Exploring the US DOE's "Industrial Decarbonization Roadmap" and Learning about Federal Funding Incentives for Industrial Energy Efficiency and Clean Energy Projects

Ohio Industrial Decarbonization and Combined Heat & Power Workshop

Nippert Stadium, West Pavilion at the University of Cincinnati

August 24, 2023

Cliff Haefke
Director
US DOE Midwest CHP Technical Assistance Partnership

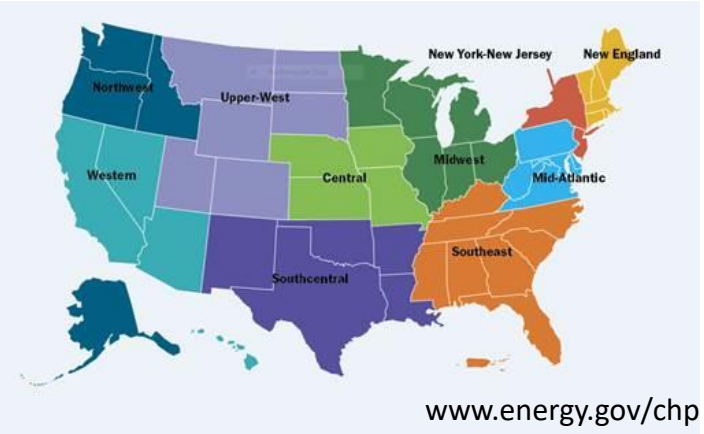
CHP Technical Assistance Partnerships

Agenda

- Key Strategic Pillars of the DOE Industrial Decarbonization Roadmap
- Federal Grant Opportunity – Bipartisan Infrastructure Law (BIL) Section 40521
- Federal Incentive Opportunity – Inflation Reduction Act (IRA) Section 48 Investment Tax Credit (ITC)

U.S. DOE CHP Technical Assistance Partnerships (CHP TAPs)

- **End User Engagement**
  Partner with strategic End Users to advance technical solutions using CHP as a cost effective and resilient way to ensure American competitiveness, utilize local fuels and enhance energy security. CHP TAPs offer fact-based, non-biased engineering support to manufacturing, commercial, institutional and federal facilities and campuses.
- **Stakeholder Engagement**
  Engage with strategic Stakeholders, including regulators, utilities, and policy makers, to identify and reduce the barriers to using CHP to advance regional efficiency, promote energy independence and enhance the nation's resilient grid. CHP TAPs provide fact-based, non-biased education to advance sound CHP programs and policies.
- **Technical Services**
  As leading experts in CHP (as well as microgrids, heat to power, and district energy) the CHP TAPs work with sites to screen for CHP opportunities as well as provide advanced services to maximize the economic impact and reduce the risk of CHP from initial CHP screening to installation.



www.energy.gov/chp


National Manufacturing Day 2019 at the University of Illinois at Chicago

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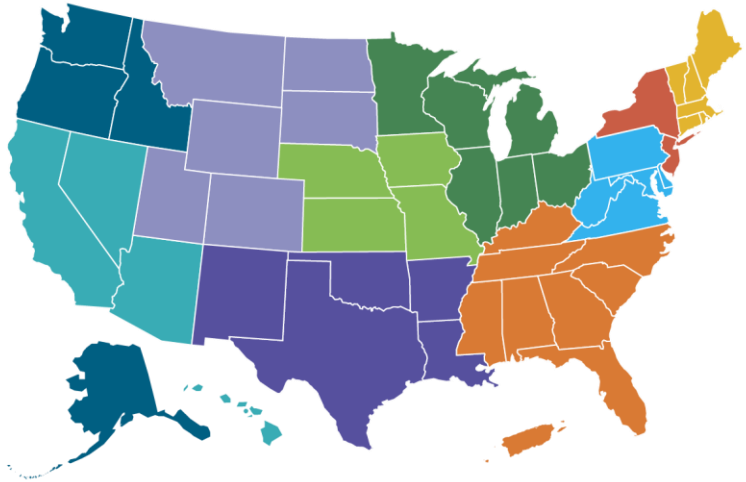

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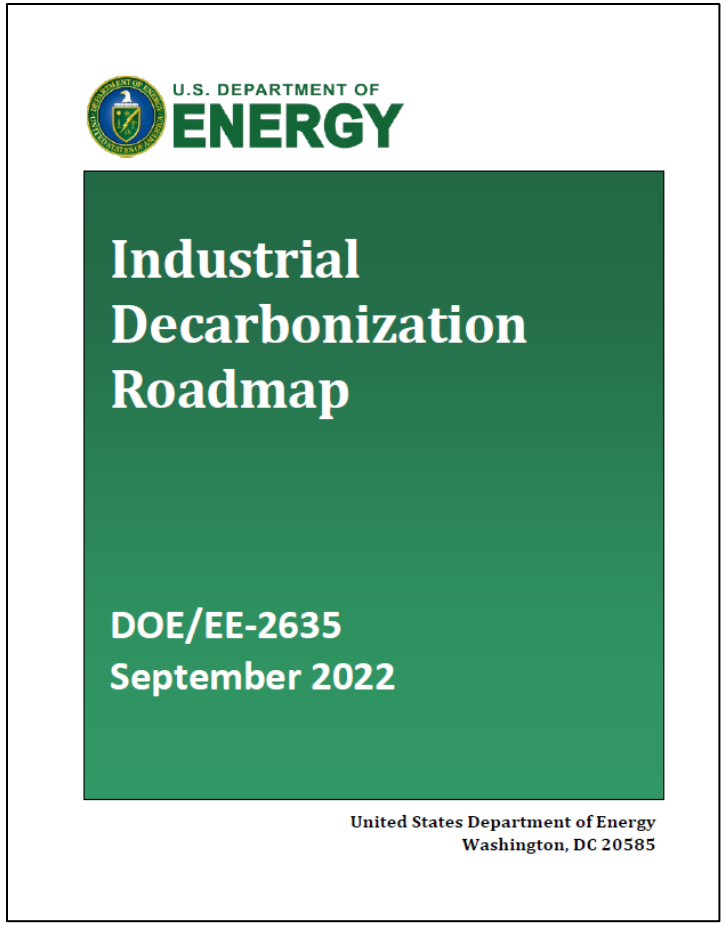
Key Strategic Pillars of the DOE Industrial Decarbonization Roadmap

U.S. DOE "Industrial Decarbonization Roadmap"

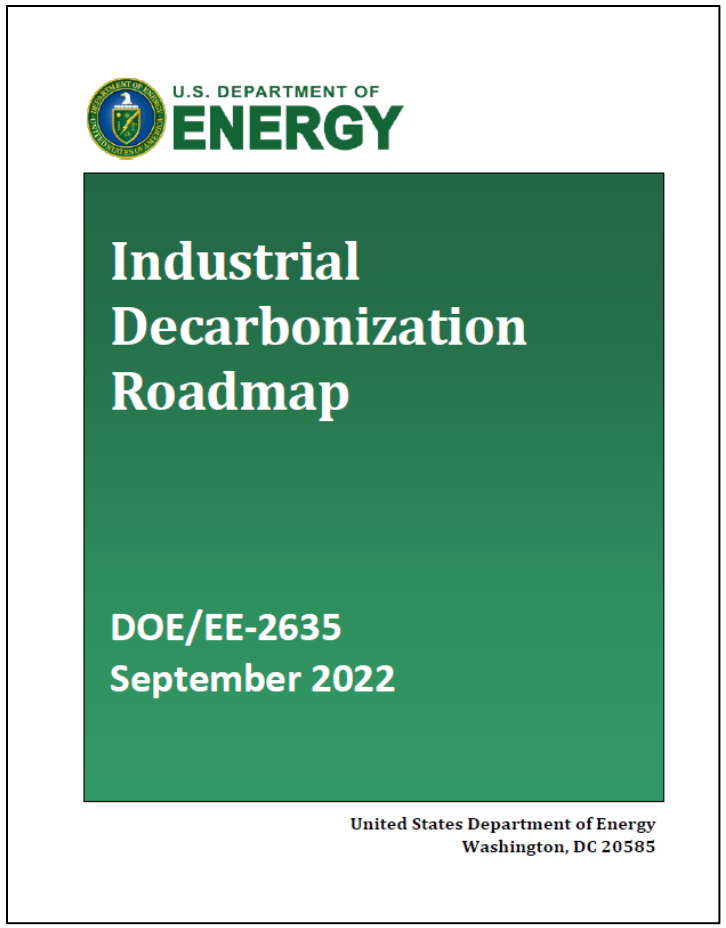


"The science is clear that significant greenhouse gas (GHG) emissions reductions are needed to moderate the severe impacts of ongoing climate change. **Bold action is needed**, and the Biden Administration has set goals of 100% carbon pollution-free electricity by 2035 and net-zero GHG emissions by 2050." – *Page 14*

"The U.S. industrial sector is considered a **"difficult-to-decarbonize" sector** of the energy economy, in part because of the diversity of energy inputs that feed into a heterogenous array of industrial processes and operations." – *Page 14*

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

U.S. DOE "Industrial Decarbonization Roadmap" (cont.)



Definition of Industrial Decarbonization:

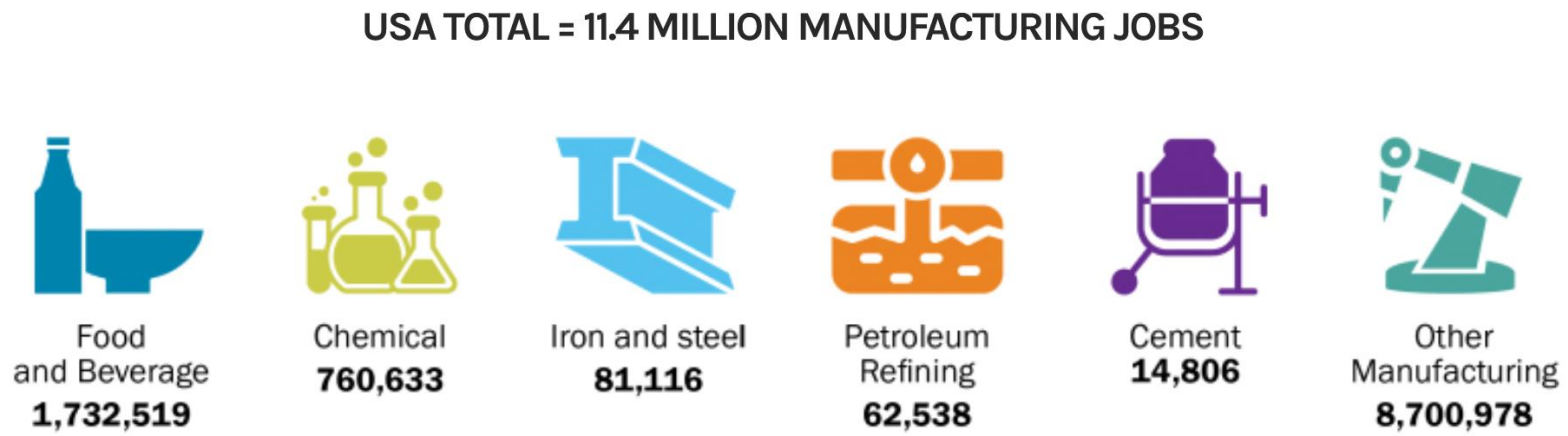
- Industrial decarbonization refers to the phasing out of GHG emissions from the industrial sector.
- Globally, the most important gases contributing to the GHG effect are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases.
- While emissions of all of these gases must be minimized to achieve U.S. industrial decarbonization, scenario modeling in this roadmap focuses primarily on energy-related CO_2 emissions attributable to industrial activity.
- In the U.S., CO_2 emissions represent over 80% of U.S. manufacturing energy-related GHG emissions on a CO_2-equivalent basis.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Key Recommendations from the Industrial Decarbonization Roadmap

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Industrial Decarbonization and American Jobs



*"**Decarbonizing the industrial sector is critical to labor and equity goals.** Workforce development and technical assistance programs, like DOE's Industrial Assessment Centers, will help prepare the existing 11.4 million American manufacturing workers and future workforce for the clean industry transition, improving health outcomes and long-term job prospects."*

*"Decarbonizing the industrial sector is critical to equity goals, specifically the Administration's Justice40 Initiative, which pledges that **at least 40% of overall benefits from Federal investments in climate and clean energy be delivered to disadvantaged communities**."*

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

U.S. Primary Energy-Related CO2 Emissions by End Use Sector and Breakout by Industrial Subsector

