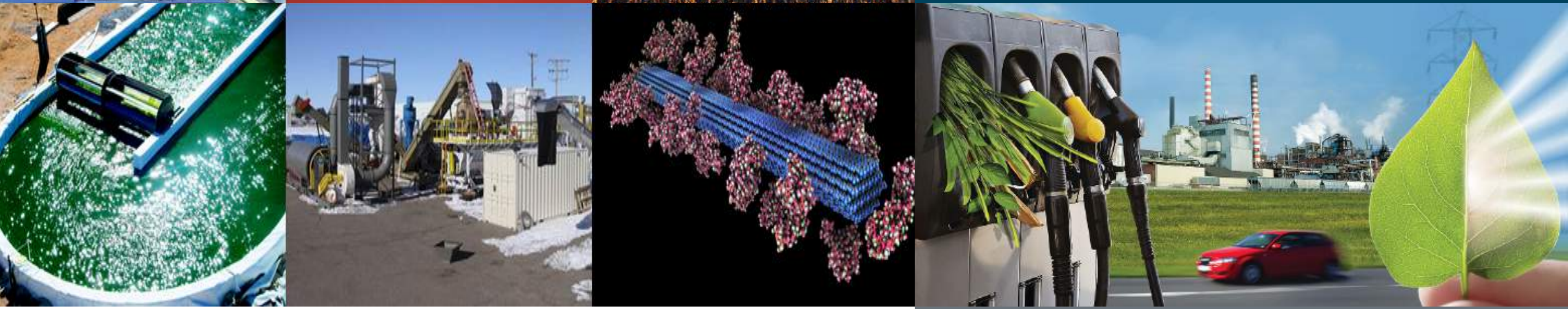
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



2019 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BIOENERGY TECHNOLOGIES OFFICE

Advanced Development & Optimization (ADO) Program Overview

March 4, 2019

Jim Spaeth

Program Manager

Advanced Development & Optimization

Advanced Development & Optimization Agenda

- Goals
- History
- Focus
- Recent FOAs
- Co-Optima
- The Team
- Peer Reviewers

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Goals and Milestones

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Advanced Development and Optimization

Strategic Goal:

- Develop and test bioenergy production technologies through verified proof of performance in engineering-scale systems and relevant environments
- Research ways to enhance scaling and integrate bioenergy production processes
- Identify innovative end uses – Co-Optima

Systems Research and Development to Enable a Robust Bioenergy

ADO: Major Milestones

By 2022, verify integrated systems research at engineering-scale for hydrocarbon biofuel technologies at mature modeled MFSP of $3.00/GGE with a minimum 50% reduction in emissions relative to petroleum-derived fuels.

By 2030, verify integrated systems research at engineering-scale for hydrocarbon biofuel technologies at mature modeled MFSP of $2.50/GGE with a minimum 50% reduction in emissions relative to petroleum-derived fuels, using economically advantaged feedstocks to produce renewable fuels and bioproducts.

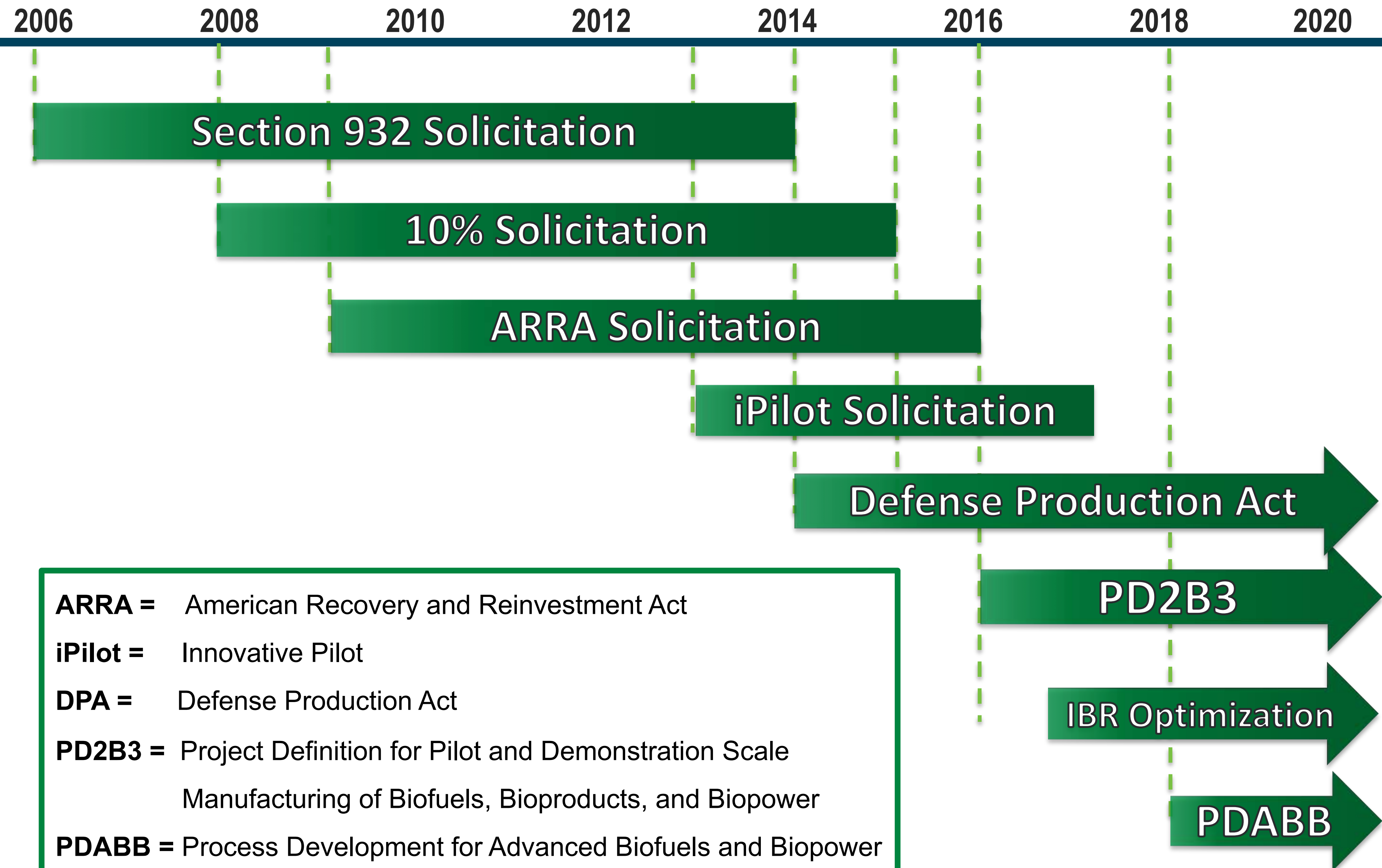
Evolution of Program Structure and Focus

