U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

You Can't Buy Clean if it's not Made Clean.

Embodied Carbon Workshop

ACEEE 2023 Industry Summer Study, July 11, 2023

Joe Cresko

Chief Engineer, DOE Industrial Efficiency & Decarbonization Office (IEDO)

Outline:

- **DOE Industrial Decarbonization Roadmap –** Pillars, and associated pathways to near-zero GHG emissions by 2050, and key industrial subsectors.
- **Rethinking the opportunity space –** The potential new and robust technology solutions.
- **Innovation -** Research, development & demonstration (RD&D) for more sustainable manufacturing.

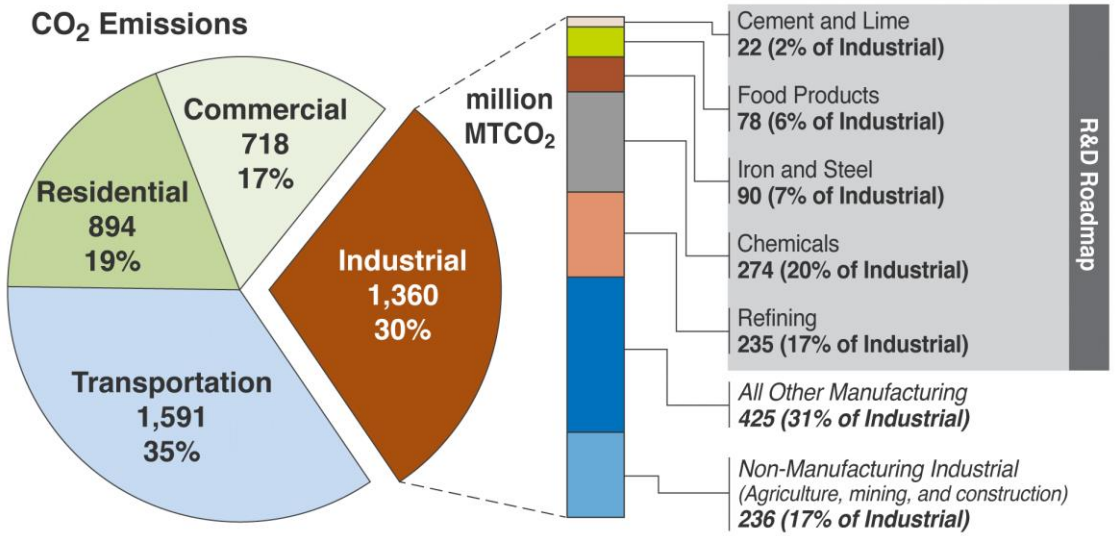
Goal: a sustainable, decarbonized, internationally competitive US industrial sector

U.S. Industry's Significant Energy Demand and CO_2 Emissions …

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

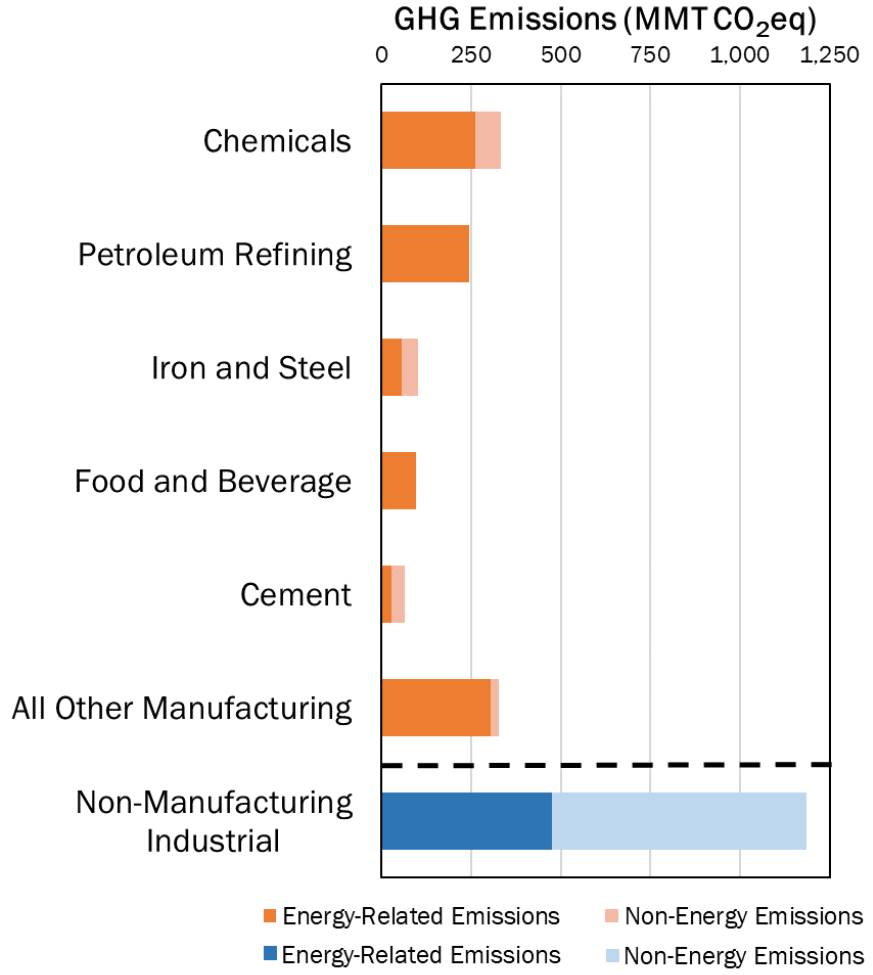
ACCOUNTS FOR **30%** of energy-related CO_2 emissions

