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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

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EEII: Chemicals Programmatic Summary

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Key Takeaways

- U.S. chemicals sector is capitol intensive sector and a significant contributor to U.S. economy
- Chemicals sector is highly diverse considering chemical products, manufacturing processes, and emission sources
- RD&D investments need to balance technical solutions capable of significant emissions reduction with high profit margin early adopters

- IEDO's RD&D investments strengths are in next generation process technologies capable transforming the sector through:
  - Reducing energy demand in chemical manufacturing processes
  - Generating energy through other means then fossil fuel combustion
  - Sourcing fundamental matter, like carbon and hydrogen, from sustainable sources

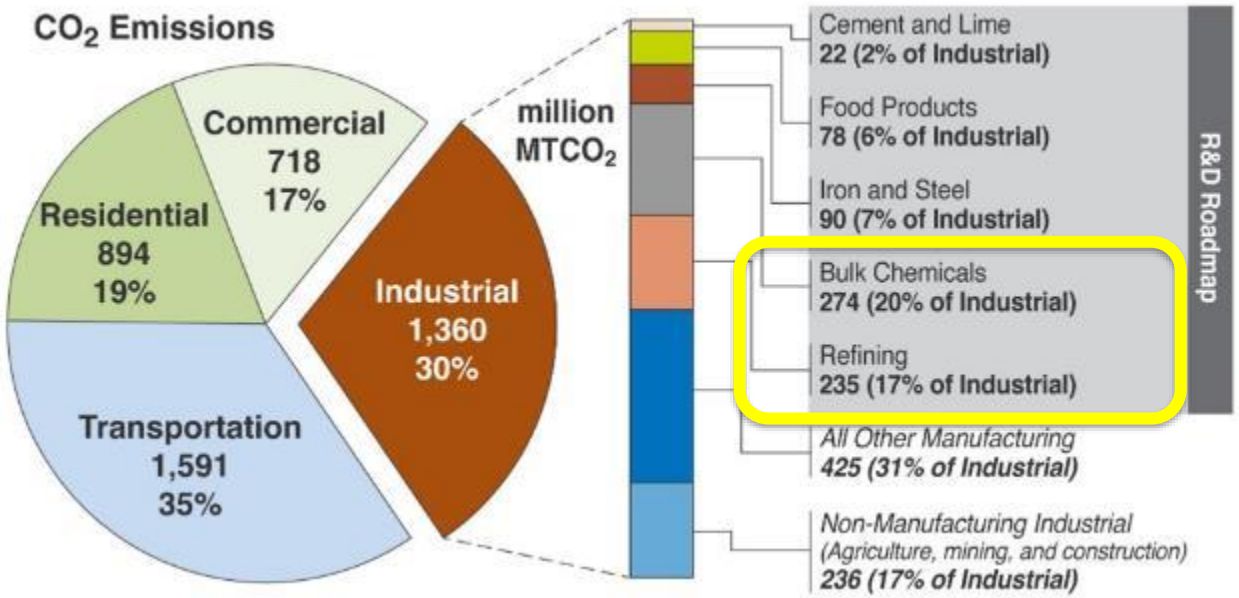
Chemicals Sector Crucial for Economy-wide Decarbonization

The industrial sector accounts for 30% of U.S. CO_2 emissions

Domestic Footprint of Chemicals Subsector

- The chemicals subsector is the highest CO_2 emitting industrial subsector expected to continue growing over the coming decades (ACC)
- Chemicals is a capital-intensive industry contributing to 25% of U.S. GDP and $565B in shipments
- Largest exporting sector in the United States ($136B), accounting for over 13% of the world's total chemical production, making the United States the second-largest chemical-producing nation (ACC)
- The domestic manufacturing footprint of major U.S. chemical companies are about 20-30% of global operations
- 30% of chemical manufacturing facilities are owned by small and medium enterprises (CISA)

U.S. Energy-related CO_2 Emissions by Sector and Subsector (2020)



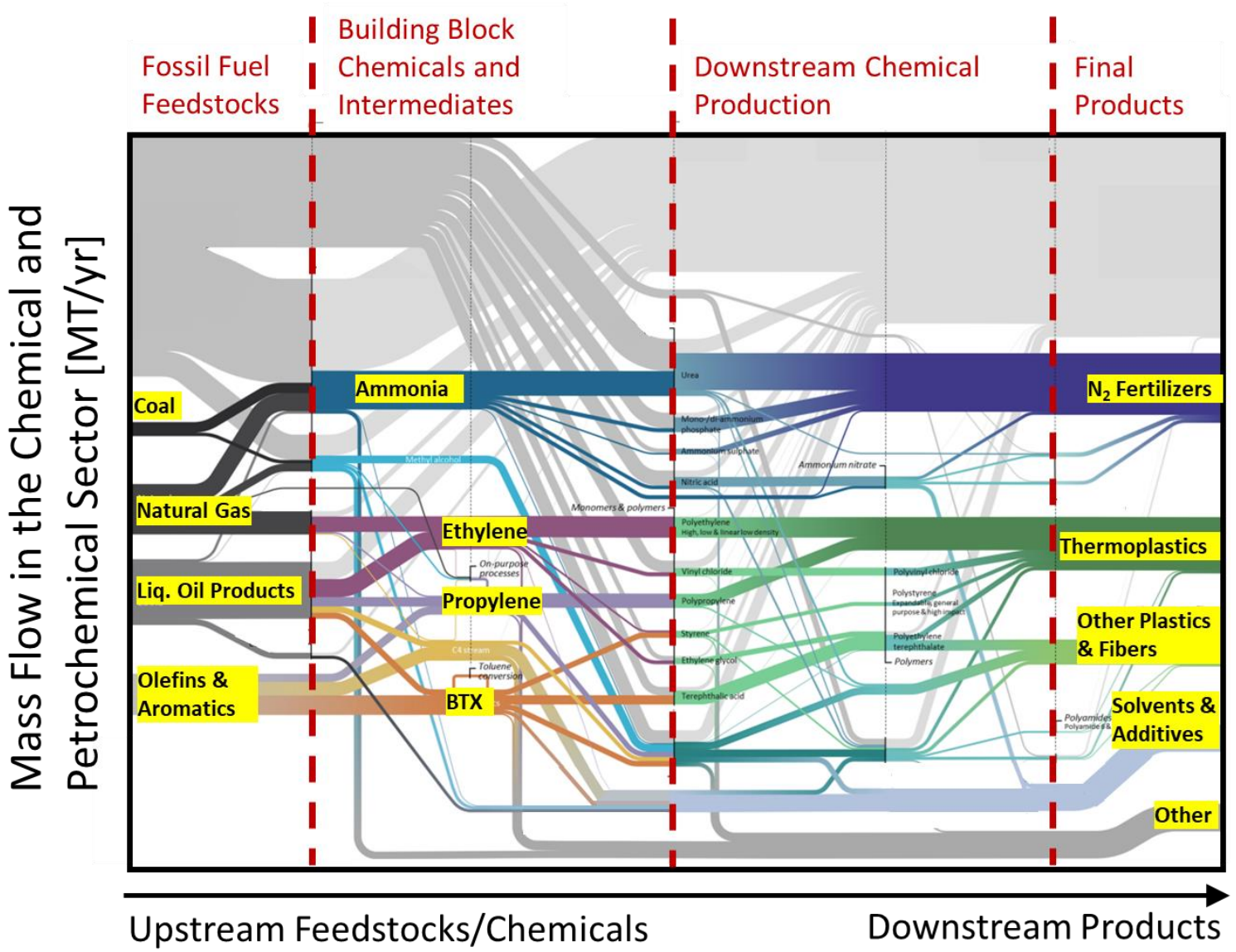
Share of the **4,563 million metric tons of CO_2** emitted by the U.S. in 2020 (EIA 2021)