Demonstration & Deployment
2009-2013

Demonstration & Market Transformation
2014-2017

Advanced Development & Optimization
2017 →

ADO Program FOA History



ARRA = American Recovery and Reinvestment Act

iPilot = Innovative Pilot

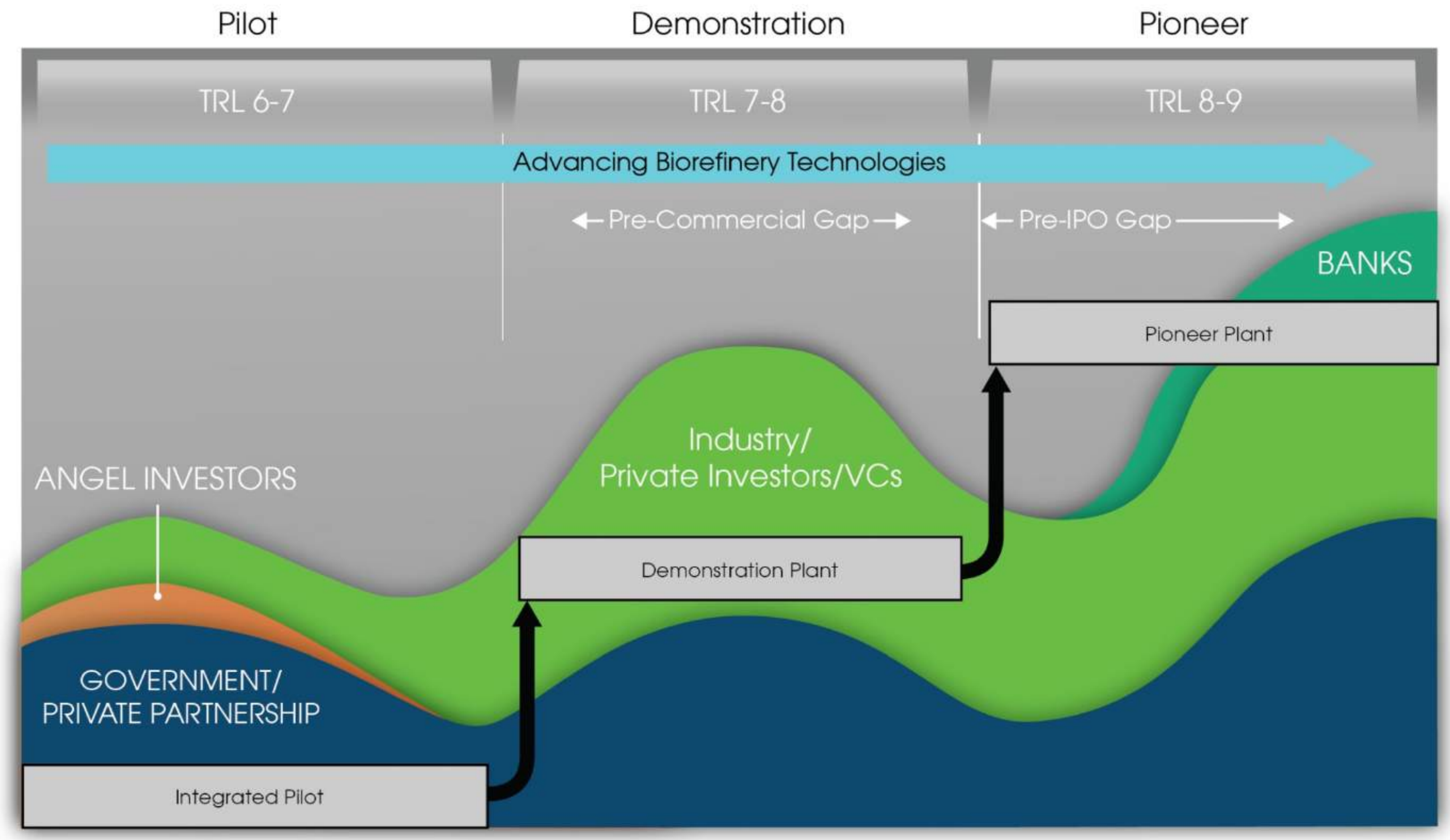
DPA = Defense Production Act

PD2B3 = Project Definition for Pilot and Demonstration Scale Manufacturing of Biofuels, Bioproducts, and Biopower

PDABB = Process Development for Advanced Biofuels and Biopower

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Prior Focus on Pilot, Demonstration and Pioneer Scales



