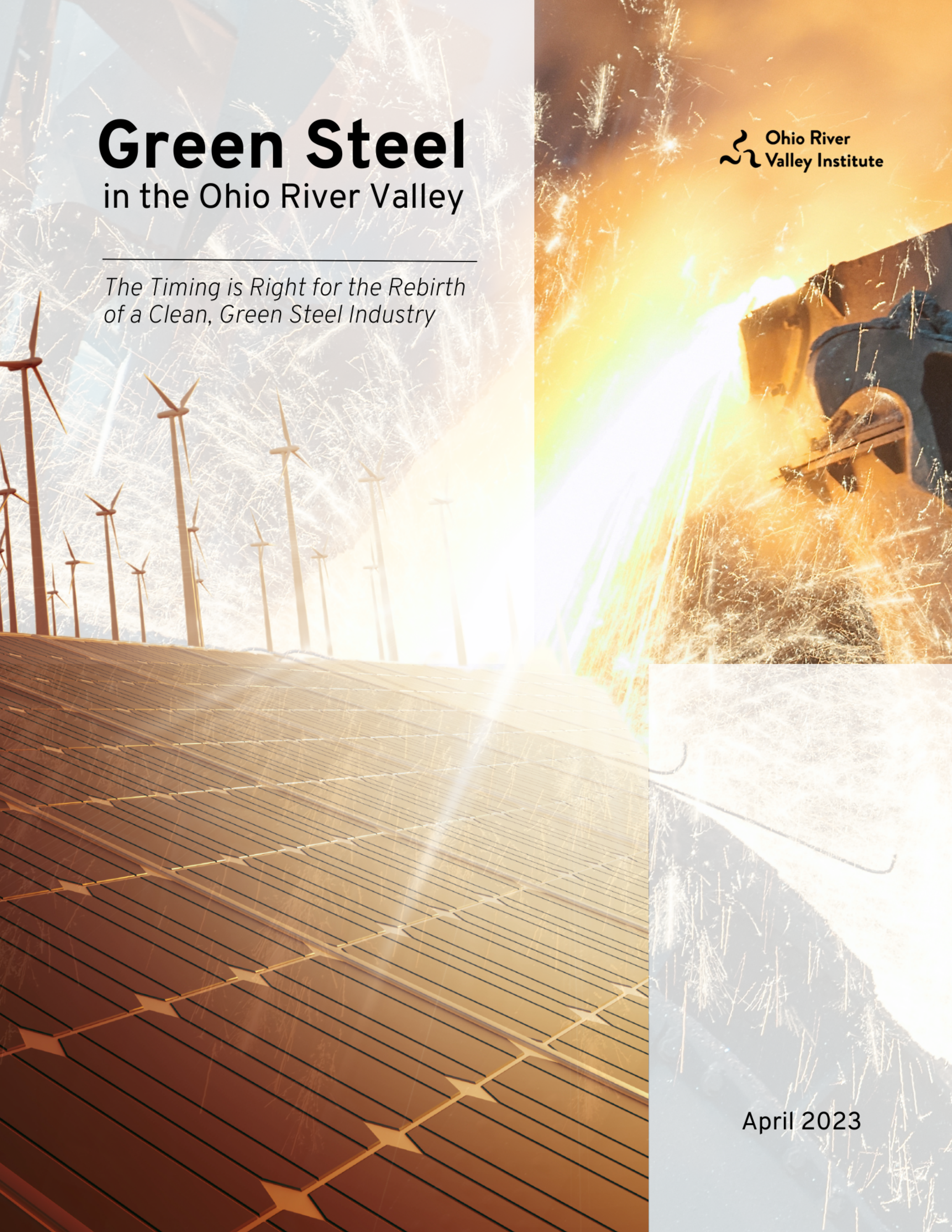

Green Steel
in the Ohio River Valley

The Timing is Right for the Rebirth of a Clean, Green Steel Industry

Ohio River Valley Institute

April 2023

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The Ohio River Valley Institute is an independent, nonprofit research and communications center founded in 2020. We equip the region's residents and decision-makers with the policy research and practical tools they need to advance long-term solutions to some of Appalachia's most significant challenges. Our work includes in-depth research, commentary, and analysis, delivered online, by email, and in-person to policy champions, emerging leaders, and a range of community partners.

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Glossary

Blast Furnace (BF)	A towering cylinder lined with heat-resistant (refractory) bricks, used by integrated steel mills to smelt iron from iron ore. Its name comes from the “blast” of hot air and gasses forced up through the iron ore, coke, and limestone that load the furnace.
Basic Oxygen Furnace (BOF)	A pear-shaped furnace, lined with refractory bricks, that refines molten iron from the blast furnace and scrap into steel. Up to 30% of the charge into the BOF can be scrap. Hot metal accounts for the rest.
Blast Furnace-Basic Oxygen Furnace (BF-BOF)	The most common production pathway for primary steel production. A major source of greenhouse gas emissions, water pollution, and soil contamination.
Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022	Legislation signed into law by President Biden on Aug. 9, 2022, investing nearly $250 billion in a combination of semiconductor and other scientific research and development (R&D).
Coke	A coal-based fuel with high carbon content and few impurities, made by heating coal or oil in the absence of air. It is an important industrial product used mainly in iron ore smelting.
Coking coal, or metallurgical (met) coal	A specific grade of hard coal with elevated carbon content.
Crude steel	The first solid steel product upon solidification of liquid steel. It also includes liquid steel, which goes into production of steel castings. Crude steel is normally processed into finished steel either by rolling or by forging processes.
Direct Reduction of Iron, or Direct Reduced Iron (DRI)	A solid state process that reduces iron ore into iron using a reducing gas in a shaft reduction (or non-coking coal in a rotary kiln). It also refers to the solid product produced from the DRI process (see sponge iron).
Direct jobs	Jobs held by employees responsible for producing a company's products or services.
Electric Arc Furnace (EAF)	A high-temperature furnace that uses high-voltage electric currents as the primary heating element.

Electrolyzer	A system that uses electricity to break water into hydrogen and oxygen in a process called electrolysis: - **Alkaline electrolyzers** use liquid electrolyte solution, such as potassium hydroxide (KOH) or sodium hydroxide (NaOH), and electric current to break water molecules into hydrogen and oxygen. - **Proton Exchange Membrane (PEM) electrolyzers** use a solid polymer electrolyte and electric current to break water into hydrogen and oxygen.
Fossil fuel-free steel	Steel manufactured without the use of fossil fuels.[1] This means no natural gas, coal, or oil is used in its production and any electricity used comes from renewable resources.
Green hydrogen	Hydrogen produced via electrolysis using renewable electricity coupled with renewably-sourced electrical energy.
"Green steel"	A general class of steelmaking technologies that provide a carbon footprint reduction. Does not imply any quantification of the actual level of greenhouse gas produced or the method of production.
Hot Briquetted Iron (HBI)	Direct reduced iron (DRI) that has been processed into briquettes. Because DRI may spontaneously combust during transportation, HBI is preferred when the metallic material must be stored or moved.
Hot metal	The molten iron produced in a blast furnace. It proceeds to the basic oxygen furnace in molten form or is cast as pig iron.
Indirect jobs	Jobs created by the suppliers of materials used in the production of a company's product(s).
Induced jobs	Jobs created in the broader economy when direct and indirect employees spend their income on goods and services.
Infrastructure Investment and Jobs Act (IIJA) of 2021	Also known as the Bipartisan Infrastructure Law (BIL). Legislation signed by President Biden on November 15, 2021, authorizing $1.2 trillion for transportation and infrastructure spending to bolster the transportation, energy, water, and utility sectors, as well as state and local governments.

[1] This is in line with the World Economic Forum and OECD definition of "green steel" as steel that is manufactured without the use of fossil fuel.
World Economic Forum, "What is green steel and why does the world need more of it?" World Economic Forum, July 11, 2022, https://www.weforum.org/agenda/2022/07/green-steel-emissions-net-zero/

Inflation Reduction Act (IRA) of 2022	Legislation enacted in August 2022 to reduce the federal deficit, lower inflation while investing in domestic energy production, create good jobs, and transform US efforts to address the climate crisis.
Local economic multiplier	Additional economic benefit to a geographic area (usually a metropolitan area, county, or region) from increased total incomes provided by new jobs.
Minimill	A relatively small-scale steel mill that uses scrap metal as starting material.
Mtpa	Million tons per annum.
Pig iron	Melted iron produced in a blast furnace that has been solidified or cast.
Primary steel, or virgin steel	Steel that uses iron ore as its main source of metallic input. Scrap typically accounts for 15-25% of the metallic input in primary production.
Secondary production	Steel production based on scrap. However, iron or direct reduced iron (DRI) is also commonly added to electric furnaces, which are the typical unit for secondary production.
Synthesis gas, or syngas	A mixture of carbon monoxide, carbon dioxide, and hydrogen. Syngas is produced by gasification of a carbon-containing fuel to a gaseous product that has some heating value. Examples of syngas production include gasification of coal emissions, waste emissions to energy gasification, and steam reforming of coke.
Sponge iron (SI)	Direct Reduced Iron (DRI) is also known as sponge iron because of its spongy micro structure.
"Zero-emission steel," or "near zero-emission steel"	While not officially defined, a term used throughout this paper to distinguish those technologies that have the potential to deliver full decarbonization.

Executive Summary

As the world moves to decarbonize emissions from hard-to-abate industrial processes, steel production must play a prominent role. For generations, the steel industry has shaped the economy and culture of the Ohio River Valley; now, fossil fuel-free steel produced with green hydrogen-based direct reduction offers the region a unique opportunity to reshape the local economy and become a global leader once again.

A transition to hydrogen-based Direct Reduced Iron-Electric Arc Furnace (DRI-EAF) steel production offers the potential for jobs and future economic growth with the lowest technical, social, and environmental risk. This report estimates that, given current downward trends due to automation, outsourcing, and offshoring, total jobs supported by steelmaking in the Ohio River Valley stand to fall by roughly 30% by 2031 if business as usual continues. An investment in fossil fuel-free hydrogen production using wind and solar infrastructure built in the region to support DRI-EAF could instead *increase* total jobs in the region by roughly 27% to 43%.[2] These jobs would largely be tied to the geography, making them more resilient to interstate and global competition. Further, a large-scale buildout of industrial renewable energy infrastructure is likely to generate significant first-mover advantages for the region as other industries face pressure to decarbonize their production processes and supply chains.

The steel industry has a far-reaching global and domestic impact and is a vital foundation for the nation's economy, security, infrastructure, and energy needs. Although steel demand is strongly influenced by global economics and geopolitics, most steel industry forecasts predict long-term global demand will remain steady or grow modestly, between 1% and 2% per year through 2035.. According to the International Energy Agency (IEA), emissions from steel must be reduced by 50% by 2050 and then continue to fall in order to meet the world's climate goals. Customer demand for "green" steel, regulatory pressure, and growth in sustainable investments have resulted in an array of announcements by steel producers of plans, goals, or at least mentions of a move towards low-emission or near-zero emission steel.

While steel produced from scrap metal in an EAF is one path to steel decarbonization, issues related to quality and scrap supply will continue to drive a need for primary steel, or steel made from iron ore. Primary steel production is expected to remain constant as a percentage of total US steel production through 2040.

The blast furnace ironmaking process accounts for approximately 70% of the greenhouse gas emissions from the integrated steelmaking process. In the Direct Reduction of Iron (DRI) process, hydrogen serves as a carbon-free source of fuel as well as the reducing agent, producing only water vapor instead of carbon dioxide (CO_2). When hydrogen is produced from renewable sources via electrolysis of water (green hydrogen) and the electricity required for the EAF process to produce crude steel is also derived from renewable sources, this fossil

[2]This includes both direct, indirect and induced jobs. This report applies two different types of local economic multipliers to estimate the indirect and induced jobs that fossil fuel-free steel could support. A uniform local economic multiplier of 1.5 is applied, following literature using econometric methods applied to observed data. The authors view this empirical multiplier as the most realistic scenario. A second set of larger local economic multipliers, taken from leading industry and policy reports and typically generated by input-output models, are also applied. These multipliers tend to be inflated because they rely on modeling assumptions that ignore cost feedbacks into the markets for land, labor, and other inputs which raise prices and wages and crowd out other non-steel economic activity.

fuel-free steel has the potential for near-zero emissions.

The steel industry remains a significant employer in the US. However, total employment in the industry today is significantly lower than its peak of roughly 700,000 jobs in the late 1970s and about half of total employment in 1990. Moreover, US steel manufacturers continue to cut jobs, shedding 12,500 jobs between 2015 and 2020. In Pennsylvania, iron and steel mills and ferroalloy manufacturing supported about 9,600 direct jobs as of 2021—down nearly 28% from 2011.

This report uses Mon Valley Works, an integrated steel manufacturing operation located in southwestern Pennsylvania, as a model for envisioning what transition to fossil fuel-free steelmaking can bring to the state and its people. The report presents a high-level analysis of the job implications of this transition and compares the potential benefits to the likely outcomes by 2031 if business as usual continues under decades-long declining steel employment trends. It is estimated that business as usual will result in the further loss of 328 direct jobs and 491 to 2,735 additional indirect and induced jobs within the economy. Conversely, under the proposed fossil fuel free-transition scenario, the Ohio River Valley could gain 458 direct jobs along with 687 to 2,212 additional indirect and induced jobs within the economy.

To estimate the broader economic impact of the transition scenario on the region, this report applies two different types of local economic multipliers to estimate the indirect and induced jobs that fossil fuel-free steel could support. A uniform local economic multiplier of 1.5 is applied, following literature using econometric methods applied to observed data. This conservative multiplier is viewed by the authors as the most realistic scenario. A second set of larger local economic multipliers are applied, which are taken from leading industry and policy reports. This second class of multipliers is typically generated by input-output models. Typically, these multipliers are inflated because they rely on modeling assumptions that ignore cost feedbacks into the markets for land, labor and other inputs which raise prices and wages and crowd out other non-steel economic activity.

Recent federal legislation, including the Bipartisan Infrastructure Investment and Jobs Act (IIJA) of 2021, the CHIPS and Science Act of 2022, and the Inflation Reduction Act (IRA) of 2022, could lend major support to domestic green steel production. The country's largest steel producers have touted this legislation, suggesting it will boost domestic production. Specific green hydrogen incentives are projected to significantly lower hydrogen production and spur regional production centers. With federal and state incentives enabling a significant first-mover advantage, Pennsylvania's steel industry has the potential to become a global leader in fossil fuel free-steelmaking. This is not an insignificant advantage. As more producers face regulatory and social pressure to decarbonize their production processes and supply chains, they are likely to invest in locations that already have significant clean energy infrastructure. In recent case studies, firms that were first-movers in carbon neutrality enjoyed significant positive economic benefits, including increased sales, customer retention, and lower operating costs.

Regional assets position the Ohio River Valley to lead in fossil fuel-free steel production. The region has ready access to iron ore, a workforce with legacy knowledge of the steel industry, and abundant natural assets. Many of the skills required to produce green steel are similar to those in traditional primary steelmaking and overlap broadly with those of coal workers. Even in cases where skills do not overlap directly, recent federal legislation includes funding for rural economic initiatives. Some of these are specifically focused on retraining workers, while others are broader but can be used to develop a workforce.

While the implementation of fossil fuel-free steel offers the Ohio River Valley a unique opportunity to reshape the local economy, it also presents multiple challenges. One such obstacle is that the cleanest, most economical and technically proven way to produce hydrogen is via electrolysis directly powered by renewable energy sources. Green hydrogen is only possible if the energy for electrolysis comes from 100% renewable sources. This will require a significant investment in infrastructure to increase renewable energy production by nearly 1.5 times that of its 2021 output. However, Pennsylvania may be ripe for this opportunity. Some of the greatest wind resources for commercial power production are found in southwestern Pennsylvania. Furthermore, the development of renewables for fossil fuel-free steel can build the experience curve and economies of scale, lowering costs and jumpstarting the state's renewable capacity to fuel a broader green economy renaissance. Water supplies and geographic features in the region are also conducive to hydrogen development. It should be noted, however, that interconnection delays within the regional PJM electricity market are an additional challenge to such a renewable buildout, as PJM currently has a two-year backup in its grid connection queue, with nearly 2,700 projects under review.

Care must be taken to ensure that the renewable capacity required to generate green hydrogen is incremental and does not displace or delay regional grid decarbonization efforts. It is also important to ensure that green hydrogen production is done in ways that reduce, rather than inadvertently increase, greenhouse gas emissions. The most direct way to achieve this is with so-called "behind the meter" solutions that connect electrolyzers directly to dedicated renewable generation. Projects that connect electrolyzers to existing power grids may generate hydrogen with the same emissions intensity of the grid, which would negate the benefit of green steel production altogether. An additional benefit of implementing renewables "behind the meter" is that emissions tracking becomes much easier for companies. Such tracking will likely have important implications for receiving federal clean energy tax credits, although the specifics of these tax credits are still in the rulemaking stage at the Internal Revenue Service (IRS).

Fossil fuel-free steelmaking offers the Ohio River Valley a tremendous opportunity to lead an emerging industry with huge growth potential. The renewable capacity required for fossil fuel-free steelmaking could jumpstart clean energy development in the region, supporting jobs for massive numbers of installers and grid maintenance employees. Green infrastructure could attract other steelmakers as well as other industrial sectors seeking to decarbonize, putting southwestern Pennsylvania on the map—globally—as a fossil fuel-free manufacturing hub.

Fossil fuel-free steel production will also bring substantial environmental and social benefits to the region and the surrounding area. As noted previously, blast furnace-basic oxygen furnace (BF-BOF) steelmaking is a major source of greenhouse gas emissions, water pollution, and soil contamination. In 2019, Pennsylvania's industrial sector emitted 86.4 million metric tons of GHG emissions, or 33% of all states' carbon dioxide equivalent (CO_2e) emissions. Replacing the production of 2 million tons per annum (Mtpa) of BF-BOF steel with fossil fuel-free DRI-EAF steel will reduce Pennsylvania's industrial sector's emissions by around 4 million metric tons of CO_2e, a 4.6% reduction compared to the state's 2019 CO_2e emissions from the industrial sector. Using a social cost of carbon (SCC) of \$95 per metric ton of CO_2e, this reduction would save the state \$380 million in health, community, and environmental costs, to say nothing of the additional economic activity spurred an increased quality of life that could draw more residents to live, work, and consume in the region.

The shift to decarbonize the industry is just beginning. Those that act swiftly are well-positioned to reap the rewards. A green manufacturing renaissance will grow the region's economy by creating and retaining hundreds of local jobs, improving quality of life, and safeguarding public health and the environment. Pennsylvania can seize this opportunity to invest in a “sunrise industry” at the beginning of the S-curve rather than continuing to rely on mature industries in decline. In a landscape where so many regions are desperately trying to replicate the economic success of other places to become “the next Silicon Valley,” the Ohio River Valley can invest smartly to become “Clean Energy Valley”—one of the world’s very first decarbonized industrial hubs.

Introduction

This paper explores the potential to revitalize the Ohio River Valley (ORV) through a transition to fossil fuel-free primary steel production—in particular, steel made via direct reduction of iron (DRI), without coal, using hydrogen made only from renewable sources.

While the focus of the paper is on primary steelmaking (virgin steel produced from iron), we include other pathways to produce steel, including using scrap metal, and note the limitations of these approaches.

The paper begins with an overview of the long history and role of steel in the region. It explores current challenges facing the domestic steel industry, particularly in the Ohio River Valley region, and contrasts those challenges with the region's abundant assets. The paper concludes that fossil fuel-free steelmaking provides a unique opportunity for the Ohio River Valley to become a global leader in this emerging industry in coming decades, including first-mover advantages. The paper analyzes the jobs and economic impact of transitioning from legacy integrated steel production to fossil fuel-free primary steel production and explores potential regional benefits of developing an industrial center around fossil fuel-free steel production. Finally, it discusses other social and environmental benefits to the region, some challenges to implementation, and a high-level roadmap to move forward. The paper forms the basis to further explore the potential for real, clean economic development for the Ohio River Valley through fossil fuel-free steel investment.

Steelmaking has a long history in the Ohio River Valley. The Mon Valley Works, for example, is an integrated steelmaking operation comprising four facilities: three in western Pennsylvania and one near Philadelphia.

As a significant source of greenhouse gas (GHG) emissions, the steel industry is under increasing pressure to decarbonize. Carbon- and energy-intensive processes, such as Blast Furnace-Basic Oxygen Furnace (BF-BOF) steelmaking—the process used at the Edgar Thomson Plant at US Steel's Mon Valley Works—are facing underinvestment in favor of lower-carbon technologies. At the same time, the industry is poised for a major transition, which presents an opportunity to steel companies that move quickly and boldly. Recent case studies have demonstrated that firms moving first to decarbonize can enjoy significant economic benefits, such as customer retention, lower operating costs, increased sales revenue, and reduced regulatory costs.[3] As firms face increasing pressure to decarbonize their production processes and supply chains, they will very likely consider existing regional clean energy infrastructure when making capital investment decisions. Investing in the transition to fossil fuel-free steelmaking in the Ohio River Valley can plant the seeds of a future carbon-neutral manufacturing hub.

[3] Zhang, A., Alvi, M. F., Gong, Y., & Wang, J. X. (2022). Overcoming barriers to supply chain decarbonization: Case studies of first movers. *Resources, Conservation and Recycling*, *186*, 106536. https://doi.org/10.1016/j.resconrec.2022.106536

There are many efforts to decarbonize steelmaking that broadly fall under the term "green steel." But there are significant differences in technology, emissions impacts, and how the steel is produced.

Sidebar: What Is Green Steel?

What exactly is Green Steel? The problem is there really isn't an agreed upon definition.

"Green steel" is commonly used to refer to steel produced in any way that reduces its carbon footprint. Some other similarly ill-defined terms include "low-emission steel" or "lower-carbon steel."

The term carries no measure of how much reduction is made or what the method is for achieving it. Claims range from innovations in blast furnace primary steel processes to DRI primary steelmaking processes or scrap EAF process. However, there are significant differences across steel decarbonization pathways in terms of overall carbon footprint, performance potential, technology readiness, costs, and risks…

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McKinsey has provided a framework based on methods that provide a CO_2 reduction and methods that offer the potential for full decarbonization (or near zero-emission steel) (Figure 1).[4]

Figure 1: Steelmaking Methods Sorted by CO_2 Reduction, Potential for Full Decarbonization

	CO_2 reduction			**Full decarbonization possible**		
	Blast furnace efficiency (BOF)	**Biomass reductants**	**Carbon capture and usage**	**Electric arc furnace (EAF)**	**DRI plus EAF using natural gas**	**DRI plus EAF using H_2**
Strategy	Make efficiency improvements to optimize BF/BOF operations	Use biomass as an alternative reductant or fuel	Capture fossil fuels and emissions and create new products	Maximize secondary flows and recycling by melting more scrap in EAF	Increase usage of DRI in the EAF	Replace fossil fuels in DRI process with renewable energy or H_2
Examples	Optimized BOF inputs (DRI, scrap), increased fuel injection in BF (e.g., hydrogen, PCI)	Tecnored process	Bioethanol production from CO_2 emissions	EAF – usage to melt scrap	Current DRI plus EAF plants using natural gas (NG)	MIDREX DRI process running on H_2 HYL DRI process running on H_2
Current outlook	Technology readily available at competitive cost	Process possible in South America and Russia, due to biomass availability	Not available on an industrial scale	Technology readily available at competitive cost	Technology readily available	Technology available at high cost

Source: McKinsey & Company

[4] Adrian Doyle and Tom Voet, "The DRI dilemma: Could raw material shortages hinder the steel industry's green transition?" McKinsey & Company, July 13, 2021, https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-dri-dilemma-could-raw-material-shortages-hinder-the-steel-industrys-green-transition#/

This paper focuses on the transition within primary steelmaking, with particular analysis of the potential of green hydrogen-based direct reduction (DRI-EAF) steelmaking. This process is the only commercially available technology capable of providing zero-emission, fossil fuel-free primary steel.

The Ohio River Valley's labor force, infrastructure, and economic ecosystem position the region to transition to fossil fuel-free steelmaking. Other regional assets, such as its legacy knowledge of the steel industry, ready access to iron ore, and proximity to rivers, can be further developed to support the transition. Recent federal incentives are expected to reduce renewables and green hydrogen costs, making them among the lowest in the world. These critical inputs can enable a significant first-mover advantage and potential for global leadership in fossil fuel-free steelmaking. Acceleration of the development of renewables to enable green steel can provide a critical stimulus to the region's green infrastructure. Together, these factors can transition the region's workforce and position it to thrive.

Overview of the Steel Industry

Steel Demand and Outlook

The Vital Role of Steel

The steel industry has a critical and far-reaching global and domestic impact. It is a vital foundation for the nation's economy, security, infrastructure, energy needs, and downstream manufacturing capabilities. It has created much of what we consider the modern world and is expected to play a prominent role as the globe decarbonizes.

Steel has played an outsized role in the history of Pennsylvania, particularly in Pittsburgh and the greater Ohio River Valley. At the height of the US steel industry, Pittsburgh produced 60% of the nation's steel and 95% of its steel rails. US Steel (X), formed when Andrew Carnegie's steel company was sold to JP Morgan in 1901, became the largest company in the world and the first billion-dollar company. Domestic steelworkers were the highest-paid industrial workers, earning a comfortable middle-class salary.

Steel was the backbone of many emerging industries. The industry produced steel rails for transcontinental railways, critical building materials like joists and beams for skyscrapers, and key inputs for industrial manufacturing in the late 1800s. Steel propelled automobile manufacturing as cars replaced horse-drawn carriages in the early 1900s. War equipment for World War I and World War II required vast quantities of steel. The very infrastructure of the nation was built on steel.

