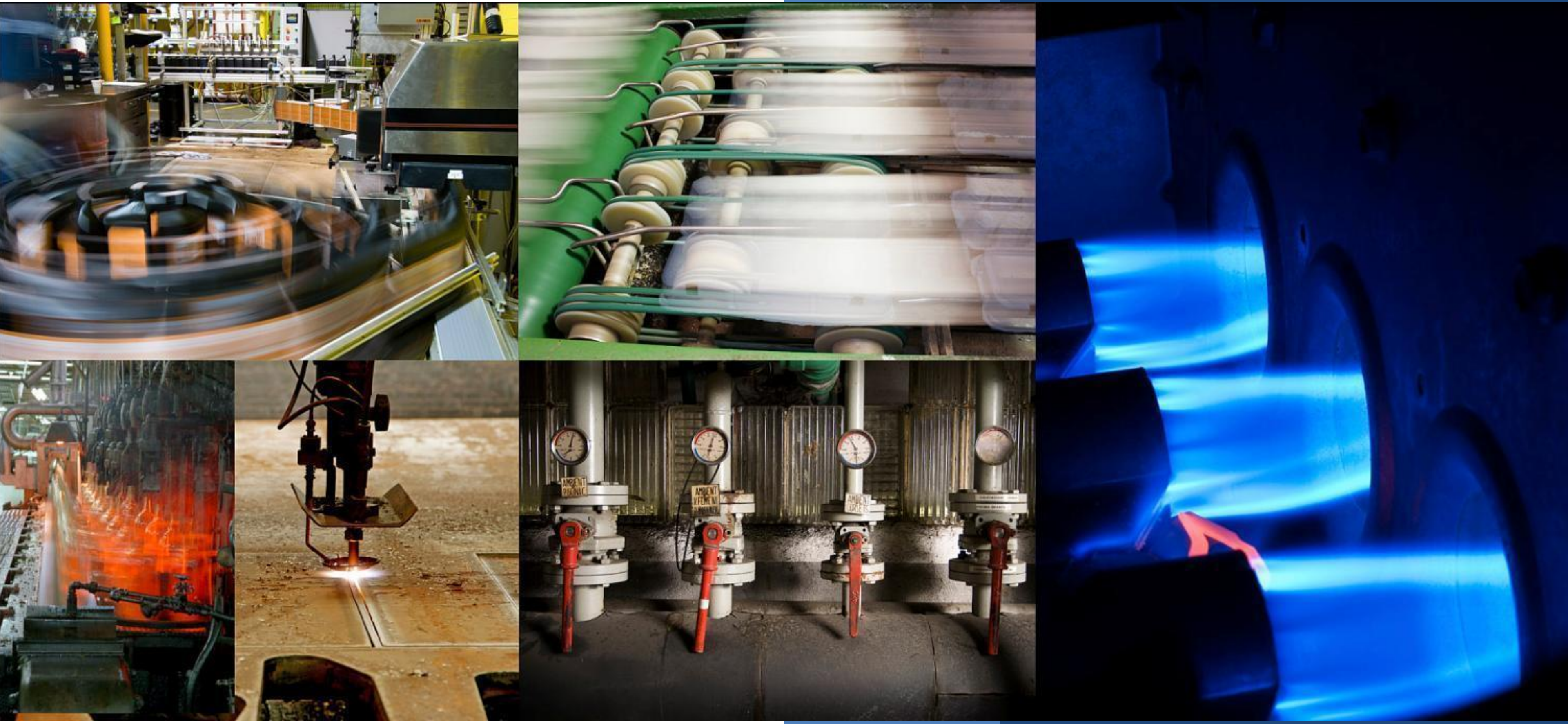
Office of Energy Efficiency & Renewable Energy
Advanced Manufacturing Office

U.S. DEPARTMENT OF ENERGY



Industrial Decarbonization: Opportunity, Challenges and RD&D Needs

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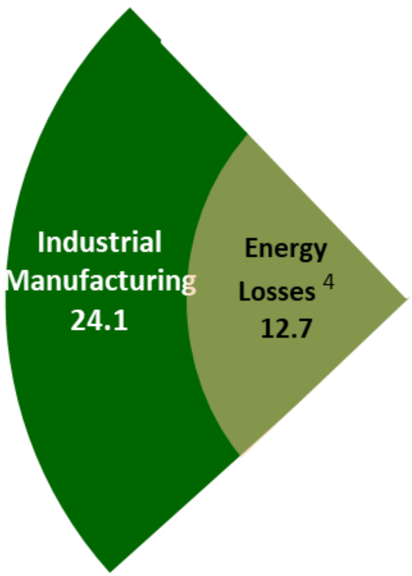
FE/NETL Carbon Utilization Program Review

