# Preliminary Recommendations of the U.S. Department of Energy Industrial Technology Innovation Advisory Committee

**January 17, 2025**

# Table of Contents

# Introduction

The Industrial Technology Innovation Advisory Committee (ITIAC) was established on April 20, 2022, pursuant to the Energy Independence and Security Act (EISA) of 2007 as amended by Public Law 116–260,[1] and in accordance with the provisions of the Federal Advisory Committee Act (FACA), as amended, 5 U.S.C. §10. The Committee was established to advise the Secretary of Energy with respect to technologies, policies, and programs to support clean, competitive U.S. industry by:

- Identifying and evaluating any technologies being developed by the private sector relating to the focus areas[2] described in section 454(c) of the EISA
- Identifying technology gaps in the private sector or other Federal agencies in those focus areas, and making recommendations on how to address those gaps
- Surveying and analyzing factors that prevent the adoption of emissions reduction technologies by the private sector
- Recommending technology screening criteria for technology developed under DOE programs to encourage adoption of the technology by the private sector

The U.S. Department of Energy's (DOE's) policies and programs can increase the global competitiveness of American industrial firms, ensure our continued leadership in technological innovation, promote the growth of jobs and the economy, expand skillsets of manufacturing workers, further energy and supply chain security, and improve our air and water quality.

To advance such benefits, the ITIAC has generated its first set of recommendations for DOE in this preliminary report. The ITIAC aimed to create transparency on the Committee's ongoing work before submitting a more detailed report to the Secretary of Energy and Congress (expected in Fall 2025). These recommendations should not be considered exhaustive given the expansiveness of the industrial sector, but ones that the Committee considers as the highest priority for DOE in the near term. While the recommendations are not expected to change substantially, the Committee expects these recommendations may be modified and/or expanded in its full report. Additional recommendations may be included. In addition to the preliminary set of recommendations, the Committee has compiled a list of publications in this document, including existing publications from DOE, that provide more detail on specific topic areas and should be helpful to those seeking additional information about topics relevant to the Committee's work.

Ensuring near- and long-term competitiveness of U.S. industry requires continued technological innovation, as well as supportive policies and workforce considerations. Although many efforts are already underway in these areas, DOE has a unique role in overseeing or coordinating action to streamline these activities for maximum benefit for the country. This initial list of recommendations is intended to emphasize the successes and benefits of DOE's current efforts in these areas, create momentum, and highlight urgency for action.



[1] U.S. Congress. 2020. *Consolidated Appropriations Act, 2021*. Public Law 116–260. https://www.congress.gov/116/plaws/publ260/PLAW-116publ260.pdf.
[2] DOE. "Focus areas of the Industrial Emissions Reduction Technology Development Program." https://www.energy.gov/eere/iedo/focus-areas-industrial-emissions-reduction-technology-development-program.

## ITIAC Members

This document was prepared by the ITIAC which includes the following members: Ms. Sharon Nolen (Chair), Mr. Jeffrey Rissman (Vice Chair), Dr. Sunday Abraham, Dr. Cathy Choi, Dr. Sue Clark, Dr. Subodh Das, Ms. Elizabeth Dutrow, Dr. Neal Elliott, Mr. Sergio Espinosa, Ms. Anna Fendley, Dr. Comas Haynes, Dr. Arun Majumdar, Dr. Joe Powell, Dr. Abigail Regitsky, Dr. Akshay Sahni, Dr. Sridhar Seetharaman, Ms. Jolene Sheil, and Ms. Sasha Stashwick. The Committee's work is supported by DOE Office of Energy Efficiency and Renewable Energy's Industrial Efficiency and Decarbonization Office (IEDO).

## Methodology

Findings and recommendations in this report are based upon input from the ITIAC's members and their institutions. The Committee voted on these recommendations during its public meeting, held virtually on January 16, 2025. Each recommendation in this report was presented individually and voted on by the Committee. Only members in attendance could vote. Recommendations were approved if more than one-half of the Committee's members voted in support of the recommendation, i.e., supported by at least 10 out of the 18 ITIAC members.

# Overarching DOE Strategy and Budget

*This section covers higher-level recommendations pertaining to DOE's overall industrial strategy, budget, or processes.*

## Budget Requests

**Recommendation 1:** In future budget requests, DOE should prioritize increases for the Industrial Efficiency and Decarbonization Office (IEDO), the Advanced Materials and Manufacturing Technologies Office (AMMTO), the Office of Clean Energy Demonstrations (OCED), and the Office of Manufacturing and Energy Supply Chains (MESC).

- *Rationale:* These offices' work is central to clean and competitive U.S. industry, and the technologies they support are typically beyond the laboratory stage and can be commercialized within ten years.

**Recommendation 2:** Some offices fund technologies across multiple sectors and should receive budget increases specifically to support an increased focus on technologies and programs important for industrial decarbonization. These include the Advanced Research Projects Agency-Energy (ARPA-E), the Loan Programs Office (LPO), the Office of Technology Transitions (OTT), and the Bioenergy Technologies Office (BETO). The Energy Information Administration (EIA) should receive a budget increase to support improved industrial data collection and publication.

