Better Climate™ CHALLENGE
U.S. DEPARTMENT OF ENERGY

Heating Up: Options for Decarbonizing Industrial Process Heat

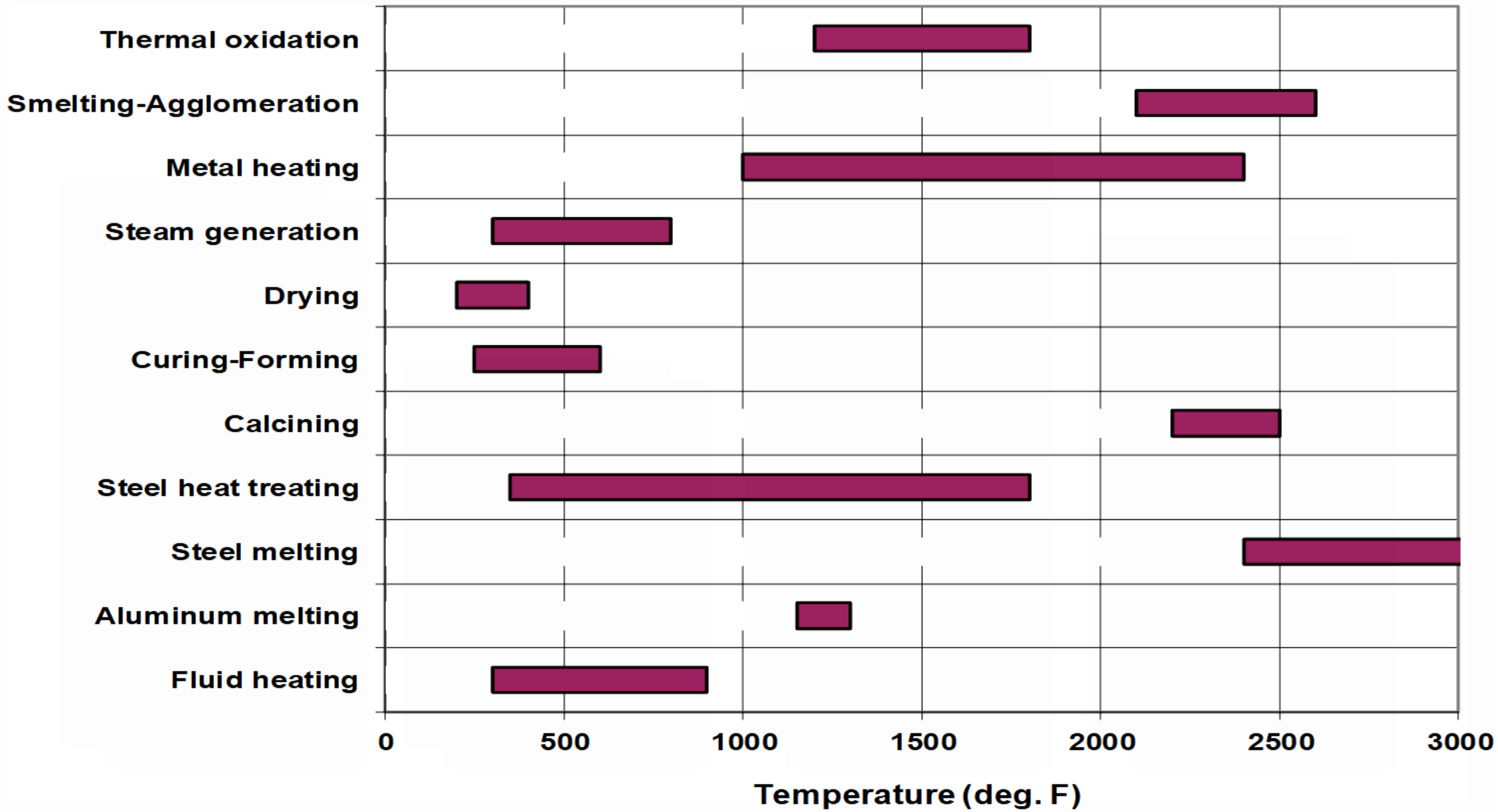
Wednesday, April 3rd, 2024
4:00 - 5:30 pm ET

U.S. DEPARTMENT OF ENERGY

Introduction to Industrial Thermal Loads and Decarbonization Technologies

What is Process Heat?

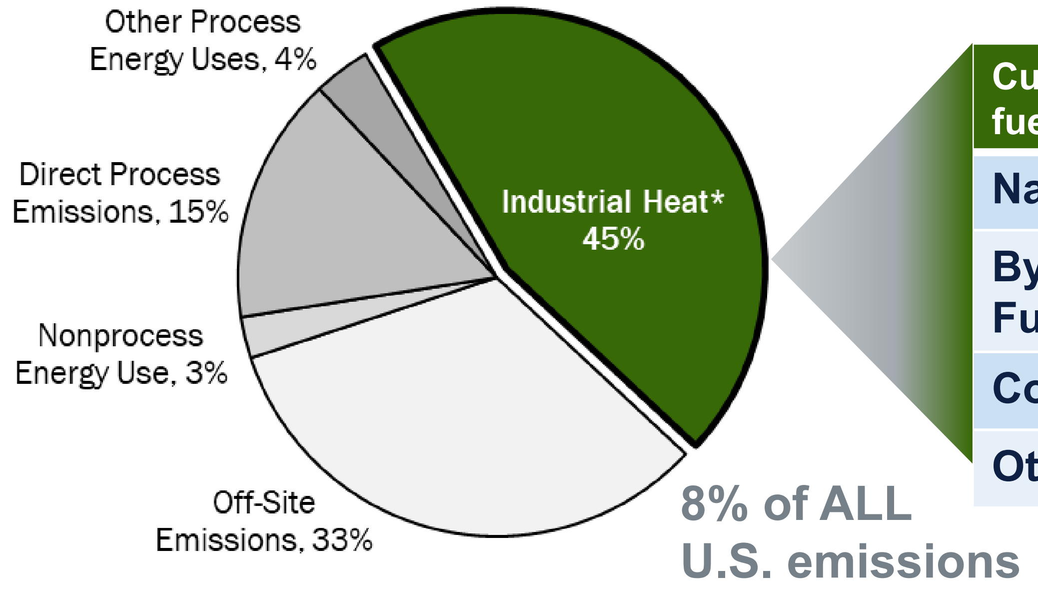
Process heat is the application of heat in industry to manufacture materials, goods, and products.



To Reach Net-Zero, We Must Decarbonize Industrial Process Heat

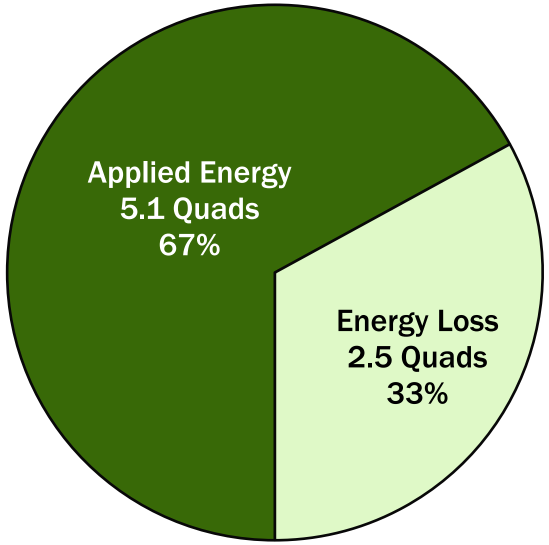
90% of process heat is generated from the unabated burning of fossil fuels

GHG emissions from U.S. manufacturing



Currently used fuels	% of total fuel usage
Natural Gas	55%
Byproduct Fuels	36%
Coal	4%
Other	5%

