Industrial Decarbonization

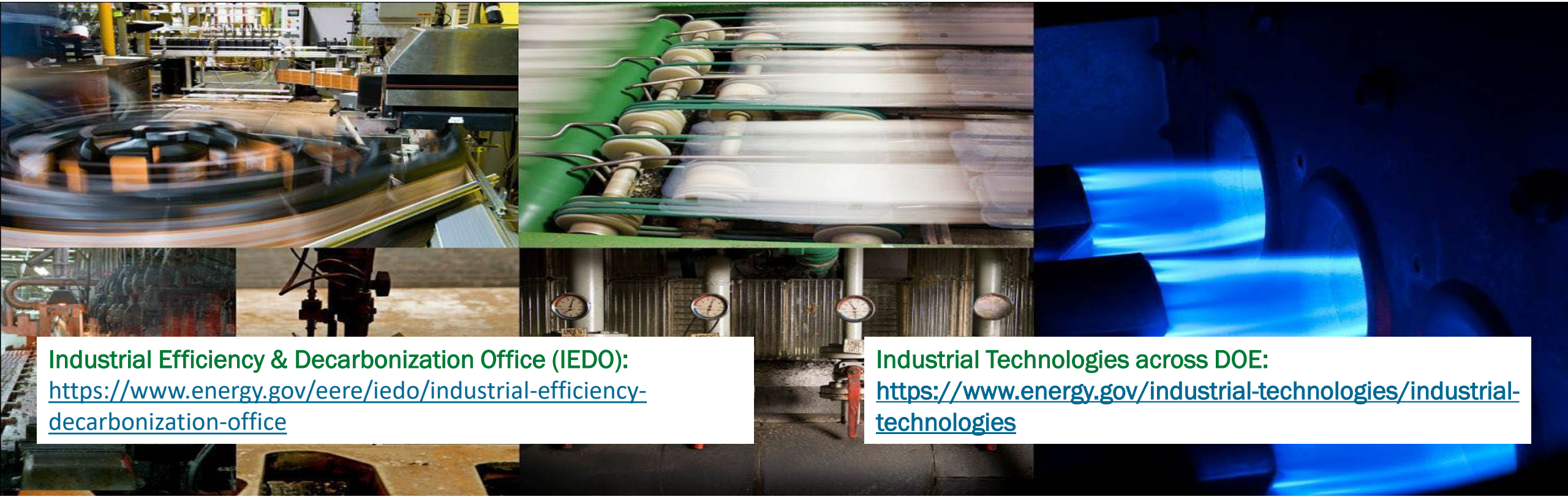
The Role of Technology

Sustainable Manufacturing

Better Plants Technology Days

February 7-8, 2024

Joe Cresko, Chief Engineer
Industrial Efficiency & Decarbonization Office (IEDO)
Office of Energy Efficiency & Renewable Energy
U.S. Department of Energy



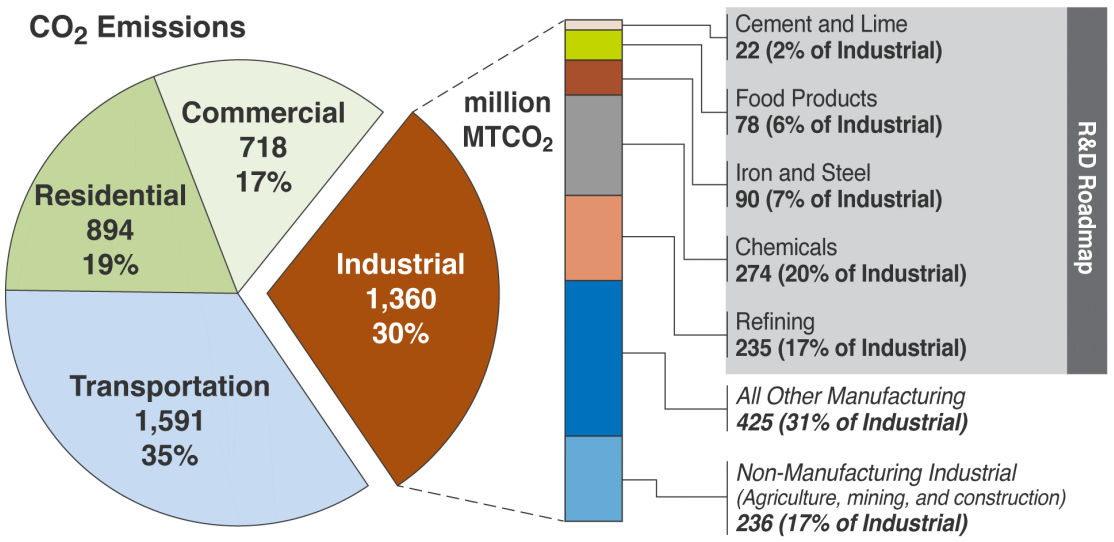
Industrial Efficiency & Decarbonization Office (IEDO): https://www.energy.gov/eere/iedo/industrial-efficiency-decarbonization-office

Industrial Technologies across DOE: https://www.energy.gov/industrial-technologies/industrial-technologies

U.S. Industry's CO_2 Emissions

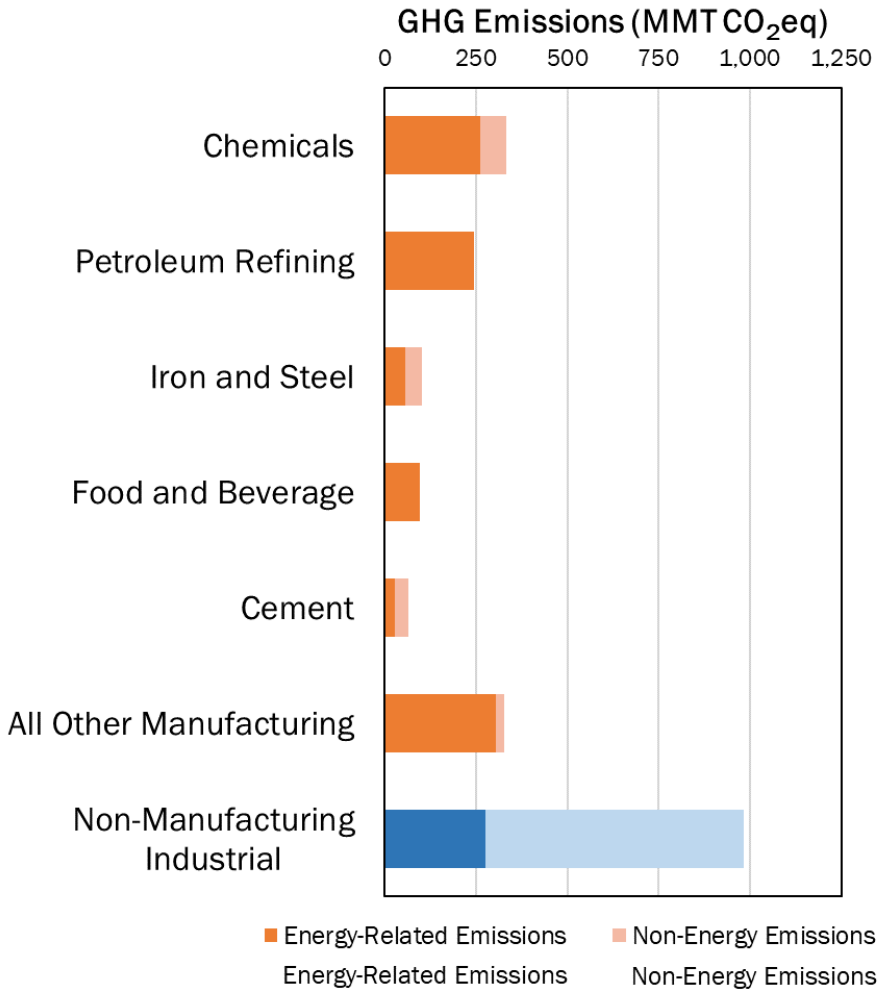
Industrial sector is comprised of
manufacturing | agriculture | mining | construction

ACCOUNTS FOR **30%** of energy-related CO_2 emissions



Energy-Related CO_2 emissions, 2020
(million metric tons)

Total Industry Emissions, 2018
(energy-related + non-energy; million metric tons CO_2eq)



EIA Monthly Energy Review, Manufacturing Energy Consumption Survey; EPA GHGRP Inventory

EIA, *Annual Energy Outlook 2020 with Projections to 2050*. Source: Industrial Decarbonization Roadmap.