- *Rationale:* The U.S. industrial sector would benefit from greater attention and focus from these offices. Budget increases would allow these offices to ratchet up their industrial work without compromising existing programs targeting other sectors.

## Technology and Program Prioritization

**Recommendation 3:** DOE should consider which subsectors have the greatest energy use and emissions when prioritizing support and crafting research, development, demonstration, and deployment (RDD&D) programs. The EIA Annual Energy Outlook[3] provides data on which subsectors are the largest energy consumers today and future energy demand projections.

## Funding Opportunity Processes

**Recommendation 4:** DOE should create an open dialogue on what is making it hard for companies to respond to funding opportunity announcements (FOAs) and to implement DOE funding. One way to do this is to expand the use of requests for information (RFIs) to solicit technological solution provider feedback, and to create a clear process to inform companies that submitted comments about how the agency has incorporated their feedback. Additionally, DOE should tailor funding opportunities to the needs of solution providers by leaning towards greater flexibility in funding opportunity design. Rather than articulating a defined/prescriptive set of technological parameters, DOE should articulate the specific problem it is seeking to address and welcome a wider range of solution providers to apply for funding.

## Improving Availability of Industrial Energy-Related Data

**Recommendation 5:** DOE should improve its collection and reporting of energy-related industrial sector data to support program prioritization and strategic planning both inside and outside of DOE. Specifically, DOE should improve EIA's Manufacturing Energy Consumption Survey[4] by conducting it more frequently, reporting data with a shorter delay, and disaggregating more fuel types, industrial end

[3] EIA. "Annual Energy Outlook." https://www.eia.gov/outlooks/aeo.
[4] EIA. "Manufacturing Energy Consumption Survey (MECS)." https://www.eia.gov/consumption/manufacturing.

uses, and manufacturing subsectors. DOE should begin providing regularly-updated, unit-level data on industrial equipment type, location, energy consumption, operating hours, and temperature, building on work done by researchers at two national laboratories.[5] DOE should also create an Industry Annual Technology Baseline (ATB), like the existing Electricity and Transportation ATBs,[6,7] that includes data on the capital costs and energy efficiencies of both conventional and clean industrial technologies, such as boilers, heat pumps, furnaces, kilns, thermal batteries, etc.



[5] McMillan, Colin, Carrie Schoeneberger, Sarang Supekar, and David Thierry. 2024. *The Foundational Industry Energy Dataset: Unit-level Characterization and Derived Energy Estimates for Industrial Facilities in 2017*. National Renewable Energy Laboratory Technical Report. NREL/TP-6A20-90442. https://www.nrel.gov/docs/fy24osti/90442.pdf.

[6] National Renewable Energy Laboratory. 2024. "2024 Electricity ATB Technologies and Data Overview." https://atb.nrel.gov/electricity/2024/index.

[7] National Renewable Energy Laboratory. 2024. "2024 Transportation Annual Technology Baseline." https://atb.nrel.gov/transportation/2024/index.

# Cross-Cutting Technologies and Opportunities

*This section covers technologies and approaches that are useful across many industrial subsectors, such as direct electrification or use of hydrogen.*

## Energy Efficiency

**Recommendation 6:** DOE should continue and expand its support for industrial energy efficiency technologies. Examples of key energy-efficient manufacturing technologies include waste heat recovery, net shape manufacturing, variable-frequency drives, high-temperature heat pumps, membranes for chemical separations, and product design alterations that enable the use of fewer or lower-energy manufacturing steps. DOE should continue to support and expand technical assistance for industrial efficiency and decarbonization, such as the Better Plants program, which provides valuable information to participating companies.[8] Additionally, the Secretary should designate additional types of industrial equipment (such as industrial boilers, furnaces, kilns, precalciners, distillation columns, chemical reactors, heaters, dryers, etc.) as "covered equipment" using his/her authority under 42 U.S.C. § 6312. Then, DOE should issue minimum energy performance standards and test procedures for each type of equipment so designated. Standard-setting bodies such as the American Society of Mechanical Engineers, the International Organization for Standardization, and ASTM International have developed standards for various types of industrial equipment. DOE should work with standard-setting organizations to write standards or incorporate existing standards into DOE's rules where appropriate.

- *Rationale:* Energy efficiency can be one of the most cost-effective opportunities for energy savings. DOE has found that "in many cases, it does not require major changes to industrial processes and can bring immediate reductions in emissions."[9] It also reduces the required build-out of non-emitting energy capacity such as electricity generation and transmission assets, hydrogen-related equipment, bioenergy, etc., making a transition to clean energy faster and cheaper.

## Circular Economy and Material Efficiency

**Recommendation 7:** DOE should continue and expand its support for technologies that allow products to be produced with less material. Additionally, DOE should publish high-quality technical guidance on how to design products for longevity and repairability.

