U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Industrial Decarbonization

Sustainable Manufacturing

Joe Cresko, Chief Engineer,
Advanced Manufacturing Office (AMO)
manufacturing.energy.gov

Industrial Process Emissions Research Workshop

SwRI

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Industry's Significant Energy Demand and CO_2 Emissions

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

ACCOUNTS FOR

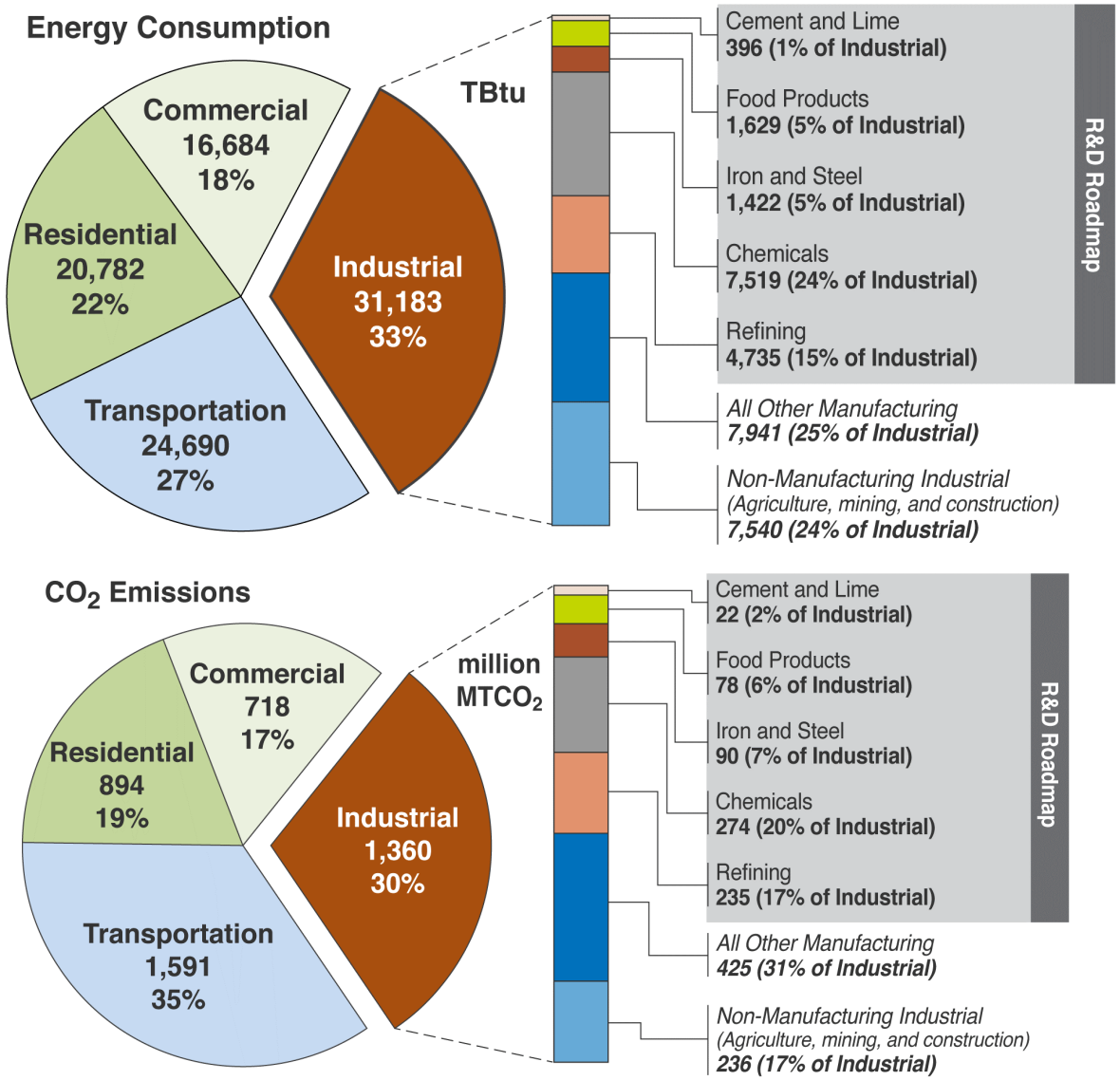
33% of the nation's primary energy use

30% of CO_2 emissions

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