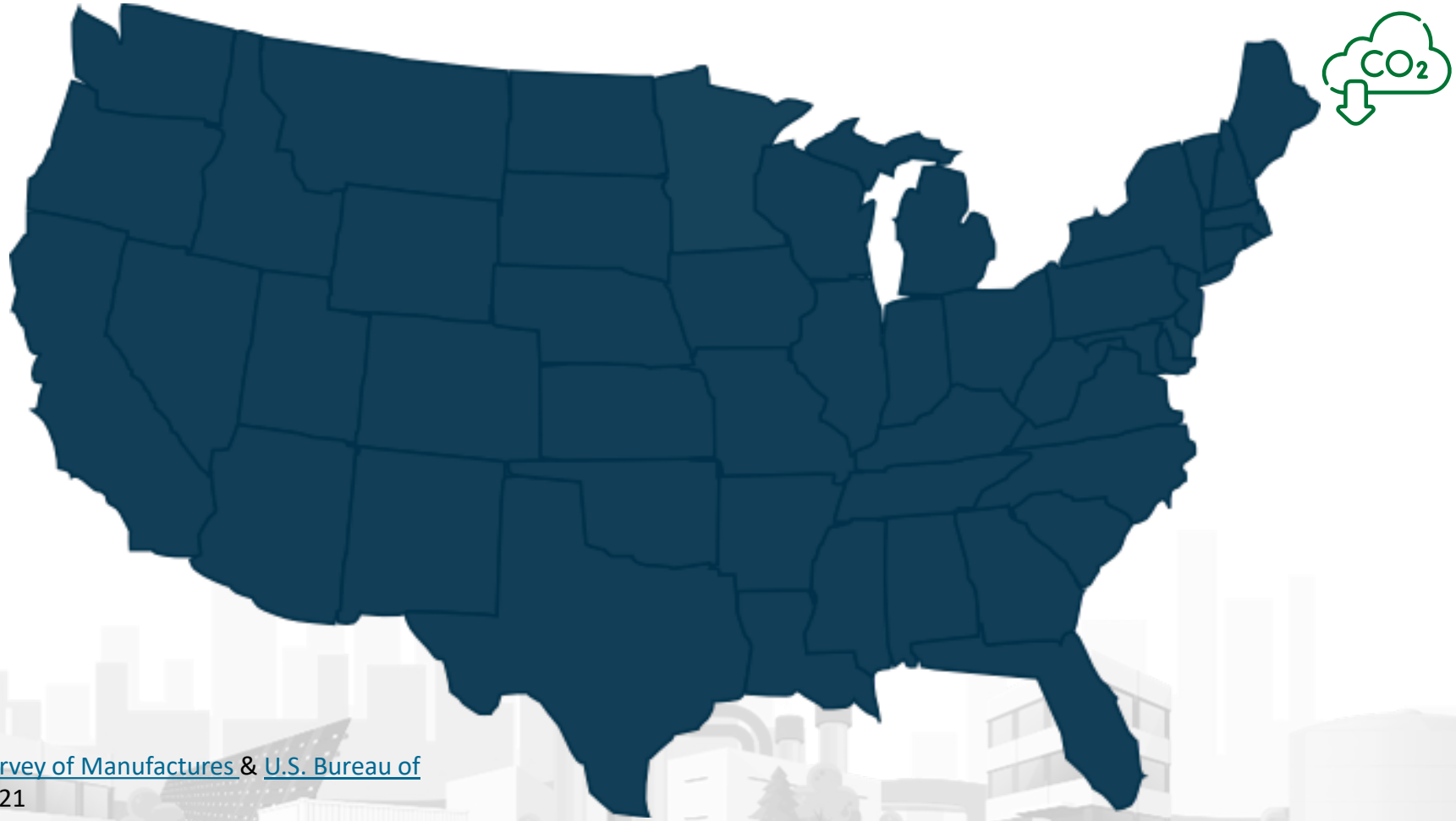
Decarbonizing Industry is an Opportunity for America's Economy

U.S. manufacturing subsector…

CONTRIBUTES
$2.79 trillion to the U.S. Economy

GENERATES
12% of U.S. GDP

SUPPORTS
11.2 million jobs



U.S. Census Bureau Annual Survey of Manufactures & U.S. Bureau of Economic Analysis data for 2021

Decarbonizing Industry is an Opportunity for America's Economy

U.S. manufacturing subsector…

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$2.79 trillion to the U.S. Economy

GENERATES
12% of U.S. GDP

SUPPORTS
11.2 million jobs

Estimated that

60% of heavy industry emission reductions

by 2050 will come from **technologies that are not currently market ready**

(IEA, 2022)

U.S. Census Bureau Annual Survey of Manufactures & U.S. Bureau of Economic Analysis data for 2021

Decarbonizing Industry is an Opportunity for America's Economy

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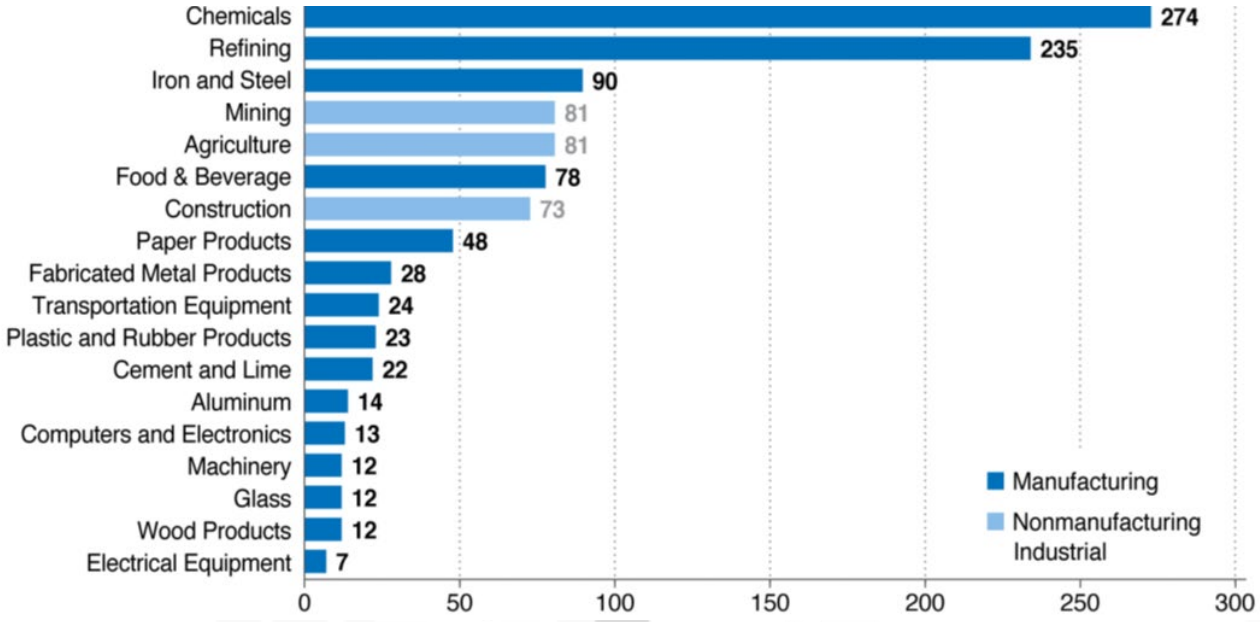


All industrial emissions

All subsectors

U.S. Census Bureau Annual Survey of Manufactures & U.S. Bureau of Economic Analysis data for 2021

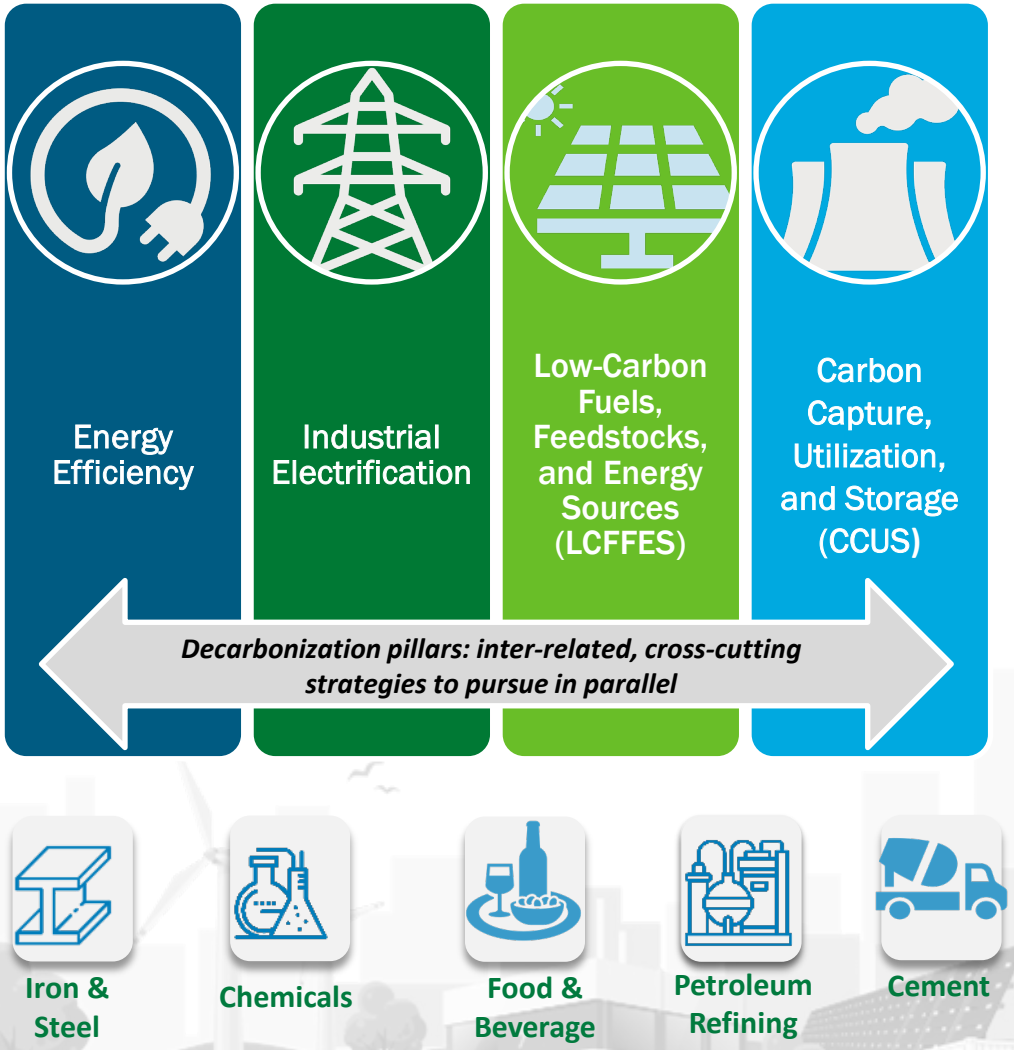
DOE Industrial Decarbonization Roadmap

- Pillars, and associated pathways to net-zero GHG emissions by 2050 for high-emitting industrial subsectors
- Rethink the opportunity for RDD&D and robust technology solutions
- Innovations for more sustainable manufacturing