October 22, 2020

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



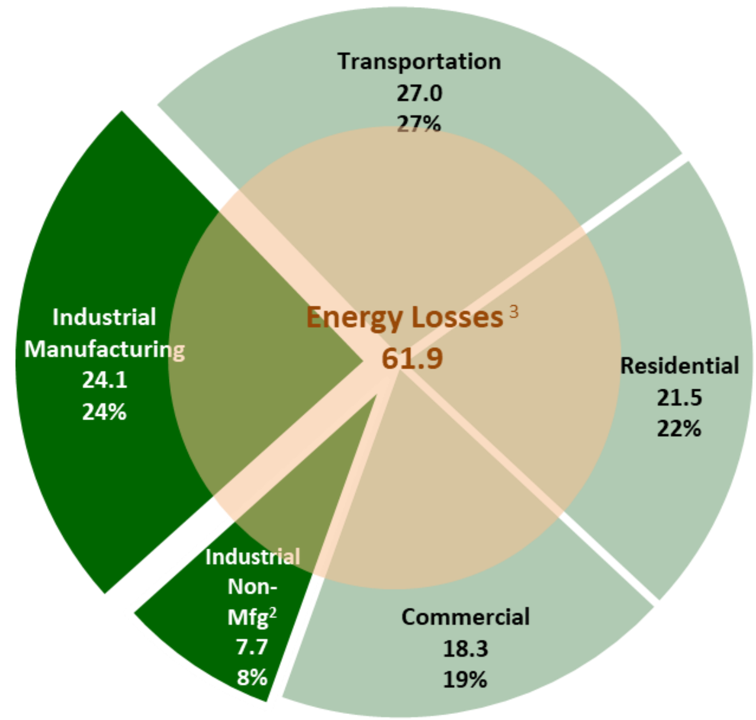
Data for 2014

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)

AMO's Approach

AMO works to **increase energy and material efficiency in manufacturing** to drive energy productivity and economic growth.

MANUFACTURING

- Uses roughly 25% of the nation's primary energy
- Represents nearly 80% of energy use in energy-intensive sectors
- Generates 11% of the U.S. GDP and 13 million jobs
- Incurs $150 billion in energy costs annually

AMO GOALS

- Improve the **productivity, competitiveness, energy efficiency, and security** of U.S. manufacturing
- Reduce the **life cycle energy and resource impacts** of manufactured goods
- Leverage diverse **domestic energy resources and materials** in U.S. manufacturing, while strengthening environmental stewardship
- Transition DOE-supported innovative technologies and practices into **U.S. manufacturing capabilities**
- Strengthen and advance the **U.S. manufacturing workforce**

Drivers to Reduce Energy & Emissions through the Product Life Cycle

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

New Processes

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

New Materials

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 Processses.

Energy Intensity

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Process integration
Waste heat recovery

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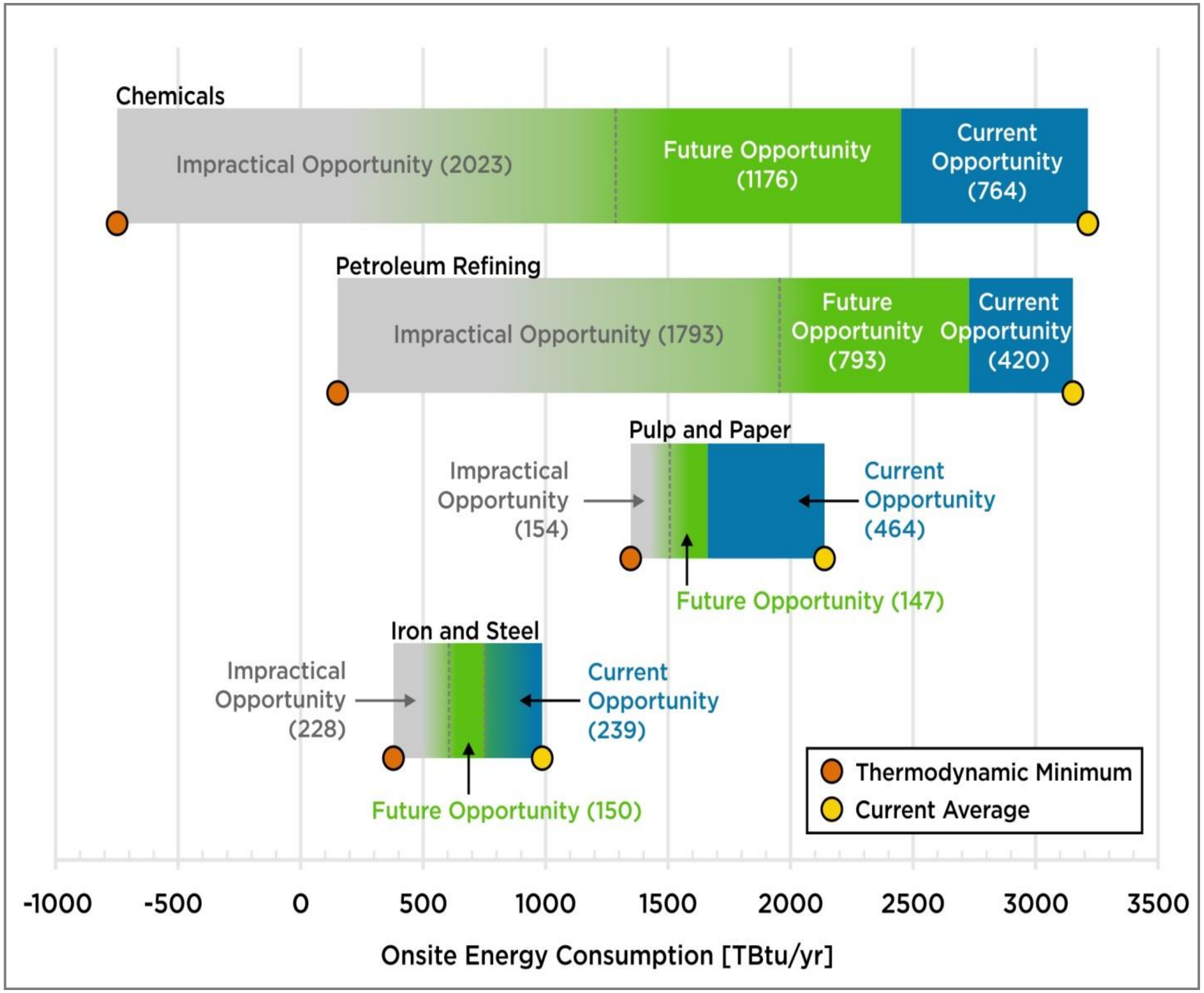
Technical Energy Savings Opportunities:



