



*Current Status of Biorefining in
USA*

October 23, 2017

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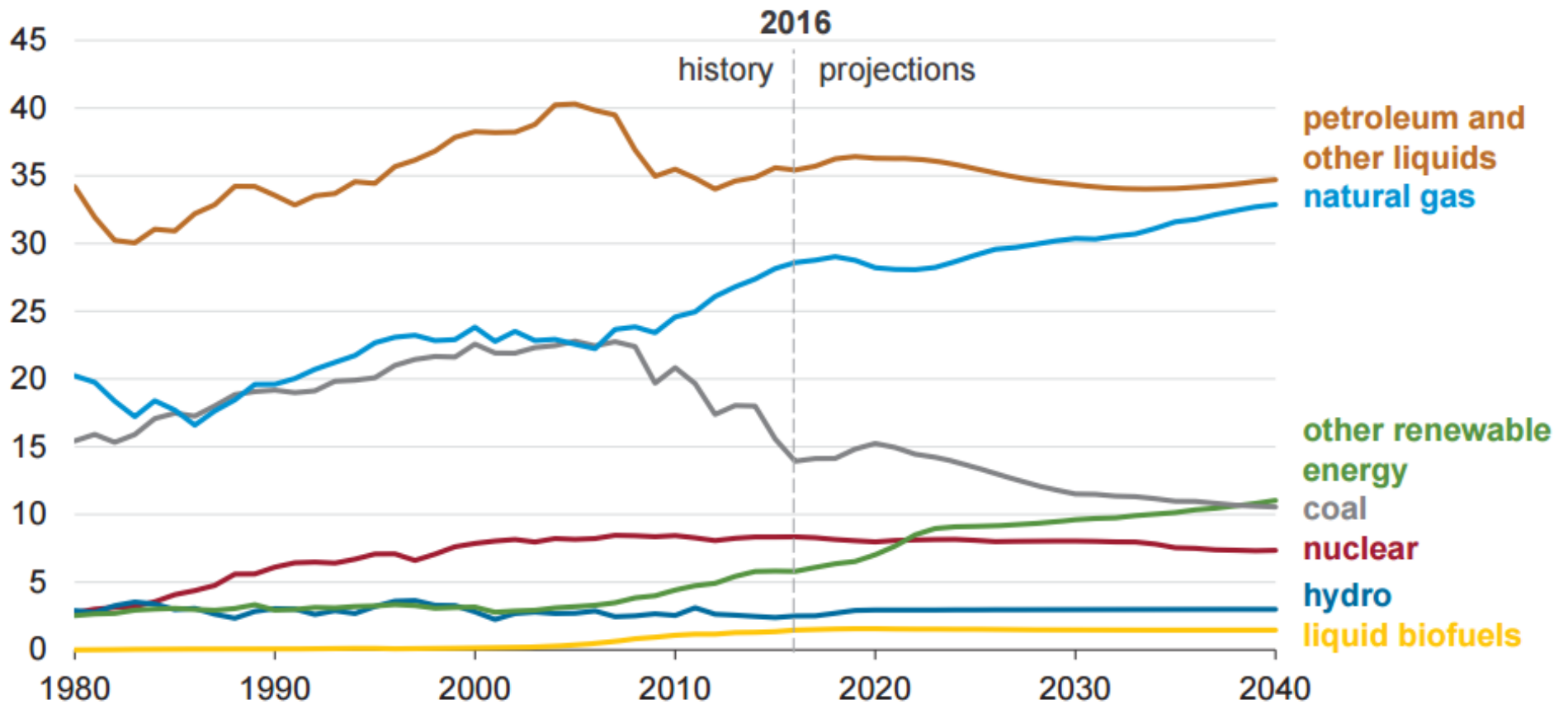
Outline

- U.S. Primary Energy Consumption
 - Biomass use for Energy and Non-Energetic Applications
- U.S Biorefining Status
 - Latest Activities in the Industry
 - New Biorefinery Demonstration and Pilot Projects
 - Research, Development, and Demonstration Successes
 - Outstanding Challenges
- Key Bioenergy Related Legislative, Regulatory, and Policy Efforts
- Major National Stakeholders and Partners Involved in Biorefining

U.S. Primary Energy Consumption: Past and Projected

Energy consumption (Reference case)
quadrillion British thermal units

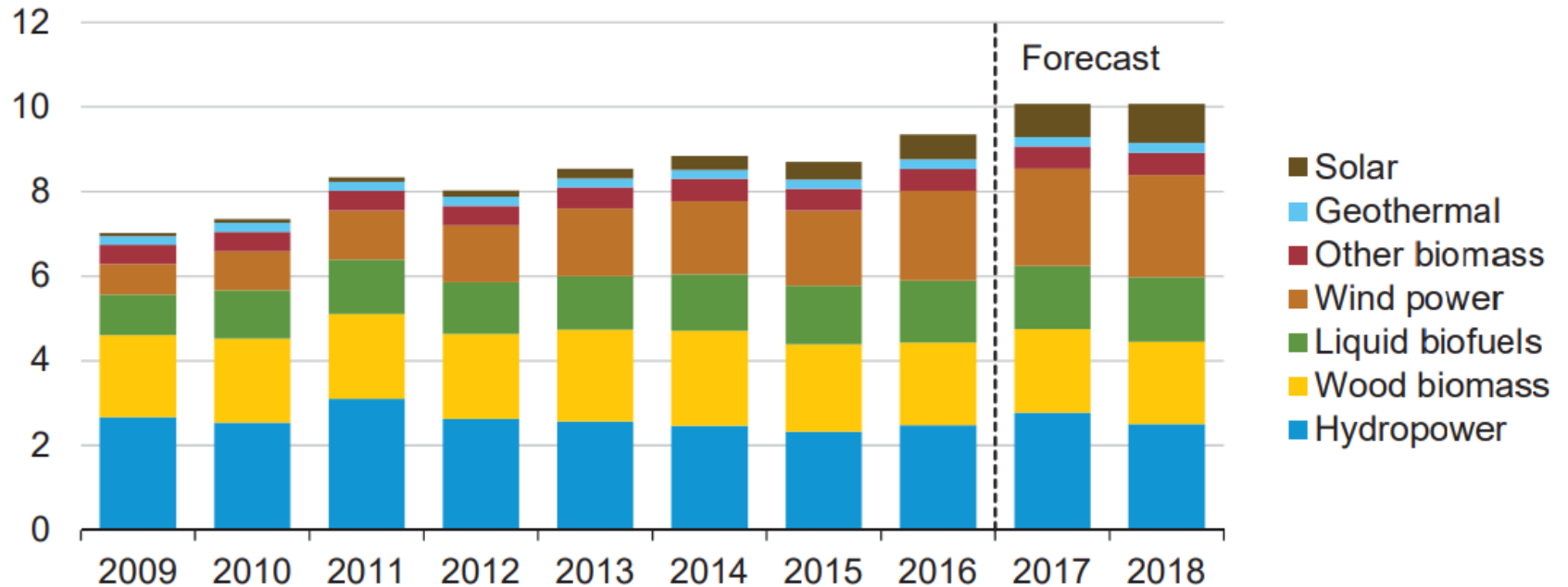
U.S. Estimated Energy Consumption in 2016: 97.3 Quads



