U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Decarbonization Priorities, Bioenergy Technologies Office (BETO)

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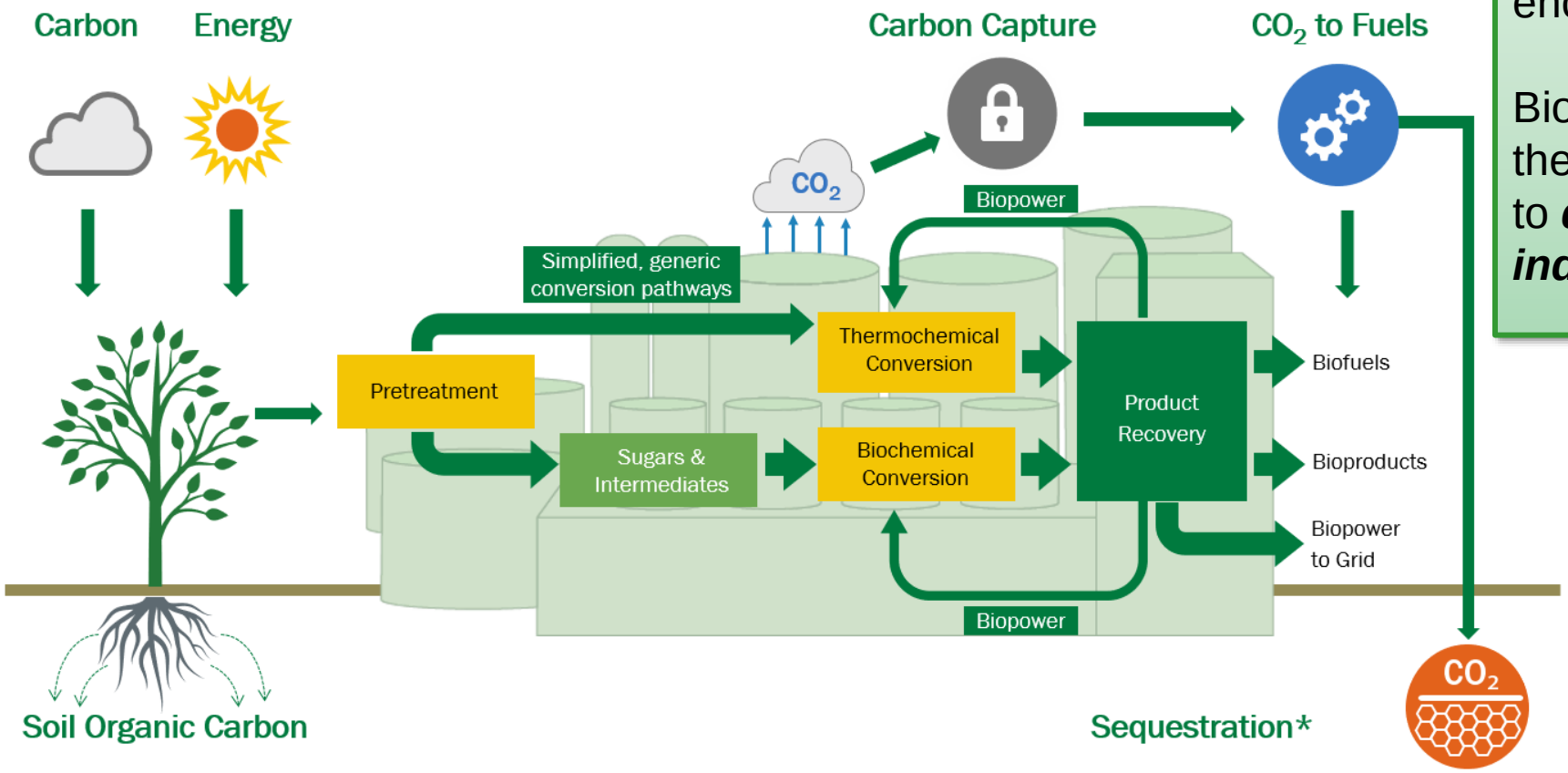
BETO develops technologies to produce fuels and chemicals from **renewable** resources, primarily biomass

- **Biomass** includes food waste, municipal solid waste, agricultural and forest wastes, animal wastes, and energy crops.
- **Bioenergy** is the conversion of biomass to energy that can replace fossil fuels.



* Office of Fossil Energy R&D on technologies of relevance to bioenergy industry.

Bioeconomy: An economy based on products, services, and processes derived from biological resources (e.g., plants and microorganisms) and encompassing multiple sectors.

Bioenergy is a key component of the U.S. bioeconomy and contributor to ***decarbonizing transportation, industry, and agriculture***.

BETO Multi-Year Program Plan (MYPP)

BETO Strategic Goals

Decarbonize Transportation

Decarbonize the transportation sector through RD&D to produce cost-effective, sustainable aviation and other strategic fuels.

- By 2030, enable SAF with >70% GHG emission reductions compared to petroleum
- By 2030, support scale up of SAF with >70% GHG reductions with >4 demo scale integrated biorefineries
- By 2030, support 3B gallons domestic SAF production, reaching 35B gallons by 2050

Decarbonize Industry

Decarbonize the industrial sector through RD&D to produce cost-effective and sustainable chemicals, materials, and processes utilizing biomass and waste resources.

- By 2030 enable commercial production of >10 renewable chemicals and materials with >70% GHG reduction relative to relevant petroleum-derived counterparts, supporting >1 million metric tons/year CO2e emissions reductions
- By 2030, enable at least one cost-effective and recyclable bio-based plastic that mitigates ≥50% GHG emissions relative to virgin resin or plastic production

Decarbonize Communities

Develop cost-effective, sustainable biomass and waste utilization technologies and innovative approaches contributing to the decarbonization of the agricultural sector, generating carbon-negative power, developing carbon drawdown strategies, or other beneficial uses.

- By 2030, demonstrate more than three place-based strategies for climate smart agriculture, waste management, environmental remediation, or other beneficial uses of renewable carbon resources

BETO's Role in Decarbonizing Industry

Strategic Goal

Decarbonize the sector through R&D to produce cost effective sustainable chemicals, materials and processes utilizing biomass and waste resources.