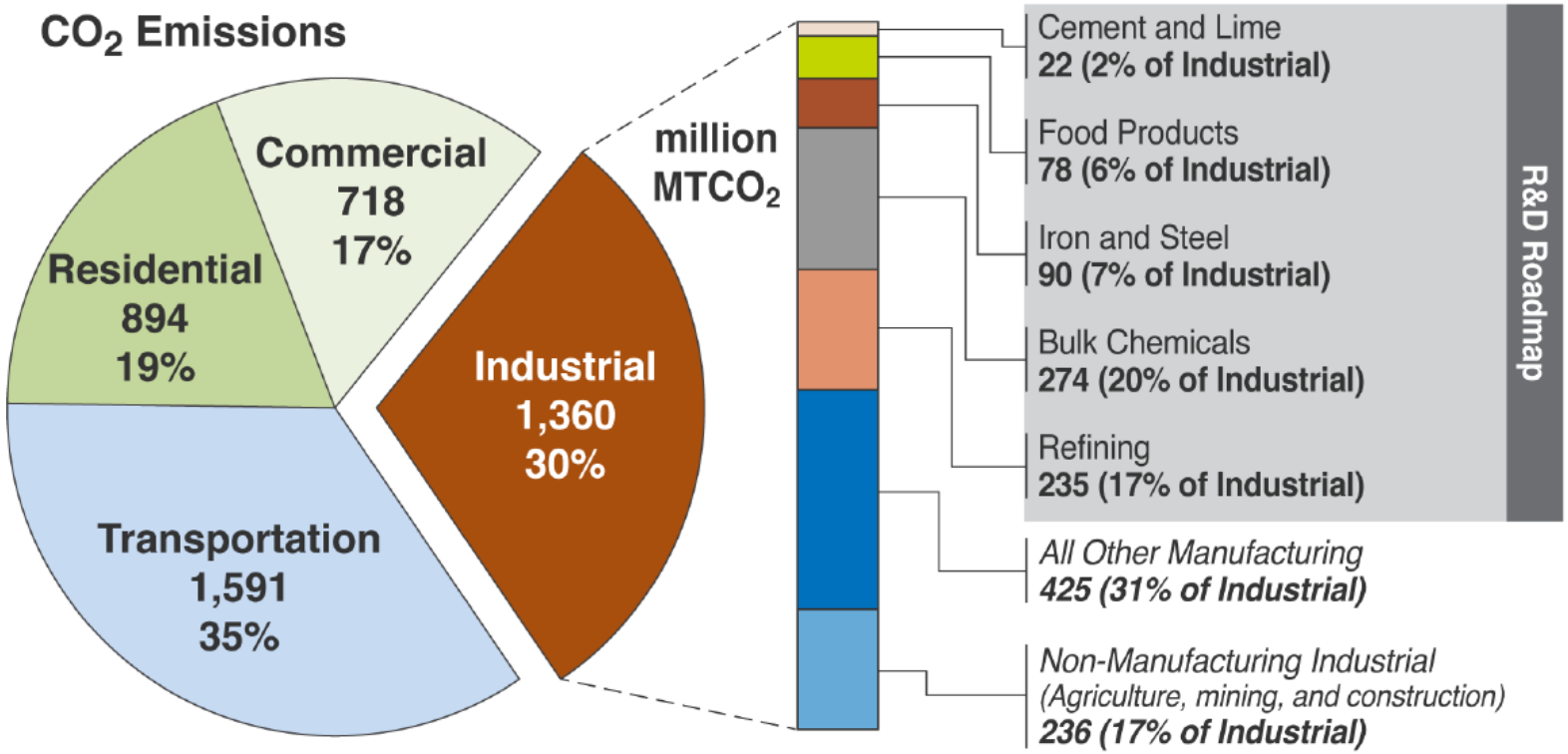


FIGURE 3. U.S. PRIMARY ENERGY-RELATED CO_2 EMISSIONS BY END USE SECTOR (LEFT PIE CHART) AND A BREAKOUT BY INDUSTRIAL SUBSECTOR (RIGHT STACKED CHART) IN 2020.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Distribution of Process Heat Temperature Ranges by Industrial Subsector

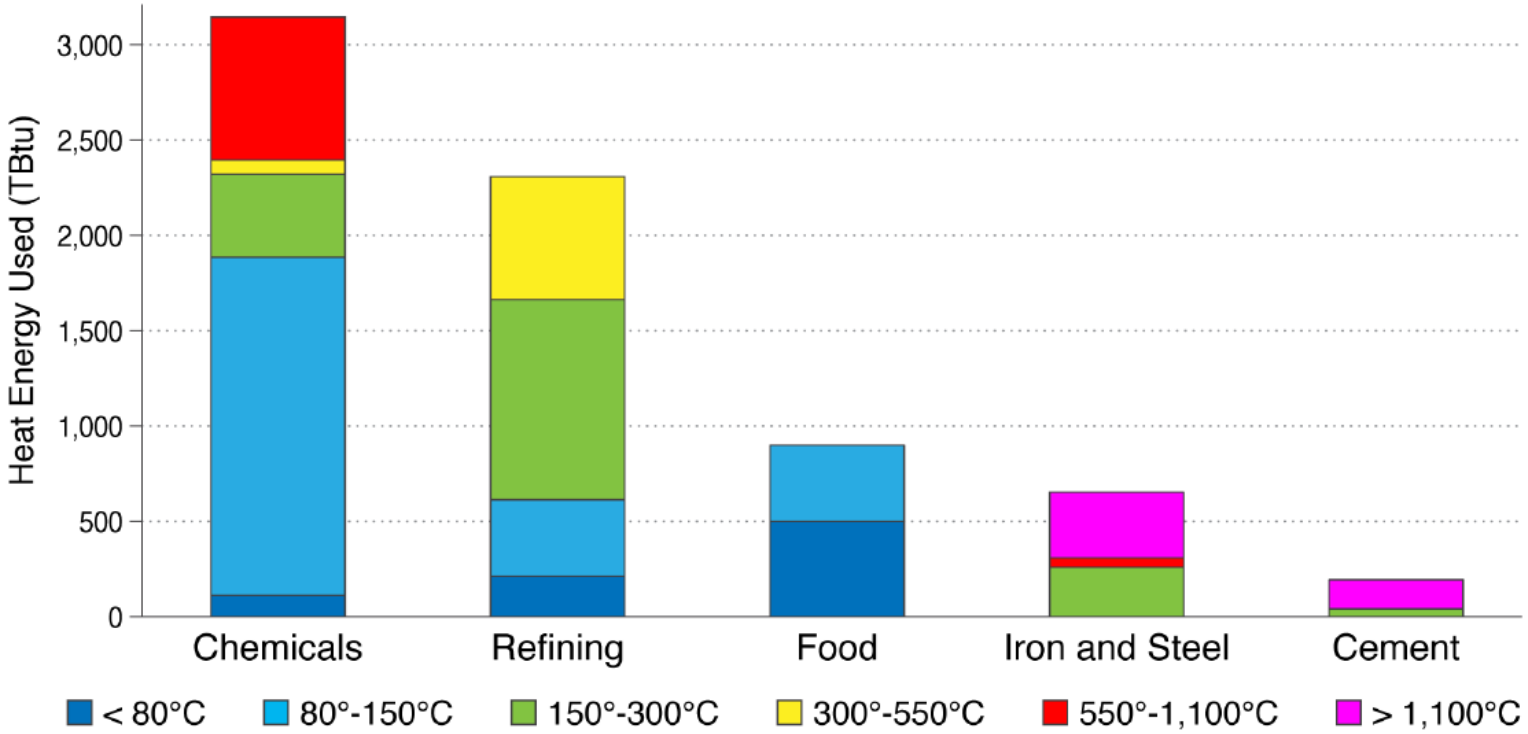


FIGURE 6. DISTRIBUTION OF PROCESS HEAT TEMPERATURE RANGES BY INDUSTRIAL SUBSECTOR IN 2014.

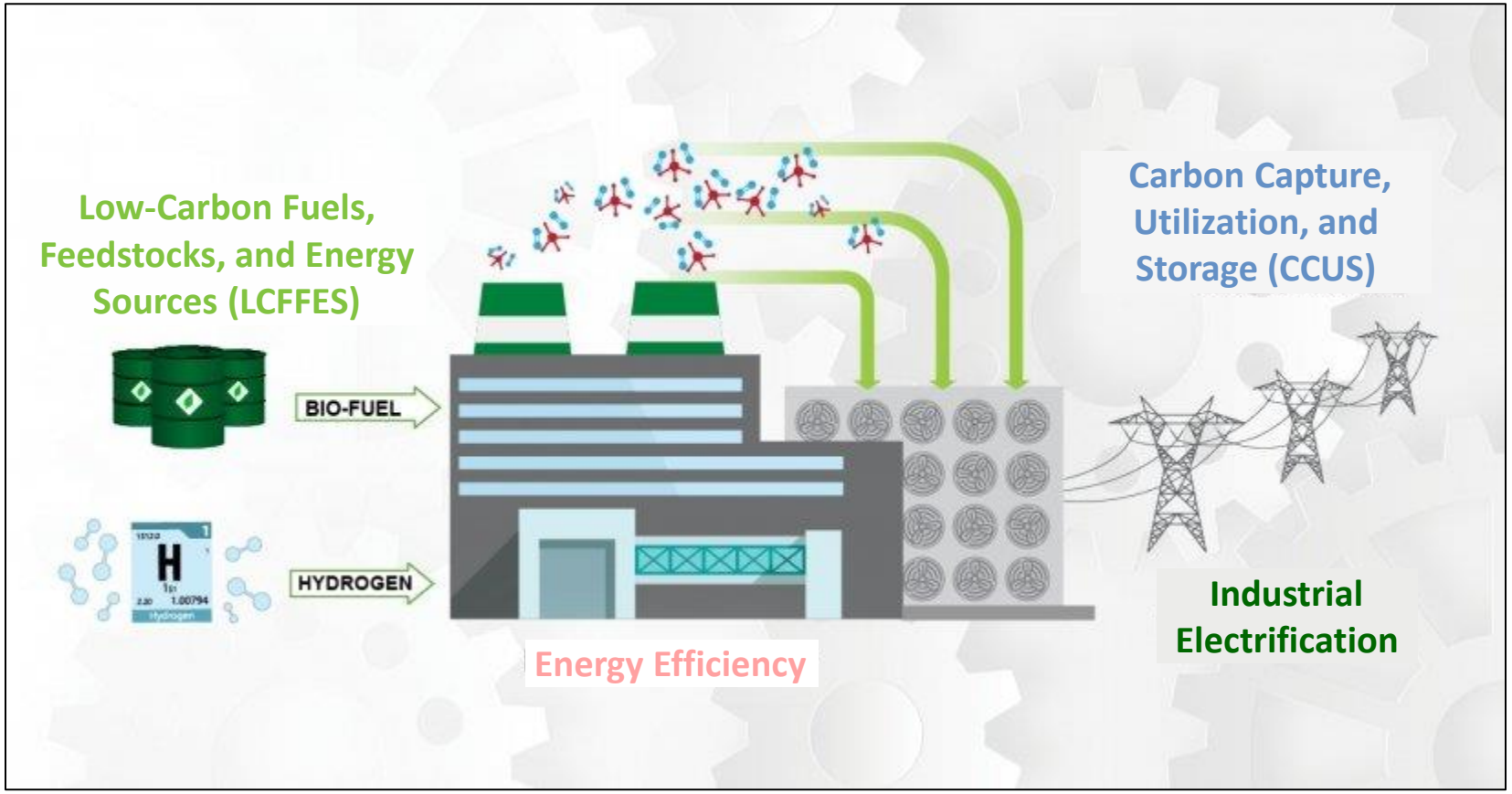
TEMPERATURE RANGES ARE IN °C AND HEAT USE IS IN TRILLION BTU (TBTU). DATA SOURCE: MCMILLAN 2019[81]

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Strategies for Decarbonizing U.S. Industries

The DOE Industrial Decarbonization Roadmap identifies 4 key technological pillars to significantly reduce emissions for these five subsectors studied. With the application of alternative approaches, 100% of annual CO2 emissions could be mitigated.