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



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

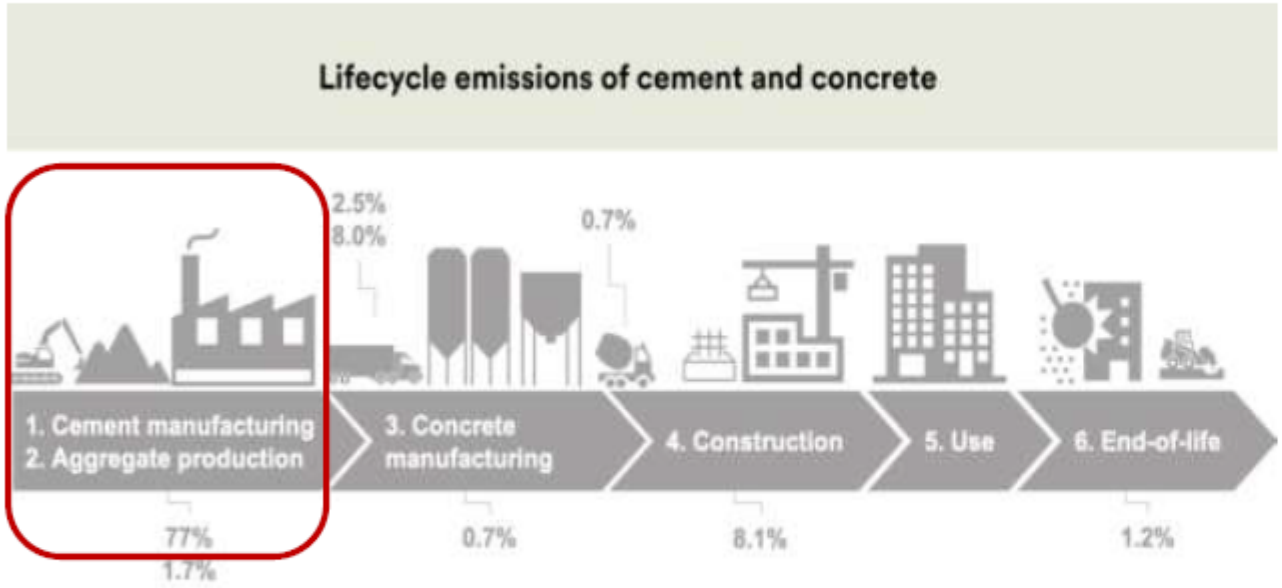
Total Industry Emissions, 2018
(energy-related + non-energy; million metric tons CO_2eq)



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

…Result in Significant Embodied Carbon

What is "Embodied Carbon"?

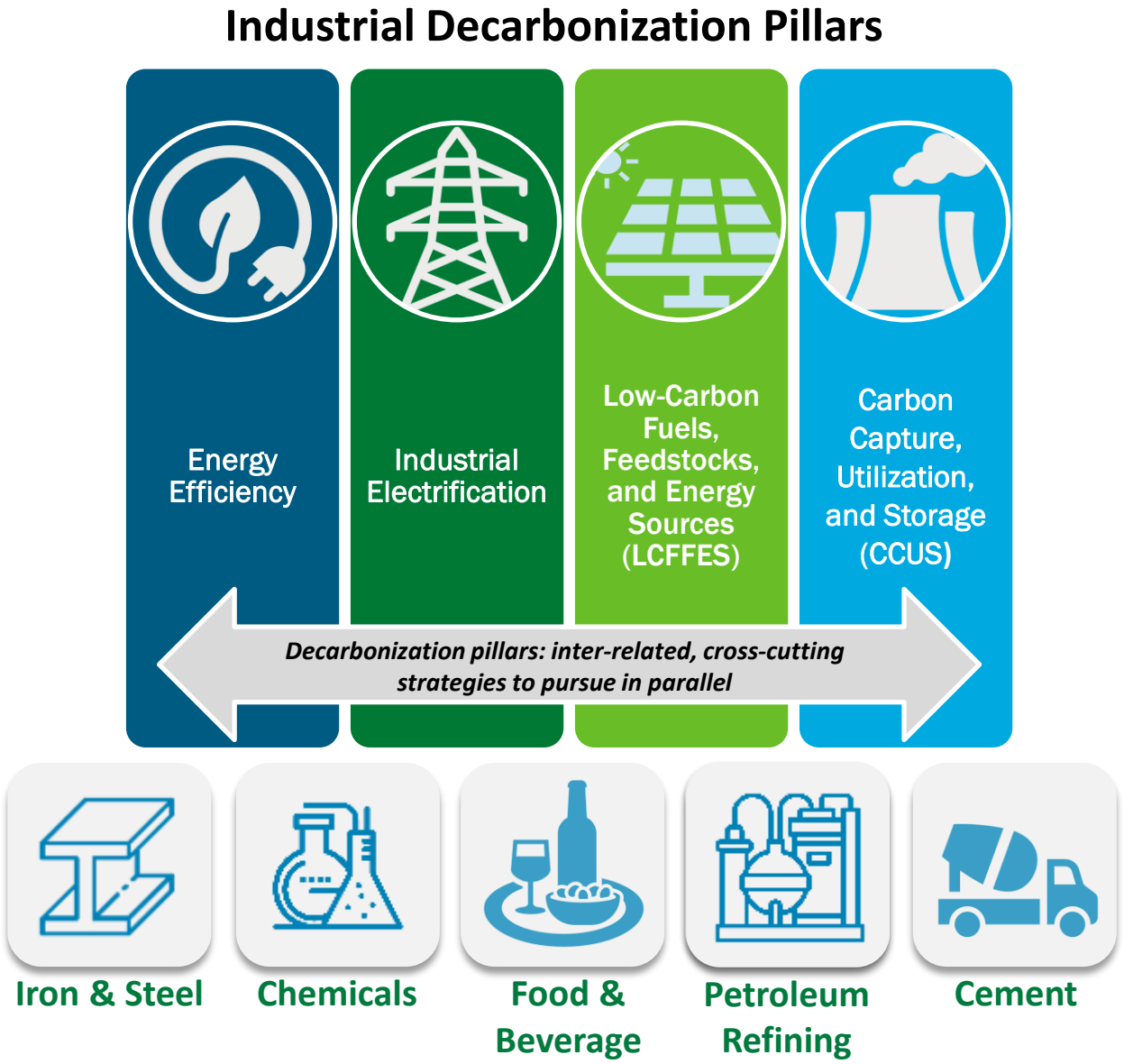


- "**Embodied carbon**" refers to the amount of greenhouse gas (GHG) emissions associated with the extraction, production, transport, and manufacturing of material
- Traditional manufacturing uses energy-intensive processes to extract raw materials like limestone, taconite ore, and silica converting those raw materials via industrial processes to produce an end product

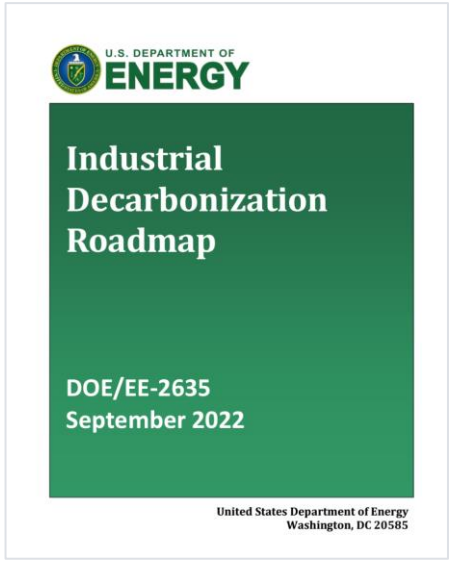
- For example, virtually all **embodied carbon in concrete** originates from the first step in the process – **cement production**
- Federal and local governments **purchase almost 50%** of the concrete poured in the U.S. each year

Figure 1. Lifecycle emissions of cement and concrete showing percent GHG emissions associated with the production of concrete. Cao & Masanet, 2021. Reprinted with permission of Eric Masanet.