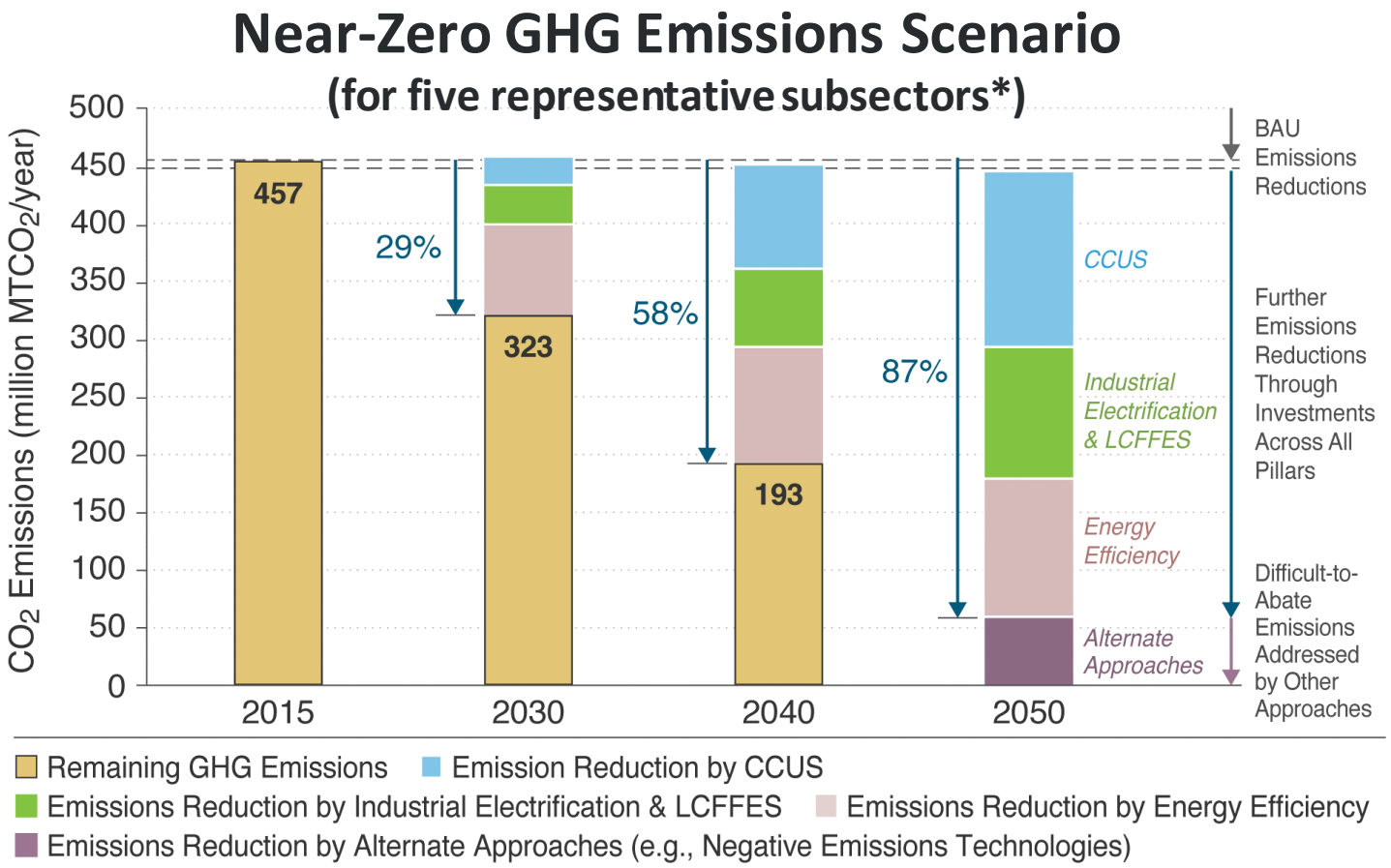
17% CO_2 emissions increase

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



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

2050 Industrial Emissions Reductions Potential

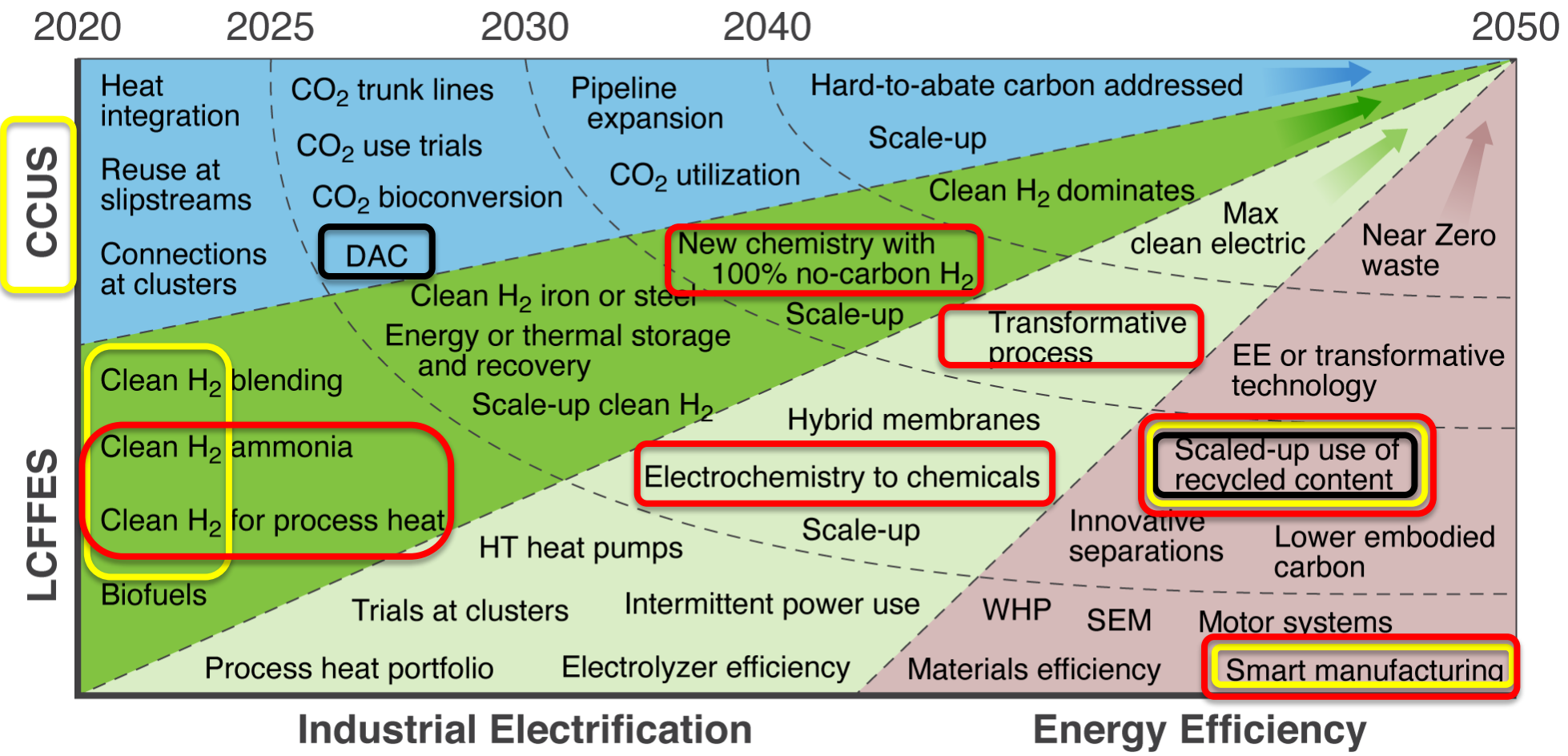


Pillars of industrial decarbonization:

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

***Subsectors included in Roadmap analysis:** Iron & Steel, Chemicals, Food & Beverage, Petroleum Refining, and Cement. *(Near zero GHG scenario, excluding feedstocks. Source: DOE Industrial Decarbonization Roadmap, forthcoming)*

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.

Addressing GHG emissions from industrial processes

- Core process
- Facility level
- Beyond plant bounds

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

Source: Industrial Decarbonization Roadmap, forthcoming.

Developing Sustainable and Decarbonized Manufacturing Technologies

Innovative Metals Processing

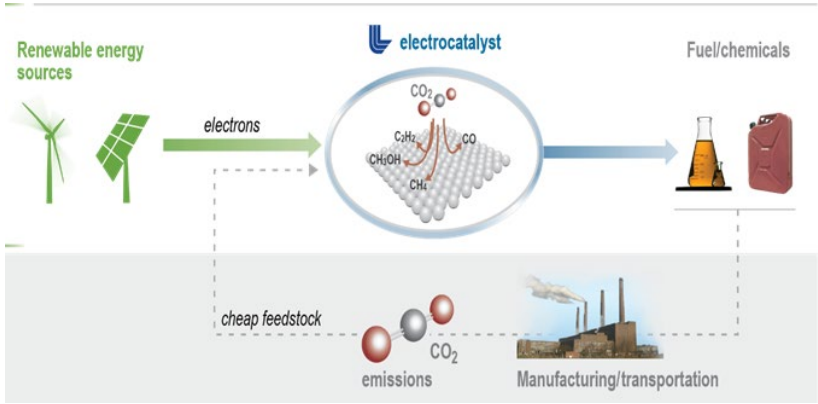
Improve the energy and carbon footprint of metals production, including through increased recycling of scrap, co-products, and process gasses.

- *Direct electrolysis*
- *Alternative reductants*
- *Electrochemical recovery*
- *Selective separations*

Flash ironmaking

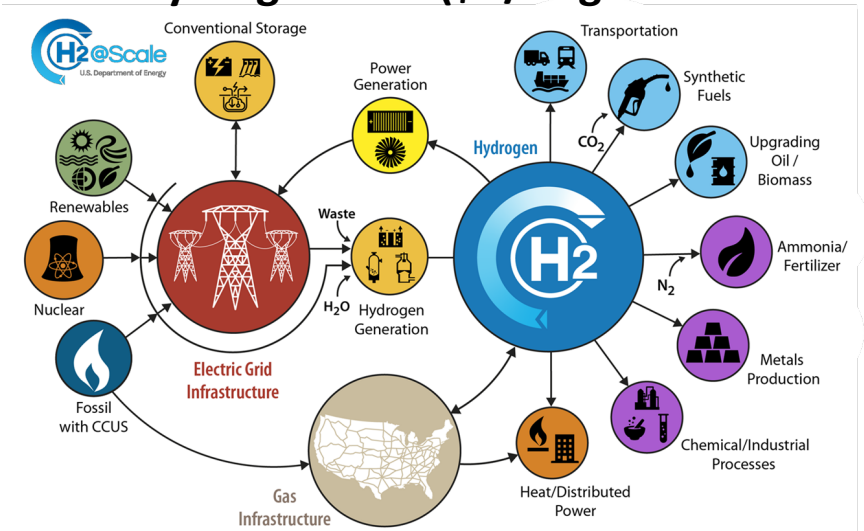
Efficiency Improvements in Chemical Manufacturing

Develop catalytic processes to optimize conversion rates & selectivity.