1. Energy Efficiency
2. **Industrial Electrification**
3. Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)
4. Carbon Capture, Utilization, and Storage (CCUS)



Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Path to Net-Zero Industrial CO_2 Emissions in U.S. for 5 Carbon-Intensive Industrial Subsectors

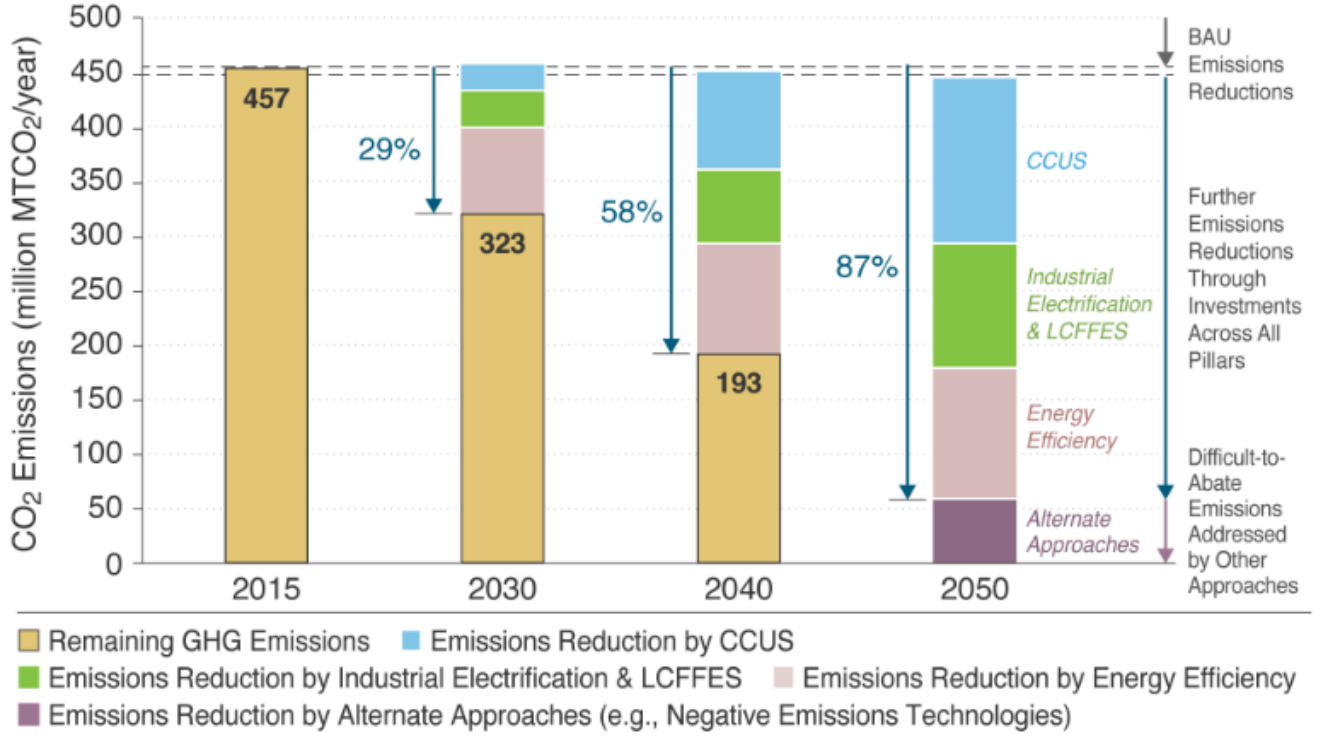


FIGURE ES 1. THE PATH TO NET-ZERO INDUSTRIAL CO_2 EMISSIONS IN THE UNITED STATES FOR FIVE CARBON-INTENSIVE INDUSTRIAL SUBSECTORS, WITH CONTRIBUTIONS FROM EACH DECARBONIZATION PILLAR: ENERGY EFFICIENCY; INDUSTRIAL ELECTRIFICATION; LOW-CARBON FUELS, FEEDSTOCKS, AND ENERGY SOURCES (LCFFES); AND CARBON CAPTURE, UTILIZATION, AND STORAGE (CCUS)). EMISSIONS ARE IN MILLIONS OF METRIC TONS (MT) PER YEAR.

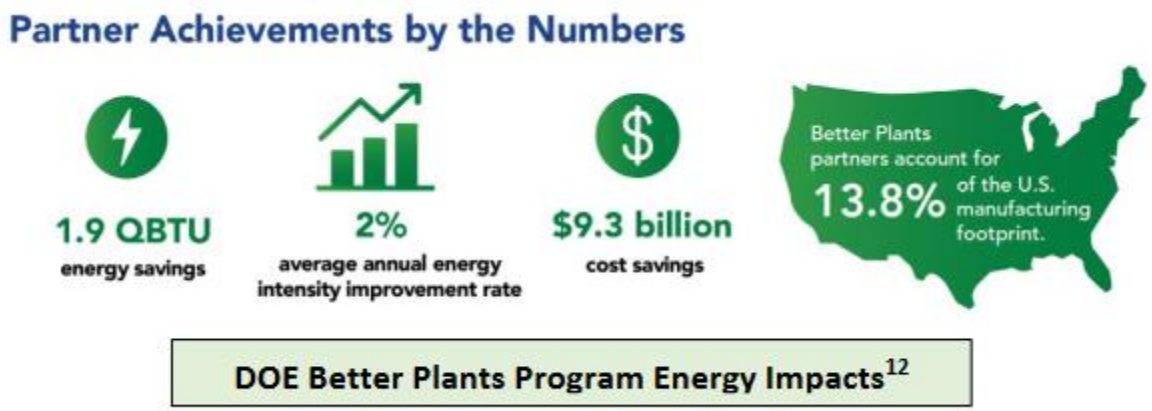
Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Key Technology Pillar: Energy Efficiency

Energy efficiency is a foundational, crosscutting decarbonization strategy and is the most cost-effective option for GHG emission reductions in the near term.

Decarbonization efforts include:

- Strategic energy management approaches to optimize performance of industrial processes at the system-level
- Systems management and optimization of thermal heat from manufacturing process heating, boiler, and combined heat and power (CHP) sources
- Smart manufacturing and advanced data analytics to increase energy productivity in manufacturing processes



Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Key Technology Pillar: Industrial Electrification

Leveraging advancements in low-carbon electricity from both grid and onsite renewable generation sources will be critical to decarbonization efforts.

Decarbonization efforts include:

- Electrification of process heat using induction, radiative heating, or advanced heat pumps
- Electrification of high-temperature range processes such as those found in iron, steel, and cement making
- Replacing thermally-driven processes with electrochemical ones

Mechanical vapor recompressor

Industrial Heat Pump Technology

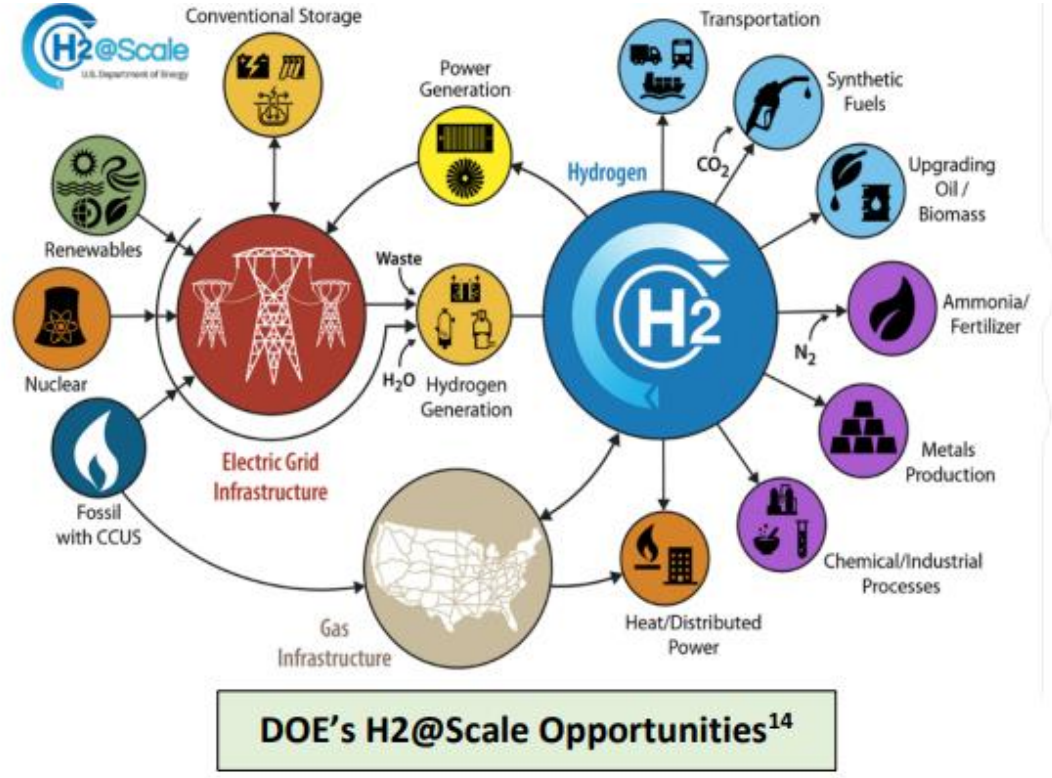
Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Key Technology Pillar: Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)

Substituting low-and no-carbon fuel and feedstocks reduces combustion associated emissions for industrial processes.

Decarbonization efforts include:

- Development of fuel-flexible processes
- Integration of hydrogen fuels and feedstocks into industrial applications
- The use of biofuels and bio feedstocks



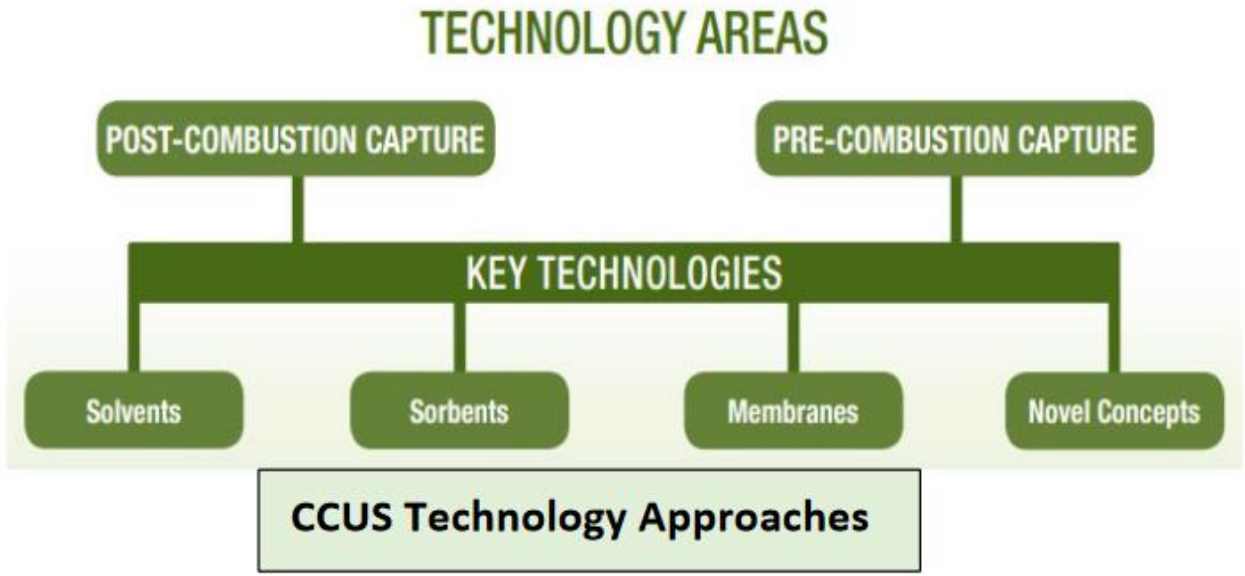
Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Key Technology Pillar: Carbon Capture, Utilization, and Storage (CCUS)

CCUS refers to the multi-component strategy of capturing generated carbon dioxide (CO_2) from a point source and utilizing the captured CO_2 to make value added products or storing it long-term to avoid release.