DOE Industrial Decarbonization Roadmap - Pillars and Sector Focus Areas



- Invest in all pillars
- Leverage cross-sector approaches
- Interdependencies require systems solutions

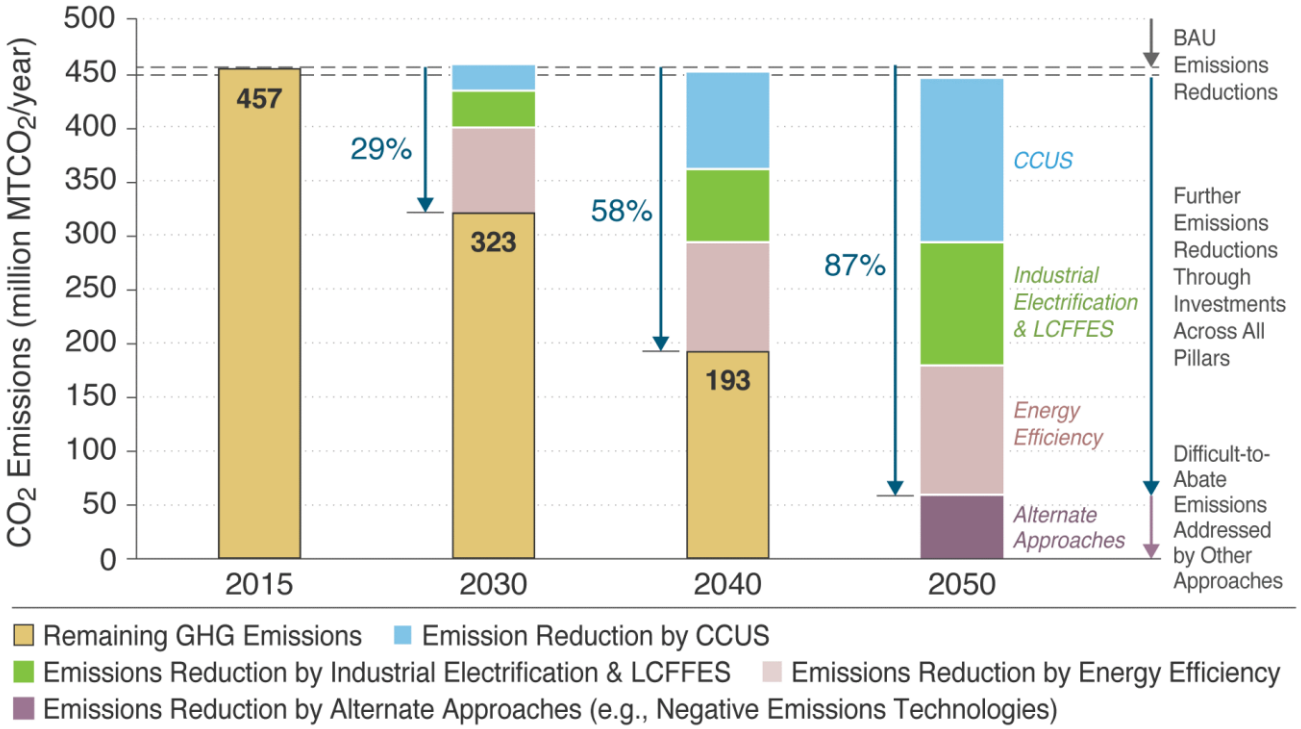


https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

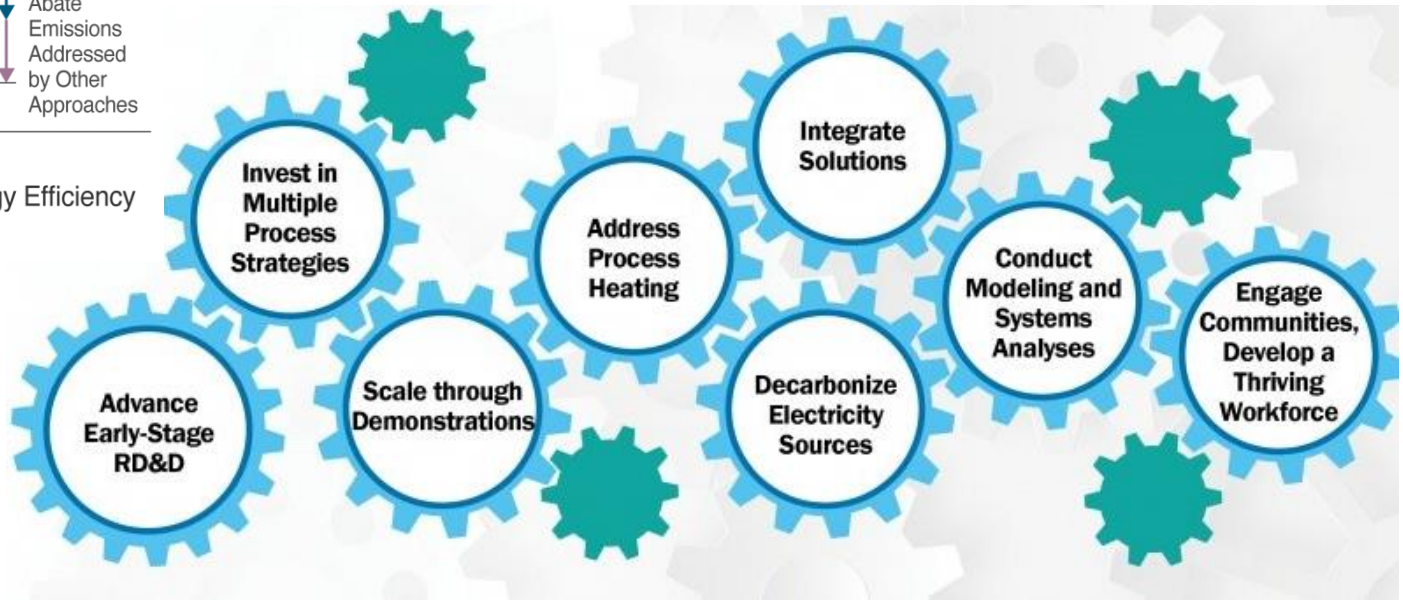
Cement & Concrete Decarbonization Levers