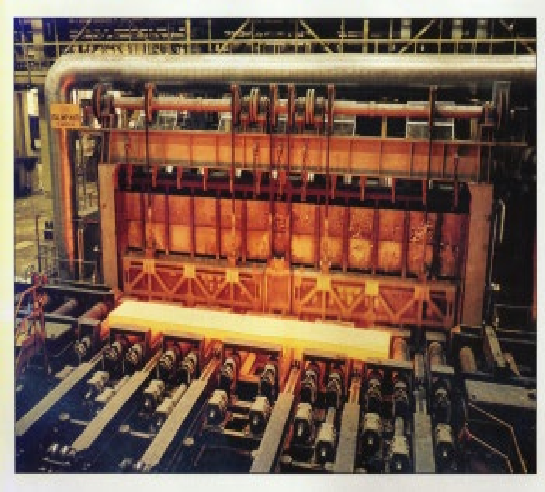
One-third of energy consumed for process heating is ultimately lost as waste heat



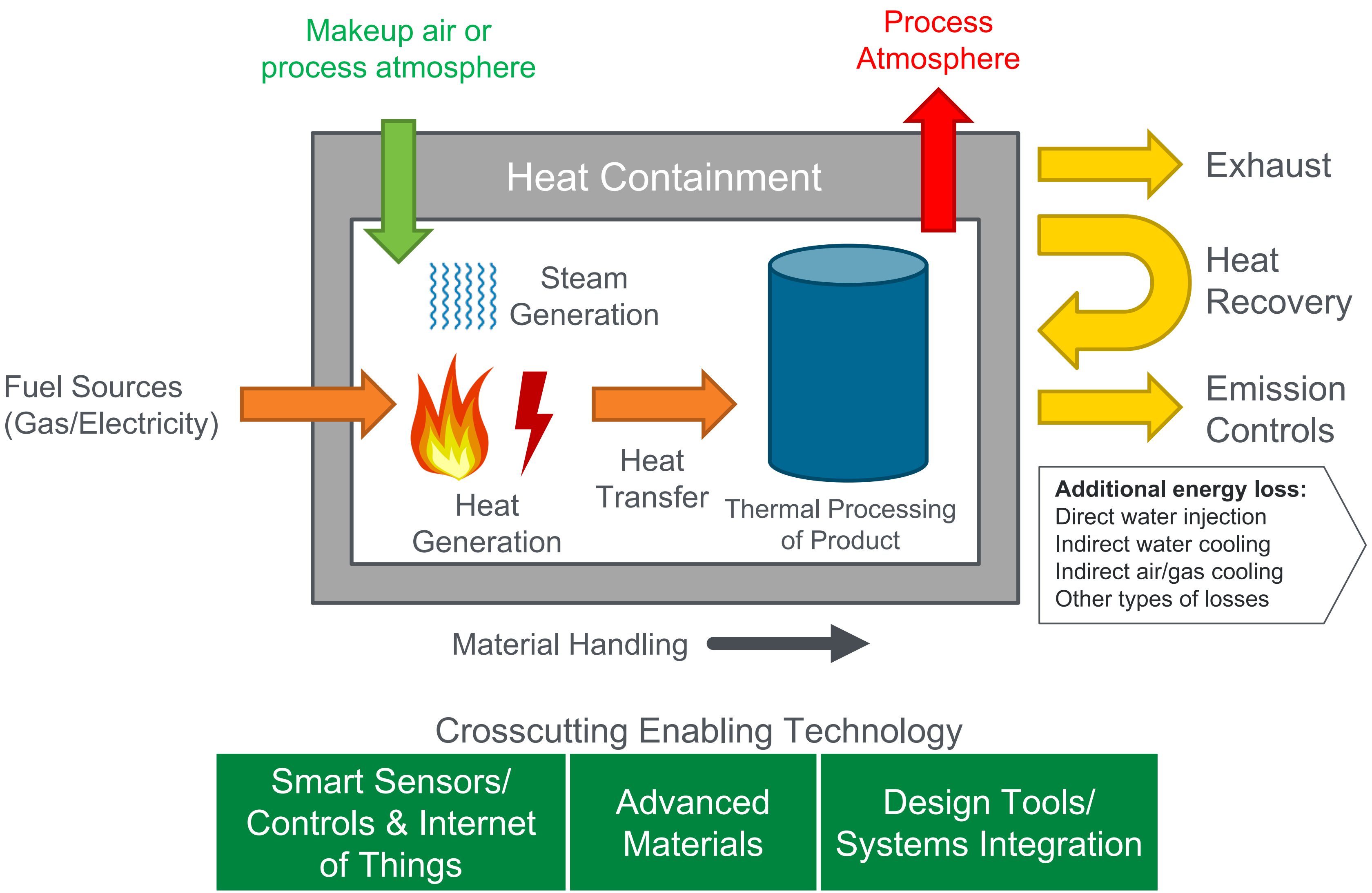
Industrial Heat includes process heating, conventional boilers, and CHP/cogeneration. Manufacturing sector excludes agriculture, construction, or mining.

DOE AMO. 2021. Manufacturing Energy and Carbon Footprints. https://www.energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2018-mecs

Process Heating Systems are Exceptionally Heterogeneous



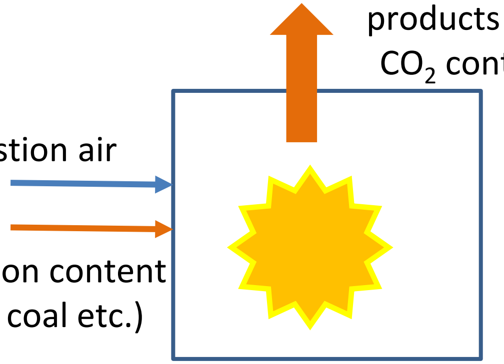
Process Heating System Components



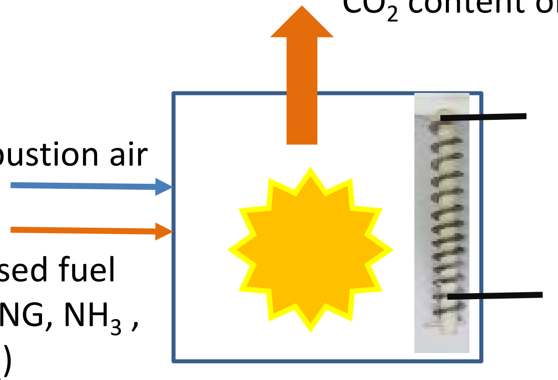
Different Categories of GHG Emissions from Industrial Thermal Processes

Category 1 – Heating system with combustion generated GHG emissions

Baseline System



Decarbonized System

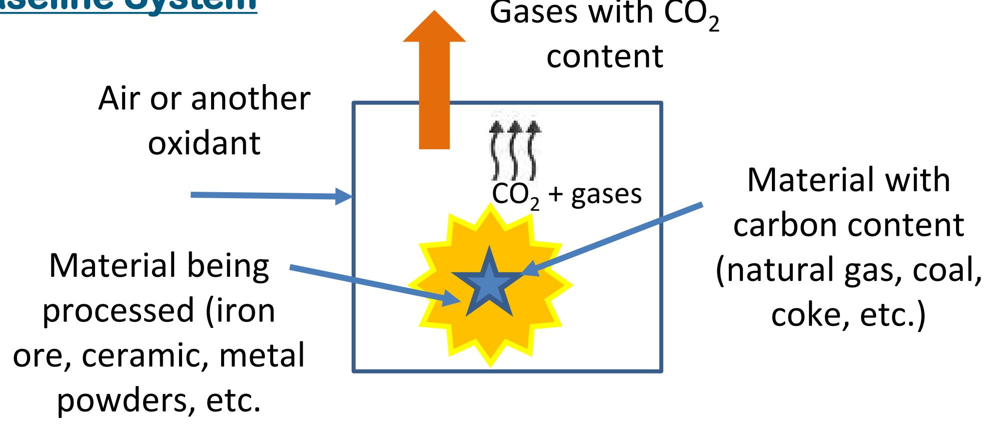


Examples: Fuel fired furnaces for metal/non-metal heating, metal melting, boilers, process heaters, etc.