Decarbonization efforts include:

- Post-combustion chemical absorption of CO_2
- Development and manufacturing optimization of advanced CO_2 capture materials that improve efficiency and lower cost of capture
- Development of processes to utilize captured CO2 to manufacture new materials



Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Landscape of Major RD&D Investment Opportunities for Industrial Decarbonization across All Subsectors by Decade & Decarbonization Pillar

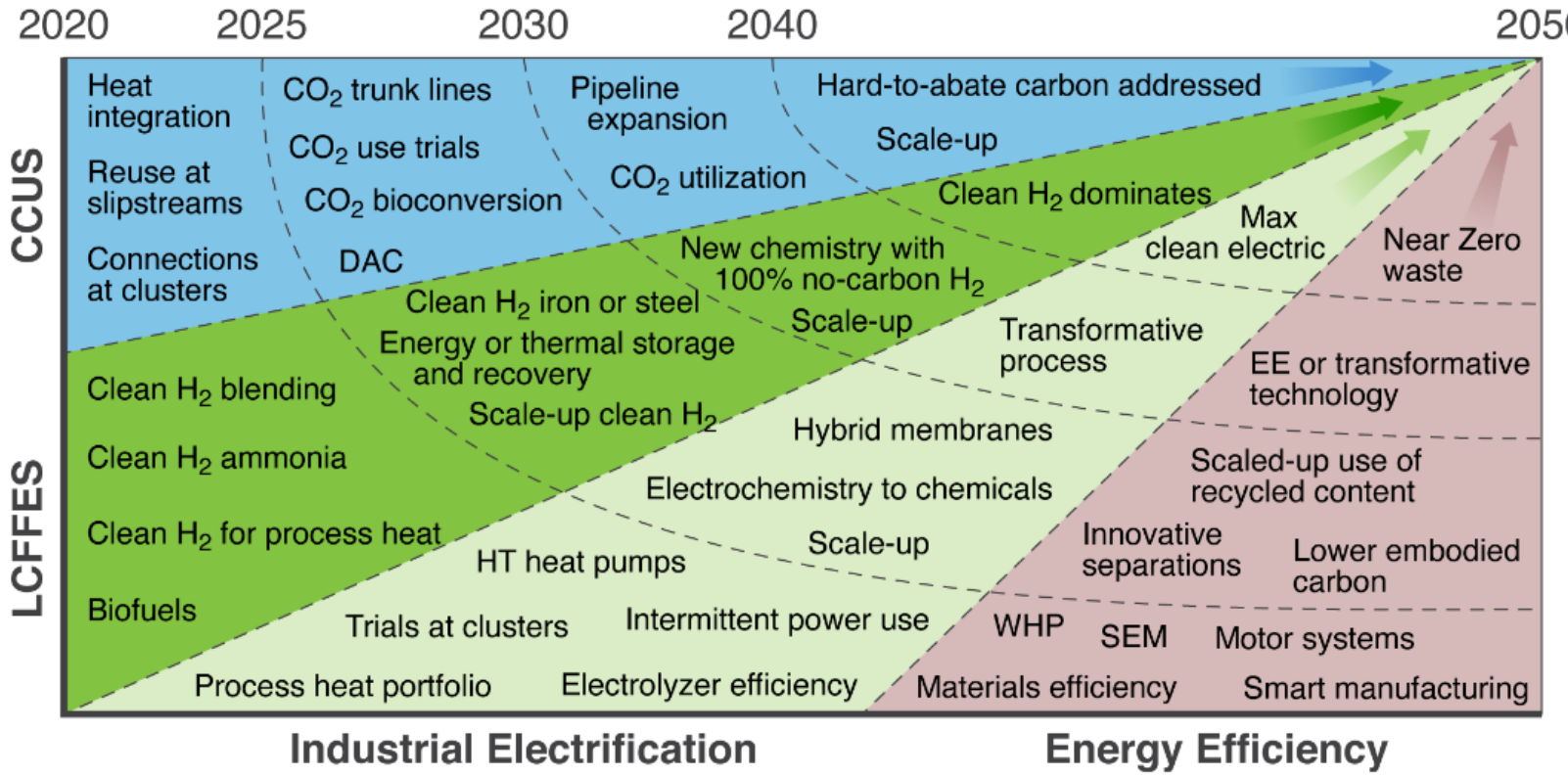


FIGURE 10. LANDSCAPE OF MAJOR RD&D INVESTMENT OPPORTUNITIES FOR INDUSTRIAL DECARBONIZATION ACROSS ALL SUBSECTORS BY DECADE AND DECARBONIZATION PILLAR.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Summary of 4 Strategic Industrial Decarbonization Pillars

	Energy Efficiency	Industrial Electrification	Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)	Carbon Capture, Utilization, and Storage (CCUS)
Summary	Energy efficiency is a foundational, crosscutting decarbonization strategy and is the most cost-effective option for GHG emission reductions in the near term.	Leveraging advancements in low-carbon electricity from both grid and onsite renewable generation sources will be critical to decarbonization efforts.	Substituting low-and no-carbon fuel and feedstocks reduces combustion associated emissions for industrial processes.	CCUS refers to the multi-component strategy of capturing generated carbon dioxide (CO2) from a point source and utilizing the captured CO2 to make value added products or storing it long-term to avoid release.
Decarbonization Efforts	• Strategic energy management approaches to optimize performance of industrial processes at the system-level • Systems management and optimization of thermal heat from manufacturing process heating, boiler, and combined heat and power (CHP) sources • Smart manufacturing and advanced data analytics to increase energy productivity in manufacturing processes	• Electrification of process heat using induction, radiative heating, or advanced heat pumps • Electrification of high-temperature range processes such as those found in iron, steel, and cement making • Replacing thermally-driven processes with electrochemical ones	• Development of fuel-flexible processes • Integration of hydrogen fuels and feedstocks into industrial applications • The use of biofuels and bio feedstocks	• Post-combustion chemical absorption of CO2 • Development and manufacturing optimization of advanced CO2 capture materials that improve efficiency and lower cost of capture • Development of processes to utilize captured CO2 to manufacture new materials

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Newer Federal Funding Opportunity for Industrial Manufacturing Plants

Bipartisan Infrastructure Law (BIL)

Section 40521

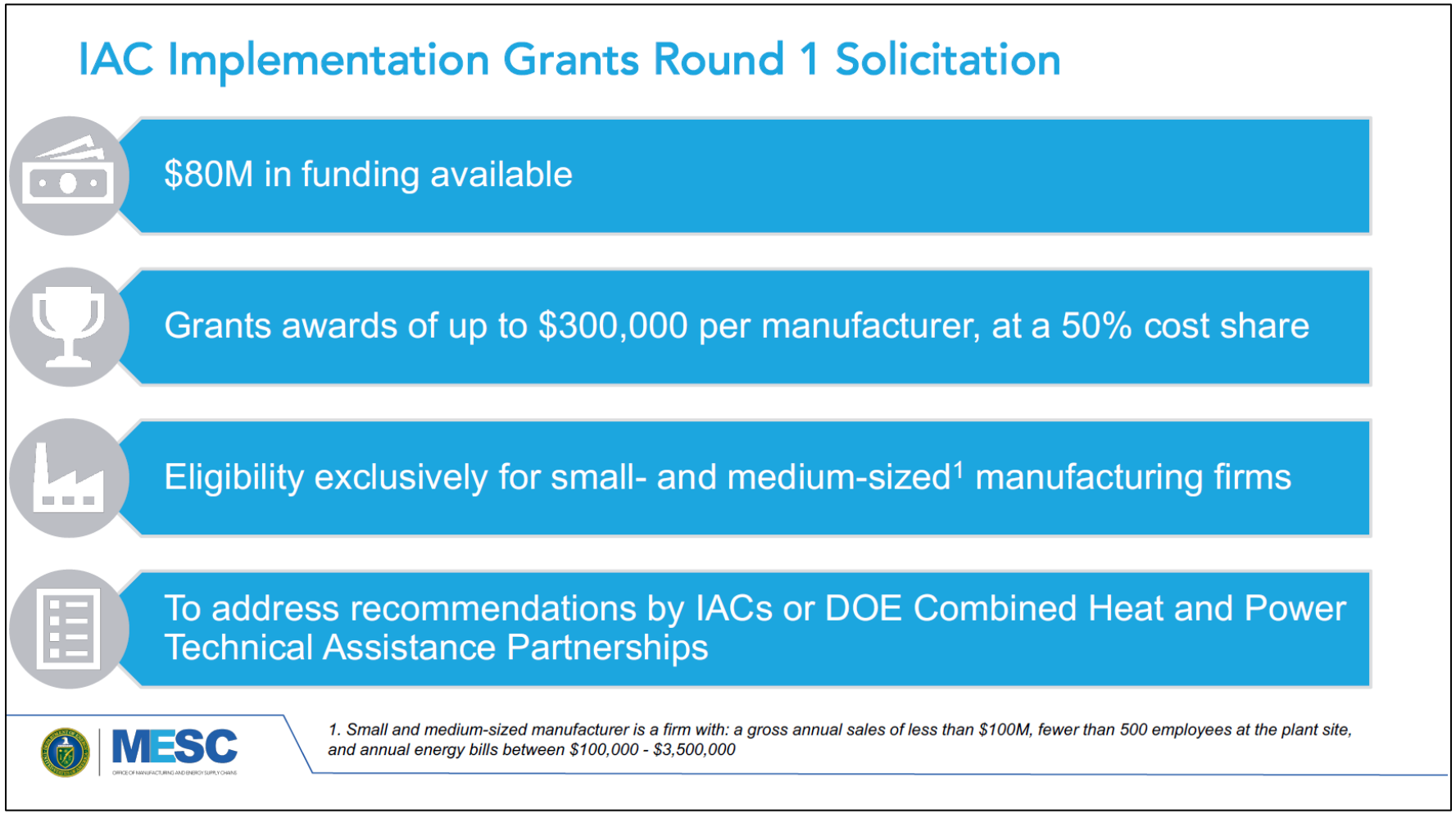
New DOE Project Grant Funding Opportunity

$300,000 per Installed Project ---> 50% Cost Shared Required

- Industrial Assessment Center (IAC) Implementation Grant Program designed to provide up to $400 million in grants over a 5-year period
- Funded by Section 40521 of the Bipartisan Infrastructure Law
- Grant program implemented by Energy Werx Corp.
- Round 1 of funding opened June 7, 2023 with applications due July 14, 2023
- Round 2 funding information not published yet
- Following slides share information from Round 1 funding (6/7/23 – 7/14/23)

For more information visit on this grant opportunity visit:
https://www.energy.gov/mesc/industrial-research-and-assessment-center-implementation-grants

IAC Implementation Grant Information (Overview)



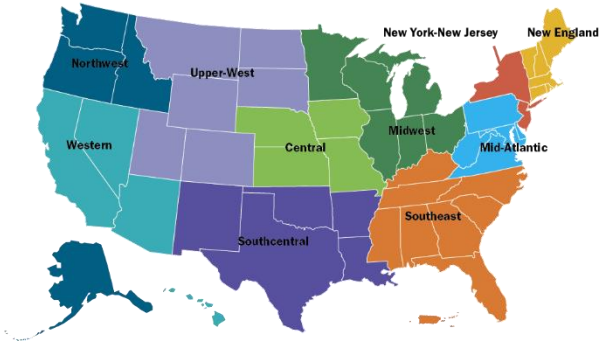
Source: https://www.energy.gov/mesc/industrial-research-and-assessment-center-implementation-grants

Overview of DOE IAC and DOE CHP TAP Programs

Industrial Assessment Centers (IACs)

- 37 universities around the country have conducted over 20,000 IAC assessments over 40+ years
- The program provides technical assistance to small- and medium-sized manufacturing firms while training the next generation of energy-savvy engineers
- Assessments typically identify >$130K in potential annual savings, with ~$50K implemented in the first year – and the potential for much more with the implementation grants
- To learn more and apply for an IAC assessment, visit iac.university

Combined Heat and Power Technical Assistance Partnerships (CHP TAPs)

