

IEA Bioenergy

Task 42 Biorefining

Country Report

United States

May 2017



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U.S. Department of Energy



IEA Bioenergy **Outline**

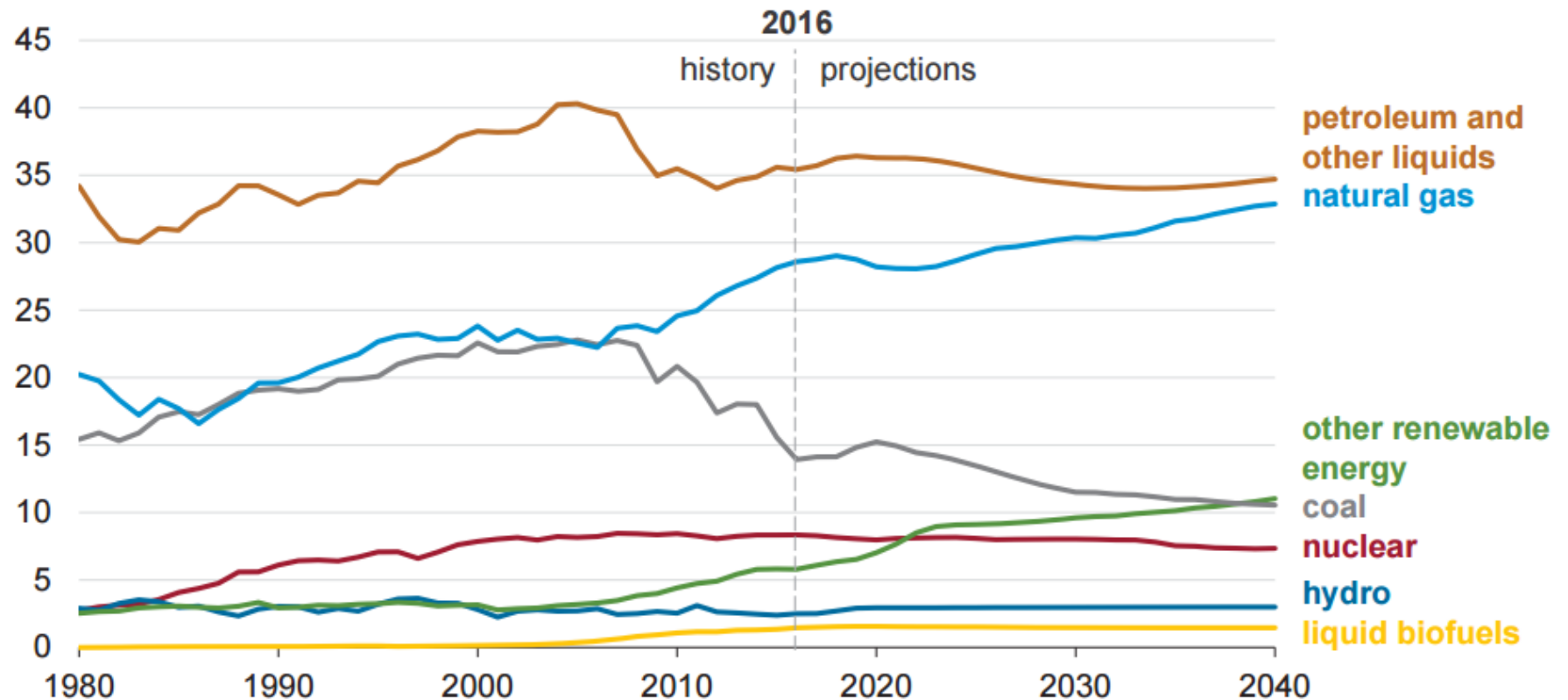
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- U.S. Primary Energy Consumption
 - Biomass use for Energy and Non-Energetic Applications
- U.S Biorefining Status
 - Latest Activities in the Industry
 - New Biorefinery Demonstration and Pilot Projects
 - Research, Development, and Demonstration 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: Source: Energy Information Administration, "Annual Energy Outlook 2017", Reference Case.

