U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# DOE Bioenergy Energy Technologies Office Update

Biomass R&D Technology Advisory Committee Q4 2018 Meeting

November 15, 2018

# Bioenergy Technologies Office (BETO)

The Bioenergy Technologies Program focuses on early stage applied research and development (R&D) of transformative, sustainable bioenergy and bioproducts technologies that can support a growing bioeconomy and a more energy secure and prosperous nation.

| (Dollars in Thousands) | FY 2017 Enacted | FY 2018 Enacted | FY 2019 Enacted |
|---|---|---|---|
| Advanced Algal Systems | 30,000 | 30,000 | 32,000 |
| Feedstock Supply and Logistics | 20,000 | 29,000 | 30,000 |
| Conversion Technologies | 90,230 | 103,000 | 95,000 |
| Advanced Development and Optimization (formerly Demonstration and Market Transformation) | 54,041 | 54,545 | 57,500 |
| Strategic Analysis and Cross-cutting Sustainability/ TBD | 10,729 | 5,000 | 11,500 |
| **Total** | **205,000** | **221,545** | **226,000** |

# FY17 Biomass R&D Initiative Selections

Two DOE selections announced on May 9, 2018*

- **University of Tennessee** ($1.4 million) will be developing an integrated biorefinery design that combines the production of liquid fuels and renewable chemicals to verify production of affordable cellulosic ethanol.

- **Northwestern University** ($1.6 million) will be developing a rapid synthesis of next-generation biofuels and bioproducts from lignocellulosic biomass. The project will employ several strategies to reduce the timeframe of discovering biosynthetic pathways to optimize fuel and chemical production, including bottom-up engineering principles, computational models, and cell-free framework systems.

* https://www.energy.gov/eere/articles/department-energy-selects-3-million-research-projects-advance-biofuels-bioenergy-and

# FY18 Funding Opportunities

- **BETO released 4 Funding Opportunities in May**
  - Affordable and Sustainable Energy Crops
  - Efficient Carbon Utilization in Algal Systems
  - Process Development for Advanced Biofuels and Biopower
  - BioEnergy Engineering for Products Synthesis
- **Peer Reviewed over 200 proposals**
- **Announced 36 selections with $80 million in DOE Federal Share on September 4**
  - Half of our selectees are new to BETO's portfolio as primary recipients

- https://www.energy.gov/articles/department-energy-announces-36-projects-bioenergy-research-and-development

# Affordable and Sustainable Energy Crops

Goal: New varieties and improved management strategies to produce better, cheaper energy crops for energy production

- Improved yields
- Lower water, nutrient and energy requirements
- Marginal lands

- Three selections totaling $14.6 million
    - 3 Growing Regions
    - Switchgrass, energy cane, biomass sorghum, miscanthus

# Efficient Carbon Utilization in Algal Systems

Goal: Increase Algal Productivity by increasing uptake of carbon dioxide

- Topic 1. $CO_2$ Utilization Improvements – taking emissions from industrial exhaust and feeding it into an algae system
  - Five selections totaling $10.6 million
  - Strategies include: algal strain development, solvents and additives, purification technologies, physical transfer technologies
- Topic 2. Direct Air Capture - earlier-stage R&D on directly capturing $CO_2$ from ambient air
  - Two selections totaling $4.3 million
  - Strategies include: surface layer enzymes, solid adsorbents

# BioEnergy Engineering for Products Synthesis

Goal: Increase efficiencies of converting feedstocks into desired fuels and products

- Topic 1. Chemical Catalysis for Bioenergy Consortium Industrial Partnerships – developing novel, chemical catalysts to enhance thermocatalytic conversion strategies
  - One selection totaling $1.9 million
  - Strategies include: multi-layered catalyst for waste biogas conversion to liquid fuel
- Topic 2. Agile BioFoundry Industrial Partnerships – engineering biology to enhance biological conversion strategies
  - Three selections totaling $5.3 million
  - Target products include: polyurethane foams, polymers, coatings
- Topic 3. Performance Advantaged Bioproducts - materials that could be better made from biomass feedstocks
  - Four selections totaling $7.5 million
  - Target products include: PET (#1 plastic), polymers, packaging materials