History of the US Steel Industry

The US, once the world leader in steel production—a position it held from the late 19th century through the 1980s—has become a net importer of steel. In the mid-1990s, China became the leading steel producer amid claims it was "dumping" steel below its fair market value. China currently produces roughly half the world's steel, churning out 12 times as much steel as the US produces.[5] As the domestic primary steel industry declined in the 1980s, mainly from increasing imports and the rise of minimills that used scrap metal, so did employment in that industry. The industry that employed about 700,000 workers from the 1950s through the 1970s halved its employment by the late 1980s. The economic and social fallout was devastating throughout steelmaking regions, as the workforce in some counties was heavily tied to the industry.

[5]World Population Review, "Steel Production by Country 2023," World Population Review, Accessed March 2023, https://worldpopulationreview.com/country-rankings/steel-production-by-country

Sidebar: History of the Steel Industry Looms Large in Pennsylvania and the Ohio River Valley

Steel has played an outsized role in the history of Pennsylvania, particularly in Pittsburgh and surrounding counties, including the Ohio River Valley. At the height of the steel industry in the US, Pittsburgh produced 60% of the nation's steel and 95% of its steel rails. Any economic narrative of Pittsburgh, Pennsylvania, or the Ohio River Valley focuses on the steel industry. Its legacy, especially in Allegheny and Beaver Counties, lives large in collective memory and serves as a reminder, for many, of good economic times. Those charged with economic development may look to the steel industry as an inspiration, especially if they seek an industrial renaissance for the Ohio River Valley.

Over much of its history, the steel industry has adapted quickly to changing technology and shifting demands for its product. Major technological advances in steelmaking are illustrated below, from the invention of the Bessemer process in England, which allowed steel to be mass-produced cost effectively, to Electric Arc Furnaces (EAF)...

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The steel industry remains a significant employer in the US, directly employing 131,400 workers, according to a 2022 Congressional Research report, or 168,000 workers, according to the Bureau of Labor Statistics (BLS).[6] These employment figures, however, are far lower than their highs of roughly 700,000 jobs in the late 1970s and down another half since 1990, when the industry produced 257,200 direct jobs. Moreover, US steel manufacturers continue to reduce jobs, shedding 12,500 jobs from 2015 to 2020.[7] This may be due to globalization, increasing imports, industrial automation, efficiency trends, and evolving technologies. Approximately a quarter of steelworkers are in a union. Minimills, largely located in the South and Midwest, have a lower percentage of union workers and less stringent collective bargaining protections for steelworkers.

In Pennsylvania, the steel and iron industry provides about 9,600 direct jobs, according to the US Bureau of Labor Statistics (BLS).[8]

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[6] The employment figures for domestic steelworkers vary widely based on different sources. In general, industry groups cite much higher employment figures for the industry. We have cited a Congressional Research Service Report 2022 and the Bureau of Labor Statistics (BLA) "Employment for Manufacturing: Iron and Steel Mills and Ferroalloy Production (NAICS 3311), 79,700; and "Steel Production Manufacturing from Purchased Steel (NAICS 3312) 88,000.

[7] Congressional Research Service, "U.S. Steel Manufacturing: National Security and Tariffs," Congressional Research Service, August 12, 2021, https://crsreports.congress.gov/product/pdf/IF/IF11897

[8] American Iron and Steel Institute, "The Economic Impact of the American Steel Industry," American Iron and Steel Institute, May 23, 2018, https://www.steel.org/economicimpact/

In 2018, the federal government determined that domestic steelmaking was necessary for the nation's security production requirements and key to the country's ability to respond to an emergency.[9] The Department of Homeland Security designated steelmakers a component of a "critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof."[10]

Furthermore, after COVID-19 revealed the limitations of the global supply chain, reshoring domestic steel assumed greater urgency. It is now viewed as vital to national security and resiliency. A 2021 Congressional Research bulletin raised the prospect of overreliance on cheaper imported steel as a potential threat to the nation's security.[11]

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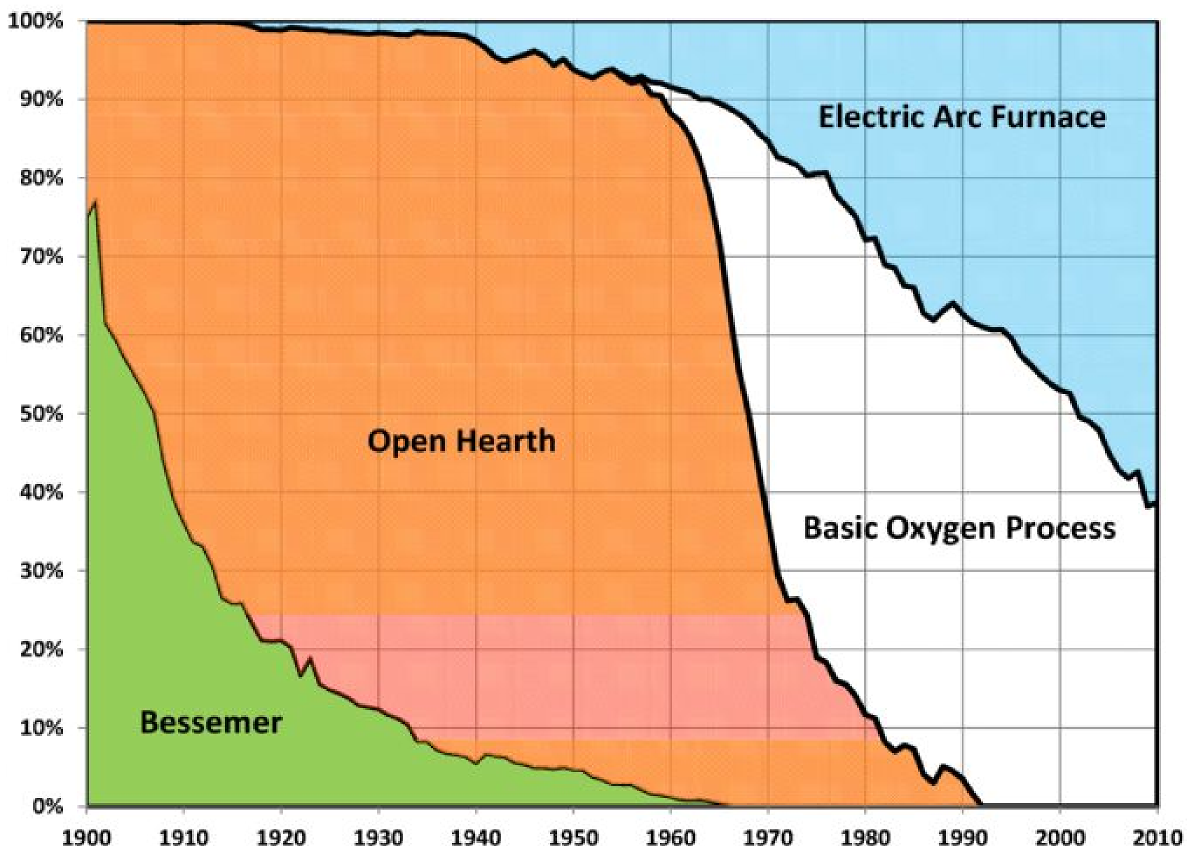
[9] Bureau of Industry and Security, Commerce, "Publication of a Report on the Effect of Imports of Steel on the National Security: An Investigation Conducted Under Section 232 of the Trade Expansion Act of 1962, as Amended," Federal Register, July 6, 2020, https://www.federalregister.gov/documents/2020/07/06/2020-14359/publication-of-a-report-on-the-effect-of-imports-of-steel-on-the-national-security-an-investigation
Bureau of Industry and Security, Office of Technology Evaluation, "THE EFFECT OF IMPORTS OF STEEL ON THE NATIONAL SECURITY," US Department of Commerce, January 11, 2018, https://www.commerce.gov/sites/default/files/the_effect_of_imports_of_steel_on_the_national_security_-_with_redactions_-_20180111.pdf

[10] Cybersecurity & Infrastructure Security Agency, "Critical Infrastructure Sectors," Cybersecurity & Infrastructure Security Agency, Accessed January 2022, https://www.cisa.gov/critical-infrastructure-sectors

[11] Congressional Research Service, "U.S. Steel Manufacturing: National Security and Tariffs," Congressional Research Service, August 12, 2021, https://crsreports.congress.gov/product/pdf/IF/IF11897

Over much of its history, the steel industry has adapted quickly to changing technology and shifting demands (Figure 2). Steel has played a central role in historic economic transitions. It propelled the Industrial Revolution in the US and remains critical to the nation's infrastructure needs. Infrastructure and reshoring manufacturing will require the steel industry to continue transitioning throughout the 21st century.

Figure 2: Evolution of Steel Production, 1900-2010



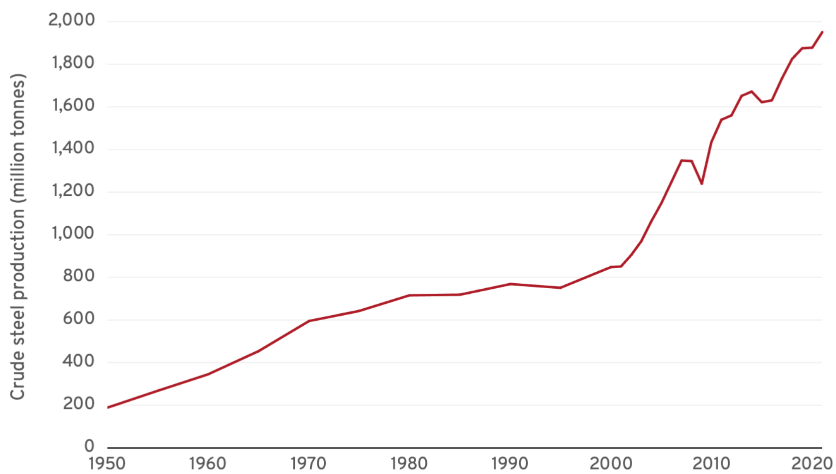
Source: MetalForming Magazine[12]

[12] Daniel Schaeffler, "A Brief History of Steelmaking," MetalForming Magazine, August 31, 2020, https://www.metalformingmagazine.com/article/?/materials/mild-steel/a-brief-history-of-steelmaking-gu

Global Demand for Steel to Grow Modestly

Steel demand is strongly influenced by global economics and geopolitics. Global steel production grew by 3.0% per year from 2010 to 2020, on average, and 3.8% from 2020 to 2021 (Figure 3).[13]

Figure 3: Global Crude Steel Production, Millions of Tonnes, 1950-2020



Source: World of Steel[14]

Despite production growth over the past two decades, current steel production is less than current global capacity of 2.3 billion.[15] Global overcapacity was estimated to be 700 million tonnes of steel in 2020, according to the Organization of Economic Cooperation and Development (OECD).[16]

Most industry forecasts predict long-term global steel demand to remain steady or grow modestly at 1% to 2% per year through 2035 (Figure 4). Estimates of growth through 2035 range from 1.87 billion tons per year[17] to 2.39 billion tons per year.[18] These global steel demand forecasts are lower than historical levels and lower than

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[13] World Steel Association, "World Steel in Figures 2022," World Steel Association, 2022, https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2022/#world-crude-steel-production-1950-to-2021

[14] World Steel Association, "World Steel in Figures 2022," World Steel Association, 2022, https://worldsteel.org/steel-topics/statistics/world-steel-in-figures-2022/#world-crude-steel-production-1950-to-2021

[15] Accenture, "Steel Demand Beyond 2030: Forecasts," Presented to OECD, Paris, September 28, 2017", Accessed January 2023, https://www.oecd.org/industry/ind/Item_4b_Accenture_Timothy_van_Audenaerde.pdf

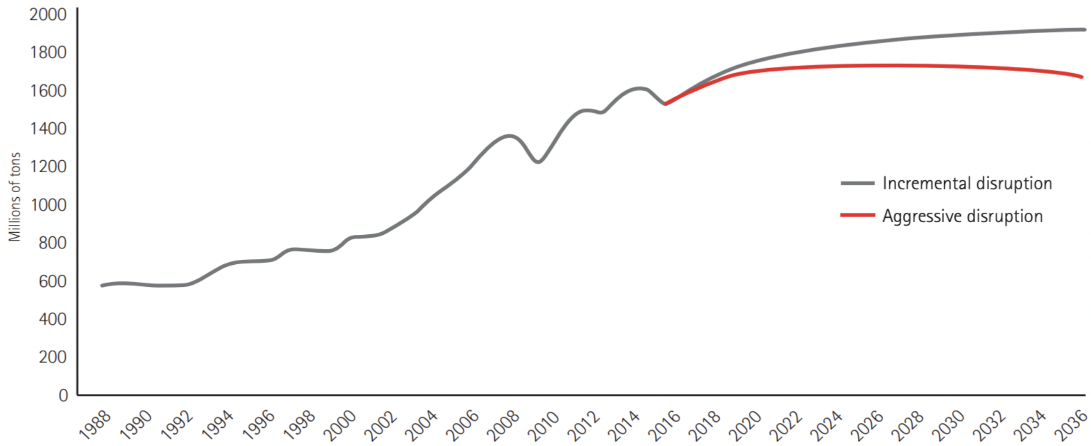
[16] Congressional Research Service, "U.S. Steel Manufacturing: National Security and Tariffs," Congressional Research Service, August 12, 2021, https://crsreports.congress.gov/product/pdf/IF/IF11897

[17] Accenture, "Steel Demand Beyond 2030: Forecasts," Presented to OECD, Paris, September 28, 2017", Accessed January 2023, https://www.oecd.org/industry/ind/Item_4b_Accenture_Timothy_van_Audenaerde.pdf

[18] Thomas Koch Blank, Chathurika Gamage, and Lachlan Wright, "Steel Yourself: Implications of Peak Demand in the Energy Transition," RMI, 2022, https://rmi.org/insight/steel-yourself/
This report references IEA, IISA and E3G forecasts.
International Energy Agency (IEA), "Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking," Part of the Energy Technologies Pathways Series, OECD Publishing, 2020, https://www.iea.org/reports/iron-and-steel-technology-roadmap

forecasted GDP growth of 3% in 2022[19] and 2.7% in 2023.[20] These estimates suggest that steel demand will track GDP growth directionally, albeit at a lower rate.

Figure 4: Global Demand for Steel, 1988-2036



Note: Under potential aggressive circular economy conditions, steel demand growth could drop by 0.4% annually to reach 1.63 billion tons by 2035, almost 13% below the incremental forecast of 1.87 billion tons.
Source: Accenture, World Steel Association[21]

Domestic Steel Outlook: Newly Optimistic after a Bumpy Ride in 2022

The domestic steel industry had an excellent first half of 2022 based on numerous market signals: roaring stock prices, increased capacity utilization, announcements of modernization and/or greenfield projects, high steel prices, and record profits. Despite the domestic industry's recent strength, however, the medium-term outlook is highly complex, influenced by global supply and demand, shifting tariff policies, evolving technology, and global decarbonization trends.

Many US steelmakers were able to pass on higher prices to their customers, allowing them to record $29.6 billion in profits in 2021 compared with $2.7 billion in 2020, according to US Census Bureau data.[22] Capacity utilization, at 81%, reached the highest level since 2007. Nucor, the nation's largest steel producer, expects to record its highest-ever profits in 2022. Imports were reduced because of international supply chain disruptions and the 25% tariffs on imported steel introduced by then-President Trump in 2018. The result was high domestic steel prices, which boosted the profits of domestic steelmakers, but negatively impacted domestic manufacturers that

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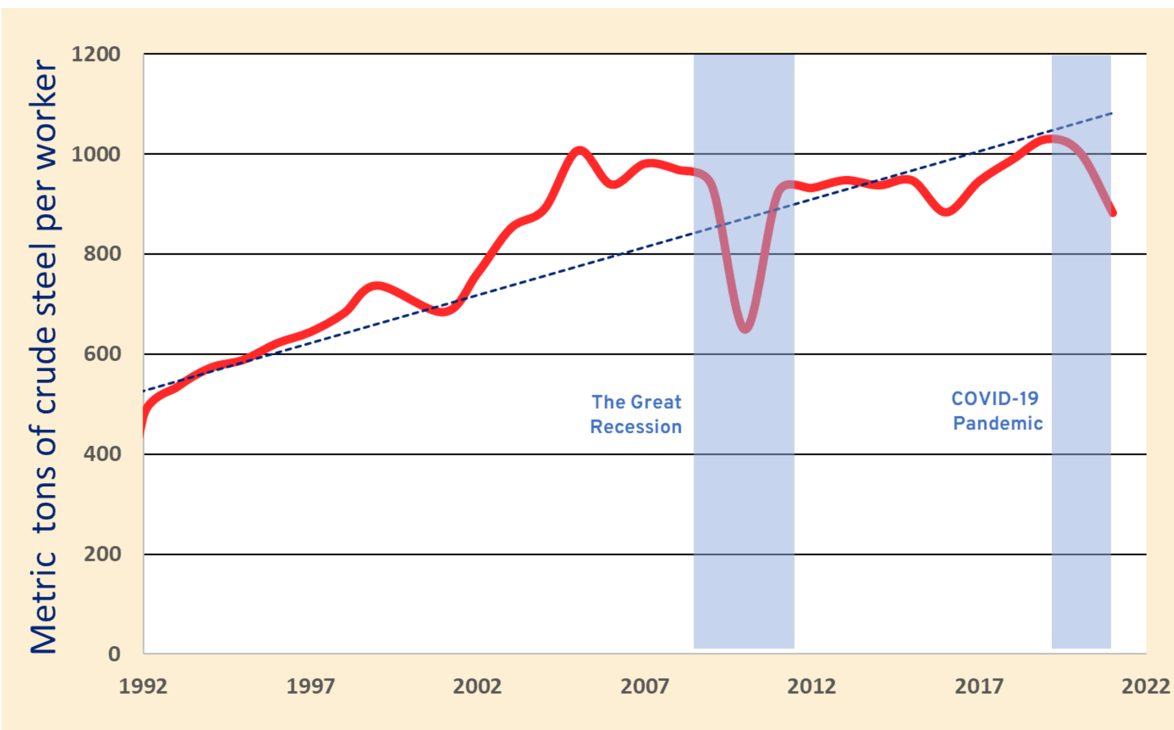
[19] Economists generally forecast 3% GDP long-term growth through 2030.
[20] International Monetary Fund, "World Economic Outlook: Countering the Cost of Living Crisis," International Monetary Fund, October 2022, https://www.imf.org/en/Publications/WEO/Issues/2022/10/11/world-economic-outlook-october-2022
[21] John Lichtenstein, "Steeling for disruption: Global steel producers must reinvent themselves as demand growth disappears," Accenture, 2017, https://www.accenture.com/_acnmedia/pdf-40/accenture-wef-steeling-for-disruption
[22] Christopher Watson, "Domestic Steel Manufacturing: Overview and Prospects." Congressional Research Service, May 17, 2022, https://crsreports.congress.gov/product/pdf/R/R47107

relied on steel as a key input.[23] Concerns about increased prices linked to tariffs have been widely criticized, and European steel tariffs have been removed under the Biden administration.

Despite higher steel prices and record industry profits, domestic steel production did not reach pre-pandemic levels through 2022.[24] Production levels reflected reduced demand during the pandemic and international supply chain disruptions as the economy recovered. As recession fears mounted throughout 2022, capacity utilization dropped from 80% early in the year to 72% by year-end.[25] Continued global market volatility and ongoing tariff issues have shifted the domestic steel industry toward reshoring and away from imports.

Figure 5 below shows the rising productivity of labor in the steel industry using data from the BLS and US Geological Survey (USGS). The positive trend implies that steelmakers are increasingly efficient, requiring fewer direct jobs to produce more output. This trend, coupled with shifts in production to other states offering lucrative tax incentive packages to attract producers (such as those given by West Virginia to NUCOR and Arkansas to US Steel) portend a decline in steel production jobs in coming decades.

Figure 5: Annual US Worker Productivity in the Steel Industry, 1992-2021



Source: Ohio River Valley Institute analysis using BLS and USGS data

[23] Chad P. Brown and Katheryn (Kadee) Russ, "Biden and Europe Remove Trump's Steel and Aluminum Tariffs, but It's Not Free Trade," Peterson Institute for International Economics, November 11, 2021, https://www.piie.com/blogs/trade-and-investment-policy-watch/biden-and-europe-remove-trumps-steel-and-aluminum-tariffs
[24] Trading Economics, "United States Steel Production," Trading Economics, December 2022, https://tradingeconomics.com/united-states/steel-production
[25] American Iron and Steel Institute, "This Week's Raw Steel Data," American Iron and Steel Institute, December 31, 2022, https://www.steel.org/industry-data/

US Remains a Net Importer of Steel

For decades, the domestic steel industry has not supplied US demand for steel. For example, when the Shell petrochemical plant in Beaver County, Pennsylvania, was under construction, it was Chinese steel that was shipped on the Ohio River to the construction site.

After producing nearly half the world's steel output in 1950, the US had become a net importer by 1959 and remained the world's largest net importer for decades through 2019. China, which had become the world's largest steel producer in 1996,[26] became both the world's largest steel producer and importer in 2020. [27] By 2021, however, the US had regained its position as the world's leading steel importer.[28] China now produces roughly 12 times as much steel as the US.

US dependence on imported steel has become a national security matter. Supply chain disruptions over the past two years have revealed the limitations of relying on imports for a critical input for the manufacturing sector. Additionally, although the US imports relatively little steel from China compared to other countries, concerns have been raised about the quality of steel imported from China, as well as the conditions of steelworkers in China.[29]

Domestic Steel Outlook, Forecast is Optimistic

Despite declining capacity utilization in the final months of 2022 due to recession fears, the domestic steel industry outlook is optimistic. This optimism is primarily due to the passage of recent federal legislation, including the Bipartisan Infrastructure Investment and Jobs Act (IIJA) of 2021, the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act of 2022, and the Inflation Reduction Act (IRA) of 2022, which have been hailed by management of Nucor (NUC), US Steel (USX), and Cleveland-Cliffs (CLF), the nation's three largest steel producers. (See Incentives section for more details.) Reshoring, or on-shoring, steel production initiatives are also bullish for the domestic steel industry.

Steel is critical to the nation's infrastructure. "Substituting steel for fuel" has become a tagline for the transitioning of the power sector. Utility-scale solar uses steel for panel mounts. Nuclear, hydroelectric, and wind all require steel for construction, as does transmission and distribution infrastructure. Steel has played an important role in providing infrastructure to support the regional natural gas boom and will also likely play an outsized role in emerging hydrogen or carbon capture infrastructure. Overall, the domestic outlook is bright, with increased demand countering dematerialization and efficiency trends.

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[26] Mark J. Perry, "Animated Chart of the Day: World's Top Ten Steel Producers from 1980 to 2020 — the Meteoric Rise of China," AEI, June 7, 2021, https://www.aei.org/carpe-diem/animated-chart-of-the-day-worlds-top-ten-steel-producers-from-1980-to-2020/#:~:text=1.,position%20in%20every%20year%20since.

[27] World Steel Association, "December 2022 crude steel production and 2022 global crude steel production totals," World Steel Association, January 31, 2023, https://worldsteel.org/media-centre/press-releases/2023/december-2022-crude-steel-production-and-2022-global-totals/#:~:text=World%20crude%20steel%20production%20for,decrease%20compared%20to%20December%202021.&text=Africa%20produced%201.1%20Mt%20in,104.9%20Mt%2C%20down%209.2%25.

