Decarbonizing Industry by 2050:

A Federal and State Policy Blueprint

I3 Industrial Innovation Initiative

a partnership between Great Plains Institute and World Resources Institute

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Participants

The development of the listed policy recommendations by the Industrial Innovation Initiative (I^3) was facilitated by Great Plains Institute and World Resources Institute, with input and involvement by the following participating entities:

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ArcelorMittal

Bipartisan Policy Center

Boston Metal

Breakthrough Energy

Clean Air Task Force

ClimateWorks Foundation

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Growth Energy

International Brotherhood of Boilermakers

Lafarge Holcim

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National Wildlife Federation

Nuclear Innovation Alliance

Oxy Low Carbon Ventures

Portland Cement Association

Renewable Fuels Association

Shell

Third Way

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The Industrial Innovation Initiative (I^3) is an ambitious coalition of key industrial and power companies, environmental and labor organizations, and state officials from Midwestern and Gulf Coast states. The initiative focuses on decarbonization solutions for the region's most important industrial sectors and seeks to accelerate adoption of those solutions through state, regional and federal policy. I^3 is co-convened by the Great Plains Institute and the World Resources Institute.

For more information, please visit www.industrialinnovationinitiative.org.

Introduction

Preface

The Industrial Innovation Initiative (I^3) convenes key industry, environmental, labor, and other stakeholders, together with state officials, to advance strategies, policies, and programs for achieving industrial decarbonization by midcentury. I^3 focuses on key industrial sectors of Midwestern and Gulf Coast states[1] that make up the Midcontinent region, home to the greatest concentration of industrial production in the United States.

I^3 participants have developed the following *I^3 Policy Blueprint* to recommend to Congress and states a suite of policies aimed at putting American industry on a long-term path to net-zero emissions, high-wage job retention and creation, technology leadership, and economic competitiveness. I^3 participants will use this *Blueprint* to (1) outline their shared policy priorities for consideration at the federal and state level, and (2) jointly advocate for implementation of those policies. Due to ongoing legislative discussions, some recommendations in this *Blueprint* are more developed than others. I^3 will use this *Blueprint* as a starting point to build out additional specificity of and prioritization among these recommendations, and to track implementation of recommendations that are included in federal or state level policy.

These recommendations aim to advance the mission of I^3 to incentivize investment in low-carbon technologies, processes, products, and markets within the industrial sector. Priority areas for long-term emissions reductions include the following:

- low- and zero-carbon process heat and energy (e.g., low- and zero-carbon hydrogen and electrification)
- a full range of carbon management options, including capture, removal, transport, utilization, and geologic storage
- energy efficiency
- other innovative industrial applications and practices that can reduce emissions well below current best practices and establish pathways to decarbonize the industrial sector by midcentury

This portfolio of policies provides not only the opportunity for decarbonization and job creation but also for local benefits. Examples of local benefits include reduction of criteria air and other pollutants and workforce development to ensure that communities benefit directly from hosting these projects.

Context and Timeframe for Decarbonization

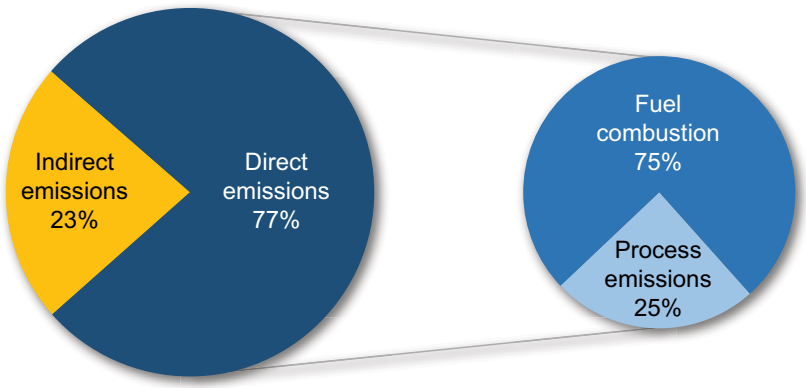
The industrial sector is essential to jobs and prosperity, producing materials that are central to many aspects of our everyday lives, from concrete and steel to chemicals and paper. Like all sectors economywide, emissions from the industrial sector need to decline significantly in the near- to medium-term for us to be on track to meet the goal of midcentury decarbonization in line with analysis by the United Nations Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA).[2] Decarbonizing the industrial sector is more difficult than others, due in part to the variety and complexity of processes and emission sources across industries. Recognizing this challenge, I[3] focuses on the following six subsectors, based on economic importance to the Midcontinent region, emissions, and potential for near-term deployment of solutions: refineries, steel, cement, petrochemicals and fertilizer, pulp and paper, and biofuels.

Industry as a whole contributes 23 percent of US greenhouse gas emissions,[3] making it the third highest-emitting sector after transport and electricity. With emissions from industrial electricity use included, the industrial sector emits 30 percent of total US emissions.[4]

Industrial sector emissions include both direct and indirect emissions (see figure 1). Direct emissions account for about three-quarters of total US industrial emissions.[5] These emissions originate from the on-site combustion of fuels or process emissions from chemical reactions inherent to the industrial production itself. Although process emissions account for around a quarter of direct emissions for industry, they contribute a much higher proportion in sectors such as cement and steel production. The remaining 23 percent of industrial emissions are indirect emissions from electricity used at industrial facilities but generated offsite.

The US Energy Information Administration (EIA) expects US demand for energy from the industrial sector to grow around 34 percent by midcentury and emissions to increase by nearly 18 percent.[6]

Figure 1. Breakdown of industrial emissions by type and origin



Source: US EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019* (April 2021).

IEA modeling recently found that emissions from the global industrial sector must decline 94 percent by 2050 to meet midcentury decarbonization goals that would help avoid the worst impacts of climate change.[7] For the US, this would mean reducing industrial emissions from 1,504 metric tons carbon dioxide equivalent ($MtCO_2e$) in 2019 to around 92 $MtCO_2e$ in 2050.

The path toward industrial decarbonization by midcentury is challenging but feasible over the next three decades. Success requires comprehensive strategies and a robust portfolio of federal and state policies to support innovation, investment, and deployment. Decarbonization needs to accelerate this decade to be on track. Several strategies apply across industrial sectors: carbon management, low- and zero-carbon hydrogen, procurement of low-carbon industrial products, electrification of key industrial processes, and energy efficiency.

US industry has a unique opportunity to become a global leader in innovation and deployment of technologies and infrastructure for decarbonization that will help

- achieve net-zero emissions,
- sustain the viability and competitiveness of US domestic industrial production,
- safeguard and create high-wage jobs, and
- improve the health and economic vitality of communities and regions of the country that have borne the brunt of plant closures and job losses in recent decades.

Investments in industrial decarbonization also can provide an opportunity to deploy technology in ways that provide local benefits through reductions in criteria air and other pollutants that improve community health and the environment. Such investments are also an opportunity to develop and tailor workforce development and training to prioritize members of local communities that host industrial facilities.

Fortunately, momentum toward industrial decarbonization is beginning to accelerate: leading industrial companies have committed to net zero by 2050, state policies on embodied carbon in concrete and other materials have been introduced in ten states and passed in two,[8] and 19 US carbon capture projects in the industrial sector have been announced and more are under development that have yet to become public.[9]

