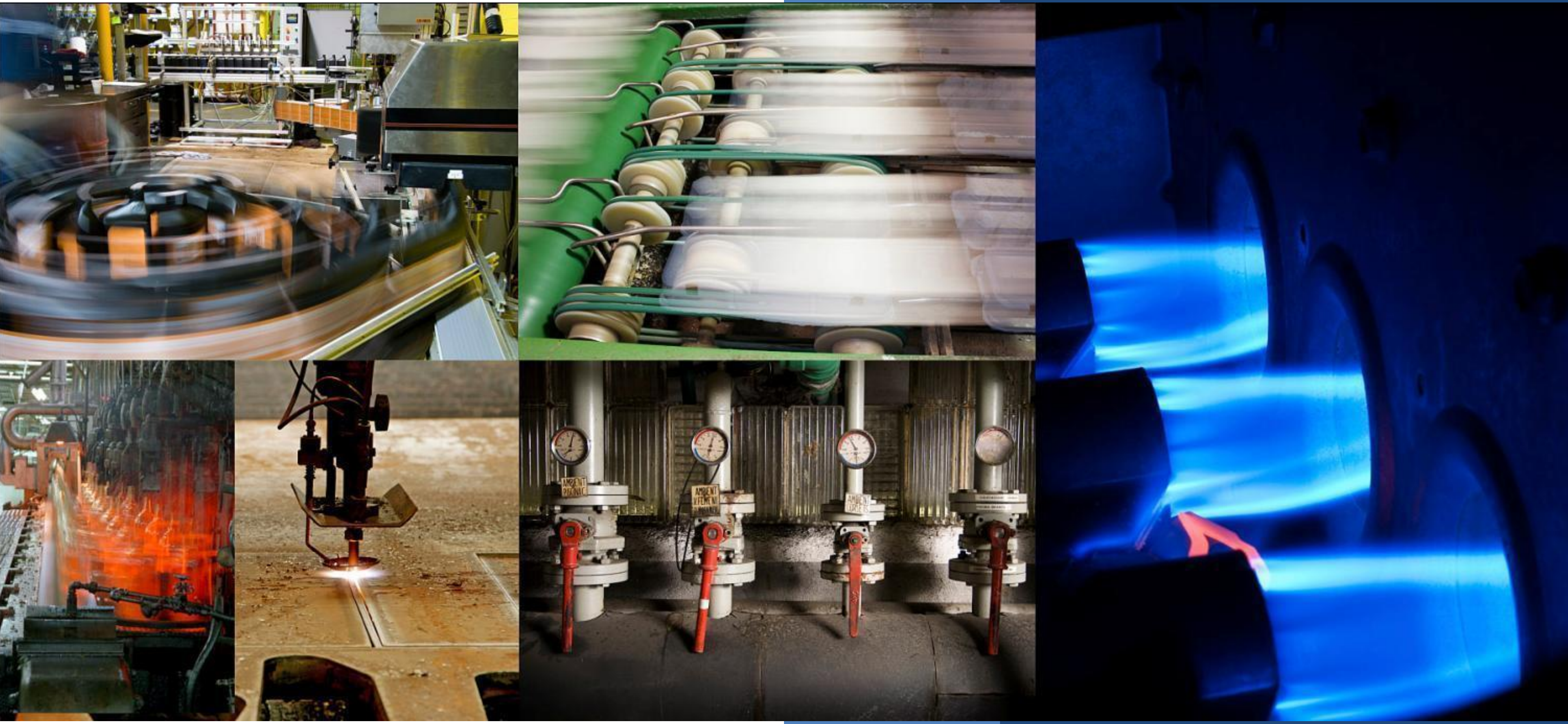
Office of Energy Efficiency & Renewable Energy
Advanced Manufacturing Office