Source: Energy Information Administration, "Annual Energy Outlook 2017", Reference Case.

U.S. Renewable Energy Consumption: Past and Projected

U.S. renewable energy supply
quadrillion British thermal units (Btu)

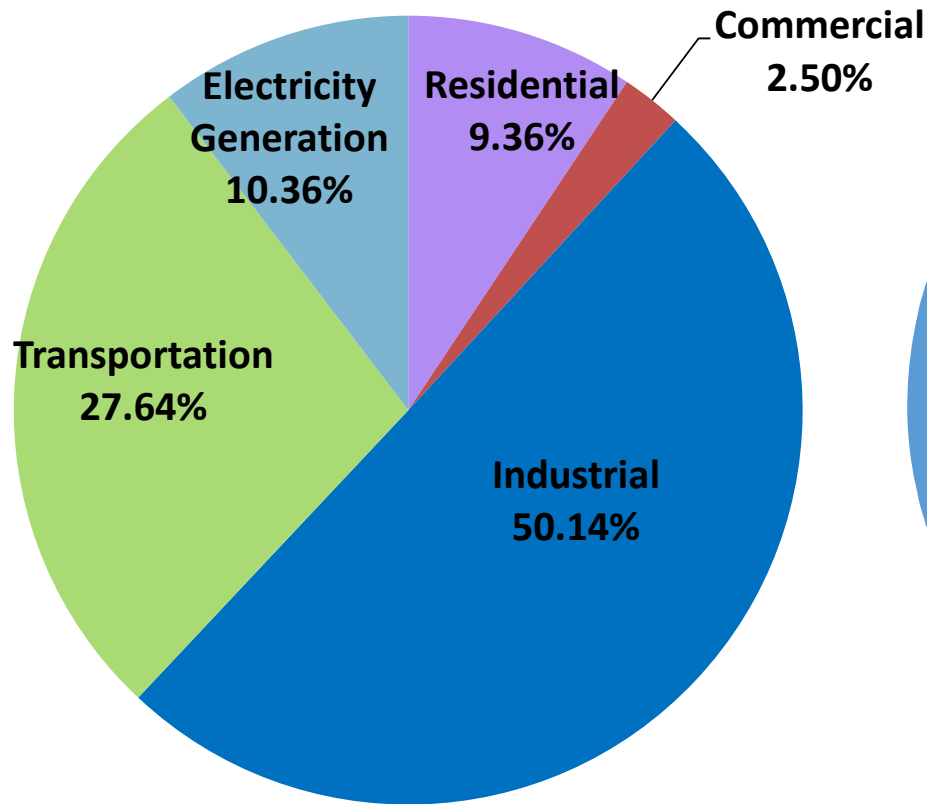


Note: Hydropower excludes pumped storage generation. Liquid biofuels include ethanol and biodiesel. Other biomass includes municipal waste from biogenic sources, landfill gas, and other non-wood waste.

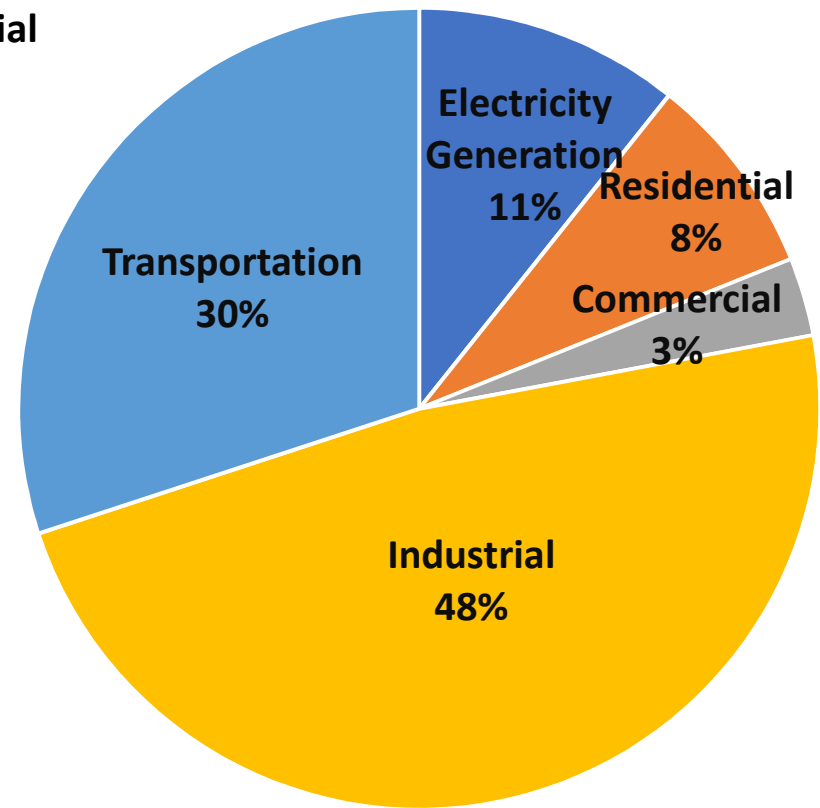
Source: Short-Term Energy Outlook, September 2017.

