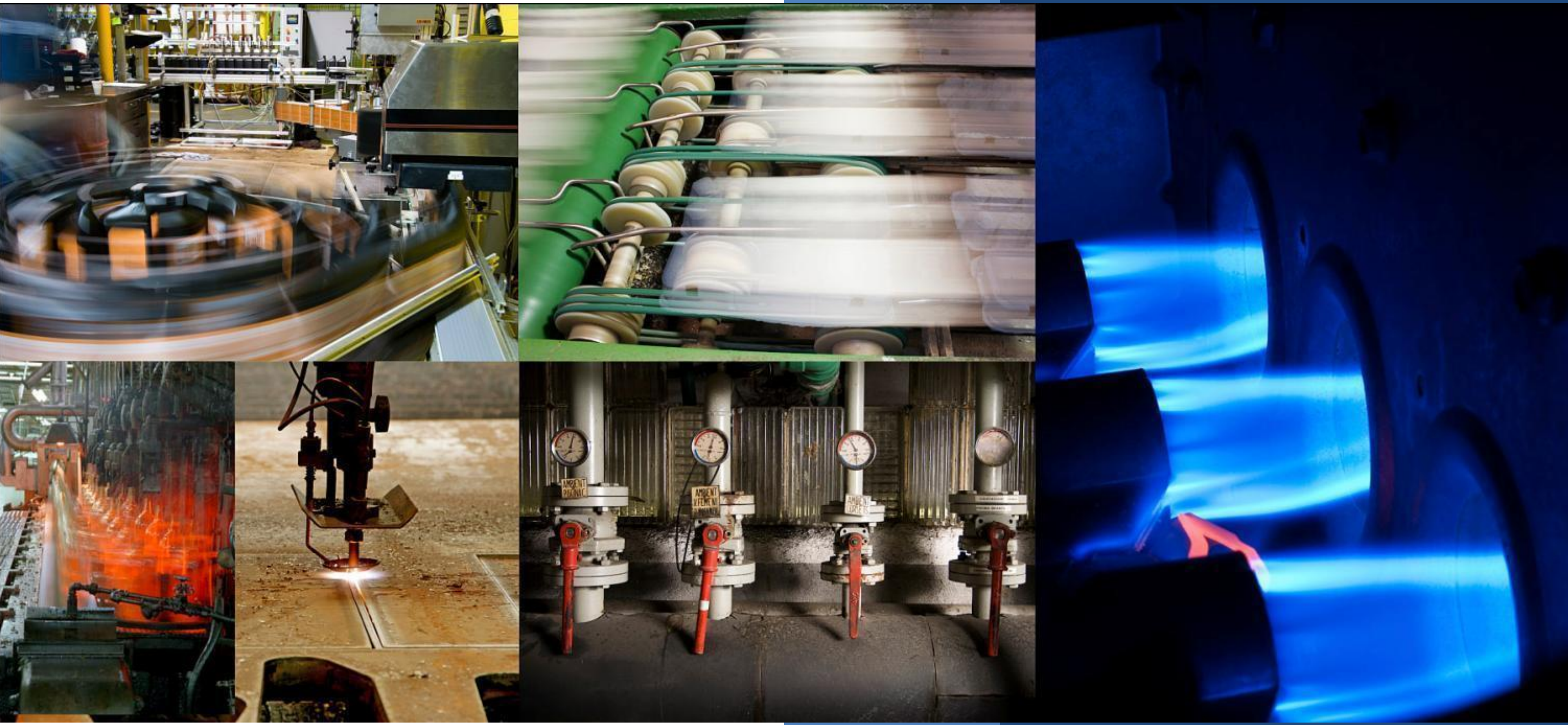
Office of Energy Efficiency & Renewable Energy
Advanced Manufacturing Office

U.S. DEPARTMENT OF ENERGY



Industrial Decarbonization: Opportunity, Challenges and RD&D Needs

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Advanced Manufacturing Office, DOE

CIBO-
Virtual Energy Committee Meeting

June 9, 2021

Industry Contributes Significantly to CO_2 Emissions

THE U.S. INDUSTRIAL SECTOR

manufacturing | agriculture | mining | construction

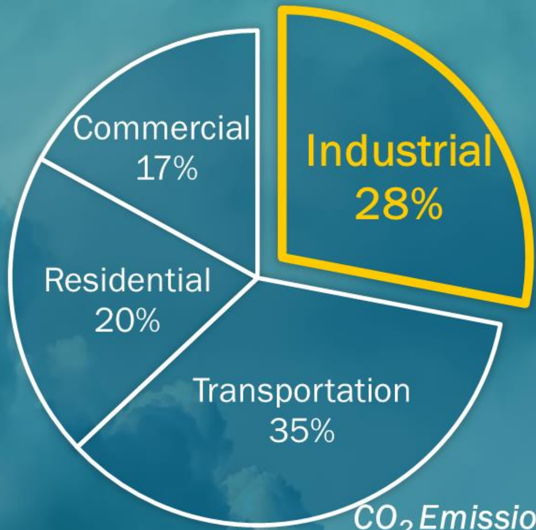
ACCOUNTS FOR

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.

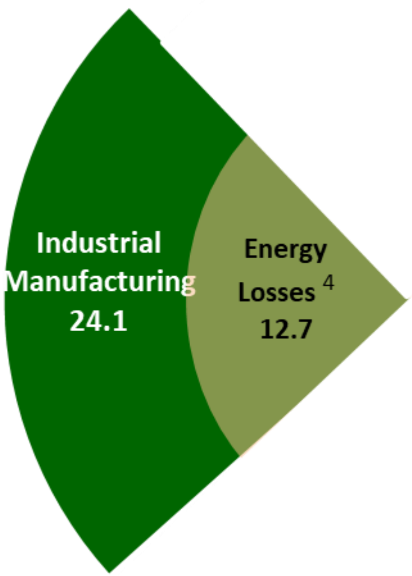
Decarbonizing the industrial sector is key to addressing the climate crisis and achieving economy-wide, net-zero emissions by 2050.