[28] World Steel Association, "Imports of semi-finished and finished steel products," World Steel Association, December 16, 2022, https://worldsteel.org/steel-topics/statistics/annual-production-steel-data/?ind=T_imports_sf_f_total_pub/USA/CHN

[29] General Steel Buildings, "Chinese Steel vs American Steel Quality," General Steel Buildings, Accessed March 9, 2023, https://gensteel.com/building-faqs/building-comparisons/chinese-steel-quality-vs-american-steel-quality/#:~:text=Dangers%20of%20Foreign%20Steel&text=A%20metallurgist%20testified%20that%20the,and%20had%20to%20be%20replaced

Industry Need to Decarbonize

The production of iron and steel is energy and carbon-intensive. It is estimated to account for 7% of global greenhouse gas emissions, approximately 3GT of carbon dioxide (CO_2),[30] and 11% of global CO_2 emissions.[31] To put it into context, if the steel industry were a country, it would be the fifth-largest contributor to global CO_2 emissions.[32] As a component of industrial sector emissions, steel accounts for nearly a quarter of global industrial emissions (Figure 6).[33]

At the recent IPCC climate conference in Sharm El-Sheikh (COP27), the cement, iron and steel, and chemicals and petrochemicals industries were called out as the most significant industrial CO_2 emitters. As the starting point of many industrial value chains and a critical component to economic development and the clean energy transition, targeting these large point sources of emissions is a priority to mitigate climate change impacts.[34]

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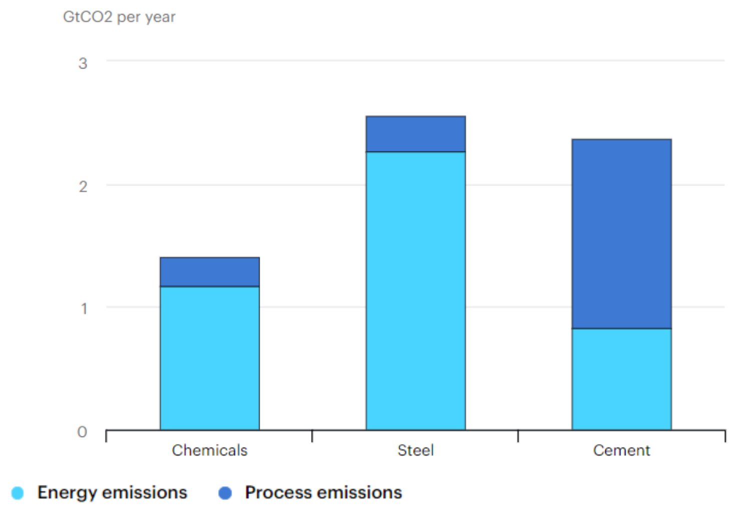
[30] Energy system CO_2 emissions include both those from combustion of fossil fuels and industrial process emission. When including indirect emissions from the power sector and the combustion of steel off-gasses (a further 1.1 Gt CO_2/yr), the share of energy system CO_2 emissions attributable to the iron and steel sector rises to 10%.
International Energy Agency (IEA), "Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking," Part of the Energy Technologies Pathways Series, OECD Publishing, 2020, https://www.iea.org/reports/iron-and-steel-technology-roadmap
UNECE & ESCWA, "Technology Brief: CARBON NEUTRAL ENERGY INTENSIVE INDUSTRIES," 2022, United Nations Economic Commission for Europe, https://unece.org/sites/default/files/2022-11/Industry%20brief_EN_2.pdf
[31] A. Hasanbeigi, "Steel Climate Impact - An International Benchmarking of Energy and CO2 Intensities," Global Efficiency Intelligence, Accessed January 2023, https://www.globalefficiencyintel.com
[32] UNECE & ESCWA, "Technology Brief: CARBON NEUTRAL ENERGY INTENSIVE INDUSTRIES," 2022, United Nations Economic Commission for Europe, https://unece.org/sites/default/files/2022-11/Industry%20brief_EN_2.pdf
[33] A. Hasanbeigi, "Steel Climate Impact - An International Benchmarking of Energy and CO2 Intensities," Global Efficiency Intelligence, Accessed January 2023, https://www.globalefficiencyintel.com
[34] UNECE & ESCWA, "Technology Brief: CARBON NEUTRAL ENERGY INTENSIVE INDUSTRIES," 2022, United Nations Economic Commission for Europe, https://unece.org/sites/default/files/2022-11/Industry%20brief_EN_2.pdf

Figure 6: Global CO_2 emissions from Heavy Industry, Gigatons per Year



Source : IEA[35]

According to the International Energy Agency (IEA), emissions from steel must be reduced by 50% by 2050 and then continue to fall to meet the world's climate goals.[36] This, combined with increased customer demand, regulatory pressure, and growth in sustainable investments, has resulted in a flurry of announcements by steel producers of plans, goals, or at least mentions of a move towards "green steel."[37]

Market Drivers of Fossil Fuel-Free Steel

In a December earnings results call, ArcelorMittal confirmed that it is achieving greater margins on its debut "green steel" products from its pilot plant in Hamburg, Germany. However, future price premiums for low-carbon steel are difficult to predict and dependent upon supply and demand outlooks. McKinsey states, "Demand for low-CO_2 steel is expected to surge from around 84 million tons in 2021 to nearly 200 million tons in 2030, mainly driven by automotive and construction demand in Europe and China." They further state that the global demand for low-carbon flat-rolled steel may outstrip supply by as much as 23 million metric tons by 2030.[38]

Steel is one of a few primary materials that make up a significant portion of the key product value chains. It therefore plays a vital role in lifecycle emissions impacts. Several automakers, including Volkswagen, Jaguar,

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[35] International Energy Agency (IEA), "Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking," Part of the Energy Technologies Pathways Series, OECD Publishing, 2020, https://www.iea.org/reports/iron-and-steel-technology-roadmap
[36] International Energy Agency (IEA), "Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking," Part of the Energy Technologies Pathways Series, OECD Publishing, 2020, https://www.iea.org/reports/iron-and-steel-technology-roadmap
[37] Thomas Koch Blank, Chathurika Gamage, and Lachlan Wright, "Steel Yourself: Implications of Peak Demand in the Energy Transition," RMI, 2022, https://rmi.org/insight/steel-yourself/
[38] M. Azevedo et. al., "Capturing the green-premium value from sustainable materials," McKinsey & Company, Accessed December 2022, https://www.mckinsey.com/industries/metals-and-mining/our-insights/capturing-the-green-premium-value-from-sustainable-materials

Land Rover, Toyota, and General Motors, have announced ambitious supply chain emissions goals, with a few companies specifically committing to green steel targets.[39] Investments or agreements between automakers and steelmakers on green steel projects have also been announced (e.g. Volvo/SSAB, Benz, Bausteel, Scania/H2Steel, Benz/H2Steel, Volkswagen/Salzgitter AG, BMW/Boston Metal, and GM/Nucor Econiq).

While demand for fossil fuel-free steel in the built environment appears to be lagging, various tools to drive adoption are emerging. These include Environmental Product Declarations (EPDs) for a variety of low-carbon steel products, which fulfill requirements of the LEED rating system (LEED V4) for the built environment, as well as standards (ASHRAE 189.1) and green building codes (IgCC) to meet specific customer requirements.

US steel producers should further benefit on the demand side from the domestic content feature of many of the proposed credits in the IRA and IIJA, as well as federal legislation and regulation that incentivizes the use of green building materials. For example, more than $4 billion will be allocated to low-carbon construction materials for government buildings and government-funded highways under the IRA.

Regulatory and Investor Pressure

Regulatory and investment pressure also continues to threaten the industry's license to operate. This includes carbon reduction targets and rising carbon dioxide emission prices, particularly in the EU (e.g., European Green Deal), as well as growth in sustainable investments by firms like the Institutional Investors Group on Climate Change and the global investment firm BlackRock, which have committed to environmentally responsible business development and sustainable investing. Recent studies cited by McKinsey estimate that the global steel industry may find approximately 14% of steel companies' potential value at risk if they are unable to decrease their environmental impact.[40]

The European Union (EU) is working on a carbon border adjustment mechanism (CBAM), also known as a carbon border tax, that would tax imports of carbon-intensive steel. Some domestic steelmakers might not be capable of selling their steel internationally due to this carbon border tax. The alternate net-zero approach to carbon steelmaking in the US, which, in some cases, defines net-zero as steel production using blue hydrogen rather than green hydrogen to power steel factories, may not meet the border tax criterion (See Sidebar: What Is the Difference Between Gray, Blue, and Green Hydrogen?). The European border tax is gaining momentum but has not been finalized, so the impact on US metal exporters is unknown.[41]

An additional factor driving the shift to green steel is that steel produced from hydrogen reduces dependency on coal and natural gas and associated price exposure. This has become particularly apparent in Europe in light of the war in Ukraine and its impacts on natural gas prices and supply constraints.

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[39] Volvo has pledged 100% green steel by 2050. Ford pledged 10% by 2030.

[40] Christian Hoffmann, Michel Van Hoey, and Benedikt Zeumer, "Decarbonization Challenge for Steel, McKinsey & Company," McKinsey & Company, June 3, 2022, https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

[41] Chad P. Brown and Katheryn (Kadee) Russ, "Biden and Europe Remove Trump's Steel and Aluminum Tariffs, but It's Not Free Trade," Peterson Institute for International Economics, November 11, 2021, https://www.piie.com/blogs/trade-and-investment-policy-watch/biden-and-europe-remove-trumps-steel-and-aluminum-tariffs

Addressing decarbonization in an industry with long term, multi-billion-dollar investment cycles requires swift action. For example, roughly every ten to 15 years, blast furnaces require relining or rebuilding at a cost of $100 million to $300 million.[42] It is estimated that this may affect nearly 97% of US blast furnace capacity before 2030.[43] This provides clear decision points for steel companies, especially those that have announced emission goals in the 2030 to 2050 timeframe.

Banks and governments continue to announce that they are halting future investments in new coal mines. Investors are also wary of the risk represented by the long working life of coke batteries. As the ironmaking industry shifts away from coke in its effort to decarbonize, it could create an imbalance in the market, leading to higher coke prices. Higher prices for coke both increase the price of steel made from coke and the price of coke steel relative to alternatives, such as hydrogen DRI-EAF (see below), accelerating the transition.[44]

Steel decarbonization also presents a disruption opportunity. Not only are existing steel mills switching to green production, but start-ups are entering the market. For example, H2 Green Steel (H2GS) was founded in 2020 and has already raised $105 million through Series A equity financing to build infrastructure to support completely green steel production.[45]

A recent article from McKinsey concluded, "The world is quickly decarbonizing—and the window of opportunity for materials producers and purchasers is rapidly closing. In the years to come, the value from green premiums will be accrued by those who make quick and bold decisions."[46]

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[42] F.D. Clercq, A. Doyle, and T. Voet, "High coking coal prices provide glimpse into steelmaking's future," McKinsey & Company, January 25, 2022, https://www.mckinsey.com/industries/metals-and-mining/our-insights/high-coking-coal-prices-provide-glimpse-into-steelmakings-future

[43] Agora Industry, "Global Steel at a Crossroads," Agora Industry, November 2021, https://static.agora-energiewende.de/fileadmin/Projekte/2021/2021-06_IND_INT_GlobalSteel/A-EW_236_Global-Steel-at-a-Crossroads_WEB.pdf

[44] M. Azevedo et. al., "Capturing the green-premium value from sustainable materials," McKinsey & Company, Accessed December 2022, https://www.mckinsey.com/industries/metals-and-mining/our-insights/capturing-the-green-premium-value-from-sustainable-materials

[45] H2 Green Steel, "H2 green steel completes strong USD 105 million initial funding round to accelerate the transition into fossil-free steel making," H2 Green Steel, May 24, 2021, https://www.h2greensteel.com/latestnews/h2-green-steel-completes-strong-usd-105-million-initial-funding-round-to-accelerate-the-transition-into-fossil-free-steel-making

[46] M. Azevedo et. al., "Capturing the green-premium value from sustainable materials," McKinsey & Company, Accessed December 2022, https://www.mckinsey.com/industries/metals-and-mining/our-insights/capturing-the-green-premium-value-from-sustainable-materials

Steelmaking Pathways

There are three dominant processes to produce steel:

1. Blast Furnace-Basic Oxygen Furnace (BF-BOF):
   This process begins with iron ore and thus is sometimes referred to as primary steelmaking or virgin steelmaking. It consists of a blast furnace (BF) followed by a basic oxygen furnace (BOF). Iron ore pellets and sinter are combined with limestone in a blast furnace. Coke, a concentrated form of coal, provides the energy source and gasses required to reduce the iron ore to iron and melt it to hot iron. The purified hot iron (or pig iron if cooled) is then charged to a basic oxygen furnace to make steel hot metal (HM). The process is very energy-intensive. The reduction using coke generates 1.6 to 2.2 tons of CO_2 per ton of steel.[47] (Casting or rolling processes are often co-located into integrated steel mills.) The BF-BOF process is currently the predominant pathway for steel production, accounting for over 70% of global production.

2. Electric Arc Furnace (EAF):
   This process consists of smelting and re-alloying already-reduced iron in an electric arc furnace (EAF). It mainly uses scrap steel as a feedstock (resulting in secondary or recycled Steel), but pig iron or direct reduced iron (DRI) can also be processed into steel this way. An EAF uses electricity as the only energy source to melt the steel. This process can have a much lower carbon footprint, at around 0.3 tons CO_2/t steel, depending on the input iron type and grid mix.[48] A typical EAF facility has a capacity of about 1 million tons (Mt) of steel production as compared to 3 Mt or larger for an integrated BF-BOF mill; thus, these are often referred to as "minimills." EAF scrap production accounts for about 20% of global steel production.

3. Direct Reduction of Iron-Electric Arc Furnace (DRI-EAF):
   Direct Reduction of Iron (DRI) is an ironmaking process that begins with iron ore; however, it uses a reducing gas (syngas or hydrogen) instead of coke to reduce the iron to pure iron. Iron ore pellets are fed into the top of a shaft furnace[49] and the gas is fed lower down. The shaft furnace operates at a lower temperature, so the direct reduced iron (DRI or sponge iron) comes out as a porous solid with a very low carbon content. The DRI then enters an electric-arc furnace (EAF), where it is melted along with electricity to produce crude steel. Currently, the DRI process is employed mainly with syngas (made from natural gas) and accounts for about 8% of steel output worldwide. The DRI-EAF process has the potential to produce primary or virgin steel with nearly zero emissions (discussed in detail later).

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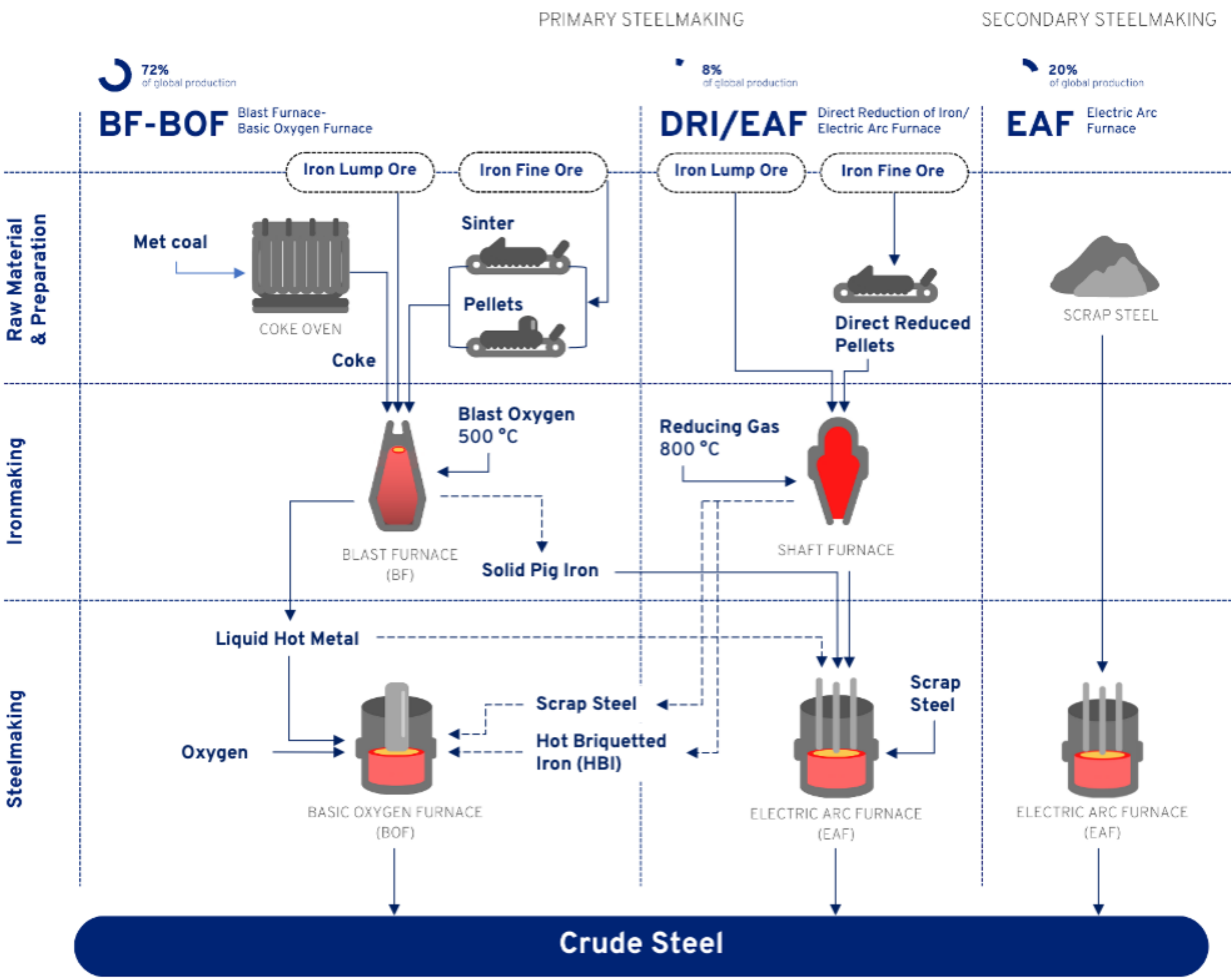
[47] Zhiyuan Fan and Julio Friedmann, "Low-Carbon Production of Iron & Steel: Technology Options, Economic Assessment, and Policy," Columbia | SIPA Center on Global Energy Policy, March 8, 2021, https://www.energypolicy.columbia.edu/research/article/low-carbon-production-iron-steel-technology-options-economic-assessment-and-policy
A. Hasanbeigi, "Steel Climate Impact - An International Benchmarking of Energy and CO2 Intensities," Global Efficiency Intelligence, Accessed January 2023, https://www.globalefficiencyintel.com
[48] Zhiyuan Fan and Julio Friedmann, "Low-Carbon Production of Iron & Steel: Technology Options, Economic Assessment, and Policy," Columbia | SIPA Center on Global Energy Policy, March 8, 2021, https://www.energypolicy.columbia.edu/research/article/low-carbon-production-iron-steel-technology-options-economic-assessment-and-policy
[49] Direct reduction of iron can also be performed in a fluidized bed reactor.

Figure 7: Steelmaking Production Pathways



Source: Ohio River Valley Institute

Primary Steel Will Continue to See Demand

Steel production from scrap requires just 1/8 of the energy used to produce steel from iron ore,[50] mainly in the form of electricity rather than coal.[51] Thus, it offers great potential to reduce the carbon footprint of steel production. As the grid continues to decarbonize, the EAF pathway can potentially produce near-zero emission steel.

According to the American Iron and Steel Institute, over 70% of US steel production is estimated to come from the EAF process, compared to 26% worldwide.[52] However, limitations prevent EAF from playing a more prominent role in decarbonizing the whole steelmaking industry. Producing steel via the scrap-based EAF route is fundamentally constrained by the availability of scrap. Scrap steel supply is determined by products manufactured decades ago reaching their end of life, which also influences the quality and grade of the supply. Appropriate infrastructure and incentives must be in place to secure scrap supply at reasonable price points in the face of international trade. High-quality scrap steel shortages have already occurred in the US.[53]

In addition, continual recycling can potentially concentrate certain impurities, and some applications, such as automotive, military and defense, or highly engineered products are not well suited to recycled material. Therefore, most forecasts suggest that scrap alone will not be able to meet steel demand well into the future. For example, BloombergNEF (BNEF) forecasts primary steel will comprise 50% of global steel demand in 2050. Wood Mackenzie estimates that primary steel production as a percentage of total US steel production will remain roughly unchanged in their 2040 scenario.[54]

Nucor's recently announced, state-of-the-art 3 Mtpa steel sheet capacity EAF minimill in West Virginia will increase the supply of secondary steel in the region. It will also tighten the regional supply of scrap steel, potentially driving up prices.

Hydrogen DRI-EAF Inflection Point

Of the various options for reducing carbon emissions in primary steelmaking, hydrogen-based direct reduction of iron (DRI) followed by electric arc furnace (EAF) using renewable electricity is considered the most viable option near-term for achieving zero-emission primary steel production.

The blast furnace ironmaking process accounts for approximately 70% of the greenhouse gas emissions from the integrated steelmaking process. In the DRI process, hydrogen can provide a carbon-free source of fuel as well as the reducing agent, producing water vapor instead of CO_2 (Figure 8). When hydrogen is produced from

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[50] Based upon the average grid mix.

[51] International Energy Agency (IEA), "Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking," Part of the Energy Technologies Pathways Series, OECD Publishing, 2020, https://www.iea.org/reports/iron-and-steel-technology-roadmap

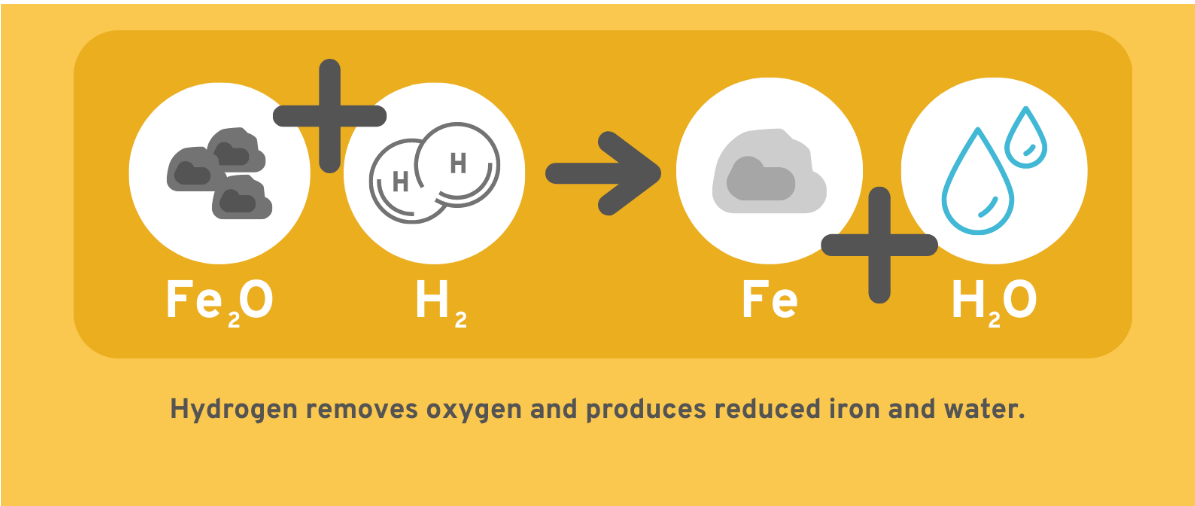
[52] American Iron and Steel Institute, "This Week's Raw Steel Data," American Iron and Steel Institute, December 31, 2022, https://www.steel.org/industry-data/

[53] Wood MacKenzie, "How Green Can Steel Go? The potential impact on coal and iron ore," Webinar, May 2022, https://www.woodmac.com/news/opinion/how-green-can-steel-go--and-what-does-it-mean-for-coal-and-iron-ore/thank-you/

[54] Wood MacKenzie, "How Green Can Steel Go? The potential impact on coal and iron ore," Webinar, May 2022, https://www.woodmac.com/news/opinion/how-green-can-steel-go--and-what-does-it-mean-for-coal-and-iron-ore/thank-you/

renewable sources via electrolysis of water ("green hydrogen") and the electricity required for the EAF process is derived from renewable sources, this fossil fuel-free steel has the potential for near zero emissions.

Figure 8: Simplified Hydrogen-based Direct Reduction of Iron



Source: Ohio River Valley Institute

Sidebar: What is the Difference Between Gray, Blue, and Green Hydrogen?

Hydrogen is a colorless, odorless gas that is the lightest and most abundant element on Earth. When used as a reducing agent for separating metallic iron and oxygen from iron ore, it releases only water vapor and does not produce any carbon emissions.

Procuring hydrogen involves separating it from other elements through chemical processes that require energy. Depending on what process is used, there are three main categories of hydrogen: gray, blue, and green...

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Direct reduction of iron is a commercialized process currently producing millions of tons of steel. Most applications currently use syngas (a mixture of carbon monoxide and hydrogen) produced from either coal or natural gas as the reducing agent. However, increasing hydrogen content up to 100% can be achieved with minor equipment retrofit and has been demonstrated.[55] Thus, it provides a pathway to fossil fuel-free, zero-emission steel. The source of the hydrogen is a determinant of the net environmental benefit, and the choice of reducing agent is often based on economic viability.

As green hydrogen approaches cost parity relative to natural gas-based alternatives and the pressure to decarbonize increases, hydrogen-based DRI steel has seen increased investment and development. Last year, HYBRIT, the Swedish venture by SSAB, Vattenfall (the state-owned utility), and Finnish iron ore producer LKAB, made history when it delivered the world's first commercial fossil fuel-free steel to Volvo group. With a carbon footprint of 25g CO_2e/ton, it represents around a 95% reduction. SSAB and its partners expect to deliver commercial quantities of green steel from 2026 onwards. Several other European ventures also have plans to achieve commercial delivery of fossil fuel-free steel by 2026, including H2GS (Sweden), ThyssenKrupp (Germany), and ArcelorMittal (Spain). Outside of Europe, progress is slower, but Korean-based POSCO announced plans to build a test facility with an annual production of one million tons in Pohang Works by 2028 to confirm the possibility of commercialisation of HyREX technology, a hydrogen reduction steelmaking method based on FINEX fluidized bed reduction reactor technology. Chinese Sinosteel and Hebei Iron and Steel (HBIS) Group have also announced projects. The US is clearly behind. However, US-based ThREE Consulting has applied for DOE FOA funding to generate integrated feasibility studies of hydrogen DRI technologies with nuclear and renewable power. [56]

[55]A number of furnace models may require some low-risk equipment modifications to enable this, while some of the more advanced furnaces would require no equipment changes.
Todd Astoria, Greg Hughes, and Noriaki Mizutani, "MIDREX NG™ with H_2 Addition: Moving from natural gas to hydrogen in decarbonizing ironmaking," Midrex, March 2022,
https://www.midrex.com/tech-article/moving-from-natural-gas-to-hydrogen-in-decarbonizing-ironmaking/
[56]H2 Green Steel (H2GS) has plans for a 2.1 Mtpa demonstration plant to begin in 2024. The plant is expected to reach full capacity by 2026, producing 5 Mtpa of fossil free zero-emissions steel by 2030. EU funded H2FUTURE, a Voestalpine- led partnership, has been testing production of fossil free steel via hydrogen DRI in its pilot plant in Linz, Austria since 2019. In Germany, ThyssenKrupp has committed funds to transition its Duisburg site to hydrogen DRI, which will begin producing around 2.5 Mtpa of low-emission steel by 2026. Salzgitter AG (Germany's second largest steelmaker) has recently installed a 2.5GW Wind Powered Electrolyzer to produce hydrogen to feed its DRI steelmaking process with plans for decarbonisation of its processes in Germany by 2050. Finally, ArcelorMittal, the world's second-largest steel producer, will be producing 1.6 Mtpa of green steel by 2025 at a new zero-carbon plant in Spain.