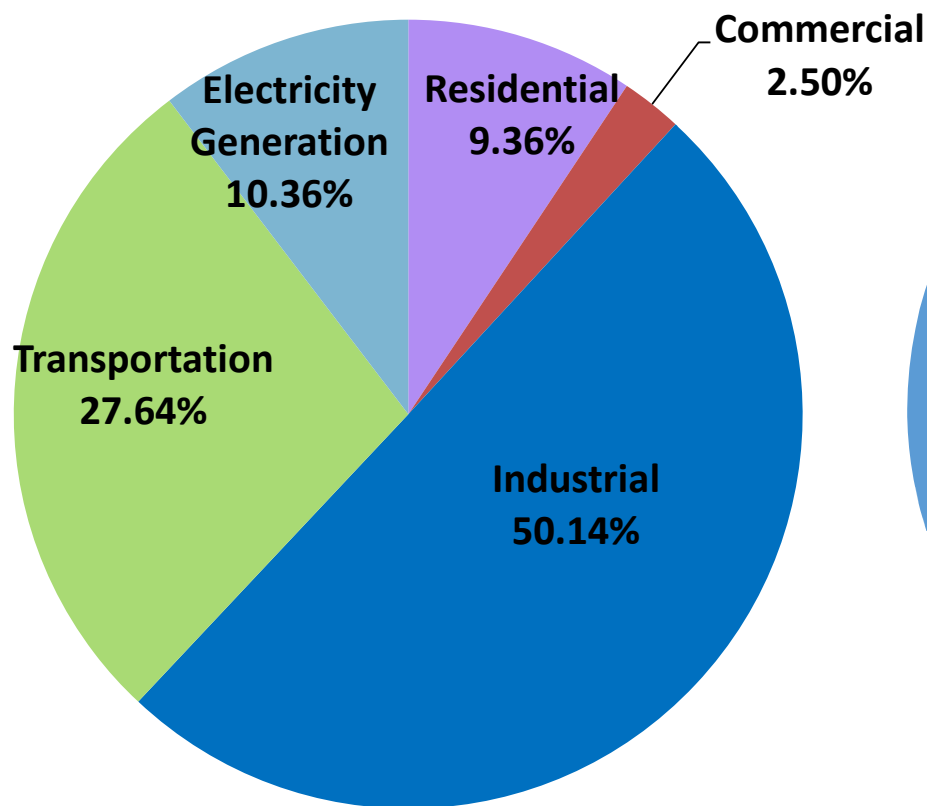


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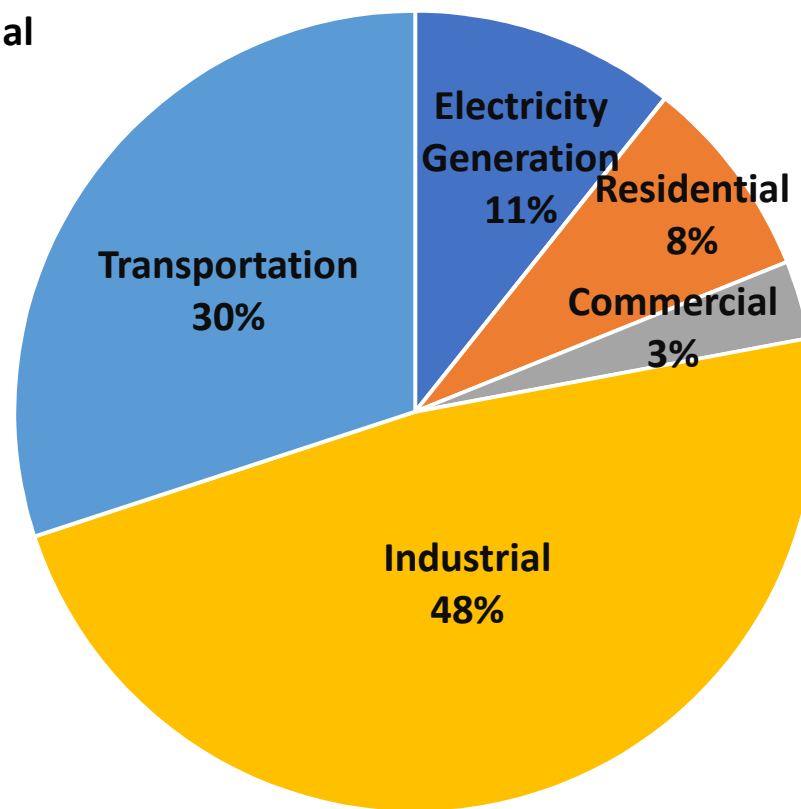
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U.S. Biomass Consumption 2013
Total: 4.49 Quads



