Exploring Industrial Decarbonization

MI HEALTHY CLIMATE CONFERENCE
APRIL 11-12, 2023

Cliff Haefke
Director
US DOE Midwest CHP Technical Assistance Partnership

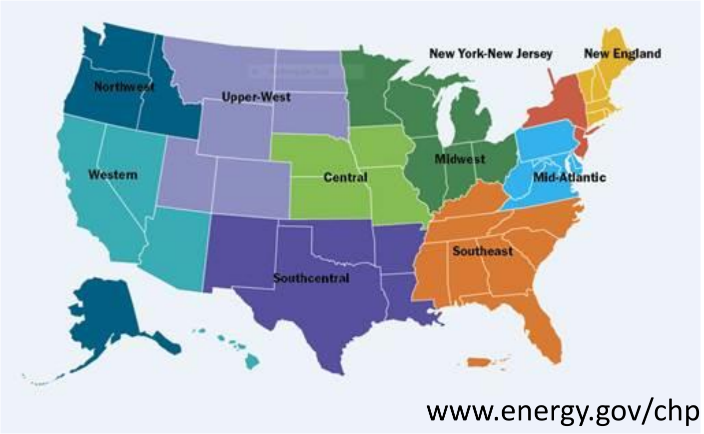
CHP Technical Assistance Partnerships

Agenda

- Key Strategic Industrial Decarbonization Pillars
- CHP, a Decarbonization Tool
- DOE Technical Assistance Services and Resources

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.



National Manufacturing Day 2019 at the University of Illinois at Chicago

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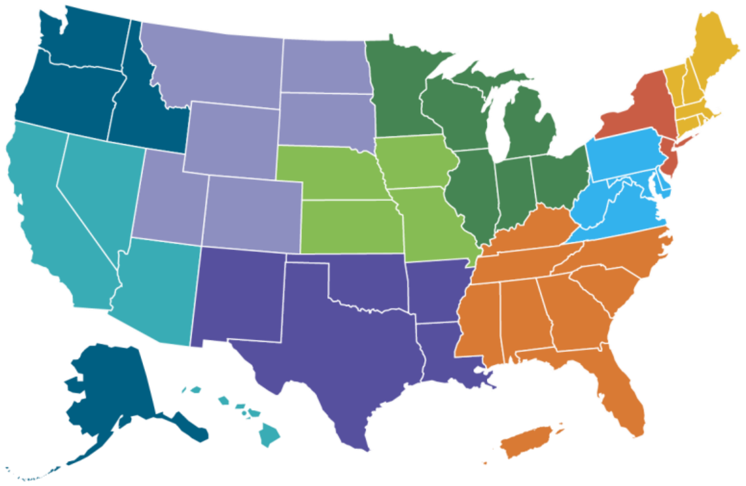

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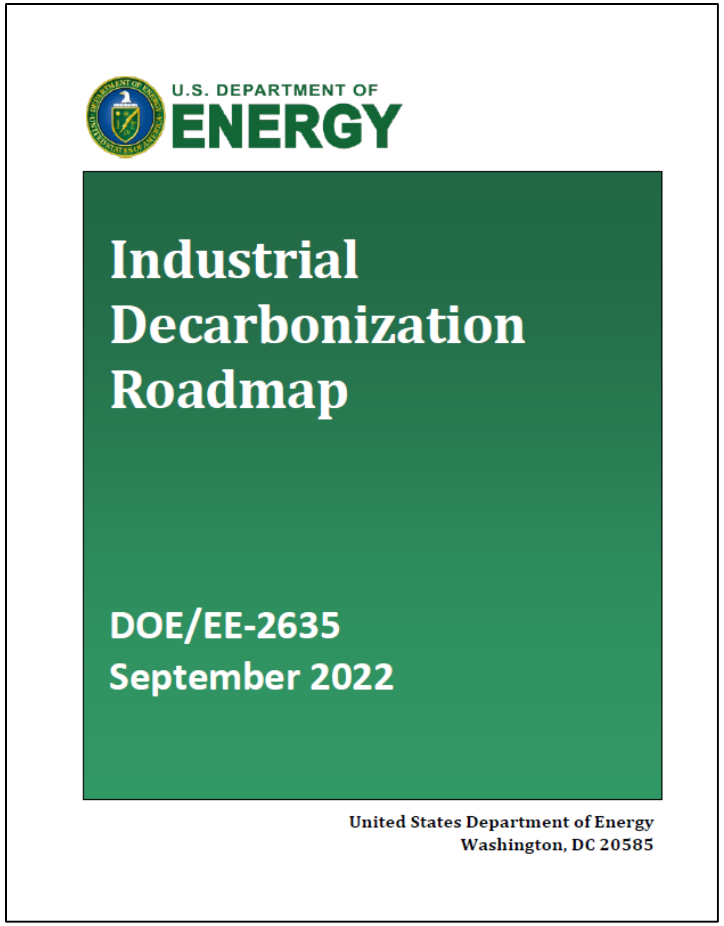
Key Strategic Pillars of the DOE Industrial Decarbonization Roadmap

U.S. DOE “Industrial Decarbonization Roadmap”


U.S. DEPARTMENT OF ENERGY

Industrial Decarbonization Roadmap

DOE/EE-2635
September 2022

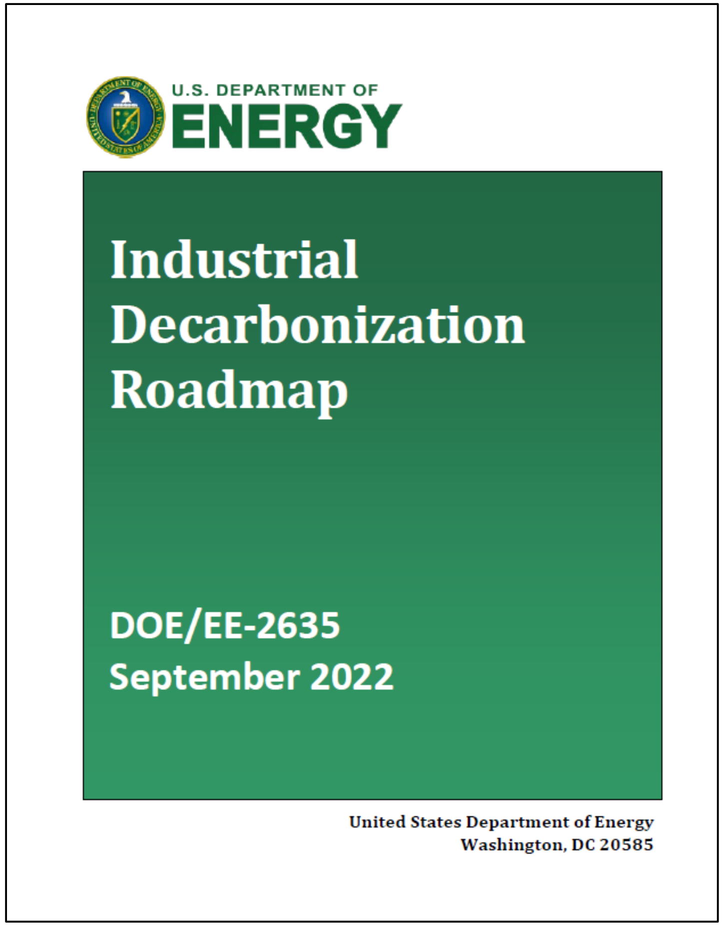
United States Department of Energy
Washington, DC 20585

“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.

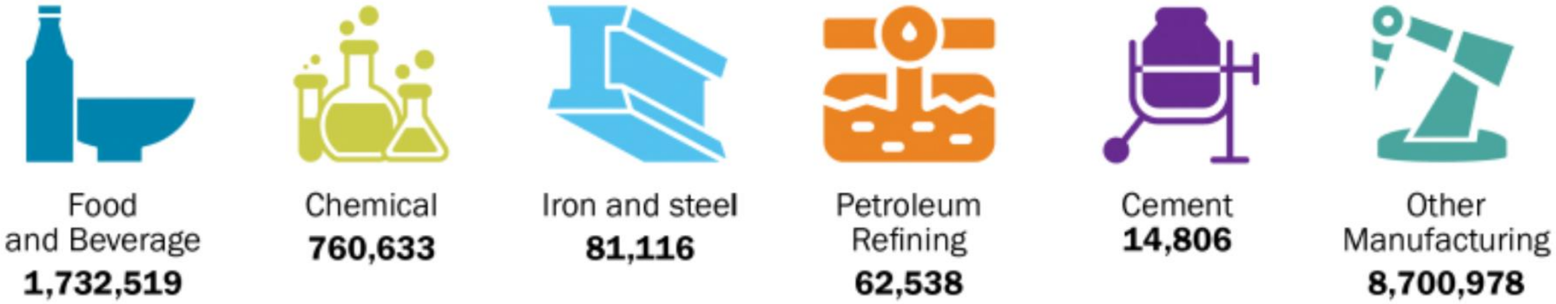
Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Key Recommendations from the Industrial Decarbonization Roadmap

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

Industrial Decarbonization and American Jobs

USA TOTAL = 11.4 MILLION MANUFACTURING 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

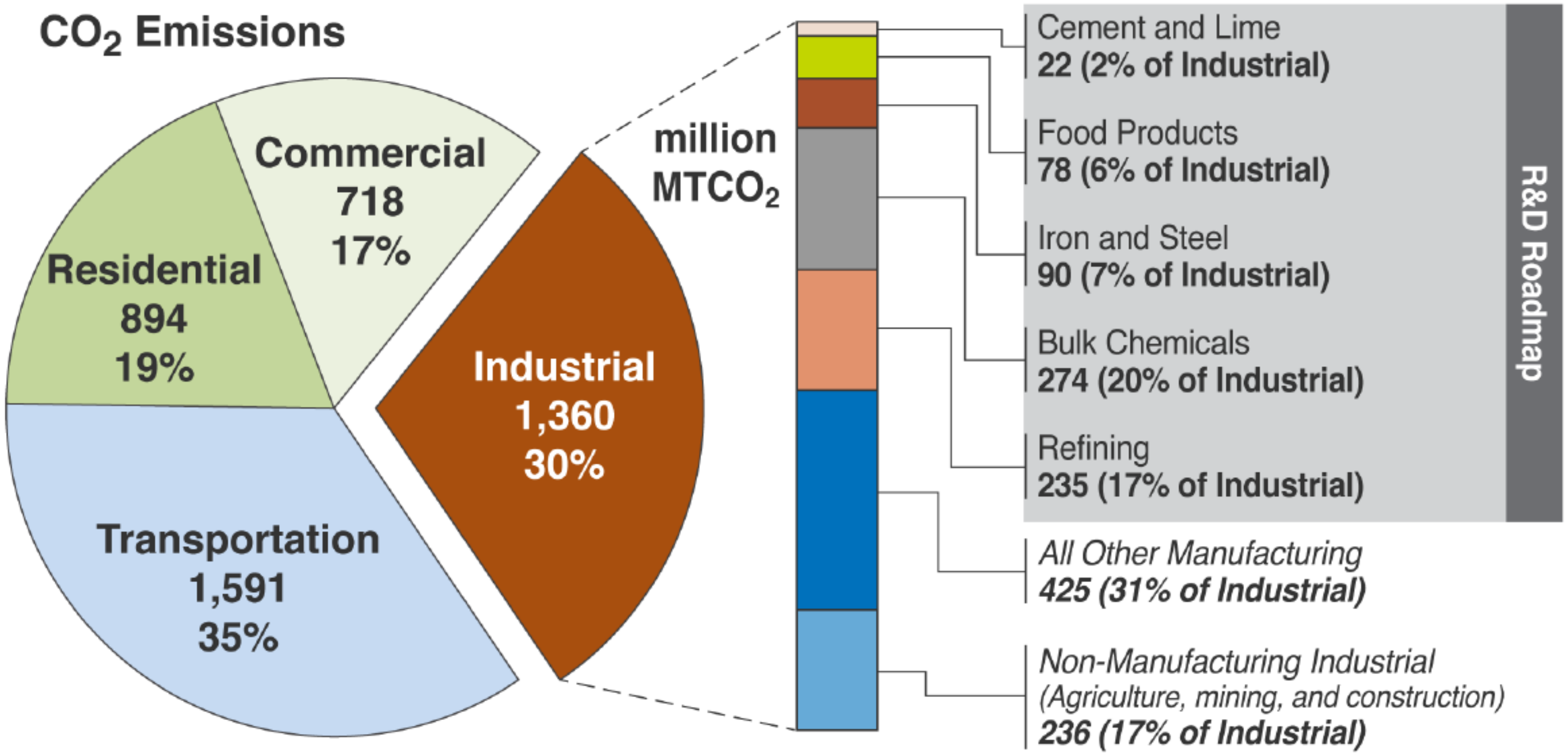


FIGURE 3. U.S. PRIMARY ENERGY-RELATED CO_2 EMISSIONS BY END USE SECTOR (LEFT PIE CHART) AND A BREAKOUT BY INDUSTRIAL SUBSECTOR (RIGHT STACKED CHART) IN 2020.