Implications for the Ohio River Valley

Mon Valley Works

Mon Valley Works is an integrated steel manufacturing operation consisting of the Clairton Plant, the Edgar Thomson Plant, and the Irvin Plant in western Pennsylvania and the Fairless Plant outside Philadelphia.

Crude steel production consists of the Clairton Plant, which produces coke and coke by-products, and the Edgar Thomson (ET) Plant, which produces hot iron in blast furnaces, that is then converted into steel at the basic oxygen shop.

The Clairton Plant has the capacity to produce 4.3 Mtpa of metallurgical (met) coke in 10 coke batteries and supplies coke for iron and steel production at the Edgar Thomson Plant as well as other steelmaking locations. Investment in both coking coal mines and coke batteries has been decreasing and is expected to continue declining. Banks and governments continue to announce future investments in new coal mines will be halted. For example, earlier in 2022, South32 announced it would abandon its plan to extend the development of its met coke mine in New South Wales, citing a "shift towards 'metals critical to a low carbon future.'" South32 CEO Graham Kerr continued by citing concerns from investors that "in 80% of our meetings people ask questions about met coal."

As investors continue to shy away from investment in mines, blast furnace steel makers will likely face higher prices for coke derived from coal. Higher costs for coke puts upward pressure on the price of steel made from coke. This in turn makes coke steel less attractive than primary steel alternatives such as hydrogen DRI-EAF, accelerating the transition. Steelmakers must take this into consideration in their longer-term scenario planning. For example, relining of the blast furnaces is the major capital expenditure that drives investment cycles in a steel mill. The median time between relining has been estimated to be 17 years.[57] During relining, production typically ceases for several months while the refractory material lining of the furnace is replaced. Such an investment can be similar in magnitude to what is required for a new blast furnace, and it extends the life of the unit and often the entire plant. Globally, most steel plants will begin their next investment cycle in the coming two decades as they reach the point of needing refurbishments and replacements. In the US, it is estimated that close to 97% of existing blast furnace capacity will reach the end of operational life and require reinvestment before 2030.[58] The timing of these capital investments provides a critical window for strategic implementation.[59]

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[57] Vogl, Valentin, Olle Olsson, and Björn Nykvist, "Phasing out the blast furnace to meet global climate targets," Joule 5.10 (2021): 2646-2662, https://www.sciencedirect.com/science/article/pii/S2542435121004359
[58] Agora Energiewende, "Global Steel Transformation Tracker," Agora Energiewende, Accessed February 2023, https://www.agora-energiewende.de/en/service/global-steel-transformation-tracker/
[59] IEA, "Iron and Steel Technology Roadmap: Towards more sustainable steelmaking," IEA, October 2020, https://www.iea.org/reports/iron-and-steel-technology-roadmap

In April 2021, US Steel announced it was canceling the $1.3 billion planned investment in Mon Valley Works and that three of the batteries at its Clairton Coke Works would be permanently idled.[60] US Steel CEO David Burritt said at the time, "With a clear vision for our future, we have evaluated how we allocate capital through the lens of sustainability, value creation, and lower capital and carbon intensity across the footprint." The company also announced that quarter that it plans to achieve net-zero carbon emissions by 2050, stating it will rely on growing its EAF fleet coupled with other technologies such as direct reduced iron, carbon-free energy sources, and carbon capture, sequestration, and utilization. Investments to transform Mon Valley Works to near zero-emission fossil fuel-free DRI provides an alternative to other options to achieve US Steel goals that would have a significant impact on the region (e.g., a shift to EAF in right-to-work states in the South).

Jobs Impact of a Transition to Fossil Fuel-Free Steelmaking

See Table 1 for a high-level analysis of the job implications of a transition to green steelmaking for the region. The full steelmaking process is analyzed, beginning with the mining of iron ore and including the mining or production of fuel and reducing agents through to the production of crude steel. Finishing processes post-crude steel production are considered largely unchanged in each scenario, regardless of how the steel is produced, and are therefore excluded. This report provides estimates of the number of direct jobs supported by ironmaking and steelmaking under several scenarios. The number of indirect and induced jobs is also estimated, using two different approaches in order to illustrate a range of total jobs in the economy.

The Scenarios

Data from the US Bureau of Labor Statistics (BLS) suggest that direct employment in iron, steel, and ferroalloy manufacturing has declined in Allegheny County over the last 10 years (Figure 9). Between 2011 and 2021, the number of such jobs in Allegheny County declined by 30.8%. This trend is expected to continue as automation trends continue, global competition increases, and more states join those such as Arkansas and West Virginia that have offered large tax incentive packages effectively designed to lure steelmaking investment away from Pennsylvania. Given that current levels of employment in the industry will likely continue to decline, it is crucial to compare job estimates for fossil fuel-free steelmaking to estimates of future jobs in the region, which account for the declining employment trend along with the present scenario. The three scenarios are discussed below.

In all three scenarios it is assumed that iron ore comes from outside of the region and thus does not contribute to regional jobs. Full-time employment in coal mining, iron and steelmaking, renewable energy production, and hydrogen electrolysis are assumed to be jobs at facilities located in the region.

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[60] Justine Coyne, "US Steel drops Mon Valley investment, idling three coke batteries at Clairton," S&P Global, April 30, 2022, https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/043021-us-steel-drops-mon-valley-investment-idling-three-coke-batteries-at-clairton

Table 1: Estimated Direct, Indirect and Induced Jobs at Present, Trended to 2031, and the Impact of a Shift from BF-BOF Steelmaking to Fossil Fuel-free Hydrogen-based DRI Steelmaking in the Ohio River Valley

In- and Out- of Region Direct Jobs Impact (FTE)

The Present...		If Employment Trends Continue through 2031...		Under Fossil Fuel-Free DRI-EAF Investment	
	Full-time direct jobs		Full-time direct jobs	**Hydrogen & renewables**	Full-time direct jobs
				Hydrogen	328
				Wind	15
				Solar	406
				Total hydrogen & renewables	**749**
Mining		**Mining**		**Mining**	
Iron ore (out of region)	365	Iron ore (out of region)	256	DR-grade iron ore (out of region)	365
Coal mining	175	Coal mining	123		
Total Mining	**540**	**Total Mining**	**379**	**Total Mining**	**365**
Iron and steelmaking		**Iron and steelmaking**		**Iron and steelmaking**	
Coking	413	Coking	286	DRI	151
BF-BOF	482	BF-BOF	334	EAF	628
Total iron and steel making	**895**	**Total iron and steel making**	**620**	**Total iron and steel making**	**779**
Estimated Regional Direct Jobs	**1070**	**Estimated Regional Direct Jobs**	**743**	**Estimated Regional Direct Jobs**	**1,528**
Total Direct Jobs, including iron ore	**1,435**	**Total Direct Jobs, including iron ore**	**999**	**Total Direct Jobs, including iron ore**	**1,893**

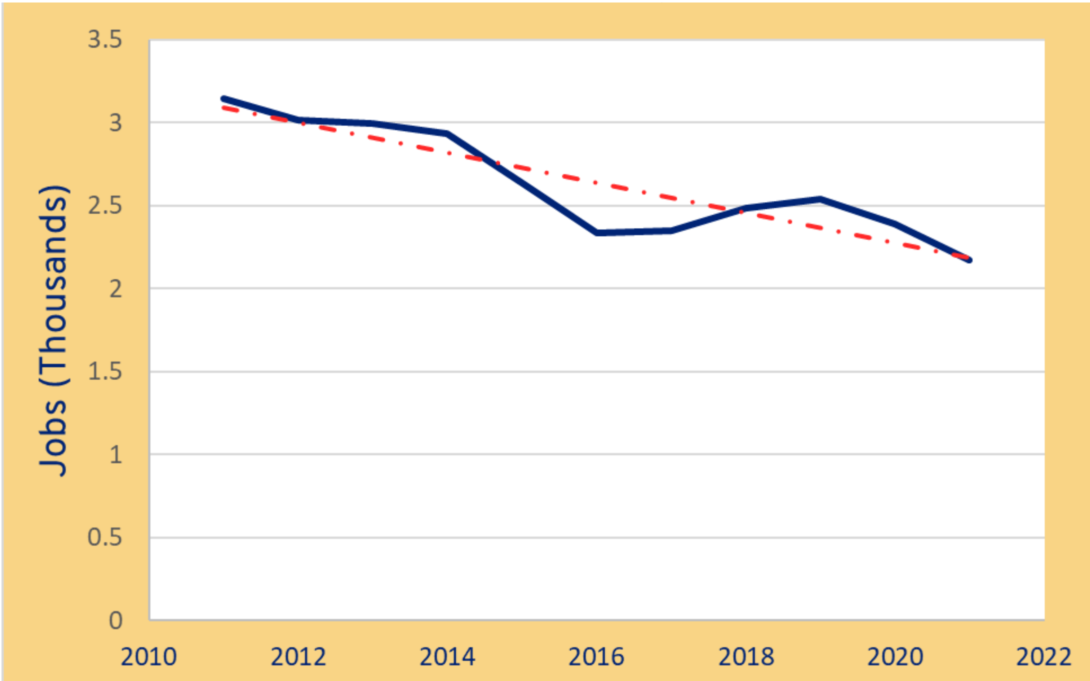
In-Region Direct, Indirect and Induced Jobs Impact (FTE)

The Present...		If Employment Trends Continue through 2031...		Under Fossil Fuel-Free Hydrogen DRI-EAF Investment	
Estimated Current Regional Direct Jobs	**1070**	**Estimated Regional Direct Jobs**	**743**	**Estimated Regional Direct Jobs**	**1,528**
Estimated Current Indirect & Induced Regional Jobs	**1,605**	**Estimated Indirect & Induced Regional Jobs**	**1,115**	**Estimated Indirect & Induced Regional Jobs**	**2,292**
Total Regional Jobs	**2,675**	**Total Regional Jobs**	**1,858**	**Total Regional Jobs**	**3,820**

***** See appendices for estimation using industry modeled multipliers and their sources.

Source: Ohio River Valley Institute

Figure 9: Allegheny County, PA Employment in Iron and Steel Mills and Ferroalloy Manufacturing, 2011-2021



Sources: US Bureau of Labor Statistics & Ohio River Valley Institute

The Present

Publicly available data from the mining and steelmaking industries was used to estimate direct jobs under the present scenario for an assumed annual production of 2 Mtpa. In the first column of Table 1 (red), there are an estimated 540 jobs in mining, excluding any jobs associated with the transportation of coal or ore. Some of these jobs are outside of the region, with the bulk coming from iron ore mines in Minnesota. Using the industry's current data, the production of 2 Mtpa via BF-BOF steelmaking supports 895 direct regional jobs. The number of indirect and induced jobs is also estimated using two different local economic multipliers in order to illustrate a range of outcomes.

In the first approach, a low local economic multiplier of 1.5 is applied. This is consistent with multipliers estimated by Bartik and Sotherland[61] and other economists using empirical methods and observed data. These empirical multipliers more realistically capture the net impact of industries on local economies without relying on modeling assumptions. The second approach uses higher economic multipliers derived from industry and policy literature. These multipliers vary for each job-creating activity and are typically derived from input-output models, which require a multitude of assumptions and can often omit important offsetting negative market-based impacts. A range of reported industry multipliers are reported, with most based on input-output modeling. For example, industry-produced local economic multipliers for iron and steel jobs can be found ranging from 2.6

[61] Timothy Bartik and Nathan Sotherland, "Realistic Local Job Multipliers," W.E. Upjohn Institute for Employment Research, April 24, 2019, https://research.upjohn.org/up_policybriefs/8/

(AISI)[62] to 9 (USS), with the full range reported as the upper limit.[63] (See Appendix for the results using the industry multipliers and sources of the multipliers.)

It is estimated that production of 2 Mtpa[64] of crude steel under the current processes supports 1,070 direct jobs in the region. These direct jobs, in turn, are estimated to support 1,605 indirect and induced jobs in the regional economy. Together, that totals an estimated 2,775 direct, indirect, and induced regional jobs.

Sidebar: Jobs Accounting—The Economic Factors Influencing Job Multipliers and Temporary Jobs

A full accounting of the jobs impact of a transition to green steelmaking must include both the direct jobs generated and supported by the proposed transitions as well as the indirect jobs. There are broadly two categories of indirect job impacts associated with direct employment changes in a given industry: supplier jobs and induced (or respending) jobs. The total of these influences make up the "employment multiplier." Additionally, there will be construction jobs which are often temporary and the associated similar indirect economic impacts.

Accounting for these jobs can be complex and depends on several different factors and how they interact over time. The first is the time horizon that is considered. A study by Tsvetkova and Partridge (2016) found that most major economic investments within a region, such as the construction of new infrastructure or the opening of new plants and extraction operations, occurs as a sequence of events over time. This sequence begins with the planning and construction phase and ends with the ongoing operation and maintenance of the project. Each phase is associated with a different level of local employment changes within various sectors. Further, sectors respond to the employment, migration, price, and wage changes induced by the new project during each phase differently over time…

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If Employment Trends Continue through 2031

In the second column of Table 1 (yellow), the 10-year employment trend shown in Figure 9 is extrapolated. In this scenario, the steel industry in the region continues to operate BF-BOF facilities and remains susceptible to national and international trends. For a variety of reasons, including automation, outsourcing, offshoring, and increasing needs for capital investment and upkeep, employment in the industry at Mon Valley will likely continue to decline.

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[62] American Iron and Steel Institute, "The Economic Impact of the American Iron and Steel Industry," Pennsylvania District 18 Jobs Impact Table, American Iron and Steel Institute, Accessed March 2023, https://www.steel.org/economicimpact/
[63] US Steel, "2022 Annual Report," US Steel, 2022, https://s26.q4cdn.com/153509673/files/doc_financials/2022/ar/2022-Annual-Report.pdf
[64] Mon Valley Works produced 2.7 Mtpa of crude steel in 2022. Iron and Steel Technology, 2022 AIST Basic Oxygen Furnace Roundup, April 2022, p. 192.

Extrapolating current trends, it is estimated that by 2031, the industry will support 620 direct steelmaking jobs—a nearly 31% decline from current levels. It is assumed that mining jobs supported by Mon Valley Steel Works, some of which are located outside of the region, scale proportionately to production. This would translate to 123 jobs related to coal mining in the region, for a total of 743 regional direct jobs. The overall reduction in regional employment and income also reduces the number of indirect and induced jobs supported in the broader economy. Using the empirical local economic multiplier, the region is estimated to lose an additional 490 indirect and induced jobs. (See Appendix for the results using the industry multipliers and sources of the multipliers.)

The overall impact of continuing business as usual for the next decade is that the Ohio River Valley region could lose 817 direct, indirect, and induced jobs.

With Fossil Fuel-Free Hydrogen-Based DRI-EAF Investment

If steel manufacturers in the region pursue decarbonization through investments in renewable energy infrastructure used to generate green hydrogen, there is likely to be a significant positive impact on the regional economy. The third column of Table 1 (green) shows job estimates under this scenario, assuming 2 Mtpa of crude steel production. There are several important items to note.

First, although DRI-EAF supports fewer direct iron and steelmaking jobs (779) than present (895), the green steelmaking pathway will actually support more jobs overall than traditional BF-BOF steelmaking by 2031 (620). One key explanation is that investing in fossil fuel-free steel will allow the region to maintain a competitive position in the industry and outsourcing and offshoring are not as likely to siphon as many of these jobs out of the state or country. Put another way, the transition to fossil fuel-free steelmaking under the scenario outlined in this report retains 87% of current iron and steelmaking jobs, while maintaining the status quo is estimated to retain only 69% of current iron and steelmaking jobs by 2031.

Second, a new category—Hydrogen & Renewables—appears in the third column of Table 1. Investment in wind and solar renewable energy infrastructure as well as hydrogen electrolyzer(s) will create new full-time jobs in the region that directly support fossil fuel-free steelmaking. The National Renewable Energy Laboratories' (NREL) Jobs and Economic Impact (JEDI) model is used to estimate jobs associated with the ongoing operation and maintenance of these renewables. The JEDI model allows users to input the specific scale and location of an energy project, such as a solar or wind farm, to estimate the number of direct jobs associated with the project in a given state. Default values used in the model are derived from NREL's interviews with industry experts and project managers as well as various industry, state, and national economic reports.

An even split between wind and solar is assumed to deliver the energy required for hydrogen and steel production. Pennsylvania-specific capacity factors for wind and solar are used in the calculations (EERE DOE, PAPUC, PADEP).[65] The total jobs associated with ongoing wind and solar operation and maintenance are estimated to be 421 additional direct regional jobs, assuming that the infrastructure is also located in the region. Of these renewable jobs, 406 come from solar with 15 from wind.

[65] Applying separate capacity factors for wind and solar separately likely results in an oversizing of required capacity due to the complementary nature of wind and solar. For example, the sun shines brightest during the day, while the wind begins to ramp up in the evening. Similarly, wind is stronger in the winter when the sun shines less.

Hydrogen for the DRI process is produced via an electrolyzer powered by renewable energy. Industry data is used to provide process inputs scaled to estimate full-time employees needed for the DRI-EAF process. Adequate storage of hydrogen is assumed in order to provide a continuous supply of hydrogen (See Appendix for key assumptions and Sidebar: System Design to Enable True Green Hydrogen). It is estimated that 328 jobs will be required to support the hydrogen production necessary for 2 Mtpa of fossil fuel-free steel production. This does not include any jobs associated with the transportation of the hydrogen.

The same methodology is applied to estimate the number of indirect and induced jobs supported in the local economy by DRI-EAF steelmaking, hydrogen electrolysis, and renewable energy generation. Using the empirically derived local economic multiplier of 1.5, 2,292 indirect and induced jobs would be supported. Using the industry multiplier would result in many more (see Appendix). In total, it is estimated that the green hydrogen DRI-EAF pathway would support 3,820 total jobs in Pennsylvania's Ohio River Valley region, if the renewables, required electrolyzer(s), and DRI-EAF facilities are all constructed locally.

This is a net increase from the present, with an estimated 458 regional direct jobs and 687 additional indirect and induced jobs for a total of 1,145 more regional jobs than steelmaking presently supports, using the more conservative empirical local economic multiplier. (If the industry-generated multipliers are used, this estimate more than doubles. See Appendix.)

It should be noted that additional training will likely be required to enable the transition from BF-BOF steelmaking to DRI-EAF, but the skillset and wages are assumed to remain similar for this analysis. The 749 jobs associated with hydrogen and renewables will likely require more significant workforce training, although there may be some skill overlap with existing jobs in the chemical and energy sectors in the region. These training jobs also represent additional gains, although the precise number is difficult to estimate.

Construction Jobs

A transition to fossil fuel-free steelmaking in the Ohio River Valley would require significant construction of new renewable infrastructure and hydrogen electrolyzer capacity and ensuring that steelmaking facilities are properly outfitted for DRI-EAF.

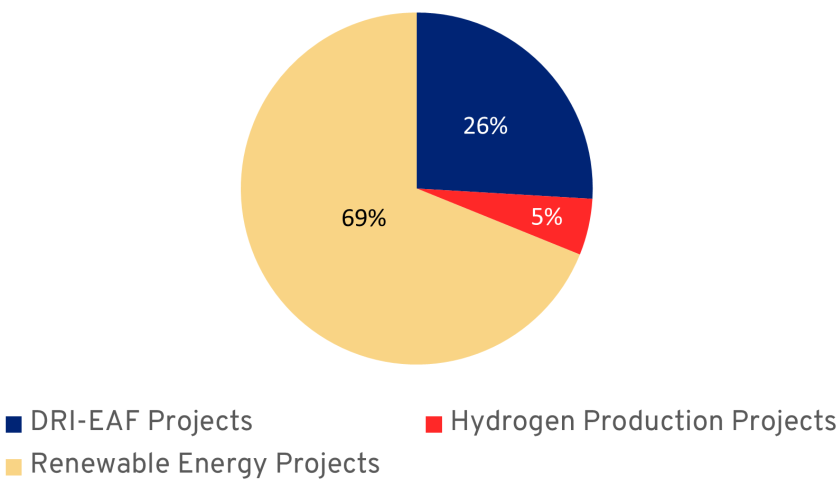
Construction jobs are challenging to estimate. They are temporary jobs and can often utilize labor that is non-local due to trade worker shortages or a desire to employ unionized construction labor. Additionally, the total number of construction workers supported by a project is dependent on the timeline of the project itself. A rapid buildout requires more workers. The timeline of a construction project, in turn, can depend on material supply chains, the regulatory environment, or labor shortages, making job estimation complex. This analysis relies on reported construction data for similar EAF and DRI projects in the last decade across the United States and Canada, which have generally lasted around 2 years and created approximately 2,500 total reported construction jobs.[66] The construction of necessary hydrogen infrastructure is similarly estimated to generate an additional 500 or so jobs.

[66]Based upon similar projects, it is estimated that this project would require about 1,500 jobs for DRI construction, about 1,000 construction jobs for EAF construction, and about 500 jobs for the electrolyzer and hydrogen production facility.

One of the large components of the transition to green steelmaking would be the dramatic buildout of solar and wind infrastructure required. This report assumes that renewable power for hydrogen production is generated 100% in-state. The JEDI model provides solar and wind construction jobs based on the capacity estimated to provide for 2 Mtpa of crude steel production as well as unique Pennsylvania capacity factors and default values that JEDI provides derived from industry reports and interviews. JEDI estimates that solar field construction on the necessary scale would create 6,560 construction jobs, while wind farm construction would support 80 construction jobs.

Multipliers for construction range from 1.5 to 1.8 (with the exception of the jobs multiplier for wind construction in the JEDI model, which is 7.19). Therefore, the indirect and induced impact of construction to enable fossil fuel-free steel transition range from an estimated 11,900 to 15,800 jobs. (See Appendix for sources of construction multipliers used.)

Figure 10: Percentage of Estimated Construction Jobs Supported by the Fossil Fuel-Free Steel Transition in Southwestern Pennsylvania



Source: Ohio River Valley Institute

These are crude estimates based on industry averages, as JEDI notes, and are not predictions. The number of construction jobs supported would ultimately be highly dependent on the timeline of the projects, final capacity scale, prevailing labor and input market conditions, and the final location of the builds.

What can be said with certainty is that the investment in steelmaking and hydrogen production, as well as the scale-up of renewables to meet the energy demands for 2 Mtpa of green steel production, would bring dramatic construction investment and would generate significant additional positive job growth in the region that would likely last into the next decade.

Opportunity Is Ripe for the Ohio River Valley

Recent Federal Legislation Presents Historic Opportunity for Green Steel

Several pieces of recent federal legislation will support the domestic green steel industry, including the Infrastructure Investment and Jobs Act (IIJA) of 2021, the CHIPS and Science Act of 2022, and the Inflation Reduction Act (IRA) of 2022.

The $1 trillion IIJA, which includes funding for roads, bridges, ports, transportation, and water infrastructure, has been hailed by the industry association, which estimates it "could increase [domestic steel demand] by as much as five million tons for every $100 billion of new investment."[67] A specific provision within the bill, Build America Buy America (BABA), includes a domestic content procurement preference, which calls for "all iron, steel, manufactured productions and construction materials for infrastructure products" to be produced in the US,[68] which could further enhance demand for domestic steel. This domestic procurement could also increase for electrical steel, a specialty steel used in transformers, EVs, and EV supply equipment. Currently, electrical steel is produced in only two facilities in the US—one in Ohio and one in Pennsylvania—though US Steel's Big River Steel Mill in Arkansas is expanding its electrical steel production.[69]

The CHIPS Act and IRA represent "two pieces of legislation that will strengthen domestic manufacturing and create opportunities in the future for the American steel industry," according to Nucor president and CEO Leon Topalian. The CHIPS Act would help "unleash a manufacturing renaissance across the United States…the Inflation Reduction Act contains provisions that encourage the procurement of American-made steel products in clean energy infrastructure…and will give us a competitive advantage."[70]

The CHIPS Act appropriated $250 billion to support the domestic semiconductor industry, which had fallen behind its Asian counterparts. Taiwan and China, in particular, have developed low-cost infrastructure and now produce most of the world's semiconductors. A shortage of imported semiconductors crippled many domestic manufacturers over the past two years. The bill is expected to advance domestic manufacturing beyond semiconductors. The American Iron and Steel Institute touted the benefits of the act for the domestic steel industry. The industry group cited the benefits to the domestic automotive supply chain, noting "steel currently makes up about 54% of the mass of the average North American vehicle, and the American steel industry is

[67] American Iron and Steel Institute, "AISI Applauds House Passage of Bipartisan Infrastructure Bill," American Iron and Steel Institute, November 6, 2021, https://www.steel.org/2021/11/aisi-applauds-house-passage-of-bipartisan-infrastructure-bill/
[68] Office of Acquisition Management, "Build America Buy America," US Department of Commerce, Accessed March 2023, https://www.commerce.gov/oam/build-america-buy-america
[69] US Steel, "Our Big River Mill: Expanding NGO Steel Leadership," US Steel, Accessed March 2023, https://www.ussteel.com/customers/solutions/electrical#:~:text=OUR%20BIG%20RIVER%20MILL%3A%20EXPANDING&text=Big%20River%20Steel%20adds%20a,of%20motor%20lam%20steel%20grades.
[70] SA Transcripts, "Nucor Corporation (NUE) Q3 2022 Earnings Call Transcript," Seeking Alpha, October 20, 2022, https://seekingalpha.com/article/4547953-nucor-corporation-nue-q3-2022-earnings-call-transcript

developing and supplying the advanced steel products needed by the American automotive industry as automakers transition to electric vehicles (EVs)."[71]

The IRA is the legislation expected to truly accelerate domestic green steelmaking. The headline number of the IRA was $350 billion in funding for renewable energy. However, the Congressional Budget Office (CBO) has underestimated the potential benefits of the legislation by more than half, according to investment firm Credit Suisse.[72] That firm estimates benefits could be as high as $800 billion over the next ten years since benefits are uncapped and "stackable." According to Credit Suisse, CBO's estimated IRA federal spending for advanced manufacturing was the greatest underestimate. The CBO estimated $31 billion, just 10% of Credit Suisse's $250 billion estimate.