- *Rationale:* Making products with less wasted material, as well as products that last longer and are easier to repair, saves energy and money. Technologies such as net-shape manufacturing and additive manufacturing allow for the creation of precisely shaped parts with reduced need for milling, sanding, or finishing steps that waste material. Approaches to enhance repairability include designing products such that individual parts can be detached and replaced, using reversible fasteners (such as screws rather than glue), making replacement parts available, publishing documentation such as schematics and pinout diagrams, and making diagnostic software, firmware, and drivers permanently available online.

**Recommendation 8:** DOE should continue and expand its support for technologies that facilitate the remanufacturing of products, reuse of parts and components, and recycling of materials. DOE should

[8] DOE. "Better Plants." https://betterbuildingssolutioncenter.energy.gov/better-plants.
[9] DOE. 2022. *Industrial Decarbonization Roadmap*. https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf.

encourage the development of energy-saving recycling technologies, including mechanical and molecular approaches, and markets for recycled materials. DOE should require that claims about recycling technologies are clear, transparent, and accountable with third-party certifications.

- *Rationale:* Remanufacturing and re-use of entire products or intact components saves more material and energy than recycling, so these approaches should be prioritized where feasible. Recycling is often the best option for packaging and for broken, heavily worn, or obsolete products.

## Direct Electrification

**Recommendation 9:** DOE should prioritize support for direct electrification of industrial heating where it is technically feasible. Two technologies that can help overcome the cost gap between electricity and fossil fuels, and therefore are particularly important to commercialize, are high-temperature industrial heat pumps and industrial thermal batteries. DOE should include industrial use of thermal batteries in electric grid-related research and programs, such as work by the Office of Electricity and ARPA-E's Grid Optimization Competition.[10]

- *Rationale:* Direct electrification can produce heat more efficiently than combustible fuels, has lower heat losses (by avoiding losses in hot exhaust gases and formed water vapor), and is sometimes able to reach higher temperatures than combustion.

## Clean Hydrogen

**Recommendation 10:** DOE should foster RDD&D and support demand-side technologies and incentives that motivate the use of clean hydrogen where it offers the lowest levelized cost of carbon emissions mitigation relative to alternative approaches. Applications where hydrogen may be the best fit include: (1) a replacement for "gray" hydrogen in applications where hydrogen is already used today, such as in the chemicals and refining industries; (2) a feedstock that enables the production of additional types of chemicals (e.g., methanol, olefins, aromatics) from non-fossil inputs; (3) a means of chemically reducing iron ore to metallic iron in the production of primary steel; (4) an indirect means of electrifying fuel-centric process heating needs where direct electrification is technically infeasible; and (5) as a clean energy storage mode for resilience in delivering electricity (e.g., via fuel cells) and process heating needs. DOE should support development of hydrogen infrastructure (e.g., LPO financing of hydrogen pipelines and storage) if the hydrogen serves these high-value end uses.

- *Rationale:* Existing policy that impacts the production and use of clean hydrogen has primarily focused on the supply side. Supply-side incentives alone are unlikely to lead to uses of clean hydrogen that are efficient and have long-term potential. Given the substantial amount of energy and cost required to produce clean hydrogen, additional policy is needed to ensure hydrogen is directed to the highest and best uses.

## Carbon Capture, Utilization, and Storage

**Recommendation 11:** DOE should prioritize industrial projects that take a rightsizing approach for their carbon capture needs and consider carbon capture as one technology amongst a suite of potential solutions. DOE should prioritize funding projects where carbon capture is most needed by requiring applicants to describe how they have considered other technology options and indicate why these options are not feasible for the project. DOE should require that supported projects store carbon underground or via mineralization.

- *Rationale:* Carbon capture adds energy requirements and costs to a project, and it does not address upstream emissions from fossil fuel production. Facilities should aim to reduce emissions

[10] ARPA-E. "Grid Optimization Competition." https://gocompetition.energy.gov.

using other technologies first, taking a rightsizing approach to any carbon capture system that may be needed. Niches where carbon capture may be most competitive include addressing carbon dioxide ($CO_2$) emissions from the calcination of limestone to form clinker and industrial processes that generate high-purity streams of $CO_2$. Although there are leakage and seismicity concerns to be addressed with underground storage, it remains a more secure option than use of captured carbon in products (such as urea-based fertilizers, carbonated drinks, or plastics) since most products do not store the $CO_2$ over sufficient timescales.

## Non-$CO_2$ Greenhouse Gases

**Recommendation 12:** DOE should support technologies that cut industrial sources of nitrous oxide ($N_2O$) emissions, primarily nitric and adipic acid manufacturing, such as through thermal or catalytic decomposition of the $N_2O$. Similarly, DOE should support research and commercialization of climate-safe alternatives to common fluorinated gases (F-gases) used today as refrigerants, propellants, and electrical insulators, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$). Hydrofluoroolefins (HFOs) are one possible option that would benefit from RDD&D to achieve cost reductions.

