legal standing support the use of Section 232 tariffs in this way.
- A mechanism to address GHG emissions associated with direct and indirect steel imports in the United States could ensure the competitiveness of the industry's deep decarbonization investments over time and provide a revenue stream that could further fund decarbonization. Such a mechanism will take time to develop, given the importance of designing a scientifically sound and broadly accepted GHG emissions accounting methodology for iron and steel products as well as steel in manufactured goods.

6.1 Motivations for Industrial, Trade, and Climate Policy

Industrial policy, as described in chapter 5, influences economic structure and governance.[193] It can take the form of support for domestic industries considered critical on economic, social, environmental, or national security grounds.[194] Industrial policies can include subsidies, tax credits, demand-side incentives, standards and regulations, and trade measures. Distinct but closely related is trade policy: the establishment, negotiation, and enforcement of global trade rules, regulation of imports and exports, and access control to global markets.[195] U.S. trade policy takes several forms, including enforcement of trade laws and tariffs, participation in global trade systems (notably the World Trade Organization or WTO), and engagement in bilateral or multilateral trade agreements. U.S. trade policy has generally supported liberalization and expansion of the rules-based trade system of the WTO to promote economic growth. However, providing domestic industries with protection against unfair trade practices has become an elevated concern in recent years.

Renewed interest in industrial policy in the United States and shifts in trade policy have been a consequence of several factors, including concerns over the waning strength of domestic industries crucial to national security, heightened awareness of how other countries' policies impact U.S. producers, disruptions to supply chains during the COVID-19 pandemic, and a growing appetite for U.S. government support of industry and labor.[196] Legislation—such as the IIJA, the IRA, and the CHIPS and Science Act—reflects these sentiments with domestic content requirements and incentives.

Climate policy to support GHG emissions reductions as well as climate change adaptation and resilience has evolved in the United States across federal, state, and local levels over the past several decades.[197] Of more recent concern is an area where trade policy and climate policy intersect: carbon leakage, or the relocation of industrial activity overseas to markets with less stringent domestic climate change policies.[198] As a result, the domestic industry may lose market share and the share of imported supply from foreign GHG emissions-intensive producers may increase. Thus, carbon leakage may undercut emissions reductions at the global level.[199]

The United States ranks as one of the cleanest global steel producers.[200] Many are concerned that additional climate policy pressure that raises costs for domestic producers could push production to foreign nations with higher GHG emissions intensities of production. A highly controversial example in this domain was the purchase of steel produced in China to rebuild the Oakland Bay Bridge in 2011, a decision widely protested by domestic steel companies, labor, and environmental organizations.[201] Five years later, California passed the first Buy Clean legislation in the world to require inclusion of supply chain CO_2 emissions in procurement requirements.[202] The phenomenon of carbon leakage, in addition to the factors outlined above, prompts careful consideration of the link between industrial, trade, and climate policy.

6.2 Trade Remedies and Steel Tariffs

Historically, the United States has broadly supported the concept of most favored nation (MFN) treatment, a core tenet of the WTO, which requires that a country give all trading partners with MFN status equally advantageous treatment.[203] When treatment is not equally advantageous, however, the U.S. has several trade remedy laws that exist to protect U.S. industries. The Tariff Act of 1930 established antidumping and countervailing duties (AD/CVD) as protection against harmful trade practices.[204] AD measures impose tariffs on imports that are sold below "fair" market prices (i.e., in cases of overproduction), while CVD measures establish tariffs on imports that have received subsidies from foreign governments. The U.S. International Trade Commission (USITC) and International Trade Administration (ITA) investigate violations and impose tariffs on specific products that are deemed to cause "material injury" to domestic producers. Additional trade remedies, such as Section 201 of the Trade Act of 1974, are classified as "safeguard laws," whose main purpose is to protect domestic industry from sudden influxes of imported goods.[205] Section 232 of the Trade Expansion Act of 1962, for example, permits the imposition of import tariffs in the interests of national security.[206] On request from any "interested party," the Department of Commerce carries out a Section 232 investigation to determine whether specific imports are a threat to national security; the president may then establish tariffs, quotas, or other trade measures to counteract the threat. Of the three trade remedies, AD investigations have served as the primary mechanism to protect domestic industry—though CVD measures have gained renewed attention in the past half century.[207]

Trade remedies have become increasingly prominent in U.S. policy for iron and steel. In 2002, for example, an estimated 130 of 260 AD tariffs and 30 of 50 CVD tariffs pertained to steel products.[208] Concurrently, the Bush administration, in response to the ongoing steel crisis in the United States (see chapter 2), imposed Section 201 "safeguard" tariffs of up to 30% on imports of 14 categories of steel products. Several legislative and executive efforts emerged during this time as well, including the Emergency Steel Loan Guarantee Act of 1999, the Continued Dumping and Subsidy Offset Act of 2000 ("Byrd Amendment"), the first cases invoking Section 421 of the Trade Act of 1974 (brought in 2002), and numerous attempted AD/CVD law reforms. Notably, the Byrd Amendment created a fund, supplied by AD/CVD revenues, for direct compensation to impacted domestic producers, especially in the steel industry. Shortly after its enactment, this direct distribution of tariff revenue to affected companies was found to be in violation of WTO rules because it went beyond rectifying the trade imbalance to subsidize domestic producers directly, leading to congressional repeal in February 2006.[209]

In March 2024, the DOC implemented reforms to AD and CVD investigation procedures.[210] The changes recognize that foreign producers may gain an unfair cost advantage due to inadequate government enforcement of legal protections, including environmental regulations, labor laws, and property and human rights.

The reforms, effective as of April 24, 2024, expand the scope of AD/CVD regulations, allowing DOC to impose duties on the basis of "weak" enforcement in these categories. It remains to be seen how the recent AD/CVD changes will impact steel trade and embodied emissions.

In the past decade, tariffs under Section 232 of the 1962 Trade Expansion Act and Section 301 of the 1974 Trade Act have been used with increasing frequency, as U.S. industrial policy has sought to address concerns over national security, domestic industrial capacity, and unfair foreign trade practices.[211] In March 2018, the Trump administration invoked Section 232 to impose a 25% ad valorem tariff on steel imports on national security grounds. Since 2018, various countries have either been exempted from the Section 232 tariffs (such as Canada and Mexico) or subject to less punitive quotas (Argentina, Brazil) or tariff rate quotas (EU countries).

Individual products have also been excluded from Section 232 tariffs on the grounds of insufficient quantity or quality of equivalent domestic products or distinct national security concerns.[212] Product exclusion requests are submitted by U.S. stakeholders and initially reviewed by Customs and Border Protection (CBP) and the Department of Commerce (DOC). Afterward, there is a 30-day window in which other parties (e.g., domestic steel producers that manufacture similar products) can object to the request. Within the DOC, the International Trade Administration then provides a recommendation to the Bureau of Industry and Security, which completes a review of national security implications before granting or denying the exclusion request. Exclusions are usually granted for a period of one year (or until the granted quantity has been exhausted, whichever comes first).

As of January 2024, the DOC Section 232 Exclusions Portal listed approximately 344,000 steel product exclusion requests dating to June 2019.[213] Of those, approximately 233,000 have been granted, 101,000 have been denied, and 10,000 are pending. CBP recognized roughly 50,000 individual product exclusions (across both steel and aluminum products) as of January 25, 2024.[214]

Over time, country and product exemptions have accumulated, resulting in a declining share of imports covered by Section 232 and Section 301 tariffs.[215] From 2018 to 2021, the share of steel imports (excluding steel derivatives) subject to Section 232 and 301 tariffs dropped from 38.9% to 27.6% by import weight—a consequence of both country and product exemptions. In contrast, the share of steel derivative products subject to tariffs over the same period jumped from 1.0% to 42.7%—likely a consequence of the inclusion of "downstream" steel products in the latter tranches of Section 301 tariff deployment. CBP collected approximately $12.9 billion in Section 232 tariff revenues on steel products in fiscal years 2018 through 2022, averaging $2.6 billion across the five years (see table 6.1).

Table 6.1: CBP Section 232 steel tariff revenues.[216]

Fiscal year	2018	2019	2020	2021	2022	**Total**
Tariffs collected	$3.4B	$4B	$1.3B	$1.6B	$2.6B	**$12.9B**

Section 232 tariffs were introduced as a national security measure, but their enforcement has increased the cost of importing from regions with higher GHG emissions intensities of steel production. From 2017 to 2023, the U.S. International Trade Association (ITA) reported a decline in steel imports from 34.7 MMT to 23.7 MMT per year—a reduction of almost 32%.[217] Eight countries accounted for roughly 9 MMT of the decline. For seven of these eight countries, the average emissions intensity of steelmaking (based on 2019 emissions intensities) was greater than the U.S. national average (see table 6.2).[218] Though the COVID-19 pandemic, supply chain issues, and geopolitical upheaval have impacted trade flows, trade tariffs remain a key factor in the recent reduction in steel imports.[219] The U.S. International Trade Commission attributes a 17.2% decline in steel imports between 2017 and 2021 to the combined effect of Section 232 and 301 tariffs.

Table 6.2: Steel imports to the U.S. from selected countries and GHG emissions intensity of production.[220]

Country of origin	Imports, 2017 (MMT)	Imports, 2023 (MMT)	Decline in imports, 2017 to 2023 (MMT)	Average Emissions Intensity, 2019 (t CO_2e/tcs)[221]
United States	N/A	N/A	N/A	1.0
Russia	2.87	0.00	2.87	1.5
Turkey	1.99	0.28	1.70	1.0
Brazil	4.67	3.58	1.10	1.7
South Korea	3.41	2.39	1.02	1.6
Japan	1.73	1.08	0.65	1.9
India	0.75	0.30	0.45	2.2
Germany	1.38	0.95	0.44	1.4

Tariffs (such as those from Section 232) could provide a ready-made revenue source for decarbonization of the industry and its impacts on communities and workers associated with iron and steel production. Though the Byrd Amendment ultimately did not withstand WTO scrutiny as a direct subsidy to trade-affected companies that were already benefiting from the tariffs levied against imported products, there are surviving precedents for allocating tariff revenues to specific programs deemed to be in the public interest. Most notably, the USDA Section 32 account, established by Congress in 1935, is funded through a permanent appropriation of 30% of import duties.[222] The account, collecting over $27 billion per year, supports agricultural commodities by encouraging exports, boosting domestic consumption, and bolstering the purchasing power of affected farmers. Section 32 was originally established to support farmers during the Great Depression, specifically for commodities that did not receive other forms of price support.[223]

The Resilient Communities Act of 2023, introduced by Senators Cassidy (R-LA) and Baldwin (D-WI) on December 6, 2023, pursues a similar strategy: seeking to establish a fund for the use of AD/CVD revenues to support economic development in communities adversely affected by international trade.[224] The bill signals bipartisan support for distribution of trade tariffs to domestic communities, specifically where producers have been "injured" by foreign imports through the idling or shutdown of plants; loss of profits, production, or market share; or inability to invest in plant improvements.[225] The use of Section 232 tariff revenues for decarbonization technology investments in the steel industry would function very differently from the direct subsidies authorized by the Byrd Amendment that were later repealed—since they would be used to advance the public interest in decarbonization and adaptation to climate change. In addition, the DOE, based on project-specific merits, would have to approve these investments, which would not be directly linked to the facilities producing tariff-targeted products.

Still other proposed legislation aims to strengthen existing trade remedies directly. For example, the Leveling the Playing Field Act 2.0 (S. 1856/H.R. 3882) was introduced in Congress in June 2023 by Representatives Terri Sewell (D-AL), Bill Johnson (R-OH), Frank Mrvan (D-IN), and Beth Van Duyne (R-TX) and to the Senate by Senators Sherrod Brown (D-OH) and Todd Young (R-IN).[226] The bipartisan bill targets unfair trade practices through reform of AD/CVD processes and enforcement. If the bill is passed, the Department of Commerce will have greater responsibility and discretion in mitigating the harmful effects of duty evasion and circumvention, currency undervaluation tactics, cross-border subsidies, and other distortive practices that fall outside of the current implementation of AD/CVD measures. In addition, domestic producers will face fewer barriers to bringing successive AD/CVD cases against foreign production. The American Iron and Steel Institute (AISI), United Steelworkers (USW), and domestic manufacturers have come out in support of the proposed legislation, speaking to the broad appeal of trade measures in enhancing U.S. competitiveness and protecting domestic steel production and jobs.[227]

6.3 Carbon Border Adjustment Mechanisms (CBAMs)

Beyond conventional trade policy tools, CBAMs have emerged as a potential solution to carbon leakage while domestic producers face increasing pressure to decarbonize. CBAMs are policy instruments that impose tariffs on imported goods at the border based on CO_2 emissions associated with production.[228] The objective is to ensure that importers face a similar pressure to reduce CO_2 emissions as domestic producers of the same goods. Key challenges in CBAM design and implementation include how to set a tariff that appropriately reflects domestic decarbonization pressure, how to measure CO_2 emissions and apply the tariff (e.g., at the level of a product, plant, company, or country), and how to discourage noncompliance. With an emissions trading system in place for almost two decades, the European Union is currently leading on CBAM implementation.[229]

Potential CBAM designs share several characteristics. The primary goal of a CBAM is to treat domestic and imported goods equivalently based on embodied GHG emissions.[230] CBAMs address a number of additional concerns from the perspective of various stakeholders. For instance, a CBAM assures domestic producers that climate policy will not place them at a competitive disadvantage relative to importers. Most commonly, a CBAM targets product-level embodied emissions. In the United States, the International Trade Commission publishes the Harmonized Tariff Schedule (HTS), which serves as the basis for defining covered products. Of the policies and proposals reviewed in this case, all cover iron and steel, aluminum, cement, and select downstream products.

6.3.1 Comparing the EU CBAM and U.S. proposals

The European Union Carbon Border Adjustment Mechanism (EU CBAM) was introduced in May 2023, starting with a transitional period through the end of 2025, and covers products in select sectors, including iron and steel.[231] Covered steel product categories include direct steel imports, spanning sheet piling, pipe and pipe fittings, railway materials, structural steel, steel containers, and hardware.[232] The policy serves as a complement to the existing European Union Emissions Trading System (EU ETS), a cap-and-trade system that limits major GHG emissions from EU sources.[233] Development of the EU CBAM will take place in two major phases: (1) a transitional period through the end of 2025, during which importers will submit quarterly GHG emissions reports for covered goods, and (2) the permanent system beginning in 2026, where importers will surrender certificates in an amount equivalent to the total embodied emissions from the preceding year's imports.[234] The price of CBAM certificates will mirror the price of ETS allowances, calculated based on weekly average auctions, while accounting for any GHG emissions pricing faced in the country of origin. Free emissions allowances, which mitigated the impact of the ETS on domestic producers prior to the CBAM, will be phased out for domestic producers and importers alike between 2026 and 2034.

