



**Chemical Conversion via  
Modular Manufacturing  
December 2, 2015**

**Bioenergy Technologies Office  
(BETO)**

# Outline

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- I. Overview
- II. Conversion Activities
- III. New Areas of Interest

# Office of Energy Efficiency and Renewable Energy

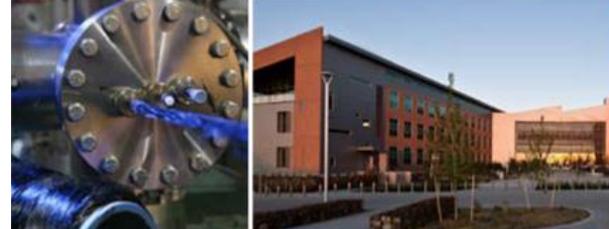
## Sustainable TRANSPORTATION



## Renewable ELECTRICITY GENERATION



## Energy Saving HOMES, BUILDINGS, & MANUFACTURING



# Mission-Critical Support OPERATIONS

# The Challenge and the Opportunity

## THE CHALLENGE

- More than **\$1 Billion** is spent every three days on U.S. crude oil imports
- Transportation accounts for **2/3<sup>rds</sup>** of petroleum consumption and **26%** of GHG emissions in the U.S.



## THE OPPORTUNITY

- More than **1 Billion tons** of biomass could be sustainably produced in the U.S.
- Biomass could displace 30% of U.S. petroleum use by 2030 and reduce annual CO<sub>2</sub>e by 550 million tons, or 10% of U.S. energy emissions