# Industrial Subsectors

*This section covers technologies and approaches specific to industrial subsectors, such as iron and steel, chemicals, pulp and paper, etc. Given space limitations and the breadth of technologies involved across the industrial sector, and especially in its diverse subsectors, the omission of any particular technology or subsector does not necessarily indicate a lack of importance by the Committee.*

## Chemicals

**Recommendation 13:** DOE should establish a center of excellence for chemicals technology development and scale-up. It should leverage artificial intelligence and machine learning, process modeling via digital twins, and bench, cold flow, and targeted pilot facilities to examine scale-up of complex multiphase reaction and separation systems. It should also address polluting or harmful chemicals (e.g., per- and polyfluoroalkyl substances (PFAS), bisphenols, phthalates, brominated flame retardants, dioxins).[11] Additionally, DOE should continue and expand work with the American Institute of Chemical Engineers (AIChE) Rapid Advancement in Process Intensification Deployment (RAPID) Institute[12] and the Electrified Processes for Industry without Carbon (EPIXC) Institute[13] to solve design challenges in scaling up chemicals industry process equipment that makes use of low-cost electricity. To date, the industry has not commercialized electrified reactors and separation equipment at scales exceeding 10 megawatts, which are needed for economic scale-up.

## Cement and Concrete

**Recommendation 14:** DOE should support the design and scale-up of technologies that increase the efficiency of cement plants and increase the purity of the $CO_2$ streams they produce, facilitating carbon capture. Electrified calciners allow more efficient use of energy (including variable renewable energy) while also producing pure $CO_2$ streams from limestone calcination. Oxy-firing of natural gas is another approach that enables more efficient $CO_2$ capture from concentrated streams.

## Iron and Steel

**Recommendation 15:** DOE should continue and expand its support for the following key approaches that hold promise for producing clean primary iron and steel: (1) technologies to reduce the cost of hydrogen – direct reduced iron ($H_2$-DRI) steelmaking, including the production of electrolytic $H_2$ and the energy efficiency, capital costs, and maintenance costs of $H_2$-DRI technology; (2) iron ore beneficiation (increasing the ore's iron content) and smelting to process lower-grade ores for use in DRI steelmaking; (3) molten oxide electrolysis of iron ore; (4) aqueous electrolysis of iron ore. Since these routes require electricity, DOE should conduct a study to map out and evaluate the economic viability of different solutions to meet the need for clean electricity 24/7 for the steel industry. The study should consider how grid electricity and on-site distributed energy (including a mixture of renewables and nuclear) could be optimally integrated with steel plants.

## Pulp and Paper

**Recommendation 16:** DOE should provide RDD&D assistance for companies to demonstrate how renewable energy can be incorporated into large-scale pulp and paper operations without adversely

[11] Resources for identifying chemicals of concern for the new DOE Center of Excellence include the U.S. Environmental Protection Agency's list of chemicals covered under the Toxic Release Inventory program (https://www.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals) and the European Chemicals Agency's listing of restricted substances (https://echa.europa.eu/substances-restricted-under-reach) and candidate list of substances of very high concern (https://echa.europa.eu/candidate-list-table).
[12] AIChE. "RAPID." https://rapid.aiche.org.
[13] "Electrified Processes for Industry without Carbon-EPIXC." https://epixc.org.

impacting costs and safety, focusing on technologies such as energy efficiency, electrification, thermal energy storage, and use of hydrogen. DOE should also facilitate the sharing of best practices across research partners and private firms.

## Food and Beverage

**Recommendation 17:** DOE should work with the RAPID Institute[14] and the EPIXC Institute[15] to optimize direct electrical (non-steam) heating vs. use of traditional steam heat. This can reduce energy usage and costs but can affect food and beverage product quality due to changes in heat transfer rates and mechanisms.



[14] AIChE. "RAPID." https://rapid.aiche.org.
[15] "Electrified Processes for Industry without Carbon-EPIXC." https://epixc.org.

# Overcoming Barriers

*This section covers ways DOE can help overcome barriers to clean industry, such as ensuring a robust electric grid and a market for cleanly-produced industrial goods.*

## Offtake of Cleanly-Produced Products

**Recommendation 18:** DOE should research specifications and standards for clean goods and materials in coordination with other federal agencies, participate fully in ongoing multilateral and multi-stakeholder efforts to align standards and methodologies related to the emissions intensity of production, and work with both producers and consumers to promote long-term offtake agreements for the purchase of clean goods. DOE should also help industrial facilities develop clean hydrogen and zero-emission electricity and heat offtake agreements, perhaps supported by guaranteed offtake prices for clean heat as a service (e.g., via a contract for difference). DOE itself can also procure clean goods and energy, aligning these efforts with existing procurement programs across governments (e.g., the Federal Buy Clean Initiative,[16] the Clean Energy Ministerial Industrial Deep Decarbonisation Initiative[17]) and the private sector (e.g., the First Movers Coalition[18]). For example, DOE should expand the Hydrogen Demand Initiative ($H_2$DI)[19] to include other clean commodities, such as steel, cement/concrete, and chemicals.