U.S. Biomass Consumption by End-use Sector – 2016

U.S. Biomass Consumption 2013
Total: 4.49 Quads



U.S. Biomass Consumption 2016
Total: 4.75 Quads



Fuels for Distillate and Jet Market

US Liquid Fuels and Products Market Size (billion gallons/year)

	2015	2050	Growth Rate 2015 – 2050 (%/year)
Gasoline	141	114	-0.7%
Diesel	61	64	0.3%
Liquefied Petroleum Gas ^[1]	39	54	1.0%
Other ^[2]	31	38	0.7%
Jet Fuel	24	39	1.4%
Residual fuel oil	4	6	0.3%
Total	300	315	

1. Includes ethane, natural gasoline, and refinery olefins.








2. Includes kerosene, petrochemical feedstocks, lubricants, waxes, asphalt, and others commodities.

Source: Energy Information Administration, “Annual Energy Outlook 2017”, Reference Case.

Defense Production Act (DPA) Initiative Accomplishments

- Fuels are approved for use as jet fuel by ASTM at up to **50/50 blends**.
- Fuels **successfully demonstrated** during Rim of the Pacific (RIMPAC) demonstration in 2012 for ships and planes.
- Fuels can be utilized in Navy's warfighting platforms with **no degradation to performance or mission**.
- January, 2017 - [Defense Production Act \(DPA\) Title III Advanced Drop-In Biofuels Production Project \(ADBPP\) Biofuels 2](#): public announcement that is forthcoming



Company	Location	Feedstock	Conversion Pathway	Off-Take Agreements	Capacity (MMgpy)
	Gulf Coast	Fats, Oils, and Greases	Hydroprocessed Esters and Fatty Acids (HEFA)	TBD	82.0
	McCarran, NV	Municipal Solid Waste	Gasification – Fischer Tröpsch (FT)	 	10.0
	Lakeview, OR	Woody Biomass	Gasification – Fischer Tröpsch (FT)	 	12.0

Latest Activities in Industry

- **AltAir** - United Airlines has begun using commercial scale alternative jet fuel volumes for regularly scheduled flights from LAX. Purchase 15 mgy from AltAir Paramount over 3 years.
- **Fulcrum** – Strategic partnership between United, Cathay Pacific, BP Ventures, Air BP businesses to invest \$30 million. 10 year off-take for 50 mgy from plants in North America. (**DOE funded**)
- **Red Rock** – 3 million gallons/year of renewable jet fuel for 3 years for FedEx Express. Southwest purchase agreement from Lakeview, Oregon facility to convert 140,000 dry tons/year of woody biomass into 15 million gallons/year of renewable jet, diesel, and naphtha. (**DOE funded**)
- **Byogy** – AVAPCO biomass-to-ethanol with Byogy alcohol-to-jet process to produce jet fuel from woody biomass. DOE award of \$3.7 million to develop demonstration scale biorefinery. (**DOE funded**)
- **ExxonMobil and Synthetic Genomics** have [announced a breakthrough](#) in their algae based biofuels work. They have modified an algae strain to produce up to twice as much oil without significantly inhibiting the growth of the algae.
- **Renewable Energy Group (REG)** [announced in June](#) that they completed a \$20 million land acquisition to expand their facility in Geismar, LA. REG plans to use the newly purchased land for future developments such as the support of existing nameplate capacity and other future expansion opportunities.

Latest Activities in Industry

- **Applied Research Associates (ARA)** have their **ReadiJet** drop-in jet fuel [undergoing ASTM certification](#) for commercial use and MILSPEC certification for operational use by the US Navy
- **GEVO** – Lufthansa agreement for alcohol-to-jet from Luverne, MN facility. 8 mgj from Gevo or up to 40 mgj over 5 years.
- **GEVO** have announced that they expect to supply Virgin Australia Group with its renewable alcohol-to-jet fuel (ATJ). It is currently expected that GEVO will ship the first gallons of ATJ to the Virgin Australia Group this month.
- **GEVO** also announced that it will be [partnering with Los Alamos National Lab \(LANL\)](#) to **improve the energy density** of some of GEVO's products such as its Alcohol-to-Jet (ATJ) fuel in order to **meet product specifications for military fuels** such as RJ-4, RJ-6, and JP-10. LANL was awarded funding in support of this project through the Department of Energy's consortium, ChemCatBio.

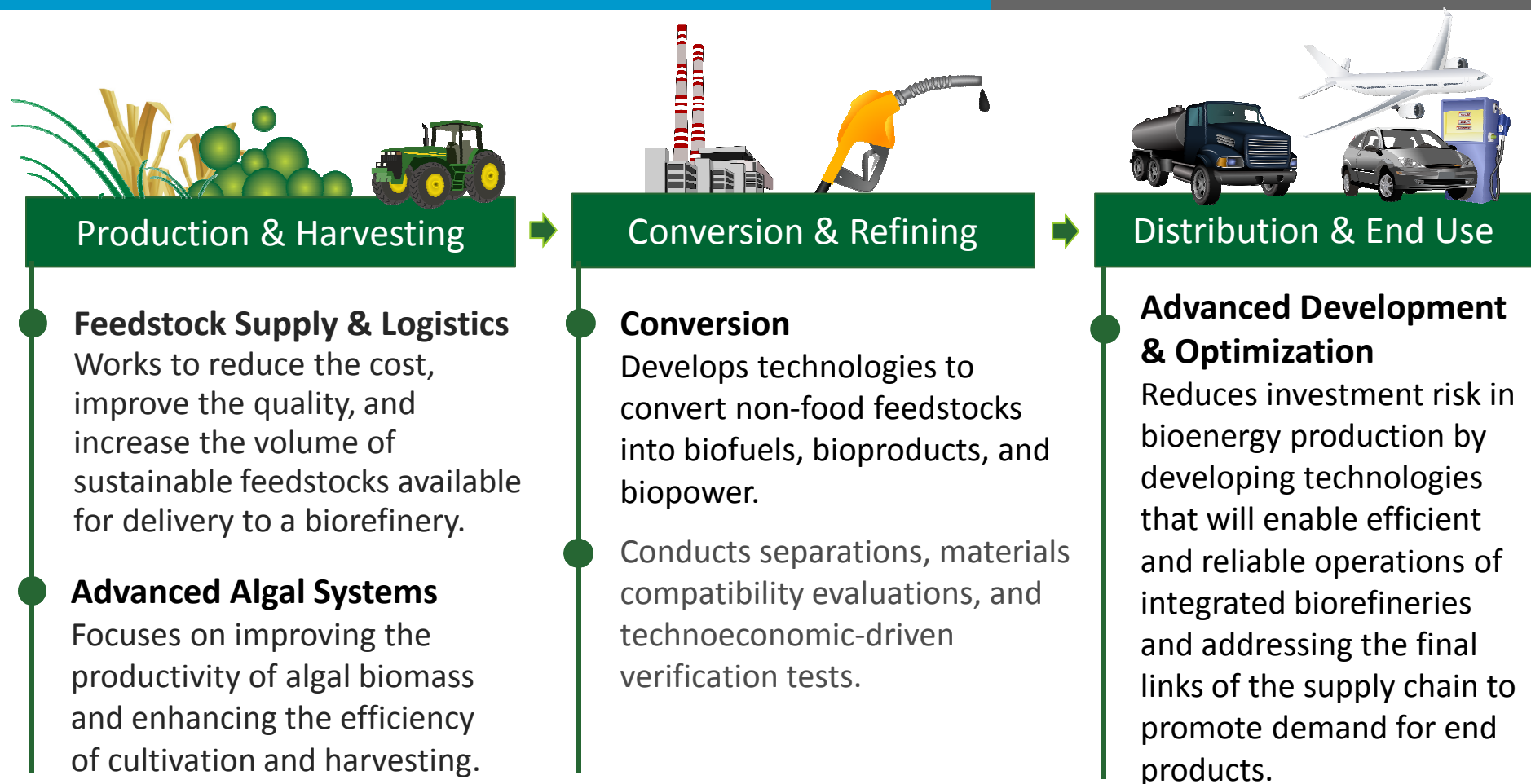
Where we are: Transitioning to AJF, Fuel Purchase Agreements