Economic modeling by the European Commission suggests that the EU CBAM, measured against a base case of domestic policy to reduce GHG emissions 40% by 2030 (maintaining free allowances in the ETS), may reduce carbon leakage by 29% in 2030.[235] For iron and steel, leakage is projected to drop by 24%. 2030 emissions in CBAM sectors for the EU and rest of the world would fall by 13.8% and 0.3%, respectively. Iron and steel imports would decline nearly 12% below the base case imports. Simulated economic and social impacts in the EU are modest; GDP would be 0.223% lower in 2030 versus the base case, and overall employment would be largely unaffected by CBAM implementation.

On average, the EU CBAM is not expected to have a profound effect on U.S. industry, since production is relatively clean in the global context.[236] However, certain producers will suffer more than others, and there is an outstanding question: how can the United States equate its various climate policies—such as subsidies, tax credits, and subnational carbon pricing systems—to the EU's economy-wide GHG price? A parallel effort to align U.S. and EU climate policy is the Global Arrangement on Sustainable Steel and Aluminum (GSA).

The United States has some familiarity with CBAMs. The American Clean Energy and Security Act of 2009 (Waxman-Markey Act) attempted to address climate change through combined energy efficiency and renewable electricity standards, voluntary energy efficiency programs, a cap-and-trade program targeting an 83% reduction in GHG emissions by 2050, and additional measures to position the United States as a "clean energy economy."[237] The legislation—passed by the House in 2009 and never voted on in the Senate—sparked a wide range of responses from industry, activists, and international actors.[238] Waxman-Markey set the stage for a CBAM through its international reserve allowance program, which would require importers to purchase emissions allowances, ensuring that they faced similar costs to domestic producers.[239]

More recent CBAM proposals in the United States include the Fair, Affordable, Innovative, and Resilient (FAIR) Transition and Competition Act of 2021, the Foreign Pollution Fee Act (FPFA) of 2023, and the Clean Competition Act (CCA) of 2022 (reintroduced in December 2023).[240] Table A6.1 in the appendix compares key elements of several CBAM proposals. Also of note is the PROVE IT Act (S. 1863), introduced in June 2023, which calls for data collection and reporting of GHG emissions for certain domestic and imported products as a first step to establishing a CBAM.[241]

The FAIR Transition and Competition Act (S. 2378/H.R. 4534) was introduced to the 117th Congress in July 2021 by Senator Christopher Coons (D-DE) and Representative Scott Peters (D-CA).[242] It defined a border adjustment fee for covered products, spanning iron and steel, aluminum, cement, and fossil fuels, defined by the "domestic environmental cost incurred"—in other words, the marginal cost to domestic producers of complying with U.S. environmental regulations. Half of revenues from the adjustment fees were to be allocated to state-level "resilient communities grants" for workforce transition assistance, climate change mitigation, and support of businesses hurt by the CBAM.[243] The remainder would fund research, development, and commercialization of GHG reduction technologies. Though the bill eventually did not advance in the 117th Congress, it set the stage for present U.S. CBAM proposals.

The Foreign Pollution Fee Act (FPFA), introduced by Senators Bill Cassidy (R-LA) and Lindsey Graham (R-SC) in November 2023, defines a tiered ad valorem border adjustment for covered products (including iron and steel direct imports, HTS 7201 through 7326) that seeks to limit imported embodied emissions to less than 10% above domestic emissions in equivalent products.[244] Covered products include iron, steel, aluminum, and cement, in addition to fuel and chemical products (biofuels, crude oil, hydrogen, methanol, ammonia, natural gas, petrochemicals, refined petroleum products), glass, plastics, pulp and paper products, and clean energy transition materials (lithium-ion batteries, critical minerals, solar cells and panels, and wind turbines). The act does not include any provisions related to domestic GHG emissions but strongly incentivizes other nations to enter "international partnership agreements" that would facilitate a harmonized GHG emissions reporting and reduction strategy in exchange for mutual removal of tariffs. Emissions intensity baselines are defined at the national average across each covered sector—a definition that may disincentivize foreign producers from decarbonizing, as their effort would not be reflected in a lower tariff.[245] Nonetheless, the FPFA may still support environmental goals by targeting imports from highly emitting countries (primarily China) and represents an opportunity to expand the coverage of climate policy through international partnerships.

In an op-ed on October 5, 2023, Senator Cassidy highlighted the following motivations for proposing the FPFA: the economic and military threat of China, the emissions advantage of U.S. manufacturing, the responsibility of large economies to address pollution, and the threat of GHG emissions leakage.[246] The FPFA has been supported by AISI and the Steel Manufacturers Association, as well as leaders in the cement, chemicals, and battery manufacturing industries.[247]

The Clean Competition Act (CCA) was reintroduced in the Senate on December 6, 2023, by Senators Sheldon Whitehouse (D-RI) and Suzan DelBene (D-WA), offering an alternative CBAM to the FPFA.[248] Covered products under the CCA include iron and steel, aluminum, cement, fossil fuels and related petroleum products, and select industrial chemicals.[249] Similar to the EU CBAM, the CCA links border adjustments to domestic emissions policy.[250] Domestic producers with emissions intensities greater than the baseline (defined as the mean GHG emissions of domestic facilities) pay a fee based on the difference. Importers are subject to the same fees on a product-level basis. The CCA includes a timeline for reduction of benchmark values to encourage emissions reduction over time—essentially instituting a carbon pricing mechanism.[251]

The proposed CCA allocates 75% of CBAM revenues to a grant program for decarbonization of existing and new facilities in the covered sectors, with the remaining 25% directed to the Department of State for bi- and multilateral assistance for foreign climate and clean energy programs.[252] Revenues are drawn from the Treasury General Account based on import fees from the preceding year, beginning in FY 2026. Exporters of covered goods may be rebated based on industry average GHG emissions intensity in the destination market. Industry reception may be mixed; AISI has already responded in support of the CCA imported emission tariffs but in opposition to the domestic emission reduction measures.[253]

6.3.2 GHG Emissions Measurement

Implementation of any form of CBAM is predicated on measurement and reporting of GHG emissions associated with the production of covered goods.[254] GHG emissions are typically categorized into three buckets: Scope 1 (direct emissions), Scope 2 (indirect emissions from electricity), and Scope 3 (other indirect emissions across the supply chain).[255] Scope 3 also includes upstream emissions such as extraction and transport of raw materials and downstream emissions of products (e.g., their use and end-of-life stages). Downstream emissions are not only difficult to estimate but also impractical to include in a CBAM context because use and end-of-life are no longer tied to specific nations or producers.[256] Accounting frameworks for measuring emissions in the steel industry have been developed by ResponsibleSteel V2.0, worldsteel CO_2 and LCI, ISO 14404/ISO 20915, and the Global Steel Climate Council.[257] Table 6.3 provides details on several of these steel GHG emissions measurement methodologies.

Table 6.3: Several steel GHG emissions measurement methodologies.[258]

	ResponsibleSteel Version 2.0	World Steel Association	Global Steel Climate Council (GSSC)
Focus	Product-level and production-level	Production-level: BF-BOF, DRI-EAF, scrap-EAF	Product-level: hot rolled steel, flat and long products
Buy-in	Steelmakers, upstream/downstream entities, affiliates	Raw steel companies and affiliates	Steelmakers, upstream/downstream entities, affiliates
Coverage	106 MMT (5% global production)	485 MMT (25% global production)	N/A; support from Nucor, Steel Dynamics
Update frequency	1.5 years	1 year	1 year; recertification every 3 years
Output	GHG intensity per process, per plant	CO_2 intensity per plant	GHG intensity per product
Omissions	N/A	Raw materials supply, upstream fossil fuel emissions, waste treatment, non-CO_2 GHGs	Carbon offsets
Verification	By ResponsibleSteel (nonprofit)	None	Third-party

Collecting and comparing GHG emissions data in the context of border adjustment presents several challenges, including the following:

1. Comparison of product emissions with different frameworks or methodologies may lead to inconsistent calculation of border fees. Consensus on

methodology and particularly on accounting boundaries is thus crucial to CBAM implementation. As seen in table 6.3, methodologies for measuring steel emissions vary. On a broader scale, the three primary carbon accounting frameworks (IPCC, ISO, and GHG Protocol Corporate Standard) differ in their definition of GHGs, level of granularity, and system boundaries.[259]
2. A comprehensive CBAM would require highly disaggregated emissions data, such as at the product level. This is inconsistent with existing emissions data reporting protocols, such as the EPA Greenhouse Gas Reporting Program (GHGRP), which records facility-level data.[260] Estimates of product-level data using facility-, firm-, or national-level emissions are likely to misrepresent the actual emissions of a product.[261]
3. The choice of default emissions data, which some systems suggest can be used in the absence of actual data, may lead to unintended (even perverse) incentives. For example, a CBAM that uses sectoral emissions averages based on country of origin may unfairly disadvantage clean foreign producers.[262]
4. Foreign producers and importers have an incentive to underreport emissions for products that are subject to carbon fees.[263] Verification of data accuracy thus becomes crucial but may not be feasible for the country imposing the CBAM.
5. Complexity of data measurement, reporting, and accounting can reduce the scope of covered products/sectors under a CBAM.[264] This may limit the CBAM's overall efficacy in reducing carbon leakage.

The EU CBAM provides detailed guidelines for emissions methodology, accounting, and reporting, defined as the "monitoring, reporting, and verification (MRV) rules."[265] By the end of the transition period (through 2025), importers are required to report emissions following the EU MRV methodology. The methodology closely mirrors that of domestic producers under current ETS regulations. Beginning in 2026, importers must also obtain verification from an independent body to ensure the accuracy of submitted emissions data.[266] The scope of emissions is defined for six steelmaking processes.[267]

While a similar reporting and verification system is in place for the existing ETS, there remains a concern that expanding the scope of monitoring to foreign production will prove cumbersome and costly.[268]

Industrial GHG emissions accounting in the United States is covered by the EPA GHGRP. Established in 2009, the GHGRP sets requirements for reporting of GHG emissions for U.S. producers across 41 industries.[269] The program covers direct (Scope 1) emissions for facilities that emit in excess of 25,000 tpa of CO_2e. The GHGRP in its current form is not a suitable platform for CBAM emissions accounting; the lack of Scope 2 and upstream Scope 3 emissions (from inputs such as iron ore or DRI, coke, and scrap) precludes accounting for important sources of GHG emissions in iron and steel production; smaller facilities may fall below the emissions threshold for reporting; and facility-level data are not readily adapted to product-level border adjustments.

How to set standards for GHG emissions accounting for steel is widely debated, due to potential impacts on the competitiveness of existing producers. This report does not take a position on which approach should be adopted, leaving that for the national commission on decarbonization (proposed in chapter 7) to resolve. In the meantime, more research is needed to understand and navigate any tradeoff between incentivizing efficient decarbonization and broader innovation in the industry, on the one hand, and limiting worker and community dislocation, on the other.

At the request of the U.S. Trade Representative (USTR), the U.S. International Trade Commission (USITC) began investigating domestic steel and aluminum production GHG emissions in June 2023.[270] A public report, to be released by January 2025, will establish detailed product-level Scope 1, Scope 2, and upstream Scope 3 emissions along with associated measurement methodologies. The data gathered by this USITC investigation are intended to aid in GSA negotiations but may have relevance for other domestic and trade-related climate policy. As part of the Buy Clean focus in the Inflation Reduction Act, the EPA is responsible for setting definitions of "clean" materials to be used in federal procurement.

6.3.3 Alternative CBAM Designs

One alternative approach to a CBAM is a Leakage Border Adjustment Mechanism (LBAM), a simplified scheme that imposes product-specific import tariffs and export subsidies with the aim of keeping trade flows constant before and after a carbon price takes effect.[271] CBAMs are potentially problematic for a number of reasons: collecting data on foreign production is difficult, foreign producers have an incentive to underreport embodied emissions, and large foreign producers can prioritize export of low-emissions products to avoid fees without actually reducing emissions. The EU CBAM only focuses on a handful of sectors (mentioned earlier) due to the practical challenges of implementation. In contrast, an LBAM calculates product-specific fees based on domestic data only for product-level trade and in-country consumption data and granular firm-level data supplied by domestic producers. Using simplified information collection limited to domestic data, an LBAM can be extended to any product sector.

The logic of an LBAM is as follows: a domestic carbon price may introduce an additional production cost to domestic manufacturers of a specific product.[272] This will be reflected in an increased demand for imports of that product—causing carbon leakage, if imports are more carbon intensive than domestic products. To counter this, an LBAM tariff is applied to all imports of that product, aimed at restoring import demand to the baseline level prior to the imposition of carbon pricing. The LBAM does not depend on actual embodied emissions; rather, it seeks to maintain existing trade flows.

Though LBAMs are untested in practice, economic modeling suggests that their implementation may offer benefits versus alternative mechanisms.[273] The EU CBAM in its current form may have limited impact on carbon leakage because it covers so few sectors. In contrast, an EU-based LBAM is predicted to have a large impact on global GHG emissions reduction with relatively small average import tariffs and export subsidies. Additionally, modeling suggests an LBAM may be complementary to a "climate club" of countries that share carbon pricing and border adjustment schemes.

Antidumping duties (AD) are another option for preventing the importation of carbon-intensive goods. AD law allows the imposition of tariffs when there is a "material injury" to domestic producers from imports sold at "less than fair value."[274] The Department of Commerce has some discretion in AD rulings, opening the door for consideration of GHG emissions intensity when establishing the definition of a "fair" value for goods. Cheap, emissions-intensive goods may be deemed unfair and thus subject to AD. However, the legal standing of such a practice is uncertain. Section 232 tariffs likely offer a stronger alternative, given that the U.S. executive has direct authority to levy them.

Climate clubs or climate alliances—trading blocs of nations with coordinated climate actions—are promising approaches for reducing emissions in trade.[275] In a climate club, countries of equal or greater climate policy ambition (e.g., as reflected in a carbon price) or of lower GHG emissions intensity in certain goods would be exempted from tariffs by the importing country in question. The United States and the EU are currently engaged in negotiations over the Global Arrangement on Sustainable Steel and Aluminum (GSA), seeking to establish a climate club to address global overcapacity and CO_2 emissions specific to steel and aluminum production.[276] Initiated in 2021, the GSA set a deadline of 2024 to establish standards for green steel and delineate an agreement between the two partners. Presently, EU steel imports are exempt from Section 232 tariffs, but quarterly tariff rate quotas (TRQs) remain in place.[277] The EU has pushed for annual TRQs (as opposed to the quarterly system), though it is reluctant to impose countervailing tariffs on U.S. imports. Concurrently, the EU is considering reopening a WTO case against the United States over the tariffs, which currently impose an approximately $350 million per year burden on EU exporters.[278] In December 2023, the two parties agreed to extend the present arrangement through March 2025, with both sides seemingly far from reaching an agreement.[279]

The FPFA would grant exemptions to border adjustment fees for nations that engage in “international partnership agreements” with the United States.[280] The USTR, in coordination with relevant congressional committees, is largely responsible for negotiating these agreements. International partnership agreements are conditional, based on establishing “compatible methods to promote pollution reduction through trade mechanisms” and “compatible pollution monitoring, reporting, and verification methods.” In other words, countries that cooperate on GHG emissions reductions can be exempt from CBAM fees, forming a kind of climate club.[281] Such an approach can align global climate policy without requiring a border adjustment for products from all countries of origin.