Many provisions within the IRA are bullish for the domestic steel industry. For example, the IRA's Manufacturing and Investment Tax Credit 48C provides $10 billion in credits for specific energy projects. Such projects might include reequipping steel facilities to sell into clean energy supply chains or creating decarbonization tools for the industry. This section also allocates $4 billion for projects located in energy communities.[73]

In addition, federal spending through the IRA could "catalyze a further $1.7 trillion in private sector spending," according to Senator Ed Markey, "which then could unleash private sector investment in technologies all over the planet. There's an appetite on Wall Street as long as there's a little bit of risk taken by the public sector." [74] Private sector investment is critically important to the clean energy transition. According to Jigar Shah, director of the loans program at the US Department of Energy, public incentives provide important catalysts in new technology, particularly in the energy space.

In addition to incentives for renewable energy and advanced manufacturing, recent legislation includes other key provisions that will benefit domestic green steel production. Specifically, the IRA incentivizes domestic green steel production through its focus on domestic content, intended to reduce outsourcing to other countries, particularly critical components for the energy transition.

Domestic content is a key feature of the IRA's Investment Tax Credits (ITC), Production Tax Credits (PTC), and Electric Vehicles (EV) and manufacturing credits. Clean electricity ITC and PTC credits have a 10% bonus (percentage points in the case of ITC) if all steel, iron, and more than 40% of the manufactured products are made in the US.

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[71] American Iron and Steel Institute, " AISI Applauds Passage of CHIPS Bill," American Iron and Steel Institute, July 28, 2022, https://www.steel.org/2022/07/aisi-applauds-passage-of-chips-bill/

[72] Betty Jiang et. al., "US Inflation Reduction Act: A Tipping Point in Climate Action," Credit Suisse, November 30, 2022, https://www.credit-suisse.com/about-us-news/en/articles/news-and-expertise/us-inflation-reduction-act-a-catalyst-for-climate-action-202211.html

[73] Bradley M. Seltzer et. al., "Treasury Department Releases Section 48C Guidance with Billions in Tax Credits up for Grabs," Holland & Knight, February 14, 2023, https://www.hklaw.com/en/insights/publications/2023/02/treasury-department-releases-section-48c-guidance#:~:text=Reinstated%20by%20the%20Inflation%20Reduction,projects%20located%20in%20energy%20communities.

[74] Bill McKibben, "Ed Markey: I'll Organize Senate Dems to Demand World Bank Chief be Fired!" The Crucial Years, November 11, 2022, https://billmckibben.substack.com/p/ed-markey-ill-organize-senate-dems?utm_source=post-email-title&publication_id=438146&post_id=83903480&isFreemail=false

The IRA also contains incentives impacting green materials:

- The Advanced Industrial Facilities Deployment Program Tax Credit creates a new $5.8 billion program under the Office of Clean Energy Demonstration (OCED) to invest in projects aimed at reducing emissions from energy-intensive industries, including iron, steel, concrete, glass, pulp, paper, ceramics, and chemical production.

- A $4.5 billion tax credit for the use of low-carbon construction materials, including $2.15 billion to the Federal Buildings Fund for GSA to acquire and install low-carbon building materials and products.

- EVs built in the US will be eligible for a $7,500 tax credit. The IRS and Treasury Department have confirmed that this credit will only be available to US manufacturers.

- Additional indirect benefits of IRA, such as increased transferability of tax credits, may broaden the pool of investors in green steel. Clean fuel production credits may also provide additional incentives for green steelmakers.

Other benefits in the IRA that could support green steel production are regional, with additional incentives for "Energy Communities," such as communities created by coal-fired unit retirements (Figure 11).

An energy community is defined as:

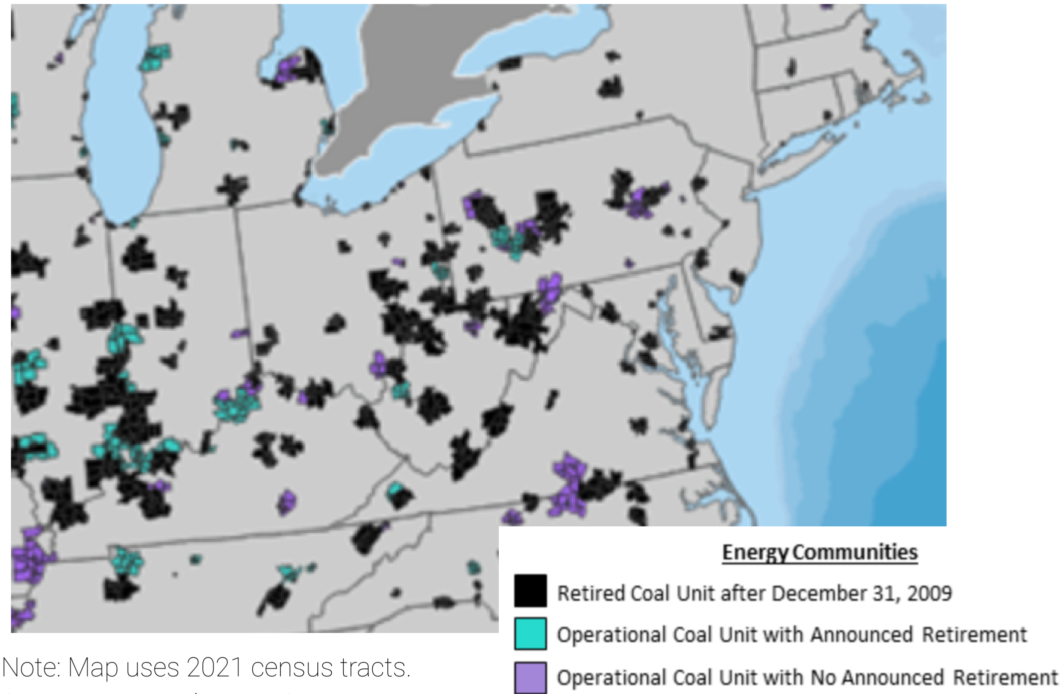
- A brownfield site, as defined by the EPA.

- Areas with an above-average unemployment rate and either greater than 0.17% direct employment or greater than 25% local tax revenues related to coal, oil, or natural gas processes.

- Census tracts containing mines or coal-fired generating units that have closed or been retired after December 31, 1999.

All projects built in an energy community eligible for PTCs and ITCs (wind, solar, storage, nuclear SMRs, carbon capture, etc.) are eligible for a 10% increase in their credits.

Figure 11: Potential Energy Communities Based on Operational Coal Units, Ohio River Valley States



Note: Map uses 2021 census tracts.
Source: BTU Analytics, US Census Bureau

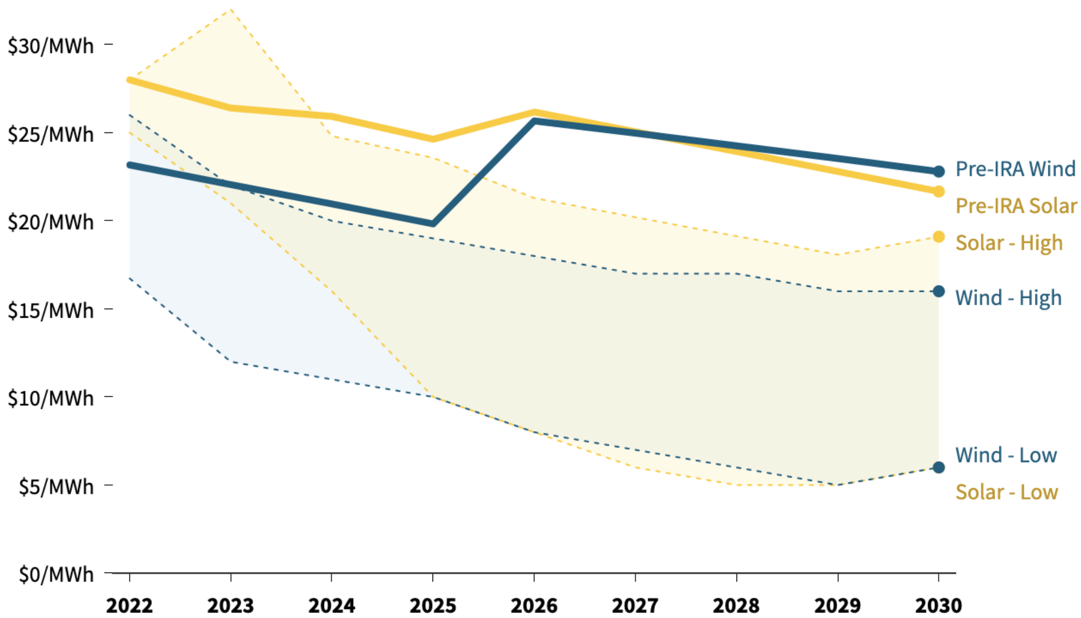
It is little wonder that domestic steel companies have reacted enthusiastically to the passage of the IRA.

Renewables Incentives to Bring Costs Down

The IRA makes producing green hydrogen and steel with renewable energy especially attractive. Even though specific projections differ, various analyses generally agree that post-IRA costs of renewable energy will fall drastically, making the production of green hydrogen and steel with renewable energy increasingly cost-effective.

A recent RMI analysis of projected levelized cost of energy (LCOE) for wind and solar concluded that post-IRA costs for solar and wind may fall to as low as $6/MWh by 2030 (Figure 12).[75]

Figure 12: Analyst Projections of Solar and Wind Levelized Cost of Energy (LCOE) Pre-IRA and Post-IRA, 2021 Dollars



Source: RMI analysis of NREL Annual Technology Baseline data, S&P and IHS Markit data, Credit Suisse data, and ICF data

Among the most impactful renewables and energy transition tax provisions for any new electricity-generating facility with zero GHG emissions are:

- The Clean Electricity Production Tax Credit, which pays $26/MWh of electricity produced and sold or stored at facilities placed into service after 2024.
- The Clean Electricity Investment Tax Credit, an emissions-based incentive that creates a credit of 30% of the investment in the year the facility is placed in service.

Both credits are set to phase out at the end of 2032 or when emission targets are achieved and will require developers to satisfy certain prevailing wage and apprenticeship requirements in order to qualify for the full credit amount. These credits cannot be stacked.[76]

Additionally, several state programs administered jointly by Pennsylvania's Department of Community and Economic Development (DCED) and the Department of Environmental Protection (DEP), under the direction of

[75] Lauren Shwisberg, "The Business Case for New Gas Is Shrinking," RMI, December 8, 2022, https://rmi.org/business-case-for-new-gas-is-shrinking/

[76] Bipartisan Policy Center, "Inflation Reduction Act Summary," US Department of Energy, October 2022, https://www.energy.gov/sites/default/files/2022-10/IRA-Energy-Summary_web.pdf

the Commonwealth Financing Authority (CFA), may be able to offset some of the wind and solar production project costs.

- The Alternative and Clean Energy Program (ACE) provides grants and loans for the utilization, development, and construction of alternative and clean energy projects in the state, including wind installations.
- The Solar Energy Program (SEP) provides grant and loan funds for the generation and use of solar energy.
- The Renewable Energy Program (REP) provides loans and grants for geothermal and wind projects.

Hydrogen Incentives to Bring Down Costs, Spur Regional Centers

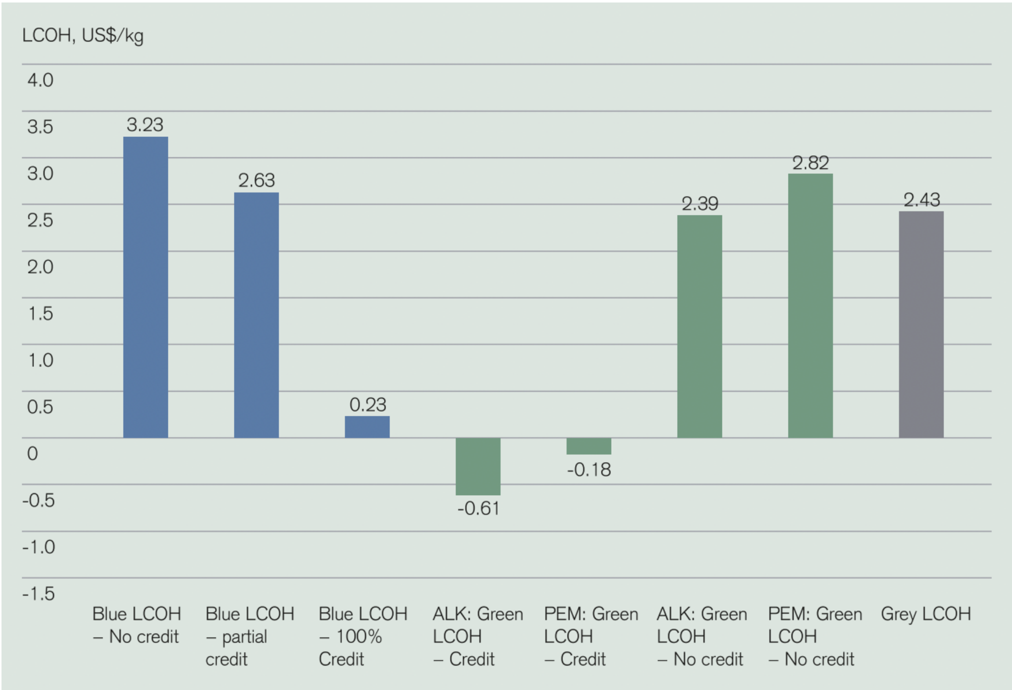
At present, producing hydrogen from fossil fuels is the cheapest option in most parts of the world. In 2021, the cost of low-emission hydrogen production in most regions was more expensive than from fossil fuels, i.e. $4/kg to $9/kg for green hydrogen vs. $1/kg to $3/kg for gray or blue hydrogen.[77]

However, according to BNEF, green hydrogen is forecasted to drop to around $2 in 2030 and under $1/kg in most international markets by 2050, making it cheaper than blue and gray hydrogen in cost per kilogram.[78]

The recent Credit Suisse report[79] supports this forecast, stating that green hydrogen will be the cheapest option due to the Renewables Investment Tax Credit (ITC) and Production Tax Credit (PTC) included in the IRA and an up to $3/kg PTC credit for electrolysis-based hydrogen for projects started before 2033. Their model estimates "a current cost of green hydrogen in the US of $2.82/kg using Alkaline electrolyzer or $2.39/kg using PEM electrolyzer, assuming a power price of $23/MWh. With the $3/kg credit, this implies a LCOH of -$0.61/kg and -$0.18/kg (for ALK and PEM, respectively."

[77] IEA, "Global Hydrogen Review 2022," IEA, September 2022, https://www.iea.org/reports/global-hydrogen-review-2022
[78] BloombergNEF, "Hydrogen Economy Outlook: Key Messages," BloombergNEF, March 30, 2020, https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf
[79] Betty Jiang et. al., "US Inflation Reduction Act: A Tipping Point in Climate Action," Credit Suisse, November 30, 2022, https://www.credit-suisse.com/about-us-news/en/articles/news-and-expertise/us-inflation-reduction-act-a-catalyst-for-climate-action-202211.html

Figure 13: US Comparative LCOH Using IRA tax credits (On-Site Generation)



Source: Credit Suisse

Lower green hydrogen costs will make producing fossil fuel-free steel at scale more achievable. "The production tax credits bring green production of steel, fertilizers and shipping fuel to cost competitiveness with current fossil-based commodity prices."[80]

Regional Assets Position the Ohio River Valley to Lead in Fossil Fuel-Free Steel Production

As the birthplace of the domestic steel industry, with more than a century of domain knowledge about all things steel, the region is well suited to lead the world in fossil fuel-free steel production. It has a century-long domestic supply chain for iron ore, a workforce it could transition, and legacy knowledge of the industry that provides insight into production processes and industry trends. It has geographic and natural assets, including rivers that can supply water for the fossil fuel-free steelmaking process, and transportation infrastructure. It has traditionally led the nation in energy production and is part of a steel manufacturing ecosystem.

[80]Oleksiy Tatarenko and Thomas Koch Blank, "The Inflation Reduction Act: The moment for US green steel and fertilizer," Energy Monitor, September 12, 2022, https://www.energymonitor.ai/tech/hydrogen/the-inflation-reduction-act-the-moment-for-us-green-steel-and-fertiliser/

150-Year-Old Supply Chain for Iron Ore to the Ohio River Valley Remains Strong, with DR-Plant Additions Coming Online

Iron ore, a key input for primary, BF-BOF, and fossil fuel-free steel production, is one of the largest commodity markets by value, second only to oil. Obtaining sufficient supplies of high-quality iron ore have bedeviled steelmakers for decades.[81] US BF-BOF steel producers have largely been spared from international iron ore supply and price issues because they are supplied by Minnesota's rich deposits of iron ore and are often captively owned. For example, in 2010, roughly half of iron ore capacity in North America was vertically owned by US Steel and Arcelor Mittal.[82] By 2020, US Steel or Cleveland Cliffs owned the five largest iron ore mines in the country.[83]

The supply chain for iron ore to the Ohio River Valley is nearly 150 years old, dating to the days when Andrew Carnegie merged three railroads to transport iron ore to southwestern Pennsylvania. This iron ore from the Midwest supplied his first mills in the 1870s, now the site of the Edgar Thomson Steel Works. The plant is still supplied by iron ore shipped from Minnesota.

Figure 14 illustrates the route from the Mesabi Range in Minnesota through three Great Lakes (Superior, Huron, and Erie) to a port in Ohio, where it is loaded onto a train for the final miles to the Mon Valley Works.

Figure 14: Iron Ore Shipment Route, Minnesota to Pennsylvania

Source: Central Penn Rail Productions[84]

[81] For example, as China increased its steel production, primarily to meet its growing domestic demand in the late 1990s and early 2000s, securing iron ore has been an ongoing constraint. As an importer of iron ore, it has been subject to volatile prices and supply issues.

[82] Rachel Tang, "China's Steel Industry and Its Impact on the United States: Issues for Congress," Congressional Research Service, September 21, 2010, https://sgp.fas.org/crs/row/R41421.pdf

[83] Mining Technology, "Five largest iron ore mines in US in 2020," Mining Technology, September 21, 2021, https://www.mining-technology.com/marketdata/five-largest-iron-ore-mines-the-us-2020/

[84] Central Penn Rail Productions, "Pennsylvania's Steel Route: Taking Ore Down the Bessemer," YouTube, February 14, 2020, https://www.youtube.com/watch?v=QZmHaCYW_Jo

The direct reduction process typically requires ore with higher iron content (DR-grade ore). The emerging fossil fuel-free steel industry's demand can be met by mines producing high-quality iron ores, or lower-grade ores can undergo further processing (beneficiation) to become DR-grade. According to the Iron Range Resources and Rehabilitation Board, most DRI pellets are imported into the US.

Although steelmakers are also developing new technologies that can utilize lower-grade ores, direct reduction steelmaking will likely continue to require vast amounts of high-quality iron ore.[85, 86] An adequate supply of high-grade ore has been cited as a potential headwind to fossil fuel-free steelmaking. However, several US steelmakers have recently announced plans to build plants in Minnesota's Iron Range to produce DR-grade iron ore pellets. These are not small investments—US Steel will spend $150 million[87] and Cleveland Cliffs will spend $100 million. Cleveland Cliffs has also said it would like to build an additional DRI plant in Minnesota. In short, proximity to DR-grade ore mines and existing transport routes are assets favoring fossil fuel-free steel in the region.

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[85] For example, melting the reduced iron before charging into a basic oxygen furnace (e.g Rio Tinto, ArcelorMittal and ThyssenKrupp) or molten oxide electrolysis (Boston Metal).

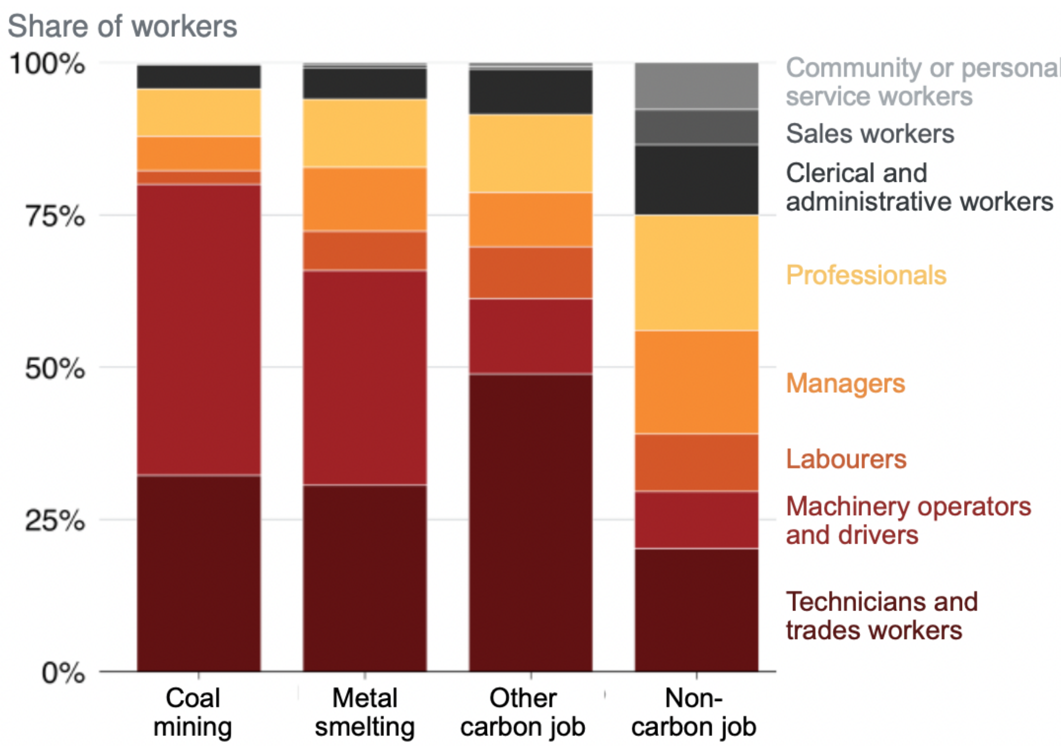
[86]For example, ThyssenKrupp, Germany's largest steel manufacturer, has developed technology to use lower-grade iron ore for DRI production. The reduced iron is then melted before charging into a basic oxygen furnace. Rio Tinto and ArcelorMittal are also developing similar processes.
ThyssenKrupp, "thyssenkrupp is accelerating the green transformation: Decision taken on the construction of Germany's largest direct reduction plant for low-CO2 steel," ThyssenKrupp, September 8, 2022, https://www.thyssenkrupp.com/en/newsroom/press-releases/pressdetailpage/thyssenkrupp-is-accelerating-the-green-transformation--decision-taken-on-the-construction-of-germanys-largest-direct-reduction-plant-for-low-co2-steel-146809

[87] Duluth News Tribune, "US Steel to build $150 million DR-grade pellet plant at one of its Iron Range mines," Duluth News Tribune, June 28, 2022, https://www.duluthnewstribune.com/news/local/us-steel-to-build-150-million-dr-grade-pellet-plant-at-one-of-its-iron-range-mines

Fossil Fuel-Free Steel Requires a Similar Job and Skills Mix as Traditional Steel and Coal

The region's primary steelmaking and coal mining workforce can transition to fossil fuel-free steelmaking. Many of the skills required to produce fossil fuel-free steel are similar to those in traditional primary steelmaking and overlap broadly with those of coal workers, according to an analysis of "carbon jobs" in Australia conducted by the Grattan Institute (Figure 15). The report found that both coal mining jobs and metal smelting require large numbers of technicians, trade workers, and machinery operators.

Figure 15: Jobs in Metal Smelting Require Similar Skills to Jobs in Coal Mining



Source: The Grattan Institute

The Grattan Institute concluded that if certain steel-producing regions "hosted direct reduction and electric arc plants of similar capacity to their existing furnaces, about 80% of the existing iron and steel jobs (including fabrication) would be retained." This is consistent with the jobs analysis presented above.

Emerging Workforce Development Opportunities

In addition to ongoing workforce development programs in Pennsylvania,[88] recent federal legislation includes specific funding for rural economic initiatives. Some are specifically focused on retraining workers, while others are broader but can be used to develop their workforce. Below is a partial list to illustrate the variety of workforce development opportunities included in recent legislation.

- The IIJA contains at least $800 million specifically dedicated to workforce development. According to a White House statement, the focus is on equitable workforce development to “provide workers in underserved communities with the skills and training to access newly created high-quality, unionized jobs in growing sectors.” Investments are targeted at critical sectors that should benefit the steel industry, including construction and electrification.

- The RECOMPETE pilot program, part of the CHIPS Act, offers large, multi-year grants to distressed communities where employment lags. The CHIPS Act also includes significant workforce training opportunities to support the domestic semiconductor industry as part of the $250 billion appropriation.