- *Rationale:* Investment in the production of clean goods requires that companies have stable markets for the purchase of these goods. A well-functioning market requires clear delineation of product characteristics so clean goods can be identified, as well as opportunities for facilitated communications between parties. DOE, together with other federal agencies, is uniquely positioned to contribute to this market transformation by developing product specifications, standards, and labeling, such as what we have seen with the ENERGY STAR program.[20] DOE, through its ongoing programs such as Better Plants,[21] can create forums that bring producers and consumers together to facilitate agreements that create a predictable market for clean goods. Successful offtake agreements can help address cost premiums of new technologies, reduce risk for early adopters, and create market pull to speed deployment.

## Electric Grid

**Recommendation 19:** DOE should work with Congress and leaders at the Federal Energy Regulatory Commission (FERC) to support reforms to electricity market rules at the state, regional, or federal level that allow flexible electrified technologies to access location- and time-specific electricity pricing available in wholesale markets.

- *Rationale:* The cost of electricity is a major barrier to industrial electrification. The economics of industrial electrification technologies depend on the relative costs of electricity and natural gas, as well as on electric rate structures. Allowing electrified technologies access to electricity prices that reflect wholesale costs can help make domestic clean energy cost-effective as a source of industrial process heat and soak up low-value electricity, increasing utilization of existing grid assets and potentially lowering electricity costs for all customers.



[16] Office of the Federal Chief Sustainability Officer. “Federal Buy Clean Initiative.” https://www.sustainability.gov/buyclean.
[17] Clean Energy Ministerial. 2025. “Industrial Deep Decarbonisation Initiative.” https://www.cleanenergyministerial.org/initiatives-campaigns/industrial-deep-decarbonisation-initiative.
[18] World Economic Forum. “First Movers Coalition.” https://initiatives.weforum.org/first-movers-coalition.
[19] “Hydrogen Demand Initiative.” https://h2di.org.
[20] ENERGY STAR. https://www.energystar.gov.
[21] DOE. “Better Plants.” https://betterbuildingssolutioncenter.energy.gov/better-plants.

**Recommendation 20:** DOE should conduct a study on the electric grid infrastructure and upgrades needed for industrial electrification (as well as other sources of demand, such as electric vehicles and data centers) that can serve as a resource to utilities, utility regulators, and industrial firms.

- *Rationale:* Past studies of U.S. electric grid requirements, such as the National Renewable Energy Laboratory's *Electrification Futures Study*,[22] did not account for the electricity demand associated with a complete transition to clean industry. A new study could be additive to past work by considering the electricity needs of a comprehensive shift to clean industrial processes (energy and feedstocks), as well as up-to-date projections of demand from data centers and non-industrial sectors.

**Recommendation 21:** DOE should expand its efforts to facilitate expansion of high-voltage transmission as well as reconductoring of existing lines. DOE's efforts should include working with relevant agencies to streamline environmental review and permitting processes for transmission lines and exploring ways to streamline interconnection queue processes to facilitate rapid construction of clean generation that can be used for industrial facilities.

- *Rationale:* Increased electricity transmission capacity will be key to ensure a more reliable and resilient grid capable of meeting the growing energy demands of industrial and manufacturing facilities and to enable the integration of additional clean electricity generation.

**Recommendation 22:** DOE should direct its electricity- and industry-related programs, national laboratories, and manufacturing institutes to pursue research, demonstration, and education about opportunities to optimize timing and utilization of electricity at industrial facilities. DOE should simultaneously encourage utilities and their regulators to implement smart grid technologies that can co-optimize generation and grid operations with these large customers to increase utilization of existing generation, transmission, and distribution assets, reducing the need for grid investments.

- *Rationale:* Electrification of industrial processes represents an important pathway to decarbonization. Increases in industrial electricity demand combined with increases in other sectors of the economy (including data centers and transportation) create a resource adequacy challenge for the production, transportation, and delivery of electricity. Large industrial users can dynamically manage their consumption through applications of smart manufacturing control technologies, improving efficiency and allowing for co-optimization with a smart utility grid. This can increase the utilization of existing assets, including renewable generation that otherwise would have been curtailed.

**Recommendation 23:** DOE should support commercialization and deployment of clean firm generation (e.g., advanced nuclear, geothermal, fusion, long duration energy storage) at or co-located with industrial sites as an option to meet industries' increasing energy demands with clean, reliable power and/or heat. This should include focusing existing LPO financing tools on deploying clean firm generation at industrial sites (new and retrofit); exploring implications of co-located or behind-the-meter clean generation solutions for grid reliability; and further exploring use of low-temperature geothermal resources for industrial applications.