EIA, *Annual Energy Outlook 2020 with Projections to 2050.*

Opportunity Space for Manufacturing

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

Manufacturing Goods



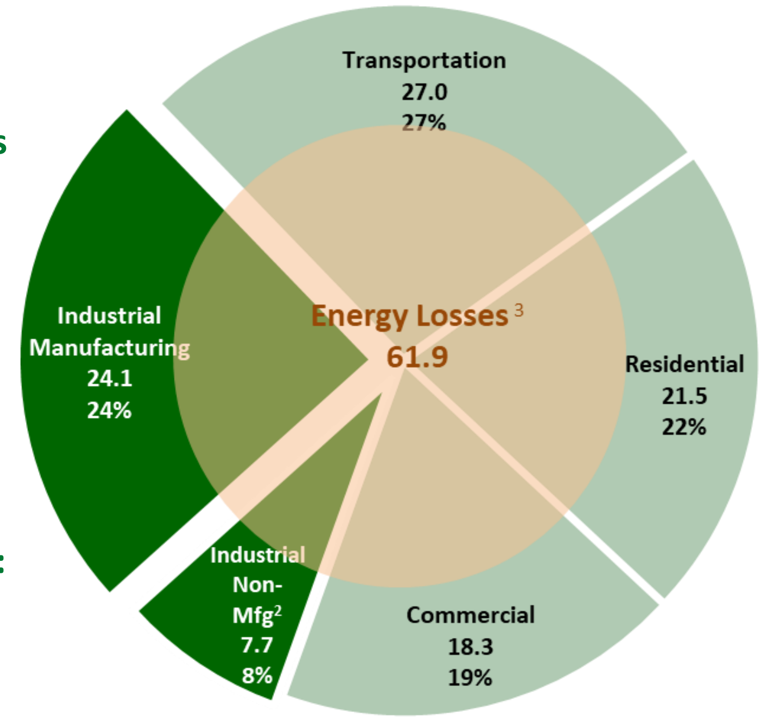
Data for 2014

More efficient manufacturing reduces energy losses

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

- Transportation
- Buildings
- Energy Production and Delivery

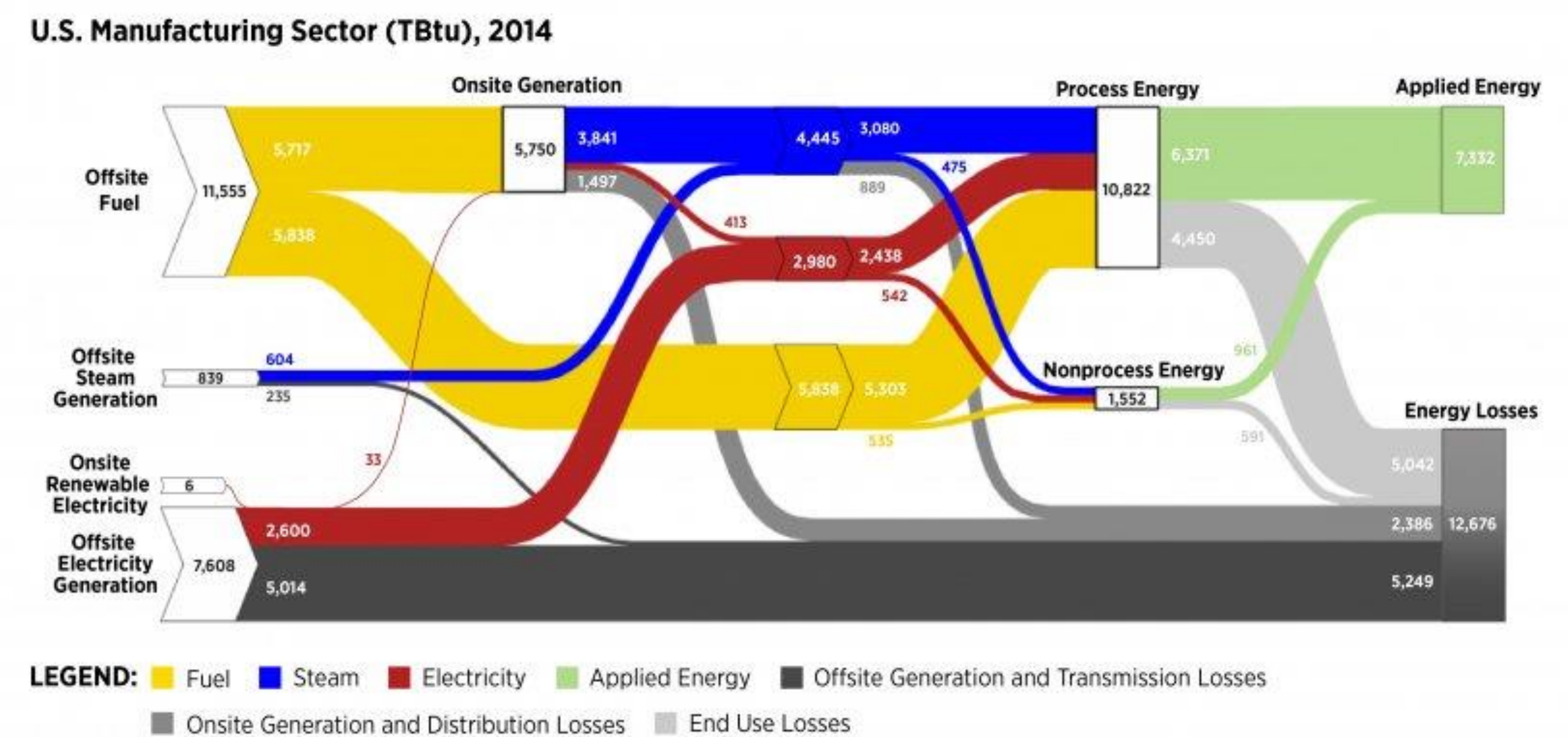
Use of Manufactured Goods



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)