U.S. Biomass Consumption 2016
Total: 4.75 Quads



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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.








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Defense Production Act (DPA) Initiative Accomplishments

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- 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.



Company	Location	Feedstock	Conversion Pathway	Off-Take Agreements	Capacity (MMgpy)
 EMERALD BIOFUELS	Gulf Coast	Fats, Oils, and Greases	Hydroprocessed Esters and Fatty Acids (HEFA)	TBD	82.0
 Fulcrum BIOENERGY	McCarran, NV	Municipal Solid Waste	Gasification – Fischer Tröpsch (FT)	 UNITED  CATHAY PACIFIC	10.0
 Red Rock Biofuels	Lakeview, OR	Woody Biomass	Gasification – Fischer Tröpsch (FT)	 FedEx  SOUTHWEST AIRLINES	12.0



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- **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.
- **Gevo** – Lufthansa agreement for alcohol-to-jet from Luverne, MN facility. 8 mgy from Gevo or up to 40 mgy over 5 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)**
- **UOP** – Petriox Oil and Gas to produce renewable jet and diesel at new refinery in Fujairah, UAE to convert 500,000 metric tonnes of renewable feedstocks into 1 million tons/year of biofuels.
- **KLM and SkyNRG** for 3 year agreement enabling LAX flights

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Where we are: Transitioning to AJF, Fuel Purchase Agreements

	+	UNITED	=	5 M gpy from 2016
AltAir Fuels	+	World Fuel Services	=	3 yr agreement 30/70 blend
	+	Sky NRG	=	3 yr agreement Enabling LAX flts
	+	KLM		
Fulcrum BIOENERGY	+	CATHAY PACIFIC	=	375M usg
	+	UNITED	=	90-180 M gpy Over 10 yrs
RED ROCK BIOFUELS	+	Southwest	=	3 M gpy
	+	FedEx	=	3 M gpy
HAWAII BioEnergy	+	Alaska Airlines	=	Supply from 2018
SG Preston	+	jetBlue	=	10M gpy, 10 yrs
gevo	+	Lufthansa	=	Up to 40M gal Over 5 yrs (MOU)



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- **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)



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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



IEA Bioenergy Alternative Aviation Fuels Workshop

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

[Link to Full Report](#)



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- Workshop held October 5-6, 2016 in Chicago, IL
- Attended by over 100 stakeholders from government, industry, and academia
- Three breakout sessions:
 - Feedstock and Materials Handling
 - Process Scale-Up, Intensification, and Cost Reduction
 - Co-Product and Waste Stream Monetization

[Link to Full Report](#)