Source: DOE/AMO, Energy Bandwidth Studies (2015)
Note: 1 quad = 1000 TBtu

Carbon Intensity

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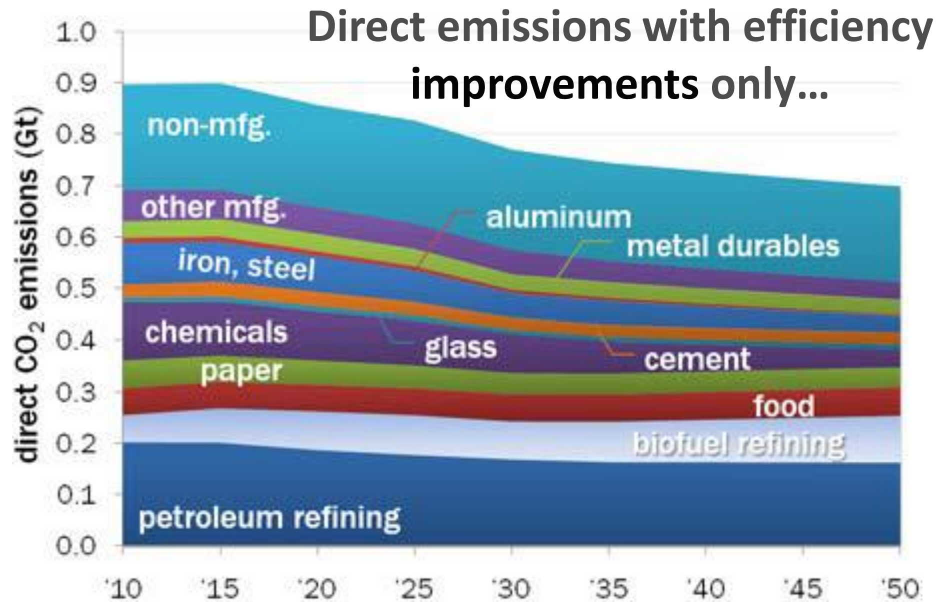

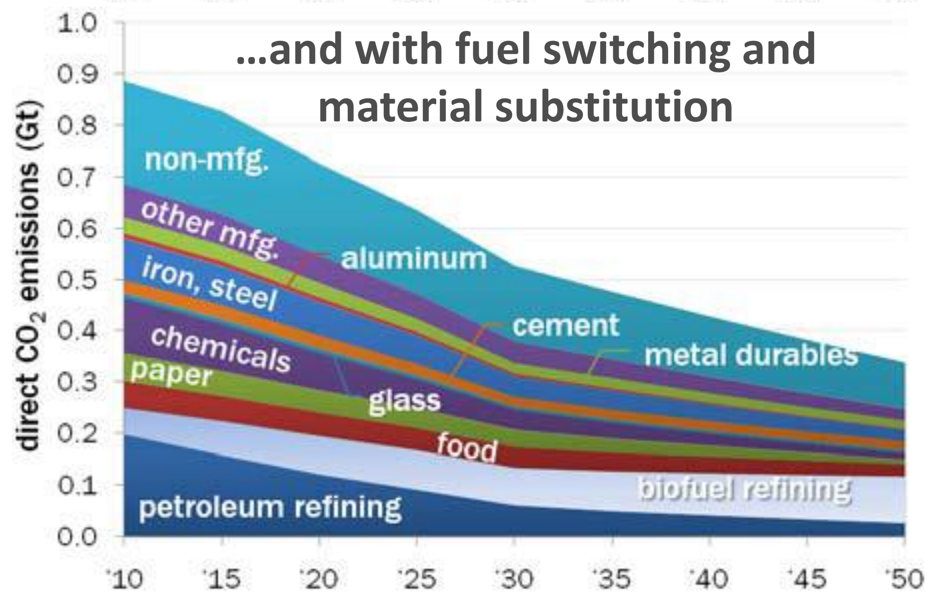

Example analysis based in part on bandwidth SOTA & PM potential, and EIA Annual Energy Outlook (AEO) forecast as baseline.

