Industrial Decarbonization and Thermal Processes

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DOE Industrial Decarbonization

Industrial Decarbonization Roadmap
• Pillars, and associated pathways to near-zero GHG emissions by 2050.
• Opportunities for RDD&D

Industrial Process Heat
• Energy for thermal processes - by subsector, by process, by temperature range.
• Thermal opportunity
Advanced Manufacturing Office – Opportunity Space

- Improve the energy and carbon productivity of U.S. manufacturing.
- Reduce life cycle energy and resource impacts of manufactured goods.

Manufacturing Goods

- More efficient manufacturing reduces energy losses

More efficient manufacturing enables technologies that improve energy use throughout the economy:
  - Transportation
  - Buildings
  - Energy Production and Delivery

Use of Manufactured Goods

- Energy Losses
  - Industrial Manufacturing: 24.1%
  - Energy Losses: 12.7%

Data for 2014

U.S. Energy Economy by Sector
98.5 quadrillion Btu, 2014

1. Energy consumption by sector from EIA Monthly Energy Review, 2018
2. Industrial non-manufacturing includes agriculture, mining, and construction
3. US economy energy losses determined from LLNL Energy Flow Chart 2014 (Rejected Energy), adjusted for manufacturing losses
4. Manufacturing energy losses determined from DOE AMO Footprint Diagrams (2014 data)
Industry’s Significant CO₂ Emissions

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

Accounts for 32% of the nation’s primary energy use of CO₂ emissions

28% of CO₂ emissions

Anticipated industrial sector energy demand growth of 30% by 2050 may result in a 15% CO₂ emissions increase

Technological advances in manufacturing will be critical to enabling decarbonization for other sectors.

Industrial Decarbonization Roadmap identifies RD&D to achieve significant, economical greenhouse gas emission reductions by 2050.

EIA, Annual Energy Outlook 2020 with Projections to 2050.
Congressional direction guided the roadmap methodology and industry engagement.

“... the Department shall develop decarbonization roadmaps in key technology areas to guide research and development at the Department to achieve significant, economical GHG emission reductions by 2050, including energy efficiency, process electrification, industrial electrification technologies, and carbon capture. Roadmaps should be developed in consultation with external stakeholders and relevant offices within the Department.

• Roadmap has solicited input from varied sources. It focuses on RDD&D needs and opportunities that align with Administration priorities, industry’s needs, and will enhance U.S. manufacturing competitiveness.

Stakeholder workshops and report drafting engaged over 180 experts from across DOE, industry, academia, and National Labs.
Multiple Pillars of Decarbonization Must be Pursued in Parallel

Technical opportunities across a range of Technology Readiness Levels (TRLs)

- **Lower TRLs:** Investments in early-stage low carbon technologies will be needed soon to ensure future market viability.
- **Higher TRLs:** Prompt investments are essential to lower adoption hurdles and rapidly scale later-stage technologies.

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

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

Source: Industrial Decarbonization Roadmap
Identified key pillars of industrial decarbonization:

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

Explored the technologies, processes, and practices of the five largest energy consuming industrial sectors in the U.S.

- Iron and Steel
- Chemicals
- Food and Beverage
- Petroleum Refining
- Cement

- GHG reduction scenarios across iron and steel, chemical manufacturing, food manufacturing, petroleum refining and cement sectors (near zero GHG scenario, excluding feedstocks).
- Industrial electrification and Low Carbon Fuels, Feedstock, and Energy Sources (LCFFES) are composite input to scenarios.

Source: Industrial Decarbonization Roadmap
<table>
<thead>
<tr>
<th>Industry Sector</th>
<th>Carbon Emissions Context</th>
<th>Emerging Decarbonization Technologies</th>
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</table>
| Iron and Steel           | Globally, every ton of steel produced in 2019 emitted on average 1.83 tons of CO$_2$, equating to about 10 percent of global CO$_2$ emissions.                                                                                   | • **LCFFES**: Alternative reductants – e.g., hydrogen direct reduction (H-DR) of iron/steel  
• **Industrial Electrification**: Advanced Electric-arc furnace technology to enable high-quality steel production from scrap; Molten-oxide electrolysis for more direct routes to products  
• **CCUS**: Carbon Capture, Utilization and Storage (CCUS) |
| Cement and Concrete      | A large amount of the CO$_2$ emissions associated with cement/concrete production result from high temperature processing and the chemical reaction that that occurs during production of Portland cement.                                           | • **LCFFES**: Alternative cement chemistries to reduce process emissions. Alternative energy sources  
• **CCUS**:  
  • Capture and utilization of carbon for emissions reduction and improved manufacturing processes/products  
  • Greater use of supplemental cementitious materials (SCMs) to sequester additional carbon dioxide |
| Chemicals and Chemical Products | Key chemicals such as ethylene, propylene, and methanol require significant fossil fuels for processing and manufacturing.                                                                                           | • **Industrial Electrification**: Reduce fossil fuel use and improve yield and productivity; New separation processes – reduce fossil energy use for heating and maintaining operating temperatures for emerging separation processes  
• **Energy Efficiency**: Catalysts – reduce fossil energy use for heating and maintaining catalyst temperatures and improve yield, selectivity, and productivity  
• **LCFFES**: Sustainable, clean processes for non-fossil-based feedstocks and energy sources  
• **CCUS**: Significant opportunity given carbon-based nature of chemical products |
The industrial decarbonization roadmap addresses the need to accelerate RDD&D of emerging & transformative technologies to achieve **near-zero GHG emissions in the industrial sector by 2050**