Technology Advancement	Examples	Advantages	Disadvantages
Alternative Binders or Process Routes to OPC	• Alternative chemical routes to OPC clinker • Non-OPC binders and non-hydraulic	• Alternative routes to OPC → **Same product** • Eliminate limestone calcination	• Processes at low TRL • Different products (code/acceptance/performance)
Carbon Capture	• Cement kiln flue gas capture at full scale	• Reduces process and energy emissions • **Same product**	• High CAPEX, OPEX (energy) • Infrastructure for CO_2 transport • Siting and permitting
Clinker Substitutes	• Waste glass, LC3 (calcined clay), synthetic pozzolans • Blended PLCs	• **High impact** (displace clinker use) • Less code compliance issues • Properties enhancement	• New standards & testing • Limited regional feedstocks • Impacted concrete property
CO_2 Mineralization	• CO_2 cured concrete (non-hydraulic/ hydraulic) • SCMs from CO2 Mineralized waste	• Durable storage of CO_2—Carbon Negative • Enhanced properties (strength) • Short cure time (concrete)	• Complex equipment/process • New codes/standards/testing • Durability (Rebar corrosion)
Energy Efficiency (Thermal & Electric)	• Smart monitoring, waste heat use • Process optimization (machine learning) • Grinding process innovations	• **High industry acceptance** • 20% improvement since 1990 • Readily implemented	• Low overall impact for electricity ~ 15% of energy consumption; < ~10% CO_2e). • State of art plants ~ 80% thermal efficiency
Electrification & Low-carbon fuels	• H_2, trash, bio-fuels, oxy-combustion • Electric heating (kiln/calciner)	• **Same product** • **Same existing standards**	• Supply & infrastructure • CAPEX for retrofitting
Alt Building Materials/ Construction	• Ultra-high strength structural concrete • Insulated precast panels • Intelligent engineering design	• Reduced concrete/material use • Existing or new cement/supply chain	• Can't eliminate cement use • Reduced safety factor

2050 Industrial Net-Zero Emissions Reductions Potential*



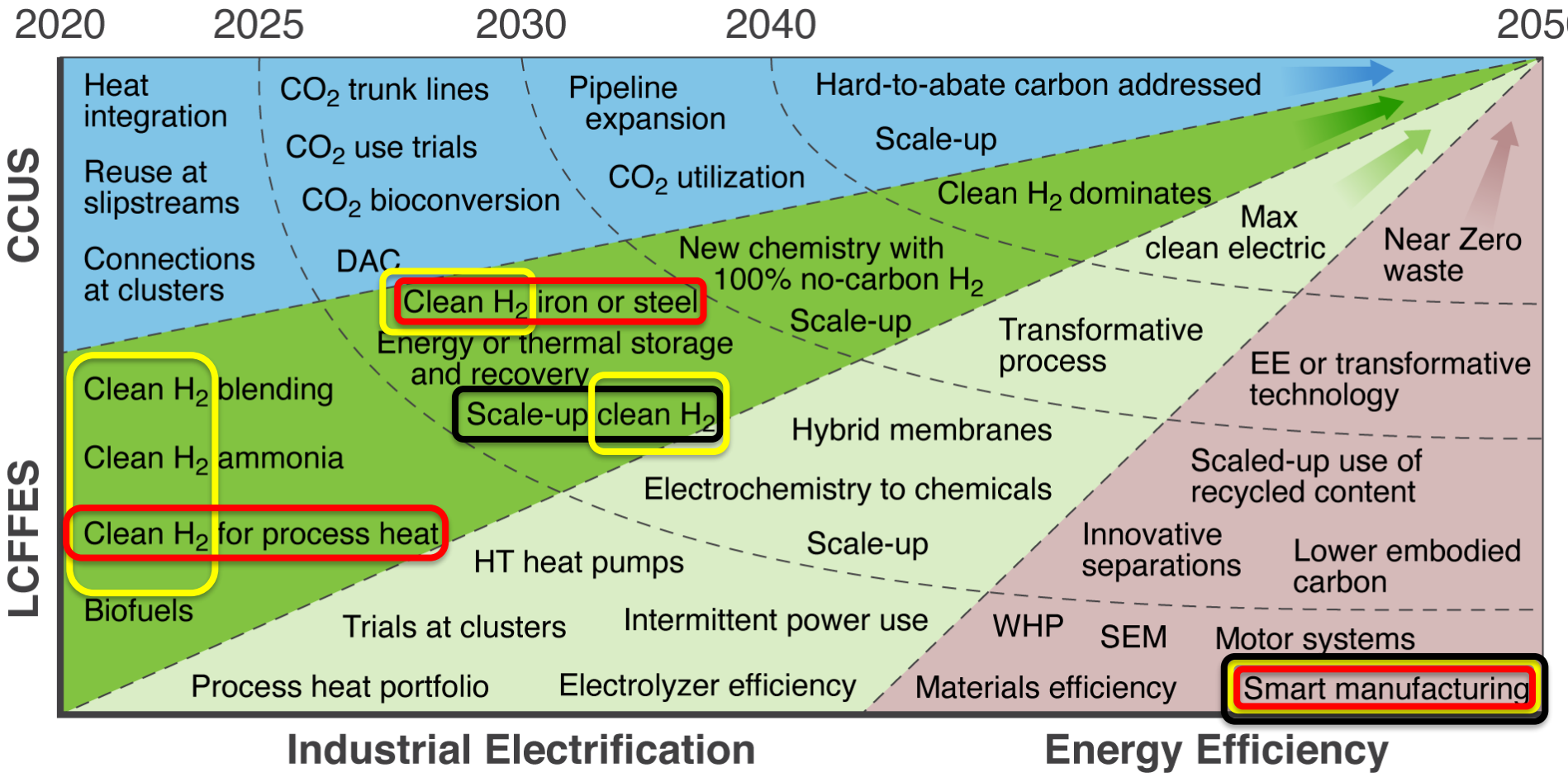
Recommendations



***Iron & Steel, Chemicals, Food & Beverage, Petroleum Refining, and Cement.** *(Net-zero GHG scenario, excluding feedstocks).*

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

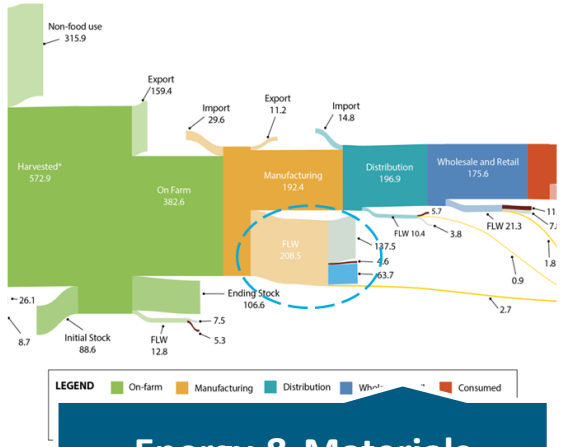
Industrial GHGs require approaches at multiple levels:

- Core process
- Facility
- Beyond plant bounds

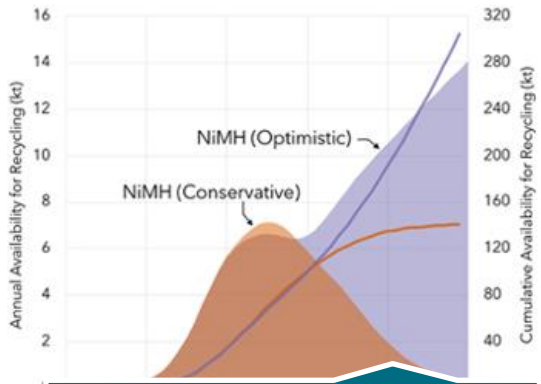
What are the implications of:

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

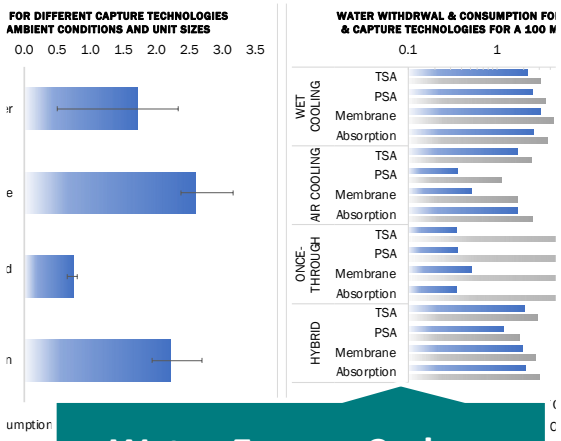
https://www.energy.gov/eere/iedo/energy-analysis-data-and-reports



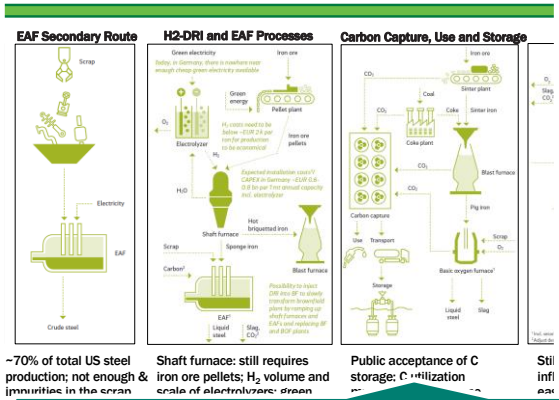
Energy & Materials Resource Flows



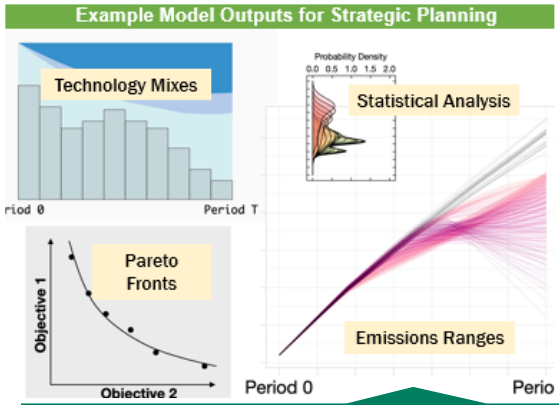
Sustainable & Circular Economy



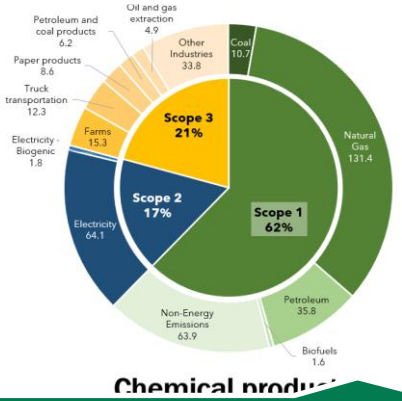
Water-Energy-Carbon Nexus



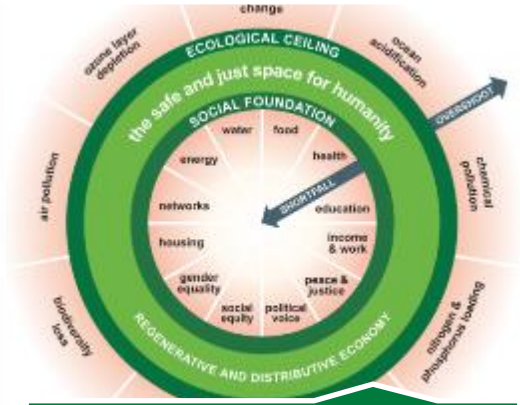
Industrial Decarbonization: Extended Pathways Analysis



Industrial Decarbonization: Integrated Systems & Deep Dives Analyses



Environmentally Extended Input-Output for Industrial Decarbonization Analysis



Project & Portfolio Impact & Environmental Justice Analysis

U.S. Federal Buy Clean Initiative - https://www.sustainability.gov/buyclean/

- The **Department of Energy (DOE)** is supporting Buy Clean with training, technical assistance, and innovation grants. The Building Technology Office is building tools such as GREET ↗ for whole building lifecycle analysis and the Advanced Manufacturing Office is supporting with tools such as LIGHTEnUp ↗ and MFI ↗ to support standard-setting for specific products.

FACT SHEET: Biden-Harris Administration Announces New Buy Clean Actions to Ensure American Manufacturing Leads in the 21st Century | The White House

NREL Transforming ENERGY

energetics Clean Energy Consulting

BERKELEY LAB Lawrence Berkeley National Laboratory

Materials Flow through Industry (MFI) Tool
Linear network model of the U.S. industrial sector. It can model a range of manufacturing scenarios, including the effects of changes in production technology and increases in industrial energy efficiency.