- *Rationale:* Many industrial facilities operate 24/7, so it is important to ensure the grid can provide reliable, non-polluting energy at all hours.



[22] Mai, Trieu, Paige Jadun, Jeffrey Logan, Colin McMillan, Matteo Muratori, Daniel Steinberg, Laura Vimmerstedt, Ryan Jones, Benjamin Haley, and Brent Nelson. 2018. *Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States*. National Renewable Energy Laboratory Technical Report. NREL/TP-6A20-71500. https://www.nrel.gov/docs/fy18osti/71500.pdf.

## Commercialization Support

**Recommendation 24:** ARPA-E should launch a dedicated program with funding and commercialization support for industrial technologies that could achieve large emissions reductions in the medium- to long- term, including alternative cement chemistries, alternative chemical and refinery feedstocks, and direct electrification of high-temperature heating of non-conductive materials (including electrification of cement kilns and chemical reactors). DOE should also expand the support available through its Seeding Critical Advances for Leading Energy technologies with Untapped Potential (SCALEUP) program[23] for innovative industrial decarbonization technologies.

**Recommendation 25:** DOE should create a Fast Track program[24] designed to help critical innovations rapidly advance along the commercialization pathway. This program should be technology-agnostic and milestone-based, provide dedicated technical and commercial support, and offer priority access to DOE resources (e.g., national laboratory facilities). The greatest gap a Fast Track program could fill at this time is pilot-scale demonstrations for key technologies moving toward commercialization.

**Recommendation 26:** DOE should conduct a study that identifies how to achieve successful technology adoption by companies when large-scale deployment of that technology does not yet exist and may not exist for a long time. The study should identify ways to mitigate risks posed by global events/conflicts, inflation, recessions, and other geopolitical and macroeconomic factors. The study should also review gaps in needs between innovators obtaining public-private partnerships with OCED and LPO to determine how solutions can bridge valleys of death.

**Recommendation 27:** DOE should more flexibly use its existing loan and funding authorities to better support industrial projects. DOE should enhance LPO's ability to finance industrial decarbonization projects by making it practical for LPO to issue smaller-value loans and broadening its investment portfolio to include innovative industrial technologies with long-term return potential to attract private investors but cannot be supported solely by the private sector today. DOE should streamline the application process and due diligence period within LPO to reduce costs, redundancies, and burden on the applicant. DOE should consider expanding the use of flexible funding mechanisms such as Partner Intermediary Agreements and Other Transaction Authorities to increase market adoption for innovative solutions supporting industry and manufacturing.

- *Rationale:* While LPO has no minimum eligible project size, the office typically only supports projects of at least $100 million due to high fixed costs of the application process and loan monitoring.[25] This excludes many important industrial technologies that need support in their early commercial deployments. Reducing the burdens associated with the loan application and monitoring process, coupled with an explicit mandate to finance industrial decarbonization technologies, may improve LPO's ability to support innovative industrial technologies and companies.

## Material Needs and Lifecycle Assessment

**Recommendation 28:** DOE should publish an assessment of the material needs to enable industrial decarbonization pathways, such as those identified in DOE's *Pathways to Commercial Liftoff*[26] and *Transformative Pathways*[27] reports, and the availability of those materials. The study should also

[23] ARPA-E. "The SCALEUP Program." https://arpa-e.energy.gov/technologies/scaleup.
[24] Wilson, Adria, Farah Benahmed, and Tori Fessenden. 2024. *Fast Track: A Breakthrough Energy Proposal to Accelerate Innovation*. https://www.breakthroughenergy.org/wp-content/uploads/2024/07/BE-Fast-Track-White-Paper_0715.pdf.
[25] DOE. "Title 17 Clean Energy Financing." https://www.energy.gov/lpo/title-17-clean-energy-financing.
[26] DOE. "Liftoff Reports." https://liftoff.energy.gov.
[27] DOE. "Transformative Pathways to U.S. Industrial Transformation: Unlocking American Innovation." https://www.energy.gov/eere/iedo/articles/transformative-pathways-us-industry-unlocking-american-innovation.

discuss the emissions intensity of specific domestic and imported industrial materials using a methodology developed in cooperation with U.S. trading partners to ensure interoperability of approaches for determining emissions intensity.

- *Rationale:* Deployment of decarbonization technologies requires critical materials for storage, catalysis, energy conversion, etc. Understanding the scale of need for specific materials can help with policy and technology planning. Additionally, the market value and acceptance of industrial products will be increasingly dependent on how they were produced. A lifecycle assessment methodology that is scientifically grounded and supported by U.S. trading partners could highlight the good environmental performance of U.S industry and reward manufacturers for utilizing clean technologies.