# BioEnergy Engineering for Products Synthesis (continued)

- Topic 4. Biofuels and Bioproducts from Wet Organic Waste Streams – new strategies to convert wet wastes
  - Three selections totaling $5.6 million
  - Strategies include: producing short-chain fatty acids through modified anaerobic digestion; corn fiber to biodiesel and products; waste paper sludge to $C_{12}$-$C_{14}$ hydrocarbons
- Topic 5. Rewiring Carbon Utilization – converting waste carbon gases to products
  - Three selections totaling $4.5 million
  - Target products include: ethylene glycol, isopropanol, propene
- Topic 6. Lignin Valorization – increasing efficiency and lower cost of converting lignin to higher value products
  - Two selections totaling $3.4 million
  - Target products include: thermoset polymers, spray insulation, carbon fiber

# Process Development for Advanced Biofuels and Biopower

Goal: developing low-cost, efficient *integrated* systems for the production of biofuels, bioproducts and biopower

- Topic 1. Drop-in Renewable Jet Fuel Blendstocks
  - Four selections totaling $10.7 million
  - Strategies include: fermentation & catalytic upgrading; hybrid process for upgrading biocrude; hydrothermal treatment of waste grease and catalytic upgrading; reforming biogas & Fischer-Tropsch
- Topic 2. Drop-in Renewable Diesel Fuel Blendstocks
  - Three selections totaling $7.3 million
  - Strategies include: catalytic conversion of cellulosic ethanol; pyrolysis and hydroprocessing of biocrude; co-processing pyrolysis oils and vacuum gas oils in a Fluid Catalytic Cracker
- Topic 3. Biomass, Biosolids and Municipal Solid Waste to Energy
  - Three selections totaling $5.0 million
  - Strategies include: Metal Organic Framework Catalysts for biogas clean-up; anaerobic membrane bioreactor with ammonia recovery; upgrading to bio-oils

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

Goal: Develop bio-derived blendstocks for co-optimized mixing controlled compression ignition (MCCI) diesel engines for medium- and heavy-duty vehicles

- Five selections totaling $8.0 million (in partnership with the Vehicle Technologies Office)
- Performance benefits include: enhance engine efficiency, reduce sooting propensity, increase cetane number, increase energy density, enhance cold weather behavior of the fuel, and help reduce cold start emissions of diesel engines

# Small Business Innovation Research

FY19 Phase I, Release II SBIR Topics just announced on October 29

- $200K awards in Phase I with possibility of $1M in Phase II
- Letters of intent due 12/17
- Full proposals due 2/4
- More info: https://science.energy.gov/sbir/funding-opportunities/

Bioenergy topic areas:

**1. Cell-Free Biochemical Platforms to Optimize Biomass Carbon Conversion Efficiency**

- Utilizing biocatalysts (enzymes) to perform complicated biochemical reactions that offer benefits in comparison to industrial inorganic catalysts
- Interested in enzyme longevity, production hosts, and cofactor regeneration

**2. Reshaping Plastic Design and Degradation for the Bioeconomy**

- Targeting bio-derived plastics designed with end-of-life considerations in mind that can enable a circular carbon economy
- Exploring challenges in plastics degradation, such as crystallinity, feedstock contamination, and enzymatic deconstruction

**3. Algae Engineering Incubator**

- Open to all applications proposing technologies that facilitate the goals of the Advanced Algal Systems R&D subprogram through non-biological, engineering approaches
- Intentionally broad to bring in novel approaches

# Appendix

# FY17 Biomass R&D Initiative Selections

DOE selections announced on May 9, 2018:
https://www.energy.gov/eere/articles/department-energy-selects-3-million-research-projects-advance-biofuels-bioenergy-and

| Selections | Approach/Objective | DOE ($M) |
|---|---|---|
| **University of Tennessee** | **Condensed Phase Catalysis Technology for Fuels and Carbon Products:** UT will be developing an integrated biorefinery design that combines the production of liquid fuels and renewable chemicals to verify production of affordable cellulosic ethanol. | $1.4 |
| **Northwestern University** | **Engineered reversal of the β-oxidation cycle in clostridia for the synthesis of fuels and chemicals:** NU will be developing a rapid synthesis of next-generation biofuels and bioproducts from lignocellulosic biomass. The project will employ several strategies to reduce the timeframe of discovering biosynthetic pathways to optimize fuel and chemical production, including bottom-up engineering principles, computational models, and cell-free framework systems. | $1.6 |

# Affordable and Sustainable Energy Crops

Goal: Produce better, cheaper energy crops that can be used for energy production.