https://www.nrel.gov/manufacturing/mfi-modeling-tool.html

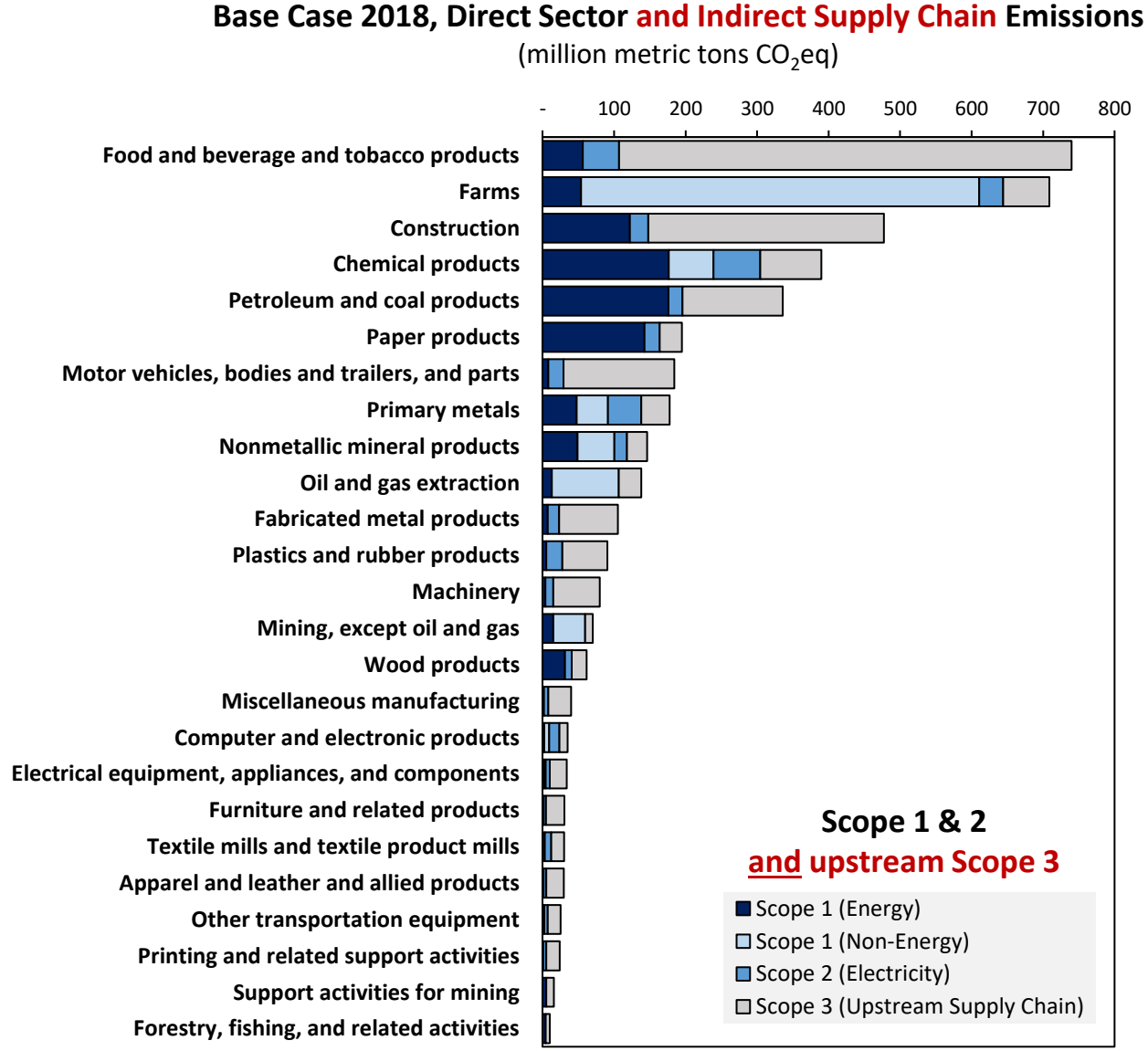
Environmentally-Extended Input/Output (EEIO) models
Input/output techniques to estimate the total impact of an industry's products on environmental metrics, such as greenhouse gas emissions.

LIGHTEn-UP Tool
Scenario framework for assessing prospective net energy impacts of a technology/product, accounting for both manufacturing and end-use life cycle phases.

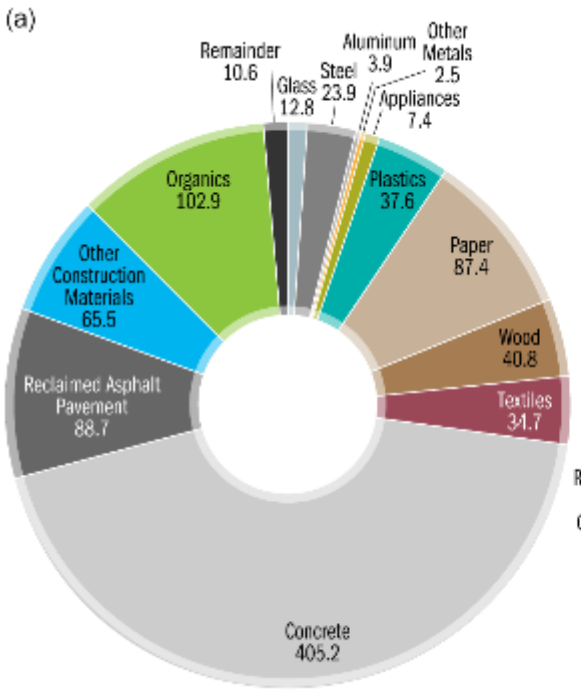
https://energyanalysis.lbl.gov/tools

LIGHTEn-UP: Lifecycle Industry GreenHouse gas, Technology and Energy through the Use Phase

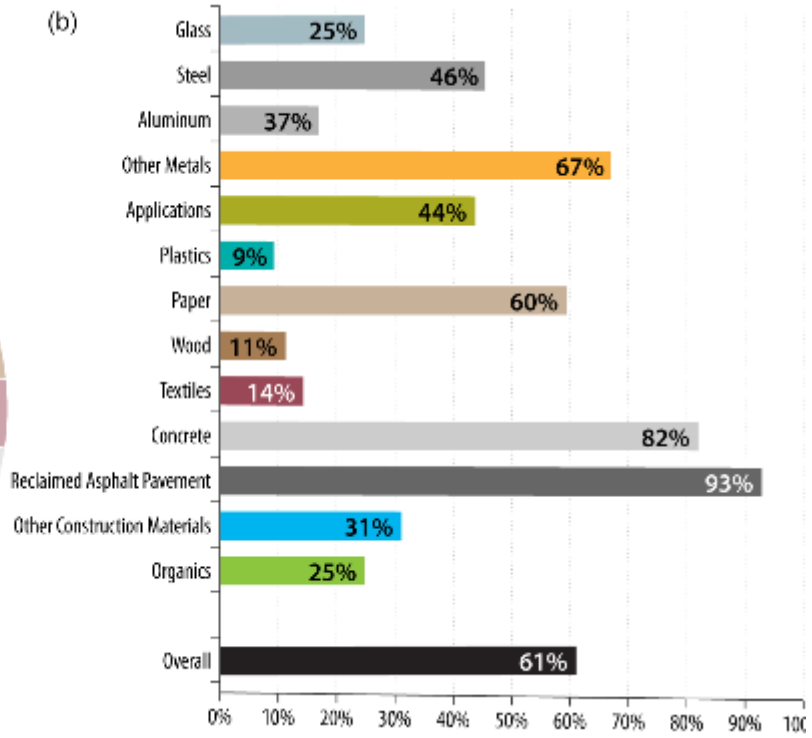
GHG Emission in Context: Significance of Supply Chain Emissions



