Office of Energy Efficiency & Renewable Energy
Advanced Manufacturing Office

U.S. DEPARTMENT OF ENERGY

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

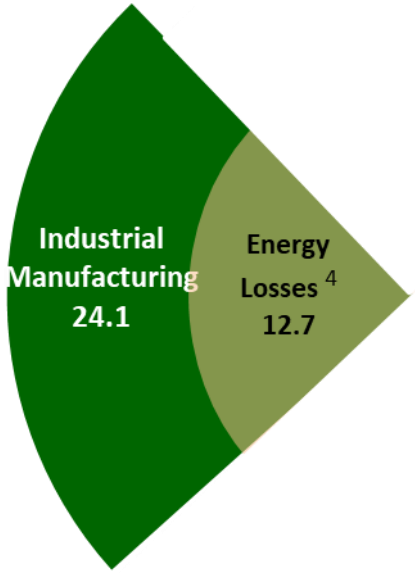
Industrial Process Heat

- 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



Data for 2014

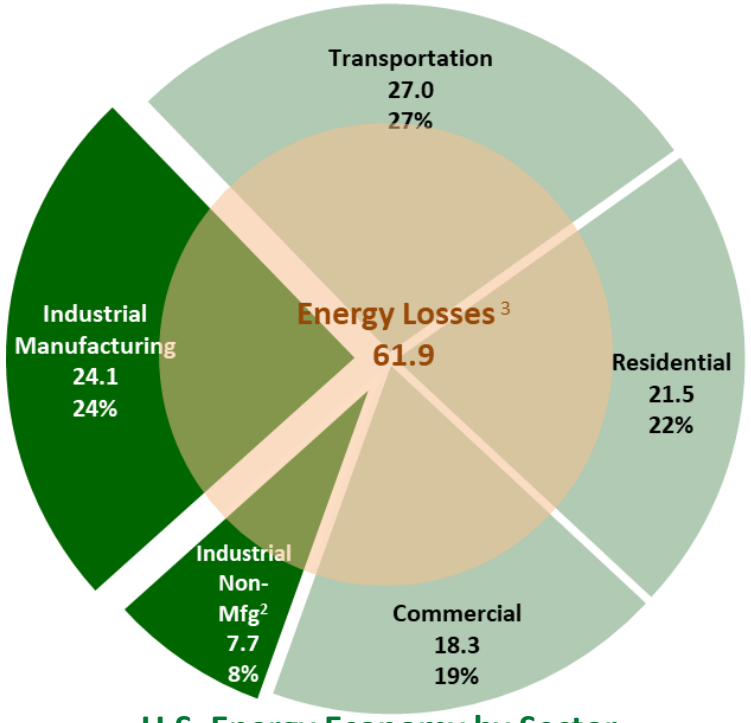
More efficient manufacturing reduces energy losses

and…

More efficient manufacturing enables technologies that improve energy use throughout the economy:

- **Transportation**
- **Buildings**
- **Energy Production and Delivery**

Use of Manufactured Goods



U.S. Energy Economy by Sector
98.5 quadrillion Btu, 2014 [1]