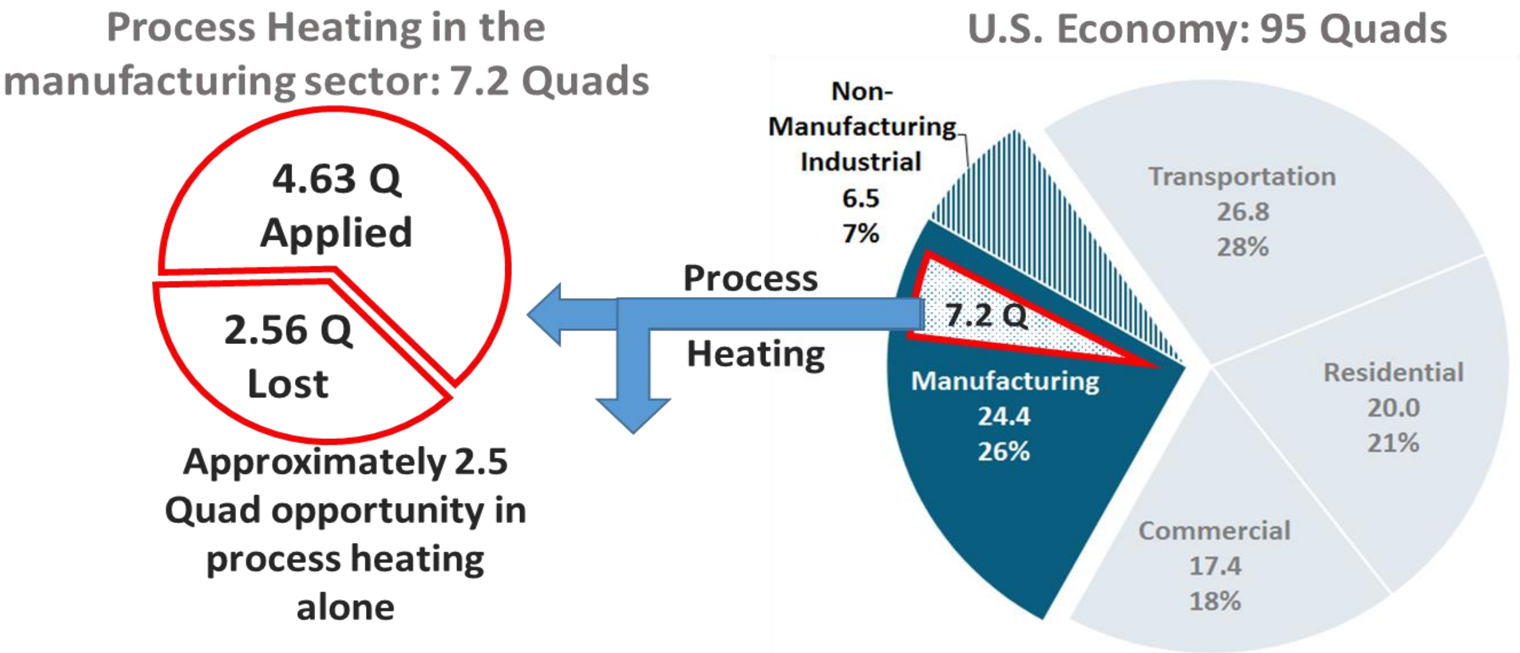
Energy use within the manufacturing sector



Note: 1 quad = 1,000 TBtu

Static Sankey Diagram Full Sector Manufacturing (2014 MECS) | Department of Energy

Cross-cutting opportunities (e.g. process heating)…



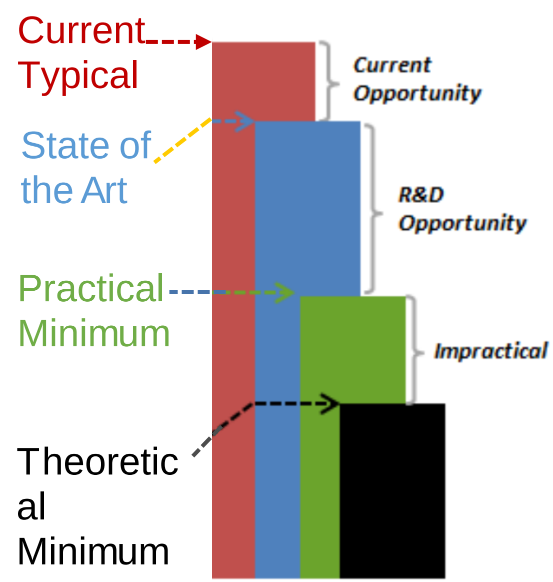
Source: EIA Monthly Energy Review, Aug 2014; AEO 2014

- **7 Quads**. 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.
- **95% fossil fuel based**.
- **Potential?** What is potential to avoid the 2.5 Q of energy losses and reduce the 4.6 Q of energy demand in process heating?
- **Opportunity for electrification?** Traditional industrial (thermal) processes can be inefficient, difficult to control and result in materials and products with compromised quality and performance.
- **Timeframe?** Can adoptions of electric arc furnaces; Hall-Herault for aluminum; induction melting & heat-treating; etc. inform future technology adoption/progression?

Energy savings by subsector – Bandwidth studies.

2015 (published)	**Manufacturing sector bandwidth studies:** • Chemicals • Iron & Steel • Pulp & Paper • Petroleum Refining
2017 (published)	**Lightweight materials bandwidth studies:** • Aluminum • Advanced High Strength Steel • Titanium • Magnesium • Carbon Fiber Reinforced Polymer Composites • Glass Fiber Reinforced Polymer Composites **Water/energy studies:** • Desalination Bandwidth Study **Manufacturing sector bandwidth studies:** • Plastics & Rubber Products • Cement • Glass • Food & Beverage