	+		=	5 M gpy from 2016
	+	 	=	3 yr agreement 30/70 blend
	+	 	=	3 yr agreement Enabling LAX flts
	+		=	375M usg
	+		=	90-180 M gpy Over 10 yrs
	+		=	3 M gpy
	+		=	3 M gpy
	+		=	Supply from 2018
	+		=	10M gpy, 10 yrs
	+		=	8M gal/year from 2020 LAX to Australia
	+		=	Up to 40M gal Over 5 yrs (MOU)

Latest Activities in Industry – Refineries/Chemicals Integration

- **Ensyn-Chevron**
 - Converting Ensyn’s RTP liquids produced from non-food cellulosic feedstocks into transportation fuels (gasoline, diesel)
 - Retrofitting a particle board manufacturing facility in Dooly County to produce 20 mil gallons/annually of renewable fuel from waste food (100 mil facility, online by January 2017)
- **ExxonMobil – REG**
 - Studying production of biodiesel by fermenting renewable cellulosic sugars from agricultural waste (one step fermentation)
- **Tesoro – Fulcrum BioEnergy Inc.**
 - Biocrude from municipal waste to be processed at Martinez, California refinery (~800 bbl/day in 2018)
- **Tesoro – Virent, Inc**
 - Scale-up and commercialization Virent’s BioForming Technology producing low carbon biofuel, chemicals
- **Tesoro – Ensyn Corp**
 - Applied for a pathway with the California Air Resources Board to co-process biocrude from tree residue – Renewable Fuel Oil – in TRMC refineries
- **Virent**
 - Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons: Conversion of Lignocellulosic Feedstocks to Aromatic Fuels and High-Value Chemicals
- **GTI – Valero/CRI/Johnson Timber/Cargill/MTU**
 - Upgrading hydro-pyrolysis oil from biomass
 - Integrated hydro-pyrolysis and hydro-conversion (no PNA, no free radicals)
- **Total – Novogy**
 - Built the platform to deliver ‘tailored’ oils that can address various specialties markets (biodiesel, jet, drilling fluids, lubricants, surfactants)

Bioenergy Technologies Office's Critical Program Areas



Crosscutting Areas: Sustainability, Strategic Analysis, & Communications

BETO works to address risks and reduce costs across the supply chain.

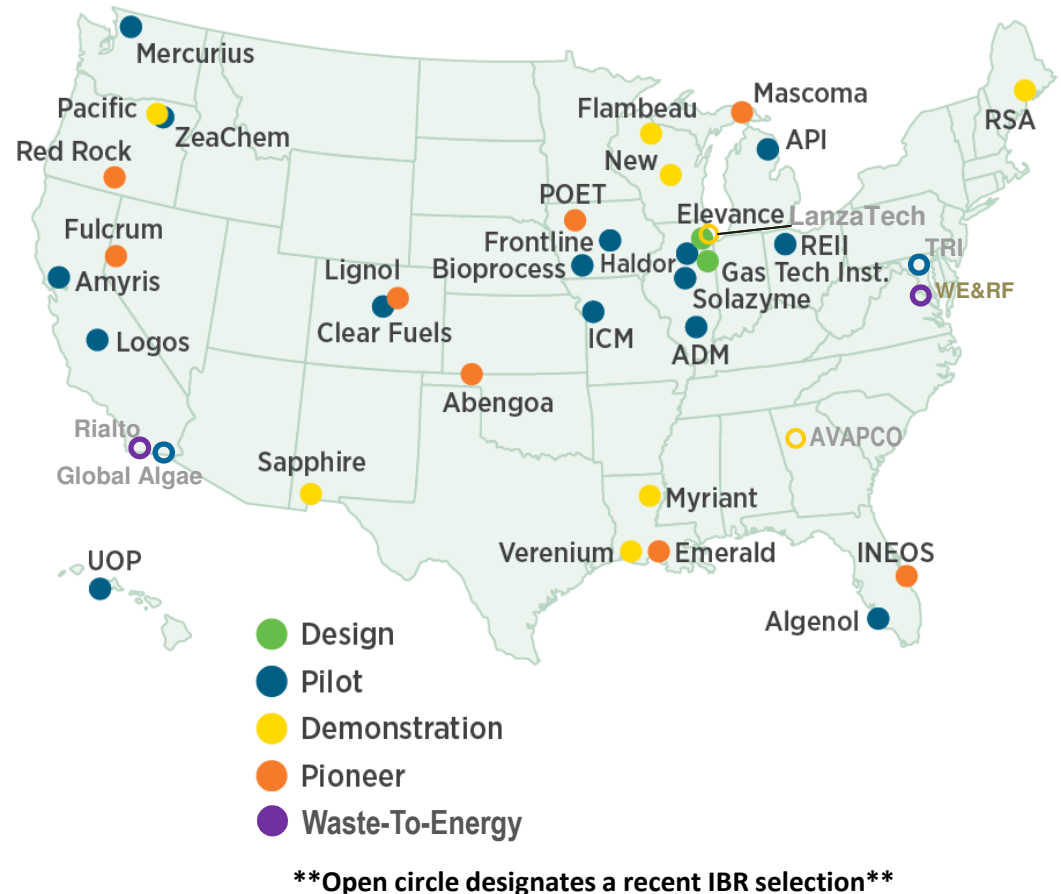
Integrated Biorefinery Geographic Distribution