- The IRA has numerous workforce development opportunities, particularly in high-demand sectors such as clean energy and construction.[89] Substantial additional benefits are available for projects that meet specific wage and apprenticeship requirements. The IRA also provides $200 million in funding to train and develop energy efficiency training programs.

- The Good Jobs Challenge, part of the American Rescue Plan, offered $500 million in grants for economic and workforce development. PhilaWorks, an economic and workforce development organization in southeastern Pennsylvania, was awarded $22.8 million as one of 32 winners. The award will deploy training opportunities to prepare 3,000 workers for jobs in a variety of industries, including manufacturing and energy.

- Coal communities received more than $550 million through the American Rescue Plan for economic recovery during the COVID-19 pandemic. The Coal Communities Commitment program awarded Southwestern Pennsylvania (SWPA) New Economy Collaborative $63 million to “ensure that its economic benefits equitably reach rural and coal-impacted communities in the 11-county region.” In part, the award will be used for upskilling workers for the “new economy.”

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[88] Pennsylvania Department of Community & Economic Development, “Developing and Delivering Talent,” Pennsylvania Department of Community & Economic Development, Accessed January 2023, https://dced.pa.gov/business-assistance/workforce-development/

[89] ApprenticeshipUSA, “Inflation Reduction Act Apprenticeship Resources,” US Department of Labor, Accessed January 2023, https://www.apprenticeship.gov/inflation-reduction-act-apprenticeship-resources

The Ohio River Valley Can Supply Regional Factories with Water and End Customers with Fossil Fuel-Free Steel

The advantages of the location of the Ohio River Valley that were conducive to traditional, primary steelmaking also favor fossil fuel-free steelmaking.

The Ohio River, formed where the Allegheny and the Monongahela rivers merge near Pittsburgh, can supply fossil fuel-free steelmaking factories with water as it currently does with traditional primary steelmakers, such as the Mon Valley Works. (See below for more detail.)

The region is well positioned to transport fossil fuel-free steel via rivers, highways, and rail to manufacturers that need steel. Industrial machinery manufacturers are highly concentrated in the Midwest, with 38% of the country's manufacturers in that region as of 2020.[90]

The auto sector in the US is increasingly moving to the South, much of it within 500 miles of Pittsburgh, including more than $45 billion in automotive investments. $21 billion was announced just in 2022.[91]

As EV production in the US ramps up, steelmakers are poised to benefit, according to the American Iron and Steel Institute, which wrote, "automakers are expected to develop cost-effective, lightweight steel BEV architectures, using the broad spectrum of steel grades available, instead of using higher-cost alternatives such as aluminum, magnesium, and composites. Cost-savings achieved from using steel can be leveraged to maximize the onboard battery capacity."[92]

The Ohio River Valley Has Led the Nation in Energy Innovation and Production

The region has been an energy production and innovation powerhouse for over a century.

The region was the birthplace of commercial oil production. The nation's first oil well was drilled in Pennsylvania in 1859. It is currently the nation's second-largest natural gas producer, helping propel the US to become the world's largest natural gas producer. Key innovations in hydraulic fracturing and horizontal wells (often termed "fracking") have been developed in the region. It is the nation's third-largest coal producer, which fueled its steel industry. In 1957, the first commercial nuclear power plant in the US was sited in Beaver County, PA. Over the next decades, Pittsburgh-based companies and research universities were instrumental in developing nuclear energy technology. Pennsylvania now produces more nuclear power than any state besides Illinois. Hydrogen

[90] IndustrySelect, "Which US States Have the Most Industrial Machinery Manufacturers?" IndustrySelect, September 16, 2020, https://www.industryselect.com/blog/top-states-for-industrial-machinery-manufacturing
[91] Michael Wayland, "The Motor City is moving south as EVs change the automotive industry," CNBC, August 14, 2022, https://www.cnbc.com/2022/08/14/automakers-investing-in-the-south-as-evs-change-the-auto-industry.html
[92] American Iron and Steel Institute, "STEEL INDUSTRY ROLE IN THE FUTURE OF ELECTRIFIED VEHICLES," American Iron and Steel Institute, April 14, 2021, https://www.steel.org/wp-content/uploads/2021/04/2021-Electrification-White-Paper-final-4-14-21.pdf

and renewables present the next step in the region's energy journey and an important opportunity for leadership.

Finally, the region's geography offers high potential for underground hydrogen storage, which will be required for industrial hydrogen utilization.[93] Underground hydrogen storage has much in common with underground gas storage, which is already abundant in the region. The DOE recently issued a report on deployment of industrial-scale underground storage, which included research recommendations to address technical challenges and safety concerns.[94] Geological surveys have identified caverns under and near the Ohio River as well as depleted gas fields, some of which may be suitable for hydrogen storage.

Proposed hydrogen hubs will have a competitive advantage, according to Credit Suisse, if they are "situated near low-cost clean energy resources, advantageous geologic storage (such as deep saline formation for CO_2 storage and salt cavern for hydrogen storage), and expandable infrastructure (such as pipelines, docks, and distribution systems)." [95]

Wind and Solar Represent Untapped Potential

Production of green hydrogen via water electrolysis is possible only if the energy for electrolysis comes from renewable sources. Pennsylvania is the third-largest producer of electricity in the nation and is a critical energy supplier to the Mid-Atlantic region and the regional PJM grid. Only Texas and Florida generate more. Yet, just 3% of net electricity generation in the state currently comes from renewable energy sources.

Research shows a transition to clean energy provides a compelling opportunity to transform the local energy profile while ending the region's overreliance on fossil fuels, reducing emissions, and pursuing a path of sustainable growth.[96] Furthermore, Pennsylvania Governor Josh Shapiro has signaled he will support a goal of increasing renewable energy to 30% of Pennsylvania's generation by 2030 to reach net-zero emissions by 2050. Other states, such as New York and California, have demonstrated the ability to make quick progress with aggressive renewable targets.

Thus, the Ohio River Valley has both a challenge and an opportunity. By providing the renewable energy required for fossil fuel-free steel production as well as for its population, it can provide quality green jobs, build local experience and efficiency, and serve as a role model for the state and country.

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[93] Geostock, "Four ways to store large quantities of hydrogen," Geostock, February 3, 2022, https://www.geostockgroup.com/en/four-ways-to-store-large-quantities-of-hydrogen/

[94] Office of Fossil Energy and Carbon Management, "FECM'S New Report Details What Would be Needed to Safely and Effectively Deploy Large-Scale Underground Hydrogen Storage," US Department of Energy, May 2, 2022, https://www.energy.gov/fecm/articles/fecms-new-report-details-what-would-be-needed-safely-and-effectively-deploy-large

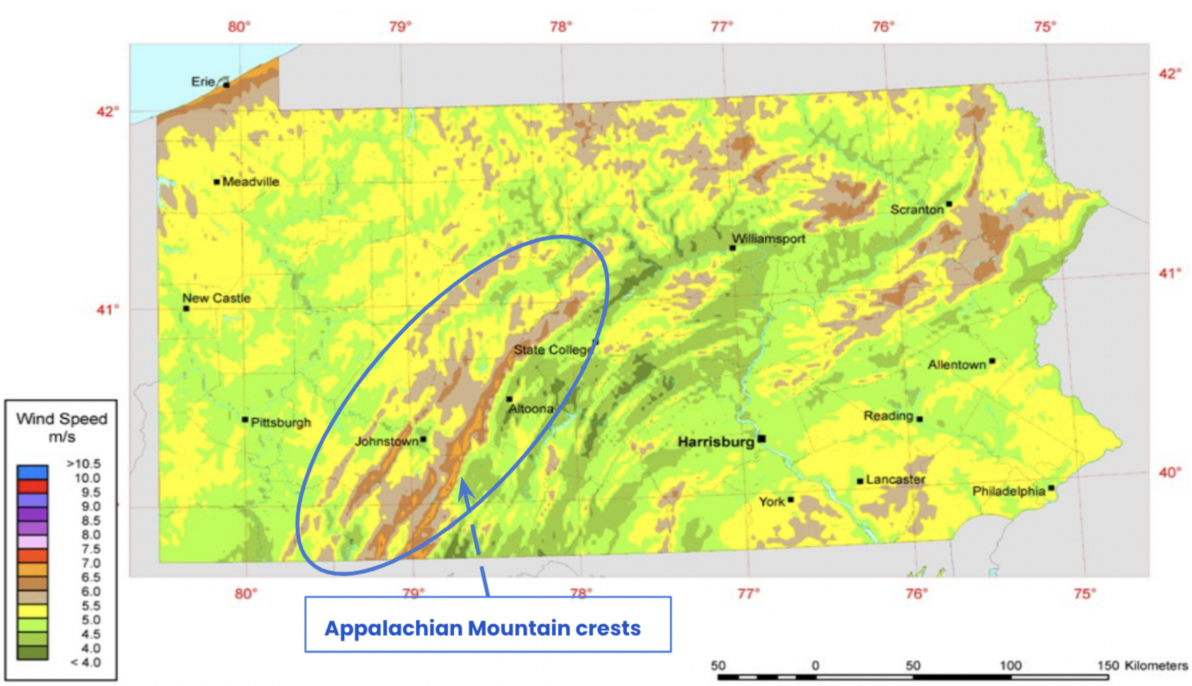
[95] Betty Jiang et. al., "US Inflation Reduction Act: A Tipping Point in Climate Action," Credit Suisse, November 30, 2022, https://www.credit-suisse.com/about-us-news/en/articles/news-and-expertise/us-inflation-reduction-act-a-catalyst-for-climate-action-202211.html

[96] Joe Goodenbery, Eliasid Animas, and Jennifer Gorman, "A Clean Energy Pathway for Southwestern Pennsylvania," Strategen & Ohio River Valley Institute, December 12, 2022, https://ohiorivervalleyinstitute.org/a-clean-energy-pathway-for-southwestern-pennsylvania/

Wind Potential in Pennsylvania

EIA's Pennsylvania state profile demonstrates that some of the greatest wind resources for commercial power production are found on the state's Appalachian Mountain crests—mainly in Pennsylvania's southwestern region, which includes parts of the Ohio River Valley (Figure 16). According to Office of Energy Efficiency and Renewable Energy (EERE) data, Pennsylvania's potential wind energy capacity is 108,946 MW. This is 75 times higher than the currently installed capacity of 1,459 MW.[97] Assuming that half of the renewables would come from wind and using the 30% capacity factor for wind in Pennsylvania, a 2 Mtpa fossil fuel-free steel plant would require 1,110 MW of wind capacity. An analysis by Strategen shows that 2,260 MW of wind capacity could be developed in the southwestern Pennsylvania region, with 50% (1,130 MW) achievable by 2050 (wind supply curves developed by NREL[98] were used for the analysis).[99] This can likely be increased with appropriate interventions and enablers.

Figure 16: Annual Average Wind Speed in Pennsylvania.[100]



Source: AWS Truepower, National Renewable Energy Laboratory

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[97] WINDExchange, "U.S. Installed and Potential Wind Power Capacity and Generation," Office of Energy Efficiency & Renewable Energy, US Department of Energy, Accessed January 2023, https://windexchange.energy.gov/maps-data/321

[98] NREL, "Wind Supply Curves," NREL, Accessed September 2022, https://www.nrel.gov/gis/wind-supply-curves.html

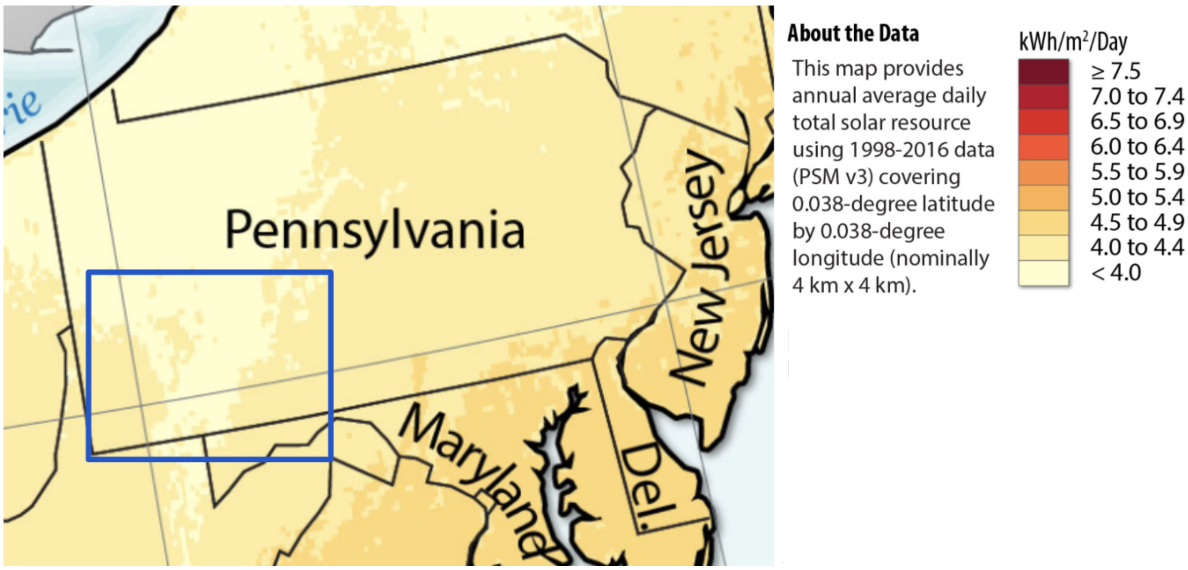
[99] Joe Goodenbery, Eliasid Animas, and Jennifer Gorman, "A Clean Energy Pathway for Southwestern Pennsylvania," Strategen & Ohio River Valley Institute, December 12, 2022, https://ohiorivervalleyinstitute.org/a-clean-energy-pathway-for-southwestern-pennsylvania/

[100] WINDExchange, "Pennsylvania 80-Meter Wind Resource Map," Office of Energy Efficiency & Renewable Energy, US Department of Energy, Accessed January 2023, https://windexchange.energy.gov/maps-data/107

Solar Potential in Appalachia

Solar energy, including both utility-scale and small-scale solar photovoltaic (PV) installations, produced only 11% of Pennsylvania's total renewable electricity in 2021.[101] Solar potential in the southwestern region is lower than in other areas of the country (Figure 17).

Figure 17: Annual Average Daily Total Solar Resource Using 1998-2016 Data



Source: National Renewable Energy Laboratory [102]

Nevertheless, solar has the potential to provide a renewable energy supply for green hydrogen and fossil fuel-free steel production in the southwestern Pennsylvania region. Strategen analysis determined that this region and its neighboring areas have the potential for the development of 19,250 MW of utility-scale solar. Given the lower efficiency of this resource in the ten-county region, Strategen assumed that 10% of this overall capacity could be deployed by 2050.[103] Assuming that half of the renewables would come from solar and using the 15% capacity factor for solar in Pennsylvania, a 2 Mtpa fossil fuel-free steel plant would require 2,220 MW capacity.

[101] EIA, "Pennsylvania Profile: State Profile and Energy Analysis," EIA, Accessed January 2023, https://www.eia.gov/state/analysis.php?sid=PA

[102] National Renewable Energy Laboratory, "Direct Normal Solar Irradiance: National Solar Radiation Database Physical Solar Model," National Renewable Energy Laboratory, Accessed January 2023, https://www.nrel.gov/gis/assets/images/solar-annual-dni-2018-01.jpg

[103] Joe Goodenbery, Eliasid Animas, and Jennifer Gorman, "A Clean Energy Pathway for Southwestern Pennsylvania," Strategen & Ohio River Valley Institute, December 12, 2022, https://ohiorivervalleyinstitute.org/a-clean-energy-pathway-for-southwestern-pennsylvania/

The Ohio River Valley Has Geological Resources and Abundant Sources of Water

Water is the main source for the production of green hydrogen via electrolysis. A reliable, consistent water supply is critical to an electrolyzer's performance.[104] The Ohio River Valley is well positioned for the production of green hydrogen due to the abundance of natural water resources. The Monongahela, Allegheny, and Ohio Rivers are central to the area and supply local industry with water.

Water for large-scale electrolysis, however, does not have to come from natural sources. As an alternative, water used for hydrogen production can be recovered as water vapor output from the DRI process. The vapor can be condensed, recirculated, and reused[105] as electrolyzer input. To achieve that, it is important to co-locate hydrogen production and the DRI facility to minimize the distance the recovered water travels. Industrial or municipal wastewater treatment facilities can also provide water for electrolysis .[106], [107]

Using recovered water vapor and recycled wastewater to produce hydrogen would create a closed-loop cycle, drastically reducing pressure on natural water resources. Moreover, green hydrogen production would reduce coke production in the region, which is a water-intensive process, leading to decreased water consumption. Finally, the region's geography offers the potential for underground hydrogen storage, which will be required for industrial hydrogen utilization. Underground hydrogen storage has much in common with underground gas storage. Geological surveys have identified caverns under and near the Ohio River as well as depleted gas fields, some of which may be suitable for hydrogen storage.[108] According to Credit Suisse, proposed hydrogen hubs will have an advantage if they are "situated nearby low-cost clean energy resources, advantageous geologic storage (such as deep saline formation for CO_2 storage and salt cavern for hydrogen storage), and expandable infrastructure (such as pipelines, docks, and distribution systems)." [109]

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[104] Depending on the type of electrolyzer, water consumption rates for the electrolysis process is usually 9 to 15 kilograms for every kilogram of hydrogen produced. Depending on the season and quality of water supply, electrolyzer system cooling and water purification may require additional amounts of water input. A typical electrolyzer plant contains a water purification system to assure that water is of highest purity before it enters an electrolyzer.

[105] James Brooks, "Steelmaker uses green hydrogen to cut carbon emissions," Power Engineering, April 7, 2022, https://www.power-eng.com/ap-news/steelmaker-uses-green-hydrogen-to-cut-carbon-emissions/#gref

[106] Scottish Water, "Cutting Edge Trial Could Boost Drive to Net Zero," Scottish Water, March 13, 2020, https://www.scottishwater.co.uk/about-us/news-and-views/2020/03/130320-british-science-week-hydrogen

[107] The Plug Power electrolyzer currently being built in Mendota, CA, will use recycled municipal wastewater to produce green hydrogen. A similar scenario could be implemented for an Ohio River Valley-based green electrolyzer in collaboration with neighboring municipal wastewater treatment facilities.

[108] Kristin M. Carter et. al., "A Geologic Study to Determine the Potential to Create an Appalachian Storage Hub for Natural Gas Liquids," West Virginia University's Appalachian Oil and Natural Gas Research Consortium, July 31, 2017, https://researchrepository.wvu.edu/aongrc/3/

[109] Betty Jiang et. al., "US Inflation Reduction Act: A Tipping Point in Climate Action," Credit Suisse, November 30, 2022, https://www.credit-suisse.com/about-us-news/en/articles/news-and-expertise/us-inflation-reduction-act-a-catalyst-for-climate-action-202211.html

Challenges

Current lack of renewable generation in the region

Only 3% of net electricity generation in Pennsylvania currently comes from renewable energy sources. This is likely the biggest challenge to producing fossil fuel-free steel in the state.

The renewable energy required for 2 Mtpa of fossil fuel-free steel would necessitate more than doubling the state's wind and utility solar energy generation from 2022 levels.[110] However, federal incentives coupled with strong state and regional support could offset some of these costs.

Furthermore, the additional demand created by fossil fuel-free steel production could strain the ongoing and emerging installation of solar and wind. Paradoxically, fossil fuel-free steel production could potentially divert or delay grid decarbonization if not designed properly. However, fossil fuel-free steel production, if designed and implemented properly, can create economies of scale and move renewable deployment down the cost curve in the region.

Potential to Increase GHG Emissions

Several approaches to designing a system can provide a near-continuous supply of hydrogen to feed an industrial process via renewable energy sources that are inherently variable in production. The first is with an electrolyzer connected to the electric grid, which provides a buffering function. When renewable energy production exceeds real-time demand, it can be stored (in batteries or other storage devices) or it can offset non-renewable energy sources required to meet grid demand. Conversely, when renewable production is less than required demand, the grid can supplement with electricity from other sources. While this enables the most efficient sizing of electrolyzer capacity, it raises some concerns in terms of carbon footprint, as discussed in a recent article in Grist.[111]

When the renewable energy provided does not match the timing and the location of the energy demand (e.g. hydrogen production), there is a risk that it could be met by non-renewable generation instead of purely incremental renewable generation. Since hydrogen produced via electrolysis—based on the current average grid electricity mix—would release about double the emissions of hydrogen produced via steam methane reforming of natural gas (gray hydrogen), this process is far from "green" hydrogen.

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[110] Electricity Data Browser, "Net generation for all sectors, annual," EIA, Accessed January 2023, https://www.eia.gov/electricity/data/browser/#/topic/0?agg=2,0,1&fuel=vtvv&geo=g001&sec=g&linechart=ELEC.GEN.ALL-US-99.A&columnchart=ELEC.GEN.ALL-US-99.A&map=ELEC.GEN.ALL-US-99.A&freq=A&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0

[111] Emily Pontecorvo, "How a new subsidy for 'green hydrogen' could set off a carbon bomb," Grist, December 12, 2022, https://grist.org/energy/how-a-new-subsidy-for-green-hydrogen-could-set-off-a-carbon-bomb/

Emerging Hydrogen Infrastructure Will Face Obstacles

Fossil fuel-free steel production may require hydrogen storage or transportation depending on how it is implemented. While there is growing momentum around green hydrogen, creating the infrastructure to transport and store hydrogen is still in its infancy. Research dating back nearly a decade was already focused on overcoming technical concerns related to pipeline transmission, including the potential for hydrogen to embrittle the steel and welds used to fabricate the pipelines and the need to control hydrogen leaks.[112] Trucking hydrogen long distances may be expensive. Concerns have also been raised around hydrogen leakage during storage.

Investment in DRI-EAF May Be a Barrier

Building DRI-EAF processes will require large investments in the deployment of new DR plants and new or expanded EAF facilities. According to GreenSteel for Europe Consortium 2021[113] estimates, a fully deployed and operational hydrogen-based direct reduction plant producing 1 Mtpa would cost approximately $266 million ($533 million, including EAF).

[112]Hydrogen and Fuel Cell Technologies Office, "Hydrogen Pipelines," US Department of Energy, Accessed January 2023, https://www.energy.gov/eere/fuelcells/hydrogen-pipelines#:~:text=Gaseous%20hydrogen%20can%20be%20transported,operating%20in%20the%20United%20States

[113] Green Steel for Europe, "Investment Needs", GreenSteel for Europe Consortium, Accessed March 2023 shttps://www.estep.eu/assets/Uploads/GreenSteel-D2.2-Investment-Needs-Publishable-version.pdf

Opportunities

Fossil Fuel-Free Steelmaking Offers the Ohio River Valley Potential to Lead Appalachian Manufacturing Renaissance

Fossil fuel-free steel could provide Appalachia with a tremendous opportunity to become a leader in an emerging industry with huge growth potential. The shift to decarbonize the industry is beginning, and those that act swiftly are well-positioned to reap the rewards.

Fossil fuel-free steel production would attract other industrial sectors, creating a fossil fuel-free steel manufacturing hub. Terms like “catalyze development,” “ecosystem,” and “cascading benefits” are often used to describe how local production of key input—in this case, both fossil fuel-free steel and green hydrogen—could lead to other industries moving in. A downstream industrial cluster, such as automobile manufacturing, would gain a competitive advantage through access to regionally-produced fossil fuel-free steel. The economic development arms of state governments in Pennsylvania, Ohio, and West Virginia have demonstrated their willingness to support projects that might lead to industrial clusters, such as Pennsylvania’s tax subsidies for Shell’s Beaver County petrochemical plant and West Virginia’s subsidies for the $2.7 billion Nucor EAF facility.[114] When proponents of these projects conducted studies to explore potential economic benefits, they used multipliers to estimate indirect upstream and downstream economic benefits (See Sidebar: Jobs Accounting—The Economic Factors Influencing Job Multipliers and Temporary Jobs).

By capitalizing on a so-called “sunrise industry” at the beginning of the S-curve rather than relying on mature industries in decline, the region would have a first-mover advantage.

Renewables and A Green Hydrogen Hub

The renewable energy required for fossil fuel-free steelmaking would jumpstart renewable development in the region, providing massive numbers of installers and grid maintenance employees, skilled and ready to roll out grid decarbonization and modernization.

Falling costs of green hydrogen create an opportunity for the Ohio River Valley to become a national leader in green hydrogen production. This can be achieved by building a green hydrogen hub in the area. “With green hydrogen hubs being set up across the country, additional opportunities for distributing green hydrogen will arise, including opportunities to expand exports at competitive global prices. US companies integrated into hubs would

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[114] Rye Druzin, “WV advances incentives for new steel mill,” Argus Metals, 11 January 2022, https://www.argusmedia.com/metals-platform/newsandanalysis/article/2290628-WV-advances-incentives-for-new-steel-mill

be well-positioned to become leaders in the international green hydrogen trade."[115]

According to Credit Suisse, "the comprehensive climate incentives included in the IRA will likely catalyze the development of hydrogen hubs in the US that could potentially leapfrog those in progress in Europe."[116] There is additional support of $8 billion in federal funding for hydrogen hubs.[117] The Infrastructure Investment and Jobs Act (IIJA) passed in 2021 can further reduce the cost of hydrogen, should the Ohio River Valley opt to build a green hydrogen hub.

A hydrogen hub may serve multiple industrial and energy purposes, including:

- Production of enough on-site green hydrogen for fossil fuel-free steel production to meet and exceed current Mon Valley steel output.

- As the production of green hydrogen requires renewable electricity, building a hub will jumpstart the development of renewable energy infrastructure, bringing clean energy and well-paying jobs to the Ohio River Valley region and beyond.