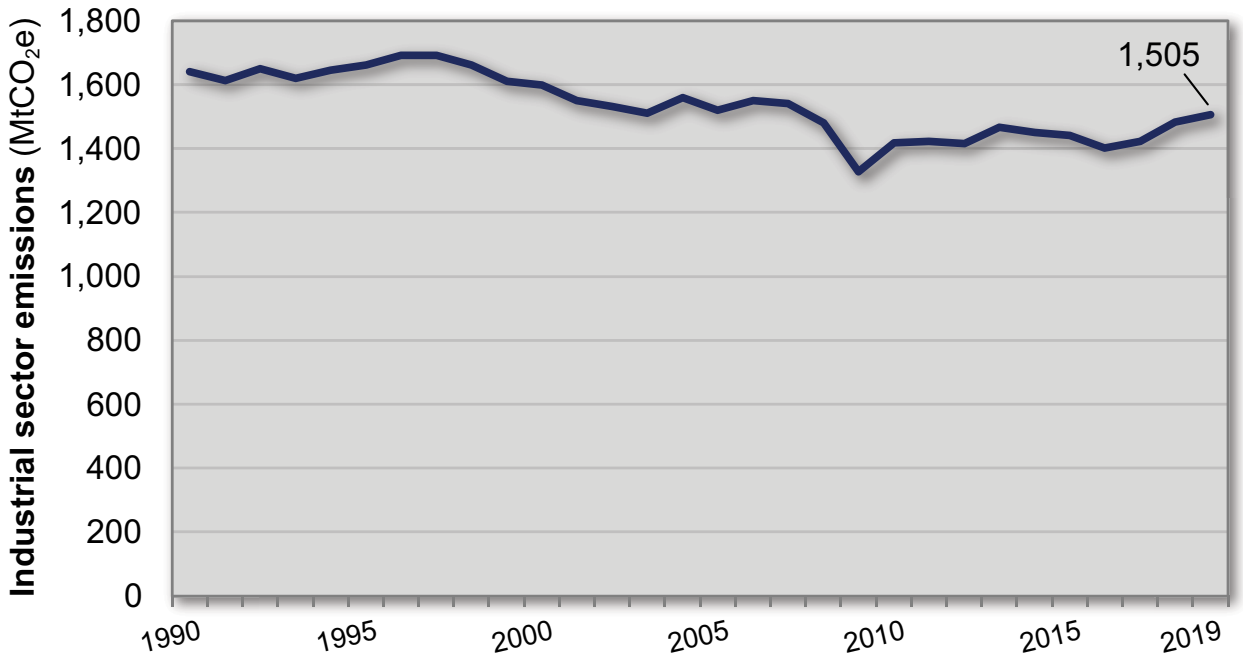
Industry's Role

Addressing Climate Change

The US is one of over 60 countries that have set targets for a net-zero carbon global economy by 2050. In accordance with international modeling from bodies such as the IPCC and the IEA, meeting a net-zero midcentury target would require reducing greenhouse gas emissions by half by 2030.

The industrial sector contributes 23 percent of total emissions in the US economy, or about 1.5 gigatons of CO_2-equivalent ($GtCO_2e$) direct emissions out of a total of 6.6 gigatons economywide, making it the third highest-emitting sector behind transportation and electricity generation.[10] As seen in figure 2, US industrial sector emissions have declined slightly over the last 40 years.

Figure 2. US industrial sector CO_2e emissions, 1990-2019

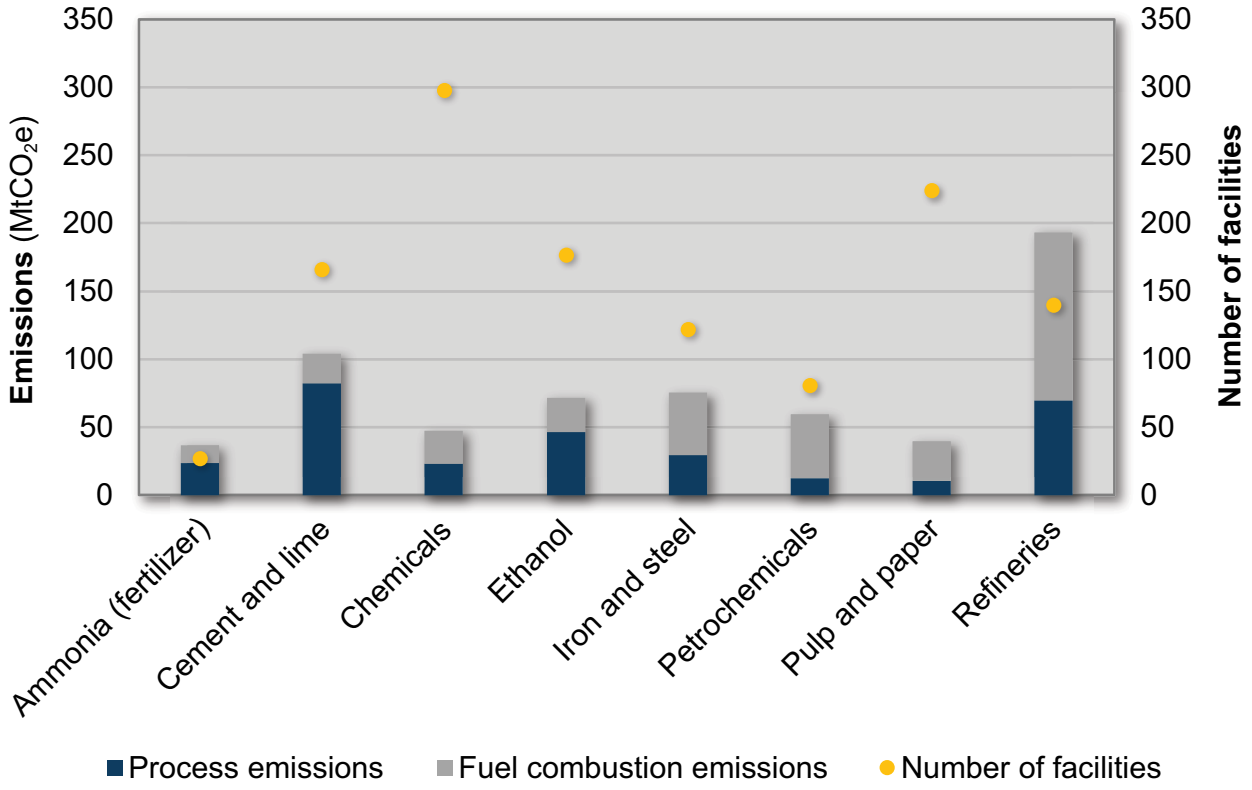


Source: US EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019* (April 2021).

While historically the US has invested heavily in power sector decarbonization, underinvestment in decarbonization of the industrial sector poses unique challenges. The diversity of industries, products, facility sizes, and configurations tends to preclude one-size-fits-all solutions. In many industries, fossil fuels are combusted to supply high- and medium-grade heat for production processes.

The manufacturing of industrial products often involves the release of CO_2 as part of chemical reactions in the production processes. There are several cross-cutting solutions that apply across industries, but each sector will ultimately have to address how to achieve emissions reduction targets such as 50 percent by 2030 and net zero by 2050 across diverse facility and equipment configurations.

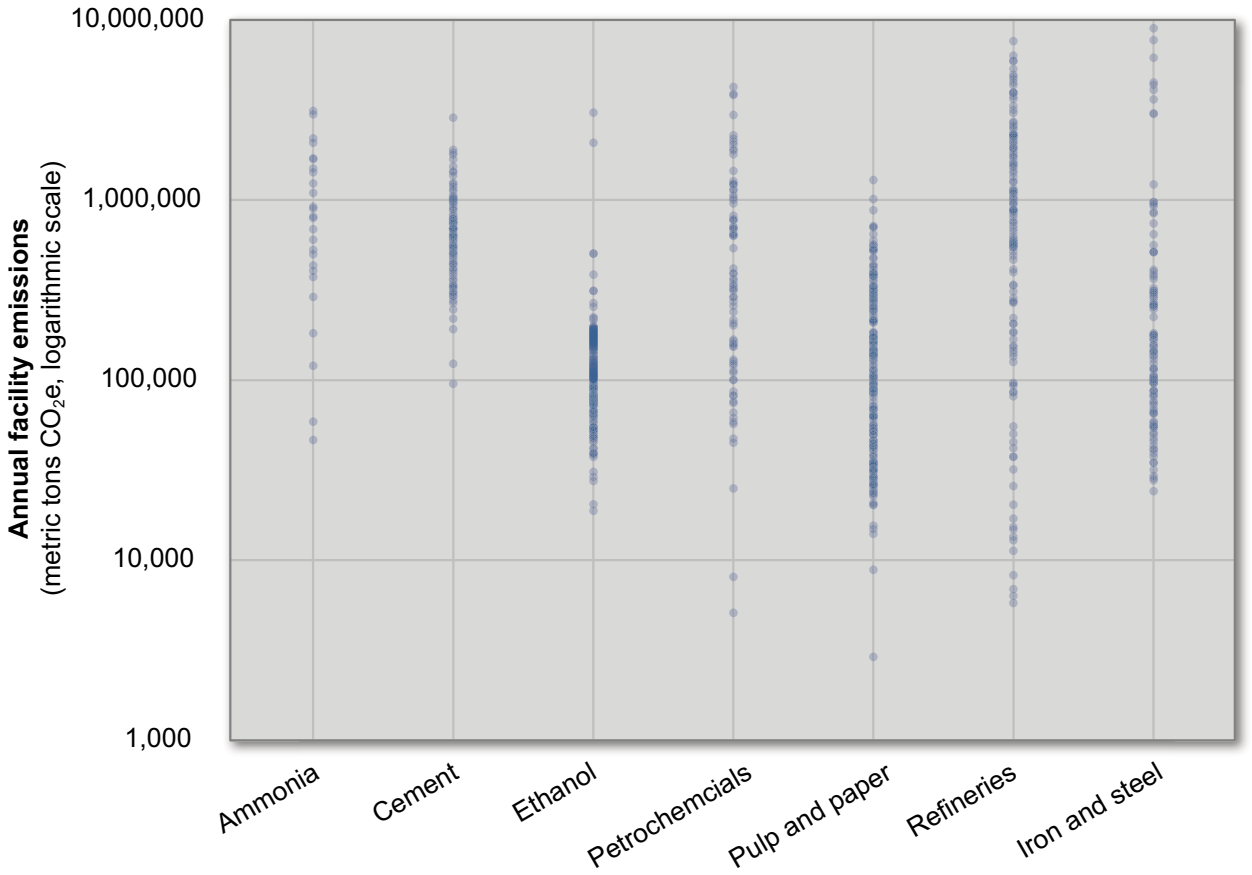
Figure 3. Select industrial sector facilities and emissions, million tons CO_2e (2019)