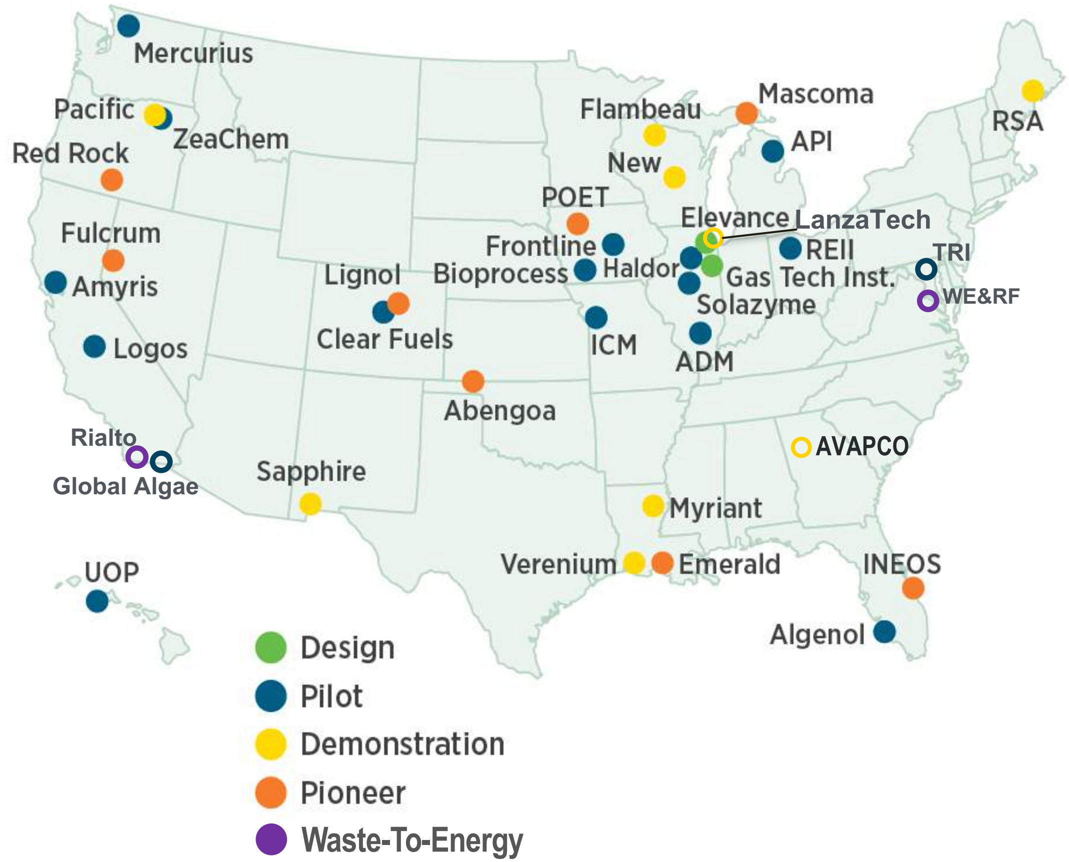
Distribution of Projects Supported since 2006

BETO has supported since 2006, a total of 42 pilot, demonstration and pioneer-scale facilities

- In 2016 selected six new projects

BETO investments have allowed industry partners to:

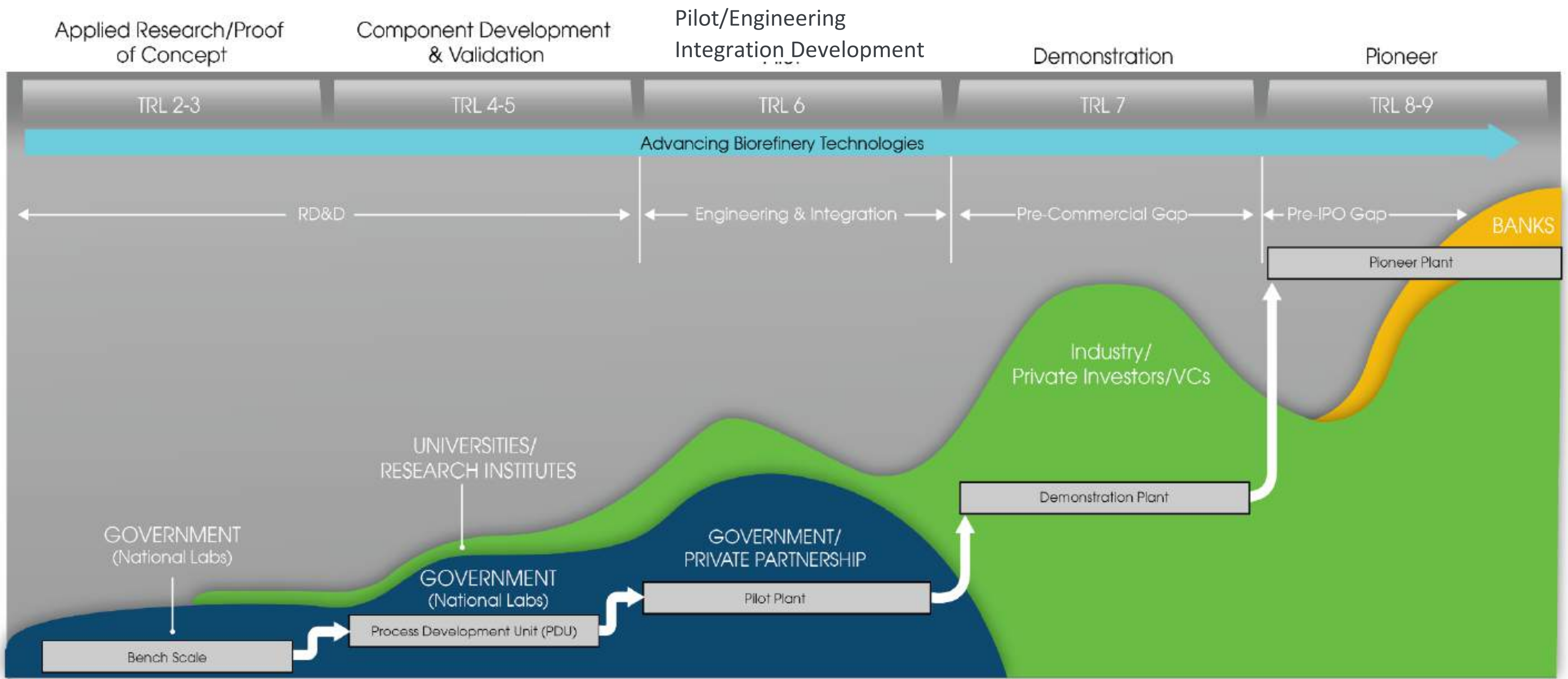
- Enable the development of first-of-a-kind IBRs
- Prove conversion technologies at scale
- Validate techno-economic assessments, and
- Gain investor confidence



Open circle designates a recent PD2B3 FOA selection

ADO Focus and Approach

Moving to Earlier TRL Focus



Average Total Project Cost				
$1-5 million	$5-10 million	$25-50 million	$50-100 million	$250-500 million +
Average Biomass Throughput				
Grams/day	Kilograms/day	<50 Tonnes/day	50-250 Tonnes/day	+ 250 Tonnes/day
Production Volumes				
mL/L (batch)	Liters/ Gallons (batch)	0.1-1 M gpy (campaign)	1-10 M GPY (extended campaign/ continuous)	>50 M GPY (continuous)

● GOVERNMENT ● PROJECT RECIPIENTS & PARTNERS ● BANKS

DOE Technology Readiness Levels

- TRL indicates the maturity level of a given technology or component
- TRL is **not an indication** of the quality of technology implementation in the design, integration readiness or system success