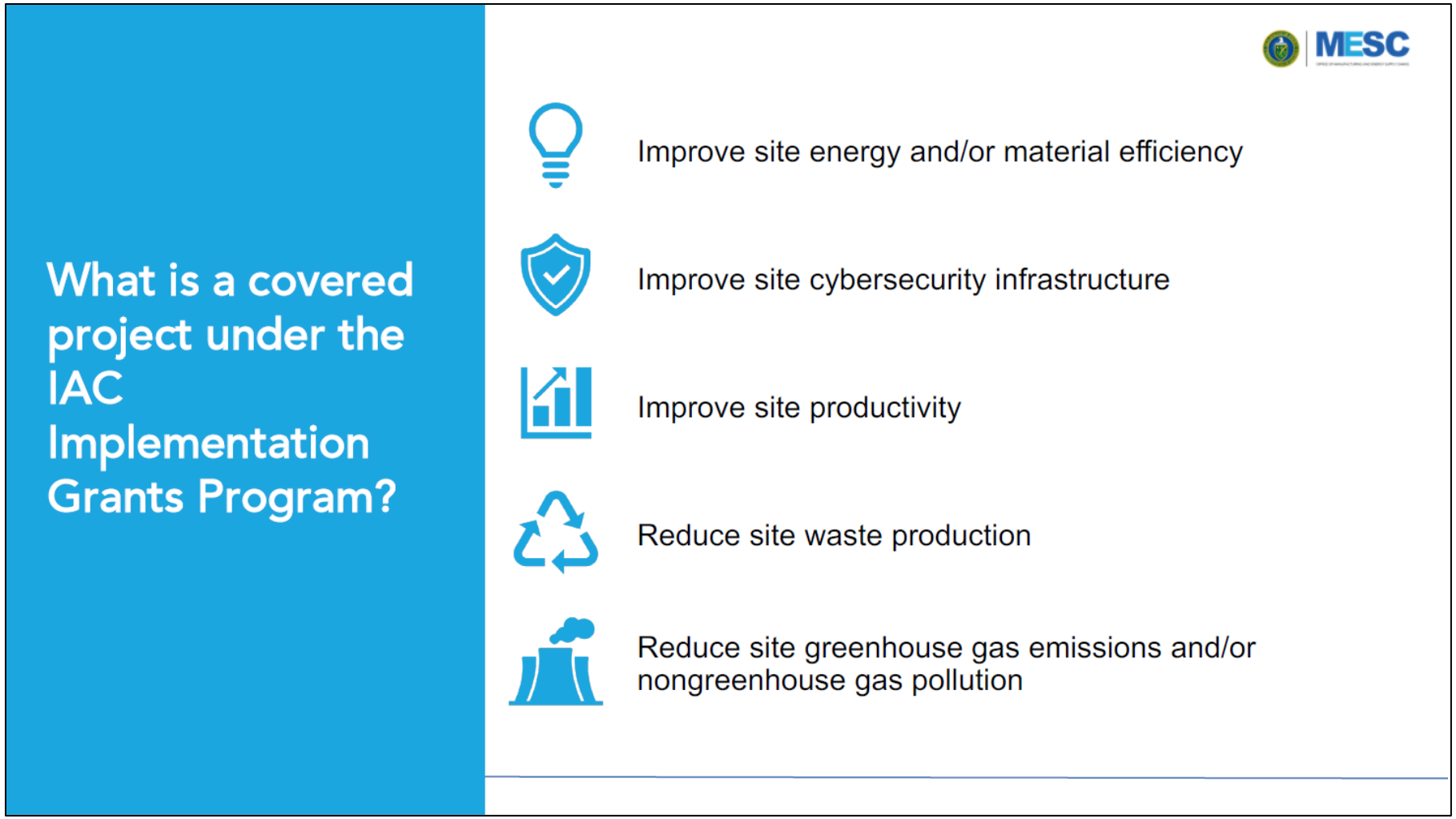


- 10 regional entities around the country have conducted >1000 technical screenings over the past 5 years
- Partner with manufacturers to identify cost effective & resilient ways to deploy combined heat & power (CHP)
- Identify and address barriers to using CHPs to advance regional efficiency, promote energy independence, & enhance the nation's grid resiliency
- To learn more and apply for a CHP TAP assessment, visit https://betterbuildingssolutioncenter.energy.gov/chp/chp-taps

CHP Technical Assistance Partnerships

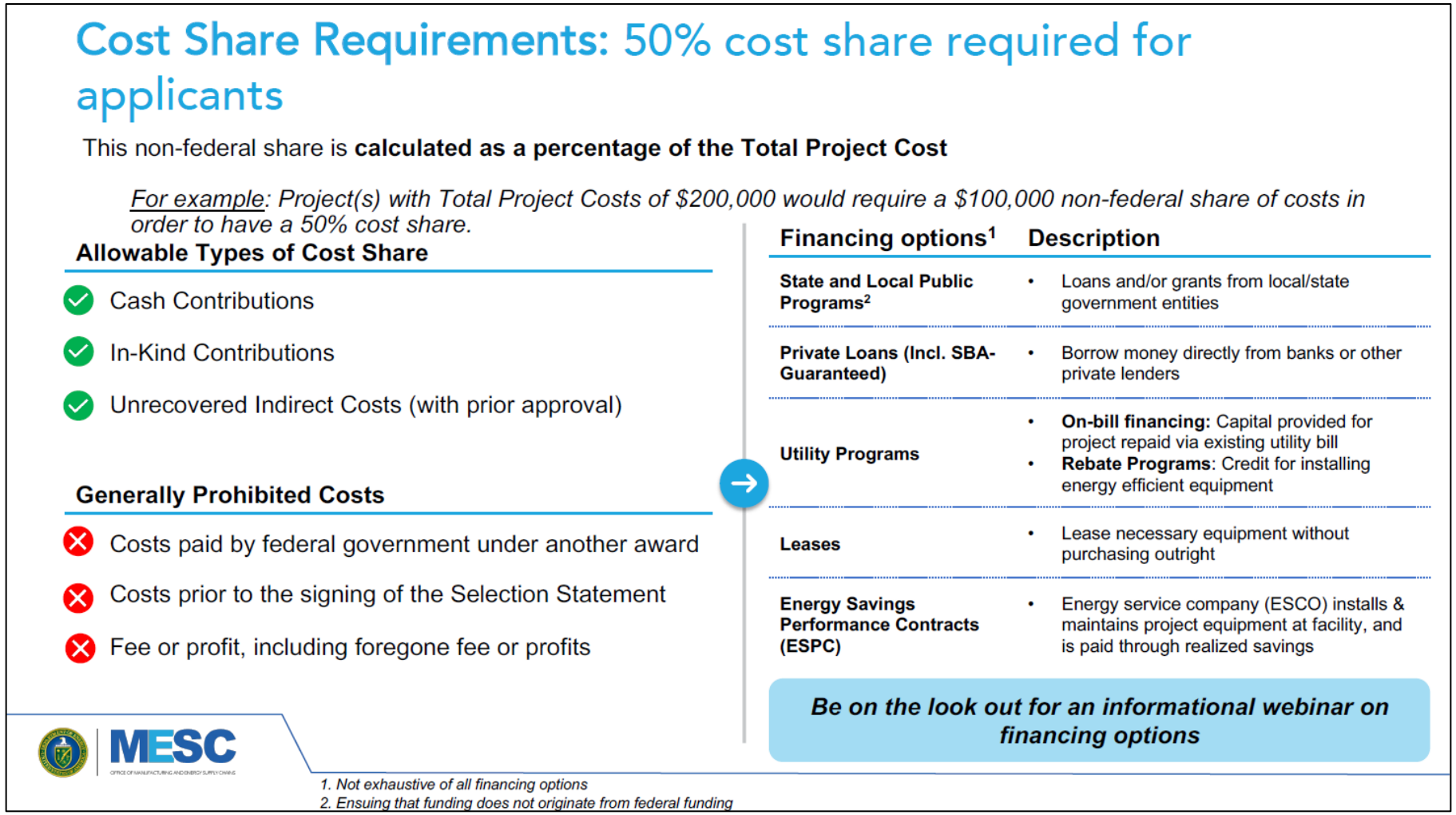
Source: https://www.energy.gov/mesc/industrial-research-and-assessment-center-implementation-grants

IAC Implementation Grant Information (Project Types)



Source: https://www.energy.gov/mesc/industrial-research-and-assessment-center-implementation-grants

IAC Implementation Grant Information (Cost Share)



Source: https://www.energy.gov/mesc/industrial-research-and-assessment-center-implementation-grants

Newer Federal Funding Opportunity for Industrial Manufacturing Plants

Inflation Reduction Act (IRA)

Section 48 Investment Tax Credit (ITC)

The source of the next seven slides is the Northeast Clean Heat and Power Initiative (NECHPI).

Inflation Reduction Act and Tax Credits – Opportunities for CHP

Source on next five slides is the Northeast Clean Heat and Power Initiative (NECHPI)

Background:

- President Biden signed the Inflation Reduction Act (IRA) on August 16, 2022, The IRA provides tax incentives for renewable and qualifying clean energy technologies that begin construction before 2025.
- The extension of Investment Tax Credit (ITC) and Production Tax Credit (PTC) applies to solar, qualified fuel cells, microturbines, CHP, waste energy, wind, energy storage, microgrid controller, and qualified biogas projects.

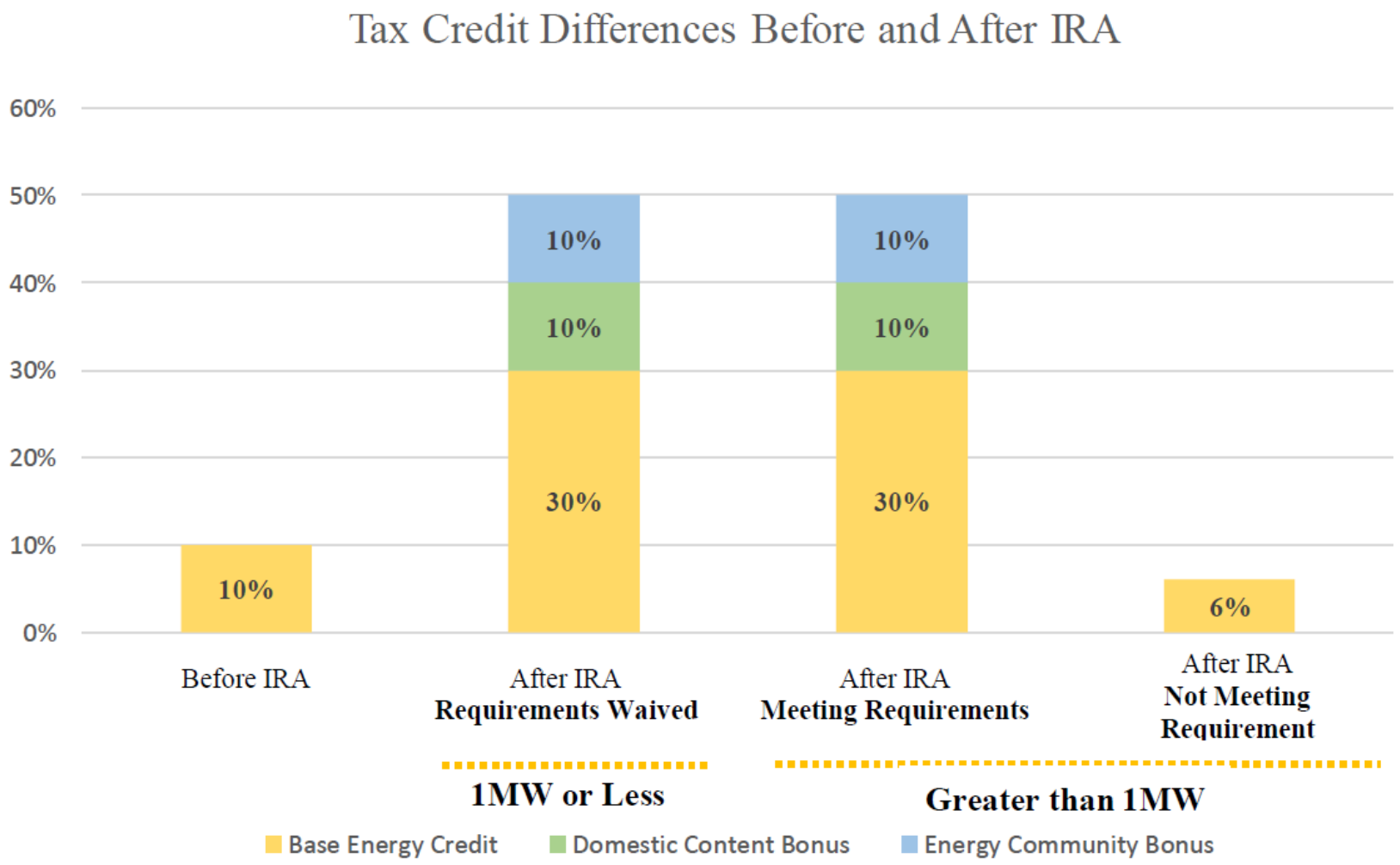
Source: Northeast Clean Heat and Power Initiative (NECHPI)

Inflation Reduction Act and Tax Credits – Opportunities for CHP

- Before the IRA, the old Section 48 for ITC qualified CHP at a lower rate. Section 45 for PTC qualified renewable powered CHP that met certain requirements.
- IRA extends Section 48 ITC to CHP gas or renewable at the 30% rate extends Section 45 PTC only available to qualifying renewable CHP and includes energy storage technologies and microgrid controllers (facilitate hybrid CHP).
- Before the bill, the ITC granted an energy credit of 10% (sunset 12/31/2021). The bill now extends the ITC under section 48 at the 30% rate for energy property beginning construction after 1/1/2022 and before 2025, and up to 30-40% through 2035.
- Credit Enhancements: There are bonus points to earn “beyond” the 30% ITC and PTC.
  - Domestic Content Bonus: additional 10% credit is rewarded for ITC or PTC if manufactured products that are components (ex: steel, iron) of the completed facility are required to be produced in the U.S.
  - Energy Community Bonus: additional 10% credit is awarded for ITC or PTC if a qualified facility is located on brownfields or in an energy community with fossil-electric plant retirements, coal mine closures, or high unemployment rates.

Source: Northeast Clean Heat and Power Initiative (NECHPI)

Inflation Reduction Act and Tax Credits – Opportunities for CHP



Source: Northeast Clean Heat and Power Initiative (NECHPI)

Inflation Reduction Act and Tax Credits – Opportunities for CHP

- **Limitations:** If the project is 1 MW or greater, it must meet the Prevailing Wages Requirement and Apprenticeship requirement to receive 30% ITC. If not, the ITC is subject to 80% reduction (30% ITC reduced to 6%). For projects <1MW, labor requirements are waived.