6.3.4 CBAMs and International Trade Regimes

The introduction of the EU CBAM has sparked debate over the international rules-based scheme established under the WTO.[282] Opponents of the CBAM point to three articles in the General Agreement on Tariffs and Trade (GATT). Article I, the most favored nation clause, forbids preferential treatment of imports from any country with MFN status.[283] In a similar fashion, Article III forbids discrimination or preferential treatment between domestic products and imports. Article XI prevents trade restrictions (such as quotas) on other WTO nations.

Proponents of the EU CBAM cite GATT Article XX, which provides exceptions to the aforementioned rules for trade measures “necessary to protect human, animal or plant life or health” or “relating to the conservation of exhaustible natural resources.”[284] Additionally, the EU has argued that the CBAM satisfies Articles I and III because the border fees apply equally to all importers and CBAM fees on foreign producers are equivalent to ETS fees on domestic producers.[285] At present, the WTO Appellate Body (responsible for settling trade disputes) appears to be nonfunctional, casting doubt on the ability of the organization to weigh in on CBAM implementation.[286]

International trade agreements are another vehicle for aligning climate goals. The USMCA, which replaced NAFTA in July 2020, defines trade terms between the three nations.[287] The USMCA provides a framework for harmonization of climate policy, specifically through mutual obligations to uphold multilateral environmental agreements (MEAs).[288] The agreement explicitly names seven MEAs (including the Montreal Protocol) and includes a mechanism for amendments to the current list. Such an arrangement opens the door for the establishment of a North American CBAM or climate alliance in the future.

6.4 The Relationship between Domestic Policy and Trade Policy

Unilateral domestic climate policy can take many forms, a full discussion of which is beyond the scope of this chapter. This chapter focuses on the ways that domestic climate policy can be used to determine the need for an appropriate and effective CBAM and to inform its design.

For example, cap-and-trade (CAT) systems with free allowances have been implemented as a remedy to carbon leakage.[289] The EU ETS is a salient example. CAT systems, in brief, define a maximum (cap) emissions level divided into a set amount of allowances.[290] Producers must obtain allowances in proportion to their actual emissions over a given period. Allowances can be purchased through auction or trade. GHG emissions leakage can be mitigated through the distribution of free allowances to producers, as determined by historical emissions (grandfathering) or production amount (output-based allocation). The EU ETS takes a slightly different approach, allocating free allowances based on capacity.[291] Modeling suggests that a border adjustment may be more effective at reducing carbon leakage than CAT with free allowances.[292] Accordingly, the EU is scheduled to gradually eliminate free allowances in the ETS between 2026 and 2034, concurrent with the scale-up of CBAM regulations.[293]

Existing CAT programs in the United States include the Regional Greenhouse Gas Initiative (RGGI), covering electricity generation across 11 states, and the California CAT system, inclusive of electricity, fossil fuel distribution, and certain industrial sectors.[294] At the federal level, several CAT bills—notably, between the 108th and 111th Congresses—have been proposed.[295] The more recent legislative proposals include a border adjustment or free allowances to address concern over potential carbon leakage.

Demand-side policy and initiatives can lower the “green premium” for decarbonized steel, improving the competitiveness of decarbonized products relative to more GHG-intensive imports.[296] Green steel demand in the United States is projected to grow to 6.7 MMT per annum by 2030, driven by domestic content and Buy Clean requirements and clean energy infrastructure investments (required by the IIJA, the IRA, etc.), as well as increasingly ambitious corporate climate commitments.[297] The Federal Buy Clean Initiative, launched by the Biden administration in 2021, seeks to spur demand for low-carbon materials (including steel) in federal construction projects.[298] The IRA contributes to this effort, allocating $2.15 billion in Section 60503 to the General Services Administration for procurement of green materials.[299] Several states have announced similar Buy Clean programs to boost demand for clean materials in state projects.[300] Procurement efforts in 13 states are supported by the Federal-State Buy Clean Partnership, started in March 2023.

Voluntary demand platforms and initiatives can also play a role in driving down costs for green steel. Rocky Mountain Institute has formed the Sustainable Steel Buyers Platform (SSBP), which aims to aggregate green steel demand from steel consumers across multiple U.S. sectors and allow flexibility in buyer contract options.[301] The SSBP, launched in September 2023, will unfold in two phases: a request for information (RFI) phase through the end of 2023 to determine green steel premiums from North American steelmakers, followed by a request for proposal (RFP) phase for the aggregated buyers to secure quotes from steelmakers.[302] As of September 2023, large corporations had committed to the purchase of 2 million short tons of steel through the SSBP.

Other voluntary green steel initiatives include the First Movers Coalition and the SteelZero Commitment Framework, summarized in table 6.4.

Table 6.4: Voluntary steel commitment platforms.[303]

	Global Steel Climate Council - Steel Climate Standard	First Movers Coalition	SteelZero
Definition of green steel	Steel product GHG intensity targets, following a decreasing trendline from 2022 through 2050 2022 baseline: 1.47 tCO_2/tcs (long products), 1.84 tCO_2/tcs (flat products)	0.1 tCO_2/tcs (100% scrap) 0.4 tCO_2/tcs (0% scrap)	ResponsibleSteel certified **OR** From producers with a science-based target approved by the Science Based Targets initiative (SBTi) **OR** 0.2 tCO_2/tcs (100% scrap) 1.4 tCO_2/tcs (0% scrap)
2030 goal	1.11 tCO_2/tcs (long products), 1.31 tCO_2/tcs (flat products)	>10% of annual steel procurement to meet/exceed near-zero emissions definition	50% “green” steel
2050 goal	0.12 tCO_2/tcs (long and flat products)	N/A	100% net-zero steel
Included emissions	“Cradle to gate”	“Cradle to gate”	Scope 1, Scope 2, and upstream Scope 3 emissions
Notable members	CELSA Group, Commercial Metals Company, Institute of Scrap Recycling Industries (ISRI), Nucor Corporation, Steel Dynamics, Inc., Steel Manufacturers Association (SMA)	Consolidated Contractors Company (CCC), Iberdrola, Orsted, Volvo	Orsted, Iberdrola, Polestar, Trane, Volvo

Standards are another tool that can drive up demand for green steel. The ResponsibleSteel standard, mentioned previously, lists requirements for GHG emissions in addition to other social and environmental stipulations.[304] As of February 2024, U. S. Steel’s Big River Works in Osceola, Arkansas, is the only U.S. site to have ResponsibleSteel certification.[305] Other standards such as the GSCC would have a similar effect. In the construction industry, the LEED standard has begun to include GHG emissions associated with the production of building materials.[306] These frameworks can complement regulations and voluntary commitments to accelerate decarbonization efforts.[307]

6.5 Recommendations: Trade and Climate Policy

Trade and climate policy recommendation 1: Support the U.S. iron and steel industry by funding capital costs and incremental operational costs over the arc of the transition to deeply decarbonized iron- and steelmaking. Direct this funding especially to producers that achieve local environmental benefits and commit to high-road labor practices.

U.S. trade policy and domestic policy should be harmonized to achieve desired environmental and labor standards. Though the United States has a relatively clean steel industry, continued investment in decarbonizing technologies will support this industry's leadership on the global stage and provide a powerful incentive for decarbonization of the global steel industry. Funding decarbonizing opex and capex through trade policy supports those aims. Designing a future carbon border adjustment mechanism, concurrent with development of an implied carbon fee, addresses U.S. climate goals while also leveling the playing field for U.S. producers—minimizing carbon leakage, strengthening domestic industry, and protecting steelmaking communities.

Trade and climate policy recommendation 2: Use Section 232 tariff revenues for steel decarbonization in the medium term. A robust U.S. green steel industry is crucial to securing U.S. industrial supply chains and preserving a national competitive advantage in decarbonizing technologies. Since Section 232 tariffs are established in the interest of national security, they are a fitting vehicle for this purpose. Furthermore, Section 232 tariffs have proven to be durable domestically. Revenues from Section 232 tariffs can fund investment tax credits to offset steel decarbonization capex costs, as outlined in chapter 3. The USDA Section 32 Account outlines an important precedent for allocation of tariff revenues in a similar fashion. Setting aside Section 232 steel tariff revenues in the medium term (i.e., five to eight years) for steel decarbonization investments provides market stability for the industry and adequate time to design a long-term CBAM solution. Upon implementation of a long-term funding source for steel decarbonization, potentially from CBAM revenues, Section 232 tariffs may revert to their current revenue design.

Section 232 tariff revenues should be allocated to dedicated steel decarbonization programs administered by the appropriate federal agencies, such as the DOE. As described in chapter 3, steel decarbonization programs should be funded in a fair manner such that both integrated and EAF steelmaking can achieve emissions reductions targets. IRA funding (45V, 45Q, 45X, or 48C) or programs such as the Industrial Demonstrations Program provide a template for administration of new, independent, dedicated steel decarbonization initiatives. Building on existing programs, DOE offices specializing in advancing different phases of research, development, and commercialization could support steel decarbonization across all levels of technological maturity.[308] Support will also be important for emerging technologies, as mentioned in chapter 3.

The product exemption process is a core component of Section 232 tariff administration. Streamlining of this process, while establishing equal footing for both exemption petitioners and objectors, is crucial for ensuring tariffs are applied under the appropriate circumstances.

Trade and climate policy recommendation 3: Relevant trade policy authorities should reach consensus on a U.S. CBAM or other mechanism to mitigate carbon leakage in the medium term (five to eight years) using a clear, broadly accepted, interoperable system for CO_2 emissions accounting based on common system elements and boundaries.

Establishing a date for a future CBAM (to eventually supersede Section 232 tariffs as a revenue source for steel decarbonization) would provide certainty to U.S.

producers and incentivize investment in decarbonizing technologies. It would further encourage negotiations with trading partners to address carbon leakage in the steel industry. It could also provide a source of revenue to replace the Section 232 tariffs. CBAM development is still in its infancy on the global stage, but there is an opportunity to lay the groundwork while policymakers develop consensus on the finer details of CBAM construction.

CBAMs are predicated on robust, transparent, and comprehensive emissions data collection. Relevant federal agencies should develop measurement, reporting, and verification protocols and adopt an accounting standard that is compatible with international standards. The EPA GHGRP, expanded to include Scope 2 and upstream Scope 3 emissions and emissions from coproduct gases, could serve as a foundation for such a standard.

In the absence of granular data, reporting guidance should be carefully designed to incentivize the desired outcomes. For example, default values based on the national average intensity may allow heavily emitting foreign producers to claim the default value and reduce their border adjustment burden without reducing emissions. An alternate approach sets default values based on the top (10% or 1%) emitting producers in that country of origin, encouraging both emissions reductions and actual data collection.

Some of the CBAM proposals discussed earlier introduce a petition process in which importers request to use lower emissions intensities than otherwise would be applied to certain products. Domestic producers should be granted a similar ability to petition for greater emissions intensities on certain products, thus maintaining a balance between interests.

Establishment of a U.S. CBAM sets the stage for coordination of climate goals with trading partners. This policy could be extended across North America through an amendment to the USMCA Multilateral Environmental Agreement list. International trade agreements or climate alliances (such as the GSA) can further broaden the environmental impact of a U.S. CBAM by granting border adjustment fee exceptions to nations with equivalent or stronger climate policy or emissions performance.

Trade and climate policy recommendation 4: Support steelmaking communities through trade policy. Trade policy has the potential to address the past and present harms to American steelmaking communities. The proposed bipartisan Resilient Communities Act is an indicator that there is support for investing in the communities most affected by harmful trade practices. The IIJA, the IRA, and the CHIPS and Science Act include some of the key components of labor and social reform, though there remain notable opportunities for strengthening, especially for Community Benefits Plan (CBP), local hire, and Project Labor Agreement (PLA) requirements.[309] Section 232 tariff revenues (or future CBAM revenues) may be used to address the issue—connecting steel decarbonization grants and tax incentives with CBPs and Community Benefits Agreements for community and workforce engagement and providing bonus tax credits for reinvestment in existing communities.

7. Recommendations for Iron and Steel Decarbonization by 2050

The analysis presented in earlier chapters supports four overarching case study recommendations. These recommendations, laid out below, provide for a self-funded framework to accelerate deep decarbonization of the iron and steel industry in the United States.

Recommendation 1: Create a national public-private commission to provide leadership and oversight of iron and steel decarbonization. This commission should be composed of industry, appropriate government agencies, labor, technical experts, and community members. Industry, government, labor, and community representatives should have the opportunity to nominate their own representatives, who would be confirmed by the executive branch. The commission would have broad responsibility to design and review a federal plan for iron and steel decarbonization by 2050. Consistent with federal advisory committee rules and SEC requirements, the commission's key responsibilities would include: (1) developing consensus criteria for net-zero compatible technologies eligible for federal support and overseeing implementation, (2) identifying critical iron and steel decarbonization infrastructure projects, and (3) producing, by December 1, 2025, a roadmap report on iron and steel decarbonization by 2050, which would be used as guidance by implementing federal agencies. The commission should also issue an annual report to the executive and Congress describing the industry's decarbonization program, tracking its progress toward decarbonization goals (based on internationally common or at least interoperable CO_2 emissions accounting boundaries), and identifying gaps in various complementary dimensions of the steel transition.

Recommendation 2: Appropriate Section 232 revenues to fund iron and steel decarbonization by 2050. Section 232 tariffs should be maintained and extended for at least five to eight years or until an agreement on a CBAM is reached with major trade partners. Section 232 revenues should be used to fund capital costs for iron and steel decarbonization. Once a CBAM is in place to provide funding for iron and steel decarbonization, Section 232 steel revenues should revert to the U.S. Department of the Treasury. A new Office of Steel Decarbonization, administered by the U.S. Department of Energy, should be established to review grant applications and award iron and steel industry decarbonization grants following the guidance supplied by the commission's roadmap report on iron and steel decarbonization and annual reports to the executive and Congress.