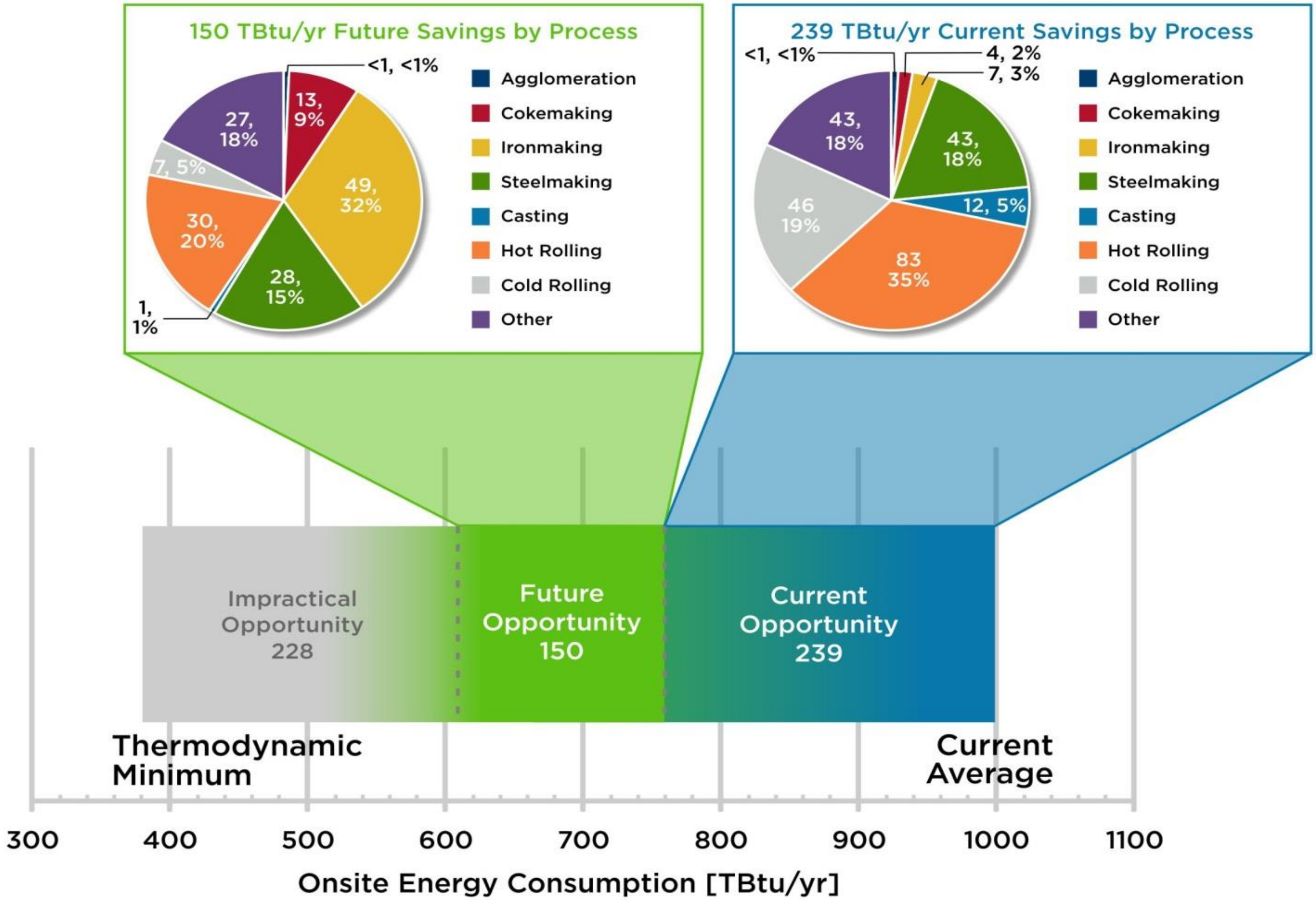
Energy bandwidth studies can frame the range (or *bandwidth*) of potential energy savings in manufacturing, and technology opportunities to realize those savings.



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

Bandwidth analyses are bottom-up studies starting at the manufacturing process/unit operation level ….

Technical Energy Savings Opportunities: Iron & Steel Industry 2015 Bandwidth Study – potential by major process area



Source: DOE/AMO, Iron & Steel Industry Energy Bandwidth Study (2015)

Note: 1 quad = 1000 TBtu

Drivers to Reduce Energy & Emissions through the Product Life Cycle

New Processes

Energy Intensity e.g.:
- Process efficiency
- Process integration
- Waste heat recovery

New Materials

Carbon Intensity, e.g.:
- Process efficiency
- Feedstock substitution
- Biomass-based fuels
- Renewables

Use Intensity e.g.:
- Circular Economy
- Design for Re-X (recycling reuse and remanufacturing)
- Material efficiency and substitution

Improved Products by Next Generation Materials and Processes.