2030 Performance Goal

- Enable production of >10 renewable chemicals and materials with >70% GHG reduction
- Enable at least one cost-effective and recyclable bio-based plastic that mitigates ≥50% GHG emissions

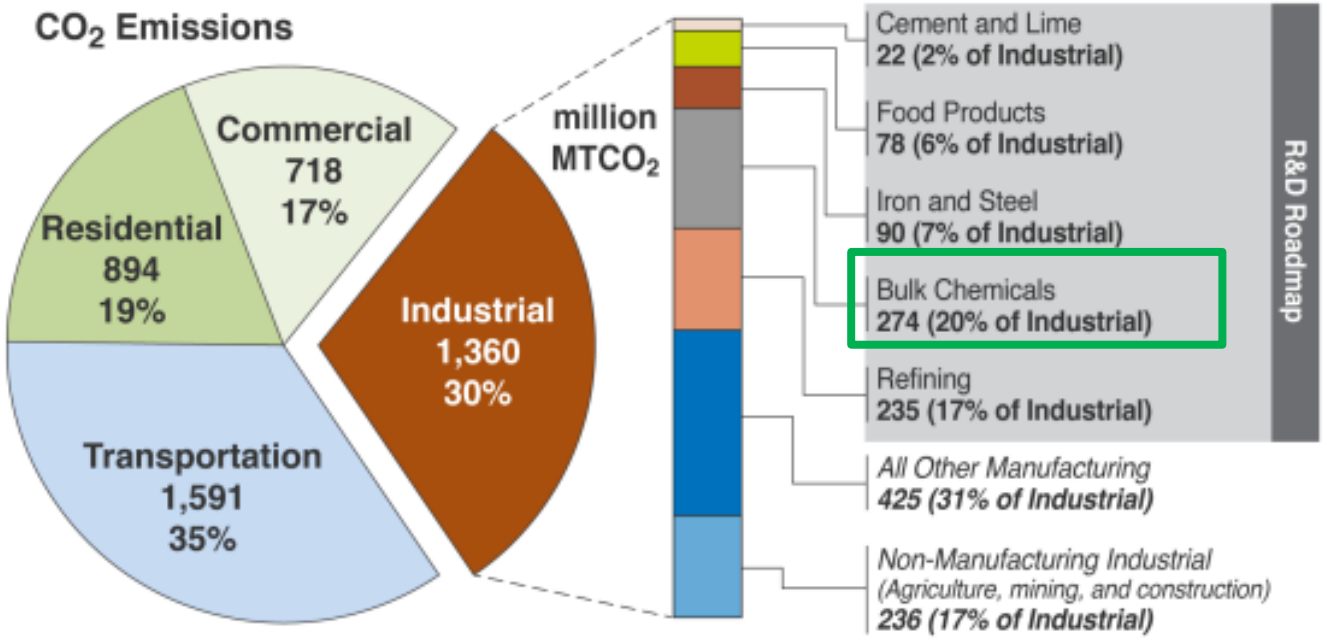


FIGURE 3. U.S. PRIMARY ENERGY-RELATED CO_2 EMISSIONS BY END USE SECTOR (LEFT PIE CHART) AND A BREAKOUT BY INDUSTRIAL SUBSECTOR (RIGHT STACKED CHART) IN 2020.

BETO Framework for Industrial Decarbonization

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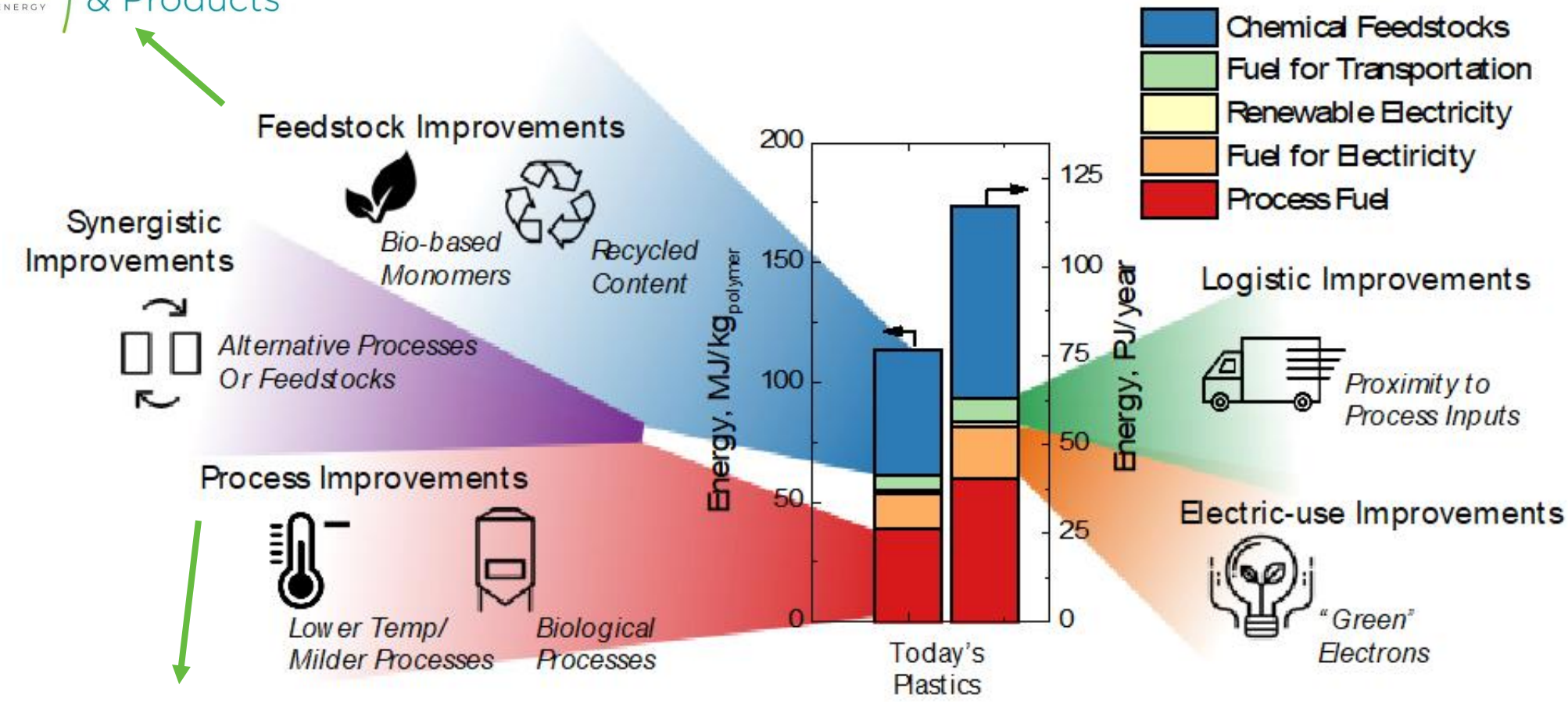
BETO focus areas