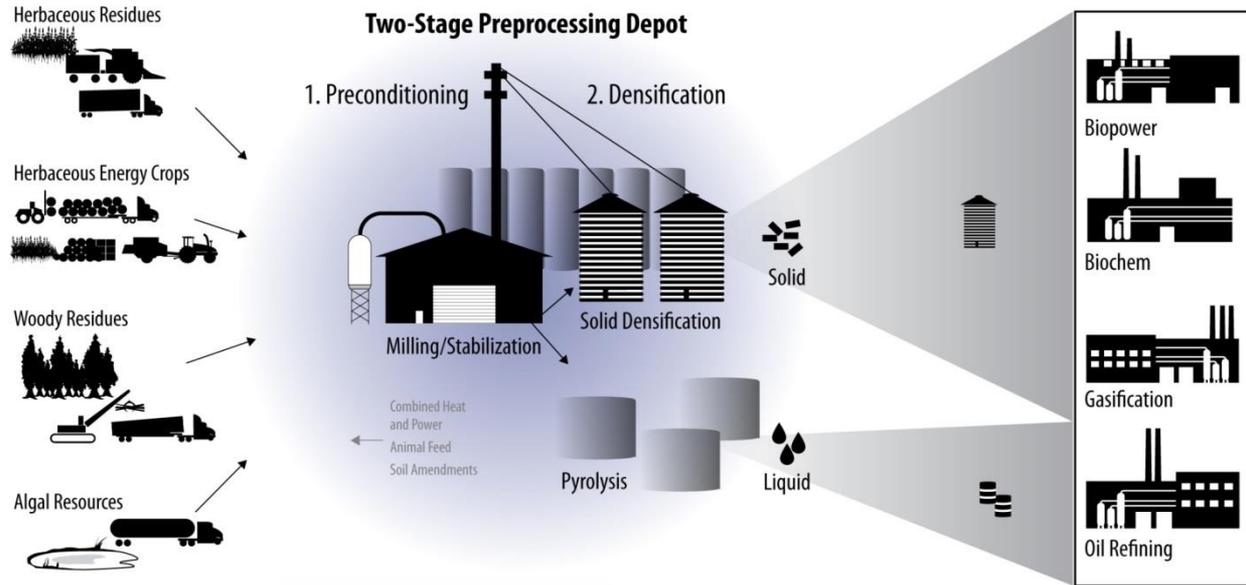


*America's biomass resources can help mitigate petroleum dependence*

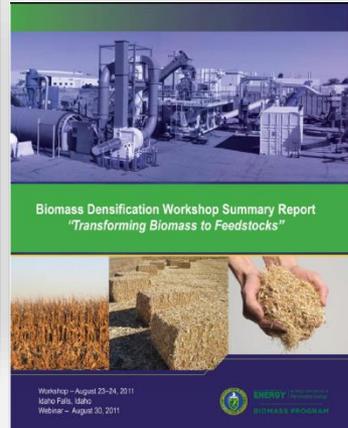
# Advanced Supply System Design

**Objective:** Transform raw Biomass into high-density, stable, commodity feedstocks:

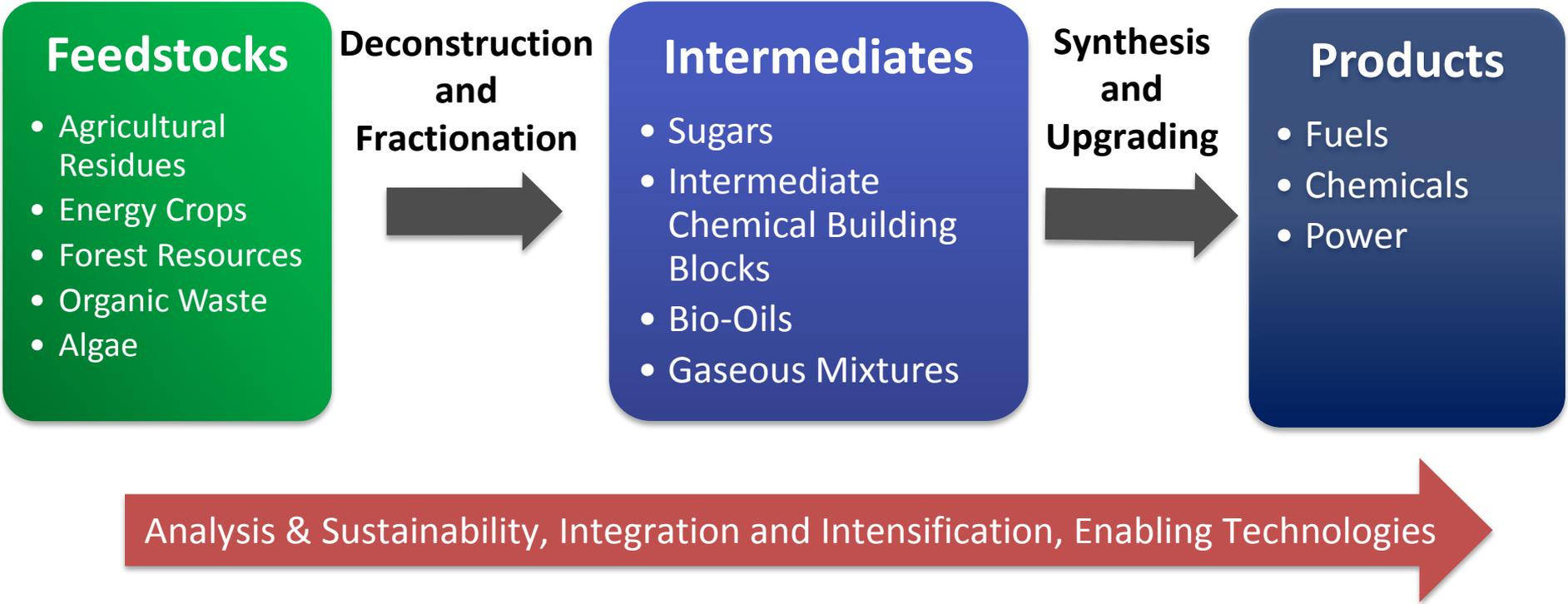
- Actively manage feedstock variability and supply uncertainty
- Feedstock specifications and conversion performance drive logistics and preprocessing
- Advanced preprocessing accesses low-grade and diffuse resources (i.e., use any and all available resources)



**Approach:** Advanced preprocessing and formulation of multiple raw biomass resources into least cost/performance-based feedstocks



# Overview of Conversion R&D

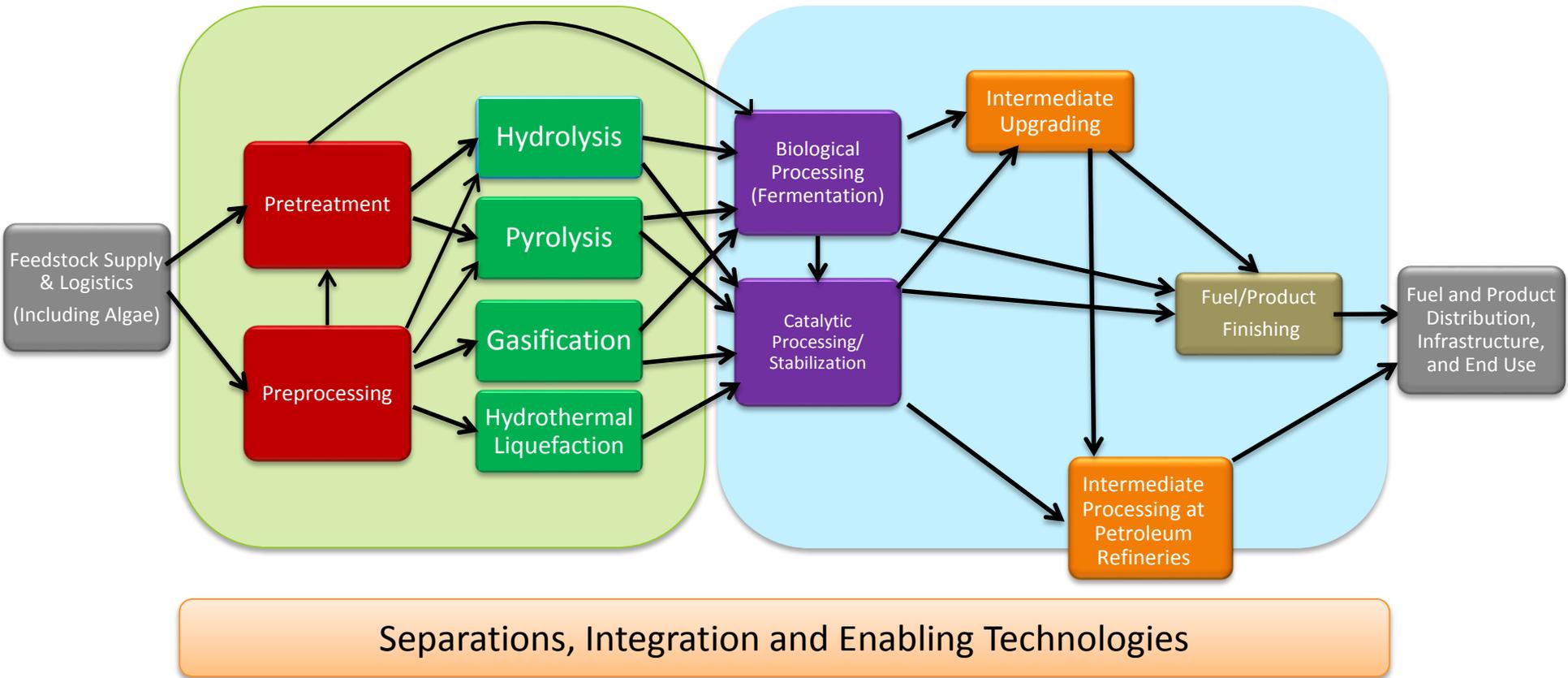


**Strategic Goal:** Develop commercially viable technologies for converting biomass feedstocks via biological and chemical routes into energy-dense, fungible, finished liquid transportation fuels such as renewable gasoline, diesel, and jet fuel, as well as bioproducts or chemical intermediates and biopower.