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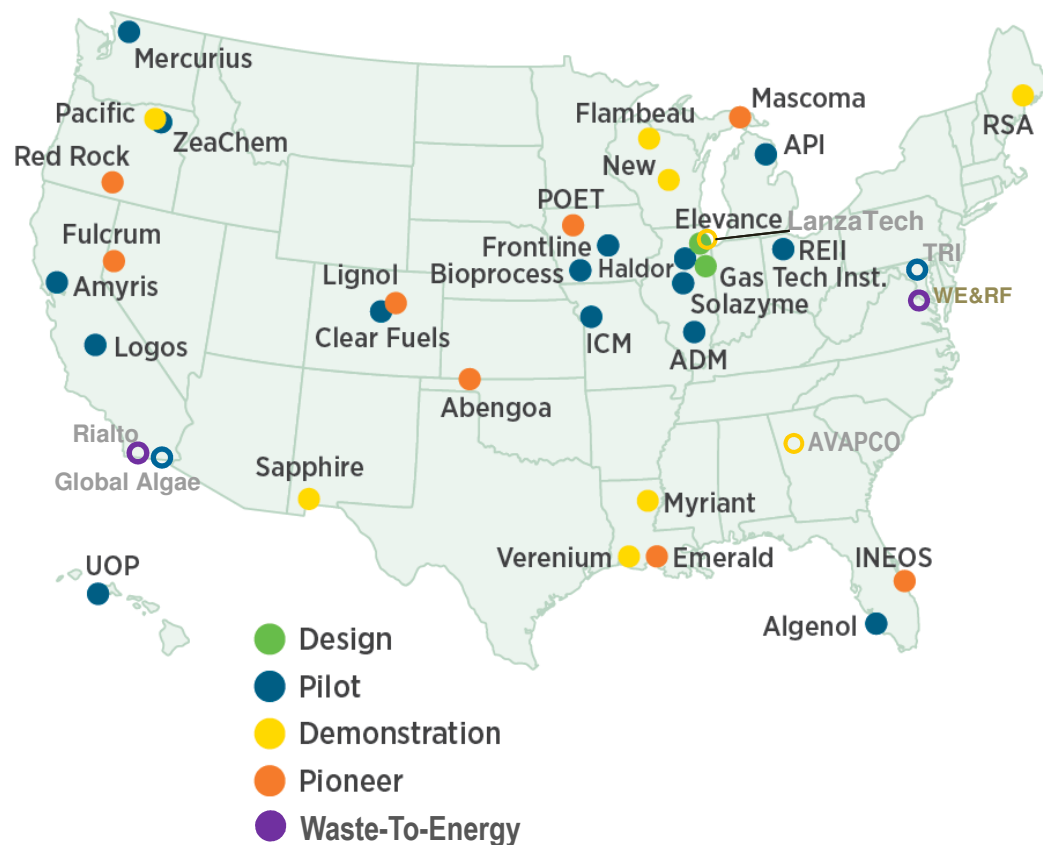
Integrated Biorefinery Geographic Distribution

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

- Recently selected six new 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



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On December 28, 2016, DOE announced up to \$12.9 million for six projects related to the 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

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Small-Scale Decentralized Fuel Production Facilities Via Advanced Heater-Enabled Biorefineries

Location: Baltimore, Maryland

Feedstock: Woody waste and agricultural feedstock

Products: Transportation fuels via Fischer-Tropsch

Scale: Pilot-scale



Technology Summary

TRI will incorporate three separate, interrelated technologies:

- Advanced heat exchanger to remove two unit operations from the current configuration
- Innovative methods for CO₂ capture
- Fischer-Tropsch microchannel reactor and a high-activity catalyst

TRI's Phase 1 funding will focus on improvement of the three key technology areas

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Pilot-scale Algal Oil Production

Location: San Diego, California

Feedstock: Algae

Products: Algae oil and co-products include aquaculture feed and polymer feedstock

Scale: Pilot-scale

Technology Summary

- 3x higher productivity than conventional raceways
- Contamination control demonstrated at large-scale
- Scalable harvesting with 100% harvest efficiency at 1/100th the energy use of centrifuges
- Using CO₂ supply from power plant flue gas



The scalable harvester and other incorporated technologies were developed or demonstrated under previous DOE projects

Low Carbon Hydrocarbon Fuels From Industrial Off-Gas

Location: Skokie, Illinois

Capacity: 3 million gallons per year

Feedstock: Industrial waste gases

Products: Jet and Diesel

Scale: Demonstration-scale

Technology Summary

- Waste gases from steel manufacturing are used to produce “Lanzanol” – LanzaTech’s ethanol
- “Lanzanol” converted to SPK and diesel via an Alcohol-to-Jet (ATJ) process