Source: US EPA, *Greenhouse Gas Reporting Program* (October 2021). Note: Facility numbers are based on EPA FLIGHT categorization and include facilities that report their emissions to the EPA; only the main industrial subsectors that I[3] focuses on are included here. Ethanol emissions includes estimated biogenic emissions not reported to the EPA.

The major industrial manufacturing sectors addressed by I[3], listed in figure 3, have close to 3,000 production facilities across the US. The hundreds of facilities across several industry sectors throughout the country create opportunities for alignment and cooperation in advancing key technologies and practices for reducing emissions. Within each of these industries, there is a wide range of facility-specific emissions (see figure 4), ranging from 10,000 metric tons CO_2e per year to between 1 million and 10 million metric tons per year. The diversity of facility sizes and configurations within sectors themselves means that facilities in the same sector may take different approaches to decarbonize. It also means that applying decarbonization approaches in some sectors or specific facilities within a sector will have a much bigger impact on total emission reduction.

Figure 4. Range of annual industrial facility emissions by sector (2019)

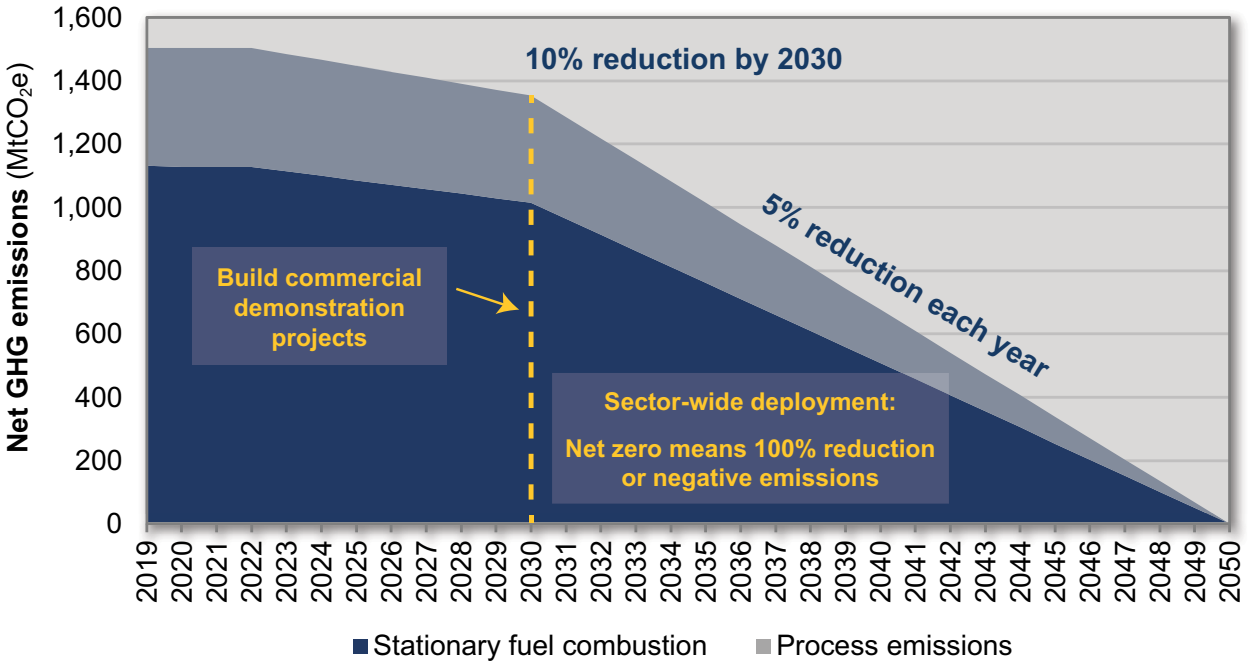


Source: US EPA, *Greenhouse Gas Reporting Program* (October 2021). Note: Only the main industrial subsectors that I[3] focuses on are included here.

Given the challenges to decarbonization within the industrial sector, a 50 percent reduction in direct emissions may be difficult to achieve by 2030. Further research, development, demonstration, and deployment (RDD&D) is needed for many of the decarbonization solutions that will be relied upon by industry in the US and globally to reach net-zero emissions. A more achievable goal may be to focus on the development and commercial demonstration of key solutions over the next decade leading to a 10 percent reduction for the industrial sector from 2019 levels by 2030. This is also equivalent to around a 20 percent reduction from 2005 levels, which aligns with recent scenario analyses for the industrial sector contribution to 50-52 percent reductions from 2005 levels by 2030.[11] From there, achieving net-zero emissions by 2050 would require scaling up deployment to achieve annual emissions reductions of approximately 5 percent of the 2030 total each year from 2030 to 2050, as figure 5 demonstrates.

Based on average facility emissions in each industry, the industrial sector could achieve a 10 percent emissions reduction by deploying decarbonization solutions, including planned retirement, at about 300 facilities across the US. This number could be lower, however, if solutions were targeted at larger than average facilities.

Figure 5. Industrial emissions: 10 percent reduction by 2030 and net zero by 2050



Source: Great Plains Institute and World Resources Institute (October 2021), based on US EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (April 2021). Note: The figure is hypothetical and illustrative of the decarbonization need in industry. The decarbonization rate may not be linear, as shown, and offsetting negative emissions that may be needed to reach net zero in industry by 2050 are not shown.

Industry as a Job Creator

The industrial sector plays a key role in providing jobs that pay above prevailing wages and sustain families, communities, and regional economies. Many additional high-wage jobs will be created locally and across supply chains through the sector-wide deployment of low- and zero-carbon technologies and other emissions reductions strategies. For example, in the steel sector, for every two jobs in steel production, there are 13 more jobs supported throughout the rest of the supply chain.[12]

Industry[13] was the fourth largest contributor to the US gross domestic product (GDP) in 2019, adding $2.4 trillion to the nation's economy while employing 12.8 million people.[14] While industrial and manufacturing activity occurs throughout the US, it has an outsized economic impact in the Midcontinent region, where the industrial sector accounts for up to 15 percent or more of total jobs in most counties.[15]

As our nation's most industrialized region, the Midwest and Gulf Coast will benefit significantly from economywide deployment of industrial decarbonization technologies and infrastructure, which analysis indicates will yield substantial benefit from high levels of investment and the creation of high-wage jobs. For example, scaling up a US hydrogen economy could lead to about $140 billion in annual revenue and support 700,000 jobs throughout the hydrogen value chain by 2030, and $750 billion in annual revenue and up to 3.4 million jobs by 2050.[16] Additionally, the anticipated industrial deployment of carbon capture, transport, and storage through 2050 is expected to create up to 17,000 annual project-related jobs through nearly $52 billion in capital investments and 13,000 jobs for ongoing annual operations.[17]

The Administration and 117th Congress: Federal Economic Recovery, Infrastructure, and Climate Policy

The Biden Administration and 117th Congress have a crucial near-term opportunity to build upon the significant bipartisan legislative accomplishments and growing momentum of the previous two sessions of Congress. They have an opportunity to advance a comprehensive and ambitious policy portfolio to realize the full climate, economic recovery, and jobs potential of industrial decarbonization. Broader legislative packages focused on economic recovery, infrastructure, and climate provide a window for action to position US industry on a path to net-zero emissions by midcentury that we cannot afford to miss.