ENERGY earthshots U.S. DEPARTMENT OF ENERGY | Industrial Heat™

Nicholson *unpublished*, Material Flow Through Industries (MFI)

Industrial Decarbonization Efforts

- BETO funds projects that use biomass, wastes, and CO_2 as alternative feedstocks to petroleum for chemical and material production
- GHG reductions are a primary focus for all of these

Agile BioFoundry

ABPDU ADVANCED BIOFUELS AND BIOPRODUCTS PROCESS DEVELOPMENT UNIT

- Biomass feedstocks for biochemicals and biofuels
- National Lab-led consortium
- 100+ industry and academic partnerships
- **>15 commercial products enabled**
- Target both SAF and chemicals
- $18M FY24

bottle changing the way we recycle™ U.S. DEPARTMENT OF ENERGY

- Biomass feedstocks for redesigned plastics
- Waste plastic feedstock
- National Lab-led consortium
- Redesign, recycling, and upcycling of plastics
- $5M/year BETO, $5M/year AMMTO
- Plastics FOA efforts $8M FY19, $10M FY20, $5M FY21

- CO_2 feedstock
- CO_2 reduction to C1 intermediates
- Microbial intermediate upgrading to chemicals
- $10M FY24 national lab call
- CO_2 FOA efforts $7.5 M FY20, $5M FY18

BIOPROCESSING SEPARATIONS CONSORTIUM

- Reduce Process Energy
- National Lab-led consortium
- 6 tasks that develop low-energy separations technologies
- $5M/year

Additional BETO efforts in performance-advantaged bioproducts, algae polyurethanes, lignin-derived products

Thank you!

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Technology Manager, DOE Bioenergy Technologies Office

Backup Slides

BETO's Role in Decarbonizing Transportation

Strategic Goal

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2030 Performance Goal

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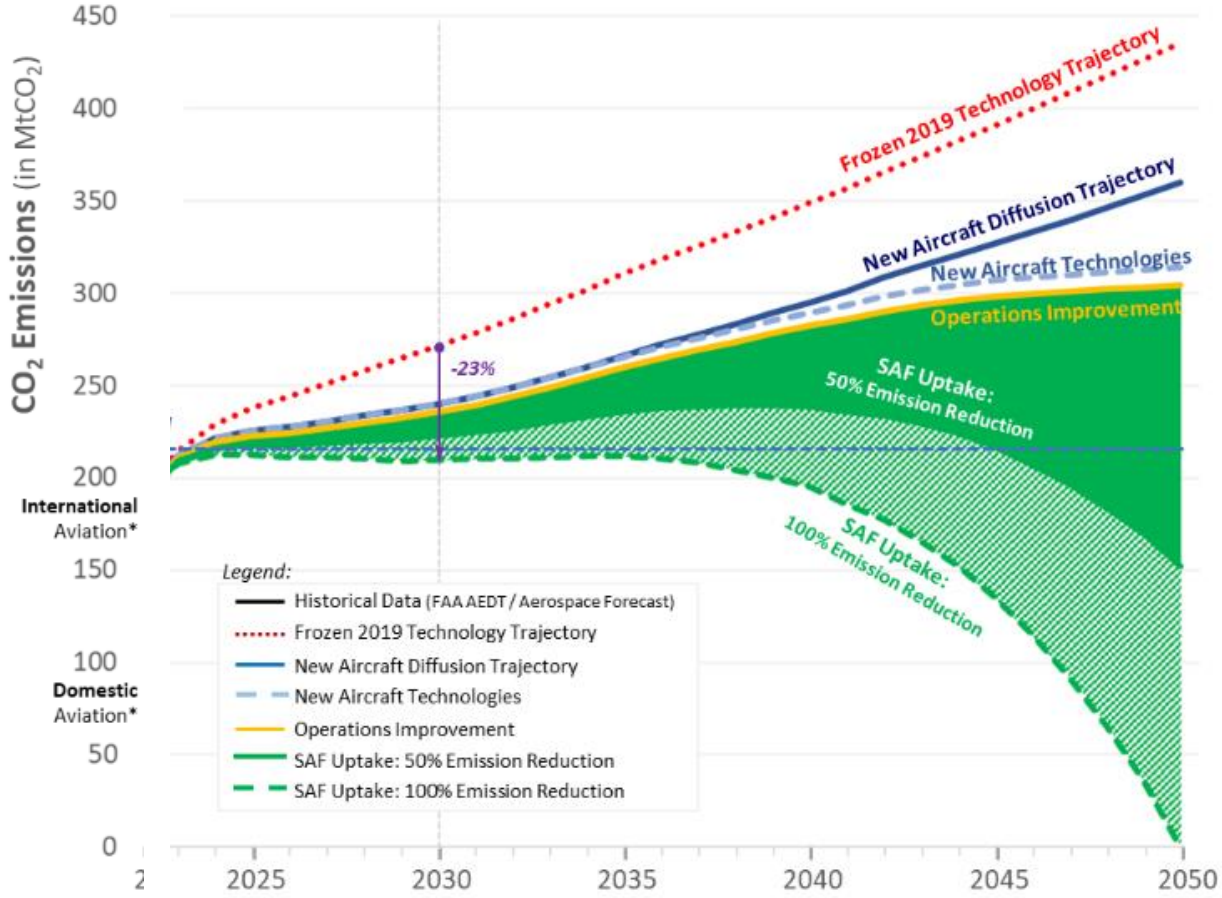
US National Blueprint for Transportation Decarbonization, BETO contributes SAF, heavy duty, rail, and marine

SAF Grand Challenge

- Government-wide initiative led by DOE, USDA, and DOT to expand the domestic production of SAF to meet **100% of domestic demand** for aviation fuel.