Biological Recycling of Industrial Waste Gas into Sustainable Fuels

LanzaTech will demonstrate jet fuel from industrial waste gases with approximately 65% GHG reduction

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Advanced Biofuels and Bioproducts with AVAP (ABBA)

Location: Atlanta, Georgia

Capacity: 50 dry tons per day

Feedstock: Woody biomass

Products: Biojet and co-products include nanocellulose and bio-butanediol (BDO)

Scale: Demonstration-scale



Technology Summary

AVAPCO integrates three demonstrated processes:

- AVAPCO's biomass to ethanol process
- Byogy's Alcohol-to-Jet (ATJ) process
- Genomatica's bio-BDO process



AVAPCO will produce several synergistic products from biomass, similar to the diversification of products from a barrel of crude

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Advanced Pyrolysis Integrated Biorefinery

Location: Carlsbad, California

Capacity: 300 tons per day

Feedstock: Organic waste

Products: High-nutrient fertilizer (bio-char) and up to 6.4 MW biopower

Scale: Pilot-scale

Technology Summary

Rialto will incorporate three technologies:

- Organics Extraction machine to access organic wastes in MSW
- Organics Polishing System to convert wastes into digester feedstock
- Low-temperature dryer/pyrolysis system
 - Produces high-nutrient bio-char, gases, and a liquid-intermediate bio-oil

Proposes to increase biogas/biopower from anaerobic digesters by more than 25%

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HYPOWERS: Hydrothermal Processing of Wastewater Solids

Location: Pilot plant will be hosted at Central Contra Costa Sanitary District, near Oakland, CA

Feedstock: Residual sludge and solids

Products: Biocrude oil, biogas, and fertilizer

Scale: Pilot-scale



Technology Summary

- Hydrothermal processing technology from Pacific Northwest National Laboratory
- HTP converts biosolids in < 1 hour
- Converts >40% of dry mass of biosolids to biocrude oil and the remainder to renewable gas
- Biocrude can be upgraded to gasoline, jet, and diesel

The biocrude oil produced through HTP will be a RIN-qualified finished product

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- **Joint FOA with USDA up to \$22.7 million in support of the optimization of IBRs**
 - DOE share of up to **\$19.8 million**
 - USDA-NIFA share of up to **\$2.9 million**
 - Projects will focus on lowering technical and financial risk, addressing challenges encountered with the successful scale-up, and reliable, continuous operation of IBRs.
- **Four topic areas:**
 - **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.

To view the full FOA, visit [EERE Exchange](#). The full applications currently under the review.









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Co-Optimization of Fuels and Engines

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- 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



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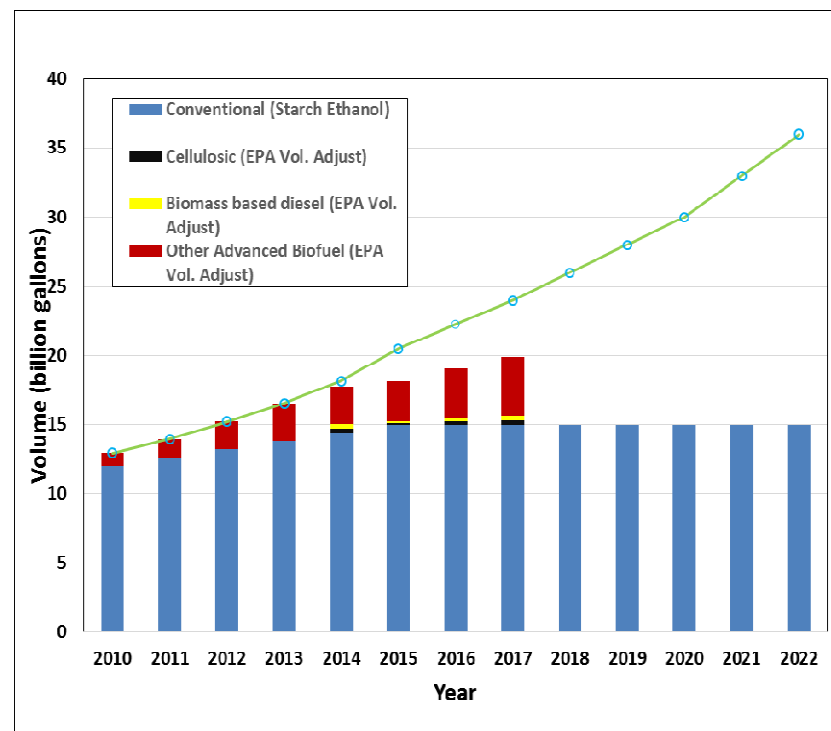
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- U.S. EPA administers the Renewable Fuel Standards (RFS) which requires certain quantities of renewable fuels to be blended into motor gasoline and diesel fuel.
 - The RFS was created under the Energy Policy Act (EPA) of 2005
 - Required 7.5 billion 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



