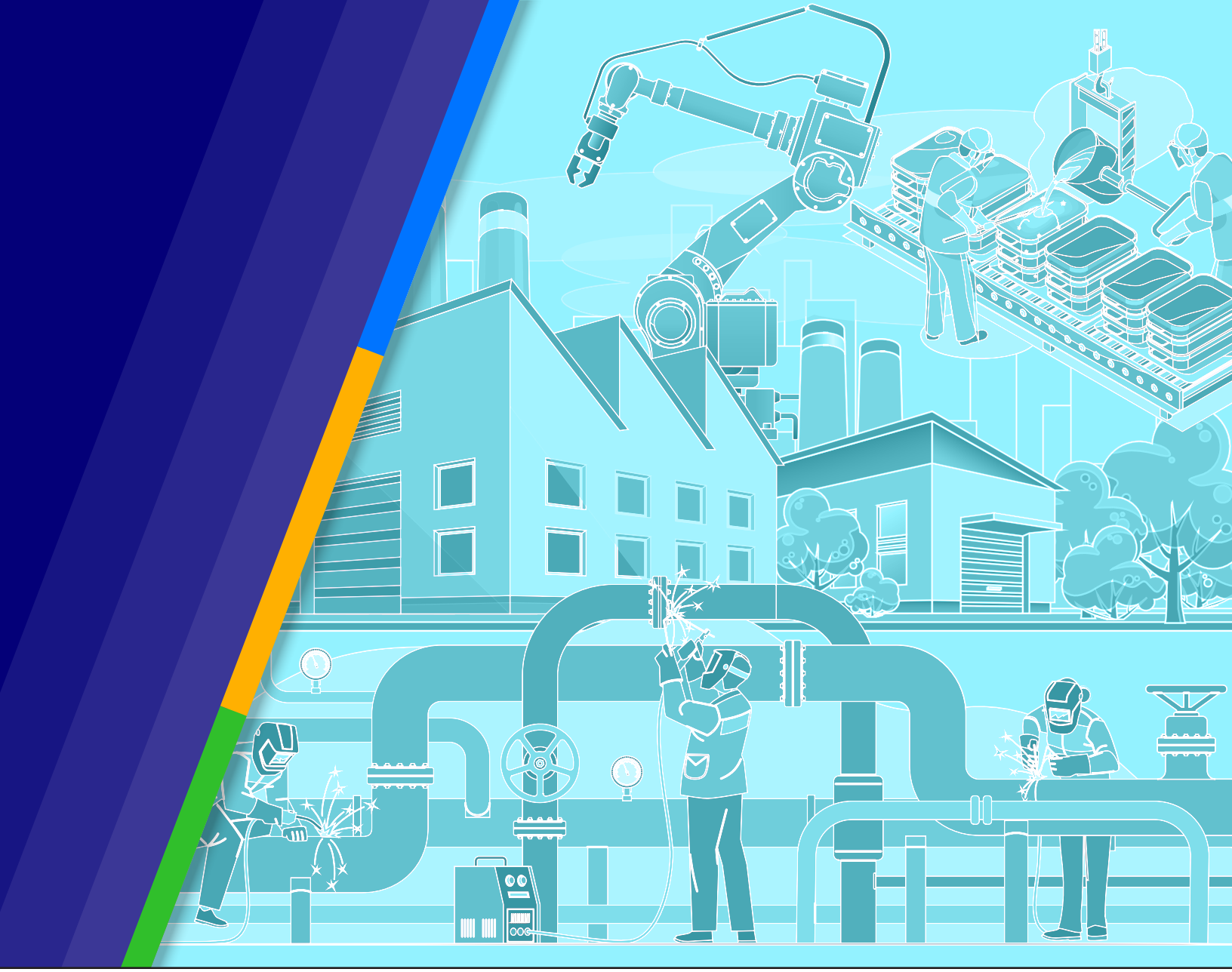

The National Blueprint for a Clean & Competitive Industrial Sector

November 2024

U.S. Department of ENERGY

About this Document

This document was developed by the U.S. Department of Energy and the Office of Science Technology Policy (OSTP) in the White House with input from the following Departments and Agencies to enable greater coordination to enhance a clean and competitive industrial sector:

- Department of Energy
- Environmental Protection Agency
- General Services Administration
- Department of Transportation
- Department of Defense
- Department of Commerce
- Department of the Interior
- Department of State
- Department of Agriculture
- Climate Policy Office
- Council on Environmental Quality

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Executive Summary

In 2021, the U.S. government published *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*[1] to set a target for economy-wide net zero greenhouse gas (GHG) emissions by 2050 and illustrate the multiple pathways to reach that target. Significant progress toward this goal is being made through a once-in-a-generation investment in building a net-zero and equitable economy of the future. These investments across a suite of historic legislation—Bipartisan Infrastructure Law,[2] CHIPS (Creating Helpful Incentives to Produce Semiconductors) and Science Act,[3] and Inflation Reduction Act[4]—support U.S. climate and clean energy goals, create high-paying jobs, invest in hard-hit communities, build stronger supply chains, bring manufacturers back to the United States, and advance American leadership around the globe. Foundational to these efforts is supporting the transition of the U.S. industrial sector to make it the cleanest and most innovative in the world.

This Blueprint lays out a pathway to achieve a low-carbon U.S. industrial sector that is less polluting; more economically competitive; resilient to changing global market conditions; and a contributor to good jobs, revitalization of industrial communities, public health, energy and environmental justice[5], and national security. The industrial sector is diverse and includes manufacturing and non-manufacturing subsectors (agriculture, mining, and construction), which together contribute ~38% of total greenhouse gas emissions.[6] This Blueprint focuses on manufacturing because it is the largest consumer of energy and source of emissions within the broader industrial sector. The objective of the Blueprint is to elicit rapid near-term GHG emissions reductions and expanded economic competitiveness while advancing transformative solutions for the long-term. Through collaborations between the U.S. government and owners and operators of manufacturing plants, labor unions, civil society organizations in industrial communities, environmental groups, technology providers, equipment manufacturers, engineering firms, and project developers, the vision of this Blueprint can become a reality. It also aims to promote communication with communities and Tribal nations to ensure all impacted stakeholders have a voice in the transition to co-produce and deploy solutions that generate benefits for all.

The Blueprint establishes five strategies to guide near-term Federal Government coordination:

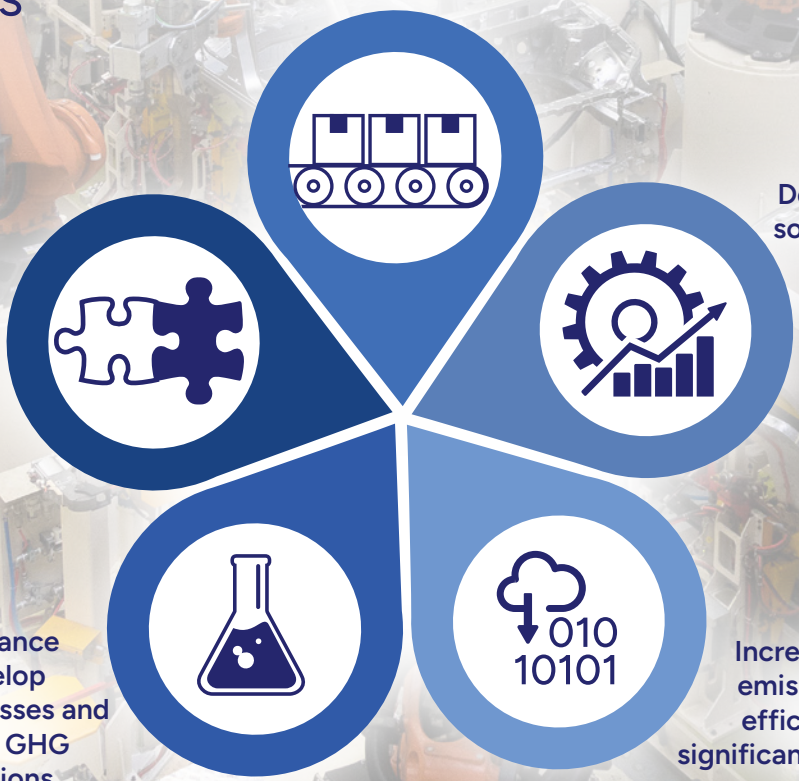
1. Accelerate deployment of commercially available, cost-effective lower carbon solutions in the near-term
2. Demonstrate emerging solutions at commercial scale to de-risk deployment
3. Increase data use to drive emissions reductions and efficiency gains that can significantly improve performance and track progress
4. Innovate and advance research to develop transformative processes and products for deep GHG emissions reductions
5. Integrate across the product life cycle to reduce embodied GHG emissions in industrial products and minimize waste

The Blueprint then details a set of levers, that is, programs available to governments to support this transition: expanding supply-side investments; creating demand-pull; implementing codes, standards, and reporting requirements; ensuring locally defined benefits for workers and communities; developing a common infrastructure; increasing data transparency; and

1 The Long-Term Strategy of the United States, Pathways to Net-Zero Greenhouse Gas Emissions by 2050 | The White House
2 Guidebook to the Bipartisan Infrastructure Law | Build.gov | The White House
3 FACT SHEET: One Year after the CHIPS and Science Act, Biden-Harris Administration Marks Historic Progress in Bringing Semiconductor Supply Chains Home, Supporting Innovation, and Protecting National Security | The White House
4 Inflation Reduction Act Guidebook | Clean Energy | The White House
5 Learn About Environmental Justice | US EPA
6 EPA (2024). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2022 U.S. Environmental Protection Agency, EPA 430R-24004. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2022.

expanding international cooperation. Implementing these levers to achieve the strategies outlined in the Blueprint will translate to substantial improvements in public health, accelerated innovation to support U.S. international competitiveness, reduced GHG emissions, mitigated fiscal and climate risk, expansion of high-paying jobs, more efficient stewardship of U.S. natural resources, renewed investments in industrial communities, and both near- and long-term financial stability. The implementation also aims to strengthen U.S. diplomatic standing and influence international policy to benefit both domestic and global environmental outcomes.