Since 2006, U.S. DOE Bioenergy Technologies Office (BETO) has supported a total of 42 pilot, demonstration, and pioneer-scale facilities

- Recently selected eight new projects for IBR optimization
- Recently selected six new pilot and demo scale projects

BETO investments have allowed industry partners to:

- Enable the development of first-of-a-kind IBRs
- Prove conversion technologies at scale
- Validate techno-economic assessments
- Gain investor confidence



Commercial-Scale Integrated Biorefineries

POET-DSM Project LIBERTY

- Grand Opening on September 3, 2014
- Capacity of 25 million gallons per year from corn stover
- Currently producing cellulosic ethanol
- Announced POET-DSM investment for On Site Manufacturing of enzymes
- DOE provided \$100 million to facility development








DuPont Cellulosic Ethanol Facility

- Grand Opening on October 30, 2015
- Capacity of 30 million gallons per year from corn stover
- DOE investment supported development work with NREL








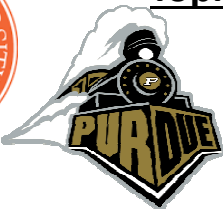


Recent Pilot and Demo Scale IBR Selections

- Announced on December 28, 2016
- Up to **\$12.9M** for six projects
- Manufacturing of advanced or cellulosic biofuels, bioproducts, refinery-compatible intermediates, and/or biopower in a domestic **pilot- or demonstration-scale** integrated biorefinery.

Demonstration-Scale Integrated Biorefineries  	AVAPCO, LLC
	LanzaTech, Inc.
Pilot-Scale Integrated Biorefineries  	Global Algae Innovations
	ThermoChem Recovery International, Inc.
Pilot-Scale Waste-to-Energy Projects 	Rialto Bioenergy, LLC
	Water Environment & Reuse Foundation

Recent IBR Optimization Selections









- Announced on September 20th
- Up to **\$15M** for eight projects
 - **Topic Area 1:** Robust, continuous handling of solid materials and feeding systems to reactors under various operating conditions.
 - **Topic Area 2:** High value products from waste and/or other under-valued streams in an IBR.
 - **Topic Area 3:** Industrial separations within an IBR.
 - **Topic Area 4:** Analytical modeling of solid materials (dry and wet feedstocks, and/or residual solids remaining in the process) and reactor feeding systems.

<p>Topic Area 1</p> 	<p>ThermoChem Recovery International, Inc.</p>
<p>Topic Area 2</p>   	<p>Texas A&M Agrilife Research</p> <p>South Dakota School of Mines</p> <p>White Dog Labs</p>
<p>Topic Area 3</p>	<p>No Selection</p>
<p>Topic Area 4</p>    	<p>National Renewable Energy Laboratory</p> <p>Clemson University</p> <p>Purdue University</p> <p>Forest Concepts</p>