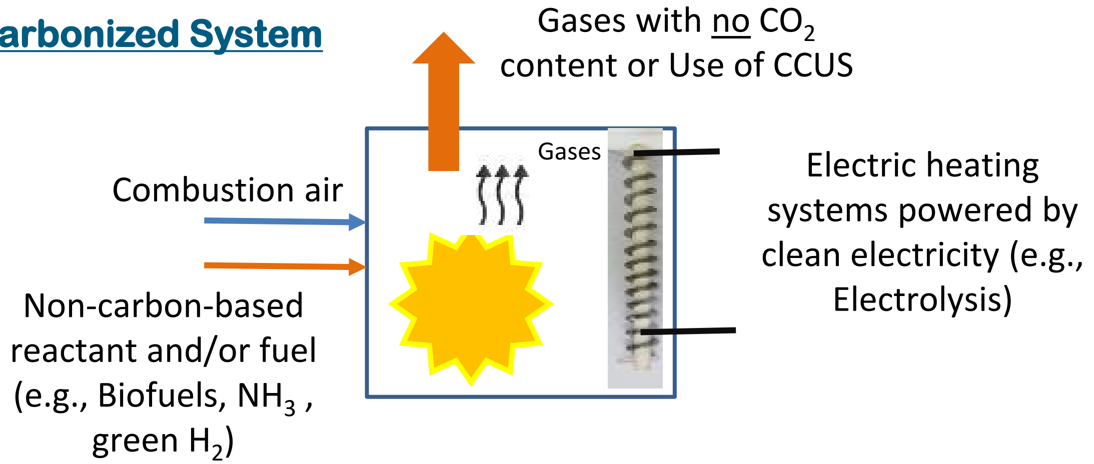
Different Categories of GHG Emissions from Industrial Thermal Processes (Cont'd)

Category 2 – Reactive heating system using carbonaceous material for heat and reactions

Baseline System



Decarbonized System



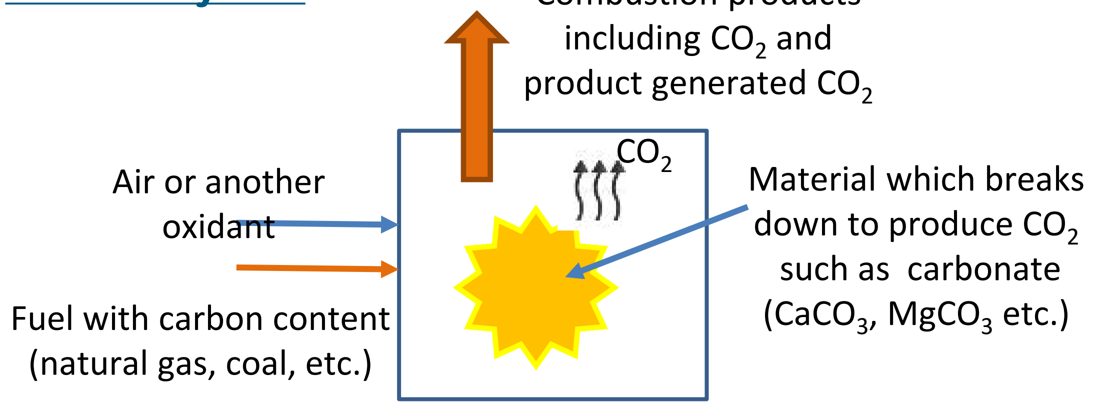
Decarbonization Strategies: Reactive heating system (e.g., reduction, oxidation) using alternative reactive material or reaction paths (i.e., electrolysis) that do not produce GHGs. Energy efficiency can help decarbonize by reducing the effective thermal load. Carbon capture is an alternative pathway to decarbonizing these systems

Examples: Blast furnace, cupola furnace, sintering furnace, etc. using mixed carbon for reaction and heat generation.

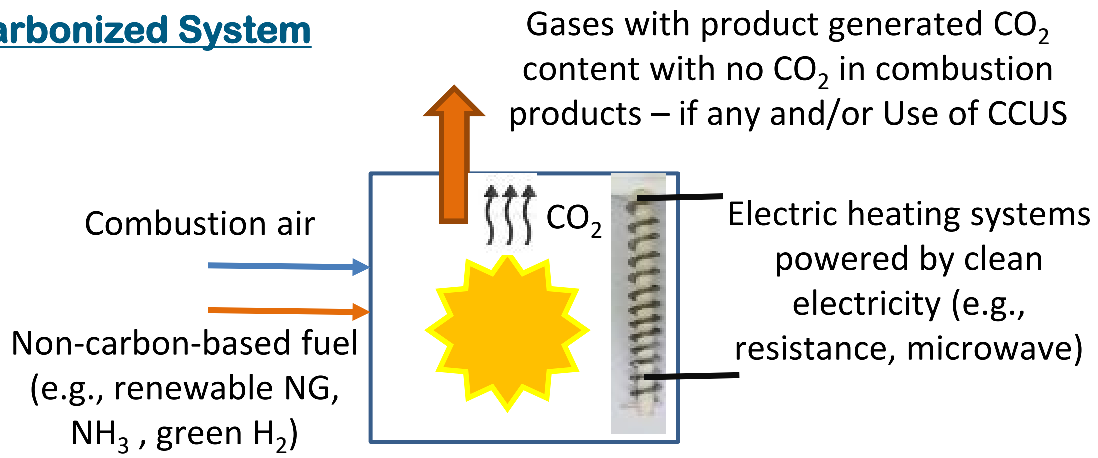
Different Categories of GHG Emissions from Industrial Thermal Processes (Cont'd)

Category 3 – Heating system with product/process generated GHG emissions

Baseline System



Decarbonized System



Decarbonization Strategies: Heating system using low carbon fuels and/or electric heating powered by clean electricity can reduce combustion related GHGs. However, the product/process generated GHGs cannot be eliminated by this and will need a suitable carbon capture technology.

Examples: Clinker making kilns in cement industry, Lime kilns, reaction vessels, certain reformers, etc.)

Industrial Decarbonization Pillars
(Source: DOE's Decarbonization Roadmap)

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Industrial Decarbonization Roadmap

DOE/EE-2635
September 2022

United States Department of Energy
Washington, DC 20585

Energy Efficiency	Industrial Electrification	Low-Carbon Fuels, Feedstocks, and Energy Sources (LCFFES)	Carbon Capture, Utilization, and Storage (CCUS)
Energy efficiency advancements minimize industrial energy demand, directly reducing the GHG emissions associated with fossil fuel combustion.	Industrial process technologies that utilize electricity for energy, rather than combusting fossil fuels directly, enable the sector to leverage advancements in low-carbon electricity from both grid and onsite generation sources.	Substitution of low- and no-carbon fuels and feedstocks for fossil fuels can further reduce combustion-associated emissions for industrial processes.	This multi-component strategy for mitigating difficult-to-abate emissions involves capturing generated CO_2 before it can enter the atmosphere; utilizing captured CO_2 whenever possible; and storing captured CO_2 long-term to avoid atmospheric release.
Energy efficiency technology examples: • Energy management approaches • Thermal integration of process heat • Smart manufacturing • Improved technologies and processes; system integration	Industrial electrification technology examples: • Electrification of process heat (e.g., heat pumps) • Electrification of hydrogen production for industrial process use	LCFFES technology examples: • Fuel-flexible processes • Clean hydrogen fuels and feedstocks • Biofuels and biofeedstocks • Concentrating solar power • Nuclear • Geothermal	CCUS technology examples: • Post-combustion chemical absorption of CO_2 • CO_2 pipelines and other CCUS-supportive infrastructure

https://www.energy.gov/sites/default/files/2022-09/Industrial%20Decarbonization%20Roadmap.pdf

Lessons Learned from our Low-Emission Alternatives to Industrial Thermal Loads Working Group

Energy Efficiency	Electrification	Low Carbon Fuel, Feedstocks, and Energy Source (LCFFES)	Carbon Capture, Utilization, and Storage (CCUS)

Discussed **EE technologies to decarbonize** industrial thermal loads.
 	
• EE improvement of process heating systems by implementing:
  • Operations-related opportunities
  • Routine maintenance activities
  • Retrofits (e.g., WHR)
  • Use of new technologies (e.g., SM/IoT)
 	
• Discussed **steps to improve thermal efficiency** and major areas for energy-saving potential
	Reviewed **common and advanced electrification strategies** in industry (i.e., infrared curing, electric boilers, electric steam generators, etc.)
	