Industrial Decarbonization Case Study.
AVAPCO - From Strain Development to Demonstration

*The project partners have invested more than 10 years in the development of low carbon footprint **cellulosic SAF** and **renewable diesel** along with **high-value co-products.***

- 2010 — Byogy ATJ Piloting
- 2011 — AVAP Bench Optimization
- 2012 — Thomaston Biorefinery Start-Up
- 2013 — AVAP Sugar to Biochemical Trials
- 2014 — Byogy SAF Testing under FAA Clean Fuels Program
- 2015 — AVAP Nanocellulose Start-Up; Petron Commercial Process Optimization
- 2016
- 2017 — AVAPCO "ABBA" DOE Award; NDC Laboratory Development with Birla Carbon

- 2018 — Byogy SAF ATJ-SPK Pathway Certification
- 2019 — "ABBA" DOE Verification Complete
- 2020
- 2021 — NDC Continuous Pilot Trials

- 2022 — Byogy 2G SAF Pilot in Japan Start-Up

- 2023 — "Enabling NET ZERO" DOE Award — $80M in 2023

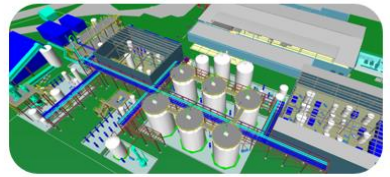


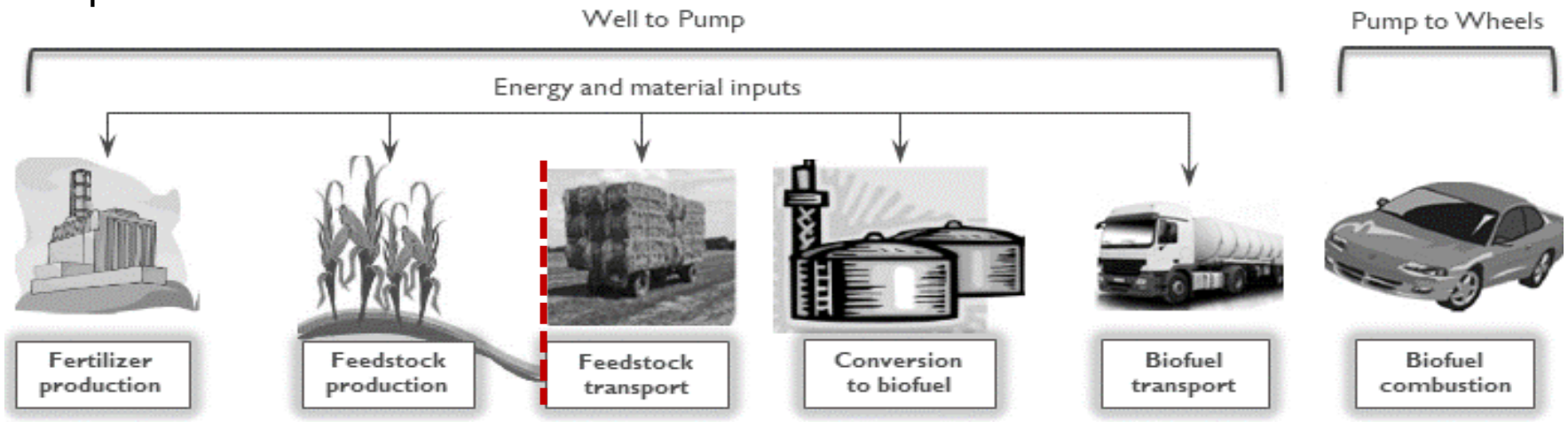
Image courtesy of AVAPCO

The Role of Biomass in Agriculture

- Agriculture activities serve as sources and sinks for GHGs.
- Decarbonizing transportation/chemicals and decarbonizing agriculture are intrinsically linked.
- By developing tools and strategies to quantify and improve soil carbon sequestration and ecosystem services, we can produce biofuels with a lower carbon intensity.

Focus areas in agriculture:

- Maximize soil CO_2 sequestration by developing healthy, productive soils and regenerating distressed soil.
- Develop climate-smart ag practices.
- Produce clean energy on-site from animal waste.
- Develop wastewater treatment strategies that produce bioenergy feedstocks.