Recommendation 3: Extend and augment existing IIJA and IRA programs and tax credits to support iron and steel decarbonization. The funds appropriated for the Industrial Demonstrations Program (IDP), CCS, and the Regional Clean Hydrogen Hubs Program (H2Hubs) will contribute to enabling both early plant-specific investments and deep decarbonization through the provision of infrastructure to access clean electricity and hydrogen. Existing IRA tax credits such as 45Q and 45V will be necessary for iron and steel decarbonization by 2050 and should be adjusted for inflation and extended for the industry beyond their current expiration at the end of 2032. Since multiple federal agencies have a range of authorities and programs that could impact the speed and success of iron and steel industry decarbonization efforts, an interagency working group, including representatives of the DOC, DOE, DOL, USDT, and EPA, should be established to coordinate federal support across federal agencies for iron and steel plants to decarbonize using new and existing programs. This working group should coordinate its activities with the commission and the DOE's Office of Steel Decarbonization and be mandated to address roadblocks to iron and steel industry access to enabling infrastructure, such as decarbonized electricity; carbon capture, transport, and sequestration; and clean hydrogen.

Recommendation 4: Involve community members and workforce representatives early and often in decarbonization planning. Iron and steel companies should proactively engage community members and workforce representatives, including labor unions, to design decarbonization plans with accountability for outcomes. These engagement strategies will need to be site-specific, addressing unique legacies and stakeholder dynamics. Training and upskilling opportunities for affected employees will be an essential component of all decarbonization plans. Companies should ensure that any public health and environmental co-benefits of decarbonization investments are key components of community engagement and part of the design of any Community Benefits Plans (CBPs). Ultimately, Community Benefits Agreements that codify job quality, public health, and environmental targets with accountability provisions are an essential outcome of both community engagement and CBPs and should be required of all federal grant recipients.

Implementing these recommendations would establish an institutional framework and overall strategy for equitable deep decarbonization of iron and steel production in the United States. It would also provide a model for other industries to adopt or adapt. Industrial strategies for decarbonization within the industrial sector that are coordinated with broader decarbonization efforts can accelerate progress by ensuring that climate, trade, and industrial policy aims are considered in an integrated fashion. Chapters 3 through 6 conclude with recommendations that elaborate on or complement the recommendations above. Taken together, the Roosevelt-style approach outlined in this case study offers a powerful starting point for ensuring that the U.S. iron and steel industry, its workers, and its connected communities can lead and thrive in the climate century.

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Appendix: Chapter 2

Table A2.1: Sustainability metrics across U.S. iron and steel companies, compiled from 2022 company reporting.

Company	2022 MMT of steel	EAF %	Scopes 1 and 2	Scope 3	BF-BOF %	Scopes 1 and 2	Scope 3	Scrap tons	GHG 2030	GHG 2050	RE usage	RE 2030	Baseline	Diversity: race	Diversity: gender	Disclosure
Nucor	29.5	100%	0.44	0.32	0%	N/A	N/A	N/A	35%	None	N/A	N/A	2015	N/A	N/A	GRI
USS	17.4	19%	0.41; 0.73	N/A	81%	1.93	N/A	5.1	20%	Net zero	N/A	N/A	2018	N/A	N/A	GRI, TCFD, SASB
CCI	14.8	22%	1.04	N/A	78%	1.6	N/A	6.5	25%	None	N/A	N/A	2017	83–17%	80–20%; 91–9%	GRI, SASB
Steel Dynamics	11.2	100%	0.41	0.4	0%	N/A	N/A	12.4	50%	Net zero	14%	30%	2018	67–33%	89–11%	N/A
Schnitzer/ Cascade	0.9	100%	0	0.19	0%	N/A	N/A	N/A	N/A	Net zero	100%	N/A	N/A	53–47%	N/A	GRI, SASB
SSAB	2.4	100%	0.57	N/A	0%	N/A	N/A	N/A	35% (*2032 goal)	Net zero	N/A	N/A	2018	N/A	N/A	GRI, TCFD, SASB
CMC	5.75	100%	0.41	0.25	0%	N/A	N/A	N/A	20%	None	23.20%	N/A	2019	51–49%	93–7%	GRI, TCFD, SASB
Gerdau	6.8	100%	0.93	N/A	0%	N/A	N/A	N/A	10%	Net zero	N/A	N/A	2020	N/A	N/A	N/A
Timken	0.7	100%	0.9	1.78	0%	N/A	N/A	0.84	40%	Net zero	N/A	N/A	2018	N/A	N/A	GRI, TCFD, SASB
North Star BlueScope	3	100%	0.179	N/A	0%	N/A	N/A	N/A	12%	Net zero	N/A	N/A	N/A	N/A	N/A	GRI, TCFD, SASB, SDG
EVRAZ	1.1	100%	N/A	N/A	0%	N/A	N/A	N/A	N/A	N/A	45%	N/A	N/A	N/A	N/A N/A	N/A

Appendix: Chapter 4

Table A4.1: Demographic profile of surveyed communities: county level.[310]

	County	Tech	Persons below poverty level	Unemployed	Without high school education	Over age 64	Minority population
Blytheville, AR	Mississippi	EAF	21.8%	9.6%	17.4%	14.6%	43.0%
Hickman, AR	Mississippi	EAF	21.8%	9.6%	17.4%	14.6%	43.0%
Osceola, AR	Mississippi	EAF	21.8%	9.6%	17.4%	14.6%	43.0%
Fairfield, AL	Jefferson	EAF	15.9%	6.1%	9.4%	15.9%	50.8%
Birmingham, AL	Jefferson	EAF	15.9%	6.1%	9.4%	15.9%	50.8%
Cleveland, OH	Cuyahoga	BF	16.7%	7.5%	9.3%	18.3%	42.0%
East Chicago, IN	Lake	BF	14.8%	7.1%	10.2%	16.5%	46.8%
Gary, IN	Lake	BF	14.8%	7.1%	10.2%	16.5%	46.8%

Appendix: Chapter 6

Table A6.1: Summarized comparison of CBAM elements.

CBAM element	EU CBAM[311]	FAIR Transition and Competition Act[312]	FPFA[313]	CCA[314]
Goals and impacts	Encourage trade partners to adopt a carbon price. Complement to EU ETS.	Protect domestic jobs. Track domestic average emissions per sector to assess U.S. climate progress.	Reduce imports of embodied emissions over 12-year interval. Encourage “international partnership agreements.”	Establish domestic carbon pricing. Complement to industrial emissions performance standard. Revenues to incentivize further decarbonization and emissions reductions.
Covered products	Iron, steel, aluminum, cement. Fertilizers, electricity, hydrogen, chemicals.	Iron, steel, aluminum, cement. Fossil fuels. Additional sectors, as determined by the U.S. Department of the Treasury (USDT).	Iron, steel, aluminum, cement. Biofuels, crude oil, hydrogen, methanol, ammonia, natural gas, petrochemicals, refined petroleum products. Glass, plastics, pulp/paper products. Li-ion batteries, critical minerals, solar cells/panels, wind turbines. Domestic producers can petition the U.S. Department of Energy (DOE) to add products to list.	Iron, steel, aluminum, cement. Primary and “finished” goods. Fossil fuels, related petroleum products, select industrial chemicals.
Fee magnitude	Price of ETS allowance (t/CO_2e). Based on weekly mean ETS auction price.	Average sector-specific cost of complying with domestic regulations. Calculated annually by USDT.	Unspecified “variable charge” particular to each product. TBD per DOE. Intended to meet scheduled reductions in imported embodied emissions.	$55/t initially, increasing by consumer price index (CPI) plus 5% YoY.

CBAM element	EU CBAM	FAIR Transition and Competition Act	FPFA	CCA
Fee application	Single fee per t/CO_2e. CBAM certificates linked to ETS allowances.	Single fee per t/CO_2e. Fees paid only for countries of origin with weaker emissions policies.	Ad valorem fee paid for products with a mean GHG intensity greater than baseline. "Tiers" based on emissions above baseline.	Single fee per ton CO_2e. Fees paid versus U.S. baseline.
GHG emissions definition	Scope 1 and 2 emissions. Limited upstream Scope 3 "precursor" emissions. May be expanded after transition period.	"Production GHG emissions" of each product—Scope 1 emissions. Upstream fossil fuel emissions.	Scope 1 and 2 emissions. Upstream Scope 3 emissions (similar to CBAM).	Scope 1 and 2 emissions. Scope 3 upstream supply chain emissions.
Emissions measurement and accounting	Importers responsible for reporting. Transition period until 2026: quarterly reporting, but no fees paid. Beyond 2024: must follow EU methodology. Beyond 2026: annual reporting, third party verification of emissions by accredited organization required.	Methodology to be developed by USDT. Importers may petition USDT to revise GHG intensity for specific products.	No direct requirement for firms to report data. Emission values TBD per DOE and National Laboratory Advisory Board on Global Pollution Challenges. Points to EPA reporting methods (e.g., GHGRP).	Domestic producers report emissions annually to DOE and EPA. Foreign emissions intensities calculated annually by USDT. Producers may petition to use specific GHG intensity of product.
Default values	Complex goods: up to 20% of emissions can be calculated with default intensities. Default values "relatively high" to encourage actual data collection.	Default values set as most-emitting 1% of U.S. producers for each sector.	Product-level data is not collected. Imported products assigned "default" emissions based on mean emissions for that specific product from given country of origin. Allows for consideration of "varied manufacturing methods."	Economy-wide mean emissions intensity used based on country of origin. Where data is sufficient, imported products assigned emissions based on mean emissions intensity for that specific sector from given country of origin. Can differentiate between technology pathways.

CBAM element	EU CBAM	FAIR Transition and Competition Act	FPFA	CCA
Emissions baseline	None: fee per t/CO_2e. Importers pay reduced fees based on carbon price in the nation of origin.	None: fee per t/CO_2e.	Mean facility-level pollution intensity of domestic producers. DOE to calculate baseline intensity and imported product intensity. Baseline recalculated periodically by DOE.	Mean GHG intensity of U.S. sectors, from plant-level data. UDST to establish domestic/imported product GHG intensities. Scheduled to reduce over time: emissions intensity baseline reduces by 2.5% through 2029; 5% thereafter.
Domestic emissions policy	Linked to EU ETS. Domestic, foreign production subject to equivalent emissions fee. Domestic producers pay plant-level fees; importers pay product-level fees. Free allowances to phase out from 2026–34.	USDT to assess compliance cost for U.S. regulations. CBAM fee linked to domestic regulatory compliance costs.	None: only addresses imported embodied emissions.	Domestic producers pay a fee for each t/CO_2e above mean domestic GHG intensity. Domestic producers pay plant-level fees; importers pay product-level.
Exemptions	Nations with equivalent (or greater) carbon price pay no fees.	Exemptions for countries with equal or higher ambition in GHG emissions reduction. Exemptions for "least developed countries."	Exemptions based on international partnership agreements (established by USTR). Product exemptions for national security purposes or where there is insufficient domestic production.	Conditional exemptions for "relatively least developed countries." Exemptions for "carbon clubs"—where products are subject to equivalent explicit GHG emissions fees.
Revenues	"Own resource"—to be used by EU.	50% to state Resilient Communities Grant Program: worker retraining, climate resilience, support of underprivileged communities, small business assistance. 50% for R&D, commercialization, proliferation of GHG-reduction technologies.	Unspecified: treated as typical customs duty.	75% to domestic decarbonization grant program—modeled off of Diesel Emissions Reduction Act. 25% to foreign climate/clean energy programs.

Notes

1. EBITDA; "SteelLens," McKinsey & Company, accessed March 20, 2024, https://www.mckinsey.com/industries/metals-and-mining/how-we-help-clients/steel-lens.
2. Benjamin F. Fairless, "Steel for the Future," *The Atlantic*, December 1, 1950, https://www.theatlantic.com/magazine/archive/1950/12/steel-for-the-future/640024.
3. "World Steel in Figures 2023," World Steel Association, 2022, https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2023.
4. "World Steel in Figures 2023."
5. "U.S. Steel Import Monitor," International Trade Administration, January 2024, https://www.trade.gov/data-visualization/us-steel-import-monitor.
6. "A Proclamation on Adjusting Imports of Steel into the United States," The White House, December 28, 2023, https://www.whitehouse.gov/briefing-room/presidential-actions/2023/12/28/a-proclamation-on-adjusting-imports-of-steel-into-the-united-states-5.
7. Up to quotas established by historically based volumes.
8. "World Steel in Figures 2023."
9. United Steelworkers of America, USWA Basic Steel Industry Conference, Pittsburgh, PA, January 10, 2005.
10. "World Steel in Figures 2023."
11. "World Steel in Figures 2021," World Steel Association, accessed March 27, 2024, https://worldsteel.org/world-steel-in-figures-2021/.
12. "World Steel in Figures 2022," World Steel Association, accessed March 20, 2024, https://worldsteel.org/data/world-steel-in-figures-2022.
13. "World Steel in Figures 2022."
14. *Report to the President, Global Steel Trade: Structural Problems and Future Solutions* (Washington, D.C.: U.S. Department of Commerce, 2000).
15. "Iron and Steel Statistical Compendium (Table 2.—U.S. Raw Steel Production, by Furnace Process and by Steel Type)," U.S. Geological Survey, accessed March 27, 2024, https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/mineral-pubs/iron-steel/stats/tbl2.txt.
16. "Iron and Steel Statistical Compendium."
17. "World Steel in Figures 2023."
18. "World Steel in Figures 2023."
19. "World Steel in Figures 2023."
20. "World Steel in Figures 2023."
21. Ali Hasanbeigi, Hongyou Lu, and Nan Zhou, *Net-Zero Roadmap for China's Steel Industry* (Lawrence Berkeley National Laboratory and Global Efficiency Intelligence, 2023).
22. *Net Zero Roadmap: A Global Pathway to Keep the 1.5°C Goal in Reach: 2023 Update* (International Energy Agency, 2023), https://iea.blob.core.windows.net/assets/13dab083-08c3-4dfd-a887-42a3ebe533bc/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf.
23. "Iron and Steel Recycling," Institute of Scrap Recycling Industries, November 2020, https://www.isri.org/docs/default-source/commodities/isri_commodities_factsheets_iron _steel_sm.pdf.
24. "Iron and Steel Recycling"; "World Steel in Figures 2023."
25. Thomas Brady and Roderick Eggert, *Ferrous Scrap's Role in Decarbonizing Steel: Assessing Steel Product Life Spans* (Global Steel Climate Council, 2023), https://globalsteelclimatecouncil.org/wp-content/uploads/2023/05/SMA-Report-Analysis-of-Steel-Lifespans.pdf.
26. *50 Years of the World Steel Association*.
27. Adrien Corneille and Aryan Agarwal, "Steel Scrap and the Circular Economy: Assessing the State of Play," OECD Steel Committee 95th Session, March 25, 2024, https://oecd.org/industry/ind/95th_Steel_Session_Circularity_Raw-Materials_Long-Term_Steel_Scrap_trends.pdf.