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

Distribution of Process Heat Temperature Ranges by Industrial Subsector

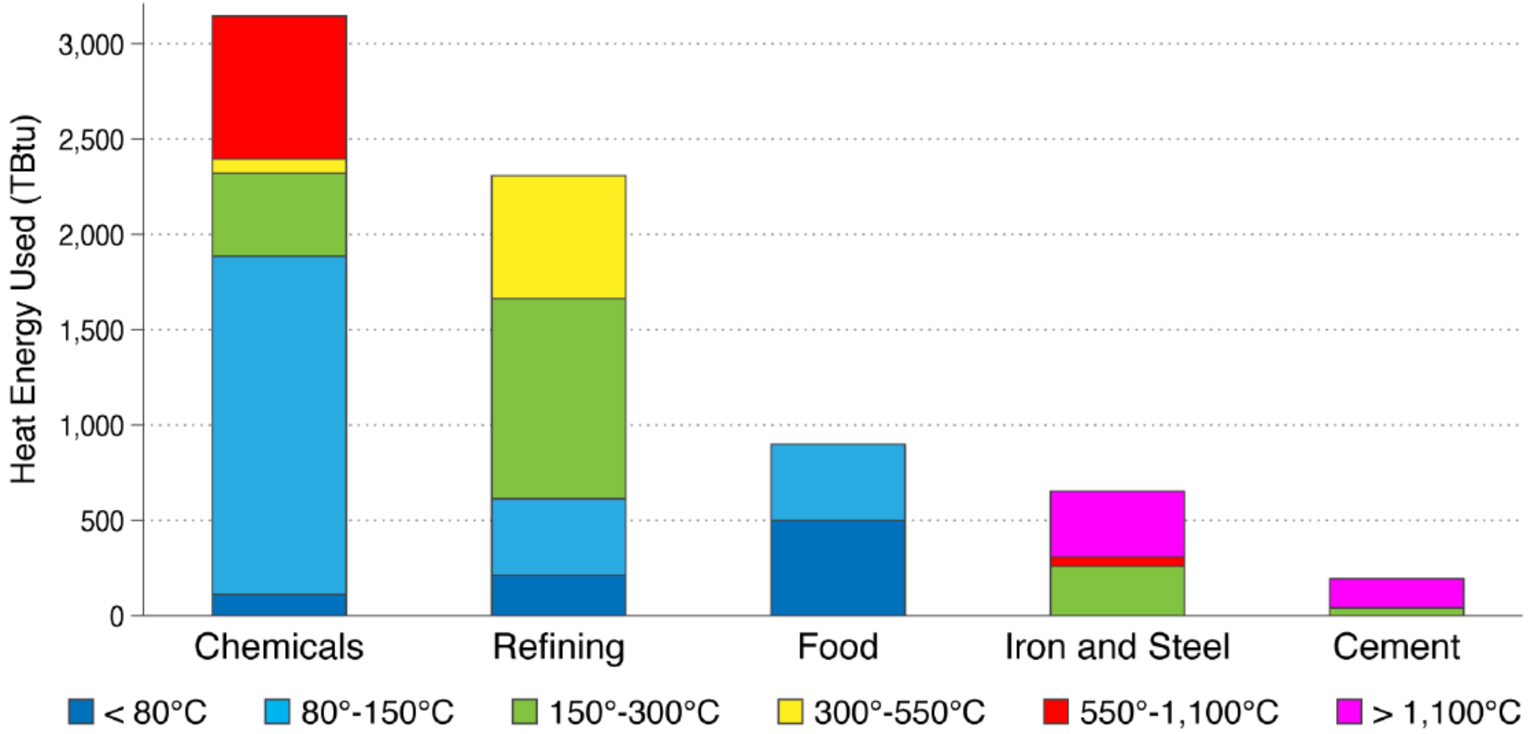


FIGURE 6. DISTRIBUTION OF PROCESS HEAT TEMPERATURE RANGES BY INDUSTRIAL SUBSECTOR IN 2014.

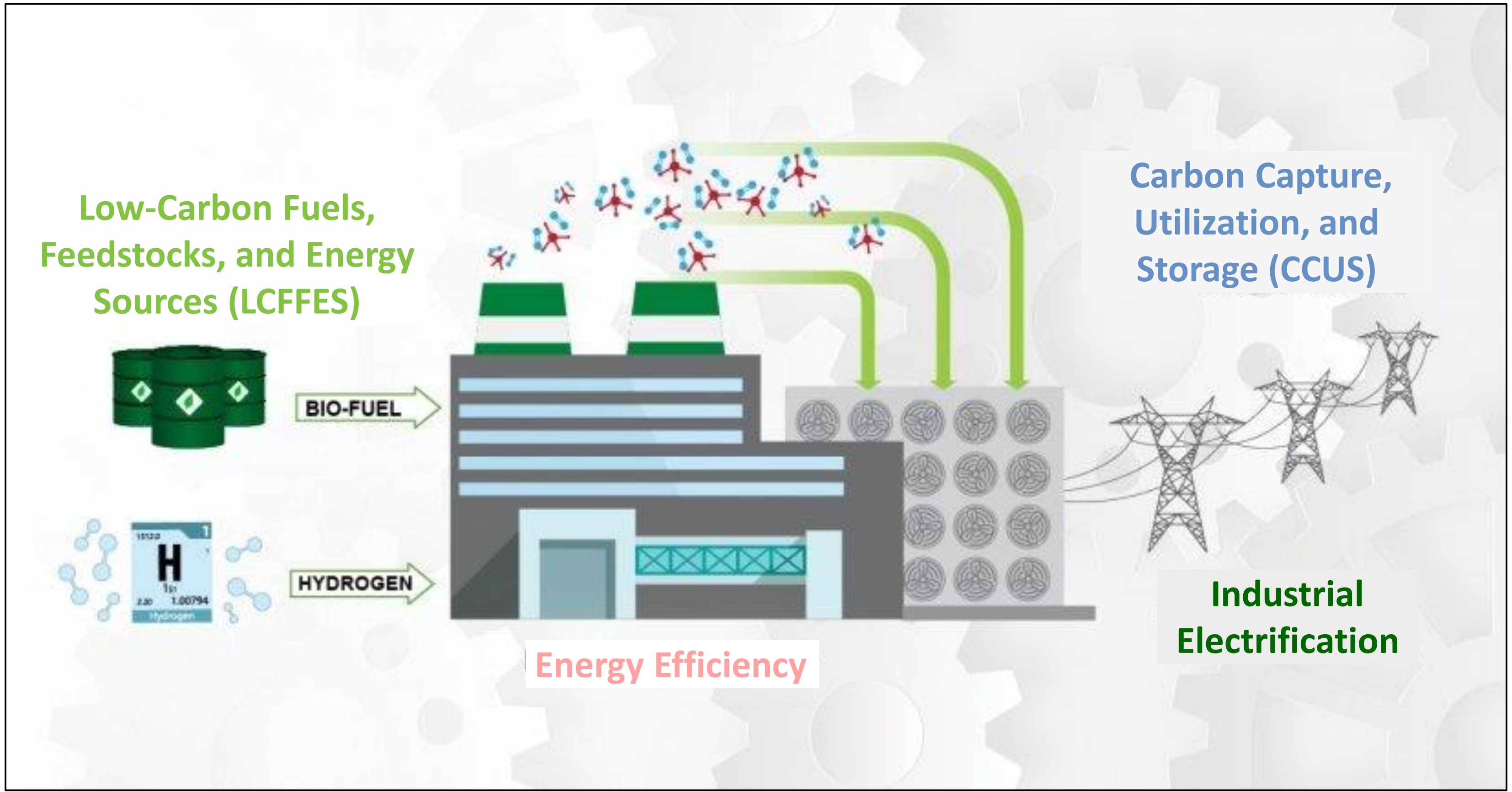
TEMPERATURE RANGES ARE IN °C AND HEAT USE IS IN TRILLION BTU (TBTU). DATA SOURCE: MCMILLAN 2019[81]

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

CHP Technical Assistance Partnerships

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

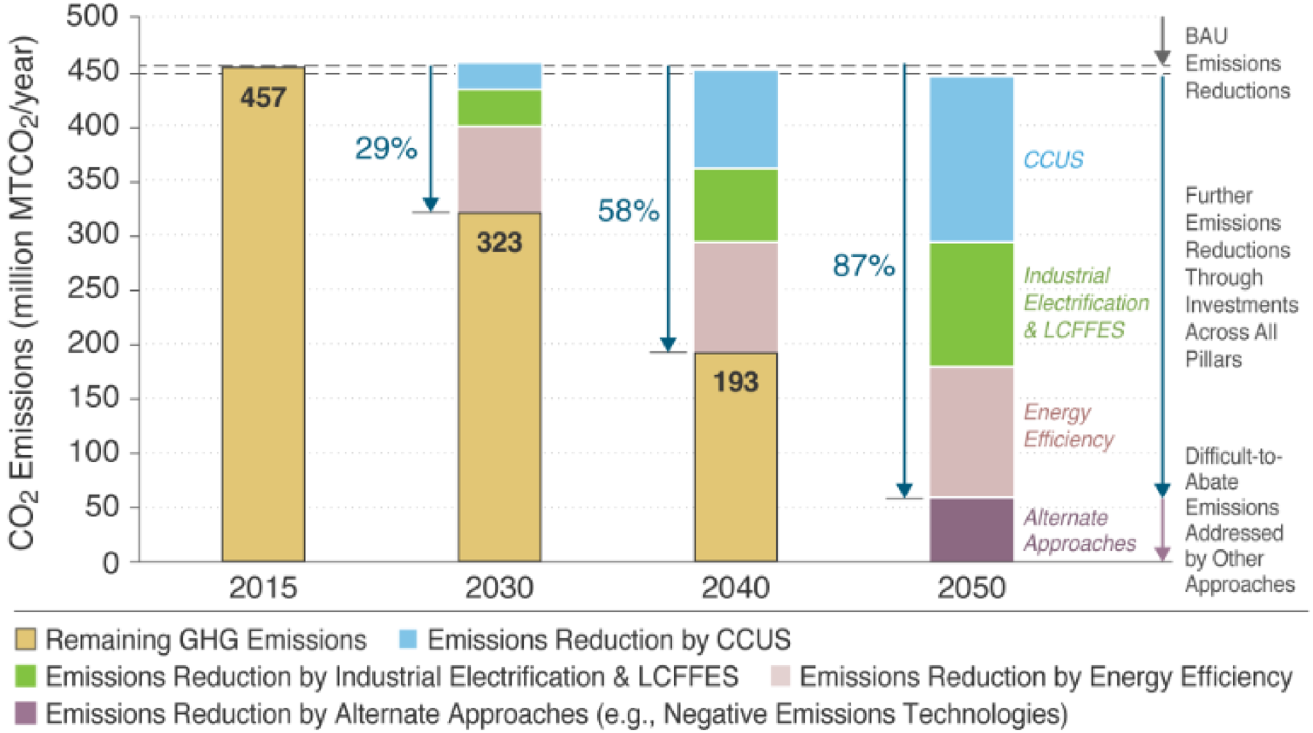


FIGURE ES 1. THE PATH TO NET-ZERO INDUSTRIAL CO_2 EMISSIONS IN THE UNITED STATES FOR FIVE CARBON-INTENSIVE INDUSTRIAL SUBSECTORS, WITH CONTRIBUTIONS FROM EACH DECARBONIZATION PILLAR: ENERGY EFFICIENCY; INDUSTRIAL ELECTRIFICATION; LOW-CARBON FUELS, FEEDSTOCKS, AND ENERGY SOURCES (LCFFES); AND CARBON CAPTURE, 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

DOE Better Plants Program Energy Impacts[12]

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

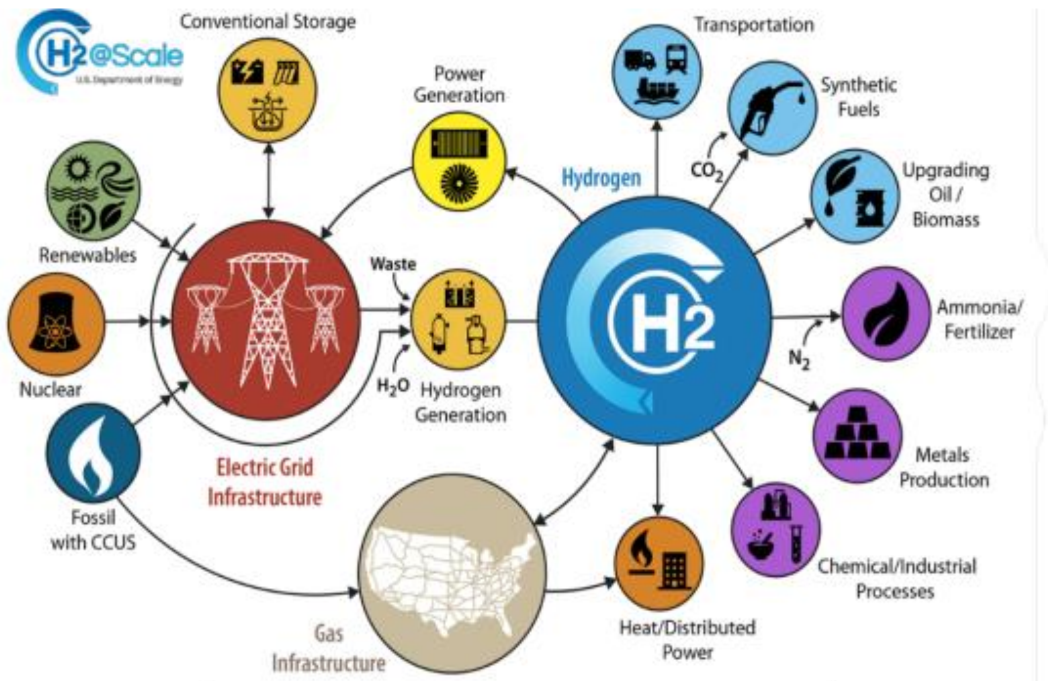
Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

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



DOE's H2@Scale Opportunities[14]

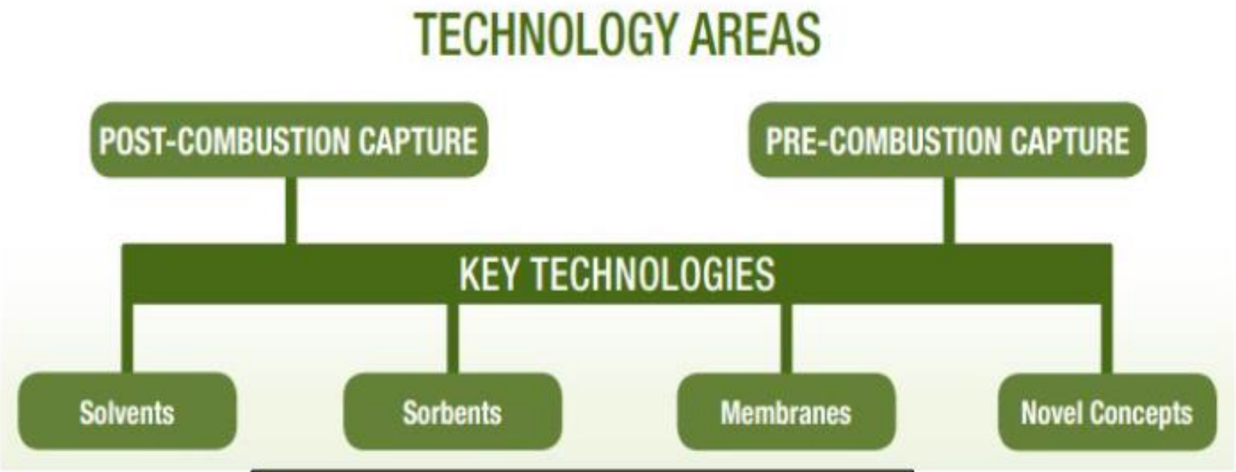
Source: https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

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



CCUS Technology Approaches

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

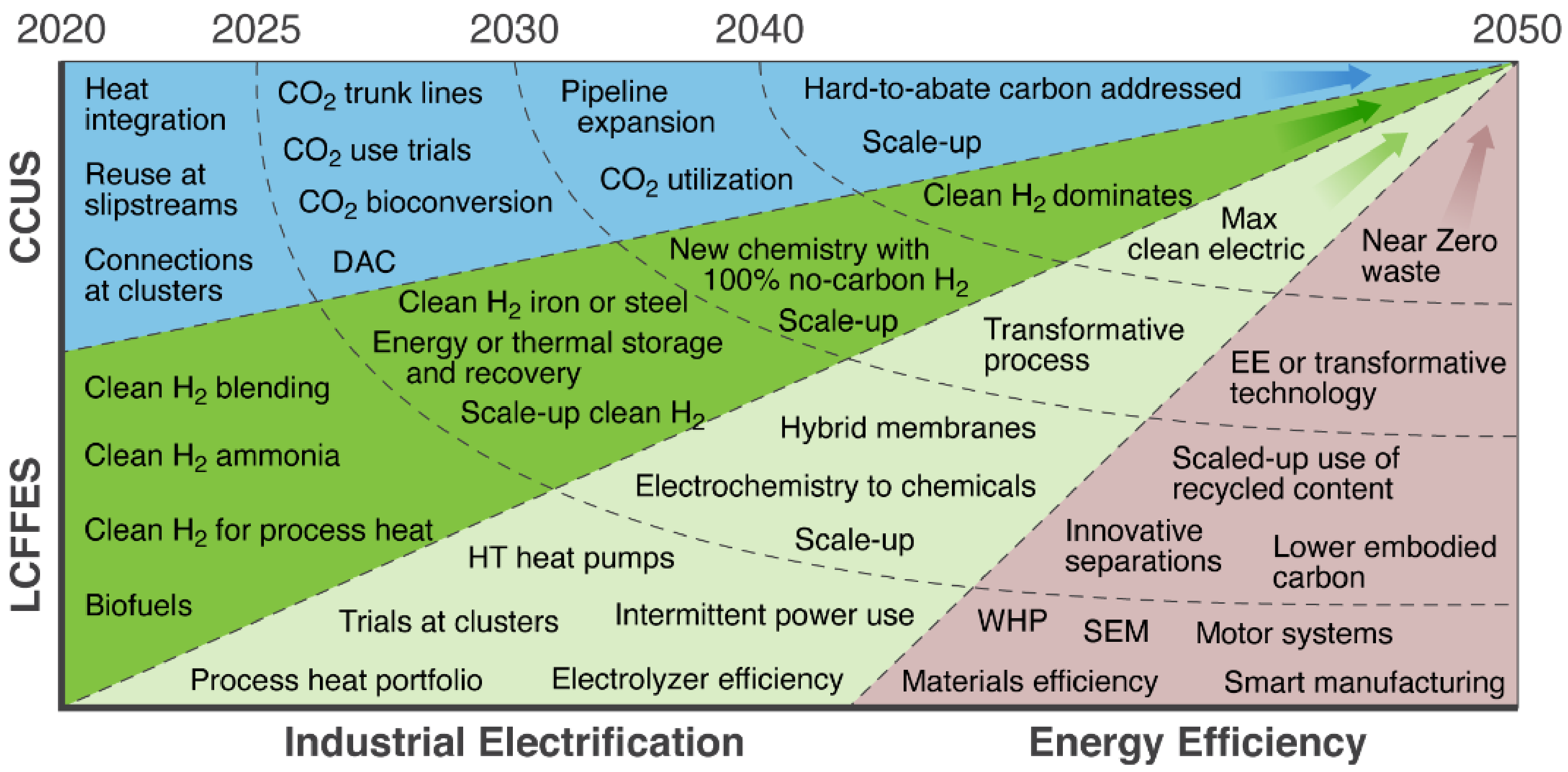


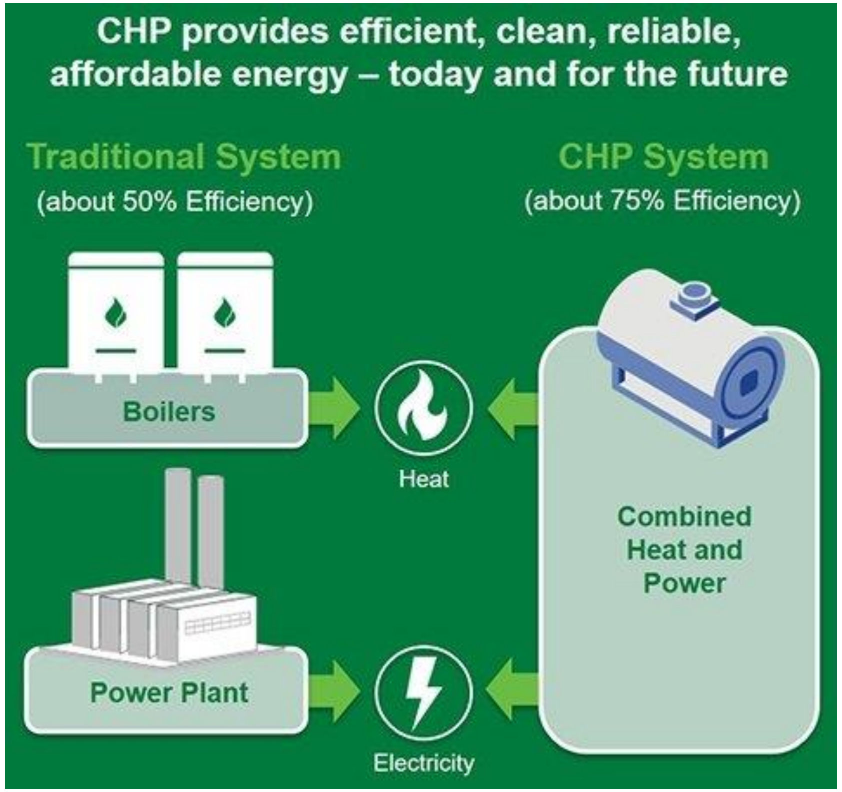
FIGURE 10. LANDSCAPE OF MAJOR RD&D INVESTMENT OPPORTUNITIES FOR INDUSTRIAL DECARBONIZATION ACROSS ALL SUBSECTORS BY DECADE AND DECARBONIZATION PILLAR.

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

Combined Heat and Power:
A Decarbonization Tool

CHP: A Key Part of Our Energy Future

- Form of Distributed Generation (DG)
- An integrated system
- Located at or near a building / facility
- Provides at least a portion of the electrical load and
- Uses thermal energy for:
  - Space Heating / Cooling
  - Process Heating / Cooling
  - Dehumidification

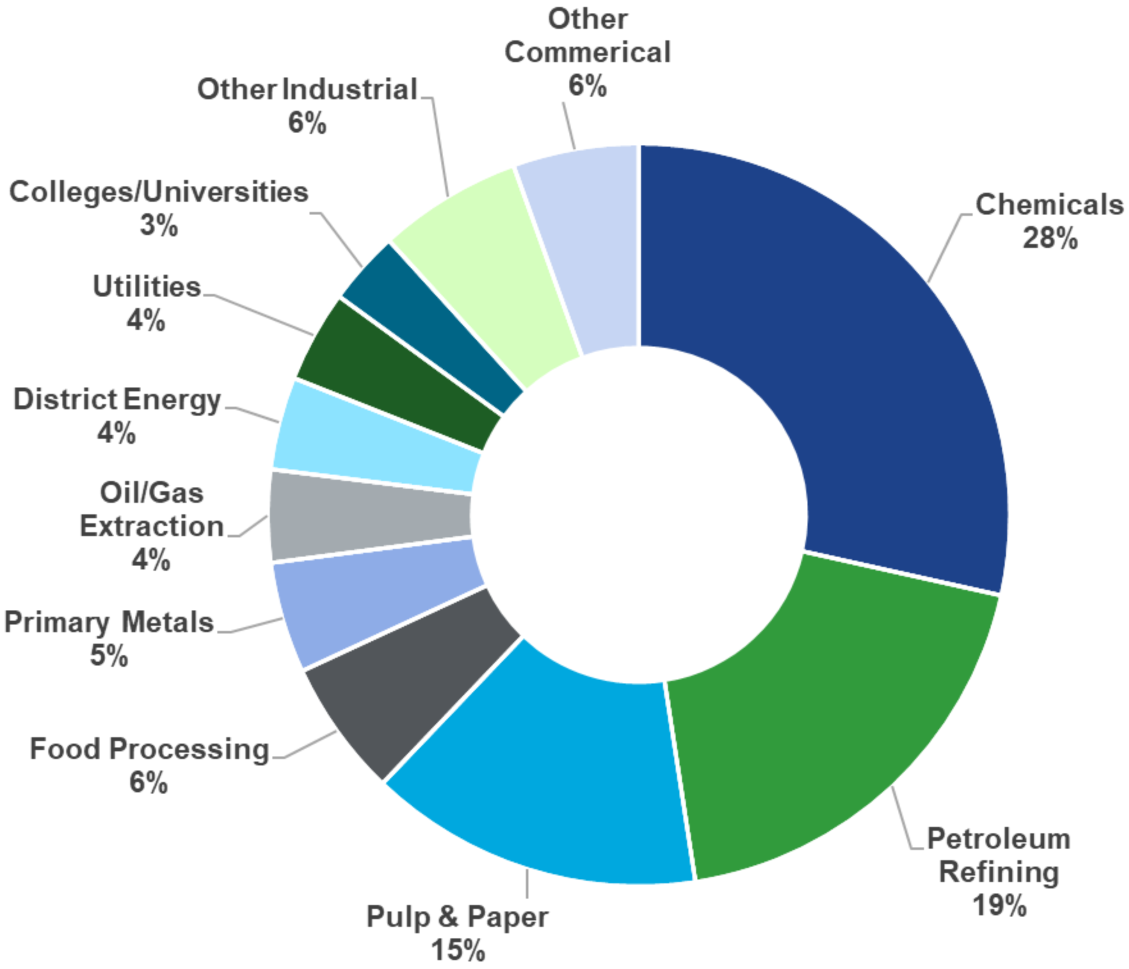


CHP applications can operate at about 75% efficiency, a significant improvement over the national average of about 50% for these services when provided separately.

Source: *https://www.energy.gov/eere/amo/combined-heat-and-power-basics*

CHP Installations Today in the United States

Existing CHP Capacity (81.5 GW)



Avoids **1.3 Quadrillion Btus** of fuel consumption annually.

Avoids **218 million tons of CO^2** compared to separate production.

81.5 GW of installed CHP at more than **4,700** industrial and commercial facilities.

7% of U.S. electric generating capacity; 13% of generation.

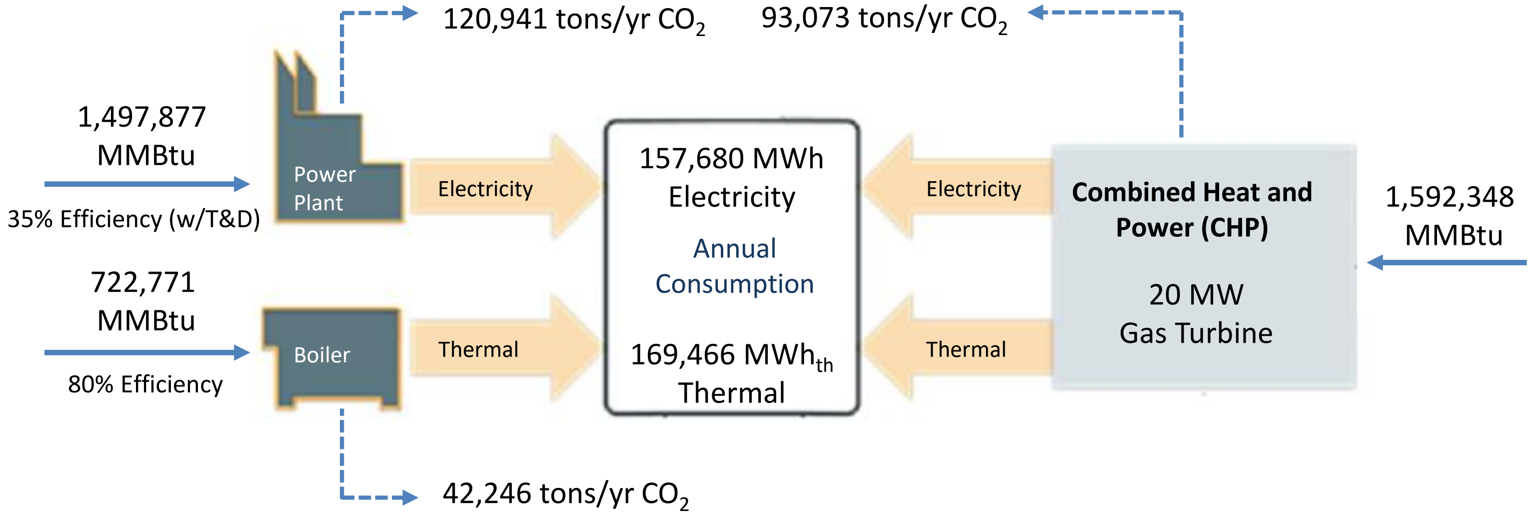
Source: DOE CHP Installation Database (U.S. Installations through December 31, 2021 as of August 2022)

CHP Provides both Energy and CO_2 Emissions Savings

20 MW Gas Turbine CHP System

- Natural gas fuel
- 90% load factor (7,884 hours)
- 33.8% electric efficiency
- 75.7 MMBtu/hr steam output
- 100% thermal utilization
- Displaces 80% efficient natural gas boiler
- CO_2 savings based on displacing EPA AVERT Uniform EE grid emissions factor (1,534 lbs CO_2/MWh)

Separate Heat and Power | **Combined Heat and Power**



49% Total Efficiency

70% Total Efficiency

Energy savings: 628,300 MMBtu/yr

CO_2 Savings: 70,114 tons/yr

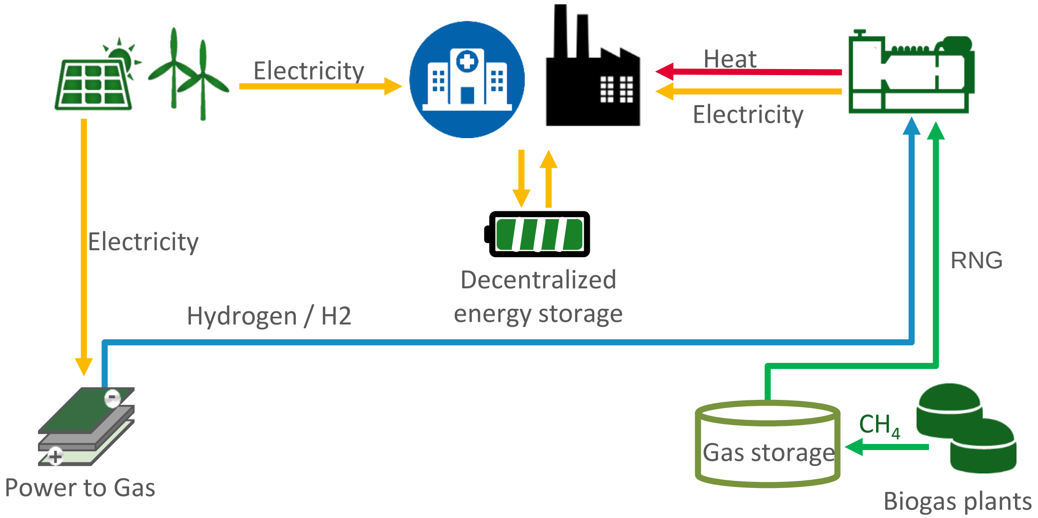
Prepared by Entropy Research, LLC, 7/28/2022

CHP Technical Assistance Partnerships

CHP's Opportunity with Decarbonization

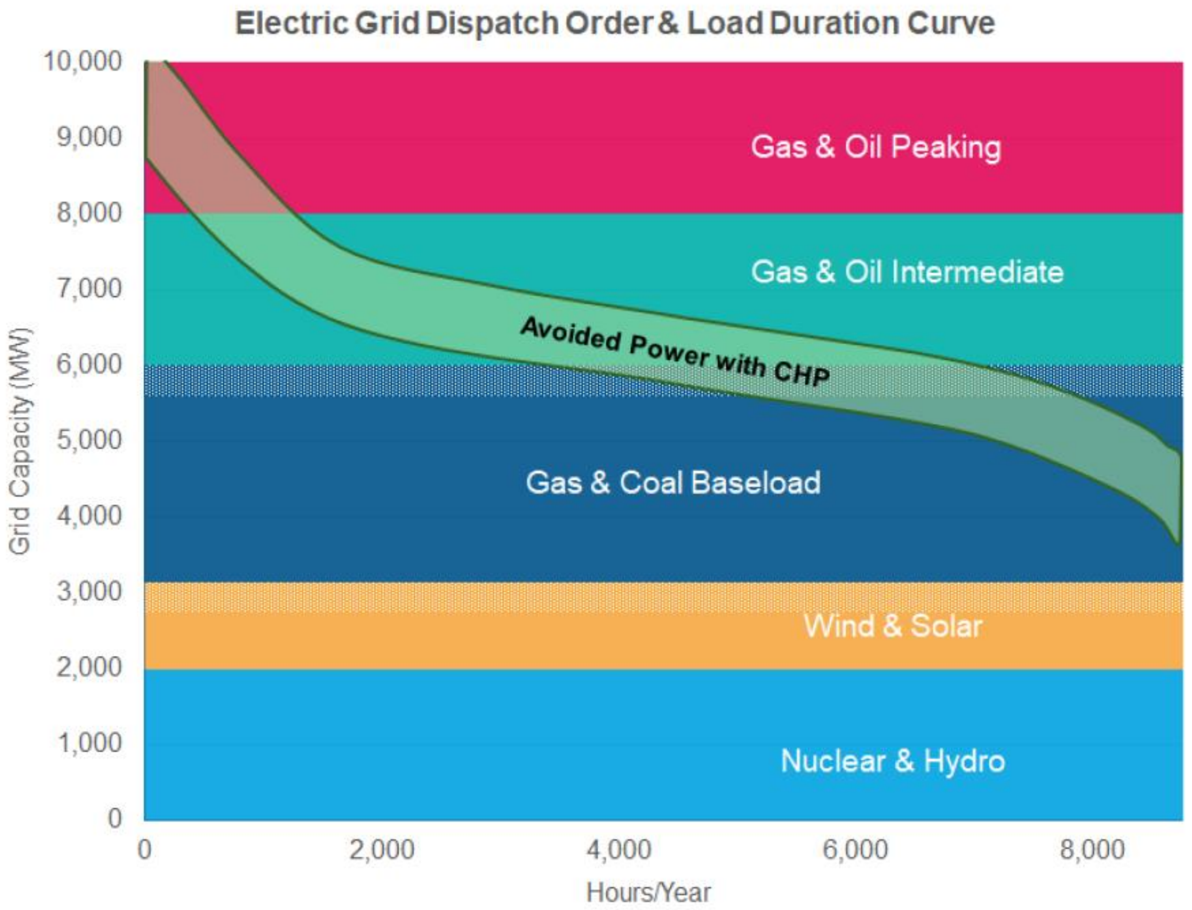
- **CHP is fuel flexible** - CHP currently uses renewable fuels, low carbon waste fuels, and hydrogen where available, and will be ready to use higher levels of biogas, renewable natural gas (RNG) and hydrogen in the future
- **CHP is the most efficient way to generate power and thermal energy**, and can reduce CO_2 emissions now and in the future
- Net-zero **CHP can decarbonize industrial and commercial facilities that are difficult to electrify**
- Net-zero **CHP can decarbonize critical facilities that need dispatchable on-site power for long duration resilience and operational reliability**
- CHP's high efficiency can **extend the supply of renewable, low carbon and hydrogen fuels**
- CHP can provide **dispatchable net-zero generation and regulation support to maintain the long-run resource adequacy of a highly renewable grid**

CHP in a Decarbonized Economy



Source: Based on 2G Energy

Average vs Marginal Rates

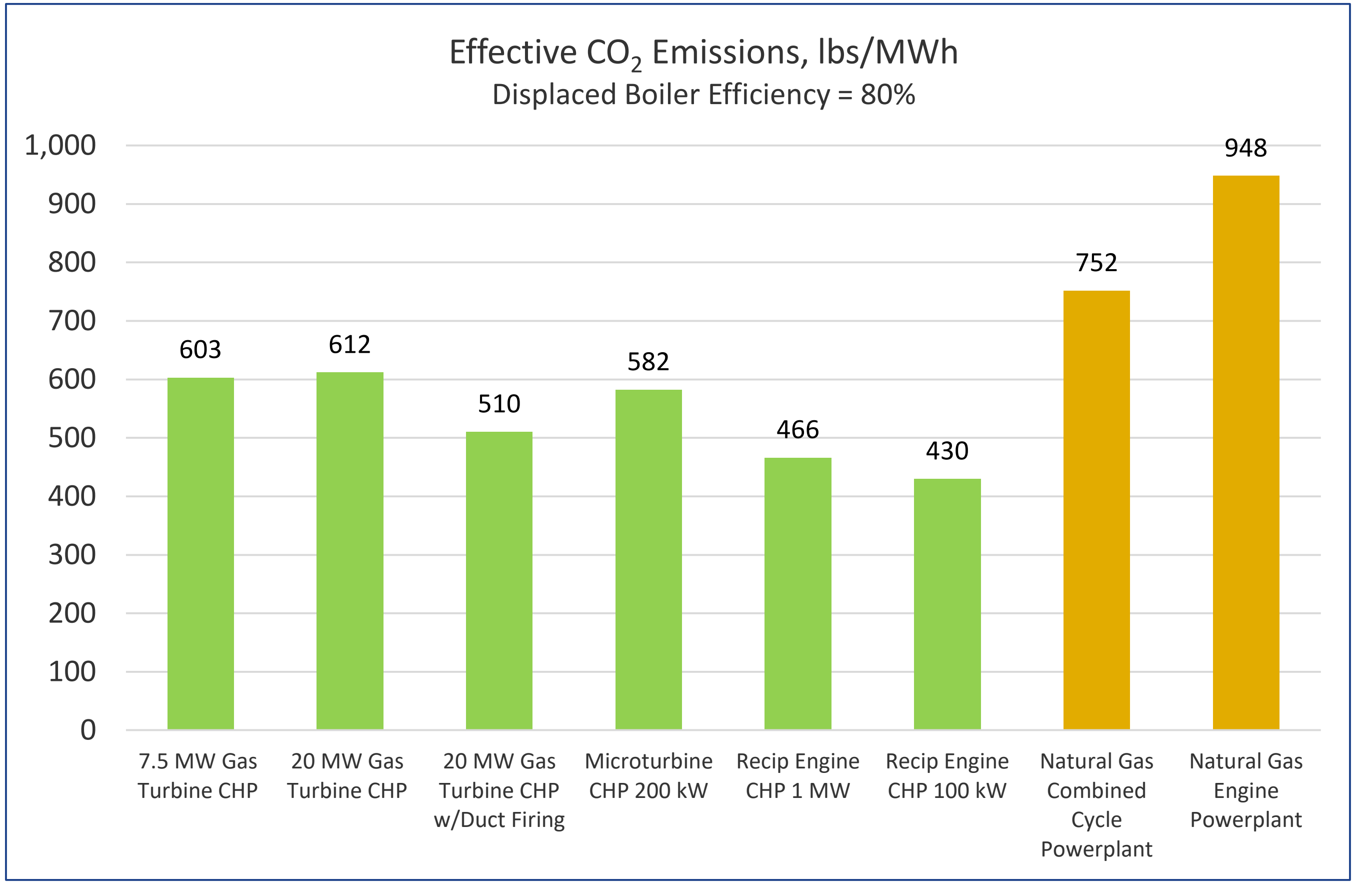


Power generation in the United States generally follows a "dispatch order", which can be thought of as a stack of resources to meet required loads at any point in time. DG such as CHP don't replace every resource in the grid, but only certain resources.

CHP Is the Most Efficient Marginal Generation

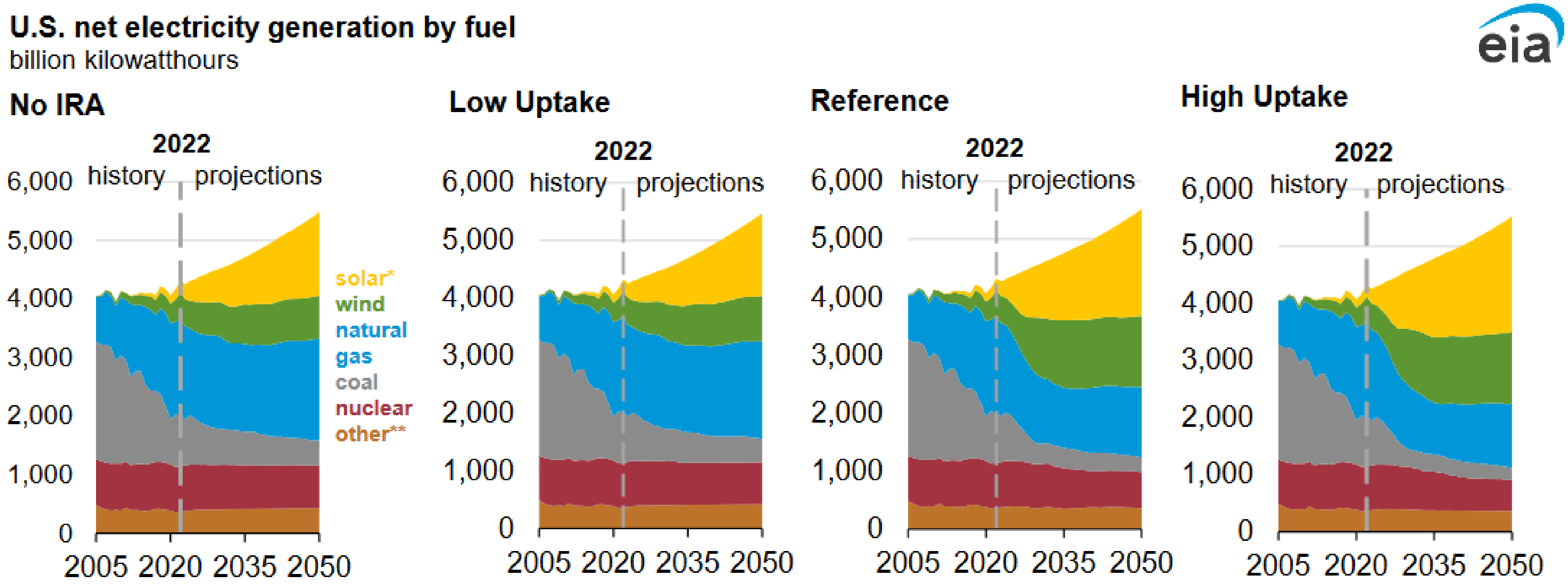
- CHP has higher net electric efficiency than state-of-the-art marginal natural gas generation (combined cycle)
- CHP systems have lower net GHG emissions than marginal natural gas generation (lbs CO_2/MWh)
- CHP can meet marginal grid loads more efficiently and with less CO_2 emissions
- CHP's efficiency and emissions advantages will remain as the natural gas infrastructure decarbonizes

Comparing Emissions of CHP and Power Plant Technologies



Prepared by: Entropy Research, LLC, 10/5/21

U.S. Net Electricity Generation by Fuel Type



Data source: U.S. Energy Information Administration, *Annual Energy Outlook 2023* (AEO2023)
Note: IRA=Inflation Reduction Act
*Includes utility-scale and end-use photovoltaic generation and excludes off-grid photovoltaics.
**Includes petroleum, conventional hydroelectric power, geothermal, wood and other biomass, pumped storage, non-biogenic municipal waste in the electric power sector, refinery gas, still gas, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.

Source: https://www.eia.gov/outlooks/aeo/

CHP's High Efficiency Saves Emissions Today

- CHP and renewables **displace marginal grid generation** (including T&D losses)
- Marginal generation is **currently a mix of coal and natural gas** in most regions of the US
- CHP's **high efficiency and high annual capacity factor** currently results in significant annual energy and emissions savings
- CHP's **efficiency advantages will continue** as the gas infrastructure decarbonizes

"Because emissions are cumulative and because we have a limited amount of time to reduce them, carbon reductions now have more value than carbon reductions in the future"

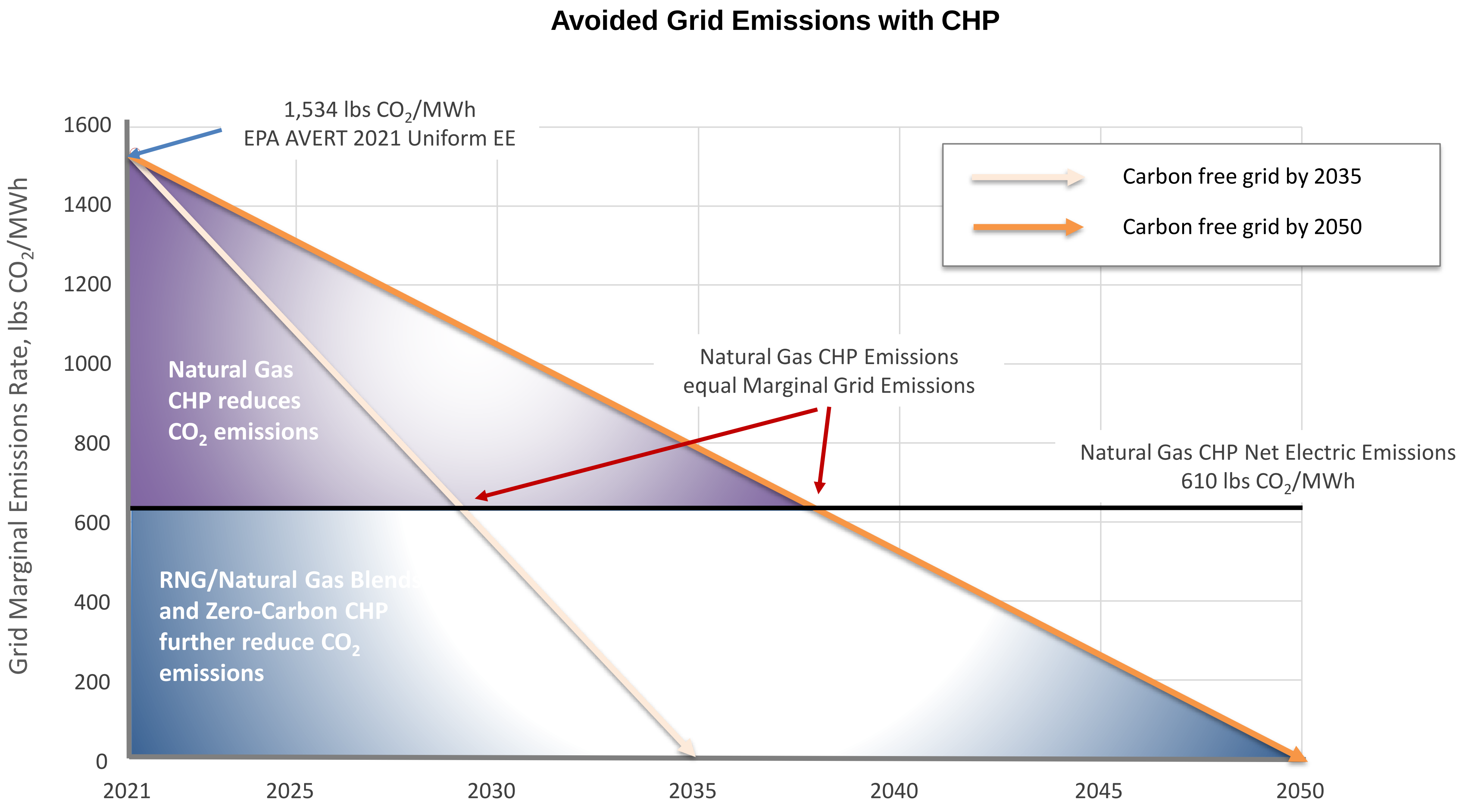
Source: "Time Value of Money", Larry Stein, Carbon Leadership Forum, April 2020

Category	Natural Gas CHP	Utility Solar PV	Utility Wind	Biogas CHP
Capacity, MW	20.0	43.3	30.7	20.0
Annual Capacity Factor	90%	24.3%	34.3%	90%
Annual Electricity, MWh	157,680	92,096	92,096	157,680
Annual Thermal Provided, MWh_{th}	169,466	None	None	169,466
Annual Energy Savings, MMBtu	689,110	863,954	863,954	689,110
Annual CO_2 Savings, Tons	71,375	71,375	71,375	164,448
Annual NOx Savings, Tons	59.8	39.1	39.1	59.8

Savings based on EPA AVERT Uniform EE Emissions Factors as a first level estimate of displaced marginal generation (https://www.epa.gov/avert)

Prepared by: Entropy Research, LLC, 9/26/21

Renewable and Net-Zero Carbon Fuels Maintain CHP's Advantage

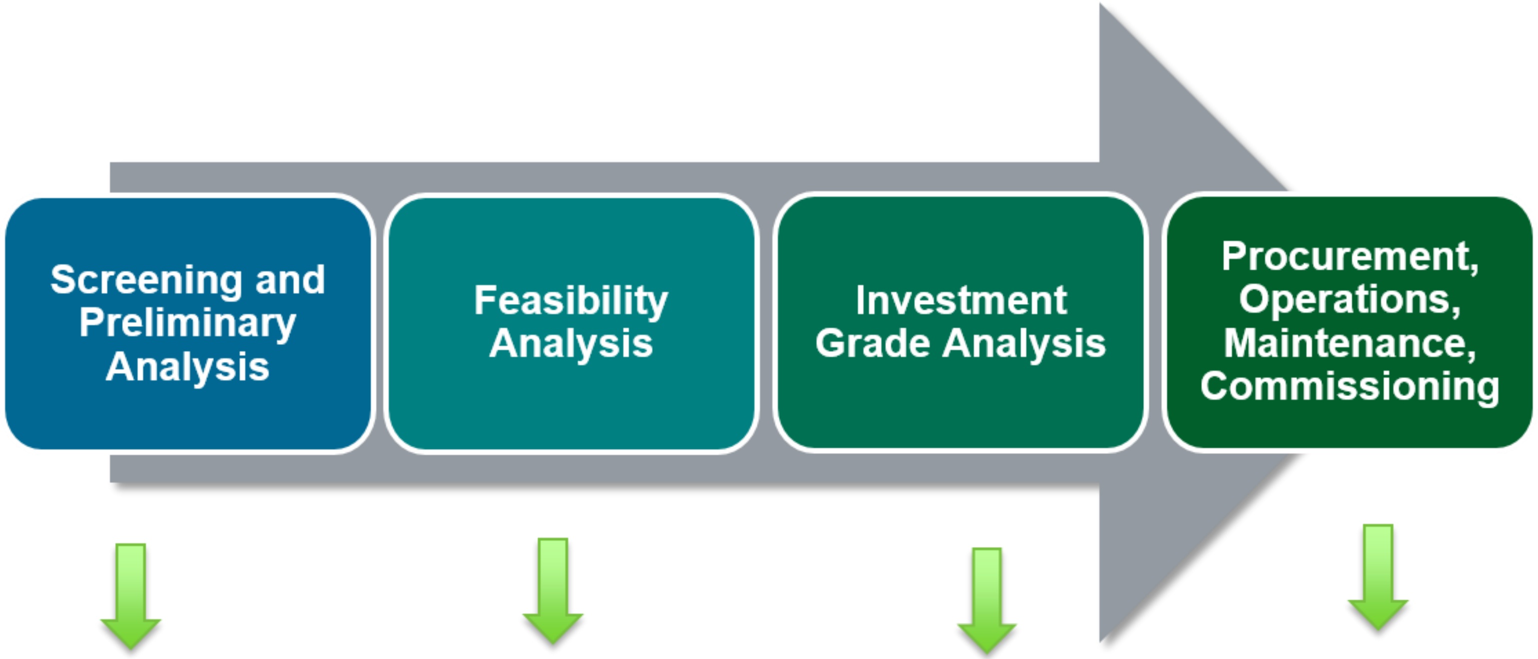


Prepared by Entropy Research, LLC, 7/28/2022

CHP Technical Assistance Partnerships

DOE CHP TAP
Technical Assistance Services and Resources

Steps to Developing a CHP Project and the Technical Assistance Available through the CHP TAPs

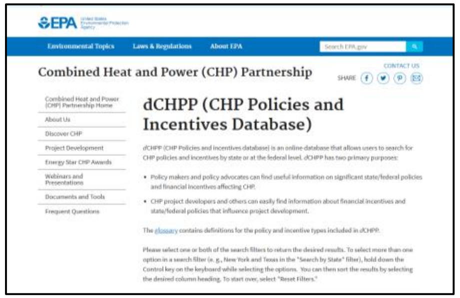


- Quick screening questions with spreadsheet payback calculator; Advanced technical assistance to explore equipment or operational scenarios.
- Perform 3rd Party reviews of site feasibility assessments: Estimates on savings, installation costs, simple paybacks, equipment sizing, and type.
- Perform 3rd Party reviews of Engineering Analysis. Review equipment sizing and choices.
- Review specifications and bids.

No-Cost CHP Resources

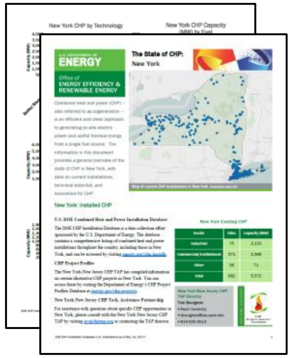
DOE CHP Installation Database

EPA dCHPP (CHP Policies and Incentives Database)



DOE CHP Technologies Fact Sheet Series

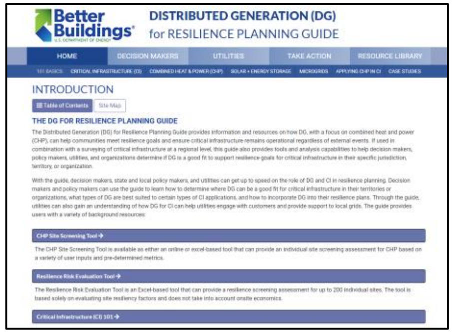
State of CHP Pages



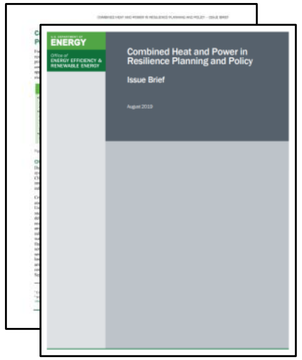
DOE Project Profile Database

DOE Policy/ Program Profiles

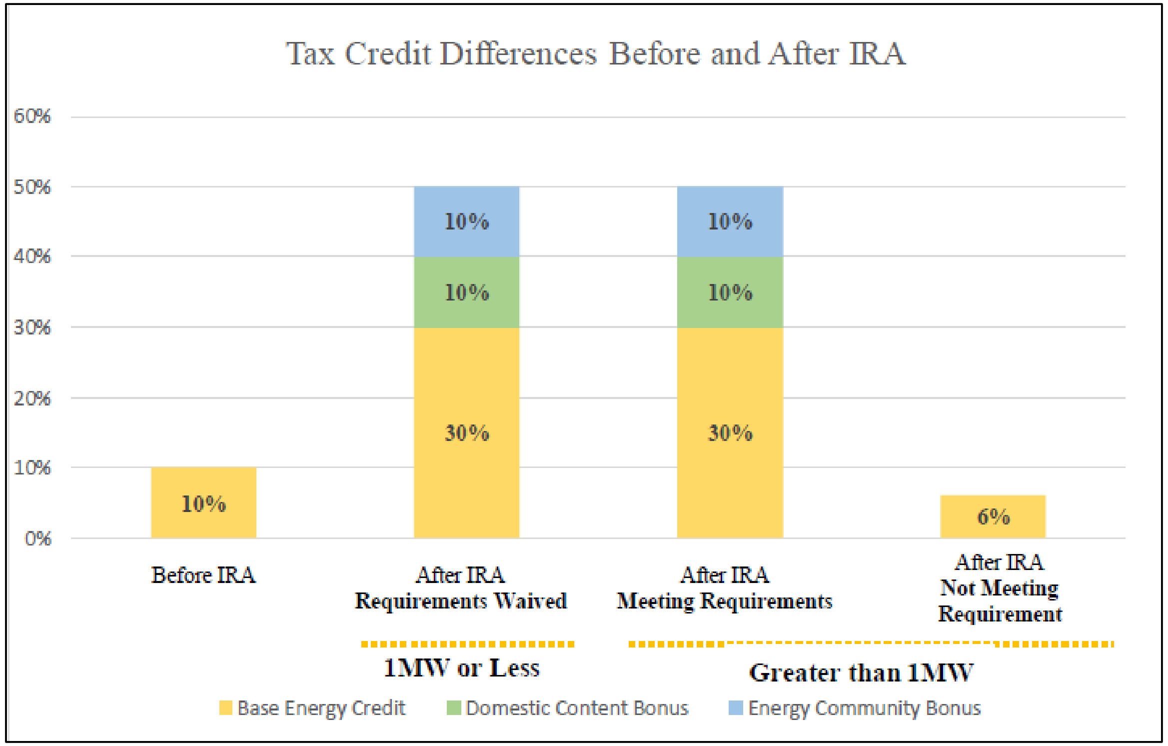
DG for Resilience Planning Guide



CHP Issue Brief Series



Newly Available Federal Incentives through the IRA



- Federal Investment Tax Credit (ITC) has been increased from 10% to 30-50%
- ITC available for natural gas-powered CHP until December 2024; a 5% Safe Harbor provision extends this deadline.
- Prevailing Wage Requirements
- Apprentice Requirements
- Bonus Credits +10%
- Available for Tax-Exempt Entities (direct pay and transferability)

Source: CHP Alliance, "CHP AND WHP IN THE INFLATION REDUCTION ACT – FREQUENTLY ASKED QUESTIONS," December 2022

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
- High efficiencies of CHP can provide carbon savings today and into the future
- Federal tax credits are available to help reduce capital costs
- DOE CHP TAP can provide no-cost technical assistance to evaluate technical and economic viability of CHP

Thank You

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CHP Technical Assistance Partnerships