	• Discussed Electrification Assessment Framework
	  • Establish inventory and energy use
	  • Assessing a facility's electrification readiness
	  • Identifying strategies for electrification
	  • Evaluating and implementing projects
	
	• Discussed Available Tools: MEASUR, Thermal Processing Cost Comparison, Electrification Impact Calculator
		LCFFES: Includes hydrogen, bioenergy, biofuels, bio-feedstocks, and renewable/clean sources of heat (solar, geothermal, and nuclear)
		
		Considerations by Energy Source:
		
		➢ **Hydrogen** - Pure H2 combustion is not deployed commercially beyond pilot and demonstration projects;
		➢ **Biomass and Biofuel** - Transport costs, process generation, cost competitiveness
		➢ **Renewable Heat** - Spatial and temporal availability; Transport and infrastructure; temperature limitations with integration into large scale plants
			The industrial sector is **difficult to attain "Net-Zero" CO2 emissions** due to hard-to-abate subsectors without the adoption of CCUS
			
			• Point Source CCUS Technologies:
			  • Pre/Post Combustion (Uses Liquid Solvent)
			  • Oxyfuel Combustion Capture (Solvent-free)
			  • Calcium or Chemical Looping (Solid Adsorbent)
			  • Pre-Combustion Membrane
			
			• Technology is not the primary challenge for CCUS deployment, rather **current cost implications impede CCUS adoption** of which government policy & regulation are needed.

INDUSTRIAL HEAT & THE INDUSTRIAL HEAT SHOT

Better Plants Summit

Heating Up: Options for Decarbonizing Industrial Process Heat

April 3, 2024

Joe Cresko, Chief Engineer

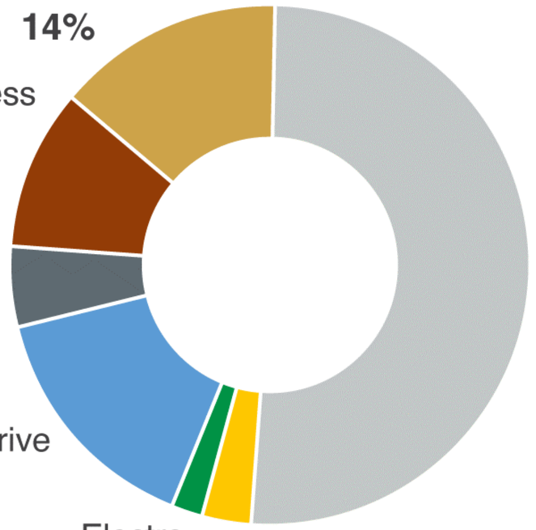
Industrial Efficiency and Decarbonization Office (IEDO)

KEY OPPORTUNITY FOR CROSS-SECTOR DECARBONIZATION

Process Heating

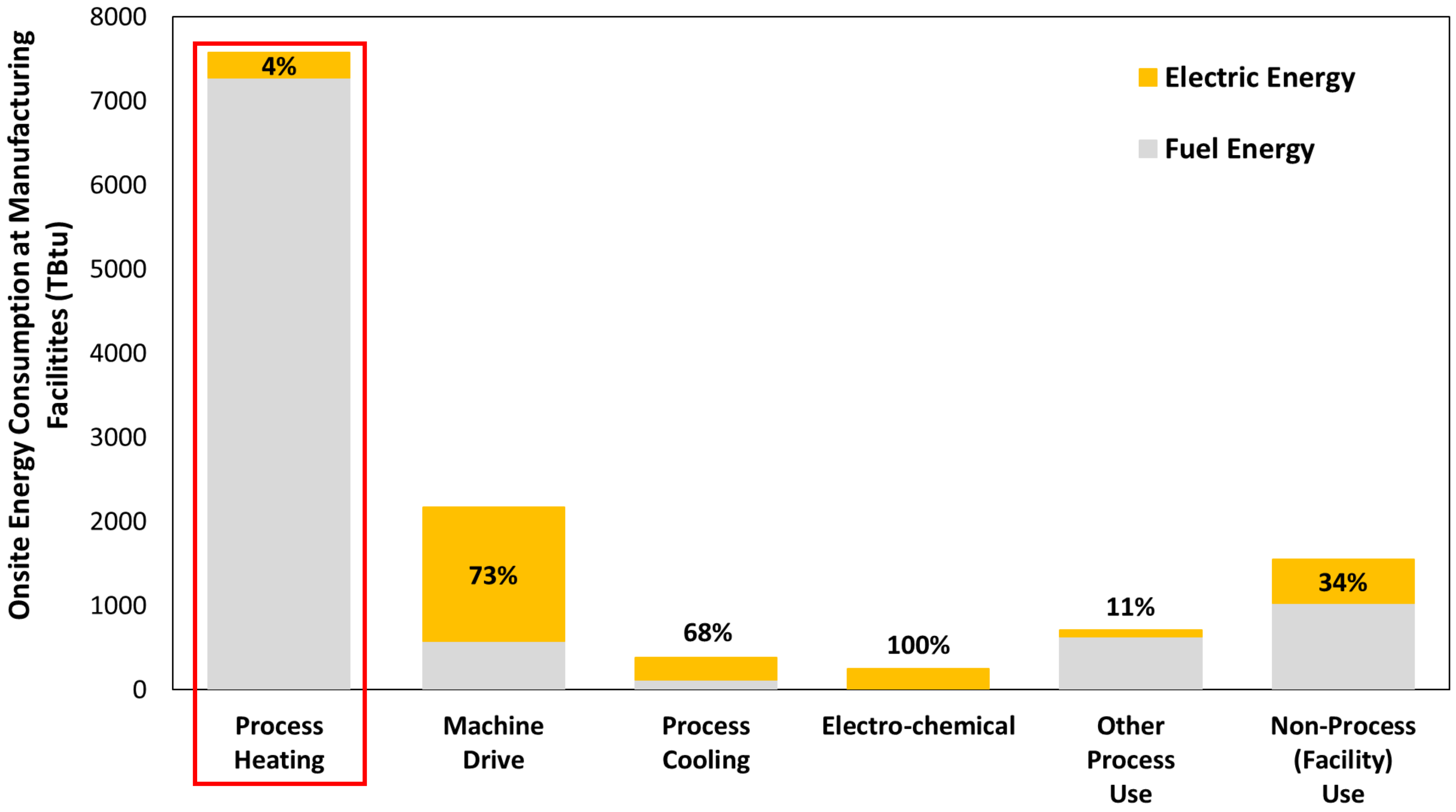
- Largest opportunity for cross-sector impact
- Accounts for **>50% of manufacturing energy use, >90% of this energy is from fossil-fuels[1]**
- Technologies that reduce heating requirements and/or convert to clean heat are critical to decarbonization

Breakdown of Energy Use Onsite at Manufacturing Facilities, 2018[1]