Use Intensity

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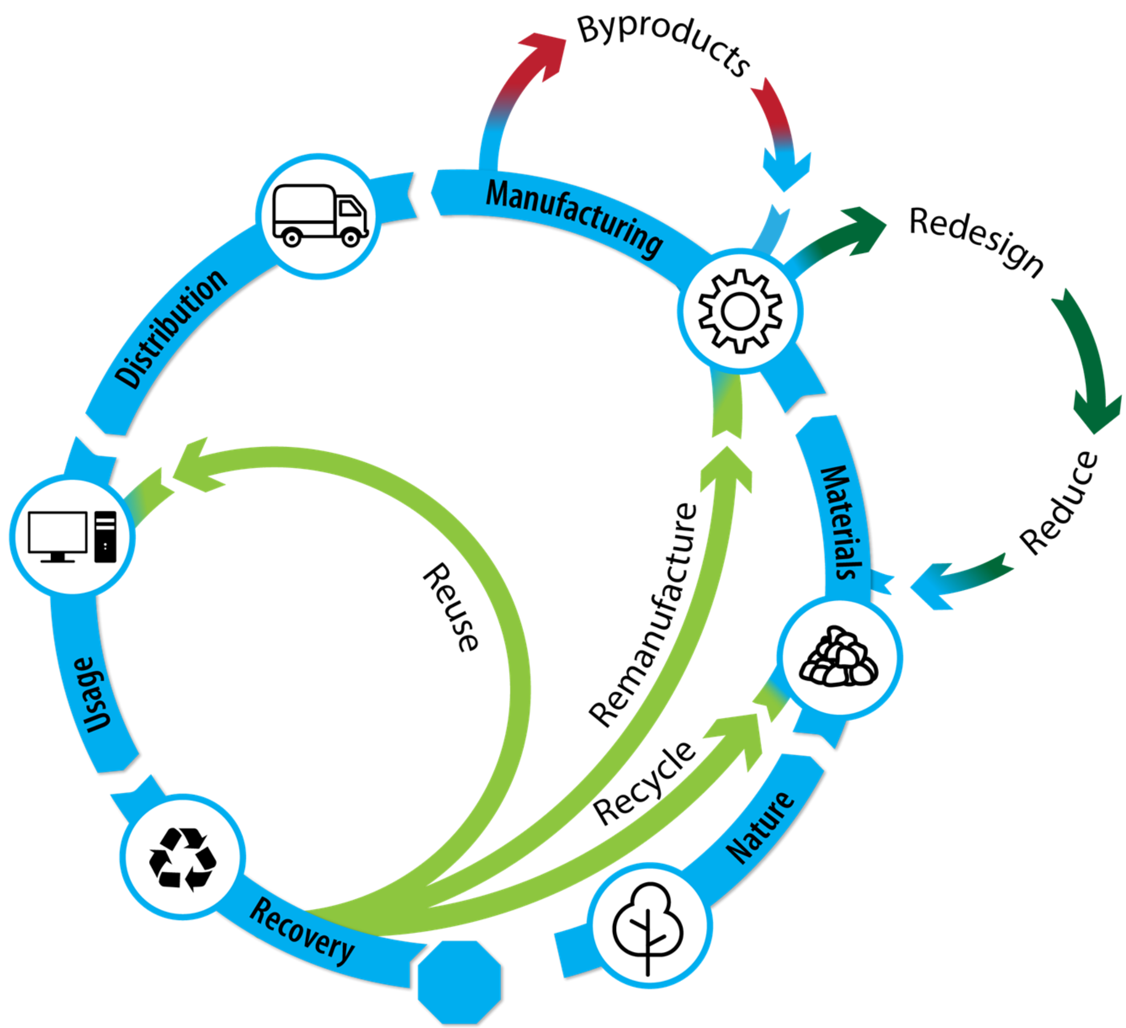
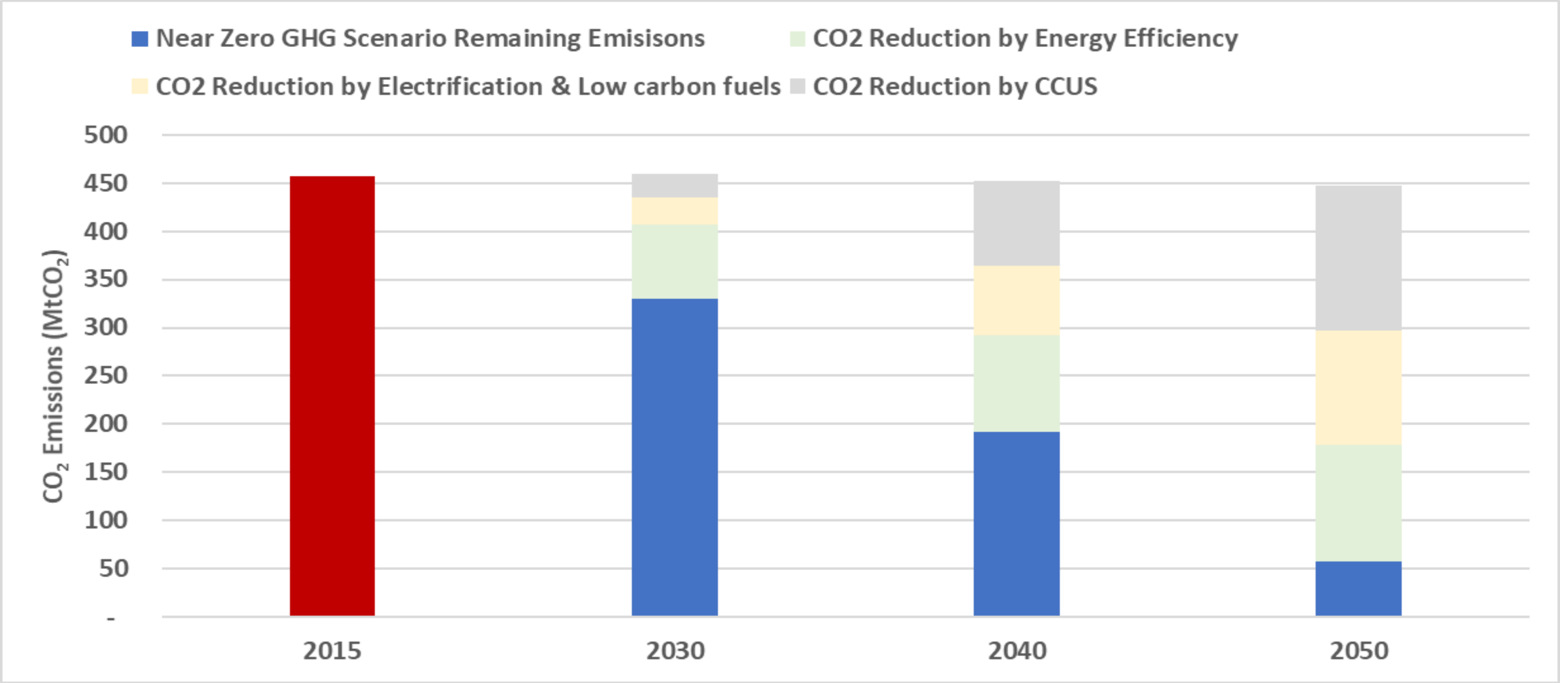


AMO Industrial Decarbonization Roadmap - Background

- Direction by Congressional House and Senate to “develop decarbonization roadmaps to guide R&D at the DOE…to phase out net GHG emissions by 2050” and opportunity to increase U.S. competitiveness in the industrial sector.
- The roadmap is the multi - lab effort (NREL, Berkeley, Argonne, Oak Ridge) in consultation with key stakeholders involved in the U.S industrial sector.
    - Focus on five industries: cement, iron & steel, food, and chemicals, petroleum refining
    - External workshops with industry held in spring 2020

Decarbonization Roadmap Main Takeaways

Fig 1. Example of projection of GHG emissions for the three decarbonization pillars across the iron and steel, chemical manufacturing, food manufacturing, petroleum refining and cement sectors for the near zero GHG scenario (excluding feedstocks)



- Identify barriers, pathways, RD&D needs, and opportunities, and propose RD&D action plan for each industry.
- Identified RD &D needs and opportunities are centered around three main decarbonization pillars for the U.S industry:
  - ✓ Energy efficiency
  - ✓ Electrification and low carbon fuels
  - ✓ Carbon capture, utilization and storage
- These pillars are explored by studying crosscutting and sector specific technologies, process, and practice for the five industries.

Barriers to Industrial Decarbonization

- While Fig. 1 indicates potential GHG reductions via the three decarbonization pillars, the road to net-zero is cluttered with barriers (sector specific and crosscutting) - that will need to be addressed.
- Crosscutting barriers can be categorized into four main groups:
    - Industrial heterogeneity
    - Incumbent technology and practices
    - High costs
    - Scale up
- These barriers can be addressed by RD&D investment

RD&D investment needs and opportunities

- A wide range of investments is needed across multiple cross-cutting and sector specific technologies.
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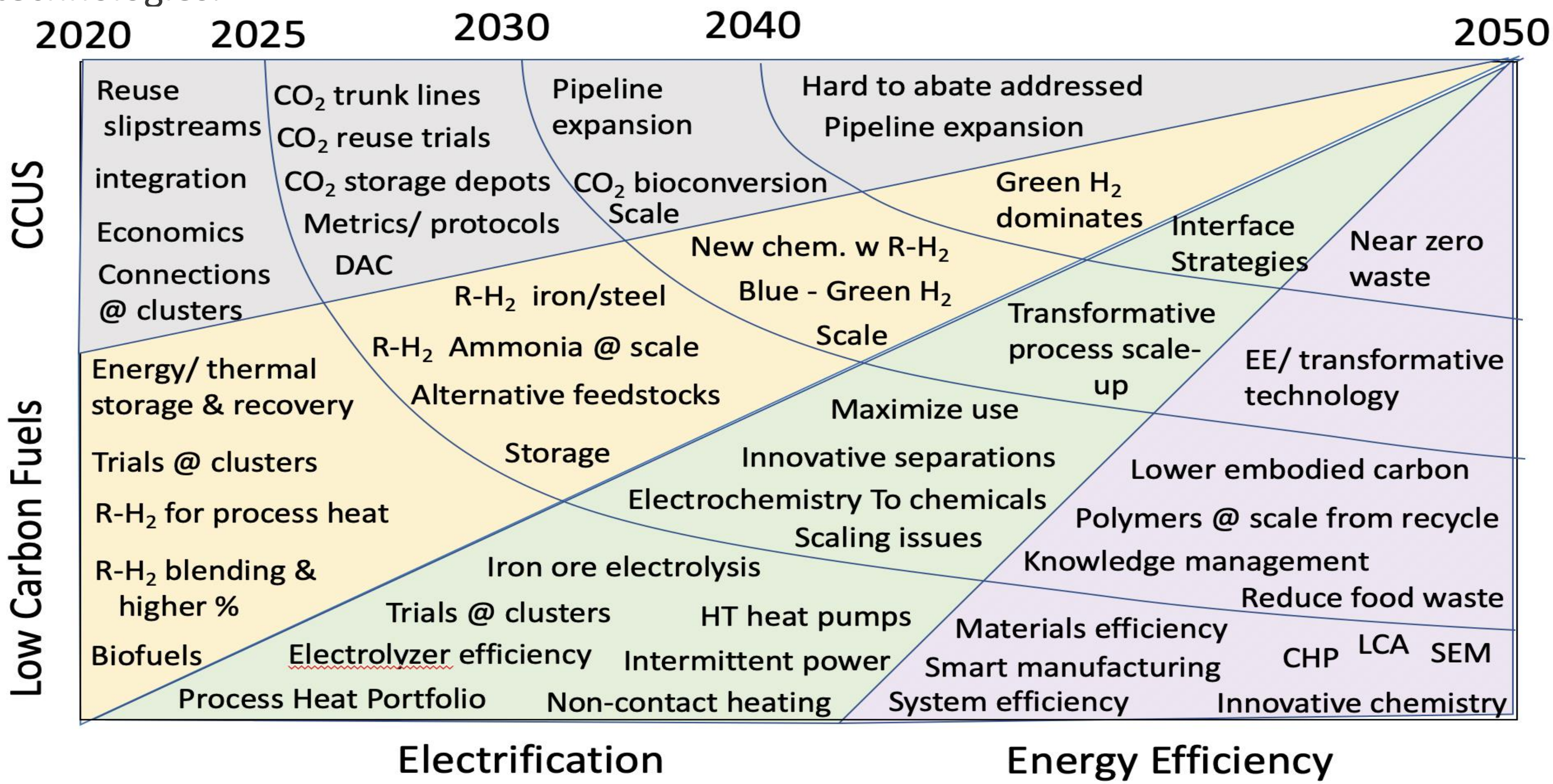


Fig 2. Landscape of RD&D investment needs and opportunities for decarbonization

Stakeholder Input to the Roadmap

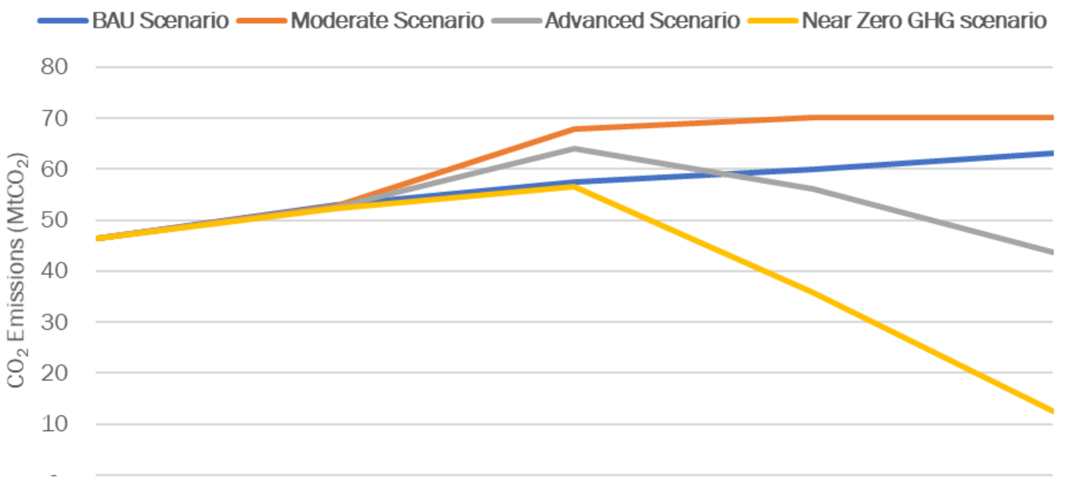
- Proactive pursuit of multiple decarbonization pillars concurrently (e.g. energy efficiency, electrification and low-carbon fuels, and CCUS) is needed by leverage current resources and programs from public and private sectors
- Investments in early, low-carbon process TRL technologies will be needed soon to ensure future market viability.
- Focus is needed not just on new technologies, but on their integration into process systems and supply chains to reduce energy and GHGs.
- Pursue low capital investment approaches highlighted by stakeholders, that have multiple benefits and spur early action to reduce GHGs (e.g. energy, materials, system efficiency).
- The timing and alignment with expansion of a renewable energy grid system will be critical
- Workforce development is needed across industries and a spectrum of skill sets.