DOE Industrial Decarbonization Roadmap:
https://www.energy.gov/eere/doe-industrial-decarbonization-roadmap

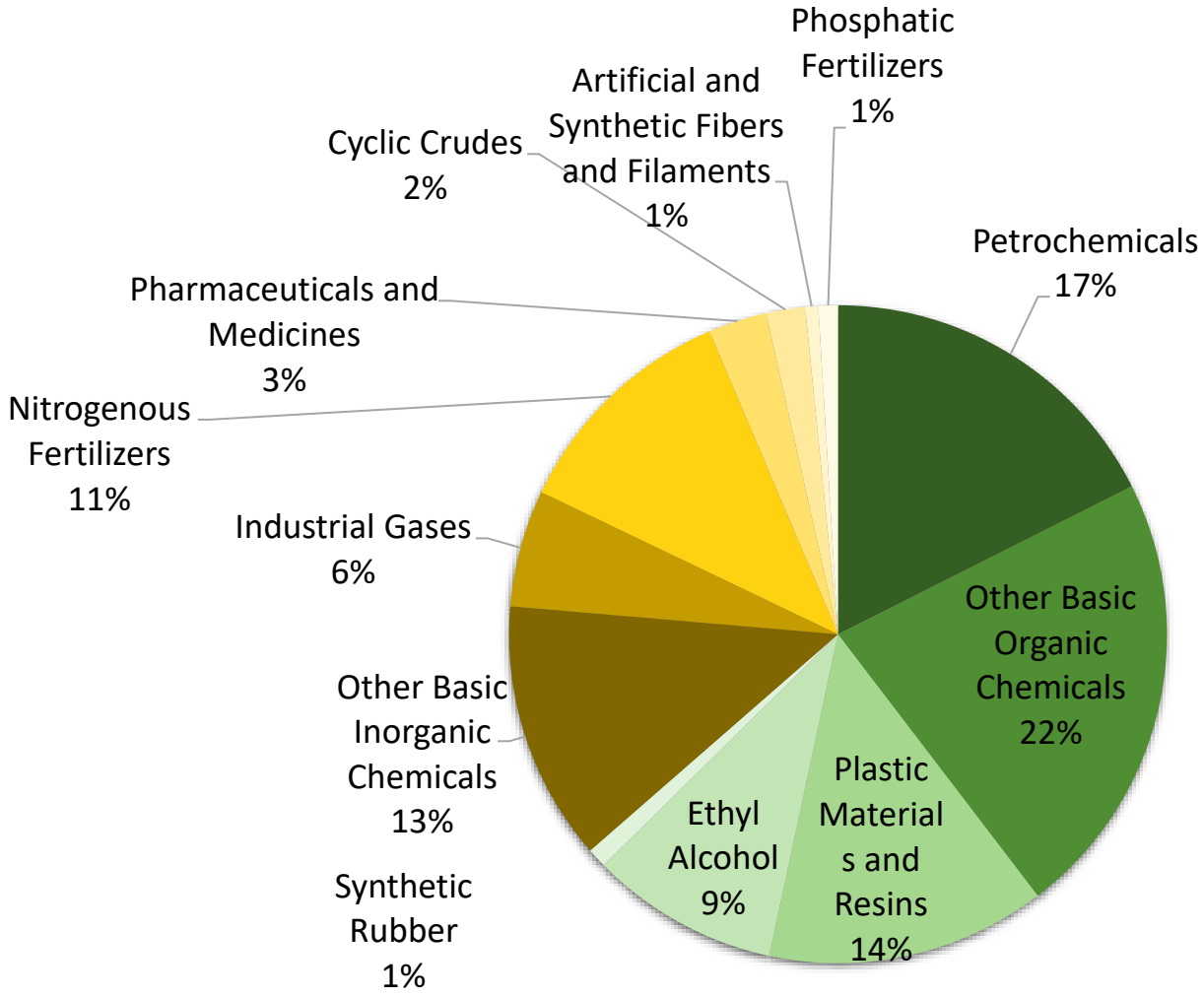
Unique Decarbonization Challenge: Complex Value Chains

- Chemicals sector is highly diverse, interconnective, and complex.
  - More than 96% of world's manufactured goods enabled by 70,000 products and 11,000 manufacturers (ACC)