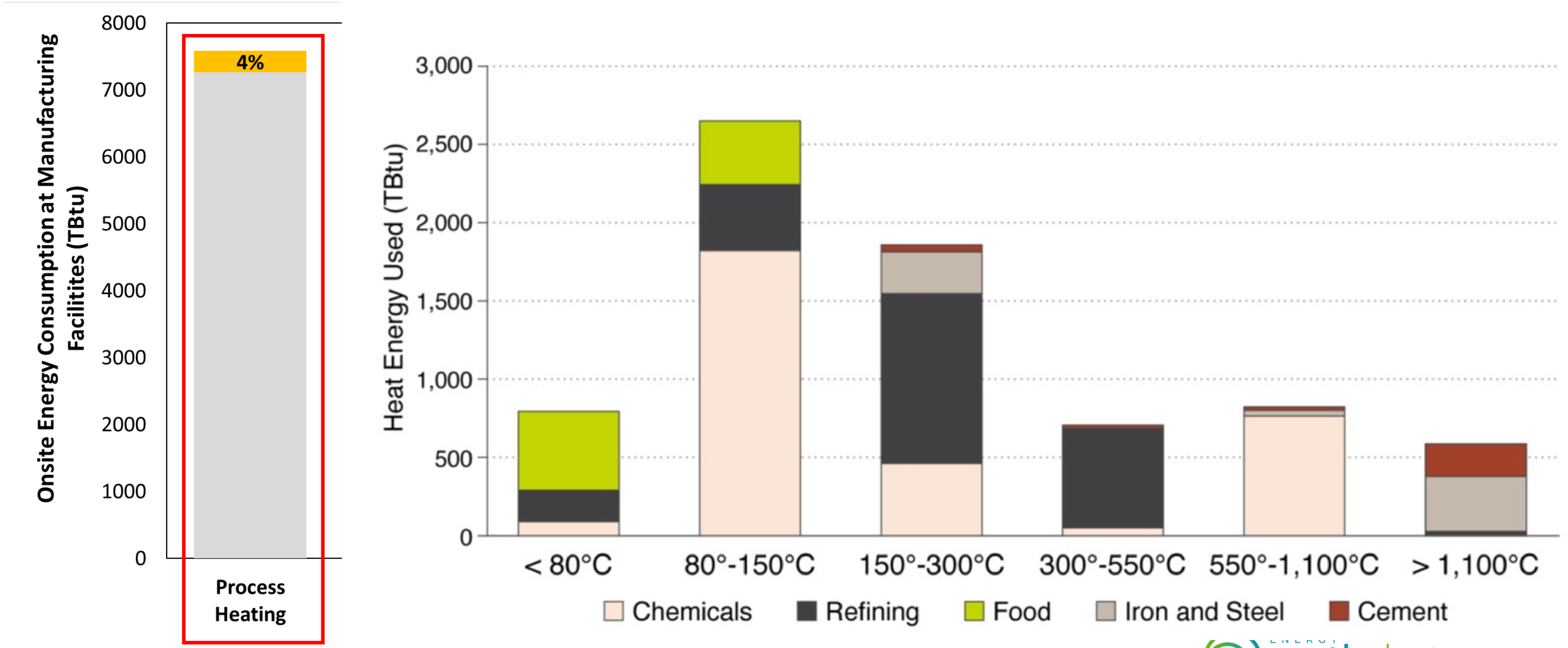
[1]DOE Industrial Decarbonization Roadmap

INDUSTRIAL HEAT DEMAND BY OPERATION



Data sources: DOE *Manufacturing Energy and Carbon Footprints*, based on EIA Manufacturing Energy Consumption Survey (MECS) data for 2018; C. McMillan, Manufacturing Thermal Energy Use in 2014. 2019. National Renewable Energy Laboratory. dx.doi.org/10.7799/1570008; AMO Thermal Process Intensification Workshop Report

INDUSTRIAL HEAT DEMAND BY TEMPERATURE



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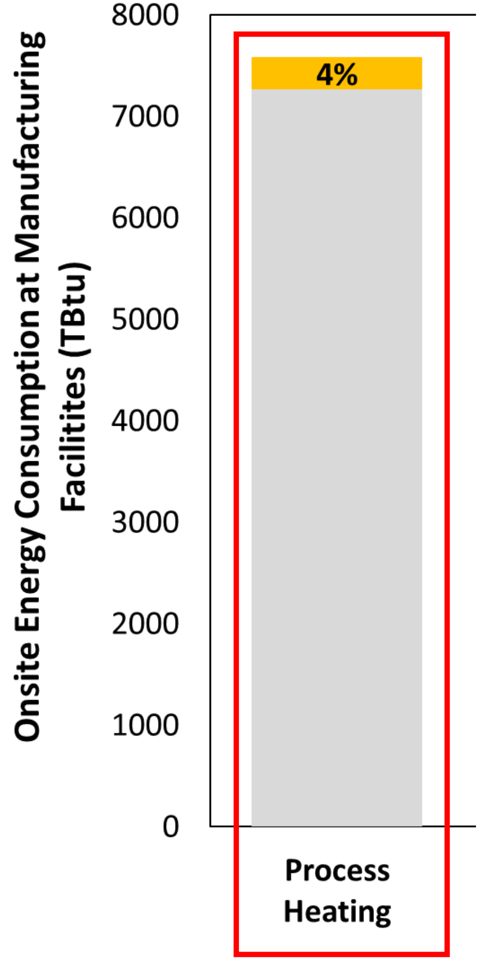
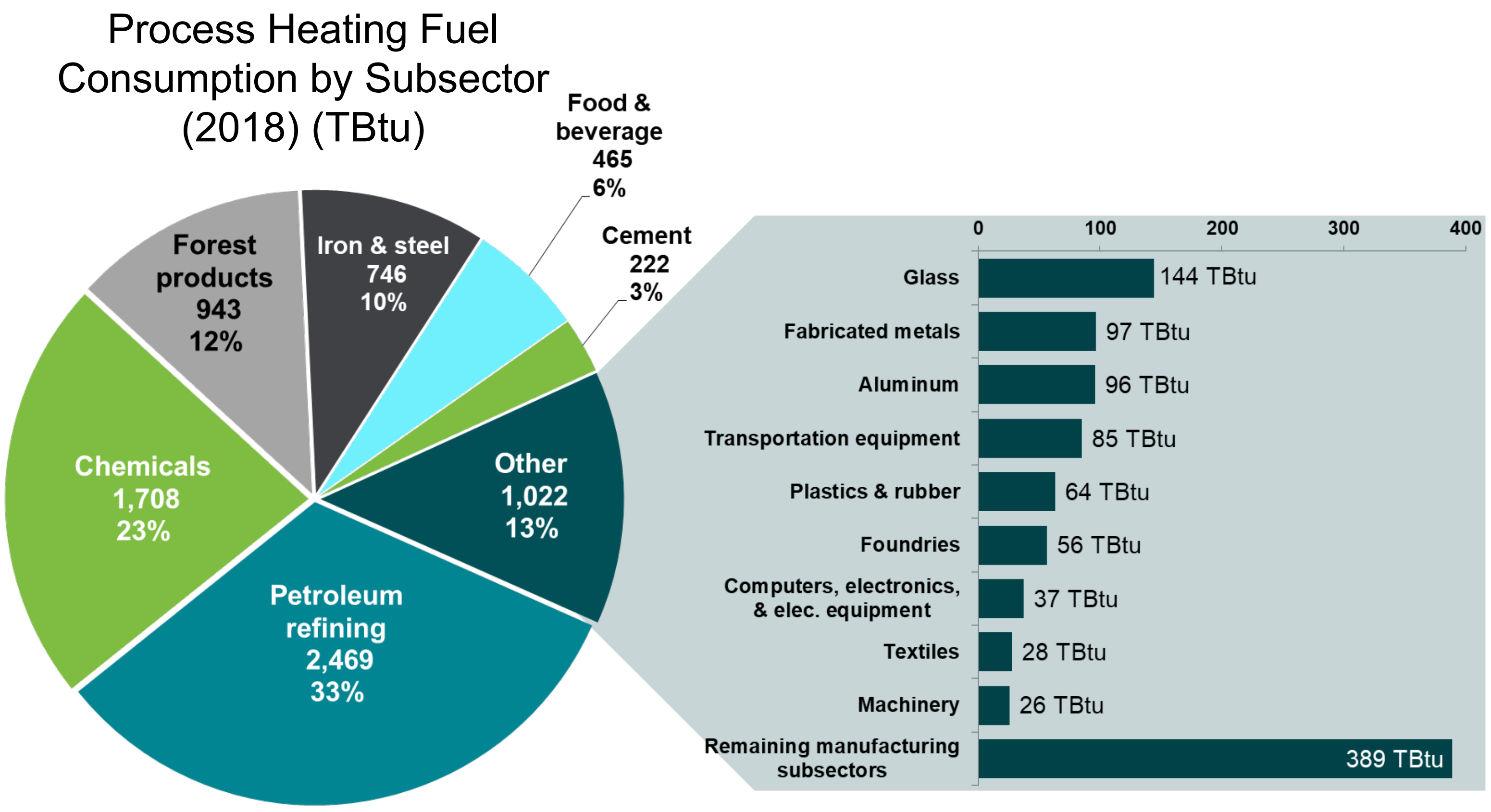
INDUSTRIAL HEAT DEMAND BY "OTHER" INDUSTRY