Tech Development Level	TRL	Definition
Systems Operations	9	Actual system operated over full range of expected mission conditions
System Commissioning	8	Actual system completed and qualified through test and demonstration
	7	Full-scale, similar system demonstrated in relevant environment
Technology Demonstration	6	Engineering / pilot scale, similar system validation in relevant environment
Technology Development	5	Laboratory scale, similar system validation in relevant environment.
	4	Component and/or system validation in laboratory environment.
Research to Prove Feasibility Basic Technology Research	3	Analytical and experimental critical function and/or characteristic proof of concept
	2	Technology concept and/or application formulated
	1	Basic principles observed and reported

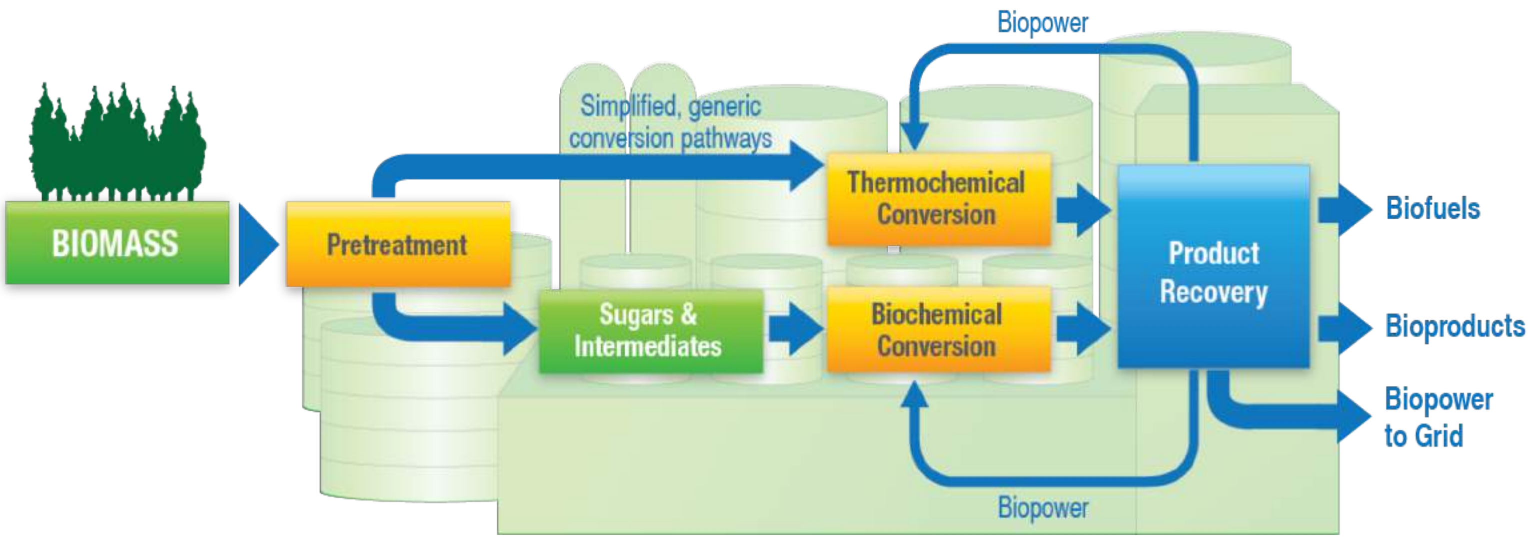
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Scaling – NREL Fermentation Example

500-mL Multi-Flask

	Lab/Bench		Pilot	Demonstration
Reactor Volume	0.1 L Shake flask	1 – 10 L Batch reactor	1000 - 10,000 L	100,000 L
Feedstock Loading	0.1 – 10 g	100 - 1000 g	100 – 1000 kg	10,000 kg
Objective	Organism Screening		Process R&D	Market Development
Fraction of Commercial Scale	1/100,000,000	1/1,000,000	1/1,000	1/100 – 1/10

ADO Key Challenges



First-of-a-Kind Technology Development	Feedstock Processing/Handling
Process Integration	Technology Scaling Uncertainty Scaling Tools
Materials Compatibility, and Equipment Design and Optimization	Variations in Performance at Different Scales

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

National Lab PDUs Within ADO Portfolio

Advanced Biofuels PDU
LBNL

Biomass Feedstock PDU
INL

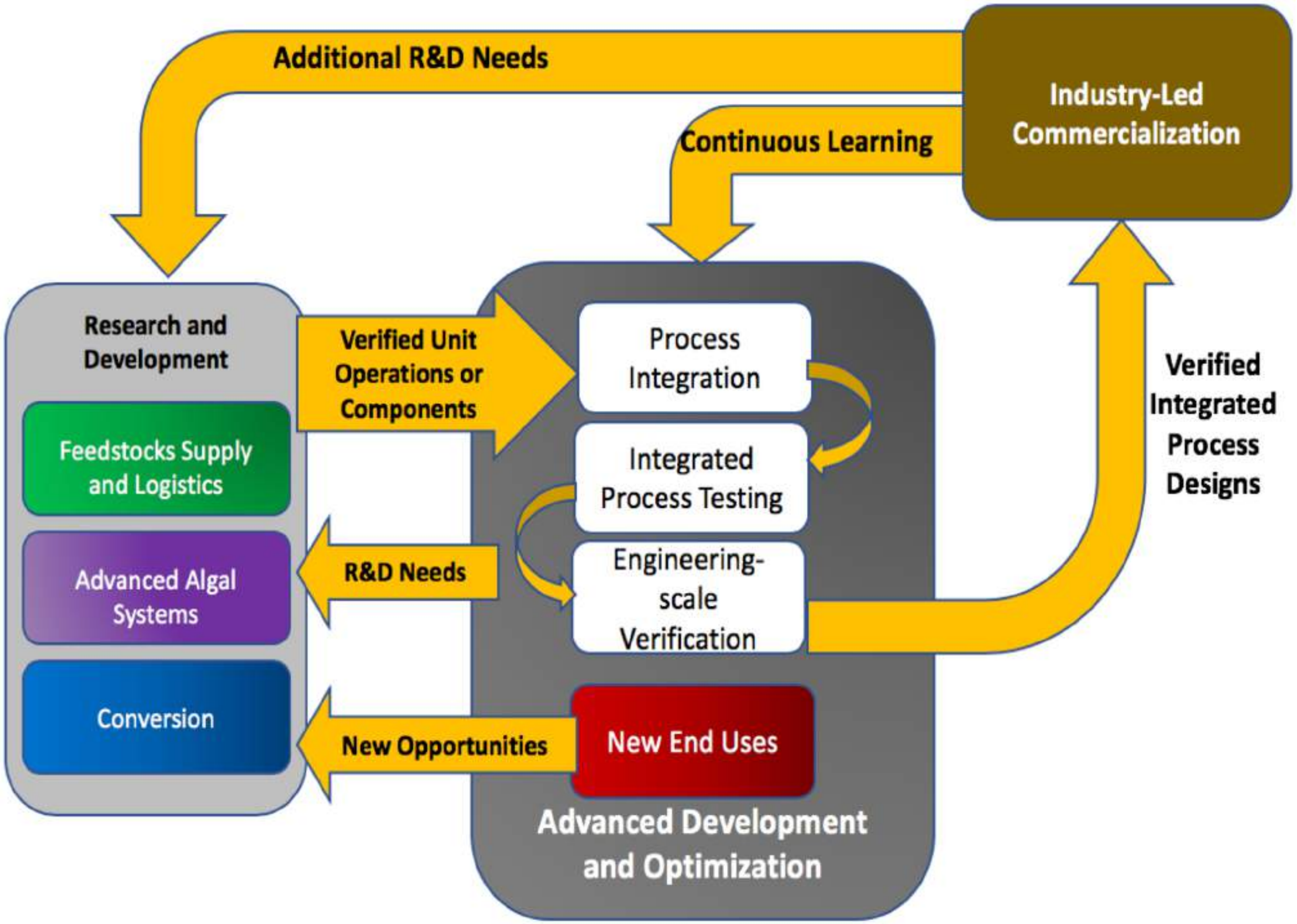
Integrated Biorefinery PDU
NREL

Hydrothermal Liquefaction (HTL) PDU
PNNL

Thermochemical PDU - NREL

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ADO Interface with R&D Programs and Industry



ADO Project Management Approach

- Modify as appropriate for scale and objective (i.e., verifications)
- Review Experimental Plans, Fabrication, Execution

Initiation		Definition	Execution		Transition / Closeout
Pre-conceptual Design	Conceptual Design / FOA/Selection	Preliminary Design	Final Design	Construction	Startup, Commissioning, and Operation