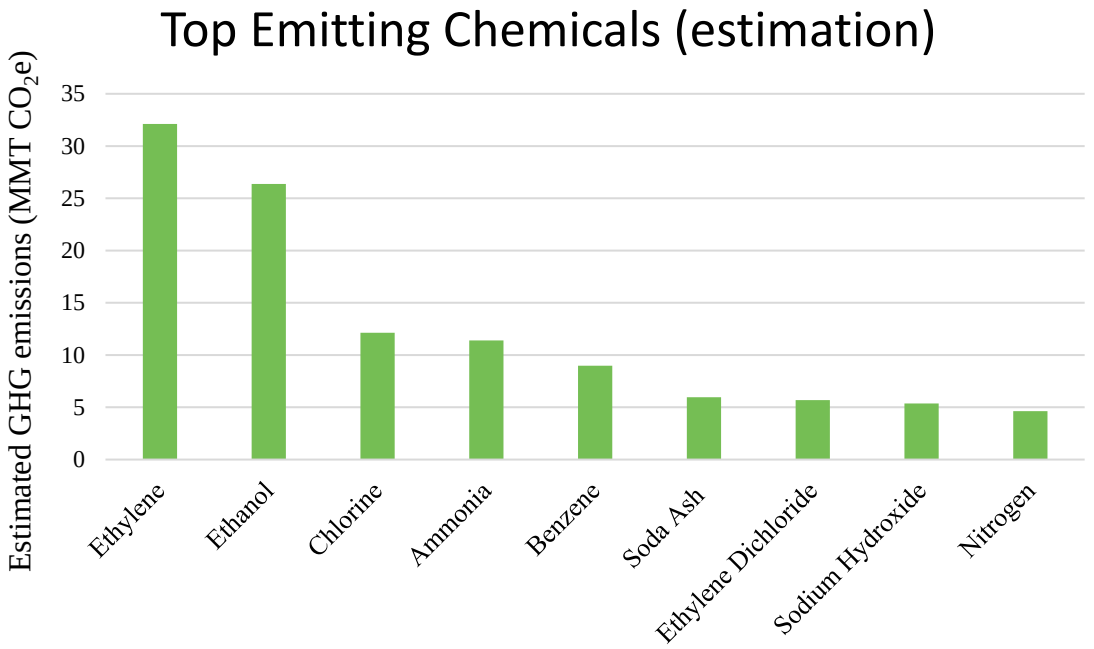
- Changes in upstream feedstocks and building block chemicals produce additional impacts down the value chain



Emissions Distributed Across Chemical Sector



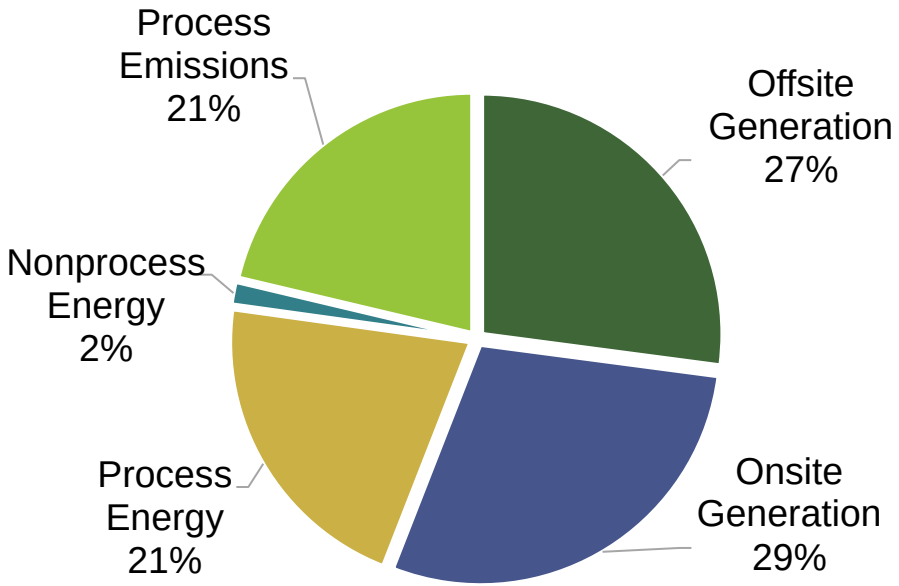
% GHG emissions by 2018 NAICS codes



The 74 High Volume Energy Intensive Chemicals Majority between 1 MMT and 0.5 MMT CO_2 annually