Five Strategies



Accelerate deployment of commercially available, cost-effective lower carbon solutions in the near-term

Demonstrate emerging solutions at commercial scale to de-risk deployment

Integrate across the product life cycle to reduce embodied GHG emissions in industrial products and minimize waste

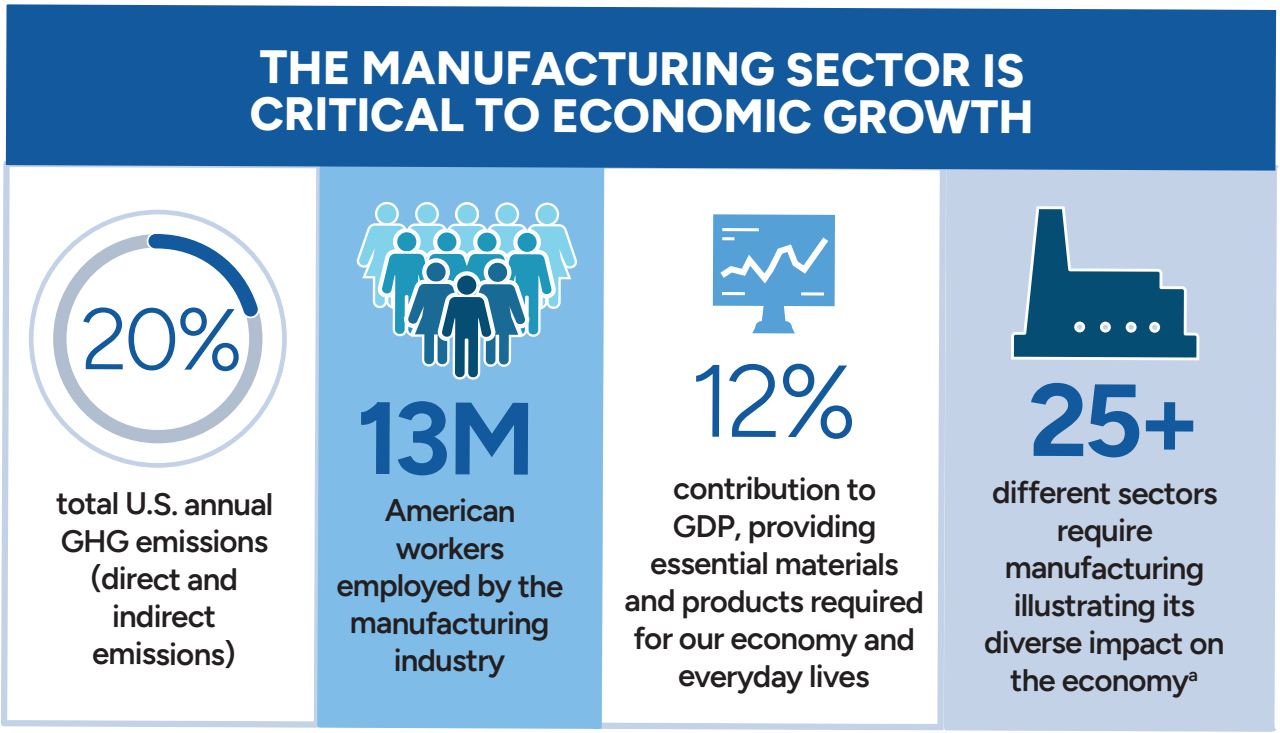
Innovate and advance research to develop transformative processes and products for deep GHG emissions reductions

Increase data use to drive emissions reductions and efficiency gains that can significantly improve performance and track progress

Introduction

In 2021, the U.S. government published *The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050*[7] to set a target for economy-wide net-zero greenhouse gas (GHG) emissions by 2050 and illustrate the multiple pathways to reach that target. Since then, Congress passed the bipartisan Infrastructure Investment and Jobs Act of 2021 (BIL) and the Inflation Reduction Act of 2022 (IRA)—providing new and expanded authorities and appropriating over $100 billion combined to further the U.S. economy. The BIL allocates substantial funding to initiatives that can reduce carbon emissions in industrial sectors, including investments in clean energy demonstration projects, upgrades to the electric grid, low-carbon fuels and feedstocks, and support for research and development in carbon capture, utilization, and storage (CCUS) technologies. The IRA goes further, providing tax credits and incentives to accelerate the transition to clean energy technologies in industrial applications. These federal policies and programs provide a strong foundation for industries to invest in projects to reduce their emissions footprint (See Appendix A).

The industrial sector is diverse and includes manufacturing and non-manufacturing subsectors (agriculture, mining, and construction). Manufacturing is a foundational part of the U.S. economy. The sector contributes 12% to Gross Domestic Product[8] and employs nearly 13 million Americans,[9] providing essential materials and products required for our everyday lives[10] and countless national security and broader economic benefits. The manufacturing sector also acts as a catalyst for innovation, accounting for nearly 58% of all private sector research, development, and demonstration (RD&D).[11] At the same time, manufacturing activities are estimated to account for about 20% of total annual U.S.



a. U.S. Census Bureau

7 The Long-Term Strategy of the United States, Pathways to Net-Zero Greenhouse Gas Emissions by 2050 | The White House
8 U.S. Bureau of Economic Analysis, "Value Added by Industry as a Percentage of Gross Domestic Product," https://www.bea.gov/itable/gdp-by-industry (accessed August 30, 2024). Included subsectors were manufacturing (10.3%), construction (4.2%), and mining (1.4%).
9 Employment by major industry sector | U.S. Bureau of Labor Statistics
10 A look at manufacturing jobs on National Manufacturing Day: The Economics Daily | U.S. Bureau of Labor Statistics
11 Manufacturing in the United States | National Association of Manufacturers

energy consumption and approximately 20% of total annual GHG emissions (direct and indirect emissions).[12, 13] Given recent progress in building low-carbon sources of electricity and transitioning light-duty vehicles to electricity, the industrial sector could soon be the largest source of emissions in the United States. Beyond GHG emissions, manufacturing facilities emit air and water pollutants that can impact the health of communities that host these factories across the country.

As part of its bold action to tackle the climate crisis, the United States has set an ambitious target to reduce net economy-wide GHG emissions by 50%–52% from 2005 levels by 2030 and to reach net-zero economy-wide GHG emissions by 2050.[14] Achieving these targets requires drastic emissions reductions across all economic sectors. Emissions from industry have long been considered "hard to abate" because of the diversity of processes and products that the sector includes, the complexity of many of the facilities, the impracticality of finding any one solution that could be economically deployed across the sector, long equipment lifespans, and the current lack of technological solutions to address the unavoidable process emissions that come from many of the highest emitting subsectors.

Despite the challenges, a rapidly evolving technical, market, and policy landscape suggests that near-term opportunities to reduce emissions exist today and that coordinated action now is necessary to realize long-term mitigation gains. Growing interest in economy-wide GHG emissions reduction from both domestic and international partners is increasingly focused on the most emissions-intensive industrial subsectors, such as chemicals, steel, and cement. Environmental justice concerns, the transitioning energy landscape in the United States, and the availability of new technologies ranging from the digital (artificial intelligence and machine learning [AI/ML]) to the thermal (industrial heat pumps) to the chemical (clean hydrogen) make this a critical moment to align federal agency action toward this common goal.

Vision

VISION STATEMENT

To transition and transform U.S. industrial manufacturing to boost competitiveness; reduce emissions; support good-paying jobs for American workers; and create a cleaner, more equitable future for all Americans.

The future envisioned through implementation of this Blueprint is a sustainable and resilient industrial sector that enhances economic competitiveness and growth, public health, energy and environmental justice, and national security. The focus of this Blueprint is the manufacturing subsector, prioritizing strategies to ensure that the transformation of raw materials into the products we need is clean and competitive. By leveraging momentum from the energy transition that is sweeping the transportation and power sectors, the United States can enhance its competitive edge, expand trade opportunities, and secure market share for a clean manufacturing subsector in a rapidly shifting global landscape.