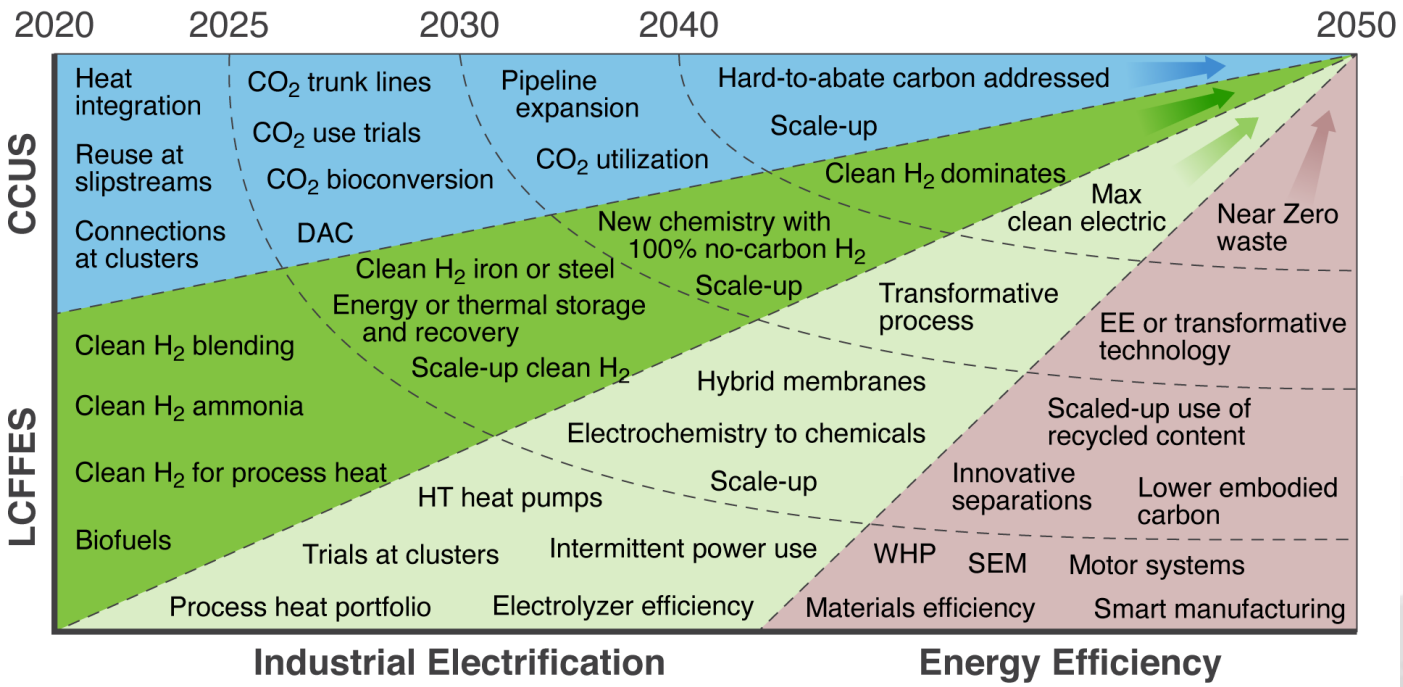
https://www.energy.gov/industrial-technologies/doe-industrial-decarbonization-roadmap

DOE Industrial Decarbonization Roadmap - Pillars and Sector Focus Areas

Industrial Decarbonization Pillars

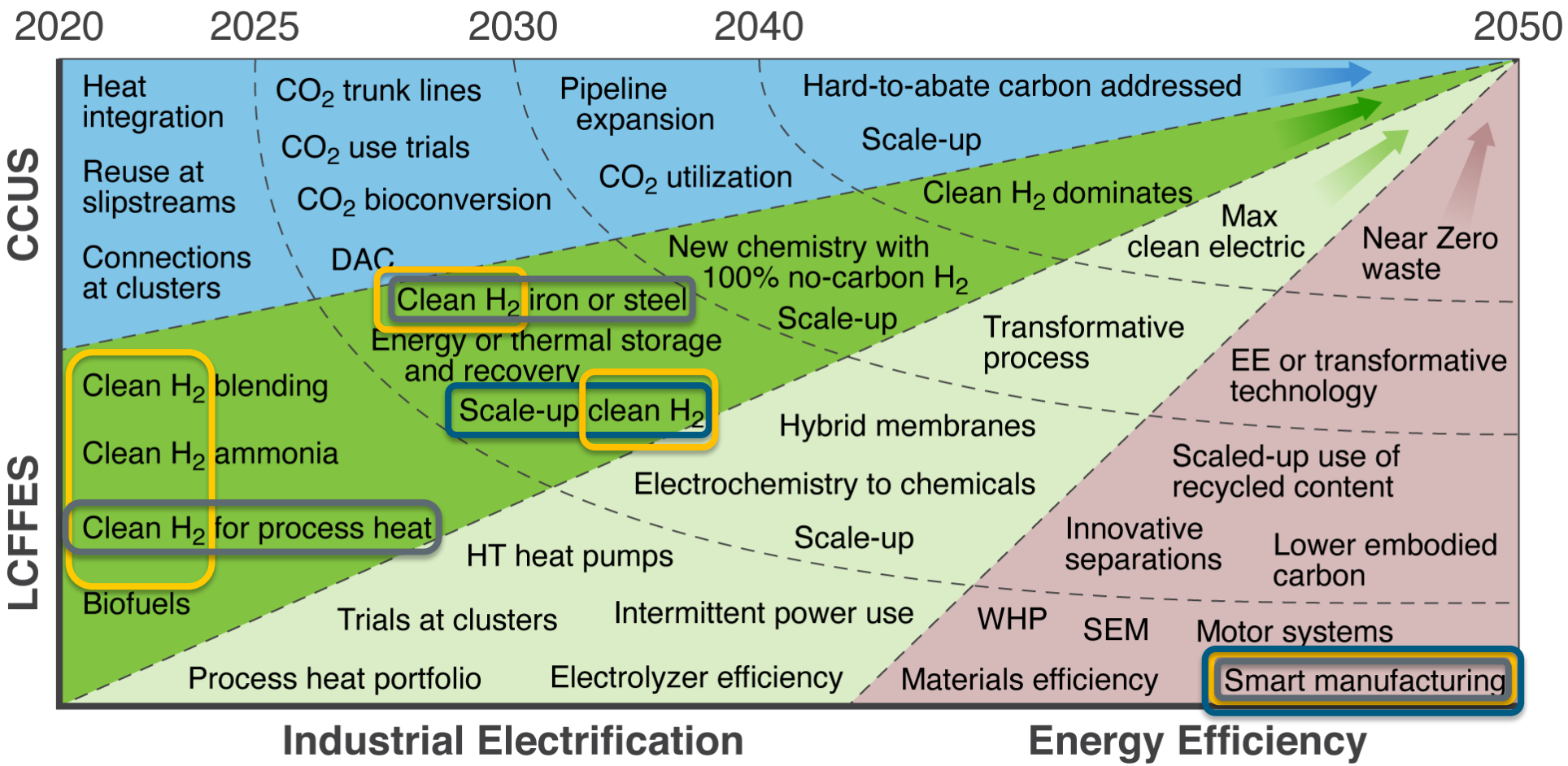


- **Invest in all pillars**
- **Leverage cross-sector approaches**
- **Interdependencies require systems solutions**
- **Strategies are needed to minimize implementation hurdles, address scale-up, and accelerate adoption**



Source: DOE Industrial Decarbonization Roadmap, Sept. 2022. https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

Industrial Decarbonization is also a systems challenge



Landscape of major RD&D investment opportunities for industrial decarbonization between now and 2050.