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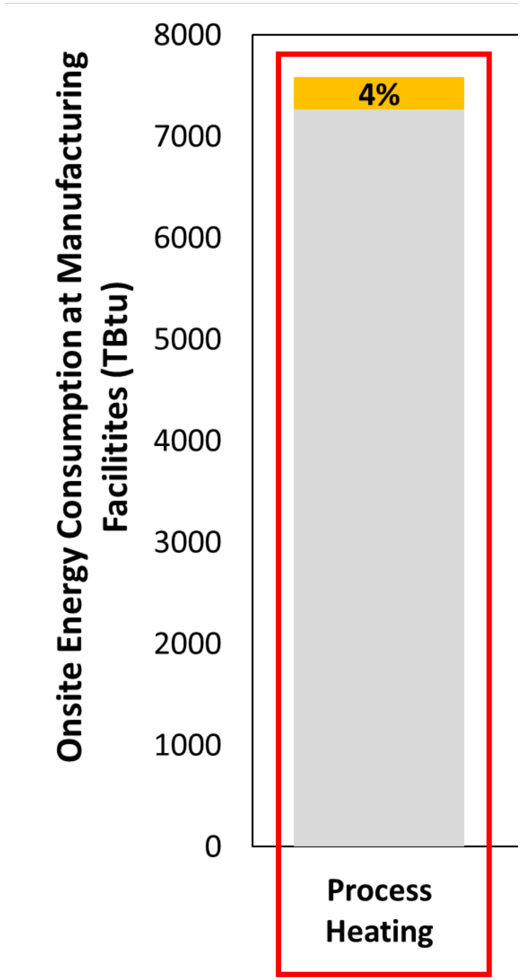
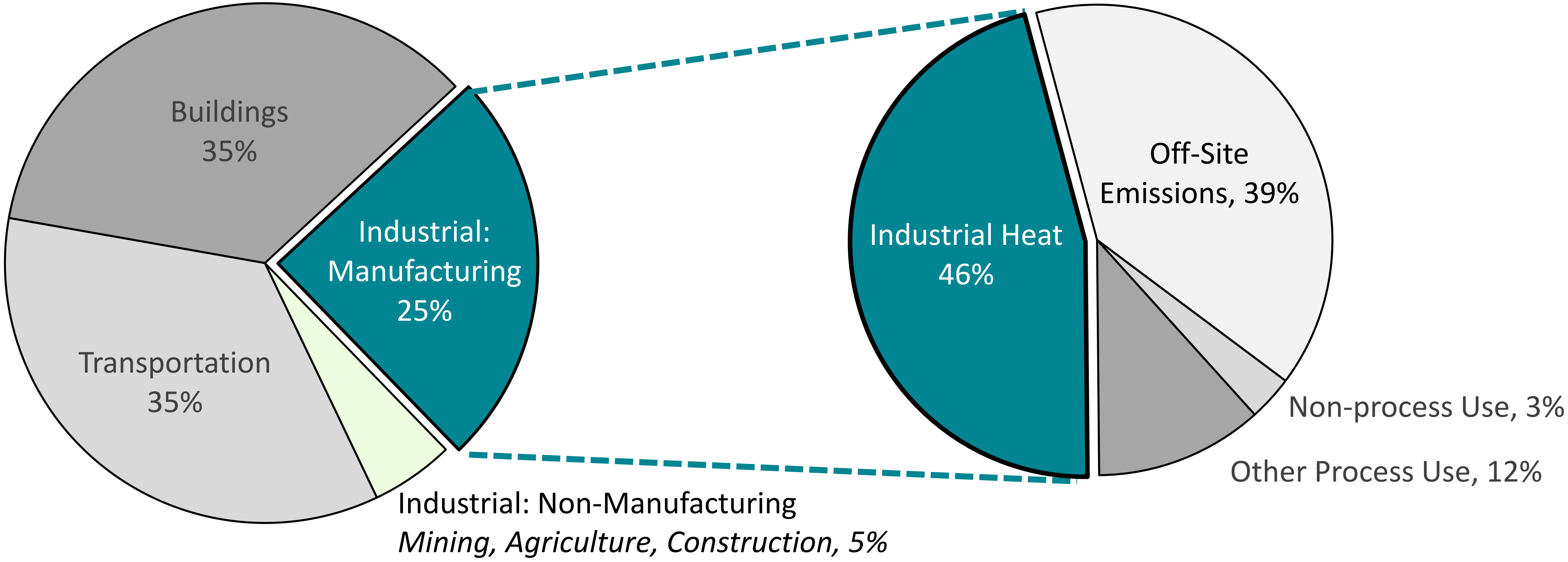
INDUSTRIAL HEAT DEMAND BY CORE PROCESSES



Thermal process	Industrial sector							
	Iron and steel	Petroleum refining	Chemical industry	Glass	Aluminum	Pulp and paper	Food processing	Cement
Calcining								
Bonding, 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								

Data sources: DOE *Manufacturing Energy and Carbon Footprints*, based on EIA Manufacturing Energy Consumption Survey (MECS) data for 2018; C. McMillan, Manufacturing Thermal Energy Use in 2014. 2019. National Renewable Energy Laboratory. dx.doi.org/10.7799/1570008; AMO Thermal Process Intensification Workshop Report

U.S. ENERGY-RELATED EMISSIONS:
~11% IS ATTRIBUTABLE TO INDUSTRIAL HEAT



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

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

The Industrial Heat Shot is an All-Hands-on-Deck Effort to Lower the Emissions from Industrial Heat.

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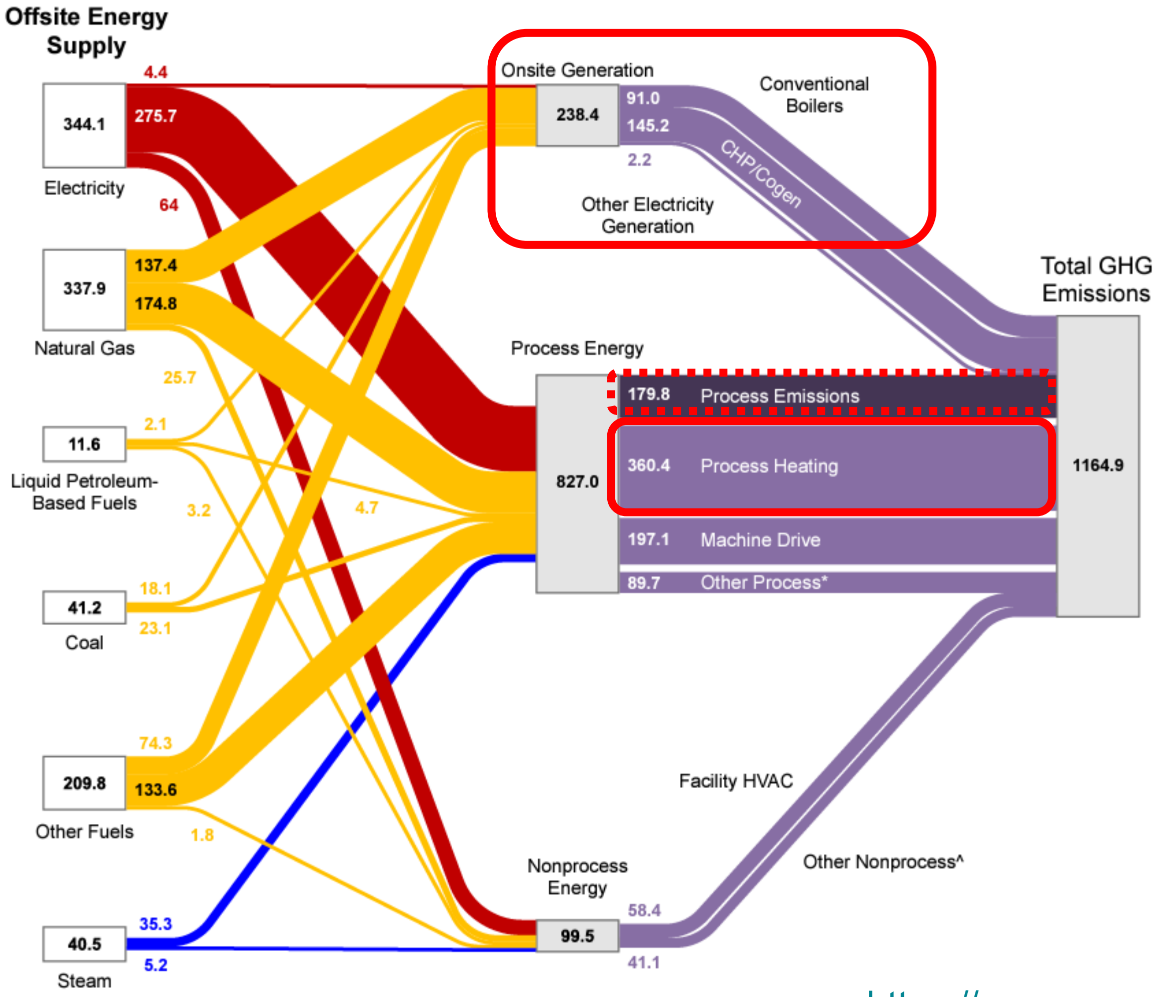
Sources: EIA Annual Energy Outlook (2021); IEDO 2018 Manufacturing Energy and Carbon Footprints (2022)