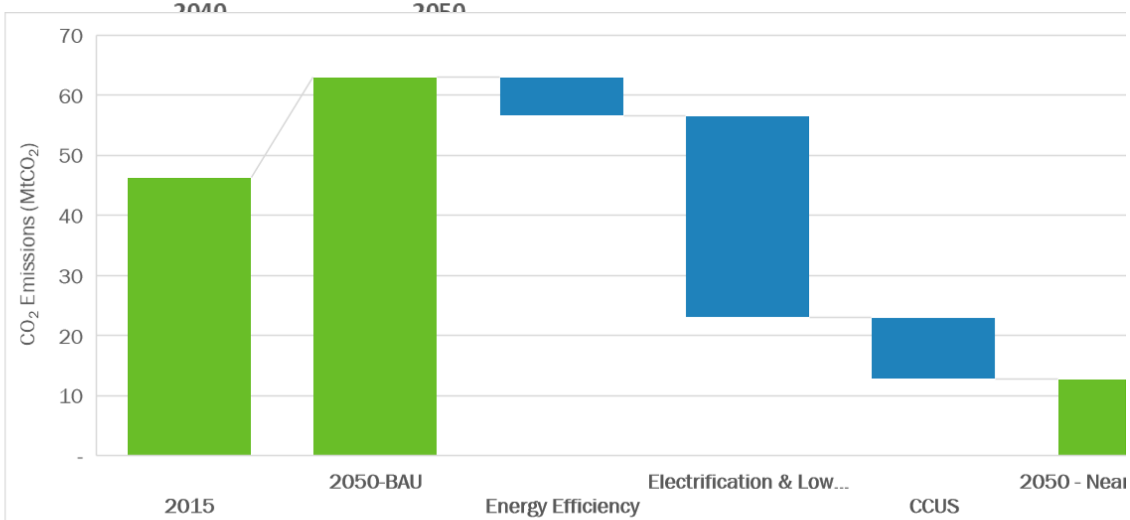
Three Decarbonization Pillars with Examples of Technologies for the Chemical Industry

Energy Efficiency	Electrification	CCUS
Strategic energy management Energy, systems, and materials efficiency (e.g., recycling and waste minimization) Smart manufacturing Combined heat and power, and waste heat to power Systems efficiency across multiple operations	Process electrification, intermittent power Process heat portfolio Electrolyzer efficiency Low-carbon processes and catalyst innovations Energy/thermal storage and recovery Innovative separations	Integration with process heat CO_2 reuse via slip streams CO_2 bioconversion

Decarbonization Pathways and Scenarios for Chemical Sector

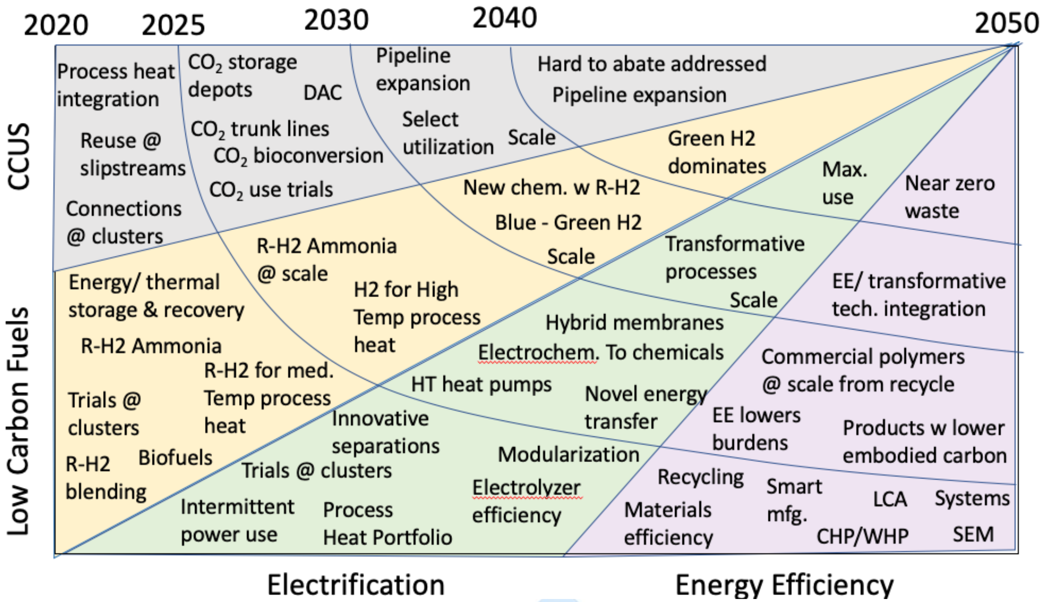
- CO2 EMISSIONS FORECAST FOR AMMONIA, METHANOL, ETHYLENE, AND BTX IN THE UNITED STATES BY SCENARIO, 2015–2050
- IMPACT OF THE THREE DECARBONIZATION PILLARS ON CO2 EMISSIONS FOR AMMONIA, METHANOL, AND ETHYLENE, AND BTX PRODUCTION IN THE UNITED STATES UNDER BAU AND NEAR ZERO GHG SCENARIOS

