U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

ARE YOU A CLEAN ENERGY CHAMPION?

Bionenergy Technologies Office Decarbonization Strategies

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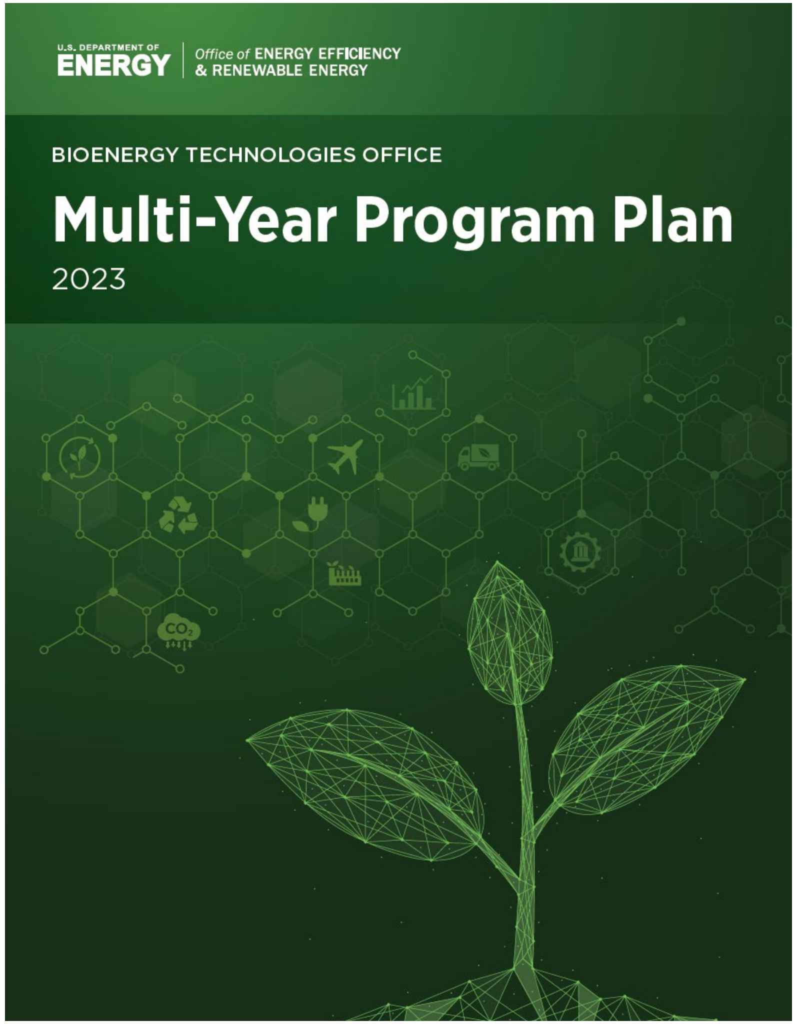
Overview

- Introduction
  - Bioenergy Technologies Office (BETO)
    - Focus on Renewable Carbon Resources to Sustainable Fuel and Energy
  - Renewable Carbon Resources – Broad Potential for the U.S. for hard to electrify economic sectors
- BETO Strategies to Strengthen a Growing Bioeconomy
  - Decarbonize Transportation
  - Decarbonize the Industry – Focus on Chemicals
  - Decarbonize Communities
- RD&D Focus Areas and Activities
- Charting Pathways to Intermediate Commodities
- Key Takeaways

Introduction – Bioenergy Technologies Office

- The Bioenergy Technologies Office (BETO) is a technology development office within the Office of Energy Efficiency and Renewable Energy at the U.S. Department of Energy, under the Sustainable Transportation Pillar.
- Together with the national labs, the universities and the industry, we work to develop and demonstrate resilient and reliable clean energy technologies that convert renewable carbon resources into fuels and products.
- Our focus is on enabling the widespread adoption of bioenergy technologies
  - Equitable and affordable solutions to contribute to the decarbonization of the transportation, industrial, and agricultural sectors, and
  - Provide for environmental equity in both rural and urban settings by promoting job creation and economic growth.



BT 23 Study Key Take Away

- US currently uses 340 million tons biomass for fuel & power
- Fully mature bioeconomy could provide 700-1700 million tons biomass
- All estimates include sustainability constraints
- No single resource type is sufficient on its own to meet demand.
- A diversified feedstock supply will:
  - Deliver economic and environmental benefits across the U.S.
  - Increase resilience across the supply chain.

Currently used for energy and coproducts

Near-term and mature market resources

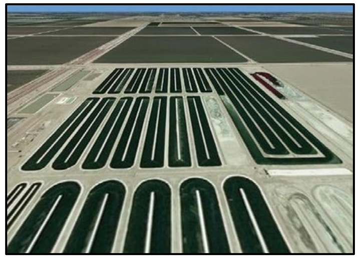
Waste/byproduct

Timberland

Agriculture

Emerging resources

Microalgae



Macroalgae

CO_2

BETO Strategic Goals

Photo by iStock

Key Themes to BETO Strategy

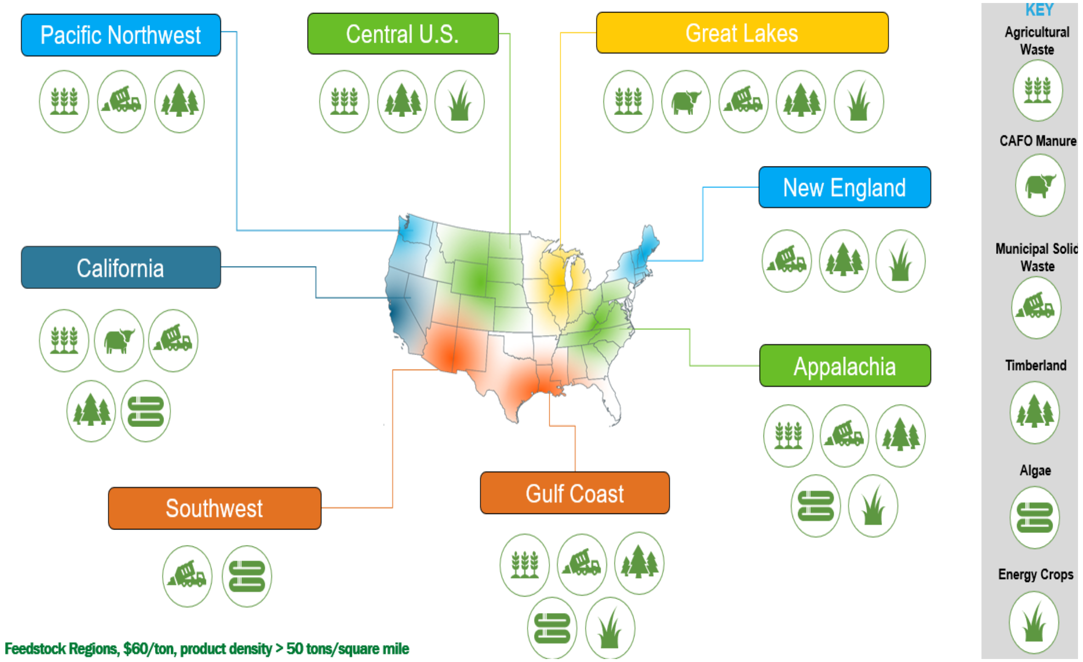
→ More GHG reductions, faster!

→ Focusing on SAF and other strategic transportation fuels.