Purpose

This Blueprint outlines a national strategy for a private-sector-led, government-enabled transition and transformation of U.S. industrial manufacturing in alignment with the vision statement. For this document, the term GHG emissions includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), fluorinated gases, and others (represented as carbon dioxide equivalents, or CO_2e). Although GHG emissions reduction is the focus of this document, co-pollutant reductions (for primary air pollutants like particulate matter and nitrogen oxides) will also offer significant benefits to human health and wellbeing.

12 Manufacturing Energy Consumption Survey (MECS) | U.S. Energy Information Administration
13 Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2022 | US EPA
14 The Long-Term Strategy of the United States, Pathways to Net-Zero Greenhouse Gas Emissions by 2050 | The White House

The Blueprint ties together existing government activities that address both the challenges and opportunities involved in reducing industrial GHG emissions across the short-, mid-, and long-term. Several published U.S. government studies have laid the foundation for this report by evaluating the potential of technologies to reduce GHG emissions in the industrial sector by 2050 (see Appendix B). Federal agencies and offices are already collaborating to advance industrial GHG emissions reduction, by leveraging public-private partnerships, funding opportunities, and policy initiatives to drive innovation and encourage industry-wide adoption of low-carbon solutions. The Blueprint expands on the work these federal agencies are implementing today, thus presenting the first comprehensive strategic approach by which U.S. federal agencies can support such a transition.

Challenges to reducing industrial manufacturing emissions

Manufacturing spans a variety of subsectors with diverse processes and sources of GHG emissions. A steel furnace operates quite differently from a cement kiln, which in turn is dissimilar to a refinery or a cracker facility used to make primary chemicals. Food and beverage, pulp and paper, aluminum, and glass manufacturers are all also distinctive processes with thousands of facilities across the United States. A one-size-fits-all solution, therefore, does not exist. Custom solutions are essential to address the specific GHG emissions profiles, resource needs, and technological capabilities of different industrial subsectors. For instance, whereas some subsectors may benefit from electrification and innovative energy sources, others might require advancements in carbon capture or more efficient production techniques. There is also a significant technological risk is associated with transitioning from existing, proven materials and production methods. Manufacturers are reluctant to risk downtime or uncertainty regarding quality and reliability from relatively unproven, although efficient, new approaches and feedstocks. Manufacturers also risk liability associated with the consequential under-performance of new materials and processes. At the R&D stage, many U.S. institutions developing new clean energy technologies are characterized by a lack focus on the full scope of market impediments to full market adoption throughout the technical development process, because of a historical separation of the R&D and commercialization parts of the development processes.

In addition to operational practices and technological risk, non-technical barriers often pose notable challenges. One of the most pressing issues is the substantial financial requirement associated with establishing new industrial facilities dedicated to low-carbon manufacturing practices or retrofitting existing facilities with low-carbon technologies. The initial capital investment for advanced technologies and infrastructure modifications can be daunting, particularly for companies operating on thin margins. In addition, many companies face high internal investment hurdles[15] because they must navigate complex approval processes and justifications for diverting funds from conventional projects to innovative emission reduction initiatives. These internal processes may be influenced by risk-averse cultures, prioritization of short-term gains, and the uncertain return on investment associated with emerging low-carbon technologies.

Within this transitional environment, industrial leaders across key sectors point to specific challenges such as low technology readiness of GHG emissions reduction solutions, limited enabling infrastructure essential to deployment (e.g., hydrogen and carbon dioxide pipelines, heating and electrical infrastructure), uncertain customer demand for low-carbon products, financier concerns, lack of standards for procurement and performance, lack of consistent policy and regulatory impetus in the United States compared with other world markets, workforce retraining required to facilitate process and product changes, and permitting and environmental review processes that are often multi-year endeavors that include state and local governments.

15 Pathways to Commercial Liftoff: Industrial Decarbonization | Department of Energy

Now is the time for action: A holistic government approach

U.S. manufacturing is at a crossroads where the global energy transition, changing domestic and international policies, and emerging technologies create the right conditions for changes that will ensure its competitiveness into the future. Whereas manufacturing processes are diverse and each facility will have its own plan for reducing emissions, this Blueprint outlines key approaches that are available today and discusses emerging solutions, the common need for better data tracking, research opportunities for the future, and the need to work across the product life cycle for maximum impact.

The U.S. Department of Energy's (DOE's) Industrial Decarbonization Roadmap, DOE's Pathways to Commercial Liftoff Reports, and published literature reviews[16] supported by the Environmental Protection Agency (EPA) have found that the industrial sector's energy-related CO_2 emissions could be reduced by 58% by 2040 and 87% by 2050—using technologies and strategies available today—and found that further work is needed to achieve net-zero. DOE's Industrial Decarbonization Roadmap[17] provides technical actions for industry broken out into cross-cutting pillars.

Each of these reports outlines how the energy transition will have broad implications for industrial production related to the availability of renewable and inexpensive carbon-free electricity, green hydrogen, and other key feedstocks with falling technology costs. In parallel, digital solutions and advanced computational tools such as AI/ML are revolutionizing a range of sectors. When combined with onsite technical actions, such as equipment upgrades and retrofits, the cumulative efficiency and performance gains can provide manufacturers with significant market advantages.

Although the private sector will lead this transition, the U.S. government must create the conditions for cost-effectiveness, financial feasibility, equitability, and feasibility of implementation. The Blueprint builds on ongoing Federal Government activities to align agency goals and outlines a holistic approach to partnering with the private sector; state, local, and Tribal governments; and communities to align demand and supply-side incentives that will catalyze industrial sector GHG emissions reduction. The Blueprint also complements similar documents published on the decarbonization of transportation and buildings sectors—*The U.S. National Blueprint for Transportation Decarbonization*[18] and *Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector*[19]—to support the United States' ambitious economy-wide GHG emissions reduction targets.

16 Bottom-up estimates of deep decarbonization of U.S. manufacturing in 2050 | ScienceDirect
17 Industrial Decarbonization Roadmap | Department of Energy
18 The U.S. National Blueprint for Transportation Decarbonization | Department of Energy
19 Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector | Department of Energy

Outcomes

This Blueprint seeks to advance a cleaner, more competitive industrial sector that will be a strategic investment in the wellbeing of our nation and the generations to come. The United States must seize this opportunity to lead the world toward a sustainable and thriving future. This Blueprint envisions the following five outcomes that will result from its execution:

Reduce industrial GHG emissions. Private and public commitments to reduce GHG emissions must span the entire industrial value chain, from raw material extraction and processing to inevitable final product end-of-life disposal.

Enhance U.S. industrial competitiveness and grow domestic manufacturing. Companies can expand global competitiveness while reducing GHG emissions by fostering innovation and technological advancements, driving economies of scale, and setting demand signals for low-carbon products.

Increase supply chain resilience. Building adaptive capacity in the face of disruptions and uncertainties stemming from climate change, growing cybersecurity concerns, material availability and security, and market price fluctuations must be a priority to protect the U.S. economy. This involves diversifying supply chains, investing in infrastructure upgrades and workforce talent, and strengthening risk management strategies, such as implementing cyber-informed engineering[20] and using supply chain cybersecurity principles.[21]

Revitalize industrial communities and protect community health. By channeling industrial sector investments to energy and deindustrialized communities, access can be expanded to higher-paying manufacturing jobs and economic development in areas hollowed out by the loss of manufacturing. Acting to reduce GHG emissions can promote environmental justice, including by addressing the disproportionate effects of pollution on overburdened and marginalized communities. For instance transitioning to cleaner or lower-carbon energy sources and adopting innovative technologies can reduce local air and water pollution and improve public health.

Support good-paying jobs and union workers. Creating the industrial workforce of the future requires retaining skilled workers, upskilling the existing workforce, and recruiting new workers through good-quality jobs and training and career awareness programs.

20 Cyber-Informed Engineering | Department of Energy
21 DOE Leads Effort to Improve the Cybersecurity of Energy Supply Chains | Department of Energy

Strategies to Accelerate a Transition to a Clean U.S. Industrial Sector

The strategies discussed in this section identify opportunities for coordinated action, presenting the first comprehensive strategic approach by which U.S. federal agencies can support a transition to a clean industrial sector. Within each strategy, the presented example approaches are intended to be illustrative rather than exhaustive. For additional examples of technologies that could fit within each strategy, refer to one of the complementary and technology-rich Pathways to Commercial Liftoff reports[22] and the Industrial Decarbonization Roadmap.[23]

Accelerate deployment of commercially available, cost-effective lower carbon solutions in the near-term

Commercially available alternatives to high-emitting industrial processes that could achieve a 10%–15% reduction in GHG emissions by 2030 already exist.[24] The Pathways to Commercial Liftoff Report identifies that another ~25% emissions reductions are possible by 2030 by actions outside of industrial facilities through the progressive reduction of GHG emissions from the U.S. power and transportation sectors. Federal Government coordination is necessary to accelerate deployment of these technologies, which often face barriers associated with industry inertia, the lack of familiarity with new materials or manufacturing techniques, lack of finance for capital-intensive upgrades, and/or risk avoidance.