[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 CO_2 Emissions

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

ACCOUNTS FOR

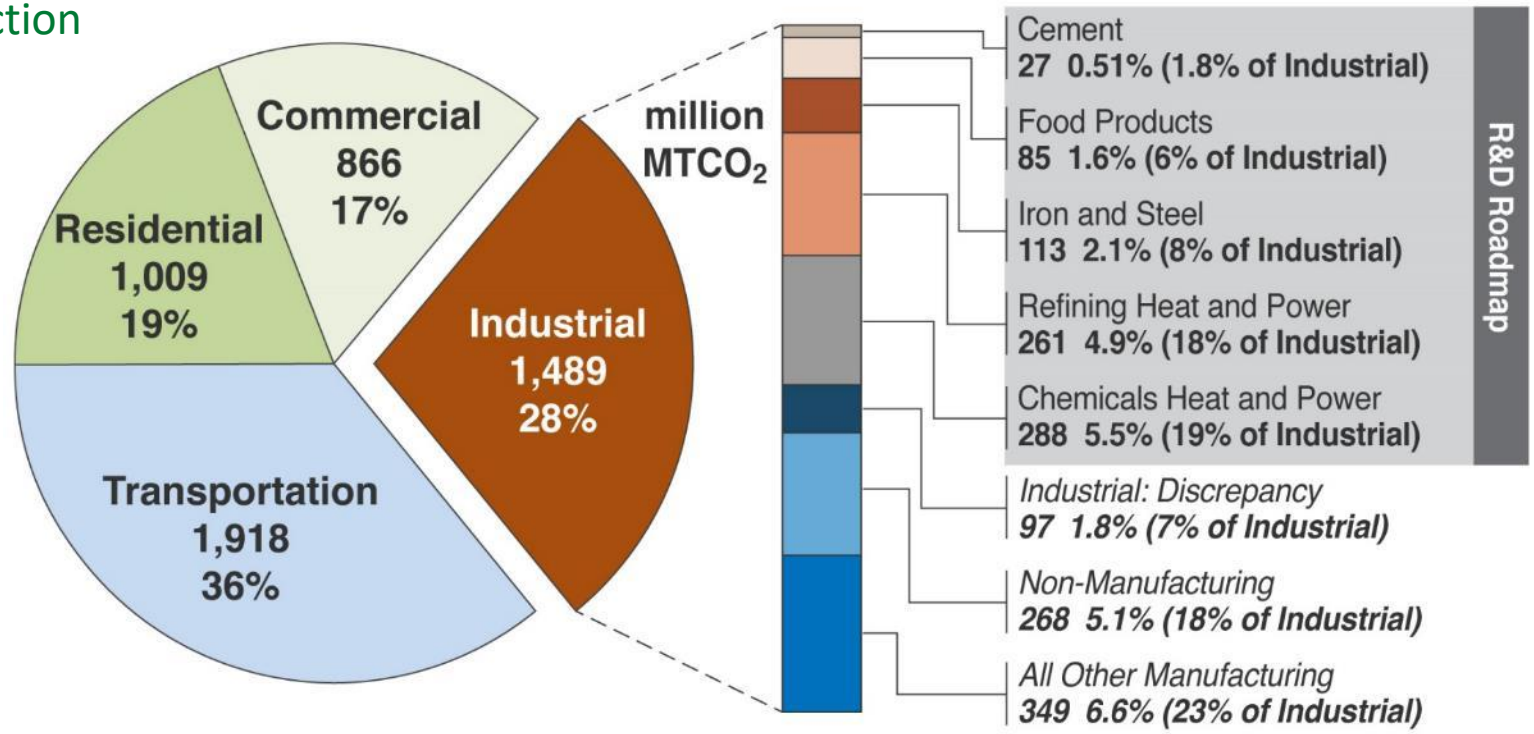
32% of the nation's primary energy use

28% of CO_2 emissions

Anticipated industrial sector energy demand growth of 30% by 2050 may result in a

15% CO_2 emissions increase

CO_2 Emissions By Sector



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*.

DOE Industrial Decarbonization Roadmap Led by AMO

Industrial operations are difficult to decarbonize due to heterogeneity of operations, facilities and energy inputs.

ACTION IS NEEDED NOW TO MEET NEAR ZERO EMISSIONS IN 2050.

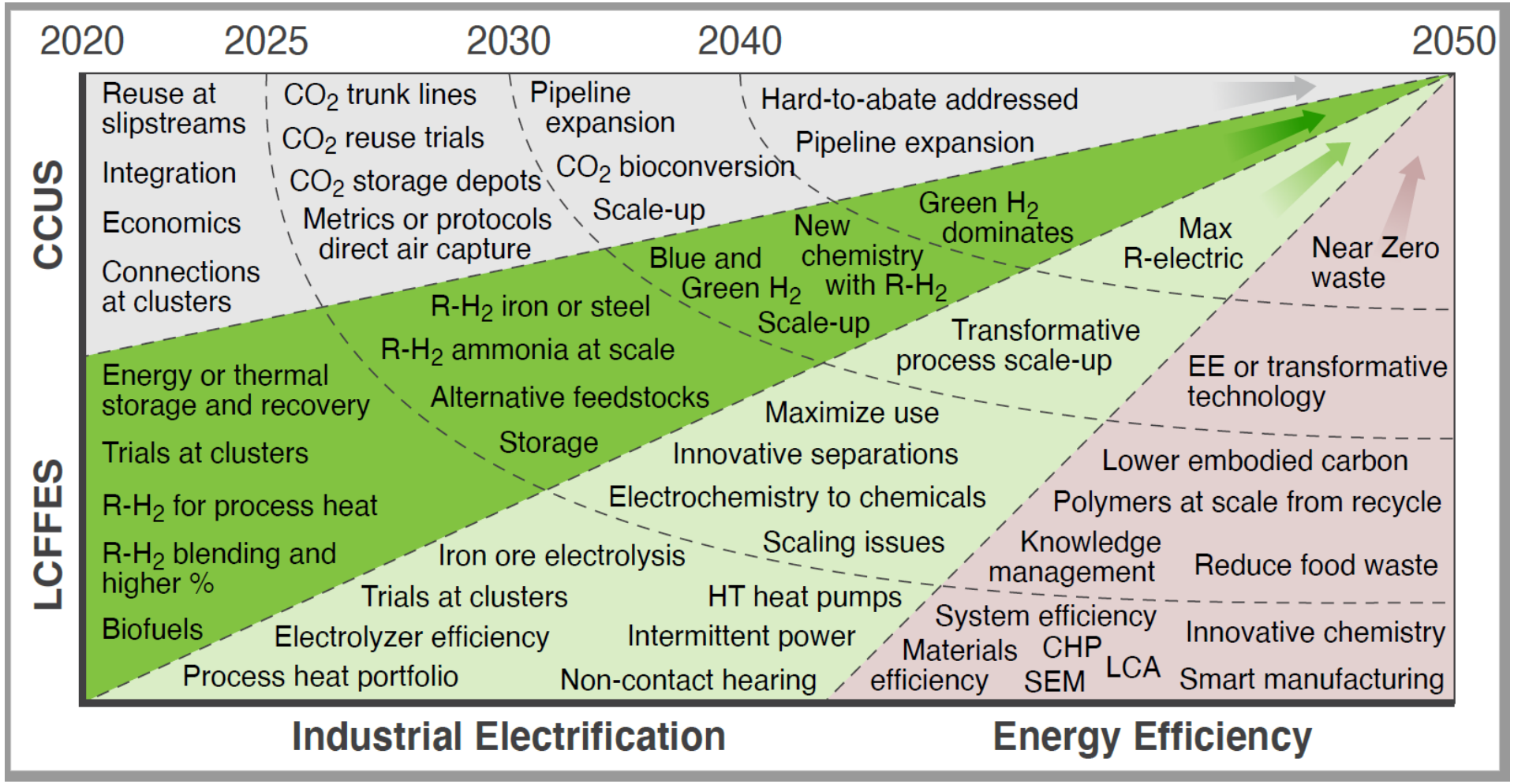
- **Congressional direction guided the roadmap methodology and industry engagement.**

  "… 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.

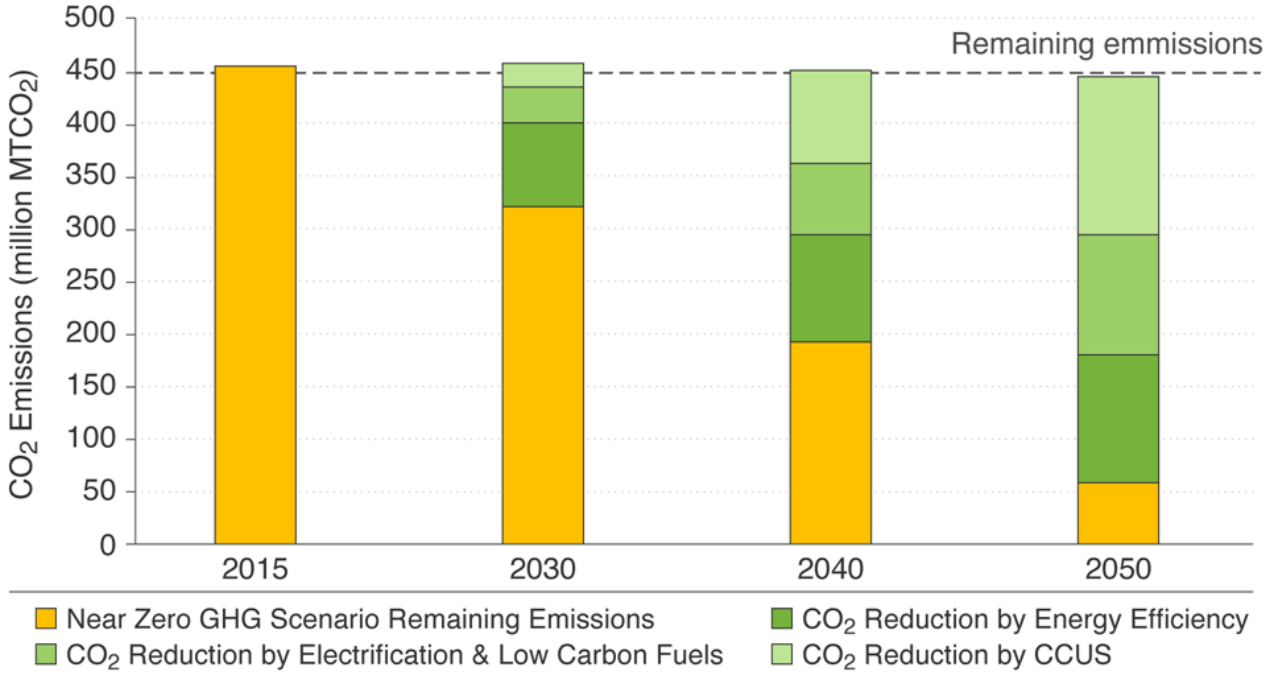
Landscape of represnetative RD&D investment opportunities for industrial decarbonization between now and 2050.

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

2050 Industrial Emissions Reduction Potential in 5 Subsectors

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.*

Representative Opportunities in the Most Carbon-Intensive Industry Sectors

Industry Sector	Carbon Emissions Context	Emerging Decarbonization Technologies
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

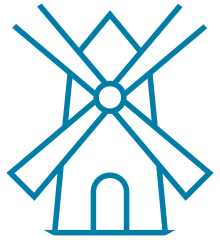
High Level Recommendations from Industrial Decarbonization Roadmap

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

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

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

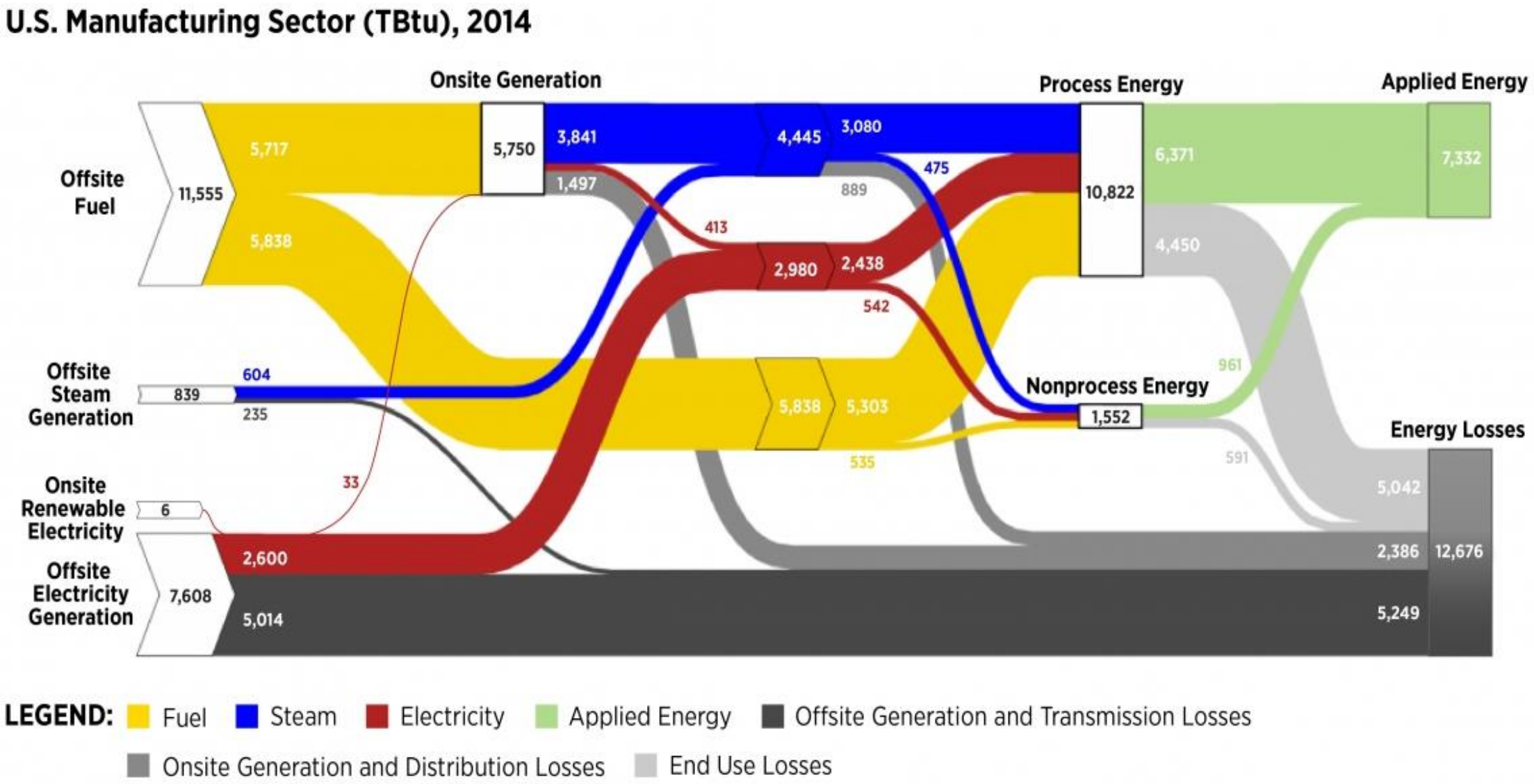


Align with expansion of renewable energy and other low-carbon assets.

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

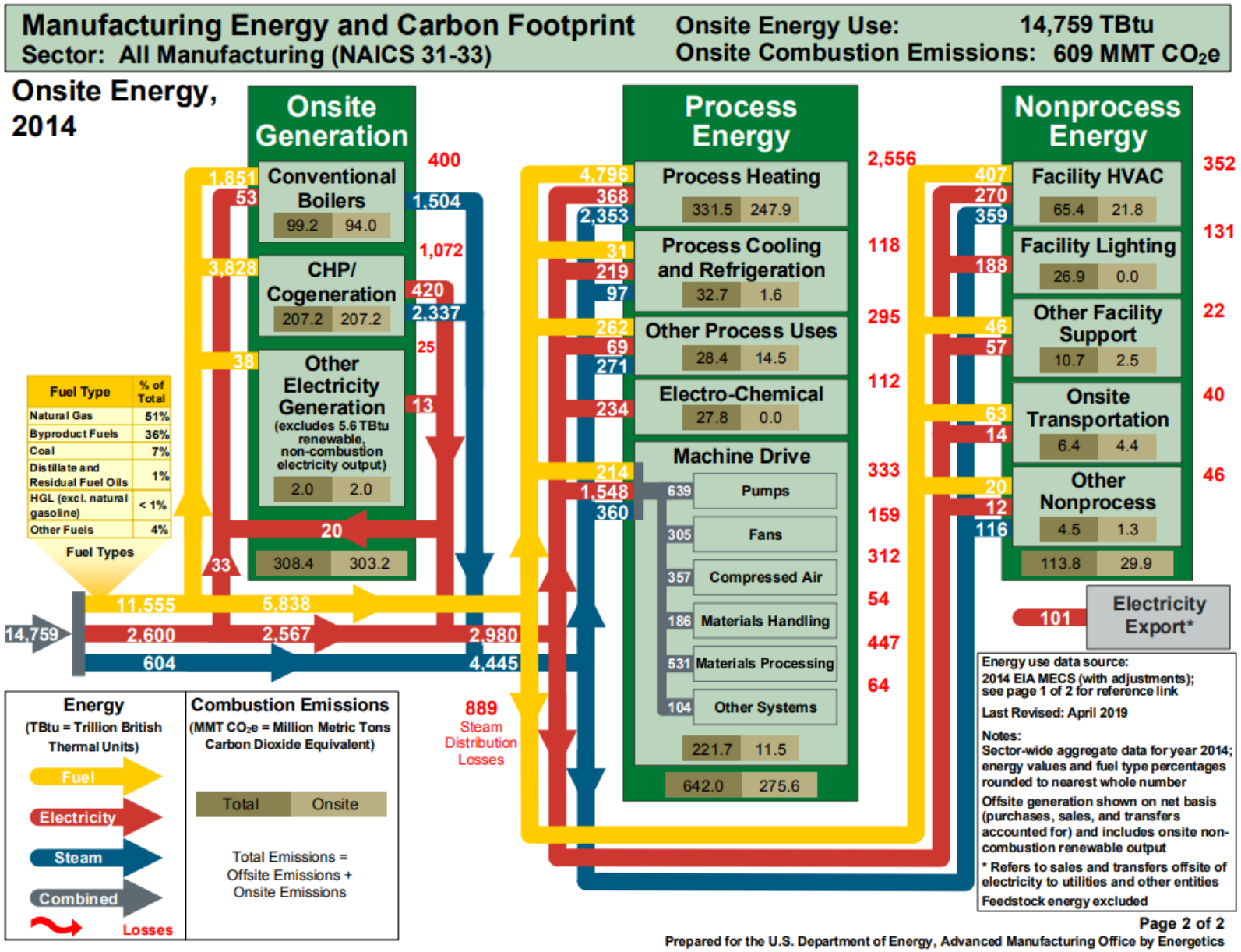
Develop workforce across industries with a spectrum of skill sets and diversity and inclusion.

Sankey Diagram of Energy Flows in the U.S Manufacturing Sector



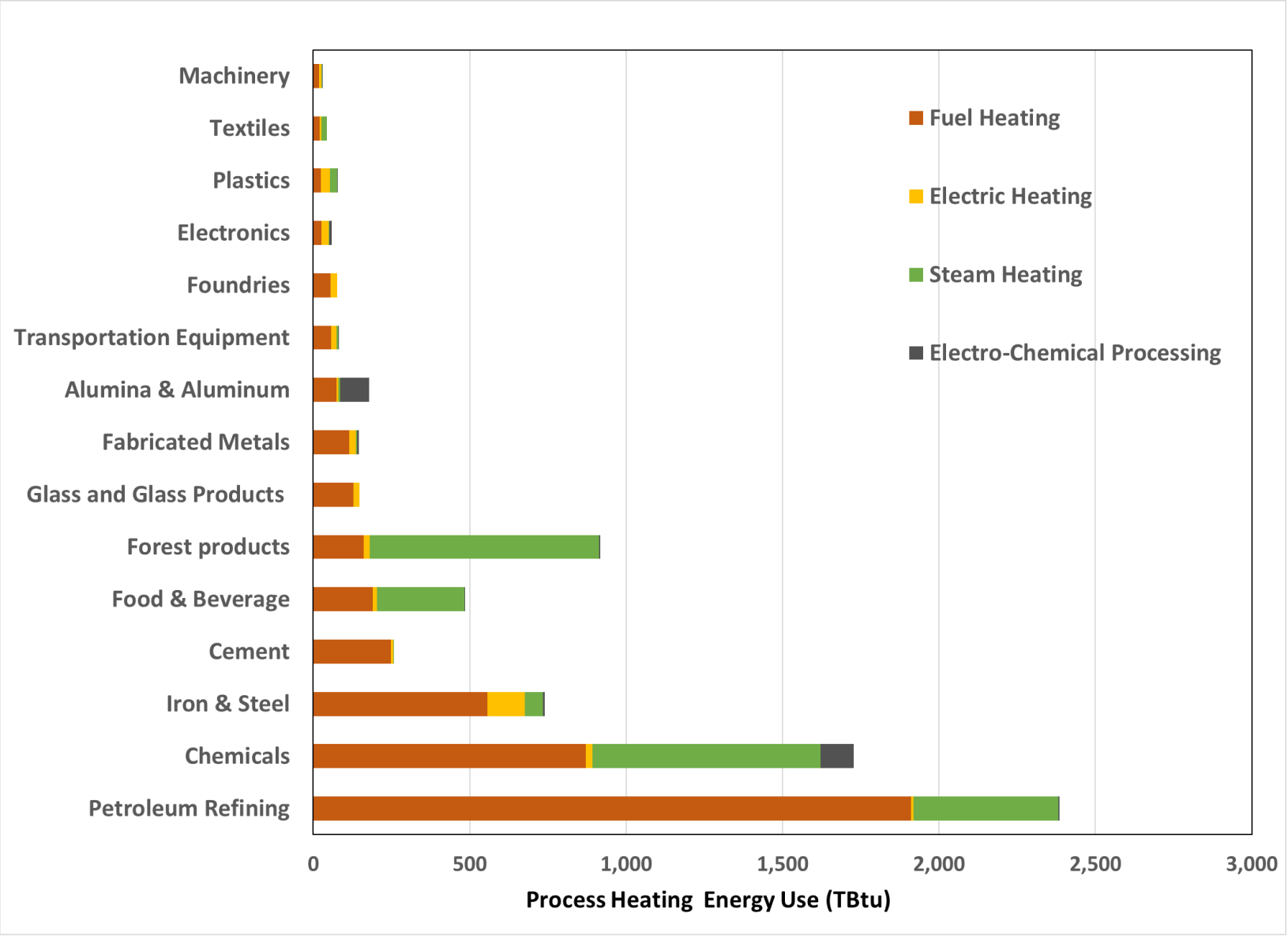
https://www.energy.gov/eere/amo/energy-analysis-data-and-reports

Energy & Associated Emissions Footprint of the U.S Manufacturing Sector



https://www.energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2014-mecs.

Energy Used for Thermal Processing



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

Type of Thermal Processes Used for Eight Large Energy Consuming Industries

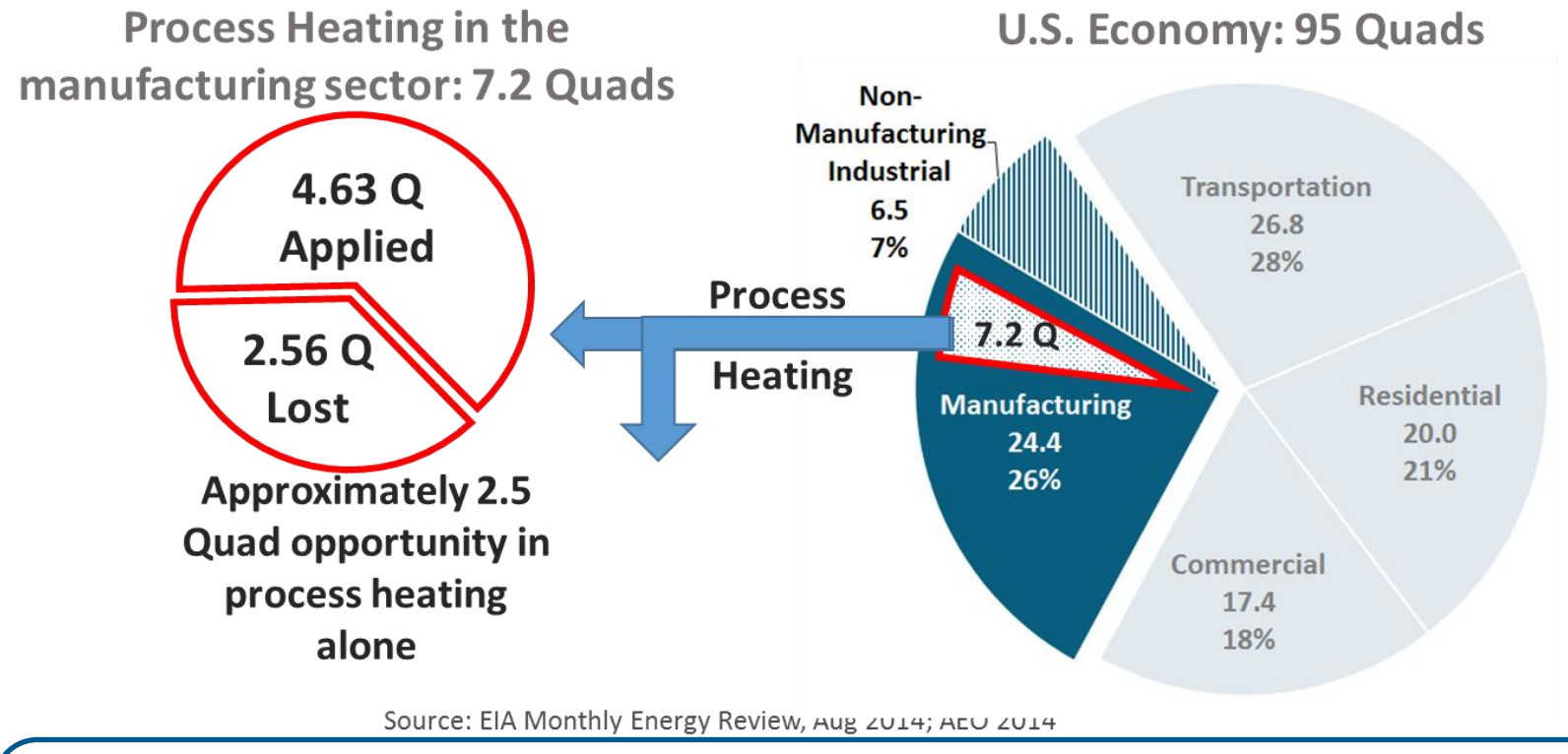
Thermal Process Step	Iron & Steel	Petroleum Refining	Chemical Industry	Glass	Aluminum	Pulp & Paper	Food Processing	Cement
Calcining								
Curing and forming								
Drying								
Fluid heating								
Heat treating (metal & nonmetal)								
Metal and non-metal reheating								
Metal and non-metal melting								
Other heating - processing								
Reactive thermal processing								
Smelting, agglomeration, etc.								
Steam generation								

Temperature Range	Color
Low Temperature (<800°F)	
Medium Temperature (800 to 1400°F)	
High Temperature (>1400°F)	

Workshop Report - Thermal Process Intensification: Transforming the Way Industry Uses Thermal Process Energy, Fall 2021 (report in development)

Thermal Opportunity

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



Source: EIA Monthly Energy Review, Aug 2014; AEO 2014

- **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

Low–thermal budget transformative technologies (mid- to long-term)	Alternative thermal processing (near- to mid-term)	Transformative supplemental technologies (near-term)	Waste heat management technologies (near-term)
• Electrolysis and electrodialysis • MW and RF processing • Ultrasound processing and membrane separation for drying • Hydrogen-based production of ammonia, methanol etc.	• Induction and resistance furnaces • Electric pre-heaters • Alternative liquid biofuels or biochemicals • Hybrid fuel systems • Solar thermal systems	• Smart IoT devices for system optimization • Smart manufacturing (e.g., digital twin, AI, predictive process controls) • Flexible, modular manufacturing and operations design	• High-temperature heat pumps • Thermal energy storage • Recuperators, regenerators, and economizers for nontraditional applications • Thermoelectric devices, heat pipes etc. • Waste heat to power, district heating, desalination etc.

Workshop was held November 5 - December 9, 2020
Report will be published soon.

Thanks!
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