U.S. DEPARTMENT OF ENERGY



# Industrial Decarbonization: Opportunity, Challenges and RD&D Needs

**Joe Cresko** – Chief Engineer
Advanced Manufacturing Office, US DOE
joe.cresko@ee.doe.gov

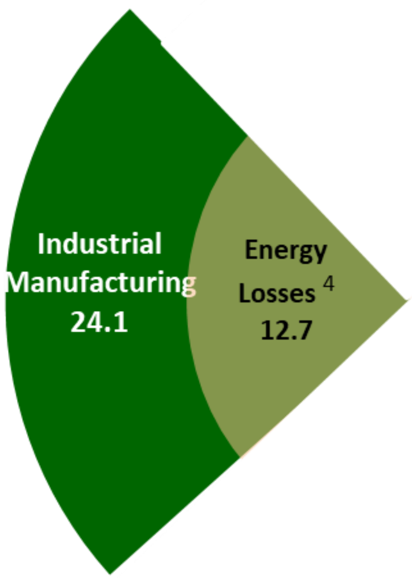
## DAC Summit

February 25, 2021

# 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



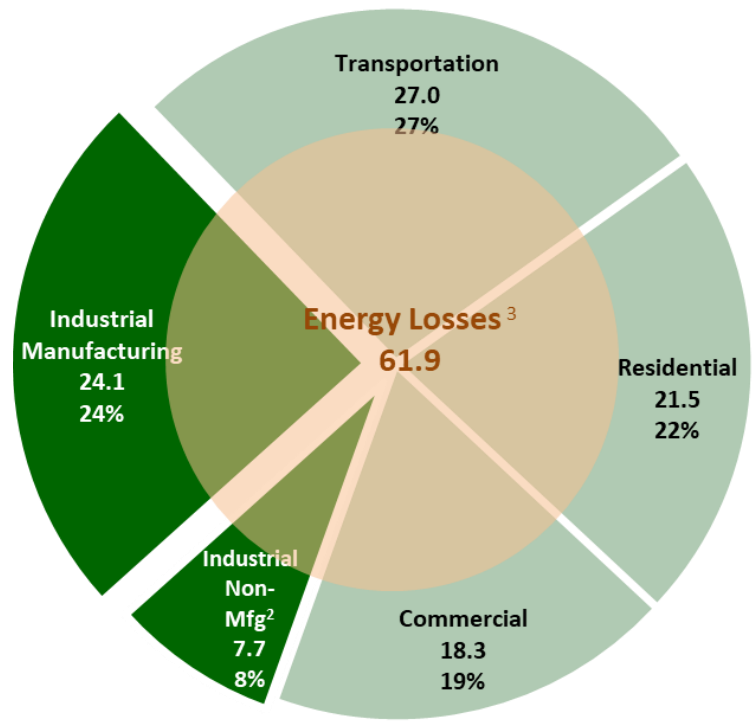

Data for 2014

**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



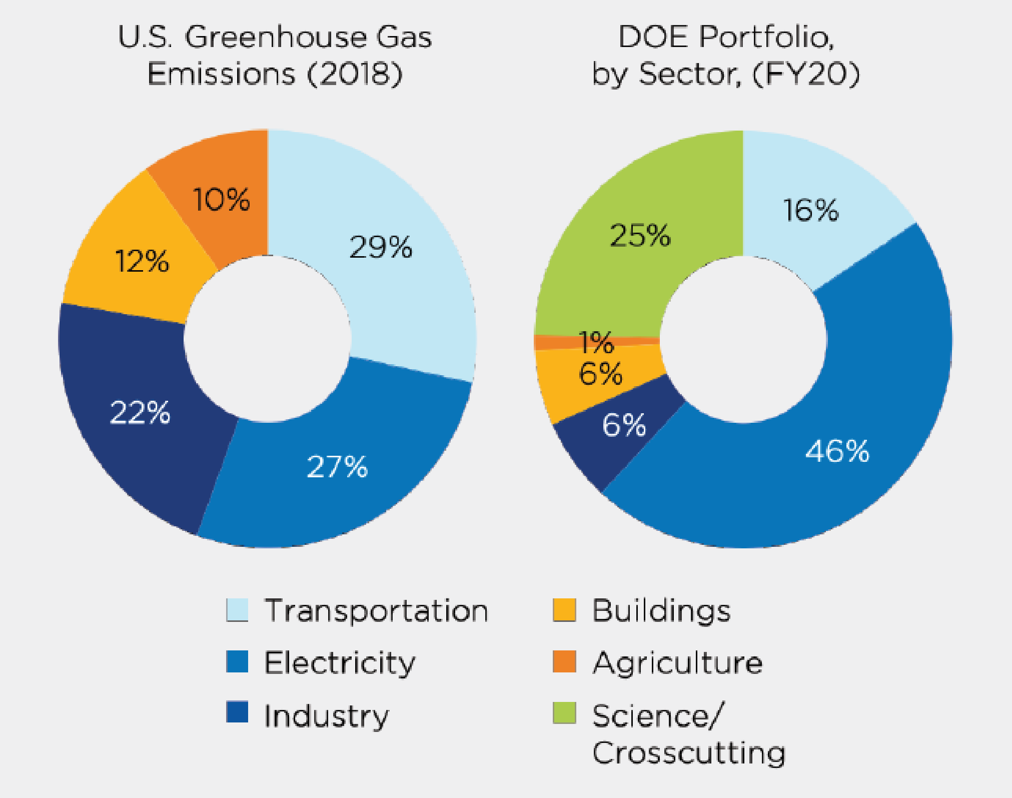

**U.S. Energy Economy by Sector**
**98.5 quadrillion Btu, 2014** [1]

[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)

# Industrial Sector is a Significant Contributor to $CO_2$ Emission

- The U.S. Industrial Sector accounts for 32% of the nation's primary energy use and 28% of $CO_2$ emissions.
- Anticipated industrial sector energy demand growth of 30% by 2050 may increase $CO_2$ emissions by 15%.
- Challenges for abating $CO_2$ emission from the industrial sector:
  - the diversity of industrial processing steps and energy inputs used in manufacturing
  - the scale of facilities and lengthy timeframe for capital turnover
  - the cost of development to validate new technology at industrially-relevant scales
  - complex supply chains
  - capital availability