LCFFES = Low Cost Fuels, Feedstocks, and Energy Sources; **CCUS** = Carbon Capture Utilization and Storage

Source: Industrial Decarbonization Roadmap

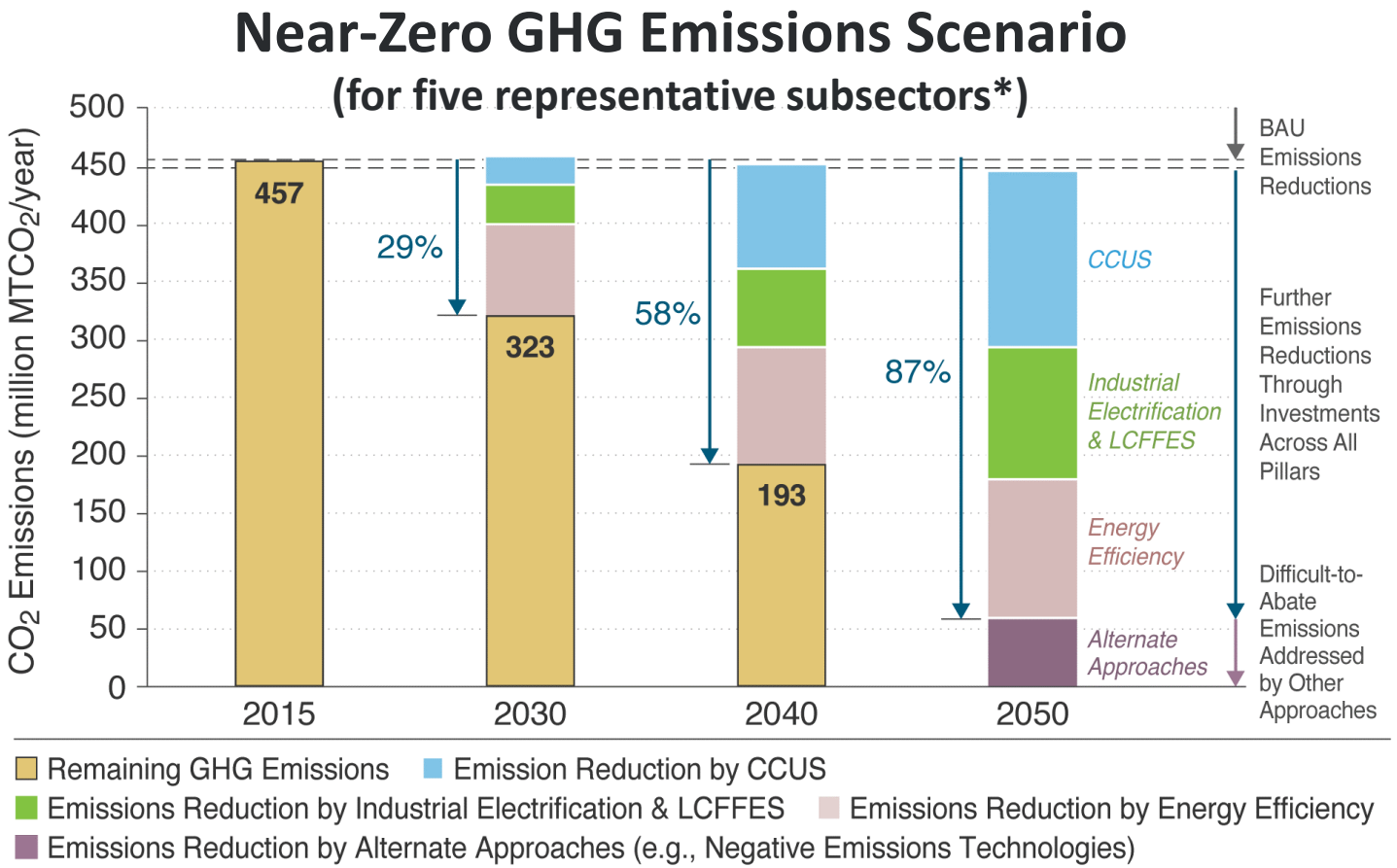
Industrial GHGs require approaches at multiple levels:

- Core process
- Facility
- Beyond plant bounds

What are the implications of:

- Expanded H_2 generation & use
- New thermal energy sources & systems
- Smart manufacturing, automation, & data analytics
- Transition to clean electricity
- Policies

2050 Industrial Emissions Reductions Potential



Pillars of industrial decarbonization:

- Energy efficiency
- Industrial electrification
- Low carbon fuels, feedstocks, and energy sources
- Carbon capture, utilization and storage

***Subsectors included in Roadmap analysis:** Iron & Steel, Chemicals, Food & Beverage, Petroleum Refining, and Cement. *Excludes feedstocks.*

Source: DOE Industrial Decarbonization Roadmap)

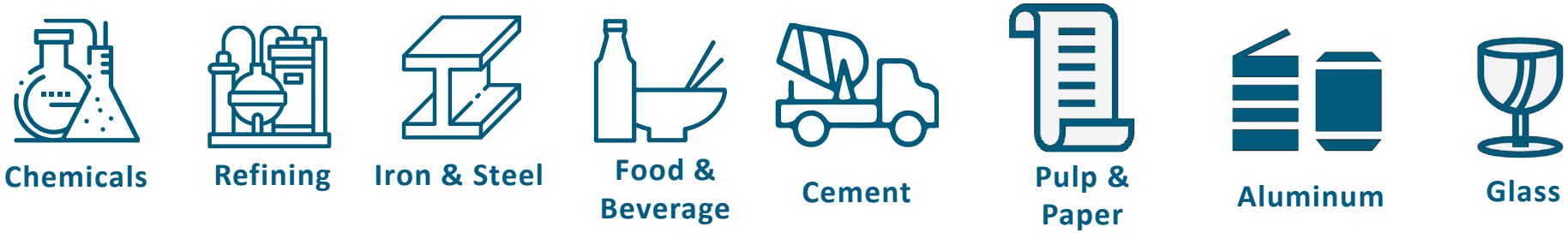
New Technologies are Required to Meet Net-Zero Goals

Investment scale → In the range of

$0.7 – $1.1T

for 8 industrial sector of focus in the IRA :

Source: DOE Pathways to Commercial Liftoff; Industrial Decarbonization



Targeted investments to overcome technical and economic barriers and accelerate uptake of new technologies

IEDO Office Structure

ENERGY- AND EMISSIONS-INTENSIVE INDUSTRIES

Chemicals, Iron & Steel, Food & Beverages, Cement, Paper & Forest Products

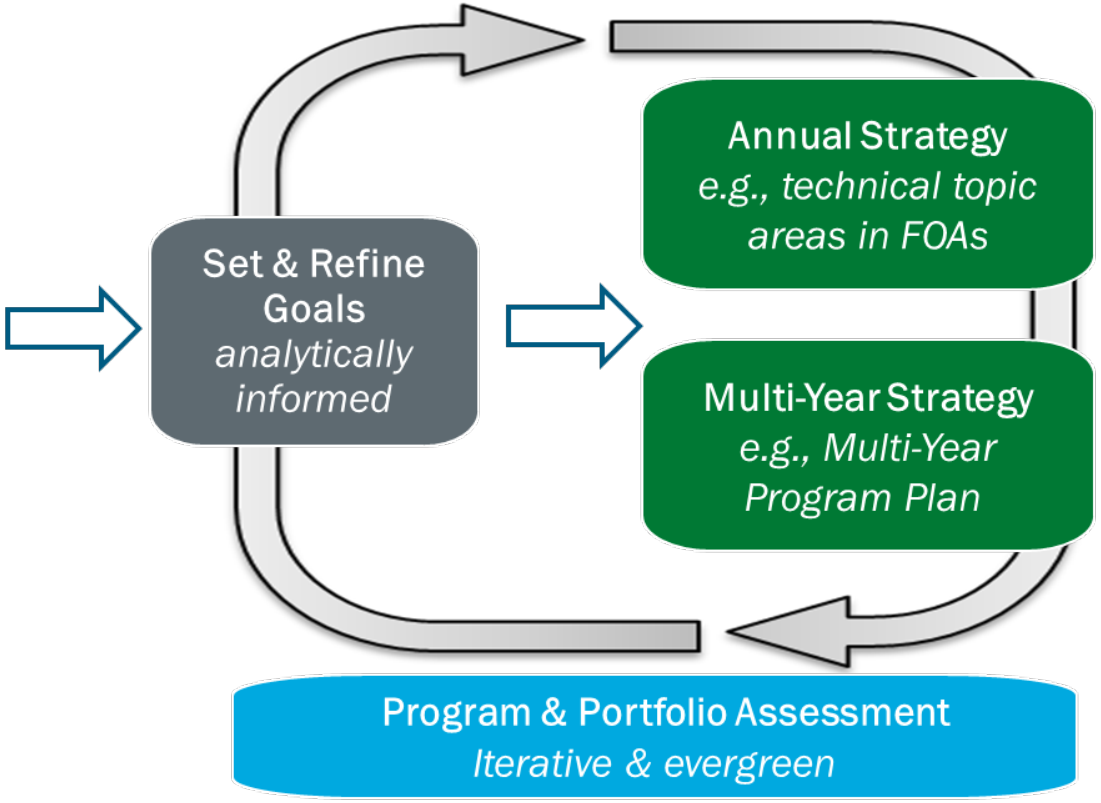
CROSS-SECTOR TECHNOLOGIES

Decarbonizing Process Heat
Low-Carbon Fuels and Feedstocks
Water and Wastewater
Energy Efficiency Technologies

TECHNICAL ASSISTANCE AND WORKFORCE DEVELOPMENT

Onsite Energy
Better Plants
Energy Management Programs
Industrial Technology Validation
Water Technical Assistance

Strategy & Planning



Goal: Investments that will catalyze an industrial transformation

IEDO's Technology Portfolio includes:

Cross-Sector

- Process Electrification
  - Electrified Processes for Industry without Carbon **(EPIXC)** Institute EPIXC ($70M/5yrs)
- Low-carbon Industrial Thermal Systems
  - Heat pumps, low carbon fuels, electromagnetic heating
  - Cogeneration of Heat & Power
  - Drying, separations, waste heat recovery
- Water-Energy Nexus
  - **National Alliance for Water Innovation (NAWI)**
- Carbon Capture Technology & Integration into industrial operations

Energy- and Emissions-Intensive Industries

- Chemicals & Fuels
  - Bulk Chemicals, value chains, separations, catalysts, intensification, alternative feeds
  - **Clean Fuels & Products Shot**
  - **RAPID Inst ($40M/5 yrs)**
- Iron & Steel
  - Alt iron processes, recycling, ore beneficiation
- Cement & Concrete
  - Alt binders & process, SCMs, CO_2 mineralization
- Food & Beverage
  - Energy recovery, alt processing, waste reduction. efficiency, electrification, separations, packaging
- Pulp & Paper, Wood Products
  - Alt pulp chemistry, waste recovery, alt fibers, alt water removal, drying , waste valorization, stranded CO_2

Our Homework → Resources

Foundational
- Technology Assessments
- Energy & Carbon
- Technology Adoption

Roadmaps
- Decarbonization
- Energy Storage
- Critical Materials
- Circular Economy

Workshops
- Energy Storage
- Critical Materials
- Thermal Intensification
- Ind. Heat Shot

Planning
- FOAs
- Prizes
- WFD Programs
- MYPP
- Big Ideas Summit
- Goal setting

Portfolio
- Peer Review
- Annual Report
- Introspective
- Technology Tracking
- TEA/LCA

Conferences, journal articles etc.