- Improved yields
- Lower water, nutrient and energy requirements
- Marginal lands

| Selections | Approach/Objective | DOE ($M) |
|---|---|---|
| **University of Illinois at Urbana-Champaign (IL)** | Switchgrass/seasonal grasses on marginal lands in SD, NE, IA, and IL. Machine learning techniques for performance, best practices, and cost reductions. | $5.0 |
| **Texas A&M AgriLife Research (TX)** | Advanced energy cane and biomass sorghum on agricultural and marginal lands in TX, LA, MS, GA, and FL. Characterize seasonal dynamics; quantify environmental impacts; and optimize production. | $5.0 |
| **North Carolina State University (NC)** | New hybrid varieties of miscanthus on marginal lands in NC to increase biomass yields, improve soil, and enhance crop production. | $4.6 |

# Efficient Carbon Utilization in Algal Systems

Goal: Increase Algal Productivity by increase uptake of carbon dioxide

- Topic 1 – Industrial waste gas streams
- Topic 2 – Direct air capture technologies

| Selections | Approach/Objective | DOE ($M) |
|---|---|---|
| **Topic 1: $CO_2$ Utilization Improvements** | | |
| **Colorado State University (CO)** | Algae organism engineering, membrane design, and computer modeling to increase carbon utilization | $2.1 |
| **Arizona State University (AZ)** | Nitrogen-based solvent additive and novel nanobubble feeding system | $2.5 |
| **Global Algae Innovations (CA)** | Low cost, high efficiency system using bicarbonate regeneration and $CO_2$ feed controls | $2.5 |
| **Arizona State University (AZ)** | Membrane technology to purify $CO_2$ from an untreated industrial gas stream | $2.0 |
| **Duke University (NC)** | Marine algae engineering, calcium carbonate delivery system | $1.5 |
| **Topic 2: Direct Air Capture Systems** | | |
| **MicroBio Engineering, Inc. (CA)** | Surface-layer enzymes to increase dissolved $CO_2$ in algal ponds | $2.3 |
| **Georgia Tech (GA)** | Chemically-modified solid adsorbents for photobioreactors | $2.0 |

# BioEnergy Engineering for Products Synthesis

Goal: Increase efficiencies of converting feedstocks into desired fuels and products

| Selections | Approach/Objective | DOE ($M) |
|---|---|---|
| **Topic 1: Chemical Catalysis for Bioenergy Industrial Partnerships** | | |
| **University of South Florida (FL)** | Conversion of waste biogas to liquid fuel using a novel, multilayered catalyst | $1.9 |
| **Topic 2: Agile BioFoundry Industry Partnership Initiative** | | |
| **Lygos, Inc. (CA)** | Conversion of cellulosic sugars to malonate, a chemical used for coatings through the use of synthetic biology/machine learning | $2.0 |
| **ZymoChem (CA)** | Conversion of cellulosic sugars to a super-absorbent polymer through metabolic pathways | $1.3 |
| **University of California, San Diego (CA)** | Conversion of cellulosic sugars to polyurethane foams using synthetic biology and machine learning on algae | $2.0 |
| **Topic 3: Performance Advantaged Bioproducts** | | |
| **Iowa State University (IA)** | Systematic process development for identifying biomass-derived molecules for polymers/materials | $2.5 |
| **University of California, Berkeley (CA)** | Produce infinitely recyclable packaging materials from biomass | $2.0 |
| **Georgia Tech (GA)** | Produce biobased PET (#1 plastic)-replacement from cellulose and chitin | $1.0 |
| **Arzeda (WA)** | Conversion of biomass to a novel polymer precursor (MBL) using a hybrid biological/chemical process | $2.0 |

