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

Embodied Carbon Workshop

ACEEE 2023 Industry Summer Study, July 11, 2023
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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 CO₂ Emissions ...

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

ACCOUNTS FOR 30% of energy-related CO₂ emissions

Energy-Related CO₂ emissions, 2020 (million metric tons)

- Commercial: 718 (17%)
- Residential: 894 (19%)
- Transportation: 1,591 (30%)
- Industrial: 1,360 (31%)
- Non-Manufacturing Industrial: 238 (17%)
- Cement: 235 (17%)
- Chemicals: 274 (20%)
- Food Products: 78 (6%)
- Iron and Steel: 90 (7%)
- Petroleum Refining: 72
- All Other Manufacturing: 425 (31%)

Total Industry Emissions, 2018 (energy-related + non-energy; million metric tons CO₂eq)

GHG Emissions (MMT CO₂eq)

- Chemicals
- Petroleum Refining
- Iron and Steel
- Food and Beverage
- Cement
- All Other Manufacturing
- Non-Manufacturing Industrial


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

**Industrial Decarbonization Pillars**

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

**Decarbonization pillars: inter-related, cross-cutting strategies to pursue in parallel**

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

Related sectors:
- Iron & Steel
- Chemicals
- Food & Beverage
- Petroleum Refining
- Cement

# Cement & Concrete Decarbonization Levers

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<th>Technology Advancement</th>
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| 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 CO₂ 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 |
| CO₂ Mineralization | • CO₂ cured concrete (non-hydraulic/hydraulic)  
• SCMs from CO₂ Mineralized waste | • Durable storage of CO₂—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% CO₂e.  
• State of art plants ~ 80% thermal efficiency |
| Electrification & Low-carbon fuels | • H₂, 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*


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

What are the implications of:
- Expanded H₂ 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
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.

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.

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.
GHG Emission in Context: Significance of Supply Chain Emissions

Base Case 2018, Direct Sector Emissions
(million metric tons CO₂e)

Scope 1 & 2 only
- Electricity
- Electricity - Biogenic
- Biofuels
- Coal
- Natural Gas
- Petroleum
- Non-Energy

Scope 1 & 2 only and upstream Scope 3
- Scope 1 (Energy)
- Scope 1 (Non-Energy)
- Scope 2 (Electricity)
- Scope 3 (Upstream Supply Chain)
Emerging Opportunities for Material Circularity

Calculations in figure based on data in “Advancing Sustainable Materials Management: 2018 Fact Sheet” (EPA 2020).

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

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| Carbon Capture, Utilization, & Storage (CCUS) |

Technologies for Industrial Emissions Reduction Development (TIEReD) Program

Industrial Demonstrations and Deployment Programs
DOE Energy EarthShots

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

>85% Lower Emissions  2035

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

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

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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