# Routes to Convert Biomass

## Deconstruction and Fractionation

## Synthesis and Upgrading



# BETO New Areas of Interest

## 1. Distillates (diesel and jet fuel)

- Address the non-light duty market by expanding collaborations into the aviation, marine, rail, trucking fields.
- Includes the need for production of bio-derived jet fuel in sufficient quantities to enable testing and certification of new fuels via the ASTM process.

## 2. Bioproducts

- Continuing to look into bio-products as long as they enable biofuels.
- Includes both the development and testing of bio-products (including animal feed and fish feed) from algae.

## 3. Natural Gas and Biogas

- The potential to co-utilize natural gas and biogas to produce fuels and chemicals via the gas/biomass to liquids (GBTL) processes.
- The development of distributed scale GBTL units that are skid mounted and mobile to utilize flared natural gas and bio-gas resources.

## 4. Infrastructure Needs

- Additional investments in infrastructure (rail, ports, barge, dams, inland waterways) to move biofuels (and other commodities) efficiently into market.

# What are Bioproducts?

- The US produces 15% of global chemicals and chemicals comprise 12% of all US exports.
- The US produces: ethylene, propylene, polyethylene, butadiene, butanol, polystyrene, EO, MEG.
- These chemicals are converted to: plastics, cosmetics, pharmaceuticals, detergents, packaging, clothing, car parts, fibers.

**C&EN**  
CHEMICAL & ENGINEERING NEWS

## Renewable Products In Use

Hexamethylenediamine

1,4-Butanediol

Ethylene glycol

Butadiene

Succinic acid

1,3 Propanediol

Adipic acid

Hydroxypropionic acid

MADE WITH thinglink. SIGN UP!

**INVISIBLE CHANGES**  
There are many ways for biobased materials to get into consumer products. Hover over the icons in the image above to learn more.

Credit: Ty Finocchiaro / Yang Ku / C&EN

Bomgardner Chemical & Engineering News. 92 (43) 10-14. Oct 27, 2014

# Bioenergy Technologies Office - Manufacturing Activities

## **Competitiveness Analysis (FY14-FY16)**

- International competitiveness for fuels and products manufacturing (Bloomberg).

## **Renewable Carbon Fiber FOA (Ongoing projects)**

- Technologies to enable manufacture of bio-derived acrylonitrile.

## **Lignin Valorization (Ongoing projects – NREL & Others)**

- Convergent strategies for funneling lignin to intermediates & Refinery Integration.

## **Biochemical Upgrading FOA (selections to start FY15)**

- NREL Muconic acid (platform intermediate) from biogas.
- Natureworks lactic acid from biogas.

## **Targeted Algal Biofuels and Bioproducts FOA (FY14-FY15)**

## **MEGA-BIO (FY16 FOA)**

- Enable fuels using products.

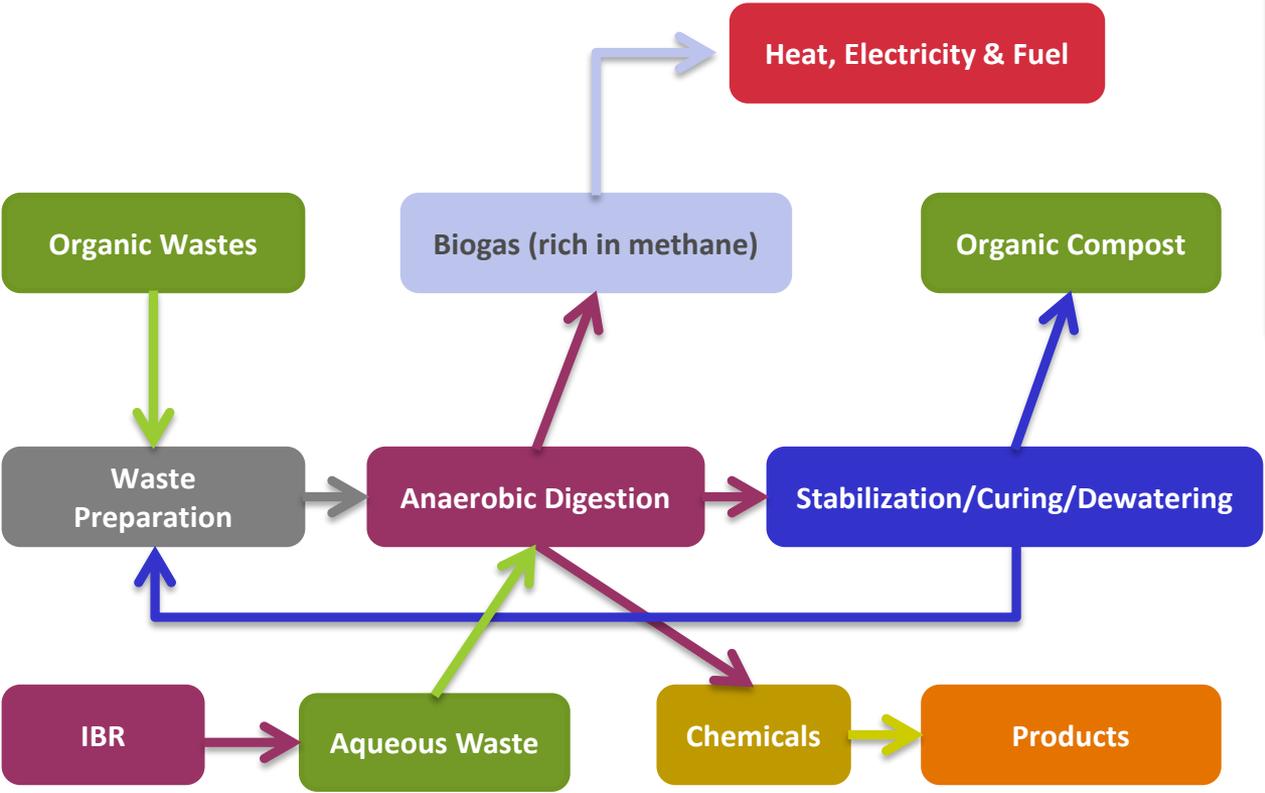
## **Demonstration and Market Transformation FOA (FY16)**

- Products that enable fuels at pilot and demonstration scale

# BETO's Waste-to-Energy (WTE) Efforts

There is a significant near-term market entry opportunity to deploy WTE technologies in the U.S., specifically with regard to anaerobic digestion at landfills to recycle organic waste biomass into renewable energy, thereby enabling a national network of distributed power and biofuel production sites.