# Workforce and Social Considerations

*This section covers recommendations that ensure the United States has a vibrant and flourishing industrial workforce and engaged communities.*

## Workforce Development

**Recommendation 29:** DOE should increase efforts to complement existing workforce initiatives with decarbonization technical training modules (e.g., electrification technology in process heating curricula, energy efficiency practices in manufacturing technician training). This includes continued support for programs operated by MESC, such as the Industrial Training and Assessment Centers,[28] which leverage best practices in workforce development to train participants for in-demand clean energy and manufacturing jobs by providing hands-on technical assistance to small- and medium-size manufacturers. Training should emphasize skills that are in demand by industrial firms and that support a transition to clean industrial energy sources and processes. When planning and developing training initiatives, DOE should formally partner with other agencies engaged in workforce training, particularly for skilled trades, such as the U.S. Department of Labor's apprenticeship initiatives and the U.S. Department of Commerce's workforce development initiatives around semiconductor manufacturing.[29,30]

## Community Engagement

**Recommendation 30:** DOE should understand the impacts of projects it funds on local communities, including health benefits and risks. DOE should continue to require companies seeking public funding to develop and implement Community Benefit Plans and to proactively address perceived or actual impacts by engaging with the local community.



[28] DOE. "Industrial Training and Assessment Centers." https://www.energy.gov/mesc/industrial-assessment-centers-iacs.
[29] U.S. Department of Labor. 2024. "Explore Registered Apprenticeship." https://www.apprenticeship.gov/sites/default/files/DOLIndFSApprent101-043024-508.pdf.
[30] U.S. Department of Commerce. 2023. "Training a World-Leading and Diverse Manufacturing Workforce." https://www.commerce.gov/news/blog/2023/10/training-world-leading-and-diverse-manufacturing-workforce.

# Recommended Publications

*This section contains a list of publications recommended by the ITIAC where readers can go to find more information on the topics covered in this document. A publication's inclusion in this list does not mean that the Committee endorses every word in that publication. Rather, it indicates that the Committee finds that the publication, taken as a whole, is a useful resource.*

## Whole Industrial Sector

- U.S. Department of Energy. 2025. *Transformative Pathways to U.S. Industrial Transformation: Unlocking American Innovation*. https://www.energy.gov/eere/iedo/articles/transformative-pathways-us-industry-unlocking-american-innovation.
- Jeffrey Rissman. 2024. *Zero-Carbon Industry: Transformative Technologies and Policies to Achieve Sustainable Prosperity*. https://zerocarbonindustry.com.
- U.S. Department of Energy. 2023. *Pathways to Commercial Liftoff: Industrial Decarbonization*. https://liftoff.energy.gov/wp-content/uploads/2024/02/LIFTOFF_DOE_Industrial-Decarbonization_REV022724.pdf.
- U.S. Department of Energy. 2022. *Industrial Decarbonization Roadmap*. https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf.

## Cement and Concrete

- Hasanbeigi, Ali, Pavitra Srinivasan, Hellen Chen, and Nora Esram. 2024. *Adoption of Limestone Calcined Clay Cement and Concrete in the U.S. Market*. www.aceee.org/research-report/i2401.
- U.S. Department of Energy. 2023. *Pathways to Commercial Liftoff: Low-Carbon Cement*. https://liftoff.energy.gov/wp-content/uploads/2023/12/20230921-Pathways-to-Commercial-Liftoff-Cement.pdf.
- Zhi Cao and Eric Masanet. 2021. *Decarbonizing Concrete: Deep decarbonization pathways for the cement and concrete cycle in the United States, India, and China*. https://www.climateworks.org/wp-content/uploads/2021/03/Decarbonizing_Concrete.pdf.
- International Energy Agency and Cement Sustainability Initiative. 2018. *Technology Roadmap: Low-Carbon Transition in the Cement Industry*. https://www.iea.org/reports/technology-roadmap-low-carbon-transition-in-the-cement-industry.

## Chemicals and Refining

- U.S. Department of Energy. 2023. *Pathways to Commercial Liftoff: Decarbonizing Chemicals & Refining*. https://liftoff.energy.gov/wp-content/uploads/2023/12/20230921-Pathways-to-Commercial-Liftoff-Chemicals-Refining.pdf.
- Centre for European Policy Studies. 2023. *Chemical Recycling of Plastics: Technologies, Trends and Policy Implications*. https://cdn.ceps.eu/wp-content/uploads/2023/07/CEPS-In-depth-analysis-2023-11_Chemical-recycling-of-plastics.pdf.
- International Energy Agency. 2018. *The Future of Petrochemicals: Towards more sustainable plastics and fertilisers.* https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf.
- IRENA and Methanol Institute. 2021. *Innovation Outlook: Renewable Methanol*. https://www.irena.org/-

/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf.

## Aluminum


- ICF. 2024. *Pathways to Decarbonization: A North American Aluminum Roadmap*. https://www.aluminum.org/sites/default/files/2024-06/North-American-Decarbonization-Roadmap_6.11.24.pdf.
- Mission Possible Partnership. 2023. *Making Net-Zero Aluminum Possible: An industry-backed, 1.5°C-aligned transition strategy*. https://3stepsolutions.s3-accelerate.amazonaws.com/assets/custom/010856/downloads/Making-1.5-Aligned-Aluminium-possible.pdf.