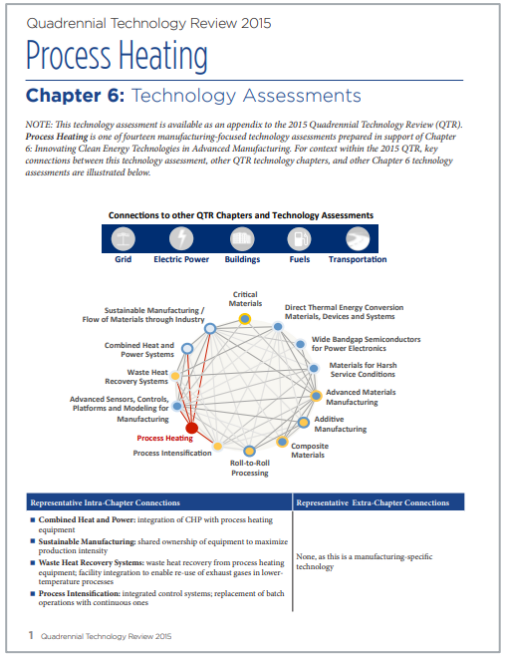
https://www.energy.gov/eere/iedo/energy-analysis-data-and-reports

Process Heating and Industrial Thermal Energy Systems

Thermal Process Intensification (TPI)

Input from subject-matter experts on transformative technologies and strategies to substantially improve the performance of thermal processing systems in the industrial sector.

- Workshop in late 2020
- Report published in May 2022

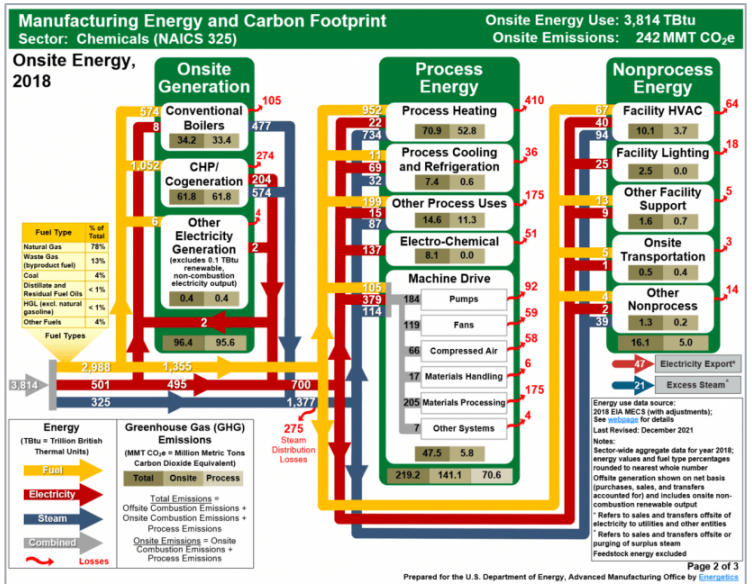


DOE Quadrennial Technology Review 2015

Technology assessment on process heating

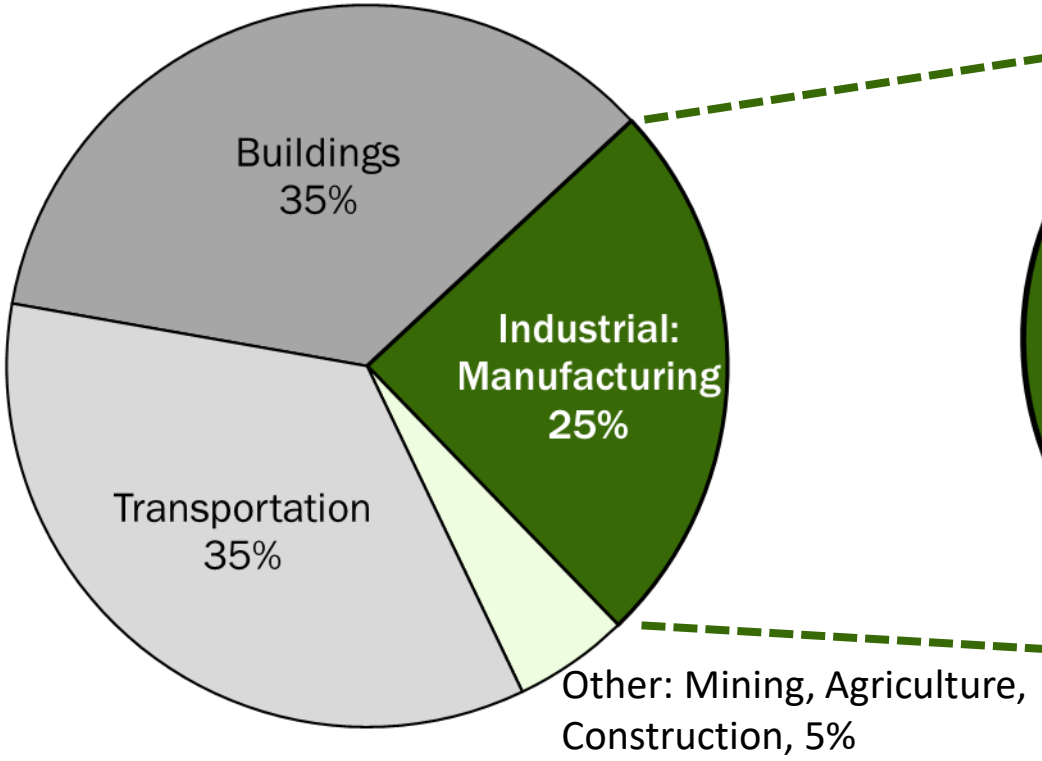
Manufacturing Energy and Carbon Footprints

The flow of energy supply, demand, and losses as well as greenhouse gas (GHG) emissions for end uses in 15 U.S. manufacturing industries and manufacturing-wide.

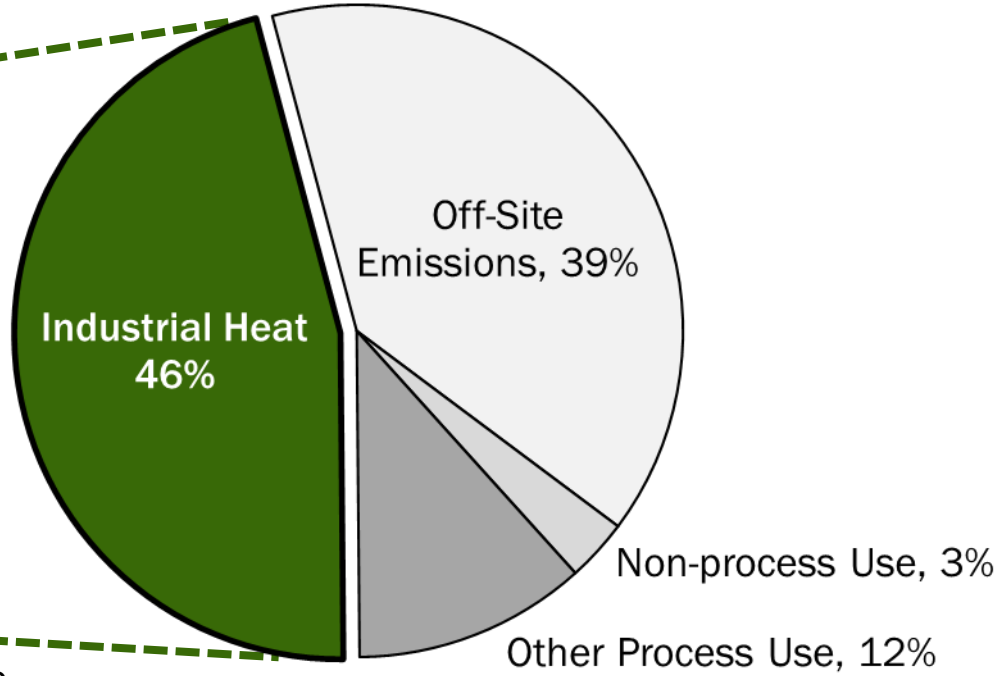


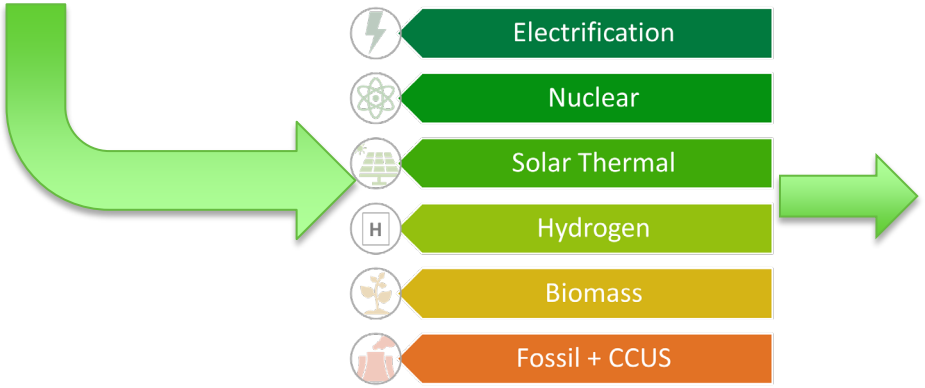
11% of All U.S. Energy-Related Emissions are from Industrial Thermal Systems