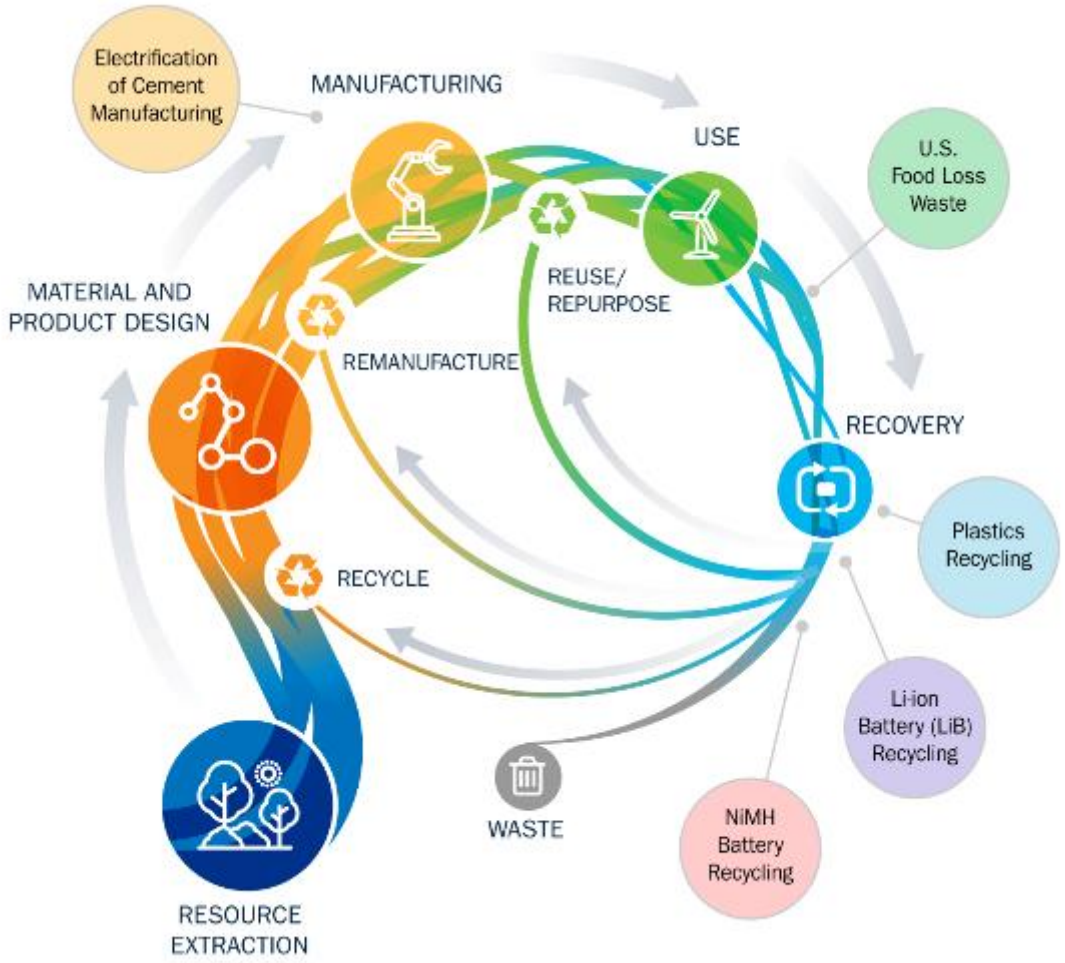
Emerging Opportunities for Material Circularity



U.S. generated waste in 2018 (million tons)



U.S. recycled waste fractions in 2018



DOE Study on *Sustainable Manufacturing*.
https://www.energy.gov/eere/amo/articles/sustainable-manufacturing-and-circular-economy

Calculations in figure based on data in "Advancing Sustainable Materials Management: 2018 Fact Sheet" (EPA 2020).
https://www.epa.gov/sites/default/files/2020-11/documents/2018_ff_fact_sheet.pdf

What will it take to decarbonize industry?

Risk to Industry's Bottom Line

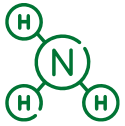
Investment scale → In the range of

$11-21 Trillion

just for 4 sectors:


cement


steel



ammonia

ethylene

(McKinsey, 2018)