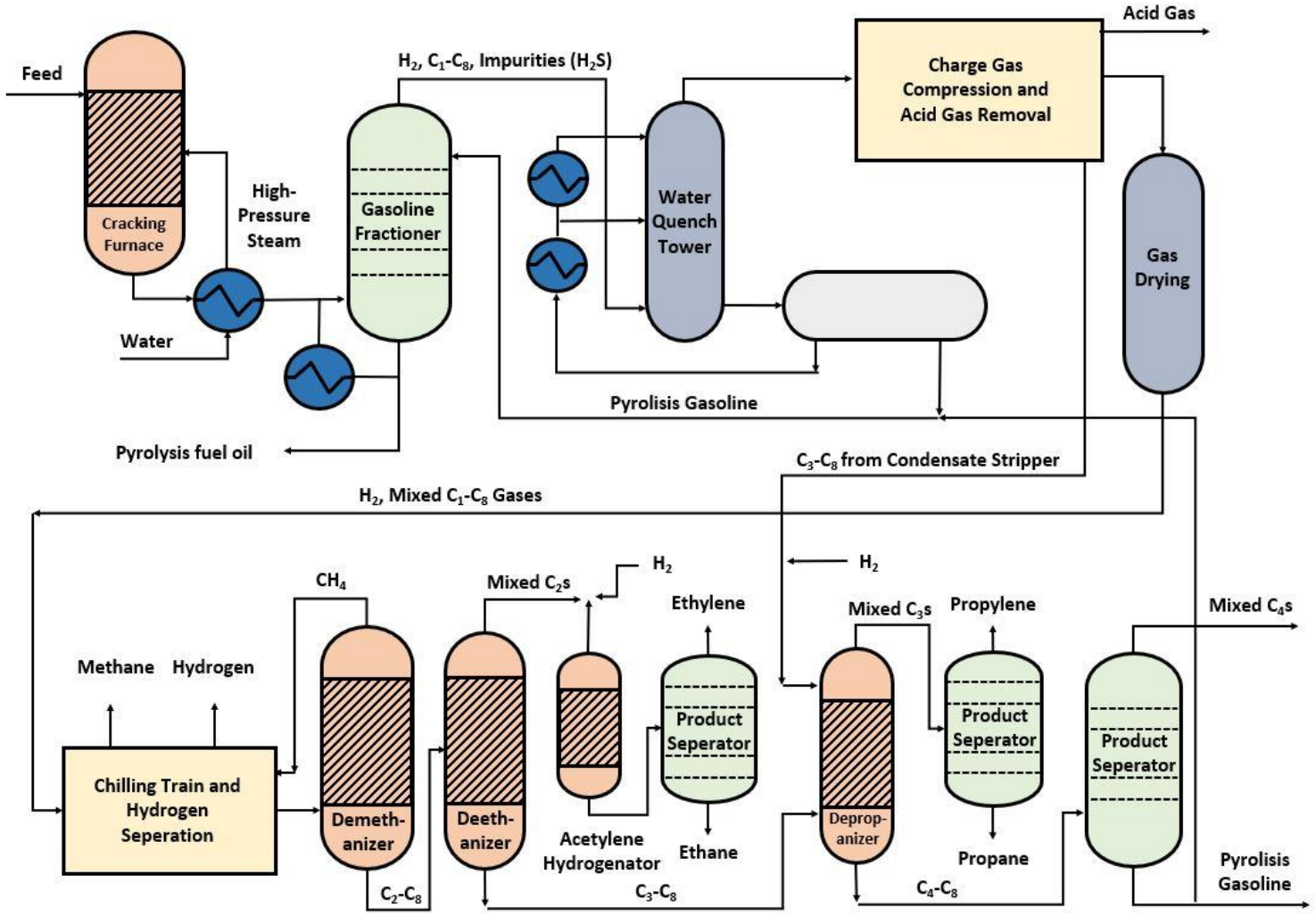
https://www.energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2018-mecs

Emissions Distributed Across Manufacturing Steps



Distribution of GHG emissions in 2018

There is a high demand for energy to produce heat, steam, and electricity to drive chemical reactions, purification of products, and operations of manufacturing facilities.

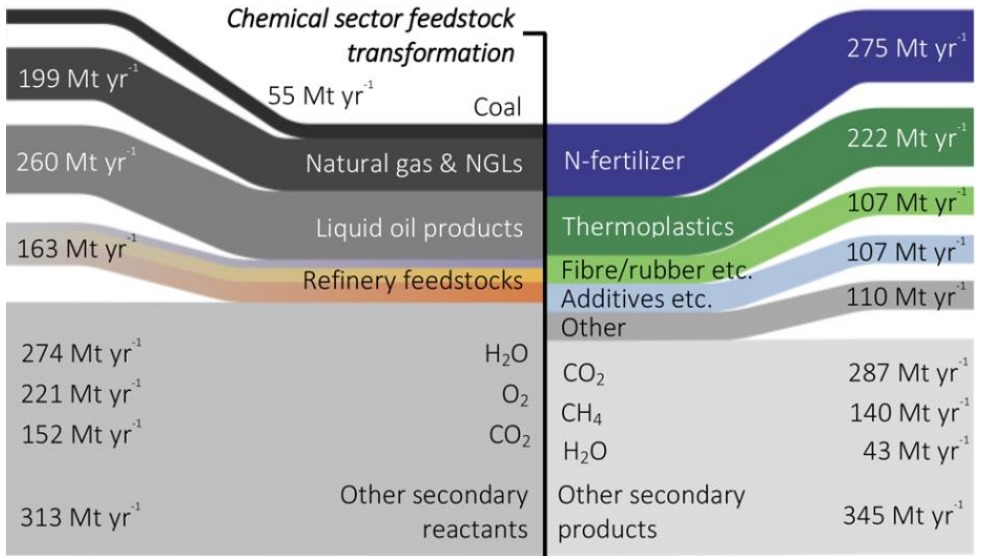


https://www.energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2018-mecs

Lifecycle Emissions Must Consider Feedstock Emission

- Chemicals subsector is highly dependent on fossil fuel feedstocks
- The refining industry is the largest producer of liquid transportation fuels and refined petroleum products in the world including chemical products and hydrocarbon-based lubricants
- Predicted to grow by 20% by 2040 with growth in chemicals expected to outpace other oil/gas products (CEN)

- Sustainable Feedstocks Considerations
  - Availability
  - Full Lifecyle emissions



Feedstocks from **Natural Gas Processing** (Ethane, Propane)
- **Significant emissions** from flaring and processing

Feedstocks from **Petroleum Refining** (Naphtha, BTX)
- Requires **energy and emissions-intensive** distillation and conversion processes

Stakeholder Informed Strategy

FY20 – FY23
Opportunities and Challenges for Chemicals Sector Decarbonization

FY23+
Balanced Risk & Reward Portfolio

Workshops and Related Activities	FY20	FY21	FY22	FY23	FY24
Dynamic Catalysis Roundtable	x				
Sustainable Chemistry Roundtable		x			
DOE Industrial Decarbonization Roadmap	x	x	x		
Industrial Decarbonization Roundtable – Chemicals & Petroleum Refining			x		
Electrochemistry in Manufacturing			x		
Platinum Group Metal Catalysts Supply Chain			x		
Sustainable Chemistry in RD&D to Transform the Chemicals Industry Roundtable				x	
EPA-Led Workshop on Chlor-Alkali Industry				x	
Working Group Meetings at Major National Meetings/Events					x
Conversations with Industry Researchers & National Labs on Dynamic Catalysts Science					x

Stakeholder Engagement to Understand the Emerging Landscape

- Decarbonization of building block chemicals such as ammonia, ethylene, propylene, butene, benzene/toluene/xylene (BTX), methanol, ethanol, and hydrogen would have positive cascading impacts throughout industry. Other chemicals include sulfuric acid, chlorine, and sodium hydroxide.