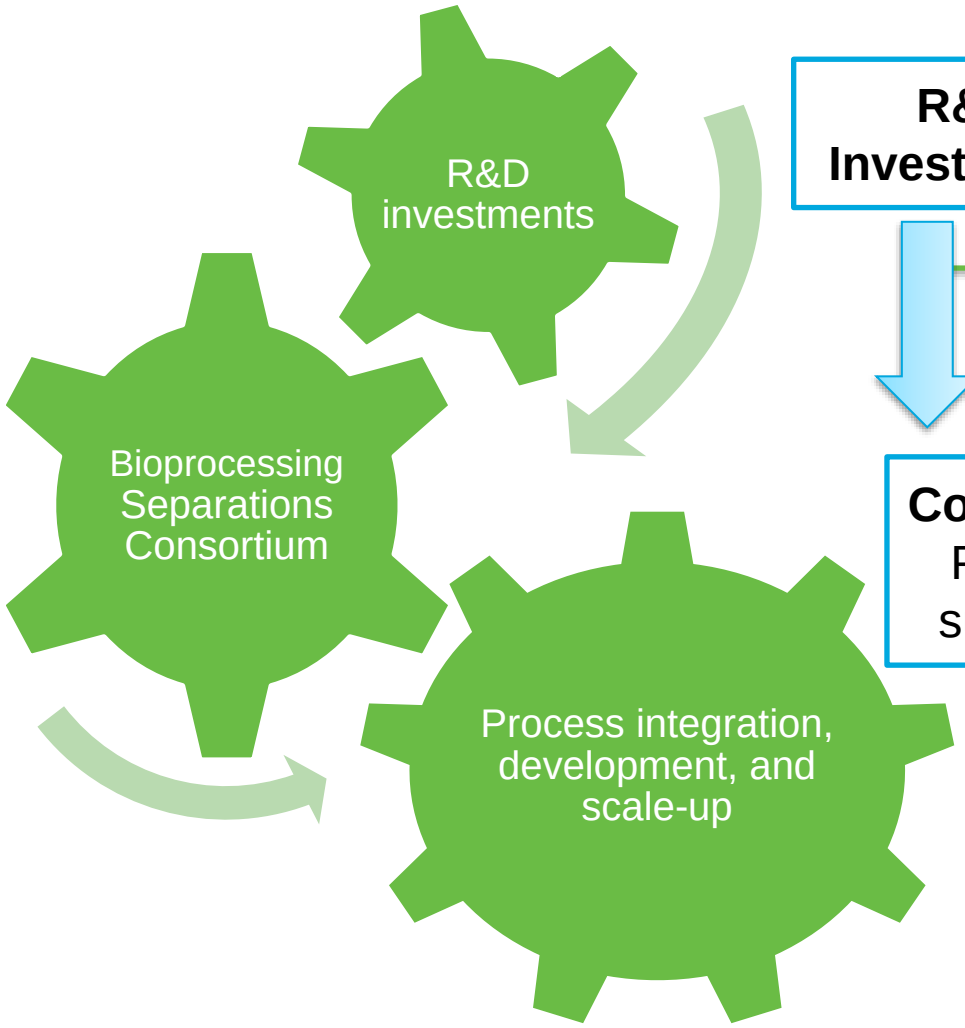


Emissions Contribution

Fertilizer production	Feedstock production	Feedstock transport	Conversion to biofuel	Biofuel transport	Biofuel combustion
16-20%	26-31%	2%	44%	2%	1%

Argonne Final Report to ARPA-E (2019): *Developing a Framework for Lifecycle Analysis of Biofuels on the Farm Level*

BETO has enabled a wide range of companies to produce renewable chemicals



R&D Investments

Commercial Products supported

BIRCH BIOSCIENCES · LanzaTech · PHYCUS BIOTECHNOLOGIES · SUPERBREWED FOOD · KALION, INC. · iMICROBES · ENDURO · Agilent · TECHNOLOGY HOLDING · huue · LYGOS · danimer scientific · North Texas · University of Georgia · Berkeley · ZymoChem · KIVERDI · PYRONE SYSTEMS INC. · University of Wyoming · invaio sciences · A FLAGSHIP PIONEERING COMPANY · teselagen BIOTECHNOLOGY · VISOLIS · c16 BIOSCIENCES · University of Nebraska Lincoln · UC San Diego · University of Delaware · AZOLLA · UNIVERSITY of WASHINGTON

BOLT THREADS · CHECKERSPOT · EVERY · AFATER · Geltor · GINKGO BIOWORKS


Silk and leather textiles


Triglyceride polymers for eco-friendly skis


EVERY Egg White


Recycled cellulose


Biodesigned, animal-free collagen


Perfume ingredients

Joywell · LYGOS · MANGO MATERIALS · VISOLIS


Sweet proteins from plants for healthier foods


Malonic acid


Sustainable PHA for bioplastics


Mevalonic acid for skincare

JUST · MYCOWORKS · PERFECT DAY · ripple · ZymoChem


JUST Egg

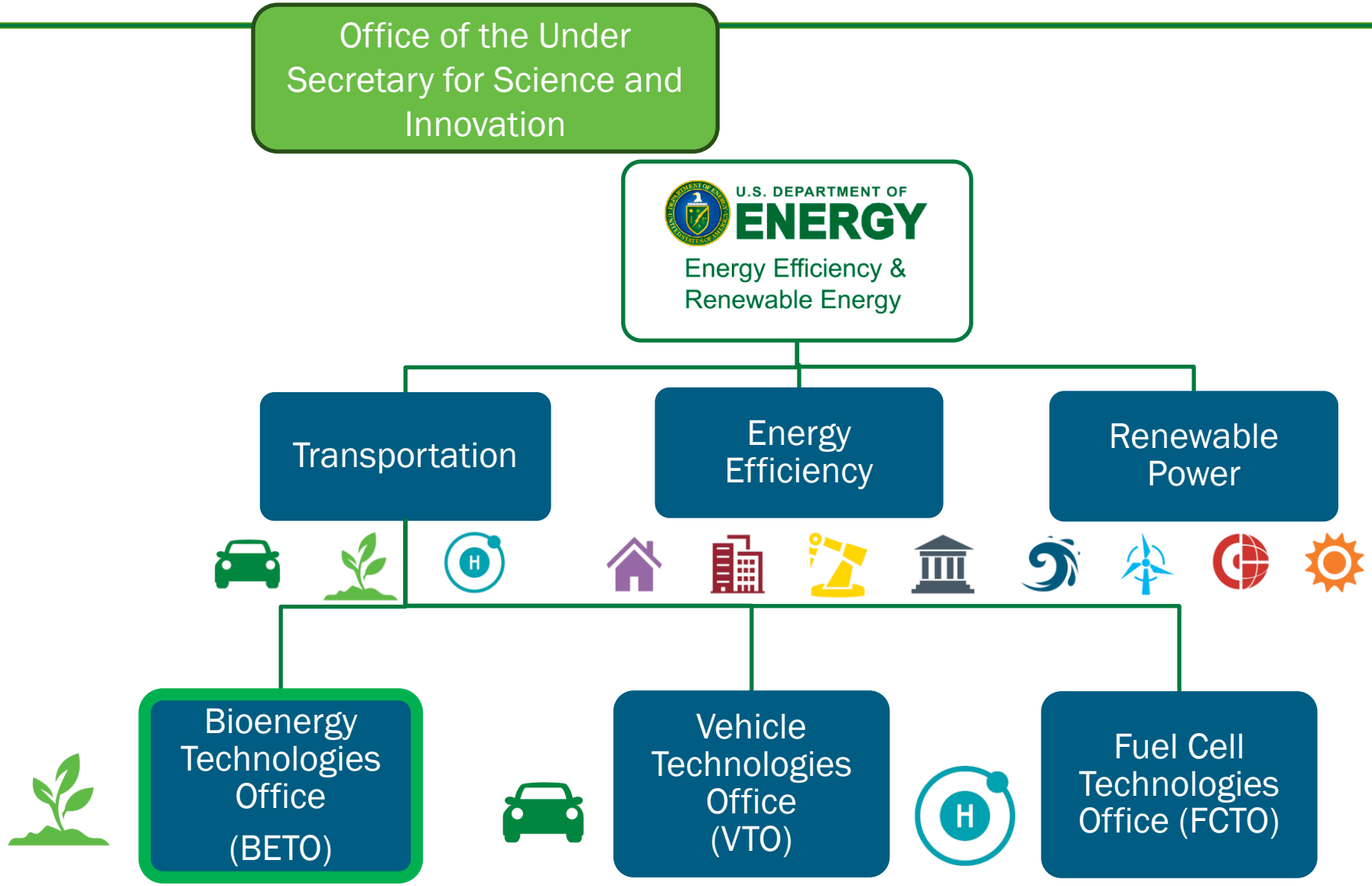

Fine mycelium for leather


Animal-free dairy proteins

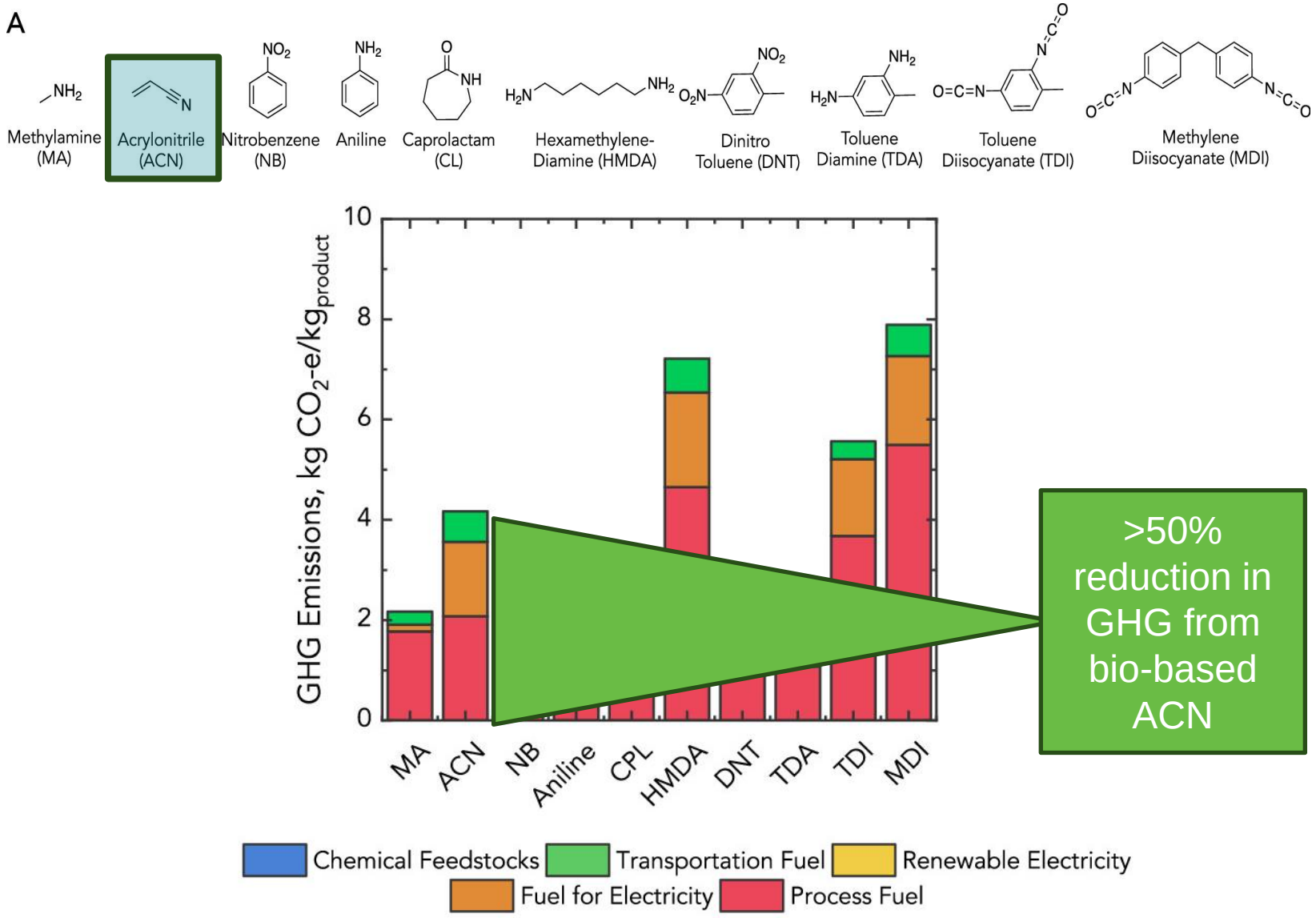

Pea protein for milk products


Organic acids for textiles

U.S. Department of Energy Sustainable Transportation Offices



Petrochemical GHG emissions are strongly driven by process fuel. Bioprocesses can dramatically reduce these needs



ACS Sustainable Chem. Eng. 2023, 11, 6, 2198-2208

Bioprocess separations are key to industrial decarbonization

BIOPROCESSING SEPARATIONS CONSORTIUM

Separations account for 10 – 15% of **TOTAL** energy consumption[1]

50 – 70% of **BIOPROCESSING COSTS** are associated with **separations**[2,3]

BETO's Bioprocessing Separations Consortium: Develop cost-effective, high-performing separations technologies through coordinated separations research that targets industry-relevant bioprocessing separations challenges

1. Sholl and Lively. "Seven chemical separations to change the world," *Nature*, **2016** 532: 425-437.
2. EERE. 2016. Strategic Plan for a Thriving and Sustainable Bioeconomy.
3. Biddy et al. "The Techno-Economic Basis for Coproduct Manufacturing To Enable Hydrocarbon Fuel Production from Lignocellulosic Biomass." *ACS Sustainable Chem. Eng.* **2016** 4: 3196-3211.

BETO's Role in Decarbonizing Industry

Strategic Goal

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2030 Performance Goal

- Enable production of >10 renewable
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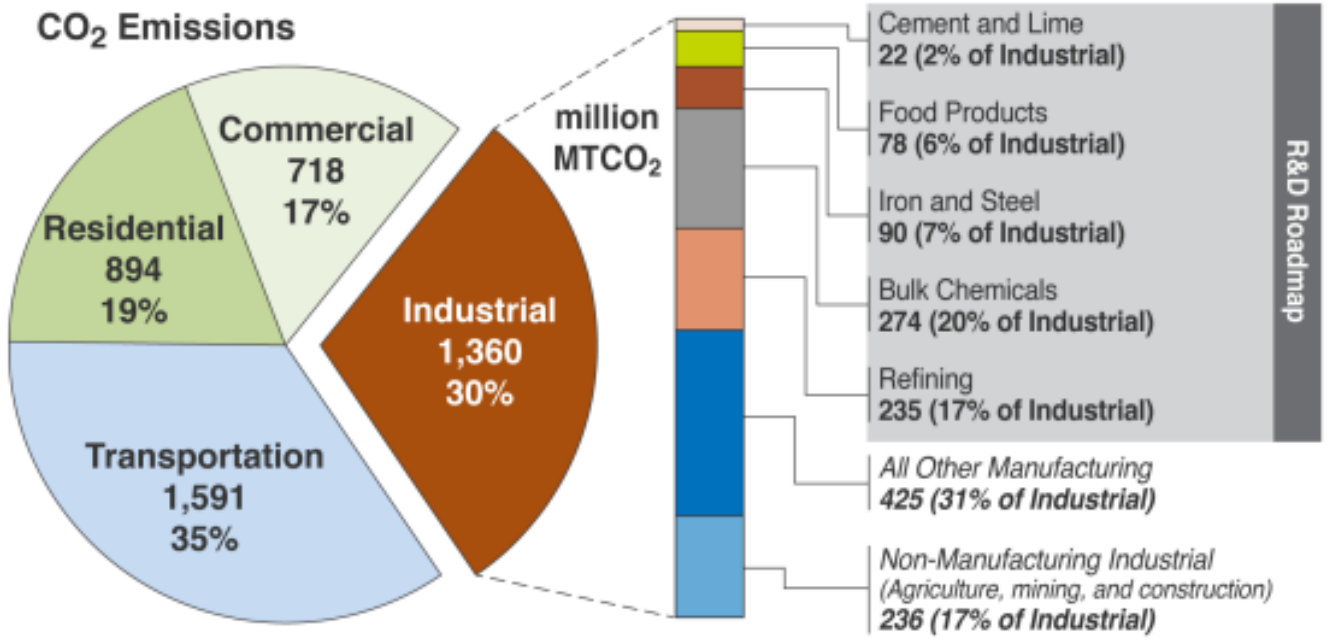
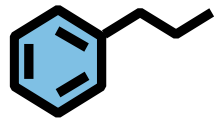
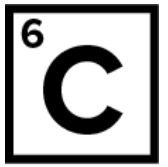


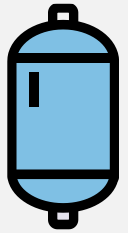
FIGURE 3. U.S. PRIMARY ENERGY-RELATED CO_2 EMISSIONS BY END USE SECTOR (LEFT PIE CHART) AND A BREAKOUT BY INDUSTRIAL SUBSECTOR (RIGHT STACKED CHART) IN 2020.

Major Challenges Addressed Within the Consortium

Lignin fractionation	Lignin fractionation enables conversion to valuable fuels and co-products that can enhance process economics and sustainability.
Recovery of carbon from dilute streams	Increasing carbon efficiency of processes from recovery of valuable co-products can lead to improved process economics.
Removal of impurities from aqueous streams	Poisons and foulants limit the lifetimes of upgrading (bio)catalysts. Impurities limit drop-in fuel compatibility. Selective removal strategies to eliminate them will extend catalyst life and decrease processing costs.
Process intensification	Reducing the number of processing steps associated with separations, including through reactive fermentation and in-situ product recovery, reduce process energy intensity and costs.