- **Cap on System Size:** ITC is not eligible for CHP systems greater than 15 MWs. Larger CHP systems (up to a maximum of 50 MW) can qualify for a reduced tax credit equal to the ratio between the actual system capacity and 15MW. For example, a 30 MW system qualifies for a tax credit worth 15/30 of otherwise allowable credit.

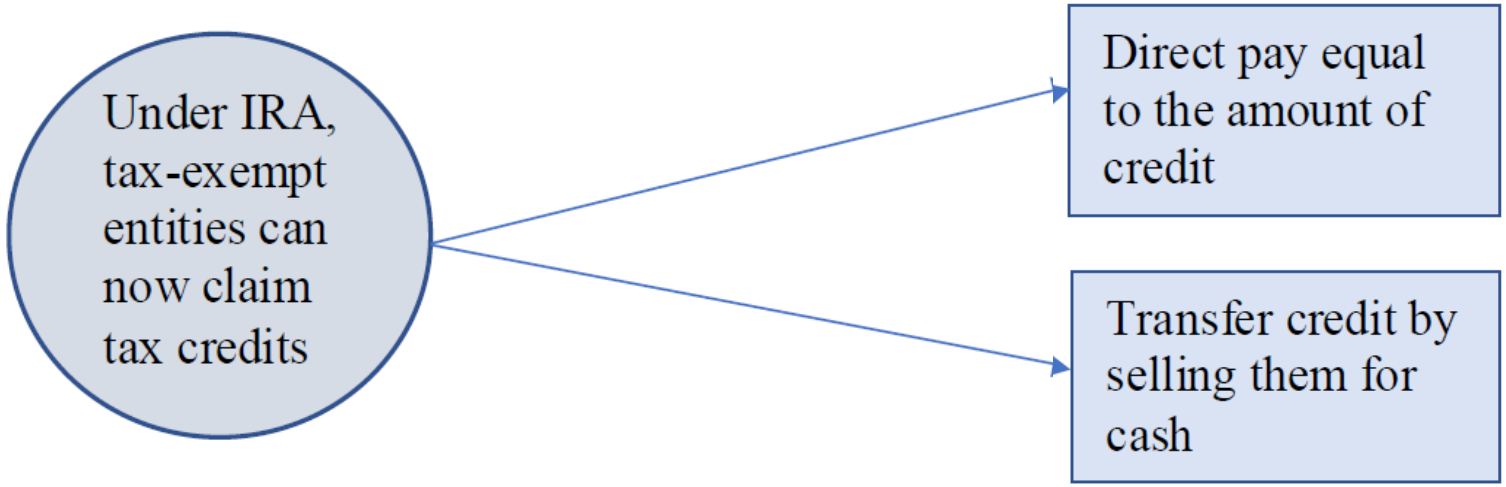
- **Treatment of non-taxpaying entities:** In an important advancement to note, under the IRA, non-taxpaying entities such as tax-exempt organizations, government, authorities, will be able to monetize tax credits. There are two mechanisms for tax-exempt entities, Direct Pay and Transfer (more info on next slide).

- **Safe Harbor:** As long as 5% of project costs are spent prior to the end of 2024, the project will qualify for the full credits, thus effectively extending the construction period for qualifying projects into 2025.
  (Source: Unison Energy)

Source: Northeast Clean Heat and Power Initiative (NECHPI)

Inflation Reduction Act and Tax Credits – Opportunities for CHP

- **Treatment of non-taxpaying entities:** In an important advancement to note, under the IRA, non-taxpaying entities such as tax-exempt organizations, government, authorities, will be able to monetize tax credits. There are two mechanisms for tax-exempt entities.
  - **Direct Pay:** The IRA allows non-taxpaying entities like cities, states, not-for-profit enterprises to take direct pay equal to the amount of the credit, or
  - **Transfer:** The IRA also allows tax-exempt entities to sell the credit to an unrelated buyer for cash.

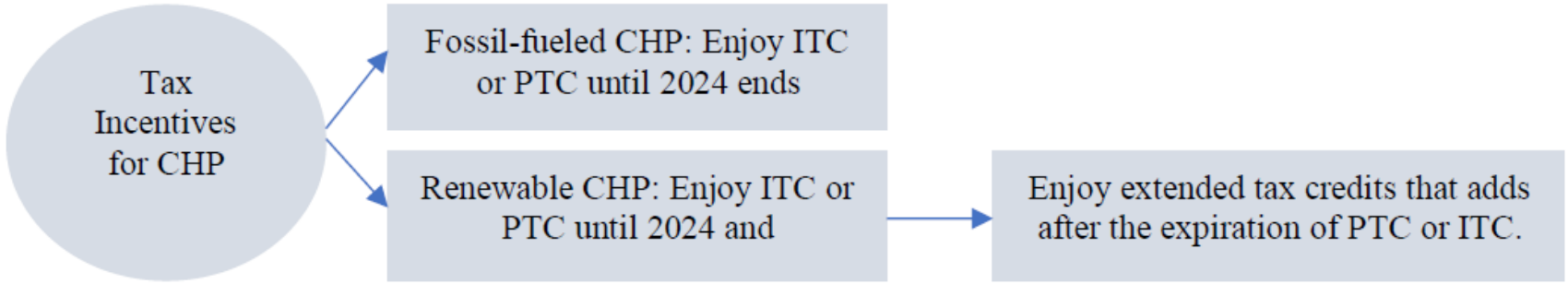


- Section 6417 (Direct Pay Option) and Section 6418 (Transfer of Credits) provide important details regarding applicability, timelines, restrictions. treatment of tax-exempt bond financings.

Source: Northeast Clean Heat and Power Initiative (NECHPI)

Inflation Reduction Act and Tax Credits – Opportunities for CHP

- **Renewable CHP**
  - Qualifying CHP using renewable sources enjoy greater benefits in the pre and post 2025 period. Public infrastructure using biogas, or organics to power may be opportunities.
  - After the bill, "Renewable" CHP system gets treated differently than "fossil-fueled" CHP system, as IRA adds extension tax credits after the expiration of the PTC and ITC.
    - Section 45Y, the **Clean Energy Production Tax Credit**: provides a base PTC of 0.3 cents and a bonus credit of 1.5 cents if prevailing wage and apprenticeship requirements are met
    - Section 48E, the **Clean Electricity Investment Tax Credit**: provides a base ITC of 8 percent and a bonus credit of 30 percent if prevailing wage and apprenticeship requirements are met.



Source: Northeast Clean Heat and Power Initiative (NECHPI)

Summary

- Industrial sector is considered a “difficult-to-decarbonize” sector of the energy economy
- Four (4) key strategic decarbonization pillars identified in DOE roadmap: 1) energy efficiency, 2) electrification, 3) low carbon fuels, and 4) carbon capture, utilization, storage
- BIL Section 40521 provides $300,000 project grants with 50% cost share, $400 million over 5 years
- IRA Section 48 Investment Tax Credit offers 30% tax incentives, with bonuses up to 50%

Thank You

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CHP Technical Assistance Partnerships

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Appendix

Landscape of DOE Office Activities Across the 4 Decarbonization Pillars to Achieve Net-Zero Emissions by 2050

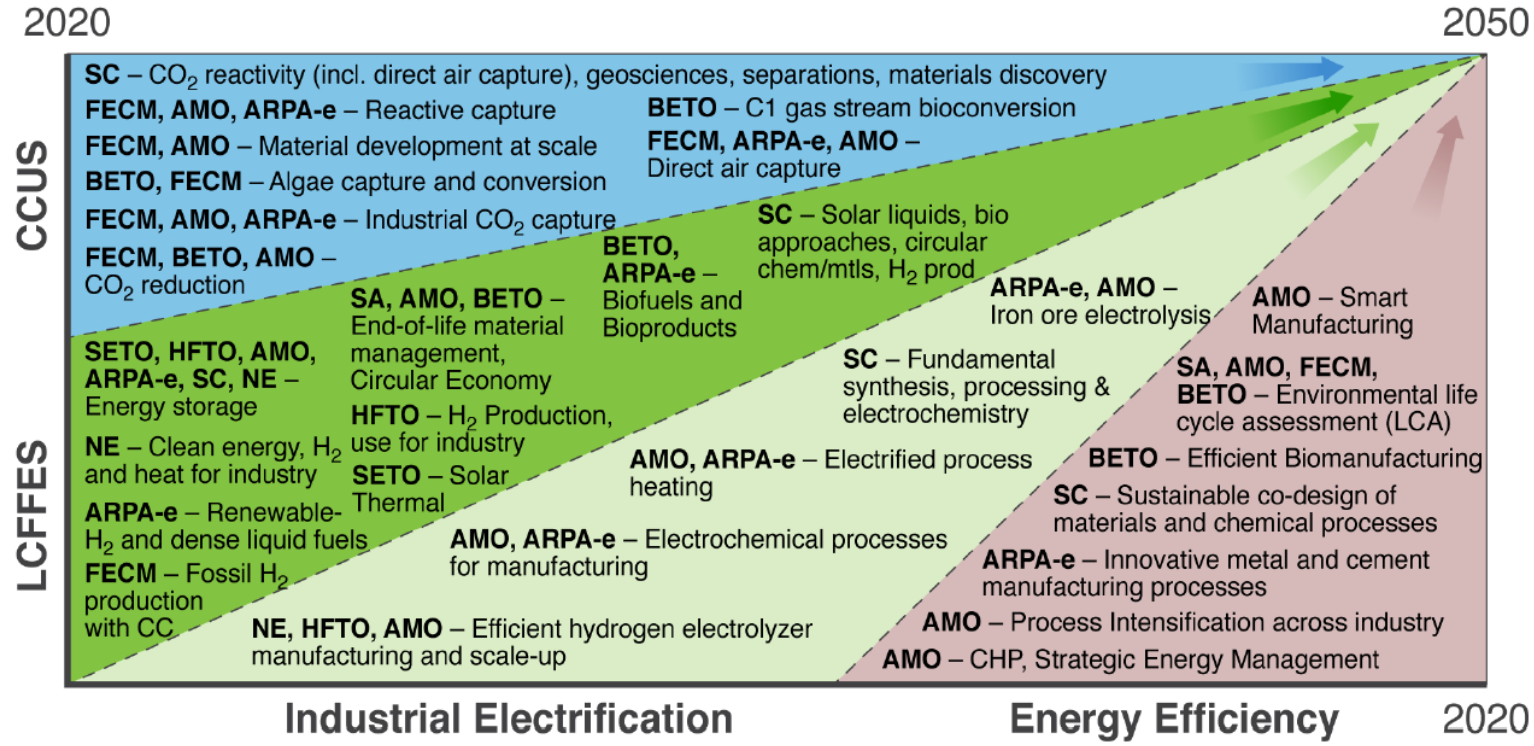
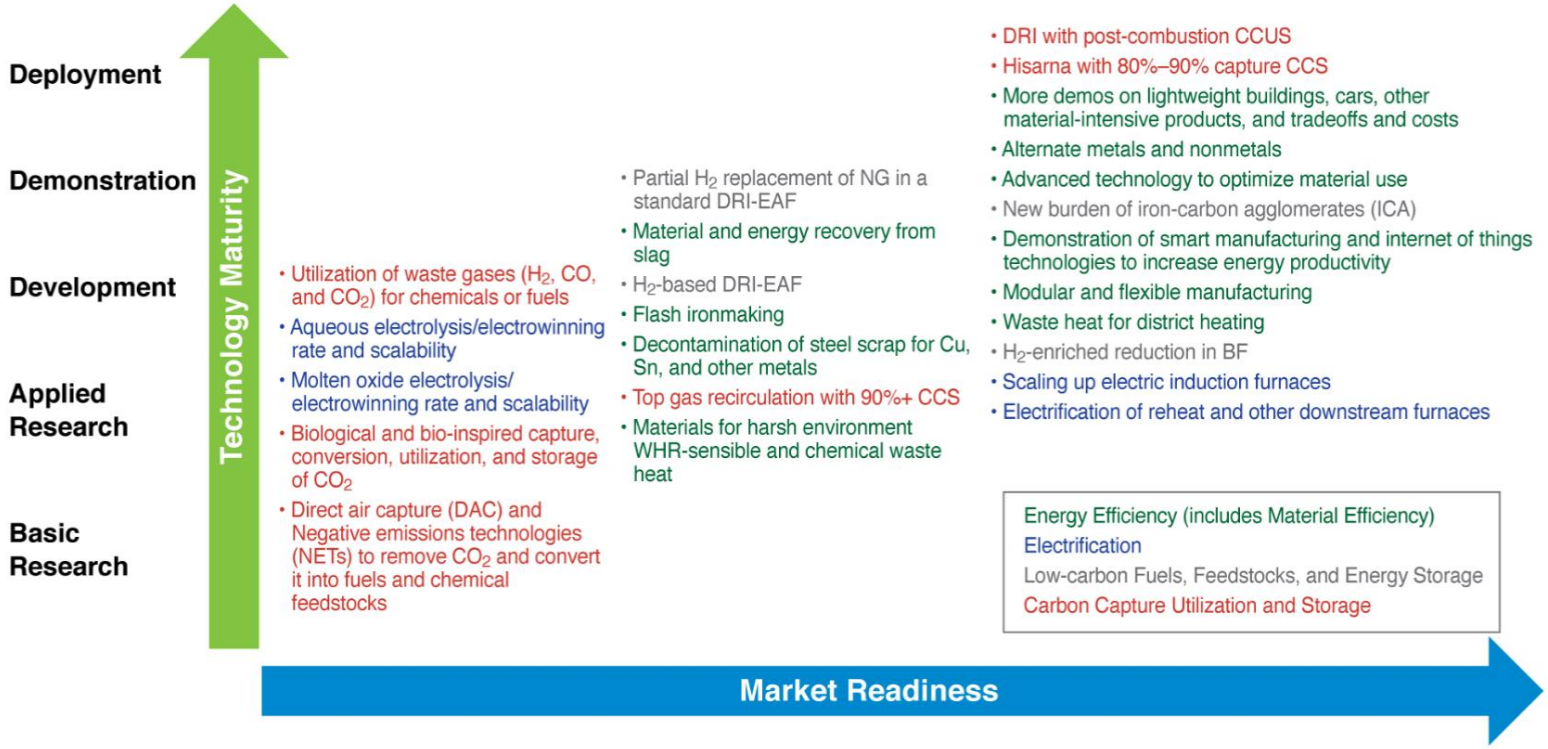