Fortunately, bipartisan legislation in this Congress features many key I[3] federal policy recommendations:

- Enhancements to the federal Section 45Q federal tax credit and other existing financial incentives;
- Low-cost financing and grants for CO_2 transport and storage infrastructure;
- Renewing and expanding the Section 48C Advanced Manufacturing Tax Credit Program;
- Removing barriers to the Title 17 US Department of Energy loan guarantee program and expanding eligibility criteria; and
- Significantly expanded RD&D funding for carbon management and hydrogen.

Taken together, these policies would leverage private investment in near- and medium-term deployment of several industrial decarbonization technologies.

Key Policy Recommendations to Drive Industrial Decarbonization

A comprehensive suite of complementary federal and state policies is needed to enable, incentivize, and assist the transition to a decarbonized industrial sector by midcentury. Policies tailored to the industrial sector must overcome particular barriers of high upfront capital costs, narrow margins, and high levels of trade exposure. These barriers exacerbate concerns about global competitiveness and potential domestic job losses if production costs rise significantly as US industry decarbonizes.

State and federal policies can play a role in driving investment and mitigating the costs of transitioning to lower carbon industrial production. State and federal policies can also ensure that affected communities realize local jobs and environmental benefits in conjunction with those investments.

The following recommendations are designed to advance technology demonstrations and deployment, infrastructure development, public and private procurement programs and initiatives, and other efforts to drive adoption of low-carbon technologies and practices. The recommendations are organized in six sections:

- Cross-cutting technologies that will be applied throughout many industrial sectors (carbon management, hydrogen, electrification, and energy efficiency);
- Building markets for low-carbon products (procurement); and
- Supporting emerging technologies and cooperation among industrial sectors (innovative approaches).

Carbon Management

I[3] participants have identified economywide implementation of carbon management—carbon capture, removal, transport, utilization, and geologic storage—as crucial to achieving midcentury climate goals, maintaining the long-term viability and competitiveness of domestic US industry in a net-zero world, and sustaining investment, high-wage employment and tax base in areas of the country that have been hard hit by plant closures and job losses in recent decades.

CARBON MANAGEMENT
FEDERAL RECOMMENDATIONS

- Enhance the federal 45Q tax credit, including through direct pay, extension for 10 years, increased credit value, and elimination of capture thresholds
- Reform and expand other federal incentives including 48C and eligibility for private activity bonds and master limited partnerships
- Responsibly accelerate the buildout of CO_2 transport and storage infrastructure including enacting the bipartisan SCALE Act
- Increase investment in RDD&D through fully funding carbon management authorizations in the 2020 Energy Act and funding commercial-scale technology demonstration projects in the American Jobs Plan
- Target jobs and environmental benefits toward affected communities by leveraging federal apprenticeship and workforce training programs in affected communities and assessing impact of industrial carbon capture retrofits on local criteria air and other pollutants

Federal Policy Recommendations

Fortunately, broad-based support and momentum for carbon management policies at the federal level continue to grow as reflected in an emerging set of common priorities in both bipartisan House and Senate legislation and President Biden's American Jobs Plan. In this context, I[3] recommends a portfolio of priority carbon management policies for consideration by Congress and the administration.*

Enhance the federal 45Q tax credit

In 2018, Congress enacted a landmark bipartisan reform and expansion of the Section 45Q tax credit for geologic storage and beneficial use of carbon emissions captured from industrial facilities, power plants, and ambient air through direct air capture. These changes have created new momentum for carbon capture and led to the announcement of more than 35 new projects in development.18 However, the existing 45Q credit continues to have significant limitations, and further improvements are needed to enable a greater number and diversity of carbon capture, direct air capture, and carbon utilization projects to achieve commercial feasibility. These improvements would help pave the way toward large-scale deployment of carbon management in the industrial sector.

* The recommendations in this section are a concise summary of comprehensive federal and state policy recommendations for carbon management supported by the members of I[3]. For these detailed recommendations, see Carbon Management Policy Approaches and Best Practices.

Reform and expand other federal incentives

While further bolstering the 45Q tax credit will have the greatest impact on future deployment of carbon management in industry, reauthorization, expanded eligibility, and technical fixes to a suite of existing federal tax credits and other incentives can helpfully supplement 45Q, often at a modest additional cost to the federal government. Improvements to these complementary incentives can enable additional carbon capture, direct air capture, and carbon utilization projects to achieve financial feasibility.

Responsibly accelerate the buildout of CO_2 transport and storage infrastructure

With proposed enhancements, the federal 45Q tax credit will facilitate economic carbon capture from many types of industrial applications, but the credit value will be insufficient to fund major new CO_2 transport and storage infrastructure. CO_2 pipelines and other infrastructure connected to large-scale saline geologic storage sites are necessary to transport CO_2 from the point of capture to where it can be securely stored or put to climate-beneficial economic use.

Over the next 30 years, scaling CO_2 transport and storage networks to form regional hubs will be necessary to realize economies of scale. These regional hubs can reduce system costs and land-use impacts and support industrial carbon management on a scale consistent with midcentury decarbonization.

Federal policy will play a vital role in overcoming a major chicken-and-egg challenge: CO_2 infrastructure must exist or be under development before companies will commit to capture projects; conversely, pipeline and storage developers will not proceed absent confidence that future capture projects will be developed and placed in service. Federal funding can also help ensure that initial infrastructure is built with extra capacity up front to accommodate cost-effective future growth in carbon capture, direct air capture, and carbon utilization over time.

Increase federal investment in research, development, commercial-scale demonstration, and deployment

Long lead times in advancing capital-intensive technologies—from concept to demonstration to commercialization—make federal investments during the next decade critical to scaling up carbon management technologies by midcentury. In the industrial sector especially, capital costs are high and the economic life of assets is measured in decades, making it difficult or impossible for companies and their investors to shoulder the risks of early commercial-scale demonstration on their own.

In this context, US Department of Energy (DOE) funding has played a crucial role in supporting recent large-scale carbon capture and storage demonstrations and engineering studies (front-end engineering and design or FEED studies), a critical step before projects can proceed to construction. Fortunately, federal policy makers from both political parties have signaled growing support for an expanded federal role in commercial-scale demonstration of critical technologies for decarbonizing industrial processes across multiple sectors.

Target jobs and environmental benefits toward affected communities

Investments in carbon capture, direct air capture, and carbon utilization projects, together with accompanying CO_2 transport and storage infrastructure, have the potential to help revitalize and sustain communities and regions reliant on traditional energy production and industries.

Carbon capture projects provide some of the most desirable clean energy and industrial jobs since employment associated with the sectors addressed in this *Blueprint* consistently pay higher than average local wages.[19] At the same time, residents of historically disadvantaged communities living close to industrial and power generation facilities have borne disproportionate impacts of pollution while often lacking access to the high-wage jobs these facilities provide.

The federal government can leverage existing apprenticeship and workforce training programs, in partnership with community colleges, trade unions, and other institutions to target workforce development to specific local and regional opportunities. The executive branch can also assess the conventional pollutant impact of carbon capture retrofits to better understand how to minimize these impacts on host communities.

State Policy Recommendations

State policies can play an important role in complementing federal policy to help individual carbon capture, transport, utilization, and geologic storage projects achieve financial feasibility and to support the buildout of integrated regional hubs. The policy approaches outlined below describe state policy options and best practices that can positively affect the economics of the entire carbon management value chain. It bears emphasizing that state policies can play important supplementary roles in leveraging the 45Q tax credit and other federal policies without significant additional fiscal impact for states. State policies can also set important precedents for responsible project development.

CARBON MANAGEMENT
STATE RECOMMENDATIONS

- Clarify rules and regulations around CO_2 storage, including agency responsibilities and rules around CO_2 ownership and responsibility
- Consider inter-state and regional planning for CO_2 transportation and storage infrastructure
- Tailor existing financial incentives to support carbon management, including through eligibility for low carbon fuel standards and other clean product programs, optimized state tax policies, and expanded eligibility for state financing programs
- Build markets for captured CO_2 with state procurement standards and programs and offtake agreements

Regulatory policies and planning

States can play a critical role in supporting the development, permitting, and financing of carbon capture, transport, utilization, and storage projects and facilitating the broader development of large-scale regional carbon and hydrogen hubs by establishing and clarifying enabling statutory and regulatory policies. Such policies do not carry a significant price tag, but they are essential to providing regulatory and financial certainty for project development. They create the confidence for multiple private sector actors to proceed with project and investment decisions together across the entire capture, transport, utilization, and storage value chain. This clarity is especially important in the realm of geologic storage.