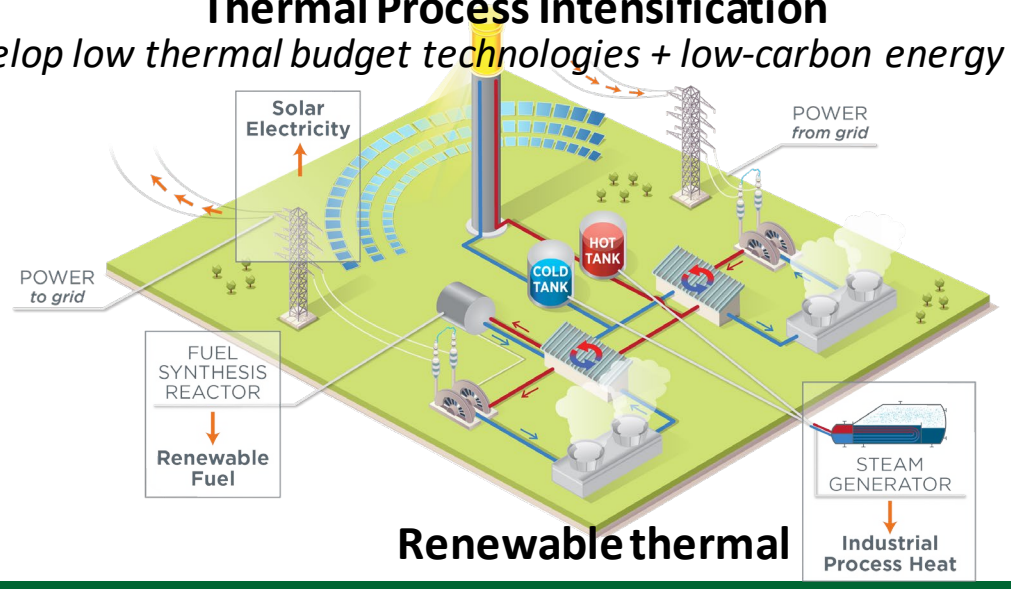
One-step electrochemical ethylene production from CO_2

H2@ Scale and Hydrogen Shot ($1/1Kg clean H2 in 1 decade).



Thermal Process Intensification

Develop low thermal budget technologies + low-carbon energy sources.