FIGURE 59. LANDSCAPE OF DOE OFFICE ACTIVITIES ACROSS THE FOUR DECARBONIZATION PILLARS TO ACHIEVE NET-ZERO EMISSIONS BY 2050.

AMO: ADVANCED MANUFACTURING OFFICE; ARPA-E: ADVANCED RESEARCH PROJECTS AGENCY – ENERGY; BETO: BIOENERGY TECHNOLOGIES OFFICE; FECM: OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT; HFTO: HYDROGEN AND FUEL CELL TECHNOLOGIES OFFICE; NE: OFFICE OF NUCLEAR ENERGY; SA: EERE STRATEGY ANALYSIS; SC: OFFICE OF SCIENCE; SETO: SOLAR ENERGY TECHNOLOGIES OFFICE.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Technical Maturity Levels of Select Decarbonization Technologies Discussed During Roadmap Virtual Meetings for the U.S. Steel Manufacturing Industry



Iron and Steel Industry: Priority Approaches

Breakthroughs are needed in furnace gas recovery, implementation of low-carbon H_2 in DRI at scale, electrification of re-heat furnaces, production of iron by electrolysis, H_2 plasma smelting reduction, and top-gas recycling.

Technical assistance on developing mature strategic energy management systems in iron and steel facilities, technical assistance on deploying existing low-capital energy efficiency, waste heat recovery (including waste heat to power), and other decarbonization technologies.

Demonstration and rapid adoption of smart manufacturing and Internet of Things technologies to increase energy productivity.

Technology deployment activities that enable and accelerate the transition to lower-carbon fuels and process heat solutions, including demonstrations at scale and techno-economic analyses that show cost competitiveness (e.g., electric induction furnaces, use of clean hydrogen in blast furnaces).

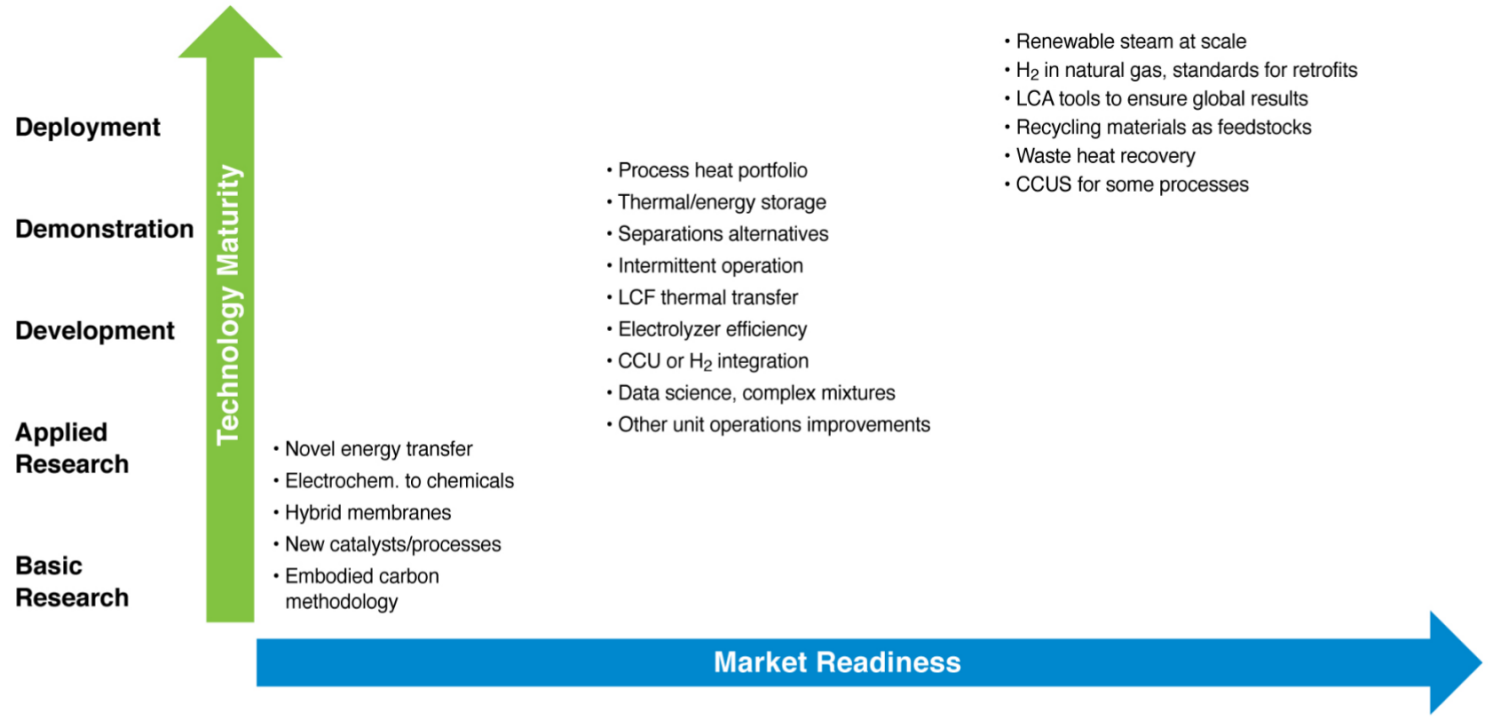
Investments focused on reducing cost and improving efficiency of carbon capture and storage (CCS) technologies to decarbonize different routes of steel production, such as top-gas recycling in blast furnaces with CCS.

FIGURE 16. TECHNICAL MATURITY LEVELS OF SELECT DECARBONIZATION TECHNOLOGIES DISCUSSED DURING ROADMAP VIRTUAL MEETINGS FOR THE U.S. STEEL MANUFACTURING INDUSTRY.

MEETING PARTICIPANTS PROVIDED INPUT ON THE RELATIVE MARKET READINESS AND TECHNICAL MATURING OF THESE TECHNOLOGIES DURING DISCUSSIONS. THERE IS A DISTRIBUTION OF TECHNOLOGIES IN SEVERAL OF THESE CATEGORIES, WHICH BROADEN THE PLACEMENT OF ITEMS. FURTHER DEFINITION OF TERMS IS PROVIDED IN THE GLOSSARY. ACRONYMS: BF: BLAST FURNACE; DRI: DIRECT REDUCED IRON; EAF: ELECTRIC ARC FURNACE; WHR: WASTE HEAT RECOVERY. SOURCE: THIS WORK.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Technical Maturity Levels of Select Decarbonization Technologies Discussed for the U.S. Chemical Manufacturing Industry



Chemical Industry: Priority Approaches

Technologies that support electrification (e.g., scaling of electrochemical processes) and the use of low-carbon fuels and feedstocks are needed. High volume, top energy consuming processes are a priority (e.g., ethylene, methanol). Additional opportunities are use of recovered CO_2, CO, and other off and flare gases and step-change improvements in efficiency and economics of chemical separations, catalysts, and process efficiency. For example, separation of ethane/ethylene, propane/propylene, CO_2/air, CH_4/air, and other separations could be made more efficient via use of hybrid membranes. Priority approaches include:

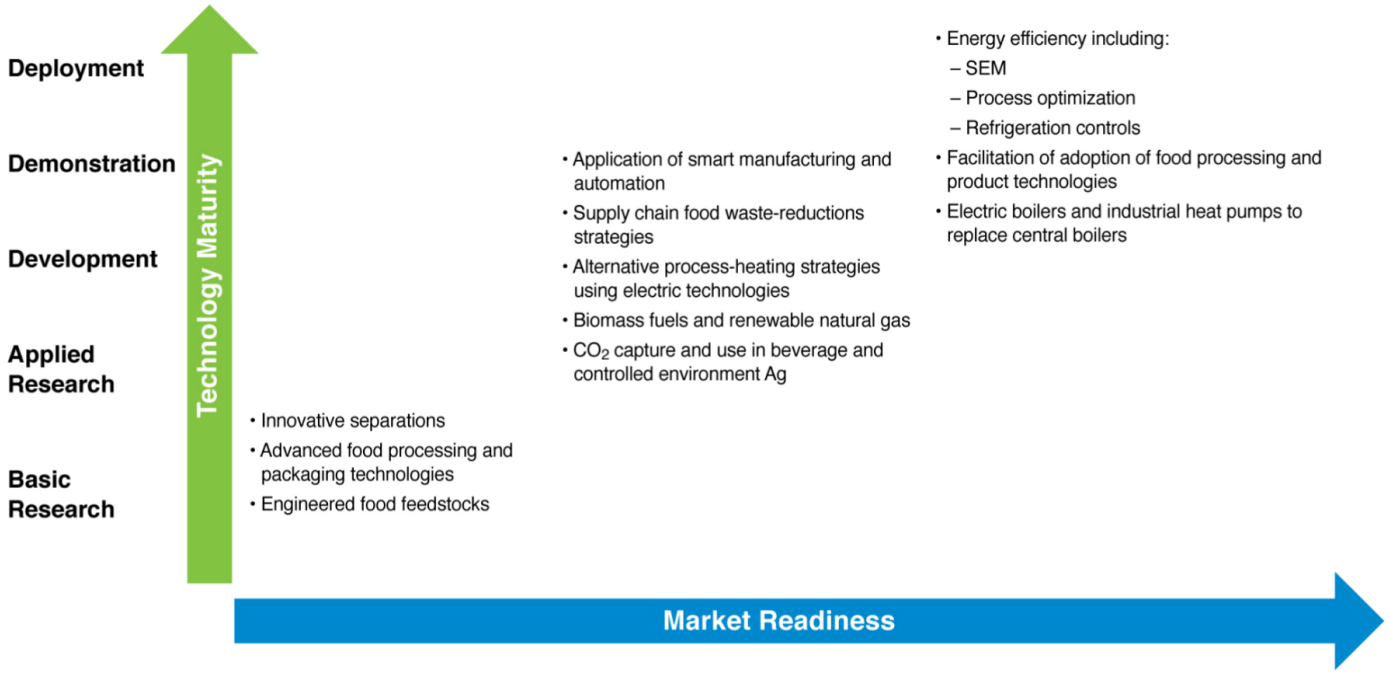
- Shift from conventional production routes for ammonia, methanol, and ethylene to processes that use hydrogen produced from low-carbon energy and/or steam methane reformers (SMR) with CCUS.
- Improve efficiency, cost, and durability for alternative, lower-energy separations methods (such as acoustic and electric field cryogenics); and develop nonequilibrium technologies to drive reactions or avoid need for separations (e.g., direct synthesis of polymers, high conversion technologies with high selectivity).
- Develop more efficient means of identifying, sorting, and recycling materials—while maintaining materials' properties.
- Invest in RD&D to improve catalysts for chemical conversion to reduce carbon footprints via improved yields.
- Improve chemical recycling (polymer to monomer or oligomer and back-to polymers) that can be incorporated into products.
- Explore opportunities for biomass and wastes to be used as feedstocks for chemicals production and as an energy source for process heat and power for chemical manufacturing; if combined with CCUS, increased use of biomass in the chemicals subsector could provide emission offsets.
- Develop processes for biosynthesis of fuels from waste gas and the conversion of CO_2 to high-value products (e.g., biopolymers and food protein).