MANUFACTURING EMISSIONS FROM PROCESS HEATING

U.S. Manufacturing GHG Emissions (MMT CO_2e), 2018



Onsite combustion of fossil fuels provides > 95% of energy used for to power thermal systems in the manufacturing sector.

- Process heating emissions are the largest source of industrial emissions
- CHP/Cogen systems contribute to onsite emissions
- Process emissions arise from chemical reactions that are typically thermochemical

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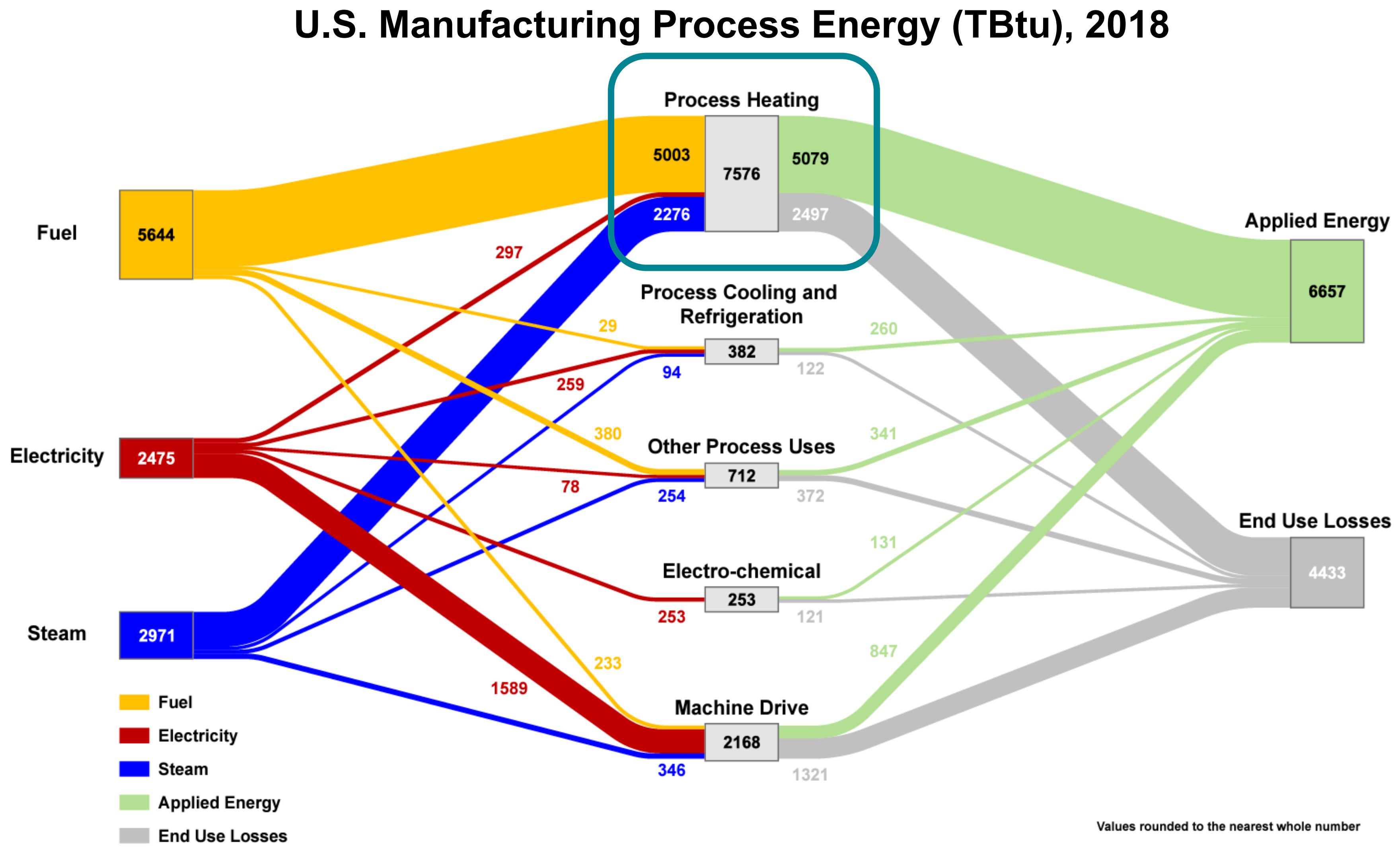
https://www.energy.gov/eere/iedo/2018-manufacturing-static-carbon-sankey-diagrams

PROCESS HEATING IS THE LARGEST SINGLE SOURCE OF ENERGY LOSS IN MANUFACTURING



- ~1/3rd of process heating energy is lost
- Energy efficiency improvements are important, but alone are insufficient
- Transformational approaches are needed to reduce emissions and improve productivity

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https://www.energy.gov/eere/iedo/2018-manufacturing-static-energy-sankey-diagrams

A CROSS-SECTORAL APPROACH IS NEEDED

Thermal processes and systems are essential and pervasive in industry, but every major industrial subsector uses heat in different ways…

drying	steam	distillation	melting	smelting	calcining
paper, batteries	pasteurization of food & beverage	high purity chemicals	formed plastics, semiconductors	iron, copper, aluminum	cement, lime

<100ºC — **Process Temperatures Needed** — >800ºC

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Industrial Heat Shot

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

>85% Lower Emissions

2035

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

INDUSTRIAL HEAT SHOT: THREE PATHWAYS TO DECARBONIZE INDUSTRIAL HEAT

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.

INDUSTRIAL HEAT SHOT: KEY CHARACTERISTICS

U.S. manufacturing is diverse, with a heterogenous array of processes and operations that use heat in multiple ways.

We need a portfolio of solutions that:

1. Meet or Exceed Operational Demands
2. Are Cost Competitive
3. Can Achieve Industrial Scale

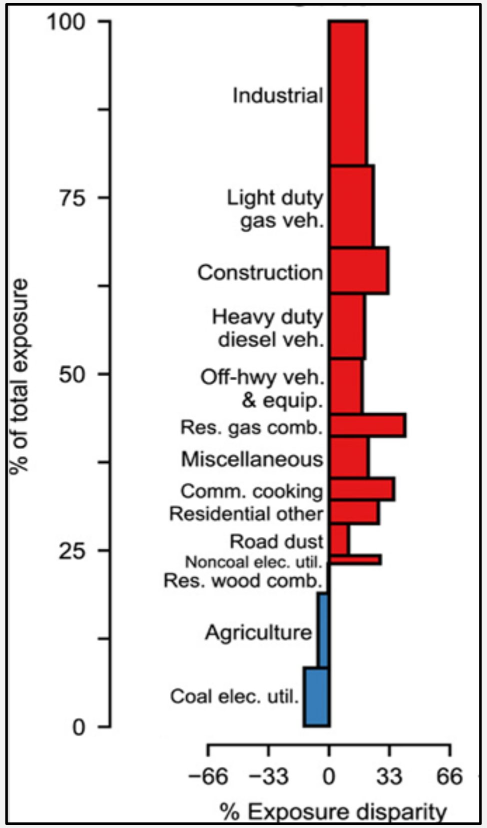
THIS IS AN OPPORTUNITY TO ADDRESS MORE THAN GREENHOUSE GASES

GHG reductions are necessary but insufficient.