# BioEnergy Engineering for Products Synthesis (Continued)

| Selections | Approach/Objective | DOE ($M) |
|---|---|---|
| **Topic 4: Biofuels and Bioproducts from Wet Organic Waste Streams** | | |
| **Visolis (CA)** | Altering the chemistry of anaerobic digestion to produce mevaloacetone as a fuel/chemical platform molecule | $2.0 |
| **Xylome Corporation (WI)** | Engineering microbes to convert waste corn fiber into lipids for upgrading to biodiesel/high-value products | $1.1 |
| **North Carolina State University (NC)** | Conversion of paper sludge waste (cellulosic) to C12-C14 hydrocarbons through furan intermediates | $2.5 |
| **Topic 5: Rewiring Carbon Utilization** | | |
| **Montana State University (MT)** | Electrocatalysis of $CO_2$ to formate, followed by biological upgrading to ethylene glycol | $1.5 |
| **LanzaTech, Inc. (IL)** | Conversion of $CO_2$ to CO, followed by biological upgrading to isopropanol | $1.5 |
| **Johns Hopkins University (MD)** | Catalytic conversion of $CO_2$ to methanol and formate to produce propene | $1.5 |
| **Topic 6: Lignin Valorization** | | |
| **Clemson University (SC)** | Conversion of lignin to high-performance carbon fiber and spray insulation through solvent fractionation | $1.8 |
| **Spero Energy, Inc. (CA)** | Conversion of lignin to high-performance thermoset polymers (e.g., fiberglass, car parts) through catalysis | $1.6 |

# Process Development for Advanced Biofuels and Biopower

Goal: developing low-cost, efficient *integrated* systems for the production of biofuels, bioproducts and biopower

| Selections | Approach/Objective | DOE ($M) |
| --- | --- | --- |
| **Topic 1: Drop-in Renewable Jet Fuel Blendstocks** | | |
| **Technology Holding LLC (UT)** | Fermentation of cellulosic sugars to isoprene and catalytic upgrading to a high energy density jet fuel | $2.5 |
| **Washington State University (WA)** | A hybrid process to upgrade bio-crude (from pyrolysis and hydrothermal liquefaction) to jet fuel | $2.8 |
| **Applied Research Associates (FL)** | Hydrothermal cleanup of waste brown grease to make free fatty acids; then catalytically transform to hydrocarbons | $2.4 |
| **Gas Technology Institute (IL)** | Reforming of $CO/CO_2$-rich biogas to syngas; fluidized bed Fischer Tröpsch conversion to jet fuel | $3.0 |
| **Topic 2: Drop-in Renewable Diesel Fuel Blendstocks** | | |
| **LanzaTech, Inc. (IL)** | Improved catalytic conversion of cellulosic ethanol to diesel | $2.5 |
| **Research Triangle Institute (NC)** | Catalytic biomass pyrolysis and hydroprocessing of bio-crude to diesel fuel | $2.6 |
| **West Biofuels Development, LLC (CA)** | Co-processing pyrolysis bio-oil with vacuum gas oil in a Fluid Catalytic Cracker. | $2.2 |
| **Topic 3: Biomass, Biosolids, and Municipal Solid Waste to Energy** | | |
| **Mosaic Materials (CA)** | Metal organic framework catalysts to remove $CO_2$ from biogas | $1.4 |
| **University of Illinois at Urbana-Champaign (IL)** | Novel anaerobic membrane bioreactor with ammonia recovery / electrolysis to produce biogas and $H_2$ from wastewater | $1.6 |
| **Worcester Polytechnic Institute (MA)** | Upgrading the biomass and food waste fractions of MSW to bio-oil, soil amendment, and purified lignin | $2.0 |

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

Goal: Develop bio-derived blendstocks for co-optimized mixing controlled compression ignition (MCCI) diesel engines for medium- and heavy-duty vehicles

| Selections | Approach/Objective | DOE ($M)* |
|---|---|---|
| **Auburn University (AL)** | Bio-production and evaluation of renewable butyl acetate as a desirable bio-blendstock for diesel fuel | $2.0 |
| **SUNY University at Stony Brook (NY)** | Naphthenic biofuel-diesel blend for optimizing mixing controlled compression ignition combustion | $1.5 |
| **University of Massachusetts Lowell (MA)** | Renewable fuel additives from woody biomass | $1.0 |
| **University of Michigan (MI)** | Tailored Bio-blendstocks with Low Environmental Impact to Optimize MCCI Engines | $2.0 |
| **University of Wisconsin-Madison (WI)** | Mono-ether and alcohol bio-blendstocks to reduce the fuel penalty of mixing controlled compression ignition engine aftertreatment | $1.5 |

* Includes funding from the Vehicle Technologies Office