- Chemicals and petroleum refining companies have invested significant capital in existing infrastructure.

    - Near-term opportunity to reduce CO_2 = technologies that leverage existing infrastructure (e.g. fuel switching, energy efficiency, waste heat recovery, carbon capture)
    - Long-term decarbonization opportunities = construction of new assets and infrastructure that Applied research is needed to advance these long-term opportunities for greater CO_2 emission reduction

- Goal is to invest in technologies capable of ambitious GHG reductions and avoid niche markets. However, there is value to identifying potential first deployers of technologies, such as
    - Specialty chemicals with high profit margins
    - End application spaces where there is a co-benefit (e.g. improvement in the product)
    - New chemical pathways to circumvent the building block chemicals

- Collaborative research centers or hubs were supported by respondents across all organization types as an opportunity to reduce cost burden, derisk technologies, encourage collaboration, and share technical advancements.

Objective and Targets

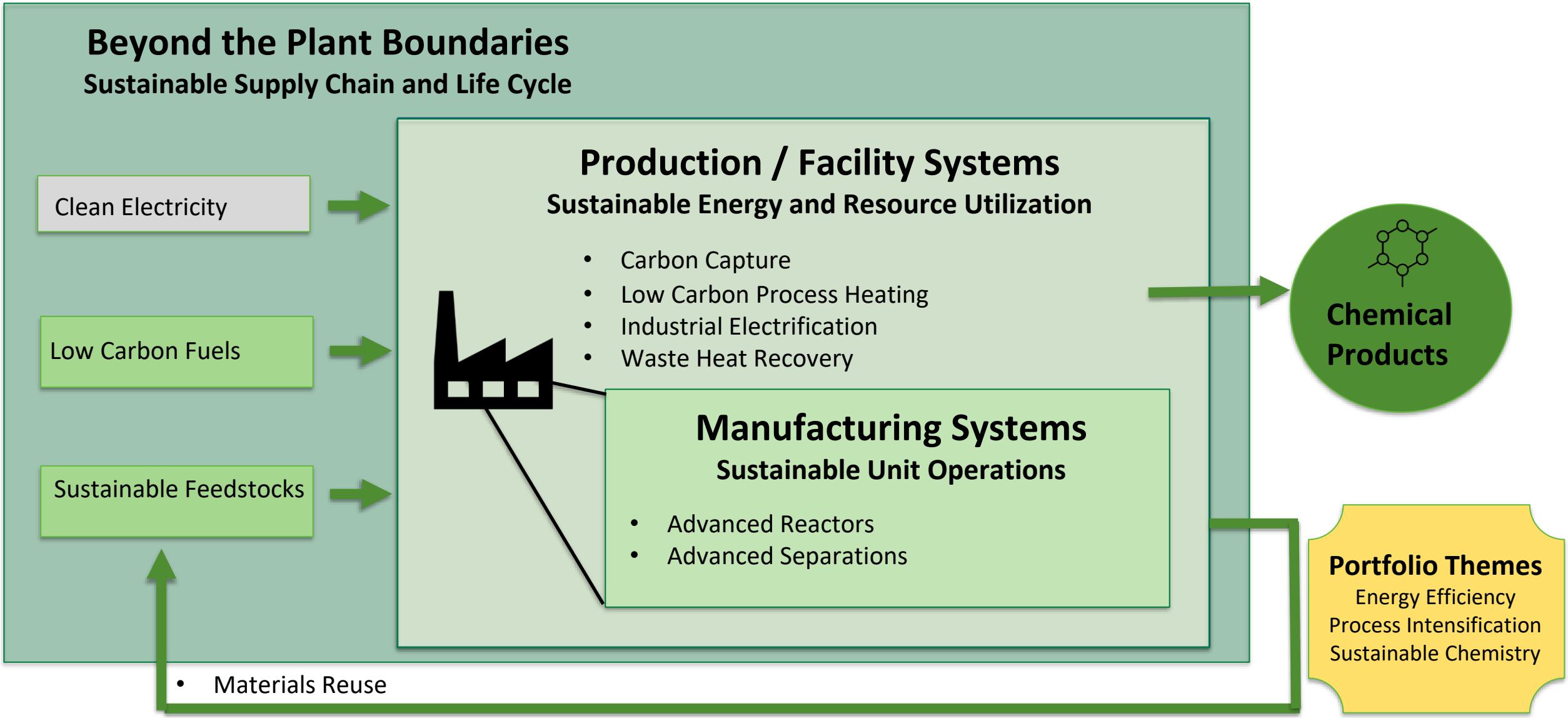
Objective:

- Reducing energy demand in chemical manufacturing processes
- Generating energy through other means then fossil fuel combustion
- Sourcing fundamental matter, like carbon and hydrogen, from sustainable sources

Targets:

- Accelerate innovations in transformative low carbon unit operations and processes to decarbonize the full value chain of high-volume, energy intensive, high emissions chemicals
- Focus on technologies capable of reducing emissions by more than 50% when broadly deployed

IEDO Strategies for Chemicals Sector Decarbonization

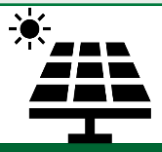


Technologies Aligned with Industrial Decarbonization Pillars

Sustainable Feedstocks Biomass (e.g. MSW, starch, lignin), CO_2, recycled plastics, renewable natural gas, H_2, materials recovery	
Low Carbon Fuels H_2, RNG, biomass, e-fuels	
Low Carbon Process Heating Electromagnetic heating, electric resistive heating	
Industrial Electrification Electrified reactors, electrified steam production	
Waste Heat Recovery Process biproducts and waste heat valorization	
Carbon Capture Facility Integration and Utilization pathways	
Advanced Reactors Thermal Catalysts, Membrane Reactors, Electrochemical Processes, Biomanufacturing, Non-contact Energy Transfer	
Advanced Separation Membranes, Electrified Distillation, Selective Reactivity	
Material Circularity	