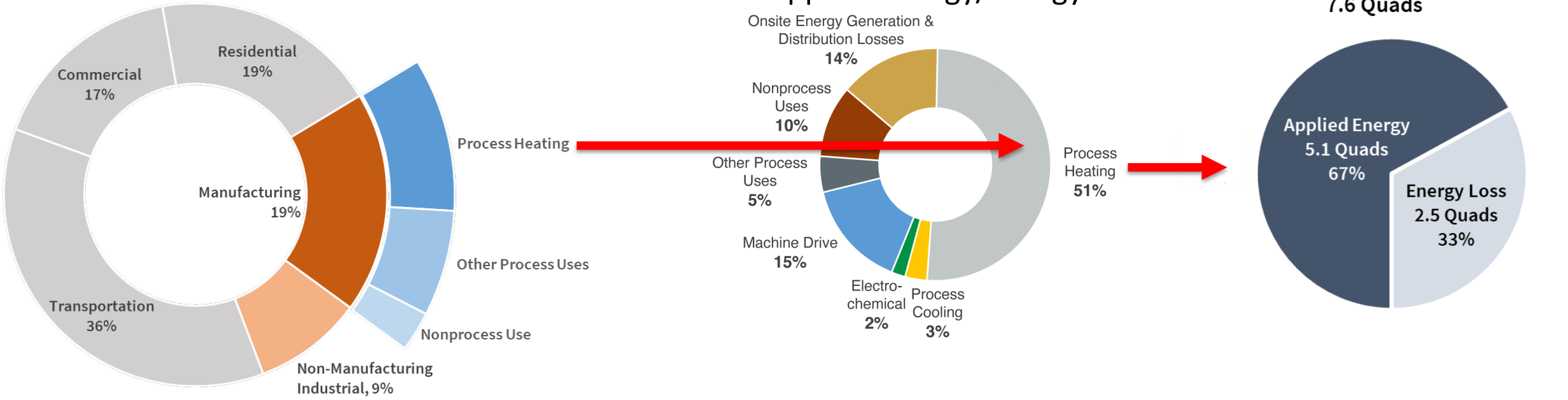
Renewable thermal

Cross-cutting opportunities - Thermal

Onsite manufacturing energy end-use facilities in the U.S. in 2018 by end-use.
2018 Manufacturing Energy Consumption Survey (MECS) data.

Process heating:

- >90% of process heat is fossil fuel-sourced. Accounts for **7% of all US emissions**
- Impacts all industries
- Reduce total thermal demand. Increase the ratio of Applied Energy/Energy Loss