Financial incentives

While states typically do not provide incentives comparable to the 45Q tax credit value, tailoring existing state taxes and other incentive policies and programs to complement 45Q can help project developers and investors reach commercial feasibility.

Market development

Tax credits, grants, loan guarantees, and other incentives are critical to financing capture, transport, utilization, and storage projects. However, project developers and investors must also have confidence in a future market for their low- and zero-carbon industrial products, fuels, and electricity that will justify their carbon management investments over the long term.

In fact, several states have taken the lead in establishing lifecycle-based procurement standards and programs, portfolio standards, and other policies to build markets that can work in synergy with supply-side financial incentives for private investment.

Hydrogen

Hydrogen holds great promise as a low- and zero-carbon fuel and chemical feedstock that can be flexibly produced from available energy resources, utilize existing workforces and infrastructure, create jobs, and achieve the high-temperature heat that industrial processes require. Today, clean hydrogen production pathways are costly compared to conventional hydrogen production. Government policies to reduce the cost of producing low- and zero-carbon hydrogen, spur deployment of new transport and distribution infrastructure, and develop the consumer market are needed in tandem with private sector investment. Enacting policy under a national hydrogen strategy as other countries are doing would improve coordination as well. These recommendations may also apply to additional hydrogen carriers like ammonia, ethanol, methanol, and hydrazine.

HYDROGEN
FEDERAL RECOMMENDATIONS

- Provide hydrogen tax credits
- Develop hydrogen hubs
- Scale hydrogen transport and storage infrastructure
- Ensure additional financing mechanisms for hydrogen
- Fund RDD&D for hydrogen
- Strengthen and modernize electricity grids

HYDROGEN
STATE RECOMMENDATIONS

- Include hydrogen in state sustainability plans and legislation
- Facilitate permitting for production, transport, and storage
- Offer financial incentives for low- and zero-carbon hydrogen production and use

Federal Policy Recommendations

Provide hydrogen tax credits

Production and investment tax credits greatly defray the upfront and operating costs of hydrogen production, particularly when paid directly to the producer of that hydrogen and stacked with other incentive programs like the renewable production and investment tax credits and 45Q carbon capture, utilization, and storage tax credit. Tax credits should be neutral towards the type of hydrogen production technology, chosen energy feedstock, and end use once it meets a minimum standard of emissions reduction relative to conventional production methods. Additionally, higher credit amounts that reward technologies with lower carbon intensities compared to conventional hydrogen production are powerful tools to incentivize newer, cleaner technologies.

Develop hydrogen hubs

Grants, loan guarantees, and other policies that build upon existing production and consumption hubs, such as in the Gulf Coast and Midwest, provide certainty for developers and investors in low- and zero-carbon

hydrogen projects that a market will exist for their product and that infrastructure will be in place to reduce costs across the supply chain. These hubs should be funded and designed to capitalize on existing comparative advantages to reduce costs, like existing co-location of steam methane reforming with refineries while also creating space for nascent production to take root, demonstrate production and use on a commercial scale, and generate economies of scale. Clean hydrogen hubs can also create jobs in distressed communities while ensuring that negative local pollution impacts are mitigated compared to traditional production.

Scale hydrogen transport and storage infrastructure

Transporting and storing hydrogen can be price prohibitive for producers and consumers that are unconnected by infrastructure to market hubs. Access to federal low-interest loans and grants for hydrogen pipelines and rail and maritime transport will incentivize the construction of infrastructure linkages between regionally dispersed producers and consumers and avoid the higher costs and emissions associated with truck transport. Blending small amounts of hydrogen into natural gas pipelines, where possible based on case-by-case assessments, can also jumpstart local usage for smaller producers distant from dedicated hydrogen pipelines or hubs.[20] Further developing storage infrastructure, like brine wells and salt caverns, enables hydrogen to be sold and dispatched when needed, which can also overcome production variability. The ability of hydrogen to provide long-term storage enables dispatchable low- and zero-carbon electricity to support the integration of variable renewable generation resources on the grid. Clear guidelines for safe transport, storage, and use of hydrogen will also be necessary to build out the requisite infrastructure for a nationwide hydrogen market.

Ensure additional financing mechanisms for hydrogen

While tax credits are perhaps the most powerful direct financing tools, additional financing mechanisms can provide the final push to make a project viable by incentivizing capital investment or enhancing revenue. These tools include the option to convert tax credits into a cash payment (direct pay), contracts for differences to ensure producers receive a minimum price, tax-exempt private activity bonds, and master limited partnerships. A project's eligibility for these mechanisms and their relative contribution will likely vary by project type, but their availability provides more optionality for financing projects and increases developer and investor confidence.

Fund RDD&D for hydrogen

There still exists great room to reduce costs of producing low- and zero-carbon hydrogen. Many innovative ideas struggle to evolve past proof-of-concept or early demonstration to full commercial scale. Funding for RDD&D will improve the likelihood that efficient and cleaner methods of production can achieve market competitiveness. In particular, demonstrations of first-of-a-kind can identify how to best deploy additional commercial-scale plants, proving viability and providing a foundation for the development of broader hydrogen hubs. Large-scale demonstration projects on the last step before commercialization should leverage the Office of Clean Energy Demonstrations, which will be implemented by FY23 if the bipartisan infrastructure package passes.

Strengthen and modernize electricity grids

Scaling up electrolytic hydrogen powered by renewable or nuclear energy will require a vast expansion of available zero-carbon electricity. Working with states and regional grid authorities, the federal government should enact policies that facilitate expansion and hardening of transmission and distribution infrastructure. In areas with abundant renewable resources, incentives that allow excess renewable capacity generation to be moved via transmission infrastructure to areas with less abundant renewable resources for hydrogen production via electrolysis would increase confidence in additional renewable resource development and in the viability of low- and high-temperature electrolysis projects.

State Policy Recommendations

Include hydrogen in state sustainability plans and legislation

The production and use of hydrogen will be a necessary clean energy pathway as states work to meet their climate and decarbonization goals. States should prioritize hydrogen by explicitly including low- and zero-carbon hydrogen within state sustainability plans and by granting state regulatory commissions the authority to include hydrogen infrastructure in resource plans. States can also prioritize hydrogen through legislation addressing hard-to-abate industries along with transportation, since use of hydrogen in both sectors will help build the hydrogen market. Including hydrogen in state economic development plans would also spur regional hubs and coordination with other relevant economic policies and planning. For already enacted plans and policies, states should expand the definition of hydrogen and eligibility, where necessary, to include all low- and zero-carbon pathways of production. Definitions of transportation electrification should include low- and zero-carbon hydrogen as well.

Facilitate permitting for production, transport, and storage

To encourage hydrogen production, transport, storage, and end-use projects within a state, an enabling regulatory framework for permitting should be established or clarified to minimize any unexpected delays or unnecessary costs and barriers to project development. The permitting process should include information from initial project scoping to final emissions testing after construction. The permitting process should also provide clear safety standards for hydrogen producers, retailers, transport, and storage. Facilitating a predictable and timely permitting process will help attract project development and investment to a state, benefiting local economies and industries and contributing to state-level decarbonization goals and plans.

Offer financial incentives for low- and zero-carbon hydrogen production and use

Offering financial incentives for low- and zero-carbon hydrogen production and use to complement existing and anticipated federal incentives can also encourage project development within a state. These incentives could include demonstration grants, tax benefits, or other financial incentives for hydrogen production and projects retrofitting energy and heat sources for hydrogen use. Incentives for hydrogen use in the transportation sector or blending hydrogen in natural gas networks where feasible and effective can also play a role in building the hydrogen market within a state.

Procurement

Given the need to accelerate market transformation in the near term to achieve midcentury decarbonization, I[3] participants have prioritized procurement policies that use government leadership by example. This approach will help increase the deployment of new market-ready and lower-carbon technologies through incentives or requirements for the public sector market. These policy recommendations may intersect with procurement recommendations in technology-focused topics of the Blueprint like hydrogen or carbon management.