- **Pursue multiple decarbonization pillars in parallel**, including energy efficiency; industrial electrification, low-carbon fuels, feedstocks, and energy sources; and CCUS.

- **Drive low capital investment approaches**, with multiple benefits that spur early action, including energy and materials efficiency.

- **Portfolio should include new technologies**, integration into process systems and supply chains.

- **Invest early in low-carbon process technologies** to ensure future market viability.

- **Align with expansion of renewable energy and other low-carbon assets.**

- **Develop workforce across industries** with a spectrum of skill sets and diversity and inclusion.

*Source: Industrial Decarbonization Roadmap*
Sankey Diagram of Energy Flows in the U.S Manufacturing Sector

U.S. Manufacturing Sector (TBtu), 2014

LEGEND:
- Yellow: Fuel
- Blue: Steam
- Red: Electricity
- Green: Applied Energy
- Brown: Offsite Generation and Transmission Losses
- Gray: Onsite Generation and Distribution Losses
- White: End Use Losses

https://www.energy.gov/eere/amo/energy-analysis-data-and-reports
Energy & Associated Emissions Footprint of the U.S Manufacturing Sector

In the U.S., the total energy consumed for thermal processing in these 8 industries is roughly 95% the total energy consumed for thermal processing in all U.S. industries.

Source: EIA MECS 2014
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<td>Reactive thermal processing</td>
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<td>Smelting, agglomeration, etc.</td>
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<thead>
<tr>
<th>Temperature Range</th>
<th>Color</th>
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<tbody>
<tr>
<td>Low Temperature (&lt;800°F)</td>
<td>White</td>
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<tr>
<td>Medium Temperature (800 to 1400°F)</td>
<td>Yellow</td>
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<tr>
<td>High Temperature (&gt;1400°F)</td>
<td>Red</td>
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Thermal Opportunity

Process Heating Energy Use/Loss in the U.S. Economy

• 7 Quads opportunity space. Process heating accounts for a sizable fraction of total U.S. energy use, and more direct energy use than any other energy consuming processes in manufacturing. Currently process heating is 95% fossil fuel based.

• 95% fossil fuel based. Traditional industrial (thermal) processes can be inefficient, difficult to control and result in materials and products with compromised quality and performance.

• > 1 Quad potential. Assuming half of the energy lost in current process heating operations can be avoided, this represents a > 1% reduction in the total energy used in the U.S. economy.

Thermal Process Intensification Workshop:
Transforming the Way Industry Uses Thermal Process Energy
November 5 - December 9, 2020

<table>
<thead>
<tr>
<th>Low-thermal budget transformative technologies (mid- to long-term)</th>
<th>Alternative thermal processing (near- to mid-term)</th>
<th>Transformative supplemental technologies (near-term)</th>
<th>Waste heat management technologies (near-term)</th>
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<tbody>
<tr>
<td>Electrolysis and electrodialysis</td>
<td>Induction and resistance furnaces</td>
<td>Smart IoT devices for system optimization</td>
<td>High-temperature heat pumps</td>
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<td>MW and RF processing</td>
<td>Electric pre-heaters</td>
<td>Smart manufacturing (e.g., digital twin, AI, predictive process controls)</td>
<td>Thermal energy storage</td>
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<tr>
<td>Ultrasound processing and membrane separation for drying</td>
<td>Alternative liquid biofuels or biochemicals</td>
<td>Flexible, modular manufacturing and operations design</td>
<td>Recuperators, regenerators, and economizers for nontraditional applications</td>
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<tr>
<td>Hydrogen-based production of ammonia, methanol etc.</td>
<td>Hybrid fuel systems</td>
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<td>Thermoelectric devices, heat pipes etc.</td>
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<td>Solar thermal systems</td>
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<td>Waste heat to power, district heating, desalination etc.</td>
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Workshop was held November 5 - December 9, 2020
Report will be published soon.
Thanks!

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