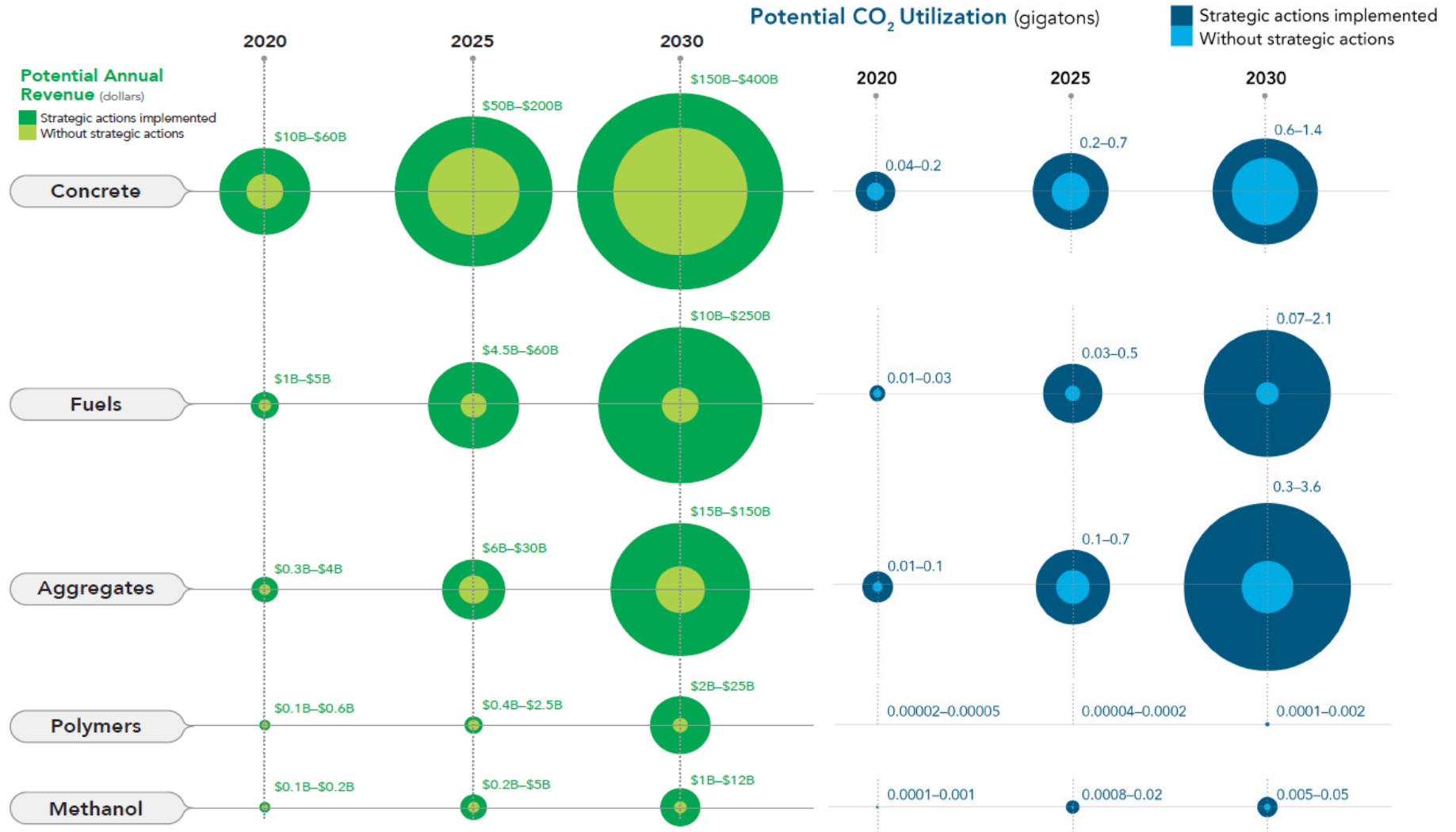
Co-Optimization of Fuels and Engines

- In 2015 U.S. DOE Bioenergy Technologies and Vehicle Technologies Office initiated the multi-national laboratory program focused on Co-Optimization of Fuels and Engines
- In 2016 Eight universities selected to accelerate the introduction of affordable, scalable, and sustainable high-performance fuels for use in high-efficiency, low-emission engines.



			
Cornell University	Massachusetts Institute of Technology	University of Michigan-Dearborn	University of Central Florida
			
Louisiana State University	University of Michigan	Yale University	University of Alabama

Potential Markets for CO₂-Derived Products and Fuels



Source: Global CO₂ Initiative, McKinsey Study, <http://www.globalco2initiative.com>

Current Projects in CO2 Utilization:

Direct CO2 Capture and Use (algal biofuel carbon capture and utilization)

- **Global Algae Innovations, Inc.** (El Cajon, California) – *Algae Production CO2 Absorber with Immobilized Carbonic Anhydrase*
 - Increase algal biomass yield by deploying innovative system to absorb CO2 from flue gas using immobilized carbonic anhydrase, Kauai, HI, 33-acre algae facility adjacent to power plant (\$1 million).
- **Arizona State University** (Mesa, Arizona) – *Atmospheric CO2 Capture and Membrane Delivery*
 - Atmospheric carbon dioxide capture, enrichment, and delivery to increase biomass productivity. Demonstrate that Moisture-Swing Sorption (MSS) can capture and concentrate atmospheric CO2 (\$1 million).
- **Pacific Northwest National Laboratory** (Richland, Washington) *Microalgae Biofuels Production on CO2 From Air*, with MicroBio Engineering Inc.,
 - Develop a process to produce microalgae directly from carbon dioxide in air at high productivities, thereby decoupling algal growth from CO2 sources. Develop and demonstrate AlgaeAirFix™, a novel process that overcomes current limitations of air-CO2 supply to microalgae cultures (\$900k).

Current Projects in CO₂ Utilization

CO₂ Utilization

- **White Dog Labs** – *2nd -Generation Mixotrophy for Highest Yield and Least Expensive Production*
 - Develop a Clostridium strain which can concurrently use C5/C6 sugars as well as CO₂ (which is given off during fermentation) via the Wood-Ljungdahl Pathway to generate acetate. The result is 3 acetate (instead of the 2 acetate which are produced during conventional oxidative reactions).
- **SBIR Awards**
 - Non-photosynthetic carbon reduction: Opus 12, Reactive Innovations LLC, Sustainable Innovations LLC, Visolis
 - Non-biological CO₂ reduction and biological upgrading: Announced for FY18
- **National Lab Projects**: 1) Feasibility Study of CO₂ Reduction to Intermediates 2) Establishing the State-of-Technology in catalytic CO₂ reduction 3) CO₂ valorization via Rewiring Carbon Metabolic Network

Biogas Utilization (platforms use both CO₂ and CH₄ as feedstock)

- **Microvi Biotech** – *Engineered Consortium-Based Conversion Platforms*
 - Combinatorial materials science approach to microbial consortium development and leverages a unique combination of organisms to use both CO₂ and CH₄. Investment includes the development of innovative methane adsorption strategies in aqueous systems with segmented reactor design scheme
- **NexTech Materials** – *Conversion of Biogas to Liquid Fuels on Superior Catalysts*
 - Uses both CO₂ and CH₄ as feedstock. Conversion strategy uses novel catalysts for mixed steam and dry methane reforming, F-T synthesis. Distribution of nanoparticle catalysts on foam and monolithic substrates.

Additional Selections

- **Additional Projects were selected under the Productivity Enhanced Algae and Tool-Kits (PEAK), Algal Biomass Yield Phase II (ABY 2), and the MEGA-BIO funding opportunities.**
- **Read more about these new projects here:**
 - **PEAK** - these projects will deliver high-impact tools and techniques for increasing the productivity of algae organisms in order to reduce the costs of producing algal biofuels and bioproducts.
 - **ABY 2** - develop technologies that are likely to succeed in producing 3,700 gallons of algal biofuel intermediate (or equivalent dry weight basis) per acre per year (gal/acre/yr) on an annualized average basis.
 - **MEGA-BIO** - supporting the development of biomass-to-hydrocarbon biofuels conversion pathways that can produce variable amounts of fuels and/or products based on external factors, such as market demand.