CD-0 Approve Mission Need

CD-1 Preliminary Planning

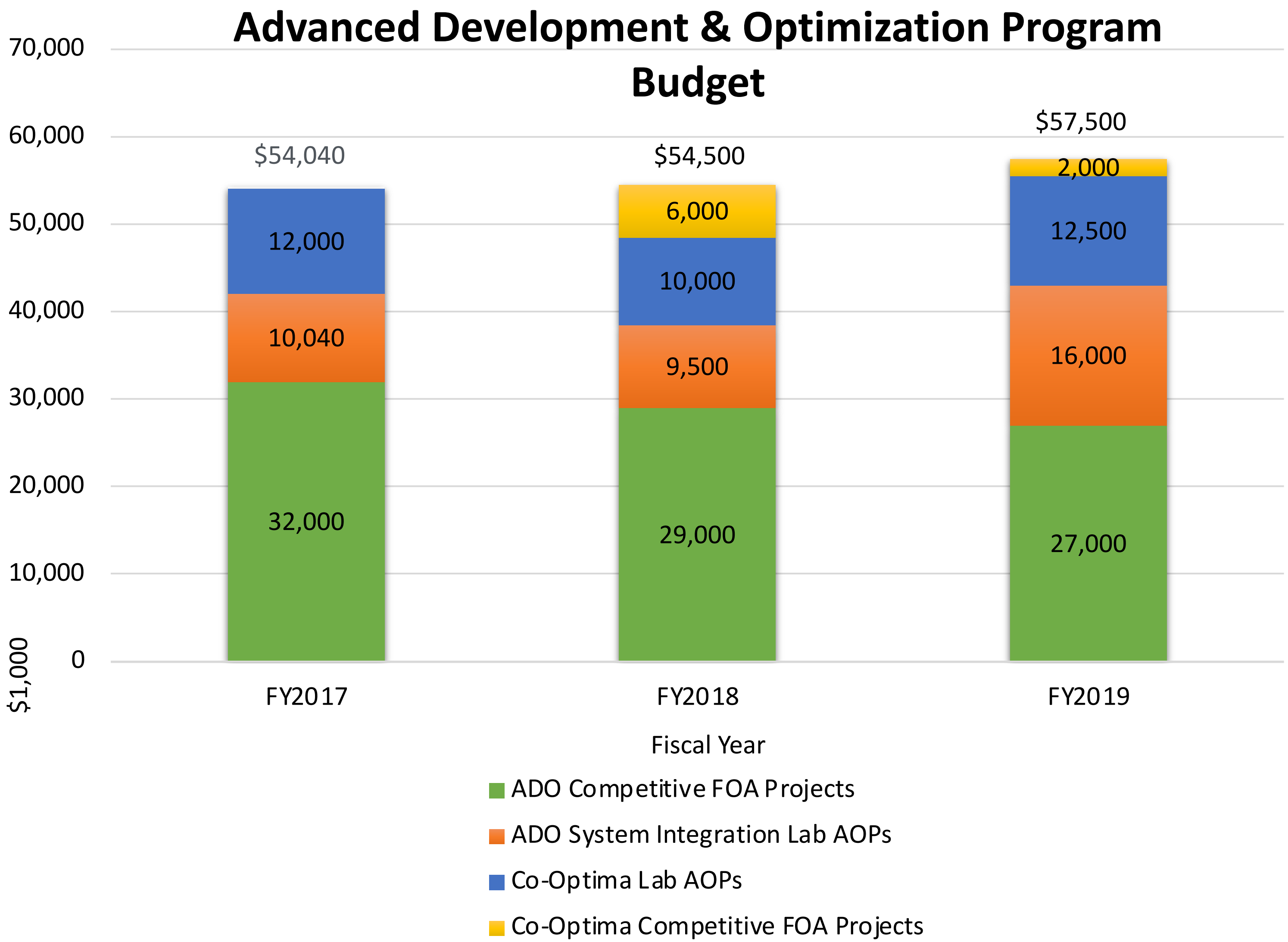
CD-2 Approve Performance Baseline

CD-3 Approve Start of Construction

CD-4 Approve Operation

Repeat within each TRL

ADO Budgets FY17-18-19



U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Recent FOAs

Process Development for Advanced Biofuels and Biopower (PDABB) FOA

Topic Area 1: Drop-in Renewable Jet Fuel Blendstocks	Technology Holding Sustainable Solutions; ARA; Washington State University; gti
Topic Area 2: Drop-in Renewable Diesel Fuel Blendstocks	WestBiofuels; RTI International; LanzaTech
Topic Area 3: Biomass, Biosolids, and Municipal Solid Waste to Energy	Worcester Polytechnic Institute 1865; Illinois University of Illinois at Urbana-Champaign; mosaic materials

On September 14, 2018, DOE announced up to $22 million for 10 selections

IBR Optimization Selections - FY17

- Announced on September 20, 2017
- Up to **$15M** for eight projects
  - **Topic Area 1:** Continuous handling of solid materials and feeding systems to reactors
  - **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 and reactor feeding systems

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

PD2B3 FOA Update – FY16

- Project Definition for Pilot and Demonstration Scale Manufacturing of Biofuels, Bioproducts, and Biopower (PD2B3)

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**
Rialto Bioenergy Facility, LLC	**Water Research Foundation**

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Defense Production Act (DPA) Initiative

Begun in July 2011, Agriculture, Energy, and Navy

Committed $510 M ($170 M from each agency)

Hydrocarbon jet and diesel biofuels in the near term

- Domestically produced fuels from non-food feedstocks.
- Drop-in, fully compatible, MILSPEC fuels
- Demonstration of the production and use of more than 100 million gallons per year **will dramatically reduce risk for drop-in biofuels production and adoption**.

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, Air bp, Cathay Pacific	10.0
Red Rock Biofuels	Lakeview, OR	Woody Biomass	Gasification – Fischer Tröpsch (FT)	FedEx, Southwest Airlines	12.0

ADO Lab AOP Projects

An Affordable Advanced Biomass Cookstove with Thin Film Thermoelectric Generator	LBNL
Development and Standardization of Techniques for Bio-oil Characterization	NREL
The Engineering of Catalyst Scale Up	NREL
Codes and Standards in IBR's	ORNL
Feedstock to Function: Improving Biobased Product and Fuel Development Through Adaptive Technoeconomic and Performance Modeling	LBNL
Integrated Computational Tools to Optimize and De-Risk Feedstock Handling & High-Pressure Reactor Feedings Systems: Application to Red Rock Biofuels' Biorefinery	NREL
Strategies for Co-processing in Refineries	NREL
Materials Degradation in Biomass Derived Oil	ORNL
Sustainable Production of JP-10	LANL
Analysis for JET High Performance Fuels	SNL
GARDN Collaboration U.S. - Canada Aviation Fuels at PNNL	PNNL
Evaluation of Bio-oils for Use in Marine Engines	ORNL

Co-Optima

Co-Optima Overview

Co-Optima's overarching goal: better fuels and better vehicles **sooner**

Engine R&D Fuel R&D

Objective: Advance the underlying science needed to develop fuel and engine technologies that will work in tandem to achieve significant efficiency and emissions benefits

- Two DOE Offices:
  - Bioenergy Technologies Office
  - Vehicle Technologies Office
- Nine National Labs
- More than 20 university and industry partners

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

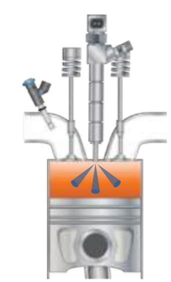
Co-Optima Approach

Light-Duty

- Near-term opportunity improved efficiency at higher load (Boosted Spark Ignition)
- Mid-term opportunity improved efficiency across drive-cycle (Multi-Mode Spark Ignition/Advance Compression Ignition)

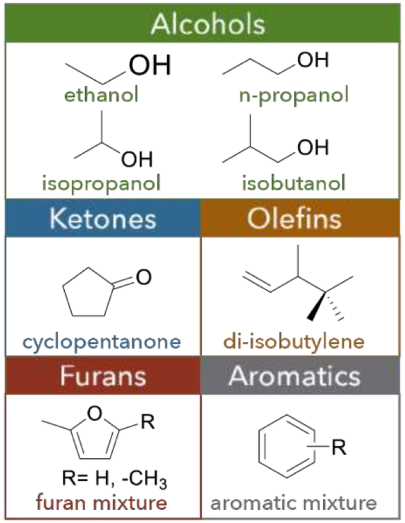
Medium/Heavy-Duty

- Near-term opportunity improved engine emissions (Mixing Controlled Compression Ignition)
- Longer-term high risk, high reward opportunity for improved efficiency and emissions (Kinetically Controlled Compression Ignition)