## Industrial Energy Efficiency


- Sutherland, John W., David A. Dornfeld, and Barabara S. Linke (eds.). 2019. *Energy Efficient Manufacturing: Theory and Applications*. ISBN 978-1-118-42384-4. https://www.wiley.com/en-be/Energy+Efficient+Manufacturing%3A+Theory+and+Applications-p-9781118423844.


## Material Efficiency


- Julian Allwood and Jonathan Cullen. 2015. *Sustainable Materials without the hot air: Making buildings, vehicles and products efficiently and with less new material*. ISBN 978-1-906-86030-1. https://www.bloomsbury.com/us/sustainable-materials-without-the-hot-air-9781906860301.


## Electrification


- Rehfeldt, Matthias, Simon Bußmann, Tobias Fleiter, and Jeffrey Rissman. 2024. *Direct electrification of industrial process heat: An assessment of technologies, potentials, and future prospects for the EU*. https://energyinnovation.org/wp-content/uploads/Direct-electrification-of-industrial-process-heat.-An-assessment-of-technologies-potentials-and-future-prospects-for-the-EU.pdf.
- International Energy Agency. 2024. “Annex 58: High-Temperature Heat Pumps.” https://heatpumpingtechnologies.org/annex58.
- Jeffrey Rissman and Eric Gimon. 2023. *Industrial Thermal Batteries: Decarbonizing U.S. Industry While Supporting a High-Renewables Grid*. https://energyinnovation.org/wp-content/uploads/2023-07-13-Industrial-Thermal-Batteries-Report-v133-2.pdf.
- Madeddu, Silvia, et al. 2020. “The $CO_2$ reduction potential for the European industry via direct electrification of heat supply (power-to-heat).” *Environmental Research Letters* 15, 12. https://doi.org/10.1088/1748-9326/abbd02.


## Carbon Capture, Utilization, and Storage


- Global CCS Institute. 2024. *Global Status of CCS 2024: Collaborating for a Net-Zero Future*. https://www.globalccsinstitute.com/wp-content/uploads/2024/11/Global-Status-Report-6-November.pdf.
- U.S. Department of Energy. 2023. *Pathways to Commercial Liftoff: Carbon Management*. https://liftoff.energy.gov/wp-content/uploads/2024/02/20230424-Liftoff-Carbon-Management-vPUB_update4.pdf.
- Stephen A. Rackley. 2017. *Carbon Capture and Storage (Second Edition)*. ISBN 978-0-12-812041-5. https://www.sciencedirect.com/book/9780128120415/carbon-capture-and-storage.

### Data Centers


- Shehabi, Arman, Sarah J. Smith, Alex Hubbard, Alex Newkirk, Nuoa Lei, Md Abu, Bakar Siddik, Billie Holecek, Jonathan Koomey, Eric Masanet, and Dale Sartor. 2024. *2024 United States Data Center Energy Usage Report*. Lawrence Berkeley National Laboratory Technical Report. LBNL-2001637. https://eta-publications.lbl.gov/sites/default/files/2024-12/lbnl-2024-united-states-data-center-energy-usage-report.pdf.
- Koomey, Jonathan, Nuoa Lei, and Eric Masanet. 2024. "To better understand AI's growing energy use, analysts need a data revolution." *Joule* 8, 9: 2427-2436. https://doi.org/10.1016/j.joule.2024.07.018.
- U.S. Department of Energy Secretary of Energy Advisory Board. 2024. *Recommendations on Powering Artificial Intelligence and Data Center Infrastructure*. https://www.energy.gov/sites/default/files/2024-08/Powering%20AI%20and%20Data%20Center%20Infrastructure%20Recommendations%20July%202024.pdf.


### Controlled Environment Agriculture


- Grammans, Luuk, Andy van den Dobbelsteen, Esther Meinen, and Cecilia Stanghellini. 2017. "Plant factories; crop transpiration and energy balance." *Agricultural Systems* 153: 138-147. https://doi.org/10.1016/j.agsy.2017.01.003.
- Kozai, Toyoki, Genhua Niu, and Michiko Takagaki (eds.). 2015. *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production (First Edition).* https://www.elsevier.com/books/plant-factory/kozai/978-0-12-801775-3.


# Conclusion

The ITIAC recognizes that many research, development, demonstration, and deployment efforts are already underway across U.S. industry to address topics prioritized in this brief. The Committee has provided these recommendations to highlight opportunities for DOE to accelerate the pace of innovation and action. The ITIAC urges DOE to lead, convene, organize, educate, and provide oversight to support clean industry in the United States. This work is urgently needed; decisions being made today are determining investments that will set the course of U.S. industry for decades. DOE, in coordination with others, must act without delay to ensure we remain at the forefront of clean, globally competitive industry.