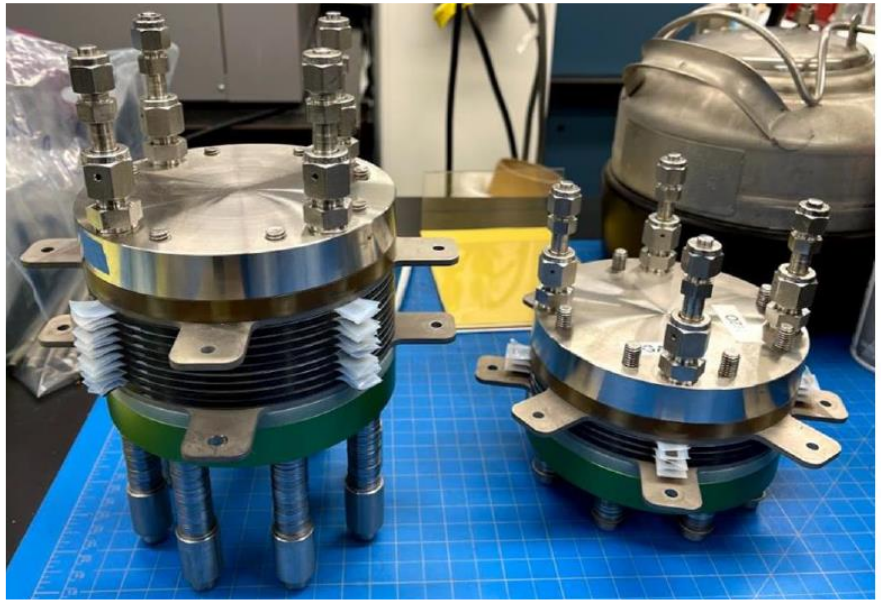
 Energy Efficiency

 Industrial Electrification

 Low-Carbon Fuels, Feedstocks, and Energy Sources

 Carbon Capture Utilization and Storage

RD&D Pipeline



Current IEDO RD&D Portfolio

Currently active awards include $55M across 23 R&D Projects

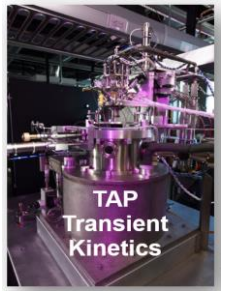
- Increase energy efficiency in the manufacturing of energy intensive chemicals through advanced catalysts and reactors for thermal and electrochemical pathways

Rapid Advancement in Process Intensification Deployment (RAPID)

- Renewal $30 - $50M for 5 years
- A Manufacturing USA Institute focused on modular chemical process intensification (MCPI) technology

Sustainable Chemistry Portfolio

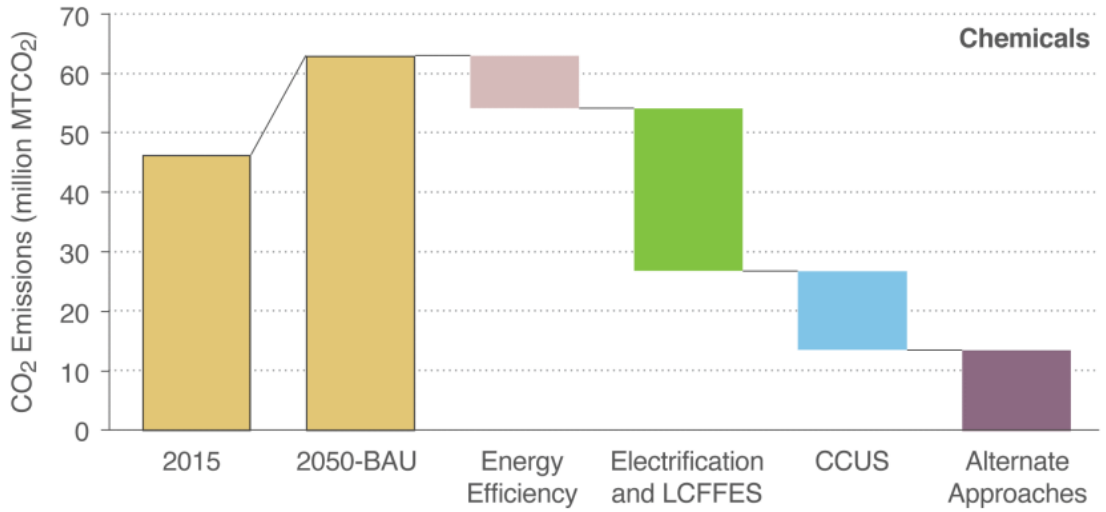
- $10M/yr Congressional Direction since FY21
- Activities to reduce impacts to human health and the environment from chemicals in manufacturing processes



Dynamical Catalyst's Science

- $5M FY20; $10M FY22; up to $20M FY23
- Program focuses on bringing advanced computational and in situ tools for predictive modeling from national laboratories/academia to industry

Decarbonization Pathways & IEDO Investments



Impact of the Decarbonization Pillars on CO_2 emissions (million MT/year) for U.S. Production of Ammonia, Methanol, Ethylene, and BTX, 2015-2050.

	Total Investment	Energy Efficiency*	Electrification & LCFFES*	Feedstocks*
AMO	$55M	$30.5	$14.7M	$22.5M

*not additive – projects address multiple pillars

Investment Funding Vehicles

2017 – 2021	FY18	FY18	FY20	FY21	FY22	FY23	FY23 – FY27	FY24
RAPID	Emerging Research FOA	Lab Call	Multitopic FOA	Multitopic FOA	Industrial Decarbonization FOA	IEDO FOA	RAPID Institute Renewal	Budget Request
Modular chemical process Intensification	Novel materials for new highly-effective chemical catalysts	Novel materials for new highly-effective chemical catalysts	Advanced Chemical Manufacturing R&D Dynamic Catalyst Science with Data Analytics	Sustainable Chemistry	Decarbonization of Unit Operations of High-Volume Energy Intensive Chemicals	Decarbonization of Unit Operations of High-Volume Energy Intensive Chemicals	Modular chemical process Intensification	Emphasis on Sustainable Feedstocks and CO_2 to Ethylene
$14M/yr for 5 years	$9M*	~$12M*	$25M*	$5M*	Max federal share per awards $3M or $10M	Max federal share per awards $3M or $10M	$6M - $10M/yr for 5 year	$58M for Chemicals, Forest Products, and Related Industries