## Waste-to-Energy Cycle



- Waste streams that could be considered for use include:**
- Municipal solid waste
  - Landfill gas
  - Waste streams from waste water treatment plants (WWTPs)
  - Bio-solids (from thermochemical or biochemical biofuel pathways)

The [DOE Loan Guarantee Office](#) released a Renewable Energy and Energy Efficiency Solicitation for a public comment period. The solicitation is expected to provide as much as \$2.5 billion in loan guarantees for commercial financing of technologies that avoid, reduce, or sequester GHG emissions. "Waste-to-Energy" is included in the list of eligible project types to be considered.

# Water Resource Recovery

## Energy Efficiency and Resource Recovery

Facilities will use energy-efficient operations to recover water, energy, and nutrients as well as to produce clean water and other products.



## Integrated Production

Facilities will produce clean water, energy, other water grades, and a slate of products for industry, agriculture, etc.



## Smart Systems

Sensors, software, and advanced devices monitor volume and content of incoming streams, inform plant operations, track performance, and verify output safety and quality.



### Outcomes

- Healthy environment
- Renewable energy supply
- Reduced carbon emissions
- Economic growth
- Vibrant and green communities



## Engaged & Informed Communities

Officials, industry, and the public will manage demand and waste better, support resource recovery goals, and contribute to integrated solutions for water, energy, and food supply.

# Project Partners

**Laboratories**

- Berkeley Lab (Lawrence Berkeley National Laboratory)
- INEL (Idaho National Laboratory)
- Oak Ridge National Laboratory
- Brookhaven National Laboratory
- Sandia National Laboratories
- Los Alamos National Laboratory (EST. 1943)
- Argonne National Laboratory
- Pacific Northwest National Laboratory
- NREL (National Renewable Energy Laboratory)
- Department of Energy, United States of America

**Universities**

- Cornell University
- HSU (Humboldt State University)
- Iowa State University
- NM State University
- Arizona State University
- OSU (Oregon State University)
- North Carolina A&T State University
- Colorado State University
- University of California, San Diego
- University of Texas (UT)
- University of Michigan (M)
- Texas A&M AgriLife Research
- University of Wisconsin (W)
- University of Arizona (A)
- University of South Carolina (S)
- University of Oklahoma (OU)
- University of Illinois (I)
- University of Florida (F)
- University of Minnesota (M)
- University of Texas at Austin (UT)
- University of Wisconsin-Madison (W)
- University of California, Berkeley (UCB)
- University of California, Davis (UCD)
- University of California, Santa Barbara (UCSB)
- University of California, San Francisco (UCSF)
- University of California, Irvine (UCI)
- University of California, Los Angeles (UCLA)
- University of California, Merced (UCM)
- University of California, Riverside (UCR)
- University of California, Santa Cruz (UCSC)
- University of California, San Diego (UCSD)
- University of California, San Jose (UCSJ)
- University of California, Santa Barbara (UCSB)
- University of California, Santa Cruz (UCSC)
- University of California, San Diego (UCSD)
- University of California, San Jose (UCSJ)

**Industry**

- POET Advanced Biofuels
- DSM
- DUPONT
- Myriant (Chemistry Refined...Naturally)
- J. Craig Venter Institute
- UOP (A Honeywell Company)
- AMERICAN PROCESS
- ceramatec (Advanced Materials & Electrochemical Technologies)
- genomatica (sustainable chemicals)
- Metabolix
- FRONTLINE BIOENERGY, LLC
- Aprovecho Research Center (Advanced Studies in Appropriate Technology Laboratory)
- SOUTHERN RESEARCH INSTITUTE
- ABENGOA
- solazyme
- VIRENT
- ADM
- TENERA
- novozymes
- POET BioLite
- CORRIM (Cooperation in Research, Production, Technical Support)
- Avelo Bioenergy
- HAWAII BioEnergy
- Sapphire Energy
- ADM
- gti
- Battelle
- ZeaChem
- LYGOS
- bioprocessalgae (Using Carbon)
- LanzaTech
- RAE (RENEWABLE ALGAL ENERGY)
- cellana (algae-based products for a sustainable future)
- GRACE
- ALGENOL BIOFUELS
- ICM
- mbi (De-Risking and Scale-Up of Bio-Based Technologies)
- HALDOR TOPSOE

**BETO works with partners in industry, universities, and the National Labs**

# Appendix

# Bioenergy Technologies Office



Accelerate the commercialization of advanced biofuels and bioproducts through RD&D of new technologies supported by public-private partnerships

Develop technologies to enable the sustainable, nationwide production of biofuels compatible with today's transportation infrastructure

Validate at least one pathway for \$3/GGE\* hydrocarbon biofuel with  $\geq 50\%$  reduction in GHG emissions relative to petroleum by 2017

\*Mature modeled price at pilot scale.