Federal and State Policy Recommendations

Support information and disclosure policies

A clear and comparable data set is a necessary starting point for setting meaningful emissions intensity benchmarks for any voluntary or mandatory industrial procurement policy. Given the low level of comparable data in many industrial sectors, disclosure of emissions intensity data through environmental product declarations (EPDs) or other independently-verified reporting mechanisms, following a consistent scope and methodology, should be the first step to build towards other procurement policies at the federal or state level. Because completing EPDs or other reporting mechanisms can have a significant cost—especially for small and medium-size manufacturers—technical assistance and grants for companies to develop EPDs or other reporting mechanisms are critical to putting in place mandatory disclosure policies.

Establish procurement bonus policies

Concurrent with information and disclosure policies, federal and state governments can put in place procurement bonus policies that encourage companies to outperform each other on low-carbon innovation. A procurement bonus provides a cost discount to a company's bid if it has lower carbon intensity than its competitors.

Federal or state governments may need additional analysis to determine the appropriate cost discount for the low-carbon bids. An additional option is to also include a fund that covers the cost differential (if any exists) between the winning low-carbon bids and the bids that use conventional technologies. This enables agencies or departments to use low-carbon options without having to cover any additional costs through their operational budgets.

PROCUREMENT
FEDERAL AND STATE RECOMMENDATIONS

- Support information and disclosure policies
- Establish procurement bonus policies
- Develop public sector procurement standards

PROCUREMENT
FEDERAL RECOMMENDATIONS

- Develop a high achievers program to increase ambition through public procurement
- Expand industrial efficiency block grant funding

Develop public sector procurement standards

Public sector procurement standards should be established to create a required carbon intensity benchmark for public purchasing at the federal or state level. It is critical to set an appropriate threshold, focused on specific product and material types, that is somewhat more ambitious than the market average. It is also critical to increase stringency over time to encourage continued innovation towards midcentury decarbonization. This type of policy, therefore, builds on information and disclosure policy and can be planned to come into effect after a few years of collecting comparable emissions intensity data. Robust direct public investment in research, development and deployment is also crucial to the success of this policy. As standards increase in stringency, investment could also be increased.

Federal Policy Recommendations

Develop a high achievers program to increase ambition through public procurement

A high achievers program would provide a voluntary certification to manufactured materials that meet a defined specification for lower greenhouse gas emissions intensities (similar to the EnergyStar approach for energy efficiency). This type of voluntary certification could then be used as a requirement for some percentage of federal or state purchasing, and as a voluntary benchmark for private sector procurement and consumer-facing programs. When additional market differentiation would be useful, a tiered approach could be developed to highlight categories even within lower-emissions materials. This approach would allow different actors to use different tiers as their procurement threshold. As with procurement standards, a high achievers program would rely on initial policies around information and disclosure for a set of clear and comparable data and would aim to align with relevant existing certification schemes to avoid duplication of effort. It would also be important to increase the ambition of emissions intensity thresholds over time to continue lowering the emissions of products that meet the high achievers certification criteria.

Expand industrial efficiency block grant funding

The federal government can expand block grant funding for states to support industrial efficiency, with increased funds for states that establish procurement programs to help build market demand for low-carbon products. State grants to increase industrial efficiency would support manufacturers to cover the upfront costs of energy-efficient retrofits. States could apply for additional funding contingent on establishing programs that help build state-level market demand for low-carbon products, such as the development of state-level low-carbon procurement standards.

A similar approach was taken in the building sector in 2009. The American Recovery and Reinvestment Act provided states with funding through state energy programs for energy efficiency and renewable energy. To receive funds, states had to update building codes to a certain threshold. State energy offices received $3.1 billion in funding in 2009-2010 (approximately 60 times current annual appropriations) and delivered projects quickly and effectively.

Electrification

Many industrial processes—particularly those that use low- and medium-temperature heat—can be electrified to reduce their direct emissions without impacting the final product while simultaneously future-proofing industrial production and the associated high-wage jobs.[21] It is important to pursue energy efficiency improvements in parallel with electrification to partially offset expected increases in overall electricity demand.

To reach the goal of decarbonization by midcentury, electrification of industrial processes will also require a strategy to decarbonize electricity generation.[22] However, the recommendations in this *Blueprint* focus on the potential interventions within industrial facilities themselves and do not address broader grid decarbonization. The recommendations in this *Blueprint* draw largely from existing work in this space. Several organizations have done extensive work looking at industrial electrification and these recommendations seek to complement and reinforce their importance. Primarily, these recommendations draw upon ACEEE's report Beneficial Electrification in Industry[23] and from Global Efficiency Intelligence and David Gardiner and Associates' report Electrifying US Industry.[24]

ELECTRIFICATION
FEDERAL RECOMMENDATIONS

- Provide incentives for RDD&D
- Provide financial incentives such as tax credits or grants for deployment
- Offer workforce training programs
- Improve federal permitting procedures

ELECTRIFICATION
STATE RECOMMENDATIONS

- Work with utilities and their regulators to facilitate pathways to electrification
- Provide financial incentives such as tax credits or grants for deployment
- Implement workforce training programs
- Improve state permitting procedures

Federal Policy Recommendations

Provide incentives for RDD&D

While many of the technologies needed for electrification are available today, some still require RDD&D support—particularly those for high-temperature heat industrial processes. Federal programs can expand partnerships between DOE national labs, industry, and technology developers to support RDD&D projects that explore and showcase emerging industrial electrification technologies. Incentives support the drive to deploy these emerging technologies at scale to demonstrate success in addressing integration challenges and lowering economic hurdles.

Provide financial incentives such as tax credits or grants for deployment

For technologies that exist in the market but require support for further commercialization, the federal government can provide incentives such as tax credits or grants

to encourage their uptake. These financial incentives can be particularly effective to accelerate the replacement of equipment having large capital costs in areas such as process heat (e.g., replacing boilers and steam systems with large service or distributed heat pumps) at opportunities of equipment turnover.

Offer workforce training programs

As industrial processes transition to electrotechnologies, federally-created workforce training programs can minimize worker displacement, encourage development of new worker capabilities, and avoiding stranded assets. This is critical to the installation, operation, and maintenance of industrial systems and retaining high-wage jobs at industrial facilities. In preparation for these workforce training programs, the federal government can also convene utilities, companies, trade groups, education providers, and labor organizations to ensure that training programs are appropriately targeted to meet the needs of all stakeholders.

Improve federal permitting procedures

Exchanging existing equipment for electrotechnologies may trigger permitting or other authorization procedures. The federal government can support staffing at state levels to provide support and help accelerate the timelines for approvals to accelerate electrification.

State Policy Recommendations

Work with utilities and their regulators to facilitate pathways to electrification

Utilities and their state regulatory commissions vary in their modes of operation across different regions and states. State governments are well-positioned to convene utilities, state regulatory commissions, and industrial customers to consider facilities' electricity needs. State governments can also work with state regulators to undertake research and disseminate information to policy makers and key stakeholders about the implications of industrial electrification. For industry to effectively utilize increased levels of low-carbon electricity additional infrastructure will be needed for conveying and delivering that electricity, ensuring it's availability 24/7, providing economic viability, and making sure that high reliability is delivered. Utilities and regulators can partner with others to support this transition.

Provide financial incentives such as tax credits or grants for deployment

State governments can provide additional incentives to complement those provided at the federal level for technologies that require support for broader commercialization. As with federal financial incentives, these can be particularly effective to accelerate the replacement of large capital investments in process heat (such as boilers and large service heat pumps) at moments of equipment turnover.

Implement workforce training programs

Workforce training needs will vary based on the predominant types of industrial facilities in a state, making state governments effective implementors of workforce training programs and funders for such programs. State governments can also identify and engage affected and disadvantaged communities, targeting programs at communities with the potential for high workforce development opportunities. Many states can develop partnerships with educational institutions, trade unions, and industrial companies to roll out curricula and apprenticeship programs and reach out to communities, further enabling the transition to electrotechnologies.

Improve state permitting procedures

State-level permitting procedures may be an additional barrier to electrification in industrial facilities, alongside the federal permitting procedures. As with the federal government, state governments can accelerate the timelines for approvals to accelerate electrification.