Clean low- to mid-temperature heat. Heat is widely used in manufacturing processes to transform materials into useful products. Heat is used to remove moisture, separate chemicals, create steam, treat metals, melt plastics, and much more. Industrial heat is primarily generated by burning fossil fuels, making it the largest source of GHG emissions across manufacturing subsectors. Electrification can be used to replace fossil-derived heat, which is often used to produce steam and is ubiquitous in industrial settings across the United States. In almost all these cases, boilers are used to create local heating infrastructure, which can be replaced using heat pumps and thermal batteries. Emerging approaches such as heat recovery, enhanced geothermal, concentrated solar thermal, advanced nuclear, and thermal storage can also deliver more economical heat production. Finally, in operations such as separations used in the food and beverage industries, unit operations like drying that were historically enabled by fossil-derived heat now can be replaced with low-temperature alternatives such as membrane technologies that can perform the same function with a fraction of energy input using clean electricity. Demonstrations of integrated clean heat with industrial processes are underway, and more are needed to address this common manufacturing challenge.

Energy efficiency and electrification of non-heat unit operations. Energy efficiency is the most cost-effective means for reducing emissions at many industrial plants. Most industrial plants can reduce energy use by 10%–20%, depending on the maturity of their energy management program.[25] Examples include replacing existing fossil fuel-based equipment such as rotary machinery or eliminating compressed-air-based systems with direct drives.[26]

Low-cost clean electricity. Meeting industrial emissions reductions targets will require a secure, affordable supply of reliable clean electricity for energy-intensive manufacturing. In some industrial sectors such as aluminum production, most of the emissions result from electricity use. Meeting this need will require converting captive power plants to clean energy, expanding transmission to access clean power, and prioritizing low-carbon grid distribution for industrial consumers.

Raw material substitution. Alternatives to carbon-intensive fossil fuel-derived feedstocks and materials, such as clean hydrogen, can lower carbon intensity and lead to cost savings in procurement and energy use,

22 Pathways to Commercial Liftoff | Department of Energy
23 Industrial Decarbonization Roadmap | Department of Energy
24 Pathways to Commercial Liftoff Report, page 27
25 Efficiency and Innovation | National Association of Manufacturers
26 Industrial Energy Management | Environmental Protection Agency

while diversifying supply chains. For example, in cement and concrete manufacturing, cement "clinker" can be blended with alternative materials such as supplementary cementitious materials that reduce the energy and carbon footprint of the final material. In the chemicals sector, new biomanufacturing approaches can produce platform chemicals from biomass.

Demonstrate emerging solutions at commercial scale to de-risk deployment

Deep emissions reductions in many subsectors will require new large-scale changes to methods of production. The private sector is uniquely positioned to envision and build these commercial first-of-a-kind projects. Although these projects will require significant investment, they will produce a critical knowledge base for the domestic industrial sector and the clean energy research and development community, not only serving as a foundation for establishing the necessary enabling supply chain, permitting, and innovation to expand these technologies to commercial scale but also allowing the supply chain to remain competitive with overseas players.

Carbon capture, utilization, and storage. For facilities that produce direct emissions of CO_2 in relatively high concentrations, the deployment of CCUS can be a financially viable path for reducing emissions. In addition to achieving 90%–95% CO_2 removal rates, post-combustion carbon capture systems also remove other air pollutants. Cost of CCUS will vary depending on the concentration of the emissions and the proximity to adequate and safe storage or pipelines. More work is needed to ensure these systems are designed to achieve the greatest environmental benefits and do not create additional risks on host communities. There are emerging opportunities to utilize the captured CO_2 into value-added products that also store the carbon molecules.

High-temperature heat electrification. High-temperature heat electrification is essential for lowering GHG emissions within heavy manufacturing processes and demonstrating this at a commercial scale is necessary to maintain a competitive advantage in a rapidly changing marketplace. By integrating advanced electric heating technologies—such as high-temperature heat pumps and resistive heating systems—industries can transition away from fossil fuel-based energy sources, significantly reducing GHG emissions.

Clean hydrogen. Hydrogen can serve as a raw material, a fuel, or a source of energy storage in many industrial processes. For example, thanks to recent investments, U.S. steel facilities may be among the first in the world to use clean hydrogen to produce direct reduced iron, offering a low-carbon pathway for primary steelmaking. Critically, the feedstocks needed for clean hydrogen (low-cost water and carbon-free electricity) could enable industrial clusters to emerge in regions that have not historically been viable locations for production facilities. Because the supply and demand for clean hydrogen are nascent, demonstrating demand to reduce GHG emissions in manufacturing processes will help ensure the market grows quickly.

Increase data use to drive emissions reductions and efficiency gains that can significantly improve performance and track progress

In recent years, emissions intensity measurement and reporting systems have grown more robust and standardized, enabling manufacturers to accurately track emissions reductions and gain access to growing low-carbon markets. Meanwhile, digital technologies, including emerging forms of sensing, and computational tools are enabling new frontiers in the ways industries manage operations that could lead to efficiency gains that reduce GHG emissions. Hardware tools such as ubiquitous sensors and cyber-physical systems can capture additional data necessary to apply software tools, such as distributed computing, AI/ML, the Internet of Things, digital twins and continuous learning. These approaches represent a shift in controls for industrial facilities that was not possible a decade ago.

Measure and report emissions to drive reductions and gain access to low-carbon markets. Implementing robust, standardized, and third party-verified measurement, reporting, and validation systems for emissions is critical for industry because of new trade policies (e.g., the European Union's Carbon

Border Adjustment Mechanism[27]), public procurement incentives (e.g., the Biden-Harris Administration's Federal Buy Clean Initiative[28]), and private purchasing commitments that offer preferential market access for manufacturers that can prove their products meet benchmarks for low emissions intensity. Companies that adhere to rigorous, widely accepted measurement and reporting protocols are well-equipped to accurately track emissions, gain insights to drive emissions reductions, verify those reductions, and gain access to growing markets for low-carbon products. For example, companies that use environmental product declarations (EPDs) and adhere to the emissions intensity thresholds set by the Environmental Protection Agency's Label Program for Low Embodied Carbon Construction Materials will gain access to public and private clean procurement markets worth billions of dollars.

Improve operational efficiency using sensor networks and advanced controls. Sensor costs have dropped precipitously in recent years, so collecting data about process performance is no longer a major barrier. Integrating comprehensive sensor networks throughout manufacturing facilities enables transformative improvements in both operational efficiency and emissions intensity. These interconnected systems provide real-time monitoring of critical parameters that enable operators to quickly identify inefficiencies, predict maintenance needs, and optimize resource use. When deployed together, the digital tools can help uncover complex patterns and opportunities for process optimization.

Use AI/ML to improve system operations. AI/ML models can optimize plant operations and support capital improvements in industrial processes by incorporating a more complex set of inputs than those of historic process engineering modeling. When paired with the expanded data collection, AI/ML models can offer insights and operator assistance to dynamically improve the performance, reliability, and resilience of industrial facilities.

Innovate and advance research to develop transformative processes and products for deep GHG emissions reductions

Bringing low-emissions industrial processes and materials innovations to market quickly and efficiently means fast-tracking the stages of innovation to maximize the impact of technology investments. The International Energy Agency (IEA) estimates 55% of emissions reductions technologies necessary to meet net zero are not yet in commercial stage. An example of this is cement, where technologically mature approaches such as use of supplementary cementitious materials or calcined clay can reduce emissions by 30%-40%, but further reductions will require new processes or products. At each stage of innovation, the government can play an important role. The first stage involves solution discovery of low-emission processes and material innovations, and partnerships with government agencies and research institutions play a crucial role in this phase. Next, the product development phase to develop a minimum viable product (MVP) can leverage agile methodologies, continuous iteration, and collaboration with potential customers. The third phase is the pilot demonstration phase to test the MVP in real-world industrial settings. Finally, in the go-to-market and scale stage, the solution transitions from pilot to full-scale deployment, and can leverage investments through incentives like tax credits, grants, and strategic partnerships.

Promote tech transfer and knowledge sharing to shorten development cycle timelines. By fostering a culture of collaboration and knowledge-sharing, industries can tap into a wealth of expertise and resources that can accelerate the development of low-emissions technologies and materials. This can be achieved through the establishment of research consortia, joint RD&D projects, and public-private partnerships and by directing government-funded research institutions to advance clean energy research focused on accelerated commercialization.