FIGURE 28. TECHNICAL MATURITY LEVELS OF SELECT DECARBONIZATION TECHNOLOGIES DISCUSSED DURING THE ROADMAP VIRTUAL MEETINGS FOR THE U.S. CHEMICAL MANUFACTURING INDUSTRY.

PARTICIPANTS PROVIDED INPUT ON THE RELATIVE MARKET READINESS AND TECHNICAL MATURING OF THESE TECHNOLOGIES DURING DISCUSSIONS. THERE IS A DISTRIBUTION OF TECHNOLOGIES IN SEVERAL OF THESE CATEGORIES WHICH BROADEN THE PLACEMENT OF ITEMS. FOR EXAMPLE, WASTE HEAT RECOVERY REPRESENTS SEVERAL COMMERCIAL TECHNOLOGIES WHICH ARE COMMERCIAL AND IN EARLIER DEVELOPMENT STAGES. FURTHER DEFINITION OF TERMS IS PROVIDED IN THE GLOSSARY. SOURCE: THIS WORK.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Technical Maturity Levels of Select Decarbonization Technologies Discussed for the Food and Beverage Manufacturing Industry



Food and Beverage Manufacturing: Priority Approaches

Technology breakthroughs needed for the food and beverage manufacturing industry include step-changes in non-thermal drying and dewatering, innovative separations, efficient electrification of ovens, fryers, improved produce yields in indoor and outdoor agriculture, and waste reduction (including both food and packaging waste). Priority approaches include:

- Shift to electric ovens, fryers, boilers, and other electrified technologies where possible, especially as electric prices drop and the electric grid shifts towards generation from clean fuel sources.
- Reduce food waste throughout the supply chain through methods identified in LCAs and collaboration between manufacturers.
- Increase RD&D into heat pumps to recover and supply process heat in food and beverage manufacturing processes.
- Pursue recycling and material efficiency through methods like alternative packaging and packaging waste reduction.
- Invest in RD&D into transformative technologies such as cryogenic separation, advanced coatings to prevent ice buildup, advanced enzymes, and low ethanol producing yeast.

FIGURE 35. TECHNICAL MATURITY LEVELS OF THE DECARBONIZATION TECHNOLOGIES FOR THE FOOD AND BEVERAGE MANUFACTURING INDUSTRY.

THE CURVES DEPICT NECESSARY INVESTMENT LEVELS. NEAR-TERM SOLUTIONS WILL REQUIRE IMMEDIATE INVESTMENT, WHILE LONG-TERM, MORE IMPACTFUL STRATEGIES WILL NEED NOT ONLY MORE AND ONGOING FINANCIAL SUPPORT, BUT ALSO THE PRIOR LEARNING AND TIME AFFORDED BY EARLY OPTIONS. THE STRATEGIC FOCAL POINTS ARE THE DEVELOPMENT OF MEANINGFUL TRANSFORMATIVE TECHNOLOGIES IN SEVERAL PATHWAYS. SOURCE: THIS WORK

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Technical Maturity Levels of Select Decarbonization Technologies Discussed for the Petroleum Refining Subsector

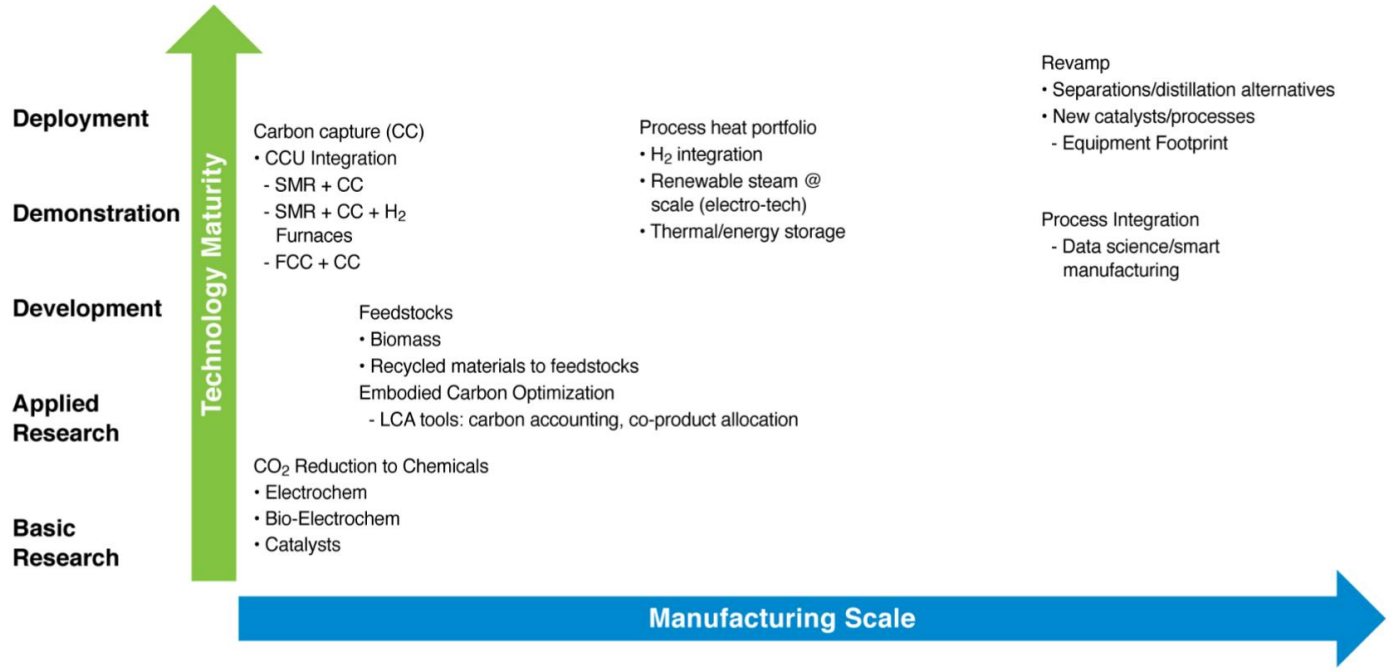


FIGURE 44. TECHNICAL MATURITY LEVELS OF DECARBONIZATION TECHNOLOGIES FOR THE PETROLEUM REFINING SUBSECTOR

Petroleum Refining Industry: Priority Approaches

Technology breakthroughs needed in the petroleum refining industry include integration and control with variable power that can be implemented reliably 24/7, electrolyzer efficiency, and drop-in low-carbon processes. Transformative process innovations are needed to yield new low-carbon ways of making hydrocarbon liquid fuels (including enhanced reuse of CO_2), lubricants, and other products. Priority approaches include:

- RD&D to enhance the impact of low-capital solutions (energy, materials, system efficiency), distillation and separations innovations, and thermal transfer efficiency.
- Reduce fugitive methane emissions to near zero.
- Pursue zero-hydrogen desulfurization processes through RD&D for adsorbents, oxidative desulfurization, and electro-desulfurization.
- Provide RD&D support for a persistent push to improve the energy efficiency of processes, eliminate waste, and lower product-embodied carbon.
- Develop capabilities for produce low-net carbon emission liquid transportation fuels from low-net carbon feedstocks (such as CO_2 and clean hydrogen, biomass, and other wastes streams) at scales comparable to current refinery capacities.
- Develop capabilities for converting excess still gas into chemical feedstocks.
- Develop capabilities for centralized carbon capture.
- Develop capabilities for use of hydrogen for combustion in high-temperature process heat.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Technical Maturity Levels of Select Decarbonization Technologies Discussed during Roadmap Virtual Meetings for the U.S. Cement Industry

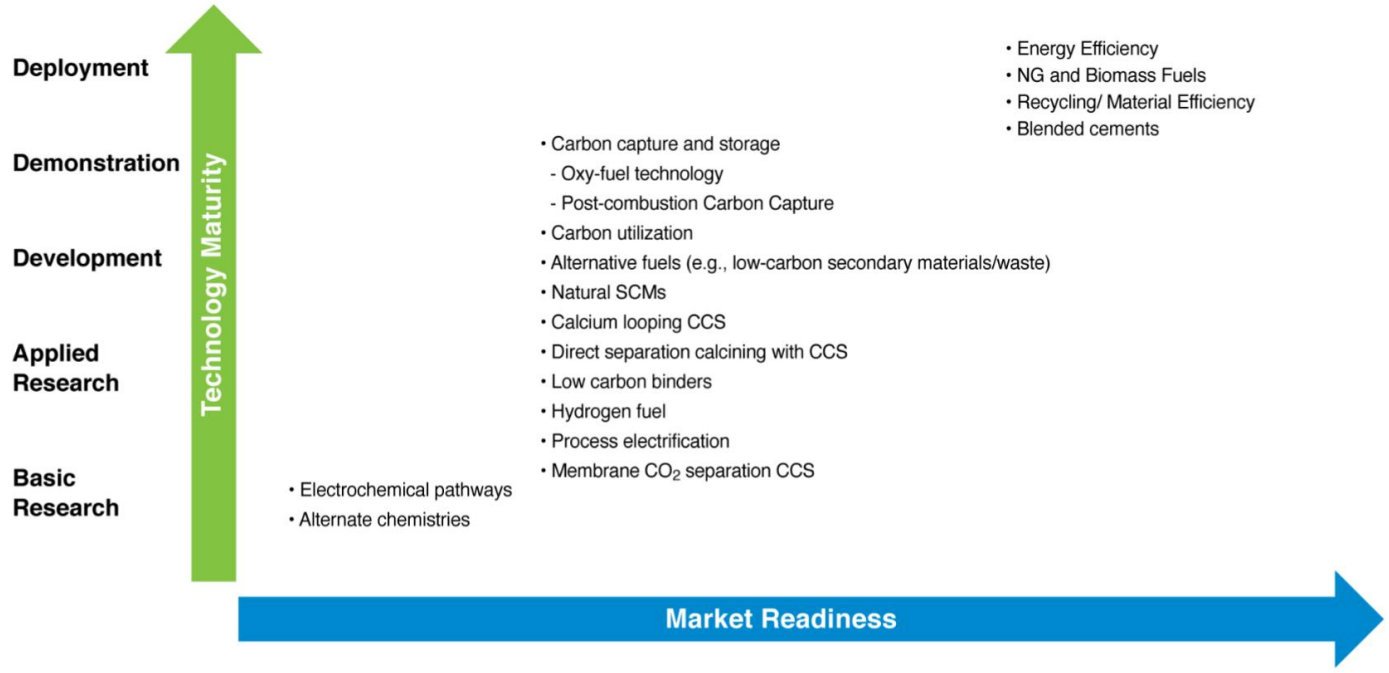


FIGURE 51. TECHNICAL MATURITY LEVELS OF SELECT DECARBONIZATION TECHNOLOGIES DISCUSSED DURING ROADMAP VIRTUAL MEETINGS FOR THE U.S. CEMENT INDUSTRY.

PARTICIPANTS PROVIDED INPUT ON THE RELATIVE MARKET READINESS AND TECHNICAL MATURING OF THESE TECHNOLOGIES DURING DISCUSSIONS. THERE IS A DISTRIBUTION OF TECHNOLOGIES IN SEVERAL OF THESE CATEGORIES WHICH BROADEN THE PLACEMENT OF ITEMS. CCS: CARBON CAPTURE AND STORAGE; SCM: SUPPLEMENTARY CEMENTITIOUS MATERIAL; NG: NATURAL GAS. FURTHER DEFINITION OF TERMS IS PROVIDED IN THE GLOSSARY. SOURCE: THIS WORK.

Cement Industry: Priority Approaches

To achieve the necessary decarbonization targets, the cement industry requires technology breakthroughs including new low-carbon manufacturing pathways, process electrification at scale, use of H_2, direct separation, carbon utilization and an enhanced circular economy approach for CO_2, and material reuse. Priority approaches include:

- Leverage relatively low-capital solutions (energy efficiency, SEM, and waste heat reduction/recovery solutions (WHP)).
- Probe routes to continue improving materials efficiency and flexibility including reuse, recycle, and refurbishment as well as innovative chemistry and blended cement with improved energy and emissions, CO_2 absorbing, and equivalent or better performance.
- Expand the infrastructure and integration capabilities and knowledge to capture, transport, and reuse CO_2 where possible (e.g., Oxy-combustion with CCUS, indirect calcination with CCUS, large scale carbon utilization for construction materials).
- Advance approaches to reduce waste, including the use of circular economy approaches for concrete construction.
- Increase use of low-carbon binding materials and natural SCMs.
- Develop additional routes for utilizing CO_2, including full scale deployment of carbon capture with innovative approaches such as calcium looping and use of membranes for CO_2 separation.

Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap