

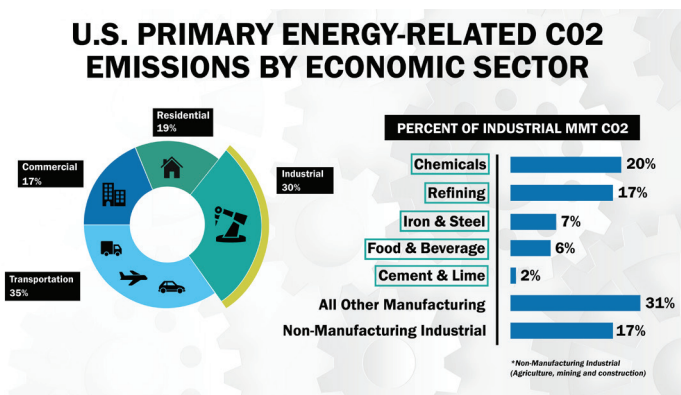


# Industrial Decarbonization Roadmap Fact Sheet

The industrial sector is the backbone of America’s economy, producing chemicals, electronics, machinery, steel, metals, textiles, and many other products that are critical to our society. However, the industrial sector currently accounts for **approximately one third** of our nation’s energy-related carbon dioxide (CO2) emissions. To achieve net zero greenhouse gas (GHG) emissions by 2050, we need to drastically reduce industry’s collective carbon footprint.

This roadmap identifies **four key pathways to reduce industrial emissions** through innovation in American manufacturing. The roadmap emphasizes the urgency of deep decarbonization across the industrial sector, and presents a staged research, development, and demonstration (RD&D) agenda for industry and government that will deliver the technologies needed to dramatically reduce emissions.

## Five Key Energy Intensive Sectors to Decarbonize



- Develop low thermal budget process heating solutions and improve the effectiveness of thermal energy use to increase energy efficiency of whole systems
- Expand advanced reactions, catalysts, and reactor systems to improve reaction performance in addition to reducing carbon emissions and improving energy efficiency
- Electrify processes and use hydrogen, biomass, or waste as fuel and feedstocks for manufacturing
- Improve materials efficiency and increase materials circularity

The roadmap focuses on five of the highest CO2-emitting industries where industrial decarbonization technologies can have the greatest impact across the nation. These key sectors—iron and steel; cement and concrete; food and beverage; chemical manufacturing; and petroleum refining— represent approximately 51% of the energy-related CO2 emissions in the U.S. industrial sector and 15% of U.S. economy-wide total CO2 emissions.



**Petroleum refining:** Most U.S. refinery CO2 emissions are from five large energy-consuming processes: hydrocracking, atmospheric distillation, catalytic cracking, steam methane reforming, and regenerative catalytic reforming. These processes represent the most cost-effective RD&D opportunities for refineries to reduce CO2 emissions. To help achieve net-zero goals, the petroleum refining sector can:

- Improve energy efficiency both in processes and on-site steam and power generation



**Chemical manufacturing:** The U.S. chemical manufacturing industry is incredibly diverse and has seen significant growth over the last decade. To help achieve net-zero goals, the chemical manufacturing sector can:

- Lower the carbon footprint of energy sources and feedstocks by using lower-carbon fossil energy and introducing low-fossil carbon sources such as nuclear heat and electricity, clean electricity, clean hydrogen, or biofuels



**Iron and steel:** Iron and steel manufacturing is one of the most energy-intensive industries worldwide. The use of coal as a feedstock in production methods, the chemical reduction of iron oxide, and the sheer volume of iron and steel produced have made the industry among the highest in GHG emissions. To help achieve net-zero goals, the iron and steel sector can:

- Transition to low-and no-carbon fuels and expand industrial electrification
- Pilot demonstrations for transformative technologies such as hydrogen-steel production, electrolysis of iron ore, and carbon capture and utilization storage
- Improve materials efficiency and increase materials circularity



**Food and beverage:** The food and beverage industry is one of the largest energy consuming and GHG-emitting industries in the United States. To help achieve net-zero goals, the food and beverage sector can:

- Improve energy efficiency by advancing the electrification of process heating, evaporation, and pasteurization processes
- Reduce food waste throughout the supply chain through methods identified in life cycle assessments and collaboration between manufacturers.
- Pursue recycling and material efficiency through alternative packaging and package waste reduction

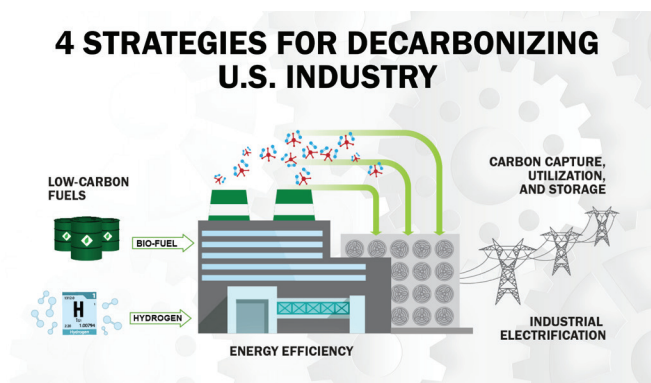


**Cement:** In the U.S. cement industry, process-related CO<sub>2</sub> emissions from calcination account for about 58% of total CO<sub>2</sub> emissions and energy-related CO<sub>2</sub> emissions accounted for 42% of total emissions. To help achieve net-zero goals, the cement sector can:

- Evolve existing processes to reduce waste, including circular economy approaches for concrete construction
- Improve materials and energy efficiency with deployment of breakthrough technologies and innovative chemistry solutions
- Expand use of carbon capture, utilization, and storage technologies
- Increase use low carbon binding materials and natural supplementary cementitious materials to lower the carbon-intensity of clinker and solid materials used to create cement

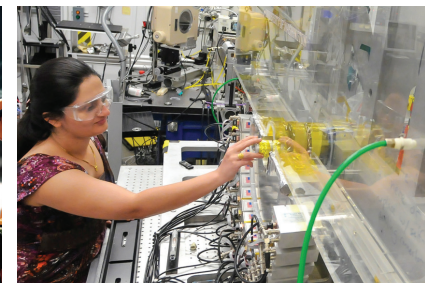
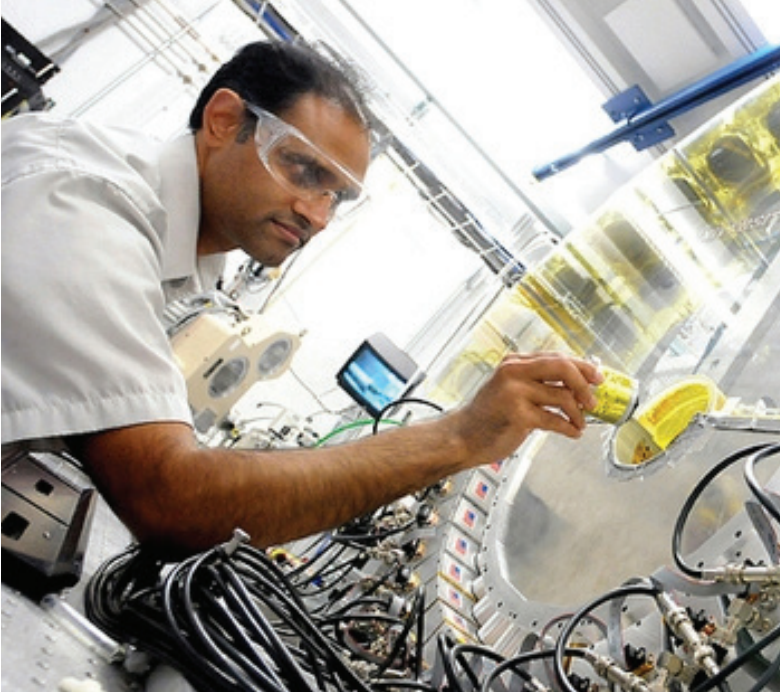
#### Four Key Pathways to Industrial Decarbonization

The roadmap identifies four key technological pillars to significantly reduce emissions for the five most energy-intensive sectors.



**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 sources
- Smart manufacturing and advanced data analytics to increase energy productivity in manufacturing processes



**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

**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

**Carbon Capture, Utilization, and Storage (CCUS):** CCUS refers to the multi-component strategy of capturing generated CO<sub>2</sub> from a point source and using the captured CO<sub>2</sub> to make value added products or storing it long-term to avoid release. Decarbonization efforts include:

- Post-combustion chemical absorption of CO<sub>2</sub>
- Development and manufacturing optimization of advanced CO<sub>2</sub> capture materials that improve efficiency and lower cost of capture
- Development of processes to utilize captured CO<sub>2</sub> to manufacture new materials

### Key Recommendations from the Industrial Decarbonization Roadmap

- **Advance early-stage RD&D:** Further applied science necessary for net-zero carbon emissions by 2050.
- **Invest in multiple process strategies:** Continue parallel pathways of electrification, efficiency, low carbon fuels, CCUS, and alternative approaches.
- **Scale through demonstrations:** Support demonstration testbeds to accelerate and de-risk deployment.
- **Address process heating:** Most industrial emissions come from fuel combustion for heat.
- **Integrate solutions:** Focus on systems impact of carbon reduction technologies on the supply chain.
- **Conduct modeling/systems analyses:** Expand use of lifecycles and techno-economic analyses.