* Currently Active Projects

Institute Focus Area: Modular Chemical Process Intensification

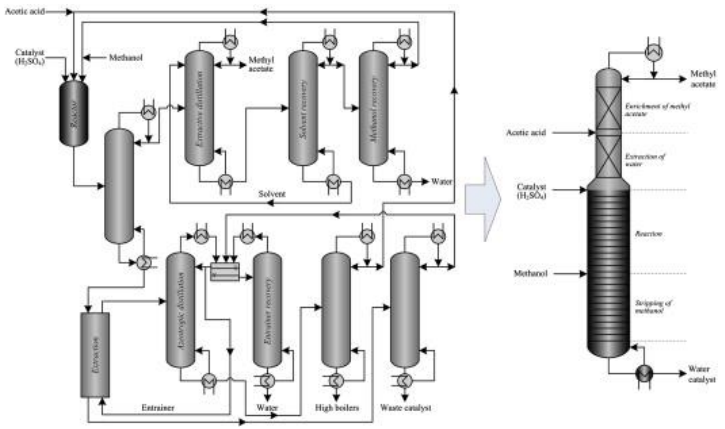
RAPID Transforming Process Industries

Modular Processing

- Rethinking systems to enable flexible, **distributed manufacturing**
- Shift from **bigger is better** paradigm to **small, modular** paradigm
- Transition from volume scaling to **numbering up**

Process Intensification

- Rethinking processes to dramatically **improve performance**
- Shift from **unit operations** paradigm to **integrative** paradigm
- Transition from **batch to continuous**



Primary Metals
1608 TBTU

Petroleum Refining
6137 TBTU

Chemicals
4995 TBTU

Wood Pulp & Paper
2109 TBTU

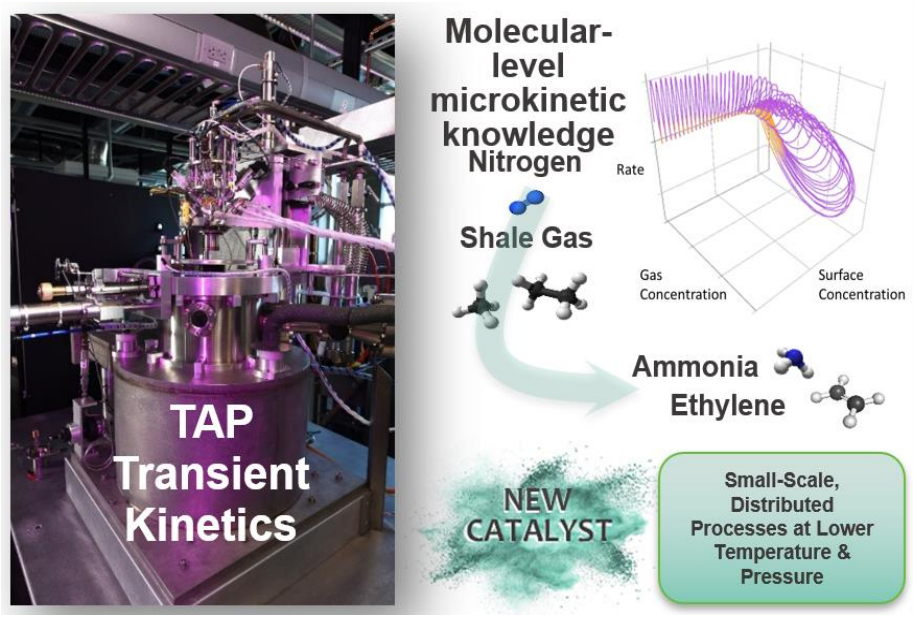
Glass & Cement
716 TBTU

Food Processing
1162 TBTU

Congressional Direction Focus Areas: Catalysts Science and Reactor Design

Dynamic Catalysts Science (DCS)

- Advanced catalysts and related process improvements could reduce energy intensity for these chemicals 20% to 40% by 2050 (IEA)
- Develop understanding of the catalytic mechanism in order to design advanced catalysts and catalytic reactors through employing computational and in situ tools to understand complex industrial catalysts
- Program focuses on bringing advanced computational and in situ tools for predictive modeling from national laboratories/academia to industry



Stakeholder Engagement

- Roundtable in 2020 https://www.energy.gov/eere/amo/events/dynamic-catalyst-science-roundtable
- One-on-one conversations with industry researchers & National Labs on *Dynamic Catalysts Science* to better identify the tools industry is seeking from national laboratories

Congressional Interest

- Congressional direction in FY20 ($5M), FY22 ($10M), FY23 ($20M)

Congressional Direction Focus Areas: Sustainable Chemistry

- CO_2 emission reductions is a pillar of Sustainability. Additionally, as the industrial sector transforms to meet the needs of decarbonization, there is an opportunity to replace equipment to reduce adverse impacts on human health and the environment

- Decarbonization should consider the pillars of Sustainable Chemistry:
  - Less toxic to human health and the environment
  - Lower energy consumption and related emissions
  - Reduced natural resource impacts
  - Optimized product design that results in the reduction of waste and the reuse or recycling of chemicals and materials across the product lifecycle

- Work under sustainable chemistry allows for us to address agile businesses for early deployment of decarbonization technologies
  - High-profit margin specialty chemicals present an opportunity to deploy transformation technologies
  - 34% of chemical manufacturing facilities are owned by small and medium enterprises (employ <500 people) (CISA)

Congressional Interest

- Congressional direction from in FY21 (HEWD/SEWD $5M), FY22 ($10M SEWD), FY23 ($10 SEWD)
- Congressional Report directed FY21 by HEWD and SEWD

Stakeholder Engagement

- Co-host roundtables with Green Chemistry & Commerce Council (GC3) in 2020 and 2023
- Environmentally-just sustainable chemistry RD&D practices; Focus on Small Businesses

https://www.energy.gov/eere/amo/downloads/sustainable-chemistry-manufacturing-processes-roundtable

Questions?