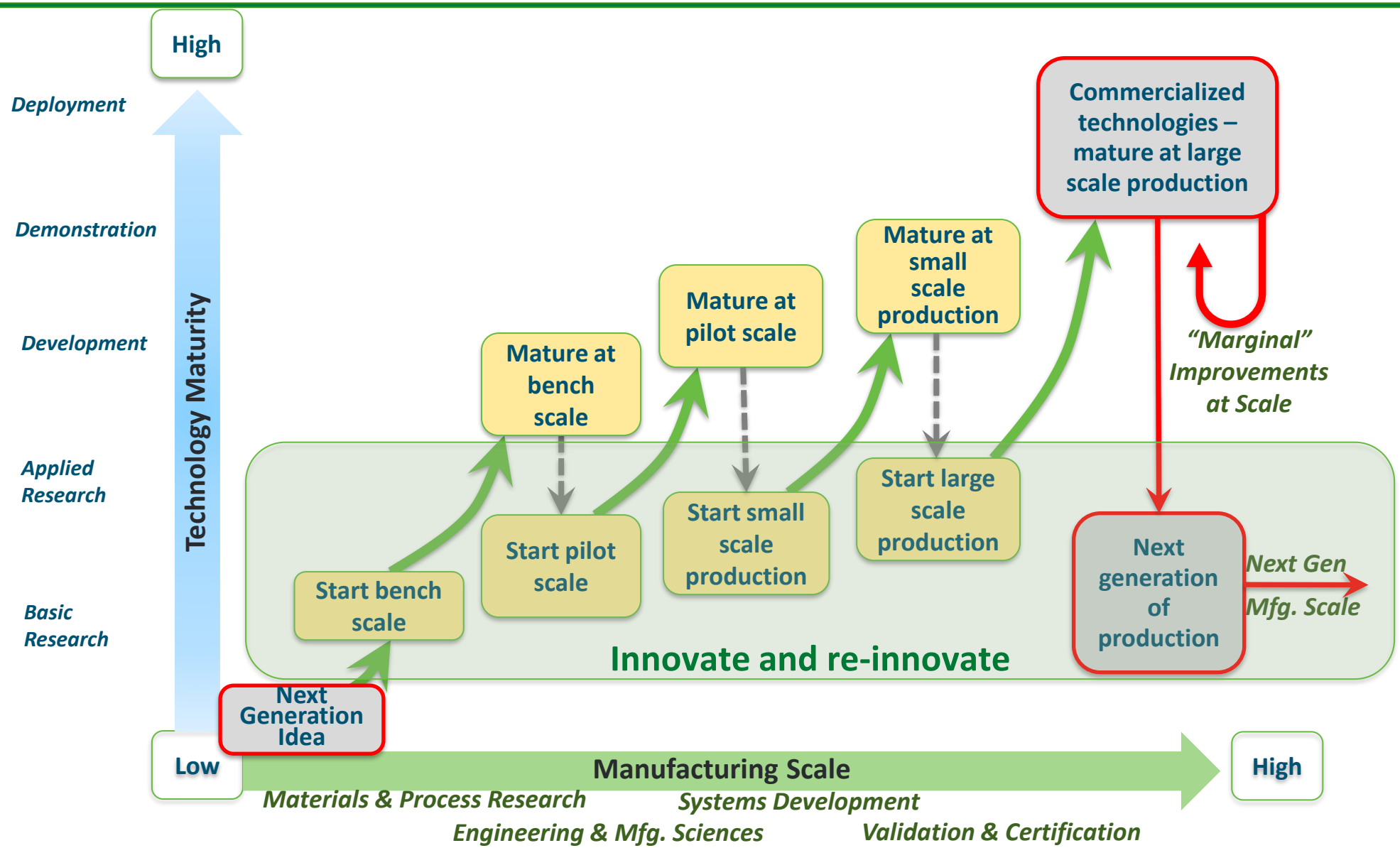
Estimated that

60% of heavy industry emissions reductions

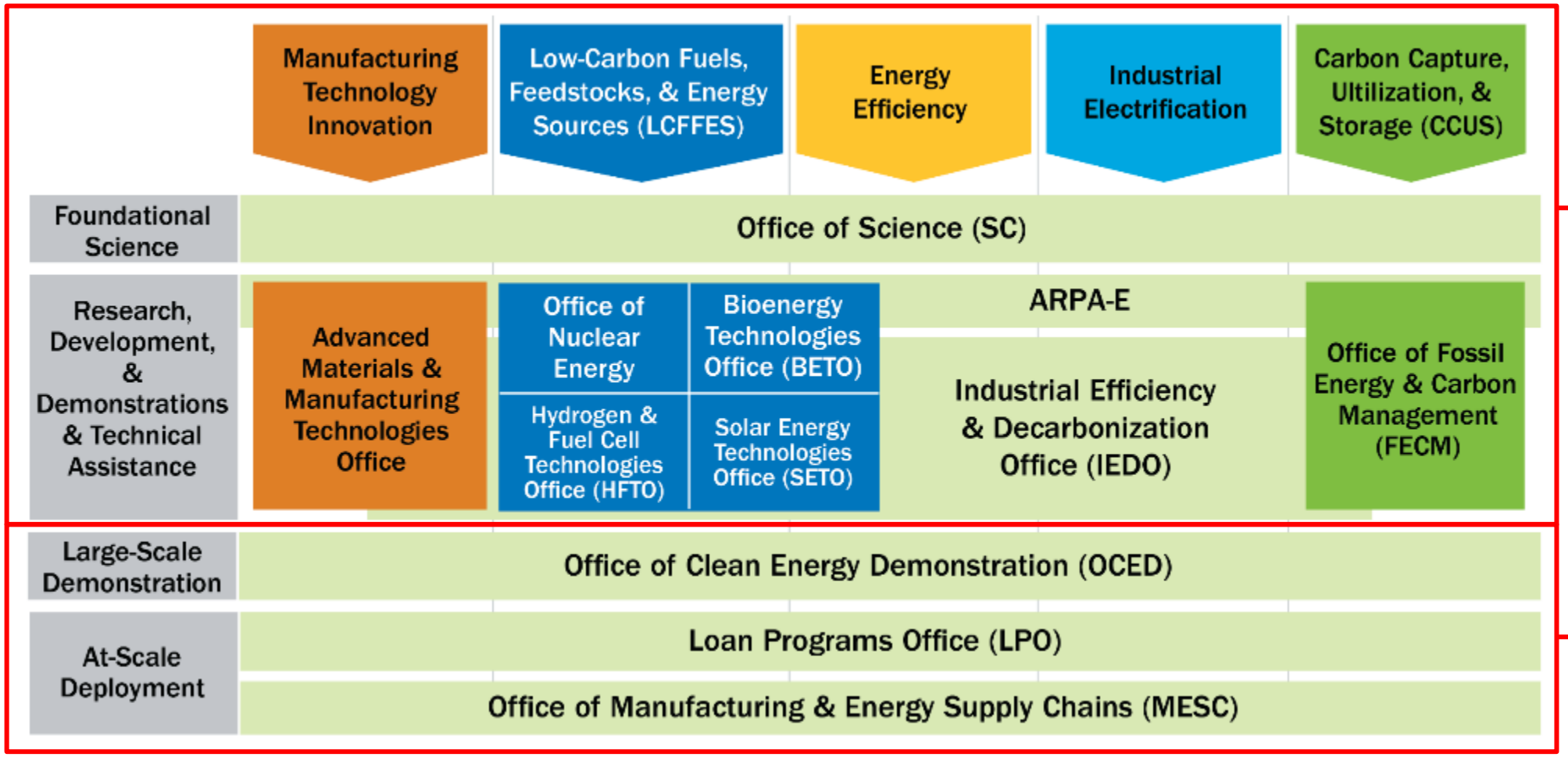
by 2050 will come from technologies that are **not currently market ready**
(IEA, 2022)

Targeted investment for research, development, and pilot-scale demonstrations can help U.S. industry overcome these barriers

Innovation is not linear – low TRL opportunities at all manufacturing scales.



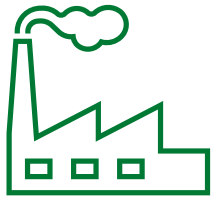
DOE Offices Share a Common Strategic Framework



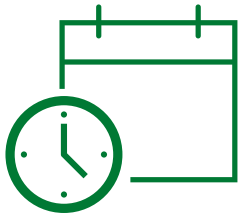
DOE Energy EarthShots

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

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Hydrogen

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Carbon Negative™

ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Clean Fuels & Products™

https://www.energy.gov/policy/energy-earthshots-initiative

IEDO Strategic Analysis Team

Thank You

joe.cresko@ee.doe.gov

For additional information:

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

ANL – Sarang Supekar, Nwike Iloeje, David Thierry, Diane Graziano

LBNL – Arman Shehabi, Prakash Rao, Jibran Zuberi

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

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

Energetics – Heather Liddell, Caroline Dollinger, Brian Ray

DOE – Zach Pritchard

Backup slides