28. Katrin E. Daehn, André Cabrera Serrenho, and Julian M. Allwood, "How Will Copper Contamination Constrain Future Global Steel Recycling?" *Environmental Science and Technology* 51, no. 11 (6599–6606).
29. "CCS Applications," Global CCS Institute, https://www.globalccsinstitute.com/resources/publications-reports-research/ccs-applications/.
30. Fred Pace, "Nucor Steel Gallatin in Kentucky Previews Things to Come in West Virginia," *Herald Dispatch*, April 16, 2023, https://www.herald-dispatch.com/business/nucor-steel-gallatin-in-kentucky-previews-things-to-come-in-west-virginia/article_3c13408d-8a41-50f1-a7e8-2cab3d12216d.html; The United States Steel Corporation, "U. S. Steel Celebrates Launch of New Electrical Steel Line with Ribbon Cutting in Osceola, Arkansas," October 12, 2023, https://investors.ussteel.com/news-events/news-releases/detail/648/u-s-steel-celebrates-launch-of-new-electrical-steel-line; SDI-Sinton Division https://www.steeldynamics.com/sw-sinton-division.
31. "World Steel in Figures 2023."
32. *2022 Sustainability Report: Recycled Metals for a Low-Carbon Future* (Schnitzer, 2022), https://www.radiusrecycling.com/documents/sustainability-report-schnitzer-2022.pdf.
33. "*Sustainability*," EVRAZ North America, 2023, https://www.evrazna.com/sustainability.
34. *Corporate Social Responsibility 2022*, Nucor, accessed March 20, 2024, https://indd.adobe.com/view/cfc4e669-fedb-4841-837a-3cf00b8d1204.
35. *2022 Sustainability Update: Intentionally Sustainable* (Steel Dynamics, 2022), https://stld.steeldynamics.com/wp-content/uploads/2023/08/SDI-2022-Sustainability-Update.pdf; 2022 Sustainability Report (CMC, 2022), https://esg.cmc.com/wp-content/uploads/CMC_Sustainability_Report_2022.pdf.
36. "World Steel in Figures 2023."
37. *Net Zero Roadmap*.
38. Faustine Delasalle, Eveline Speelman, et al., *Making Net-Zero Steel Possible: An Industry-Backed, 1.5°C-Aligned Transition Strategy* (Mission Possible Partnership, September 2022), https://missionpossiblepartnership.org/wp-content/uploads/2022/09/Making-Net-Zero-Steel-possible.pdf.
39. *Economic Impact of Section 232 and 301 Tariffs on U.S. Industries* (United States International Trade Commission, May 2023), https://www.usitc.gov/publications/332/pub5405.pdf.
40. Cleveland-Cliffs has demonstrated this process refinement at its plants in Middletown, Ohio, and Indiana Harbor, Indiana.
41. "Cleveland-Cliffs Selected to Receive $575 Million in US Department of Energy Investments for Two Projects to Accelerate Industrial Decarbonization Technologies," Cleveland-Cliffs, March 25, 2024, https://www.clevelandcliffs.com/news/news-releases/detail/629/cleveland-cliffs-selected-to-receive-575-million-in-us.
42. "ArcelorMittal Breaks Ground on First Transformational Low-Carbon Emissions Steelmaking Project," ArcelorMittal, October 13, 2022, https://corporate.arcelormittal.com/media/press-releases/arcelormittal-breaks-ground-on-first-transformational-low-carbon-emissions-steelmaking-project.
43. See, for instance: Daniel Sekulich, "Vale to Build $345 Million 'Green' Pig Iron Plant in Brazil," *MINING.COM* (blog), April 6, 2022, https://www.mining.com/vale-to-build-345-million-green-pig-iron-plant-in-brazil.
44. Kali Benavides et al., "Mitigating Emissions in the Global Steel Industry: Representing CCS and Hydrogen Technologies in Integrated Assessment Modeling," *International Journal of Greenhouse Gas Control* 131 (January 2024): 103963, https://doi.org/10.1016/j.ijggc.2023.103963.
45. "U. S. Steel and CarbonFree Ink MoU to Capture CO2 Emissions at One of the Largest Integrated Steel Mills in North America," *CarbonFree* (blog), March 2, 2023, https://carbonfree.cc/u-s-steel-and-carbonfree-ink-mou-to-capture-co2-emissions-at-one-of-the-largest-integrated-steel-mills-in-north-america.
46. "NETL Collaborates with U.S. Steel to Capture Greenhouse Gas at Edgar Thomson Plant," United States Steel, September 20, 2023, https://investors.ussteel.com/news-events/news-releases/detail/644/netl-collaborates-with-u-s-steel-to-capture-greenhouse.

47. “World’s Leading Steel Company, ArcelorMittal and LanzaTech Announce First Ethanol Samples from Commercial Flagship Carbon Capture and Utilisation Facility in Ghent, Belgium,” *LanzaTech* (blog), June 14, 2023, https://lanzatech.com/worlds-leading-steel-company-arcelormittal-and-lanzatech-announce-first-ethanol-samples-from-commercial-flagship-carbon-capture-and-utilisation-facility-in-ghent-belgium.
48. Jennifer Pett-Ridge et al., “Roads to Removal: Options for Carbon Dioxide Removal in the United States” (US Department of Energy, December 1, 2023): https://doi.org/10.2172/2301853.
49. Gustavo León et al., “Treatment of Hazardous Waste by Carbon Dioxide Capture from an Electric Arc Furnace,” *ISIJ International* 55, no. 3 (2015): 559–63, https://doi.org/10.2355/isijinternational.55.559.
50. Pett-Ridge et al., “Roads to Removal.”
51. *National Transmission Needs Study* (U.S. Department of Energy, October 2023), https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf.
52. Katheryn Scott et al., “Pathways to Commercial Liftoff: Industrial Decarbonization” (U.S. Department of Energy, September 2023), https://liftoff.energy.gov/wp-content/uploads/2023/09/20230918-Pathways-to-Commercial-Liftoff-Industrial-Decarb.pdf; *Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking* (Paris: International Energy Agency, October 2020), https://www.iea.org/reports/iron-and-steel-technology-roadmap; Igor A. Bashmakov et al., “Industry,” in *Climate Change 2022: Mitigation of Climate Change: Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. P.R. Shukla et al., 1st ed. (Cambridge, UK: Cambridge University Press, 2023), 1161–1244, https://doi.org/10.1017/9781009157926.013; Delasalle et al., *Making Net-Zero Steel Possible*.
53. Delasalle et al., *Making Net Zero Steel Possible*.
54. *CCUS in Clean Energy Transitions* (International Energy Agency, 2020), https://iea.org/reports/ccus-in-clean-energy-transitions.
55. Bas J. van Ruijven et al., “Long-Term Model-Based Projections of Energy Use and CO_2 Emissions from the Global Steel and Cement Industries,” *Resources, Conservation and Recycling* 112 (September 2016): 15–16, https://doi.org/10.1016/j.resconrec.2016.04.016.
56. Paulina Jaramillo et al., “The Costs and Distributional Impacts of Decarbonizing the Iron and Steel Industry in the United States,” December 6, 2023, https://conference.nber.org/conf_papers/f176895.pdf.
57. Petrus Christiaan Pistorius, “Steelmaking Decarbonization Options with Current Technology,” *Metallurgical and Materials Transactions B* 3 (March 2022) https://www.springerprofessional.de/en/steelmaking-decarbonization-options-with-current-technology/20159326.
58. We have already cited the initiatives of several companies and research institutes, both within the United States and abroad, to commercialize decarbonizing processes for the steel industry. To these can be added the venture between U.S. EAF producer Steel Dynamics and Aymium to provide bioproduct alternatives to coal and the investment made by CMC, a U.S. EAF producer, in Danieli technology to generate on-site renewable electricity. U.S. EAF plants Nucor Sedalia and EVRAZ Pueblo already rely on zero-carbon electricity, and other EAF producers are pursuing similar initiatives.
59. Emily J. Moore, Valerie J. Karplus, and M. Granger Morgan, “Expert Elicitation of the Timing and Uncertainty to Establish a Geologic Sequestration Well for CO_2 in the United States,” *Proceedings of the National Academy of Sciences* 121, no. 1 (January 2, 2024): e2307984120, https://doi.org/10.1073/pnas.2307984120.
60. “Quarterly Census of Employment and Wages: Private, NAICS 3311 Iron and Steel Mills and Ferroalloy Manufacturing, All States and U.S. 2023 Third Quarter, All Establishment Sizes,” U.S. Bureau of Labor Statistics, September 7, 2022, https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=0&year=2023&qtr=3&own=5&ind=3311&supp=0.
61. Scott Buckiso, “People: The Real Power of Community Engagement,” United States Steel, accessed March 20, 2024, https://www.ussteel.com/perspective-detail/-/blogs/people-the-real-power-of-community-engagement.

62. “Cleveland Works,” Cleveland-Cliffs, https://www.clevelandcliffs.com/operations/steelmaking/cleveland.
63. “Steel Industry Heats Up in Arkansas,” Arkansas, February 10, 2022, https://www.arkansasedc.com/news-events/arkansas-inc-blog/post/active-blogs/2022/02/10/steel-industry-heats-up-in-arkansas.
64. “American Community Survey 2017–2021 5-Year Data Release,” U.S. Census Bureau, December 8, 2022, https://www.census.gov/newsroom/press-kits/2022/acs-5-year.html.
65. Cris Candice Tuck, “Mineral Commodity Summaries: Iron and Steel,” U.S. Geological Survey, January 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-iron-steel.pdf; “2022 Greenhouse Gas Emissions from Large Facilities,” EPA Facility Level Information on GreenHouse Gases Tool (FLIGHT), 2022, https://ghgdata.epa.gov/ghgp/main.do.
66. “2022 Greenhouse Gas Emissions from Large Facilities.”
67. “2022 Greenhouse Gas Emissions from Large Facilities.”
68. “EJ Screen—EPA’s Environmental Justice Screening and Mapping Tool,” United States Environmental Protection Agency, accessed March 20, 2024, https://ejscreen.epa.gov/mapper; “2022 Greenhouse Gas Emissions from Large Facilities.”
69. Robin H. Shutt et al., “Exposure to Air Pollution near a Steel Plant Is Associated with Reduced Heart Rate Variability: A Randomised Crossover Study,” *Environmental Health* 16, no. 1 (January 28, 2017): 4, https://doi.org/10.1186/s12940-016-0206-0; Ling Liu et al., “Exposure to Air Pollution near a Steel Plant and Effects on Cardiovascular Physiology: A Randomized Crossover Study,” *International Journal of Hygiene and Environmental Health* 217, no. 2–3 (March 2014): 279–86, https://doi.org/10.1016/j.ijheh.2013.06.007.
70. Abhilash T. Nair et al., “Use of Hazardous Electric Arc Furnace Dust in the Construction Industry: A Cleaner Production Approach,” *Journal of Cleaner Production* 377 (December 1, 2022): 134282, https://doi.org/10.1016/j.jclepro.2022.134282.
71. *Proposed Rule for National Emission Standards for Hazardous Air Pollutants: Integrated Iron and Steel* (U.S. Environmental Protection Agency, July 12, 2023), https://www.epa.gov/system/files/documents/2023-07/IronSteel_NPRM.pdf.
72. “EJ Screen”; “2022 Greenhouse Gas Emissions from Large Facilities.”
73. “EJ Screen.”
74. “EJ Screen”; “2022 Greenhouse Gas Emissions from Large Facilities.”
75. “EJ Screen.”
76. Tuck, “Iron and Steel.”
77. “Employment and Output by Industry,” U.S. Bureau of Labor Statistics, September 6, 2023, https://www.bls.gov/emp/tables/industry-employment-and-output.htm.
78. “Quarterly Census of Employment and Wages: Private, NAICS 3311.”
79. “Quarterly Census of Employment and Wages: Private, 1013 Manufacturing, All Counties 2023 Third Quarter, All Establishment Sizes,” U.S. Bureau of Labor Statistics, 2023, https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=1&year=2023&qtr=3&own=5&ind=1013&supp=0.
80. “Quarterly Census of Employment and Wages: Private, NAICS 3311.”
81. Christopher D. Watson, *Domestic Steel Manufacturing: Overview and Prospects* (Congressional Research Service, May 17, 2022), https://crsreports.congress.gov/product/pdf/R/R47107.
82. James B. Lane, *City of the Century: A History of Gary, Indiana* (Bloomington: Indiana University Press, 1978); “U. S. Steel’s Footprint,” United States Steel, accessed March 20, 2024, https://www.ussteel.com/about-us/locations.
83. Steve McShane, “The Magic City of Steel,” U. S. Steel Gary Works Photograph Collection, 1906–1971, Indiana University, October 13, 2010, https://webapp1.dlib.indiana.edu/ussteel/context/essay.jsp; McShane; “Gary, Indiana Population 2024,” World Population Review, 2024, https://worldpopulationreview.com/us-cities/gary-in-population.
84. Aydali Campa, Phil McKenna, and Victoria St. Martin, “Industrial Plants in Gary and Other Environmental Justice Communities Are Highlighted as Top Emitters,” *Inside Climate News* (blog), September 14, 2023, https://insideclimatenews.org/news/14092023/gary-steel-works-top-emitter-environmental-justice; “Gary, Indiana Population 2024.”