27 Carbon Border Adjustment Mechanism | European Commission
28 Federal Buy Clean Initiative | Office of the Federal Chief Sustainability Officer

Encourage a culture of innovation and engage workers. Driving innovation in industrial processes and materials requires a culture of innovation and a market-focused view within organizations. This involves fostering a mindset that encourages experimentation, risk-taking, and continuous learning about both technical and market aspects of clean energy technology adoption. By empowering employees to think creatively and challenge the status quo, industries can unlock the full potential of their RD&D investments and drive innovation in the pursuit of a more sustainable future. Enabling workers to join the innovation cycle is critical, particularly at small- and medium-sized industrial facilities that may not be large enough to support innovation staff or offices. Training workers to support changes to existing industrial facilities could greatly accelerate efforts to reduce GHG emissions and improve the economic competitiveness of U.S. industries.

Validate and share information. Proving the performance of emerging new industrial processes and materials requires validation and information sharing[29] among government, academia, industry, and the financial sector. Expanding industry-led consortia could provide additional platforms for collaboration, validation, and information exchange among companies, research institutes, and government agencies to accelerate the innovation cycle and help ensure understanding and acceptance of deployment risks by financial interests, leading to an accelerated commercialization timeline.

Integrate across the product life cycle to reduce embodied GHG emissions in industrial products and minimize waste

Establishing standards and evaluation methods to monitor emissions across supply chains, from raw material extraction to end-of-life disposal, can create important efficiencies. Many opportunities to reduce embodied emissions are driven by mitigation opportunities outside the industrial facility fence line. Manufacturers must deepen their understanding of both the upstream and downstream effects associated with all input and output materials. This knowledge is crucial for maximizing circularity within their operations. By doing so, they can extend the lifespan of existing materials and contribute to a more sustainable manufacturing process. Additionally, co-locating with other manufacturers can create opportunities for mutual benefits. It will be important for manufacturers to inform any co-location decisions to ensure partnerships enhance resource efficiency and promote a circular economy. Scaling these efforts will require the advancement of standards and evaluation methods to share data on carbon production and reductions across supply chains.

Work across the entire value chain of a product to identify opportunities to reduce impact. Most industrial products are diversified, involving several suppliers and customers who make decisions that indirectly affect the emissions intensity of industrial products. Signaling demand for low-carbon materials, actively sharing data, and increasing understanding of what mitigation opportunities are possible can create efficiencies as producers seek the lowest-cost path to emissions goals. Designers, engineers, building owners, and consumers all have a role to play in increasing the demand and use of low-carbon materials—whether that is the concrete in a building or the materials used in cars or clothing.

Promote circularity. By rethinking production methods to prioritize resource efficiency, industries can significantly reduce waste by transforming refuse into valuable inputs for new processes. This not only conserves natural resources but also lowers operational costs, creating a more sustainable business model. It will also be critical to extend product lifespans through repair and remanufacture, promote product-sharing and leasing models, optimize maintenance practices to minimize waste and emissions, and develop new methods to recycle complex materials.

29 Validation is the process of ensuring that new technologies and materials meet their intended performance targets thereby reducing risk of failed investments or unexpected consequences and accelerating adoption. Information sharing is the exchange of knowledge and best practices that allows organizations to identify gaps and opportunities to identify where further innovation is needed and potential solutions that can be explored. Sharing research findings, technical specifications, and case studies accelerates the development of new technologies and materials.

Cultivate responsible, geographic industrial clusters. Industries have historically been clustered based on skilled labor and the availability of feedstocks or energy sources. As these resource inputs begin to shift, it will become increasingly important to understand how industrial hubs might geographically realign in response. This is particularly true when considering where renewable energy is likely to be most abundant as well as the future availability of other low-carbon critical inputs and material substitutions, such as clean hydrogen. Co-locating facilities so waste products from one facility can be more readily used as feedstocks for another facility can provide cost and sustainability benefits that are currently unrealized. Communities impacted by industrial clusters should be actively involved in planning and decision-making processes to ensure their needs and concerns are considered.

To support planning and curate relevant solutions, the U.S. Department of Energy's Office of Fossil Energy and Carbon Management (FECM) is developing a series of regional reports by referencing specific regions' unique energy and industry mixes, local energy resources, and current initiatives and priorities aligned to FECM's research, development, and demonstration portfolio.[30]

30 Regional Reports: Building a Clean Energy and Industrial Economy and the Supporting Role of DOE's Office of Fossil Energy and Carbon Management | Department of Energy

Levers to Accelerate Progress[31]

The Federal Government has a variety of tools to help address challenges to reduce GHG emissions in the industrial sector and support implementation of the strategies outlined in this Blueprint. These build on recent policy momentum from unprecedented investments, new procurement programs, and climate-focused trade initiatives. By advancing these and other tools, the government can foster the conditions to support long-term private sector–led industrial transformation.

Supply-side investments

Many existing technologies could reduce emissions in the industrial sector. However, some of these technologies are not being implemented at scale because they cannot yet compete economically with traditional manufacturing processes, tools, and feedstocks. The following financial mechanisms could help accelerate adoption of these low-carbon technologies:

Tax incentives, grants, and loans for demonstration and deployment. Existing demonstrated technologies could be implemented to reduce emissions in the industrial sector. However, these technologies are not being installed at scale because they cannot currently compete economically with traditional manufacturing processes, tools, and feedstocks. The following financial mechanisms could help accelerate adoption of these low-carbon technologies and enable them to become more economically competitive:

- Expand grants available for first-of-a-kind demonstrations to prove and de-risk emerging technologies and to accelerate adoption at commercial scale. These demonstrations are critical in industries where new plants or significant changes to unit operations will demonstrate innovative technologies at scale.
- Offer low-interest loans for scaling up existing low-carbon technologies to make replacement of carbon-intensive unit processes with low-carbon alternatives more cost-effective.
- Provide clean manufacturing production tax credits to incentivize the process of retrofits such as electrification and efficiency to produce goods with lower carbon intensity.
- Expand investment tax credits for deployment of proven technologies to incentivize the construction of new low-carbon manufacturing plants.
- Promote availability of private and small community revolving loan financing with below-market interest rates for strategic activities to reduce GHG emissions to create flexible financing tools that are attractive for industrial sector developers.
- Use and expand existing public programs and authorities, such as the Defense Production Act, to provide financial support for expanding clean production capacity or retrofitting facilities with clean technologies or feedstocks.

Examples of existing supply side investments

- **DOE's Industrial Demonstration Program recently announced a $5.7 billion (federal funding, >$20B total when including private cost share) investment in demonstration-to-deployment projects scheduled to be operational in the next 3–7 years. The program will provide a significant investment in and knowledge base specifically for the domestic industrial sector, serving as a foundation for the supporting supply chain, permitting, and innovation ecosystem enabling U.S. industry to remain globally competitive.A**
- **DOE created the Technologies for Industrial Emissions Reduction Development Program to invest in fundamental science, research, development, initial pilot-scale demonstrations projects, technical assistance, and workforce development. The program is building an innovation pipeline to accelerate the development and adoption of industrial decarbonization technologies.**

31 Levers are defined here as tools or mechanisms that governments can use to enable the private sector to enact an industrial strategy supportive of national prioritizes.

Expand federal investment in R&D to accelerate innovation. R&D is needed to enable innovation in new and emerging low-carbon solutions and to reduce the cost of existing solutions. Important gaps in the federal R&D landscape for some processes still require a clear pipeline from bench scale solutions to the market, including by advancing educational programming on market adoption risks among federally funded researchers. Some of that work is ongoing, but in many industrial sectors, there is more room for coordination across agencies to accelerate innovation. Energy and environmental justice are often overlooked in early-stage R&D contexts and should be incentivized to be considered from the earliest stages of the research process.

Prioritize supply-side investments and demand-side support in disadvantaged, deindustrialized, and energy communities. Through the Biden-Harris Administration's Justice40 Initiative,[32] federal agencies currently aim to ensure that 40% of the overall benefits from certain federal climate, clean energy, and other investments flow to disadvantaged communities that are marginalized by underinvestment and overburdened by pollution, including federally recognized Tribes and Tribal entities. Grants and loans should continue to prioritize clean manufacturing investments in disadvantaged communities, along with energy and deindustrialized communities, to support economic revitalization, public health, and environmental justice in communities that have endured decades of divestment.

Facilitate partnerships through research consortia and joint RD&D projects. The U.S. government plays a pivotal role in facilitating partnerships among national laboratories, universities, and private companies through targeted incentives that promote collaboration in low-emissions industrial processes and material development efforts. By establishing funding mechanisms aimed at joint RD&D projects, the government can encourage diverse stakeholders to work together on innovative solutions.

Secure affordable clean electricity for energy-intensive industries. Access to a reliable supply of affordable clean electricity is essential for certain industries to significantly reduce emissions. Agencies could use grants and loans to incentivize utilities to provide access to low-cost clean electricity for major industrial consumers.