Energy Efficiency

The industrial sector has adopted energy efficiency measures faster than other sectors. This is partially because energy efficiency measures also provide a range of significant non-energy benefits, such as lower production costs, diminished risks, and increased competitiveness. Increasing energy efficiency may also make other emission reduction mechanisms more technically viable and cost-effective.[25] An assessment of the DOE "bandwidth studies" found there is potential to reduce energy use by nearly 20 percent by deploying currently available technologies.[26] A large body of research shows the impact of energy efficiency in reducing energy use and greenhouse gas emissions for the industrial sector.

The recommendations in this *Blueprint* draw upon this existing body of research. Primarily, the recommendations utilize ACEEE's extensive work and Kanako Tanaka's "Review of policies and measures for energy efficiency in the industrial sector.[27]" Two recent studies illustrate that energy efficiency measures could yield nearly half of the needed greenhouse gas reductions by 2050.[28] While additional measures will be vital to reaching net zero, as noted in this *Blueprint*, the potential for early, low capital, substantial reductions via energy efficiency is clear. Industry could achieve further reductions with additional RDD&D for innovative efficiency technologies.

ENERGY EFFICIENCY
FEDERAL RECOMMENDATIONS

- Expand strategic energy management programs
- Assist facilities in conducting energy assessments
- Support RDD&D for emerging technologies
- Expand state block grants to support industrial efficiency
- Provide tax credits

ENERGY EFFICIENCY
STATE RECOMMENDATIONS

- Implement state workforce training programs

Federal Policy Recommendations

Expand strategic energy management programs

Strategic energy management encompasses a suite of solutions and practices aimed at continual improvement of energy performance. Tracking and monitoring energy use is integral to strategic energy management by helping facilities understand and improve their energy performance. These efforts can include hiring energy managers, creating efficiency targets, or implementing new technologies or processes. The DOE should expand programs to provide education and technical assistance for strategic energy management efforts, including through the Better Buildings' Better Plants program.[29]

Assist facilities in conducting energy assessments

Energy assessments or audits are often the starting point for efficiency measures. They allow facilities to identify the most cost-effective areas of opportunity for improvement and provide information to policy makers to develop effective policies to increase energy efficiency. The DOE can support and expand programs that assist facilities in conducting energy audits and implementing the findings. Several existing programs that could be expanded, or former programs that could be restarted, include the Industrial Assessment Centers, the Flex-Tech program in New York, and DOE's Save Energy Now Program.[30]

Support RDD&D for emerging technologies

While many technologies for energy efficiency improvements are available today, additional RDD&D can enable the development of technologies that further reduce energy consumption. Federal programs can expand partnerships between DOE national labs, industry, and technology developers to support RDD&D projects that explore and showcase emerging technologies. Deployment of these technologies is also critical and will require support for increasing uptake.

Expand state block grants to support industrial efficiency

The federal government can provide state grants to expand industrial efficiency support to manufacturers to cover the upfront costs of energy-efficient retrofits. Overlapping with the procurement recommendations in this *Blueprint*, the federal government could provide additional funding to states contingent on establishing programs that help build state-level market demand for low-carbon products, such as the development of state low-carbon procurement standards.

Provide tax credits

One of the barriers that many facilities face when implementing energy efficiency upgrades is the high upfront cost of the investment, particularly for small to medium-sized companies. Tax credits for companies that meet energy efficiency targets or help them offset the cost of efficiency upgrades will help drive the deployment of efficiency technologies. Furthermore, having economic incentives such as tax credits can strengthen the emissions reduction potential of other policies like strategic energy management efforts. Enabling these financing opportunities apply equally at both the federal and state level.

State Policy Recommendations

Implement workforce training programs

Workforce training needs will vary based on the predominant types of industrial facilities in a state, making state governments effective implementors and funders of workforce training programs and Industrial Assessment Centers. State governments can also identify and engage affected and disadvantaged communities, targeting programs at communities with the potential for high workforce development opportunities. Many states can develop partnerships with educational institutions, industrial companies, and trade unions to roll out curricula and apprenticeships and reach out to communities.

Innovative Approaches

The industrial sector can apply and tailor approaches successfully taken to achieve technology innovation in other sectors. These innovative approaches can help increase collaboration among industrial facilities, build a market for new innovations, and examine specific place-based needs to enable industrial decarbonization by midcentury. Some recommendations in this section were based on similar actions taken from other sectors, such as appliances and buildings.[31]

Federal Policy Recommendations

Employ competitive grantmaking for clean industrial hubs

Federal funding can provide competitive grants to regions with a large concentration of industrial facilities. This will promote cooperation to advance decarbonization technologies and understand relationships among different sectors to create opportunities or ease challenges to adopting new technologies and processes.[32]

Spur market innovation with competitions and challenges

The federal government can create competitions or challenges in which they develop ambitious performance criteria for emissions reductions and establish a prize for the entity that first meets the challenge (or all entities that meet the challenge). To spur companies to meet the reach specification through technology or process innovations, the prize can consist of commitments from purchasers (particularly the private sector) for products that meet the reach specification. Prizes could alternatively consist of a financial award or recognition.

INNOVATIVE APPROACHES
FEDERAL RECOMMENDATIONS

- Employ competitive grantmaking for clean industrial hubs
- Spur market innovation with competitions and challenges
- Fund and support RDD&D for innovative technologies

INNOVATIVE APPROACHES
STATE RECOMMENDATIONS

- Establish a state task force on industrial decarbonization

Fund and support RDD&D for innovative technologies

In addition to carbon management and hydrogen (covered in earlier sections), each industrial sector needs many innovations to decarbonize by midcentury. Continued funding and support for RDD&D are critical across these sectors to continue advancing innovation.

State Policy Recommendations

Establish a state task force on industrial decarbonization

The full-scale context of challenges and opportunities can be realized by developing a state task force that includes participation from state and local officials and representatives of locally relevant industrial, energy, and technology companies; environment, clean energy, environmental justice, and community organizations; and labor unions. This will allow states to identify local opportunities and challenges in planning clean energy infrastructure, synergies or overlap between nearby industrial facilities, and where benefits to local communities are most needed.

Conclusion

Achieving midcentury decarbonization targets requires emissions reductions across all sectors of the US economy. The industrial sector, which accounts for 30 percent of total US emissions with indirect emissions included,[33] presents greater challenges to decarbonize due to the diversity of processes and products within and across different industries. Furthermore, the production of many industrial products requires high-temperature heat that cannot easily be generated from electricity. Many industries also produce "process emissions" that cannot be addressed by decarbonizing energy inputs and require carbon capture or other technology options.

Key technologies and solutions to decarbonize the US industrial sector must be deployed at scale and well established commercially within this decade. Delayed action in the near term will prevent the subsequent scaling of critical industrial decarbonization technologies by midcentury, thus increasing the risk of failure to meet midcentury climate goals as modeled by the IPCC and IEA.

The suite of solutions necessary to achieve decarbonization in the industrial sector will require complementary federal and state policies to address barriers to implementation and deployment. There is a unique opportunity for the US to become a leader in the deployment of technologies and infrastructure for decarbonization—helping achieve net-zero industrial emissions while sustaining the viability and competitiveness of US domestic industrial production and the high-wage jobs base it provides.

Carbon management, electrification, energy efficiency, and hydrogen are key solutions that can drive decarbonization in key industrial sectors. While these cross-cutting solutions will greatly reduce emissions from the industrial sector, additional innovation to increase collaboration, build new markets, and further examine specific place-based solutions will be necessary to meet midcentury targets.

With the right state and federal policy framework in place, the goal of achieving net-zero emissions in the US industrial sector by midcentury becomes achievable. The breadth of agreement and support for the recommendations outlined in this *Blueprint* among leading industrial companies, labor unions, environmental organizations, and states participating in I^3 underscores the potential to develop and implement the kinds of transformative policies and investments needed to drive decarbonization in this essential sector.

Acronym Guide

CO_2 – Carbon Dioxide

DOE – US Department of Energy

EPA – US Environmental Protection Agency

EPD – Environmental Product Declaration

EIA – US Energy Information Administration

FEED studies – Front-end engineering and design

GDP – Gross domestic product

Gt – Billion metric tons (gigaton)

I^3 – Industrial Innovation Initiative

IEA – International Energy Agency

IPCC – Intergovernmental Panel on Climate Change

Mt – Million metric tons (megaton)

RDD&D – Research, development, demonstration, and deployment

Notes

[1] The Midcontinent region includes Arkansas, Illinois, Indiana, Iowa, Louisiana, Michigan, Minnesota, Mississippi, Missouri, North Dakota, and Wisconsin.