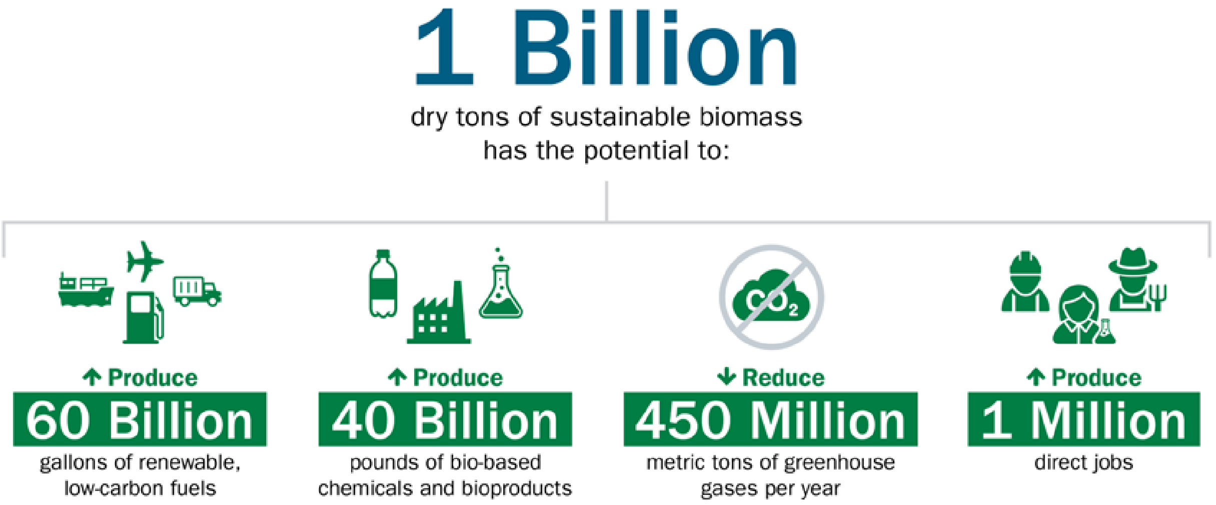
→ Unlocking the potential of the full range renewable carbon resources. Nationwide.

→ Creating market pull through high-ROI opportunities (e.g., chemicals).

→ Expanding beneficial-use cases for relevant technologies (e.g., waste management).



Feedstock Regions, $60/ton, product density > 50 tons/square mile



BETO Mission & Goals: Maximizing Biomass's Potential to Decarbonize the US Economy

MISSION

Develop and demonstrate technologies to accelerate reduction of GHG emissions through the cost-effective, sustainable use of biomass and waste feedstocks across the U.S. economy.

BETO Strategic Goals

Decarbonize Transportation	Decarbonize Industry	Decarbonize Communities
Decarbonize the transportation sector through RD&D to produce cost-effective, sustainable aviation and other strategic fuels.	Decarbonize the industrial sector through RD&D to produce cost-effective and sustainable chemicals, materials, and processes utilizing biomass and waste resources.	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.

Decarbonize Transportation targets:

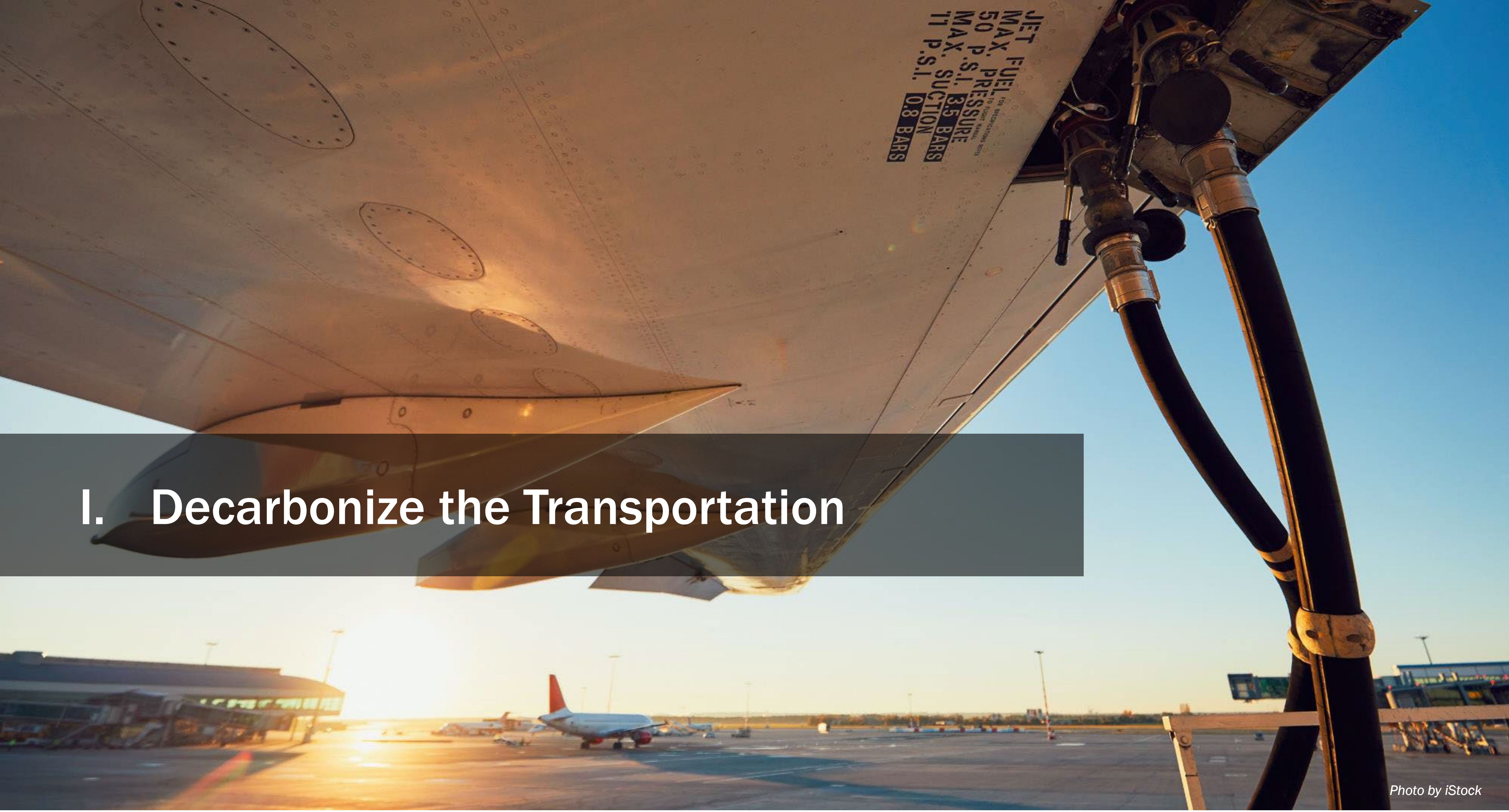
- >70% GHG Reductions over Jet A
- Scale-up >4 Technology Pathways
- Enable production of 3B gal by 2030 and 35B gal by 2050.

Decarbonize Industry targets:

- >70% GHG Reductions over Petrochem
- Enable >10 New Chemicals by 2030
- Enable >1 recyclable biopased plastic > 50% GHG reduction by 2030

Decarbonize Communities target:

- Demonstrate 3 Community Based Beneficial Uses of Renewable Carbon Resources by 2030



I. Decarbonize the Transportation

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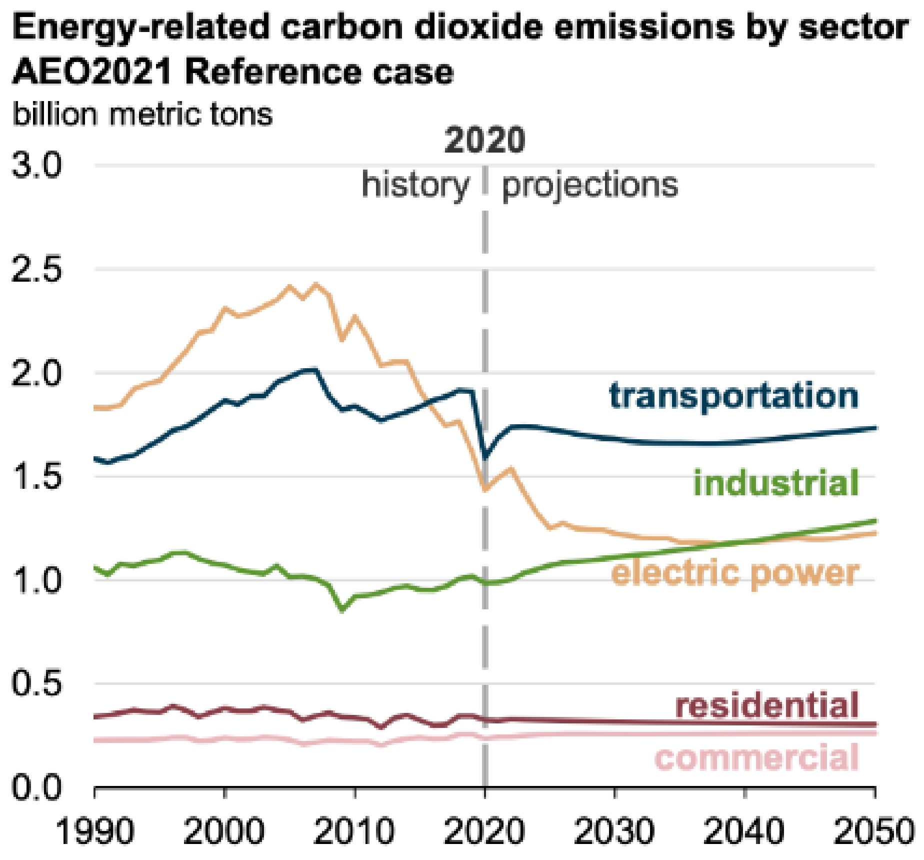
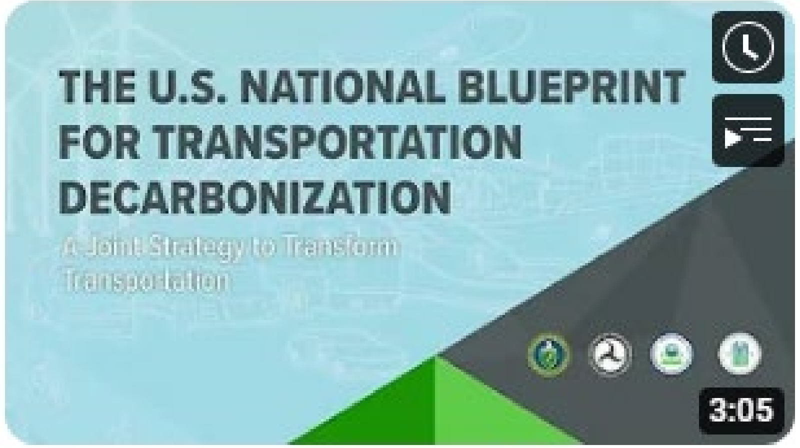
Decarbonization of the Transportation



- Decarbonize the transportation sector through RD&D to produce cost-effective, sustainable aviation and other strategic fuels.
- Along with industrial and federal partners, support 3 billion gallons of domestic SAF production and use, consistent with a trajectory to ultimately producing 35 billion gallons by 2050.

Clean Solutions for All Modes of Transportation – DOE, DOT, EPA, HUD

Achieving net-zero emissions requires a suite of technology solutions across all modes of transportation



1 icon represents limited long-term opportunity
2 icons represents large long-term opportunity
3 icons represents greatest long-term opportunity

	BATTERY/ELECTRIC	HYDROGEN	SUSTAINABLE LIQUID FUELS
Light Duty Vehicles (49%)*	[3 icons]	–	TBD
Medium, Short-Haul Heavy Trucks & Buses (~14%)	[2 icons]	[1 icon]	[1 icon]
Long-Haul Heavy Trucks (~7%)	[1 icon]	[3 icons]	[2 icons]
Off-road (10%)	[2 icons]	[1 icon]	[1 icon]
Rail (2%)	[2 icons]	[2 icons]	[2 icons]
Maritime (3%)	[1 icon]	[2 icons]†	[3 icons]
Aviation (11%)	[1 icon]	[1 icon]	[3 icons]
Pipelines (4%)	[2 icons]	TBD	TBD
Additional Opportunities	• Stationary battery use • Grid support (managed EV charging)	• Heavy industries • Grid support • Feedstock for chemicals and fuels	• Decarbonize plastics/chemicals • Bio-products
RD&D Priorities	• National battery strategy • Charging infrastructure • Grid integration • Battery recycling	• Electrolyzer costs • Fuel cell durability and cost • Clean hydrogen infrastructure	• Multiple cost-effective drop-in sustainable fuels • Reduce ethanol carbon intensity • Bioenergy scale-up

* All emissions shares are for 2019

† Includes hydrogen for ammonia and methanol

SAF Grand Challenge – DOE, FAA, USDA

Sustainable Aviation Fuel Grand Challenge

Sep 2021
White House Announcement

Nov 2021
U.S. Aviation Climate Action Plan

Sep 2022
Grand Challenge Roadmap

Jan 2023
Transportation Decarbonization Plan

2030
3 BGY Goal

2050
35 BGY Goal

II. Decarbonize the Industry

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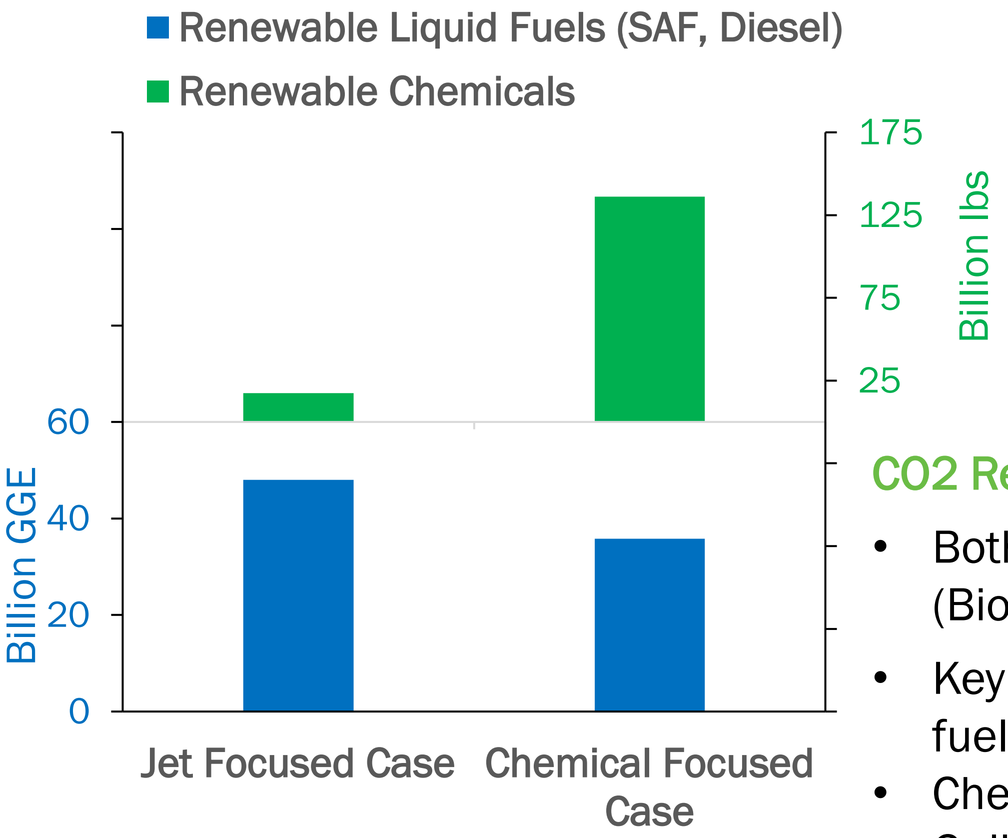
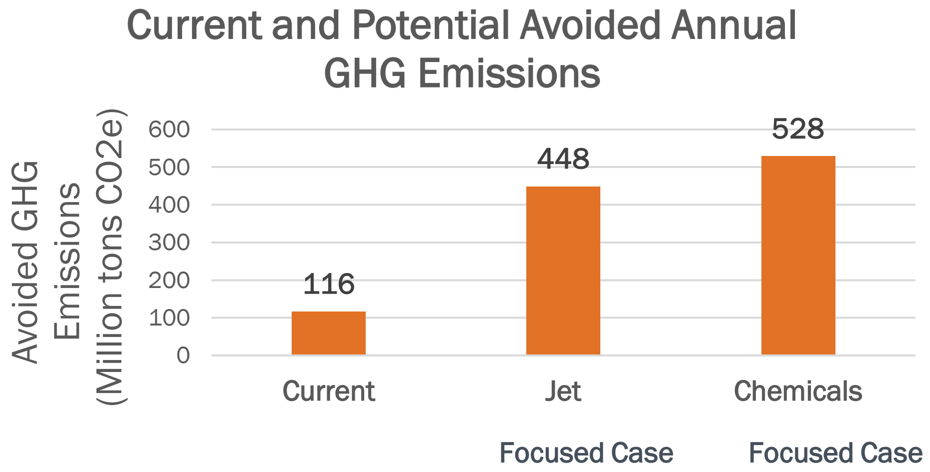
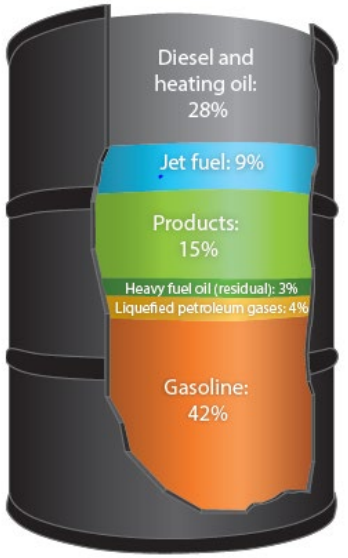
Decarbonization of Industry: Chemicals





CO2 Reduction

- Both cases include equal production of other products: (Biogas, CNG and LNG, Electricity, Heat)
- Key differences between cases reside in the amount of fuels vs. chemicals produced.
- Chemicals focused case still produces >35 Billion Gallons of liquid fuel production for transportation

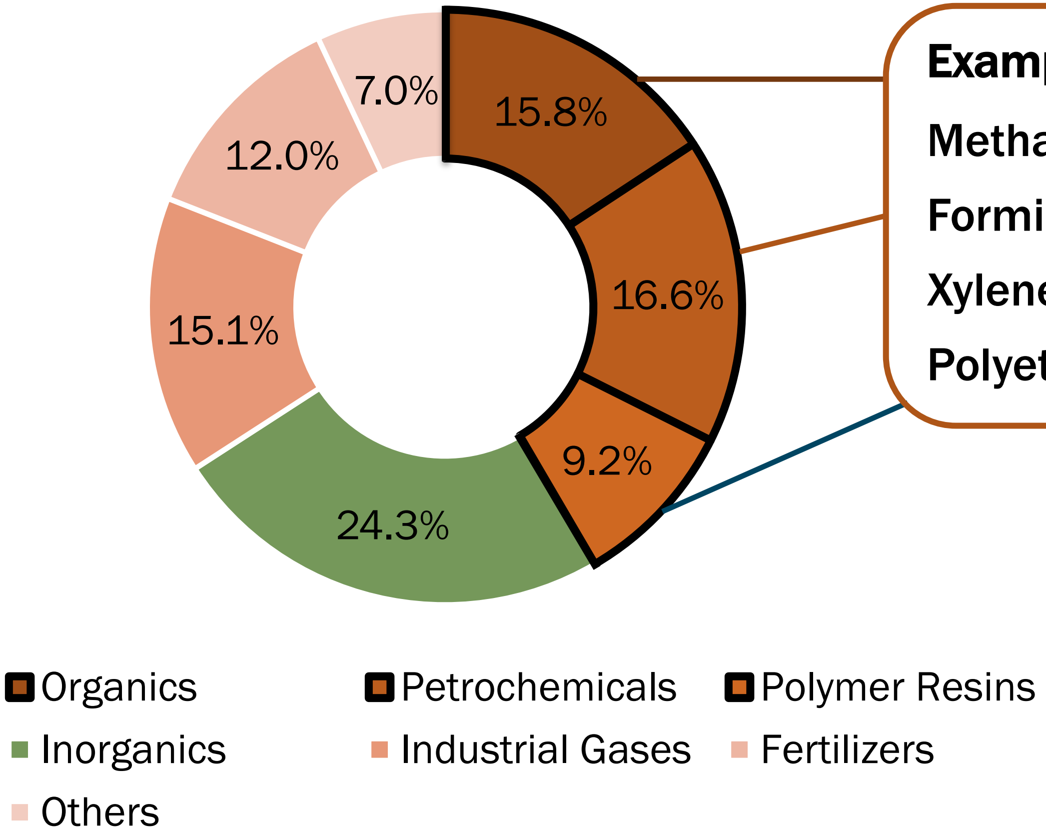


Economics

- Fuels makes up 76% of the volume of U.S. oil products and is worth $935B.
- Chemicals make up 17% of the volume of U.S. oil products and worth $812B.
- Optimizing Biofuels production biofuels with the development of chemical intermediates will drive down the cost per gallon.

Industrial Decarbonization Strategy - Chemicals

Total U.S. Industrial Chemicals by Mass



Example Targets

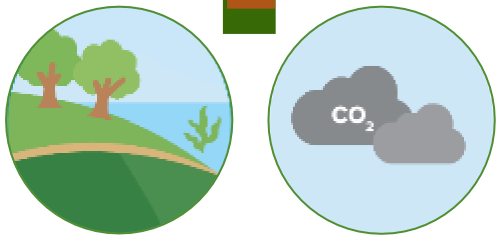
Methanol	Acrylonitrile
Formic Acid	Butadiene
Xylenes	Polyester
Polyethylene	Polypropylene

1,000s of consumer products

Replacements

Biopolymers

Biodegradable polymers

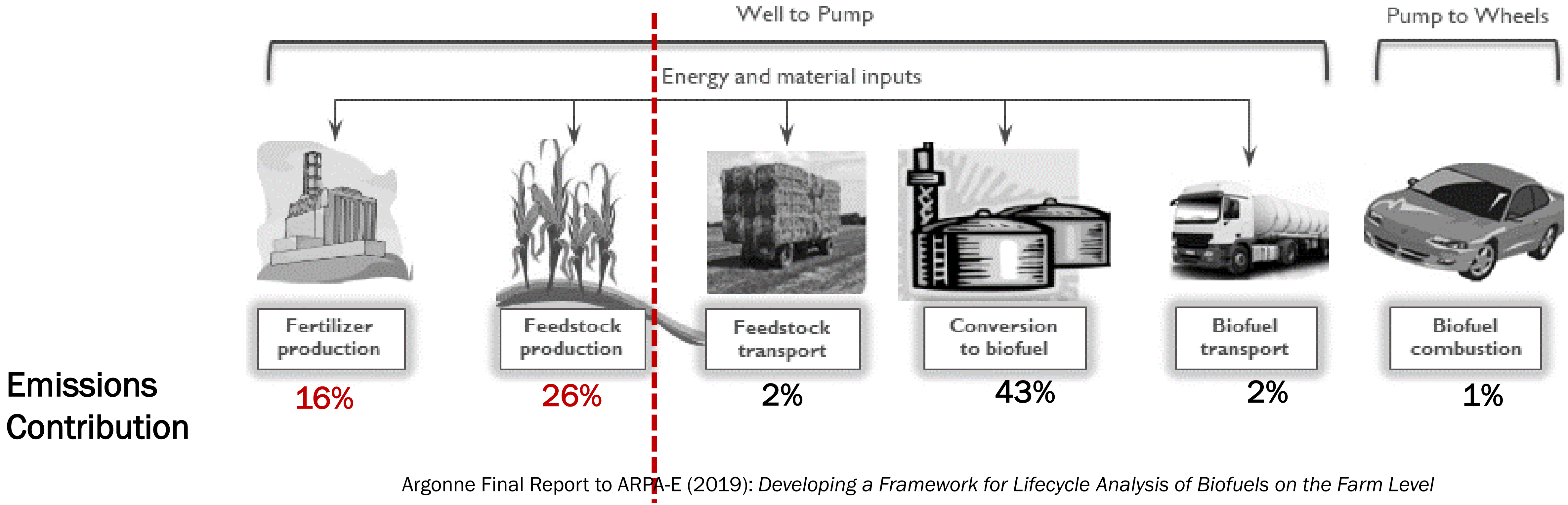


III. Decarbonize Communities

Photo by iStock

Decarbonization of Agriculture:
>40% of biofuels emissions are due to feedstocks

- Agriculture activities serve as both sources and sinks for GHGs
- Decarbonizing transportation 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

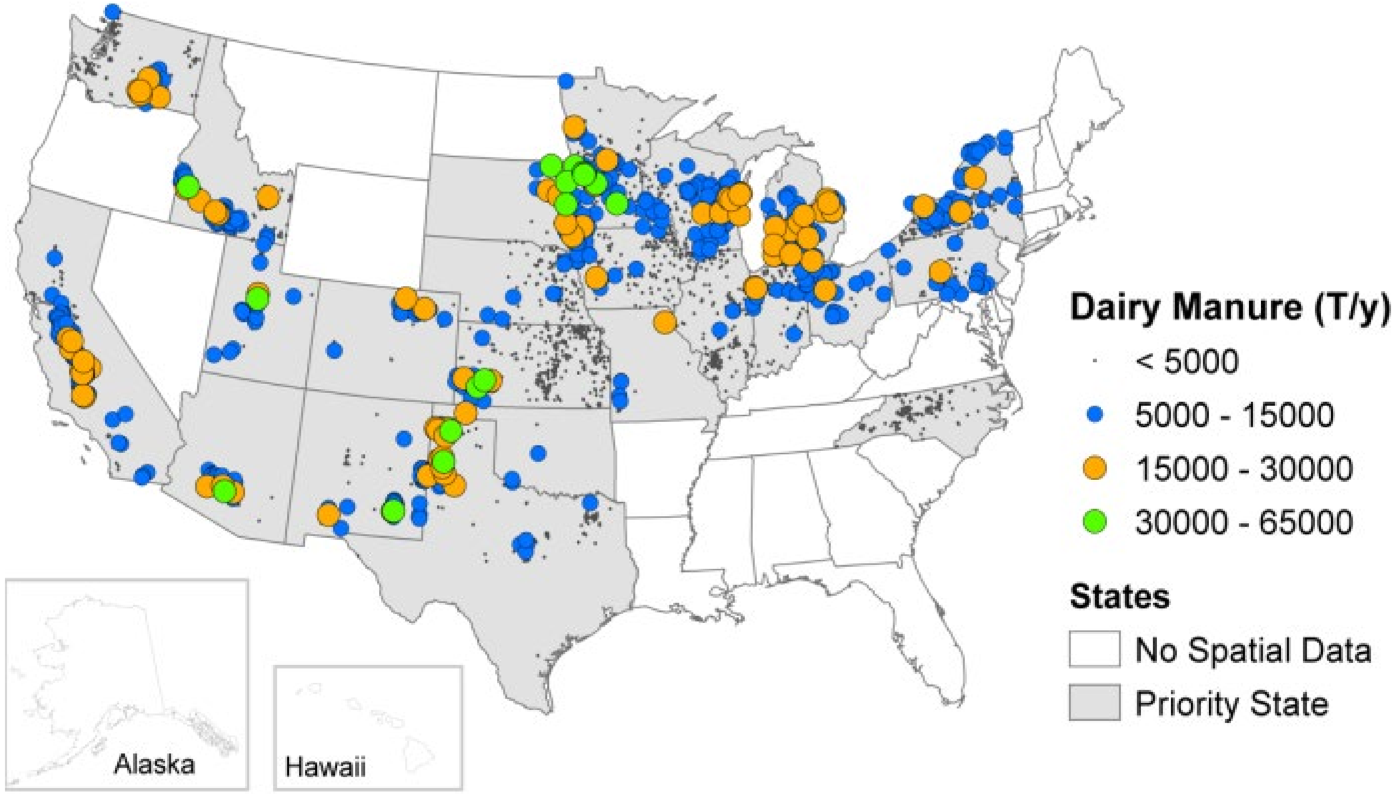


Argonne Final Report to ARPA-E (2019): *Developing a Framework for Lifecycle Analysis of Biofuels on the Farm Level*

Decarbonize Communities: Waste-to-Energy Technical Assistance Program

Objectives:

- Deploy the analyses that have been developed for a variety of energy/resource recovery strategies
- Provide data to local decision makers
- Foster local public-private partnerships.



Based on this example, consider:

- Audience/users
- Accessibility
- Utility (i.e. what questions do people need answered to make informed decisions?)
- Integrating local information into models
- Replicability

IV. BETO RD&D Focus and Activities

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BioEnergy Technologies Office National Lab Infrastructure

Agile BioFoundry

Robust platform for faster, cheaper biological engineering
$20M/year

ABPDU

Rapid bioprocess development
$~2.5 M/year

ChemCatBio
Chemical Catalysis for Bioenergy

Catalyst development
$~8 M/year

CCPC
Consortium for Computational Physics and Chemistry
U.S. DEPARTMENT OF ENERGY

Computational modeling for bio
$~2.5 M/year

fcic
FEEDSTOCK-CONVERSION INTERFACE CONSORTIUM
U.S. DEPARTMENT OF ENERGY

Understand biomass feedstock and process variability
$12M/year

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

Plastic redesign and upcycling
$10M/year

DISCOVR
DEVELOPMENT OF INTEGRATED SCREENING, CULTIVAR OPTIMIZATION, AND VERIFICATION RESEARCH

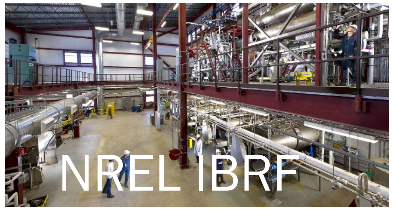
Outdoor algae test beds
~$2M/year

CO_2 Utilization Consortium

NEW CO_2 utilization
~$8M/year

BIOPROCESSING SEPARATIONS CONSORTIUM

Cost-effective bio separations
~$2M/year



Pilot plant with preprocessing and fermentation
~$2 M/year

Biomass National User Facility
~$2 M/year (variable)

*funding amounts are approximate & dependent on appropriations

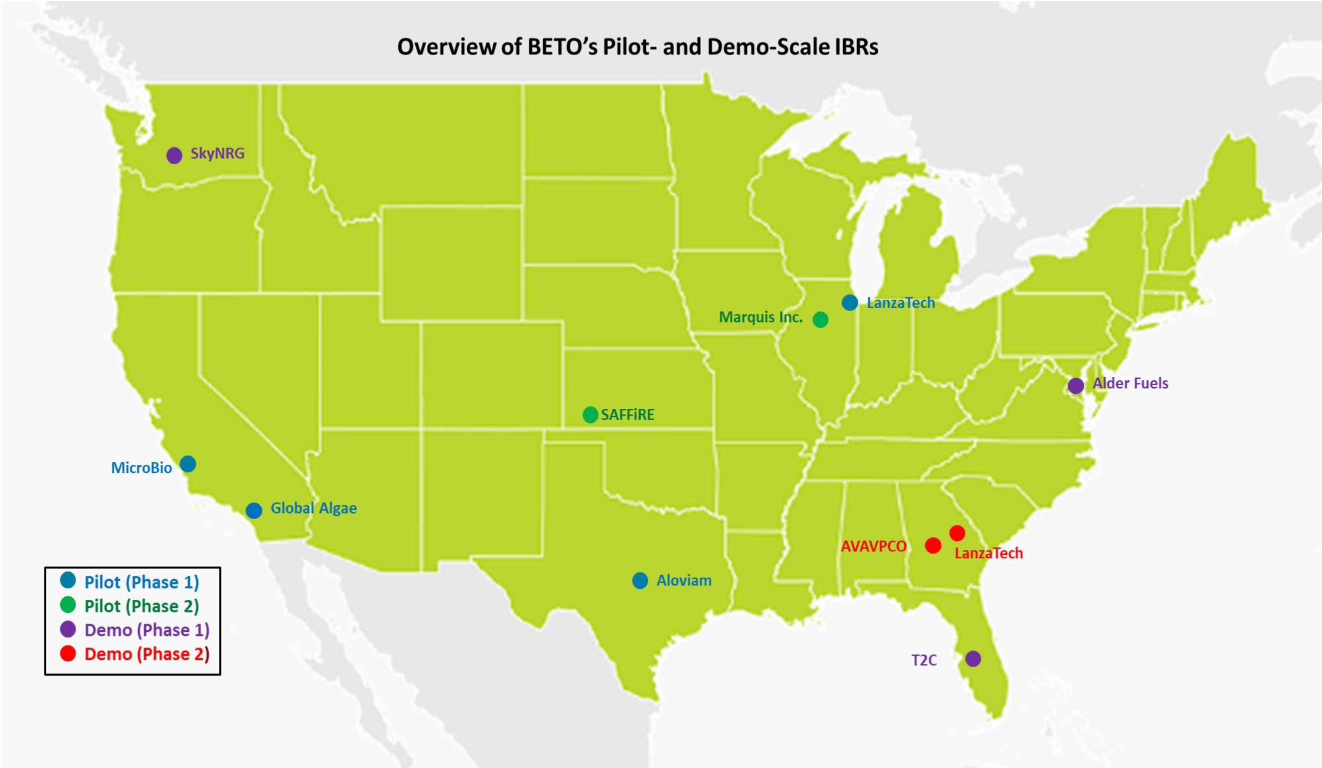
BETO's Scale Up Approach

Lower the risk of scaling technologies from Bench to Demonstration

Pre-pilot (20% cost share)
- Scale up key process steps from lab scale unit operation(s) to industrially-relevant piece(s) of equipment
- TRL 3-4 -> TRL 5
- $2,000,000 - $4,000,000 per award

Pilot (50% cost share)
- 20,000 gallons per year for aviation, marine, or heavy-duty applications
- TRL 5 -> TRL 6
- Phased - $3,000,000 for design -> $15,000,000 for construction and operation

Demonstration (50% cost share)
- 1,000,000 gallons per year for aviation, marine, or heavy-duty applications
- TRL 6 -> TRL 7-8
- Phased - $3,000,000 for design -> $97,000,000 for construction and operation



Pilot and Demo Distributions

Feedstock	Count
Woody	3
Stover	1
Algae	1
Wet Waste	2
Biogas/RNG	2
CO_2	1
Ethanol	1

Technology	Count
Alcohol to Jet*	6
Fischer-Tropsch	1
Pyrolysis / Hydrotreating	2
Gasification	1
Biochemical Conversion	4
Hydrothermal Liquifaction	2
Power to Liquids	1

Scale	Count
Pilot Phase 1	4
Pilot Phase 2	2
Demo Phase 1	3
Demo Phase 2	2

Sustainable Aviation Fuel | **Renewable Diesel** | **E-Fuels**

LanzaJet
LanzaTech
SAFFiRE RENEWABLES
AVAPCO
SkyNRG
ALDER FUELS
TRASH 2 CASH
GLOBAL ALGAE
μBIO MicroBio Engineering
Aloviam, Inc.
MARQUIS ENERGY

* Also counts projects using other conversion technologies to get to Ethanol

Success Story: From Strain Development to Commercial Operation

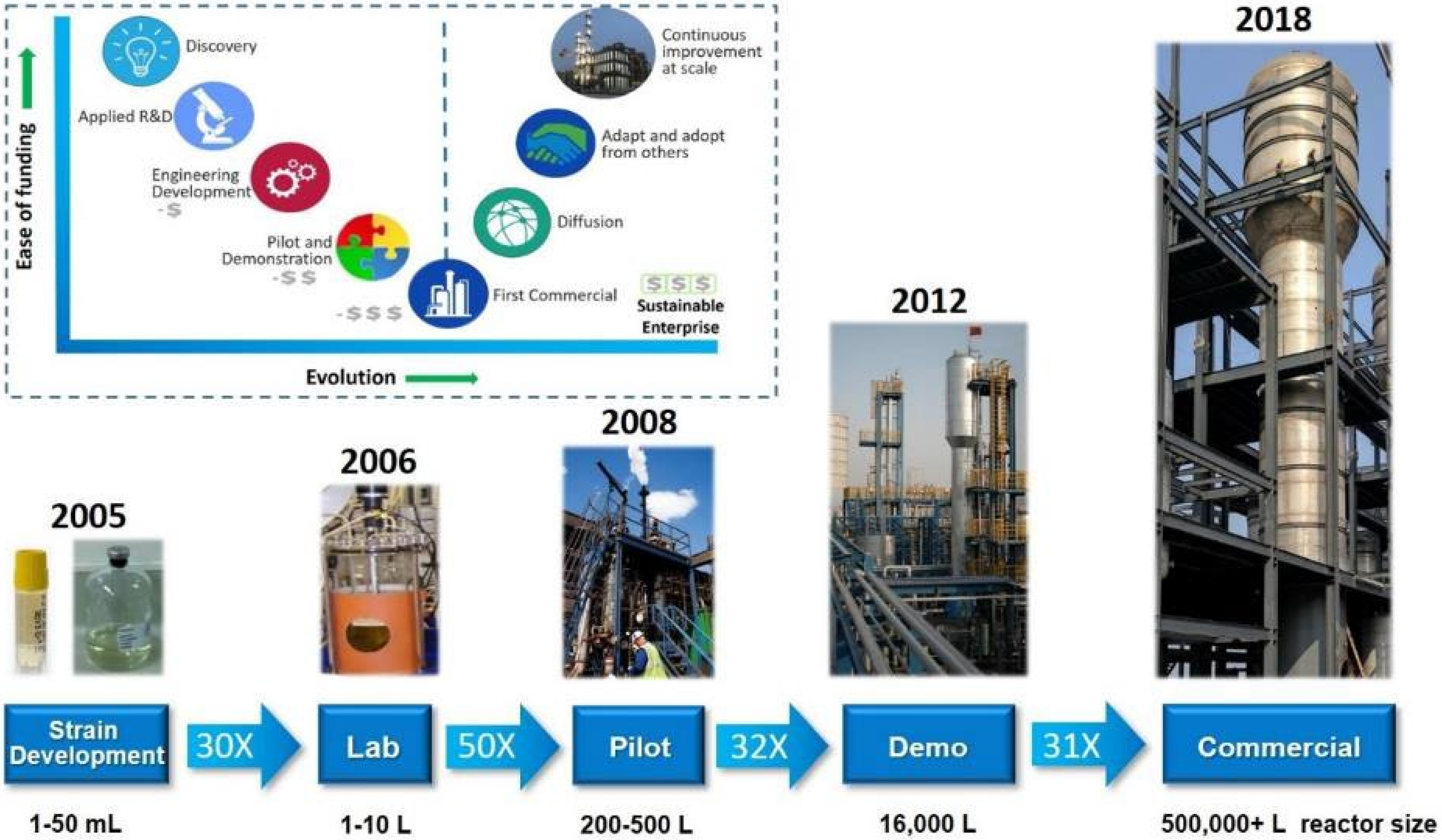


Image courtesy of LanzaTech

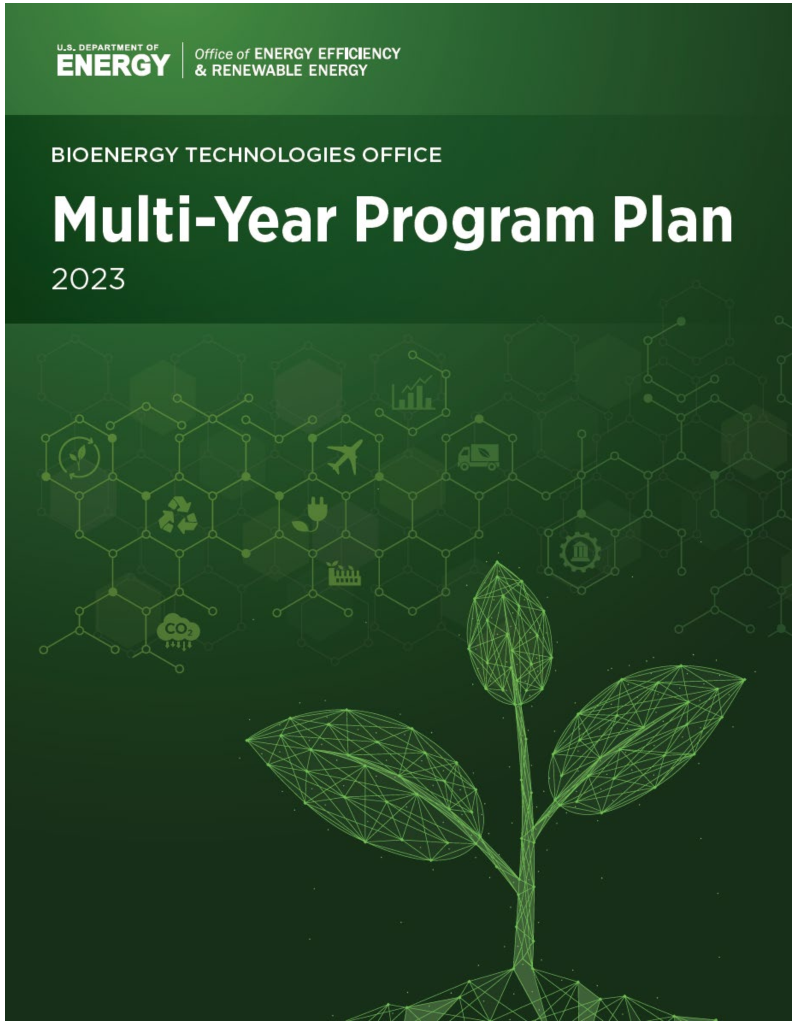
V. Charting Pathways to Produce Intermediate – a U.S. Bioeconomy Need

Photo by iStock

Multi-Year Program Plan 2023

MYPP's Performance Goal

"Enable delivery, preprocessing, and deconstruction of sufficient volumes of biomass and waste feedstocks to biofuel <u>intermediates</u> that can meet industry-relevant cost and performance requirements, with a focus on sustainable aviation fuels (SAF) capable of >70% reduction in GHG emissions relative to petroleum."



SAF Grand Challenge Goals & Biomass Resources

2023 Billion-Ton Report

Potential Biomass Resources are abundant, diverse and widely distributed

	Near-term	**Mature-market low**
Currently used for energy and coproducts	342	342
Waste and byproducts (including FOG)	179	217
Forest Resources	30	63
Agricultural Resources	140	510
Grand Total	**691**	**1131**

BETO Goals

<u>3 billion gallons/year</u> of SAF by 2030

<u>35 billion gallons/year</u> of SAF by 2050

What we know – Quantity and Quality Barriers

- Feedstock quality is a barrier - limits the expansion of the biorefining industry
  - Stability – Feedstock needs to be chemically, physically, and thermally stable
  - Consistency in quality – Biorefineries cannot deal with variable quality
  - Ash content – High ash content is a detriment to many technologies
  - Moisture content
  - Energy content
  - Density
  - Flowability



What we know – Quantity and Quality Barriers

- Feedstock quantity at acceptable price and hauling CI (sourcing radius) is a barrier – this barrier limits the size of biorefineries, which in turn affects its viability
- Feedstock supply should be decoupled from their conversion in biorefineries
  - Various conversion technologies require various feedstock qualities
  - Biorefineries should not be at the mercy of the variances in feedstock qualities
  - Several depots can feed a single biorefinery, so the decoupling also helps with the barrier of affordable quantity

Benefits of Converting Biomass into Intermediate Commodities

- **Start with various renewable resources:**
  - Forestry materials,
  - Purpose grown crops,
  - Dry municipal solid waste (MSW)
  - Wet waste such as sludges
  - Wet biomass such as algae
- **Commoditize to solid or liquid intermediates to accelerate scaleup and deployment by:**
  - Enabling specialization of supply chain participants,
  - Reducing risk,
  - Reducing costs, and
  - Increasing diversity of feedstock,
  - Increasing availability of large volumes
- **Commodities should be**
  - Uniformly graded
  - Properly characterized
  - Chemically, physically, and thermally stable
  - Suitable for being safely shipped to central conversion locations

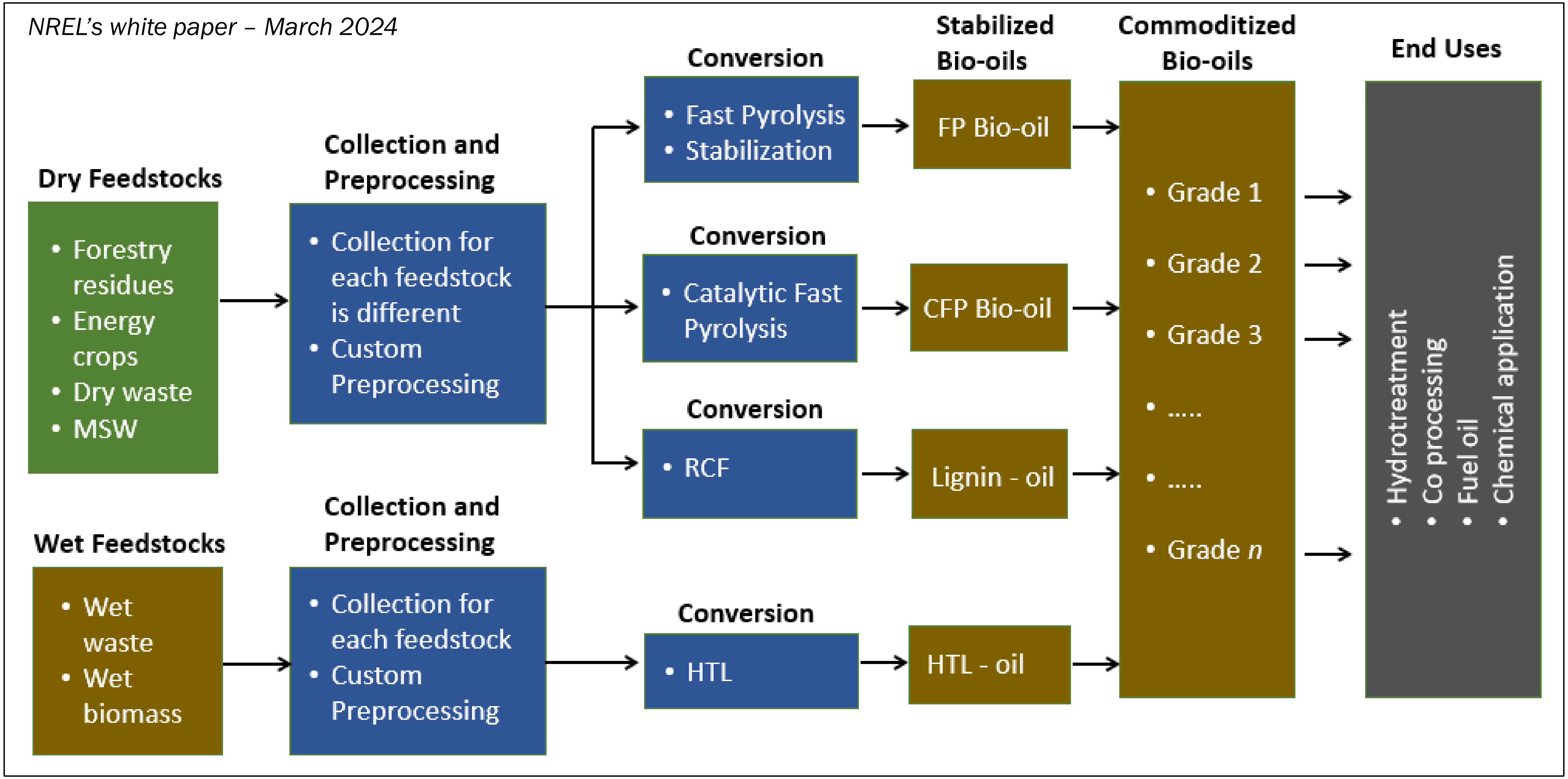
Pathways to convert biomass to intermediates

- Including but not limited to:
  - Biological pathways
  - Biochemical pathways
  - Thermochemical pathways
  - Hybrid pathways

Pathways to convert biomass to intermediates

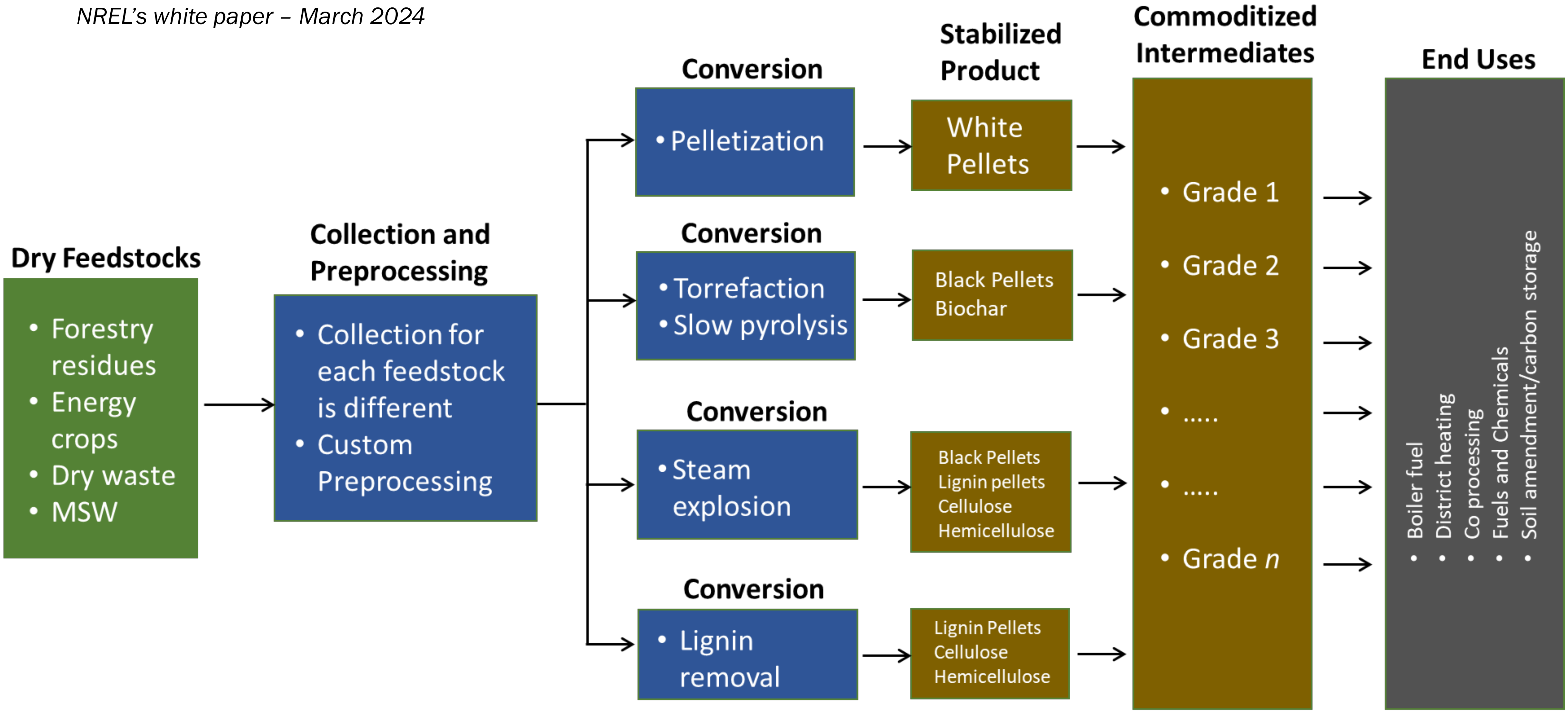
- Including but not limited to:
  - Biological pathways
  - Biochemical pathways
  - **Thermochemical pathways**
  - Hybrid pathways

Pathways for commoditized liquid intermediates for diverse applications



Pathways for commoditized solid intermediates for diverse applications

NREL's white paper – March 2024



Key Takeaways

- Biomass can play a significant role in decarbonizing several sectors of the economy.
- Biomass can create good jobs, economic opportunities, and environmental benefits for all states and regions in the U.S.
- Near-term deployment is driven by strong market pull.
- Continued investments in technology R&D and scale-up demonstration are needed to ensure access to all feedstocks in all regions and meet decarbonization goals
- Strong sustained policies are necessary to accelerate investments.

Thank You!

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Questions for the BETO team?

General email: eere_bioenergy@ee.doe.gov

Learn more about BETO: energy.gov/bioenergy