Create demand pull

One of the biggest hurdles to private sector investment is the uncertain market demand for low-carbon products. The timing and coordination between supply- and demand-side levers is important to ensure a holistic approach. Sustained demand can facilitate a positive feedback loop, stimulating technological advancements and reducing costs over time. Levers that could expand demand for low-carbon materials include the following:

Use public procurement authority to establish market signals for low-carbon materials. The U.S. government, the world's largest purchaser with annual purchasing power of over $760 billion,[33, 34] has begun implementing programs to signal and stimulate demand for low-carbon technologies and reduced carbon footprint of federally funded projects. For example, Executive Order 14057 launched the Buy Clean Task Force and Federal Buy Clean Initiative to promote the procurement of low-carbon materials and products by federal agencies. Federal agencies are currently deploying more than $4 billion under Buy Clean to purchase low-carbon steel and glass for federal buildings or asphalt and concrete for federal roads, highways, and bridges. Federal procurement also provides a greater base of deployed technologies, establishing a track record that eases performance and adoption concerns by industry and financiers.

32 Justice40 Initiative; see also Explore the map - Climate & Economic Justice Screening Tool | (geoplatform.gov).
33 Federal Buy Clean Initiative | Office of the Federal Chief Sustainability Officer
34 A Snapshot of Government-Wide Contracting for FY 2023 (interactive dashboard) | U.S. GAO

Examples of public procurement programs:A

- The EPA is developing a low embodied carbon (LEC) label program that establishes GHG emission limits for construction materials and encourages the use of products with a lower environmental impact.
- The General Services Administration is incorporating LEC material into construction planning and projects; the total embodied carbon emissions associated with these projects will be reduced by an estimated 40,000 metric tons of carbon dioxide equivalent.
- The Department of Transportation's Federal Highway Administration is funding the procurement of low-carbon materials and products that create less pollution by reducing the levels of embodied GHG emissions within the product categories of concrete (and cement), glass, asphalt mix, and steel.
- The Department of Agriculture-led BioPreferred Program enables all federal agencies and federal contractors to purchase biobased products, helping to reduce emissions by up to 5.4 million metric tons of carbon dioxide equivalent.

Use financial assistance to expand private procurement of clean materials. Private procurement can generate stable demand for low-carbon technologies and services, providing a clear investment signal to businesses and encouraging them to develop and commercialize innovative solutions. Integrating clean manufacturing incentives into public financial assistance, as stipulated in Executive Order 14057, can expand private procurement of low-carbon, made-in-America construction materials. For example, requirements or incentives for private developers to incorporate LEC materials that align with the embodied carbon thresholds established by EPA would complement public procurement and produce enough demand to fully shift regional markets for materials.

Advanced market commitments for breakthrough technologies. Advanced market commitments are contracts for offtake (that is, purchase of a product) that can provide innovative companies with the demand certainty they need to attract investments in next-generation, emissions-cutting technologies. Federal agencies can offer advanced market commitments for novel technologies that have the potential for sector-wide impact to help de-risk investments in emissions-cutting solutions.

> The First Movers Coalition, a public-private partnership to commercialize low-carbon technologies through advanced product purchase commitments, has a crucial role in this process.[35] By embracing low-carbon technologies early on, members demonstrate the feasibility and profitability of these solutions, encouraging others to follow suit. There is also an opportunity to develop a consortium of companies that adopt Buy Clean standards.

Contracts for difference (CfD). A CfD is a financial agreement that helps manufacturers mitigate the risk of investing in low-carbon materials by providing cost parity with traditional materials. CfDs are particularly important in certain markets, such as construction materials, and have been widely used as a means of private sector investment in clean energy generation. A price guarantee reduces the uncertainty for both producers and buyers, making it easier to grow the market for innovative materials with lower financial risk. Federal agencies could offer CfDs in which they pay manufacturers for low-carbon materials and resell the materials at standard market prices to buyers, effectively subsidizing the price differential to reduce risk as economies of scale are realized and consumer demand for low-carbon materials grows.

35 First Movers Coalition

Federal Buy Clean InitiativeA

An inter-agency task force is charged with developing recommendations on policies and procedures, including the following:A

- Identifying the highest embodied carbon construction materials and products to prioritize for LEC consideration in federal procurement and federally funded projects.A
- Increasing transparency of embodied emissions through supplier reporting of EPDs, including incentives and assistance to help domestic manufacturers better report and reduce embodied emissions.A
- Launching pilot programs to boost federal procurement of lower-carbon construction materials and learn more about their performance in real-world applications.A

Regulations, codes, standards, and reporting requirements

Enhancing regulatory frameworks that encourage GHG mitigation practices can drive demand for innovative emissions reduction solutions. By establishing clear emissions reduction targets and timelines, the government can motivate industries to invest in research and development. At the same time, by modernizing regulatory processes and providing a clear pathway to permitting, agencies can foster certainty and expedite the implementation of facility retrofits or all new plants. Furthermore, fostering collaboration and information sharing among stakeholders and rightsholders can help identify and address potential challenges and opportunities, ensuring that infrastructure and permitting frameworks effectively support the transition to a cleaner industrial sector.

Accelerate permitting through regulatory reforms to reduce risk for project developers. The Biden-Harris Administration has developed a cohesive approach to permitting and environmental review through implementation of recent permitting and regulatory reforms. These efforts assist agencies to avoid confusion and advance efficient processes, thereby encouraging businesses and researchers to engage in bold, forward-thinking projects, while also ensuring effective review that considers environmental effects and public input. Federal agencies also continue to collaborate and work with states, Tribes, and local authorities to enhance the clarity, predictability, effectiveness, and timeliness of permitting pathways to expedite industrial GHG emissions reduction projects while ensuring federal agencies are responsible stewards of the environment and protecting communities.[36] This may involve continuing to modernize regulatory requirements, coordinating interagency reviews, establishing dedicated permitting frameworks tailored to the projects' complexities, and implementing technological best practices (e.g., electronic permitting platforms and streamlined carbon emission tracking and reporting).

Provide technical assistance to help navigate regulatory and reporting requirements. One effective approach is to establish dedicated task forces with government officials, industry stakeholders, and environmental experts to evaluate and prioritize projects based on their potential impact on emissions.

Make environmental product declaration ubiquitous. EPDs provide environmental performance information for products that offer robust, standardized, third party-verified accounting of emissions across product lifecycles. EPDs are critical for effective investment, procurement, and trade policies that seek to stimulate clean manufacturing. Having clear, comprehensive, consistent guidelines for reporting embodied emissions is also important for private buyers to build trust that clean materials are truly clean. More work is needed to improve the development and use of EPDs and their underlying Product Category Rules. EPA is currently leading this work as part of its LEC Label Program.

36 FACT SHEET: Biden-Harris Administration Delivers on Permitting Progress to Build America's Infrastructure and Clean Energy Future Faster, Safer, and Cleaner | The White House

Create an official U.S. measurement of emissions intensity. To date, the U.S. government has not had an official metric to quantify the emissions intensity of U.S. industries. As the Federal Government and private companies invest billions of dollars to reduce industrial emissions, such a metric is necessary to measure progress. A consistent calculation of industrial emissions intensities would also help to ensure that the emissions intensity of U.S. exports is accurately assessed in countries that are developing carbon-based border measures. It also would better position the United States to work with trade partners to help build an interoperable framework for calculating emissions intensity for trade purposes, thereby avoiding a costly patchwork of divergent approaches. For example, a factory might produce multiple products, which raises important allocation challenges in terms of assigning emissions to a product. Embodied carbon, which is the preferred international means of reporting intensity, does not reflect full life cycle impacts of a product.[37] Data are needed to project environmental performance post-production of a product. In addition, anticipated material recovery scenarios, which may vary regionally, need to be factored into quantification approaches.

Locally delivered benefits for workers and communities

An industrial transformation that makes U.S. manufacturing cleaner and more competitive must not only support U.S. climate goals but also create good jobs for workers without a four-year degree, support cleaner air and better public health outcomes in industrial communities, and offer economic revitalization opportunities in communities that have endured decades of environmental divestment. The nature of these effects will vary widely, according to the existing burdens and needs of the communities as well as the levers of GHG emissions reduction that are pursued.[38] The following mechanisms could support workers and communities throughout the industrial transformation:

Create accountability for projects that negotiate legally binding agreements with unions and community groups. Investments in clean manufacturing will only serve the needs of industrial workers and communities if those workers and communities are able to name their priorities and negotiate for tangible, locally defined benefits. Legally binding agreements between companies and stakeholders as part of federal funding, such as project labor agreements and community benefits plans, offer a means for unions, community groups, and other impacted stakeholders to engage with companies and ensure that new projects deliver the economic, health, and environmental benefits they want to see. Meanwhile, these agreements offer companies access to a stable and skilled workforce and community support, helping to ensure that projects reach completion on schedule. That is why various federal programs have been incentivizing companies to negotiate such agreements with unions, community groups, and other stakeholders.