85. Campa, McKenna, and St. Martin, "Industrial Plants in Gary"; "EJScreen."
86. Campa, McKenna, and St. Martin, "Industrial Plants in Gary."
87. Quote provided by Eddie Melton and the Gary mayor's office, May 2024.
88. Matt Fry et al., *Carbon Capture Co-Benefits: Carbon Capture's Role in Removing Pollutants and Reducing Health Impacts* (Great Plains Institute, August 2023), https://carboncaptureready.betterenergy.org/wp-content/uploads/2023/08/Carbon-Capture-Co-Benefits.pdf.
89. Jana Hollingsworth, "How Important Was the Iron Range to Winning World War II?" *Star Tribune*, March 17, 2023, https://www.startribune.com/minnesota-iron-range-mesabi-world-war-2-ore-steel-mining/600259684.
90. *The Minnesota Iron Ranges: An Industrial Frontier* (Macalaster College, n.d.), https://www.macalester.edu/geography/wp-content/uploads/sites/18/2012/03/F08_Iron_Range_GEOG111.pdf.
91. *Explore Minnesota: Iron Ore* (Minnesota Department of Natural Resources Division of Lands and Minerals, March 2016), https://files.dnr.state.mn.us/lands_minerals/mcc_docs/2016_explore_iron_ore.pdf.
92. Linda Tyssen, "Book Review: 'Taconite: History of Erie Mining Company' Is a True Gem," Boreal.org, February 26, 2020, http://www.boreal.org/2020/02/27/298881/book-review-taconite-history-of-erie-mining-company-is-a-true-gem.
93. *Mining and Mineral Products* (U.S. Census Bureau, 1980), https://www2.census.gov/library/publications/1980/compendia/statab/101ed/1980-08.pdf.
94. Harvey D. Shapiro, "Taconite Rejuvenates the Iron Range," *New York Times*, August 3, 1975, https://www.nytimes.com/1975/08/03/archives/taconite-rejuvenates-the-iron-range.html.
95. Monica Haynes et al., *Economic Impact of Ferrous and Nonferrous Mining on Minnesota and the Arrowhead Region Including Douglas County, Wisconsin* (Bureau of Business and Economic Research, Labovitz School of Business and Economics, University of Minnesota Duluth, June 3, 2020), https://conservancy.umn.edu/bitstream/handle/11299/216463/UMD%20BBER%20Mining%20Economic%20Impact%20Report%202020.pdf.
96. Lee Bloomquist, "Iron Ore Pellet Shipments up on Great Lakes," *Mesabi Tribune*, January 5, 2024, https://www.mesabitribune.com/news/iron-ore-pellet-shipments-up-on-great-lakes/article_84ad959e-ab2b-11ee-91ac-37caeb07a660.html.
97. Haynes et al., "Economic Impact of Ferrous and Nonferrous Mining."
98. "Quarterly Census of Employment and Wages: Private, NAICS 21221 Iron Ore Mining, All States and U.S. 2023 Second Quarter, All Establishment Sizes," U.S. Bureau of Labor Statistics, September 7, 2022, https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=0&year=2023&qtr=2&own=5&ind=21221&supp=0.
99. "Quarterly Census of Employment and Wages: Private, 10 Total, All Industries, All States and U.S. 2023 Second Quarter, All Establishment Sizes," U.S. Bureau of Labor Statistics, September 7, 2022, https://data.bls.gov/cew/apps/table_maker/v4/table_maker.htm#type=0&year=2023&qtr=2&own=5&ind=10&supp=0.
100. Mike Hughlett, "Construction Begins on $150M U. S. Steel Taconite Pellet Plant in Keewatin," *Star Tribune*, October 5, 2022, https://www.startribune.com/construction-started-on-150m-u-s-steel-taconite-pellet-plant-in-keewatin/600213244.
101. "Nu-Iron Unlimited Point Lisas DRI Plant," Global Energy Monitor Wiki, September 25, 2023, https://www.gem.wiki/Nu-Iron_Unlimited_Point_Lisas_DRI_plant.
102. *Direct Reduced Iron By-Product Fines (DRI D): A Guide to Handling, Storage & Shipping* (International Iron Metallics Association, October 2020), https://www.metallics.org/assets/files/Public-Area/Guides/DRI_Fines_Guide_FinalOct20.pdf.
103. "NREL Researchers Find Minnesota Is a Promising State for Low-Emission and Economically Feasible Steel Production," Energy.gov, January 22, 2024, https://www.energy.gov/communitiesLEAP/articles/nrel-researchers-find-minnesota-promising-state-low-emission-and.
104. Jeffrey Tomich, "U.S. Readies First Wind-Powered Steel Plant," E&E News, November 15, 2019, https://www.eenews.net/articles/u-s-readies-first-wind-powered-steel-plant.

105. Mark Slavit, "Sedalia Steel Plant to Open in November, Bring 250 High-Paying Jobs," KRCG, August 28, 2019, https://krcgtv.com/news/local/sedalia-steel-plant-to-open-in-november-bring-250-high-paying-jobs.
106. Jacob Douglas, "First US Steel Plants Powered by Wind, Solar Energy Are Coming for Industry with Big Carbon Footprint," CNBC, December 7, 2019, https://www.cnbc.com/2019/12/07/first-us-steel-plants-powered-by-wind-solar-energy-are-coming.html.
107. "Nucor Steel Sedalia to Be Featured as 2021 Sedalia Showcase Company," Associated Industries of Missouri, May 13, 2021, https://www.voiceofmobusiness.com/post/nucor-steel-sedalia-to-be-featured-as-2021-sedalia-showcase-company.
108. Tomich, "U.S. Readies First Wind-Powered Steel Plant."
109. "Nucor Plans First Wind-Powered Steel Plant," Smart Energy Decisions, December 9, 2019, https://www.smartenergydecisions.com/renewable-energy/2019/12/09/nucor-plans-first-wind-powered-steel-plant.
110. "Docket Sheet EO-2019-0244," Missouri Public Service Commission Electronic Filing and Information System, January 30, 2020, https://efis.psc.mo.gov/Case/Display/10843.
111. Douglas, "First US Steel Plants Powered by Wind, Solar Energy."
112. Douglas, "First US Steel Plants Powered by Wind, Solar Energy"; Slavit, "Sedalia Steel Plant to Open in November."
113. Tomich, "U.S. Readies First Wind-Powered Steel Plant."
114. Shanna Lewis, "Boomtimes and Long Declines Shadow Pueblo's Most Iconic Industry," *Colorado Public Radio*, March 19, 2020, https://www.cpr.org/2020/03/19/boomtimes-and-long-declines-shadow-pueblos-most-iconic-industry.
115. "CF&I Historical Highlights," *Pueblo Chieftain*, May 19, 2007, https://www.chieftain.com/story/opinion/columns/2007/05/20/cf-i-historical-highlights/8502713007.
116. Daniel Victor Martinez, "Colorado Fuel and Iron Strike of 1997," *Colorado Encyclopedia*, May 28, 2020, https://coloradoencyclopedia.org/article/colorado-fuel-and-iron-strike-1997.
117. "Pueblo Steelworkers to Vote on Oregon Steel Proposal," *Northwest Labor Press*, February 6, 2004, https://nwlaborpress.org/2004/2-6-04USWA.html.
118. Karen Vigil, "Evraz Announces Mill Name Change," *Pueblo Chieftain*, June 15, 2008, https://www.chieftain.com/story/news/2008/06/16/evraz-announces-mill-name-change/8733833007.
119. "Bighorn Solar: 300 MW Powering the World's First Steel Mill to Run Almost Entirely on Solar Power," Lightsource bp, May 10, 2023, https://lightsourcebp.com/project/bighorn-solar; "World's Largest Solar-Powered Steel Plant: World Record in Pueblo, Colorado," World Record Academy, April 10, 2023, https://www.worldrecordacademy.org/2023/4/worlds-largest-solar-powered-steel-plant-world-record-in-pueblo-colorado-423186.
120. Derek Brower, "Solar-Powered Steel Mill Blazes Trail for Green Energy Transition," *Financial Times*, October 11, 2021, https://www.ft.com/content/f6693948-2c3d-4508-96cf-c374ef0fa6ad.
121. Jan Ellen Spiegel, "A Tale of Two Steel Mills, and yet They're the Same One," *Yale Climate Connections*, February 10, 2022, http://yaleclimateconnections.org/2022/02/a-tale-of-two-steel-mills-and-yet-theyre-the-same-one.
122. Spiegel, "Tale of Two Steel Mills."
123. "Bighorn Solar Moving Forward," Lightsource bp, September 27, 2019, https://lightsourcebp.com/us/news/one-of-colorados-largest-solar-projects-moving-forward.
124. Spiegel, "Tale of Two Steel Mills."
125. "Proceeding No. 18A-0569E, Staff Witness Erin T. O'Neill Public Version Answer Testimony," September 7, 2018, https://www.dora.state.co.us/pls/efi/EFI.Show_Filing?p_session_id=&p_fil=G_747993.
126. "Pueblo Steel Plant Plans Large Solar Project," Colorado Public Radio, September 29, 2019, https://www.cpr.org/2019/09/29/pueblo-steel-plant-plans-large-solar-project.
127. Brower, "Solar-Powered Steel Mill Blazes Trail."
128. "Lightsource bp Completes $285M Financing and Mobilizes Construction on Bighorn Solar Project in Colorado," Business Wire, October 1, 2020, https://www.businesswire.com/news/home/20201001005425/en/Lightsource-bp-Completes-285M-Financing-and-Mobilizes-Construction-on-Bighorn-Solar-Project-in-Colorado.

129. Spiegel, "A Tale of Two Steel Mills."
130. "Bighorn Solar: 300 MW," Lightsource bp.
131. Brower, "Solar-Powered Steel Mill Blazes Trail."
132. Chase Woodruff, "Low-Key Green," *American Prospect*, October 12, 2023, https://prospect.org/environment/2023-10-12-low-key-green-pueblo-colorado.
133. Miguel Otárola, "Pueblo's Comanche Coal Plant Is Closing Earlier Than Expected. Is Its Future with Nuclear, or Renewables?" Colorado Public Radio, September 13, 2021, https://www.cpr.org/2021/09/13/pueblo-comanche-coal-plant-closing-early-nuclear-renewable-energy; Tracy Harmon, "Comanche 3 to Close Early but Settlement Assures Millions for Pueblo County," *Pueblo Chieftain*, November 30, 2021, https://www.chieftain.com/story/business/2021/11/30/pueblo-county-inks-settlement-xcel-energy-close-comanche-plant/8798344002; Tracy Harmon, "Pueblo County Approves Early Closure of Comanche 3 Coal Power Plant," *Pueblo Chieftain*, April 28, 2022, https://www.chieftain.com/story/business/2022/04/28/pueblo-county-approves-closure-comanche-3-coal-power-plant/9571525002.
134. Mark Jaffe, "Xcel Will Raise Electric Bills Again Next Month. A Quarter of the Hike Will Cover Closing Coal-Fired Power Plants," *Colorado Sun*, August 17, 2023, http://coloradosun.com/2023/08/17/xcel-bills-colorado-coal-plant-closure.
135. Logan Smith, "Xcel Plans to Replace Colorado Power Plant in Pueblo with Renewable Energy Battery System," CBS News Colorado, September 25, 2023, https://www.cbsnews.com/colorado/news/xcel-colorado-pueblo-power-plant-renewable-energy-storage-ldes.
136. Kelly Poe, "US Steel Closing Blast Furnace at Fairfield Permanently," AL.com, August 17, 2015, https://www.al.com/business/2015/08/us_steel_closing_blast_furnace.html.
137. "US Steel Postpones Construction of Alabama Furnace," AL.com, December 22, 2015, https://www.al.com/news/2015/12/us_steel_postpones_constructio.html.
138. Jeffrey Bonior, "How Section 232 Trade Action Brought Alabama's Fairfield Works Back to Life," *Alliance for American Manufacturing* (blog), October 15, 2021, https://www.americanmanufacturing.org/blog/how-section-232-trade-action-brought-alabamas-fairfield-works-back-to-life.
139. Jeffrey Bonior, "There's Reason to Celebrate in Fairfield, Alabama," *Alliance for American Manufacturing* (blog), October 28, 2020, https://www.americanmanufacturing.org/blog/theres-reason-to-celebrate-in-fairfield-alabama.
140. Hannah Denham, "An Alabama City Wants to Leave Bankruptcy, Even as It Owes Millions," AL.com, September 24, 2023, https://www.al.com/news/2023/09/an-alabama-city-wants-to-leave-bankruptcy-even-as-it-owes-millions.html.
141. Bonior, "Section 232 Trade Action."
142. Bonior, "Reason to Celebrate."
143. Bonior, "Section 232 Trade Action."
144. Stanley Reed, "Britain's Largest Steel Mill to Become Greener, at a Cost of Jobs," *New York Times*, January 19, 2024, https://www.nytimes.com/2024/01/19/business/tata-steel-britain-job-cuts.html.
145. Denham, "Alabama City."
146. Moore, Karplus, and Morgan, "Expert Elicitation."
147. Jeffrey Bonior, "The Next Generation of Factory Workers Prepare to Take the Helm," *Alliance for American Manufacturing* (blog), June 5, 2018, https://www.americanmanufacturing.org/blog/the-next-generation-of-factory-workers-prepare-to-take-the-helm.
148. "Cassidy, Baldwin Introduce Bill to Stop China from Taking Advantage of Lax U.S. Trade Laws," Bill Cassidy, M.D., U.S. Senator for Louisiana, June 14, 2023, https://www.cassidy.senate.gov/news/press-releases/cassidy-baldwin-introduce-bill-to-stop-china-from-taking-advantage-of-lax-us-trade-laws/.
149. Lynn Williams, *One Day Longer: A Memoir* (Toronto, ON: University of Toronto Press, 2011), 226–40.
150. Joseph E. Stiglitz, Justin Yifu Lin, and Célestin Monga, *The Rejuvenation of Industrial Policy*, Policy Research Working Papers (Washington, D.C.: The World Bank, 2013), https://doi.org/10.1596/1813-9450-6628.