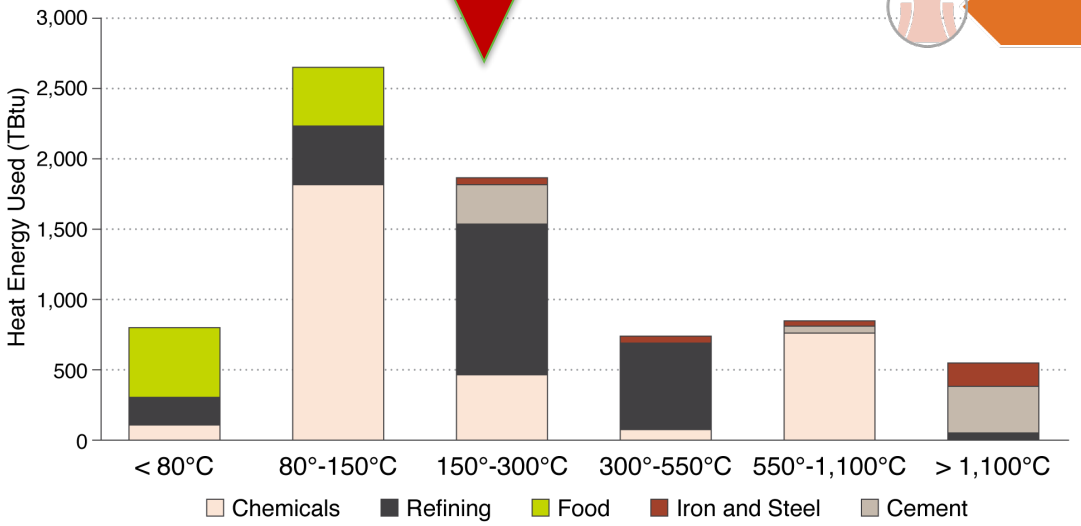


Low Carbon Process Heating Options

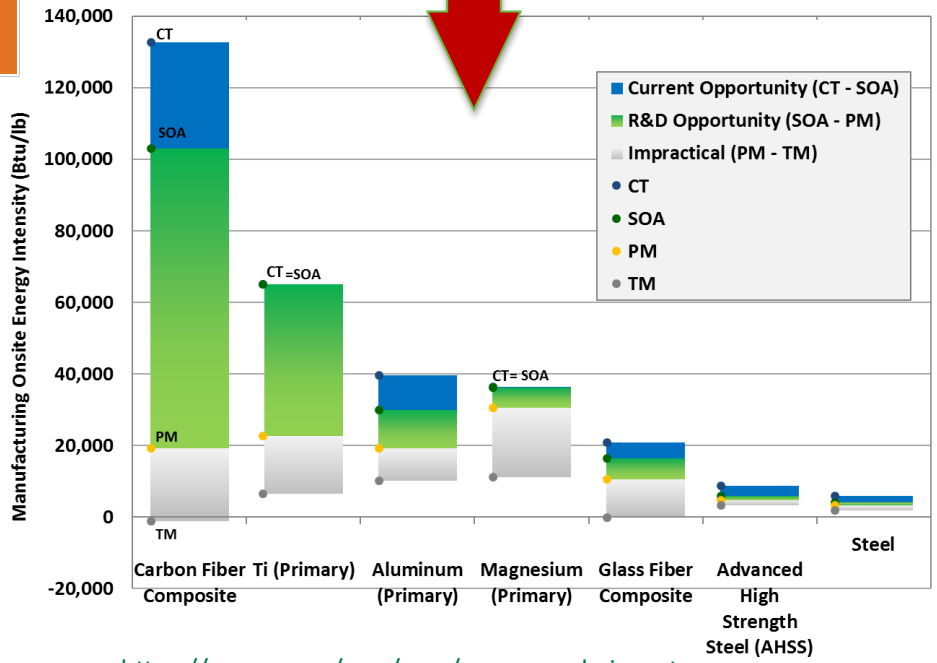
Transforming today's industries

- Electrification
- Nuclear
- Solar Thermal
- Hydrogen
- Biomass
- Fossil + CCUS

Addressing emerging challenges



Distribution of process heat temperature ranges by industrial subsector in 2014.
Temperature ranges are in °C and heat use is in trillion Btu (TBtu). Data source: McMillan 2019



https://energy.gov/eere/amo/energy-analysis-sector

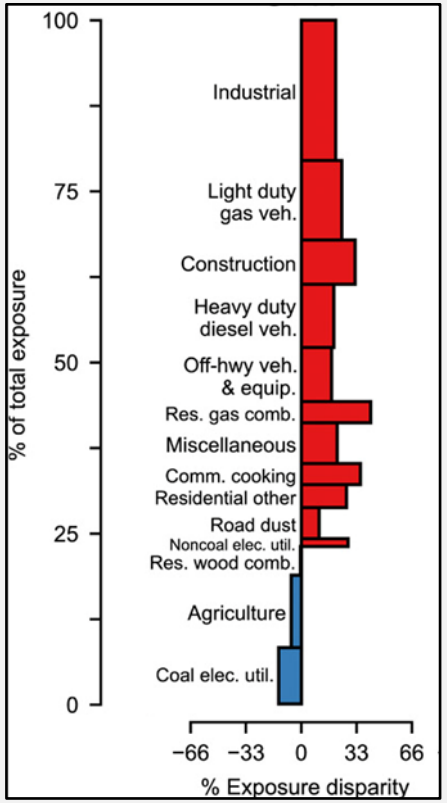
Decarbonized and Sustainable Industrial Operations Advance Env. Justice

GHG reductions are necessary but insufficient.
We must also address the disproportionate impacts experienced by 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 pact categories.**