Energy Intensity

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Process efficiency
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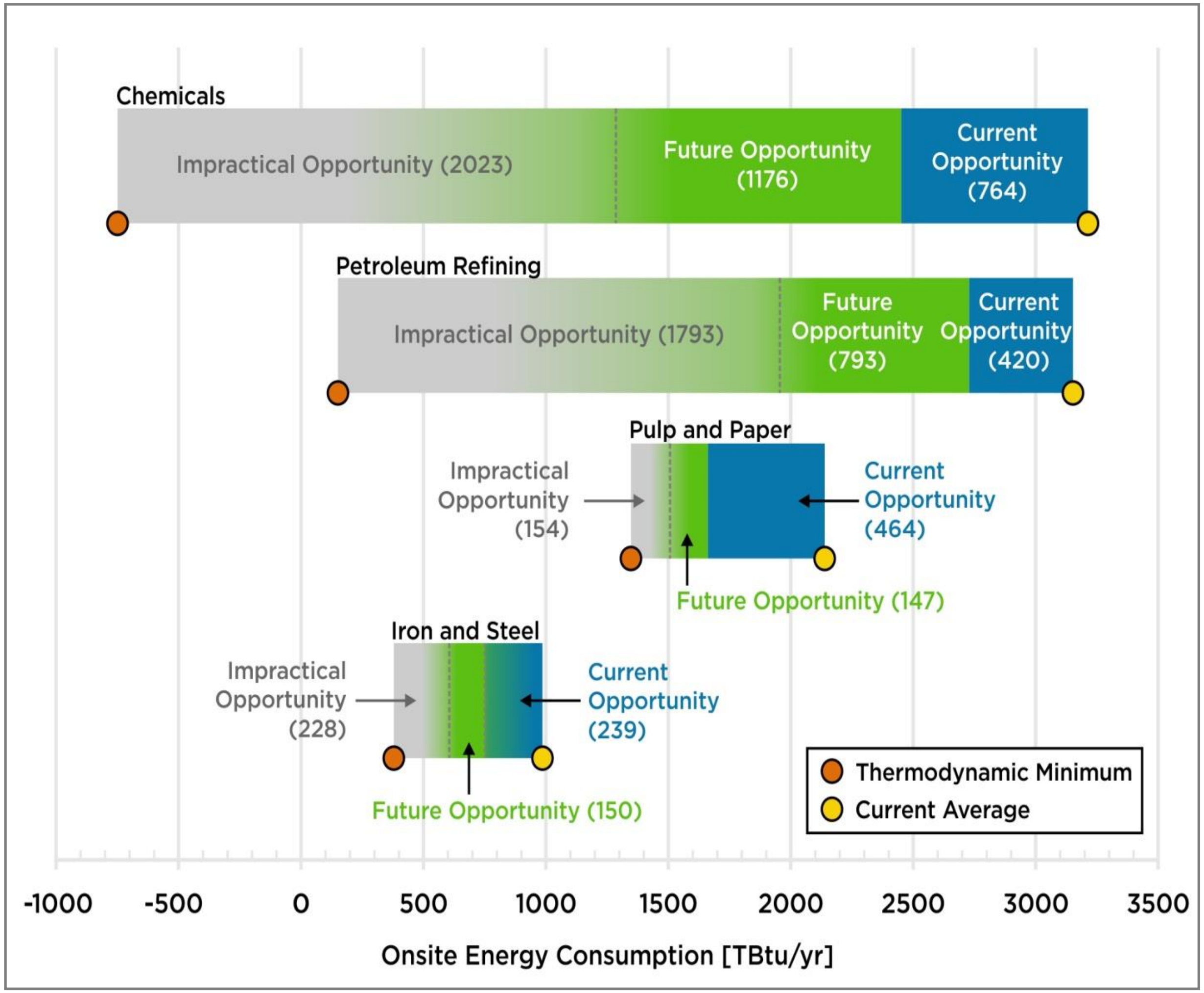
Technical Energy Savings Opportunities:



Source: DOE/AMO, Energy Bandwidth Studies (2015)
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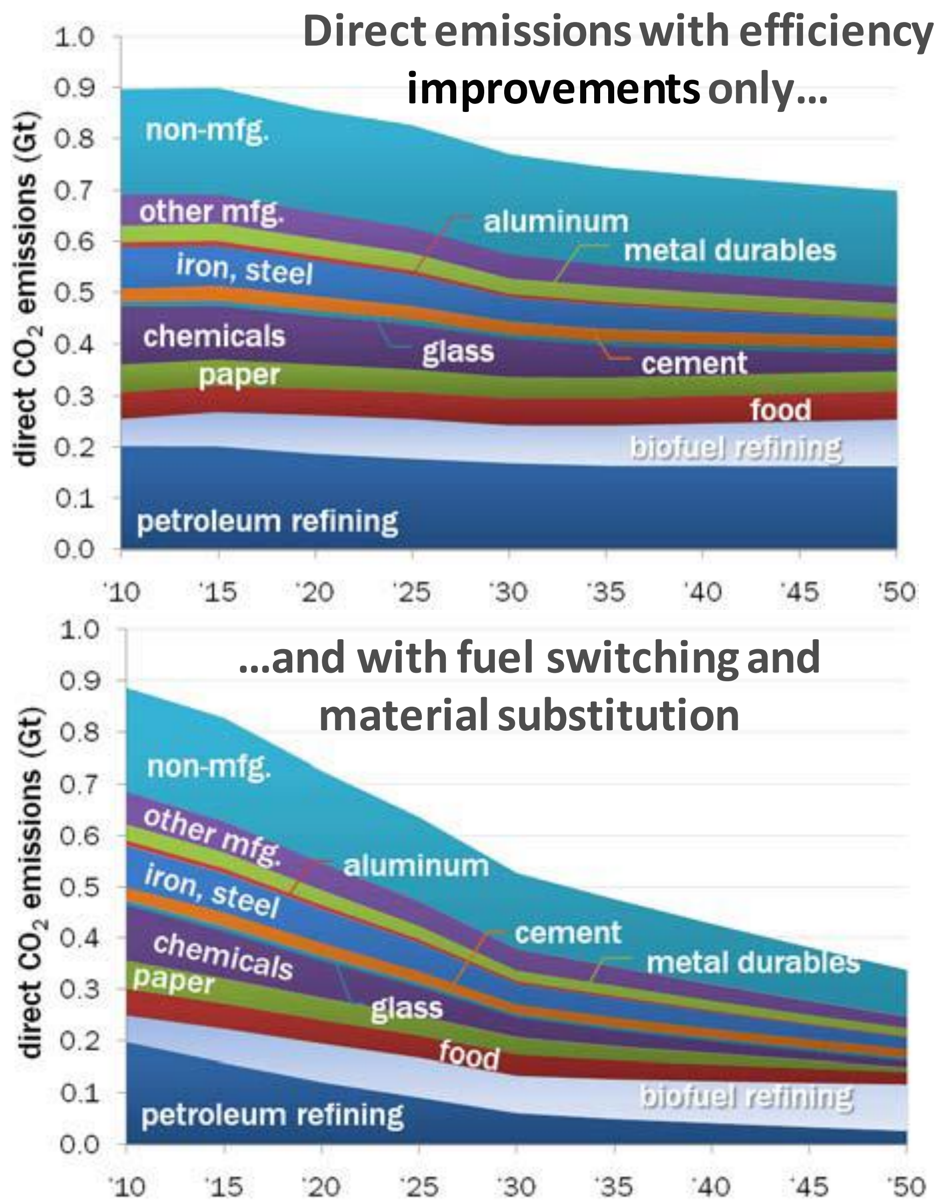

Example analysis based in part on bandwidth SOTA & PM potential, and EIA Annual Energy Outlook (AEO) forecast as baseline.