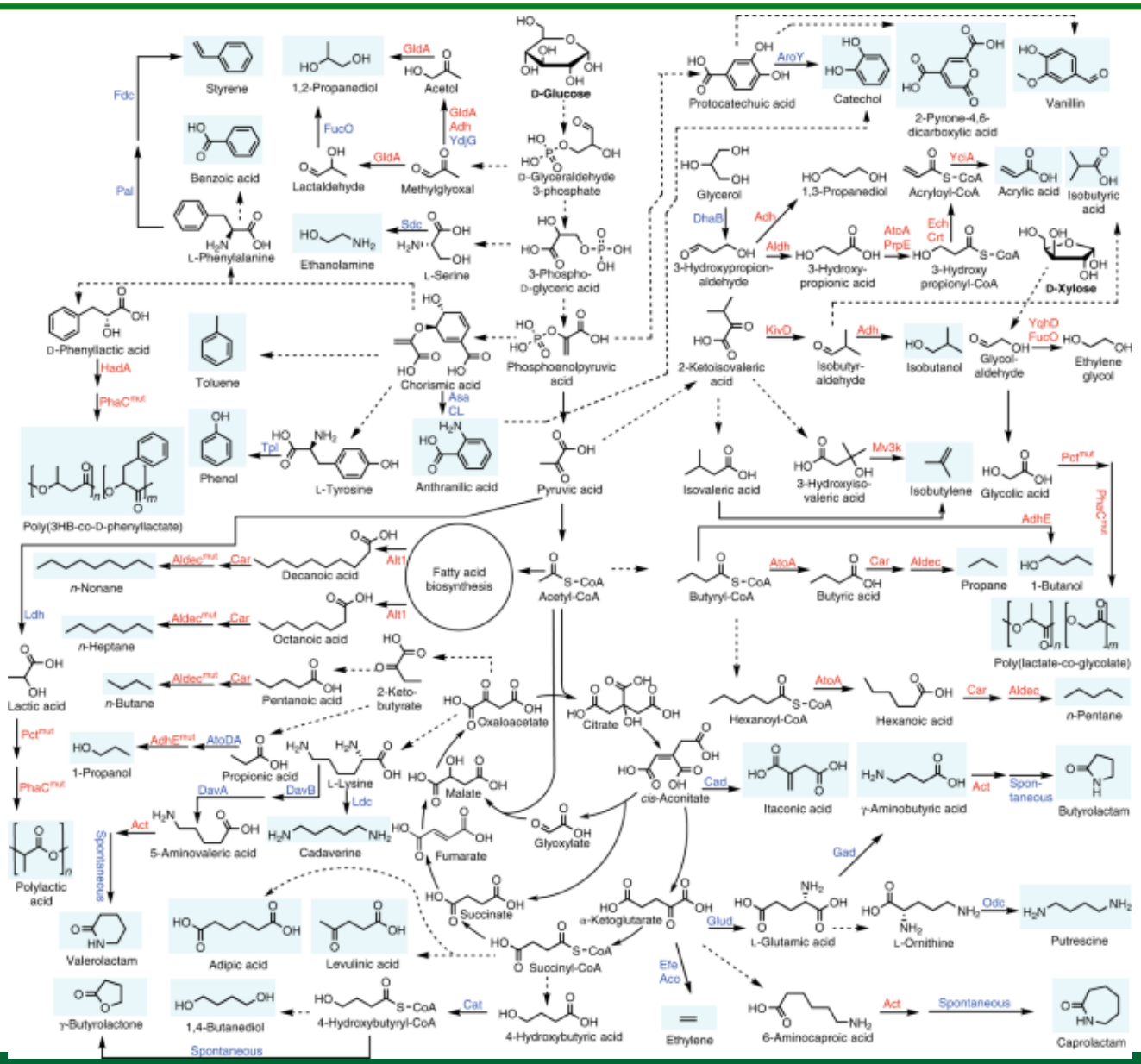






Nature is replete with chemical complexity

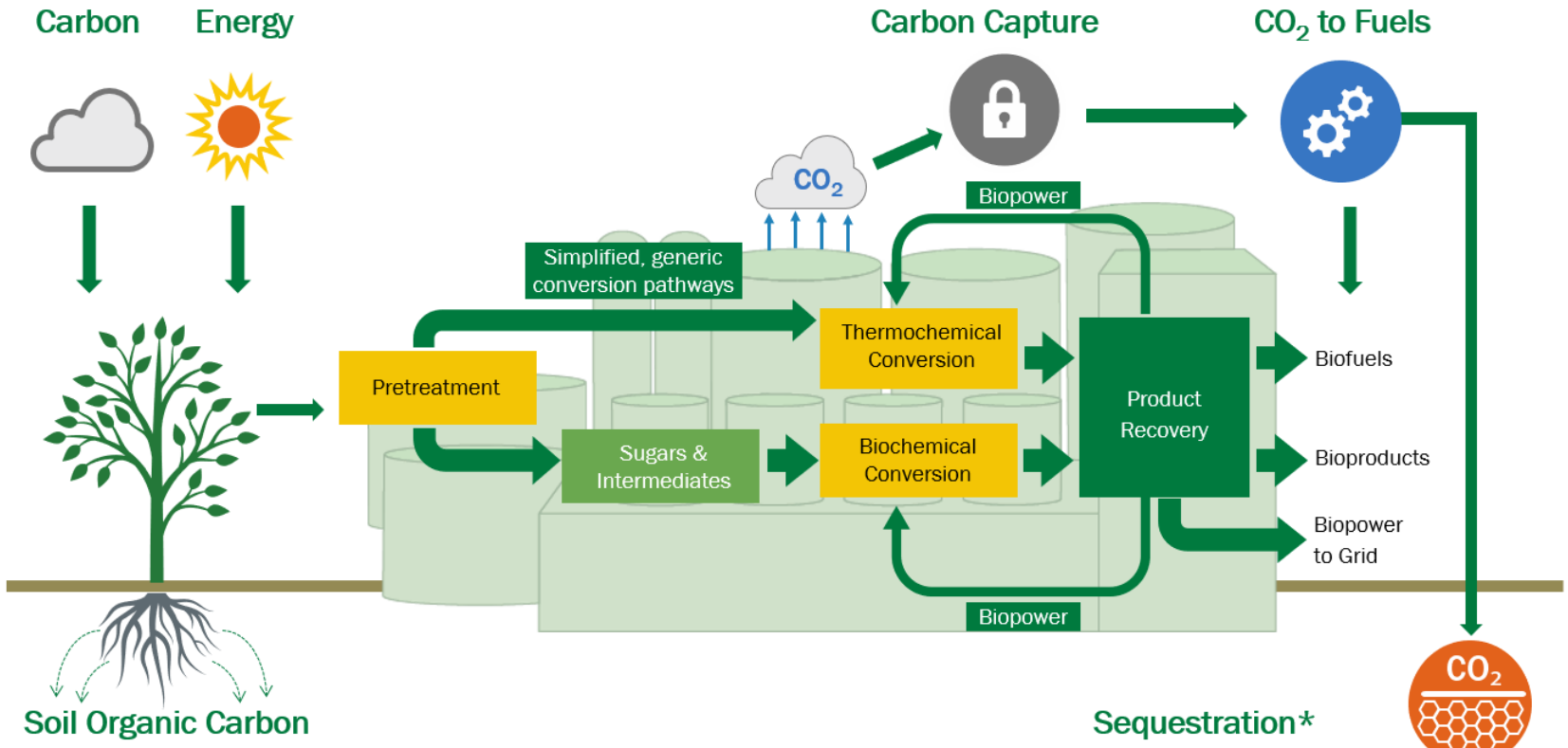
Many bio-based chemicals can be accessed through conserved, central carbon pathways with a wide range of functionalities-including products with heteroatoms



Industrial Heat Shot Summit

October 2023

Biomanufacturing Process Improvements



** Office of Fossil Energy R&D on technologies of relevance to bioenergy industry.*