*BETO reduces risks and costs to commercialization through RD&D*

# BETO's Core Focus Areas

## Program Portfolio Management

- Planning
- Systems-Level Analysis
- Performance Validation and Assessment
- MYPP
- Peer Review
- Merit Review
- Quarterly Portfolio Review
- Competitive
- Non-competitive
- Lab Capabilities Matrix

## Research, Development, Demonstration, & Market Transformation

### Feedstock Supply & Logistics R&D

- Terrestrial
- Algae
- Product Logistics Preprocessing



### Conversion R&D

- Biochemical
- Thermochemical
- Deconstruction
- Biointermediate
- Upgrading



### Demonstration & Market Transformation

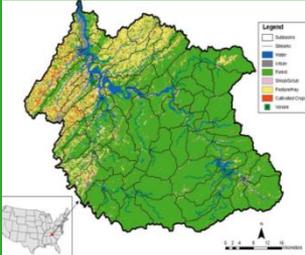
- Integrated Biorefineries
- Biofuels Distribution Infrastructure



## Cross Cutting

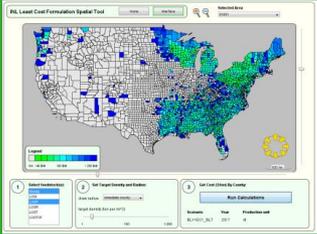
### Sustainability

- Sustainability Analysis
- Sustainable System Design



### Strategic Analysis

- Technology and Resource Assessment
- Market and Impact Analysis
- Model Development & Data compilation



### Strategic Communications

- New Communications Vehicles & Outlets
- Awareness and Support of Office
- Benefits of Bioenergy/Bioproducts



# Bioenergy Administration Goals

**National Energy Goals & Climate Action Plan**

**Net Oil Imports**  
↓ **50% by 2020**

**GHG Emissions**  
↓ **26-28% by 2025**  
**>80% by 2050**

**BETO Performance Goal: Hydrocarbon Biofuel Production**

**\$3.00/GGE by 2017** ↓ **50% GHG reduction vs. petroleum fuel**

**BETO Performance Goal: Hydrocarbon Pathway Validation**

**Two Additional Pathways by 2022**      **Pilot or Demo Scale (>1 ton/day)**

*BETO's goals support the Presidential Initiatives on Energy*

# Program Achievements in FY15

- **Feedstocks Supply and Logistics**
  - Idaho National Laboratory (INL) successfully completed two State Of Technology (SOT) reports on herbaceous and woody energy crops. The SOT reports highlight progress towards meeting the 2017 goal of validating a supply and logistics system that is capable of delivering feedstocks to the conversion reactor throat at \$80/dry ton.
- **Advanced Algal Systems**
  - Establishment of CalPoly's Delhi Field Site (9,000 L system with continuous automated process controls and harvest equipment at Delhi, CA WWT facility for the ABY project).
- **Conversion Technologies:**
  - Reduce the modeled conversion cost contribution from \$4.09/gge to \$3.70/gge via fast pyrolysis for converting biomass to a hydrocarbon fuel blendstock in a mature commercial-scale plant.
  - Reduce modeled mature biochemical conversion cost from \$9/GGE to \$6.40/GGE of combined hydrocarbon fuel on a pathway to a \$3.17/gge conversion cost demonstrated in 2017 at the bench and pilot scale by improving co-product organisms, primary fermentation organisms for fatty acid production and reducing operating costs.
- **Demonstration and Market Transformation**
  - The Abengoa Bioenergy Biomass of Kansas (ABBK) biorefinery celebrated its grand opening. The facility is the third commercial-scale cellulosic ethanol biorefinery in the U.S. and has a capacity of 25 million gallons of cellulosic ethanol per year. The plant will produce cellulosic ethanol from non-edible corn stalks, stems, and leaves harvested within a 50-mile radius of the plant.
- **Analysis and Sustainability**
  - ANL released WATER 3.0 to enable in-depth analysis of water consumption for multiple biofuels pathways. NREL assessed applicable federal air quality regulations and estimates of seven criteria air pollutant emissions for the fast pyrolysis pathway.

# FY 2016 Priority Activities

- **Algae:** Pursue new research in advanced biology and carbon dioxide utilization to address yield, productivity, and integration of downstream logistics at the pre-pilot scale.
- **Conversion:** Select and complete preparation of at least two pathways for validation at integrated bench or pilot scale in FY 2017 of modeled mature \$3/gge gasoline/diesel blendstock price and progress toward FY 2022 price goals (\$3/gge).
- **Feedstock Supply:** Focus on feedstock supply and logistics technologies to help meet biomass feedstock price targets of \$80/Dry Matter Ton in 2017.
- **New Fuels and Vehicle Systems Optima:** Establishes a link early in the R&D cycle of both fuels and engines for a systems-based approach and to create optimized solutions for fuels and engines. Collaboration with Vehicles Technologies.
- **New Investments in the Integrated Production and Scale-Up of Drop-in Hydrocarbon Fuels:** New competitive awards (up to three pilot projects or one demonstration project) to scale-up integrated production systems of drop-in hydrocarbon biofuels to accelerate advanced biofuel manufacturing.
- **DPA:** Support the military-specification jet fuel in collaboration with DoD and USDA through the Defense Production Act.

# Defense Production Act (DPA) Initiative

In September 2014, 3 projects were selected under the DPA Initiative to build commercial biorefineries to produce:

- Drop-in fuels for military applications
- Domestic fuels from non-food biomass feedstocks
- Cost-competitive biofuels (w/o subsidies)



Company	Location	Feedstock	Capacity	Groundbreaking	Off-Take Agreements
	Gulf Coast	Fats and Greases	82.0 MM g/y	TBA	TBD
	McCarran, NV	MSW	10.0 MM g/y	Winter of 2015	 
	Lakeview, OR	Woody Biomass	12.0 MM g/y	TBA	

*Interagency initiative to produce more than 100 MM g/y of advanced biofuels*

# Sustainability Projects

## Climate Change and Air Quality



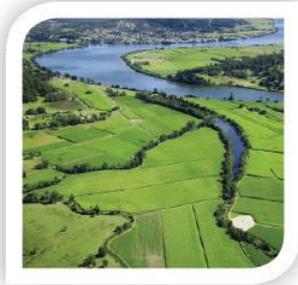
Analyzing biofuel pathways to quantify progress towards reducing [lifecycle greenhouse gases, regulated emissions, and fossil energy use](#).

## Soil Quality



[Developing strategies and tools](#) for producing biomass feedstocks while maintaining or enhancing soil quality.

## Land Use and Productivity



Advancing landscape design approaches that increase biomass production while maintaining or enhancing ecosystem services and food, feed, and fiber production.

## Water Quantity and Quality



Assessing the [water resource use and water quality](#) of bioenergy production, and investigating opportunities for bioenergy crops [to improve water quality](#).

## Biological Diversity



Investigating relationships between [bioenergy crops and biodiversity](#), and engaging with diverse experts to understand and promote practices that conserve wildlife and biodiversity.

Efforts also include evaluating [sustainability indicators](#) across the bioenergy supply chain, contributing to [global scientific dialogues](#) on bioenergy sustainability, and engaging with [international organizations](#) to understand and promote more sustainable outcomes.

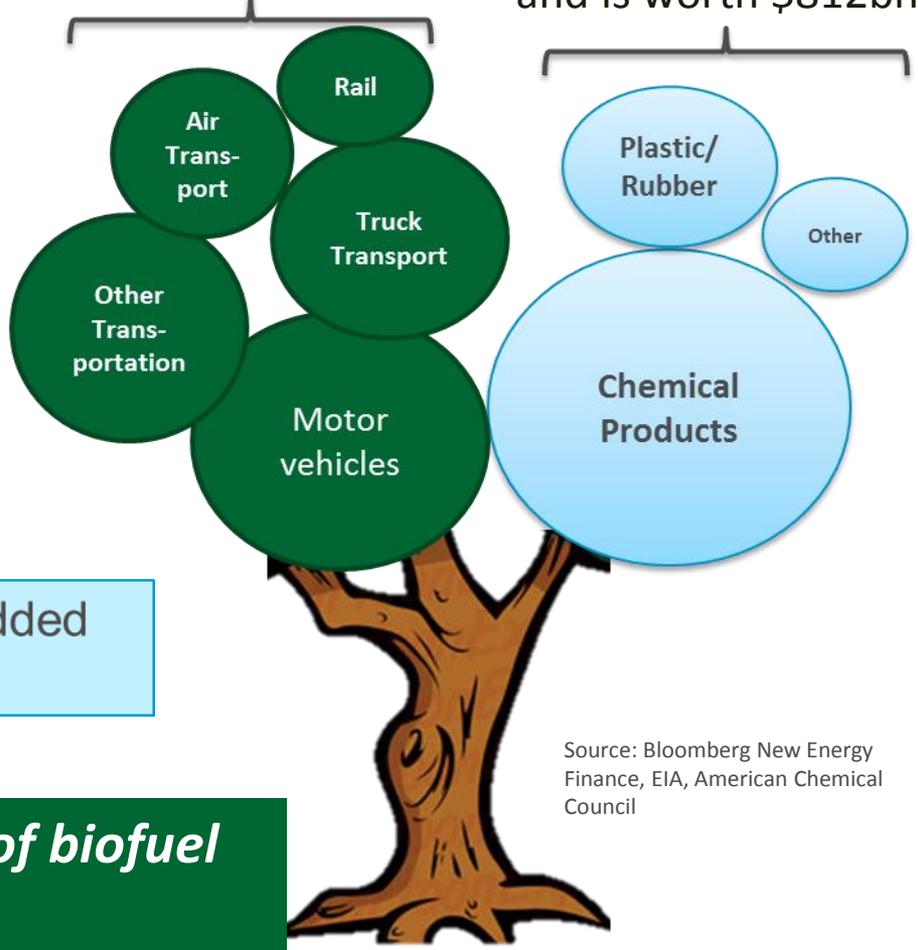
# Oil products in the US: Opportunity for Bioproducts in the Bioeconomy

- The US produces 15% of global chemicals and chemicals comprise 12% of all US exports.
- The US produces: ethylene, propylene, polyethylene, butadiene, butanol, polystyrene, EO, MEG
- These chemicals are converted to: plastics, cosmetics, pharmaceuticals, detergents, packaging, clothing, car parts

Bioproducts provide much higher value-added margins, relative to transportation fuels.

Fuel makes up 76% of the volume of US oil products and is worth \$935bn

Chemicals make up 16% of the volume of US oil products and is worth \$812bn



Source: Bloomberg New Energy Finance, EIA, American Chemical Council

***Bioproducts enhance the economics of biofuel production***

# What is the Bioeconomy?

“The biological sciences are adding value to a host of products and services, producing what some have labelled the “bioeconomy.” From a broad economic perspective, the bioeconomy refers to the set of economic activities relating to the invention, development, production and use of biological products and processes.”

*OECD: The Bioeconomy to 2030: Designing a Policy Agenda, 2009*

“A bioeconomy is one based on the use of research and innovation in the biological sciences to create economic activity and public benefit.”

*White House Bioeconomy Blueprint, 2012*

“The U.S. is a world leader in technology and agricultural prowess, which puts it in a powerful position to capitalize on the vast potential of bio-based alternatives to petrochemicals. The potential markets are huge, given the importance of petrochemicals in industrial economies.”

*Unleashing the Power of the Bio-economy, 2013*

**For the purpose of this presentation, the “bioeconomy” is defined “the global industrial transition of sustainably utilizing renewable aquatic and terrestrial biomass resources in energy, intermediate, and final products for economic, environmental, social, and national security benefits.”**

*--From 2014 Report: Why Biobased? Opportunities in the Emerging Bioeconomy: Why BioPreferred*

# Potential Impacts of a Billion Ton Bioeconomy

## A BILLION DRY TONS\* OF SUSTAINABLE BIOMASS

HAS THE POTENTIAL TO PRODUCE

**1.5 MILLION JOBS**  
and keep about  
**\$200 BILLION**  
dollars in the U.S.  
and contributes over  
**\$600 BILLION**

**100 BILLION\*\***  
kWh of electricity  
to power  
**7 MILLION**  
households. Plus  
**1450 TRILLION BTUs**  
of thermal energy.