Use Intensity

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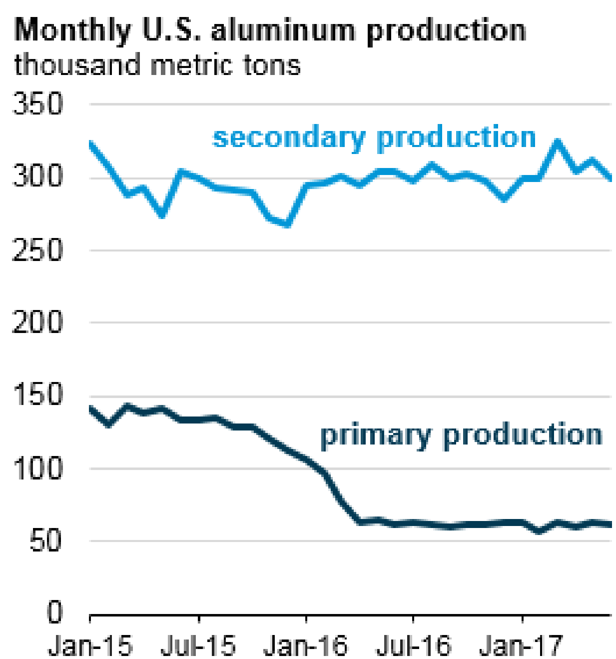
Aluminum

btu/lb	primary	secondary
Current average	26,000	2,200
Practically achievable	20,000	925
Current savings potential	6,000 btu/lb Process improvement	1,275
Theoretical minimum	10,200	510

Energy Intensity

23,800 btu/lb Materials shift

Use Intensity



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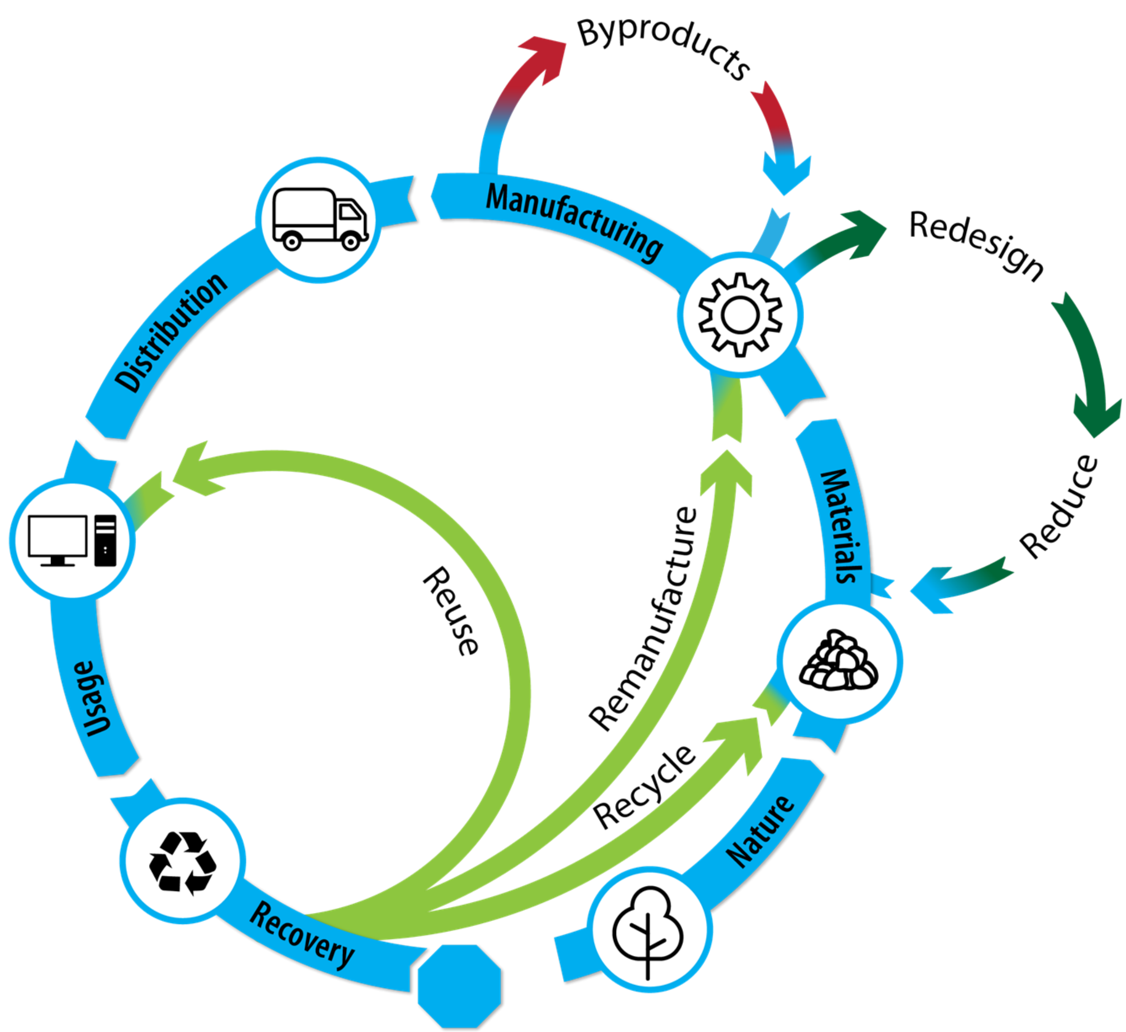
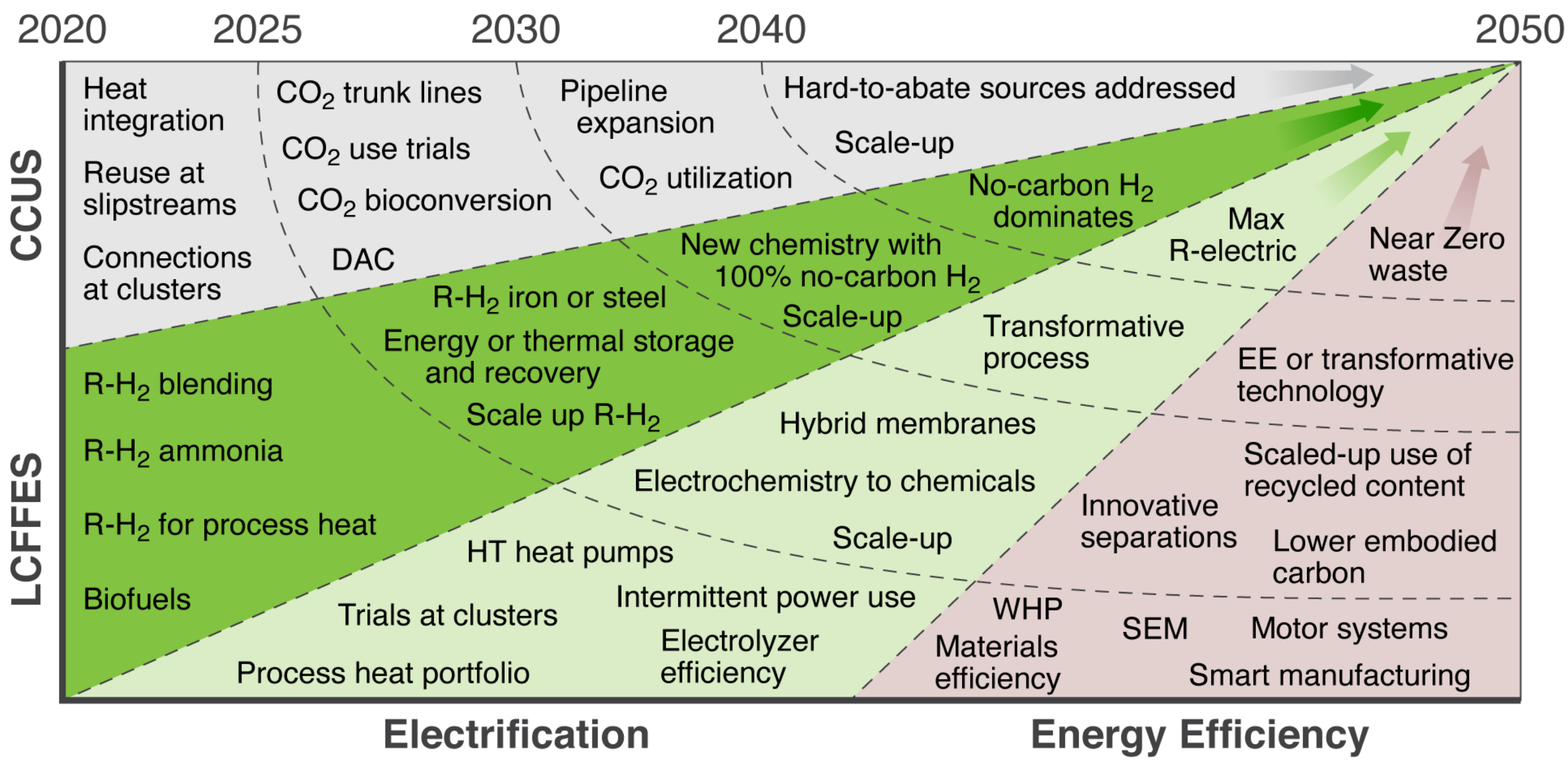