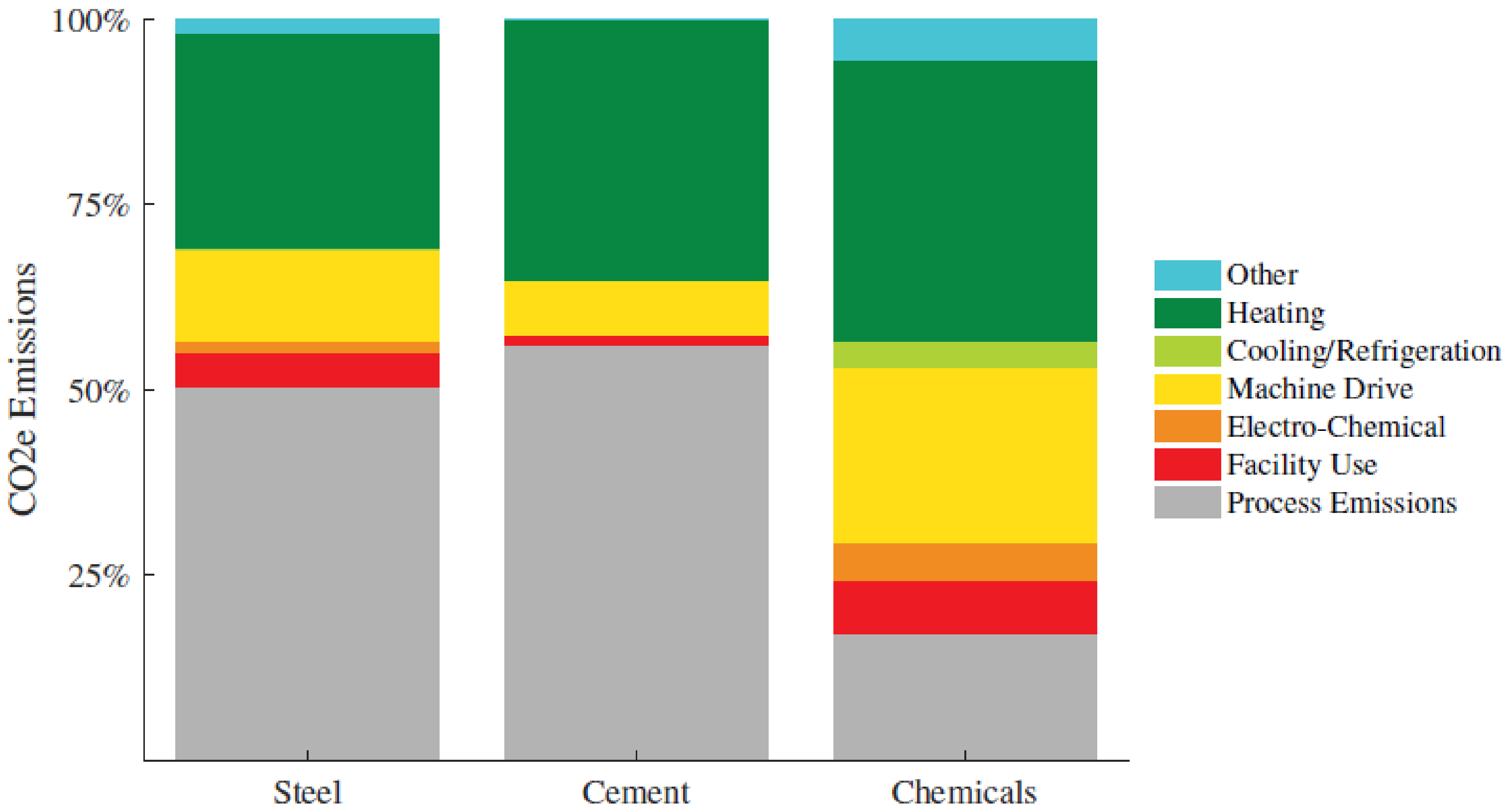
**2018 U.S. GHG emissions and FY20 DOE RD&D Funding**




V. Sivaram, *Energizing America 2020*

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

# Process Emissions are significant

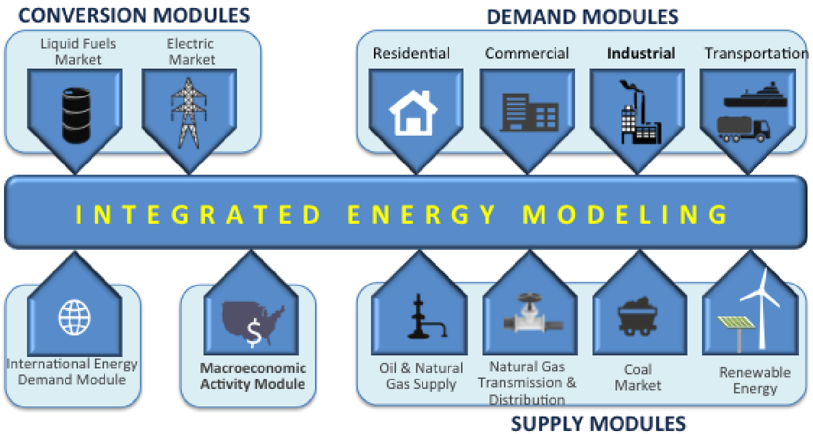



**Steel:** $Fe_3O_4 + 2C + \text{heat} \rightarrow 3Fe + 2CO_2$

**Cement:** $CaCO_3 + \text{heat} \rightarrow CaO + CO_2$

Sources: DOE (2014), EPA (2018).
Rebecca Dell (2019).

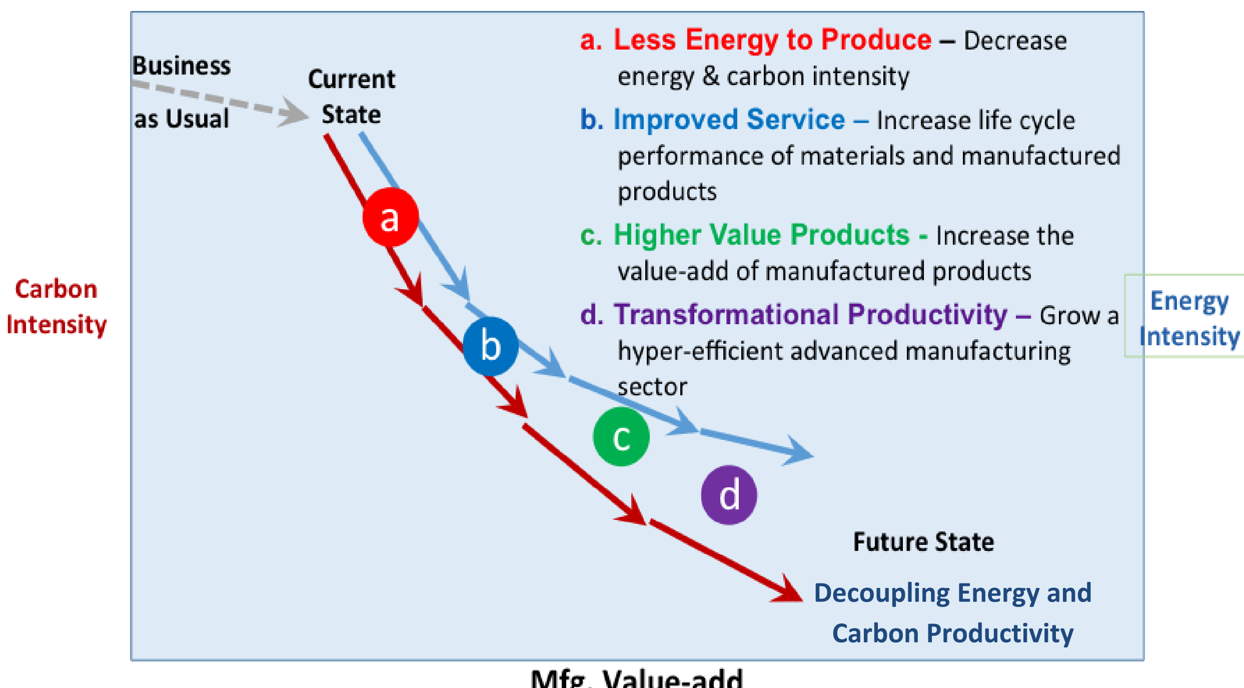
# Do our current frameworks demonstrate a lack of vision?