**50 BILLION**  
gallons of biofuels  
displacing almost  
**26%**  
of all transportation  
fuels.

**45 BILLION POUNDS**  
of biobased  
chemicals and bio-  
products, replacing  
a significant portion  
of the chemical  
market.

**550 MILLION TONS**  
of CO<sub>2</sub>e  
reductions  
every year.



- ### STEPS TO BUILDING THE BIOECONOMY
- 1 Accelerate research & technology development
  - 2 Develop production, conversion and distribution infrastructure
  - 3 Deploy technology
  - 4 Create markets and delivery systems

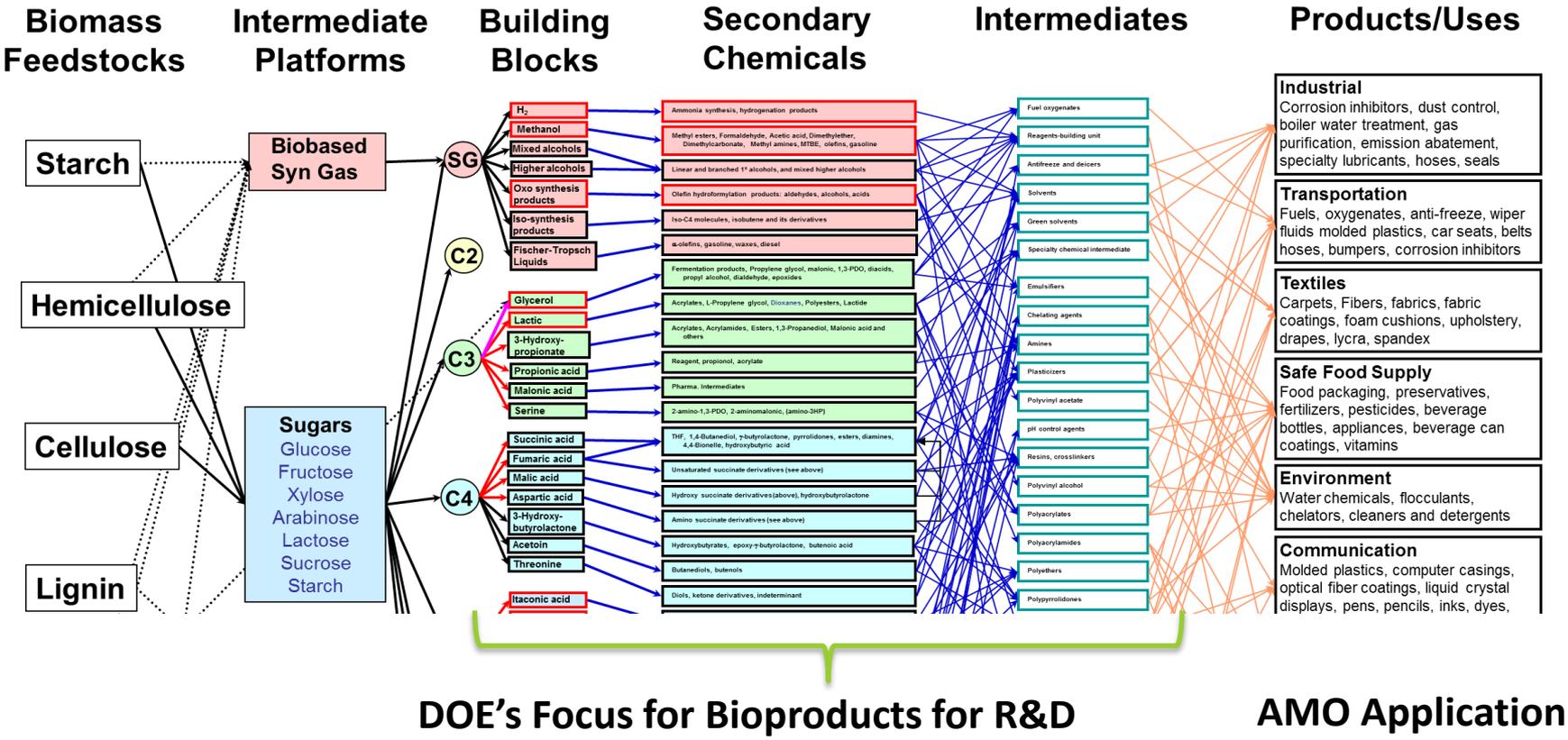
**Projections based on:**

- 2011 Billion Ton Study Report
- EIA 2015 AEO
- 2013 USDA Long-Term Forecast
- Various data sources

\*Estimates are based on a future usage of 1.3 billion dry tons.  
\*\*Include 27 billion kWh and 90 TBtu from livestock anaerobic digestion