2020 Energy-Related CO_2 Emissions by U.S. Economic Sector



2020 Estimated Industrial: Manufacturing Energy-Related CO_2 Emissions by Source

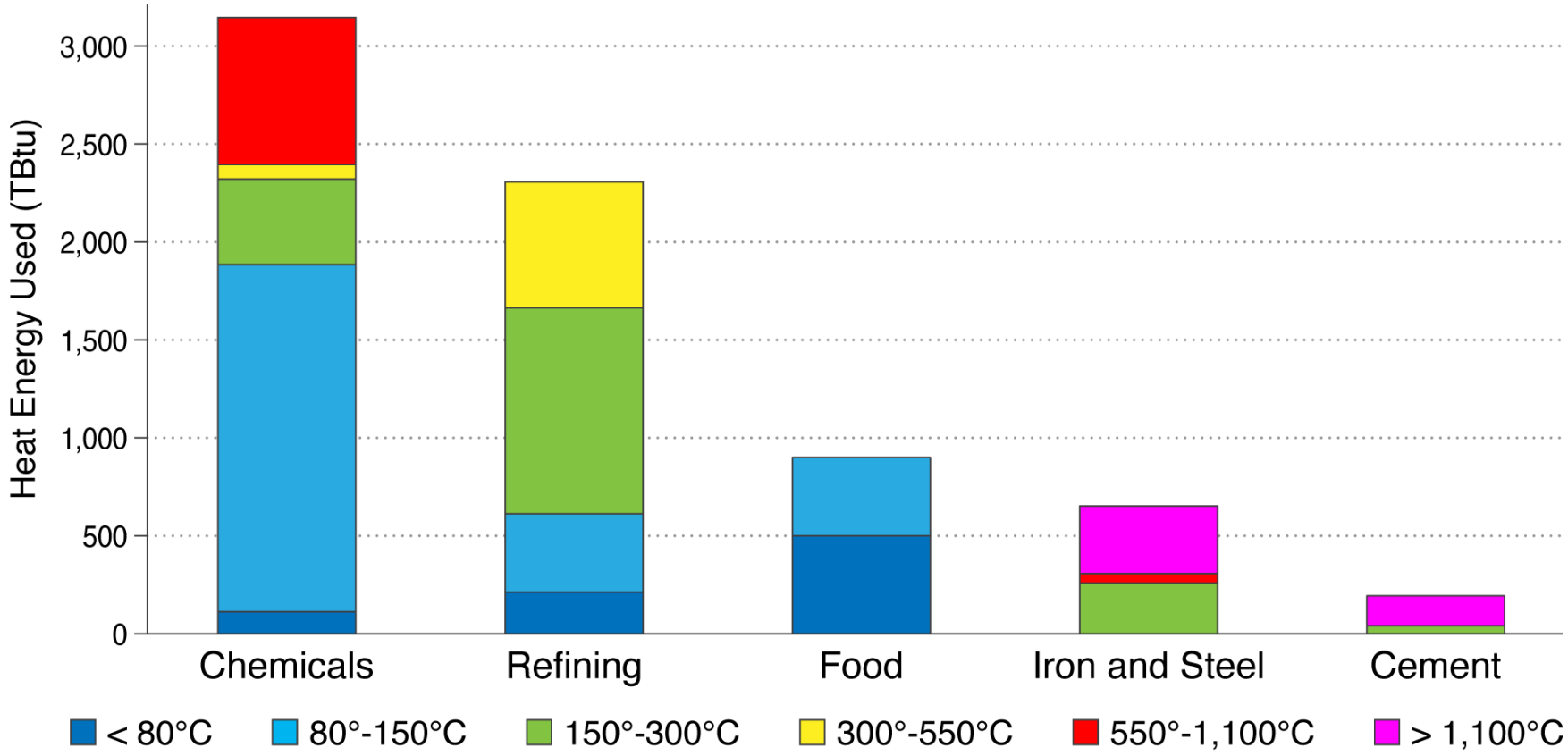




Opportunity for improved energy productivity and reduced emissions

Sources: EIA Annual Energy Outlook (2021); AMO 2018 Manufacturing Energy and Carbon Footprints (2022)

Thermal breakdown by temperature ranges



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

Thermal Processes – opportunities for innovation of fundamental unit operations

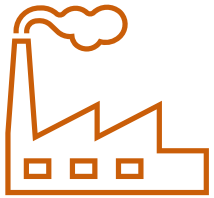
Table 1a. Types of thermal processes used for eight large energy consuming industries. Colors indicate upper-bound temperature range for a given application. Blue = low temperature (<800°F); yellow = medium temperature (800°F to 1,400°F); red = high temperature (>1,400°F).

Thermal process step	Iron and steel	Petroleum refining	Chemical industry	Glass	Aluminum	Pulp and paper	Food processing	Cement
Calcining								
Curing and forming								
Drying								
Fluid heating								
Heat treating (metal and nonmetal)								
Metal and nonmetal reheating								
Metal and nonmetal melting								
Other heating: processing								
Reactive thermal processing								
Smelting, agglomeration etc.								
Steam generation								

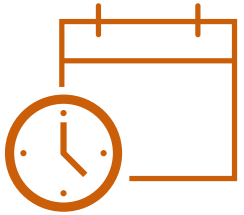
ENERGY earthshots
U.S. DEPARTMENT OF ENERGY

Industrial Heat Shot

Develop cost competitive industrial heat decarbonization technologies with **at least 85% lower greenhouse gas emissions by 2035**



>85% Lower Emissions



2035

Baseline	65 kg CO_2 equivalent per MMBtu	Current Average GHG Emissions Intensity of Industrial Heat
2035 Target	8.8 kg CO_2 equivalent per MMBtu	Aligned with Clean Hydrogen (1 kg CO_2 per kg H_2)

Industrial Heat Shot

Goal: Reduce the amount of heat and/or emissions from heat to make cleaner products

Generate Heat from Clean Electricity

Reduce Emissions:
electrify equipment & use clean electricity, improve energy efficiency

Examples:
heat pumps, microwave heating, resistive heating, etc.

Integrate Clean Heat from Alternative Sources

Reduce Emissions:
switch to low-emissions heat sources and increase thermal storage

Examples:
solar thermal, nuclear, geothermal, hydrogen, some sustainable fuels, etc.

Innovative Low- or No-Heat Process Technologies

Reduce Emissions:
new chemistry and emerging approaches to reduce heat demand

Examples:
advanced separations, electrolysis, ultraviolet curing, biobased manufacturing, etc.

Enabling technologies and systems: e.g. energy storage, materials, modeling, data analytics, etc.

www.energy.gov/eere/industrial-heat-shot

New DOE Institute Focused on Electrifying Process Heat

- The Electrified Processes for Industry without Carbon **(EPIXC)** Institute is DOE's 7th Clean Energy Manufacturing Innovation Institute.
- EPIXC will:
  - Allocate up to **$70M** in federal funding over the next 5 years to fund RD&D projects to electrify process heating.
  - Mobilize a multisector coalition of private companies, National Labs, universities, labor unions, and community partners to create an innovation ecosystem.
  - Bridge the gap between research and commercialization to move novel electrification processes out of the lab and into the market.

EPIXC
ELECTRIFIED PROCESSES FOR INDUSTRY WITHOUT CARBON

ASU Arizona State University

Sustainable and Decarbonized Industrial Technologies are Systems Solutions

Innovative Metals Processing

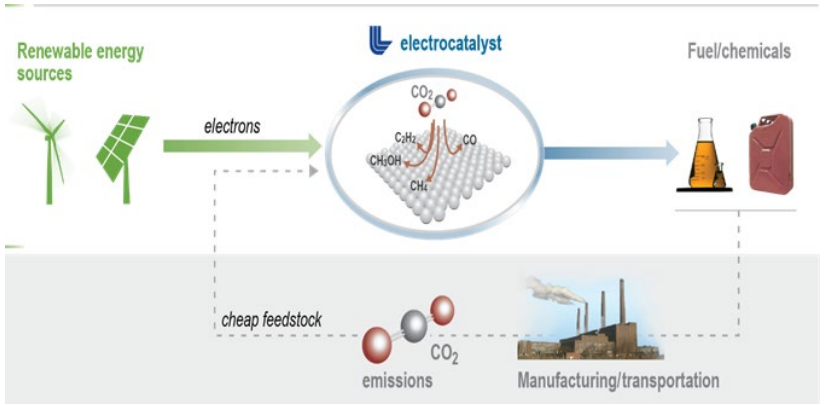
Improve the energy and carbon footprint of metals production, including through increased recycling of scrap, co-products, and process gasses.