EEII: Chemicals Programmatic Summary

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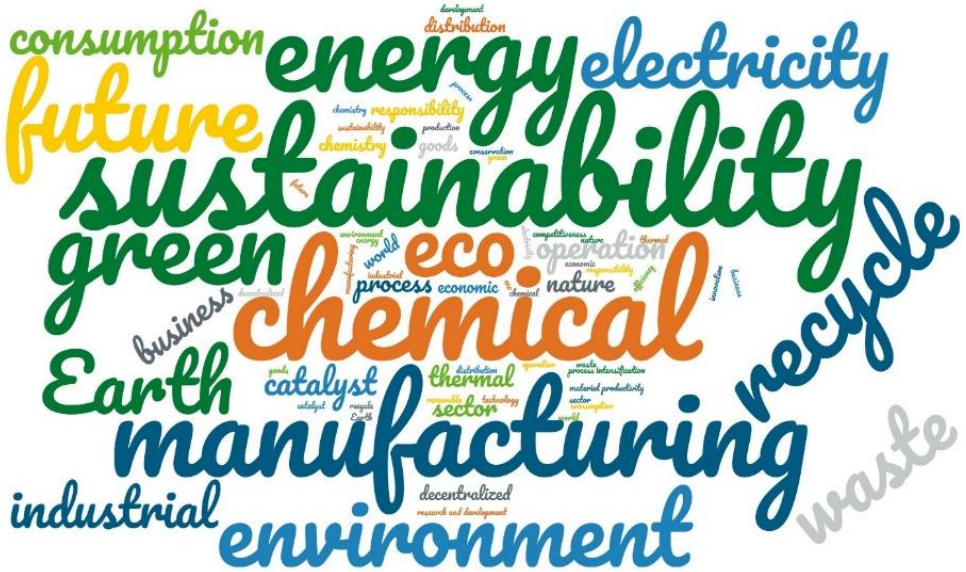
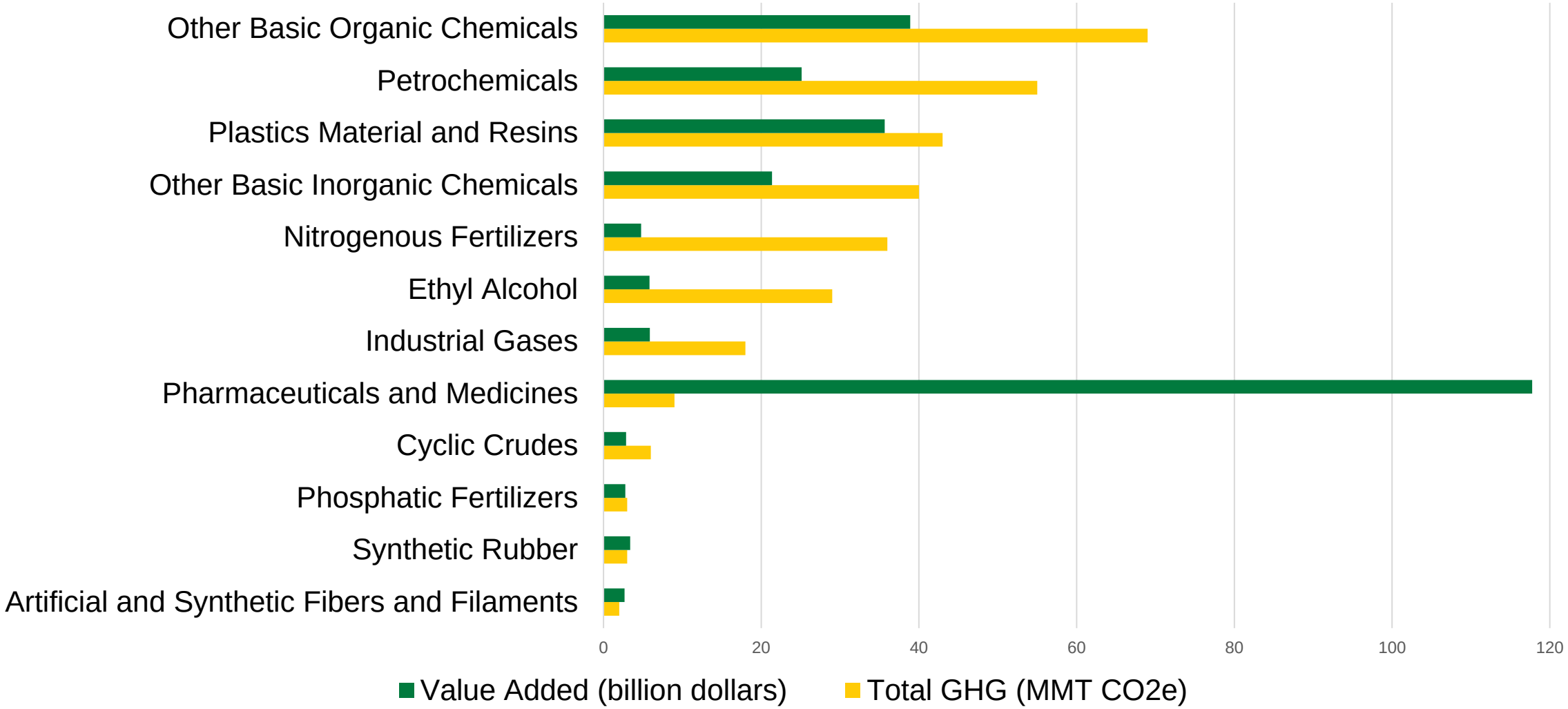
Industrial Efficiency and Decarbonization Office (IEDO)



Backup

Highest Emissions from High Volume, Low Profit Margin Chemicals



https://www2.census.gov/programs-surveys/asm/data/2021

https://www.energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2018-mecs

Decarbonization of Ethylene

Decarbonization of Ammonia

Hydrogen Decarbonization

- Clean Hydrogen