FY17 BETO's Programmatic Highlights and Accomplishments

Alternative Aviation Fuels Workshop

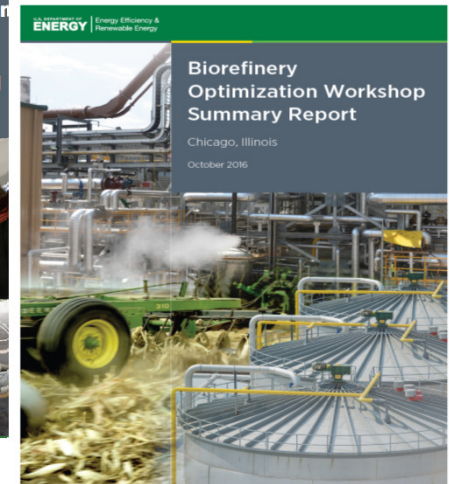
- Workshop held September 14-15, 2016 in Macon, GA
- Four breakout sessions:
 - Economic and Technical Competitiveness
 - Fuel Conversion and Scale-up
 - Environmental Sustainability and Life-cycle Benefits
 - Feedstock and Product Supply Chains

Biorefinery Optimization Workshop

- Workshop held October 5-6, 2016 in Chicago, IL
- Three breakout sessions:
 - Feedstock and Materials Handling
 - Process Scale-Up, Intensification, and Cost Reduction
 - Co-Product and Waste Stream Monetization

Jet fuels & Engine Co-Optimization (JET) Workshop

- Collaboration between DOE, U.S. Air Force, and NASA
- Report in development
- Four breakout sessions:
 - High Performance Fuel (HPF) Options
 - Engine and Combustor Options
 - Aircraft On-Board HPF Considerations
 - HPF Development to Deployment Considerations



Bioeconomy 2017: Domestic Resources for a Vibrant Future

- BETO annual conference engaged a diverse stakeholder community that discussed critical issues such as:
 - **Innovative technologies** for the emerging bioeconomy
 - The **economic opportunities** of reliable American feedstock
 - New and **growing markets** for the bioeconomy
 - Bioenergy as part of the **modern transportation future**
 - Leveraging the bioeconomy to create new jobs and **address global challenges**

Annual BETO Conference: *Bioeconomy 2018*

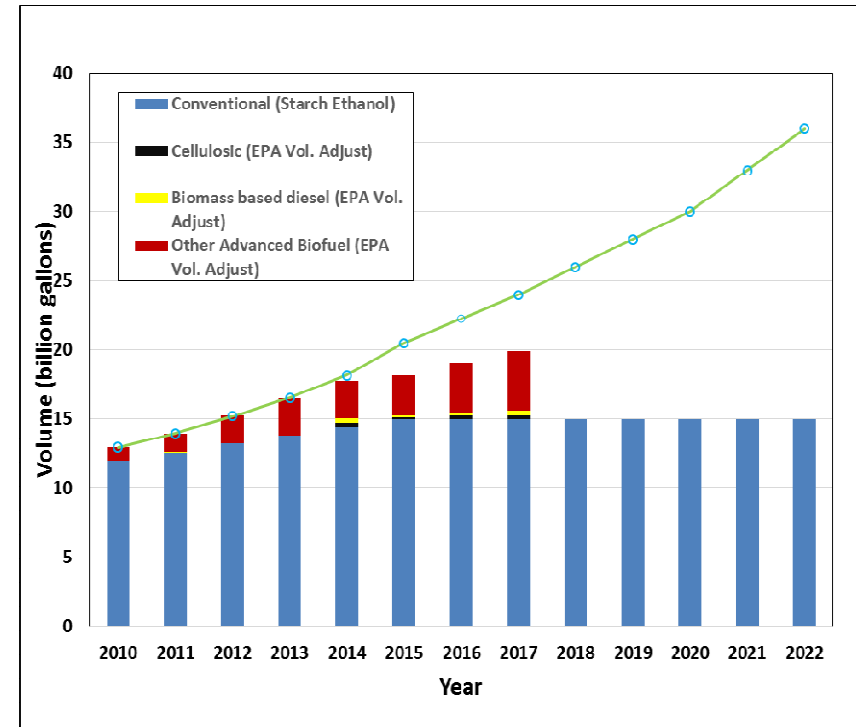
- In lieu of its annual conference, in 2018 BETO will be co-hosting the ABLCNext 2018 conference with ABLC
 - BETO will provide content for a full day of the conference
- The conference will engage a diverse stakeholder community spanning the entire bioenergy supply chain.
- To be held on November 5-9, 2018 in San Francisco, CA at the [Hotel Nikko](#)



ABLCCNEXT

Bioenergy Related National Policy Efforts

- U.S. EPA administers the Renewable Fuel Standards (RFS) which requires certain quantities of renewable fuels to be blended into motor gasoline and diesel fuel.
 - The RFS was created under the Energy Policy Act (EPAAct) of 2005
 - Required 7.5 billion gallons of renewable-fuel to be blended into gasoline by 2012
 - Under the Energy Independence and Security Act (EISA) of 2007 it was expanded to RFS2 and changed in several times
 - RFS2 increased the volume of renewable fuel required to be blended into transportation fuel from 9 billion gallons in 2008 to 36 billion gallons by 2022



- EPA approved volumes have fallen short of the trajectory in recent years and are not on track to meet the originally proposed goal

Bioenergy Related National Policy Efforts

- U.S. EPA recent proposal for bio-intermediates
 - Allow renewable fuel produced from biointermediates to generate RINs for existing approved pathways, supporting the growth of advanced
 - Only the renewable fuel producer would be permitted to generate RINs biofuels
 - Biointermediate producers would be subject to requirements similar to those for renewable fuel producers
- U.S. CARB is considering developing a proposal to:
 - Allow alternative jet fuel (AJF) to generate LCFS credits as an opt-in fuel
 - Allow credit generation for AJF loaded to all planes in California, whether destinations are in state or out of state
 - Allow credit generation for military use of AJF
- U.S. CARB granted (February 2016) approval for refinery co-processing:
 - This approval relate to the application of Ensyn's Renewable Fuel Oil as a renewable feedstock for refineries in California for the production of renewable gasoline and diesel (refinery co-processing).

Outstanding Challenges

- Properties
- Infrastructure Impacts and Market Acceptance
- Scale
- Co-product handling methods in LCA
- ASTM Approval process
- Off-take Agreements
- Competitiveness
- Policies and Regulations
 - EPA
 - LCFS
 - IMO, ICAO

Interagency Coordination on AJF

- **Farm to Fly 2.0**

- In 2013, USDA and FAA made a commitment to the aviation industry to help meet their goals with the Farm to Fly 2.0 agreement. This effort seeks to enable the use of commercially viable and sustainable renewable jet fuel in the United States.
- In July 2014, DOE Secretary Moniz signed an amendment officially making DOE a partner agency in this significant initiative.
- DOE brings technical expertise at our national laboratories and years of experience that staff at DOE have to offer.
- Senate FY16 appropriations language requests DOE to indicate commitment to Farm to Fly 2.0.