- *Direct electrolysis*
- *Alternative reductants*
- *Electrochemical recovery*
- *Selective separations*
- *ITMP*
- *Flash Steelmaking*

Flash ironmaking

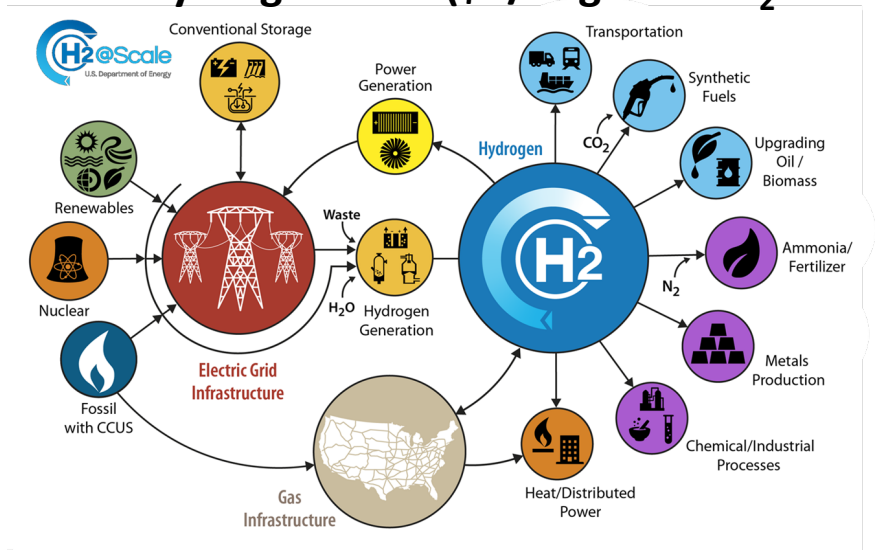
Efficiency Improvements in Chemical Manufacturing

Develop catalytic processes to optimize conversion rates & selectivity.



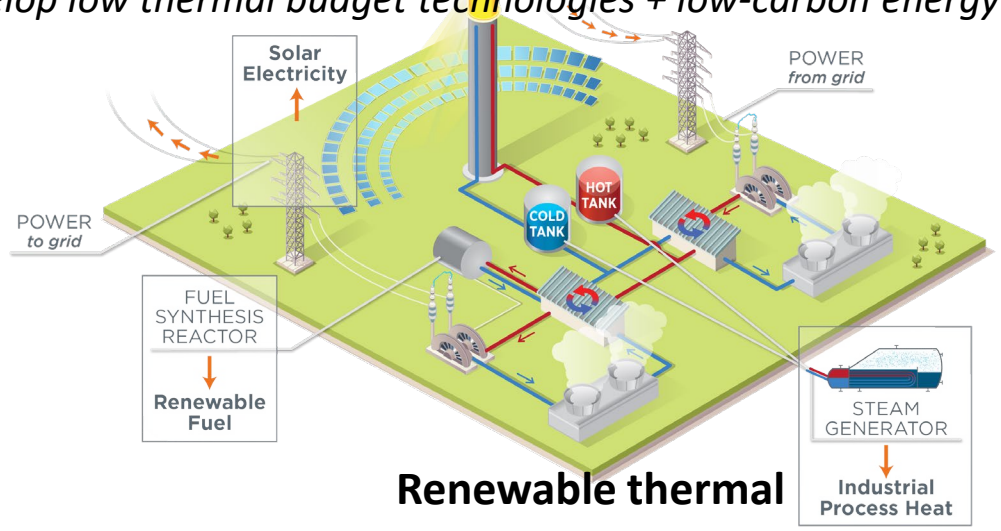
One-step electrochemical ethylene production from CO_2

H_2@ Scale and Hydrogen Shot ($1/1Kg clean H_2 in 1 decade).



Thermal Process Intensification

Develop low thermal budget technologies + low-carbon energy sources.



Renewable thermal

Sustainable manufacturing via circular economy approaches

Estimated emissions reduction:

Material efficiency – 10%

- Product design
- Waste reduction
- Lightweighting

Reuse/Repurpose – 12%

- Longer usable lifetimes
- Repair and remanufacturing

Recycling – 18%

- Supply chain logistics
- Design for circularity
- Improved recycling processes
- Improved separation/purity

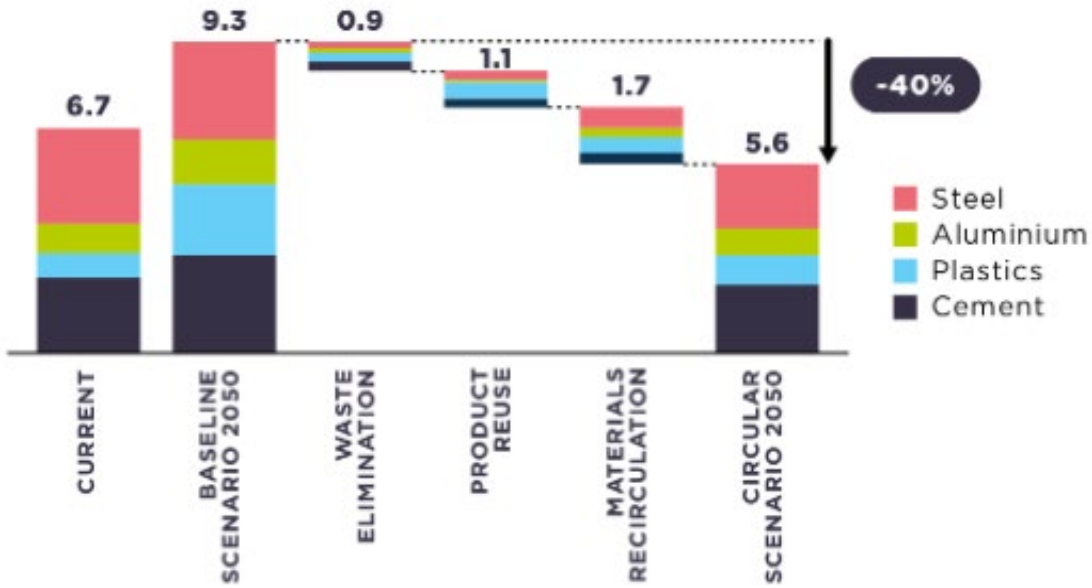
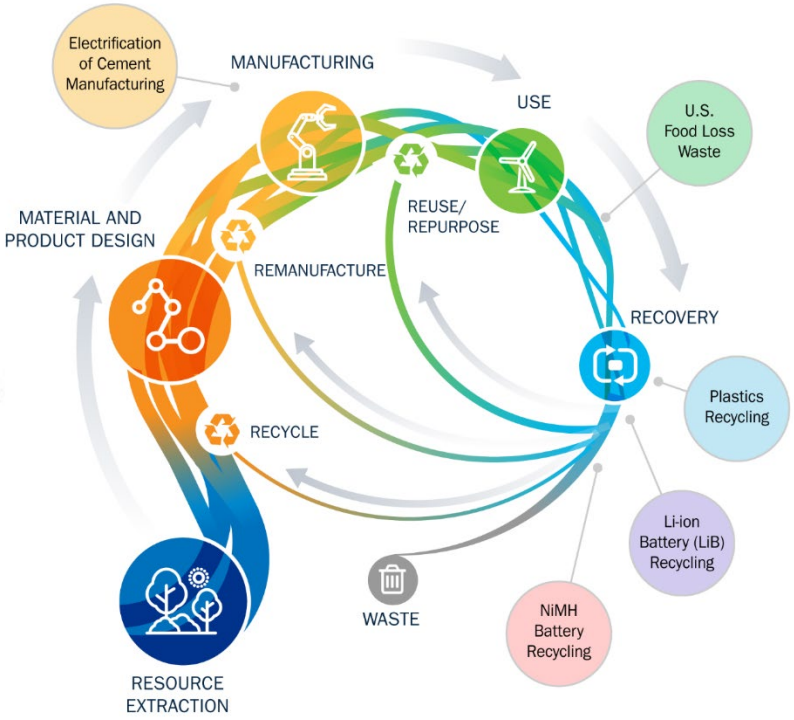


FIGURE 4: A CIRCULAR ECONOMY COULD REDUCE ANNUAL GLOBAL CO_2e EMISSIONS FROM KEY INDUSTRY MATERIALS BY 40% OR 3.7 BILLION TONNES IN 2050

GLOBAL CO_2e EMISSIONS FROM FOUR KEY MATERIALS PRODUCTION BILLION TONNES OF CO_2e PER YEAR

[Completing the picture: How the circular economy tackles climate change (ellenmacarthurfoundation.org)]