Technology static over decades.
Future structure largely based on current structure.

**Pessimistic or pragmatic?**

**Moving Towards High Energy & Carbon Productivity**




Future looks very different.

**Optimistic or delusional?**

# 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.:**

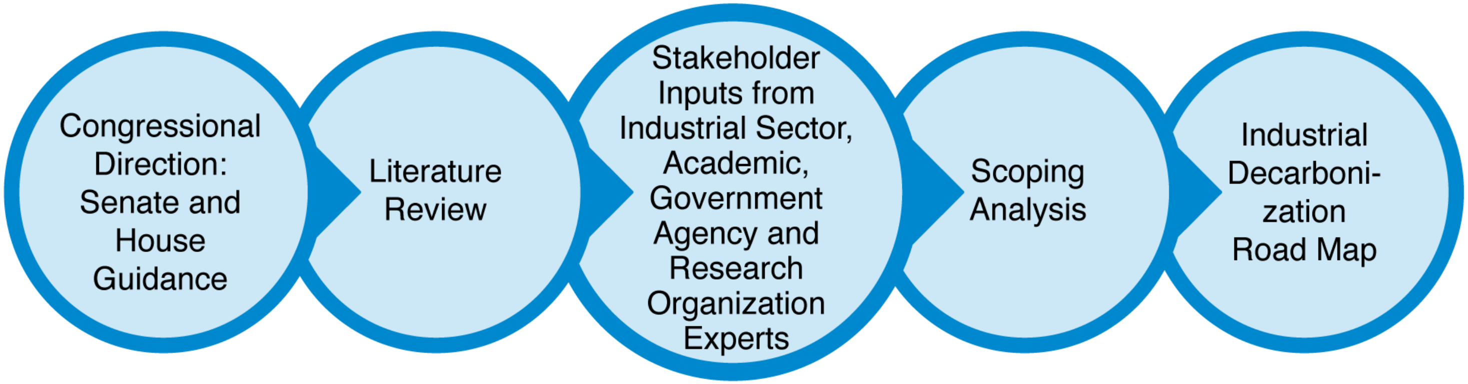
- Circular Economy
- Design for Re-X (recycling reuse and remanufacturing)
- Material efficiency and substitution

**Improved Products by Next Generation Materials and Processses.**

# 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

# Motivation by Congressional Direction and the Opportunity for Enhanced U.S. Competitiveness



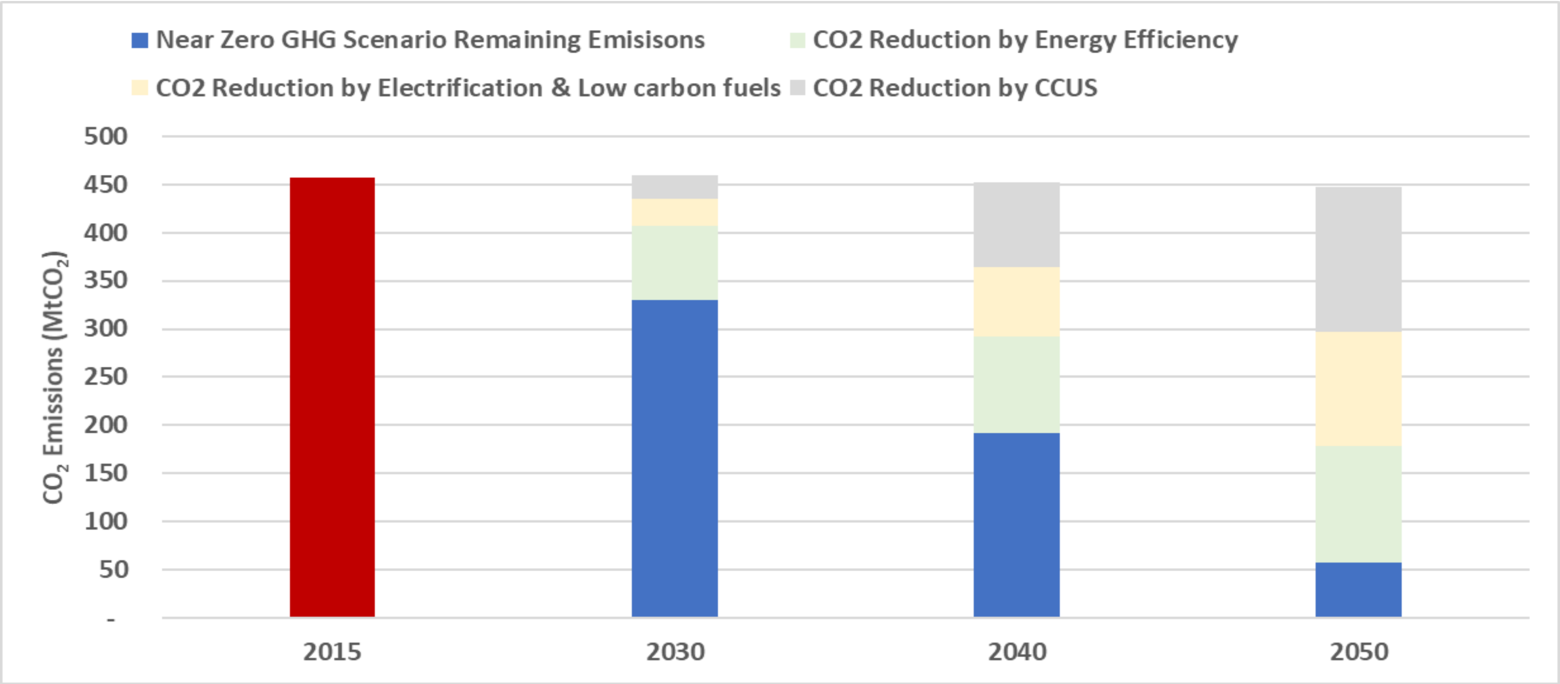

- The congressional direction guided the methodology and industry engagement.
  - *The Department shall develop decarbonization roadmaps in key technology areas to guide research and development at the Department to achieve significant, economical greenhouse gas emission reductions by 2050, including 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 and Carbon Emission studies.