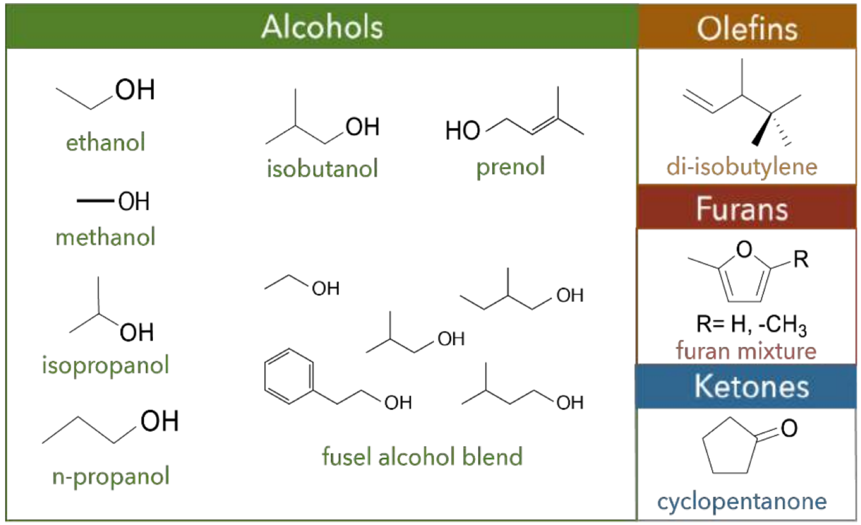


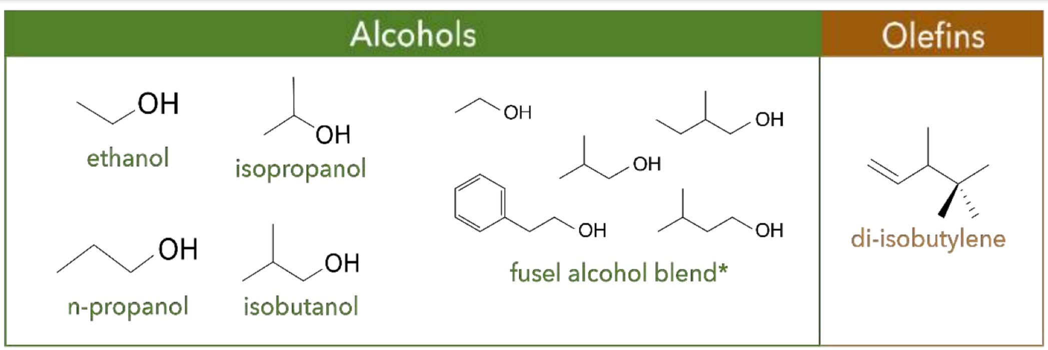
FY18 Programmatic Accomplishment: Final List of Blendstocks for Boosted Spark Ignition

Preliminary (2017) list of blendstocks selected for more detailed evaluation



Blendstocks which increase turbocharged engine efficiency the most





*Fusel alcohol blend: 57% isobutanol, 15% phenyl ethanol, 12% 3-methyl-1-butanol, 10% ethanol, 6% 2-methyl-1-butanol

Highest efficiency blendstocks with fewest barriers identified by Co-Optima

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Co-Optima FY18 FOA: Bioblendstocks to Optimize MCCI Engines

Awardees will develop and demonstrate single- or multi-component bioblendstocks for use in medium- and heavy-duty mixing controlled compression ignition (MCCI) engines.

Bioblendstocks will improve at least two of 4 properties: energy density, sooting propensity, cetane number, and cold weather behavior.

Auburn University (Auburn, AL) - In partnership with Microvi Biotech, Cornell University, University of Alabama, EcoEngineers, and Virginia Tech, Auburn will develop enhanced bioprocess methods for butyl acetate production, and test its MCCI potential through droplet and engine testing.

SUNY-Stony Brook (Stony Brook, NY) - In partnership with RTI International, Stony Brook will develop and test a naphthenic distillate as an MCCI bioblendstock.

University of Massachusetts Lowell (Lowell, MA) - In partnership with University of Maine and Mainstream Engineering, will develop a bioblendstock of upgraded fast pyrolysis bio-oil, and test its MCCI potential through engine testing.

University of Michigan (Ann Arbor, MI) - In partnership with Penn State University and Volvo Group Truck Technology, Michigan will develop a bioblendstock of upgraded algae hydrothermal liquefaction liquids, and test its MCCI potential through engine and particulate matter testing.

University of Wisconsin-Madison (Madison, WI) - Will develop a catalytic process for ethanol conversion to C8+ ethers, and test the potential for the bioblendstock to reduce the fuel penalty of MCCI engine after treatment

The Team

BETO ADO Team

Jim Spaeth
Program Manager

Liz Moore
Technology Manager

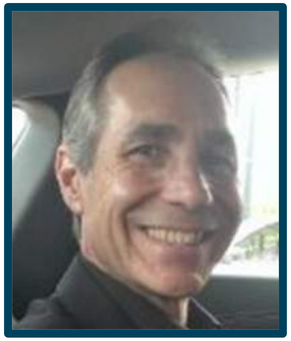
Mark Shmorhun
Technology Manager

Mohan Gupta
Technical Advisor (FAA/DOT)

Siva Sivasubramanian
ORISE Fellow

Josh Messner, AST
Team Leader

Remy Biron, AST
Project Monitor



Art Wiselogel, AST
Project Monitor

Camryn Sorg, The Building People
Program Support

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BETO ADO - Co-Optima Team

Alicia Lindauer
Technology Manager,
Co-Optima Lead

Trevor Smith, AST
Project Monitor

Robert Natelson, AST
Project Monitor

Camryn Sorg, The Building People
Program Support

Co-Optimization of
Fuels & Engines

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Peer Review

ADO Projects Presenting at Peer Review

POET | DSM Advanced Biofuels

Los Alamos National Laboratory EST. 1943

South Dakota School of Mines & Technology

AVAPCO

UIC

TRI

Global Algae Innovations

Anaergia Breaking Barriers to Sustainability

Rialto Bioenergy Facility LLC

Pacific Northwest National Laboratory

Ohio State

NREL National Renewable Energy Laboratory

Berkeley Lab

The Water Research Foundation

UCF

Cornell University Founded A.D. 1865

forestconcepts™ bioenergy

White Dog Labs

LanzaTech capturing carbon. fueling growth.

Texas A&M AgriLife Research

Purdue University

MIT

Red Rock Biofuels

RTI International

Fulcrum Bioenergy

Sandia National Laboratories

Oak Ridge National Laboratory

Clemson University

U.S. Department of Energy | Energy Efficiency & Renewable Energy

Reviewers – ADO Integration & Scaling (I&S) Session

Name	Affiliation
Dr. Raghubir Gupta (Lead)	Susteon, Inc.
Mr. Mike Fatigati	Independent Consultant
Dr. Daniel Lane	Sallie Consulting
Ms. Andrea Slayton	Slayton Technical Services
Mr. Mark Warner	Warner Advisors
Dr. Luca Zullo (Only Wednesday)	VerdeNero

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Reviewers – ADO Analysis & Modeling (A&M) Session

Name	Affiliation
Dr. Luca Zullo (Lead)	VerdeNero
Mr. Mike Fatigati	Independent Consultant
Dr. Raghubir Gupta	Susteon, Inc.
Dr. Daniel Lane	Sallie Consulting
Mr. Mark Warner	Warner Advisors

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Reviewers – Co-Optima Session