We must also address the disproportionate impacts experienced by historically disadvantaged communities.

- **Communities of color** and **low-income communities** are more likely to be located near polluting industrial facilities
- Natural gas, coal, and fuel oil combustion for process heat produces **criteria air pollutants like NO_x, CO, and particulate matter (PM)** that impact health
- Fugitive methane emissions drive global warming and **ozone formation.**
- **Sustainable manufacturing processes must address all human health and environmental impact categories.**

People of Color are disproportionately exposed to $PM_{2.5}$ from industrial sources



Tessum, et al. *Science* (2021)

OTHER IMPACTS AND CO-BENEFITS

Environmental Justice

- Improve health of local communities

Economic Competitiveness

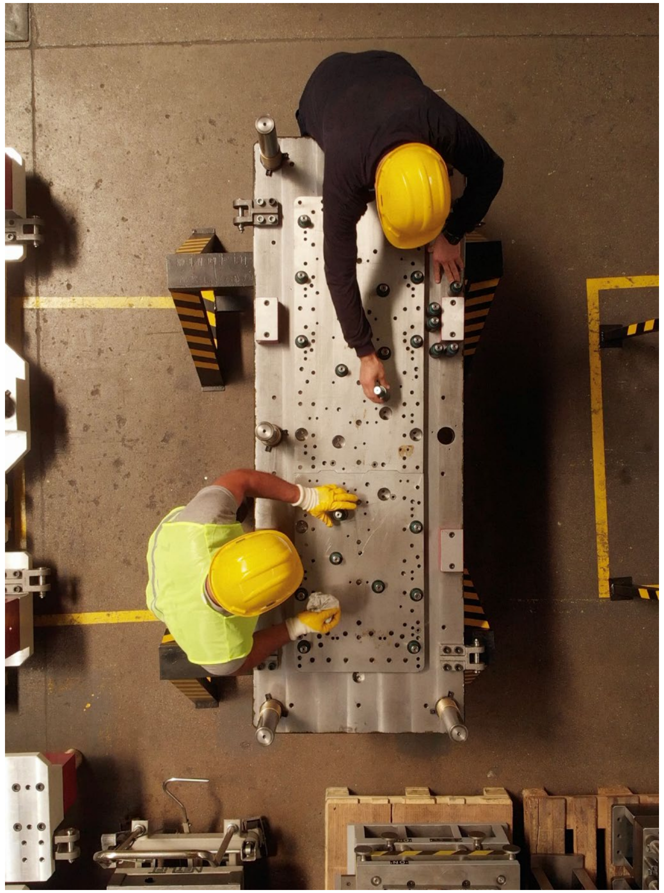
- U.S. leadership in low-carbon products
- Sustain and create new jobs

Energy and Material Efficiency Improvements

- Cost and Value

Energy Security

- Reduce exposure to volatile energy markets



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LEVERAGING DOE RESOURCES

Optimize the source, type, and amount of heat used to minimize emissions and enable production of cleaner products by…

Challenges & Opportunities	RDD&D
Develop diverse technology portfolio to address industry's heterogeneous heat demands	Advance Key Technologies • Electrotechnologies & alternative heat systems • Innovative low- and no-heat processes & advanced non-thermal separations (e.g., membranes) • Advanced equipment and process control technologies
Address cost competitiveness and quantify non-energy/non-emissions benefits	DOE tools and resources for technoeconomic analysis and life cycle assessment
Scale-up towards commercialization	Technical assistance, workforce development, and advanced demonstration offices
Meet or exceed operational demands	Multi-scale modeling

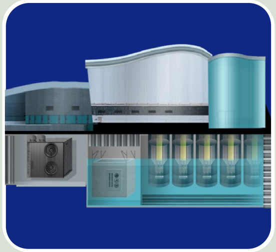
ALL-HANDS-ON-DECK EFFORT

Office of Science

- Foundational R&D Capabilities at the User Facilities
- High Performance Computing for Manufacturing

Industrial Efficiency and Decarbonization Office

- RD&D in manufacturing processes, technologies, products, facilities, and supply chains



Nuclear Energy

- RD&D to expand nuclear energy to industrial, transportation, and energy storage applications

Bioenergy Technologies Office

- RD&D development of processes using alternative feedstocks and low/no heat manufacturing options

Hydrogen and Fuel Cell Technologies Office

- RD&D of clean hydrogen technologies for low-carbon feedstocks and fuels

Fossil Energy and Carbon Management

- RD&D to convert captured carbon into products without the need for heat or using substantially less heat

Solar Energy Technologies Office

- RD&D in concentrated solar thermal and thermal storage technologies

Office of Clean Energy Demonstrations

- Industrial Decarbonization Demonstration projects

DOE National Laboratories RD&D

INDUSTRIAL HEAT SHOT SUMMARY

PATHWAYS

- Heat from Clean Electricity
- Clean Heat from Alternative Sources
- Low- or No-Heat Process Technologies

APPLICATIONS

- Drying
- Distillation
- Steam
- Melting
- Smelting
- Calcining

TARGET

Develop technologies with an 85% reduction in GHG emissions

INDUSTRIES

- Concrete & Cement
- Chemicals
- Metals
- Refining
- Food Products
- Semiconductors
- Other Manufacturing

IMPACT

- Decarbonization
- Environmental Justice
- Economic Competitiveness
- Energy Security

DOE INDUSTRIAL HEAT RD&D INVESTMENT EXAMPLES

OCED Industrial Decarbonization Program (IDP) – Selections include "Process Heat":

- Steam-Generating Heat Pumps for Cross-Sector Deep Decarbonization | Skyven Technologies (Up to $145 million - TBD)
- Vikrell Electric Boiler & Microgrid System | Kohler (Up to $51.2 million - Casa Grande, Arizona)

Regional Clean Hydrogen Hubs

Office of Clean Energy Demonstration

$7B in federal funding to launch seven H_2 Hubs to accelerate commercial scale deployment of low-cost, clean hydrogen

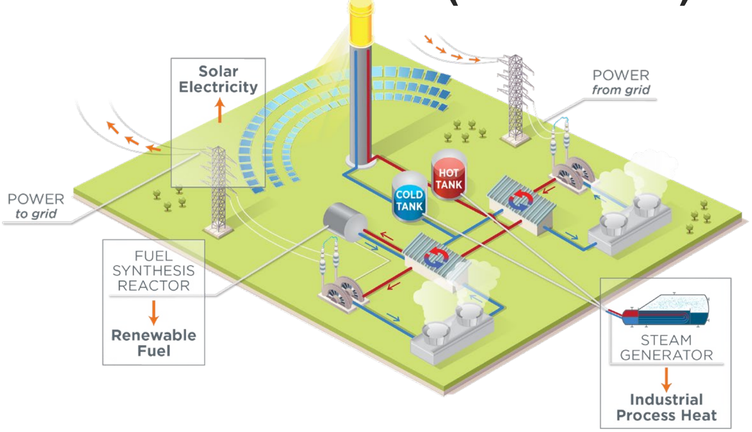
EPIX

ELECTRIFIED PROCESSES FOR INDUSTRY WITHOUT CARBON

Industrial Efficiency and Decarbonization Office

DOE's 7th Clean Energy Manufacturing Innovation Institute. $70M in federal funding over the next 5 years to fund RD&D projects to replace fossil fuel-based heating with electric heating

Generation 3 Concentrating Solar Power (Gen3CSP)



Solar Energy Technologies Office

$25M in federal funding for demonstration of integrated high-temperature particle system for CSP

THANK YOU!

https://www.energy.gov/industrial-technologies/industrial-technologies

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