- Roadmap solicited input from varied sources. It focuses industry's interests to enhance U.S. competitiveness through pursuing RD&D needs and opportunities.

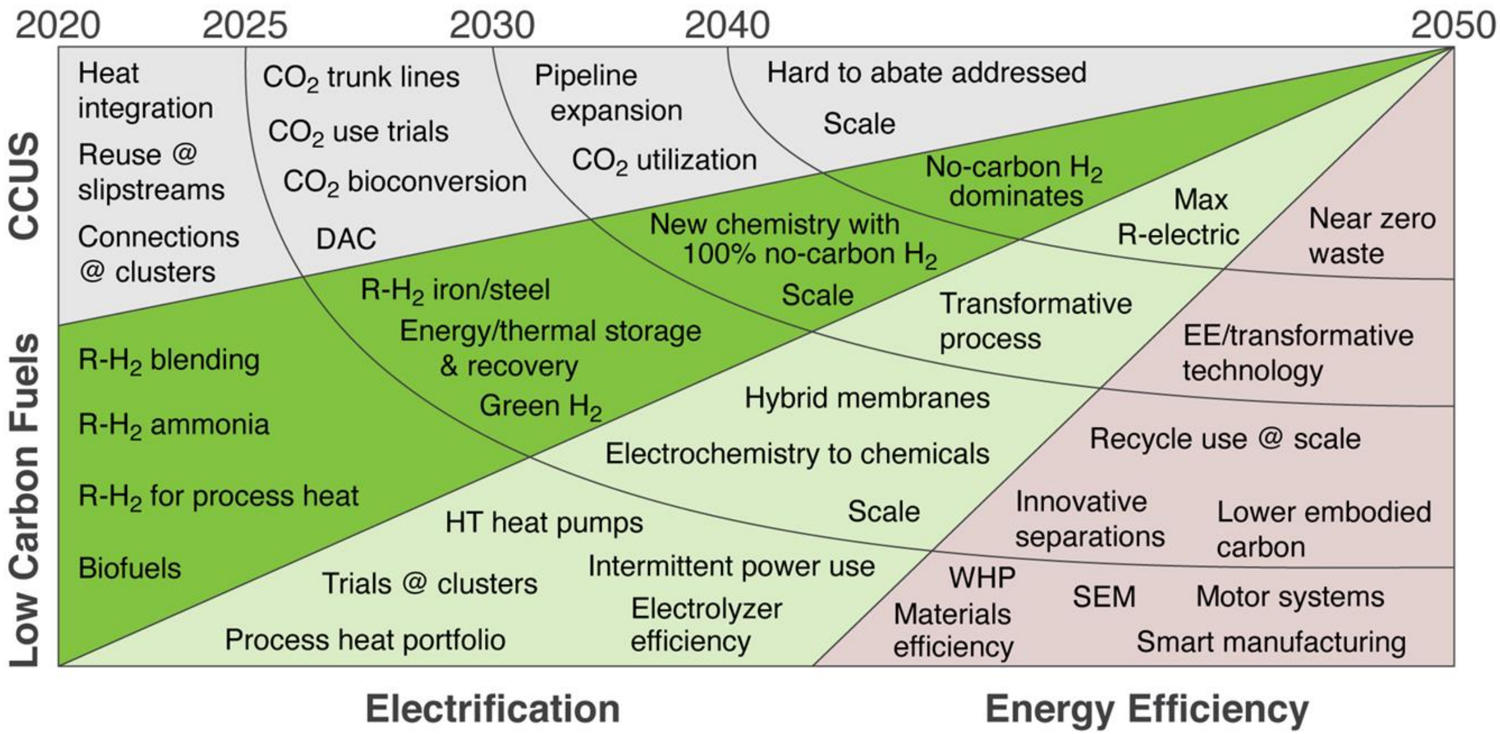
# Decarbonization Roadmap Main Takeaways

Composite plot of GHG emissions reduction scenarios for the three decarbonization pillars across the iron and steel, chemical manufacturing, food manufacturing, petroleum refining and cement sectors. (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.

# Multiple Pillars of Decarbonization Must be Pursued in Parallel




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

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

# AMO FY20 Multi-Topic FOA* Topic 3.1: Integrating Carbon Capture and Utilization into Industrial Processes

**Objective**:

Reduce the carbon intensity of manufacturing and lower the barriers to deploying carbon capture systems.

**Goal:**

Develop innovative solutions that will integrate carbon capture systems in industry; develop manufacturing processes for new technologies that are effective at capturing carbon dioxide from dilute sources including direct air capture (DAC); and enable the cost-effective utilization of captured carbon dioxide in the industrial sector.

**Focus Areas:**

- Manufacturing processes, including material scale up, for new technologies that are effective at capturing carbon from industrial and dilute sources.
- System integration challenges associated with integrating carbon capture technologies in industry.
- Scale-up and "numbering up" (i.e. replication; nth plant) challenges of emerging carbon capture technology to achieve enonomies-of-scale cost reductions.
- New technologies to enable the utilization of captured carbon as a feedstock in a specific industrial processing step(s). The carbon captured could be from concentrated and dilute industrial sources or from ambient air. CCUS in co-located processes are encouraged.

*** Funding Opportunity Announcement (FOA) Number: DE-FOA-0002252**

# Topic Selections

https://www.energy.gov/eere/amo/articles/doe-announces-approximately-1236-million-bolster-domestic-manufacturing-through-0

### Sorbent Development and Scale-up for Industrial and DA Capture

| Project Title | Lead PI |
|---|---|
| Intensified Water-Lean Solvent CO2 Capture System for Cement Flue Gas | Research Triangle Institute |
| Sorbents Tailored for Emission Abatement in Manufacturing (STEAM) | Palo Alto Research Center, Inc. |
| Developing Low-Cost Mfg. Processes for an Ultra-High Capacity Carbon Capture Material | Mosaic Materials, Inc. |

### Integrating CO2 Capture into Manufacturing Processes

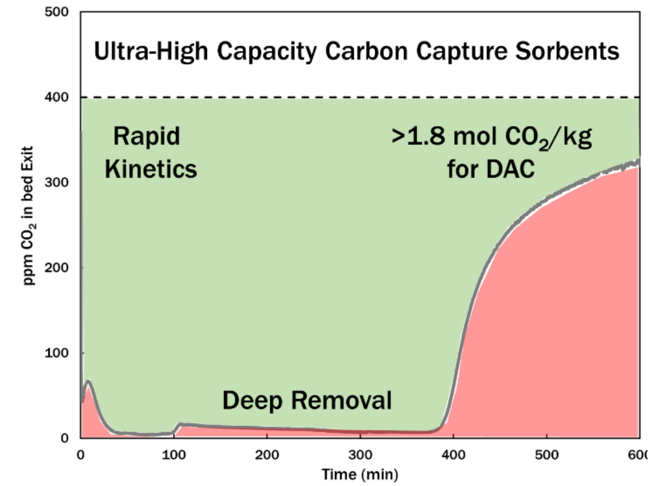
| Project Title | Lead PI |
|---|---|
| An Innovative Process for Direct Utilization of CO2 in Solid Synthetic Pozzolan Production | Solidia Technologies |
| Performance-Advantaged Chemicals & Materials made from Lignocellulose and CO2 | ReSource Chemical Corp. |
| Integrating CCUS into Chemical Pulp Processes | NC State University |
| Decarbonization of Hydrogen Production by Flameless Oxidation | Praxair, Inc. |

### Direct Air Capture and Utilization Integration

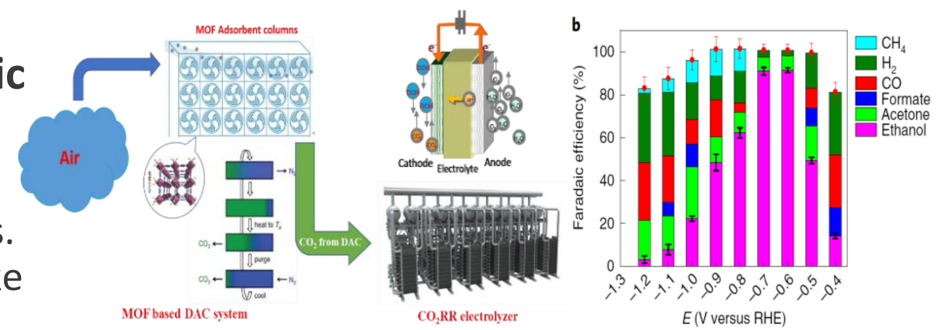
| Project Title | Lead PI |
|---|---|
| Scalable Integration of CO2 Capture and Electrocatalytic Conversion to Organic Liquids | Northern Illinois University |
| Modular Reactors for the Capture and Electro-conversion of CO2 in Various Industrial Processes to Value-Added Chemicals | University of Louisiana at Lafayette |

# Highlighted Selections

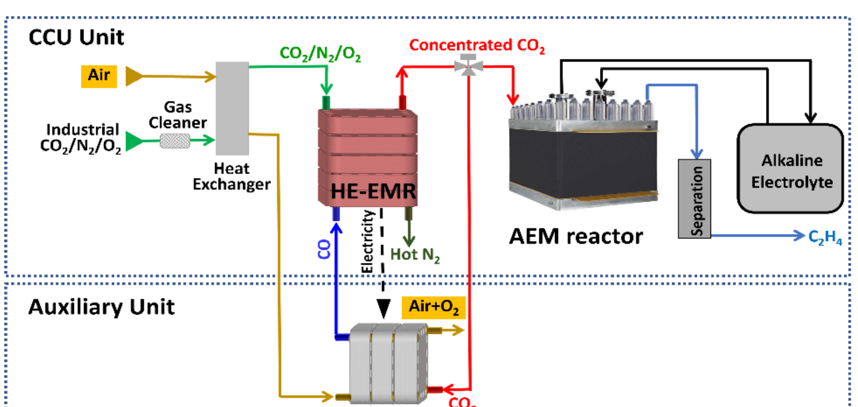
- **Mosaic Materials: Developing Low-Cost Manufacturing Processes for an Ultra-High Capacity Carbon Capture Material.**
  - Work is aimed at improving and scaling the manufacturing of MOFs for DAC. Improvements include: reduced carbon intensity, increased scale, and reduced cost while retaining performance.




- **Northern Illinois University: Scalable Integration of $CO_2$ Capture and Electrocatalytic Conversion to Organic Liquids.**
  - Development of devices for DAC and $CO_2$ utilization using state of the art active materials. Devices will be integrated and scaled up to make ethanol from air.




- **University of Louisiana at Lafayette: Modular Reactors for the Capture and Electro-conversion of $CO_2$ in Various Industrial Processes to Value-Added Chemicals.**
  - Developing modular system that combines a capture unit capable of DAC, with $CO_2$ electrochemical conversion unit.



# Thank You.

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

**ANL** - Sarang Supekar
**LBNL** –William Morrow
**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

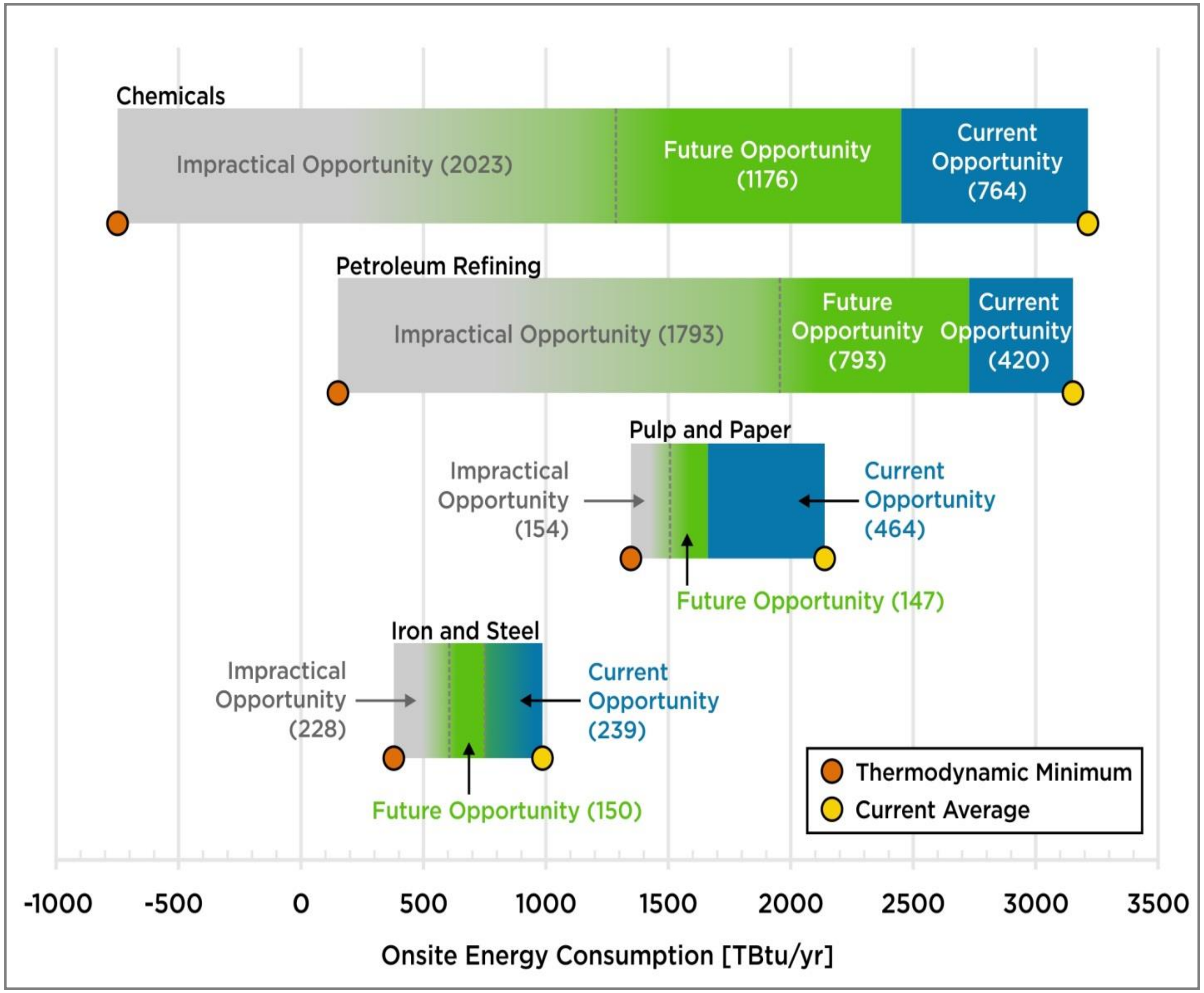
# Energy Intensity

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

**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

## Technical Energy Savings Opportunities:



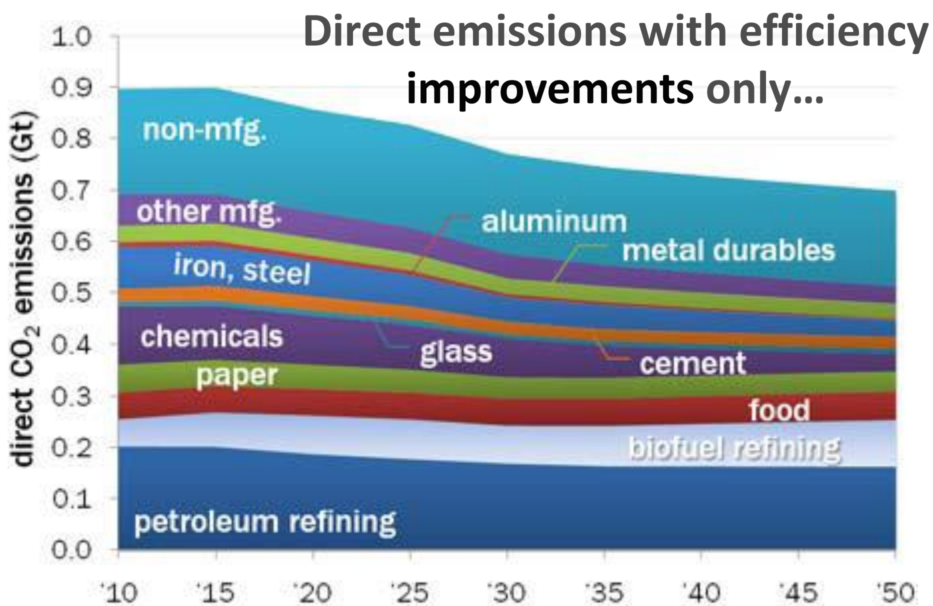

***Source:*** DOE/AMO, Energy Bandwidth Studies (2015)
***Note:*** 1 quad = 1000 TBtu

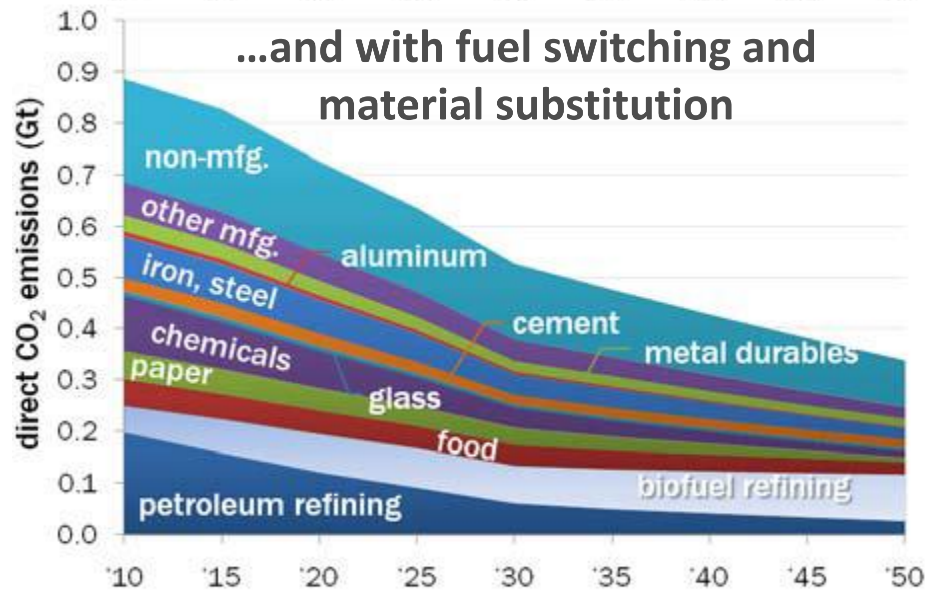
# Carbon Intensity

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

**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



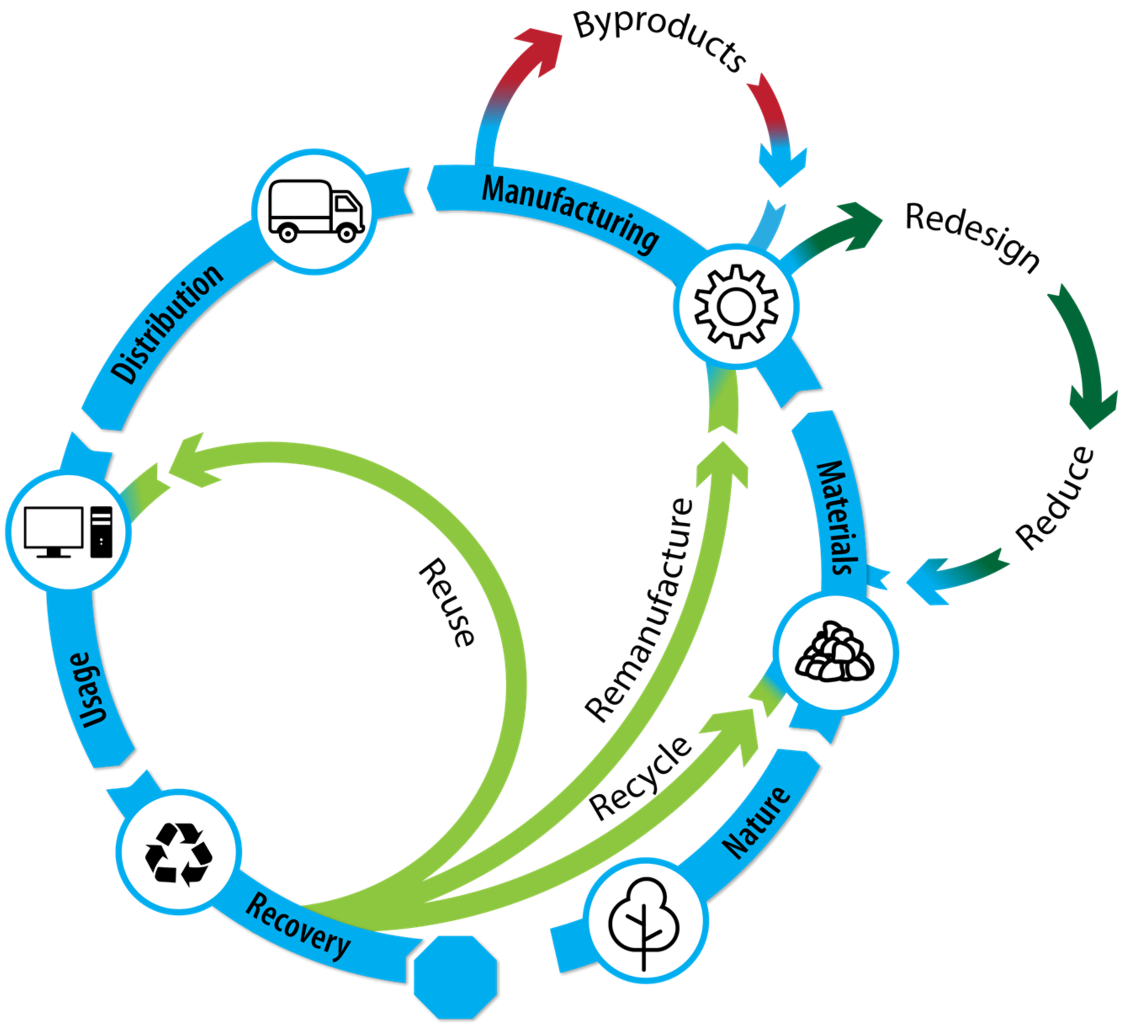

Example analysis based in part on bandwidth SOTA & PM potential, and EIA Annual Energy Outlook (AEO) forecast as baseline.

# Use Intensity

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

**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



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