[2] IPCC, "Summary for Policymakers," in *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, eds. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, et al. (Geneva, Switzerland: World Meteorological Organization, 2018), https://www.ipcc.ch/sr15/chapter/spm/; International Energy Agency (IEA), World Energy Outlook 2020, (Paris: IEA, 2020), https://www.iea.org/reports/world-energy-outlook-2020/achieving-net-zero-emissions-by-2050.

[3] Industry makes up 23 percent of total US emissions if emissions from land use, land use change, and forestry (LULUCF) are not included in the total. Industry without electricity contributed 1,504 metric tons carbon dioxide equivalent (MtCO2e) in 2019 and industry with electricity contributed 1,947 $MtCO_2e$ out of a total 6,558 $MtCO_2e$ without LULUCF included.

[4] "Sources of Greenhouse Gas Emissions," US Environmental Protection Agency (EPA), https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

[5] US EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019* (April 2021, 430-R-21-005), https://www.epa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf?VersionId=wEy8wQuGrWS8Ef_hSLXHy1kYwKs4.ZaU.

[6] US Energy Information Administration (EIA), *Annual Energy Outlook 2020* (January 29, 2020), https://www.eia.gov/outlooks/archive/aeo20/.

[7] IEA, *Net Zero by 2050: A Roadmap for the Global Energy Sector* (Paris: IEA, May 2021), https://www.iea.org/reports/net-zero-by-2050.

[8] *Current Embodied Carbon Policy in the US* (map), "CLF Embodied Carbon Policy Toolkit," Carbon Leadership Forum, accessed October 8, 2021, https://carbonleadershipforum.org/clf-policy-toolkit/.

[9] Potential Carbon Capture Projects Database, database of potential projects under 45Q federal tax credit, maintained by Clean Air Task Force (accessed October 8, 2021), https://docs.google.com/spreadsheets/d/115hsADg3ymy3lKBy4PBQRXz_MBknptqlRtlfuv79XV8/edit#gid=1540463113.

[10] "Sources of Greenhouse Gas Emissions," US EPA.

[11] Larsen et al., *Pathways to Paris: A Policy Assessment of the 2030 US Climate Target* (Rhodium Group, October 19, 2021), https://www.rhg.com/wp-content/uploads/2021/10/Rhodium-Group_Pathways-to-Paris-A-Policy-Assessment-of-the-2030-US-Climate-Target.pdf; K. Kennedy, W. Jaglom, N. Hultman, E. Bridgwater, R. Mendell, H. Leslie-Bole, L. Rowland et al., *Stronger Together: An All-In Climate Strategy for Faster, More Durable Emissions Reductions* (America Is All In, 2021), https://www.americaisallin.com/wp-content/uploads/2021/09/blueprint-2030-report.pdf.

[12] Oxford Economics, *The Role of Steel Manufacturing in the Global Economy* (May 2019), 3, https://www.worldsteel.org/en/dam/jcr:fdf44918-de3b-455b-9083-f770afa4a214/OE%2520Executive%2520Summary.pdf.

[13] Industry in this context is based on the highest-level manufacturing classification from the US Bureau of Economic Analysis, including both industrial non-industrial manufacturing.

[14] US Bureau of Economic Analysis Interactive Data (Value added by Industry as a Percentage of Gross Domestic Product; accessed October 18, 2021), https://apps.bea.gov/iTable/iTable.cfm?reqid=150&step=2&isuri=1&categories=gdpxind; US Bureau of Economic Analysis Interactive Data (Table 6.4D. Full-Time and Part-Time Employees by Industry; accessed October 18, 2021), https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=2&isuri=1&1921=survey; US Bureau of Economic Analysis Interactive Data (Value Added by Industry; accessed October 18, 2021), https://apps.bea.gov/iTable/iTable.cfm?reqid=150&step=2&isuri=1&categories=gdpxind.

[15] US Bureau of Economic Analysis Interactive Data (Total Full-Time and Part-Time Employment by NAICS Industry [CAEMP25N]; accessed October 1, 2020), https://apps.bea.gov/iTable/iTable.cfm?reqid=70&step=1&acrdn=4.

[16] Fuel Cell and Hydrogen Energy Association, Road Map to a *US Hydrogen Economy*, accessed October 8, 2021, 21, https://www.fchea.org/us-hydrogen-study.

[17] John Larsen, Whitney Herndon, Galen Hiltbrand, and Ben King, *The Economic Benefits of Carbon Capture: Investment and Employment Estimates for the Contiguous United States* (Rhodium Group, April 20, 2021), commissioned by the Great Plains Institute, https://rhg.com/research/state-ccs/.

[18] Potential Carbon Capture Projects Database, maintained by Clean Air Task Force.

[19] Larsen, Herndon, Hiltbrand, and King, *The Economic Benefits of Carbon Capture*.

[20] M.W. Melania, O. Antonia, and M. Penev, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues* (National Renewable Energy Laboratory, March 2013), https://www.nrel.gov/docs/fy13osti/51995.pdf. The efficacy and feasibility of blending hydrogen into existing pipeline networks is dependent on several factors and would require further study and improvements to maintenance and monitoring systems.

[21] Ali Hasanbeigi et al., *Electrifying U.S. Industry: A Technology- and Process-Based Approach to Decarbonization* (Global Efficiency Intelligence, LLC and David Gardiner & Associates, January 2021); Ed Rightor, Andrew Whitlock, and R. Neal Elliot, *Beneficial Electrification in Industry* (American Council for an Energy-Efficient Economy [ACEEE], July 2020), https://www.aceee.org/research-report/ie2002.

[22] Midcontinent Power Sector Collaborative, A *Road Map to Decarbonization in the Midcontinent: Electricity Sector* (Great Plains Institute, July 2018), https://roadmap.betterenergy.org/wp-content/uploads/2018/08/GPI_Roadmap_Web.pdf.

[23] Rightor, Whitlock, and Elliot, Beneficial Electrification in Industry.

[24] Ali Hasanbeigi et al., Electrifying U.S. Industry.

[25] Andrew Whitlock, Neal Elliott, and Edward Rightor, *Transforming Industry: Paths to Industrial Decarbonization in the United States* (ACEEE, May 2020), https://www.aceee.org/sites/default/files/pdfs/ie2001.pdf.

[26] Lowell Ungar and Andrew Whitlock, *Energy Efficiency and Corporate Sustainability: Saving Money While Meeting Climate Goals* (ACEEE, 2019), 4, www.aceee.org/sites/default/files/pdfs/eecs-smmcg_0.pdf.

[27] Kanako Tanaka, "Review of Policies and Measures for Energy Efficiency in Industry Sector," Sustainability of Biofuels 39, no. 10 (October 1, 2011): 6532–50, https://www.sciencedirect.com/science/article/abs/pii/S0301421511005933?via%3Dihub.

[28] Steven Nadel and Lowell Ungar, *Halfway There; Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050* (ACEEE, September 2019), https://www.aceee.org/sites/default/files/publications/researchreports/u1907.pdf; *Energy Efficiency 2018: Analysis and Outlooks to 2040*, (IEA, 2018), https://iea.blob.core.windows.net/assets/d0f81f5f-8f87-487e-a56b-8e0167d18c56/Market_Report_Series_Energy_Efficiency_2018.pdf.

[29] *Strengthening Industrial Energy Management*, (ACEEE, April 2021), https://www.aceee.org/sites/default/files/pdfs/strengthening-industrial-energy-management-fact-sheet.pdf.

[30] *Strengthening Industrial Energy Management*, ACEEE.

[31] "L-Prize Competition," Energy.gov, accessed October 27, 2021, https://www.energy.gov/eere/ssl/l-prize-competition; Better Buildings Beat Team, "Infographic, Results from DOE's High-Performance RTU challenge," (U.S. Department of Energy Better Buildings Initiative, May 31, 2018), https://betterbuildingssolutioncenter.energy.gov/beat-blog/infographic-results-doe-high-performance-rtu-challenge.

[32] Ed Rightor, "U.S. Can Cut Emissions by Helping Transform Industrial Clusters," ACEEE, July 15, 2021, https://www.aceee.org/blog-post/2021/07/us-can-cut-emissions-helping-transform-industrial-clusters.

[33] "Sources of Greenhouse Gas Emissions," US EPA.

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