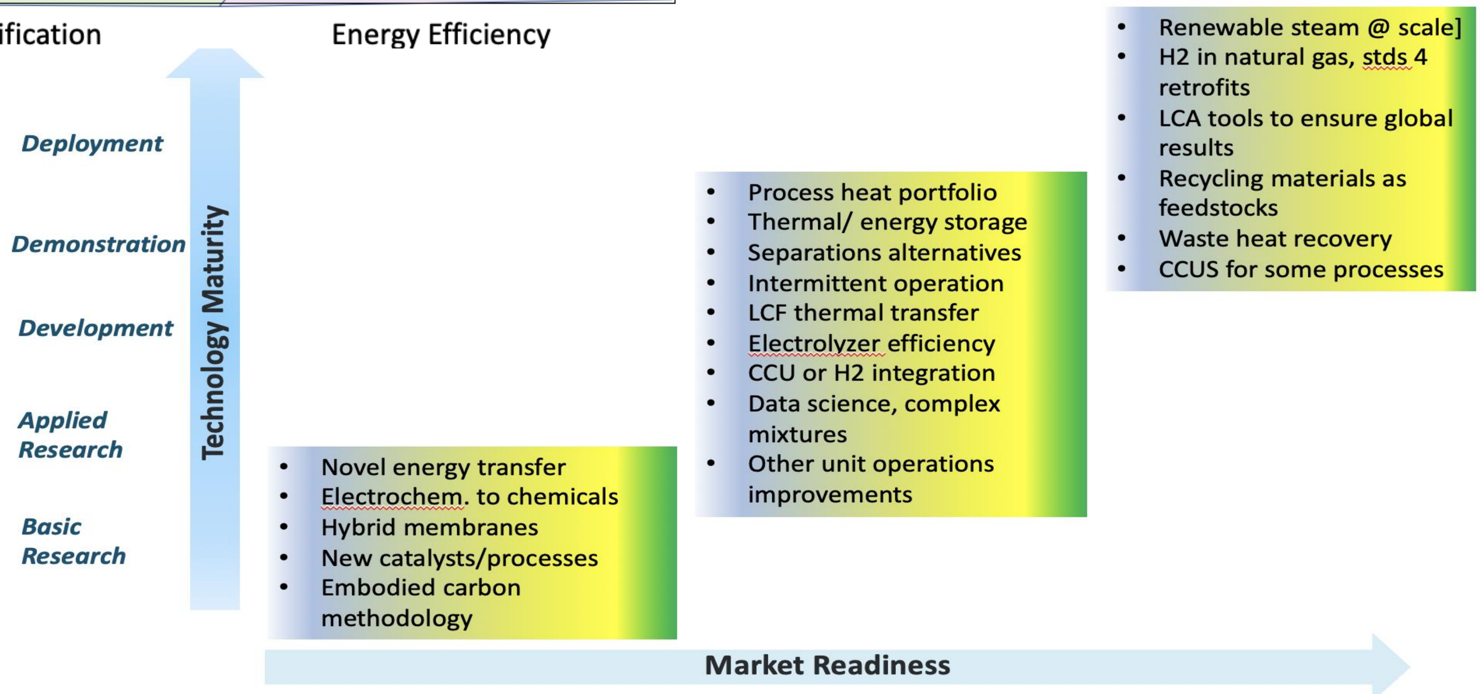




Decarbonization technology options and transitions

- SEQUENCE OF RD&D INVESTMENTS OPPORTUNITIES BY DECADE
- TECHNICAL MATURITY LEVELS OF DECARBONIZATION TECHNOLOGIES





Thank You.

For additional information:
energy.gov/eere/amo/advanced-manufacturing-office

ANL - Sarang Supekar
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NREL – Alberta Carpenter, Tsisilile Igogo, Colin McMillan
ORNL –Sachin Nimbalkar
ACEEE – Ed Rightor, Neal Elliott
Consultants – Ali Hasanbeigi, Bruce Hedman
AMO – Kate Peretti, Felicia Lucci, Joe Cresko