- **DPA**

- In July 2011, the Secretaries of Agriculture, Energy, and Navy signed a Memorandum of Understanding to commit \$510 M (\$170 M from each agency) to produce hydrocarbon jet and diesel biofuels in the near term
- DPA Round II has recently concluded and a public announcement is forthcoming

Interagency Coordination on AJF

- **Federal Alternative Jet Fuels R&D Strategy (2016)**
 - Overarching Statement: Enable the development, production, and use of environmentally sustainable, cost-competitive and socially responsible alternative jet fuel with stable supply to significantly meet the needs of U.S. jet aviation.
 - R&D Goals & Objectives
 - Feedstock Development, Production, and Logistics
 - Fuel Conversion and Scale-Up
 - Fuel Testing and Evaluation
 - Integrated Challenges
 - 8 participating Federal Agencies: USDA, DOC, DOD, NASA, FAA, DOE, EPA, NSF, DOS
 - [https://www.whitehouse.gov/sites/default/files/federal alternative jet fuels research and development strategy.pdf](https://www.whitehouse.gov/sites/default/files/federal_alternative_jet_fuels_research_and_development_strategy.pdf)

Interagency Coordination on Bioenergy R&D



**Feedstock-
Conversion
Interface**

**Co-
Optimization
of Fuels and
Engines
(Co-Optima)**

**Agile
BioFoundry
(ABF)**

**Separations
Consortium**

**Chemical
Catalysis for
Bioenergy
(ChemCatBio)**

Bioenergy Partners

Laboratories

- Los Alamos NATIONAL LABORATORY EST. 1943
- NREL NATIONAL RENEWABLE ENERGY LABORATORY
- SRNL™ SAWYER RIVER NATIONAL LABORATORY
- Argonne NATIONAL LABORATORY
- Sandia National Laboratories
- INL Idaho National Laboratory
- Pacific Northwest NATIONAL LABORATORY
- BERKELEY LAB LAWRENCE BERKELEY NATIONAL LABORATORY
- AMES LABORATORY U.S. DEPARTMENT OF ENERGY
- OAK RIDGE National Laboratory
- BROOKHAVEN NATIONAL LABORATORY

Universities

- UT
- W
- ARIZONA
- OHIO
- N
- Duke UNIVERSITY
- COLORADO
- UC RIVERSIDE
- SC
- IOWA STATE
- T
- ATM
- ESF
- OHIO STATE
- MIT
- OU
- UCF
- M

Government

- DEPARTMENT OF ENERGY - UNITED STATES OF AMERICA
- USDA
- NSF
- DEPARTMENT OF DEFENSE - UNITED STATES OF AMERICA
- EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
- DEPARTMENT OF TRANSPORTATION - UNITED STATES OF AMERICA
- UNITED STATES - AGRICULTURE - ENVIRONMENTAL PROTECTION AGENCY
- U.S. DEPARTMENT OF THE INTERIOR - MARCH 3, 1849
- NIST

Industry

- Dow
- MultiLab
- Yield10 Bioscience
- MicroBio ENGINEERING
- WHITE DOG LABS
- gti
- FOET | Advanced Biofuels
- DSM
- cellana
- Kiverdi
- RTI INTERNATIONAL
- SR SOUTHERN RESEARCH
- LanzaTech
- CPBR
- NatureWorks ir@gcc: naturally advanced materials
- AMERICAN PROCESS
- LYGOS
- Cargill
- ALGENOL BIOFUELS
- Sapphire Energy
- FRONTLINE BIOENERGY, LLC
- ANTARES Group Incorporated
- AMYRIS
- CORRIM
- FDCE Conservation & Bioenergy
- SRI International
- J. Craig Venter™ INSTITUTE
- VIRENT
- MB
- CERAMATEC™ TOMORROW'S CERAMIC SYSTEMS
- GLOBAL ALGAE INNOVATIONS
- PICHTER
- ITIME
- novozymes

Bioenergy Research, Development, and Demonstration Successes

☐ Bioenergy Success Stories

- Industry
 - The Algae Technology Education Consortium (ATEC) completes its first semester
 - “Algal Turf Scrubbers” help clean up Baltimore Harbor and fuel cars
- Government
 - 2016 Billion-Ton Report Confirms U.S. Potential to Produce 1 Billion Tons of Biomass Annually
 - BETO funded project Lygos won an award for its bio-based method to produce malonic acid
 - Co-Optimization of Fuels and Engines initiative (Co-Optima) verifies benefits of high-octane fuels
 - Regional Feedstock Partnership Report Highlights Seven Years of Work to Enable Billion-Ton Vision
- Universities, National Labs
 - INL develops artificial intelligence-based control system that improves biomass preprocessing
 - ORNL develops new membrane technology to improve efficiency of biofuel production
 - Aviation biofuel milestone reached: Five gallons of jet fuel produced from industrial waste gasses

Bioeconomy Initiative and Bioenergy Publications

- ❑ The Billion Ton Bioeconomy Initiative (Bioeconomy Initiative) aims to develop innovative approaches to barriers in order to expand the sustainable use of America's biomass resources and maximize economic, social, and environmental outcomes.
 - [The Billion Ton Bioeconomy Initiative](#)
 - [Federal Activities Report on the Bioeconomy \(FARB\)](#)
 - [Strategic Plan for a Thriving and Sustainable Bioeconomy](#)
 - [2016 Billion-Ton Report: Volume 1](#)
 - [2016 Billion-Ton Report: Volume 2](#)

- ❑ Program plans, technology reviews, and reports provide guidance for the adoption of bioenergy technologies
 - [Bioenergy Technologies Office Multi-Year Program Plan](#)
 - [BETO 2015 Peer Review Report](#)
 - [2017 U.S. Energy and Employment Report](#)
 - [Integrated Biorefinery Optimization Workshop Report](#)



Source: U.S. Department of Energy – Alternative Fuels Data Center

[Click Here for a Full list of Publications](#)

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