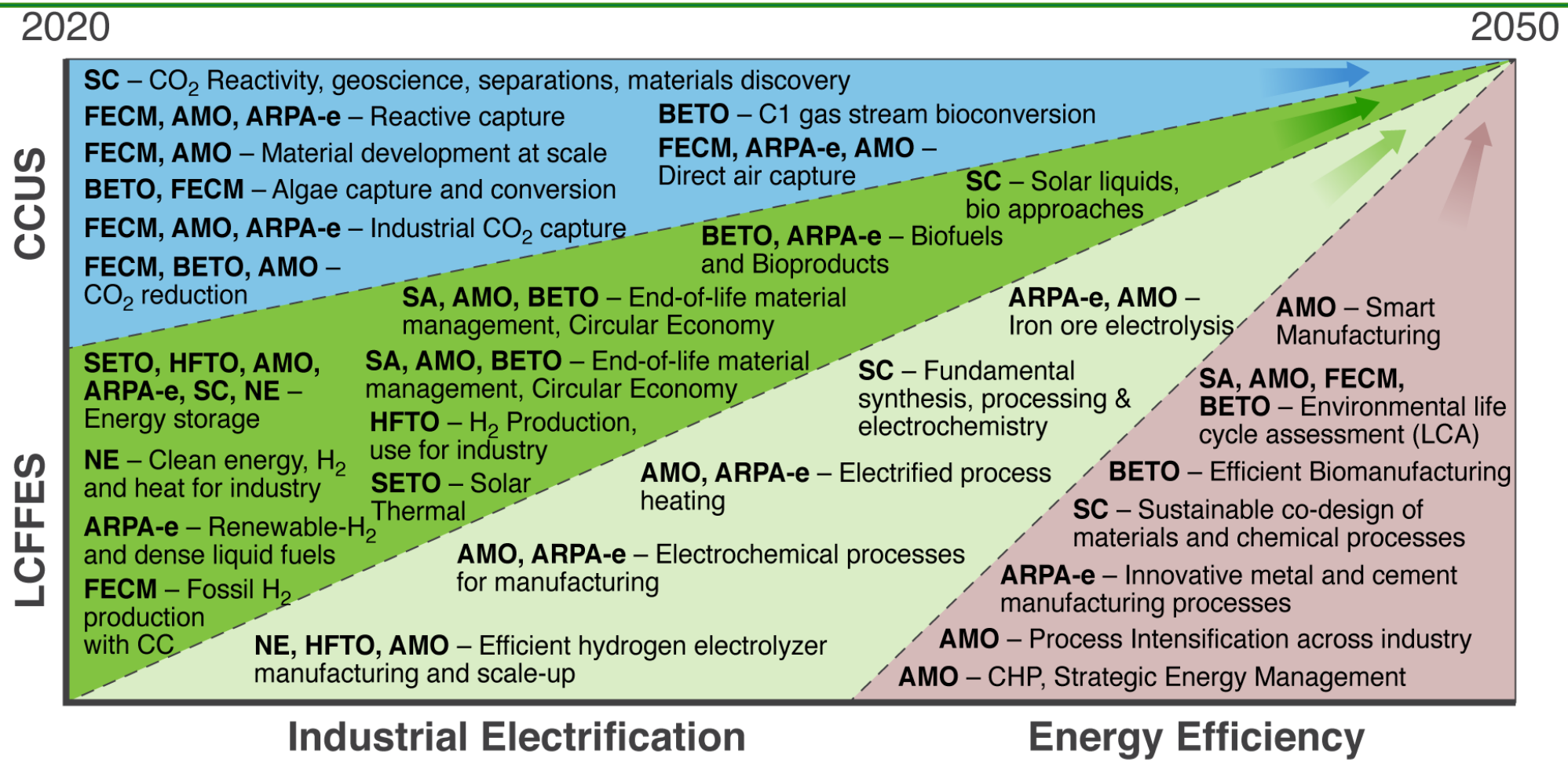
[The Most Detailed Map of Cancer-Causing Industrial Air Pollution in the U.S. | ProPublica]; https://projects.propublica.org/toxmap/

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



Tessum, et al. *Science* (2021)

This is an all-of-DOE effort.



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; **TRT** = top pressure recovery turbine; **SEM** = strategic energy management; **CDQ** = coke dry quenching; **WHP** = waste heat to power; **BF** = blast furnace; **DRI** = direct reduced iron

What is the future for a sustainable, decarbonized industrial sector?

Adapting to a continuously evolving energy sector.

Clean and productive industrial processes.

Increasingly connected economic sectors.

Building new capabilities and rebuilding lost capabilities.

Highly flexible and resilient manufacturing operations, systems and facilities.

Data analytics, machine learning, artificial intelligence for robust cyber-physical systems.

Reverse, dynamic, adaptable supply chains.