- As the amount of zero-carbon renewable power production grows in the area, green hydrogen may play an important role as a demand-side resource to help achieve reliability in the high-renewables grid. Variable renewable (solar and wind) pairs well with electrolyzers because they can be opportunistic about consuming clean power when available or reducing consumption when the grid needs it.[118]

- Excess produced green hydrogen may be applied for other uses. BNEF founder Michael Liebreich's "Hydrogen Ladder" (Figure 18) prioritizes various end uses for clean hydrogen depending on where it is sure to be part of a net-zero future—starting with where gray, polluting hydrogen is currently used—and where there are almost certainly other, better solutions, such as direct electrification and batteries.

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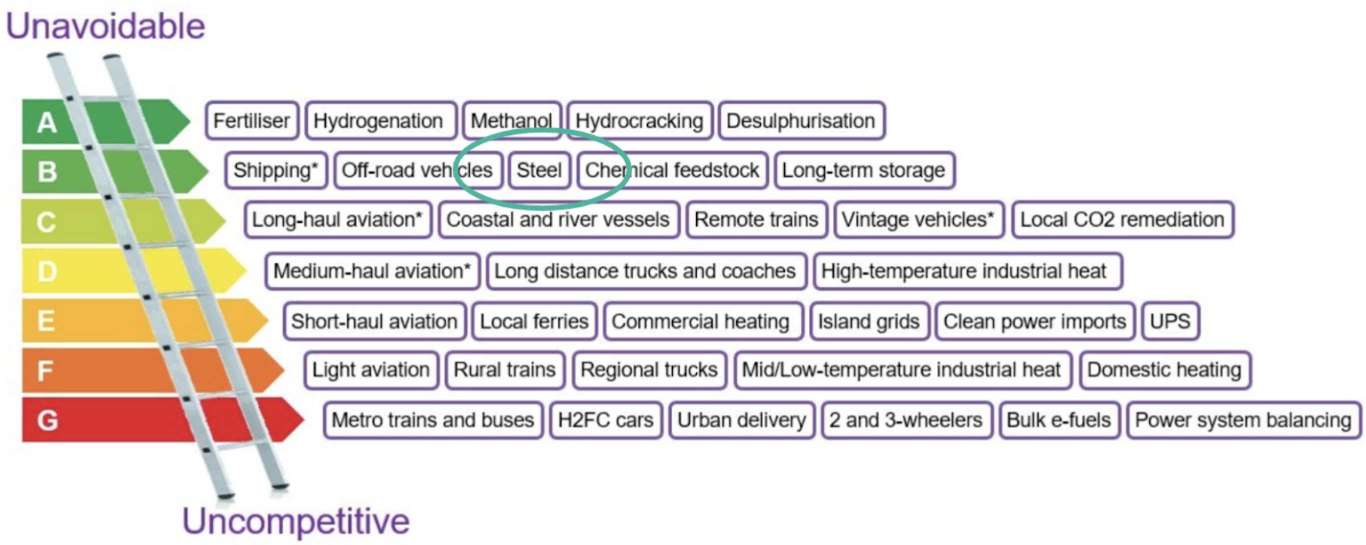
[115] Oleksiy Tatarenko and Thomas Koch Blank, "The Inflation Reduction Act: The moment for US green steel and fertilizer," Energy Monitor, September 12, 2022, https://www.energymonitor.ai/tech/hydrogen/the-inflation-reduction-act-the-moment-for-us-green-steel-and-fertiliser/
[116] Betty Jiang et. al., "US Inflation Reduction Act: A Tipping Point in Climate Action," Credit Suisse, November 30, 2022, https://www.credit-suisse.com/about-us-news/en/articles/news-and-expertise/us-inflation-reduction-act-a-catalyst-for-climate-action-202211.html
[117] US Department of Energy, "DOE Establishes Bipartisan Infrastructure Law's $9.5 Billion Clean Hydrogen Initiatives," Department of Energy, February 15, 2022, https://www.energy.gov/articles/doe-establishes-bipartisan-infrastructure-laws-95-billion-clean-hydrogen-initiatives
[118] Eric Gimon, "How utilities can harness green hydrogen production's flexibility in balancing a high-renewables grid," Utility Dive, June 27, 2022, https://www.utilitydive.com/news/how-utilities-harness-green-hydrogen-productions-flexibility/626096/

Figure 18: Hydrogen Ladder[119]



Source: Liebrich Associates

Social and Environmental Benefits

BF-BOF steelmaking is a major source of greenhouse gas emissions, water pollution, and soil contamination. In addition to the projected cheaper production costs and job creation opportunities, replacing this status quo process with green hydrogen-based direct reduction steelmaking (DRI/EAF) will bring substantial environmental and social benefits to the Ohio River Valley region and the surrounding area.

Utilization of zero-emissions green hydrogen for iron ore reduction will replace coke now used for that purpose. Coke oven emissions are complex mixtures of dust, vapors, and gasses that typically include carcinogens like cadmium and arsenic.[120] Although most emitted gasses and particles are captured and reused, some escape, threatening the health of factory workers and surrounding communities with increased risks of hospital visits, respiratory disease, childhood asthma, cancer, and premature death.[121] The American Lung Association rates Allegheny County's air quality as some of the worst in Pennsylvania.[122] Replacing coke with hydrogen provides an opportunity for reduced demand for coke, thereby reducing environmental pollution.

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[119] Michael Liebreich, "The Clean Hydrogen Ladder," LinkedIn, August 15, 2021, https://www.linkedin.com/pulse/clean-hydrogen-ladder-v40-michael-liebreich/

[120] GASP-PGH, "What You Need to Know About Allegheny County's Proposed Coke Oven Regulation Revisions & How to," Group Against Smog & Pollution, September 13, 2022, https://www.gasp-pgh.org/what-you-need-to-know-about-allegheny-county-s-proposed-coke-oven-regulation-revisions-how-to-1

[121] National Cancer Institute, "Coke Oven Emissions - Cancer-Causing Substances," National Institute of Health, December 5, 2022, https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/coke-oven

[122] State of the Air, "Report Card: Pennsylvania," American Lung Association, 2022, https://www.lung.org/research/sota/city-rankings/states/pennsylvania#show-tabs-1

Producing green hydrogen using renewable power opens up a huge opportunity for the region to leapfrog into a new era of clean energy. As a major producer of energy, 65% of which comes from burning coal and natural gas, Pennsylvania emits more than 73 million metric tons of climate-warming gasses into the air each year.[123] Introducing commercial-size wind and solar installations to supply fossil fuel-free steelmaking in southwestern Pennsylvania will avoid producing yet more emissions. It will create an example for steel and other industries in the state. Building up renewable capacity for fossil fuel-free steel in the state would also coincide with such state programs and initiatives as "Pennsylvania's Solar Future" plan,[124] Pennsylvania's entrance into the Regional Greenhouse Gas Initiative (RGGI),[125] and planned renewable energy legislation by Governor Josh Shapiro, thus adding to the combined state effort to transition to clean energy generation.

Using green hydrogen produced with just water and renewable energy will not only improve the lives of hundreds of thousands of people living in southwestern Pennsylvania and adjacent regions, but will also save the state a significant amount of money.

In 2019, Pennsylvania's industrial sector emitted 86.38 million metric tons of GHG emissions, or 33% of all of the state's CO_2e emissions.[126] Replacing production of 2 Mtpa[127] of BF-BOF steel with fossil fuel-free DRI-EAF steel will reduce Pennsylvania's industrial sector's emissions by around 4 million metric tons CO_2e, a reduction of 4.6% compared to 2019 CO_2e emissions. Using the social cost of carbon[128] of $95 per metric ton of CO_2e[129] (the value PADEP used for its 2019 Climate Action Plan as the benchmark for cost-effectiveness), this reduction will save the state $380 million in health, community, and environmental costs. Examples of savings include fewer visits to hospitals, increased productivity, and increased housing values, among others.[130]

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[123] Joanna Foster, "Climate hope — and cleaner air for millions — as Pennsylvania puts a price on carbon," Environmental Defense Fund, May 16, 2022, https://www.edf.org/article/pennsylvania-puts-price-carbon

[124] Pennsylvania Department of Environmental Protection Energy Programs Office, "Pennsylvania's Solar Future Plan," Pennsylvania Department of Environmental Protection, November 2018, https://www.dep.pa.gov/Business/Energy/OfficeofPollutionPrevention/SolarFuture/Pages/Pennsylvania's-Solar-Future-Plan.aspx

[125] Pennsylvania Department of Environmental Protection, "Regional Greenhouse Gas Initiative (RGGI)," Pennsylvania Department of Environmental Protection, Accessed January 2023, https://www.dep.pa.gov/Citizens/climate/Pages/RGGI.aspx

[126] Pennsylvania Department of Environmental Protection, "Pennsylvania Greenhouse Gas (GHG) Inventory", Pennsylvania Department of Environmental Protection, Accessed January 2023, https://www.dep.pa.gov/Citizens/climate/Pages/GHG-Inventory.aspx

[127] Based on an assumption of 2 Mtpa of crude steel production modeled for this report.

[128] The social cost of carbon (SCC) is an estimate, in dollars, of the economic damages that would result from emitting one additional metric ton of carbon dioxide into the atmosphere. The SCC puts the effects of climate change into economic terms to help policymakers and other decision-makers understand the economic impacts of decisions that would increase or decrease emissions.

[129] Pennsylvania Department of Environmental Protection, "The 2018 Pennsylvania Climate Action Plan", Pennsylvania DEP, Accessed February 7, 2023 http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=1454161&DocName=2018%20PA%20CLIMATE%20ACTION%20PLAN.PDF

[130] Pennsylvania Department of Environmental Protection calculated its SCC based on the SCC presented by the EPA in 2016. In November 2022, EPA proposed increasing that number to $190 (at a 2% discount rate; open for public review until February 13, 2023). Assuming that this increase leads to the increase in Pennsylvania's SCC, the financial savings the switch to fossil fuel-free steel production brings to the state will be even higher.

Conclusion

This report explores the potential to revitalize the Ohio River Valley (ORV) through a transition to fossil fuel-free primary steel production. Mon Valley Works, an integrated steel manufacturing operation located in southwestern Pennsylvania, models what a transition to fossil fuel-free steelmaking can bring to the state and its people.

This report finds that investing in fossil fuel-free steel production using 100% additional, local renewable energy could support 27% to 43% more total jobs than the steel industry presently supports in the Ohio River Valley. These potential gains more than double when the decades-long declining trend in regional steel industry employment is considered.

Regional assets, including ready access to iron ore, a workforce with legacy knowledge of the steel industry, and abundant natural assets, position the Ohio River Valley to lead in fossil fuel-free steel production.

Recent federal and state legislation is expected to boost domestic steel production, including specific green hydrogen incentives that offer Pennsylvania a significant first-mover advantage. Fossil fuel-free steel production also presents multiple challenges, since the cleanest, most economical and technically proven way to produce hydrogen is via electrolysis directly powered by additional renewable energy sources. This will require a significant investment in infrastructure to expand the state's renewable energy production, taking advantage, for example, of southwestern Pennsylvania's abundant wind assets.

The shift to decarbonize the industry is beginning. Those that act swiftly are well positioned to reap the rewards. Pennsylvania's historic steel industry has the potential for global leadership in fossil fuel free-steelmaking, leading a green manufacturing renaissance to grow the region's economy while offering health and environmental benefits.

Pennsylvania should seize the opportunity to invest in a "sunrise industry" at the beginning of the S-curve rather than continuing to rely on mature industries in decline. The Ohio River Valley can invest smartly to become "Clean Energy Valley"—one of the world's very first decarbonized industrial hubs.

Sidebar: What Is Green Steel?

What exactly is green steel? The problem is that there really is not an agreed-upon definition. "Green steel" is commonly used to refer to steel produced in any way that reduces its carbon footprint. Other similarly ill-defined terms include "low-emission steel" or "lower-carbon steel."

The term carries no measure of how much reduction is made or what the method is for achieving it. Claims range from innovations in BF primary steel processes, DRI primary steelmaking processes, or scrap EAF processes. However, there are significant differences across the steel decarbonization pathways in terms of their overall carbon footprint, performance potential, technology readiness, costs, and risks.

Accordingly, the term "green steel" has come under increasing criticism for potential greenwashing. The issue was highlighted at COP27, where governments of countries responsible for half of global gross domestic product (GDP) called for better definitions to enhance the transparency and credibility of the green steel sector as a follow-up to their Breakthrough Agenda.[131] A convergence on definitions of the terms "zero-emission steel" and "near zero-emission steel" is anticipated.

For the purposes of this report, we adopt the term "green steel" when referring to the general class of steelmaking technologies that provide a carbon footprint reduction. It is used to provide a context for decarbonization efforts related to the steel market or industry trends. Therefore, secondary steelmaking using scrap steel in an electric arc furnace (EAF) is included in that discussion. However, the focus of this paper is on primary steelmaking.

The terms "zero-emission steel" or "near zero-emission steel," while not officially defined, are used throughout this paper to distinguish those technologies that have the potential to reduce carbon footprints below 200 kilograms per ton of steel, or a 90% reduction relative to conventional BF-BOF primary steel production.

"Fossil fuel-free steel" is defined as steel manufactured without the use of fossil fuels.[132] This means no natural gas, coal, or oil is used in its production, and any electricity used comes from renewable resources.

Specifically, "Fossil fuel-free green steel" refers to the subject of this analysis—primary steel produced through green hydrogen[133]- based direct reduction of iron (DRI) (See Sidebar: What Is the Difference Between Gray, Blue, and Green Hydrogen?).

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[131] COP26, "Breakthrough Agenda," UN Climate Change Conference UK 2021, November 11, 2021, https://ukcop26.org/the-breakthrough-agenda/

[132] This is in line with the World Economic Forum and OECD definition of "green steel" as steel that is manufactured without the use of fossil fuel.
World Economic Forum, "What is green steel and why does the world need more of it?" World Economic Forum, July 11, 2022, https://www.weforum.org/agenda/2022/07/green-steel-emissions-net-zero/

[133] Green hydrogen is hydrogen produced via electrolysis powered by renewable energy.

Sidebar: History of the Steel Industry Looms Large in Pennsylvania and the Ohio River Valley

Steel has played an outsized role in the history of Pennsylvania, particularly in Pittsburgh and surrounding counties, including the Ohio River Valley. At the height of the steel industry in the US, Pittsburgh produced 60% of the nation's steel and 95% of its steel rails. Any economic narrative of Pittsburgh, Pennsylvania, or the Ohio River Valley focuses on the steel industry. Its legacy, especially in Allegheny and Beaver Counties, lives large in collective memory and serves as a reminder, for many, of good economic times. Those charged with economic development may look to the steel industry as an inspiration, especially if they seek an industrial renaissance for the Ohio River Valley.

Over much of its history, the steel industry has adapted quickly to changing technology and shifting demands for its product. Major technological advances in steelmaking are illustrated in Figure 2,[134] from the invention of the Bessemer process in England, which enabled cost-effective mass production of steel, to Electric Arc Furnaces (EAF).

Pennsylvania became ground zero for the US steel market in the late 1800s through a combination of geography, geology, and extraordinary entrepreneurial spirit. Traditional steel production required coal and iron ore. Pennsylvania benefited from an abundance of coal. Rich iron ore from Minnesota's Mesabi Range was shipped through the Great Lakes to a port in Ohio and then by rail to Pennsylvania's steel mills. Three rivers, where the Allegheny and Monongahela join to form the Ohio River in Pittsburgh, provided water used in the steel mills. The entrepreneurial efforts of Andrew Carnegie and his contemporaries in the steel and railroad industries propelled Pennsylvania to lead the nation and the US to lead the world in steel production by the late 19th century.

It was Andrew Carnegie who was instrumental in making Pittsburgh the center of the steel industry. A penniless immigrant from Scotland, he parlayed a job in the railways that paid $1.20 a week into a massive fortune. As a railroad employee, he foresaw the importance of the emerging steel industry and invested his modest earnings early on. After forming Carnegie Steel in 1892, Carnegie expanded that operation organically and bought several other steel companies over the next several years. Less than a decade later, in 1901, Carnegie sold his operation for $492 million to J.P. Morgan, who merged Carnegie Steel with his own steel holdings to create US Steel, becoming the world's largest steel corporation, the first billion-dollar company, and ultimately, the nation's largest employer for many decades.

Steel production in the US grew from 380,000 tons in 1875 to 60 million tons in 1920,[135] playing a vital part in the Industrial Revolution and creating much of what we consider modern America. Railroads were US Steel's first and most important customer. In 1860, there were 30,000 miles of railroad tracks in the US, which ballooned to

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[134] Daniel Schaeffler, "A Brief History of Steelmaking," MetalForming Magazine, August 31, 2020, https://www.metalformingmagazine.com/article/?/materials/mild-steel/a-brief-history-of-steelmaking-gu

[135] Wikipedia, "History of the steel industry (1850-1970)," Wikipedia, Accessed March 2023, https://en.wikipedia.org/wiki/History_of_the_steel_industry_(1850%E2%80%931970)

250,000 miles by 1900. [136] The US had embarked on a "fever for westward expansion that produced a boom in transcontinental railroad building and demands for iron and steel."[137]

The 1860s and 1870s also saw the rise of industrial manufacturing, creating a massive market for steel. By the early 20th century, as global demand for steel continued to grow, new markets emerged. Among them were skyscrapers for the rapidly urbanizing country and armor plate for the expanding domestic naval fleet. Automobiles gradually replaced the nation's 26 million horses in 1915, creating yet another growing market.[138] The Great Depression devastated the steel industry along with most industries. But World War II was a boon to the industry, setting industry production records (90 million tons of finished steel in 1944) and spurring factories to operate at full capacity. By 1945, the US was producing nearly two-thirds of the world's steel. The post-war economic boom boosted steel production, pushing production to nearly 150 million tons by 1960.

After a century of growth, domestic demand for steel flattened in the 1970s. Foreign countries increased their steelmaking capacity and increasingly competed for business in the US. Plastic, aluminum, and ceramics could be substituted for steel. Technological advances were not readily adopted by domestic primary steelmakers. American mini-mills, which used scrap metal, invested in modern equipment and could compete with lower labor costs.

By 1982, steel imports and mini-mills, which used scrap metal, accounted for more than a quarter of steel sold in the US, and traditional, integrated steel mills were operating at less than 50% of capacity.[139]

During the late 1980s, the Chinese steel industry ramped up production to meet its growing domestic demand. It became the world's largest steel manufacturer by 1996, displacing the US, which had been the largest producer for a century.[140] China has continued to ramp up steel production. By 2009, it produced nearly half the world's supply.[141] By 2010, the US had become the largest importer of steel.[142]

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[136] Wikipedia, "History of the steel industry (1850-1970)," Wikipedia, Accessed March 2023, https://en.wikipedia.org/wiki/History_of_the_steel_industry_(1850%E2%80%931970)
[137] Thomas J. Misa, "A Nation of Steel: The Making of Modern America, 1865-1925," Johns Hopkins University Press, September 4, 1998, https://www.press.jhu.edu/books/title/1035/nation-steel
[138] John Browne, "Make, Think, Imagine: Engineering the future of civilization," Pegasus Books, August 27, 2019, http://pegasusbooks.com/books/make-think-imagine-9781643132129-hardcover
[139] John Browne, "Make, Think, Imagine: Engineering the future of civilization," Pegasus Books, August 27, 2019, http://pegasusbooks.com/books/make-think-imagine-9781643132129-hardcover
[140] Peter Harmsen, "China's steel imports soar as industry warns against anti-dumping moves," IndustryWeek, October 31, 2006, https://www.industryweek.com/the-economy/article/21944638/chinas-steel-exports-soar-as-industry-warns-against-antidumping-moves
[141] Rachel Tang, "China's Steel Industry and Its Impact on the United States: Issues for Congress," Congressional Research Service, September 21, 2010, https://ecommons.cornell.edu/bitstream/handle/1813/78320/China_s_Steel_Industry_and_Its_Impact_on_the_United_States.pdf?sequence=1&isAllowed=y
[142] Terence P. Stewart et. al., "Surging Steel Imports Put Up To Half a Million U.S. Jobs at Risk," Economic Policy Institute, May 13, 2014, https://www.epi.org/publication/surging-steel-imports/

Since then, allegations of unfair trade practices against Chinese steelmakers have been repeatedly levied. Duties on imported Chinese steel have been imposed,[143] and in 2018, then-President Trump imposed 25% tariffs on imported steel. This had a devastating impact on US manufacturers that relied on steel, as prices rose.[144] In late 2022, the World Trade Organization (WTO) ruled that the US violated international trade rules by imposing steel and aluminum tariffs.

China now produces roughly half the world's steel, and more than 12 times US production. By 2021, the EU, India, and Japan had also overtaken the US in steel production.

Employment in the Steel Industry

Even in its earliest days, during the late 1800s, the employment picture was mixed. Steel mills required vast manpower, which was in short supply. European immigrants, initially from Britain and Germany and later from Eastern Europe, found ready jobs in the steel mills. Labor conditions were deplorable. The history of the steel industry is filled with deadly strikes that left a lasting legacy of labor-management issues.

Outside the factories, pollution and toxic substances were the norm. Even decades later, before the passage of the Clean Air and Water Acts and the Toxic Substances Act, Pittsburgh and the surrounding areas were often completely dark, even at noon, when inversions kept smoke trapped beneath low-lying clouds for days at a time. Clothes did not remain white for long. Within the steel mills, the air could only have been worse.

Employment from the 1950s to the Present: From Best of Times to Worst of Times

Financially speaking, the 1950s to the 1970s represented a high peak for steel workers. Wages had grown steadily throughout the century and US Steel was one of the world's largest, most respected companies. Company stores that took advantage of captive employees had become a thing of the past. By the 1970s, steel workers had become the highest paid industrial workers in the US, if not the world.[145] Golf was a favorite pastime.

National jobs in the steel industry are illustrated in Figure 19 below. Aside from strikes and World War II-related dislocations, American steel mills employed nearly 700,000 workers, compared to the 83,000[146] as of 2018. The

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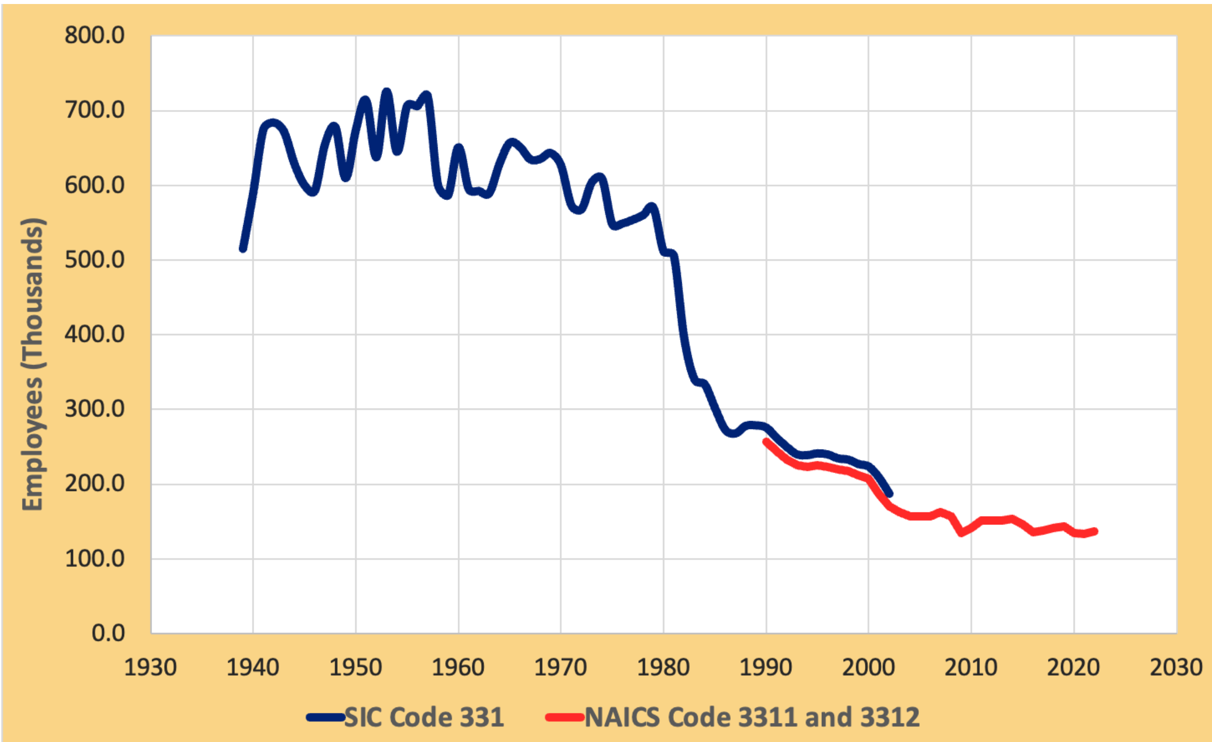
[143]Chad Brown and Katheryn Russ, "Biden and Europe remove Trump's steel and aluminum tariffs, but it's not free trade," PIIE, November 11, 2021, https://www.piie.com/blogs/trade-and-investment-policy-watch/biden-and-europe-remove-trumps-steel-and-aluminum-tariffs
[144]Chad Brown and Katheryn Russ, "Biden and Europe remove Trump's steel and aluminum tariffs, but it's not free trade," PIIE, November 11, 2021, https://www.piie.com/blogs/trade-and-investment-policy-watch/biden-and-europe-remove-trumps-steel-and-aluminum-tariffs
[145] The industry average was approximately $14/hour in 1982, according to BLS data. Hoerr, however, writes that in 1981-82, the cost to steel companies was $22-23/hour on average for hourly workers, between salaries, vacations, pensions and other benefits, which had been negotiated for decades.
John Hoerr, "And the Wolf Finally Came: The decline of the American steel industry," University of Pittsburgh Press, July 1988, https://upittpress.org/books/9780822953982/
[146]Chris Isidore, "When American steel was king," CNN Business, March 9, 2018, https://money.cnn.com/2018/03/09/news/companies/american-steel-history/index.html

drop between 1982 to 1987 was especially noteworthy and has left a lasting legacy in the Pittsburgh area. In 1982, nearly 200 steel plants closed nationwide, and 340,000 steelworkers found their jobs were eliminated permanently or they'd been laid off.[147] By 1987, the bottom had dropped out. The industry has not recovered.