**1 billion tons of biomass could be sustainably produced in the U.S.**

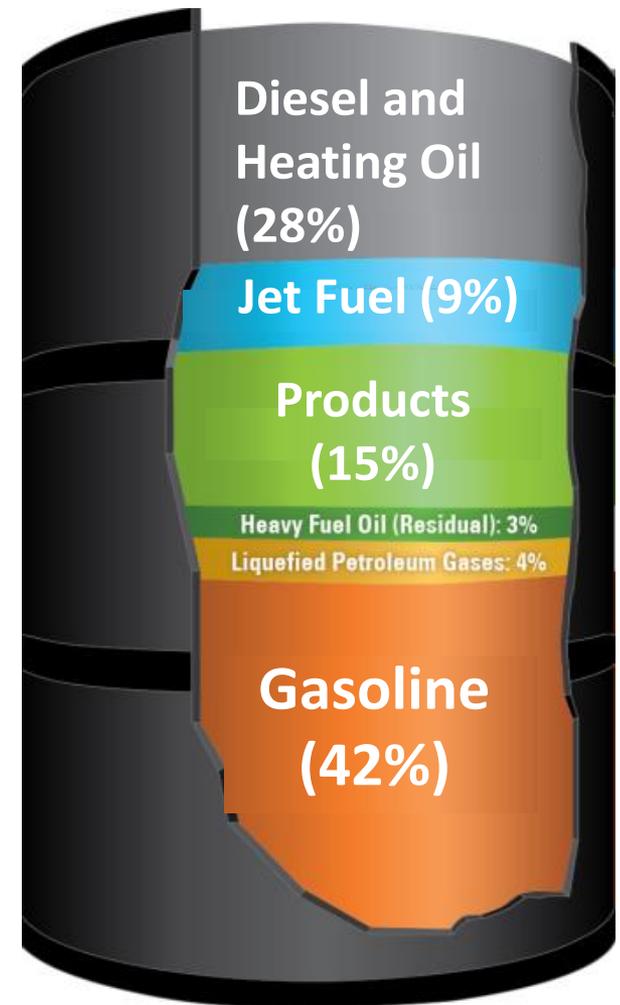
# Bioproducts to Enable Biofuels



- Innovative approaches for bioproducts:
  - Molecular replacements for petroleum derived chemicals
  - Performance replacements for petroleum derived chemicals
    - Infancy stage – play to the strength of the oxygenated polymers in biomass
  - Lignin and waste streams to value added products (X2 the cost of biofuels on a mass basis)

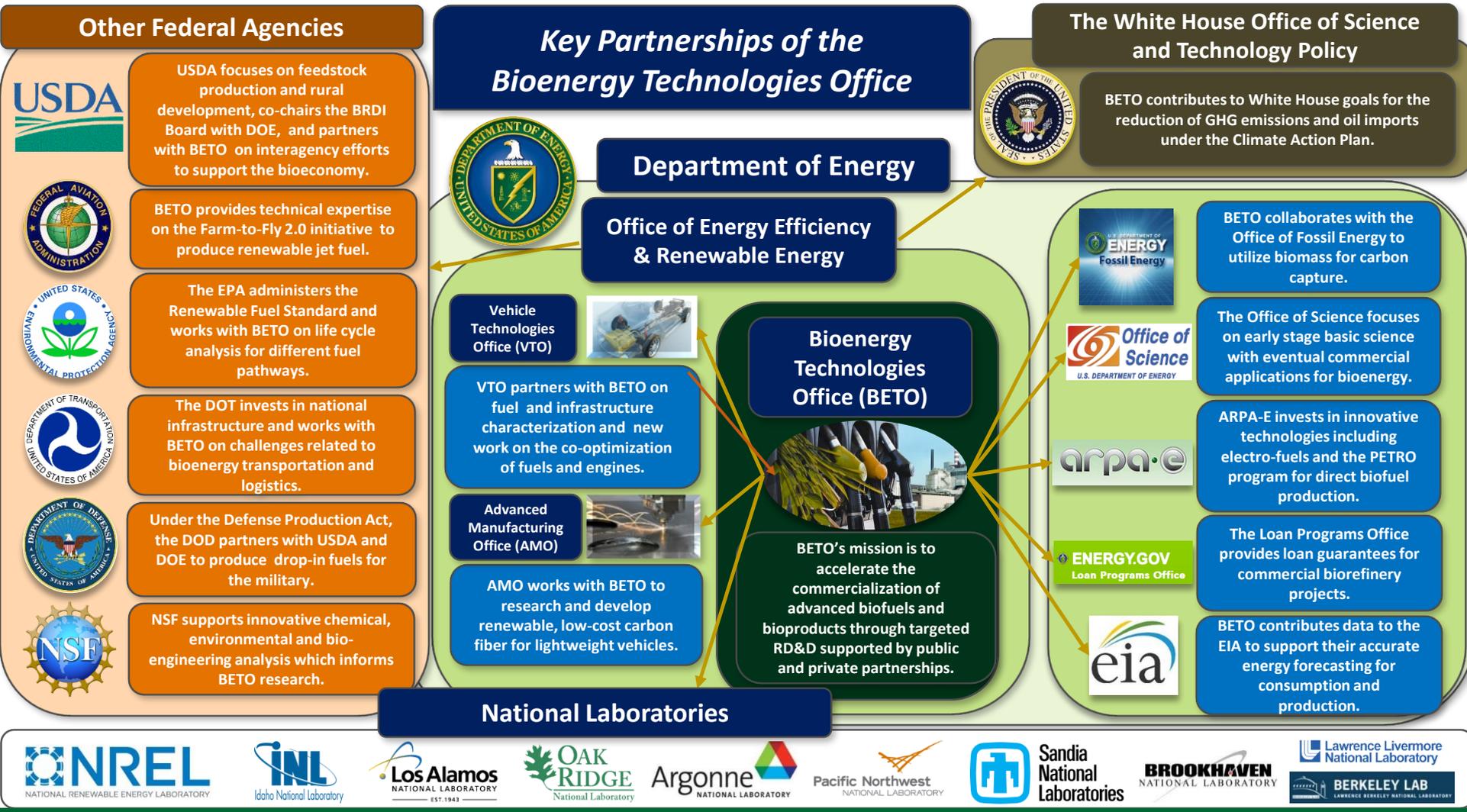
# Replacing the Whole Barrel

- Only ~40% of a barrel of crude oil is used to produce petroleum gasoline
- Reducing oil dependence requires replacing diesel, jet fuel, heavy distillates, and other products
- EERE successfully achieved modeled mature cost goals for cellulosic ethanol in 2012
- EERE shifted its R&D to focus on hydrocarbon “drop-in” biofuels, jet fuels, and bio-based products



***BETO is working to displace the entire barrel of petroleum crude***

# Inter-Agency Collaboration



*BETO partners with other DOE Offices, other Federal agencies, and the national labs to achieve U.S. goals on bioenergy*