www.energy.gov/chp

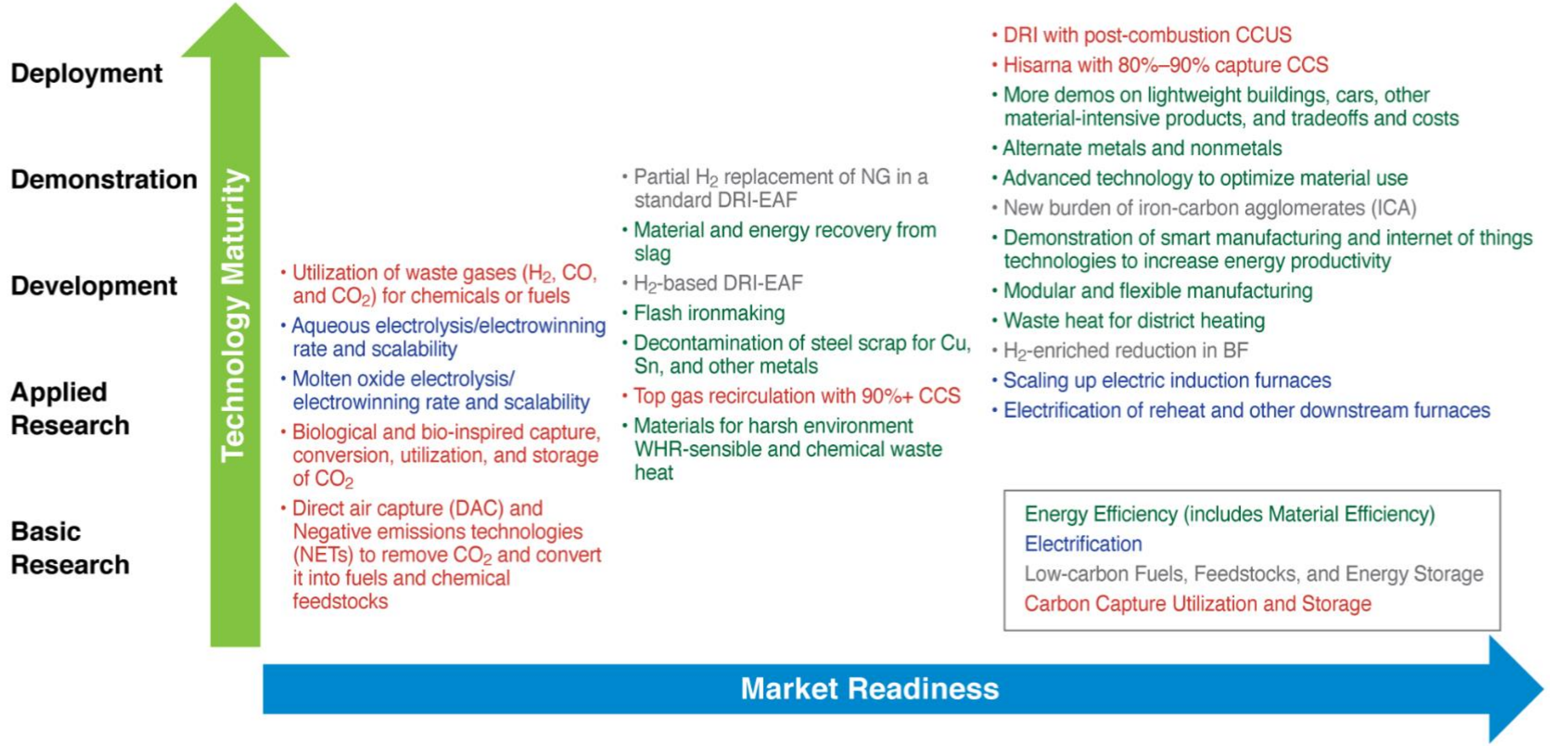
Appendix

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

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

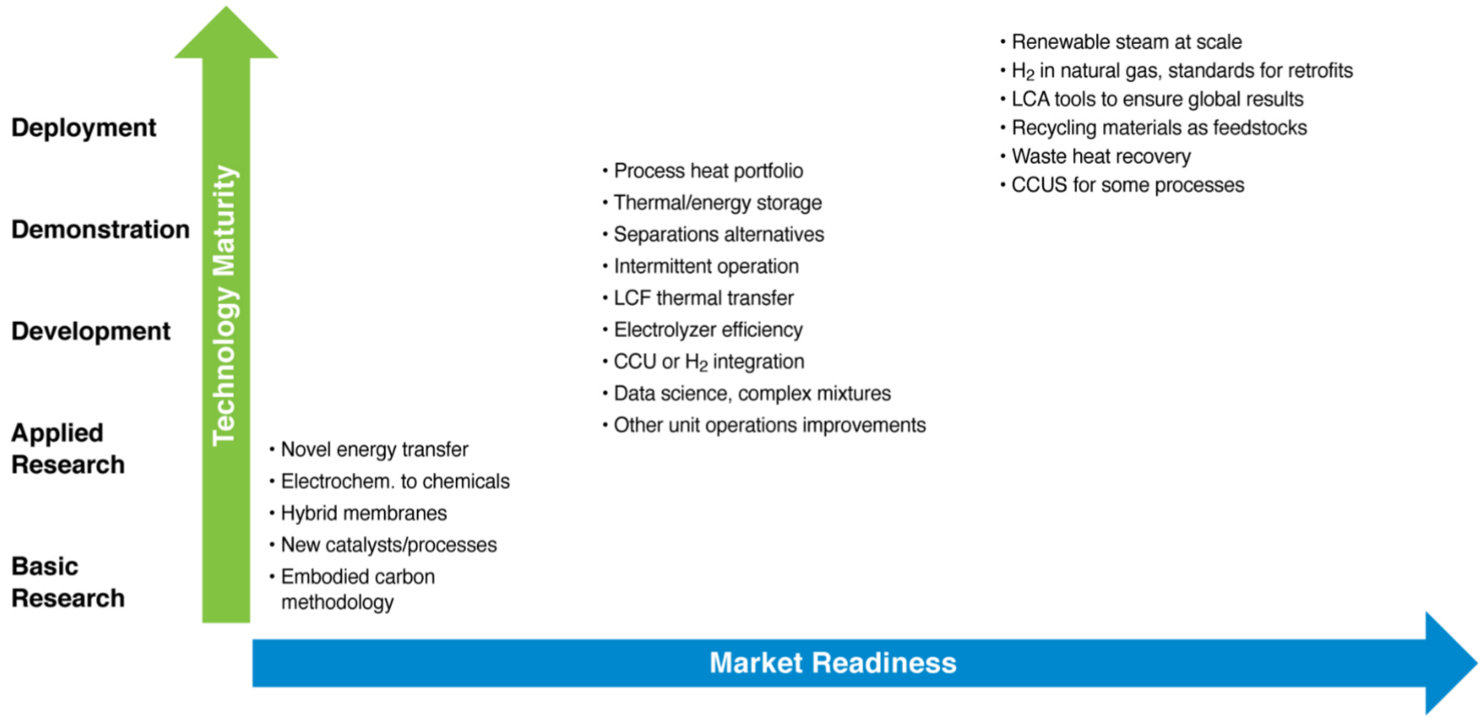


FIGURE 28. TECHNICAL MATURITY LEVELS OF SELECT DECARBONIZATION TECHNOLOGIES DISCUSSED DURING THE ROADMAP VIRTUAL MEETINGS FOR THE U.S. CHEMICAL MANUFACTURING INDUSTRY.

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.

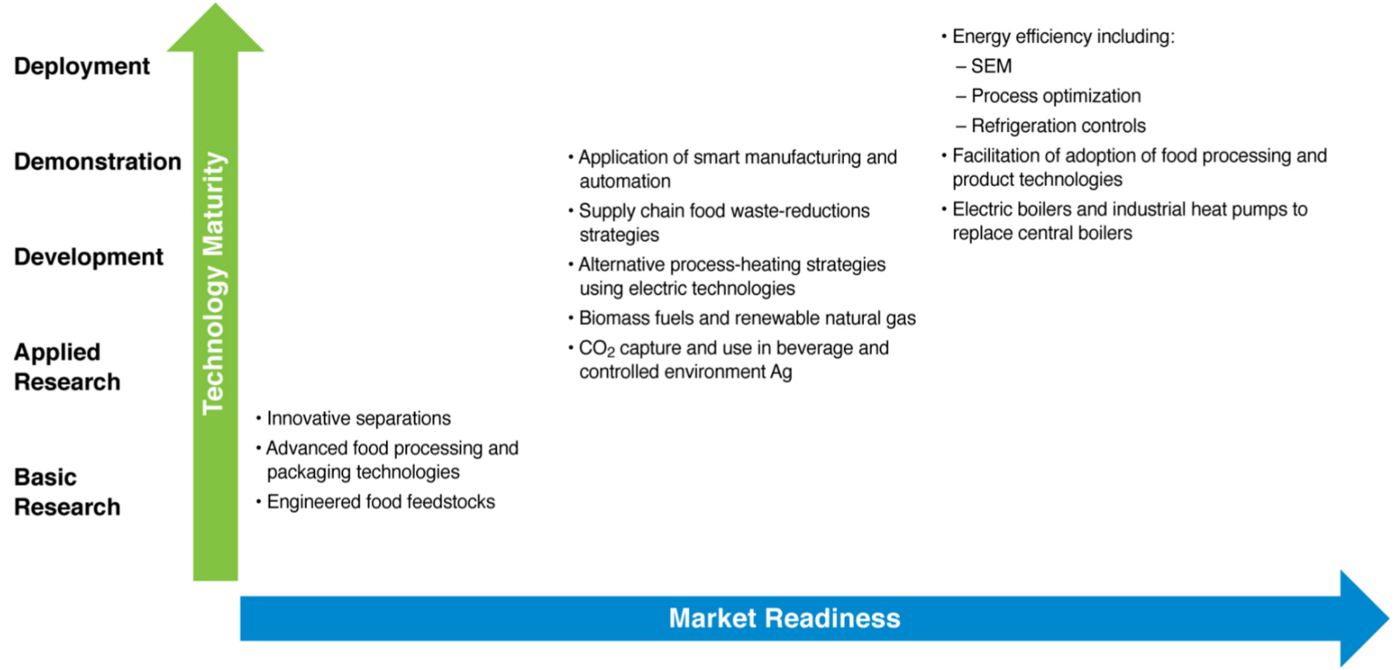
Chemical Industry: Priority Approaches

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).

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

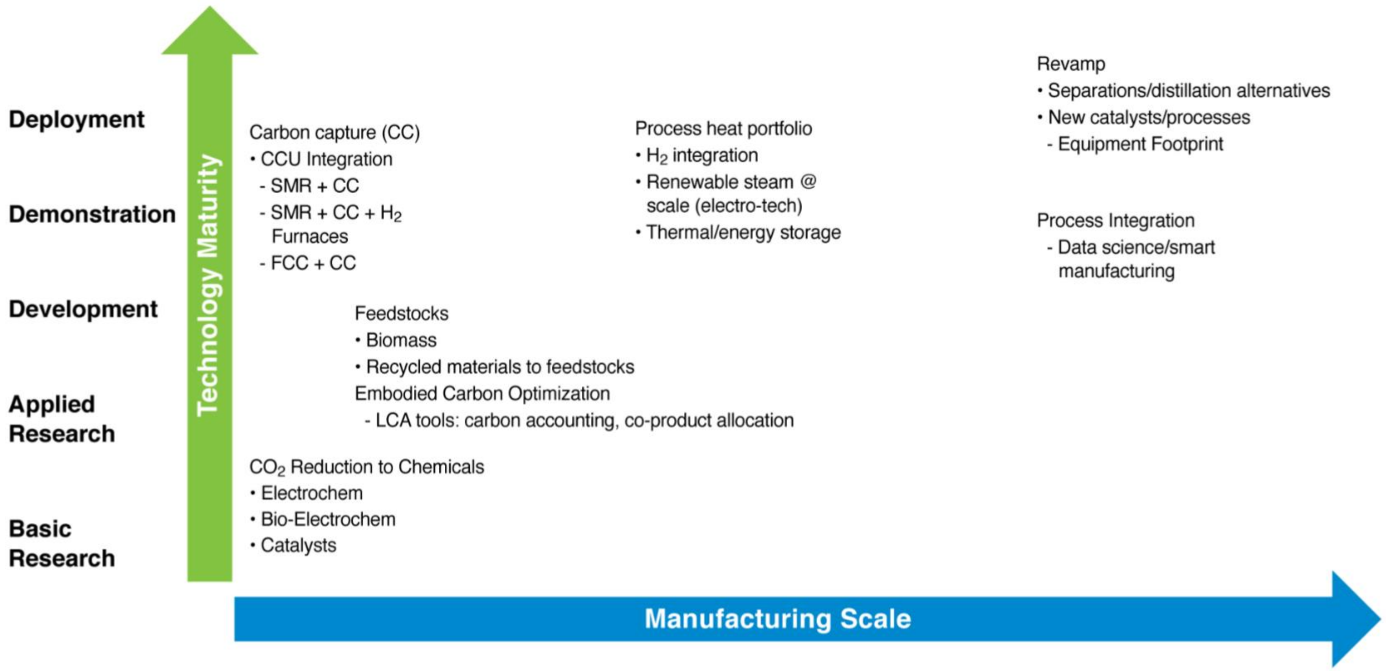


FIGURE 44. TECHNICAL MATURITY LEVELS OF DECARBONIZATION TECHNOLOGIES FOR THE PETROLEUM REFINING SUBSECTOR

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

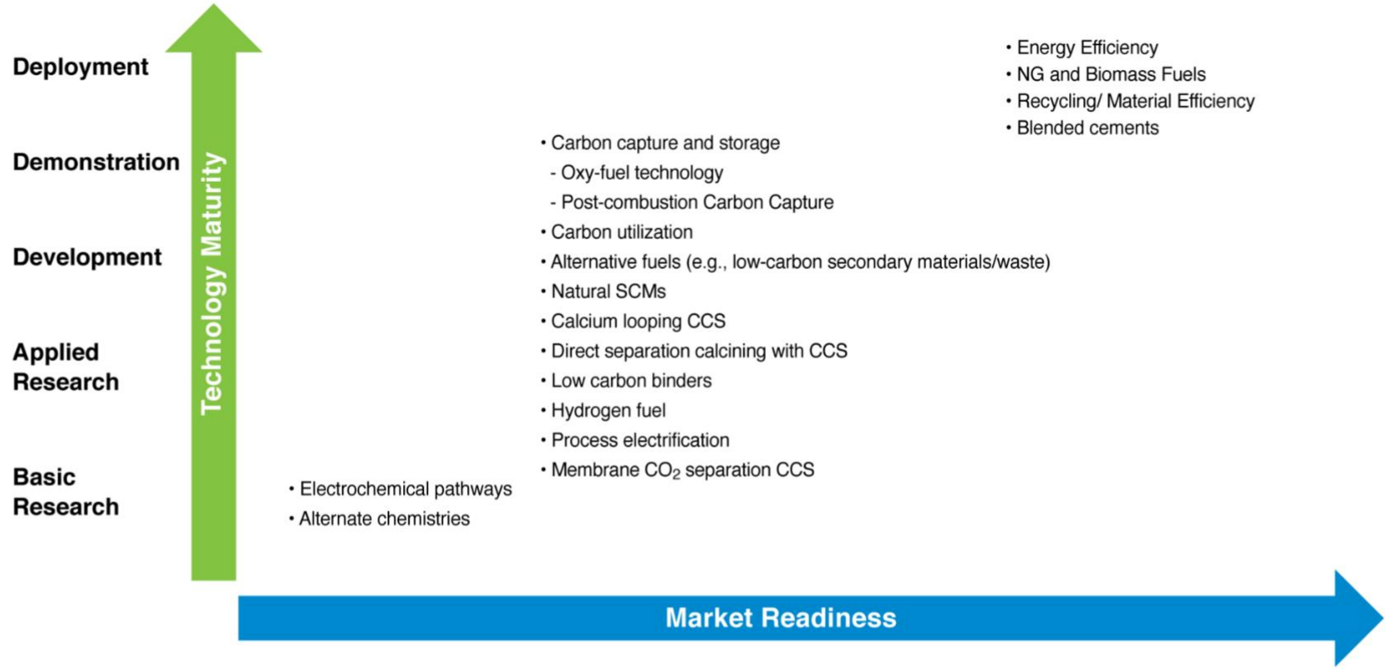


FIGURE 51. TECHNICAL MATURITY LEVELS OF SELECT DECARBONIZATION TECHNOLOGIES DISCUSSED DURING ROADMAP VIRTUAL MEETINGS FOR THE U.S. CEMENT INDUSTRY.