151. Paul F. Clark, Peter Gottlieb, and Donald Kennedy, eds., *Forging a Union of Steel: Philip Murray, SWOC, and the United Steelworkers* (Ithaca, NY: ILR Press, 1987), 97–102.
152. "Challenges to Industrial Unionism—Steel, Aluminum and Tire in the Global Economy" (presentation), United Steelworkers of America, Minneapolis, MN, January 27, 2004.
153. Barry T. Hirsch, David A. Macpherson, and William E. Even, "Union Membership, Coverage, Density and Employment by Industry: 2022," Unionstats.com, 2024, https://unionstats.com/ind/htm/ind_2022.htm; "Challenges to Industrial Unionism," United Steelworkers of America.
154. "Challenges to Industrial Unionism," United Steelworkers of America.
155. *2023 AIST Electric Arc Furnace Roundup* (Association for Iron & Steel Technology, 2023).
156. John P. Hoerr, *And the Wolf Finally Came: The Decline of the American Steel Industry, Pittsburgh Series in Social and Labor History* (Pittsburgh, PA: University of Pittsburgh Press, 1988), 94.
157. Grant McConnell, *Steel and the Presidency*, 1962 (New York: W.W. Norton, 1963), 55–57; McConnell, Steel, 55–57; "American Steel Industry Statement on the Revitalization Program," American Presidency Project, September 30, 1980, https://www.presidency.ucsb.edu/documents/american-steel-industry-statement-the-revitalization-program.
158. Stuart Auerbach, "Reagan Plans Steel Industry Advisory Panel," *Washington Post*, August 5, 1983, https://www.washingtonpost.com/archive/business/1983/08/05/reagan-plans-steel-industry-advisory-panel/be986196-da07-4999-8b61-056131ccd005/.
159. McConnell, *Steel and the Presidency*, 1962, 28–29.
160. Hoerr, *And the Wolf Finally Came*, 99–100.
161. Hoerr, *And the Wolf Finally Came*, 99–100.
162. Hoerr, *And the Wolf Finally Came*, 105.
163. Salman Ahmed et al., *U.S. Foreign Policy for the Middle Class: Perspectives from Ohio* (John Glenn College of Public Affairs at the Ohio State University and Carnegie Endowment for International Peace, 2018), https://carnegieendowment.org/files/USForeignPolicy_Ohio_final.pdf.
164. Amanda K. Woodrum, *The Roosevelt Project: Industrial Heartland Electric Vehicle Case Study Working Paper Series: Reimagine Manufacturing in the Heartland* (MIT Center for Energy and Environmental Policy Research, November 2021), https://ceepr.mit.edu/wp-content/uploads/2022/03/2021-RP-IH-5.pdf.
165. "American Steel Industry Statement."
166. "American Steel Industry Statement."
167. Hoerr, *And the Wolf Finally Came*, 416–18.
168. *Steel Statistical Yearbook 1989* (Brussels: International Iron and Steel Institute, 1989), https://worldsteel.org/wp-content/uploads/Steel-Statistical-Yearbook-1989.pdf.
169. The Minimill Sector & North Star Steel: Future Directions (New York: Locker Associates, USW, 1992), notes 158–60.
170. *The Minimill Sector & North Star Steel*.
171. *The Minimill Sector & North Star Steel*.
172. Hoerr, *And the Wolf Finally Came*, 111–14.
173. *Steel Statistical Yearbook 1981* (Brussels: International Iron and Steel Institute, 1981), https://worldsteel.org/wp-content/uploads/Steel-Statistical-Yearbook-1981.pdf.
174. Noel Tichy and Ram Charan, "Speed, Simplicity, Self-Confidence: An Interview with Jack Welch," *Harvard Business Review*, September 1, 1989, https://hbr.org/1989/09/speed-simplicity-self-confidence-an-interview-with-jack-welch.
175. Dan Swinney, "Hiding in Plain Sight: How Manufacturing Can Save Chicago," *Manufacturing Renaissance* (blog), 2020, https://mfgren.org/hiding-in-plain-sight-how-manufacturing-can-save-chicago.
176. Agis Salpukas, "National Steel to Acquire United Financial Corp.," *New York Times*, March 7, 1979, https://www.nytimes.com/1979/03/07/archives/national-steel-to-acquire-united-financial-corp-acquisition-by.html.
177. Williams, *One Day Longer*, 258–60.
178. Terence P. Stewart et al., *Surging Steel Imports Put up to Half a Million U.S. Jobs at Risk* (Economic Policy Institute and Stewart and Stewart, May 13, 2014), https://files.epi.org/2014/Surging-Steel-Imports-05-13-2014.pdf.

179. *The Crisis in American Steel* (United Steelworkers of America, January 23, 2001).
180. *The Crisis in American Steel*.
181. *The Crisis in American Steel*.
182. *Steel Statistical Yearbook 1981*.
183. *Steel Statistical Yearbook 2001* (Brussels: International Iron and Steel Institute, 2001), https://worldsteel.org/wp-content/uploads/Steel-Statistical-Yearbook-2001.pdf.
184. Stephen Cooney, *The American Steel Industry: A Changing Profile* (Congressional Research Service, November 10, 2003), https://www.everycrsreport.com/files/20031110_RL31748_d1c2f25f8d34b8191b3d873c8a53698e9ff6365f.pdf; Report to the President.
185. *Report to the President*.
186. *OECD Steel Outlook 1999/2000* (Organisation for Economic Co-operation and Development, 1999), https://doi.org/10.1787/steel_outlook-1999-en.
187. David Foster, Sade Nabahe, and Benny Siu Hon Ng, *Energy Workforce Development in the 21st Century* (MIT Center for Energy and Environmental Policy Research, September 2020), https://ceepr.mit.edu/wp-content/uploads/2021/09/The-Roosevelt-Project-WP-7.pdf.
188. Aaron Steelman, "Full Employment and Balanced Growth Act of 1978 (Humphrey-Hawkins)," Federal Reserve History, November 22, 2013, https://www.federalreservehistory.org/essays/humphrey-hawkins-act.
189. Foster, Nabahe, and Ng, "Energy Workforce Development."
190. Katherine Baicker and M. Marit Rehavi, "Policy Watch: Trade Adjustment Assistance," *Journal of Economic Perspectives* 18, no. 2 (May 1, 2004): 239–56, https://doi.org/10.1257/0895330041371196.
191. Joanne Guth and Jean Lee, "A Brief History of the U.S. Trade Adjustment Assistance Program for Workers," U.S. International Trade Commission, January 2017, https://www.usitc.gov/publications/332/executive_briefings/ebot_historyoftaaguthlee_corrected.pdf.
192. Andres B. Schwarzenberg, *Industrial Policy and International Trade* (Congressional Research Service, February 14, 2024), https://crsreports.congress.gov/product/pdf/IF/IF12119.
193. Stiglitz, Lin, and Monga, *Rejuvenation of Industrial Policy*.
194. Schwarzenberg, *Industrial Policy and International Trade*.
195. Shayerah I. Akhtar, Cathleen D. Cimino-Isaacs, and Karen M. Sutter, U.S. Trade Policy: Background and Current Issues (Congressional Research Service, January 30, 2023), https://crsreports.congress.gov/product/pdf/IF/IF10156.
196. Schwarzenberg, *Industrial Policy and International Trade*.
197. Richard K. Lattanzio et al., *U.S. Climate Change Policy* (Congressional Research Service, October 28, 2021), https://crsreports.congress.gov/product/pdf/R/R46947.
198. Jonathan L. Ramseur, Brandon J. Murrill, and Christopher A. Casey, *Border Carbon Adjustments: Background and Developments in the European Union* (Congressional Research Service, February 21, 2023), https://crsreports.congress.gov/product/pdf/R/R47167.
199. Rigorous evidence of so-called carbon leakage is still limited, in part due to the limited settings in which to observe it. Several studies of the EU Emissions Trading System (ETS) suggest that the imposition of the cap-and-trade system in 2005 (discussed in further detail below) has had a negligible impact on competitiveness in EITE industries in the EU. This is explained in part by (1) generous free emissions allocations given to EU producers, (2) relatively modest carbon prices, (3) the relatively low ratio of energy cost to overall production cost in most covered industries, and (4) the ability of producers to pass costs on to consumers.
200. Ali Hasanbeigi, *Steel Climate Impact: An International Benchmarking of Energy and CO2 Intensities* (Florida: Global Efficiency Intelligence, April 2022), https://www.globalefficiencyintel.com/steel-climate-impact-international-benchmarking-energy-co2-intensities.
201. David Barboza, "Bridge Comes to San Francisco, with Made-in-China Label," *New York Times*, June 25, 2011, https://www.nytimes.com/2011/06/26/business/global/26bridge.html.

202. Elizabeth Daigneau, "A First among States, California Plugs the 'Carbon Loophole,'" Governing, November 28, 2017, https://www.governing.com/archive/gov-california-targeting-supply-chain-emission.html.
203. Christopher A. Casey and Liana Wong, T*rade Remedies: Countervailing Duties* (Congressional Research Service, August 23, 2021), https://crsreports.congress.gov/product/pdf/R/R46882.
204. Christopher A. Casey, *Trade Remedies: Antidumping and Countervailing Duties* (Congressional Research Service, February 28, 2023), https://crsreports.congress.gov/product/pdf/IF/IF10018.
205. Casey and Wong, *Trade Remedies: Countervailing Duties*.
206. Rachel F. Fefer, *Section 232 of the Trade Expansion Act of 1962* (Congressional Research Service, April 1, 2022), https://crsreports.congress.gov/product/pdf/IF/IF10667.
207. Casey and Wong, *Trade Remedies: Countervailing Duties*.
208. Stephen Cooney, *Steel: Legislative and Oversight Issues* (Congressional Research Service, July 30, 2003), https://digital.library.unt.edu/ark:/67531/metacrs3884/m2/1/high_res_d/RL31792_2003Jul30.pdf.
209. Tudor N. Rus, "The Short, Unhappy Life of the Byrd Amendment," *Legislation and Public Policy* 10 (2007): 427–43.
210. David E. Bond et al., "United States Expands and Strengthens Enforcement of Antidumping and Countervailing Duty Laws," White & Case LLP, April 16, 2024, https://www.whitecase.com/insight-alert/united-states-expands-and-strengthens-enforcement-antidumping-and-countervailing-duty; "U.S. Department of Commerce Updates Trade Enforcement Regulations to Level the Playing Field for U.S. Producers and Workers," US International Trade Association, March 22, 2024, https://www.trade.gov/press-release/us-department-commerce-updates-trade-enforcement-regulations-level-playing-field-us.
211. *Economic Impact of Section 232 and 301 Tariffs*.
212. *232 Exclusion Process Frequently Asked Questions (FAQs)*, U.S. Department of Commerce, June 19, 2019, https://www.bis.doc.gov/index.php/documents/section-232-investigations/2409-section-232-faq/file.
213. "Published Exclusion Requests: Section 232 Steel and Aluminum," U.S. Department of Commerce, January 31, 2024, https://232app.azurewebsites.net/steelalum.
214. "Active Section 232 Product Exclusions in ACE—Effective January 18, 2024," U.S. Customs and Border Protection, January 18, 2024, https://www.cbp.gov/document/publications/active-section-232-product-exclusions-ace.
215. *Economic Impact of Section 232 and 301 Tariffs*.
216. *CBP Trade and Travel Report: Fiscal Year 2018* (U.S. Customs and Border Protection, July 2019), https://www.cbp.gov/sites/default/files/assets/documents/2019-Jul/CBP%20FY18%20Trade%20and%20Travel%20Report-compliant.pdf; *CBP Trade and Travel Report: Fiscal Year 2019* (U.S. Customs and Border Protection, January 2020), https://www.cbp.gov/sites/default/files/assets/documents/2020-Jan/CBP%20FY2019%20Trade%20and%20Travel%20Report.pdf; *CBP Trade and Travel Report: Fiscal Year 2020* (U.S. Customs and Border Protection, February 2021), https://www.cbp.gov/sites/default/files/assets/documents/2021-Feb/CBP-FY2020-Trade-and-Travel-Report.pdf; *CBP Trade and Travel Report: Fiscal Year 2021* (U.S. Customs and Border Protection, April 2022), https://www.cbp.gov/sites/default/files/assets/documents/2022-Apr/FINAL%20FY2021_%20Trade%20and%20Travel%20Report%20%28508%20Compliant%29%20%28April%202022%29_0.pdf; *CBP Trade and Travel Report: Fiscal Year 2022* (U.S. Customs and Border Protection, June 1, 2023), https://www.cbp.gov/sites/default/files/assets/documents/2023-Jun/fy-2022-cbp-trade-and-travel-report.pdf.
217. "U.S. Steel Import Monitor."
218. "World Steel in Figures 2023"; Hasanbeigi, *Steel Climate Impact*.
219. *Economic Impact of Section 232 and 301 Tariffs*.
220. "U.S. Steel Import Monitor"; "World Steel in Figures 2023"; Hasanbeigi, *Steel Climate Impact*.

221. Emissions intensity includes Scope 1, Scope 2, and limited upstream Scope 3 (coke, pig iron, and DRI production) emissions. See Hasanbeigi, *Steel Climate Impact* for detailed methodology.
222. Jim Monke, *Farm and Food Support Under USDA's Section 32 Account* (Congressional Research Service, September 5, 2023), https://crsreports.congress.gov/product/pdf/IF/IF12193.
223. Geoffrey S. Becker, *Farm and Food Support Under USDA's Section 32 Program* (Congressional Research Service, November 28, 2006), https://nationalaglawcenter.org/wp-content/uploads/assets/crs/RS20235.pdf.
224. "Baldwin, Cassidy Introduce Bipartisan Bill to Support Communities Hurt by Chinese Trade Cheating," Tammy Baldwin, United States Senator for Wisconsin, December 6, 2023, https://www.baldwin.senate.gov/news/press-releases/baldwin-cassidy-introduce-bipartisan-bill-to-support-communities-hurt-by-chinese-trade-cheating.
225. "S.3425—Resilient Communities Act of 2023," Congress.gov, December 6, 2023, https://www.congress.gov/bill/118th-congress/senate-bill/3425/text.
226. Timothy C. Brightbill et al., "Leveling the Playing Field 2.0 Act Introduced to Update and Strengthen U.S. Trade Remedy Laws," Wiley Law, June 7, 2023, https://www.wiley.law/alert-Leveling-the-Playing-Field-2-0-Act-Introduced-to-Update-and-Strengthen-US-Trade-Remedy-Laws.
227. "Reps. Sewell, Johnson Introduce Bipartisan Legislation to Level the Playing Field for American Workers," U.S. Congresswoman Terri Sewell, June 7, 2023, https://sewell.house.gov/2023/6/reps-sewell-johnson-introduce-bipartisan-legislation-to-level-the-playing-field-for-american-workers.
228. Ramseur, Murrill, and Casey, *Border Carbon Adjustments*.
229. Raymond Kopp, William Pizer, and Kevin Rennert, "Carbon Border Adjustments: Design Elements, Options, and Policy Decisions," Resources for the Future, October 2023, https://www.rff.org/publications/reports/carbon-border-adjustments-design-elements-options-and-policy-decisions.
230. Milan Elkerbout, Ray Kopp, and Kevin Rennert, "Comparing the European Union Carbon Border Adjustment Mechanism, the Clean Competition Act, and the Foreign Pollution Fee Act," Resources for the Future, December 2023, https://www.rff.org/publications/reports/comparing-the-european-union-carbon-border-adjustment-mechanism-the-clean-competition-act-and-the-foreign-pollution-fee-act/.
231. "Carbon Border Adjustment Mechanism," European Commission Taxation and Customs Union, accessed September 25, 2023, https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.
232. European Parliament and Council of the European Union, "Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 Establishing a Carbon Border Adjustment Mechanism," in *Fundamental Texts on European Private Law*, edited by Oliver Radley-Gardner, Hugh Beale, and Reinhard Zimmermann, Pub. L. No. 32023R0956 (2023), https://eur-lex.europa.eu/eli/reg/2023/956/oj.
233. Emily Benson et al., "Analyzing the European Union's Carbon Border Adjustment Mechanism," Center for Strategic and International Studies, February 17, 2023, https://www.csis.org/analysis/analyzing-european-unions-carbon-border-adjustment-mechanism.
234. European Commission Taxation and Customs Union, "Carbon Border Adjustment Mechanism."
235. "Impact Assessment Report: Accompanying the Document Proposal for a Regulation of the European Parliament and of the Council Establishing a Carbon Border Adjustment Mechanism" (Brussels: European Commission, July 14, 2021), https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021SC0643.
236. Benson et al., "Analyzing the European Union's Carbon Border Adjustment Mechanism."
237. "H.R.2454: American Clean Energy and Security Act of 2009," Congress.gov, July 7, 2009, https://www.congress.gov/bill/111th-congress/house-bill/2454.
238. ZhongXiang Zhang, "The U.S. Proposed Carbon Tariffs, WTO Scrutiny and China's Responses," *International Economics and Economic Policy* 7, no. 2–3 (August 2010): 203–25, https://doi.org/10.1007/s10368-010-0166-8.