Figure 19: US Steel Production Employees, 1939-2022



Source: US Bureau of Labor Statistics

Changes in state-level steel employment in Pennsylvania have actually further lagged the nationally declining trend since 2000 and were harder hit by the COVID-19 pandemic, as shown in Figure 20. As of 2022, Pennsylvania has roughly 53% of the iron and steel jobs that it had in 2000. This trend began long before the turn of the century, however. Using the North American Industrial Classification Systems (NAICS) data from the US Bureau of Labor Statistics (BLS), in 1990 the number of Pennsylvania jobs in iron and steel mills and ferroalloy manufacturing was 31,000, declining to fewer than 10,000 in 2021.[148] The Bureau of Labor Statistics (BLS) provides employment levels for various parts of Pennsylvania, including the Pittsburgh area, defined by BLS as including Allegheny, Butler, Beaver, Washington, Westmoreland, Armstrong and Fayette Counties.[149] Declines in Pittsburgh, unsurprisingly, have mirrored the state and national levels since 1990.

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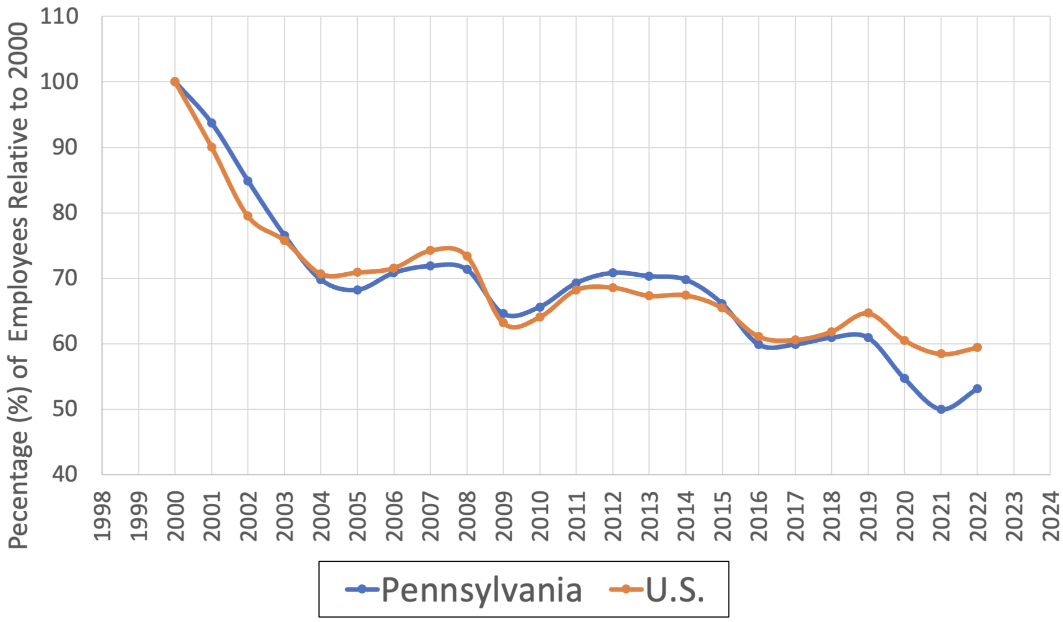
[147] Jacob Roth, "Bethlehem Steel: The Rise and Fall of an Industrial Titan," Pennsylvania Historical Society, April 27, 2020, https://pa-history.org/wp-content/uploads/2021/01/Roth-Marcus-prize-pdf.pdf
[148] Using "All Employees in Private NAICS 3311 Iron and steel mills and ferroalloy manufacturing for All establishment sizes in Pennsylvania—Statewide, NSA", BLS Quarterly Census of Wages and Employment
[149] US Bureau of Labor Statistics, "Pittsburgh area Economic Summary," US Bureau of Labor Statistics, February 1, 2023, https://www.bls.gov/regions/mid-atlantic/summary/blssummary_pittsburgh.pdf

Figure 20: Percentage Change in Iron and Steel Mill and Ferroalloy Manufacturing Employees, 2000-2021



Source: Ohio River Valley Institute analysis using BLS data

Legacy of the Steel Industry in Pittsburgh Area, including Ohio River Valley

Steel has played a central role in historical economic transitions. It propelled the industrial revolution in the US and remains critical to the nation's infrastructure needs. Infrastructure and reshoring manufacturing will require the steel industry to continue to transition throughout the 21st century. The steel industry has also played an outsized role in the history of Pittsburgh and the surrounding areas, especially its history of creating great wealth for the lucky few and decent pay for thousands.

Those charged with economic development may look to the steel industry as both a cautionary tale and an inspiration, especially if they seek an industrial renaissance for the Ohio River Valley.

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Sidebar: What is the Difference between Gray, Blue, and Green Hydrogen?

Hydrogen is a colorless, odorless gas and the lightest, most abundant element on Earth. When used to separate metallic iron and oxygen from iron ore, it releases only water vapor and does not produce any carbon emissions. Procuring hydrogen involves separating it from other elements through chemical processes that require energy. Depending on what process is used, there are three main categories of hydrogen: gray, blue, and green.

Green hydrogen is made using electrolysis: the separation of hydrogen and oxygen molecules by applying electrical energy to water. It produces only oxygen as a by-product. Renewable energy sources, such as wind and solar power, generate the electricity for this process. No fossil fuels are used and no GHG emissions are created during the production of green hydrogen, making it an ecologically friendly hydrogen option.

Gray hydrogen is produced using coal or natural gas and has a significant carbon footprint. Most of the gray hydrogen produced today is made by a process called steam methane reforming (SMR), which converts methane to hydrogen and carbon dioxide by using heat, steam, and pressure. SMR generates between nine and twelve kilograms of carbon dioxide for each kilogram of hydrogen produced.[150]

Blue hydrogen is created using the same processing technique as gray hydrogen. However, with blue hydrogen, CO_2 produced is not released into the environment. Instead, using carbon capture and storage (CCS) technology, it is captured at the production facility and either transported via pipeline and stored in underground geologic formations, or used for the manufacture of fuels, building materials, and more. This technique still produces emissions due to some methane leakage into the atmosphere during its production and consumption.

Clean hydrogen is usually defined as hydrogen produced with very low or zero carbon emissions. The Infrastructure Investment and Jobs Act's definition of clean hydrogen is "hydrogen produced with a carbon intensity equal to or less than two (2) kilograms of CO_2e produced at the site of production per kilogram of hydrogen produced." This definition encompasses green hydrogen and blue hydrogen. RMI, however, argues that "all 'clean hydrogen' is not equally clean." According to their estimates, due to methane leakage, blue hydrogen production will still emit 2 to 4 kilograms of CO_2e per kilogram of hydrogen.[151]

As of the end of 2021, almost 96% of the global hydrogen production was from fossil fuels and only around 4% came from electrolysis. Electricity had a global average renewable share of about 33% in 2021, which means that only about 1% of global hydrogen output was produced with renewable energy.[152]

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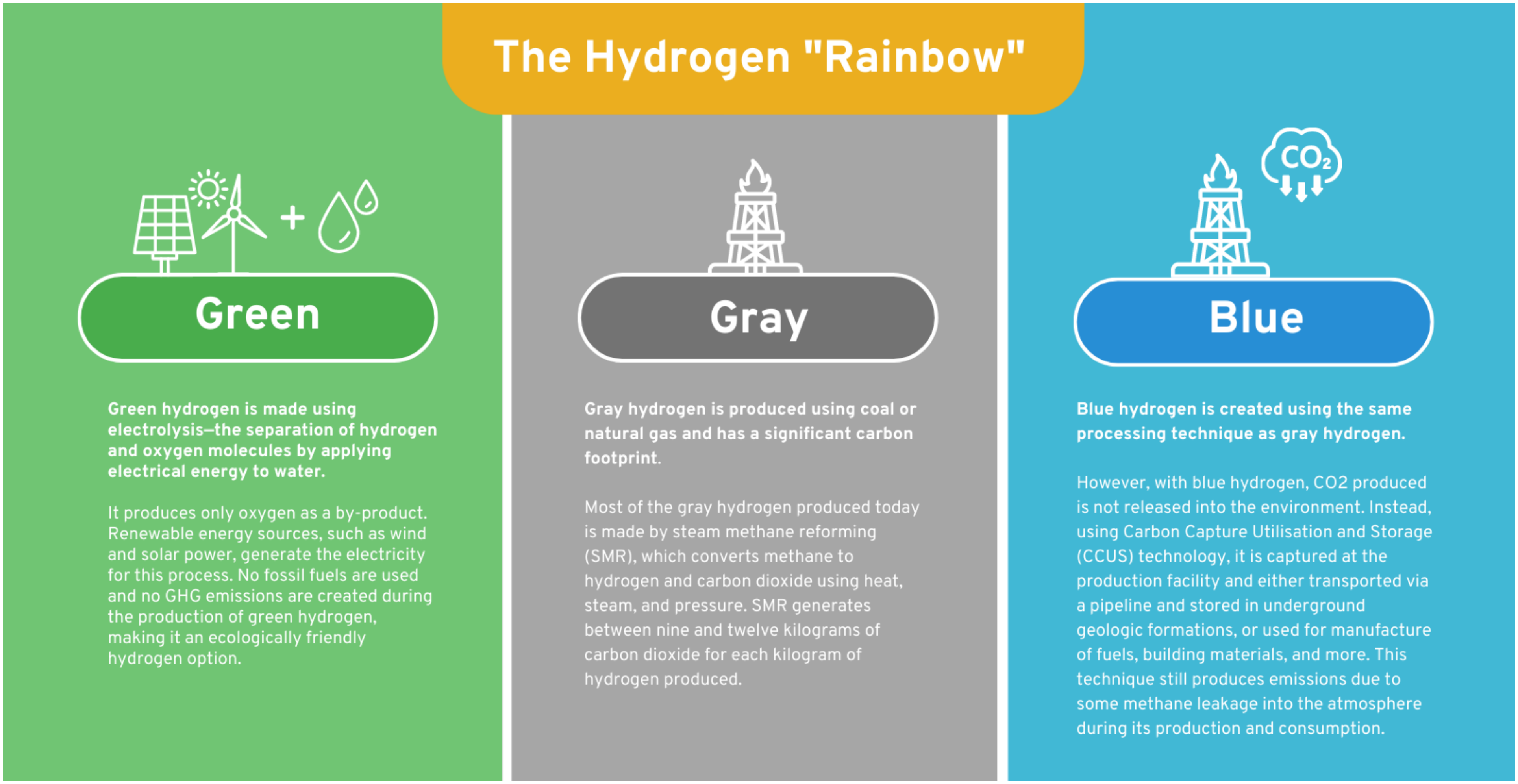
[150]IEA, "IEA G20 Hydrogen report: Assumptions," IEA, December 2020, https://iea.blob.core.windows.net/assets/29b027e5-fefc-47df-aed0-456b1bb38844/IEA-The-Future-of-Hydrogen-Assumptions-Annex_CORR.pdf
Maddie Ewing et. al., "Hydrogen on the path to net-zero emissions: costs and climate benefits," Pembina Institute, July 2020, https://www.pembina.org/reports/hydrogen-climate-primer-2020.pdf
[151]Tessa Weiss et. al., "Hydrogen Reality Check: All "Clean Hydrogen" Is Not Equally Clean," RMI, October 4, 2022, https://rmi.org/all-clean-hydrogen-is-not-equally-clean/
[152] IRENA, "Hydrogen Overview," IRENA, Accessed March 2023, https://www.irena.org/Energy-Transition/Technology/Hydrogen

Figure 21: The Hydrogen “Rainbow”



Source: Ohio River Valley Institute

Sidebar: Jobs Accounting—The Economic Factors Influencing Job Multipliers and Temporary Jobs

A full accounting of the jobs impact of a transition to green steelmaking must necessarily include both the direct jobs generated as well as the indirect and induced jobs in the broader economy. There are broadly two categories of indirect job impacts associated with direct employment changes in a given industry: supply chain jobs and induced jobs supported by the re-spending of income in the local economy on goods and services. The total of these indirect and induced influences make up the local economic multiplier.

Accounting for these jobs can be complex and depends on several different factors and how they interact over time. The first is the time horizon that is considered. A study by Tsvetkova and Partridge found that most major economic investments within a region, such as the construction of new infrastructure or the opening of new plants and extraction operations, occurs as a sequence of events over time.[153] This sequence begins with the planning and construction phase and ends with the ongoing operation and maintenance of the project. Each phase is associated with a different level of local employment changes within various sectors. Further, sectors respond differently to the employment, migration, price, and wage changes induced by the new project over time.

For example, consider the short-term and long-term effects of a massive infrastructure investment. A new major construction project may put pressure on other smaller local construction projects that had been planned. These may be postponed as firms shift their behavior due to rising materials prices or shortages or due to increased wages from the elevated demand for construction workers. But these negative effects are generally transient, lasting just several years while construction is ongoing. Once the project moves into normal operation, other economic actors in the region may once again change their behavior to respond to the new economic environment. Accordingly, the local economic impact on the region of a major investment such as green steelmaking will be different depending on what time horizon is considered. Predicting too far into the future, given lack of knowledge about what other additional changes may occur, is exceedingly difficult to do.

Recent empirical literature, driven by observable data and more highly specific models of demand shocks within a region, provide the most robust and generalized study of local economic multipliers and conclude that most economic shocks produce a multiplier of around 1.5—significantly lower than most multipliers produced by industry models.[154] This approach assumes that local multipliers are derived from four underlying things:

1. Indirect effects on local industries that supply the incoming industry,

2. Induced effects from new direct job wages that raise demand for locally produced goods and services,

[153] A. Tsvetkova and Mark Partridge, "Economics of modern energy boomtowns: Do oil and gas shocks differ from shocks in the rest of the economy?" Energy Economics, September 2016, https://doi.org/10.1016/j.eneco.2016.07.015
[154] Timothy Bartik and Nathan Sotherland, "Realistic Local Job Multipliers," W.E. Upjohn Institute for Employment Research, April 24, 2019, https://research.upjohn.org/up_policybriefs/8/

3. Agglomeration economy effects, such as the productivity gains from concentrating similar industries in geographic clusters,

4. Congestion effects that occur with in-migration and increased job growth, such as increased land prices, increased local good prices, and increased wages, which may adversely affect the region and its economy. Further, congestion can lead to negative externalities, like increasing pollution or traffic.

Industry estimates of job multipliers are often based upon IMPLAN input-output modeling. One major concern with this approach, which often produces large and attractive multipliers, is that it excludes prices from the model. However, it is reasonable to conclude that as the supply and demand dynamics (such as for labor or construction materials) change within a region, prices for those materials and wages will also change. These price changes and wage changes induce behavior changes by other actors in the region, who may substitute or shift their economic consumption in response. As such, these predictive models often overstate the indirect impact of economic development projects.

Bartik notes that the magnitude of these elements depends on many different decisions by many actors, but generally predictive models fail to fully capture (or capture at all) the potential congestion effects that manifest through rising land prices, wages, and good prices in response to a local economic shock, such as a major infrastructure build-out. These increases almost assuredly change the behavior of other local businesses and consumers in ways that partially offset some of the economic gains from the direct jobs generated by the investment project. A further implication of this is that multipliers generally diminish over time. Major economic development projects may bring high initial multipliers—since it takes time for businesses to adjust to new labor market conditions and price levels—that then diminish over time into a new long-run local equilibrium that incorporates the new employees. Bartik and Sotherland's results are consistent at various geographic levels, including counties, commuting zones, and states. Additionally, beyond the scope of their study, housing supply restrictions within a specific location or geography may play a role in limiting new employees from effectively purchasing and living in the region where they work, diminishing the multiplier effect of their spending and their contribution to the local tax base.[155] Given the complex nature of how these various variables interact, the only conclusion that can be drawn is that many existing studies overstate (sometimes dramatically) local multiplier effects. We apply Bartik and Sotherland's modeled multiplier of 1.5 to our direct job estimates and construction job estimates but also provide a range based upon other commonly reported multipliers in the Appendix.

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[155] Albert Saiz, "THE GEOGRAPHIC DETERMINANTS OF HOUSING SUPPLY," The Quarterly Journal of Economics, Vol. 125, No. 3, August 2010, https://www.jstor.org/stable/27867510

Sidebar: System Design to Enable True Green Hydrogen

Fossil fuel-free green hydrogen relies on renewable energy, which is inherently variable. Several viable solutions to the problem of variability and a need for consistent industrial processes exist. It is critically important to address green hydrogen production in the design phase to avoid inadvertently creating more greenhouse gas (GHG) emissions.

Green hydrogen electrolysis requires renewable energy as an input to split water (H_2O) into hydrogen and oxygen. Because the electric grid is required to match electricity supply with electricity demand at each instant, if renewable energy is not available to drive the electrolyzer at exactly the instant it is needed, then the needed electricity could be met by fossil fuel power plants, ultimately *increasing* greenhouse gas emissions. How can that be? If the renewable resources are not incremental, then the electrolyzer could divert the renewable energy from meeting grid requirements, thus necessitating additional fossil fuel power plants to come online to meet demand. If renewable energy is not available at a time of day and in a location where the electrolyzer is running, fossil fuel power plants may also be required to meet that demand. In such a case, the electrolyzer would—counter-intuitively—create new greenhouse gas emissions, making it more carbon-intensive than traditional steelmaking and substantially worse than utilizing gray hydrogen.

For electrolysis to reduce greenhouse gas emissions, the electricity it uses must meet three requirements: additionality, regionality, and time-matching.

- Additionality:
  Clean electricity from new projects explicitly built to provide power to a specific electrolyzer. Additional new renewable energy projects built to supply a specific electrolysis project would *not* result in lost generation elsewhere on the grid.

- Regionality:
  Renewable energy must be utilized within the same interconnection (e.g., PJM) it is produced and it must account for transmission losses. Renewable energy generated in another geographic region will not affect the local grid mix.

- Time-matching:
  Electrolyzers must operate only when their dedicated renewable energy resources generate power. Otherwise, the electrolyzer may end up drawing power from the grid that is generated by fossil fuels.

The IRA creates significant new incentives for "qualified clean hydrogen" production under Sections 45V and 48V. The US Treasury is currently working out specific details on these production and fuel tax credits. These credits rely on measuring the greenhouse gas intensity of hydrogen production. Ensuring additionality, regionality, and temporal matching is complex and will require careful rulemaking.

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Appendix

Table 2: Key Assumptions and Inputs Summary

	Key Assumptions	Inputs	Source
BF-BOF	Iron ore tons per ton steel	1.6	World Steel Association
	FTE per million tons (Mt) iron ore	114	Calculated for Minntac mine (2019)—employment (Duluth News), production (Mining Technology)
	FTE per Mt coal	102	Calculated from EIA employment and production data for Pennsylvania
	Coal charge ton per ton Coke	1.36	Clairton Environment Report
	Ton coke / ton steel	0.63	Transparency Market Research
	FTE per MTt steel	241	Edgar Thompson Environment Report 2022, Iron and Steel Technology
DRI-EAF	Tons iron per ton DRI	1.4	Energiron, 2020
	DRI per ton steel	1.17	Mesabi Tribune
	Scrap content	0.2	Assumed
	FTE per ton DRI	81	Nucor (2013), Voestalpine (2017b), Cleveland Cliffs (2017). 10% reduction on Midrexas gas reformer not required.
	FTE/MT steel EAF	314	Steel on the Net (2020a), ArcelorMittel-Alabama, NuCor-West Virginia, SSAB-Alabama, SSAB-Montpelier, US Steel-Osceola, Arkansas
Hydrogen & Renewables	H2 kg per ton DRI	79	Midrex
	KWh/Kg H2	56	Vogel et al. (2018), based on 70% efficiency
	DRI per ton steel	1.17	

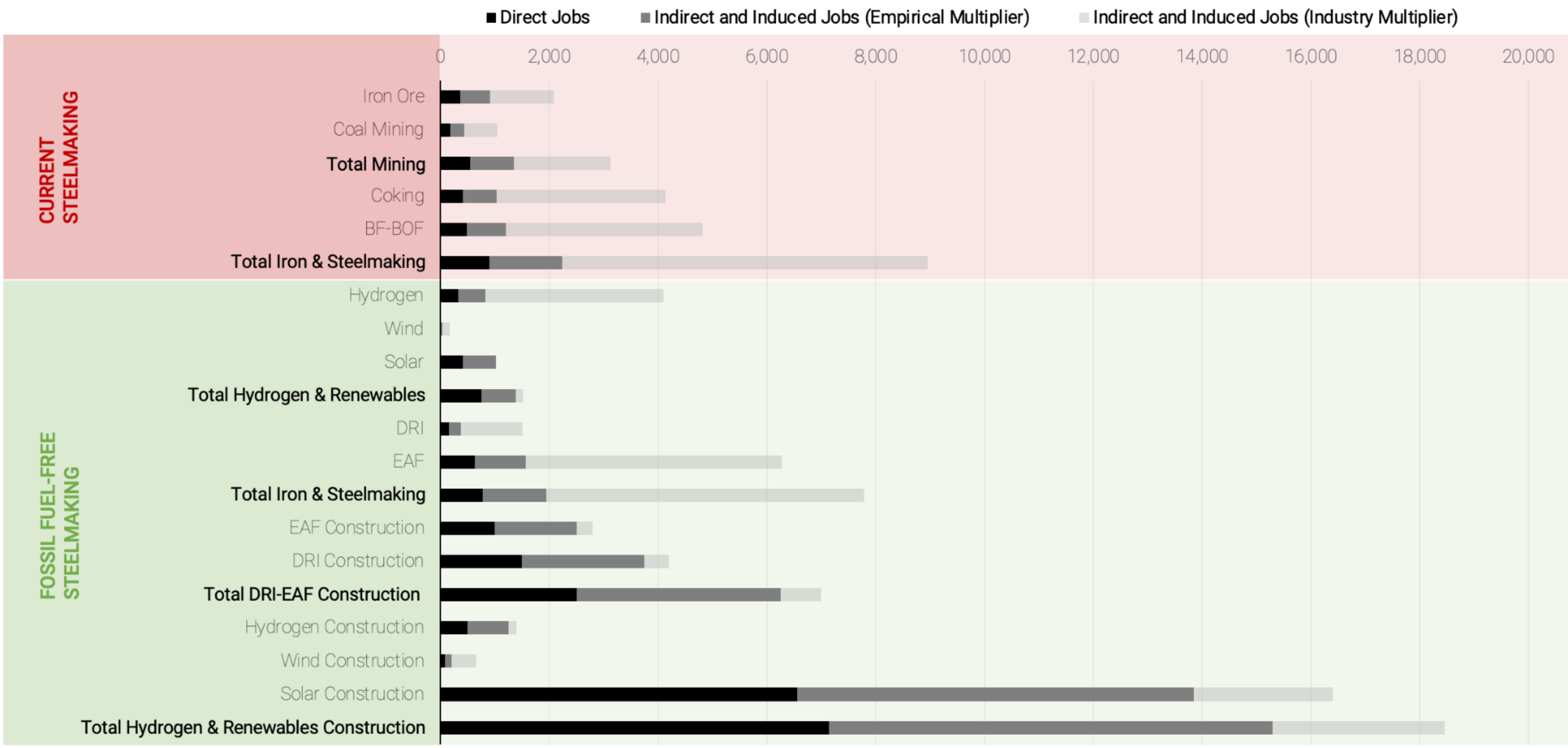
Source: Ohio River Valley Institute

Table 3: Job Multipliers Summary

		Empirical Multiplier	Industry Multiplier	Source
BF-BOF	Iron Ore	1.5	4.7	Economic Policy Institute
	Coal mining	1.5	5	Economic Policy Institute
	Mining			Economic Policy Institute
	Coking	1.5	9	Mon Valley Works 2021 Report
	BF-BOF	1.5	9	Mon Valley Works 2021 Report
	Steelmaking	1.5	4.7	Economic Policy Institute
Green Hydrogen DRI-EAF	Mining			
	DRI Direct	1.5	9	Cleveland Cliffs-Toledo, ArcellorMittel-Ontarion
	EAF Direct	1.5	9	Estimated based on NuCor, WV, ArcelorMittal/Nippon Steel-Alabama ,, US Steel-Osceola, Arkansas
	Steelmaking			
	Hydrogen Direct	1.5	11.5	Economic Policy Institute
	Wind Renewables Direct	1.5	10.3	JEDI L
	Solar Renewables Direct	0.51	1.5	JEDI PV
Construction	EAF Construction	1.5	1.8	Economic Policy Institute
	DRI Construction	1.5	1.8	Economic Policy Institute
	DRI-EAF Construction			
	Hydrogen Construction	1.5	1.8	CE Delft
	Wind Construction	1.5	7.19	JEDI LBW
	Solar Construction	1.11	1.5	JEDI PV

Source: Ohio River Valley Institute

Figure 22: Jobs Estimates Comparison, Fossil Fuel-Free Steelmaking vs. Current Steelmaking Methods



Source: Ohio River Valley Institute