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

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

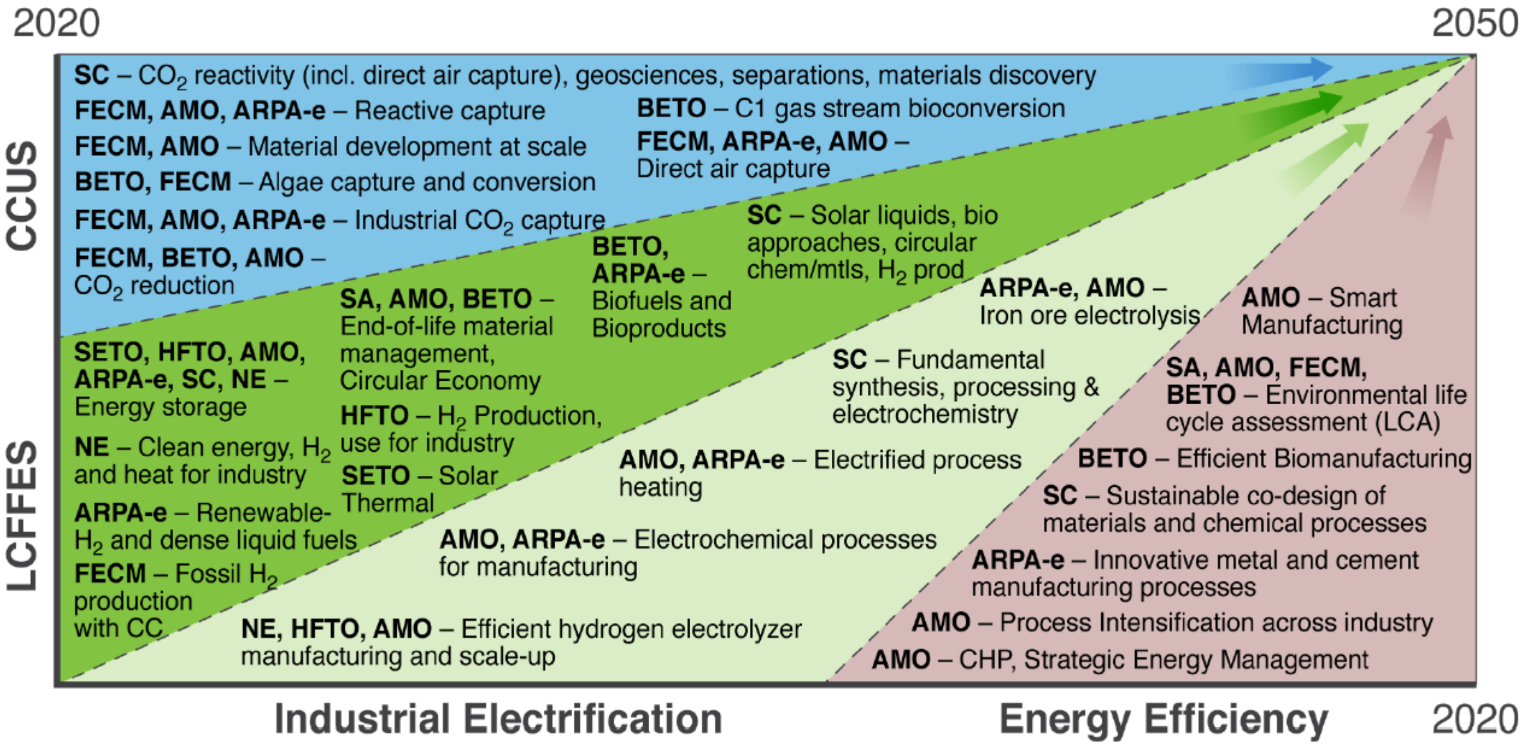


FIGURE 59. LANDSCAPE OF DOE OFFICE ACTIVITIES ACROSS THE FOUR DECARBONIZATION PILLARS TO ACHIEVE NET-ZERO EMISSIONS BY 2050.

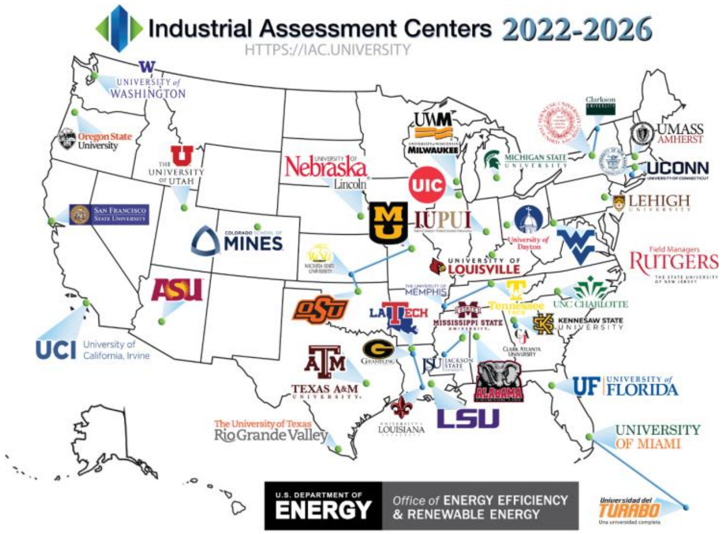
AMO: ADVANCED MANUFACTURING OFFICE; ARPA-E: ADVANCED RESEARCH PROJECTS AGENCY – ENERGY; BETO: BIOENERGY TECHNOLOGIES OFFICE; FECM: OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT; HFTO: HYDROGEN AND FUEL CELL TECHNOLOGIES OFFICE; NE: OFFICE OF NUCLEAR ENERGY; SA: EERE STRATEGY ANALYSIS; SC: OFFICE OF SCIENCE;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

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

Industrial Energy Efficiency Assessments with US DOE Industrial Assessment Centers (IACs)

Three Main Objectives:

1. **Assessments** – IACs provide no-cost energy assessments to small-to-medium sized manufacturing plants and wastewater treatment plants
2. **Workforce Development** – IACs train the next-generation of energy savvy engineers to implement energy efficiency assessments.
3. **Research** – IACs conduct research on cutting edge technologies to identify new potential methods of cost effective energy reduction.



The IAC program has already conducted over 20,475 assessments with more than 153,108 associated recommendations. Average recommended yearly savings is $138,295 (as of 3/15/23).

Source: https://iac.university/

Eligibility Requirements

- Within Standard Industrial Codes (SIC) 20-39
- Located less than 150 miles of a participating university
- Gross annual (site) sales below $100 million
- Fewer than 500 employees at the plant site
- Annual energy bills more than $100,000 and less than $3.5 million
- No professional in-house staff to perform assessments

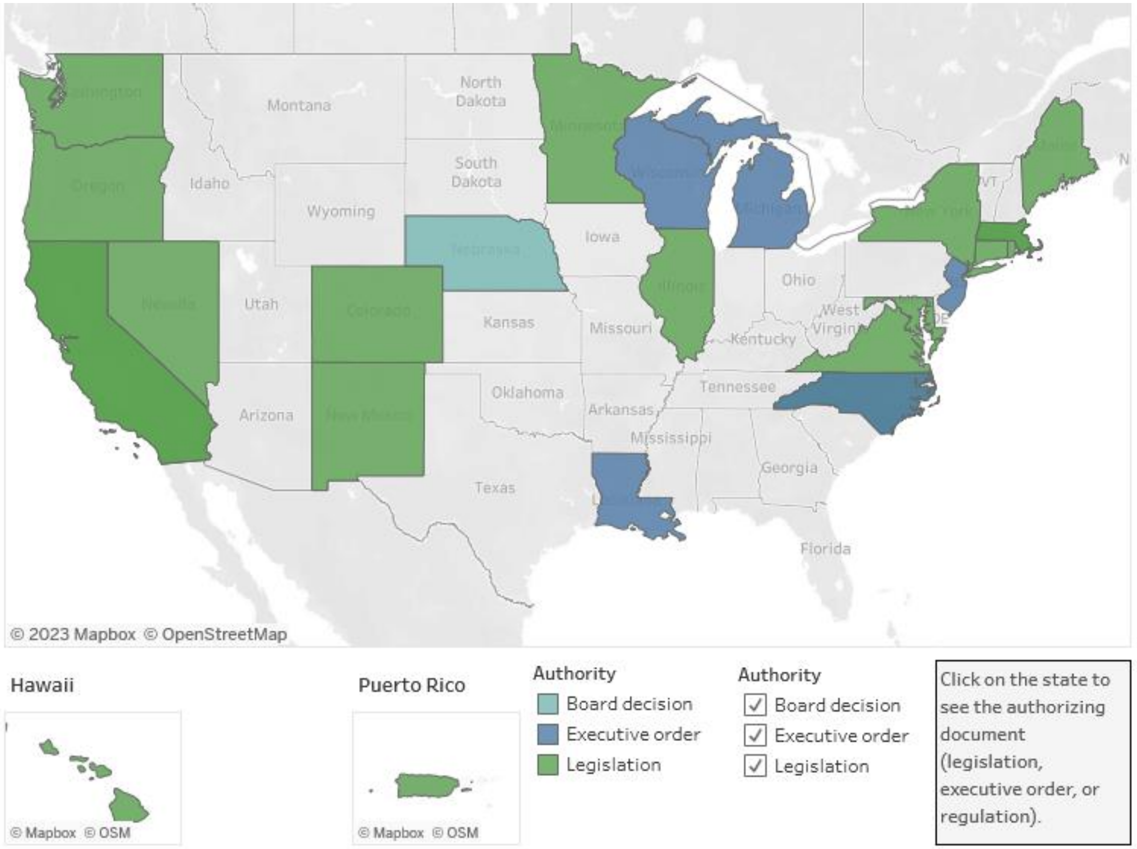
Contact the DOE IAC at MSU for a future assessment: https://iac.msu.edu/

CHP Technical Assistance Partnerships

100% Clean Energy States

100% Clean Energy States

Regions that have adopted official zero-GHG or 100% renewable energy goals for their power sector or whole economy.



Midwest State	Goal	Comments
Illinois	100% clean energy by 2050	2021 legislation (SB2408) established a goal of 100% clean energy by 2050, with interim targets of 40% by 2030 and 50% by 2040.
Michigan	Economy-wide carbon neutrality by 2050	Governor Gretchen Whitmer's order in 2020 (Executive Directive 2020-10) set a goal "to achieve economy-wide carbon neutrality no later than 2050." It directed the Department of Environment, Great Lakes, and Energy to develop a plan by the end of 2021.
Minnesota	100% carbon-free electricity by 2040	2023 legislation (SF 4) requires electric utilities to get 100% of the electricity they sell from carbon-free sources by 2040, including renewables and nuclear power. There are interim targets of 80% carbon-free power in 2030 and 90% in 2035. The legislation also increases the state's Renewable Energy Standard to 55% by 2035.
Wisconsin	100% carbon-free electricity by 2050	Governor Tony Evers' Executive Order (EO38) in 2019 directed a new Office of Sustainability and Clean Energy to "achieve a goal" of all carbon-free power by 2050.

Source: https://www.cesa.org/projects/100-clean-energy-collaborative/