239. “H.R.2454: American Clean Energy and Security Act of 2009.”
240. Milan Elkerbout, Raymond Kopp, and Kevin Rennert, “Foreign Pollution Fee Act: Design Elements, Options, and Policy Decisions,” Issue Brief, Resources for the Future, November 2023, https://www.rff.org/publications/issue-briefs/foreign-pollution-fee-act-design-elements-options-and-policy-decisions.
241. “S.1863: PROVE IT Act of 2023,” Congress.gov, June 7, 2023, https://www.congress.gov/bill/118th-congress/senate-bill/1863/text.
242. “Legislation to Impose ‘Border Carbon Adjustment’ Fee on Imported Steel and Other ‘Carbon-Intensive’ Goods Introduced in US Congress,” White & Case, July 26, 2021, https://www.whitecase.com/insight-alert/legislation-impose-border-carbon-adjustment-fee-imported-steel-and-other-carbon.
243. “H.R.4534: FAIR Transition and Competition Act,” Congress.gov, July 20, 2021, https://www.congress.gov/bill/117th-congress/house-bill/4534/text.
244. “S.3198: Foreign Pollution Fee Act of 2023,” Congress.gov, November 2, 2023, https://www.congress.gov/bill/118th-congress/senate-bill/3198/text.
245. William Alan Reinsch and Thibault Denamiel, “Insights into the Foreign Pollution Fee Act,” Center for Strategic and International Studies, November 13, 2023, https://www.csis.org/analysis/insights-foreign-pollution-fee-act.
246. “ICYMI: Cassidy Previews Foreign Pollution Fee in Foreign Affairs,” Bill Cassidy, M.D., U.S. Senator for Louisiana, October 23, 2023, https://www.cassidy.senate.gov/news/press-releases/icymi-cassidy-previews-foreign-pollution-fee-in-foreign-affairs.
247. “What They Are Saying: Support Grows for the Foreign Pollution Fee,” Bill Cassidy, M.D., U.S. Senator for Louisiana, November 14, 2023, https://www.cassidy.senate.gov/newsroom/press-releases/what-they-are-saying-support-grows-for-the-foreign-pollution-fee.
248. “Whitehouse and DelBene Reintroduce Carbon Border Adjustment Bill to Boost Domestic Manufacturers and Tackle Climate Change,” Sheldon Whitehouse, U.S. Senator for Rhode Island, December 6, 2023, https://www.whitehouse.senate.gov/news/release/whitehouse-and-delbene-reintroduce-carbon-border-adjustment-bill-to-boost-domestic-manufacturers-and-tackle-climate-change.
249. “S.3422: Clean Competition Act,” Congress.gov, December 6, 2023, https://www.congress.gov/bill/118th-congress/senate-bill/3422/text.
250. Kopp, Pizer, and Rennert, “Carbon Border Adjustments.”
251. Elkerbout, Kopp, and Rennert, “Foreign Pollution Fee Act.”
252. “DelBene, Whitehouse Introduce Bill to Boost Domestic Manufacturers, Tackle Climate Change,” U.S. Congresswoman Suzan DelBene, December 6, 2023, https://delbene.house.gov/news/documentsingle.aspx?DocumentID=3711.
253. Lisa Harrison, “AISI Comments on ‘Clean Competition Act’ Introduced Today,” American Iron and Steel Institute, December 6, 2023, https://www.steel.org/2023/12/aisi-comments-on-clean-competition-act-introduced-today.
254. Kopp, Pizer, and Rennert, “Carbon Border Adjustments.”
255. Janet Ranganathan et al., *The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard* (World Resources Institute, World Business Council for Sustainable Development, 2004), https://ghgprotocol.org/corporate-standard.
256. *Technical Note: Trade and Carbon Accounting for Traded Goods, Net Zero Trade Policy* (Silverado Policy Accelerator, December 4, 2023), https://silverado.org/news/technical-note-carbon-accounting-for-traded-goods.
257. *Emissions Measurement and Data Collection for a Net Zero Steel Industry* (International Energy Agency, April 12, 2023), https://iea.blob.core.windows.net/assets/8f6568aa-1dd8-4578-bc61-24ceba4a07dd/EmissionsMeasurementandDataCollectionforaNetZeroSteelIndustry.pdf; Wendy Merz and Christi M. Wilson, *The Steel Climate Standard: Framework for Steel Product Certification and Corporate Science-Based Emissions Targets* (Global Steel Climate Council, August 2023), http://globalsteelclimatecouncil.org/wp-content/uploads/2023/08/GSCC-Standard-August2023.pdf.
258. *Emissions Measurement and Data Collection for a Net Zero Steel Industry*; Merz and Wilson, *The Steel Climate Standard*.

259. *Technical Note: Trade and Carbon Accounting for Traded Goods*.
260. "Fact Sheet: Greenhouse Gas Reporting Program (GHGRP) Implementation," U.S. Environmental Protection Agency, July 2023, https://www.epa.gov/system/files/documents/2023-08/ghgrp-overview-fact-sheet.pdf.
261. *Technical Note: Trade and Carbon Accounting for Traded Goods*.
262. Reinsch and Denamiel, "Insights into the Foreign Pollution Fee Act."
263. Alessia Campolmi et al., "Designing Effective Carbon Border Adjustment with Minimal Information Requirements. Theory and Empirics," *SSRN Electronic Journal*, November 24, 2023, https://doi.org/10.2139/ssrn.4644941.
264. Campolmi et al., "Designing Effective Carbon Border Adjustment."
265. "Guidance Document on CBAM Implementation for Installation Operators Outside the EU," European Commission Taxation and Customs Union, August 17, 2023, https://taxation-customs.ec.europa.eu/document/download/2980287c-dca2-4a4b-aff3-db6374806cf7_en?filename=Guidance%20document%20on%20CBAM%20implementation%20for%20installation%20operators%20outside%20the%20EU.pdf
266. Sebastian Klotz and Oliver Hulliger, "EU Deal Reached on the CBAM: What You Need to Know," PwC, April 10, 2023, https://www.pwc.ch/en/insights/tax/eu-deal-reached-on-the-cbam.html.
267. "Guidance Document on CBAM Implementation," 55.
268. Campolmi et al., "Designing Effective Carbon Border Adjustment."
269. "Fact Sheet: Greenhouse Gas Reporting Program (GHGRP) Implementation."
270. Lisa R. Barton, "Greenhouse Gas Emissions Intensities of the U.S. Steel and Aluminum Industries at the Product Level," U.S. International Trade Commission, July 5, 2023, https://www.usitc.gov/secretary/fed_reg_notices/332/332_598_notice_07052023sgl_0.pdf.
271. Campolmi et al., "Designing Effective Carbon Border Adjustment."
272. Campolmi et al., "Designing Effective Carbon Border Adjustment."
273. Campolmi et al., "Designing Effective Carbon Border Adjustment."
274. Stephen C. Tosini, "Trade Remedies and Climate Change: How the United States Can Use Its Buying Power and Trade Laws to Encourage Clean Energy," *Vanderbilt Journal of Transnational Law 56*, no. 4 (2023): 1005–24, https://www.cit.uscourts.gov/sites/cit/files/Trade%20Remedies%20and%20Climate%20Change.pdf.
275. Elkerbout, Kopp, and Rennert, "Foreign Pollution Fee Act."
276. Emily Benson, Andrea L. Palazzi, and William A. Reinsch, "The U.S.-EU Trade and Technology Council: Assessments and Recommendations," Center for Strategic & International Studies, November 2022, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/221116_Benson_TTC_Recommendations.pdf.
277. Alberto Nardelli, Eric Martin, and Jorge Valero, "US, EU Seek to Extend Steel Truce Amid Stalemate on Longer Fix," Bloomberg, November 16, 2023, https://www.bloomberg.com/news/articles/2023-11-16/us-eu-seek-to-extend-steel-truce-amid-stalemate-on-longer-fix.
278. Alberto Nardelli, "EU Considers Restarting WTO Case Against US Over Steel Tariffs," Bloomberg, December 8, 2023, https://www.bloomberg.com/news/articles/2023-12-08/eu-may-restart-wto-case-against-us-over-steel-tariffs.
279. Jorge Valero and Joe Deaux, "EU and US Pause Steel Tariff War Until After Elections," Bloomberg, December 19, 2023, https://www.bloomberg.com/news/articles/2023-12-19/eu-and-us-pause-steel-tariff-war-until-after-elections.
280. "S.3198: Foreign Pollution Fee Act of 2023."
281. Elkerbout, Kopp, and Rennert, "Foreign Pollution Fee Act."
282. Benson et al., "Analyzing the European Union's Carbon Border Adjustment Mechanism."
283. Zhang, "U.S. Proposed Carbon Tariffs, WTO Scrutiny and China's Responses."
284. Zhang, "U.S. Proposed Carbon Tariffs, WTO Scrutiny and China's Responses."
285. Benson et al., "Analyzing the European Union's Carbon Border Adjustment Mechanism."
286. Elkerbout, Kopp, and Rennert, "Foreign Pollution Fee Act."
287. M. Angeles Villarreal, *U.S.-Mexico Trade Relations* (Congressional Research Service, September 1, 2023), https://crsreports.congress.gov/product/pdf/IF/IF11175.

288. "USMCA Chapter 24: Environment," July 1, 2020, https://ustr.gov/sites/default/files/files/agreements/usmca/24_Environment.pdf.
289. Campolmi et al., "Designing Effective Carbon Border Adjustment."
290. Meredith Fowlie, Mar Reguant, and Stephen P. Ryan, *Market-Based Emissions Regulation and Industry Dynamics* (MIT Center for Energy and Environmental Policy Research, January 15, 2013), https://ceepr.mit.edu/wp-content/uploads/2021/11/2013-004.pdf.
291. Campolmi et al., "Designing Effective Carbon Border Adjustment."
292. Fowlie, Reguant, and Ryan, "Market-Based Emissions Regulation and Industry Dynamics."
293. "Carbon Border Adjustment Mechanism," European Commission Taxation and Customs Union.
294. Lattanzio et al., *U.S. Climate Change Policy*.
295. Jonathan L. Ramseur, *Market-Based Greenhouse Gas Emission Reduction Legislation: 108th through 117th Congresses* (Congressional Research Service, July 18, 2022), https://crsreports.congress.gov/product/pdf/R/R45472/24.
296. Delasalle et al., *Making Net-Zero Steel Possible*.
297. Chathurika Gamage et al., "US Businesses Need Low-Emissions Steel, and It's Time for US Steelmakers to Get It to Them," RMI, July 14, 2023, https://rmi.org/us-businesses-need-low-emissions-steel-and-its-time-for-us-steelmakers-to-get-it-to-them.
298. "Federal Buy Clean Initiative," Office of the Federal Chief Sustainability Officer, 2023, https://www.sustainability.gov/buyclean.
299. Andrew Chase, "Advocating for Building Materials with Low Embodied Carbon," U.S. Green Building Council, August 7, 2023, https://www.usgbc.org/articles/advocating-building-materials-low-embodied-carbon.
300. "Federal Buy Clean Initiative."
301. "Major Corporations Come Together to Advance the First Commercial Batch of Sustainable Steel in the US," RMI, September 20, 2023, https://rmi.org/press-release/major-corporations-come-together-to-advance-the-first-commercial-batch-of-sustainable-steel-in-the-us.
302. Alesha Alkaff, "Green Steel: RMI Unveils New Procurement Platform to Facilitate 2 Million Ton Green Steel Order," Fastmarkets, September 21, 2023, https://www.fastmarkets.com/insights/rmi-new-procurement-platform-green-steel.
303. "FMC COP 28 Impact Brief" (First Movers Coalition, November 2023), https://www3.weforum.org/docs/WEF_2023_FMC_COP28_Impact_Brief.pdf.
304. "ResponsibleSteel International Standard Version 2.0," ResponsibleSteel, September 14, 2022, https://www.responsiblesteel.org/standard.
305. "Issued and Ongoing Certifications," ResponsibleSteel, accessed February 2, 2024, https://www.responsiblesteel.org/certification/issued-certificates.
306. Emma Hughes, "How LEED v4.1 Addresses Embodied Carbon," U.S. Green Building Council, May 29, 2019, https://www.usgbc.org/articles/how-leed-v41-addresses-embodied-carbon.
307. Tracy Huynh et al., *Driving Action on Embodied Carbon in Buildings*, RMI and U.S. Green Building Council, September 2023, https://www.usgbc.org/resources/driving-action-embodied-carbon-buildings.
308. "Qualifying Advanced Energy Project Credit (§ 48C) Program Informational Applicant Webinar," https://www.energy.gov/sites/default/files/2023-12/48C%20-%20Informational%20Webinar%2011_28_2023_FINAL.pdf.
309. Hannah Sachs and David Foster, *Job Quality: The Keystone of Clean Energy Industrial Policy*, EFI Foundation, August 2023, https://efifoundation.org/wp-content/uploads/sites/3/2023/08/Report_HighQualityJobs_8-7-23.pdf.

310. "American Community Survey, 5-Year Average (2021)," n.d.
311. "Carbon Border Adjustment Mechanism," European Commission Taxation and Customs Union; European Parliament and Council of the European Union, Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 establishing a carbon border adjustment mechanism; "Guidance Document on CBAM Implementation for Installation Operators Outside the EU"; Elkerbout, Kopp, and Rennert, "Comparing the European Union Carbon Border Adjustment Mechanism, the Clean Competition Act, and the Foreign Pollution Fee Act"; Kopp, Pizer, and Rennert, "Carbon Border Adjustments: Design Elements, Options, and Policy Decisions."
312. "H.R.4534- FAIR Transition and Competition Act"; Kopp, Pizer, and Rennert, "Carbon Border Adjustments: Design Elements, Options, and Policy Decisions."
313. Elkerbout, Kopp, and Rennert, "Comparing the European Union Carbon Border Adjustment Mechanism, the Clean Competition Act, and the Foreign Pollution Fee Act"; Elkerbout, Kopp, and Rennert, "Foreign Pollution Fee Act: Design Elements, Options, and Policy Decisions"; "S.3198- Foreign Pollution Fee Act of 2023."
314. Elkerbout, Kopp, and Rennert, "Comparing the European Union Carbon Border Adjustment Mechanism, the Clean Competition Act, and the Foreign Pollution Fee Act"; Kopp, Pizer, and Rennert, "Carbon Border Adjustments: Design Elements, Options, and Policy Decisions"; "S.3422- Clean Competition Act."

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