Industrial Decarbonization Roadmap

- **Industrial decarbonization is a key component within EERE expertise to build a 100% clean energy economy. Action is needed now to meet net zero emissions in 2050.**
- **The congressional direction guided the 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.*
- **The industrial decarbonization roadmap builds off AMO prior analysis work including 2015 Energy Bandwidth studies.**
- **Roadmap has solicited input from varied sources. It focuses industry's interests to enhance U.S. competitiveness through pursuing RD&D needs and opportunities.**

Multiple Pillars of Decarbonization Must be Pursued in Parallel



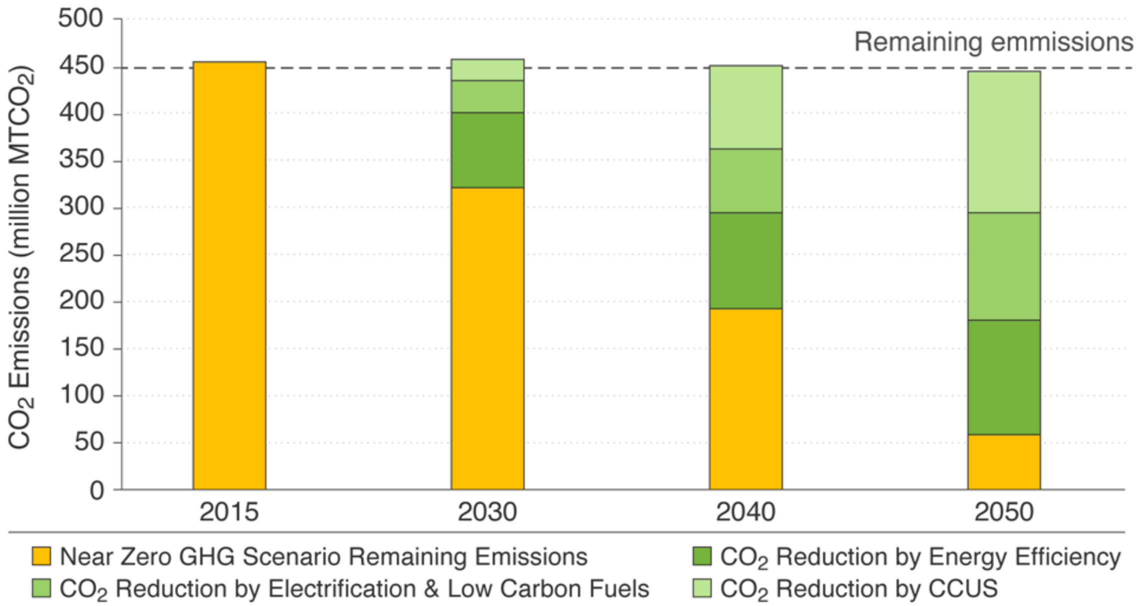
Landscape of major RD&D investment opportunities for industrial decarbonization between now and 2050.
LCFFES = Low carbon fuels, feedstocks, and energy sources. CCUS = Carbon capture, storage, and utilization.