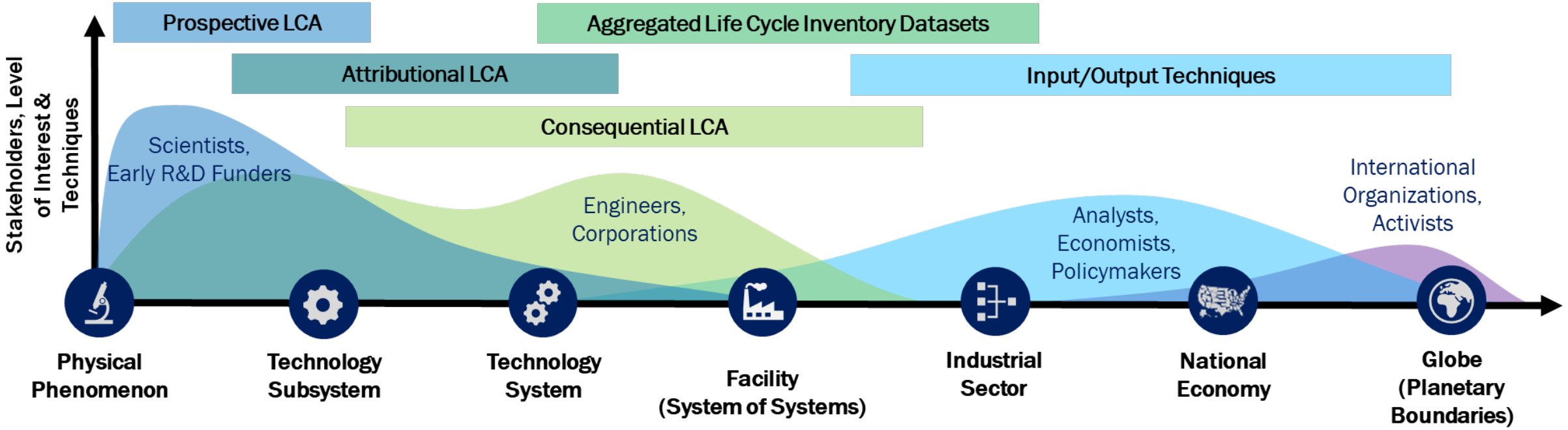
If done well, circular economy can reduce:

- Industrial emissions and energy consumption
- Water use and wastewater generation
- Need for extraction
- Broad environmental impacts

[Sustainable Manufacturing and the Circular Economy | Department of Energy]

[Sustainable Materials Selection in Manufactured Products | Department of Energy]

Industrial decarbonization is a complex systems challenge



The imperatives for U.S. industrial decarbonization

Incremental solutions are insufficient:

- The need for an industrial re-revolution

CO_2 emissions from inefficient materials flows are a problem:

- The opportunity for more thoroughly efficient production processes

GHGs are one environmental impact factor:

- The need for more thoroughly sustainable manufacturing

Looking Forward - Funding Opportunity

$83M for Applied RD&D to Decarbonize Heavy Industry

Date	Milestone
Jan 25	FOA Issue Date
Mar 19	**Concept Papers Due**
Jun 11,	Full Application Due
Oct '24	Award Announcements

Topic 1: Chemicals & Fuels

1. Sustainable feedstocks → chem/fuel
2. Non-hydrocarbon products
3. Value chain approach

Topic 2: Iron and Steel

1. Alternative ironmaking (non-H_2 DRI)
2. Ore beneficiation
3. Recycling (tramp metal solutions)
4. Steelmaking with low-carbon iron

Topic 3: Food and Beverage

1. Food packaging
2. Commercial food services
3. Energy recovery/redistribution
4. Post-Harvesting activities

Topic 4: Cement, Asphalt, Glass

1. Binders & SCMS → Concrete
2. Novel lime/OPC processing
3. Asphalt
4. Glass

Topic 5: Forest Products

1. Dewatering & drying
2. Fiber prep, pulping, chemical recovery

Topic 6: Industrial Pre-FEEDs

1. H_2 feedstock integration **(HFTO)**
2. Carbon Capture, heavy industry **(FECM)**
3. Process integration **(IEDO, FECM, HFTO)**

www.energy.gov/eere/iedo/iedo-fy24-energy-and-emissions-intensive-industries-foa

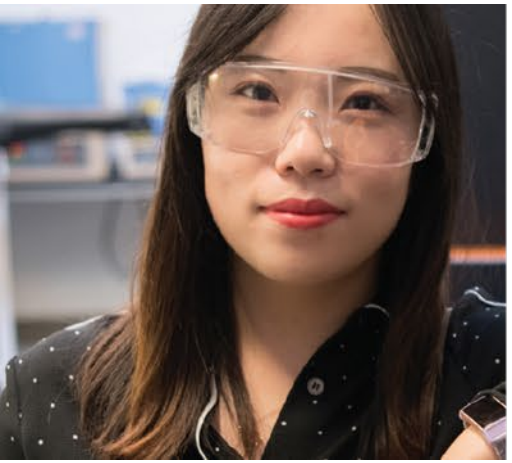
Also …

1. IEDO is Hiring!
   - Cross-Sector Technology Manager, Iron & Steel, Cement & Concrete.

Email: IEDOJobs@ee.doe.gov

www.energy.gov/eere/iedo/iedo-careers

2. Coming: Industrial Decarbonization Pathways Strategy Initiative
   - Led by IEDO (follow on to the Roadmap); broad DOE initiative
   - Workshop planned (seeking participation and engagement)



Closing Thoughts

Technology Investment Portfolios

- Investment strongly influences outcomes
- Too much diversification is a bad strategy
- It is essential to make targeted investments
- Should put a few eggs in the right baskets

ELSEVIER

Journal of Economic Dynamics and Control
Volume 101, April 2019, Pages 211-238

Wright meets Markowitz: How standard portfolio theory changes when assets are technologies following experience curves

Rupert Way [a b], François Lafond [a b c], Fabrizio Lillo [d e], Valentyn Panchenko [f], J. Doyne Farmer [a g h]

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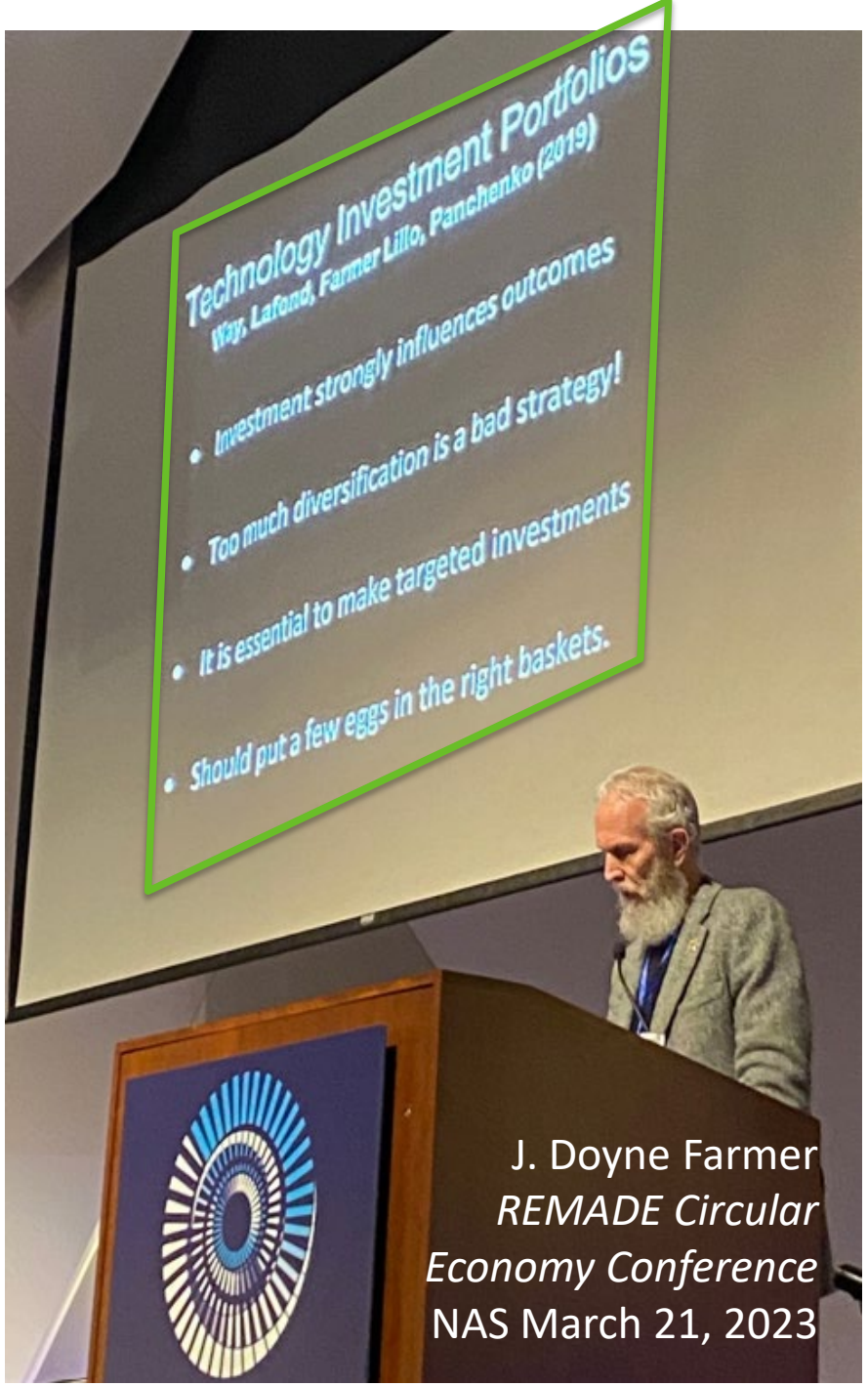

J. Doyne Farmer
REMADE Circular Economy Conference
NAS March 21, 2023

Special Thanks to the IEDO Strategic Analysis Team

ANL – Sarang Supekar, Nwike Iloeje, Diane Graziano

LBNL – Arman Shehabi, Prakash Rao, Jibran Zuberi

NREL – Alberta Carpenter, Samantha Reese, James McCall, Darlene Steward, Taylor Uekert, Hope Wikoff

ORNL – Sachin Nimbalkar, Kristina Armstrong, Prashant Nagapurkar, Kiran Thirumaran, Ikenna Okeke, Dipti Kamath

Energetics – Caroline Dollinger, Sam Gage, Brian Ray

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For additional information:

https://www.energy.gov/eere/iedo/energy-analysis-data-and-reports