Name	Affiliation
Harry Baumes (Lead)	USDA, Retired
Charles Abbas	IBiocat
Bhupendra Khandelwal	University of Sheffield
Kristin Lewis	DOT-Volpe
Cory Phillips	Phillips 66
Steve Przesmitzki	Aramco

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Thank You

Jim Spaeth

Program Manager

Advanced Development & Optimization

Jim.Spaeth@ee.doe.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Integration & Scale-Up Session

An Affordable Advanced Biomass Cookstove with Thin Film Thermoelectric Generator	LBNL
Development and Standardization of Techniques for Bio-oil Characterization	NREL
The Engineering of Catalyst Scale Up	NREL
LIBERTY - Launch of an Integrated Bio-refinery with Eco-sustainable and Renewable Technologies in Y2009	POET Project Liberty, LLC
Biomass - Feedstock User Facility	INL
Improved Feeding and Residual Solids Recovery System for IBR	Thermochemical Recovery International Inc.
Biomass Gasification for Chemicals Production Using Chemical Looping Techniques	The Ohio State University
Building Blocks from Biocrude: High Value Methoxyphenols	Research Triangle Institute (RTI)
Pilot-Scale Algal Oil Production	Global Algae Innovations
Integration and Scale Up - NREL	NREL
Strategies for Co-processing in Refineries	NREL
Improved Hydrogen Utilization and Carbon Recovery for Higher Efficiency Thermochemical Bio-oil Pathways	Research Triangle Institute
Low Carbon Hydrocarbon Fuels From Industrial Off Gas	LanzaTech, Inc.

Integration & Scale-Up Session

Small Scale Decentralized Fuel Production Facilities Via Advanced Heat Exchanger-Enabled Biorefineries	ThermoChem Recovery International, Inc.
Converting MSW Into Low-Cost, Renewable Jet Fuel	Fulcrum Bioenergy
Woody Biomass Biorefinery Capability Development	Red Rocks Biofuels
Upgrading of Stillage Syrup into Single Cell Protein for Aquaculture Feed	White Dog Labs
Pilot-Scale Biochemical and Hydrothermal Integrated Biorefinery (IBR) for Cost-Effective Production of Fuels and Value Added Products	South Dakota School of Mines and Technology
Multi-stream Integrated Biorefinery Enabled by Waste Processing	Texas A&M Agrilife Research
Hydrothermal Processing of Biomass	PNNL
HYPOWERS: Hydrothermal Processing of Wastewater Solids	Water Research Foundation (WRF)
Rialto Advanced Pyrolysis Integrated Biorefinery	Rialto Bioenergy Facility LLC
LBNL ABPDU Support	LBNL
Pilot Scale Integration	NREL
Advanced Biofuels and Bioproducts with AVAP	AVAPCO LLC
Materials Degradation in Biomass Derived Oil	ORNL

Analysis & Modeling Session

Codes and Standards in IBR's	ORNL
Feedstock to Function: Improving Biobased Product and Fuel Development Through Adaptive Technoeconomic and Performance Modeling	LBNL
Integrated Computational Tools to Optimize and De-Risk Feedstock Handling & High-Pressure Reactor Feedings Systems: Application to Red Rock Biofuels' Biorefinery	NREL
Integrated Process Optimization for Biochemical Conversion	Clemson University
Analytical Modeling of Biomass Transport and Feeding Systems	Purdue University
Improved Biomass Feedstock Materials Handling and Feeding Engineering Data Sets, Design Methods, and Modeling/Simulation Tools	Forest Concepts, LLC
Sustainable Production of JP-10	LANL
Analysis for JET High Performance Fuels	SNL
GARDN Collaboration U.S. - Canada Aviation Fuels at PNNL	PNNL
Evaluation of Bio-oils for Use in Marine Engines	ORNL

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ADO Manages: Technology Commercialization Fund Projects

Project Title	Lead Institution	Partners
Fully Renewable Polyurethane Resins Produced from Algae and other Feedstocks	NREL	Patagonia
Sustainable Graphite for Lithium Ion Batteries	NREL	Ensyn Technologies
Lignin-Derived Ionic Liquids: Synthesis and Application in Biopolymer Processing	LBNL	Domtar Corp Illium Technologies LLC Natural Fiber Welding Proionic, GmbH
Transfer & Validation of Copyrighted NREL Spectroscopy IP for Rapid Biomass Composition to Next-Generation Ultra Low-Cost Near-Infrared (NIR) Spectrometers	NREL	KS Technologies Texas Instruments
Reactive Distillation: Alcohol-to-Jet Application	PNNL	Lanzatech
Advanced Cellobiohydrolases	NREL	Novozymes
SIS Biofuel Adsorbents	Argonne	

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

ADO: Major Goals FY19-25

– **By 2019**, select three or more drop-in jet and/or diesel candidate pathways for potential verification in 2022.

– **By 2020**, assess technology readiness of candidate pathways and identify any required capital enhancements for process development unit (PDU) for 2022 verification.

– **By 2021**, confirm the selected pathway for 2022 verification and complete related PDU capital enhancements.

– **By 2023**, identify three or more additional technologies capable of utilizing economically advantaged feedstocks and support the 2030 MFSP goal of $2.5/GGE.

– **By 2025**, select three additional technologies capable of utilizing economically advantaged feedstocks and support the 2030 MFSP goal of $2.5/GGE.

RFI - Catalyst Production and PDU Enhancements

Understanding Catalyst Production and Development Needs at National Laboratories

- **Objectives**
  - ✓ Information to identify and understand areas of research, capabilities, and yet-to-be-addressed challenges pertinent to production scale-up challenges of novel catalysts employed in biological, thermochemical or hybrid processes for the efficient conversion of lignocellulosic, waste, and algal feedstocks to produce biofuels and bioproducts.
  - ✓ Additionally, information on capabilities and functionalities that need to be developed at process development units (PDUs) located at National Laboratories to enable successful transition of early stage research to engineering-scale research.

- **Categories**
  1. Catalyst production for biological processes
  2. Catalyst production for thermochemical processes
  3. Capabilities and functionalities to be developed in PDUs located at National Laboratories

- **Closed on October 22, 2018**

- **Total of 23 responses from academic institutions, national laboratories and industries**
  - 4 for biochemical
  - 14 for thermochemical
  - 10 for PDU enhancement and development needs