A host of technical opportunities across a range of Technology Readiness Levels (TRLs)

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

2050 Industrial Emissions Reduction Potential in 5 subsectors

- Identified key pillars of industrial decarbonization:
  - Energy efficiency
  - 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



Composite plot of GHG reduction scenarios for the decarbonization pillars across iron and steel, chemical manufacturing, food manufacturing, petroleum refining and cement sectors. (near zero GHG scenario, excluding feedstocks)

Barriers for Abating CO_2 Emission in the Industrial Sector

Key Crosscutting barriers:

- Diversity of industrial processing steps and energy inputs used in manufacturing
- Scale of facilities and lengthy timeframe for capital turnover
- Cost of development to validate new technology at industrially-relevant scales
- Complex supply chains
- Capital availability

Examples of sector specific barriers:

- Low feedstock cost (chemicals)
- By-product interdependencies (petroleum refining)
- Market acceptance and regulatory barriers to blended cement variants
- Regulatory and food safety issues across heterogeneous food manufacturing sector

- Many barriers can be addressed by RD&D investment, but some will require policy support.

Key Recommendations

- Accelerate RD&D of emerging and transformative technologies to achieve net-zero GHG emissions in the industrial sector by 2050

Pursue multiple decarbonization pillars in parallel

* energy efficiency,

* electrification & low-carbon fuels

* CCUS

Drive low capital investment approaches, with multiple benefits that spur early action

* energy efficiency

* materials efficiency

* system efficiency

Portfolio should include:

* new technologies,

* integration into process systems; and

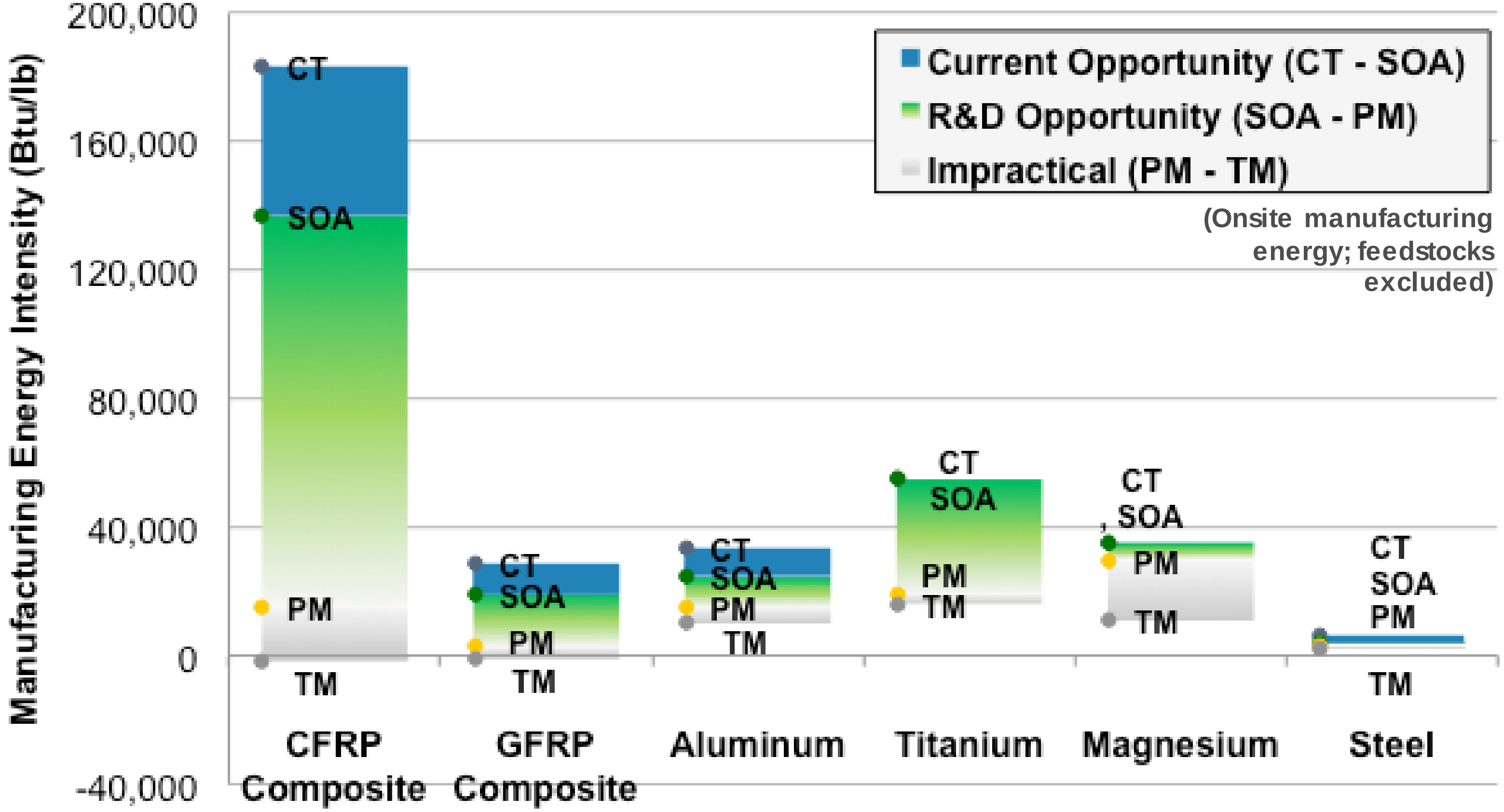
* supply chains

Invest in early, 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 & inclusion

Looking forward - anticipate and address tomorrow's energy intensive materials with R&D today



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

Thank You.

For additional information:

energy.gov/eere/amo/advanced-manufacturing-office

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ACEEE – Ed Rightor, Neal Elliott
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