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

Source: <https://www.epa.gov/renewable-fuel-standard-program/renewable-fuel-annual-standards>

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- 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 biofuels
- Biointermediate producers would be subject to requirements similar to those for renewable fuel producers
 - Primarily registration, recordkeeping, reporting, and product transfer document (PTD) requirements
 - Biointermediate production would be tracked in EPA's IT systems
 - Allows EPA to verify appropriate use of renewable biomass as feedstock
- Only the renewable fuel producer would be permitted to generate RINs
 - Too many opportunities for fraud otherwise

- U.S CARB is considering developing a proposal to:
 - Allow alternative jet fuel (AJF) to generate LCFS credits as an opt-in fuel
 - Conventional jet fuel would not be subject to the regulation and would not generate deficits
 - Not developing new set of specifications for jet 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
 - Potential amendment would be included in the subsequent rulemaking amendment process, proposed to go into effect on January 1, 2019
- 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).
 - The approvals have been granted pursuant to California's Low Carbon Fuel Standard. Ensyn, Chevron U.S.A. Inc. and Tesoro Corp. were co-applicants in this process.

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- 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

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- **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

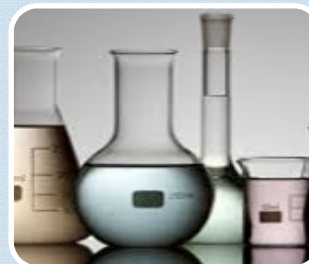
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- **Federal Alternative Jet Fuels R&D Strategy (2016)**
 - Overarching Statement: Enable the development, production, and use of environmentally sustainable, cost-competitive and socially responsible alternative jet fuel with stable supply to significantly 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

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Interagency Coordination on Bioenergy R&D

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Feedstock-
Conversion
Interface

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

Agile
BioFoundry
(ABF)

Separations
Consortium

Chemical
Catalysis for
Bioenergy
(ChemCatBio)

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Bioenergy Partners

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☐ Bioenergy Successes from FY16

- Industry
 - DuPont Opens World's Largest Commercial-Scale Cellulosic Ethanol Facility
- 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
 - PNNL's hydrothermal liquifaction converts wet sewage sludge to biocrude oil in less than 60 minutes – the process is being licensed to Genefuel
 - NREL scientists developed a process known as Combined Algal Processing, which is highly effective at producing ethanol from algae
 - NREL partnership with W.R. Grace, and Zeton Inc., to build a unique pilot-scale facility that can produce biomass-derived fuel intermediates using existing petroleum refinery infrastructure
 - The Consortium for Algal Biofuel Commercialization (CAB-Comm), led by the University of California, San Diego, released its final report which covers six years of algal research





Bioeconomy 2017: Domestic *Resources for a Vibrant Future*

Google:
Bioeconomy 2017

July 11–12, 2017

**Sheraton Pentagon City
900 South Orme Street
Arlington, VA 22204**

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- ❑ 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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