Technical assistance for unions and community groups. Often the most impacted workers and communities have the fewest resources to negotiate with companies for project labor agreements, community benefits agreements, or other binding agreements for locally defined benefits. Programs to support labor unions, community groups, and other stakeholders in project negotiations can help to fill this gap and ensure that industrial workers and communities play an active role in guiding America's industrial transformation. DOE's Community Workforce Readiness Accelerator for Major Projects initiative offers one example of a promising federal effort to fill the technical assistance gap.[39]

Worker retraining. Policies that incentivize companies to retrain workers during transitions, such as technological upgrades or GHG emissions reduction efforts, will ensure long-term employment stability in impacted communities. Grants and loans for reducing industrial emissions, for example, can condition the funding on the provision of such training.

37 ASTM Specialty Reports: Workshop on Decarbonization: A Gap Analysis of LCA Standards for Industry

38 For a more detailed treatment, see Pathways to Commercial Liftoff: Overview of Societal Considerations and Impacts.

39 Regional Initiative for Technical Assistance Partnerships (RITAP) to Advance Deployment of Basin-Scale Carbon Transport and Storage and Community Engagement and Regional Technical Assistance Through Carbon Storage Partnerships

The Federal Government supports workforce development through programs like:

- The Industrial Training and Assessments Centers to help train and retrain skilled manufacturing labor and benefit small businesses.[40A]
- The Good Jobs Principles Factsheet jointly developed by the Departments of Commerce and Labor to focus on common principles of what comprises a good job.[41A]
- The Registered Apprenticeship Program is an industry-driven, high-quality career pathway where employers can develop and prepare their future workforce, and individuals can obtain paid work experience with a mentor, receive progressive wage increases, classroom instruction, and a portable, nationally recognized credential. Registered Apprenticeships are industry-vetted and approved and validated by the U.S. Department of Labor or a state apprenticeship agency.[42A]

Track labor and equity outcomes. To help ensure that the industrial transformation supports high quality jobs and investments for marginalized workers and hard-hit communities, agencies can track and report a short list of labor and equity outcomes, as stipulated in the Executive Order on Investing in America and Investing in American Workers.

Support voluntary programs. Voluntary programs play a crucial role in encouraging industries to take proactive steps toward reducing their GHG emissions. In these initiatives, companies are empowered to set their own targets and goals, often reflecting their unique operational contexts and capabilities. This self-regulation not only fosters a sense of ownership but also drives innovation as firms explore new technologies and practices to meet their objectives.

Internal motivation is often complemented by external pressures from stakeholders, including consumers, investors, and regulatory bodies, all of whom increasingly demand accountability and transparency in corporate environmental practices. As industries navigate this complex landscape, the interplay of self-imposed goals and external expectations can create a powerful momentum for achieving meaningful emissions reductions, ultimately benefiting both the environment and the companies' reputations.

> Through the EPA ENERGY STAR Challenge for Industry[43] and DOE Better Climate Challenge[44], companies are voluntarily pledging to reduce facility energy intensity by 10% within 5 years and reduce portfolio-wide GHG emissions (scopes 1 & 2) by at least 50% within 10 years, respectively.

Develop common infrastructure and strengthen supply chains

The industrial sector transformation requires significant investments in new technologies and infrastructure, which in turn can create novel supply chain risks. Several levers can help anticipate and avert some of these risks.

Prioritize infrastructure investments. Access to raw materials, resources, and product distribution channels has always been among the most important considerations for any production facility. However, as the energy transition proceeds, these channels will likely change, and infrastructure investments will be needed to unlock the ability for companies to transition to lower-carbon options. Examples of key infrastructure upgrades that will need to proceed with industrial projects include expansion of the electric grid, development of clean hydrogen production and distribution networks, recycling/remanufacturing systems investments for circularity, modernization of transportation and

40 Industrial Training and Assessment Centers (ITACs) | Department of Energy
41 Good Jobs Principles | Department of Labor
42 Registered Apprenticeship Program
43 ENERGY STAR Challenge for Industry | ENERGY STAR
44 Better Climate Challenge | Better Buildings Initiative (energy.gov)

distribution systems (everything from inland waterways to pipeline infrastructure for CO_2 and other gases), and improved water and wastewater infrastructure.

Increase supply chain resiliency and security. The U.S. has been proactive in addressing the risks associated with manufacturing supply chain disruptions. Government investment to strengthen critical supply chains needed for industrial systems includes support for RD&D, providing financial incentives for companies to establish or expand production facilities within the country; improving data and information sharing; and supporting risk assessments, contingency planning, and ongoing monitoring and evaluation to ensure that supply chains remain resilient. A critical component of this strategy involves strategic procurement and investment in essential equipment and materials. By diversifying sources and establishing relationships with multiple suppliers, manufacturers can mitigate risks associated with single-source dependency. Incorporating advanced technologies enhances real-time monitoring of the supply chain, allowing for swift identification of potential disruptions.

Increase collaboration and data transparency

Developing and implementing low-emissions industrial processes and materials requires significant innovation and collaboration. Validation and information sharing[45] among government, academia, and industry play vital roles in accelerating this innovation cycle. By fostering a culture of collaboration and knowledge-sharing, industries can tap into a wealth of expertise and resources that can accelerate the development of low-emissions technologies and materials.[46, 47]

Encourage the use and further development of methods to address rigorous comparisons across an integrated life cycle. Life cycle assessment (LCA) methods play a crucial role in emissions tracking by comprehensively quantifying the environmental effects of a product or service throughout an entire life cycle, from raw material extraction to end-of-life disposal. These methods need further refinement and standardization to support rigorous comparisons of products across intended life cycles and to address evolving applicability to GHG emissions reduction needs.[48] Standardized LCA data are also needed to improve consistency and comparability of LCA results. The Federal LCA Commons has been formalized through a memorandum of understanding to coordinate LCA data, research, and information systems among several federal agencies.[49] This initiative is bolstered by other participating agencies across government mission areas.

Leverage international cooperation opportunities

The U.S. government's broader international industrial strategy (e.g., imports, exports, and licensing of GHG emissions reduction technologies) can better position domestic manufacturing for global competitive advantages while accelerating technological deployment through knowledge exchange.

Promote frameworks that encourage knowledge sharing. The government can enable industries to adopt innovative approaches that have been successfully implemented in different regions by participating in international and regional economic cooperation bodies that develop international best practices (e.g., Organisation for Economic Co-operation and Development, Asia-Pacific Economic Cooperation[50]) and contributing to international research consortia. By leveraging international collaboration opportunities, the United States can work with global partners to collectively address the challenges of GHG emissions reduction and shape a more equitable global marketplace.

45 Validation is the process of ensuring that new technologies and materials meet their intended performance targets, thereby reducing risk of failed investments or unexpected consequences and accelerating adoption. Information sharing is the exchange of knowledge and best practices to enable organizations to identify gaps and opportunities where further innovation is needed and potential solutions to explore. Sharing research findings, technical specifications, and case studies accelerates the development of new technologies and materials.

46 Research & Development Consortia | Department of Energy

47 Advanced Research Projects Agency—Energy

48 ASTM Specialty Reports: Workshop on Decarbonization: A Gap Analysis of LCA Standards for Industry

49 Memorandum of Understanding | Life Cycle Assessment Commons

50 Environment & Natural Resources | United States Trade Representative

Promote interoperable climate and trade policies. Several U.S. trade partners are currently developing climate-aligned trade policies that incentivize clean manufacturing and penalize embodied emissions in traded goods. An interoperable framework of such policies holds the potential to reward clean manufacturing—a boon to the many industries in which U.S. producers are among the world's cleanest—and spur reductions in industrial emissions across borders. To achieve this end, countries will need to coordinate to design-compatible climate and trade policies that send a powerful market signal rather than a patchwork of divergent approaches that result in a weak market signal and a high reporting burden for manufacturers that export.

Establish transparency across borders. The U.S. government institutes standardized metrics, sets regular communication among nations, and contributes to international initiatives like the Global Methane Pledge[51] to establish common regulatory frameworks that outline clear data management protocols and transparency requirements. These efforts need to be expanded to provide industry with the clarity and consistency needed to make investment decisions and minimize overhead.

Provide export and licensing of industrial technology opportunities. International agreements and frameworks can enhance protections, thereby fostering a stable environment for American companies to confidently invest in, export, and license innovative technologies that enhance energy efficiency, reduce GHG emissions, and transform traditional industrial practices abroad. The Federal Government can work with trade partners to promote the dissemination of US-based technologies to ensure that global emissions reductions targets are met while promoting U.S. intellectual property and industrial competitiveness.

51 The Global Methane Pledge – Global Methane Tracker 2022 – Analysis | IEA

Conclusion: A Call to Action

The industrial sector has historically been referred to as "hard-to-abate." And although the challenges are real, that understanding is changing. The market for low-carbon materials such as green steel and low-carbon cement is growing. The technologies that producers have available to them to initiate these emissions reductions are being proven at commercial scale. There are innovative deep decarbonization solutions in research and development, attracting new talent to solve these challenges. Whereas the transition will take time, the next few years are vital for building the momentum needed to propel the economy forward over the coming decades. This Blueprint lays out federal actions that would support decarbonization of U.S. industry in line with the U.S. long-term strategy, while ensuring the greatest realization of co-benefits are achieved to strengthen economic prosperity, health, employment, and security across the country. Successful implementation of the programs already in progress, increased interagency cooperation, and a detailed plan with continued private sector engagement are the next steps for putting this Blueprint into action.

APPENDIX

Appendix A: **Highlighted Programs Mapped to the Blueprint**

Agency	Statutory Location	Program Name	Amount	Details*
DHS	IRA 70001	DHS Office of Chief Readiness Support Officer	$500M	Funding for carrying out various DHS sustainability programs
DOE	EPAct 2005 1703	Innovative Energy and Supply Chain	—	Loan funding for innovative commercial energy projects
DOE	BIL 40314	Regional Clean Hydrogen Hubs	$7B	Grant funding for future clean hydrogen production hubs
DOE	BIL 40521	Industrial Research and Assessment Center Grants	$400M	Grant funding for SMMs to implement clean energy projects
DOE	BIL 41004	Carbon Capture Demonstration Projects Program	$2.5B	Grant funding for new commercial carbon capture projects
DOE	BIL 41004	Carbon Capture Large-Scale Pilot Programs	$937M	Grant funding for scale-up of carbon capture projects
DOE	BIL 40209	Advanced Energy Manufacturing and Recycling Grants	$750M	Grant funding for SMMs to build new facilities in coal-mining communities
DOE	BIL 40534	State Manufacturing Leadership Program	$50M	Grant funding for states supporting smart manufacturing technologies
DOE	BIL 41001	Energy Storage Demonstration and Pilot Grant Program	$355M	Grant funding for energy storage demonstration projects
DOE	BIL 40302	Carbon Utilization Program	$310M	Grant funding for municipalities to purchase carbon recycled products
DOE	BIL 40207	Battery and Critical Mineral Recycling	$125M	Grant funding for domestic battery materials processing
DOE	BIL 40208	Electric Drive Vehicle Battery Recycling and 2nd Life Apps	$200M	Grant funding for battery and critical component reuse
DOE	BIL 40555	Extended Product System Rebates	$10M	Rebates for qualified extended products (i.e., electric motors)
DOE	BIL 40555	Energy Efficient Transformer Rebates	$10M	Rebates for replacement of energy-inefficient transformers
DOE	IRA 50142	Advanced Technology Vehicle Manufacturing Loan Program	$3B	Loans for facilities to produce low-emissions vehicles
DOE	IRA 50143	Domestic Manufacturing Conversion Grants	$2B	Grant funding for domestic production of clean vehicles
DOE	EPAct 2005 1706	Energy Infrastructure Reinvestment	—	Loan funding for existing energy infrastructure
DOE	IRA 50161, BIL 41008	Industrial Demonstrations Program	$5.8B	Grant funding for decarbonization of energy-intensive facilities

Agency	Statutory Location	Program Name	Amount	Details*
EPA	IRA 60109	Implementation of the AIM Act	$38.5M	Funding for monitoring, managing, and phasing out hydrofluorocarbons
EPA	IRA 60112	Environmental Product Declaration Assistance	$250M	Funding for developing and reporting embodied carbon of emissions of construction materials
EPA	IRA 60116	Low Embodied Carbon Labeling for Construction Materials	$100M	Funding for identifying and labeling low-carbon construction materials
EPA	Pollution Prevention Act, NTTAA, EO15407	Recommendations of Specifications and Standards for Federal Purchasing	—	Tool that FAR requires federal purchasers to use to identify and procure low-carbon, sustainable products and services
EPA	IRA 60113	Methane Emissions Reduction Program	$1.6B	Financial and technical assistance for methane monitoring and mitigation
GSA	IRA 60503	Use of Low-Carbon Materials	$2.2B	Funding for acquiring low-carbon materials and products
TREAS	IRA 13104	45Q Credit for Carbon Oxide Sequestration	—	Credit for carbon captured and/or sequestered
TREAS	IRA 13502	45X Advanced Manufacturing Production Credit	—	Credit for expanding supply chain of critical components
TREAS	IRA 13204	45V Clean Hydrogen Production Tax Credit	—	Credit for production of clean hydrogen
TREAS/ DOE	IRA 13501	48C Advanced Energy Project Credit	$10B	Credit for advanced energy project investments
USDA	Section 9007, IRA 22002	Rural Energy for America Program	$2B	Funding to agricultural producers and rural small businesses for renewable energy systems or to make energy-efficiency improvements
USDA	Section 9002 of Farm Bill	Biobased Market Program (BioPreferred)	—	Program to increase the purchase and use of biobased products
USDA	Section 9003 of Farm Bill	Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program	$167M	Loan guarantees of up to $250 million to assist in the development, construction, and retrofitting of new and emerging technologies
USDA	Commodity Credit Corporation	Fertilizer Production Expansion Program (PROGRAM CLOSED)	$900M	Funding to expand domestic manufacturing of fertilizer and nutrient alternatives and enhance U.S. competitiveness in this sector

* Sources: Details were taken from the following publications from The White House—Building a Better America: A Guidebook to the Bipartisan Infrastructure Law for State, Local, Tribal, and Territorial Governments, and Other Partners and Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action.

AIM = American Innovation and Manufacturing; DHS = U.S. Department of Homeland Security; FAR = Federal Acquisition Regulation; GSA = U.S. General Services Administration; NTTAA = National Technology Transfer and Advancement Act; SMMs = small- and medium-sized manufacturers; TREAS = U.S. Department of the Treasury.

Appendix B: **Relevant Government Published Documents (January 2021–October 2024)**

Document/Strategy	Publishing Agency	Date Published
The Long-Term Strategy of the United States: Pathways to Net-Zero Greenhouse Gas Emissions by 2050	Executive Office	2021
P100 Facilities Standards for the Public Buildings Service	GSA	2021
Energy Earthshots™ Initiative	DOE	2021
U.S. Methane Emissions Reduction Action Plan	Executive Office	2021
Bipartisan Infrastructure Law (BIL)	Passed by Congress	2021
The Path to Achieving Justice40	Executive Office	2021
Catalyzing America's Clean Energy Economy through Federal Sustainability	Executive Office	2021
Federal Buy Clean Initiative	Executive Office	2021
Industrial Decarbonization Roadmap	DOE	2022
National Strategy for Advanced Manufacturing	Executive Office	2022
Securing Defense-Critical Supply Chains	DoD	2022
America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition	DOE	2022
U.S. Innovation to Meet 2050 Climate Goals: Assessing Initial R&D Opportunities	Executive Office	2022
Inflation Reduction Act (IRA)	Passed by Congress	2022
Strategic Vision: The Role of Fossil Energy and Carbon Management in Achieving Net-Zero Greenhouse Gas Emissions	DOE	2022
Thermal Process Intensification: Transforming the Way Industry Uses Thermal Process Energy	DOE	2022
Building a Better America (BIL Guidebook)	Executive Office	2022
The U.S. National Blueprint for Transportation Decarbonization	DOE/DOT/EPA/HUD	2023

Document/Strategy	Publishing Agency	Date Published
Pathways to Commercial Liftoff Reports	DOE	2023
On the Path to 100% Clean Electricity	DOE	2023
U.S. National Clean Hydrogen Strategy and Roadmap	DOE	2023
National Defense Industrial Strategy	DoD	2023
REMADE Institute Technology Roadmap 2023	REMADE Institute	2023
Annual Report on the U.S. Manufacturing Economy: 2023	NIST	2023
National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System	Executive Office	2023
Decarbonizing the U.S. Economy by 2050: A National Blueprint for the Buildings Sector	DOE	2024
Implementation Approach for the U.S. EPA Label Program for Low Embodied Carbon Construction Materials	EPA	2024
U.S. Department of Energy Carbon Management Strategy	DOE	2024
U.S. Geological Survey (USGS) Climate Science Plan—Future Research Directions	DOI/USGS	2024
Workshop: Basin Scale Issues for Carbon Storage	DOE/DOI	2024

DoD = U.S. Department of Defense; DOI = U.S. Department of the Interior; DOT = U.S. Department of Transportation; GSA = U.S. General Services Administration; HUD = U.S. Department of Housing and Urban Development; NIST = National Institute of Standards and Technology; REMADE = Reducing EMbodied-energy And Decreasing Emissions.

List of Abbreviations and Acronyms

AI	artificial intelligence
BIL	Infrastructure Investment and Jobs Act of 2021
CCUS	carbon capture, utilization, and storage
CfD	contract for difference
CHIPS	Creating Helpful Incentives to Produce Semiconductors Act
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPD	environmental product declaration
FECM	Office of Fossil Energy and Carbon Management
GHG	greenhouse gas
GSA	U.S. General Services Administration
IRA	Inflation Reduction Act of 2022
LCA	life cycle assessment
LEC	low embodied carbon
ML	machine learning
OSTP	White House Office of Science and Technology Policy
R&D	research and development
RD&D	research, development, and deployment
USDA	U.S. Department of Agriculture

DOE/MESC-0108 | November 2024